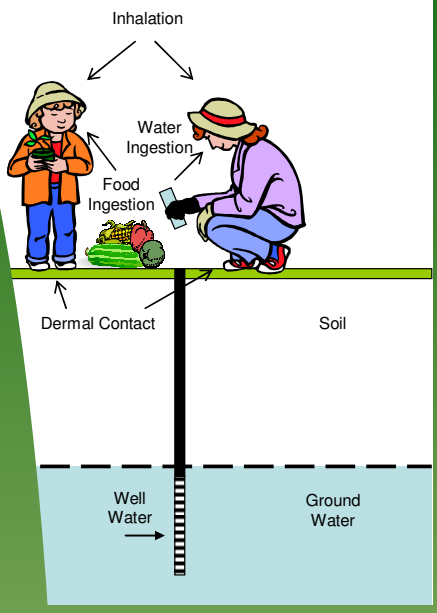
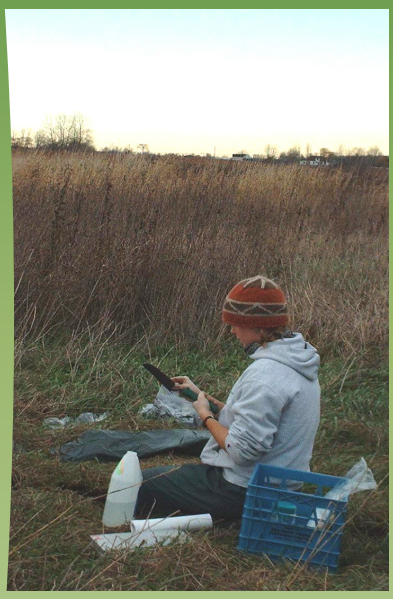
Port Colborne Community Based Risk Assessment



Human Health Risk Assessment



Volume I: Main Report

December, 2007

Jacques Whitford

VALE INCO

PORT COLBORNE COMMUNITY BASED RISK ASSESSMENT – HUMAN HEALTH RISK ASSESSMENT FINAL REPORT

Volume I

Project No. ONT34643

Prepared for

Vale Inco Limited
Toronto, Ontario

Prepared by

Jacques Whitford Limited
7271 Warden Avenue
Markham, Ontario
L3R 5X5

December 2007

Jacques Whitford

PORT COLBORNE COMMUNITY BASED RISK ASSESSMENT – HUMAN HEALTH RISK ASSESSMENT

December 2007

Prepared for Vale Inco Limited

by

Jacques Whitford Limited

This report of December 2007 presents the scope, methodology, results and findings, and conclusions of the Human Health Risk Assessment (HHRA), one of three components of the Port Colborne Community Based Risk Assessment (CBRA). The other two CBRA components include an Ecological Risk Assessment and a Phytotoxicity Study on Agricultural Crops; documentation on both have been included in separate reports prior to 2007. All three CBRA components involved the assessment of risk to receptors of Port Colborne from exposure to concentrations of Chemicals of Concern (CoC), Nickel, Copper, Cobalt and Arsenic in soil; ie. Port Colborne soil that had become impacted from airborne particulate deposition of 60 years of historical stack emissions by the then Inco Nickel Refinery.

This HHRA report should be interpreted within the overall context and goals of the CBRA Technical Scope of Work of November 2000. This Technical Scope of Work was prepared by Jacques Whitford and reviewed and accepted by the Ontario Ministry of the Environment, the Niagara Regional Health Department, the CBRA Public Liaison Committee (PLC), and the PLC's consultant.

Cecile Willert, P.Eng.
Report Writer and Principal Investigator

LICENSED PROFESSIONAL ENGINEER
C.E. WILLERT
90287533
PROVINCE OF ONTARIO

Eric Veska, Ph.D., P. Geo., C.Chem.
Project Manager

PROFESSIONAL GEOSCIENTIST
ERIC VESKA
PRACTISING MEMBER
0280
ONTARIO

William Stiebel, M.Sc., P.Geo.
Project Officer

PROFESSIONAL GEOSCIENTIST
WILLIAM H. STIEBEL
PRACTISING MEMBER
0004
ONTARIO

ACKNOWLEDGEMENT

Jacques Whitford Limited would like to first express thanks to Vale Inco Limited for the opportunity to conduct one of the first major community wide risk assessments in Canada, if not in North America. Their support has allowed for the collection of an extensive amount of field data and the initiation of scientific research and experimentation involving nickel speciation and bioavailability to better assess the potential exposure of receptors to nickel in the environment.

Appreciation is extended to our reviewers of the Public Liaison Committee, its Technical SubCommittee consisting of the Ontario Ministry of the Environment, the Niagara Regional Health Department, Dr. Evert Nieboer, and the PLC's consultant, as well as to the general public. We would also like to thank the HHRA third-party reviewer, CH2M HILL for their insightful review. Comments and suggestions made by all of the reviewers have helped to improve the overall quality of the HHRA report.

Lastly, we would like to thank those employees of Jacques Whitford Limited who have had involvement throughout the 7 year HHRA process, including but not limited to: Mahaboob Alam, Chad Amirault, Rena Chung, Anthony Ciccone, Ian Collins, Greg Crooks, Kristine Ewing, Jennifer Foell, Dolores Forde, Wai Chi Kwan, Christopher Ollson, Van Ortega, Sanya Petrovic, Alison Ronson, Mary Spano, William Stiebel, Eric Veska, Cecile Willert, Shannon Wolfe, and Kevin Wong.

ES.0 EXECUTIVE SUMMARY

ES.1 Introduction

This report presents details on the Human Health Risk Assessment (HHRA) conducted for Vale Inco Limited (Inco) by Jacques Whitford Limited (Jacques Whitford) as part of the Port Colborne Community Based Risk Assessment (CBRA). The HHRA was conducted according to the guidelines of the Ontario Ministry of the Environment (MOE), as described in *Guidance in Site-specific Risk Assessment for Use at Contaminated Sites in Ontario* (MOE, 1996c) and in general accordance with more recent guidance in *Procedures for the Use of Risk Assessment under Part XV.1 of the Environmental Protection Act* (MOE 2005).

Inco operated a nickel refinery (the Refinery) in the City of Port Colborne during the years 1918 through 1984. Airborne particulates resulting from Refinery operations were emitted and deposited on soils adjacent to, and downwind of, the Refinery site. The particulates deposited from the emissions contained traces of Refinery process metals (e.g. nickel), and the soils in which they accumulated may now contain elevated concentrations of these same metals. Inco has acknowledged responsibility for the airborne particulate emissions of nickel, copper, cobalt and arsenic and is the proponent in the Port Colborne CBRA process.

The CBRA was conducted for chemicals of concern (CoCs) that appear at elevated concentrations in Port Colborne soils as a result of historical emissions from the Inco Refinery. The CoCs included in the CBRA and HHRA are nickel, copper, cobalt, and arsenic.

The primary objective of the HHRA was to determine whether the soil concentrations of CoCs in Port Colborne area present an unacceptable risk to human health in the Port Colborne community.

ES.2 Site Characterization

Site parameters specific to Port Colborne were, to the maximum extent practical, used in the estimation of human exposure to CoCs. Site-specific parameters measured and adopted in the HHRA included those addressing land use, time-activity patterns and lifestyle characteristics of Port Colborne residents, and CoC concentrations in a range of water, air, food, and soil matrices.

ES.3 Problem Formulation

The Study Area within the Port Colborne community was divided into 5 separate HHRA Zones (lettered Zones A through E) (Figure ES-1). The HHRA Zones were selected based on similar land uses to provide generalized areas from which typical CoC exposures could be assessed. Two background zones, Zone E and Zone F for local and regional background, respectively, were included in the HHRA assessment for comparative purposes.

Figure ES-1

HHRA Zones
Port Colborne, ON

Legend

HHRA Zones
- A
- B
- C
- D
- E
- F (Southern Ontario)
- Inco Property

Topographic Features
- Inco Refinery
- Roads

0 500 1000 1500
Metres

N

Job Number: ONT34644
Date: October 2003
Dwn by: C. Amirault
Approved by: Kevin Wong

Map Parameters
Projection: UTM
Datum: NAD 83
Scale 1 : 30,000

Regional NIAGARA

Jacques Whitford
Consulting Engineers
Environmental Scientists
Risk Consultants

Receptors for the HHRA were Port Colborne residents, of life stages infant through adult, with reasonable maximum opportunities for potential CoC exposure. Receptor characteristic data utilized in the HHRA were obtained from a questionnaire administered to the residents of Port Colborne, literature values, or a combination thereof.

ES.4 Toxicity Assessment

The components of the toxicity assessment included an examination of CoC routes of exposure and associated toxicity, the identification of CoC carcinogenicity/non-carcinogenicity based on the route of exposure, and the selection of inhalation and ingestion (oral) CoC Toxicity Reference Values (TRVs). Potential risks associated with absorption (dermal) exposures were evaluated using oral TRVs adjusted for absorption efficiency as per U.S. EPA (1989) guidelines.

The TRVs used in the HHRA are based on the bioavailability of specific chemical species under documented conditions. A relative oral bioavailability factor is necessary to adjust for differences in the chemical form of the CoCs between Port Colborne soils and the TRVs. Relative oral bioavailabilities specific to Port Colborne soils were established through the testing of *in vivo* and/or *in vitro* CoC bioavailability of Port Colborne soils. When no site-specific information was available the default relative bioavailability was taken as 100%.

ES.5 Exposure Assessment

In the HHRA, the potential exposures of residents to CoCs were assessed in a conservative manner. The three major routes of CoC exposure considered in the HHRA were inhalation, ingestion, and dermal exposure.

Representative surface soil CoC concentrations were selected from sampling data primarily collected by the MOE (1998-1999) and Jacques Whitford (2000-2003), as well as other soils studies conducted in the area that were made available for this purpose. Indoor exposure to particulate-bound CoCs was examined via a program of dust sampling in Port Colborne homes undertaken by Jacques Whitford.

The selection of representative CoC concentrations in drinking water was based on sampling of the municipal water supply, dug and drilled wells, and background sources. The data for each of these sources were obtained from sampling by Jacques Whitford, the Ontario Drinking Water Surveillance Program (DWSP), and the MOE. Samples of surface water were obtained from the off shore area of Nickel Beach.

Ambient air CoC concentrations were selected based on data of air filter samples collected throughout Port Colborne for chemical analyses. These samples were collected at short term monitor sites at several locations, at several monitor locations during simulated agricultural activities and at a long term monitoring site within the community. Measured ambient air CoC concentrations were used to calibrate an atmospheric dispersion transport model which estimated the long term CoC concentrations in ambient air for each HHRA Zone. Indoor air sampling data were also included in the HHRA; although limited, these data were used to generalize trends, support assumptions on the relationship between indoor and ambient air, and decrease reliance on literature values.

Potential exposures to CoCs in the diet of Port Colborne residents were estimated for supermarket food, as well as for foods grown and/or harvested locally.

Arsenic was not detected in a large number of samples of supermarket foods, garden produce and drinking water. Because the levels of arsenic were smaller than the lowest-achievable analytical detection limits obtained at the time of the chemical analysis of the samples, the measured concentrations below the analytical detection limit required estimation. The impact of this estimation on the exposure estimates introduced a large range of uncertainty of about an order of magnitude. Since arsenic exposures could thus not be estimated reliably, they were not carried forward to a quantitative estimation of risks.

ES.6 Risk Characterization

Cancer and non-cancer risks to nickel, copper and cobalt were estimated quantitatively in each HHRA Zone. Hazard quotients (HQs, non-cancer) and exposure ratios (cancer threshold effects) were compared to the MOE benchmark of one for acceptable threshold type risks. For non-threshold effects, total and incremental lifetime cancer risks (ILCRs) were estimated. The ILCRs were compared to the MOE benchmark of one in one million as an acceptable level of risk.

No non-cancer HQs exceeded the threshold benchmark of one for oral, dermal or inhalation exposures to nickel, copper or cobalt.

The results of this assessment indicate that nickel inhalation risks to residents of Port Colborne are very low. There is unlikely to be an elevated risk from nickel inhalation even for residents of the single home with the highest measured nickel concentrations in indoor air.

Potential risks associated with arsenic were evaluated on a qualitative basis because of the absence of detectable concentrations in foods, produce and drinking water. Oral and dermal exposures in Port Colborne were evaluated by comparison of arsenic in soils in Port Colborne to arsenic soil concentrations in other Ontario communities where health studies, in particular bioassays, were performed. Since the soil arsenic concentrations in Port Colborne are lower than

those in soil in other communities where bioassays were completed, and since health effects were not observed from exposure to higher soil concentrations in those communities in which the bioassays were completed, by extension, no health risks are expected to residents of Port Colborne. This conclusion is considered applicable to inhalation as well as oral and dermal exposures to arsenic since the primary source of arsenic in air is likely to be resuspension of soil.

ES.7 Conclusion

The results of the assessment of conservative exposure scenarios indicate that the concentrations of nickel, copper, cobalt and arsenic in the Port Colborne environment do not pose an unacceptable risk to residents as defined by the MOE target risk levels. In a quantitative evaluation of uncertainties, arsenic oral/dermal exposures were found to have uncertainties too large to make the evaluation reliable.

Sensitivity analyses did not reveal any major sources of uncertainty that would be expected to have the potential to change the conclusions of this assessment.

A Risk Based Soil Concentration (RBSC) was derived for nickel in soil. The evaluation determined that RBSCs were not required for copper or cobalt because the computed values were less than the maximum measured. The objective of the RBSC is to provide a concentration that would serve as a future Port Colborne-specific human health remediation guideline for soil. The benchmark ensures that soil concentrations below this value are protective of human health. The evaluation of RBSCs for Port Colborne is summarized in Table ES-1.

Table ES-1: Evaluation of Final Risk Based Soil Concentrations (RBSCs)

CoC	Risk Based Soil Concentration (mg/kg)
Nickel	20,000
Copper	RBSC not required
Cobalt	RBSC not required
Arsenic	RBSC not required

There are no residential areas in Port Colborne where measured soil concentrations exceed the 20,000 mg/kg nickel RBSC. Concentrations higher than the nickel RBSC were measured in two samples in the Inco owned woodlot on the east side of Reuter Road, immediately east of the Inco refinery property. Although no risk is present to human health based on the current land use in this area (woodlot), if this woodlot was to be redeveloped for residential use, an appropriate remedial action and soil management plan for soils above the 20,000 mg/kg nickel RBSC would have to be implemented at that time.

The Nickel RBSC of 20,000 mg/kg nickel differs from the intervention level of 8,000 set by the MOE (2002). There are two dominant factors that cause this difference. The first is the re-evaluation of the intake of nickel from supermarket foods. In the current study, actual foods from local supermarkets, farmers markets and shops were analyzed for nickel content in a comprehensive study of dietary nickel. The second factor is the fraction of nickel in Port Colborne soils that after ingestion is absorbed into the blood. In the current study, a weight of evidence approach weighted several methods of analyzing this factor including the results of live animal tests using actual soils from Port Colborne, literature studies documenting absorption in humans and animals, studies of nickel speciation in Port Colborne soils, and laboratory methods of measuring nickel solubility in various media including acids. The result was a lower estimate of dietary nickel intake from supermarket foods and a lower absorption of nickel from ingested soils, yielding an overall increase in the RBSC over the previous intervention level.

LIST OF REPORTS FOR THE

PORT COLBORNE COMMUNITY BASED RISK ASSESSMENT

Technical Scope of Work – Community Based Risk Assessment Plan for Port Colborne, Ontario. Jacques Whitford Project No. 33826. November 2000.

Summary Report On Chemicals Of Concern Evaluation. Port Colborne Community Based Risk Assessment, Port Colborne, Ontario, Jacques Whitford Project No. ONT34645. November 2001 a.

Potential CoC Identification using Soil Chemical Concentration Data in Exceedance of MOE Generic Guidelines. Port Colborne Community Based Risk Assessment, Port Colborne, Ontario, Jacques Whitford Project No. ONT34645. November 2001 b.

Potential CoC Identification Using Emission Inventories and Dispersion Modelling of Inco and Algoma Operations. Jacques Whitford Project No. ONT34648. November 2001c.

Potential CoC Identification using Statistical Analyses. Port Colborne Community Based Risk Assessment, Port Colborne, Ontario, Jacques Whitford Project No. ONT34647. November 2001d.

Re-evaluation of Lead as a Potential Chemical of Concern (CoC). Port Colborne Community Based Risk Assessment, Port Colborne, Ontario, Jacques Whitford Project No. 35313. June 2004.

Port Colborne CBRA – Ecological Risk Assessment, Natural Environment, Volume I. Main Report. Jacques Whitford Project No. 33828.1. Final Report, September 2004.

Port Colborne CBRA – Ecological Risk Assessment, Natural Environment, Volume II. Protocols. Jacques Whitford Project No. 33828.1. Final Report, September 2004.

Port Colborne CBRA – Ecological Risk Assessment, Natural Environment, Volume III. Supporting Data. Jacques Whitford Project No. 33828.1. Final Report, September 2004.

Port Colborne CBRA – Ecological Risk Assessment, Natural Environment, Volume IV. Consultants Reports. Jacques Whitford Project No. 33828.1. Final Report, September 2004.

Port Colborne CBRA – Ecological Risk Assessment, Natural Environment, Volume V. Laboratory Analytical Data. Jacques Whitford Project No. 33828.1. Final Report, September 2004.

Crop Studies – Port Colborne CBRA – Volume I – Main Report. Jacques Whitford Project No. ONT34651. Final Report, December 2004.

Crop Studies – Port Colborne CBRA – Volume II – Protocols. Jacques Whitford Project No. ONT34651. Final Report, December 2004.

Crop Studies – Port Colborne CBRA – Volume III – Laboratory and Analytical Data and Quality Assurance/ Quality Control. Jacques Whitford Project No. ONT34651. Final Report, December 2004.

Crop Studies – Port Colborne CBRA – Volume IV – Soil Characterization. Jacques Whitford Project No. ONT34651. Final Report, December 2004.

GLOSSARY OF ABBREVIATIONS AND ACRONYMS

Abbreviation/Acronym	Definition
µg/g	Micrograms per gram; a measure of the mass of a chemical in a solid matrix such as soil or food.
µg/L	Micrograms per litre; a measure of concentration used in this report as a unit for concentration of a chemical in water, juice, and milk, among other media.
$\mu g/m^3$	Micrograms per cubic metre; a measure of concentration used in this report as a unit for both concentration of a chemical in air and inhalation exposure.
µm	Micrometre, a measure of length.
AAQC	Ambient Air Quality Criteria; the maximum concentrations of various elements in ambient air that are deemed acceptable and safe by the MOE.
ABS	The dermal absorption fraction from soil.
Absorption	The uptake of substances, such as nutrients, water, or light, by cells or tissues.
ACGIH	American Conference of Industrial Hygienists
Acute	In toxicology, describes a short exposure, usually 24 to 96 hours in an experimental setting.
Adverse Health Effect	A change in body function or cell structure that might lead to disease or health problems.
AF	Adherence Factor; how much a particular soil type will stick to an individual's skin after contact.
Ambient Air	Refers to air in the outdoor environment.
AMEC	AMEC Earth and Environmental Inc.
Analytical Detection Limit	The lowest concentration of the substance of interest that can be accurately distinguished above zero in an analytical laboratory.
Antagonistic	In the context of toxicology, refers to a relationship between two substances, in which the interaction between them lessens their toxicity. In other words, the toxicity of a mixture of antagonistic substances is less than the individual toxicities of the individual substances.
Anthropogenic	Objects or materials created from human activities.
Aquiclude or Aquitard	The layer of impermeable rock surrounding an aquifer.
Aquifer	An underground geological formation, or group of formations, containing water. Aquifers are sources of groundwater for wells and springs.
As	Symbol for the metalloid arsenic.
AT	Averaging Time; the duration during which exposure is assumed to occur.
Atmospheric Dispersion	The behaviour of a substance once released into the ambient air.

Abbreviation/Acronym	Definition
ATSDR	Agency for Toxic Substances and Disease Registry
Background	A dose corresponding to natural occurring concentrations of a chemical in the environment.
Beak	Beak International Inc., the PLC's consultant for the CBRA until 2002. Beak is now known as Stantec.
BMD	Benchmark Dose; the dose associated with a specified measure or change of a biological effect.
Bioaccessibility	Fraction of a substance that is soluble in the gastrointestinal environment and is available for absorption.
Bioassays	An assay for determining the potency (or concentration) of a substance that causes a biological change in experimental animals.
Bioavailability	Oral bioavailability is defined as the fraction of an administered dose that reaches the central (blood) compartment from the gastrointestinal tract.
Bioaccumulation	The increase in concentration of a substance in plant or animal tissue.
Biomonitoring	Monitoring of biological responses in people as a measure of effects of environmental toxins.
Biota	The flora and fauna of a particular region.
BW	Body Weight
CALMET	A software program for pre-processing meteorological data.
CalPuff	Air modeling software.
CAPCOA	California Air Pollution Control Officers Association
Carcinogen	Any substance capable of producing or inducing cancer.
CBRA	Community Based Risk Assessment; a comprehensive and community wide assessment of environmental and human health risks associated with elevated concentrations of the chemicals of concern in Port Colborne soils.
CCA	Chromated Copper Arsenate; a preservative for pressure treated wood products.
CCME	Canadian Council of Ministers of the Environment
CD	Compact Disc
CDC	Center for Disease Control
CEPA	Canadian Environmental Protection Act
Chronic	In toxicology, describes repeated or long term (chronic) exposures
City	City of Port Colborne
CNR	Canadian National Railway
Co	Symbol for the metal element cobalt
CoCs	Chemicals of concern, identified for the CBRA. The CoCs are as follows: nickel, copper, cobalt, and arsenic.

Abbreviation/Acronym	Definition
Cohort	A well-defined group of people who have had a common experience or exposure, who are then followed up for the incidence of new diseases or events, as in a cohort or prospective study.
Community	All potential receptors (human and ecological) within an area of Port Colborne defined by previous MOE studies as having concentrations of CoCs in soil from Inco's historical operations above the MOE generic Table A guideline.
Conc	Concentration
Concs	Concentrations
Cu	Symbol for the metal element copper.
DDT	Dichloro-diphenyl-trichloroethane. a pesticide.
Dermal	Relating to the skin.
Dermal Absorption	The movement of a substance or chemical into or across the skin.
Dermal Contact Dose	The amount of a chemical absorbed by the body into the blood stream through the skin.
Dermal Exposure	Exposure of the skin
Dermatitis	A disease that effects the skin that is characterized by inflammation.
Detection Limit	The lowest concentration of a chemical that can reliably be distinguished from a zero concentration.
DFO	Department of Fisheries and Oceans
Dimensionless	Describing a quantity without units of measure.
Dose	The intake of a CoC after adjusting for relative bioavailability. Although a true dose would be the amount of the chemical absorbed into the body, dose in the current assessment has been used to represent intake adjusted to be directly comparable to the applicable toxicity reference value.
DW	Dry Weight; the weight of material remaining after removing the water.
DWSP	Drinking Water Surveillance Program; MOE regulated program which routinely collects water quality data from water treatment and distribution systems.
EC	Environment Canada / European Commission
Emissions	That which is sent out, or put in circulation.
EPA	U.S. Environmental Protection Agency
EPC	Exposure Point Concentration
Exposure Point Concentration	A concentration of a CoC in a specified media that a person comes into contact with.
Epidemiological Studies	The study of the distribution and determinants of health-related states or events in specified populations.
Epidermal Tissue	Refers to the layers of tissue that comprise the skin.
EQL	Estimated Quantitation Limit; the minimum level of a substance that can be estimated within specified boundaries of precision and accuracy.

Abbreviation/Acronym	Definition
ER	Exposure Ratio; a numerical evaluation of risk for carcinogenic substances, utilizing a threshold response applicable to individual life stages and total life stages instead of incremental doses. An ER less than 1 indicates that exposures are below the threshold of cancer effects.
ERA	Ecological Risk Assessment; a process which quantifies risks to plants and/or wildlife associated with exposure to chemicals of concern.
ERG	Eastern Research Group
Estimated Exposure Dose	The measured or estimated dose to which humans are likely to be exposed considering all sources and routes of exposure.
Exposure	Contact between an organism and a chemical, physical, or biological agent. Also, the total amount of the CoC that an individual comes in contact with.
Exposure Pathway	Routes for transfer of CoCs to receptors.
Extrapolation	The process of constructing new data points outside of the range of a discrete set of known data points.
Fauna	The local animal life of a particular area.
Flora	The local plant life of a particular area.
FW	Fresh Weight; weight before drying.
GAF or GAIF	Gastrointestinal Absorption Factor: the fraction of a chemical that is absorbed into the blood after ingestion.
Gastrointestinal Absorption	The uptake of water or dissolved chemicals by the gastrointestinal tract. The movement of a chemical into or across gastrointestinal tissues.
Gavage	Forced feeding through a stomach tube.
Geophagia	Deliberate ingestion of clay.
GIS	Geographic Information Systems
Glaciolacustrine Sediments	Rock deposited on the bottom of a glacial lake; usually varved clays.
GPS	Global Positioning System. Refers to a method for accurately determining locations on the surface of the earth using electronic triangulation using satellites.
Gradient	A difference in ground water elevation over distance.
Groundwater	Water located in saturated zones below the soil surface. Many wells and springs are fed by groundwater.
h	Hour
ha	Hectare
Heterogeneous	A combination of two or more un-like components.
Hepatic	Pertaining to the liver.
Hematological	The science related to blood or blood producing organs.
HHRA	Human Health Risk Assessment
Histopathology	The study of diseased tissues, can also refer to the actual diseases of tissues.

Abbreviation/Acronym	Definition
Homeogeneity	To be uniform or made up of similar components.
Homeostatic	The ability for an organism or cell to maintain an internal equilibrium.
HQ	Hazard Quotient, the ratio of an estimated dose to a reference dose for a particular chemical. The HQ serves as an indicator of daily intake compared to health benchmarks, where a HQ less than 1 indicates that the estimated exposure is within an acceptable limit.
Hydraulic Capture Zone	The area over which groundwater is drawn towards a well where groundwater pumping is occurring.
Hydrostratigraphy	The geological characteristics of a distinct area that determine the physical and chemical behaviour of water for that area.
IARC	International Agency for Research on Cancer
ICNCM	International Committee on Nickel Carcinogenesis in Man
ILCR	Incremental Lifetime Cancer Risk
Inco	Vale Inco Limited, proponent of the CBRA
Ingestion	The act of eating; to take into the body by mouth for digestion or absorption.
Inhalation	The act of breathing. A hazardous substance can enter the body this way.
Intake	The intake is the total amount of the CoC that an individual comes in contact with.
Inter-species	Between two or more species.
Intervention Level	The concentration of a hazardous substance at or above which steps must be taken to clean it up.
Intra-species	Within a single species.
in vitro	Laboratory methods that attempt to simulate *in vivo.*
in vivo	Studies conducted with laboratory animals.
IOM	Institute of Medicine
IRIS	Integrated Risk Information System (U.S. EPA)
Jacques Whitford	Jacques Whitford Limited
LADD	Lifetime Average Daily Dose
Lesion	Abnormal tissue caused by an injury
Limit Value	A threshold below which a carcinogenic response is not expected in sensitive individuals.
LOAEL	Lowest Observed Adverse Effects Level, the lowest level of exposure, concentration or dose at which adverse effects have been observed.
Max.	Maximum
MCE filters	Mixed Cellulose Ester filters; air sampling filters.
MCL	Maximum Contaminant Levels (U.S. EPA)
MDL	Method Detection Limit

Abbreviation/Acronym	Definition
Media	Environmental materials (*e.g.* soil, water, air) through which exposure to potentially hazardous substances (*e.g.* heavy metals) is known to occur. Singular form is medium.
Meteorological	Relating to weather and weather conditions.
mg/kg	Milligrams per kilogram; a measure of concentration used in this report as a unit of concentration of chemicals in soil and solid foods, among other media.
Min.	Minimum
Model	A simplified hypothetical description of a real-world process.
MOE	Ontario Ministry of the Environment, formerly known as Ontario Ministry of Environment and Energy (or MOEE)
MRL	Minimal Risk Level; estimates of the daily human exposure to a chemical that is likely to be without appreciable risk of a non-cancer health effect over a specified exposure duration.
NA	Not Applicable
NCDC	National Climatic Data Centre
NE	Not Evaluated
Neurological	Relating to the nervous system of an organism.
Ni	Symbol for the metal element nickel.
Nickel Speciation Analysis	Used to determine the amount of nickel bearing particulates (species) on each of the samples.
NOAEL	No Observed Adverse Effects Level, a level of exposure, concentration or dose at which no adverse effects have been observed.
Non-Carcinogen	Describing a substance that has not been observed to produce or induce cancer.
Normality	In statistics, normality refers to the extent to which a set of sample data reflects the true distribution of a measured characteristic in the entire population.
NPRI	National Pollutant Release Inventory
Occluded	When something is blocked or cut off.
ODWS	Ontario Drinking Water Standards
OMAFRA	Ontario Ministry of Agriculture, Food and Rural Affairs
Oral	Refers to the mouth, generally in relation to oral-intake or oral dose.
OTR	Ontario Typical Ranges
Oxidic nickel	A form of nickel having oxygen atoms attached to nickel atoms.
Particulate Matter	1. Fine liquid or solid particles such as dust, smoke, mist, fumes, or smog, found in air or emissions (PM). 2. Very small solids suspended in water; they can vary in size, shape, density and electrical charge and can be gathered together by coagulation and flocculation.

Abbreviation/Acronym	Definition
Permeable	A permeable material is one that allows the passage of other materials through it (*i.e.* water passing through a layer of sandy soil).
Phytotoxicology	The study of plant toxicology, that is, how plants may be adversely affected by the application of external chemicals.
Pica behaviour	The deliberate ingestion of non-food items, commonly seen in toddlers. Soil pica, or the deliberate ingestion of soil, is a type of pica behaviour.
PLC	Public Liaison Committee
PM_{10}	Particulate matter in air with an aerodynamic diameter of less than 10 µm (*i.e.*, fine dust)
$PM_{2.5}$	Particulate matter in airwith an aerodynamic diameter of less than 2.5 µm (*i.e.*, very fine dust)
Protocol	Sets of procedures used to define how the various testing activities were to be carried out. These were presented to and reviewed by the PLC's consultant, the TSC and the PLC.
Public Health Department	Regional Niagara Public Health Department
Purge Well System	A system of wells being used to extract groundwater.
QA/QC	Quality Assurance and Quality Control, assesses the reliability and variability in concentrations on CoCs measured
Quality Control Limit	Statistically determined control limit of 30%
RAF	Relative Absorption Factor; describes the ratio of the absorbed fraction of a substance from a particular exposure medium relative to the fraction absorbed from the dosing vehicle used in the toxicity study for that substance.
RBA	Relative Bioavailability Adjustment; the comparative bioavailabilities of different forms of a substance or for different exposure media containing the substance.
RBC	Risk Based Concentrations (U.S. EPA Region III)
RBSC	Risk Based Soil Concentrations; an estimate of the concentration of that CoC in soil that is expected to be protective of human health for a worst case exposure of sensitive receptors.
(Human) Receptor	Person that is potentially exposed to Chemicals of Concern.
Refinery	The Vale Inco facility at Port Colborne, Ontario.
REL	Reference Exposure Level; the estimated concentrations or doses at or below which adverse non-cancer health effects are not likely to occur.
ROB	Relative Oral Bioavailability; an adjustment to intake of a CoC made so that the dose can be compared directly to the toxicity reference value.
Remediation	Cleanup or other methods used to remove or contain a toxic spill or hazardous materials from a Superfund site.
Renal	Related to the kidneys.
Residual Contamination	Refers to contamination that remains after efforts have been made to remove it.

Abbreviation/Acronym	Definition
Respirable	Capable of being taken into the lungs through breathing.
RF	Resuspension Factor; the degree to which settled particles such as dust become airborne following a disturbance.
RfC	Reference Concentration. Defined by U.S. EPA as an estimate (with uncertainty spanning perhaps an order of magnitude) of a continuous inhalation exposure to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime.
RfD	Reference Dose. Defined by U.S. EPA as an estimate (with uncertainty spanning perhaps an order of magnitude) of a daily oral exposure to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime.
Risk Assessment	A qualitative or quantitative evaluation of the environmental and/or health risk resulting from exposure to a chemical or physical agent (pollutant); combines exposure assessment results with toxicity assessment results to estimate risk. This is an isolated community affair.
Risk Management Plan	A plan prepared to predict, assess, manage, and remediate risks presented by hazards as they pertain to receptors in an area of interest, in this case, the City of Port Colborne.
RME	Reasonable Maximum Exposure; the maximum exposure expected to reasonably occur in a population.
RME Concentration	The concentration of a CoC in an environmental medium that is considered to correspond to a Reasonable Maximum Exposure (RME) scenario.
SE	Sequential Chemical Extraction
Sebum	The oily secretion forming part of the skin's acid mantle.
SEM	Scanning Electron Microscopy; a powerful method of viewing a specimen at very large magnifications
SENES	SENES Consultants Limited
Sensitivity Analysis	Refers to the study of how output from an evaluation changes when input data are changed. Sensitivity analysis models may be used to simulate a real-life hazard scenario when little or no experimental data is available.
Skew	In statistical distribution curves, the degree by which data differs from a symmetrical distribution.
Slope Factor	Upper bound estimate of the increase in cancer risk due to lifetime exposure to a chemical.
Soluble	A physical property in which one substance is able to dissolve, or, is soluble in another.

Abbreviation/Acronym	Definition
Standardized Mortality Ratio (SMR)	This is the relative measure of the difference in risk between the exposed and unexposed populations in a cohort study. The SMR is similar to the relative risk in both definition and interpretation. This measure is usually standardized to control for any differences in age, sex, and/or race between the exposed and reference populations. It is frequently converted to a percent by multiplying the ratio by 100.
Stantec	Stantec Consulting Limited, the PLC's consultant for the CBRA from 2002 until September 2004.
Std Dev	Standard Deviation; a measure of the spread of a set of data. In other words, measures how far around the average the data are distributed
Study Area	Lands in the City of Port Colborne and lands in adjacent areas where soil concentrations are greater than generic soil standards..
Surface Water	Water at the soil surface in open bodies such as streams, rivers, ponds, lakes and oceans.
Synergistic	In relation to human health, two hazardous substances act synergistically when together their negative health impacts are greater than a simple sum of their known individual impacts.
TC	Tolerable Concentration
TDI	Tolerable Daily Intake by ingestion to which a person can be exposed without adverse health affects.
Threshold	Refers to a limit below which no effects are known to occur.
Threshold dose	The dose or exposure below which no deleterious effect is expected to occur.
TLCR	Total Lifetime Cancer Risk
TLV	Threshold Limit Value; the level to which persons may be exposed for an 8-hour workday without adverse effects.
Toxicity	Production of any type of damage to the function or structure of any part of the body.
Toxicology	The study of harmful interactions between chemical, physical, or biological agents and biological systems.
TRV	Toxicity Reference Value; a general term representing several types of values used in the quantitative evaluation of cancer and non-cancer health risks.
TSC	Technical Sub-Committee to the PLC
TSOW	Technical Scope of Work; the document outlining how the HHRA will be conducted
TSP	Total Suspended Particulate Matter; the total mass of dust particles suspended in the air.
UCLGM	Upper confidence limits of the geometric mean. Similar to UCLM but based on the logarithms of the data.

Abbreviation/Acronym	Definition
UCLM	Upper Confidence Limit of the Mean; the upper limit that one can be confident, to a specified level of confidence and assuming a normal distribution of data, that the mean value does not exceed that limit.
UF	Uncertainty Factor; a factor applied to account for uncertainties in extrapolating estimates of adverse effects.
UK	United Kingdom
UL	Tolerable Upper Limit; the highest level of intake of nutrient that can be tolerated without risk of adverse health effects to healthy individuals.
Unit Risk (UR)	The upper bound of the increase in cancer risk estimated for continuous lifetime exposure to a chemical at a concentration of 1 µg/L in water, or 1 $\mu g/m^3$ in air.
Unitless	A number have no units of measure applicable to it.
U.S.	United States
USDA	United States Department of Agriculture
U.S. EPA	United States Environmental Protection Agency
U.S. EPA MCL	U.S. Environmental Protection Agency Maximum Contaminant Level
U.S. NRC	United States Nuclear Regulatory Commission
Varved Clay	Alternating silt and clay layers deposited in a glacial lake
Watters	Watters Environmental Group Inc., the PLC's consultant for the CBRA since September 2004.
Weight of Evidence	A system to evaluate the extent that available data supports a particular hypothesis.
WHO	World Health Organization
Wider Area of Abatement Risk Assessment	A series of studies and estimates of risk to humans and the natural environment from exposure to chemicals of concern within a defined Study Area.
XAS	X-ray Absorption Spectroscopy; an analytical method allowing, among other things, speciation of nickel in samples of solid materials
yr	Year

UNIT EQUIVALENCES

Unit	Equivalency
Mass	
Kg	1 kg = 1000 g
G	1 g = 1000 mg
Mg	1 mg = 1000 µg
µg	1 µg = $1x10^{-9}$ kg
Volume	
m^3	1 m^3 = 1000 L
L	1L = 1000 mL
mL	1 mL = 1000 µL
µL	1 µL = $1x10^{-6}$ L
Distance	
M	1 m = 100 cm
Cm	1 cm = 10 mm
Mm	1 mm = 1000 µm
µm	1 µm = $1x10^{-6}$ m
Time	
yr	1 yr = 365 days
day	1 day = 24 hrs
h	1 h = 60 min
min	1 min = 60 sec
Concentration	
1 mg/kg = 1 µg/g = 1 part per million	
1 mg/L = 1 g/m^3	

Port Colborne Community Based Risk Assessment

Human Health Risk Assessment

List of Volumes

Volume I: **Main Report**

Volume II: **Protocols**

Appendix 1	Introduction to Protocols
Appendix 1.1	Human Health Risk Assessment Sampling and Analysis: Quality Assurance and Quality Control
Appendix 1.2	Residential Food Basket Survey and Questionnaire Protocol
Appendix 1.3	*In Vivo* Protocol for Estimation of Oral Bioavailability of Nickel in Port Colborne Soils
Appendix 1.4	Protocol for Air Quality Dispersion Modelling Human Health Risk Assessment Input
Appendix 1.5	Protocol for Ambient Air Monitoring in the Community, Human Health Risk Assessment Input
Appendix 1.6	Protocol for Ambient Air Monitoring in the Vicinity of Farming Activities, Human Health Risk Assessment Input
Appendix 1.7	Indoor Air Dust and Sampling Protocol
Appendix 1.8	Indoor Air Dust and Sampling – Renovation Study Protocol
Appendix 1.9	Private Well Water Sampling Program Protocol
Appendix 1.10A	Year 2000 Garden Produce Sampling Protocol
Appendix 1.10B	Year 2001 Garden Produce Sampling Protocol
Appendix 1.11	Game, Fish, Milk and Poultry Food Basket Analysis Protocol
Appendix 1.12	Maple Sap Sampling Protocol
Appendix 1.13	Local Supermarket Food Basket Analysis Protocol
Appendix 1.14	Technical Scope of Work, Community Based Risk Assessment Plan for Port Colborne, Ontario.
Appendix 1.15	Deviations to Technical Scope of Work (Appendix 1.14)
Appendix 1.16	Approach to Data Analysis and Interpretation
Appendix 1.17	Deviations from Approach (Appendix 1.16)
Appendix 1.18	Applicability of Ontario Regulation 153/04
Appendix 1.19	Glossary of Abbreviations and Acronyms

TABLE OF CONTENTS

Page No.

TABLE OF CONTENTS

(Continued)

Page No.

TABLE OF CONTENTS

(Continued)

Page No.

TABLE OF CONTENTS

(Continued)

Page No.

TABLE OF CONTENTS

(Continued)

Page No.

TABLE OF CONTENTS

(Continued)

Page No.

TABLE OF CONTENTS

(Continued)

Page No.

LIST OF FIGURES

Page No.

LIST OF FIGURES

(Continued)

Page No.

CHAPTER 4.0

CHAPTER 5.0

LIST OF FIGURES

(Continued)

Page No

CHAPTER 6.0

CHAPTER 7.0

LIST OF TABLES

Page No.

EXECUTIVE SUMMARY

CHAPTER 1.0

CHAPTER 2.0

CHAPTER 3.0

LIST OF TABLES

(Continued)

Page No.

CHAPTER 4.0

CHAPTER 5.0

CHAPTER 6.0

LIST OF TABLES

(Continued)

Page No

CHAPTER 7.0

LIST OF TABLES

(Continued)

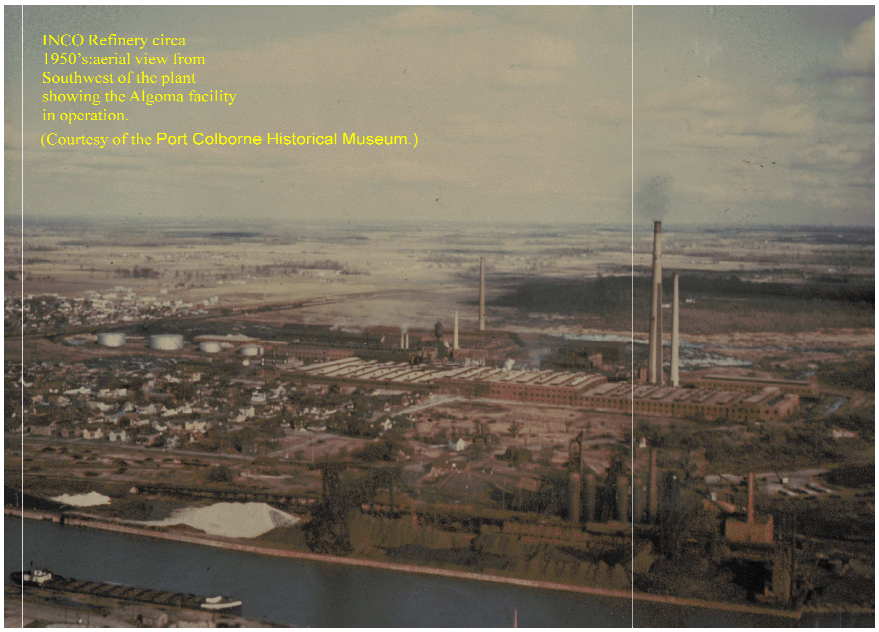
1.0 INTRODUCTION

This report presents details on the Human Health Risk Assessment (HHRA) conducted by Jacques Whitford Limited (Jacques Whitford) for Vale Inco Limited (Inco) as part of the Port Colborne Community Based Risk Assessment (CBRA). The following sections detail the:

- Background to the Port Colborne CBRA
- Purpose of the CBRA
- CBRA process
- General study design and approach of the HHRA

1.1 Background to the Port Colborne CBRA

The City of Port Colborne, with a population of 18,450 (2001 census), is located on the north shore of Lake Erie in the Regional Municipality of Niagara, Ontario (Figure 1-1). The Welland Canal runs through Port Colborne—dividing the city into east and west sections—and continues north across the Niagara Peninsula to Lake Ontario at the City of St. Catharines. Over 80% of developed areas (commercial/residential) in the City of Port Colborne lie to the west of the Welland Canal, but the Port Colborne Inco Nickel Refinery (the Refinery) is situated approximately half a kilometre to the east of the Canal (Figure 1-1). The Refinery site is bounded by Nickel Beach to the south, residential subdivisions to the west and north and rural agricultural lands to the east and northeast (Figure 1-1). The prevailing wind direction is from the Southwest to the Northeast.



The Refinery began operating in 1918, with peak commercial production of nickel occurring during the 1940s. The Refinery ceased operations for the production of electrolytic nickel in 1984. Refinery operations during the period 1920 to 1960 were responsible for the majority of airborne dust emitted by the Refinery to the local environment. These particulate emissions are now understood to be

responsible for the increased soil metal concentrations near the Refinery, a trend that is particularly pronounced on properties located directly downwind (prevailing wind to the north-east) of the Refinery site.

The Ontario Ministry of the Environment (MOE) has conducted sampling over the past three decades to determine the levels of metals in Port Colborne soils. The results and conclusions of these studies are available in the following reports:

- MOE. 2000a. Phytotoxicity Soil Investigation: Inco – Port Colborne (1998). Ontario Ministry of Environment, January 2000;
- MOE. 2000b. *Phytotoxicity Soil Investigation: Inco – Port Colborne (1999)*. Ecological Standards and Toxicology Section, Standards Development Branch, Ontario Ministry of the Environment, July 2000;
- MOE. 2000c. *Soil Contamination in Port Colborne Woodlots: 2000.* Ontario Ministry of the Environment, February 2000;
- MOE. 2000d. *Phytotoxicology Soil Investigation: School Yards and Beaches Port Colborne (April 2000)*. Ontario Ministry of Environment, December 2000; and
- MOE. 2002. *Soil Investigation and Human Health Risk Assessment for the Rodney Street Community, Port Colborne.* Ontario Ministry of the Environment, March 2002.

The Port Colborne CBRA was conducted for Chemicals of Concern (CoCs) that have elevated soil concentrations as a result of historical emissions from the Refinery. Details regarding the selection of CoCs (nickel, copper, cobalt and arsenic) are provided in Section 2.2.

Inco has acknowledged Refinery particulate emissions to be a cause of elevated soil metal concentrations in Port Colborne. To address any human or environmental health concerns that may result from elevated soil metal concentrations, Inco has made a commitment to the community of Port Colborne (represented by the Public Liaison Committee, or PLC), the City of Port Colborne (the City) and the MOE to conduct a CBRA.

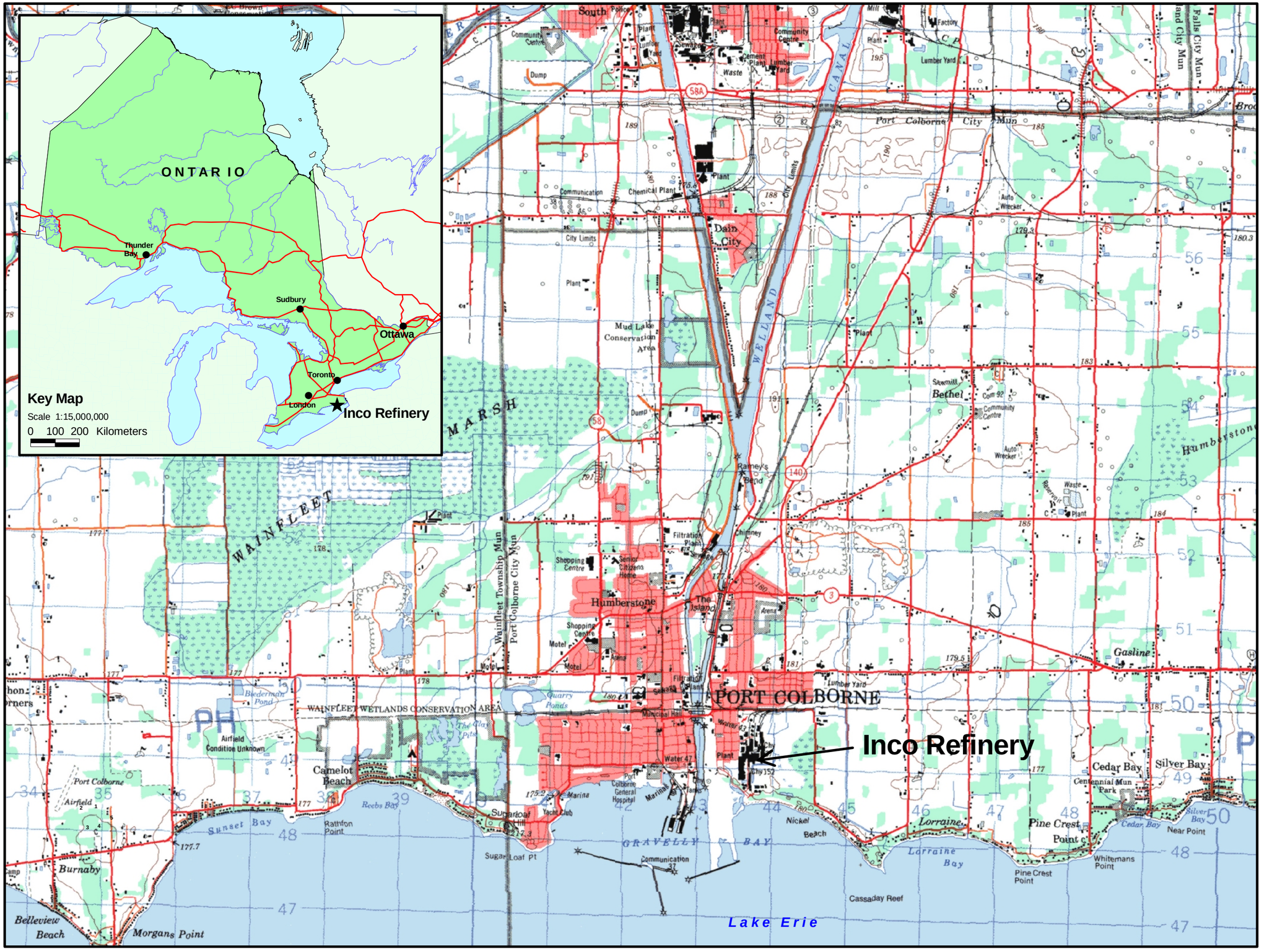


Figure 1-1

Geographic Location of Port Colborne

0 1 2 3

Kilometres

N

Legend

- Roads
- Drainage
- Waterbody

Job Number: ONT34644
Date: October 2003
Dwn by: C. Amirault
Approved by: Oliver Curran

Map Parameters
Projection: UTM
Datum: NAD 83

Regional NIAGARA

Jacques Whitford

Consulting Engineers
Environmental Scientists
Risk Consultants

1.2 Purpose of the CBRA

The purpose of the CBRA is to assess, on a comprehensive and community-wide basis, the environmental and human health risks associated with elevated concentrations of the CoCs in Port Colborne soils.

1.3 CBRA Process

The components of the CBRA process include:

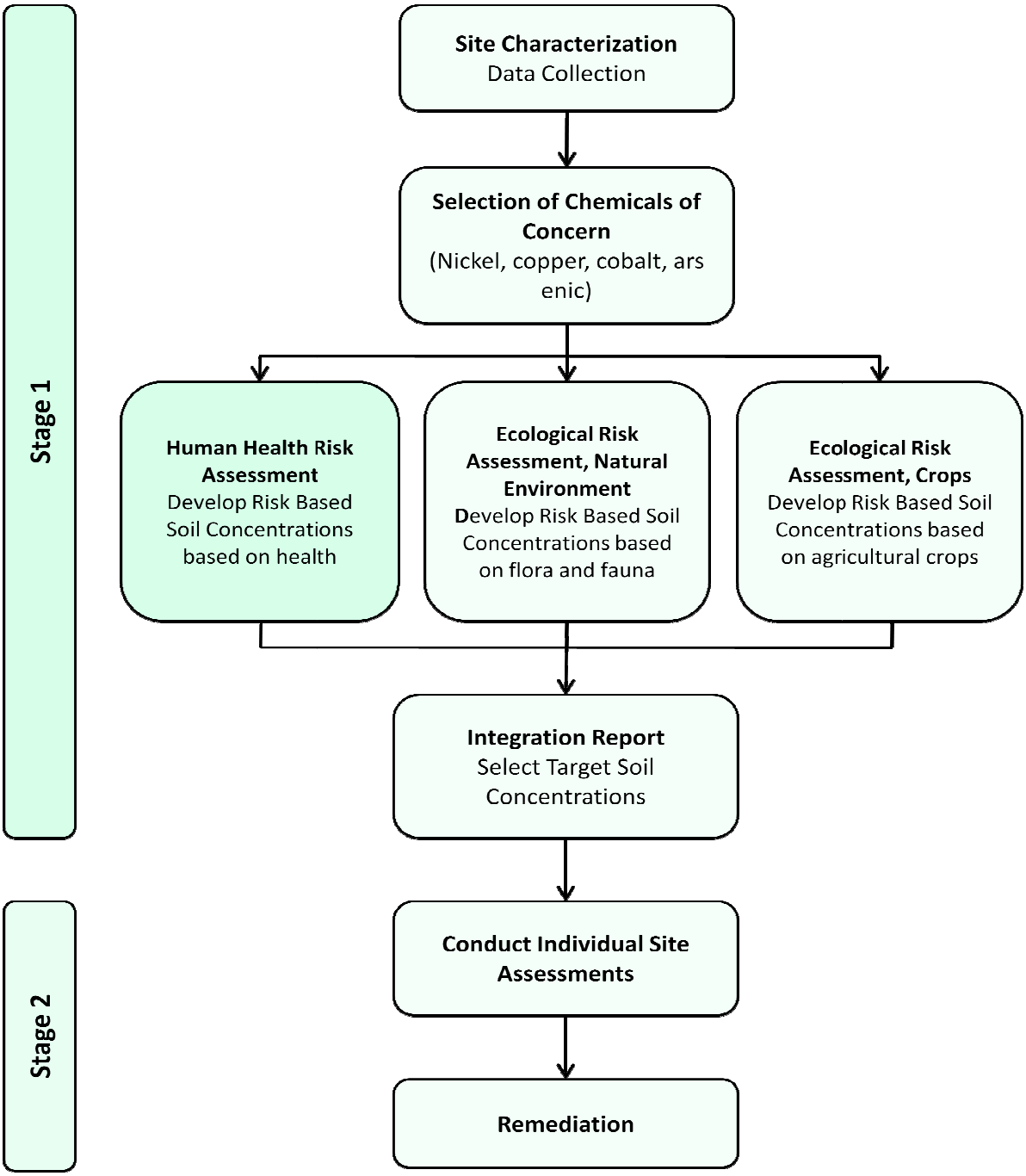
- An evaluation to confirm that all relevant CoCs have been considered;
- A quantitative ecological risk assessment (ERA) for the natural environment;
- A quantitative crop study (phytotoxicity testing) ERA;
- A quantitative HHRA (***the focus of this report***); and,
- An evaluation of applicable remediation options.

Other components of the CBRA are reported separately, as outlined above. The HHRA is therefore only one component of the overall CBRA process depicted in Figure 1-2.

Inco is committed to identifying and resolving potential health and environmental issues resulting from historical operations at the Port Colborne Refinery. The MOE 1997 *Guideline for Use at Contaminated Sites in Ontario* (MOE, 1997) and *Ontario Regulation 153/04* (Ontario, 2004a), provide several approaches to managing site-associated risk; of these approaches, a wider area of abatement risk assessment has been adopted by Inco for use in the CBRA. A wider area of abatement assessment consists of a series of studies and estimates of risk to humans and the natural environment from exposure to CoCs within a defined Study Area. Using this approach, risk management solutions that are effective, practical and protective of human and environmental health can be developed for Port Colborne.

In addition to the estimate of risk, wider area of abatement risk assessments are also used to estimate environmental concentrations of selected chemicals (CoCs) that are protective of human and/or environmental health within a specific site or Study Area. The Study Area in this assessment is defined as the City of Port Colborne and adjacent areas where soil concentrations are greater than generic soil standards. To accomplish site specificity, the risk assessment process and estimates include data and site characteristics acquired from and reflective of, the defined Study Area. This inclusion of site-specific information in a wider area of abatement risk assessment makes it unlikely that the Risk-Based Soil Concentrations (RBSCs) estimated through the risk assessment process will be identical to the applicable MOE standard; RBSCs developed through a risk assessment may be higher or lower than the generic standards provided by the MOE for a generic site. RBSCs, as developed through a risk assessment process will, however, achieve the same standard of human health and environmental protection as is intended by the MOE generic site standards.

Figure 1-2: CBRA Process



Soil studies in the Port Colborne area have indicated that historic Refinery operations are responsible for the distribution of CoCs over a large area that encompasses hundreds of properties with some concentrations in soil exceeding the MOE generic soil standards. While it might be possible to conduct an individual risk assessment for each affected property, such an approach is impractical for reasons of expense and methodological consistency. An individual risk assessment approach would also place untenable demands on MOE review and approval processes, potentially requiring ten years or more for individual risk assessment approvals. To address the challenges of applying the risk assessment approach, Inco initiated discussions with the MOE as to whether a CBRA could be done more efficiently. The MOE agreed that a CBRA could be carried out, in which the concepts and approach used in individual property risk assessments could be applied over a large area. During the conduct of the CBRA, *Ontario Regulation 153/04* was released, confirming the MOE's general acceptance of a CBRA type of process as a wider area of abatement risk assessment.

The CBRA process involves two stages (see Figure 1-2). In Stage 1, the site characterization involved site sampling and the collection of technical and scientific information from the general scientific literature and previous Port Colborne studies. This information was used to identify CoCs and derive a process with which to estimate the risk associated with CoC exposures to each of human health, the natural environment and crops. The natural environment ecological risk assessment (ERA) quantified risks from the CoCs to non-human, biotic receptors (*e.g.* flora and fauna) and involved an analysis of exposure pathways for CoCs to biotic receptors in the local environment. The crops risk assessment was also an ecological risk assessment, but specific to affects of the CoCs on agricultural crops. The HHRA quantifies the risks of adverse human health consequences and accompanying uncertainties, resulting from CoC exposure. The HHRA includes considerations that CoC exposure may occur simultaneously in several media such as food, air, water, soil or dust and may reach humans through multiple exposure pathways.

At the end of stage 1, the HHRA and the ERA (crops and natural environment) results are integrated in the integration report and a general remediation plan is formulated. The assessments are used to estimate community wide RBSCs using the specific characteristics of Port Colborne's environmental media.

The development and outcome of the CBRA project has proceeded with scrutiny and benefit of formal peer review of the scientific methodology used. Additional input from the PLC and the MOE was received to ensure, to the extent possible, that the estimation of risks and the development of RBSCs were acceptable as defined by applicable MOE guidance (Ontario 2004a; MOE 2005).

The objective of Stage 2 of the CBRA will be to assess individual properties which, on the basis of the risks estimated for various typical reasonable worst case conditions (several zones), are approximated to have risks near or exceeding the community wide RBSCs for any CoCs derived by the CBRA in Stage 1. If property-specific risks are found to be unacceptable for any of the CoCs, then a risk management plan (remediation) will be developed by Inco for that specific property or properties. Stage 2 will follow after completion of this HHRA study and the ERA studies and involves application of the risk estimation developed in Stage 1 to individual properties, as required. This stage will only be carried out if the property owner gives consent.

The CBRA process has the objective of finding out what risks exist, if any and determining how to minimize such risks in a scientifically sound and practical manner. Each identified property owner will determine whether to participate in having the CBRA process applied to their property.

1.3.1 CBRA Participants

Vale Inco Limited (Inco) is the proponent of the CBRA process and receives input from the Community, the City and the appropriate government agencies for conducting the CBRA.

The ***Ontario Ministry of the Environment*** *(MOE)* is the government agency responsible for ensuring that Inco conducts the CBRA according to the principles of the risk assessment process, as outlined in applicable MOE guidance (Ontario 2004a; MOE 2005). The Director of the West Central Region of the MOE makes decisions pursuant to the provisions of the *Environmental Protection Act*.

The ***Regional Niagara Public Health Department*** *(Public Health Department)* of the Regional Municipality of Niagara is the government agency ensuring health issues are suitably addressed by the CBRA.

The ***property owners*** of Port Colborne are informed of and invited to comment on, the CBRA process and issues.

The ***City of Port Colborne*** is a participant in the CBRA process.

A ***Public Liaison Committee*** (PLC) provides a number of functions including: 1) to solicit public input; 2) to inform the public; and 3) to provide input to Inco and to the Director of the MOE with respect to the scope of work for conducting the CBRA.

The PLC Consultant, Stantec Consulting Limited (Stantec) and formerly Beak International Incorporated prior to 2002, provided technical support and advice to the City and the PLC respecting the CBRA from 2002 to September 2004. Stantec's role was replaced by Watters Environmental Group Inc. in September 2004.

Jacques Whitford is the environmental consultant retained by Inco to conduct the CBRA for Port Colborne.

A ***Technical Sub-Committee*** (TSC) of the PLC has members from the PLC, the PLC's consultant, the MOE, Jacques Whitford, the Public Health Department and Inco. This committee reports its findings to the PLC and is chaired by the PLC's consultant. The purpose of the TSC is to resolve technical issues throughout the CBRA process. The public is invited to attend and observe TSC meetings.

CH2M Hill conducted a third party peer review of Preliminary Draft #3 of the HHRA report.

SENES Consultants Limited completed a third party review of the HHRA spreadsheets in early 2007.

1.4 General Study Design and Approach of the HHRA

The sections that follow summarize:

- MOE studies in the Port Colborne area
- The HHRA process
- The outline of the HHRA report
- The HHRA process within the context of the CBRA
- Key changes from the public draft HHRA report
- The objectives of this HHRA
- The scope of work
- The community approach

Specific HHRA components are presented in greater detail in subsequent chapters and are supported by other volumes of the CBRA.

1.4.1 MOE Studies in the Port Colborne Area

In 1997, the MOE and the Public Health Department conducted a HHRA for nickel, copper and cobalt in Port Colborne (MOE, 1998). Based on a maximum nickel soil concentration of 9,750 mg/kg, the authors concluded that no adverse health effects were expected from exposure to these chemicals in Port Colborne soils. Included in that report was a review of the health status of the Port Colborne population which also did not indicate any adverse effects related to the assessed chemicals.

Following the release of the 1997 assessment, the MOE conducted additional soil sampling from 1998 to 1999 at the 0 to 5 cm depth (MOE, 2000a; 2000b). These studies involved sampling across the Port Colborne community, particularly around the Refinery (MOE, 2000a). Soil samples were analysed for 20 parameters: aluminium, antimony, arsenic, barium, beryllium, cadmium, chromium, cobalt, copper, iron, lead, manganese, molybdenum, nickel, phosphorous, selenium, silver, titanium, vanadium and zinc.

The results of the MOE 1998 soil sampling reported nickel soil concentrations of up to 5,050 mg/kg (MOE, 2000a). The highest nickel soil concentrations were generally found in areas close to or downwind of the Refinery, with concentrations decreasing with distance from the Refinery (MOE, 2000a). Soil concentrations of copper and cobalt were measured at up to 355 mg/kg and 195 mg/kg, respectively. As with nickel, the concentrations of copper and cobalt were found to be highest near the site of the old Refinery stack and decreased with distance from this source. The soil concentrations of nickel, copper and cobalt in excess of the MOE Table A Generic guidelines (200 mg/kg, 300 mg/kg and 50 mg/kg for nickel, copper and cobalt, respectively (MOE, 1997)), generally occurred in the eastern portions of the City and in agricultural and woodlot areas to the north and east of the Refinery. The area affected by elevated soil metal concentrations above the guidelines was estimated to be approximately 19 km^2. The area of concentrations above background (defined as the areas above the 98^{th} percentile of Ontario Typical Range (OTR_{98}) of the CoCs in soils) was estimated at 140 km^2.

The conclusion drawn by the MOE from the 1998 (2000a) soil study was that soil concentrations of nickel, copper and cobalt were elevated above MOE effects-based generic soil clean up guidelines and should be considered to be CoCs. Although the generic soil guidelines (MOE, 1997) have been replaced by soil standards (Ontario, 2004b), the values of the MOE soil standards remained the same as the former soil guidelines for the identified CoCs.

In 1999, the MOE conducted a phytotoxicology soils investigation of the Port Colborne area that focussed on further delineation of the area of soil nickel guideline exceedances. The results of the 1999 study increased the area in which soil nickel concentrations exceeded the MOE Table A Guidelines (MOE, 1997) from 19 km^2 to 29 km^2 (MOE, 2000b).

In reviewing the data from the 1998 and 1999 soil investigations, the MOE noted that soil nickel concentrations in woodlots were higher than those measured in adjacent fields. In the fall of 2000, the MOE conducted further soil sampling in five woodlots and adjacent fields to assess the spatial distribution of soil metals. The woodlot study concluded that, in woodlots nearby and downwind of the Refinery, the highest soil nickel concentrations occurred at the interface between the field and the upwind edge of the woodlot (MOE, 2000c). Soil nickel concentrations were also consistently higher within the woodlots than in the adjacent field(s) and the lowest soil nickel concentrations occurred in the field(s) located immediately downwind of the woodlots (MOE, 2000c). In woodlots located farther from the Refinery, the only soil nickel distribution pattern noted was that soil nickel concentrations were higher in the centre of woodlots than at woodlot edges or in adjacent fields.

In April 2000, additional sampling included school properties, commercial day-care centers and beaches (MOE, 2000d). This report concluded that there were no health risks.

In June 2000, the MOE conducted soil sampling in the Rodney Street neighbourhood immediately west of the Inco property. Elevated concentrations of nickel, copper, cobalt and arsenic in soil were found in this area. The MOE used these data to conduct a HHRA specific to this neighbourhood. The outcome of this assessment was a recommended site-specific soil intervention level of 8,000 mg/kg nickel that was found to be protective of toddlers, the receptors deemed most sensitive. The report also concluded that soil arsenic concentrations were unlikely to produce an, "undue health risk" (MOE, 2002) and that human exposure to cobalt and copper in soil were well below levels of concern. Accordingly, no soil intervention levels for arsenic, cobalt, or copper were proposed.

Table 1-1 highlights key differences in approach between the MOE (2002) assessment of the Rodney Street area and the HHRA described in this report as part of the CBRA. One key difference is a greater reliance in this report on newly-acquired, community-specific data in the CBRA for the past five years to better estimate potential risks in Port Colborne.

Table 1-1: Summary of Selected Key Differences in CBRA Approach to HHRA Compared to that in MOE Rodney Street Report

Aspect	MOE Report Approach	CBRA Approach, this report
Area included in study	Rodney Street area	The Rodney Street area was one of several areas of Port Colborne investigated. The CBRA assessed risks for affected areas, referred to as Zones
Soil concentrations	Use of maximum CoC concentrations measured in the soils from Rodney Street area, regardless of sample depth	Selection of reasonable maximum exposure concentrations of CoCs in soil in each Zone with consideration for exposures varying with depth. Maximum exposure concentrations were also considered.
Ambient air concentrations	Localized sampling in Rodney Street area	Community wide sampling (15 air sampling units at 7 locations) combined with longer term MOE sampling and air modelling to estimate long-term air concentrations across the community
Indoor air concentrations	Estimated	Estimated as a fraction of ambient air results; measured indoor air concentrations (30 homes) used to develop a ratio to ambient air; measured maximum (1 additional home) evaluated for maximally exposed individuals
Indoor settled dust concentrations	Estimated	Measured settled dust concentrations in 30 homes throughout community
Attic dust concentrations	Pathway not included	Measured attic dust concentrations in 12 swipe samples from homes throughout community
Municipal drinking water concentrations	8 samples from Drinking Water Surveillance Program (DWSP) 1996 to 1999	11 years of data from DWSP, 1990 to 2001 complemented by measurement of concentrations in 11 tap water samples in Port Colborne homes
Cistern concentrations	Not considered	Measurement of water concentrations at properties with cisterns
Well water concentrations	Not considered	Use of measured water concentrations in 150 well water samples collected by Jacques Whitford and 16 collected by MOE from properties with dug and drilled wells
Bioavailability of nickel	Test tube (*in vitro*) test using acid extraction to estimate bioaccessibility. Method not validated for nickel.	Measurement of actual bioavailability of nickel in rats fed Port Colborne soils. Weight of evidence approach including consideration of literature on absorption in humans, nickel speciation and multiple soil types.
Bioaccessibility of copper, cobalt and arsenic	*In vitro* test using acid extraction with glycine to estimate bioaccessibility. Method not validated for copper or cobalt, with limited acceptance for arsenic.	Weight of evidence evaluation of *in vitro* results which include additional analyses and multiple soil types.

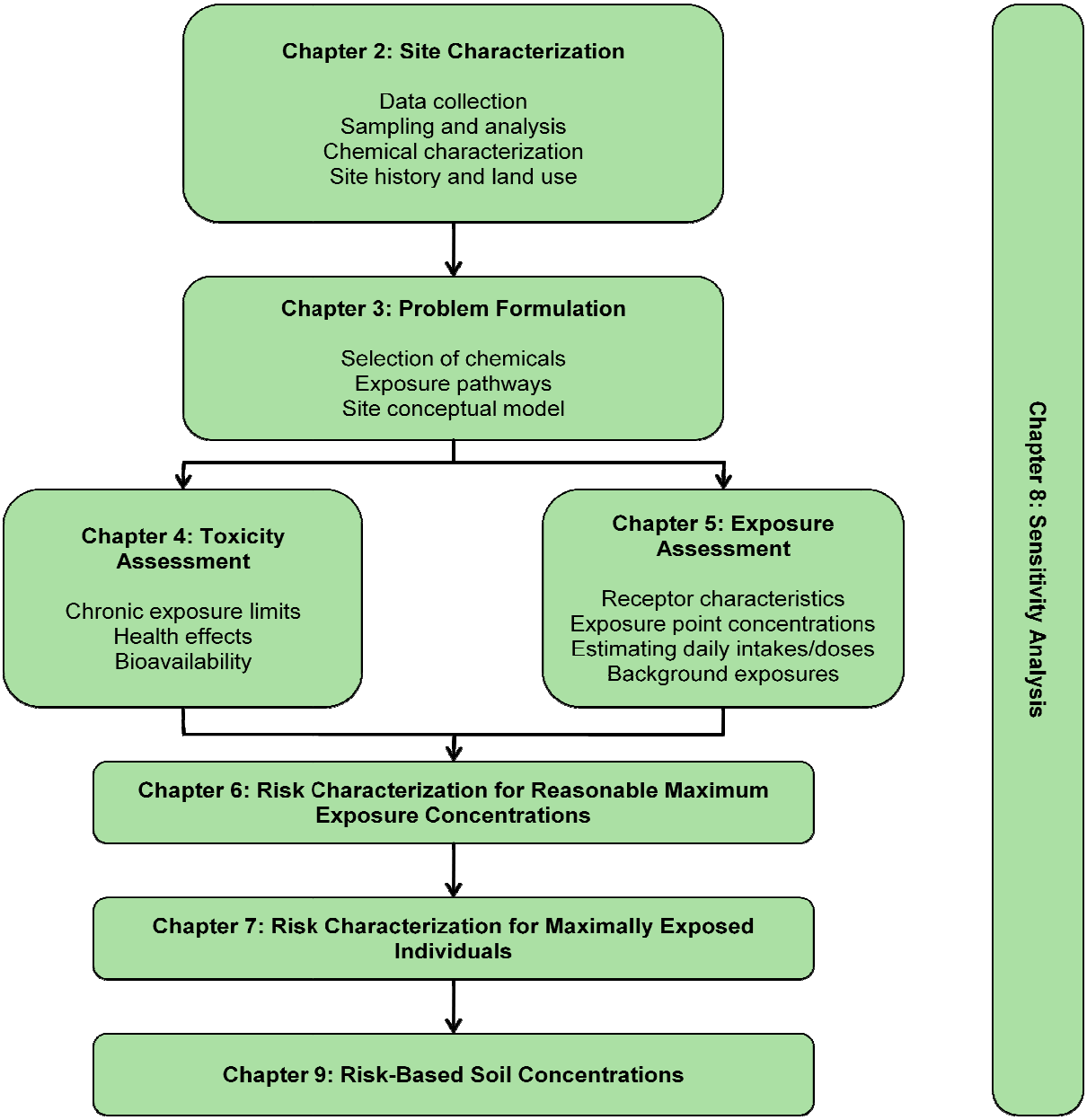
Aspect	MOE Report Approach	CBRA Approach, this report
Eating habits of infants 0 to 6 months	Infants consume solid foods based on 1970s Canadian data or are exclusively bottle fed	Infants are either exclusively breast fed or exclusively bottle fed
Activity patterns of infants 0 to 6 months	Infants exposed to outdoor soils	Infants not exposed to outdoor soils before 6 months
Concentrations of CoCs in supermarket foods	Based on Dabeka and Mackenzie's (1995) Montreal study. Study results are inconsistent with other literature	Based on concentrations measured in foods purchased locally in Port Colborne. Study results are compared to and consistent with other literature
Dietary intake of foods	Based on early 1970s data (stated by Health Canada (1994) to be out of date)	Partially based on 1996 to 1998 North-eastern U.S. data which demonstrated similar total intake to the Canadian data. Also based on intake of garden produce, local (farm) produce, local fish and game estimated based on survey of Port Colborne residents
Exposures associated with inorganic arsenic	Qualitatively evaluated	Quantitatively evaluated where possible
Exposure to CoCs in wild game and fish flesh	Not included	Measured concentrations in fish, deer and rabbit
Exposure to CoCs in local farm produce	Not included	Measured concentrations in eggs, milk and chicken
Exposures to CoCs in maple syrup	Not included	Measured concentrations in sap and syrup
Lifestyle habits of local residents	Assumed	Based on survey of Port Colborne residents
Exposures at school, work, parks and beaches	Not included	Evaluated

1.4.2 HHRA Process

The HHRA was conducted in general accordance with technical aspects of guidelines from the MOE as described in *Procedures for the Use of Risk Assessment under Part XV.1 of the Environmental Protection Act* (MOE, 2005), which includes the tasks presented in Figure 1-3. The reporting format differs from *Ontario Regulation 153/04*, to which the study is not required to conform (See Volume II, Appendix 1.18).

Protocols (sets of procedures used to specify how a given testing activity was performed) were developed by Jacques Whitford for each type of sampling. Throughout the Site Characterization stage as depicted in Figure 1-3, any protocol developed by Jacques Whitford was provided to and reviewed by, the PLC's consultant, members of the TSC and members of the PLC prior to the initiation of any work related to that protocol. One or more representatives of the PLC's consultant accompanied Jacques Whitford staff in data gathering activities to witness Jacques Whitford's collection of samples (*e.g.* soil, groundwater, surface water, ambient air, indoor air and dust, local produce, fish, wild game, farm produce, supermarket foods).

Figure 1-3: Design Approach to a HHRA



The Port Colborne HHRA used quantitative methods based on a combination of site-specific collected data and existing information found in the literature. The HHRA therefore followed a detailed quantitative assessment approach based on an extensive set of site-specific data.

1.4.3 Outline of the HHRA Report

The HHRA conducted for the Port Colborne CBRA is presented in six volumes. Volume I, presented under this cover, provides an overview of the methodology and findings of the HHRA. Volume I is not intended to convey all of the details of the analyses performed, but rather summarizes the objectives and approach, major assumptions, results, conclusions and recommendations. Volumes II through V of the HHRA Report are technical appendices that present all supporting documentation related to the specific details of the conduct of the study. These include technical appendices for exposure and risk estimations, additional results of the study, additional supporting studies, data collection protocols and raw data from field and laboratory sample analyses. Volume VI of the HHRA Report includes comments made by reviewers and the public, as well as Jacques Whitford's responses to those comments. Details of the public communication program are also presented in Volume VI. The contents of each of the supporting Volumes are as follows:

Volume II – Protocols	Provides the data collection and analyses protocols developed for and applied in, the HHRA;
Volume III – Exposure Estimates and Toxicity	Provides supporting documentation and detailed results with respect to receptor characteristics, methods of analysis, exposure estimates and assessment of toxicity;
Volume IV – Input Data - Air	Provides supporting documentation with respect to monitoring of ambient air, farming activities, indoor air and dust and soils speciation;
Volume V – Input Data – Soil, Water and Food	Provides supporting documentation with respect to hydrogeology of the Port Colborne area and studies with respect to the sampling and analysis of drinking water, beach sand and surface water, garden produce, game, fish, poultry, supermarket foods, soils and maple sap and syrup; and
Volume VI – Report Review Comments	Provides peer review comments made by the PLC's consultant, other TSC members, an independent third party peer reviewer and the public, as well as Jacques Whitford's responses outlining how these comments were addressed.

Volume I can be read as an overview report; however, readers are advised to consult all six volumes of the HHRA for a comprehensive technical review. Additional supporting appendix documentation is provided on compact disc (CD) and is referenced in the applicable sections.

Under this cover, Volume I of the HHRA report is presented in eleven chapters. A summary of each Chapter is provided below:

Chapter 1 – Introduction provides the background to the CBRA process and outlines the HHRA process, the study's objectives and the scope of work.

Chapter 2 – Site Characterization provides a historical overview of the operation of the Refinery and an overview of the Port Colborne community and local environment. A summary of the field data collection programs undertaken within the community and other data available from previous studies used to characterize the area is provided in this section.

Chapter 3 – Problem Formulation provides a summary of the identification of the CoCs (Jacques Whitford, 2001a; 2001b; 2001d), the selection of relevant human exposure pathways and the representative receptors used to characterize a range of reasonable human characteristics and exposure scenarios in the Port Colborne community. The selection of reasonable maximum exposure point concentrations for input to the Exposure Assessment is outlined.

Chapter 4 – Toxicity Assessment describes the Toxicity Reference Values (TRV) and endpoints selected for evaluation of each CoC. The treatment of relative bioavailability and uptake of the CoCs in this assessment are also discussed. A detailed Toxicity Assessment is provided in Volume III, Appendix 7 with a detailed assessment of bioavailability presented in Volume III, Appendix 8.

Chapter 5 – Exposure Assessment outlines the exposure parameters for the identified receptors. Pathways, magnitude, duration and frequency of exposure of receptors to CoCs are described. The methods for conducting the estimation of exposure are discussed and an overview of the results is provided.

Chapter 6 – Risk Characterization for Reasonable Maximum Exposure Concentrations identifies the potential for health risks to typical residents in the Port Colborne community as a population, based on conservative characteristics and lifestyle assumptions and using reasonable maximum exposure concentrations. Potential risks are quantitatively estimated and discussed.

Chapter 7 –Risk Characterization for Maximally Exposed Individuals evaluates potential risks to residents in the Port Colborne community who are likely to have the highest potential exposures. The evaluation uses conservative characteristics and lifestyle assumptions and using maximum exposure values. Potential risks to maximally exposed individuals are quantitatively estimated and discussed.

Chapter 8 – Sensitivity Analysis reviews how assumptions and data uncertainties inherent in each step of the risk assessment process are likely to impact on the results and conclusions of the assessment. Selected aspects of the assessment considered to have the greatest potential to impact the assessment findings are analyzed in greater detail, including quantitative evaluations of selected sensitivities.

Chapter 9 – Risk-Based Soil Concentrations describes the basis of and presents values for Risk-Based Soil Concentrations developed. The applicability of the developed concentrations is outlined.

Chapter 10 – Provides a **Summary** of the major findings of this study.

Chapter 11 – Provides a list of **References** cited in this report.

1.4.4 HHRA Process within the Context of the CBRA

For the CBRA, the HHRA was undertaken following a process developed and agreed to by all CBRA participants. The key steps for the HHRA included:

- Development of the Technical Scope of Work (TSOW) for the CBRA – 2nd and 3rd Quarter of 2000;
- Preliminary Site Characterisation – 2nd and 3rd Quarter of 2000;
- Development of Data Collection Protocols – 2nd and 3rd Quarter 2001;
    - PLC/TSC review of Protocols – 2nd and 3rd Quarter of 2001;
- Collection of Site-specific Data – 2nd and 3rd Quarter 2001;
- Development of Additional Studies and Data Collection Protocols – 1st and 2nd Quarter 2002;
    - PLC/TSC review of Protocols – 1st , 2nd and 3rd Quarter of 2002;
- Conduct of Additional Studies and Collection of Additional Site-specific Data – 3rd and 4th Quarter of 2002;
- Development of Data Interpretation Approach Document – 2nd and 3rd Quarter of 2002;
    - PLC/TSC review of Approach – 3rd and 4th Quarter of 2002;

- Qualitative and Quantitative Analysis of Data – 4th Quarter of 2002 and 1st Quarter of 2003;
- Preliminary Draft #1 HHRA Report – 3rd Quarter of 2003;
  - Stantec review of Preliminary Draft Report – 3rd Quarter of 2003;
- Preliminary Draft #2 HHRA Report – 4th Quarter of 2003;
  - Health Department review of Preliminary Draft Report – 4th Quarter of 2003;
- Preliminary Draft #3 HHRA Report – 3rd Quarter of 2004;
  - External Peer Review (CH2M Hill) of Preliminary Draft Report- 1st Quarter of 2005;
- Public Draft HHRA Report – May 2005;
  - PLC, TSC and public review of Draft Report– 2nd Quarter of 2005-1st Quarter 2007; and,
- Release of Final HHRA Report – 4th Quarter of 2007.

1.4.5 Key Changes From the Public Draft HHRA Report

Extensive comments on the public draft HHRA report (May 2005) were received and considered in the finalization of the study. While the details of the full comments and summaries of how these were addressed can be found in Volume VI of this report, key areas of change are summarized in Table 1-2.

Table 1-2: Summary of Selected Key Changes in the Final HHRA Report

Aspect	Comments on Draft HHRA Report	Action Taken By Jacques Whitford
Report readability and level of detail	Significant technical detail contained in main report. Report is that difficult to read, highly technical and level of detail not complete.	Report rewritten to provide more readable overview of approach and significant findings in the main text, with specific technical details only provided in appendices.
Depth of soil concentrations considered	Evaluated 0-5 cm surface soils.	Evaluated soil data available for all depths.
Dietary intake of CoCs from supermarket foods	Based on average of specific foods weighted by typical component of average diet.	Based on average of specific foods, not weighted and therefore more conservative for nickel since study design was weighted towards foods expected to be higher in nickel.
Ambient air concentrations for cobalt, copper and arsenic	Based on short term monitoring.	Based on long term monitoring by MOE and long term air modelling ground-truthed against short term monitoring data.
Differentiation of oral bioavailability by soil type	Differentiated fill, clay, organic and sandy soils for oral bioavailability	Selection of conservative oral bioavailability values reflective of highly varied characteristics of amended lawn and garden soils as well as range of native soil characteristics.
Oral bioavailability of nickel (amount of ingested nickel that reaches the blood stream)	Based on findings of study of rats fed Port Colborne soils.	Based on weight of evidence approach involving detailed review of human and animal literature, nickel speciation, animal and non-animal based laboratory studies.
Oral bioavailability of cobalt and copper (amount of ingested copper or cobalt that reaches the blood stream)	Based on methodology modified for this application.	Based on weight of evidence approach considering both modified and non-modified methods and larger pool of data.
Evaluation of maximum exposed individuals	Maxima included in Sensitivity Analysis	Maxima removed from Sensitivity Analysis and more clearly presented in Chapter 7.
Interpretation of risks evaluated for arsenic	Quantitative evaluation of non-carcinogenic risks	More comprehensive evaluation of uncertainties in arsenic oral exposures and review of reliability of findings. Since findings concluded to be highly uncertain, quantitative risk estimations were removed.
Coding of calculations	Calculations implemented and checked internally.	Calculations checked, line by line, by third party external consultant with specialization in human health risk assessment and statistical sciences.
Selection of Risk-Based Soil Concentrations	Developed using arbitrary uncertainty factors	Arbitrary factors removed and key factors replaced by conservative inputs based on real data.

1.4.6 Objectives of this HHRA

The primary objective of the HHRA is to evaluate current risks to human health in Port Colborne due to the presence of CoCs in soils resulting from historical Refinery emissions. The HHRA has the follow-up objective of estimating the environmental concentrations of CoCs in soil at which no adverse effects on human health are expected to occur.

1.4.7 Scope of Work

This HHRA focuses on human health in the Port Colborne community. The CoC exposure incurred by individuals accessing restricted (*i.e.*, signed or fenced) areas of the Inco property covered under the *Mining Act* are not included in this assessment.

The HHRA focuses on human health in areas of the community where one or more of the CoCs exceed MOE generic guidelines (MOE, 1997) or standards (Ontario, 2004b). The HHRA acknowledges that sampling on every property in the community is not necessary to the estimation of CoC levels protective of human health.

The CoCs considered in the HHRA are nickel, copper, cobalt and arsenic. The identification and selection of CoCs within the CBRA are reported elsewhere (Jacques Whitford, 2001a; 2001b; 2001d).

1.4.8 Community Approach

A general overview of the approach to the HHRA assessment of community wide health risks is provided below. Where required, details on methodology are provided in subsequent sections of the report. A complete discussion of the study approach to data analysis and interpretation is provided in Volume II, Appendices 1.14 through 1.18.

For the purposes of characterization, the Port Colborne community was divided into different land and receptor classifications based on:

- Whether concentrations of CoCs in soils in a general area of the community exceed the MOE Table A guidelines (MOE, 1997; now known as Table 2 standards: Ontario, 2004b);
- General ranges of nickel concentrations in soils;
- Land use;
- Soil type;
- Source of drinking water; and
- Socio-economic considerations (*e.g.* school zones, general housing types, *etc*.)

Understanding of community complexity, as characterized by the above considerations and measured CoC soil concentrations, developed progressively throughout the HHRA process. The final selection of zones and subdivision of communities therein, reflects the aggregate sum of information acquired throughout the HHRA and characterization of the community.

Within the community, potential health risks are evaluated for

1. Typical exposures representative of most people in the community
2. Maximally exposed individuals represented by specific scenarios for the highest measured concentrations at individual properties in the community

Further detail is given in Chapter 3, Section 3.1.

2.0 SITE CHARACTERIZATION

This section provides a characterization of the Port Colborne Community Based Risk Assessment (CBRA) Study Area, in the form of an overview of the human environment within the Study Area and the natural environment as it may impact on human exposures. This Site Characterization serves as an introduction to the history of contamination in the area, the nature of the community and the Chemicals of Concern (CoCs). Additionally, behaviour, fate, and transport of the CoC's and concentrations in various environmental media have been reviewed.

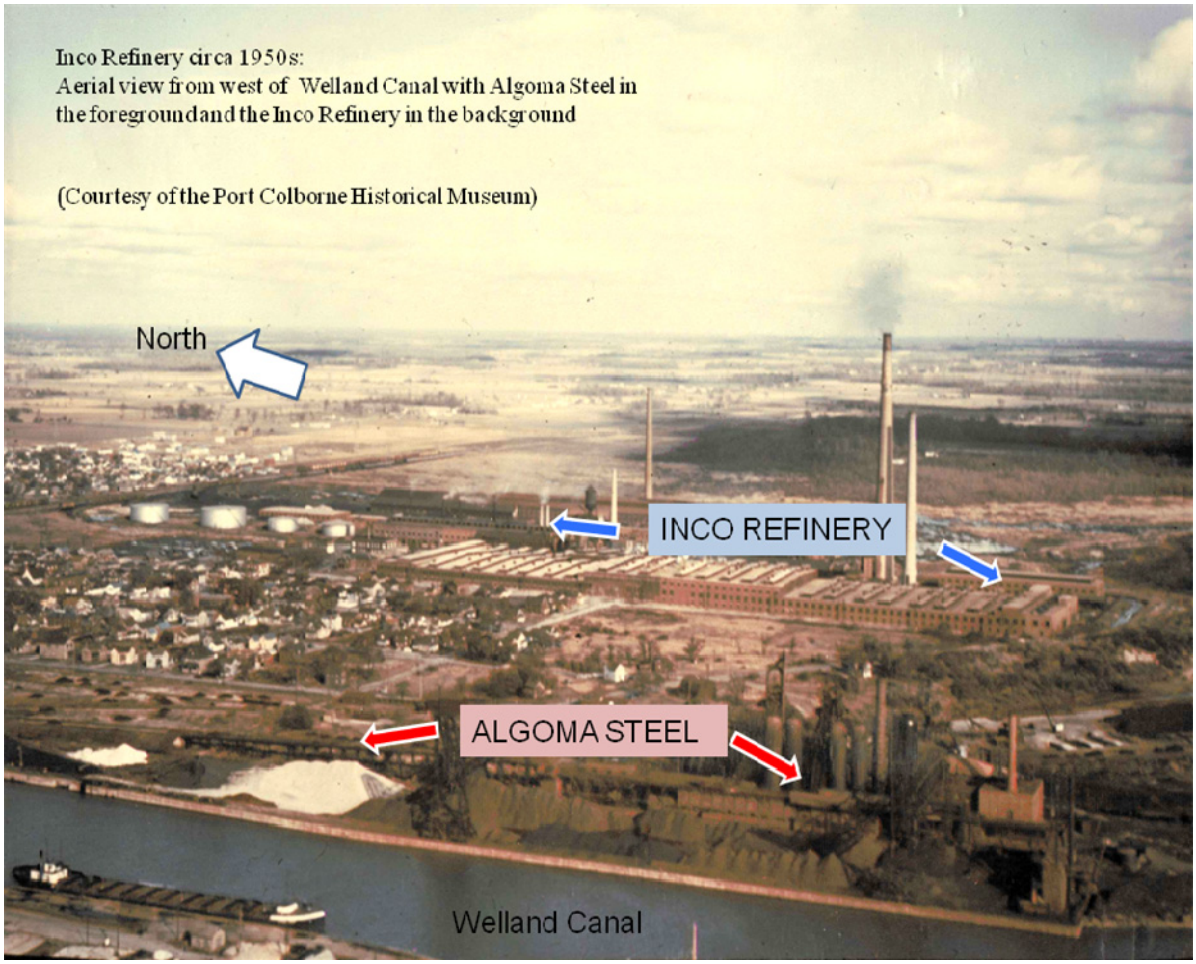
The Site Characterization detailed in this Chapter covers the following topics:

- Historical overview of contamination within the Study Area;
- Identification of the Study Area;
- CBRA Chemicals of Concern;
- Land use;
- Soil parameters;
- Hydrogeology and water quality
- Air quality;
- Local foods; and,
- Supermarket foods.

Information obtained from the Site Characterization is carried forward to Chapter 3 for use in developing the Site Conceptual Model.

2.1 Historical Overview of Contamination

Vale Inco Limited (Inco) began operations in the City of Port Colborne in 1918. Historical operations at the Inco Refinery produced particulate emissions that subsequently resulted in atmospheric deposition of these particulates on soils surrounding the Inco Refinery.



2.1.1 Process Description

When the Port Colborne Refinery was first constructed, operations were conducted using the Orford process for the high temperature extraction of copper-nickel matte supplied from the Copper Cliff mine. This process separated nickel subsulphide “bottoms” from copper sulphide “tops”, which were passed to additional on-site operations. The nickel subsulphide "bottoms” from the Orford process underwent leaching, roasting, reducing and fire refining to produce nickel ingots. The copper sulphide “tops” were reduced to produce blister copper for further refining off-site. The primary operations for these processes included calcining furnaces for roasting, mechanical separation, grinding and crushing, and sintering to reduce the sulphur content of the nickel and copper products.

2.1.1.1 Orford Process

The original Orford process operations consisted of three cupola furnaces (two for nickel, one for copper), three copper reverberatory furnaces, three copper converter stands and two slag reverberatory furnaces. The combined air emissions from these operations were routed through two common plenums to a Cottrell precipitator that discharged to a 350-foot stack. Significant fugitive losses from the furnaces were associated with these processes, and the Cottrell precipitator was shut down in December 1920.

In the 1930s, the Orford process in Port Colborne was discontinued and transferred to the facility in Copper Cliff. The Refinery then focused on the coal fired reverberatory furnaces and calcining furnaces necessary to process the Orford "bottoms" received from Copper Cliff.

2.1.1.2 Leaching, Calcining, and Sintering

The leaching, calcining and sintering operations were designed to **oxidize** the nickel subsulphide "bottoms" created by the Orford process (Doll *et al.*, 1990).

The calcining furnaces were part of the copper-nickel separation leaching operations conducted to selectively remove the nickel and copper as **oxides**. Incoming material was ground, crushed and partially roasted on the upper deck of the calcining hearth furnace. The partially roasted material was subsequently mixed with salt for chloridizing the copper and nickel and transferred to a series of leaching tanks. At this stage, the majority of the copper was removed, and left over material was impure **nickel oxide**. Subsequent roasting at high temperatures (1,200°C) and additional leaching resulted in a more pure nickel **oxide material**, with an approximate composition of 77.5% nickel, 0.1% copper, 0.25% iron and 0.008% sulphur.

Sintering operations were intended primarily as a desulphurization step for the conversion for nickel sulphides to **nickel oxides**, with the sulphur content being reduced from approximately 25% to 0.4%. The incoming matte and nickel oxide materials were crushed through a series of jaw crushers and cone crushers, prior to high temperature roasting to **reduce** the amount of sulphur. The sintering machines were operational from 1926 to 1958 (Doll *et al.*, 1990).

The calcining and sintering operations were known to produce large amounts of dust (Doll *et al.*, 1990), and air emissions from those two operations, as well as from grinding and material handling, were therefore routed through an underground flue to a large dust chamber for the inertial separation of particulate matter before being exhausted to the atmosphere through a dedicated 350 foot exhaust stack.

2.1.1.3 Reverberatory Anode Furnaces

The crude **oxide**, or sinter, was further processed on-site using a series of reverberatory type anode furnaces. These operations consisted of high temperature reduction of the **nickel oxide** to produce impure nickel metal, which was cast into nickel ingots or nickel shot for electrolytic nickel production. Fugitive dust generated by this process would therefore be **high in oxidic species of nickel**.

2.1.1.4 Electro-Refining

In the mid 1920s, electro-refining, or electrolysis, operations were introduced, which allowed for the production of nickel in electrolytic tanks, gradually removing the need for fire refining. Over time, the proportion of fire refining conducted by the facility was gradually reduced in favour of an increased emphasis on electro-refining. Unlike fire refining operations, electrolytic refining, being a low temperature electrochemical process, has a negligible potential to result in any significant air emissions. Because the electrolysis process takes place in water, however, any nickel species emitted to the air from the electrolytic tanks would likely be soluble, and not oxidic or sulphidic.

The electrolysis of nickel ceased in 1984, and current operations at the Refinery now consist primarily of cobalt electrolysis, as well as precious metal refining.

2.1.2 Nickel Air Concentrations INSIDE the Refinery

The description of the processes in use at the Port Colborne Refinery, indicates that the speciation of nickel in air around the calcining and sintering operations would consist mostly of **nickel oxides** with some sulphidic nickel, while the speciation around the electrolysis tanks would be mostly soluble nickel. This is supported by the work of the International Committee on Nickel Carcinogenesis in Man (ICNCM, Doll *et al.*, 1990); Table 2-1 presents the ICNCM's summary of estimated air concentrations in various departments in the Port Colborne nickel refinery (from Doll *et al.*, 1990).

Table 2-1: Estimated Speciation of Nickel in Indoor Air in Refinery

Department		Total (mg Ni/m^3)	Metallic (mg Ni/m^3)	Oxidic (mg Ni/m^3)	Sulphidic (mg Ni/m^3)	Soluble (mg Ni/m^3)
Sinter Plant [a]	1926-1935	30 to 80	0	20 to 40	10 to 20	<3
	1936-1945	5 to 25	0	3 to 15	2 to 10	<3
	1946-1958	8 to 40	0	5 to 25	3 to 15	<3
Electrolysis	General	<1	<0.5	<0.2	<0.5	<0.3
	Pumping Anode Slimes / Washing Anode Scrap	<4	<0.2	<0.2	<0.8	1 to 3
Nickel Anode, Foundry Additives		<5	<0.2	<5	<5	<0.05
Yard, Transportation		<1	<0.2	<1	<1	<0.2

Notes:

Source: Doll *et al.*, 1990.

The sinter plant estimates were used by Doll *et al.* to represent the entire leaching, calcining, and sintering department, even though the concentrations presented here were strictly representative of only the sintering plant.

Doll *et al.* (1990), rated oxidic and sulphidic nickel concentrations in the sinter plant as "high or very high," while exposures to soluble nickel in the sinter plant were rated as "low to medium" (Doll *et al.*, 1990). It can also been seen in Table 2-1 that greater than 60% of nickel in the indoor air in the sinter plant was estimated by Doll *et al.* (1990) to be present in **oxidic species**. The remaining 40% of nickel in the indoor air in the sinter plant was estimated as sulphidic species.

In the electrolysis operation, most of the nickel species were estimated to be present at much less than their concentrations in the sinter plant. The exception to this rule was soluble nickel, which was elevated for the anode slime pumping and anode washing operations. Indeed, the majority of the total nickel was estimated to derive from soluble nickel for these two anode-related operations.

For the other departments in Table 2-1, no firm conclusions could be drawn about the speciation of nickel in the Refinery air, as only upper limits on air concentrations were estimated.

2.1.3 Emissions

An assessment of historical emissions from the Inco Refinery (Jacques Whitford, 2001c) has indicated that peak total particulate air emissions occurred during the period of operation spanning 1918 to 1930, when total emissions exceeded 1,300 tonnes/year (Figure 2-1). Nickel particulate emissions in the same period were estimated at 700 tonnes/year (Figure 2-2). Refinery emission levels were subsequently reduced to approximately 400 tonnes/year in the period 1930 to 1960, and further reduced to approximately 60 tonnes/year airborne particulate from 1960 to 1980 (Jacques Whitford, 2001c).

Over a more than forty-year period, from 1918 to 1960, the heaviest atmospheric deposition of particulate matter occurred predominantly northeast (prevailing wind from the southwest) of the Inco Refinery. During this time, the particulate matter accumulated primarily in surface soils in this area. From the 1980s on, and particularly through the 1990s to the present, the potential harmful environmental effects on local biota due to direct atmospheric deposition were greatly reduced. The concentrations of historic accumulated particulate matter in the local surface soils, however, have likely remained unchanged from the late 1970s to the present (McLaughlin and Bisessar, 1994).

The period up to 1930 accounted for roughly half of the total nickel emissions over the operating life of the Refinery.

2.1.4 Environmental Fate

While sulphidic nickel may have been significant in the Refinery indoor environment during the sinter plant operation, these nickel sulphides were sintered at high temperature in the refinery and converted to nickel oxides. At high temperatures, nickel sulphide decomposes readily though a desulphurization process, producing sulphur oxides, e.g.:

$$2Ni_3S_2 + 7O_2 \Rightarrow 6NiO_2 + 2\ S_2O$$

$$4NiS + 5O_2 \Rightarrow 4NiO_2 + 2S_2O$$

With oxidic nickel already accounting for greater than half the nickel species in indoor air of the sinter plant, high temperature emissions would have led to further oxidation of the nickel sulphides in the emissions stream and oxidic forms of nickel as the dominant nickel species in the environment surrounding the refinery. The latter was confirmed through analytical speciation techniques involving Scanning Electron Microscopy (SEM) and high energy X-Ray Absorption Spectroscopy (See Section 2.5.3) that indicated that the forms of nickel in Port Colborne soil are almost entirely made up of nickel oxides/hydroxides, along with lesser amounts of nickel

complexes with iron and other metals, and metallic nickel. Oxidic forms of nickel are insoluble. SEM photos showed visual evidence of oxidic nickel as either liberated spheres within the soil matrix, or as spheres of oxidic nickel attached to the silicate matrix of the soil. No evidence of nickel sulphides in soil could be found by SEM analyses, or by analyses using X-Ray Absorption Spectroscopy.

Over time, some of the oxidic nickel weathers and soluble nickel is released to the natural environment. Environment Canada and Health Canada (1994) indicate that preferential absorption of nickel onto iron and magnesium occurs in soil; thus it is expected from this association that the soil nickel bioavailability would be low.

Soluble nickel in the environment is washed out of the air or soil by precipitation and readily ionizes, being transported to lakes, rivers and groundwater and eventually deposited in sediments or soils, bound to iron and magnesium (*i.e.*, no longer soluble) (Environment Australia 2001). Significant levels of soluble nickel would thus not be expected in Port Colborne soils after the decades that have passed since local nickel Refinery operations ceased. This also has been confirmed by the soil nickel speciation conducted.

Figure 2-1: Historical Particulate Matter (PM) Emissions of the Inco Refinery, Port Colborne

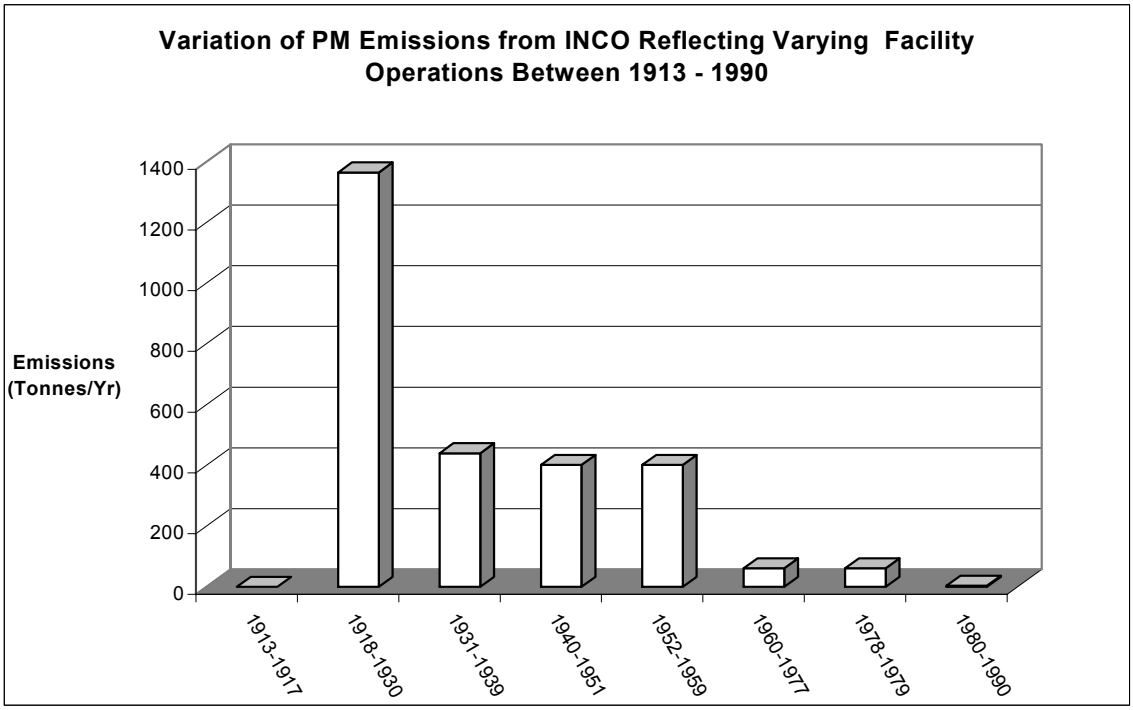
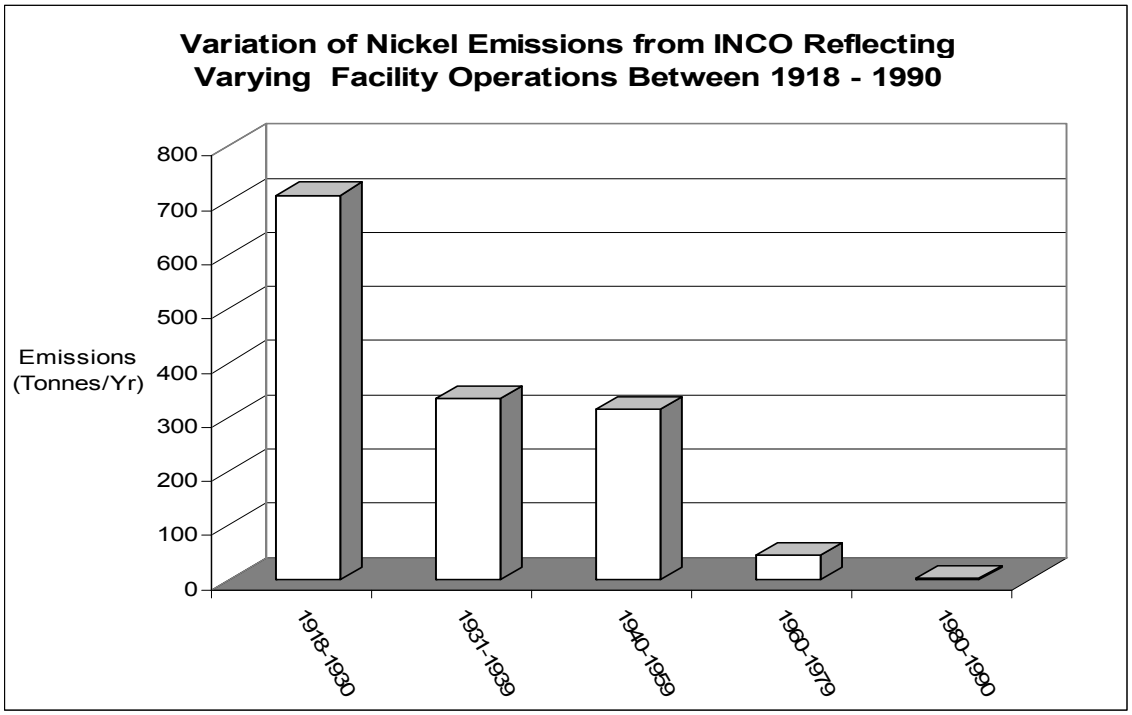


Figure 2-2: Historical Emissions of Nickel from the Inco Refinery, Port Colborne



2.2 Identification of the Study Area

The Study Area in this assessment is defined as the City of Port Colborne and adjacent areas where soil concentrations are greater than one or more of the applicable MOE Table A guidelines (MOE, 1997; or Table 2 standard, Ontario, 2004b) for the CoCs in soil. Because soil nickel concentrations exceed the MOE guideline in more areas, and by greater amounts, than do other CoCs, nickel was used as an indicator compound of CoC soil contamination. Areas in the vicinity of soil nickel concentrations that exceed 200 mg/kg (MOE Table A guideline for nickel) are considered to be within the Study Area (approximately 29 km^2). The entire City of Port Colborne is considered in the HHRA to account for those residents who may frequent areas both inside and outside of the Study Area.

The boundaries of the Study Area cannot be clearly defined and are recognized as being somewhat arbitrary, but necessary for the purposes of conducting the study. In Stage 2 of the CBRA, the designation of properties for remedial action must account for the uncertainties of boundaries; however, this is of less importance in conducting the HHRA.

CBRA data for the nickel, copper, cobalt and arsenic concentrations in the upper 5 cm of Study Area soil were compiled from reports by the MOE (1998; 2000a; 2000b; 2000c; 2000d; 2001a; 2001b; 2002), AMEC (2001a; 2001b; 2001c) and additional sampling done by Jacques Whitford (2001a). All the data used in this assessment are presented in Volume V, Appendix 20, and all soil sampling locations are indicated in Figure 2-3. The distribution of CoC concentrations in soils of selected woodlots is shown in Figure 2-4. The distributions of nickel, copper, cobalt and arsenic in soils in open spaces of the Study Area are shown in Figures 2-5 through 2-8, respectively. Concentrations of CoCs in woodlots (Figure 2-4) that are not characteristic of the surrounding open spaces are excluded from the contour figures (Figures 2-5 to 2-8). The higher concentrations of CoCs in woodlots are acknowledged as significant and are considered separately in both the HHRA and ERA.

The maximum degree to which CoC concentrations exceeded the guideline values are generally greater for nickel than for other CoCs (Figures 2-5, 2-6, 2-7 and 2-8). The sole exception to this pattern is an area located to the west of the Canal where concentrations of copper exceeded those of nickel in several soil samples.

2.3 CBRA Chemicals of Concern

For the Community Based Risk Assessment (CBRA), various studies and soil investigations were done to evaluate all potential relevant Chemicals of Concern (CoCs), namely nickel, copper, cobalt, and arsenic that originated from the Inco Refinery. The Study Area has also been assessed to determine if emissions from other industrial sources may have contributed significantly to potential CoCs (Jacques Whitford, 2001a).

For the CBRA, the definition of a CoC is a chemical found in Port Colborne soils originating from the Inco Refinery where **all** of the following conditions are met:

Condition 1) Chemicals that were historically used or generated by the Inco Refinery or its processes, **and**

Condition 2) Chemicals that are present at a community level at concentrations greater than MOE generic effects-based guidelines (MOE, 1997), **and**

Condition 3) Chemicals whose presence in soil shows a scientific linkage to the historical operations of the Inco Refinery.

Note that the MOE generic effects-based guidelines, as defined in Condition 2 refer to the MOE Table A Generic Guidelines (MOE, 1997). For the CoCs in the CBRA, these are the same as the more recent MOE Table 2 standards (Ontario, 2004b).

Documentation on the studies and investigations done to evaluate each of the three Conditions are as follows:

- Condition 1, CoC Identification using an Emissions Inventory and Dispersion Modelling dated November 23, 2001 (Jacques Whitford, 2001c);
- Condition 2, Potential CoC Identification using Soil Chemical Concentration Data in Exceedance of MOE Generic Guidelines dated November 23, 2001 (Jacques Whitford, 2001a); and
- Condition 3, Potential CoC Identification using Statistical Analyses dated November 16, 2001 (Jacques Whitford, 2001b) and CoC Identification using an Emissions Inventory and Dispersion Modelling dated November 23, 2001 (Jacques Whitford, 2001c).

Jacques Whitford's evaluation of potential CoCs in Port Colborne-area soils concluded that the CoCs in the Port Colborne CBRA are nickel, copper, cobalt and arsenic.

Arsenic was measured as total arsenic in all media evaluated in this study. No speciation of arsenic was undertaken. The potential presence of organic arsenic and the impact on the assessment outcomes were evaluated in the Sensitivity Analysis presented in Chapter 8.

2.4 Land Use

Land use information was obtained from a number of sources as outlined in Table 2-2. Land use zoning shown in Figure 2-9 include

- Commercial/Industrial
- Recreational
- Residential
- Schools
- Woodlots, Parkland, and
- Agricultural

Victoria Playground

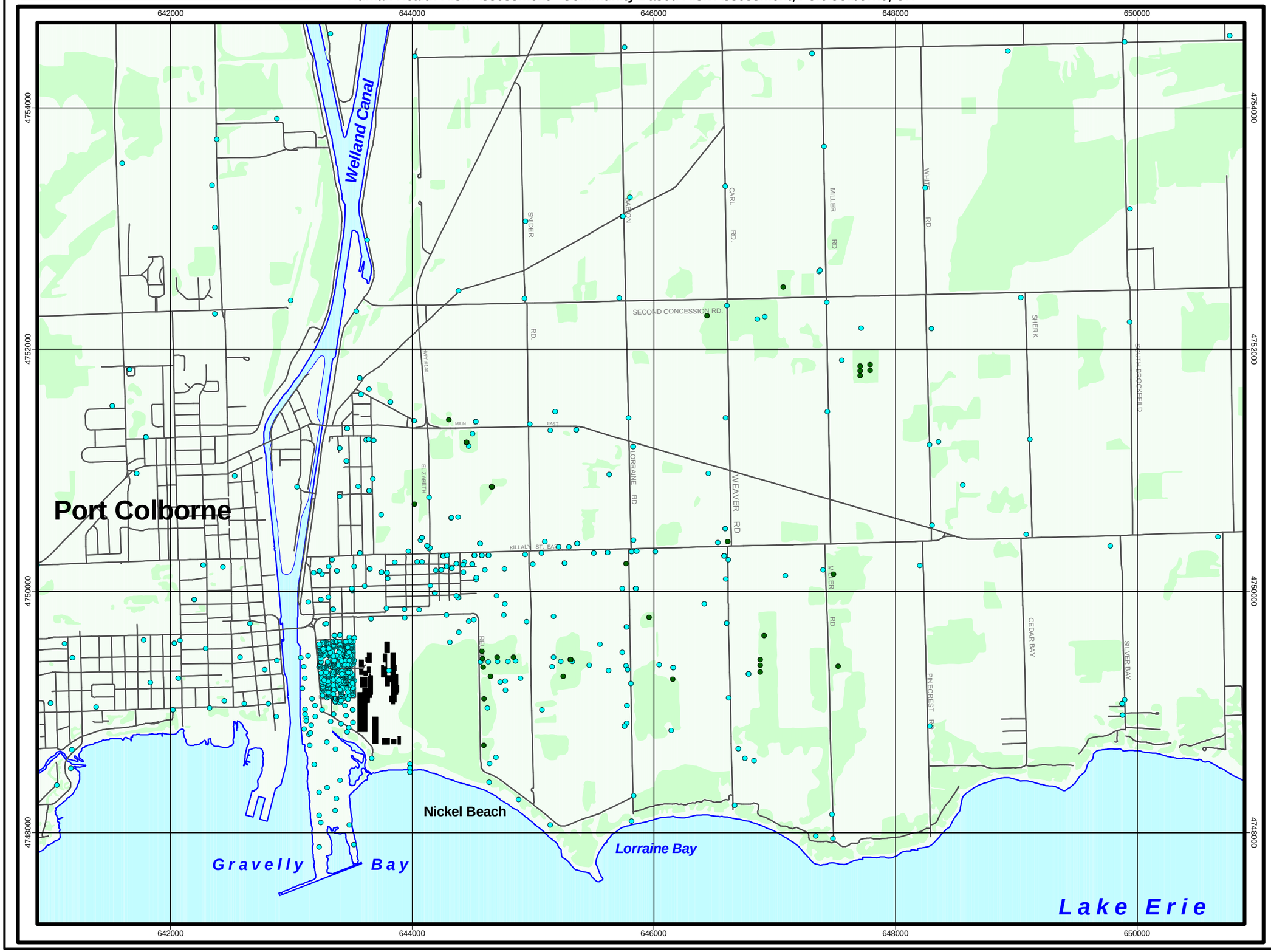
For the purposes of this assessment, woodlots and parkland were evaluated as one land use, namely recreational, recognizing that these areas are frequented by a variety of people for hiking, etc. Beaches are depicted in Figure 2-9 as being recreational land use; however, beaches were evaluated separately from the recreational land uses in the assessment due to the unique nature of beach sands compared to other soils. In the land use zoning depicted on Figure 2-9, residentially zoned areas exist within largely agricultural areas. People living in these areas may be exposed on their entire property regardless of the portion specifically zoned for construction of their house versus agricultural. Residential and agricultural land uses in these areas were therefore pooled for the purposes of the HHRA.

Table 2-2: Summary of Sources of Information on Land Use

Reference Material	Source	Details
Digital Air Photos	Regional Municipality of Niagara (April 2000a) Public Works Department- Operational Support Services	Flown April 26th 2000 From 1:20,000 Aerial Photography
Southern Ontario Topographic Maps	Department of Energy Mines and Resources, Surveys and Mapping Branch	(2000)
Digital Zoning Maps	Regional Municipality of Niagara, Public Works Department- Operational Support Services	(2000b) CAD maps for roads, sewer lines, property boundaries, property buildings, woodlots, shorelines, etc.
Zoning By-Law (1996)	City of Port Colborne, City Planning Office	Zoning By-Law 1150/97/81 Consolidation of zoning by-law 1150/97/81 (and subsequent amendments) as approved by the Ontario Municipal Board on March 19th 1984. Updated on January 13th 1992.
Municipal Assessment roles	City of Port Colborne (2001) City Planning Office	Names, addresses and zoning code of every property in Port Colborne
Inco property plan	Vale Inco Ltd.	Vale Inco Ltd. Port Colborne Outlying Property Plan, Drawing 70-052-B-31413
Maps and school zone information	District School Board of Niagara (2002a)	Facsimile, Apr. 9, 2002, Planning & Transportation Dept.
Maps and school zone information	Niagara Catholic District School Board	Facsimile, Apr. 24, 2002, Plant Dept.
Elementary school boundaries map, school year 2001-02	District School Board of Niagara (2002b)	Email, Apr. 8, 2002. Map dated July 2001, Planning & Transportation Dept.
MOE school assessment report	Ontario Ministry of Environment	MOE, 2000d. *Phytotoxicology Soil Investigation: School Yards and Beaches Port Colborne (April 2000)*

Figure 2-3

Soil Sampling Locations Port Colborne, ON



0 500 1000 1500

Metres

N

Legend

Sampling Locations
- Woodlot
- Open Space

Topographic Features
- Woodlot
- Inco Refinery
- Road

Job Number: ONT34644
Date: October 2003
Dwn by: C. Amirault
Approved by: Kevin Wong

Map Parameters
Projection: UTM
Datum: NAD 83
Scale 1 : 30,000

Regional NIAGARA

Jacques Whitford
Consulting Engineers
Environmental Scientists
Risk Consultants

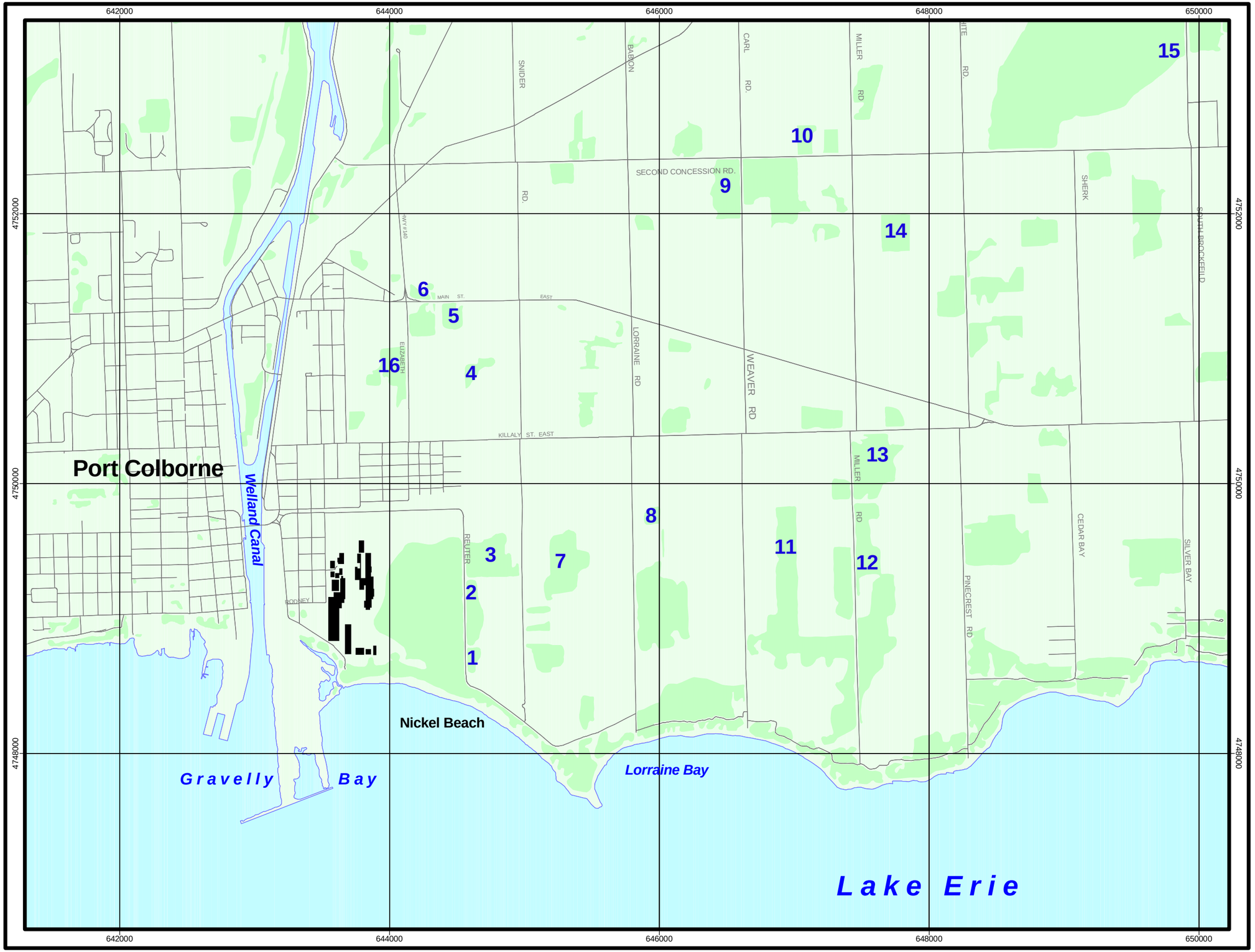


Figure 2-4

CoC Concentrations in Selected Woodlot Soils (0-5 cm Deep) Port Colborne, ON

0 0.5 1 1.5

Kilometres

N

Woodlot Number	Calculation	Soil CoC (mg/kg) from 0-5 cm deep			
		Ni	Cu	Co	As
1	*	12,900	1,453	211	92.5
2	*	22,700	2,755	311	127.5
3	Maximum	33,000	3,930	427	137
	Mean	15,257	2,094	218	82.2
	SD	9,290	1,160	125	38.5
	n	11			
4	Maximum	4,650	320	56	16
	Mean	2,530	227	39	13.1
	SD	1,274	63	12	2.5
	n	5			
5	Maximum	3,100	270	65	16
	Mean	2,166	200	43	13.4
	SD	830	59	16	2.1
	n	5			
6	*	780	106	17	8.2
7	Maximum	4,745	680	79	45
	Mean	2,498	343	47	23.5
	SD	1,249	173	20	9.5
	n	9			
8	*	2,025	252	40	14.0
9	*	1,505	176	23	7.4
10	*	550	73	16	7.7
11	Maximum	1,070	125	28	15
	Mean	642	94	19	7.7
	SD	325	30	6	5.2
	n	4			
12	*	288	125	12	8.2
13	*	709	95	18	6.9
14	Maximum	2,110	275	57	12
	Mean	1,161	162	33	9.0
	SD	716	89	19	3.0
	n	5			
15	*	431	80	17	5.4
16	*	4,130	436	70	29.9

* indciates a value based on the results of one soil sample that was collected and chemcially analysed.

CoC Values in selected woodlots are based on MOE woodlot data (2000), and data collected by Jacques Whitford for the CBRA.

Inco Refinery
Woodlot
Road

Job Number: ONT34644
Date: October 2003
Dwn by: C. Amirault
Approved by: Kevin Wong

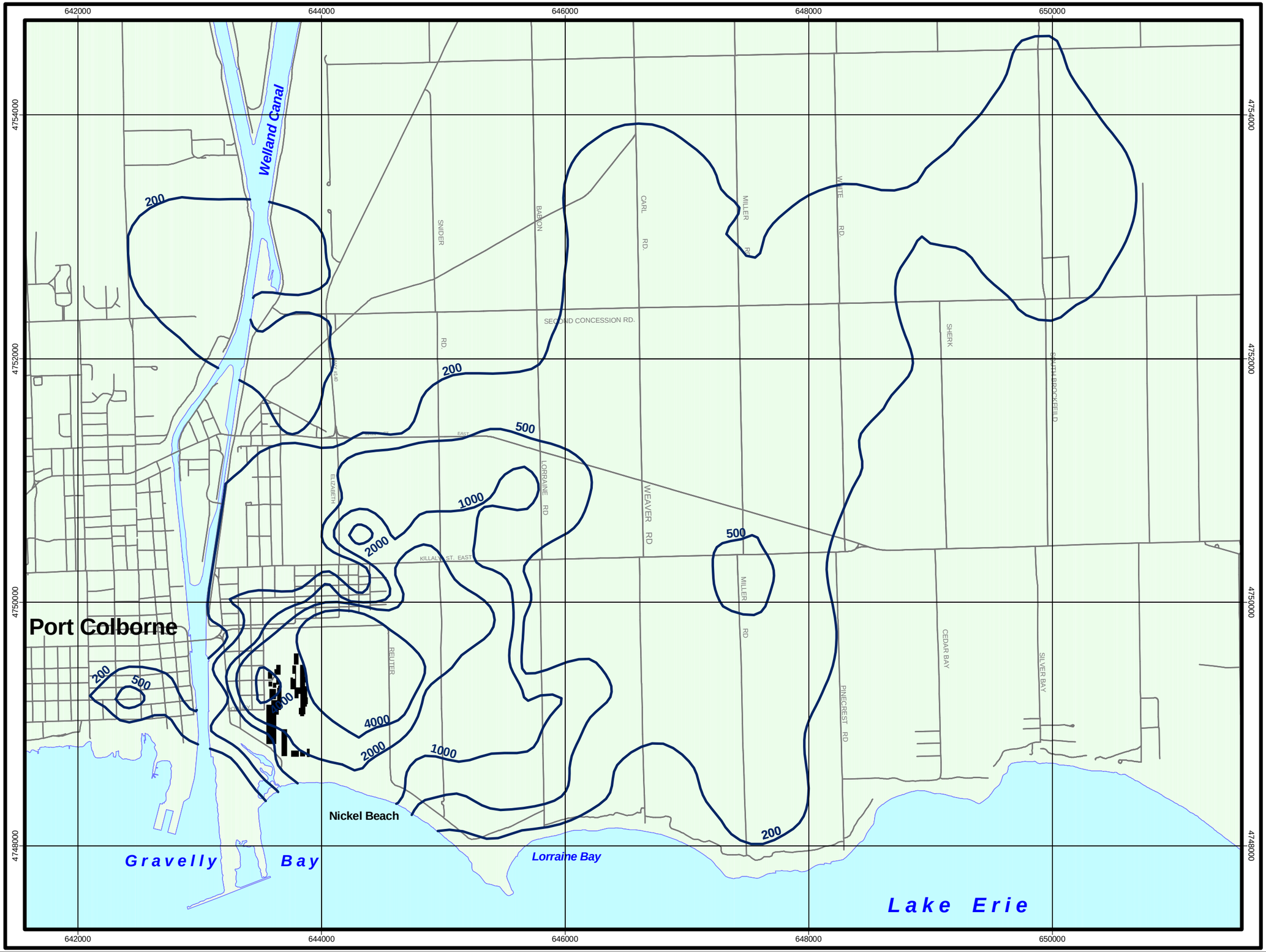
Map Parameters
Projection: UTM
Datum: NAD 83
Scale 1 : 27,500

Regional NIAGARA

Jacques Whitford
Consulting Engineers
Environmental Scientists
Risk Consultants

Figure 2-5

Nickel in Soils (0-5 cm deep) Port Colborne, ON



0 500 1000 1500
Metres

N

Legend

Nickel Contours
200, 500, 1000, 2000 and 4000 mg/kg

Topographic Features
- Inco Refinery
- Roads

The approximation is based on:
- 0-5cm surface soil data from MOE 1999, MOE 2000 (Rodney Street Community)
- AMEC 2001 (Seaway Properties)
- JWEL 2001 Programs

Job Number: ONT34644
Date: October 2003
Dwn by: C. Amirault
Approved by: Cecile Willert

Map Parameters
Projection: UTM
Datum: NAD 83
Scale 1 : 30,000

Regional NIAGARA

Jacques Whitford
Consulting Engineers
Environmental Scientists
Risk Consultants

Figure 2-6

Copper in Soils (0-5 cm deep) Port Colborne, ON

642000 644000 646000 648000 650000

4754000 4752000 4750000 4748000

Welland Canal

SNIDER RD.
BARRON
CARL RD.
MILLER RD
WHITE RD.
SHERK
SOUTH BROCKFIELD
SECOND CONCESSION RD.
HWY #140
MAIN ST. EAST
ELIZABETH
LORRAINE RD
WEAVER RD
KILLALY ST. EAST
REUTER
MODEY
MILLER RD
PINECREST RD
CEDAR BAY
SILVER BAY

Port Colborne

200
500
1000

Nickel Beach

Gravelly Bay

Lorraine Bay

Lake Erie

0 500 1000 1500
Metres

N

Legend

Copper Contours
200, 500 and 1000 mg/kg

Topographic Features
- Inco Refinery
- Roads

The approximation is based on:
- 0-5cm surface soil data from MOE 1999, MOE 2000 (Rodney Street Community)
- AMEC 2001 (Seaway Properties)
- JWEL 2001 Programs

Job Number: ONT34644
Date: October 2003
Dwn by: C. Amirault
Approved by: Cecile Willert

Map Parameters
Projection: UTM
Datum: NAD 83
Scale 1 : 30,000

Regional NIAGARA

Jacques Whitford
Consulting Engineers
Environmental Scientists
Risk Consultants

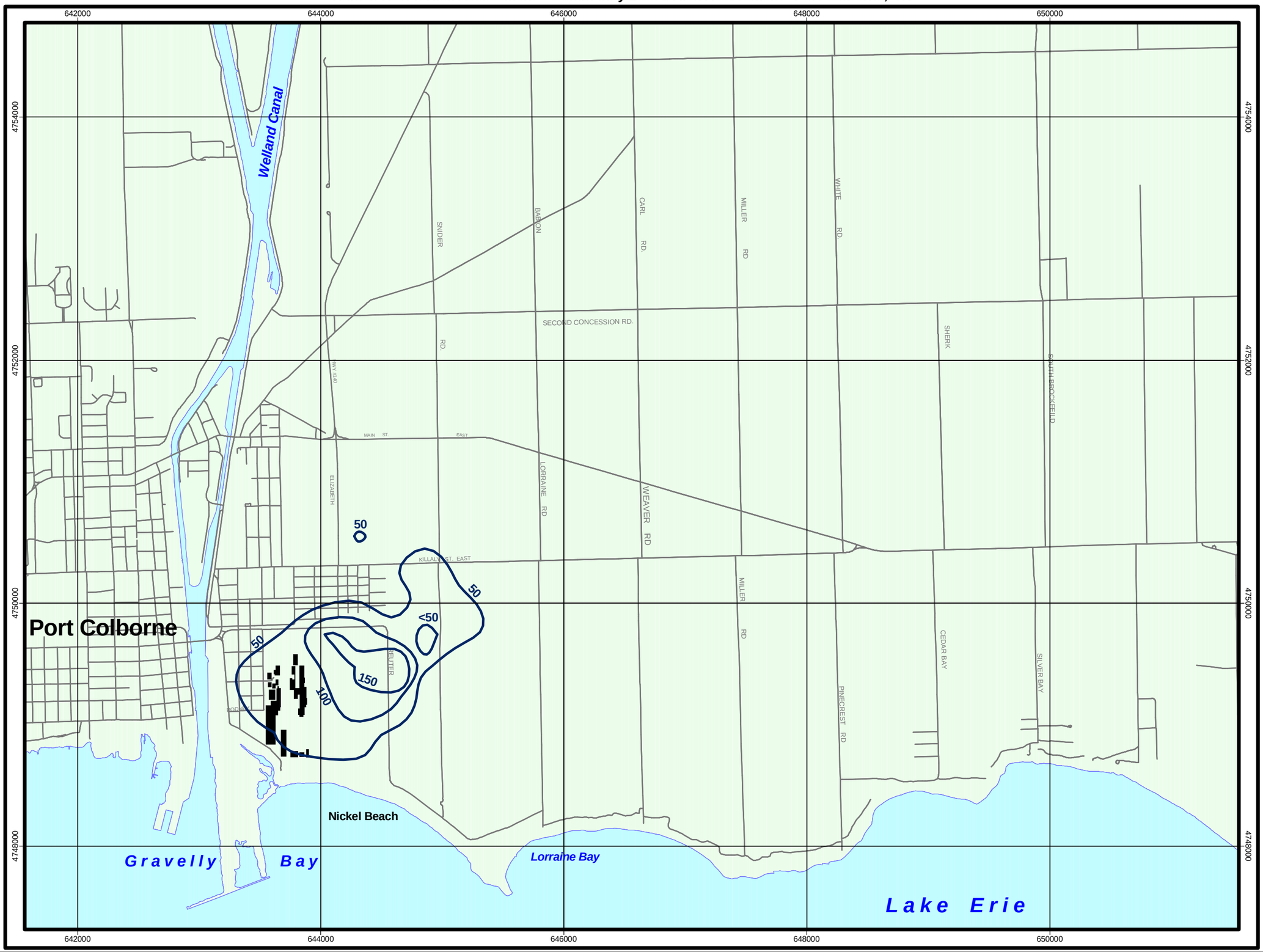


Figure 2-7

Cobalt in Soils (0-5 cm deep) Port Colborne, ON

0 500 1000 1500

Metres

N

Legend

Cobalt Contours

50, 100 and 150 mg/kg

Topographic Features

Inco Refinery

Roads

The approximation is based on:
- 0-5cm surface soil data from MOE 1999, MOE 2000 (Rodney Street Community)
- AMEC 2001 (Seaway Properties)
- JWEL 2001 Programs

Job Number: ONT34644
Date: October 2003
Dwn by: C. Amirault
Approved by: Cecile Willert

Map Parameters
Projection: UTM
Datum: NAD 83
Scale 1 : 30,000

Regional NIAGARA

Jacques Whitford

Consulting Engineers
Environmental Scientists
Risk Consultants

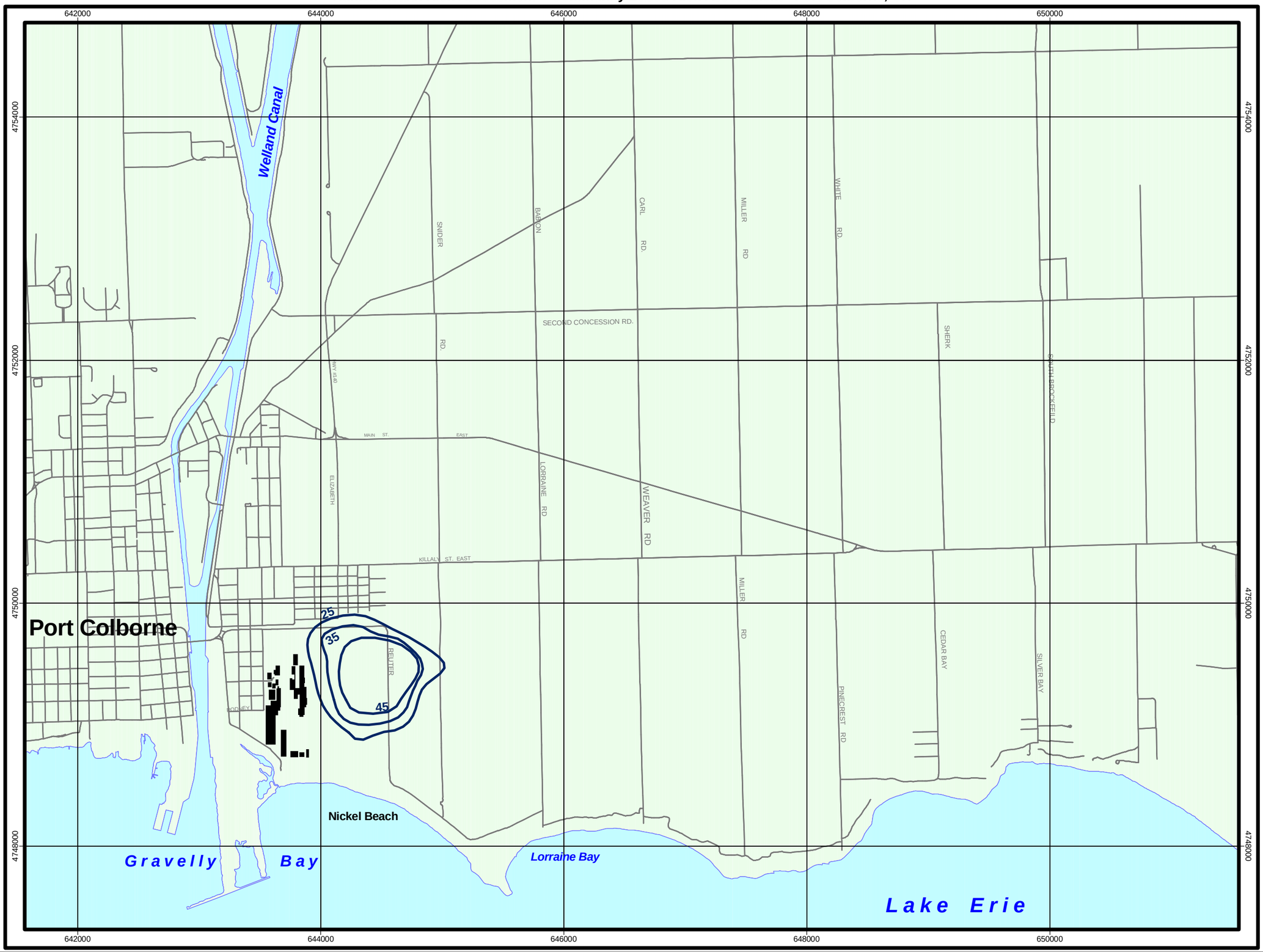


Figure 2-8

Arsenic in Soils (0-5 cm deep) Port Colborne, ON

0 500 1000 1500
Metres

N

Legend

Arsenic Contours
25, 35 and 45 mg/kg

Topographic Features
Inco Refinery
Roads

The approximation is based on:
- 0-5cm surface soil data from MOE 1999, MOE 2000 (Rodney Street Community)
- AMEC 2001 (Seaway Properties)
- JWEL 2001 Programs

Job Number: ONT34644
Date: October 2003
Dwn by: C. Amirault
Approved by: Cecile Willert

Map Parameters
Projection: UTM
Datum: NAD 83
Scale 1 : 30,000

Regional NIAGARA

Jacques Whitford
Consulting Engineers
Environmental Scientists
Risk Consultants

Figure 2-9

Land Use
Port Colborne, ON

0 500 1000 1500

Metres

N

Legend

Land Use Classification

- Commercial/Industrial
- Recreational
- Residential
- Schools
- Woodlot/Parkland
- Agricultural

Topographic Features

- Inco Refinery
- Roads

Job Number: ONT34644
Date: May 2005
Dwn by: C. Amirault
Approved by: C. Willert

Map Parameters
Projection: UTM
Datum: NAD 83
Scale 1 : 30,000

Jacques Whitford
Consulting Engineers
Environmental Scientists
Risk Consultants

.../AV_Projects/HHRA_Report_Figures.APR

The District School Board of Niagara and the Niagara Catholic District School Board provided detailed maps of school zones for elementary and high schools in their districts. Information from members of the public, MOE assessments and other research in the community was used to compile the following list of schools in and around the Study Area:

- Dewitt-Carter Public School
- McKay Public School
- Steele Street Public School
- Oakwood Public School & Day-care
- Port Colborne High School
- St. Therese Catholic School
- St. Patrick Catholic School
- St. John Bosco Catholic School
- Lakeshore Catholic Secondary School
- Ecole St. Joseph
- Port Colborne Regional Day-care
- A Child's World Family Child Care Services of Niagara
- Humberstone Public School and C.M. Thompson Public School (closed in June 2002).

2.4.1 Potable Water Distribution System

Detailed mapping of the Port Colborne water distribution system was obtained from the City of Port Colborne in 2002. The City obtains treated water from the Regional Municipality of Niagara's water treatment plant located on King Street, Port Colborne, which in turn obtains raw water from the Welland Canal and treats it using conventional technology. The water distribution system services the residential areas of Port Colborne, including those immediately west and north of the Inco Refinery. The areas to the east and northeast of the Inco Refinery are not serviced by the water distribution system and instead rely on private water wells, some of which are supplemented by cisterns. Some residents use bottled water for drinking. Survey results on sources of drinking water are detailed in Volume III, Appendix 5.

2.5 Soil Parameters

2.5.1 Drainage Characteristics and General Soil Type

The City of Port Colborne falls within the Limestone Plain region of the Niagara area. The Limestone Plain is characterized by shallow bedrock commonly exposed or covered with a thin veneer of clayey silt to stoney silt till and glaciolacustrine sediments. Soils of the Port Colborne area have developed on soil parent materials ranging in texture from heavy clays to coarse sand.

The native soils in Port Colborne area are primarily heavy textured soils with poor drainage, dotted with wet depressions of irregular size and shape (Chapman and Putnam, 1984).

Existing Ontario Ministry of Agriculture, Food and Rural Affairs soil maps of the Regional Municipality of Niagara (OMAFRA, 1989) were reviewed to identify soil types occurring within the area affected by historical Refinery CoC emissions (Jacques Whitford 2001a,b). Detailed soil studies of the Port Colborne area, undertaken primarily for the purposes of the CBRA crops study component, have identified and mapped five primary soil groupings. The five common parent types of soils identified on the East Side of Port Colborne are:

- heavy clay (glaciolacustrine origin)
- shallow clay (till clay)
- clay loam (till clay)
- organic soils
- sand

A sixth soil type, fill, is found overlying clay and organic parent materials within the residential community located to the west of the Inco Refinery. The fill soils reflect a mix of the native soil types found in the area and soil amendments. Figure 2-10 illustrates parent soil groupings and approximate fill areas found in the Study Area.

The soil map in Figure 2-10 was not extended to the residential and commercial areas west of the canal because this was not an area of significant CoC impact on soils and because soil type was considered a more important parameter to the evaluation of impacts on crops than for human health. Amendment of lawn and garden soils to the west of the Welland Canal would be expected, as was noted in residential areas on the east side of the Welland Canal. High variability in such amendments and sources of fill reduces the value of a detailed soil survey in the residential areas when the assessment is conducted on a community wide basis. Soil mapping did, however, continue in agricultural areas west of the canal to establish background soil conditions for the crop phytotoxicity study. For purposes of the HHRA, the soils characterization adopted from the CBRA crops study (Jacques Whitford, 2004a) for the east side of Port Colborne is considered sufficient.

2.5.2 Distribution of CoCs in Soils

Within the Study Area, the range of CoC concentrations in soil, as well as absolute soil CoC concentrations (Figures 2-5 to 2-8, inclusive), generally decrease with increasing distance from the Refinery source. Surface (0 to 20 cm) soil CoC concentrations are similar for both the organic and clay soils located at similar distance from the Refinery, even though the organic soils are more permeable than the clays (Jacques Whitford, 2001a).

Table 2-3 summarizes the recommended MOE generic Table A soil concentration guidelines for the CBRA CoCs (MOE, 1997). The derivation of these guidelines is based on literature values related to generic CoC effects to plants, livestock, and humans (MOE, 1997). Figures 2-5 through 2-8 illustrate the distribution of each CoC with respect to soil concentrations in and around the Refinery site.

Table 2-3: MOE Generic Table A Guidelines For CoC Concentrations For Fine to Medium Textured Soils (Equivalent to current Table 2 Soil Standards)

CoCs	Agricultural (mg/kg)	Residential/Parkland (mg/kg)	Industrial/Commercial (mg/kg)
Nickel	200	200	200
Copper	200	300	300
Cobalt	50	50	100
Arsenic	25	25	50

The portion of lands where soil CoC concentrations exceed MOE generic guidelines or standards (MOE, 1997; Ontario, 2004b) by soil type are provided in Table 2-4. Grain size analyses indicated medium to fine textured soils throughout the Study Area; these analyses are provided in Volume IV, Appendix C of the Port Colborne CBRA - Crops Report.

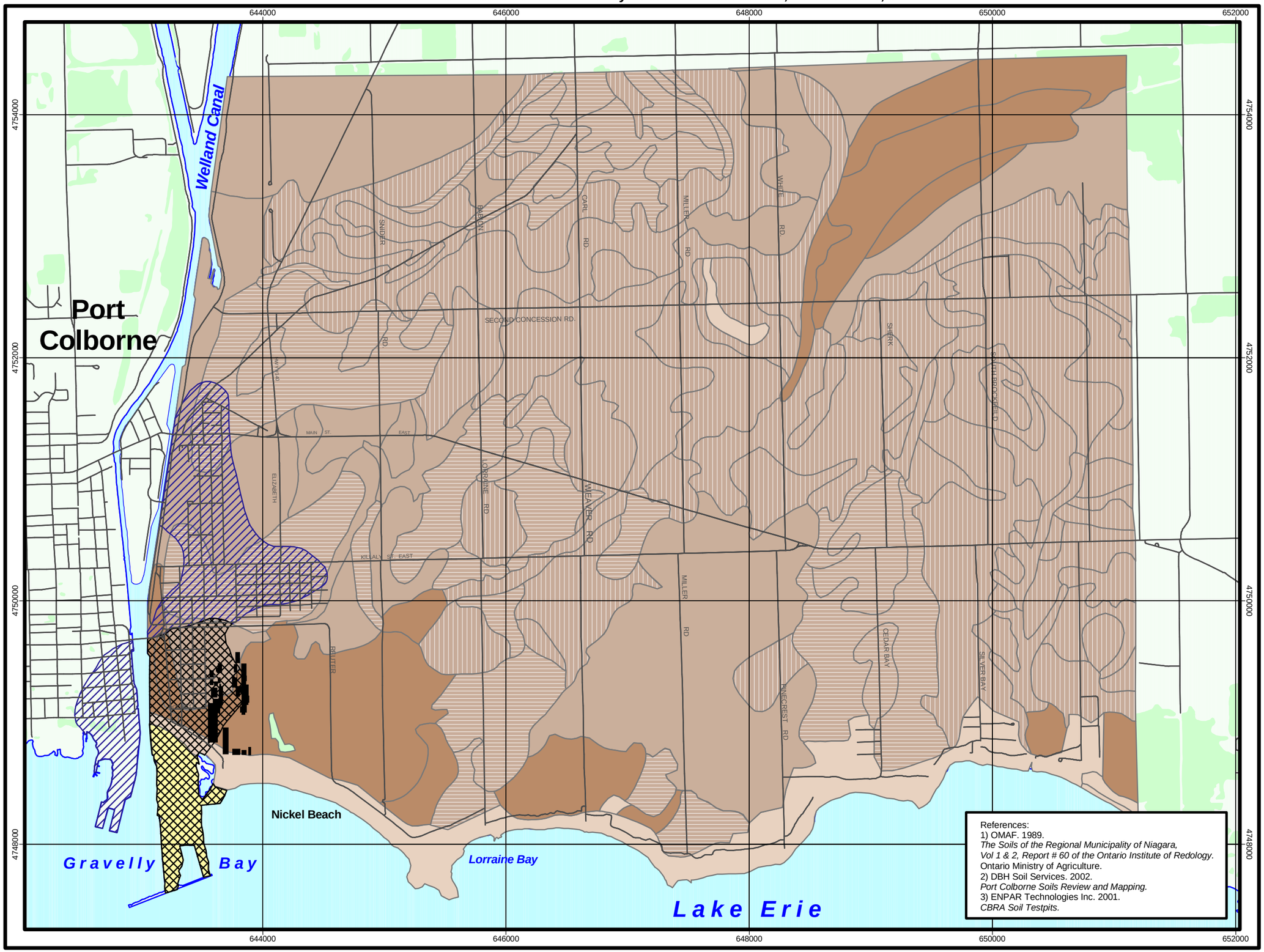
Table 2-4: Areal Distribution of Soil CoC Concentration Exceedances by Soil Type

Respective Areas and Percentage of Area	CoC			
	Nickel	Copper	Cobalt	Arsenic
Organic Soil Area East of Welland Canal (ha)	429	158	104	62
Clay Soil Area East of Welland Canal (ha)	1968	106	77	16
Sand Area East of Welland Canal (ha)	58	<1	<1	0
Soils West of Welland Canal (ha)	176	28	0	0
Total Area (ha)	2630	293	182	78
Organic soil Area East of Welland Canal (%)	16	54	57	80
Clay soil Area East of Welland Canal (%)	75	36	43	20
Sand Area East of Welland Canal (%)	2	0	0	0
Soils West of Welland Canal (%)	7	9	0	0
Total Area (%) [a]	100	100	100	100

Note:
Detailed explanation of soil sampling can be found in Volume V, Appendix 20.
Total area equals 100% before rounding.

Figure 2-10

Soil Groupings East Side Port Colborne, ON



0 500 1000 1500

Metres

N

Legend

Parent Soil Groupings

- Heavy Clay
- Shallow Clay
- Clay Loam
- Organic
- Sand
- Built Land

Approximate Fill Areas

- Fill Topsoil (Clay Loam)
- Fill Topsoil (Mildly Alkaline Clay Loam)

Topographic Features

- Inco Refinery
- Roads

References:

1) OMAF. 1989. *The Soils of the Regional Municipality of Niagara, Vol 1 & 2, Report # 60 of the Ontario Institute of Redology.* Ontario Ministry of Agriculture.
2) DBH Soil Services. 2002. *Port Colborne Soils Review and Mapping.*
3) ENPAR Technologies Inc. 2001. *CBRA Soil Testpits.*

Job Number: ONT34644
Date: July 15, 2003
Dwn by: C. Amirault
Approved by: K. Wong

Map Parameters
Projection: UTM
Datum: NAD 83
Scale 1 : 30,000

Regional NIAGARA

Jacques Whitford
Consulting Engineers
Environmental Scientists
Risk Consultants

A test pit program was done by Jacques Whitford to examine the vertical distribution of CoCs in soil horizons (0 to 100 cm). This program found that CoCs are generally restricted to upper regions of the soil profile (0 to 20 cm) in both clay and organic soils. In undisturbed clay soils near the Refinery, concentrations of the CoCs were found to be highest within surface topsoil (0 to 5 cm). In agricultural fields with a dominant clay component, the CoCs were evenly distributed through the plough zone (0 to 20 cm). In organic soils, concentrations of CoCs remain relatively constant and evenly distributed through the top 20 cm of the soil profile, below which they drop off sharply to below MOE (MOE, 1997) generic guideline levels (Jacques Whitford, 2001a).

Reasonable Maximum Exposure concentrations (RMEs, further explained in Chapter 3) of CoCs in surface soil (0 to 5 cm soil depth) were adopted for use in the HHRA, with additional consideration given to maximum CoC concentrations in residential soil from all depths. Although soil CoC concentrations may exceed MOE guideline values at depths greater than 5 centimetres, the 0 to 5 cm horizon is considered to represent the primary site of interaction between CoC contaminated soil and most human receptor activities. The data set for the 0 to 5 cm soil horizon is also the most complete soil CoC concentration data set, as compared with those available for other soil horizon depths. Summaries of surface soil (0 to 5 cm) concentrations of CoCs and for the entire database of soils data are provided in Volume V, Appendix 20.

Maximum measured soil concentrations for the CoCs outside of woodlots are 17,000 µg/g for nickel, 8,400 µg/g for copper, 270 µg/g for cobalt, and 350 µg/g for arsenic. Higher nickel and cobalt concentrations have been measured in woodlots, up to 33,000 µg/g for nickel and 427 µg/g for cobalt.

2.5.3 Speciation of CoCs in Soil

A total of 14 soil samples were examined using various analytical techniques including Scanning Electron Microscopy (SEM) and high energy X-Ray Absorption Spectroscopy. The sample locations are depicted in Figure 1 of Volume IV, Appendix 12. A more comprehensive review of the available CoC speciation data, including additional speciation work done by others, is provided in Volume IV, Appendix 12. The speciation of nickel in the analyzed soil samples indicates **oxidic forms of nickel** as the predominant nickel species in Port Colborne soils. This finding is supported by the MOE (2002).

2.5.4 Leaching Characteristics of Soil

Because CoCs are distributed primarily in upper soil horizons (Section 2.5.2), the leaching capacity of soils is an important consideration in assessing availability of CoCs for uptake by plants and into garden and farm produce. In order to investigate the leaching capacity of clay and organic soils in the Study Area, sequential chemical extraction work was conducted on two samples (one clay and one organic soil) to assess the likely physical/chemical associations of the nickel, copper and cobalt in soil (see Volume IV, Appendix 12). Sequential chemical extraction work was conducted by Enpar Technology at their laboratory in Guelph, Ontario (Enpar, 2001).

In general, the organic matter, iron oxide and residual fractions in both clay and organic soils contained the majority (more than 90%) of total nickel, copper and cobalt. The total nickel, copper and cobalt in the exchangeable fractions are low with less than 5% of total CoCs readily available for uptake by plants and humans.

2.6 Hydrogeology and Water Quality

2.6.1 Hydrogeology and Groundwater Flow Direction

The Haldimand Clay Plain is a physiographic region that covers all of the Niagara area (Chapman and Putman, 1984) including the CBRA Study Area. The Haldimand Clay Plain is best summarized as a limestone plain overlain with glaciolacustrine clay and glacial till deposits. The limestone bedrock of the Haldimand Clay Plain forms an aquifer, underlying the clay aquitard or glacial till. The main conduit for groundwater flow in the bedrock is through fractures, joints and along the bedding planes.

Locally perched and overburden water tables are also found in the area. Perched groundwater is isolated from the main body of groundwater by very low permeability material (aquiclude or aquitard). The elevation of a perched groundwater table does not reflect the elevation of the true water table for an aquifer. An overburden aquifer occurs locally in sand, gravel, sandy till, peat and/or fill material.

The general groundwater flow direction on the East Side of Port Colborne is to the south towards Lake Erie (Figure 2-11). The hydrostratigraphy along this flow path is shown in Figure 2-12. Additional discussion of the hydrogeology of the area is provided in Volume V, Appendix 14.

Based on the hydrogeological conditions of the Port Colborne area, and the results of water well testing in the Study Area (see Section 2.6.2), the contamination of groundwater from historical atmospheric deposition of particulates containing CoCs is not present and is not expected to occur.

As the groundwater flow approaches the Welland Canal, there is a component of groundwater that flows west and southwest towards the Canal (Figure 2-13). The groundwater at the Inco Refinery site and to the south and south-west of the Refinery are affected by elevated nickel concentrations. The primary source of these elevated nickel concentrations is not local air particulate deposition on soils from Inco's historical air emissions, but rather Inco's abandoned electrolytic nickel refining building and residual contamination from Inco's decommissioned No. 1 building (See Volume V, Appendix 14).

Sources of groundwater nickel contamination on Inco's property, such as that from the sumps of the Refinery No. 1 building, have been addressed and remediated since 1995. The installation and operation of a drainage system around the Refinery No. 1 building and a purge well system create a hydraulic barrier to the offsite migration of contaminated groundwater, thereby containing groundwater contamination on Inco property (Figure 2-14). The purge wells create an effective hydraulic capture zone by controlling groundwater movement in the bedrock aquifer and containing groundwater contamination on the Inco property (Figure 2-14). The purge wells have reversed the natural southwest to west groundwater flow direction in the area of the Refinery site to a radial pattern of east, southeast and north flow directions (Figure 2-14). The recovered contaminated groundwater from the purge well system is collected and treated on the Refinery property before being released as clean water to Lake Erie.

Figure 2-11

Groundwater Flow in Bedrock, North and East of the Inco Refinery Port Colborne, ON

642000 644000 646000 648000

4752000 4750000 4748000

Welland Canal

SNIDER RD.

BABION RD.

CARL RD.

MILLER RD

WHITE RD.

SHERK

SECOND CONCESSION RD.

HWY #140

MAIN EAST

ELIZABETH

LORRAINE RD

WEAVER RD

MAIN ST. EAST

RIEVER

RODNEY

CEDAR BAY

PINECREST RD

177.5

177

176.5

176

175.5

175

174.5

174

Port Colborne

Nickel Beach

Gravelly Bay

Lorraine Bay

Lake Erie

0 250 500 750 1000 1250

Metres

N

Legend

- Well Location Sample with no subsurface information
- Well Location Sample with subsurface information
- 175 Groundwater Elevation Contour (masl)
- Direction of Groundwater Flow

Topographic Features

- Inco Refinery
- Woodlots
- Roads

Job Number: ONT34644
Date: May 2005
Dwn by: C. Amirault
Approved by: C. Willert

Map Parameters
Projection: UTM
Datum: NAD 83
Scale 1 : 25,000

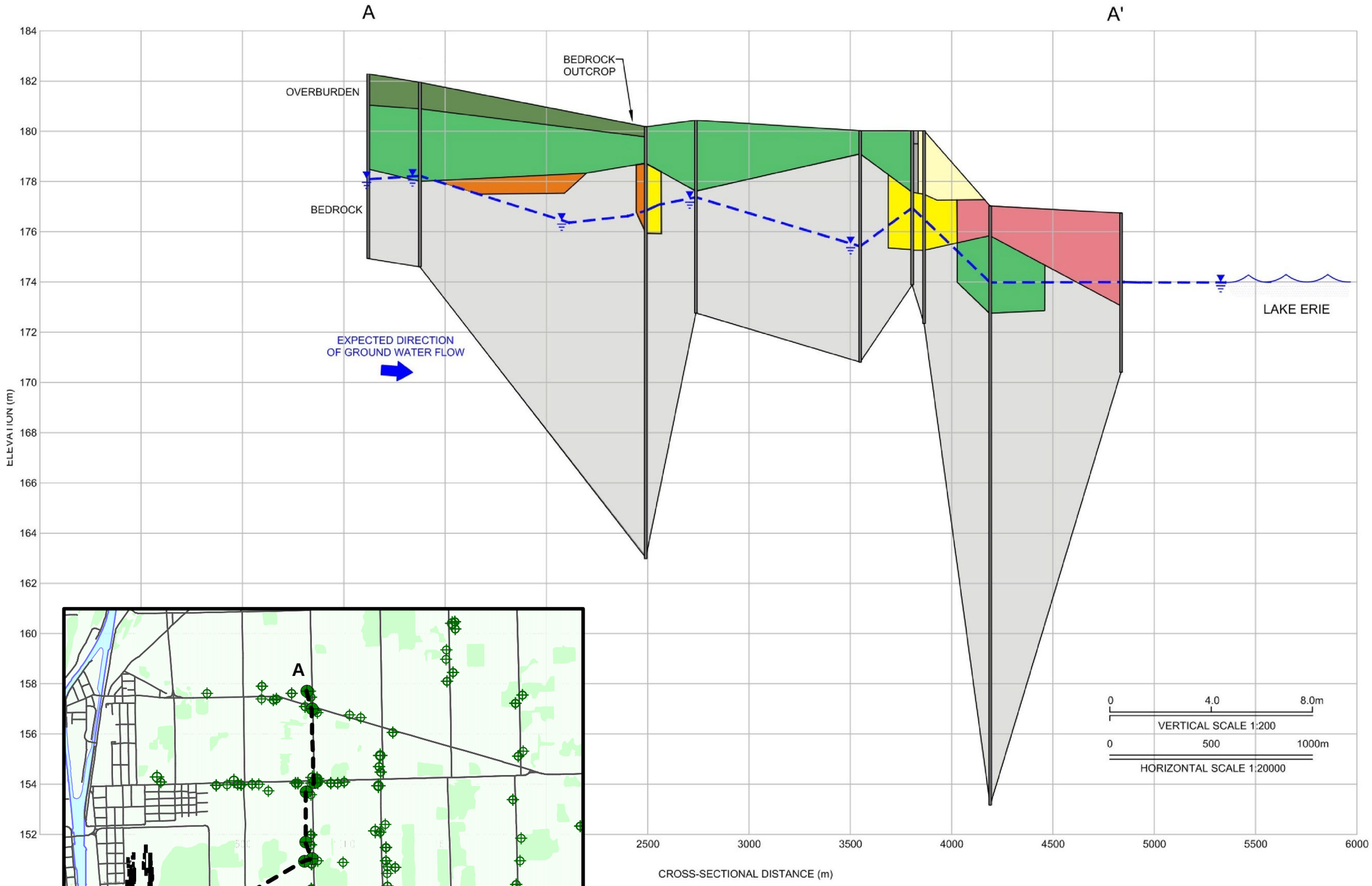
Regional NIAGARA

Jacques Whitford

Consulting Engineers
Environmental Scientists
Risk Consultants

Figure 2-12

Hydrostratigraphy Northeast and East of the Inco Refinery Port Colborne, ON



Notes:
1) Statigraphy based on driller's notes recorded in the MOE well water records.
2) Water table depths were taken in August 2001
3) Water table elevations are approximate only, based on the water table depths and a rough estimation of the surface elevation based on topographic maps (i.e., Not from surveyed points).
4) Depths of residential well screens are unknown. Thus the source water could be from the overburden and/or bedrock aquifers.
5) Dewatering is occuring in the area near golf course on Lorraine Road, lowering the water table.

Legend

Hydrostratigraphy
- Residential Well
- Ground Water Table
- Sand
- Organic Muck
- Clay
- Clay Loam
- Gravel
- Shale
- Limestone Bedrock

Sample Locations
- Well Location Sample with subsurface information
- Well Location Sample with no subsurface information

Topographic Features
- Inco Refinery
- Roads

Job Number: ONT34644
Date: May 2005
Dwn by: C. Amirault
Approved by: C. Willert

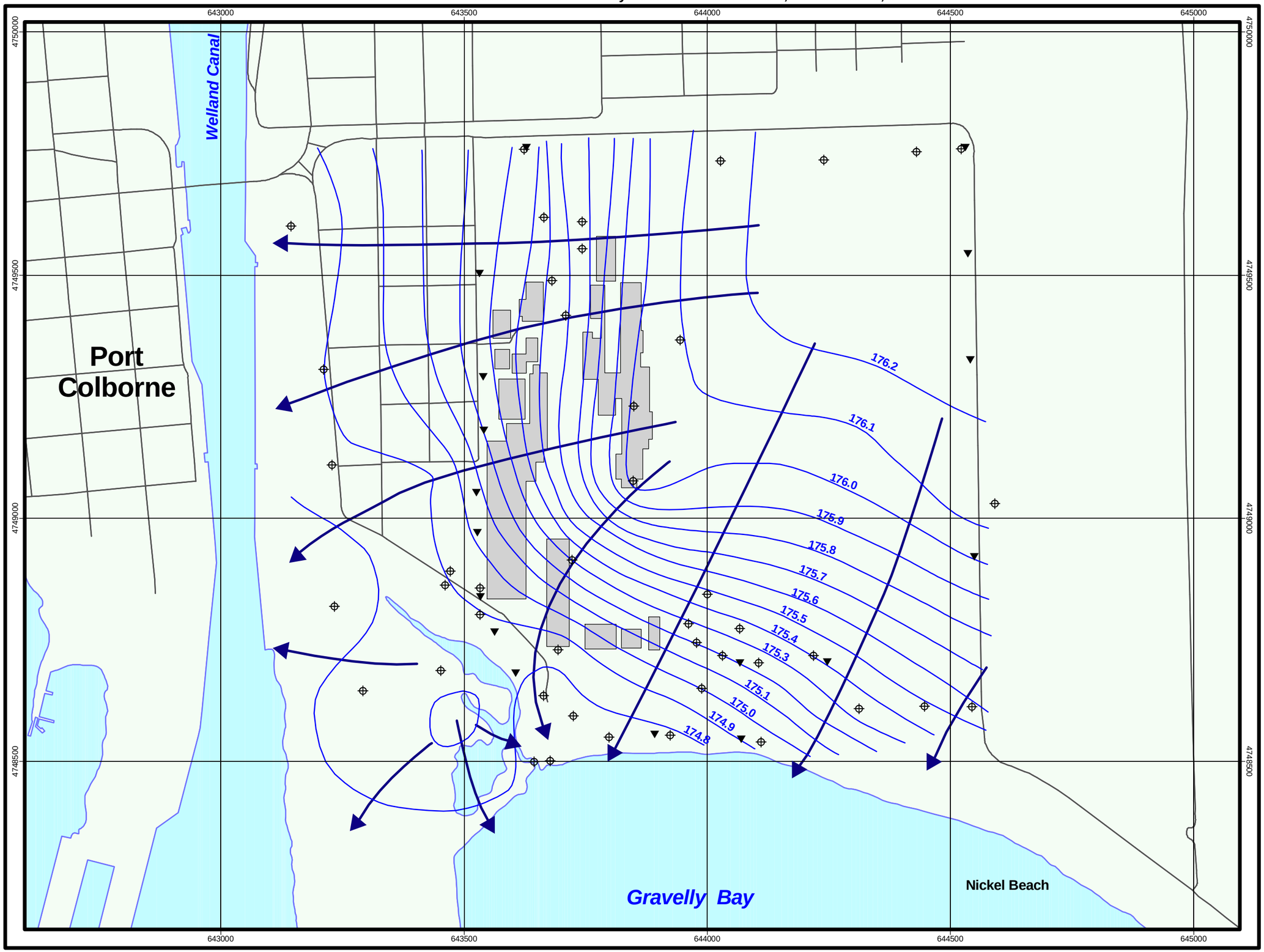
Map Parameters
Projection: UTM
Datum: NAD 83

Regional NIAGARA

Jacques Whitford
Consulting Engineers
Environmental Scientists
Risk Consultants

Figure 2-13

Groundwater Flow Direction in Bedrock, Prior to Purge Well Operation, West of Inco Refinery Port Colborne, ON



0 100 200 300 400

Metres

N

Legend

Groundwater

- Cone Penetrometer Test
- Monitoring Well
- Groundwater Piezometric Elevation (m)
- Interpreted Groundwater Flow Direction

Source: Klohn-Crippen (2000)
Port Colborne Refinery: Phase III - Purge Well Feasibility Study - January 17, 2000

Topographic Features

- Inco Refinery
- Roads

Job Number: ONT34644
Date: October 2003
Dwn by: C. Amirault
Approved by: Kevin Wong

Map Parameters
Projection: UTM
Datum: NAD 83
Scale 1 : 7,500

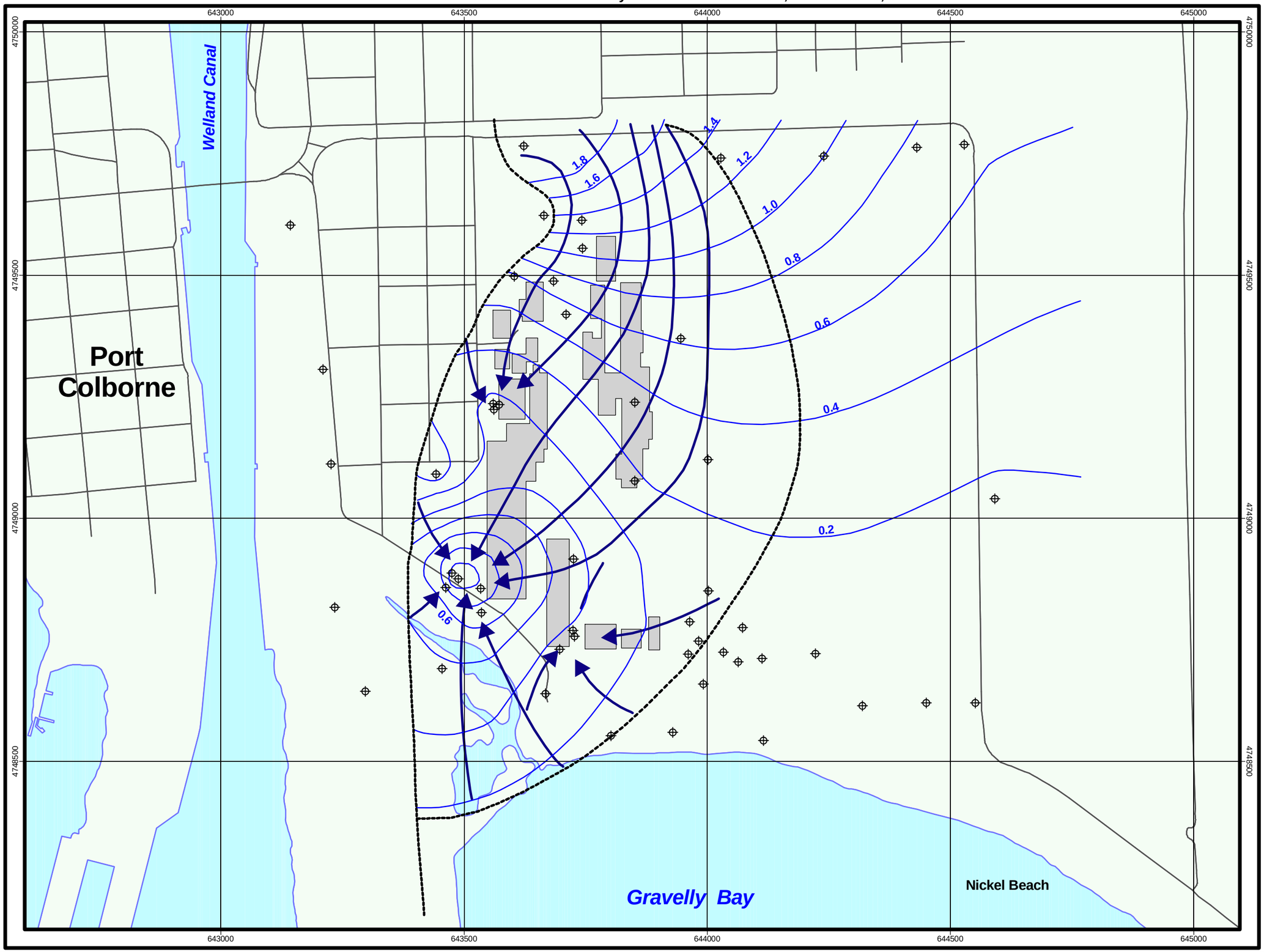
Regional NIAGARA

Jacques Whitford
Consulting Engineers
Environmental Scientists
Risk Consultants

.../AV_Projects/Contouring_Oct7.APR

Figure 2-14

Hydraulic Capture Zone During Purge Well Operation, West of Inco Refinery Port Colborne, ON



0 100 200 300 400

Metres

N

Legend

Hydraulic Capture in Fracture 2

- Monitoring Well
- Equipotential Line respective to the Canal (static water level in metres)
- Capture Zone

Source: Klohn-Crippen (2000)
Port Colborne Refinery: Phase III - Purge Well Feasibility Study - January 17, 2000

Topographic Features

- Inco Refinery
- Roads

Job Number: ONT34644
Date: October 2003
Dwn by: C. Amirault
Approved by: Kevin Wong

Map Parameters
Projection: UTM
Datum: NAD 83
Scale 1 : 7,500

Regional NIAGARA

Jacques Whitford
Consulting Engineers
Environmental Scientists
Risk Consultants

The bedrock aquifer is not hydraulically connected to the overlying overburden aquifer in the area of the Refinery No. 1 building and the East Side Community west of Inco. As a result, pumping from the purge wells within the bedrock aquifer does not significantly affect the movement of groundwater within the overburden aquifer of this area. As the residents of the East Side Community receive their drinking water from municipal sources and not from well water, and because the bedrock groundwater flow within the area of the East Side Community has been reversed east towards the Inco Refinery in the direction of the purge wells, potential adverse effects of CoCs in groundwater to residents in the East Side Community were not considered a factor in assessing human health risk for this HHRA.

2.6.2 Residential Well Water Sampling

Water from residences in the Port Colborne area was sampled in 2000 and 2001. Samples were obtained from residential dug wells, drilled wells, indoor taps, cisterns and municipal tap water.

Within the Study Area, more than 300 properties are located in the rural area on the east side of Port Colborne. A review of available MOE water well records indicates that hundreds of water wells are registered and documented within this area. Some of these wells may have been formerly active but are not currently used, and the exact number of drinking water wells currently in use in the Port Colborne area is therefore not available.

Jacques Whitford conducted private water well sampling on the east side of Port Colborne, collecting 150 unique well water samples (in addition to duplicate samples), representing approximately one third of the wells in the area. Every third home was solicited. If a sample could not be obtained from a selected home, the next home was approached. Full results of the local well water sampling are included in Volume V, Appendix 15.

Additional residential well water sampling data were obtained from the MOE. The MOE data were pooled with Jacques Whitford data, and the combined data set was evaluated in this HHRA (See Volume V, Appendix 15).

Field records collected at the sites visited and from well water records included recording of available information on the type and nature of well including depth, the manner of well construction, and other pertinent information. When available, this information was considered in the analysis of the well water data. Samples were separated by source categories that included drilled well, dug well, cistern, and municipal systems. Each category was analyzed separately.

In general, dug wells were found along the north shore of Lake Erie in the areas of sandy soils. Drilled wells were generally found in rural areas, further from Lake Erie, in the organic and clay soil regions.

The Ontario Drinking Water Standards or ODWS (MOE, 2001a; 2003) provided an appropriate basis of comparison for data on the unfiltered tap water samples. The U.S. EPA Region III Risk Based Concentrations (RBC) for cobalt and nickel (U.S. EPA, 2002) were used as comparative criteria in the absence of MOE criteria. Samples collected directly from well heads or other locations other than taps (*e.g.,* bailed) were considered representative of drinking water only if the samples were filtered in the field. When the MOE separately collected unfiltered samples and preserved them in the field, Jacques Whitford collected both filtered and unfiltered samples at some of the MOE locations to provide comparison with MOE data.

The statistical summaries for drilled wells, dug wells and cisterns are provided in Volume V, Appendix 15. RME concentrations derived for wells were used in this assessment (see Chapter 6) as well as maximum concentrations reflective of residents with highest potential exposures (see Chapter 7).

The maximum measured concentrations in dug wells (excluding unfiltered samples taken directly from the well) were all below the ODWS (arsenic and copper) and the U.S. EPA Region III RBC (cobalt and nickel).

The maximum concentrations of CoCs measured in drinking water from drilled wells (excluding unfiltered samples taken directly from the well) were below the ODWS, the U.S. EPA MCL (U.S. EPA, 2002a) (arsenic), and U.S. EPA Region III Risk Based Concentrations (nickel and cobalt). The maximum concentration of copper exceeded the applicable ODWS, however the ODWS copper value is based on aesthetic criteria and not toxicity.

All maximum concentrations of CoCs measured in drinking water from cisterns were below the ODWS for arsenic and copper, the U.S. EPA MCLs and the U.S. EPA Region III Risk Based Concentrations (RBC) for cobalt and nickel.

Table 2-5 presents the uses, according to the residents of the sampled sites, of the cistern water.

Table 2-5: Summary of Water Usage Reported for Sampled Cisterns

Cistern	Reported Uses	Other Notes
RS2-53C	Domestic	Municipal water also used
RS2-55C	Domestic	Municipal water also used
RS2-74C	Not Specified	Cistern filled on average once per month; Eavestroughs flow into cistern
RS2-76C	Domestic	Eavestroughs do not flow into cistern
RS2-92C	Domestic, but not used for drinking	Cistern fills with rainwater
RS2-95C	Domestic	Municipal water also used; Eavestroughs flow into cistern
17	Not Specified	
40	Not Specified	Samples taken from cistern tap and bailed from cistern itself
RS-200C	Not Specified	

Note:
Details of water sampling can be found in Volume V, Appendix 15.

2.6.3 Port Colborne Municipal Drinking Water

Municipal water in Port Colborne is supplied by a local water treatment plant that draws water from the Welland Canal.

The MOE, through the Drinking Water Surveillance Program (DWSP), routinely collects treated water quality data following treatment and throughout the water distribution system. Data from the Port Colborne treatment plant were obtained, as available, from the MOE for the years 1990 through 2001.

Municipally supplied tap water samples were collected by Jacques Whitford from a limited number of residences in Port Colborne. All available Port Colborne municipal drinking water data were pooled for a total of 136 samples for arsenic and cobalt, and 137 samples for copper and nickel. A detailed listing of the available data and details of the data analysis is provided in Volume V, Appendix 15.

2.6.4 Drinking Water from Other Municipalities

Treated water samples collected by the MOE between 2000 and 2002 were obtained for fourteen water treatment facilities acquiring drinking water from Lake Erie, including Dunnville, Fort Erie (Rosehill), Haldimand-Norfolk, Port Dover and Port Rowan. These water treatment facilities were selected to provide representative background CoC concentrations in treated drinking water obtained from Lake Erie for comparison to the Port Colborne municipal water source that is located within the Welland Canal, near Lake Erie.

Data for treated water available through the drinking water surveillance program (DWSP) were used to estimate background concentrations of arsenic, cobalt, copper and nickel in drinking water from municipal supplies. One hundred samples were analyzed for arsenic, ninety-seven for cobalt and one hundred two for copper while ninety-nine samples were analyzed for nickel. A detailed listing of the available data and details of the data analysis are provided in Volume V, Appendix 15.

Background concentrations of CoCs in groundwater are also considered in the HHRA. Concentrations of CoCs in drinking water obtained from groundwater sources differ relative to other sources due to natural concentrations of metals in the environment. The MOE background groundwater concentrations provided by the *Soil, Ground Water and Sediment Standards for Use Under Part XV.1 of the Environmental Protection Act* (March, 2004) were the values adopted for use in the HHRA.

2.6.5 Surface Water

The landscape of the Study Area and surrounding areas consist mainly of agricultural lands that are hydrologically manipulated through agricultural drainage tiles, ditches, and municipal drains. No naturally occurring (unaltered) streams or creeks occur in the Study Area. The main surface water drainage features are the Wignell Drain and Beaverdam Drain that drain the lands from north to south. Each of these drains function as such, and should therefore not be considered natural water courses. The Wignell drain, which runs parallel to Snider Road 400 m east of the Refinery property boundary, has a watershed of approximately 1200 ha and is connected to the majority of the Study Area's agricultural ditches and smaller drains between Reuter Road and Weaver Road. The Beaverdam Drain has a watershed of approximately 1400 ha and collects surface water from lands in around Miller Road to the eastern limits of the Study Area. Both the Wignell and Beaverdam drains empty into Lake Erie with flood gate and pump controls at the mouth of the drains at the Lake Erie shore.

The use of municipal drains for draining the lands in the Port Colborne surrounding areas is historical. The Wignell and Beaverdam drains were established over one hundred years ago, with associated records of the drains dating back to the early 1900s (AMEC, 2001c). As a result of surface water management practices, the landscape is efficiently drained; only a small percentage of ditches and drains contain flowing or standing surface water during comparatively dry summer months. In a similar fashion, the combined result of clay based soils and ditching has caused shallow standing water in woodland swamps to be present in early spring but typically drying by early June. A Department of Fisheries and Oceans (DFO) review of the drainage systems in the Study Area identified all branches to the Wignell and Beaverdam Drains as intermittent in nature and accordingly concluded that neither of the drain systems support fish populations (reported by City of Port Colborne, 2000). Based on DFO assessment, and further supported by field investigations conducted for this study (Jacques Whitford 2004b), the potential effects of CoCs on inland fisheries are not a concern. Surface water that persists year round is present only in man-made farm ponds dug deep into the clay soil and at the very lower sections and mouth of the larger collector municipal drainage ditches that feed directly into Lake Erie.

2.6.5.1 Lake Erie Nearshore

Jacques Whitford sampled surface water in Lake Erie in July 2001 off the shore of Nickel Beach, a popular location for swimming, to assess exposure to surface water via accidental ingestion at this location. Beach sand was also sampled. Details of this sampling are provided in Volume V, Appendix 16. The MOE also collected beach sand samples at Nickel, Lorraine and Lakeshore beaches.

Although Lake Erie surface water and sediments could represent a potential CoC exposure route to human receptors swimming or wading in Gravelly Bay and Lorraine Bay, the nearshore area and beach along the lakeshore represent a zone of dynamic wave action. In this area, significant wave action during high water periods and winter months results in continual replacement and movement of sediments and sands along the lake shore. The sediments, sands and bare limestone bedrock of the nearshore environments have therefore been continually washed, mixed and replaced the over the period of Refinery operations.

Chemicals of Concern (CoCs) along the shoreline of Lake Erie, however, can be considered to have direct linkage to the occurrence of CoCs in soils, and exposure to beach sands is included in the HHRA.

2.7 Air Quality

2.7.1 Ambient Air Monitoring

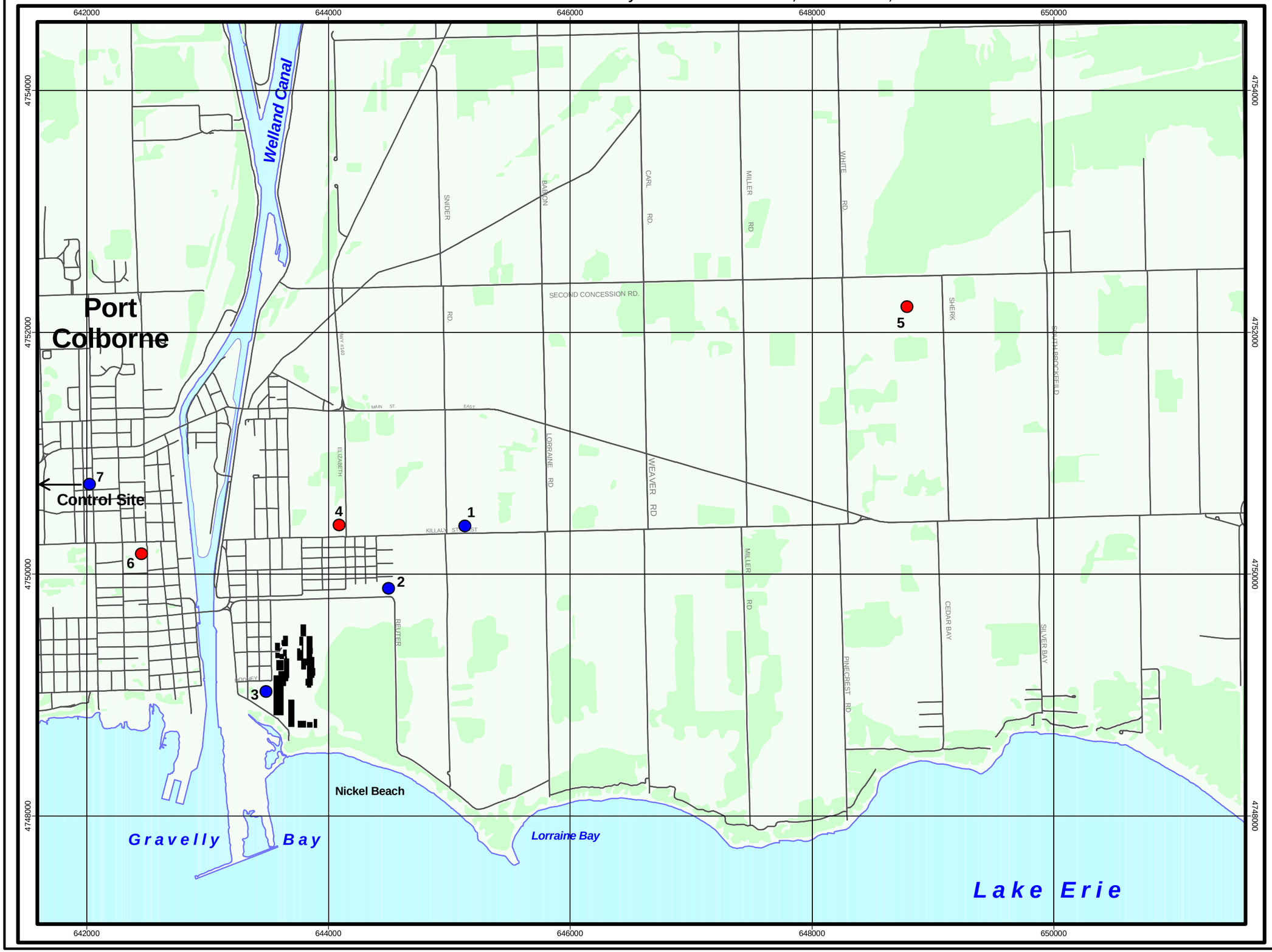
An ambient air monitoring program was conducted in the Port Colborne community to estimate the concentrations of particulate matter and metals in the ambient air. Sampler locations are depicted in Figure 2-15. Monitoring was conducted between August 11th, 2001 and September 15th, 2001, during one of the hottest and driest summers (drought conditions) reported for this area of Ontario. The ambient air concentrations of particulate and CoCs measured are therefore considered to represent a worst possible scenario.

The ambient air sampling program focused on the measurement of all dust in air (total suspended particulate matter, TSP), fine dust particles in air small enough to be reach the lungs (PM_{10}), and very fine dust particles, small enough to reach the deepest parts of the lungs ($PM_{2.5}$). Laboratory analysis of collected particulate matter involved the quantification of 28 different elements, although the HHRA is concerned only with the concentrations of the four CoCs.

Important criteria in the evaluation of ambient air quality include the MOE (2001b) Ambient Air Quality Criteria (AAQC). The AAQC quantify the maximum concentrations of various elements in ambient air that are deemed acceptable and safe by the MOE. These criteria therefore provide maximum air concentration limits over a 24-hour period that are directly comparable to the results from the ambient air monitoring program conducted in Port Colborne. All ambient air CoC concentrations obtained from the Port Colborne ambient air sampling program were below the associated AAQC guidelines. Details of the ambient air monitoring program are provided in Volume IV, Appendices 10 and 11.

Figure 2-15

Locations of the Ambient Air Sampling Stations Port Colborne, ON



0 500 1000 1500

Metres

N

Legend

Ambient Air Sampling Stations

- PM2.5 Air Sampling Unit
- PM2.5, PM10 + TSP Air Sampling Unit

Topographic Features

- Inco Refinery
- Woodlot
- Roads

Job Number: ONT34644
Date: October 2003
Dwn by: C. Amirault
Approved by: K. Wong

Map Parameters
Projection: UTM
Datum: NAD 83
Scale 1 : 30,000

Regional NIAGARA

Jacques Whitford

Consulting Engineers
Environmental Scientists
Risk Consultants

2.7.1.1 Nickel Speciation Scan of Ambient Air Samples

Fifteen filters (five each of TSP, PM_{10} and $PM_{2.5}$) were submitted to SGS Lakefield Research (2002a) for nickel speciation analysis using scanning electron microscopy. The purpose of this analysis was to estimate the amount of nickel-bearing particulates on each of the samples, with special attention to oxidic nickel particulates (*i.e.* major nickel species found in soils). Sets of three ambient air filters from each sampling site (Site #1, #2, #3 and #7, Figure 2-15) were collected on one date in August and September, 2001, per location.

In the ambient air filter samples, **oxidic forms of nickel** were found to be dominant. Nickel oxide/hydroxide was found to be the dominant constituent (about 80%) in nickel-containing particulates. Metallic nickel was detected in particles greater than 2.5 µm size fraction and ranged up to 11.9%. Sulphate complexes containing nickel were identified in the control samples (up to 30%) and some samples from Stations 1 and 3. The detailed speciation results and full report are provided in Volume IV, Appendix 12.

2.7.2 Monitoring of Farming Activities


Monitoring of Farming Activities

Ambient air quality was monitored during staged agricultural activities to estimate the concentrations of particulate matter and CoCs in Port Colborne ambient air, as per the Ambient Air Monitoring in the Vicinity of Farming Activities Protocol (Volume II, Appendix 1.6). The purpose of the staged agricultural activities was to obtain scientifically credible worst-case air quality measurements, in particular those related to potential community-wide CoC exposure resulting from airborne dust generated by agricultural activities. The sampling program focused on the measurement of TSP, PM_{10} and $PM_{2.5}$. The monitoring program was conducted from October 1st to October 7th, 2001, and the results are provided in Volume IV, Appendix 11.

All of the measured CoC concentrations in the vicinity of the farming activities were above background ambient air CoC concentrations, but below the MOE ambient air quality criteria (MOE, 2001b).

2.7.3 Differences Between Year 2000 and 2001 Ambient Air Studies

A previously completed ambient air study was conducted in the summer of 2000 in the Port Colborne area to estimate CoC concentrations in ambient air during staged agricultural activities (Jacques Whitford, 2000). A summary of the results from the year 2000 study was presented to the PLC in February 2001. Because the study in 2000 was conducted during a period when local soils were particularly wet, the PLC recommended conducting an additional study during a drier period which was initiated in 2001 (Section 2.10.1). The PLC also requested that the sampling period for the 2001 study be extended from 8 hours to 24 hours. These recommendations from the PLC were incorporated into the protocol design of the 2001 farming activities study to ensure maximum dust exposure scenarios during a dry period in the summer.

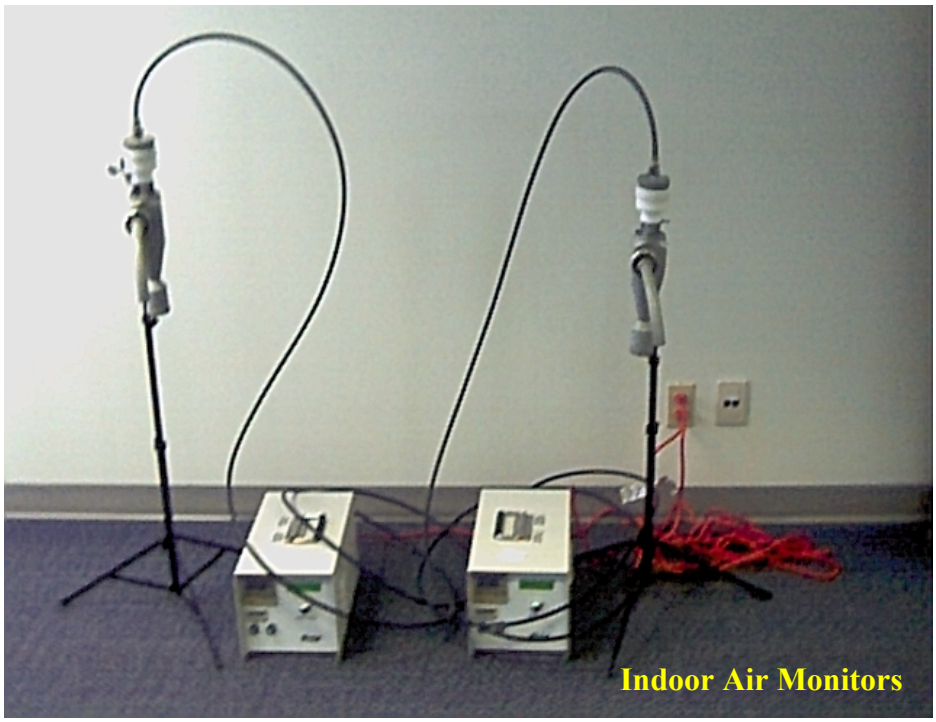
The 2000 study outlined worst-case concentrations of TSP, PM_{10} and $PM_{2.5}$, as measured from a mobile sampling platform located 200 m or greater away from actual farming activities. COC concentrations measured in the 2000 study were compared to CoC concentrations measured in the 2001 study at the NE Test Field Station (Site #5) and the Soccer Club Station (Site #1) during harrowing activities (harrowing activities resulted in the highest CoC and particulate matter concentrations). These stations were chosen for comparison as they have a similar proximity to the agricultural activities as the mobile station used in the 2000 study. Though a direct comparison of results between the 2000 data and the 2001 data could not be made, the year 2000 results from the mobile station did exhibit some agreement with the 2001 results (Site #1). The year 2000 samples were taken from agricultural activities at an approximate distance of 200 m, whereas year 2001 samples were taken from the agricultural activities five metres or more away.

2.7.4 Indoor Air Quality

The indoor air quality of Port Colborne residences was investigated by a community wide study (Jacques Whitford's Indoor Air and Dust Sampling Protocol, Volume II, Appendix 1.7). The study involved the sampling of PM_{10} and TSP in indoor air in 30 residences divided in three study zones in Port Colborne. The indoor air study zones were delineated as the area in which soil nickel concentrations exceeded 5,000 mg/kg and general surrounding area (Zone 1), areas of the community with soil nickel concentrations falling between approximately 200 and 5000 mg/kg (Zone 2) and soil nickel concentrations less than 200 mg/kg (Zone 3). The sampling zones used in the Indoor Air Study are depicted in Figure 2-16.

The results of the study for both TSP and PM_{10} samples are summarized in Volume IV, Appendix 13. Results from all 30 houses included in the study were grouped together for statistical analysis. There are no applicable criteria for the CoCs in residential indoor air, however none of the measured maximum CoC concentrations in indoor air exceeded the applicable MOE AAQC. In general, nickel concentrations in indoor air were found to be lower than concentrations of nickel in ambient air.

Of the 30 houses measured in the study, the data set obtained from one house was excluded from the Risk Characterization for RME concentrations as being atypical of most area residences and warranting separate consideration for maximally exposed individuals. The data from this single house, as well as re-sampling data for this and other houses, have been included in Volume IV, Appendix 13. Data included in the assessment consist of measurements in homes that were randomly selected in accordance with the protocol. Additional non-random sampling was conducted in some homes for residents who requested it. Data from the homes of these volunteers were excluded from the indoor air quality analyses.



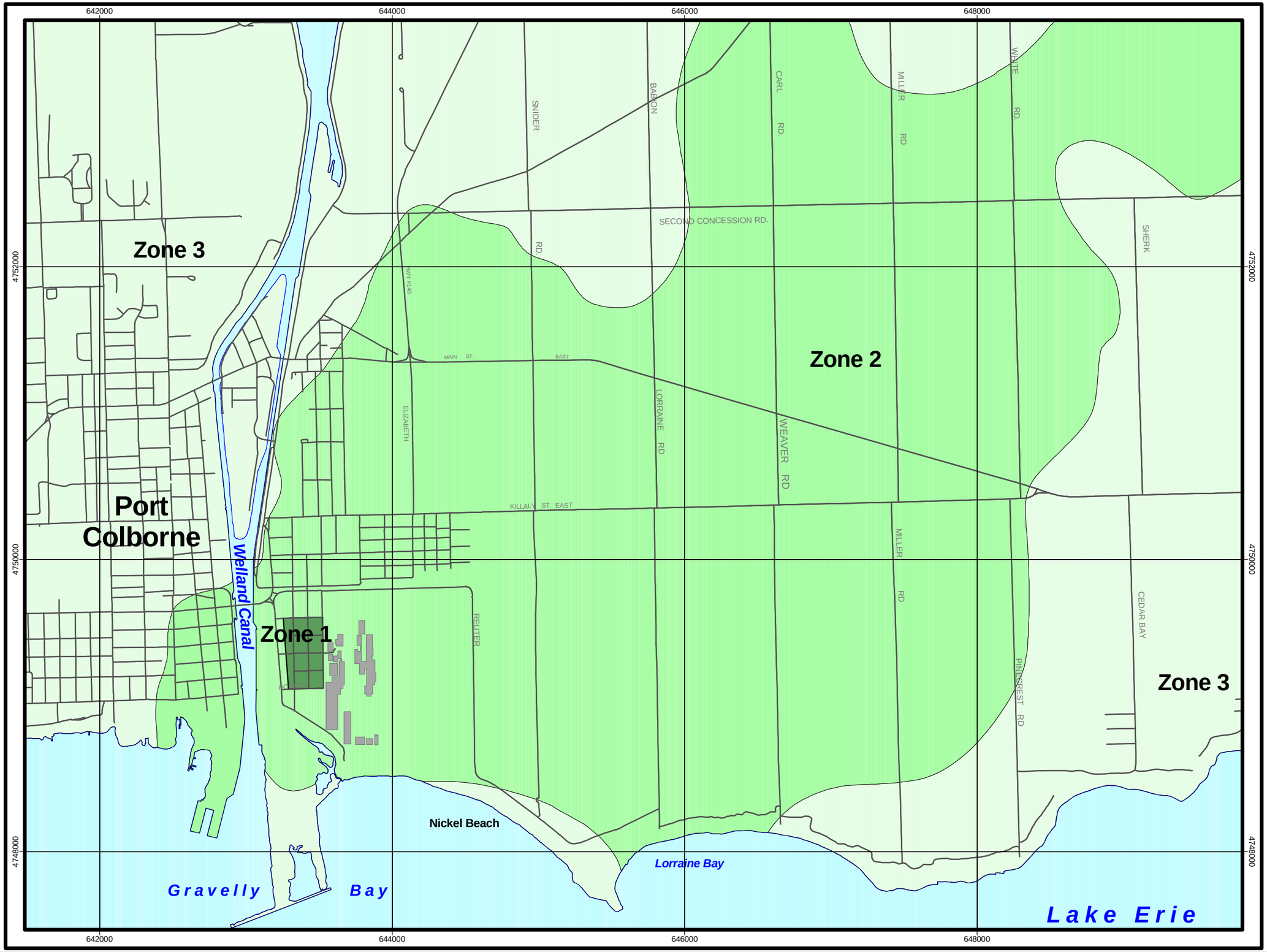


Figure 2-16

Sampling Zones Used in the Indoor Air Study Port Colborne, ON

0 250 500 750 1000 1250

Metres

N

Legend

Samples Zones

- Zone 1 — Highest Area of Soil Nickel
- Zone 2 — >200 mg/kg of Soil Nickel (Excluding zone 1)
- Zone 3 — <200 mg/kg of Soil Nickel

NOTE: Zones based on nickel contour mapping at the start of sampling program

Topographic Features

- Inco Refinery
- Roads

Job Number: ONT34644
Date: October 2003
Dwn by: C. Amirault
Approved by: Kevin Wong

Map Parameters
Projection: UTM
Datum: NAD 83
Scale 1 : 25,000

Jacques Whitford
Consulting Engineers
Environmental Scientists
Risk Consultants

2.7.4.1 Nickel Speciation Scan of Indoor Air Samples

Four indoor air filters (two each of TSP and PM_{10}) were submitted to SGS Lakefield Research for particulate nickel speciation using Scanning Electron Microscopy (SEM). No indoor air filter samples were submitted for analyses by X-Ray Absorption Spectroscopy (XAS). The purpose of this limited SEM analysis was to estimate the amount and type of nickel-bearing particulates in some of the samples. In order to ensure that there was sufficient nickel-containing samples for nickel speciation, filters from Zone 1 (the zone with the highest soil nickel concentrations for a residential area in Port Colborne) were chosen for submission. These included two homes with the highest measured indoor air concentrations. The detailed results and the full report are provided in Volume IV, Appendix 12.

Oxidic nickel and oxides with nickel and other metals were the dominant constituents in indoor air PM_{10}. Samples from the home with the second-highest indoor air nickel concentrations showed no nickel sulphide in PM_{10}, but 24% nickel sulphide in TSP. Samples collected at the home with the highest nickel indoor air concentrations showed about 9% nickel sulphide in PM_{10} and higher amounts of nickel sulphide in TSP.

Even at the low levels found, the identification of nickel sulphide in indoor air samples by SEM is contrary to the findings by SEM and XAS analyses on soil samples and ambient air samples; *i.e.* an absence of nickel sulphides. Considering the advantages and disadvantages of various leading-edge analytical techniques, it is apparent that no single technique such as SEM alone can provide a comprehensive analysis of nickel-bearing species in air samples. The analyses of indoor air samples by SEM alone without XAS as confirmation, therefore, do not provide adequate information on the speciation of nickel in these indoor air media.

The MOE (2002) noted that speciation of nickel compounds other than nickel oxide in soils is speculative until confirmed by repeat analyses by different laboratories using different methods. Speciation of nickel compounds other than nickel oxide in indoor air and dust samples is certainly no less speculative than for soil or ambient air samples.

2.7.4.2 Indoor Settled Dust

Concentrations of indoor settled dust were measured as a portion of the indoor dust sampling program as described in the Indoor Dust Sampling Protocol (Volume II, Appendix 1.7). Samples of dust were collected from both hard and fabric surfaces in 30 randomly chosen residences in Port Colborne. Attic dust samples were collected from these same houses in which the attic space was accessible. Samples were collected in each of the same three zones described for indoor air quality (Volume IV, Appendix 13, Section 2.2), and the results of the indoor settled dust sampling are provided in Volume IV, Appendix 13.

2.7.4.3 Nickel Speciation Scan of Attic Samples

Two attic dust samples were submitted to SGS Lakefield Research (2002b) for nickel speciation by SEM analysis. One was a grab sample, obtained from a residence north of the Inco property. The other was a swipe sample from a home to the west of the Inco property.

Oxidic nickel compounds appear to be the dominant constituents (85% and 95%) of the attic dust samples collected from these residences. Approximately 11% nickel sulphide was estimated in the sample collected to the north of the Inco refinery. The sample collected to the west of the Inco refinery showed 4.7% nickel-iron sulphide. No confirmation of speciation was done by XAS analysis. The detailed results and the full report of the findings of the SEM scan are provided in Volume IV, Appendix 12.

2.8 Local Foods

2.8.1 Garden Produce and Soil

The purpose of the garden produce study was to estimate CoC concentrations in backyard foods grown in the Port Colborne area. Sampling protocols for Year 2000 and 2001 Garden Produce Sampling are provided in Volume II, Appendix 1.10.

The results of the garden produce study, provided in Volume V, Appendix 17, were statistically analyzed for concentrations of CoCs in vegetable and fruit samples. Only edible portions of the produce were analyzed.

Soils were sampled where garden produce was collected in order to provide additional information on the relationship, if any, between CoCs in the sampled produce and in soils. Correlational analyses were conducted between root vegetables, leafy vegetables, other vegetables and fruits grown in Port Colborne and their corresponding soil concentrations (see Volume V, Appendix 17). The only statistically significant relationship identified was that between nickel concentrations in garden soil and leafy vegetables.

Reasonable Maximum Exposure (RME) concentrations were derived for garden produce for use in the HHRA risk assessment. Maximum garden produce analysis was also undertaken; results and discussion from this maximum scenario can be found in Chapter 7.

2.8.2 Farm Products and Maple Syrup

Samples of milk, eggs, chicken and maple syrup were obtained from local farms and residences in order to characterize the concentrations of CoCs in these products in the Study Area. Farm animals were not common in the Study Area and additional samples of these were not available. The sampling program for farm produce is detailed in Volume II, Appendix 1.11. The maple sap sampling program is detailed in the CBRA's Ecological Risk Assessment – Natural Environment report (Jacques Whitford, 2004b) and Volume II, Appendix 1.12. Soil samples near the maple trees yielding sap were collected in order to provide a reference for comparison.

2.8.2.1 Farm Products

One sample of milk and one duplicate sample were obtained from a dairy farm in the Study Area. Details of milk sampling are provided in Volume V, Appendix 18.

A total of thirteen egg samples were obtained from four properties in the Study Area. A statistical summary of the concentrations of CoCs in the egg samples (shell removed) is presented in Volume V, Appendix 18.

Only one sample of chicken was made available for collection from local residents. This chicken, reported to be an old, former egg-laying hen was obtained in July 2002. The chicken obtained was thin and not considered typical of chickens raised for human consumption. The inclusion of this sample in the HHRA was at the request of the public due to concerns with possible CoC exposure through this dietary route. Details of chicken tissue sampling are provided in Volume V, Appendix 18.

2.8.2.2 Maple Syrup

Sampling of local maple trees was conducted to evaluate concentrations of CoCs in maple sap. A total of 23 collected samples of maple sap and two (2) samples of maple syrup donated by the public were obtained at seven locations in the Study Area. The detailed results of the maple sap sampling program are provided in the CBRA's Ecological Risk Assessment – Natural Environment report (Jacques Whitford, 2004b) and in Volume V, Appendix 21.

Copper concentrations in syrup increase in greater proportions than other CoCs due to the local residents' use of copper-containing equipment in the collection and production of the two syrup samples. No copper equipment was used by Jacques Whitford in the collection of sap samples. With the exception of copper, the concentrations of CoCs in public-supplied syrup samples ranged from approximately 2 to 10 times higher than in sap.

2.8.3 Fish and Wild Game

Twenty-four samples of perch were collected by a biologist fishing in Gravelly Bay. Following collection, the fish were filleted and only flesh was analyzed. Copper was the only CoC detected in all of the samples. Arsenic was detected in one sample, cobalt in three and nickel in four.

Two wild rabbits were collected and sampled. Separate analyses were conducted for samples obtained from the carcass (hip and front) and for the liver. Details of fish and game sampling are provided in Volume V, Appendix 18.

Two venison samples were obtained from local residents. These two samples consisted of one venison sample from a deer reported to have been harvested from an area of Port Colborne containing moderate soil nickel concentrations (Zone D) and one control deer sample was harvested from elsewhere in Ontario.

2.9 Supermarket Foods

The purpose of the local supermarket foods program was to estimate the background dietary intake of CoCs in foodstuffs purchased in stores and retail food outlets in the Port Colborne area. Foodstuffs were purchased and prepared from a variety of local supermarkets, food outlets, butchers, eateries, and markets in the summer of 2002 as per the protocol provided in Volume II, Appendix 1.13. Every effort was made to prevent cross contamination during food preparation and sample digestion.

The results of the program, as presented in Volume V, Appendix 19, indicate that the concentration of CoCs measured in foodstuffs varied depending on the food category.

Two different analyses of the supermarket mass-based concentrations were conducted. In the first analyses, mean concentrations were weighted by United States Department of Agriculture (USDA) subcategories. This was done in order to minimize bias resulting from specific subcategories of food which may have distinctly different concentrations of specific chemicals than subcategories of food within the same larger category.

The second method estimated mean concentrations weighted by USDA categories, covering broad food groups. This method produced a more conservative estimate of dietary nickel intake, as sampling was conducted to include foods from every category and, in particular, foods higher in nickel content.

2.10 Summary

The Site Characterization presented in this section outlined the following areas relevant to the CBRA:

- An historical overview of contamination within the Study Area;
- Identification of the Study Area;
- Identification of the relevant CBRA Chemicals of Concern;
- Identification of land use Zones within the Study Area;
- Identification of Soil, hydrogeology, water (surface water and groundwater), and air characteristics; and
- Identification of local and supermarket foods as possible CoC routes of exposure.

Based on data obtained by Jacques Whitford, the primary CoC's relevant to the CBRA were identified as nickel (specifically **oxidic nickel**), copper, cobalt, and arsenic, and were shown to have historic ties to the Inco Refinery located in Port Colborne. Concentrations of these CoC's were shown to decrease in concentrations in soil with increasing distance from the Refinery source. Characterization of CoC concentrations in soils revealed that the 0 to 5 cm surface soil horizon is considered the primary site of interaction between CoC contaminated soil and most human receptors.

The results of this Site Characterization feed into the creation of the Site Conceptual Model detailed in Chapter 3, Problem Formulation, as well as into the Exposure Assessment (Chapter 5), Risk Characterization for Reasonable Maximum Exposure Concentrations (Chapter 6), and Risk Characterization for Maximally Exposed Individuals (Chapter 7). Local and supermarket food data was considered further in the Sensitivity Analysis (Chapter 8).

3.0 PROBLEM FORMULATION

The Human Health Risk Assessment (HHRA) Problem Formulation involves the development of a Site Conceptual Model and selection of CoC concentrations in various media to be evaluated for use in the risk analysis. The Site Conceptual Model identifies the approach to evaluating the Port Colborne community through the selection of Zones within the Study Area, who may be exposed (Receptor Selection) and the selection of exposure pathways and media by identification of how the receptors may be exposed to the CoCs. The Site Conceptual Model provides a simplified representation of how people may be exposed to chemicals in various media in Port Colborne. The Problem Formulation examines the Site Characterization conducted in Chapter 2 for CoC concentrations in various exposure media, known as Exposure Point Concentrations (EPCs).

The Site Conceptual Model divides the Study Area into six Zones including local (i.e. within the Study Area) and regional (i.e. outside the Study Area) background Zones, and four Zones within areas of Port Colborne having soil concentrations exceeding the applicable Ontario default soil condition standards. The Zones within the Study Area were selected based on whether drinking water was obtained from wells or from municipal supply, areas of high, medium, and low soil concentrations of CoCs above the generic MOE soil standards, as well as land use considerations and various socioeconomic factors.

Receptors selected encompass all age groups from infant through adult for a 70-year life span. The receptors are assumed to move within Zones in the community, to go to work, school or the beach, according to the Zone in which they are most likely to receive the highest exposures.

Exposure pathways have been selected to include all significant routes of potential exposure, eliminating from further evaluation only the exposure pathways expected to have an insignificant impact on total exposures.

For each medium associated with a complete exposure pathway, reasonable maximum exposure (RME) concentrations have been selected as well as maximum exposure concentrations. RME concentrations were selected to represent an upper estimate of long-term average exposures to most individuals in the Zone. Maximum concentrations have been selected to investigate potential exposures to maximally exposed individuals. Note that not all parameters are expected to be maximized for the same receptor.

The human receptors selected, potential exposure pathways and selected exposure point concentrations are carried forward to Chapter 5 where potential CoC intakes and doses are estimated quantitatively for RME concentrations. Maximum concentrations are carried forward to Chapter 7 where specific selected scenarios of potential maximally exposed individuals are evaluated quantitatively. Some exposure pathways and receptors identified as special cases, or small subgroups of the population, are carried forward to Chapter 8 where specific selected scenarios are evaluated to test whether the results of the assessment are sensitive to the characteristics of people in these subgroups.

3.1 Site Conceptual Model

3.1.1 Selection of Zones Within Study Area

Land use information including maps, zoning information, school zones, water supply information (including well water survey results) and other local information were reviewed (see Section 2.4). HHRA team members also visited local community areas and met with community representatives and members of the public.

HHRA Zones within the City of Port Colborne were created based on areas with similar characteristics such as land use, soil nickel concentration, proximity to the Vale Inco Ltd. (Inco) Refinery, and the drinking water source in order to best assess typical CoC exposures to human receptors. For selected HHRA Zones and rationales see Table 3-1. See Figure 3-1 for the boundaries of each HHRA Zone selected for evaluation.

Individual circumstances will differ within each HHRA Zone; therefore, conservatism was used when selecting exposure components, such as reasonable maximum exposure (RME) concentrations, maximum exposure concentration scenarios and time-activity factors. RME concentrations were selected based on the U.S. EPA (1989) guidance. A detailed Sensitivity Analysis was done (see Chapter 8). The Sensitivity Analysis considered variables that might affect exposure scenarios and, ultimately, the potential human health risk. The combined application of conservatism and Sensitivity Analysis provides confidence in the Risk Characterization.

Table 3-1: HHRA Zones and Rationale

HHRA Zone	Zone Location	Basis for Selection
A	Bordered by the Welland Canal to the east and Lake Erie to the south with soil nickel levels generally greater than 200 mg/kg (area of low soil nickel levels).	• Medium soil concentrations exceeding the MOE guidelines for the CoCs in soil (MOE 1997) • Serviced by municipal water supply • West of the Welland Canal as a divider of different socioeconomic areas and school zones
B	Bordered by railway tracks to the north, Davis St. to the east, Lake Erie to the south and the Welland Canal to the west (area of some of the highest soil nickel levels).	• High soil concentrations exceeding the MOE guidelines for the CoCs in soil (MOE 1997) • Serviced by municipal water supply • East of the Welland Canal (see above) • South of Railway tracks as a divider based on soil conditions, proximity to historical sources and socioeconomic factors
C	Bordered by the railway tracks to the south, the Welland Canal to the west, east and north to the limits of the residential area (area of moderate to high soil nickel levels).	• Medium soil concentrations exceeding the MOE guidelines for the CoCs in soil (MOE 1997) • Serviced by municipal water supply • East of Welland Canal (see above) • North of Railway tracks (see above)
D	Bordered by Zone C and the Inco property to the west, Lake Erie to the south and including properties to the north and east of these boundaries with CoC concentrations in soil exceeding the MOE guidelines (area of low to moderate soil nickel levels).	• Medium to High soil concentrations exceeding the MOE guidelines for the CoCs in soil (MOE 1997) • Not serviced by municipal water supply
E	Area of Port Colborne west of the Welland Canal (excluding Zone A) and northeast and east of Zone D with soil nickel levels generally less than 200 mg/kg (area of soil nickel levels below guideline).	• Low soil concentrations generally below the MOE guidelines for the CoCs in soil (MOE 1997) • Representing local background
F	Southern Ontario in general (OTR_{98} from MOE 1997) (area of background soil nickel levels).	• Low soil concentrations generally below the MOE guidelines for the CoCs in soil (MOE 1997) • Representing regional background

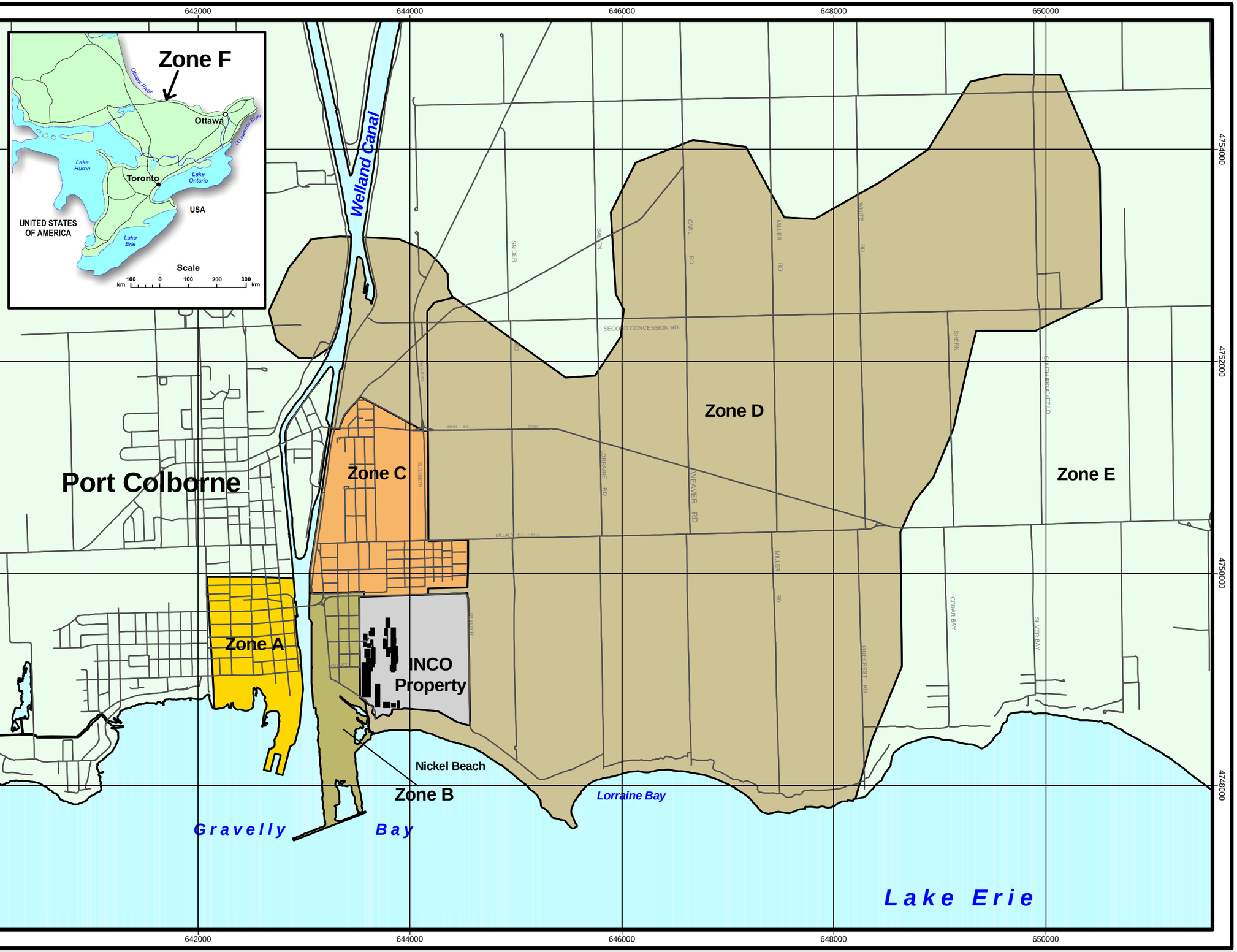
Note:

For details of zone designation see Volume III, Appendix 3.

Land use has been categorized into residential land use, rural residential and agricultural land use, commercial and industrial land use, school properties, beaches, and other recreational land uses (which includes parks and woodlot areas).

Figure 3-1

HHRA Zones
Port Colborne, ON



0 500 1000 1500
Metres

N

Legend

HHRA Zones
- A
- B
- C
- D
- E
- F (Southern Ontario)
- Inco Property

Topographic Features
- Inco Refinery
- Roads

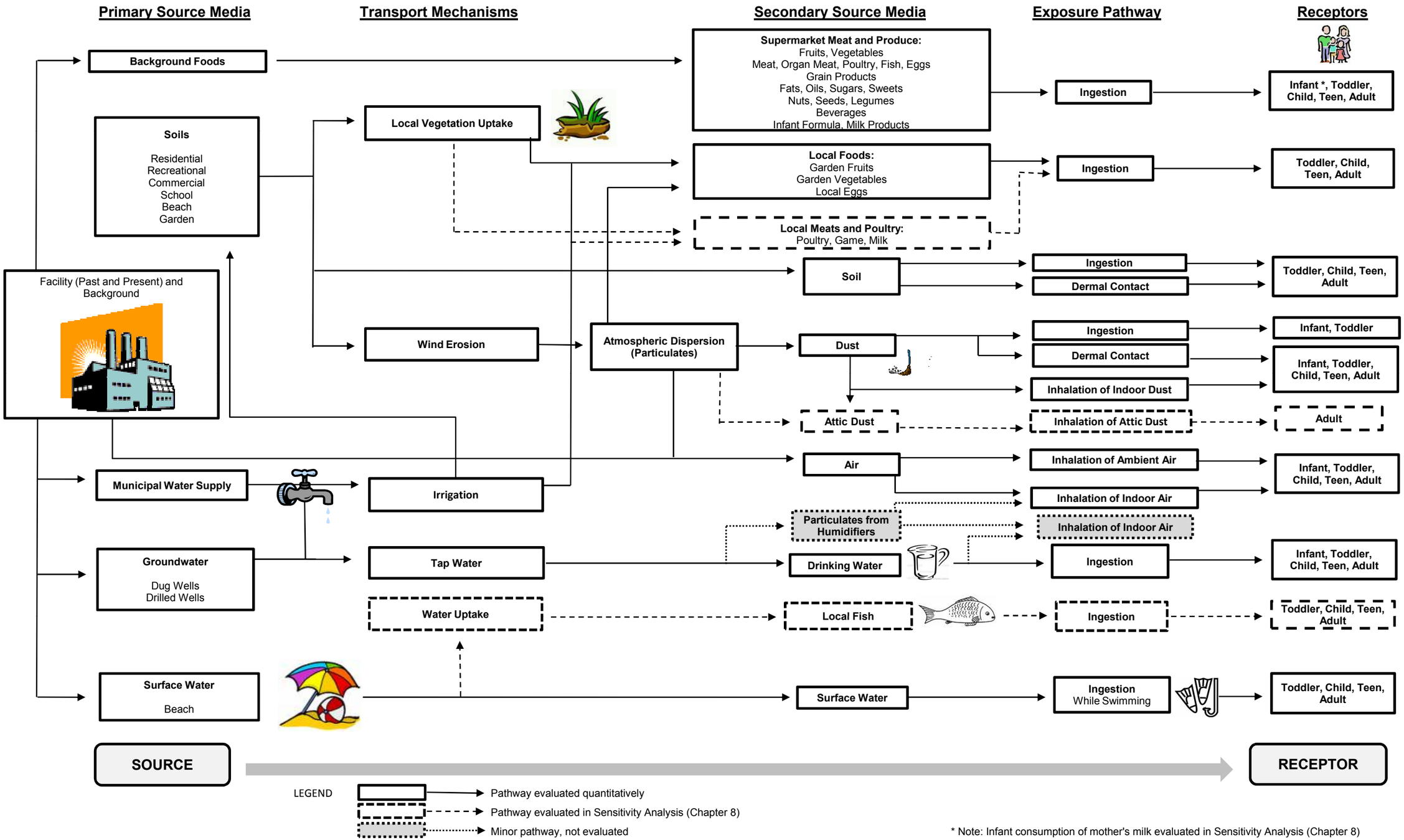
Job Number: ONT34644
Date: October 2003
Dwn by: C. Amirault
Approved by: Kevin Wong

Map Parameters
Projection: UTM
Datum: NAD 83
Scale 1 : 30,000

Regional NIAGARA

Jacques Whitford
Consulting Engineers
Environmental Scientists
Risk Consultants

Figure 3-2 Schematic Illustration of Site Conceptual Model for Human Receptors



In addition to the review of the municipal water supply, types of wells were reviewed. Wells were found to fall into two distinct categories, drilled wells and dug wells. In the area on the north shore of Lake Erie where sandy soils occur, dug wells were common. Not all of these wells met the current MOE regulations for wells supplying drinking water. An uncased well can allow surface runoff (carrying any variety of chemicals, bacteria or other pollutants) to enter the well, which might also contaminate the aquifer. Further north from Lake Erie in the areas of organic and clay soils, almost all wells were installed by drilling. Since the types of wells in most cases could be related to proximity to the region of sandy soils proximate to Lake Erie and the residential land use in that area, these were considered separately from drilled wells in organic and clay soils, in agriculturally zoned areas. For a summary of the general characteristics of the Zones, see Table 3-2.

Dominant soil types were reviewed for the selected Zones, as detailed previously in Section 2.5. The dominant soil types identified in each Zone are identified in Table 3-2. Note that recreational land use was not differentiated according to soil type in Zone D.

Areas of Zones A, B and C have been covered by fill. Fill was noted as the predominant soil type in Zone B based on test pit records for this Zone. This was the direct result of historical infilling of former low-lying marsh areas in Zone B, as evidenced in test pit records showing fill overlying layers of organic peat and/or beach sand. Zones A and C contain predominantly clay soils. In Zone D, three soil types, namely clay soils and organic soils in agricultural areas and sandy soils along the north shore of Lake Erie, were found. Each of these three soil type areas of Zone D were selected for separate consideration in the Zone D assessment. In other Zones, further review of field records indicated that the soils in residential areas have been highly amended and that soil classifications in these areas are not particularly useful.

Daycare centres were not specifically evaluated; exposures to preschool children were evaluated based on home exposure levels. Home exposure levels would be expected to be similar to those at daycare centres or home daycare in the same Zone. This does not account for increased exposures to children living in areas of lower CoC soil concentrations who might attend daycare centres or home daycare in areas with higher CoC soil concentrations. However, the assessment of children living in higher CoC soil concentration areas is a worse-case scenario for potential exposure. The assessment of exposures for the child living in the Zone with the highest CoC soil concentration is therefore considered a RME concentration scenario.

Table 3-2: Summary of HHRA Zone Characteristics

HHRA Zone	Zone Subgroup	Characteristics			
		Drinking Water Source	Land Use	Schools	Surface Soils
A	Not Applicable	Municipal	Residential Commercial/Industrial Recreational	Public Elementary	Significant amendment of soil
B	Not Applicable	Municipal	Residential Commercial/Industrial Recreational	No schools	Significant amendment of soil
C	Not Applicable	Municipal	Residential Commercial/Industrial Recreational	Public Elementary Catholic High School Private Elementary	Significant amendment of soil
D residential	Near Shore, Sandy Soils	Dug wells	Residential Recreational Beach	No schools	Sandy soils
D farm, clay soils	Away from Shore, Clay soils	Drilled wells	Residential Commercial/Industrial Agricultural	Catholic Elementary	Clay soils
D farm, organic soils	Away from Shore, Organic soils	Drilled wells	Residential Agricultural	No schools	Organic soils
Zone D (all sub-areas)	All, recreational	Not Applicable	Recreational	Not Applicable	All soil types
E	Not Applicable	Municipal*	Residential Commercial/ Industrial Recreational Beach Agricultural	Public Elementary Public High School Catholic Elementary	Significant amendment of soil in residential areas
F	Not Applicable	Representative of regional background	Residential Commercial/Industrial Recreational Beach Agricultural	Elementary Public High School	All soil types

Notes:
For details of zone designation, see Volume III, Appendix 3.
* Use of well water in Zone E evaluated in the Sensitivity Analysis (see Chapter 8).

3.1.2 Receptor Selection

Receptors for the HHRA were people that have maximum opportunities for potential exposures to CoCs under normal, everyday living conditions. People who reside or work (including farmers and field workers) in the City of Port Colborne and surrounding area were considered receptors for the HHRA. CoCs are present in residential and agricultural areas, therefore, infants, toddlers, children, adolescents and adults were all considered as receptors for the purposes of the HHRA. See Table 3-3 for a summary of the receptor age groups selected for evaluation. See Figure 3-2 for the Site Conceptual Model depicting the receptors and their respective exposure pathways selected for evaluation.

The infant is defined as an infant in arms, up to six months of age, before being able to crawl or eat solid foods. Potential exposure to this age group is limited by these characteristics. While an infant might be placed on a floor, carpet or blanket, the infant is considered unlikely to be placed in an exposed soil area. Most of the infants' diet is expected to be either breast milk or infant formula. Breast milk is considered in the Sensitivity Analysis (see Chapter 8).

The toddler age group captures the range of characteristics of children from the time they first become mobile through preschool years. This age group has a varied diet and is assumed to consume infant formula (for part of their toddler years) and other foods. Breast milk consumption by toddlers was not evaluated, as this was considered to be a reduced portion of the diet. Toddlers were assumed to frequently play outdoors and in close proximity to soil and dust, which might be incidentally ingested by hand to mouth frequency.

Children are defined as school-aged preteens. The soil ingestion rate of children might be greater than for teens and adults; however, there is less direct soil contact for this age group and less hand to mouth activity than for the toddler age group.

Teens display many of the characteristics expected of adults but might have increased exposures to soils by playing sports. Teens might also be employed part time and might work on farms. Adult exposures are similar to teens, with amount of time working being greater. Adults are assumed to do the majority of work in home gardens.

Characteristics of residents living in agriculturally zoned areas of Zone D were assumed to have different lifestyle characteristics than residents living in the non-agriculturally zoned area along the north shore of Lake Erie (also Zone D). These receptors were considered separately within the assessment of Zone D. For Zone E, which encompasses areas of Port Colborne with soil CoC concentrations below guideline values (*i.e.,* local background), two scenarios were considered. In one scenario (Zone E1 City), residents were evaluated as attending high school or working

within Zones A through D. In the other scenario (Zone E2 Background), only exposures in Zone E were evaluated. Only the Zone E2 Background receptors were considered as representing local background conditions.

Table 3-3: Receptors Summary

Land Use	Age Group	Age (yrs)	School/Work	Recreation
Residential	Infant	<0.5	No	Recreational
Residential	Toddler	0.5 to <5	No	Beach, Recreational
Residential	Child	5 to <12	Elementary School	Beach, Recreational
Residential	Teen	12 to <20	High School Work locally	Beach, Recreational
Residential	Adult	20 +	Work Locally	Beach, Recreational
Agricultural	Infant	<0.5	No	Recreational
Agricultural	Toddler	0.5 to <5	No	Beach, Recreational
Agricultural	Child	5 to <12	Elementary School	Beach, Recreational
Agricultural	Teen	12 to <20	High School Work on Farm	Beach, Recreational
Agricultural	Adult	20 +	Work on Farm	Beach, Recreational

Note:
For detailed discussion of receptor characteristics see Volume III, Appendix 3.

Since the public high school is in Zone E, attendance at the Catholic high school in Zone C was considered a RME concentration scenario for teens in Zones A, B, C, D and E1 City.

Elementary school children residing east of the canal might attend public or private school in Zone C or Catholic school in Zone D. When looking at concentrations in soil and air, some are higher for Zone C while others are higher for Zone D. All elementary school students were assumed to go to school in Zone C and Zone D was selected for evaluation in the sensitivity analysis.

Elementary school children residing west of the canal might attend public school in Zone A, Catholic school in Zone E or private school in Zone C. Attendance of school in Zone C was selected as the RME concentration scenario for these students based on CoC concentrations in soil and air for these Zones.

In order to evaluate RME concentration scenarios, teens were assumed to work in the same Zone in which they reside and adults were assumed to work in the Zone of the highest CoC concentrations in soils. All residents in the agricultural areas were assumed to work on farms while residents from other Zones were assumed not to. See Table 3-4 for a summary of the HHRA Zones to which each receptor's exposures were assigned.

Table 3-4: Exposure Components for Each Receptor Summary

Receptor	Potential Area and Exposure Component Combinations				
	Residence	**School**	**Work**	**Recreational[1]**	**Beach**
Zone A Resident	Zone A	Child – Zone C Teen – Zone C	Teen – Zone A Adult – Zone B [3]	Zone A	Zone D
Zone B Resident	Zone B	Child – Zone C Teen – Zone C	Teen – Zone B Adult – Zone B [3]	Zone B	Zone D
Zone C Resident	Zone C	Child – Zone C Teen – Zone C	Teen – Zone B [2] Adult – Zone B [3]	Zone C	Zone D
Zone D Resident, Farm, Drilled Well. Clay or Organic Soils	Zone D	Child – Zone C Teen – Zone C	Teen and Adult - Zone D, Farm	Zone D	Zone D
Zone D Resident, Non-Farm, Dug Well, Sandy Soils	Zone D	Child – Zone C Teen – Zone C	Teen – Zone D, Non-Farm Adult – Zone B [3]	Zone D	Zone D
Zone E1 City Resident	Zone E1 City	Child – Zone C Teen – Zone C	Teen – Zone E Adult – Zone B [3]	Zone E	Zone D
Zone E2 Background Resident	Zone E2 Background	Child – Zone E Teen – Zone E	Teen – Zone E Adult – Zone E	Zone E	Zone E
Zone F Background Resident	Background	Background	Background	Background	Background

Notes:

For details of receptor characteristics see Volume III, Appendix 3.

[1] Includes parks and woodlots.

[2] The Zone C Teen was assumed to work in Zone B as no commercial soils were sampled from Zone C.

[3] Zone B was assumed to be the Zone of highest soil nickel concentrations that workers other than farmers would be exposed to.

Table 3-5: Screening of Exposure Pathways and Media

Exposure Pathway	Medium	Resident	Location	Screening (Yes or No)
Dermal	Soils	Zones A, B, C, D residential and E	Residence	Yes, all ages except infant.
			School	Yes, child and teen only.
			Work	No, assumed to work indoors; considered in Sensitivity Analysis.
			Beach, Recreation	Yes, all ages except infant.
		Zone D farm	Residence	Yes, all ages except infant.
			School	Yes, child and teen only.
			Work	Yes, on farm, teen and adult.
			Beach Recreation	Yes, all ages except infant.
	Indoor Dust	Zones A, B, C, D residential and E	Residence, School, Work	Yes, all ages.
		Zone D farm	Residence, School	Yes, all ages.
			Work	No, assumed to work outdoors.
	Attic Dust	All Zones	Residence	No, only inhalation evaluated. Infrequent pathway; not a significant exposure route.
	Surface Water	All Zones	Beach	No, not a significant exposure route. Screened out based on U.S. EPA Superfund dermal exposure guidelines.
	Tap Water (municipal or well)	All Zones	Residence, School, Work	No, not a significant exposure route. Screened out based on U.S. EPA Superfund dermal exposure guidelines.
	Air	All Zones	Residence, School, Work, Beach, Recreation	No, not a significant exposure route. No expectation for absorption of inorganic chemicals from this route.

Table 3-5: Screening of Exposure Pathways and Media (Continued)

Exposure Pathway	Medium	Resident	Location	Screening (Yes or No)
Ingestion	Soils	All Zones	Residence	Yes, all ages except infant.
			School	Yes, child and teen only.
			Work	No, assumed to work indoors; considered in Sensitivity Analysis.
			Beach, Recreation	Yes, all ages except infant.
		Zones A, B, C, D residential and E	Work	No, assumed to work indoors; considered in Sensitivity Analysis.
		Zone D farm	Work	Yes, teen and adult on farm.
	Indoor Dust	All Zones	Residence	Yes. Soil ingestion rates include both soil and dust. For infants and toddlers, indoor dust ingestion was evaluated separately using recent guidance identifying higher hand to mouth activity frequency. This results in a double counting for toddlers and is considered conservative. Evaluation of older age groups as ingesting only soil, at generally higher CoC concentrations (rather than the same total amount of soil plus dust) was concluded to be conservative for this pathway.
	Garden produce	All Zones	Residence	Yes, all ages except infant.
	Farm produce (milk, eggs, *etc*.)	Zones A, B, C and E	Residence	No, considered as source of uncertainty only; based on results of resident survey.[1]
		Zone D farm and Zone D residential	Residence	Yes, consumption of eggs evaluated based on results of resident survey.[2] Infants excluded.
	Supermarket produce	All Zones	Residence	Yes, all ages.
	Municipal Water	Zones A, B, C and E	Residence, Work, School	Yes, all ages.
		Zone D farm and Zone D residential	Residence, Farm Work	No, consumes well water. Non-farm residents may also carry beverages from home to work.
			Vacation	Yes, all ages.
			School	Yes, applies to child and teen.
	Well Water	Zones A, B, C and E	Residence, Work, School	No, consumes municipal water.
		Zone D farm and Zone D residential	Residence, Work, School	Yes, all ages (drilled and dug wells). All drinking water was assumed to be consumed at home.

Notes:
Details of receptor characteristics can be found in Volume III, Appendix 3.
[1] 22% of Zone A residents, 13% of Zone B and 11% of Zone C consume locally produced eggs.
[2] 48% of Zone D residents consume locally produced eggs.

Table 3-5: Screening of Exposure Pathways and Media (Continued)

Exposure Pathway	Medium	Resident	Location	Screening (Yes or No)
Ingestion	Surface Water	All Zones	Beach	Yes, incidental ingestion, all ages except infant.
	Attic Dust	All Zones	Residence	No. Infrequent pathway; not a significant exposure route.
	Local Game	All Zones	Residence	No, considered as source of uncertainty only, based on results of resident survey.[3]
	Local Fish	All Zones	Residence	No, considered as source of uncertainty only, based on results of resident survey.[4]
Inhalation	Indoor Air	Zones A, B, C, D residential and E	Residence, Work, School	Yes, all ages.
			Beach, Park, Recreation	No, no opportunity for exposure.
		Zone D farm	Residence, School	Yes, all ages.
			Work, Beach, Recreation	No, no opportunity for exposure.
	Attic Dust	All Zones	Residence	No, intermittent exposure evaluated as source of uncertainty only.
	Ambient Air	Zones A, B, C, D residential and E	Residence	Yes, all ages.
			Work	No, assumed to work indoors; considered in Sensitivity Analysis.
			School, Beach, Recreation	Yes, all ages.
		Zone D farm	Residence, Work, School, Beach, Recreation	Yes, all ages (child, teen at school; teen, adult at work).

Notes:

For details of receptor characteristics see Volume III, Appendix 3.

[3] Only 4% of Port Colborne residents consume local game.

[4] The percentage of residents who consume local fish is 21%, varying from 15 to 33% in different zones.

3.1.3 Selection of Exposure Pathways and Media

The potential for adverse health effects from CoCs can increase with increasing exposure. Exposure from each pathway was considered in the HHRA. As certain exposure pathways have been found to be minimal or inapplicable, a screening was done to identify inapplicable pathways. Exposure pathways that were deemed as not being significant exposure routes were not considered further for quantitative assessment under the HHRA.

See Table 3-5 for a matrix of exposure routes considered for receptors for each exposure location. The U.S. EPA (2001a) has assessed the relative contribution of arsenic, copper and nickel to exposures for dermal absorption from water as a percentage of oral dose. Because the percentage contribution of dermal absorption from water of these three CoCs is extremely small relative to oral exposure, evaluation of this exposure route is not considered necessary and, therefore, dermal absorption of CoCs in water was not evaluated.

The U.S. EPA (2001a) method for estimating the relative contribution of dermal absorption from water indicated that less than 1% of absorbed dose would be from ingestion of water. This exposure pathway was therefore considered insignificant and was not considered further.

Other pathways were excluded based on assumptions that most workers work indoors, except farm workers who were evaluated as working exclusively outdoors. An outdoor worker scenario was investigated as part of the Sensitivity Analysis. This worker was assumed to be exposed to RME concentrations in Zone B, but to work exclusively outdoors, as a landscaper, for example (see Chapter 8).

Not evaluated in the context of RME concentration scenarios were ingestion of local:

- farm produce by residents outside of Zone D;
- farm produce other than eggs by Zone D farm residents; and,
- fish and game and exposure to attic dust.

The resident survey (see Volume III, Appendix 5 for detailed results and Volume III, Appendix 3 for evaluation of the results) in Port Colborne determined that these ingestion pathways were not common and were, therefore, not considered "typical" or RME concentration scenarios. Exposures of excluded pathways were considered in the Sensitivity Analysis (see Chapter 8), which includes estimates of risk for receptors exposed to attic dust and receptors who might incur increased exposure levels, such as hunters or fishers who regularly consume locally-caught game or fish.

See Chapter 7 for a detailed analysis of maximum scenarios considered within the context of the HHRA.

Public trails through woodlots were considered in the HHRA. Woodlot soils were included in the "recreational soils" category (see Volume V, Appendix 20, Attachment A). Most of the woodlots are on private or industrial (*e.g.,* Inco) property.

The Site Conceptual Model (see Figure 3-2) draws together the land uses, receptors and exposure pathways evaluated for each medium. For the summary of exposure scenarios for each receptor see Table 3-6. Each applicable exposure pathway selected (see Table 3-6) was quantitatively evaluated for each receptor (see Table 3-5). The combinations of Zones assumed for each resident were designed to maximize potential exposures. For example, a receptor might work in any Zone, but the highest estimated exposures at work was applied to each receptor. Background exposures (Zone E2 Background and Zone F) were evaluated for receptors based on Ontario typical concentrations, literature review and sampling conducted during this study from outside of the study area and are not included in Table 3-6. Note that Zone B residents reported in the resident survey that they vacation in Port Colborne and, therefore, are not exposed to the background concentrations during vacation time (see Volume III, Appendix 5).

Sample Calculation: Introduction

Throughout the report, sample calculations are provided as a guide to the reader to better understand the Problem Formulation, exposure calculations and risk assessment within this HHRA. These sample calculations illustrate a conservative estimate of risk from nickel (Ni) by using the maximum surface soil concentration from the most heavily impacted area of the HHRA (*i.e.,* Zone B), as well as the most sensitive receptor (*i.e.,* the toddler). Steps of the sample calculations that follow are in text boxes like this one.

Note that the sample calculation is a simplified calculation, evaluating exposure at only one location in the community and is not precisely equal to any scenario evaluated.

Table 3-6: HHRA Exposure Scenarios

Medium	Exposure Pathway	Location	Zones	Receptors				
				Infant	Toddler	Child	Teen	Adult
Soils	Ingestion	School Outdoors	A – E			✓	✓	
		Home Outdoors, Not Gardening	A – E		✓	✓	✓	✓
		Home Gardening	A – E					✓
		Beach	A – E		✓	✓	✓	✓
		Park (Recreation)	A – E		✓	✓	✓	✓
		Work Outdoors	D – Farms only				✓	✓
		Vacation Outdoors, Outside Port Colborne	A – E except Zone B		✓	✓	✓	✓
	Dermal Contact	School Outdoors	A – E			✓	✓	
		Home Outdoors, Not Gardening	A – E		✓	✓	✓	✓
		Home Gardening	A – E					✓
		Beach	A – E		✓	✓	✓	✓
		Park (Recreation)	A – E		✓	✓	✓	✓
		Work Outdoors	D – Farms only				✓	✓
		Vacation Outdoors, Outside Port Colborne	A – E except Zone B		✓	✓	✓	✓
Dust	Ingestion	Home Indoors	A – E	✓	✓	✓	✓	✓
	Dermal Contact	School Indoors	A – E			✓	✓	
		Home Indoors	A – E	✓	✓	✓	✓	✓
		Work Indoors	A – E except D Farms				✓	✓
		Vacation Indoors, Outside Port Colborne	A – E except Zone B	✓	✓	✓	✓	✓
Municipal Water	Ingestion	Home	A – E except all Zone D	✓	✓	✓	✓	✓
		Vacation In and Outside Port Colborne	A – E	✓	✓	✓	✓	✓
		Vacation	Zone B	✓	✓	✓	✓	✓
Background Water	Ingestion	Vacation	A – E except Zone B	✓	✓	✓	✓	✓
Drilled Well Water	Ingestion	Home	D – Farms Only	✓	✓	✓	✓	✓
Dug Well Water	Ingestion	Home	D – Rural, Non-Farms Only	✓	✓	✓	✓	✓
Surface Water	Ingestion	Beach	A – E		✓	✓	✓	✓

Table 3-6: HHRA Exposure Scenarios (continued)

Medium	Exposure Pathway	Location	Zones	Receptors				
				Infant	Toddler	Child	Teen	Adult
Indoor Air	Inhalation	School Indoors	A – E			✓	✓	
		Home Indoors	A – E	✓	✓	✓	✓	✓
		Work Indoors	A – E except D – Farms				✓	✓
		Vacation Outdoors Outside Port Colborne	A – E except Zone B	✓	✓	✓	✓	✓
Ambient Air	Inhalation	School Outdoors	A – E			✓	✓	
		Home Outdoors	A – E	✓	✓	✓	✓	✓
		Beach	A – E		✓	✓	✓	✓
		Park (Recreation)	A – E	✓	✓	✓	✓	✓
		Work Outdoors	D Farms				✓	✓
		Vacation Indoors Outside Port Colborne	A – E except Zone B	✓	✓	✓	✓	✓
Supermarket Foods	Ingestion	Home	A – E	✓[a]	✓	✓	✓	✓
		Vacation In and Outside Port Colborne	A – E	✓[a]	✓	✓	✓	✓
Garden Produce	Ingestion	Home	A – E		✓	✓	✓	✓
Farm Produce (Eggs)	Ingestion	Home	D-Farms and D-Non-Farms		✓	✓	✓	✓

Note:
Details of receptor characteristics can be found in Volume III, Appendix 3.
[a] Infant formula only.

3.2 CoC Concentrations

CoC concentrations used in the HHRA report are summarized in Tables 3-10 to 3-15. These tables include RME concentrations used to estimate risks to typical Port Colborne residents and maximum concentrations used in selected scenarios of maximally exposed receptors. Note that maximum concentrations do not apply to all media since not all parameters are at maximum concentrations for any receptor. For further details of the actual scenarios evaluated, see Chapter 7.

3.2.1 Quality Assurance and Quality Control

Quality assurance and quality control (QA/QC) are essential in order to assess reliability and variability in concentrations of CoCs measured in samples collected in the field. For a detailed protocol, see Volume II, Appendix 1.1.

Jacques Whitford staff collected field duplicate samples during sampling programs while the laboratory analyzed replicate samples. The results of the duplicate and replicate samples were used to calculate relative percentage differences between the analyses of the original samples and those of the duplicates or replicates, as applicable. Relative percentage differences were calculated for sample concentrations greater than three times the Estimated Quantification Limit (EQL, the lowest achievable measurement of a compound in an analytical laboratory), where 30% was the quality control limit. The results for each sampling program have been included as attachments to the corresponding appendices, where applicable. For the locations of these attachments, see Table 3-7.

Table 3-7: Location of QA/QC Attachments in HHRA Report

Sampled Medium	Location of Corresponding Appendix	Appendix Number	QA/QC Attachment
Soils (Indoor Air)	Volume IV	Appendix 13	Attachment G
Drinking Water	Volume V	Appendix 15	Attachment D
Surface Water	Volume V	Appendix 16	Attachment D
Garden Produce / Garden Soils	Volume V	Appendix 17	Attachment C
Game / Milk / Fish / Poultry	Volume V	Appendix 18	Attachment B
Supermarket Food	Volume V	Appendix 19	Attachment C
Maple Sap / Syrup	Volume V	Appendix 21	Attachment A

The percentage differences for the replicates indicated good overall reproducibility of results in the laboratory. Most replicate sample concentrations were averaged with the original to account for variability and this average was carried forward into the data analysis step. However, in the cases where the relative percentage difference was much higher than 30%, the maximum reported concentration between the original and replicate sample was used instead.

A small number of duplicate samples were noted to exceed the 30% quality control limit. These results were examined and considered minor and were likely the result of a lack of homogeneity in the samples.

The overall conclusion of the analysis of field duplicates and laboratory replicates for each sample set was that the data were of adequate quality and reproducibility to support the risk assessment.

3.2.2 Statistical Analyses

The various statistics and data have been reviewed to select statistical parameters and data most relevant for use in the assessment. Decisions as to which statistical parameters were used were made after completion of the initial evaluation of the distributions of the data. Each data set is unique and requires unique considerations for detection limits, skewness, number of samples, location, applicability to the analysis and data quality. Consideration was given to each case based on the data and statistics associated with the data set. For a detailed description of the statistical analysis approach used in the HHRA, see Volume III, Appendix 4.

Statistical analyses were performed primarily using SPSS (Version 11.0). Bootstrapping analyses were performed using Systat, Version 10.0. Geographically distributed data sets were stored in a Geographical Information System (GIS) database (ArcView, Version 3.2a) and used to analyze these data. Additional analyses were performed on the GIS database using SPSS. Resident questionnaire data were housed in a relational Microsoft Access '97 database. Additional data analyses were also performed using Microsoft Excel '97.

The overall approach to the selection of appropriate statistics was to select both RME concentrations and concentrations to which maximally exposed individuals would be exposed. A RME concentration is defined as the statistically estimated concentration that represents the typical upper estimate of the average concentration of a given medium, taking into account concentration variability. Steps in estimating the RME concentrations included the comparison of statistical parameters such as the mean, the maximum, the 75th percentile and the 95% upper confidence limit of the mean (UCLM) or the 95% upper confidence limit of the geometric mean (UCLGM).

In all cases, results for laboratory replicate samples and field duplicate samples were averaged with results for the original samples. For detailed results for laboratory replicate and field duplicate samples, see the appendices outlined in Table 3-7.

3.2.3 Chemicals of Concern (CoC) Concentrations in Soils

The available data on concentrations of CoCs in soils were categorized according to HHRA Zone and land use type. Data from residential soils at all depths were analysed and incorporated into the HHRA as a maximum scenario analysis (see Chapter 7). Statistical analyses (see Volume V, Appendix 20) on surface soils (0 to 5 cm depth plus garden soils and beach sand for 0 to 15 cm depth) were performed to select concentrations representative of reasonable maximum exposures. For the analyses for the selection of RME CoC concentrations, see Volume V, Appendix 20. Grain size analyses were also performed on the data and the results of these analyses were used to select appropriate soil criteria for comparison.

In order to specifically evaluate potentially higher exposures to soils while gardening, garden soil CoC concentrations obtained during the garden produce sampling were differentiated from other residential soil CoC concentrations. Garden soils were taken from the top 0 to 15 cm of sampled soil.

Sample Calculation Input

Input: Soil Concentration

Zone B Maximum soil concentration (depth of 10 cm) 17,000 µg/g [a]

This concentration serves as an input into Step 3 (see Chapter 5).

a. Volume V, Appendix 20

Background (Zone F) concentrations were selected based on Ontario typical concentrations (OTR_{98} from MOE, 1997), which are considered representative of the upper limit of normal soil concentrations. Only one scenario (the RME concentration scenario) was evaluated for Zone F. Zone F maximum exposed receptors were not evaluated.

3.2.4 Concentrations in Drinking Water and Surface Water

3.2.4.1 Concentrations in Drinking Water

Much of the City of Port Colborne is serviced by municipal water supply. Drinking water data were collected from drilled and dug wells, from the municipal supply and from MOE Drinking Water Surveillance Program (DWSP) data.

The municipal water supply data is considered applicable to the HHRA Zones A, B, C and E, which are serviced by the municipal water supply. Further consideration for areas of Zone E on well water is given in the Sensitivity Analysis (see Chapter 8).

Included in the municipal water supply data are MOE water samples collected at the treatment plant and in the water distribution system. All samples were included in the evaluation, even though some samples of standing water showed higher concentrations (particularly noted for copper) than other samples, making the data set highly skewed.

Data from MOE and samples obtained in this study were pooled and analyzed together. All tap water samples were included in the analysis of drinking water. Additional samples were collected at wellheads and elsewhere in the water supply and treatment systems. Most of these samples were field filtered for direct comparison to groundwater criteria.

Data for dug wells and drilled wells were evaluated as two data sets. This was due to the fact that dug and drilled wells are quite distinct in terms of depth and screening material. Dug wells were screened through the overburden, while drilled wells were screened within a section of the bedrock aquifer. The cobalt and nickel data sets for dug wells were found to be log-normally distributed and were assigned upper confidence limits on the geometric means as representative concentrations. The other data sets were found to be neither normally nor log-normally distributed and 75th percentile concentrations were selected except in three cases where the data were highly skewed and the UCLM concentrations exceeded the 75th percentiles. In these cases, the UCLM concentrations were selected. A maximum scenario is estimated in which Zone D residents are exposed to maximum CoC concentrations in drinking water from their drilled or dug wells (see Chapter 7).

Sample Calculation Input

Input: Drinking Water Nickel Concentration

75th percentile of drinking water total nickel concentration:	0.0016 mg/L [a]

This concentration serves as an input into Step 4 (see Chapter 5).

a. Volume V, Appendix 15

Treated water samples collected by the MOE between 1998 and 1999 were obtained for five water treatment facilities located on Lake Erie. The treatment facilities included the Dunnville, Fort Erie (Rosehill), Haldimand-Norfolk, Port Dover and Port Rowan water treatment plants. These stations were selected as representative of background concentrations in treated drinking water obtained from Lake Erie and are considered applicable to Zone F exposures and to residents of Port Colborne while vacationing outside of the City.

3.2.4.2 Concentrations in Surface Water

In July 2001, a total of three surface water samples were collected in Lake Erie off the shore of Nickel Beach (see Volume V, Appendix 16). Representative concentrations of arsenic, cobalt, copper and nickel were selected from the data available. The statistical summary of the sampling data indicate little difference between the average and maximum concentrations measured for each of the CoCs. Given the small sample size (three samples), the maximum concentrations measured were selected as exposure concentrations in surface water. Very little variability in concentrations was noted.

3.2.5 Concentrations in Air

3.2.5.1 Modelling of CoCs in Ambient Air

The focus of the air quality dispersion modelling was the estimation of the long-term average ambient air CoC concentrations in the Port Colborne area under current conditions. The sources of the CoCs used in the study were derived from a number of sources identified in the study protocol, *Protocol for Air Quality Dispersion Modelling, Human Health Risk Assessment Input* (see Volume II, Appendix 1.4). For details of the application of the air quality dispersion model, CALPUFF version 5.4, see Volume III, Appendix 9. Monitoring of dust emissions from farming activities was considered in the selection of emission factors for the ambient air model.

Approximately five years of environmental monitoring data (July 2001 through March 2006) available from the ongoing MOE monitoring program, was used in the modelling. Comparison of the model computations with measured ambient data was made at the location of the monitor with highest CoC concentrations. These measured data were used to validate the modelling results. The maximum annual average concentrations of nickel and arsenic from this monitor were selected as the RME concentrations when modelled data exceeded the measured levels. This assumption is considered valid since the actual measured data are more representative than the modelled data.

Modelling of CoCs included data on ambient air integrated local industrial emission sources (including industrial emissions and re-suspension of chemicals in soils and dust) as well as local and regional meteorological data to estimate RME and maximum location long-term average air concentrations. Monitoring data from all of the MOE and Jacques Whitford monitors were used to calibrate and validate the model output.

Emissions Sources

The emissions estimated in this study were partly derived from U.S. EPA AP-42 equations (U.S. EPA 2002d). Input data included current Inco nickel emissions from the Port Colborne Refinery 2001 National Pollution Release Inventory (NPRI 2001) report. Other non-Inco emission sources of PM_{10} (the respirable component of total suspended particulate [TSP]) included the following (emission estimation technique listed in brackets):

- dust entrainment as a result of road traffic (AP-42 EF)
- dust entrainment as a result of wind erosion off of open fields (AP-42 EF)
- dust entrainment as a result of farming activities (ISC3)
- emissions from current Inco site activities (NPRI, 2001)
- burning of carbon based fuels

A particle-size analysis on Port Colborne soil was done in order to estimate the amount of nickel expected to reside in the particulate matter of diameter 10 µm or less (PM_{10}). PM_{10} data were used in the HHRA. These fractionation data, in conjunction with AP-42 PM_{10} emission factors, were used to estimate ambient nickel concentrations in a systematic grid pattern at a number of points throughout the Port Colborne area. For current nickel emissions from the Inco Refinery, it was assumed that all the nickel is released in the PM_{10} fraction range. PM_{10} data are considered the most relevant to an evaluation of human health since they represent the total respirable particulate in air. Larger particle sizes, *i.e.* TSP, would not be expected to reach the lungs. Smaller size fractions (e.g. $PM_{2.5}$, particulate matter of diameter 2 µm or less) would reach the deepest parts of the lung; however, use of these data may underestimate the total amount of the CoCs reaching the lungs.

Meteorological Data

The CALMET meteorological pre-processor was executed to generate gridded fields of model parameters including wind speed, wind direction and mixing layer heights. Raw hourly meteorological data from January 1996 to the end of November 2000 were obtained from the Inco on-site meteorological tower, the Environment Canada (EC) Port Colborne meteorological station, as well as data from Buffalo and Niagara Falls, New York from the National Climatic Data Center (NCDC) in the United States.

Twice daily, upper air sounding data were obtained from NCDC for Buffalo (station 14733)—the nearest upper air station to Port Colborne. Hourly lake temperatures for 1996 to 2000 were obtained from the DFO for the nearest buoy to Port Colborne (Buoy 1645142).

Dispersion Modelling Predictions

Model predictions were validated against existing monitoring data (see Volume IV, Appendix 10). Annual average ambient air concentrations were estimated for the five HHRA Zones in the Port Colborne region. These zones corresponded to the same HHRA Zones A to E, see Figure 3-1.

3.2.5.2 Selected CoC Concentrations in Ambient Air

The results of the ambient air quality modeling for CoCs in each HHRA Zone were analyzed statistically. Long-term (5 year) average modeled concentrations distributed across each HHRA Zone were analyzed to estimate RME concentrations. Specifically, 95% Upper Confidence Limits on the Mean (UCLMs) were calculated for each data set, and were carried forward into the selection of the RME concentrations.

Examination of the ambient air modeling results revealed that the maximum air concentrations were found at discrete receptor location 25 in the modeling grid (at the baseball diamond at Rodney and Davis Streets in Zone B. This is also the location of the MOE's long-term monitoring station. For this reason, the highest year average concentrations from the MOE's monitoring data were selected as the RME concentrations for Zone B. Since the highest year was selected at this highest point, these concentrations were also considered maxima. Modelling results (UCLMs) were selected as RME concentrations in the other Zones, provided these were not higher than the Zone B highest year averages of the measured concentrations.

Measured copper concentrations in Zone B were noted to be over two orders of magnitude greater than the UCLM of the modeled concentrations in this Zone. The MOE data for copper was noted to include many instances where the copper in PM_{10} exceeded the copper in TSP (logically cannot happen as the PM_{10} measurement is theoretically a subset of the TSP measurement), an observation which may have been indicative of a data quality issue.

To ensure that copper concentrations in ambient air were not underestimated, the maximum exposure scenario adopted the Zone B measured copper concentrations for application to all Zones. Since the modeled Zone B copper concentration is the highest of all five Zones, measured copper concentrations in other Zones would be expected to be less than the maximum measured Zone B value. This maximum scenario was considered highly conservative. For other CoCs in Zones A, C and D, modelled concentrations from the highest location in each Zone were selected as maxima.

Background (Zone F) concentrations for each of the CoCs were obtained from typical Niagara Region data. The background concentration value for nickel was taken from the Ontario MOE ambient monitoring data for nickel in other areas of Niagara Region (MOE 2002), see Table A1-2b of the MOE Report *Soil Investigation and Human Health Risk Assessment for the Rodney Street Community, Port Colborne: March 2002*. The background value was taken to be 0.0018 µg/m^3, the mean nickel in PM_{10} concentration at Walpole Island and Point Petre. These locations were chosen because they are rural locations and are probably not unduly affected by any nearby industrial sources of nickel. These sites were sampled in spring 1995 for Walpole Island and summer 1996 through the end of 1998 for Point Petre.

For copper (0.018 µg/m^3), cobalt (0.002 µg/m^3) and arsenic (0.0016 µg/m^3), typical Ontario air concentrations were selected based on the average air concentrations reported in the Environment Canada air monitoring program (1995-1999, presented in MOE 2002).

Sample Calculation Input

Input: Ambient Air Concentration

Selected Nickel Maximum concentration in Ambient Air: 0.022 µg/m^3 [a]
(Based upon monitor at Rodney Street baseball diamond)

This concentration serves as an input into the following Step and is also used to estimate an inhalation dose rate for outside air as was demonstrated for indoor air in Step 6 (see Chapter 5).

a. Volume III, Appendix 9

3.2.5.3 Concentrations in Indoor Air

For the results of the study and data analyses for both TSP (total dust in the air) and finer PM_{10} (respirable dust) samples, see Volume IV, Appendix 13. As with settled dust, samples were collected in three study zones in Port Colborne.

The indoor air samples were collected over 24-hour periods at each location, which limits applicability to the evaluation of long-term average concentrations. Samples were collected in only one season and conditions from one home to another are highly variable. A long-term base of ambient air monitoring data is available in Port Colborne. Hence, the indoor air monitoring data were pooled for the three zones to provide the largest data set possible and compared to data from the long-term ambient air monitoring and modelling to assess whether any relationship could be found.

Concentrations of CoCs in indoor air in Port Colborne were measured as a part of the indoor air sampling program. In the study, PM_{10} and TSP samples were collected from 30 residences in Port Colborne from August to December 2002. Concentrations obtained were considered representative of the concentrations of indoor particulate for the majority of the Port Colborne community. The data, however, represent a snap shot of indoor air concentrations in time and, as a result, the direct application to the chronic Exposure Assessment was not considered appropriate. The data, however, might be used to generalize trends and support assumptions regarding the relationship between indoor air and ambient air concentration, thereby reducing our reliance on literature values.

Note that the investigation of a relationship between indoor and ambient air presumes that ambient air is the source of CoCs in indoor air in homes. This is expected to be a reasonable assumption for most homes. Should renovations or deteriorating conditions in specific homes cause CoCs that might have been historically entrained in the building structure (*e.g.*, walls, attic) to be re-entrained in indoor air, this assumption might not be valid. Since the focus on this assessment is the community at large, the establishment of a relationship between indoor and outdoor air was considered appropriate for the evaluation of chronic exposures.

Ambient air samples were collected at the baseball diamond (Rodney and Davis Street) on a six-day cycle.

A paired comparison between the ambient air data generated by the MOE during the indoor air sampling program and the indoor air results failed to generate any meaningful comparison because the relationship is complex and ambient air samples were not collected at precisely the same time as indoor samples. As a result, a paired comparison between the two data sets was not warranted. All comparisons were undertaken for nickel concentrations since nickel is the most prevalent and abundant CoC.

Concentrations of nickel from indoor air were instead compared to:

- long-term average nickel concentrations from ambient air modelling
- short-term ambient air sampling at various locations in the community during the summer of 2002
- long-term average ambient air concentration measured by MOE

For the latter two comparisons, indoor air samples were compared to ambient concentrations measured in the same zone. The three lines of analysis resulted in estimated ratios of indoor to outdoor air of 0.41, 0.47 and 0.58, respectively. These ratios are based on the 95% confidence limit on the mean (UCLM). Based on these results, a ratio of indoor to outdoor air of 0.6 was selected as conservative (*i.e.*, higher than the estimated values) for use in this HHRA to not underestimate indoor air concentrations. This value is considered reasonably conservative compared to values found in the literature. Shilton *et al.* (2002) measured a mean indoor/outdoor ratio of 0.4. Jones *et al.* (2000) measured an indoor outdoor particulate ratio of 0.6 for PM_{10}, the size fraction considered most relevant in the current assessment.

Sample Calculation Step 1

Input: Indoor Air Concentration

Selected Ratio of Indoor Air compared to Ambient Air: 0.6
Nickel Concentration in Indoor air = 0.6 x Maximum Concentration in Ambient Air
= 0.6 x 0.022 $\mu g/m^3$
= 0.013 $\mu g/m^3$

This concentration serves as an input into Step 6 (see Chapter 5).

3.2.5.4 Concentrations in Indoor Settled Dust

Results of the indoor air study were pooled for all three zones and evaluated statistically. Two types of distributions were noted in the indoor dust analysis. For the fabric dust samples, the arsenic, copper and nickel data sets were neither normally nor log-normally distributed. These data distributions were highly skewed and in all cases the UCLM exceeded the 75th percentile. For each of these data sets, the UCLM concentrations were selected as RME concentrations because the UCLM values exceeded the 75th percentile concentrations. All of the hard surfaces data sets and the fabric dust cobalt data set were found to be log-normally distributed and the upper confidence limits on the geometric means of these distributions were selected for these data.

No similar data on concentrations of the CoCs in house surface dust were identified for other areas in Ontario. The Zone E (Indoor air Zone 3) concentrations of CoCs in house surface dust were selected as the best available data for background exposures and were applied to Zone F. Note that only toddlers and infants were expected to ingest indoor settled dust, as measured hand –to mouth frequency was available only for these receptors.

For the detailed calculations, the average of values selected for fabric and hard surface dust concentrations was used. This number was then converted to a concentration of dust found on the toddler's hands based on methodology from New Jersey (1992). It was this concentration that was carried forward through the Exposure Assessment.

Additional consideration of exposure of receptors to attic dust is included in the Sensitivity Analysis in this HHRA. Receptors are not expected to be exposed to attic dust frequently. For the rationale behind the Sensitivity Analysis, see Chapter 8.

3.2.6 Concentrations in Local Foods

3.2.6.1 Concentrations in Garden Produce

The large data set for garden produce sampled in the Port Colborne area was reviewed and statistically analyzed (see Volume V, Appendix 17). Soil to plant uptake rates were investigated where sufficient data were obtained for individual produce types as well as for broad groupings of produce, namely root vegetables, leafy vegetables, other vegetables and fruit.

Overall, total CoC concentrations in soils were poorly predictive of vegetable CoC concentrations, although statistically significant relationships were often noted for nickel, rarely for copper and not at all for cobalt or arsenic. Graphical inspection of these relationships did not indicate strong relationships for most types of produce. The strongest relationships were obtained for uptake to root vegetables. The variability among vegetables within and among species in the generic vegetable groupings and the differences among soils in properties that affect CoC bioavailability (the majority of garden soils have been significantly amended with peat, manure, etc.) are likely factors that contributed to the overall variability observed in plant CoC accumulation.

Statistically, the actual measured concentrations in garden produce were accepted as the best information available for evaluation of potential exposures through this pathway. Since the sampling was conducted during unusually dry conditions, the location of the highest recorded concentrations is considered a reasonable, yet conservative, representation of the long-term potential exposures to maximally exposed individuals.

The data set was divided according to the HHRA study Zones as well as between fruits and vegetables. Selection of which produce were considered fruits versus vegetables followed the same divisions as used for the dietary intakes by food category in order to be consistent.

In Zone B, few samples of fruits were available so results from Zone C for fruits were pooled with the Zone B results to obtain sufficient data to select a representative concentration. Similarly, few vegetable samples were collected in Zone A so results from Zones B and C for vegetables were pooled with the Zone A results.

For each data set, representative concentrations were selected from the data. CoCs not detected were evaluated as being present in the sample at one half the detection limit, on a dry weight basis. Dry weight concentrations were converted to wet weight (or fresh weight) concentrations before statistical analysis.

Arsenic was not detected in any fruit samples and only a very limited number of vegetable samples. In these cases the average fresh weight concentrations estimated from one half the detection limit were selected as RME arsenic concentrations. Statistical distributions were fit to most other data and UCLMs or UCLGMs were selected. If the data were neither normally nor log-normally distributed, then either the UCLMs or the 75th percentile concentrations (depending on which was greater) were selected. For small data sets (*i.e.,* n <10) the maximum concentration was adopted.

For an estimate of risk from exposure to the maximum concentration of CoCs in backyard produce, see Chapter 7.

Background concentrations in garden produce were assumed to be the same as supermarket produce. Zone F residents were therefore assumed to obtain all of their produce from the supermarket.

Sample Calculation Input

Input: Garden Vegetable Concentration

Backyard vegetable maximum nickel concentration in Zone B:
2.5 µg/g Fresh Weight [a]

This concentration serves as an input into Step 5 (see Chapter 5).

a. Volume V, Appendix 17

3.2.6.2 Concentrations in Eggs

Thirteen egg samples were collected from Port Colborne residences. Each egg collected was considered as a single sample with several eggs harvested from one residence. Arsenic was not detected in any samples; therefore, one-half the EQL (EQL of 0.02 mg/kg; half EQL is 0.01 mg/kg) was selected as the RME arsenic concentration in local eggs. The remaining cobalt, copper and nickel data sets were tested for normality and log-normality. The cobalt and nickel data sets were found to be neither normally nor log-normally distributed, while the copper data set was normally distributed. The 75th percentile concentrations of cobalt and nickel, as well as the UCLM concentration for copper, were selected as RME concentrations. The use of the 75th percentiles was considered conservative given that the data appear to be positively skewed (skewed towards lower concentrations) in the case of nickel concentrations.

Background concentrations in eggs were assumed to be the same as those for supermarket eggs and Zone F residents were thus evaluated as obtaining all of their eggs from the supermarket.

3.2.7 Concentrations in Supermarket Foods

Concentrations of CoCs in supermarket foods were estimated using mean concentrations in each food group (see Volume V, Appendix 19). The analysis conducted provides a conservative estimate of concentrations. Since food samples were selected to obtain a robust sampling of foods tending to be higher in nickel, the dataset is biased towards higher concentrations of metals. In order to examine the potential variability in estimates of the CoCs in dietary intake, a comprehensive comparison of results with results from other dietary intake studies was conducted (see Volume V, Appendix 19).

Arithmetic mean concentrations of CoCs in Port Colborne foods by food type were selected for use in this assessment as conservative estimates of average concentrations. Supermarket foods concentrations were considered representative for all Zones evaluated in this assessment, including background.

The use of the mean concentrations for items analyzed in each food group is consistent with the approach previously adopted by Dabeka and McKenzie (1993), MOE (2002), U.S. FDA (2000), Tao and Bolger (1998), Pennington and Jones (1987) and the UK (Ysart *et al.*, 2000). This is considered appropriate for the estimation of background exposures.

Various literature studies have shown that nickel concentrations in food might, under certain circumstances, be influenced by the cooking process. In particular, the literature (see Section 1, Volume V, Appendix 19) indicates that larger amounts of nickel might be leached from new stainless steel utensils during cooking than from older, more used utensils. This was not considered as a significant contributor to long-term exposures, however, the studies showed that leaching decreases rapidly over the first few uses, making the total long-term contribution from this source minimal.

The results on the cooked food screening study conducted by Jacques Whitford in Port Colborne (see Attachment D, Volume V, Appendix 19) indicated that the contribution to levels of CoCs as a result of cooking surface (using old pans) is minimal. In fact, in all samples the concentration of CoCs in foodstuffs was decreased after cooking. These findings are consistent with those of Flint and Packirisamy (1995, 1997), European Commission (2001) and Brun (1979). Significant differences in concentrations were observed when comparing the wet weight concentrations between cooked foodstuffs and uncooked foodstuffs; this was attributed to a change in moisture content as a result of the cooking process. A more accurate comparison of dry weight concentrations of the four CoCs between the cooked samples and the uncooked samples showed little variation.

3.2.8 Selected Exposure Point Concentrations by Zone

See Tables 3-10 to 3-15 for the RME and maximum concentrations, together known as exposure point concentrations, chosen as inputs into the HHRA calculations.

Table 3-8: Selected Exposure Point Concentrations for Zone A

Zone	Medium	Units	Nickel		Copper		Cobalt		Arsenic	
			RME	Maximum	RME	Maximum	RME	Maximum	RME	Maximum
A	Residential Soil	mg/kg	430 [b]	1,700	77 [b]	210	13 [b]	30.	8.0 [a]	15
	Recreational Soil	mg/kg	1,100 [c]	1,100	96 [c]	96	22 [c]	22	4.9 [c]	4.9
	Commercial Soil (Zone A, teen)	mg/kg	430 [c]	430	69 [c]	69	14 [c]	14	5.8 [c]	5.8
	Commercial Soil (Zone B, adult)	mg/kg	410 [a]	16,000	770 [a]	8,400	20 [a]	270	13 [b]	140
	School Soil (Zone C)	mg/kg	590 [c]	590	72 [c]	72	17 [c]	17	8.7 [c]	8.7
	Beach Soil (Zone D)	mg/kg	240 [c]	240	11 [c]	11	15 [c]	15	4.6 [c]	4.6
	Garden Soil	mg/kg	320 [c]	320	47 [c]	47	9.0 [c]	9.0	5.1 [c]	5.1
	Garden Soil (Max. Produce Scenario)	mg/kg	NE	2,350	NE	138	NE	38	NE	NE
	Drinking Water (Municipal)	mg/L	0.0016 [d]	NE	0.022 [a]	NE	0.00017 [a]	NE	0.0005 [d]	NE
	Surface Water	mg/L	0.01 [c]	NE	0.0026 [c]	NE	0.00055 [c]	NE	0.011 [c]	NE
	Ambient Air	µg/m^3	0.0092 [a]	0.022	0.00061 [a]	0.51	0.0018 [a]	0.0026	0.0038 [a]	NE
	Indoor Air (estimated)	µg/m^3	0.0055 [f]	0.013 [f]	0.00037 [f]	0.31 [f]	0.0011 [f]	0.0016 [f]	0.0023 [f]	NE
	Indoor Air (measured)	µg/m^3	NE	NE	NE	0.045	NE	0.0067	NE	NE
	Fabric Surface Dust	µg/m^2	35 [a]	NE	26 [a]	NE	0.31 [b]	NE	3.8 [a]	NE
	Hard Surface Dust	µg/m^2	57 [b]	NE	84 [b]	NE	16 [b]	NE	7.9 [b]	NE
	Attic Dust	µg/m^2	NE	NE	NE	NE	NE	NE	NE	NE
	Garden Fruit	mg/kg FW	2.2 [c]	2.2	1.3 [c]	1.3	0.017 [c]	0.017	0.019 [c]	0.019
	Garden Vegetables	mg/kg FW	0.45 [b]	4.1	0.72 [b]	2.1	0.0059 [b]	0.054	0.016 [a]	0.076
	Local Eggs	mg/kg	NE	NE	NE	NE	NE	NE	NE	NE

Note:

a. RME concentration based upon upper confidence limit on the mean (UCLM)
b. RME concentration based upon upper confidence limit on the geometric mean (UCLGM)
c. RME concentration based upon the maximum due to small sample size
d. RME concentration based upon the 75th percentile
e. RME concentration based upon ½ of the detection limit
f. Estimated based on ambient air concentration

FW – Fresh Weight
NE – Not Evaluated in scenario

Table 3-9: Selected Exposure Point Concentrations for Zone B

Zone	Medium	Units	Nickel		Copper		Cobalt		Arsenic	
			RME	Maximum	RME	Maximum	RME	Maximum	RME	Maximum
B	Residential Soil	mg/kg	2,500 [d]	17,000	260 [d]	2,700	39 [b]	260	16 [d]	350
	Recreational Soil	mg/kg	1,300 [c]	9,300	120 [c]	720	23 [c]	180	6.6 [c]	43
	Commercial Soil (Zone B)	mg/kg	410 [a]	16,000	770 [a]	8,400	20 [a]	270	13 [b]	140
	School Soil (Zone C)	mg/kg	590 [c]	590	72 [c]	72	17 [c]	17	8.7 [c]	8.7
	Beach Soil (Zone D)	mg/kg	240 [c]	240	11 [c]	11	15 [c]	15	4.6 [c]	4.6
	Garden Soil	mg/kg	1,100 [b]	6,700	230 [a]	570	37 [a]	100	18 [b]	45
	Garden Soil (Max. Produce Scenario)	mg/kg	NE	6,700	NE	230	NE	37	NE	NE
	Drinking Water (Municipal)	mg/L	0.0016 [d]	NE	0.022 [a]	NE	0.00017 [a]	NE	0.0005 [d]	NE
	Surface Water	mg/L	0.01 [c]	NE	0.0026 [c]	NE	0.00055 [c]	NE	0.011 [c]	NE
	Ambient Air	µg/m^3	0.022 [g]	NE	0.51 [g]	NE	0.0026 [g]	NE	0.0033 [g]	NE
	Indoor Air (estimated)	µg/m^3	0.013 [f]	NE	0.31 [f]	NE	0.0016 [f]	NE	0.0020 [f]	NE
	Indoor Air (measured)	µg/m^3	NE	NE	NE	0.045	NE	0.0067	NE	NE
	Indoor Air (Max House)	µg/m^3	NE	0.15	NE	NE	NE	NE	NE	NE
	Indoor Air (2nd Highest House)	µg/m^3	NE	0.023	NE	NE	NE	NE	NE	NE
	Indoor Air (3rd Highest House)	µg/m^3	NE	0.0082	NE	NE	NE	NE	NE	NE
	Fabric Surface Dust	µg/m^2	35 [a]	NE	26 [a]	NE	0.31 [b]	NE	3.8 [a]	NE
	Hard Surface Dust	µg/m^2	57 [b]	NE	84 [b]	NE	16 [b]	NE	7.9 [b]	NE
	Attic Dust	µg/m^2	NE	44,000	NE	7,200	NE	690	NE	NE
	Garden Fruit	mg/kg FW	0.19 [b]	0.95	1.0 [a]	1.9	0.0072 [b]	0.037	0.016 [a]	0.024
	Garden Vegetables	mg/kg FW	0.78 [b]	2.5	0.89 [b]	2.1	0.0083 [b]	0.052	0.016 [a]	0.033
	Local Eggs	mg/kg	NE	NE	NE	NE	NE	NE	NE	NE

Note:

a. RME concentration based upon upper confidence limit on the mean (UCLM)
b. RME concentration based upon upper confidence limit on the geometric mean (UCLGM)
c. RME concentration based upon the maximum due to small sample size
d. RME concentration based upon the 75th percentile
e. RME concentration based upon ½ of the detection limit
f. Estimated based on ambient air concentration
g. RME concentration based upon maximum average annual concentration of MOE data

FW – Fresh Weight
NE – Not Evaluated in scenario

Table 3-10: Selected Exposure Point Concentrations for Zone C

Zone	Medium	Units	Nickel		Copper		Cobalt		Arsenic	
			RME	Maximum	RME	Maximum	RME	Maximum	RME	Maximum
C	Residential Soil	mg/kg	490 [b]	3,300	82 [b]	380	18 [b]	73	7.2 [b]	26
	Recreational Soil	mg/kg	4,100 [c]	7,300	440 [c]	650	70 [c]	$1.0x10^2$	30 [c]	30
	Commercial Soil (Zone B)	mg/kg	410 [a]	16,000	770 [a]	8,400	20 [a]	270	13 [b]	140
	School Soil	mg/kg	590 [c]	590	72 [c]	72	17 [c]	17	8.7 [c]	8.7
	Beach Soil (Zone D)	mg/kg	240 [c]	240	11 [c]	11	15 [c]	15	4.6 [c]	4.6
	Garden Soil	mg/kg	510 [b]	2,400	93 [b]	260	15 [b]	38	8.0 [b]	94
	Garden Soils (Max. Produce Scenario)	mg/kg	NE	2,400	NE	140	NE	38	NE	NE
	Drinking Water (Municipal)	mg/L	0.0016 [d]	NE	0.022 [a]	NE	0.00017 [a]	NE	0.0005 [d]	NE
	Surface Water	mg/L	0.01 [c]	NE	0.0026 [c]	NE	0.00055 [c]	NE	0.011 [c]	NE
	Ambient Air	$\mu g/m^3$	0.014 [a]	0.022	0.0010 [a]	0.51	0.0025 [a]	0.0026	0.0033 [g]	NE
	Indoor Air (estimated)	$\mu g/m^3$	0.0081 [f]	0.013 [f]	0.00062 [f]	0.31 [f]	0.0015 [f]	0.0016 [f]	0.0020 [f]	NE
	Indoor Air (measured)	$\mu g/m^3$	NE	NE	NE	0.045	NE	0.0067	NE	NE
	Fabric Surface Dust	$\mu g/m^2$	35 [a]	NE	26 [a]	NE	0.31 [b]	NE	3.8 [a]	NE
	Hard Surface Dust	$\mu g/m^2$	57 [b]	NE	84 [b]	NE	16 [b]	NE	7.9 [b]	NE
	Attic Dust	$\mu g/m^2$	NE	NE	NE	NE	NE	NE	NE	NE
	Garden Fruit	mg/kg FW	0.2 [b]	0.95	1.0 [a]	1.9	0.0074 [b]	0.037	0.016 [a]	0.024
	Garden Vegetables	mg/kg FW	0.41 [b]	4.1	0.71 [b]	2.1	0.0057 [b]	0.054	0.017 [a]	0.076
	Local Eggs	mg/kg	NE	NE	NE	NE	NE	NE	NE	NE

Note:

a. RME concentration based upon upper confidence limit on the mean (UCLM)
b. RME concentration based upon upper confidence limit on the geometric mean (UCLGM)
c. RME concentration based upon the maximum due to small sample size
d. RME concentration based upon the 75th percentile
e. RME concentration based upon ½ of the detection limit
f. Estimated based on ambient air concentration
g. RME concentration based upon maximum annual average concentration of MOE data
Estimated based on ambient air concentration
FW – Fresh Weight
NE – Not Evaluated in scenario

Table 3-11: Selected Exposure Point Concentrations for Zone D

Zone	Medium	Units	Nickel		Copper		Cobalt		Arsenic	
			RME	Maximum	RME	Maximum	RME	Maximum	RME	Maximum
D	Residential Soil (Non-farm)	mg/kg	780[b]	3,900	100[b]	360	24[b]	74	9.6[c]	9.6
	Residential Soil (Farm Clay)	mg/kg	620[b]	5900	94[b]	710	19[b]	120	7.5[b]	28
	Residential Soil (Farm Organic)	mg/kg	2,300[a]		380[a]		38[b]		23[a]	
	Recreational Soil	mg/kg	1,900[b]	33,000	730[a]	3,900	88[a]	430	32[a]	140
	Commercial Soil (Zone D)	mg/kg	290[c]	290	64[c]	64	12[c]	12	4.0[c]	4.0
	Commercial Soil (Zone B)	mg/kg	410[a]	16,000	770[a]	8,400	20[a]	270	13[b]	140
	School Soil (Zone C)	mg/kg	590[c]	590	72[c]	72	17[c]	17	8.7[c]	8.7
	Beach Soil	mg/kg	240[c]	240	11[c]	11	15[c]	15	4.6[c]	4.6
	Garden Soil	mg/kg	440[a]	2,700	81[a]	360	13[d]	54	7.7[a]	46
	Garden Soils (Max. Produce Scenario)	mg/kg	NE	450	NE	92	NE	14	NE	NE
	Drinking Water (Municipal)	mg/L	0.0016[d]	NE	0.022[a]	NE	0.00017[a]	NE	0.0005[d]	NE
	Drinking Water (Drilled Well)	mg/L	0.0077[a]	0.076	0.059[a]	0.76	0.0022[a]	0.035	0.001[a]	0.0051
	Drinking Water (Dug Well)	mg/L	0.0049[b]	0.017	0.20[a]	0.84	0.00034[b]	0.0012	0.0013[a]	0.0025
	Surface Water	mg/L	0.01[c]	NE	0.0026[c]	NE	0.00055[c]	NE	0.011[c]	NE
	Ambient Air	µg/m^3	0.0067[a]	0.022	0.00085[a]	0.51	0.00096[a]	0.0026	0.0020[a]	NE
	Indoor Air (estimated)	µg/m^3	0.0040[f]	0.013[f]	0.00051[f]	0.31[f]	0.00058[f]	0.0016[f]	0.0012[f]	NE
	Indoor Air (measured)	µg/m^3	NE	NE	NE	0.045	NE	0.0067	NE	NE
	Fabric Surface Dust	µg/m^2	35[a]	NE	26[a]	NE	0.31[b]	NE	3.8[a]	NE
	Hard Surface Dust	µg/m^2	57[b]	NE	84[b]	NE	16[b]	NE	7.9[b]	NE
	Attic Dust	µg/m^2	NE	NE	NE	NE	NE	NE	NE	NE
	Garden Fruit	mg/kg FW	0.32[b]	2.7	0.82[b]	2.1	0.0088[b]	0.051	0.027[a]	0.16
	Garden Vegetables	mg/kg FW	0.37[b]	6.4	0.78[b]	2.9	0.0058[b]	0.26	0.016[d]	0.04
	Local Eggs	mg/kg	0.010[d]	NE	0.73[a]	NE	0.0045[d]	NE	0.010[e]	NE

Note:

a. RME concentration based upon upper confidence limit on the mean (UCLM)
b. RME concentration based upon upper confidence limit on the geometric mean (UCLGM)
c. RME concentration based upon the maximum due to small sample size
d. RME concentration based upon the 75th percentile
e. RME concentration based upon ½ of the detection limit
Estimated based on ambient air concentration
FW – Fresh Weight
NE – Not Evaluated in scenario

Table 3-12: Selected Exposure Point Concentrations for Zone E

Zone	Medium	Units	Ni		Cu		Co		As	
			RME	Maximum	RME	Maximum	RME	Maximum	RME	Maximum
E	Residential Soil	mg/kg	77 [b]	NE	26 [b]	NE	8.7 [a]	NE	3.7 [a]	NE
	Recreational Soil	mg/kg	87 [b]	NE	29 [b]	NE	13 [d]	NE	5.4 [a]	NE
	Commercial Soil (Zone E)	mg/kg	200 [c]	NE	50 [c]	NE	14 [c]	NE	4.8 [c]	NE
	Commercial Soil (Zone B)	mg/kg	410 [a]	NE	770 [a]	NE	20 [a]	NE	13 [b]	NE
	School Soil (Zone E)	mg/kg	120 [a]	NE	28 [a]	NE	8.4 [a]	NE	7.0 [c]	NE
	School Soil (Zone C)	mg/kg	590 [c]	NE	72 [c]	NE	17 [c]	NE	8.7 [c]	NE
	Beach Soil (Zone E)	mg/kg	3.0 [c]	NE	1.0 [c]	NE	5 [c]	NE	0.8 [c]	NE
	Beach Soil (Zone D)	mg/kg	240 [c]	NE	11 [c]	NE	15 [c]	NE	4.6 [c]	NE
	Garden Soil	mg/kg	61 [b]	NE	28 [a]	NE	6.1 [a]	NE	4.8 [a]	NE
	Drinking Water (Municipal)	mg/L	0.0016 [d]	NE	0.022 [a]	NE	0.00017 [a]	NE	0.0005 [d]	NE
	Drinking Water (Background)	mg/L	0.0012 [b,e]	NE	0.0034 [a,e]	NE	0.00013 [d,e]	NE	0.0005 [d,e]	NE
	Drinking Water (Drilled Wells)	mg/L	0.001 [f]	NE	0.00005 [f]	NE	0.105 [c]	NE	0.002 [c]	NE
	Surface Water (Local)	mg/L	0.01 [c]	NE	0.0026 [c]	NE	0.00055 [c]	NE	0.011 [c]	NE
	Surface Water (Background)	mg/L	1.6 [b]	NE	3.7 [b]	NE	0.09 [b]	NE	1.0 [a,d]	NE
	Ambient Air	$\mu g/m^3$	0.0022 [a]	NE	0.00028 [a]	NE	0.00035 [a]	NE	0.00072 [a]	NE
	Indoor Air (estimated)	$\mu g/m^3$	0.0013 [g]	NE	0.00017 [g]	NE	0.00021 [g]	NE	0.00043 [g]	NE
	Fabric Surface Dust	$\mu g/m^2$	35 [a]	NE	26 [a]	NE	0.31 [b]	NE	3.8 [a]	NE
	Hard Surface Dust	$\mu g/m^2$	57 [b]	NE	84 [b]	NE	16 [b]	NE	7.9 [b]	NE
	Attic Dust	$\mu g/m^2$	NE	NE	NE	NE	NE	NE	NE	NE
	Garden Fruit	mg/kg FW	0.088 [c]	NE	0.73 [c]	NE	0.0067 [c]	NE	0.019 [c]	NE
	Garden Vegetables	mg/kg FW	0.04 [a]	NE	0.62 [b]	NE	0.0026 [b]	NE	0.012 [a]	NE
	Local Eggs	mg/kg	NE	NE	NE	NE	NE	NE	NE	NE

Note:

a. RME concentration based upon upper confidence limit on the mean (UCLM)
b. RME concentration based upon upper confidence limit on the geometric mean (UCLGM)
c. RME concentration based upon the maximum due to small sample size
d. RME concentration based upon the 75th percentile
e. MOE, 2004
f. RME concentration based upon ½ of the detection limit
g. Estimated based on ambient air concentration
NE – Not Evaluated in scenario
FW – Fresh Weight

Table 3-13: Selected RME Exposure Point Concentrations for Zone F

Zone	Medium	Units	Ni	Cu	Co	As
F	All Soils	mg/kg	43	85	21	17
	Drinking Water (Background)	mg/L	0.0012 [b]	0.0034 [a]	0.00013 [c]	0.0005 [c]
	Surface Water (Background)	mg/L	2.0 [a]	3.7 [c]	0.14 [a,c]	1.0 [a,c]
	Ambient Air (PM_{10})	$\mu g/m^3$	0.0018	0.018	0.002	0.0016
	Indoor Air	$\mu g/m^3$	0.0011 [d]	0.011 [d]	0.0012 [d]	0.00096 [d]
	Fabric Surface Dust	$\mu g/m^2$	35 [a]	26 [a]	0.31 [b]	3.8 [a]
	Hard Surface Dust	$\mu g/m^2$	57 [b]	84 [b]	16 [b]	7.9 [b]

Note:

a. RME concentration based upon upper confidence limit on the mean (UCLM)
b. RME concentration based upon upper confidence limit on the geometric mean (UCLGM)
c. RME concentration based upon 75th percentile
d. Estimated based on ambient air concentration

3.3 Summary

In this chapter, the development of a Port Colborne Site Conceptual Model has been detailed and exposure point CoC concentrations in various media have been selected.

The Site Conceptual Model has been developed for five specific Zones within the Study Area (Figure 3-1) for specific receptors, and specific exposure media and pathways, pictorially illustrated in Figure 3-2. Zones considered for risk analysis include five local Zones (A through E) and one regional background Zone (F). Zones D and E also have been divided in Sub-Zones based on different soil types, well constructions and land uses in Zone D (Zone D Residential, Zone D Farm organic soils, Zone D Farm clay soils) and whether or not receptors are assumed to access parts of the City with soil concentrations above MOE guidelines (Zone E1 City and Zone E2 Background). Zone E2 Background is considered representative of local background.

The Site Conceptual Model describes how the exposures to Port Colborne residents were evaluated in the Exposure Assessment documented in Chapter 5 and the subsequent Risk Characterization step, documented in Chapters 6 and 7. The review of concentrations of CoCs conducted as part of the development of the Site Conceptual Model has considered the data quality and concluded that the data are of adequate quality and reproducibility to support the risk assessment. Specific concentrations have been selected for various media including soil, drinking water and surface water, ambient air and indoor air and dust, local foods and supermarket foods. The selected concentrations have been identified as RME concentrations and concentrations for scenarios of maximally exposed individuals. The RME concentrations were carried forward for evaluation of exposures in Chapter 5 and potential risks in Chapter 6. The concentrations for scenarios of maximally exposed individuals were evaluated in the scenarios detailed in Chapter 7.

Some additional media sampled, as detailed in Chapter 2, did not have concentrations selected in Chapter 3. These media which include meats from local farms, milk, maple syrup, fish and wild game, have been considered further in the Sensitivity Analysis detailed in Chapter 8.

4.0 TOXICITY ASSESSMENT

4.1 Introduction

This Toxicity Assessment gives a general overview of the concept of Toxicity Reference Values (TRVs) and outlines those chosen for use in this risk assessment. More detailed information may be found in Volume III, Appendices 7 (Toxicity Assessment) and 8 (Oral Bioavailability and Bioaccessibility of CoCs in Port Colborne Soils). The following discussion addresses non-carcinogenic and/or carcinogenic potential of the Chemicals of Concern (CoCs) based on route of exposure, contact dermatitis, bioavailability of CoCs as affected by route of exposure, and finally, combined effects of exposure to multiple CoCs. Table 4-1 summarizes the carcinogenicity evaluation of the CoCs.

The following section discusses and summarizes the TRVs and bioavailability adjustments used in the Human Health Risk Assessment (HHRA). The TRVs have all been selected from agencies that meet the definition of "credible agencies" under *Ontario Regulation 153/04*. These agencies include an Ontario Working Group on Nickel Oral Reference Dose for Non-Carcinogenic Effects (Nickel Working Group), the United States Environmental Protection Agency (U.S. EPA), California Air Pollution Control Officers Association (CAPCOA), Agency for Toxic Substances and Disease Registry (ATSDR), the Institute of Medicine (IOM), the European Union (Lepicard *et al.,* 1997) and the European Commission (EC, 2001; Lewis and Caldwell, 1999).

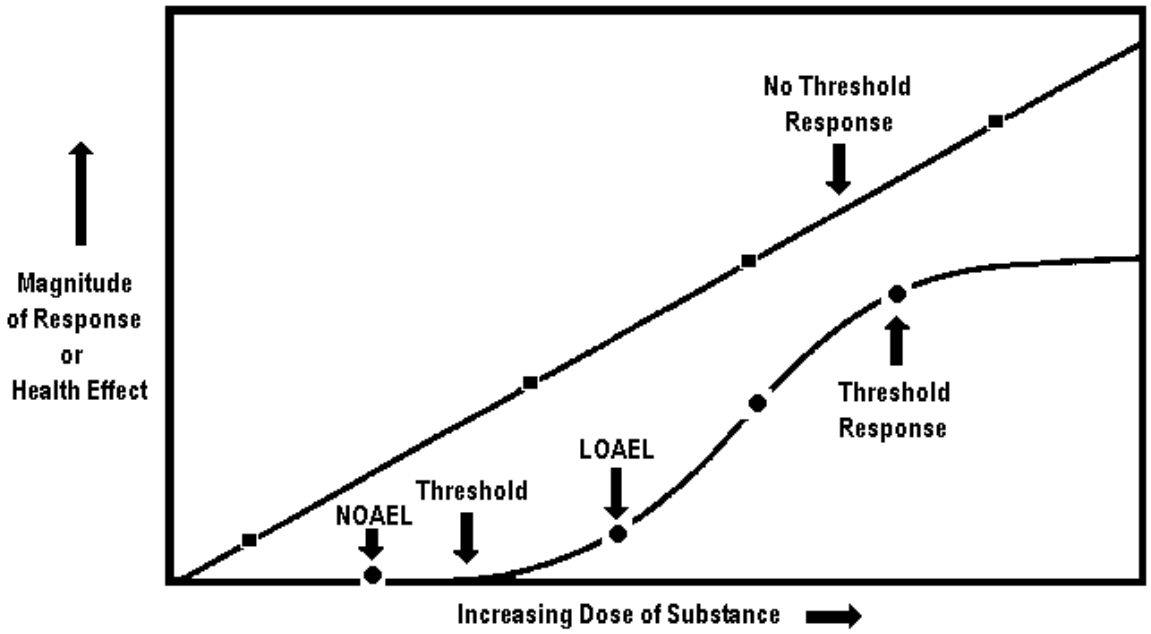
In TRV identification, certain CoC TRVs were not available. A non-carcinogenic inhalation TRV was not selected for arsenic because suitable toxicological data could not be identified, but carcinogenic effects associated with arsenic are considered to be a greater concern than non-carcinogenic effects. Dermal exposure TRVs were also not available, however the associated risks can and have been evaluated using oral TRVs adjusted for absorption efficiency (U.S. EPA, 1989). Dermatitis is evaluated as a separate endpoint in the Sensitivity Analysis in Chapter 8.

4.1.1 Toxicity Reference Values

Toxicity can be described as the production of any type of damage to the function or structure of any part of the body. There are many measures of toxicity which characterize and evaluate carcinogenic and non-carcinogenic effects observed in toxicological and epidemiological studies. TRVs are values used to describe, with a high degree of protection, the doses of chemicals that receptors can receive with no anticipated adverse health effects (*i.e.* no damage to the function or structure of any part of the body). The range and severity of health effects are primarily dictated by the specific chemical and the amount, duration, frequency and route of the received dose.

The measurement of the dose of a chemical and the observed toxicological response can be plotted graphically (Figure 4-1) to determine whether the substance yields a threshold response or no threshold response. Threshold-based chemicals are assumed to cause adverse effects only when a certain dose is reached or exceeded. The doses at which the adverse effects occur are determined from animal laboratory tests and, in a few circumstances, through epidemiological studies.

Figure 4-1: Dose-Response Relationship (Adapted from Health Canada, 1995)



Points of interest on the threshold response curve are the No-Observed-Adverse-Effects-Level (NOAEL) and Lowest-Observed-Adverse-Effects-Level (LOAEL). The NOAEL is the highest level of dose given at which no adverse health effect is observed. The LOAEL is the lowest level of dose given at which an adverse effect is observed. The NOAEL is commonly used, along with uncertainty factors (UFs), in calculating TRVs; however, benchmark dose methods can also be used for threshold effects and provide additional information about the dose-response relationship.

The use of uncertainty factors (UFs) in the calculation of TRVs provides a margin of safety in the extrapolation of estimates of CoC adverse effects to humans. UFs are applied in instances where the mechanisms causing adverse effects are unknown and/or CoC toxicological data are obtained from *in vitro* and *in vivo* laboratory tests on non-human receptors. Uncertainty factors often range between 100 to 1000.

Averaging time (AT) for non-carcinogenic effects is the duration during which exposure is assumed to occur (U.S. EPA, 1989). In this assessment, the exposure duration has been taken as 70 years; however, exposures were evaluated for five life stages and risks were evaluated for life stage exposures using averaging times equivalent to each life stage. The appropriate averaging time is dependent on the manner in which the TRV is derived and the data on which it is based. Some TRVs are derived from exposure data specific to a single life stage without the addition of uncertainty factors to adjust for lifetime exposure (*e.g.* copper and cobalt ingestion and copper inhalation) and are thus appropriate for comparison to exposures obtained in the respective life stage (*e.g.* there are 8 years spent in the teen life stage from age 12 to 20). Other TRVs are obtained from long term exposure studies of all life stages including reproduction (*e.g.* nickel) and a greater degree of conservatism exists in the resulting estimates of risk based on single life stages.

For carcinogenic effects, the averaging time was taken as 70 years (U.S. EPA, 1989), based on a 70 year lifetime and a 70 year exposure duration evaluated in this study. Carcinogenic effects evaluated included both threshold and non-threshold response mechanisms. Although a non-threshold effect is generally assumed for carcinogenic effects, a threshold effect can be evaluated when sufficient supporting information is known on the mechanism of carcinogenicity. This is the case for inhalation of oxidic nickel. The mechanisms of carcinogenicity are discussed in detail in Volume III, Appendix 7.

The toxicology of each CoC is dependent on the exposure pathway. For some chemicals, the route of exposure can have a distinct influence on the resulting human health effect. When the toxicological effects of a chemical differ between pathways of exposure, inhalation and ingestion/dermal exposures are assessed separately. Therefore, in the Port Colborne HHRA, inhalation exposures are evaluated as well as combined ingestion and dermal exposures. The latter evaluation also takes into account inhalation exposure by assuming that inhaled dust is ingested and evaluating a whole body dose.

Chemical toxicity can also be highly dependent on the species of the chemical to which a receptor is exposed. An attempt has been made to differentiate between different forms of CoCs in the environment (*e.g.* elemental speciation with emphasis on nickel) that may affect toxicity. The bioavailabilities of CoCs were evaluated for each route of exposure, based on the available literature and experiments conducted using Port Colborne soils.

TRVs were obtained from literature sources. The rationale for selection of each TRV is provided in Volume III, Appendix 7.

4.2 TRVs for Non-Carcinogenic Effects

A threshold-based approach is used for exposure to non-carcinogenic chemicals. Inhalation TRVs are often expressed as Reference Concentrations (RfCs). An RfC is a concentration below which no adverse health effects are expected. Inhalation TRVs for non-carcinogenic effects derived by the CAPCOA are referred to as chronic inhalation reference exposure levels (RELs). RELs are estimated concentrations or doses at or below which adverse non-cancer health effects are not likely to occur. TRVs derived by the ATSDR are referred to as inhalation and oral Minimal Risk Levels (MRLs). The MRLs are based on toxicological and epidemiological information and are protective of the most sensitive health effect. MRLs can be described as estimates of the daily human exposure to a chemical that is likely to be without appreciable risk of a non-cancer health effect over a specified exposure duration. Neither RELs nor MRLs are derived to be protective of carcinogenic effects.

Oral and dermal TRVs are often expressed as Reference Doses (RfD, a term used and defined by the U.S. EPA) for non-carcinogens. The RfD is an estimate of lifetime daily exposure to a non-carcinogenic substance that, for the general human population, appears to be without appreciable risk of causing deleterious effects over the lifetime. The RfD is expressed in units as the amount of chemical (usually µg or mg)/kg body weight – day. Other TRV terms that express non-carcinogenic effects are summarized in Table 4-1.

Table 4-1: Summary of Non-Carcinogenic TRV Terms

Route	*TRV*	*Organization*
Inhalation	Reference Exposure Levels (REL)	CAPCOA [a]
	Minimal Risk Levels (MRL)	ATSDR [b]
	Tolerable Concentration (TC)	Health Canada
	Threshold Limit Value (TLV)	ACGIH [d]
Ingestion	Minimal Risk Levels (MRL)	ATSDR [b]
	Reference Dose (RfD)	U.S. EPA [c]
	Tolerable Daily Intakes (TDI)	Health Canada
	Tolerable Upper Limit (UL)	IOM [e]

Note:

a. California Air Pollution Control Officers Association
b. Agency for Toxic Substances and Disease Registry
c. United States Environmental Protection Agency
American Conference of Governmental Industrial Hygienists
Institute of Medicine

Table 4-2 summarizes the non-carcinogenic inhalation and oral TRVs for nickel, copper, cobalt and arsenic selected for use in the HHRA. Detailed discussion of TRV determination for each CoC can be found in Volume III, Appendix 7.

Table 4-2: Selected TRVs (Non-Carcinogenic) and End Points for CoCs

CoC	*Route of Exposure*	*Type*	*Non-Cancer End Points*		*Reference*	*Appendix Reference*
			TRV	*End Point*		
Nickel	Inhalation	MRL for nickel sulphate	0.09 µg/m^3	Chronic active inflammation in lungs of rats	ATSDR, 2005	App 7, Section 2.4.2.1
	Ingestion	Life stage RfD	0.02 mg/kg-day	Reproductive toxicity	Nickel Working Group, 2007	App 7, Section 2.4.1.1
Copper	Inhalation	Chronic inhalation REL	2.4 µg/m^3	Respiratory effects	CAPCOA, 1993	App 7, Section 3.4.2
	Ingestion	Lifetime TDI	0.13 mg/kg-day	Liver function	IOM, 2001	App 7, Section 3.4.1
Cobalt	Inhalation	MRL	0.1 µg/m^3	Decreased respiratory function in exposed workers	ATSDR, 2004a	App 7, Section 4.4.2
	Ingestion	Lifetime RfD	0.02 mg/kg-day	Increased hemoglobin in anemic dialysis patients	U.S. EPA, 2001c	App 7, Section 4.4.1
Arsenic	Inhalation	NA	No suitable values identified			App 7, 5.5.2
	Ingestion	Lifetime RfD	0.0003 mg/kg-day	Increased rate of Blackfoot disease in exposed human population	U.S. EPA, 2002c	App 7, 5.5.1

Sample Calculation Input

Input: Non-Cancer TRVs

RfD for Oral Nickel Exposure (as nickel sulphate hexahydrate):
0.02 mg Ni/kg-day [a]
This concentration serves as an input into Step 2 (Chapter 4), and Step 9 (see Chapter 6).

MRL for Inhalation Nickel Exposure (as nickel sulphate):
0.09 µg/m^3 [b]
This concentration serves as an input into Step 10 (see Chapter 6).

a. Volume III, Appendix 7
b. Volume III, Appendix 7

4.3 TRVs for Carcinogenic Effects

Carcinogens are generally assumed to exhibit a no threshold response (see Figure 4-1) and, as such, to cause deleterious effects at any dose and any exposure duration. This assumption of no-threshold is precautious. With more recent studies of carcinogenicity (U.S. EPA, 2005), it is becoming increasingly accepted within the scientific community that the development of cancer is a multi-step process and that such a process would likely fit threshold models. However, unless such a threshold is observed in the experimental data for a specific chemical, precaution usually demands that risk assessors apply the conservative no-threshold dose-response model. For those CoCs that are carcinogens, namely nickel and arsenic, potency estimates reflective of carcinogenic potential are used to assess the risks for these chemicals.

TRVs are often expressed as slope factors for carcinogens. The cancer slope factor is an upper-bound estimate of the increase in cancer risk due to lifetime exposure to a chemical. In other words, the cancer slope factor is used to estimate the risk of cancer as a result of exposure at a particular level over a lifetime. Slope factors are usually estimated as mathematical extrapolations from measured risks which are typically observed at high doses. Slope factors are expressed as risk per mg of chemical/kg body weight/day or $(mg/kg\text{-}day)^{-1}$.

Another TRV that can be used to express carcinogenic potency is unit risk. The unit risk is the upper bound of the increase in cancer risk estimated for continuous lifetime exposure to a chemical at a concentration of 1 µg/L in water, or 1 $\mu g/m^3$ in air. Unit risks are used to estimate an upper bound probability of an individual developing cancer as a result of exposure to a particular level of a potential carcinogen. For example, if the unit risk is 2×10^{-6} $(\mu g/L)^{-1}$ then the incidence of tumours would be expected to increase by 2 cases in an exposed population of 1,000,000 people exposed to 1 µg of that chemical in 1 L of drinking water. Unit risks are estimated by dividing the slope factor by body weight and multiplying that quotient by the applicable inhalation or drinking rate.

Some carcinogens can also be considered as having a threshold below which cancers are not observed. Limit values are used to characterize these thresholds. A limit value is similar to an RfD or an RfC with units of dose (*e.g.* mg/kg-day) or concentration (*e.g.* $\mu g/m^3$).

Table 4-3 summarizes oral and inhalation cancer potency values used in the HHRA for nickel, and arsenic. Arsenic is known to cause cancer via oral and inhalation exposures. Nickel was determined to cause cancer only via the inhalation route. Additionally carcinogenicity was found to vary between different nickel species. For the purposes of this assessment, nickel was evaluated as an inhalation carcinogenic.

Copper is an essential element, not known to cause cancer. Limited information is available with which to assess whether cobalt may cause cancer. The U.S. EPA (2002e) classified cobalt as a probable cancer causing agent. The classification has been withdrawn. The assessment was based on a study of rats and mice (NTP, 1998) using cobalt sulphate heptahydrate. Cobalt sulphate is reported to have reactive properties (IPCS CEC, 1994). Cobalt sulphate is used in electroplating and electrochemical industries (NTP, 1998) and is not expected in the Port Colborne environment. The results were concluded to not be applicable to people in the Port Colborne environment; therefore, cobalt was not evaluated as causing cancer.

A detailed discussion of the determination of carcinogenic potencies can be found in Volume III, Appendix 7.

Table 4-3: Selected Cancer Potency Values for Inhaled and Ingested CoCs

CoC	*Route of Exposure*		*Value*	*Units*	*Type*	*Reference*	*Appendix Reference*
Nickel	Inhaled	Approach I, Nickel Refinery Dust Unit Risk	0.00024	$(\mu g/m^3)^{-1}$	Unit risk	U.S. EPA, 1986; 2003	App 7, Section 2.4.2.2
		Approach II, Oxidic nickel Unit Risk	4×10^{-5}	$(\mu g/m^3)^{-1}$	Unit risk	European Union; Lepicard *et al.*, 1997	App 7, Section 2.4.2.2
		Approach III, Nickel Refinery Dust Limit Value	0.6	$\mu g/m^3$	Limit Value	European Commission, 2001; Lewis and Caldwell, 1999	App 7, Section 2.4.2.2
Arsenic	Inhaled		0.0043	$(\mu g/m^3)^{-1}$	Unit Risk	U.S. EPA, 2002c	App 7, Section 5.5.2
	Ingested		1.5	$(mg/kg\text{-}day)^{-1}$	Slope Factor	U.S. EPA, 2002c	App 7, Section 5.5.1

Notes:
Detailed discussion of TRVs used for CoCs can be found in Volume III, Appendix 7.
RfD: Reference Dose
MRL: Minimal Risk Level
TDI: Tolerable Daily Intake
REL: Reference Exposure Level
NA: No data available on non-carcinogenic TRV

Sample Calculation Input

Input: Cancer inhalation TRVs

Approach II Oxidic Nickel Unit Risk: 4×10^{-5} per $\mu g/m^3$ [a]

This concentration serves as an input into Step 11 (see Chapter 6).

Approach III Nickel Refinery Dust Limit Value: 0.6 $\mu g/m^3$ [b]

This concentration serves as an input into Step 12 (see Chapter 6).

a. Volume III, Appendix 7
b. Volume III, Appendix 7

4.4 Contact Dermatitis

4.4.1 Nickel Contact Dermatitis

Metallic nickel and soluble nickel salts consistently rank as the most common allergens in allergic contact dermatitis, and in particular tend to affect females as a result of frequent use in nickel-plated jewellery. The ease of oxidation of nickel to its allergenic ionic form is an important causative factor for allergy (Hostynek *et al*., 1993). In non-occupational exposures, the primary exposure to nickel as a sensitizing event in non-sensitized individuals occurs primarily as a result of prolonged skin contact with nickel-containing metal objects.

Elicitation of nickel dermatitis is common in alloys releasing more than 1 $\mu g/cm^2$/week (based on the surface area of the article) and rare from alloys releasing less than 0.5 $\mu g/cm^2$ of the article/week (Menne, 1994). An arbitrary, non-sensitizing nickel concentration of 0.5 $\mu g/cm^2$ of the article/week has been suggested for consumer items made of nickel alloys (Menne, 1994). As of July 1989, selling objects releasing nickel at a rate greater than 0.5 $\mu g/cm^2$/week became illegal in Denmark (Menne, 1994). Eliciting of nickel dermatitis for sensitized individuals is unlikely for concentrations less than 0.1 to 1 $\mu g/cm^2$ during occluded exposure (*i.e.* broken skin) and 15 $\mu g/cm^2$ when non-occluded. These concentrations were used to address the issue of nickel contact dermatitis in the Sensitivity Analysis (Chapter 8).

4.4.2 Cobalt Contact Dermatitis

Contact dermatitis has been associated with acute exposure to cobalt compounds (ATSDR, 2004a; Kanerva *et al*., 2000; U.S. EPA, 1992). Most reports of cobalt hypersensitivity involve occupational exposure (*e.g.* metal fabricating, contact with cement in construction).

Sensitization is an increased susceptibility that a subject has to a particular chemical when exposed to that chemical over time, and may manifest in the form of a contact allergy. Human sensitization to cobalt has been observed following repeated topical exposure to 5% cobalt chloride applications (Wahlberg and Bowman, 1978), and can be detected in sensitized individuals at concentrations as low as 0.01% (Allenby and Basketter, 1989).

4.4.3 Cross-Sensitization

Nickel and cobalt appear to occupy different binding sites in epidermal tissue, thus confirming the view that nickel does not cross-sensitize with cobalt (Hostynek *et al*. 1993). Nickel cross-sensitivity to cobalt has often been assumed but also has been refuted by experimentation (Hostynek *et al*. 1993). Although nickel allergy is often diagnosed as being concurrent with cobalt allergy, this is best explained by the close association of the two metals in nature and in alloys and not by cross-sensitization (Hostynek *et al*. 1993).

4.5 Bioavailability

The following definitions assist towards the understanding of bioavailability (Ruby *et al*., 1999):

Bioaccessibility: *The oral bioaccessibility of a substance is the fraction that is soluble in the gastrointestinal environment and is available for absorption. The bioaccessible fraction is not necessarily equal to the Relative Absorbtion Fraction (or Relative Bioavailability Adjustment) but depends on the relation between results from a particular in vitro test system and an appropriate in vivo model.*

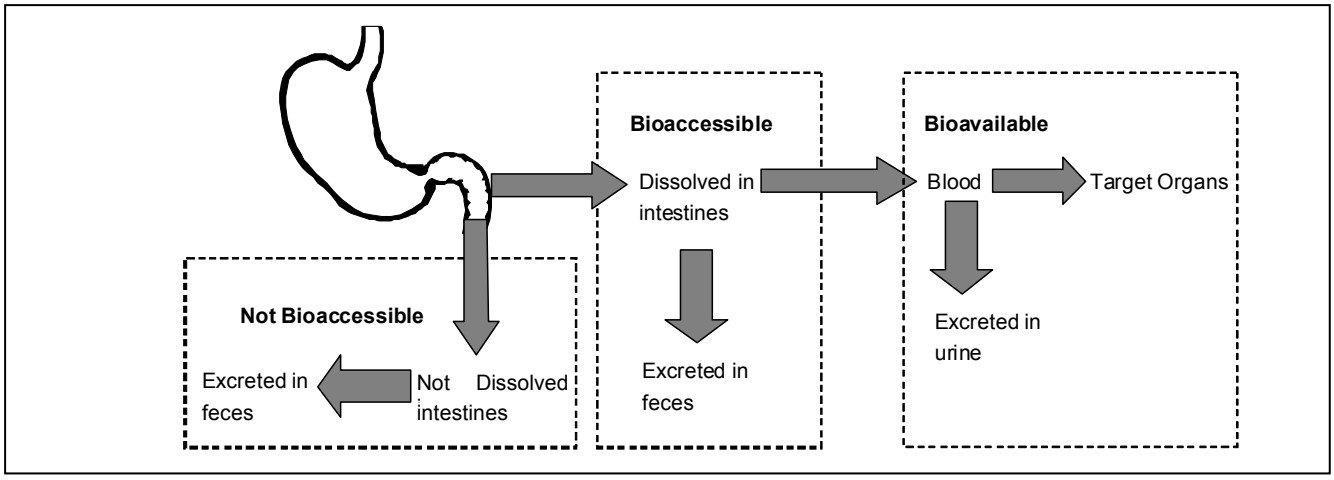
Relative Absorption Fraction: *The relative absorption fraction (RAF) describes the ratio of the absorbed fraction of a substance from a particular exposure medium relative to the fraction absorbed from the dosing vehicle used in the toxicity study for that substance (the term relative bioavailability adjustment (RBA) is also used to describe this factor).*

Relative Bioavailability: *The relative bioavailability adjustment (RBA) refers to the comparative bioavailabilities of different forms of a substance or for different exposure media containing the substance (e.g., bioavailability of a metal from soil relative to its bioavailability from water), expressed in this document as a relative absorption factor (RAF).*

Bioavailability: *Oral bioavailability is defined as the fraction of an administered dose that reaches the central (blood) compartment from the gastrointestinal tract. Bioavailability defined in this manner is commonly referred to as "absolute bioavailability" and is equal to the oral absorption fraction.*

Figure 4-2 depicts the bioaccessible and bioavailable fractions of an ingestion chemical.

Figure 4-2: Bioaccessibility and Bioavailability of a Compound



4.5.1 Inhalation Bioavailability

For inhalation, the TRVs selected for all CoCs and the exposures evaluated are all based on exposure point concentrations with speciation considered in the selection of appropriate TRVs. For these reasons, no adjustment for inhalation bioavailability is required for any of the CoCs and the bioavailability of CoCs via inhalation is 100%. Further details of this rationale are provided in Volume III, Appendix 7.

4.5.2 Relative Bioavailability via Ingestion

TRVs are based on the exposure of humans or animals to specific forms of chemicals under documented conditions, and the environmental forms of all chemicals are not necessarily the same as those on which the TRVs are based. Exposures may differ in the manner in which they are administered (*e.g.* internal dose versus externally administered dose). Chemicals in different forms or in different media may be absorbed into the body at differing rates or to different extents. Absorption and transport and interactions within the body may differ between animals that toxicity values are based on and people. In order to compensate for these differences a relative bioavailability factor is used to account for how well chemicals in the environment are expected to be absorbed in comparison to the substance used in deriving the TRV. Volume III, Appendices 7 and 8 outline the development of relative oral bioavailabilities and bioaccessibilities selected for use in this study. All oral doses reported in the HHRA are adjusted for bioavailability where appropriate and are the dose equivalent to the TRV. The adjustment for dermal uptake is applied to the dermal TRVs.

Due to constraints associated with other CoCs, nickel was the only CoC for which an *in vivo* oral bioavailability study was possible. Constraints associated with the other CoCs included the relatively low concentrations of cobalt and arsenic in the Port Colborne soil, and the environmental ubiquity of copper and cobalt. The low soil concentrations of cobalt and arsenic would have required a rat to ingest a large quantity of soil in order to generate a quantifiable amount of either element in its bloodstream, while the ubiquity of copper and cobalt at low levels made their ingestion by experimental animals difficult to control. For these reasons, *in vivo* methods for establishing copper, cobalt and arsenic bioavailability were deemed impractical, and a conservative *in vitro* method for these CoCs was developed for, and adopted by, the Port Colborne HHRA. The resulting values selected for relative bioavailability via ingestion from these studies and from the literature for other media are summarized in Table 4-4.

Table 4-4: Summary of Selected Relative Bioavailability via Ingestion

CoC	*Exposure Medium*	*Basis*	*Selected Value for Relative Oral Bioavailability (%)*
Nickel	Soil and Dust	Weight of Evidence	4
	Dietary Intake	Default	100 [a]
	Drinking Water	Default	100 [a]
Copper	Soil and Dust	*In vitro* weight of evidence	36
	Dietary Intake	Default	100 [a]
	Drinking Water	Default	100 [a]
Cobalt	Soil and Dust	*In vitro* weight of evidence	26
	Dietary Intake	Default	100 [a]
	Drinking Water	Default	100 [a]
Arsenic	Soil and Dust	*In vitro* weight of evidence	36
	Dietary Intake	Hopenhayn-Rich, *et al*. (1993)	75
	Drinking Water	Default	100 [a]

Note:

Detailed discussion on bioavailability can be found in Volume III, Appendix 8.

a. Default is indicated for relative bioavailability of 100%, indicating that no difference is indicated between the exposure medium and the applicable TRV(s).

The default relative bioavailability is often taken as 100% when no site specific information is available. This assumption may lead to substantial overestimation of exposures for some chemicals. The selected relative bioavailability factors for chemicals in soils are based on site specific testing of Port Colborne soils. These tests and literature reviewed are detailed in Volume III, Appendix 8.

For nickel in soils, a weight of evidence approach was used which evaluated the results of both *in vitro* and *in vivo* tests of Port Colborne soils, literature and human and rat ingestion of various nickel species and speciation of nickel in Port Colborne soils. The resulting estimated oral bioavailability value was selected as being at the upper end of values considered in the weight of evidence and receiving medium or high weightings. The results of methods receiving low weightings were considered less reliable and provided inconsistent results. Full details of the weight of evidence approach can be found in Volume III, Appendix 8.

Sample Calculation Input

Input: Bioavailability

Bioavailability of nickel in Port Colborne soils: 4% [a]

This value serves as input into Step 3 (see Chapter 5).

Bioavailability of nickel in drinking water or diet: 100% [b]

This value serves as input into Step 4 (see Chapter 5).

a. Volume III, Appendix 8
b. Volume III, Appendix 8

4.5.3 Dermal Absorption

Dermal absorption rates are discussed in Volume III, Appendix 7, and selected values considered appropriate to this assessment are summarized on Table 4-5. The information available from the literature is based on *in vivo* tests on animals and humans and on *in vitro* tests on human skin. Site specific chemical absorption testing was not conducted for Port Colborne.

Table 4-5: Dermal Absorption Fraction from Soil

Chemical	*Dermal Absorption Fraction from Soil (ABS) (unitless)*	*Reference*
Nickel	2.8×10^{-6}	Based on Lloyd (1980)
Copper	0.001	U.S. EPA (2001b)
Cobalt	0.0004	Paustenbach (2000)
Arsenic	0.03	U.S. EPA (2004)

Note:
Detailed discussion on dermal absorption of CoCs from soil can be found in Volume III, Appendix 7.

Sample Calculation Step 2

Calculation: Dermal TRV

$$Dermal\ TRV = Oral\ TRV \times GAF \quad \text{(Equation 4-1)}$$

Where:

Dermal TRV = Dermal TRV for nickel sulphate hexahydrate (mg/kg-day)
Oral TRV = Oral TRV for nickel sulphate hexahydrate (0.02 mg/kg-day)
GAF = Gastrointestinal Absorption Factor for nickel sulphate (0.26, dimensionless)

$$Dermal = 0.02\ mg/kg \cdot day \times 0.26$$
$$= 0.05\ mg/kg \cdot day$$

4.5.3.1 TRVs as Absorbed Dose

While most TRVs are expressed as administered doses, dermal exposures are expressed as absorbed doses. The absolute oral bioavailability, or the gastrointestinal absorption fraction (GAF), is the fraction of a chemical that is absorbed into the blood after ingestion. The GAF was used to estimate the absorbed dose corresponding to the TRV for direct comparison to the absorbed dose estimated for dermal exposure. The adjustment for absorption is applied so that the two values (oral TRV and dermal exposure) are compared on an equivalent basis. The GAF is discussed further in Volume III, Appendix 7.

Table 4-6 summarizes the absolute oral bioavailabilities or GAFs selected as appropriate to the oral TRVs and adjusts the oral TRV values to a dermal TRV comparable to the absorbed dermal dose based on the following equation:

$$Dermal\ TRV = Oral\ TRV \times GAF \quad \text{Equation 4-1}$$

Where:

GAF = Gastrointestinal absorption factor (dimensionless)

Table 4-6: Adjustment of Oral TRVs to an Absorbed Dose TRV

Chemical	*Gastrointestinal Absorption Factor (GAF) (%)*	*Reference*	*Oral TRV*	*Estimated Dermal TRV*
Nickel	26	Nielson *et al*. (1999)	0.02 mg/kg-day	0.005 mg/kg-day
Copper	30	U.S. DOE (2002)	0.13 mg/kg-day	0.039 mg/kg-day
Cobalt	20	Conservative value based on ATSDR (2004a)	0.02 mg/kg-day	0.004 mg/kg-day
Arsenic	100	U.S. EPA (2004)	0.0003 mg/kg-day 1.5 $(mg/kg\text{-}day)^{-1}$	No adjustment required (same as oral TRV)

4.6 Combined Effects

When a receptor is exposed to more than one CoC in the environment, there is the potential for biophysical and biochemical interactions to result in a hazard greater than or less than that occurring from exposure to a single CoC. Additive effects of CoCs typically increase receptor risk by the targeting of the same organs or tissues (causing histopathology such as lesions, tumours, etc.) or affecting specific biochemical processes in a similar manner and magnitude. Greater than additive (synergistic) or less than additive (antagonistic) effects of multiple CoC exposures can occur in instances of toxicological interactions, such as one CoC increasing or decreasing the uptake, bioavailability, depuration, and/or toxic effect of another CoC. Effects of the CoCs as a mixture were not identified. Although effects related to the CoCs on the same target organs were identified, a review of these (See Volume III, Appendix 7, Chapter 6) indicated that similar effects do not occur on the same target organ or the effects are independent. A quantitative evaluation of sensitivity to toxicologically independent effects of the CoCs is considered appropriate as a sensitivity analysis.

Since the assessment indicated that effects of the CoCs are not toxicologically similar, only the addition of independent effects is appropriate. Addition of independent effects for copper and cobalt for inhalation and for nickel and cobalt for oral and dermal exposures is considered appropriate. Responses are considered additive if a response is estimated for both chemicals. If the exposure level of either CoC is below the threshold expected to cause a response, there are no responses to add and there is no combined effect.

The evaluation of response addition for these combinations of CoC and exposure pathways is considered conservative and applicable to the Sensitivity Analysis, as recommended by the U.S. EPA (2000). Other potential effects and hazard indices are not considered additive. For more detailed information on the assessment, refer to Volume III, Appendix 7.

4.7 Summary

In the Toxicity Assessment, reference toxicity values have been selected for evaluating cancer and non-cancer effects of the CoCs according to the matrix of effects shown in Table 4-7.

Table 4-7: CoCs Evaluated for Each Type of Effect

Effect	Direct Effects of Inhalation Exposures	Oral/Dermal Exposures (i.e., Absorbed Dose)	Dermatological Effects of Direct Skin Contact
Non-Cancer Effects	Nickel, Copper, Cobalt	Nickel, Copper, Cobalt, Arsenic	Nickel, Cobalt (Sensitivity evaluation)
Cancers	Nickel, Arsenic	Arsenic	NA
Reduction in Relative Oral Bioavailability in Soils and Dust	None	Nickel, Copper, Cobalt, Arsenic	NA
Reduction in Relative Bioavailability in Foods	NA	Arsenic	NA
Reduction in Relative Bioavailability in water or air	None	None	NA
Combined effects	Copper and Cobalt for independent effects (Sensitivity evaluation)	Nickel and Cobalt for independent effects (Sensitivity evaluation)	None

Each of the CoCs indicated in Table 4-7 is evaluated in the Exposure Assessment in Chapter 5 Exposure Assessment, where the dose of each CoC is estimated for inhalation, ingestion and dermal routes of exposure. Relative oral bioavailability values are applied in the Exposure Assessment in Chapter 5 to estimate doses. The TRVs selected are used in the Risk Characterization in Chapters 6 and 7 (Risk Characterization for Reasonable Maximum Exposure Concentrations, and Risk Characterization for Maximally Exposed Individuals, respectively), for typical and maximally exposed receptors, to quantitatively estimate health risks. Combined effects and an evaluation of the potential for dermatitis to occur are evaluated in Chapter 8 Sensitivity Analysis, due to the higher degree of uncertainties associated with these evaluations.

5.0 EXPOSURE ASSESSMENT

Exposure in this HHRA is defined as the contact that a resident in Port Colborne has to the four Chemicals of Concern (CoCs), nickel, copper, cobalt, and arsenic. The estimation of exposure requires the selection of receptor characteristics (Section 5.1) which are input into exposure equations (Section 5.2) along with exposure point concentrations detailed previously (see Chapter 3), to yield results in terms of exposure estimates (See Section 5.3).

5.1 Receptor Characterization

5.1.1 Approach

In order to estimate the magnitude of exposure, the general tendencies, physical characteristics, and socioeconomic factors of residents in Port Colborne must be estimated in a process known as receptor characterization. Data on receptor characteristics such as age, consumption of local foods and time-activity factors were obtained from a questionnaire administered to residents of the community (Volume III, Appendix 5). Available literature was also reviewed for information similar to that obtained from the survey and additional parameters such as body weight, inhalation rates and skin surface area. The literature review and comparison of questionnaire results to literature information are detailed in Volume III, Appendix 3. The final receptor characteristics were selected from a combination of the questionnaire results and literature information. The literature was used to ground truth survey results that in some cases were interpreted differently by respondents that the precise wording of the question. For instance, local foods was interpreted by residents as including foods purchased locally and included several foods that are not native to the region.

5.1.2 Resident Questionnaire

Volume III, Appendix 5 of this report details the administration and results of a questionnaire that was distributed in Port Colborne. The objectives of the questionnaire were to determine typical community exposure factors and to compare the values for Port Colborne with those of literature-derived standard reference values.

While the questionnaire is considered comprehensive, it was not designed to cover all characteristics required for a Human Health Risk Assessment (HHRA). All characteristics that were not investigated in the questionnaire have been well studied in literature based upon years of data collection. The questionnaire was targeted at elucidating Port Colborne resident characteristics and lifestyle habits for use in the HHRA.

At the time of the survey in 2001, the Port Colborne community was comprised of 8,400 residential properties with a population of approximately 18,450. A stratified random sampling method was used to establish a representative sample size of Port Colborne's population and to reduce bias in the selection of survey homes. A sample of 354 homes was selected with a desired confidence level of 95% to ensure a maximum sampling error of +/- 5% on the data.

The survey study area was divided into four quadrants (Volume III, Appendix 5, Figure 1), with homes sampled through random, blind address selection in each quadrant. A contingency plan consisting of 20% additional homes was formulated to account for potential non-response. Residents were called to schedule appointments for completing the questionnaire. One adult from each household was surveyed. Detailed results of the resident questionnaire can be found in Volume III, Appendix 5.

5.1.3 Literature Review

A variety of receptor characteristics such as body weight, skin surface area and time-activity were reviewed based upon literature values, or both literature values and results of the Port Colborne resident questionnaire. Some of the literature sources (see Volume III, Appendix 3 for a complete listing) included:

- CCME (1996), A Protocol for the Derivation of Environmental and Human Health Soil Quality Guidelines. Canadian Council of Ministers of the Environment;
- CCME (2000), Canada Wide Standards for Petroleum Hydrocarbons (PHCs) in Soil: Scientific Rationale. Canadian Council of Ministers of the Environment;
- Finley *et al.*. (1994). Recommended Distributions for Exposure Factors Frequently Used in Health Risk Assessment;
- Health Canada (1993), Reference Values for Canadian Populations;
- Health Canada (1994), Human Health Risk Assessment for Priority Substances;
- Richardson (1997), Compendium of Canadian Human Exposure Factors for Risk Assessment;
- United States Environmental Protection Agency (U.S. EPA, 1997), Exposure Factors Handbook. United States Environmental Protection Agency;
- U.S. EPA (2002b), Child-Specific Exposure Factors Handbook. United States Environmental Protection Agency; and,
- U.S. EPA (2006), Child-Specific Exposure Factors Handbook. United States Environmental Protection Agency.

Whenever possible, Canadian references were selected for use, however, where Canadian documentation was weak or lacking, data reported by United States government agencies were employed. Volume III, Appendix 3 outlines the review of receptor characteristics from various literature sources and provides a comparison to the results of the resident survey.

5.1.4 Selected Characteristics

Additional characteristics, taken from a combination of questionnaire and literature data, were identified as affecting receptor exposures to CoCs. The following characteristics were examined by life stage and/or HHRA Zone to estimate parameters and constants used in the Exposure Assessment:

- snow cover days/days without snow cover
- time spent outside the study zones (e.g., on vacation)
- primary drinking water source
- primary sources of meat and produce
- time spent doing different activities

A summary of parameters applicable through Port Colborne is presented in Table 5-1.

Table 5-1: Summary of Parameters Affecting Receptor Characteristics

Characteristics	Units	Value
Days without snow cover	Days/year	309 [a]
Number of snow cover days	Days/year	56 [a]
Location of work	-	Port Colborne [b]
Number of school days	Days/year	190 [c]
Percentage of domesticated animal meats from local sources	%	0 [b]
Percentage of game and fish from local sources	%	0 [b]

Note:
Detailed discussion of receptor characteristics can be found in Volume III, Appendix 3.

a. Based upon an average of 56 snow-covered days, (Environment Canada Canadian Climate Normals 1971-2000, St. Catharines station, Station ID 6137287)
b. Based upon Port Colborne resident survey indicating minor pathway; Evaluated further in Sensitivity Analysis (see Chapter 8)
c. District School Board of Niagara, 2002c

Five receptor life stages (infant, toddler, child, teen and adult) were evaluated, each having different age-specific characteristics. Volume III, Appendix 3 details the basis of selection of these values from the literature and the resident survey.

Of particular importance to this assessment are ingestion rates for drinking water and incidental ingestion of soil and dust. These are displayed in Table 5-2.

The selected soil ingestion rates actually include both soil and dust ingestion. Since dust ingestion is evaluated separately, this results in a double counting of dust ingestion for toddlers. Because soil and dust ingestion rates have a large associated uncertainty and variability between individuals, the double counting for toddlers was selected to ensure that exposures to these receptors with the highest potential exposures are not underestimated. Although dust is not evaluated separately for children, teens and adults, the evaluation of the entire soil and dust ingestion rate as soil means that potential exposure to these receptors are not underestimated.

Table 5-2: Summary of Soil and Dust Ingestion Rates

Receptor	Soil Ingestion Rate (mg/day)	Hand to Mouth Frequency (Dust Ingestion) (events/h)
Infant (0 to 6 months)	NA (dust only)	20
Toddler (6 months to under 5 years)	**100*** (most representative)	13.8
Child (5 to under 12 years)	80*	NA
Teen (12 to under 20 years)	20*	NA
Adult (20 to 70 years)	20*	NA

Notes:

NA - Not applicable. Age group is for infants in arms, prior to being old enough to be mobile and therefore only exposed to house dust.

*** - Dust exposures are included in soil ingestion rates.**

Bold – Value used in sample calculation Step 3.

Sample Calculation Step 3

Calculation: Toddler Ingestion Dose of nickel in soil

$$DR_{soil} = \frac{C_{soil} \times IR_{soil} \times EF \times ED \times BIO_{soil}}{BW \times AT \times CF}$$

Where:

DR_{soil}	=	Estimated dose from soil ingestion of Nickel (mg Ni/kg BW-day); BW = body weight
C_{soil}	=	Nickel concentration in soil (maximum 17,000 mg Ni/kg soil)
IR_{soil}	=	Soil ingestion rate (100 mg/day or 0.0001 kg/day) [a]
EF	=	Exposure frequency (365 days/year)
ED	=	Exposure duration (4.5 years)
BW	=	Body weight (16.5 kg)
AT	=	Averaging time (4.5 years – same as exposure duration)
BIO_{soil}	=	Relative bioavailability factor via ingestion of soil (0.04, dimensionless)
CF	=	Conversion factor (365 days/yr)

$$DR_{soil} = \frac{(17{,}000\, mg\ Ni/kg) \times (0.0001\, kg/day) \times (365\, days/yr) \times (4.5\, yr) \times (0.04)}{(16.5\, kg) \times (4.5\, yr) \times (365\, days/yr)}$$

$$DR_{soil} = 0.0041\, mg\ Ni/kg \cdot day$$

Note: Actual calculations performed estimated dose for different concentrations of soil nickel in different parts of the community and summed these. The sample calculation assumes that all exposures occur at one concentration.

This concentration serves as an input into Step 8 (Chapter 5).

a. Detailed discussion of receptor characteristics can be found in Volume III, Appendix 3.

Some receptor characteristics were found to vary by HHRA study Zone based on the results of the resident questionnaire, the drinking water survey and the known extent of the municipal water supply system. These are summarized in Table 5-3. Details of the selection of these characteristics are given in Volume III, Appendix 3.

Table 5-3: Summary of Zone-Specific Receptor Characteristics

Characteristics	Units	Zone						
		A	B	C	D Residential	D Farms	E	F
Duration of vacations outside of Port Colborne	Weeks	2.0 [g]	0 [g]	1.0 [g]	1.0 [g]	1.0 [g]	1.0 [g]	1.0 [g]
Vacation season	-	Winter [h]	Summer [h]	Summer [h]	Summer [h]	Summer [h]	Summer [h]	Summer [h]
Fraction of produce from gardens	%	27 [a]	15 [a]	30 [a]	13 [a]	23 [f]	25 [a]	0 [e]
Fraction of eggs from local hens	%	0 [d]	0 [d]	0 [d]	100 [d]	100 [d]	0 [d]	0 [e]
Drinking water source	-	Municipal [b]	Municipal [b]	Municipal [b]	Dug Well [c]	Drilled Well [c]	Municipal [b]	Municipal [b]

Note:
Detailed discussion of receptor characteristics can be found in Volume III, Appendix 3.

a. 75th percentile from Port Colborne Resident Survey
b. City of Port Colborne map of water distribution system
c. Port Colborne well water survey
d. Based on local survey indicating most eggs are obtained from supermarkets other than in the farming area (Zone D).
e. Value assumed to be zero.
f. 90th percentile from Port Colborne Resident Survey
g. 25th percentile from Port Colborne Resident Survey
h. Most common response from Port Colborne Resident Survey

Sample Calculation Step 4

Calculation: Toddler Drinking Water (DW) Ingestion Dose

$$DR_{DW} = \frac{C_{DW} \times IR_{DW} \times EF \times ED \times F_{LOC} \times BIO_{DW}}{BW \times AT \times CF}$$

Where:

DR_{DW}	=	Dose rate of Nickel from ingestion of drinking water (mg/kg-day)
C_{DW}	=	Nickel concentration in drinking water (0.0016 mg/L)
IR_{DW}	=	Ingestion rate of drinking water (1.1 L/day) [a]
EF	=	Exposure frequency (365 days/yr)
ED	=	Exposure duration (4.5 yr)
BW	=	Body weight (16.5 kg)
AT	=	Averaging time (4.5 yr)
F_{LOC}	=	Fraction of drinking water obtained locally (1, dimensionless)
BIO_{DW}	=	Relative bioavailability of chemical via ingestion of drinking water (1, dimensionless)
CF	=	Conversion factor (365 days/yr) [constant]

$$DR_{DW} = \frac{(0.0016\,mg/L) \times (1.1\,L/day) \times (365\,days/yr) \times (4.5\,yr) \times (1) \times (1)}{(16.5\,kg) \times (4.5\,yr) \times (365\,days/yr)}$$

$$DR_{DW} = 0.00011\ \ mg/kg \cdot day$$

This concentration serves as an input into Step 8 in (Chapter 5).

The time-activity patterns were obtained from the resident survey as outlined in Volume III, Appendix 5 and Volume III, Appendix 3. As summarized in Table 5-4, these include data such as time spent outdoors, time spent indoors, and time spent at work. The time spent indoors, outdoors and at work varied between Zones and for adults and teens. Average values were selected as summarized in Table 5-4.

Time spent indoors and outdoors other than time at work was further subdivided to include time away from home at school indoors and out, outdoors at the beach and outdoors at the park. The remaining time was assumed to be spent at home either indoors, outside at home or outside gardening, as applicable. The method of analysis using time-activity factors is detailed in Volume III, Appendix 6.

Table 5-4: Summary of HHRA Zone-Specific Time-activity by Life Stage and Location

Assessment Zone	Location	Infant (h/week)	Toddler (h/week)	Child (h/week)	Teen (h/week)	Adult (h/week)
A	Outdoors	13	33	33	50	34
	Indoors	155	136	135	106	84
	Work	NA	NA	NA	11	50
B	Outdoors	13	50	49	43	34
	Indoors	155	118	120	116	107
	Work	NA	NA	NA	98	28
C	Outdoors	13	29	46	35	29
	Indoors	155	139	122	125	109
	Work	NA	NA	NA	8.4	30
D	Outdoors	13	44	45	29	34
	Indoors	155	124	123	133	102
	Work	NA	NA	NA	5.6	33
E and F	Outdoors	13	36	46	37	32
	Indoors	155	133	122	123	104
	Work	NA	NA	NA	8.4	32

Note:
Average daily totals may not add to 24 hours due to rounding; full values that totaled 24-hours were used in the assessment.
NA: Not Applicable

5.1.4.1 Garden Produce Consumption Rates

The percentage of diet from garden produce was estimated based upon results from the resident questionnaire (Volume III, Appendix 5) with results summarized in Volume III, Appendix 3. The results of the survey indicate that 13 to 30% of the produce diet for residents in Zones A through D comes from backyard produce.

For fruits, the dietary intake information indicated that a substantial portion of fruits in the diet do not grow locally. This is due to a high percentage of tropical fruits such as oranges, bananas, pineapple, grapefruit, lemons, etc., in the diet, including juices. When the types of fruits and juices that are not local are removed from the dietary intake, the fraction of total fruit in the diet that is from local sources was indicated in the survey as ranging from 2.8 to 8.0%.

In comparison, the Ontario Ministry of the Environment (MOE 2002) assumed an annual vegetable and fruit consumption originating from the backyard garden of 7.29 and 2.91%, respectively. The fruit intake used by the MOE is at the low end of values resulting from the survey of local residents. The intake of vegetables from gardens used in the current assessment is substantially higher than that assumed in the MOE assessment. Although public comments were

received raising concern about potentially underestimating how much garden produce is grown in Zone B (See map of HHRA Zones in Chapter 3, Figure 3-1), the survey results and the selected values can be seen to be quite conservative and do not indicate any underestimation in garden produce consumption associated with public perception.

According to the United States Environmental Protection Agency (U.S. EPA), home grown intake was generally higher among individuals who indicated that they operate a farm (1997). This would correspond to Zone D, at which garden produce consumption of fruits and vegetables for the adult receptor are 6.2 and 23%, respectively. In contrast, garden produce consumption of fruits and vegetables for the Zone A adult receptor were 7.2 and 27%, respectively. These data were used without adjustment, even though they may introduce a bias. Differences between consumption patterns in the Zones were concluded to be consistent with dominant socio-economic patterns in the various zones.

Sample Calculation Step 5

Calculation: Zone B Garden Vegetables Intake by Toddler

$$DR_{veg} = \frac{C_{veg} \times IR_{veg} \times EF \times ED \times F_{LOC} \times BIO_{veg}}{BW \times AT \times CF_1 \times CF_2}$$

Where:

DR_{veg}	=	Dose rate of Nickel from consumption of vegetables (mg/kg-day)
C_{veg}	=	Nickel concentration in vegetables (2.5 µg/g fresh weight)
IR_{veg}	=	Ingestion rate of vegetables (84 g/day) [a]
EF	=	Exposure frequency (365 days/yr)
ED	=	Exposure duration (4.5 yr)
F_{LOC}	=	Fraction of vegetables obtained from garden (0.15, dimensionless)
BIO_{veg}	=	Relative bioavailability of chemical via ingestion of food (1, dimensionless)
BW	=	Body weight (16.5 kg)
AT	=	Averaging time (4.5 yr)
CF_1	=	Conversion factor (365 days/yr)
CF_2	=	Conversion factor (1,000 µg/mg)

$$DR_{veg} = \frac{(2.5\,\mu g/g) \times (84\,g/day) \times (365\,days/yr) \times (4.5\,yr) \times (0.15) \times (1)}{(16.5\,kg) \times (4.5\,yr) \times (365\,days/yr) \times (1000\,\mu g/mg)}$$

$$DR_{veg} = 0.0019\ mg/kg \cdot day$$

This concentration serves as an input into Step 8 (Chapter 5).

a. Detailed discussion of receptor characteristics can be found in Volume III, Appendix 3.

On review of the questionnaire, it was hypothesized that the higher than expected dietary intakes from garden produce may have been attributable to the requirement for judgement of consumption patterns over the full year rather than just in the growing season. The data were concluded to be conservative, but of adequate quality for use in the risk estimate.

5.2 Human Health Exposure Equations

Details of the equations used in the Exposure Assessment are provided in Volume III, Appendix 2. Selected exposure equations are based on published equations and a review of recent literature. Emphasis was placed on evaluating exposure pathways with actual measured concentrations of CoCs to the extent practical.

For each pathway identified for evaluation in the Site Conceptual Model (see Chapter 3 Problem Formulation, Table 3-5), the exposure was estimated based on the Volume III, Appendix 2 exposure calculations and inputs from the site and receptor characterization. Samples of detailed exposure calculations are given in Volume III, Appendix 6, and the main report sample calculations seen throughout Chapters 3 and 4 continue in Chapter 5.

Exposure is a function of the duration of exposure and the concentration in a given medium. For example, it is estimated that a child ingests 100 mg of soil/day (Table 5-2). The ingestion rate, however, does not take into account the various places a child may come into contact with soil. That is to say, a child may come in contact with soil at the park, the yard of their home, and the school yard all in the same day at varying concentrations. Therefore, the overall ingestion per day was divided based upon time-activity patterns, as discussed in Section 5.1, to estimate long-term average individual ingestion rate (*e.g.* ingestion of soil from the park). Once the individual ingestion rates for each location were estimated, the ingestion rate was multiplied by the concentration of CoCs in the soil at the location in question to estimate the dose. The estimated dose was summed together at the various locations in order to estimate the overall ingestion of CoCs from inadvertent ingestion of soils.

Similar methodologies were used to estimate doses for all receptors to each environmental exposure medium for the various locations they may frequent throughout Port Colborne. The time-activity patterns were based on typical behavioural patterns reported by Port Colborne residents in the resident survey of time and were thus considered a best estimate of typical behaviour patterns for these residents.

5.3 Results

The following section presents the daily exposures to CoCs estimated for receptors residing in the Study Area as well as regional background exposures. The daily exposures are presented by HHRA Zone and pathway (*i.e.* inhalation, ingestion and dermal) for selected receptors. Results for other life stages are detailed in Volume III, Appendix 6. Ingestion exposures are presented as both intakes and doses. The distinction between these is outlined below.

Difference Between Exposure Terms:

Intake: The intake is the total amount of the CoC that an individual comes in contact with.

Exposure: The same as intake.

Dose: The dose is the intake of the CoC after adjusting for relative bioavailability. Although a true dose would be the amount of the chemical absorbed into the body, dose in the current assessment has been used to represent intake adjusted to be directly comparable to the applicable toxicity reference value.

Relative Oral Bioavailability (ROB): An adjustment to intake of a CoC made so that the dose can be compared directly to the toxicity reference value.

$$Oral\ Dose = Intake \times ROB$$

Note that for inhalation, 100% relative bioavailability has been assumed; therefore exposures are directly applicable to the toxicity reference values, without adjustment.

For nickel in soil, the ROB is 4% or 0.04. An intake of 100 mg nickel in soil therefore results in a dose, after adjustment of 4 mg (100 mg x 0.04 = 4 mg).

Tabulated results in this section are for doses only. Oral intakes and doses are compared graphically.

5.3.1 Background Exposures

In order to estimate the background exposures to CoCs, two approaches were taken. First, the exposure to CoCs of individuals who reside in Zone E, but do not work or go to school in the areas with soil concentrations above the generic soil standards were considered representative of local background exposure. This scenario has been named Zone E2 Background and utilizes home soil and dust concentrations adopted for Zone E. Second, typical Niagara Region concentrations, identified as Zone F concentrations, were used for estimating exposures representative of a regional background (See Chapter 3). In order to accurately compare the exposures and risks between regional background (Zone F) and receptors in Port Colborne,

similar exposure pathways were adopted. This includes inhalation of particulate, ingestion (includes incidental ingestion of soil, dust ingestion, dietary intake from supermarket foods, dietary intake of garden produce, incidental ingestion of swimming water), and dermal contact (with soil or dust). The range in CoC concentrations used in estimating background (*i.e.* Zone E2 Background and Zone F concentrations) was identified previously in Chapter 3 of this report.

In estimating the Lifetime Average Daily Dose (LADD) for arsenic inhalation, ingestion, and dermal contact, as well as nickel inhalation , Equation 5.1 was used. LADD estimates were only required for the indicated CoC exposure route combinations, based on the results of the dose-response assessment of carcinogenicity (see Chapter 4).

Equation 5-1:

$$LADD = \frac{1}{70}\left(0.5 \times D_{infant} + 4.5 \times D_{toddler} + 7 \times D_{child} + 8 \times D_{teen} + 50 \times D_{adult}\right)$$

Where:

LADD = Lifetime Average Daily Dose (mg/kg-day or µg/m^3)

D_{infant} = Infant dose (mg/kg-day or µg/m^3)

$D_{toddler}$ = Toddler dose (mg/kg-day or µg/m^3)

D_{child} = Child dose (mg/kg-day or µg/m^3)

D_{teen} = Teen dose (mg/kg-day or µg/m^3)

D_{adult} = Adult dose (mg/kg-day or µg/m^3)

As presented in Tables 5-5 and 5-6 which outline toddler doses and LADDs, background doses to CoCs were almost identical for both Zone E2 background and Zone F ingestion and inhalation pathways. Detailed information on other receptors can be found in Volume III, Appendix 6. Note that the differences between dermal contact doses between Zone E2 background and Zone F are much greater than the difference for other exposure routes. While ingestion doses are dominated by supermarket foods, masking differences due to soil and dust concentrations, this is not the case for dermal exposures. The differences in soil and dust concentrations account for most of the observed differences between the two zones. Zone E2 background doses were used in the assessment and Zone F background doses were evaluated for comparative purposes.

Table 5-5: Zone E2 Background Doses of CoCs

Receptors	Pathway	Units	Ni	Cu	Co	As
Toddler	Inhalation	mg/m^3	1.6×10^{-6}	4.5×10^{-7}	2.8×10^{-7}	5.3×10^{-7}
	Ingestion	mg/kg-day	0.0059	0.051	6.1×10^{-4}	0.0016
	Dermal Contact	mg/kg-day	4×10^{-9}	5×10^{-7}	7.1×10^{-8}	2.4×10^{-6}
Lifetime (LADD)	Inhalation	$\mu g/m^3$	1.6×10^{-6}	NA	NA	5.2×10^{-7}
	Ingestion	mg/kg-day	NA	NA	NA	7.2×10^{-4}
	Dermal Contact	mg/kg-day	NA	NA	NA	6.2×10^{-7}

Note:
NA: Not Applicable

Table 5-6: Zone F Background Doses of CoCs

Receptors	Pathway	Units	Ni	Cu	Co	As
Toddler	Inhalation	mg/m^3	1.3×10^{-6}	1.3×10^{-5}	1.5×10^{-6}	1.2×10^{-6}
	Ingestion	mg/kg-day	0.0059	0.05	6.4×10^{-4}	0.0016
	Dermal Contact	mg/kg-day	2.2×10^{-9}	1.4×10^{-6}	1.4×10^{-7}	8.5×10^{-6}
Lifetime (LADD)	Inhalation	$\mu g/m^3$	1.3×10^{-6}	NA	NA	1.1×10^{-6}
	Ingestion	mg/kg-day	NA	NA	NA	7.3×10^{-4}
	Dermal Contact	mg/kg-day	NA	NA	NA	2.1×10^{-6}

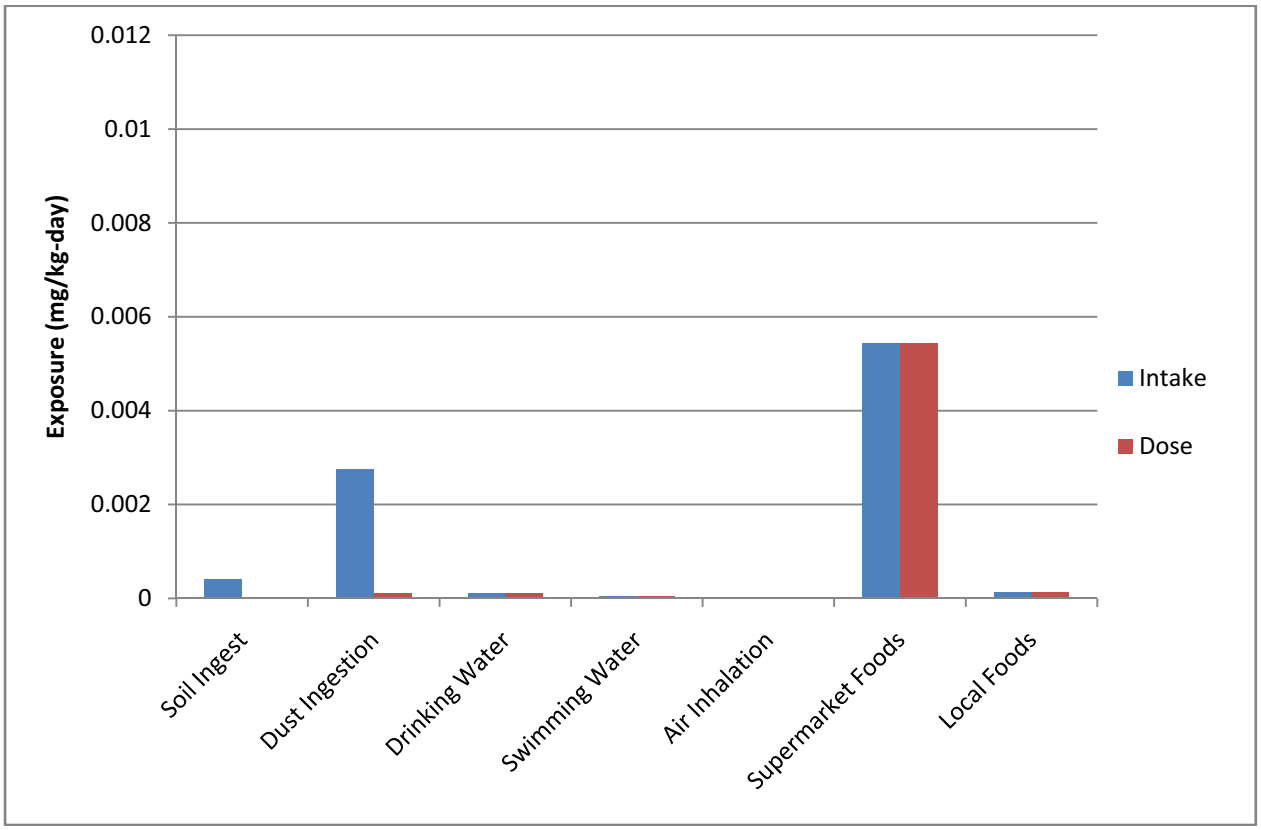
Note:
NA: Not Applicable

As seen in Tables 5-5 and 5-6, dermal doses are approximately 3 to 6 orders of magnitude less than oral (ingested) doses. Dermal exposures for other receptors have been presented in detail in Volume III, Appendix 6, but have not been tabulated in the main report since they constitute a comparatively small component of the total dose.

As discussed in Chapter 3, the ingestion pathway is comprised of a number of exposure pathways including ingestion of supermarket foods, soil, drinking water, household dust, and water while swimming. Dermal contact dose is comprised of dermal contact with soil and dust.

To better understand the relative contribution of each pathway and the affect of adjusting intakes for relative oral bioavailability of the CoCs compared to the toxicity reference values, the contribution of each ingestion pathway to the total toddler intake of each CoC is displayed in Figures 5-1 through 5-4 along with the toddler dose for each CoC and pathway, after adjusting for relative oral bioavailability. The toddler was selected for closer review since this is expected to generally be the most highly exposed life stage based on the nature of the elevated CoCs in Port Colborne. Specifically, the toddler will be more likely to have higher exposures to surface soils than other receptors in this study.

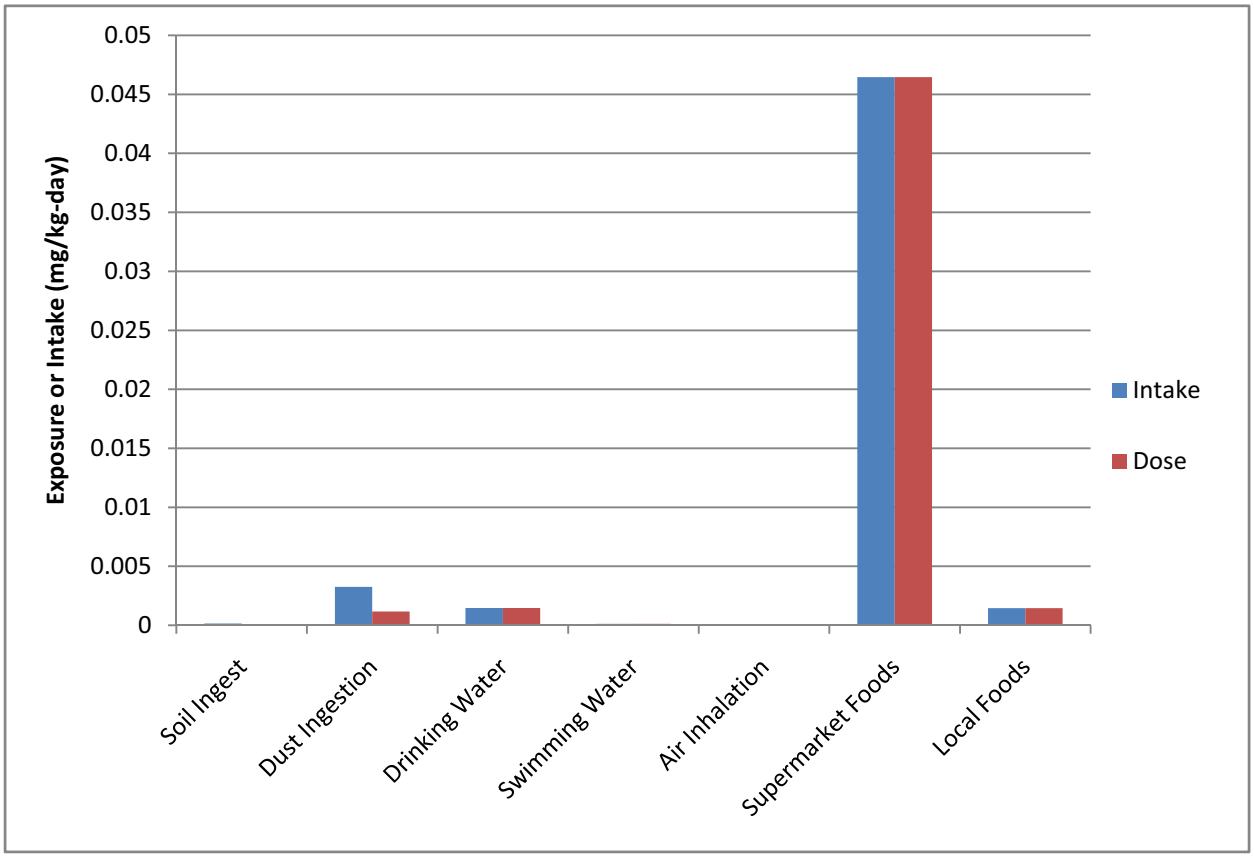
Figure 5-1: Toddler Nickel Ingestion Intakes Before and Doses After Adjustment for Relative Oral Bioavailability - Zone E2 Background



From Figure 5-1, dietary intake of nickel is the largest contributor to the daily background intake of nickel for the toddler. The second highest nickel intake is from ingestion of household dust based on the most recent guidance from U.S. EPA on hand to mouth activity. After adjusting for relative oral bioavailability, the dust and soil doses are quite small compared to ingestion of nickel from supermarket foods. For nickel, only intakes of soil and dust (both surface and inhaled) are adjusted for relative oral bioavailability. The same is true for exposures to copper and cobalt.

Figure 5-2 displays toddler copper intakes and doses after adjusting for relative oral bioavailability for the Zone E2 background toddler. Supermarket foods are the only significant contributor to either total intake or adjusted dose.

Figure 5-2: Toddler Copper Ingestion Intakes Before and Doses After Adjustment for Relative Oral Bioavailability - Zone E2 Background



For the Zone E2 background toddler, Figure 5-3 indicates that cobalt intake from dust ingestion is slightly higher than cobalt intake from supermarket foods. After adjustment for relative oral bioavailability, the dose from dust ingestion is significantly less than the dose from supermarket foods.

Figure 5-3: Toddler Cobalt Ingestion Intakes Before and Doses After Adjustment for Relative Oral Bioavailability - Zone E2 Background

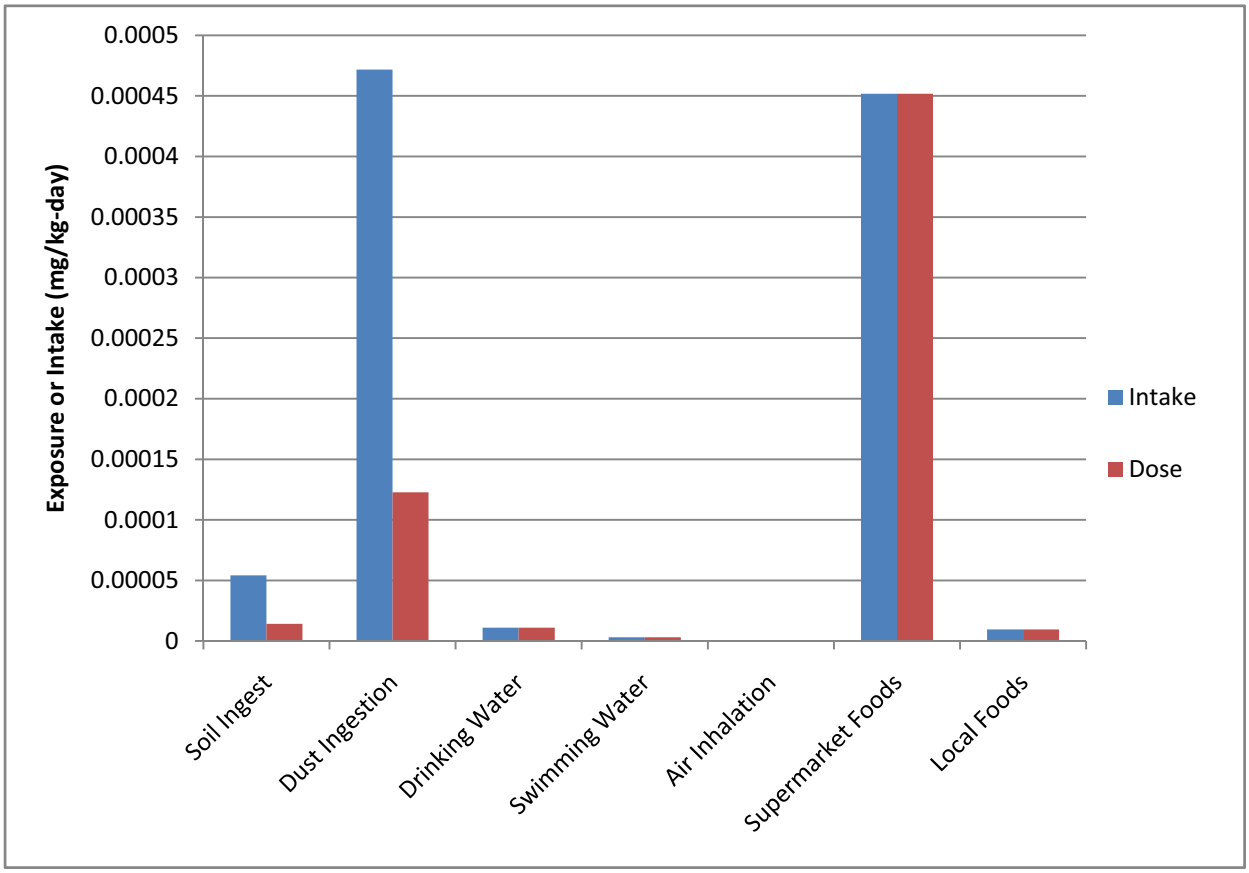
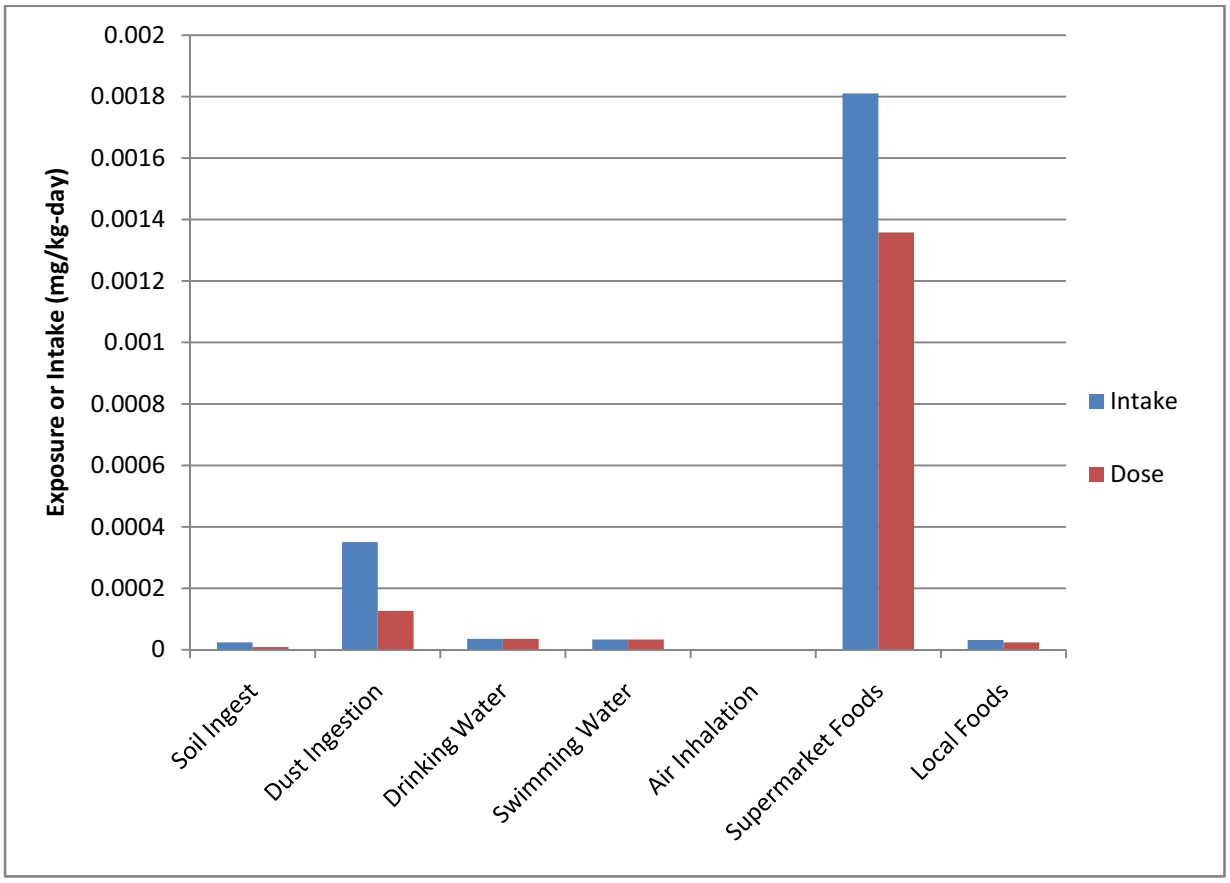


Figure 5-4 displays both toddler intakes of arsenic by ingestion and toddler doses of arsenic by ingestion, after adjusting for relative oral bioavailability. For arsenic, in addition to adjustment for relative bioavailability of arsenic in soil and dust, the intake of arsenic in foods (both local and supermarket) are also adjusted, to a lesser degree by a relatively oral bioavailability of 70% in foods compared to 100% absorption of arsenic in water. Supermarket foods are the largest contributor to intake and dose for the Zone E2 background toddler.

Figure 5-4: Toddler Arsenic Ingestion Intakes Before and Doses After Adjustment for Relative Oral Bioavailability - Zone E2 Background



To summarize, the Zone E2 toddler background exposures to nickel, copper, cobalt and arsenic all show that the largest contributor to dose, after adjustment for relative oral bioavailability, is the dietary intake of CoCs from supermarket foods. For cobalt, and to a lesser extent, nickel, dust is a significant contributor to CoC intakes; however, adjustment for relative oral bioavailability reduces the amount taken in to a relative minor contribution to adjusted dose.

5.3.2 Daily Exposure to Nickel

Daily exposure to nickel occurs via the pathways previously stated for each receptor used in this risk assessment. Generally, exposure occurs via inhalation of vapours or soil dust, ingestion of soil, food, and water containing nickel, and dermal contact.

The daily inhalation exposure to nickel for the HHRA Zones is presented in Table 5-7. Detailed results for all receptors can be found in Volume III, Appendix 6.

Table 5-7: Daily Inhalation Exposure to Nickel (mg/m^3)

Zones	Receptor		
	Toddler	Adult	Lifetime
A	6.4×10^{-6}	8.0×10^{-6}	7.7×10^{-6}
B	1.7×10^{-5}	1.5×10^{-5}	1.5×10^{-5}
C	9.4×10^{-6}	9.8×10^{-6}	9.7×10^{-6}
D Farm	5.0×10^{-6}	5.1×10^{-6}	5.2×10^{-6}
D Residential	5.0×10^{-6}	6.0×10^{-6}	5.9×10^{-6}
E1 City	1.6×10^{-6}	3.3×10^{-6}	3.1×10^{-6}
E2 Background	1.6×10^{-6}	1.5×10^{-6}	1.6×10^{-6}
F	1.3×10^{-6}	1.2×10^{-6}	1.3×10^{-6}

Note:
Detailed discussion of daily inhalation exposure to CoCs can be found in Volume III, Appendix 9, and Volume IV, Appendices 10, 11and 13.

Sample Calculation Step 6

Calculation: Indoor inhalation of nickel in Zone B by Toddler

$$DR_{indoor} = \frac{IR_{indoor} \times C_{indoor} \times BIO \times EF_{indoor} \times ED}{IR_{avg} \times AT \times CF_1 \times CF_2 \times CF_3}$$

Where:

DR_{indoor}	=	Dose rate of Nickel from inhalation (mg/m^3)
IR_{indoor}	=	Indoor inhalation rate (0.3 m^3/h)
C_{indoor}	=	Nickel concentration (maximum 0.013 µg/m^3)
BIO	=	Relative bioavailability of Nickel via vapours in indoor air (1, dimensionless)
EF_{indoor}	=	Exposure time indoors (1697 h/yr)
ED	=	Exposure duration (4.5 yr)
IR_{avg}	=	Average inhalation rate (0.3 m^3/h)
AT	=	Averaging time (4.5 yr)
CF_1	=	Conversion factor (24 h/day)
CF_2	=	Conversion factor (365 days/yr)
CF_3	=	Conversion factor (1000 µg/mg)

$$DR_{indoor} = \frac{(0.3\,m^3/h) \times (0.013\,\mu g/m^3) \times (1) \times (1698\,h/yr) \times (4.5\,yr)}{(0.3\,m^3/h) \times (4.5\,yr) \times (24\,h/day) \times (365\,days/yr)}$$

$$DR_{indoor} = 0.0025\ \mu g/m^3$$

This exposure concentration serves as an input into the following Step.

Sample Calculation Step 7

Calculation: Inhalation Exposure

$$DR_{inh} = DR_{indoor} + DR_{outdoor}$$

Where:
DR_{inh} = Dose rate from inhalation (µg/m^3)
DR_{indoor} = Dose rate from indoor air (0.0025 µg/m^3)
$DR_{outdoor}$ = Dose rate from outdoor air (0.0043 µg/m^3) (Example calculation not shown)

$$DR_{inh} = 0.0025\ \mu g / m^3 + 0.0043\ \mu g / m^3$$
$$= 0.0068\ \mu g / m^3$$

This exposure concentration serves as an input into Step 10, 11, and 12 (see Chapter 6).

The daily inhalation exposure to nickel, as presented in Table 5-7, indicates that nickel exposures are above background for Zones A through E.

The daily ingestion dose of nickel for the HHRA Zones is presented in Table 5-8 for selected receptors. Other receptor information can be found in Volume III, Appendix 6.

Table 5-8: Daily Ingestion Dose of Nickel (mg/kg-day)

Zones	Receptor		
	Infant	Toddler	Adult
A	0.0015	0.0085	0.0023
B	0.0016	0.0070	0.0021
C	0.0016	0.0069	0.0020
D Farm, Clay	0.0020	0.0070	0.0021
D Farm, Organic	0.0020	0.0072	0.0021
D Residential	0.0018	0.0066	0.0019
E1 City	0.0016	0.0058	0.0016
E2 Background	0.0016	0.0059	0.0017
F	0.0015	0.0059	0.0017

Table 5-8, shows that there are minor differences between ingestion dose of nickel in Port Colborne and background dose. Differences in amount ingested were observed for toddlers between Zones A through D compared to background Zone F.

Figure 5-5 shows the Zone B toddler contribution by pathway of nickel ingestion intakes before, and ingestion doses after, adjusting for relative oral bioavailability. **The greatest contributor to intakes is nickel in soil. Intake of nickel in supermarket foods is roughly half the intake from soil. After adjusting for relative oral bioavailability, the nickel dose from soil is much less than the dose from supermarket foods.**

Figure 5-5: Toddler Nickel Ingestion Intakes Before and Doses After Adjustment for Relative Oral Bioavailability - Zone B Receptor

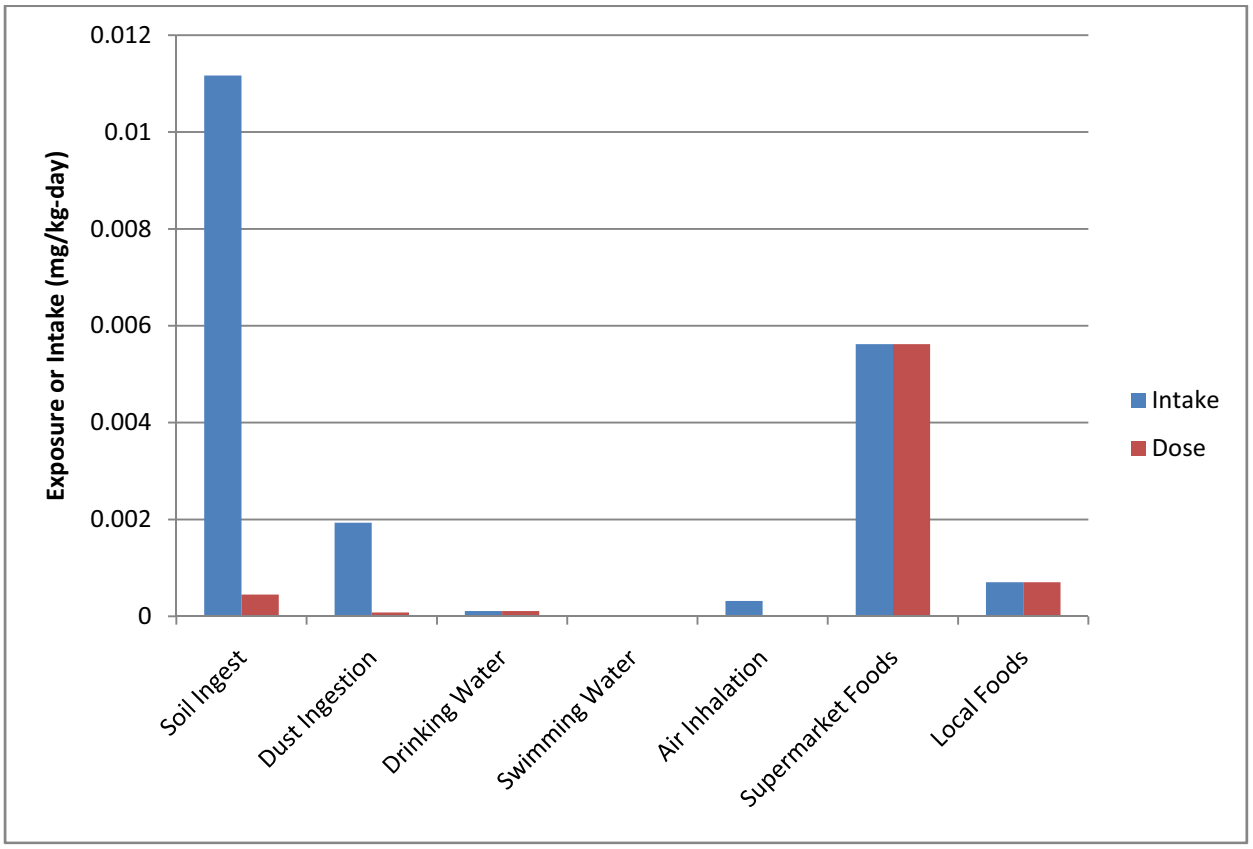
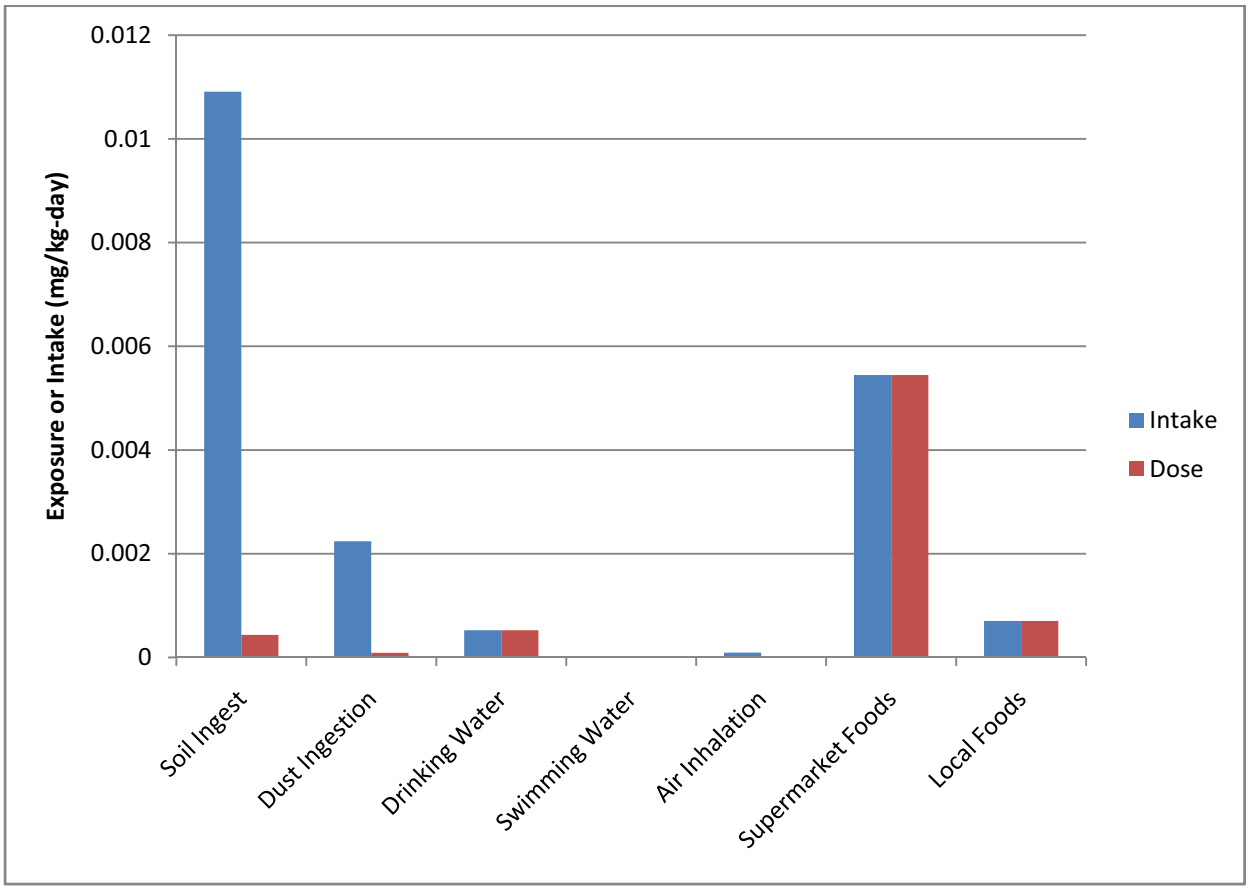


Figure 5-6 shows the same information as shown in Figure 5-5, but for the toddler living on a farm with organic soils in Zone D. Again, the largest contributor to the toddler's nickel intake is nickel in soil. The nickel intake from supermarket foods is about half that of the intake of nickel in soils. After adjusting for relative oral bioavailability, the nickel dose from soil is much less than the nickel dose from supermarket foods. The contribution of nickel from local foods is slightly higher for the Zone D farm receptor than for the Zone B receptor and the supermarket foods intake is slightly lower for Zone D farm receptors than for those in Zone B. In Zone D, the nickel intake and dose from drinking water are higher than those in Zone B due to the use of well water rather than municipally supplied water.

Figure 5-6: Toddler Nickel Ingestion Intakes Before and Doses After Adjustment for Relative Oral Bioavailability - Zone D Farm Organic Soil Receptor



Sample Calculation Step 8

Calculation: Toddler Nickel Dose from Ingestion

$$DR_{ing} = DR_{soil} + DR_{Veg} + DR_{DW} + DR_{dust,ing} + DR_{dust,inh} + DR_{swimming} + DR_{supermarket} + DR_{fruit}$$

Where:

DR_{ing}	=	Total Nickel ingestion dose (mg/kg-day)
DR_{soil}	=	Total Nickel dose from soil ingestion (0.0041 mg/kg-day)
DR_{Veg}	=	Total Nickel dose from backyard food vegetable ingestion (0.0019 mg/kg-day)
DR_{DW}	=	Total Nickel dose from drinking water ingestion (0.00011 mg/kg-day)
$DR_{dust,ing}$	=	Total Nickel dose from ingested dust (0.00008 mg/kg-day)
$DR_{dust,inh}$	=	Total Nickel dose from inhaled dust subsequently ingested (2×10^{-6} mg/kg-day)
$DR_{swimming}$	=	Total Nickel dose from surface water ingested while swimming (3×10^{-7} mg/kg-day)
$DR_{supermarket}$	=	Total Nickel dose from supermarket foods (0.0056 mg/kg-day)
DR_{fruit}	=	Total Nickel dose from backyard fruit ingestion (0.00011 mg/kg-day)

$$DR_{ing} = [0.0041 + 0.0019 + 0.00011 + 0.00008 + (2 \times 10^{-6}) + (3 \times 10^{-7}) + 0.0056 + 0.00011]$$

$$mg / kg \cdot day$$

$$DR_{ing} = 0.012\ mg / kg \cdot day$$

This concentration serves as an input into Step 9 in (see Chapter 6).

Daily dermal contact doses of nickel were noted to be approximately three to four orders of magnitude less than doses from oral exposures.

5.3.3 Daily Exposure to Copper

The daily exposure to copper through inhalation for the HHRA Zones is presented in Table 5-9. For detailed information on each receptor, refer to Volume III, Appendix 6.

Table 5-9: Daily Inhalation Exposure to Copper (mg/m^3)

Zones	Receptor	
	Toddler	Adult
A	9.2×10^{-7}	7.3×10^{-5}
B	4.0×10^{-4}	3.5×10^{-4}
C	9.6×10^{-7}	4.3×10^{-5}
D Farm	8.9×10^{-7}	8.8×10^{-7}
D Residential	8.9×10^{-7}	4.9×10^{-5}
E1 City	4.5×10^{-7}	4.6×10^{-5}
E2 Background	4.5×10^{-7}	4.3×10^{-7}
F	1.3×10^{-5}	1.2×10^{-5}

The daily inhalation exposure to copper, as presented in Table 5-9, indicates that a distinguishable difference exists between background exposure and exposures in Zone B.

The daily dose of copper through ingestion for the HHRA Zones is presented in Table 5-10. The daily dose of copper through ingestion for all receptors can be found in Volume III, Appendix 6.

Table 5-10: Daily Ingestion Dose of Copper (mg/kg-day)

Zones	Receptor		
	Infant	Toddler	Adult
A	0.070	0.050	0.016
B	0.073	0.052	0.017
C	0.071	0.052	0.016
D Farm, Clay	0.074	0.054	0.017
D Farm, Organic	0.074	0.054	0.017
D Residential	0.084	0.063	0.020
E1 City	0.071	0.051	0.016
E2 Background	0.071	0.051	0.016
F	0.070	0.050	0.016

The results in Table 5-10, indicate no appreciable difference between background exposure and exposure in Port Colborne. In examining the various exposure results for copper, slightly higher exposures were noted for Zone D farm receptors, however, the difference in dose amount, 0.01 mg/kg-day, was considered minor. The slight change was attributed to the higher concentration of copper in drinking water from dug wells in comparison to municipally supplied water.

The daily dose of copper through dermal contact was noted to be roughly four orders of magnitude less than the dose for oral exposures.

In summary, the ingestion showed no distinguishable difference between background dose and dose in Port Colborne. In contrast, the inhalation exposure to copper indicated higher levels of exposure for all HHRA Zones.

Figures 5-7 and 5-8 illustrate the contribution of each ingestion pathway to total daily ingestion intakes before adjustment and doses after adjustment for relative oral bioavailability for toddler in Zone B and Zone D farm organic soil, respectively.

Figure 5-7: Toddler Copper Ingestion Intakes Before and Doses After Adjustment for Relative Oral Bioavailability - Zone B Receptor

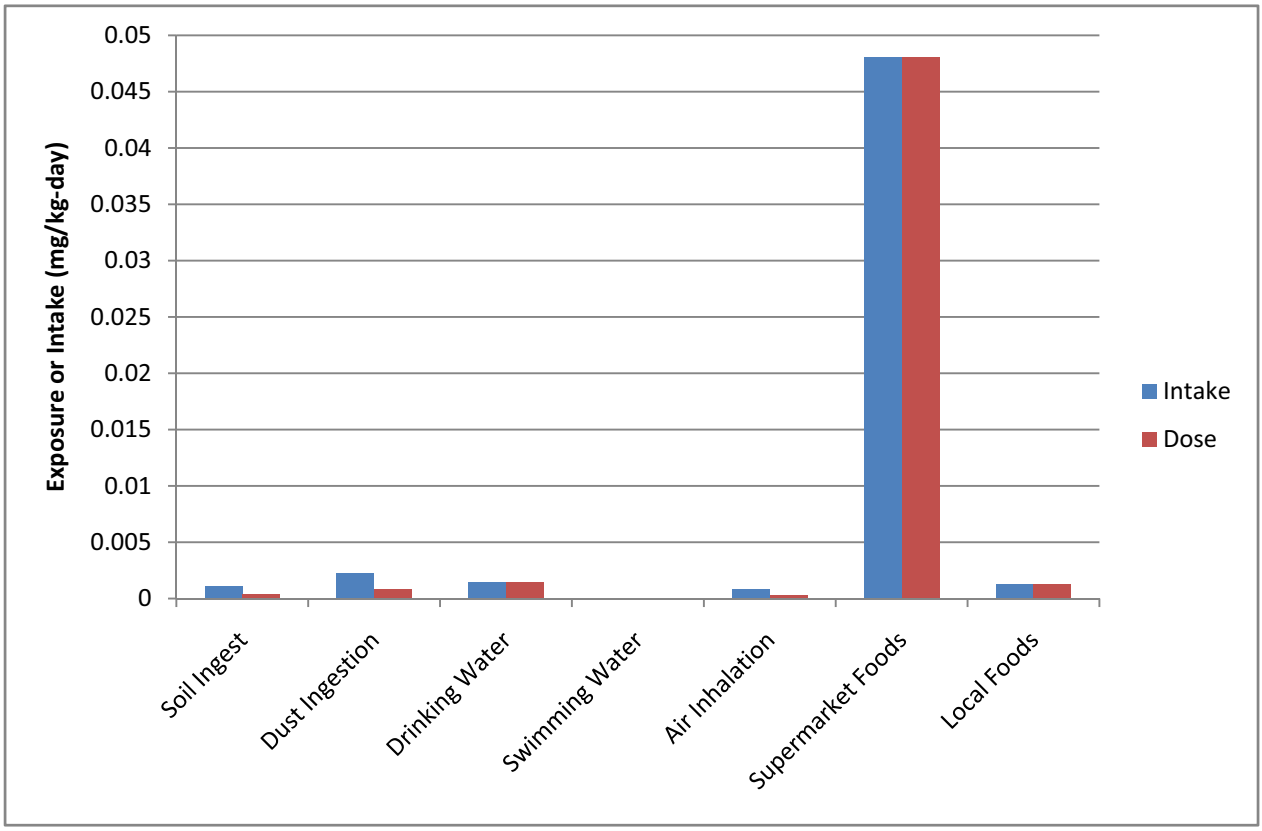
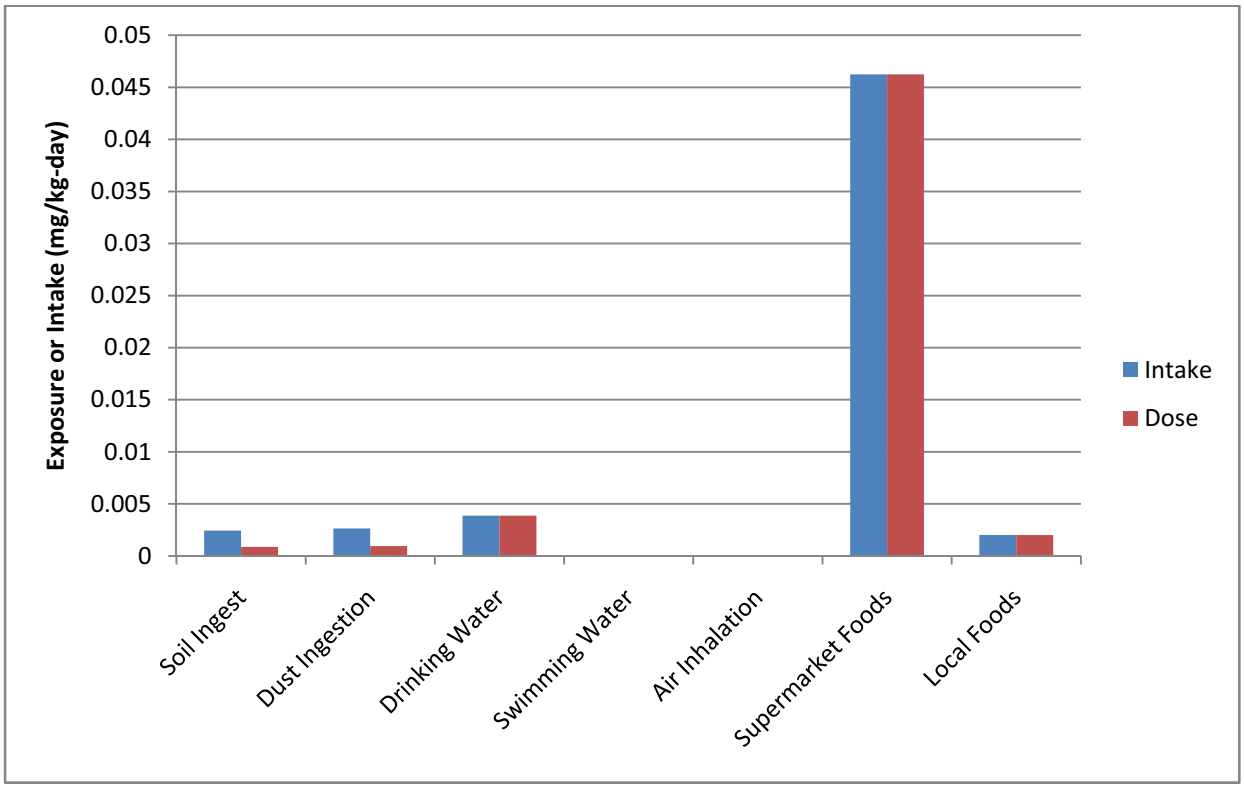


Figure 5-8: Toddler Copper Ingestion Intakes Before and Doses After Adjustment for Relative Oral Bioavailability - Zone D Farm Organic Soil Receptor



The toddler intakes and doses in both Zones are dominated by copper ingested in supermarket foods. For the Zone D receptor, higher average soil concentrations and drinking water concentrations lead to higher intakes and doses through these pathways. Consumption of local foods is also higher for the farm toddler.

5.3.4 Daily Exposure to Cobalt

The daily exposure to cobalt through inhalation for the HHRA Zones is presented in Table 5-11. Detailed daily exposure information for all receptors considered can be found in Volume III, Appendix 6.

Table 5-11: Daily Inhalation Exposure to Cobalt (mg/m^3)

Zones	Receptor	
	Toddler	Adult
A	1.3×10^{-6}	1.4×10^{-6}
B	2.0×10^{-6}	1.8×10^{-6}
C	1.7×10^{-6}	1.7×10^{-6}
D Farm	7.4×10^{-7}	7.4×10^{-7}
D Residential	7.4×10^{-7}	8.4×10^{-7}
E1 City	2.8×10^{-7}	4.7×10^{-7}
E2 Background	2.8×10^{-7}	2.7×10^{-7}
F	1.5×10^{-6}	1.4×10^{-6}

The results in Table 5-11 indicate that inhalation exposure to cobalt is higher than background in Zones B, C, D and E. Since cobalt is assessed as a threshold chemical, the total risk from inhalation of cobalt was estimated for all zones.

The daily exposure to cobalt through ingestion for the HHRA Zones is presented in Table 5-12.

Table 5-12: Daily Ingestion Dose of Cobalt (mg/kg-day)

Zones	Receptor		
	Infant	Toddler	Adult
A	5.4×10^{-4}	6.3×10^{-4}	1.5×10^{-4}
B	5.6×10^{-4}	6.2×10^{-4}	1.6×10^{-4}
C	5.5×10^{-4}	6.7×10^{-4}	1.6×10^{-4}
D Farm, Clay	6.9×10^{-4}	7.7×10^{-4}	2.0×10^{-4}
D Farm, Organic	6.9×10^{-4}	7.8×10^{-4}	2.0×10^{-4}
D Residential	5.6×10^{-4}	6.5×10^{-4}	1.6×10^{-4}
E1 City	5.5×10^{-4}	6.1×10^{-4}	1.5×10^{-4}
E2 Background	5.5×10^{-4}	6.1×10^{-4}	1.5×10^{-4}
F	5.5×10^{-4}	6.4×10^{-4}	1.6×10^{-4}

The results of the ingestion exposure calculation for cobalt, as presented in Table 5-12, indicate no significant differences between background exposure and exposure in urban areas of Port Colborne. A detailed table of all receptor results can be found in Volume III, Appendix 6.

A difference is observed between background exposures and exposures in the rural areas of Port Colborne, *i.e.* Zone D Farms. The increase in exposure may be attributed to the higher cobalt concentrations measured in water from drilled wells relative to the municipally supplied water.

Dermal exposures to cobalt were estimated at more than three orders of magnitude less than oral exposures.

Figure 5-9 illustrates the Zone B toddler relative contributions of cobalt from each ingestion pathway to intake and to dose after adjustment for relative oral bioavailability. The highest intake and dose are for supermarket foods. The dust and soil ingestion pathways are the next highest contributors. The relative oral bioavailability adjustment reduces the dust and soil ingestion pathways to minor contributors to dose.

Figure 5-9: Toddler Cobalt Ingestion Intakes Before and Doses After Adjustment for Relative Oral Bioavailability - Zone B Receptor

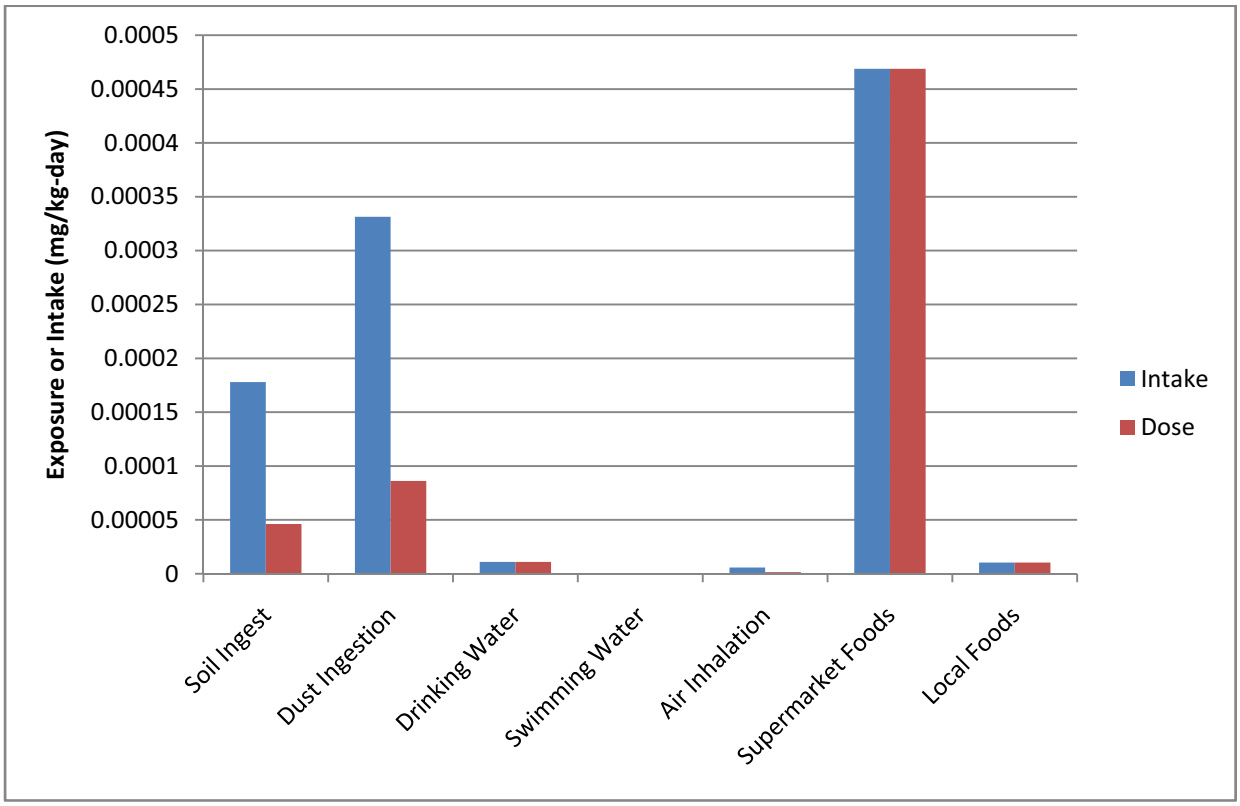
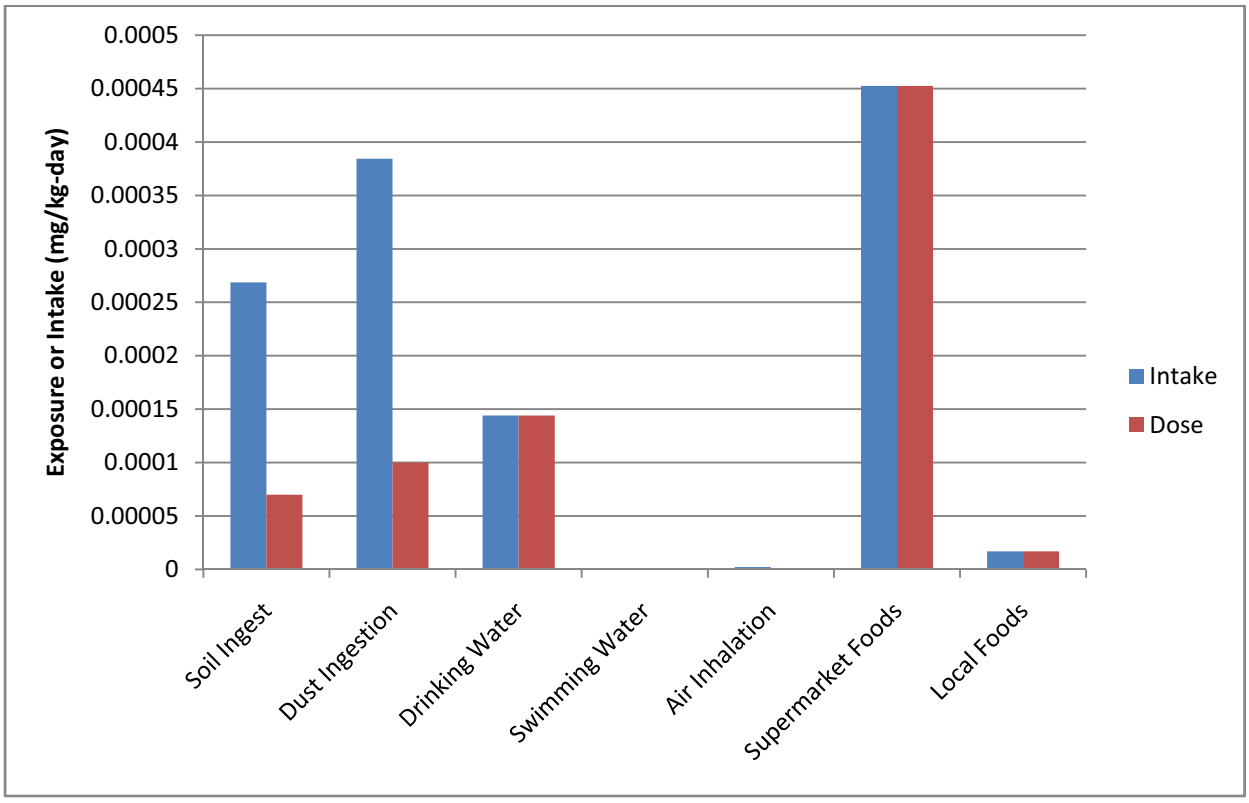


Figure 5-10 illustrates the same information for the toddler on a farm with organic soils in Zone D as is shown for the Zone B toddler in Figure 5-9. The drinking water intake and dose are significantly higher for the Zone D toddler due to higher cobalt concentrations in well water than those in municipally supplied drinking water. The consumption of local foods is higher for the Zone D farm residents, and the intake of cobalt from supermarket foods is slightly decreased.

Figure 5-10: Toddler Cobalt Ingestion Intakes Before and Doses After Adjustment for Relative Oral Bioavailability - Zone D Farm Organic Soil Receptor



5.3.5 Daily Exposure to Arsenic

The average daily inhalation exposure to arsenic for the HHRA Zones is presented in Table 5-13.

Table 5-13: Daily Inhalation Exposure to Arsenic (mg/m^3)

Zones	Receptor		
	Toddler	Adult	Lifetime
A	2.6×10^{-6}	2.5×10^{-6}	2.6×10^{-6}
B	2.5×10^{-6}	2.3×10^{-6}	2.3×10^{-6}
C	2.3×10^{-6}	2.2×10^{-6}	2.2×10^{-6}
D Farm	1.5×10^{-6}	1.5×10^{-6}	1.5×10^{-6}
D Residential	1.5×10^{-6}	1.5×10^{-6}	1.5×10^{-6}
E1 City	5.4×10^{-7}	7.4×10^{-7}	7.5×10^{-7}
E2 Background	5.3×10^{-7}	5.1×10^{-7}	5.2×10^{-7}
F	1.2×10^{-6}	1.1×10^{-6}	1.1×10^{-6}

The average daily inhalation exposure to arsenic shows a distinguishable difference from the background inhalation of arsenic although the highest concentrations are seen in Zone A, in the upwind direction.

The daily exposure to arsenic through ingestion for the HHRA Zones is presented in Table 5-14. Results for other receptors can be found in Volume III, Appendix 6.

Table 5-14: Daily Ingestion Dose of Arsenic (mg/kg-day)

Zones	Receptor			
	Infant	Toddler	Adult	Lifetime
A	0.001	0.002	6×10^{-4}	7×10^{-4}
B	0.001	0.002	6×10^{-4}	7×10^{-4}
C	0.001	0.002	6×10^{-4}	7×10^{-4}
D Farm, Clay	0.001	0.002	6×10^{-4}	7×10^{-4}
D Farm, Organic	0.001	0.002	6×10^{-4}	7×10^{-4}
D Residential	0.002	0.002	6×10^{-4}	7×10^{-4}
E1 City	0.001	0.002	6×10^{-4}	7×10^{-4}
E2 Background	0.001	0.002	6×10^{-4}	7×10^{-4}
F	0.001	0.002	6×10^{-4}	7×10^{-4}

Table 5-14 shows there is no distinguishable difference between ingestion dose of arsenic in Port Colborne and background dose estimates. The daily arsenic dermal contact dose was noted to be approximately three orders of magnitude less than the oral doses.

Figures 5-11 and 5-12, for the Zone B toddler and the Zone D organic soil farm toddler respectively, show the relative contributions of each ingestion pathway to intake by ingestion and to ingestion dose after adjustment for relative oral bioavailability. Note that an adjustment for relative oral bioavailability is applied to dietary intake as well as to arsenic in soil and dust (See See Section 4.4.1).

Little difference between the two receptors can be seen. The intake and dose of arsenic from supermarket foods are slightly lower in Zone D due to the higher fraction of the diet assumed to be local for the farm residents. Arsenic concentrations and thus intakes and doses are also higher for Zone D well water than for municipally supplied water in Zone B.

Figure 5-11: Toddler Arsenic Ingestion Intakes Before and Doses After Adjustment for Relative Oral Bioavailability - Zone B Receptor

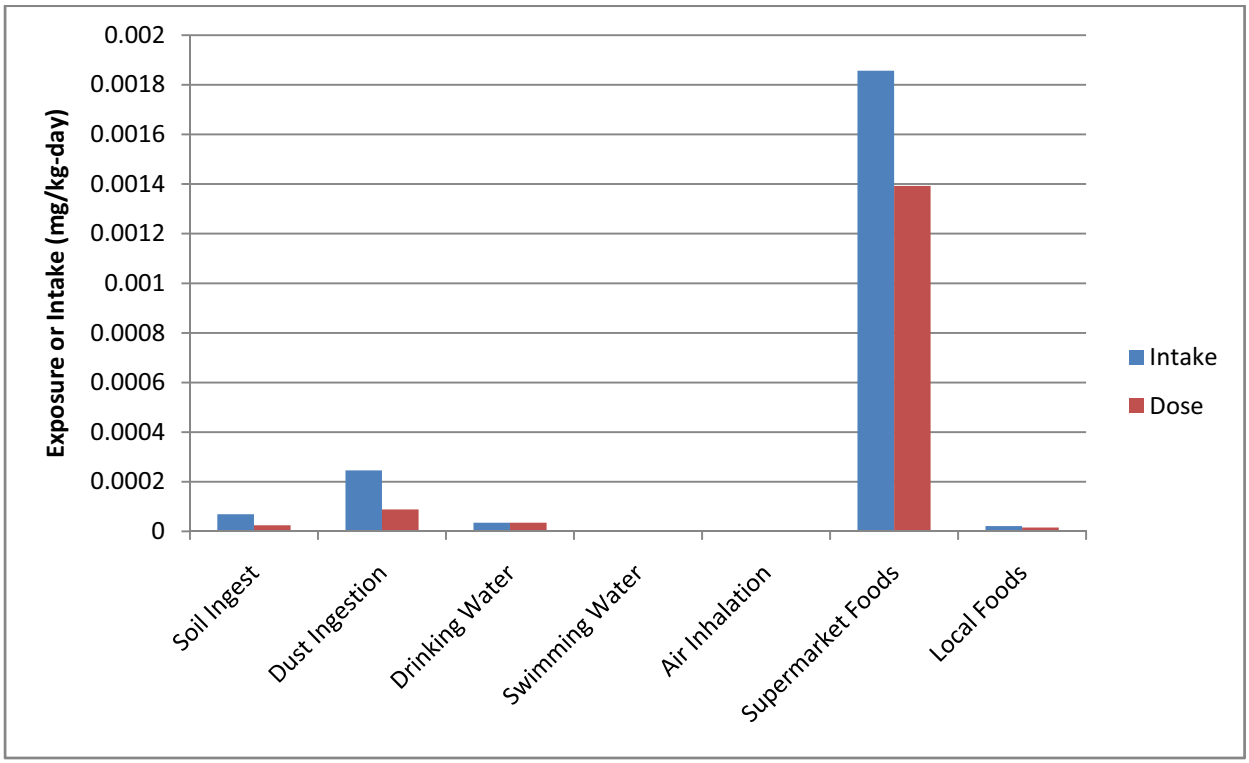
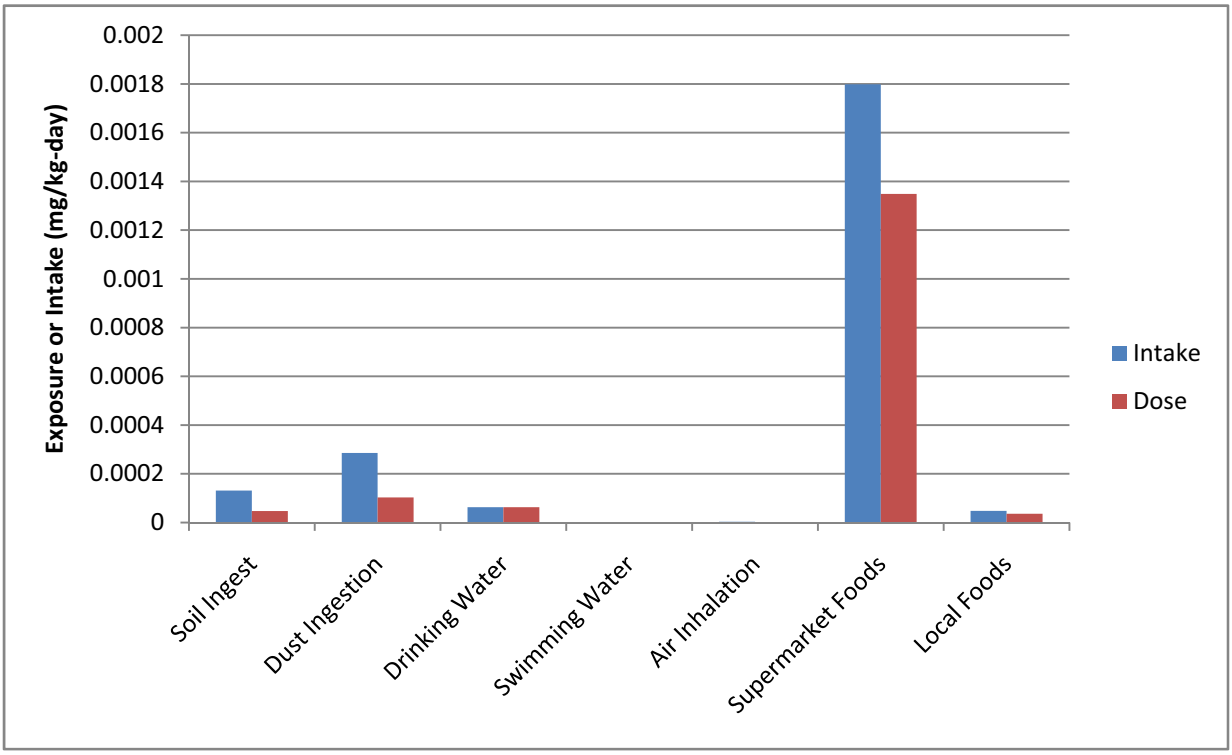


Figure 5-12: Toddler Arsenic Ingestion Intakes Before and Doses After Adjustment for Relative Oral Bioavailability - Zone D Farm Organic Soil Receptor



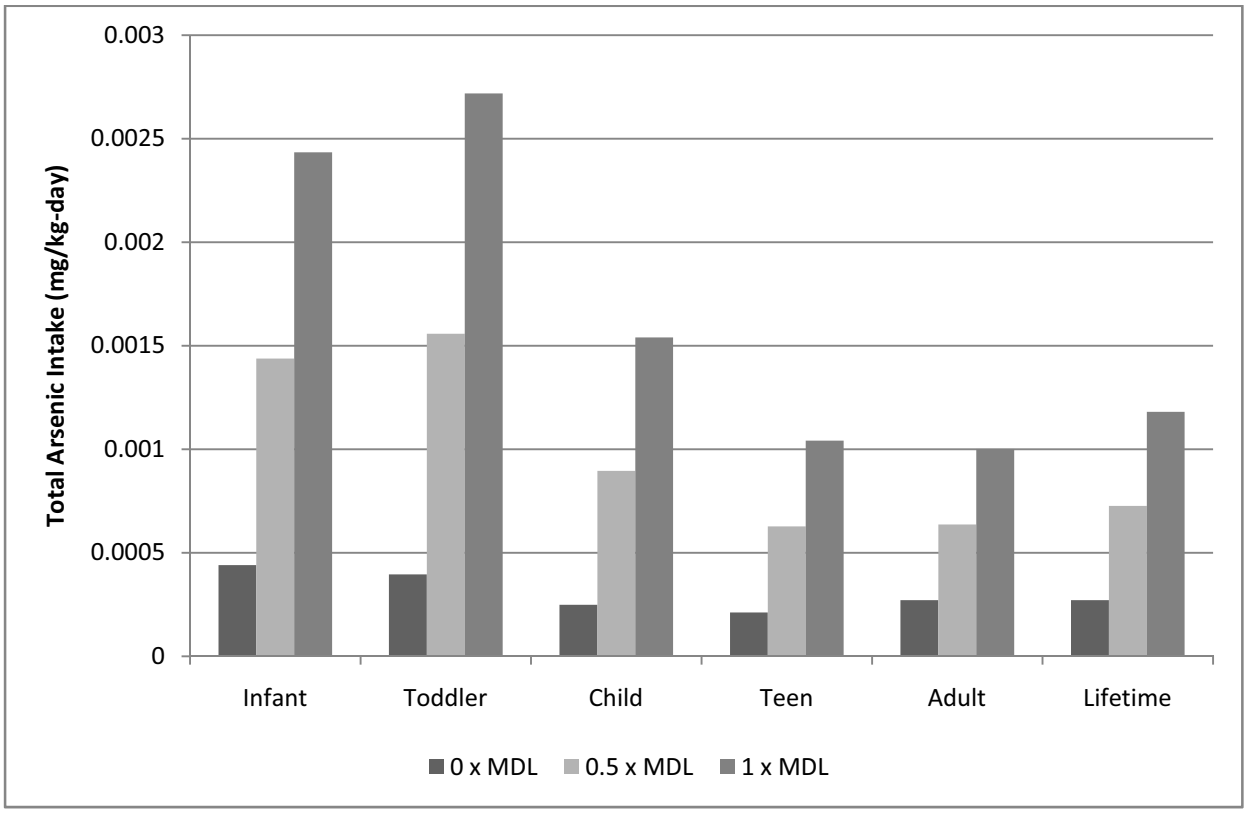
5.3.5.1 Uncertainty in Arsenic Exposures

Throughout the exposure calculations, it was assumed that concentrations reported as less than the estimated quantification limit (EQL) were equal to half the value of the EQL. In the case of the supermarket study, the method detection limit (MDL) was used rather than the EQL.

In order to assess the effect of this assumption on estimated exposures, the assumed value of concentrations less than the EQL (or MDL for the supermarket study) were varied in three different trials to equal zero, to equal one-half the value of the EQL or MDL and to equal the value of the EQL or MDL. This alteration affected the value of undetected concentrations of arsenic, cobalt, copper and nickel in well water, municipal water, supermarket foods and garden produce. The resulting estimated exposures, for Zone B receptors, are illustrated graphically in Figure 5-13 for arsenic.

The variation in EQL and/or MDL (from zero, to one-half the value of the EQL or MDL, to equal to the EQL or MDL) had very little affect on results for nickel, copper, and cobalt, indicating that the assumption is of minor importance and exposure and risk estimates for these CoCs are not sensitive to this assumption. This was not true for arsenic.

Figure 5-13: Effect of Varying the MDL on Arsenic Exposure Estimates for Zone B Receptors



As seen in Figure 5-13, the exposure estimates vary by close to an order of magnitude depending on the assumption made regarding the detection limit. As a result, the exposure estimates are very sensitive to this assumption and the results have a high degree of uncertainty. When the uncertainty in the exposure estimates is compared to the relative difference in exposure estimates between the zones, the differences are insignificant compared to the range of uncertainties.

In summary, the arsenic oral and dermal exposures were concluded to have too great an uncertainty associated with them for the valuation of exposures to be reliable.

5.4 Summary

In this chapter, receptor characteristics were selected and inhalation, ingestion and dermal intakes and doses of the four CoCs were estimated for reasonable maximum exposure concentration scenarios. Estimated exposures for maximally exposed individuals are characterized in Chapter 7.

Inhalation exposures have been estimated as average exposure concentrations based on Zones in the community where different age groups spend time.

The toddler is generally the age group most susceptible to ingestion exposures to chemicals in soils. Dermal doses are relatively small compared to ingestion doses. Oral intakes are adjusted by the relative oral bioavailability to estimate the oral dose for each exposure pathway.

The adjustment for relative oral bioavailability has a large impact on nickel ingestion dose estimates. Supermarket foods are the largest contributor to total nickel dose, after adjustment for relative oral bioavailability. For nickel intakes before bioavailability adjustment, intake from soil ingestion is greater than the intake from supermarket foods.

For copper, oral/dermal exposures are estimated to be higher for the infant than for the toddler due to copper concentrations in infant formula.

The adjustment for relative oral bioavailability has a significant impact on cobalt ingestion dose estimates. Supermarket foods are the largest contributor to total dose, after adjustment for relative oral bioavailability.

Oral/dermal intakes and doses estimated for arsenic are highly uncertain due to most measured concentrations being below the achievable analytical detection limits. The degree of uncertainty in the estimates has been quantitatively estimated at about an order of magnitude. This uncertainty is considered too large to make exposure estimates reliable. A quantitative evaluation of arsenic risks associated with oral/dermal exposures cannot be undertaken for this reason.

The oral/dermal doses have been seen to be dominated by supermarket foods, with adjustments for relative bioavailablity of the CoCs in soil and dust having a significant impact on estimated doses. For nickel, the impact of the bioavailability adjustment is quite large. The estimated inhalation exposure concentrations and oral/dermal doses are carried forward to Chapter 6, *i.e.* the Risk Characterization for reasonable maximum exposure concentration scenarios. In Chapter 6, inhalation exposure concentrations and oral/dermal doses are used to estimate the potential for risk by comparison to toxicity reference values developed in Chapter 4.

6.0 RISK CHARACTERIZATION FOR REASONABLE MAXIMUM EXPOSURE CONCENTRATIONS

Risk Characterization is the final stage of a quantitative risk assessment, using the results of the exposure assessment and the results of the dose-response assessment. In this Human Health Risk Assessment (HHRA), the Risk Characterization is presented in two parts. First, in this chapter, potential risks to the population of Port Colborne, based on reasonable maximum exposure (RME) concentrations, are estimated. This is done by evaluating exposures throughout the community based on RME concentrations of the Chemicals of Concern (CoCs). These concentrations are higher than typical or average concentrations and therefore yield a conservative estimate of risks.

Risk Characterization does not take into account places where concentrations of CoCs in various environmental media might be above the selected RME concentrations. This might include a specific well with higher groundwater concentrations, a home with high soil concentrations or the location with the highest indoor or ambient air concentrations. Since these highest levels for each media tested are unlikely to all occur at any one location, the RME concentration approach is considered more representative, conservative and will cover a broad range of exposures in the community. Scenarios for residents who might be maximally exposed individuals are evaluated in the second part of the Risk Characterization (see Chapter 7).

6.1 Risk Estimation Equations

In Risk Characterization, the potential health risks from exposure to CoCs are estimated. An estimate of the potential risks from exposure to CoCs in various media was made by comparing the dose estimate to the toxicity reference value (TRV). For a threshold-acting chemical, risk characterization is expressed as a hazard quotient (HQ). Equation 6-1 is used for oral and dermal exposures, which are summed together:

$$HQ = \text{estimated dose (mg/kg-day)} / \text{TRV (mg/kg-day)} \qquad \text{(Equation 6-1)}$$

Sample Calculation Step 9

Calculation: Ingestion and Dermal Hazard Quotient

$$HQ_{ing/derm} = \frac{DR_{ing}}{RfD_{oral}} + \frac{DR_{derm}}{RfD_{derm}}$$

Where:

$HQ_{ing/derm}$	=	Hazard quotient for Nickel (dimensionless)
DR_{ing}	=	Summed dose of Nickel from all ingestion pathways (0.012 mg/kg-day)
DR_{derm}	=	Dose of Nickel from Dermal exposure (8.4×10^{-6} mg/kg-day)
RfD_{oral}	=	Nickel Sulphate Reference Dose for Ingestion exposure (0.02 mg/kg-day)
RfD_{derm}	=	Nickel Sulphate Reference Dose for Dermal exposure (0.0052 mg/kg-day)

$$HQ_{ing/derm} = \frac{0.012\,mg/kg-day}{0.02\,mg/kg-day} + \frac{8.4\times10^{-6}\,mg/kg-day}{0.0052\,mg/kg-day}$$

$$HQ_{ing/derm} = 0.6$$

Equation 6-2 is used for inhalation exposures for non-carcinogenic chemicals:

HQ = inhalation concentration (µg/m^3) / TRV (µg/m^3) (Equation 6-2)

Sample Calculation Step 10

Calculation: Non-Cancer Inhalation Hazard Quotient

$$HQ_{inh} = \frac{DR_{inh}}{RfD_{inh}}$$

Where:

HQ_{inh}	=	Hazard Quotient for Nickel and Nickel Compounds (dimensionless)
DR_{inh}	=	Nickel Exposure from inhalation (0.0068 µg/m^3)
RfC_{inh}	=	Reference Concentration for Nickel and Nickel Compounds (0.09 µg/m^3)

$$HQ_{inh} = \frac{0.0068\mu g/m^3}{0.09\,\mu g/m^3}$$

$$HQ_{inh} = 0.08$$

An HQ is an indicator of the potential for adverse human health effects. An HQ of less than or equal to one indicates that no observable adverse human health effects are expected and is considered by the Ontario Ministry of Environment (MOE) to be an acceptable level of risk (MOE 1996; 2002) when a multi-media exposure assessment, such as that used in this HHRA, is undertaken. TRVs are inherently conservative values, containing multiple uncertainty factors or being upper confidence limits of risk estimates, or both. An HQ greater than one is often within the bounds of uncertainty of the TRV value and therefore does not specifically indicate that a risk exists, only that the potential for a risk cannot be ruled out.

As part of the Risk Characterization, doses associated with concentrations of CoCs in the Port Colborne area were compared to doses associated with local and regional background concentrations (*i.e.,* naturally occurring levels of CoCs identified from literature sources and measurement). For threshold acting chemicals, doses from all sources, including background, can contribute to total dose and impact whether a threshold is reached.

This is not the case for non-threshold acting chemicals. For these, background doses are not included when estimating incremental doses (*i.e.,* dose of soil CoCs in Port Colborne). Where background doses are used, these are used for comparative purposes only; effects smaller than 10 to 20% above natural background cannot be reliably distinguished or quantified. For non-threshold acting chemicals, doses that are small (*i.e.,* cannot be distinguished) compared to background or naturally occurring doses are considered minimal and indicative of an acceptable level.

For each non-threshold acting chemical, the incremental lifetime cancer risk (ILCR) was estimated for the incremental dose discernible from background (see Equation 6-3) or the incremental concentration in the case of inhalation risks (see Equation 6-4).

$$\text{ILCR} = [\text{incremental dose (mg/kg-day)}] \times [\text{slope factor (mg/kg-day)}^{-1}] \quad \text{(Equation 6-3)}$$

$$\text{ILCR} = [\text{incremental exposure concentration } (\mu g/m^3)] \times [\text{unit risk } (\mu g/m^3)^{-1}] \quad \text{(Equation 6-4)}$$

Total lifetime cancer risk (TLCR) can be estimated in the same manner by substituting Lifetime Average Daily Dose (LADD) for incremental doses.

Sample Calculation Step 11

Calculation: Inhalation Cancer Risk – Non-Threshold

$$Risk_{inh} = DR_{inh} \times UR_{inh}$$

Where:

$Risk_{inh}$	=	Inhalation Risk (dimensionless)
DR_{inh}	=	Nickel Exposure from inhalation (0.0068 µg/m^3)
UR_{inh}	=	Oxidic Nickel Unit Risk (Approach II) (4 x 10^{-5} per µg/m^3)

$$Risk_{inh} = (0.0068 \mu g / m^3) \times [4 \times 10^{-5} (\mu g / m^3)^{-1}]$$

$$Risk_{inh} = 3 \times 10^{-7}$$

According to the United States Environmental Protection Agency (U.S. EPA 1996), an ILCR in the range of one in ten thousand to one in one million represents a potential health concern that should be examined more closely. An ILCR of one in one hundred thousand has been accepted by the Ontario Ministry of Environment (MOE 2002) and Health Canada as being an extremely small or acceptable level of risk. The actual ILCRs estimated are presented in this section and compared to a one in one million risk reference level.

All estimated ILCRs and HQs in the following sections have been rounded to the number of significant digits in the selected TRVs.

Threshold effects can also be evaluated for carcinogenic chemicals. Exposure Ratios (ERs) are used to evaluate these potential risks in a similar manner to HQs. Like HQs, the ERs are applicable to individual life stages and total exposures rather than incremental. Equation 6-5 is used to estimate the inhalation ER from a limit value.

ER = [estimated exposure concentration (µg/m^3) / [Limit value (µg/m^3)] (Equation 6-5)

Sample Calculation Step 12

Calculation: Inhalation Cancer Risk - Threshold

$$ER_{inh} = DR_{inh} / LV_{inh}$$

Where:
ER_{inh} = Inhalation Exposure Ratio (dimensionless)
DR_{inh} = Nickel exposure from inhalation (0.0068 µg/m^3)
LV_{inh} = Nickel Refinery Dust Limit Value (Approach III) (0.6 µg/m^3)

$$ER_{inh} = \frac{0.0068 \mu g / m^3}{0.6 \mu g / m^3}$$

$$Risk_{inh} = 0.01$$

Like an HQ, the ER is compared to an acceptable value of one, below which no observable adverse effects are expected.

6.2 Results and Discussion

6.2.1 Nickel

6.2.1.1 Inhalation

Inhalation exposure to nickel is assessed for both carcinogenic and non-carcinogenic risks. The non-carcinogenic risk (the HQ), was estimated based on the total exposure, see Table 6-1.

Table 6-1: Hazard Quotient for Inhalation Exposure to Nickel

Zone	Receptor	
	Toddler	Adult
A - Residential	0.07	0.09
B - Residential	0.2	0.2
C - Residential	0.1	0.1
D - Farm	0.06	0.06
D - Residential	0.06	0.07
E1 - City	0.02	0.04
E2 - Background	0.02	0.02
F - Background	0.01	0.01

Note:
For detailed examples of exposure and risk calculations, see Volume III, Appendix 6.

The results of the threshold risk calculation indicate that the highest estimated risk for all seven zones is 0.2 for the Zone B receptors. The HQ for all receptors are well below the MOE benchmark of one.

The ILCR and the TLCR were estimated using the Approach I and II unit risks (U.S. EPA 1986; EC 2001) based on nickel refinery dust and oxidic nickel, respectively. See Table 6-2 for total and incremental LADDs. For results of the ILCR and TLCR estimations for nickel inhalation see Table 6-3. See Table 6-4 for ERs for nickel refinery dust.

The ILCR for nickel refinery dust inhalation (Approach I) is estimated to range from 0.4 in one million to 3 in one million depending on the receptor zone selected. Only the ILCRs estimated using Approach I (*i.e.,* the U.S. EPA refinery dust unit risk) result in a risk greater than the MOE one in one million benchmark (MOE 1996). For Approach II, oxidic nickel unit risk, all ILCRs are less than the one in one million benchmark. The highest ER for oxidic nickel inhalation is estimated at 0.03 in Zone B—well below the MOE acceptable threshold benchmark of one.

Table 6-2: LADD to Nickel Inhalation

Zone	LADD ($\mu g/m^3$)	Background LADD ($\mu g/m^3$)	Incremental LADD ($\mu g/m^3$)
A – Residential	0.0077	0.0013	0.0064
B – Residential	0.015	00013	0.014
C – Residential	0.0097	0.0013	0.0085
D – Farm	0.0052	0.0014	0.0038
D – Residential	0.0059	0.0013	0.0046
E1 - City	0.0031	0.0013	0.0018

Note:
For detailed examples of exposure and risk calculations, see Volume III, Appendix 6.

Table 6-3: Lifetime Cancer Risks for Inhalation Exposure to Nickel

Zone	Cancer Risk Approach I: Nickel Refinery Dust Unit Risk (U.S. EPA)		Cancer Risk Approach II: Oxidic Nickel Unit Risk (European Union)	
	TLCR	ILCR	TLCR	ILCR
A – Residential	2×10^{-6}	2×10^{-6}	0.3×10^{-6}	0.3×10^{-6}
B – Residential	4×10^{-6}	3×10^{-6}	0.6×10^{-6}	0.6×10^{-6}
C – Residential	2×10^{-6}	2×10^{-6}	0.4×10^{-6}	0.3×10^{-6}
D – Farm	1×10^{-6}	0.9×10^{-6}	0.2×10^{-6}	0.2×10^{-6}
D – Residential	1×10^{-6}	1×10^{-6}	0.2×10^{-6}	0.2×10^{-6}
E1 - City	0.7×10^{-6}	0.4×10^{-6}	0.1×10^{-6}	0.07×10^{-6}

Table 6-4: Exposure Ratios for Inhalation Exposure

Zone	Exposure Ratio Approach III: Nickel Refinery Dust Limit Value (European Commission)	
	Toddler	Adult
A – Residential	0.01	0.01
B – Residential	0.03	0.03
C – Residential	0.02	0.02
D – Farm	0.008	0.008
D – Residential	0.008	0.01
E1 – City	0.003	0.005

Note:
For detailed examples of exposure and risk calculations, see Volume III, Appendix 6.

Approach I is a unit risk for nickel refinery dust while Approach II is a unit risk for oxidic nickel. Since literature indicates that nickel carcinogenesis acts through a threshold mechanism for nickel inhalation (see Volume III, Appendix 7), the unit risks are considered applicable only when the cancer threshold is reached. The lower (more conservative) of estimated cancer thresholds for nickel refinery dust and oxidic nickel species were used in this assessment. The selected Approach III nickel refinery dust limit value is also considered protective of oxidic nickel exposures. **The highest ER in Approach III is 0.03 for Zone B toddler and adult residents—well below the applicable benchmark of one, indicating that concentrations of nickel in air are well below the threshold necessary to precipitate an effect. Additionally, the Approach II risks estimated from the nickel oxide unit risk are all below the applicable benchmark of one in one million (*i.e.*, 1×10^{-6}).**

Approach I, based on the U.S. EPA nickel refinery dust unit risk, yields only a minor exceedance of the MOE's benchmark and is within the range considered by MOE as acceptable when applying the U.S. EPA refinery dust benchmark (MOE 2002). **Since HQs are also less than their applicable MOE benchmark (*i.e.*, less than one), no elevated risk from nickel inhalation is expected for the RME concentration assessment.**

6.2.1.2 Ingestion and Dermal Contact

The ingestion and dermal dose to nickel was assessed as a threshold, non-cancer response. Results from the dose estimation indicated that the dose estimated for nickel was 18% above regional background (Zone F) via the ingestion and dermal pathways for the Zone B toddler. HQs were estimated for the total nickel ingestion and dermal dose, see Table -6-5.

Table 6-5: Hazard Quotient for Nickel Ingestion and Dermal Dose

Zone	Receptor		
	Infant	Toddler	Adult
A - Residential	0.08	0.4	0.1
B - Residential	0.08	0.3	0.1
C - Residential	0.08	0.3	0.1
D - Farm, Clay	0.1	0.3	0.1
D – Farm, Organic	0.1	0.4	0.1
D - Residential	0.09	0.3	0.1
E1 - City	0.08	0.3	0.08
E2 - Background	0.08	0.3	0.08
F - Background	0.08	0.3	0.09

Note:
For detailed examples of exposure and risk calculations, see Volume III, Appendix 6.

Very little difference in estimated HQs exists among the Zones (see Table 6-5). Similar results were found for the background receptors compared to HQs for toddlers in Zone F.

The highest estimated HQ of 0.4 for the Zone A toddler and the Zone D organic farm toddler, exceeds the toddler HQ in Zone B. This difference is due to, for the Zone A receptor, the higher fraction of diet from garden produce and garden produce concentrations. The Zone D farm receptors also obtain a greater percentage of their diet from garden produce, and in addition, obtain their drinking water from wells, whereas receptors from Zones A and B obtain theirs from municipal sources. All HQs estimated were well below the acceptable MOE benchmark of one.

See Figures 6-1 and 6-2 for the percent contribution of individual ingestion pathways to the total ingestion HQ for Zone B and Zone D farm clay toddler and adult receptors.

Figure 6-1: Percent Contribution of Ingestion Pathways to Total Nickel Ingestion HQ, Zone B

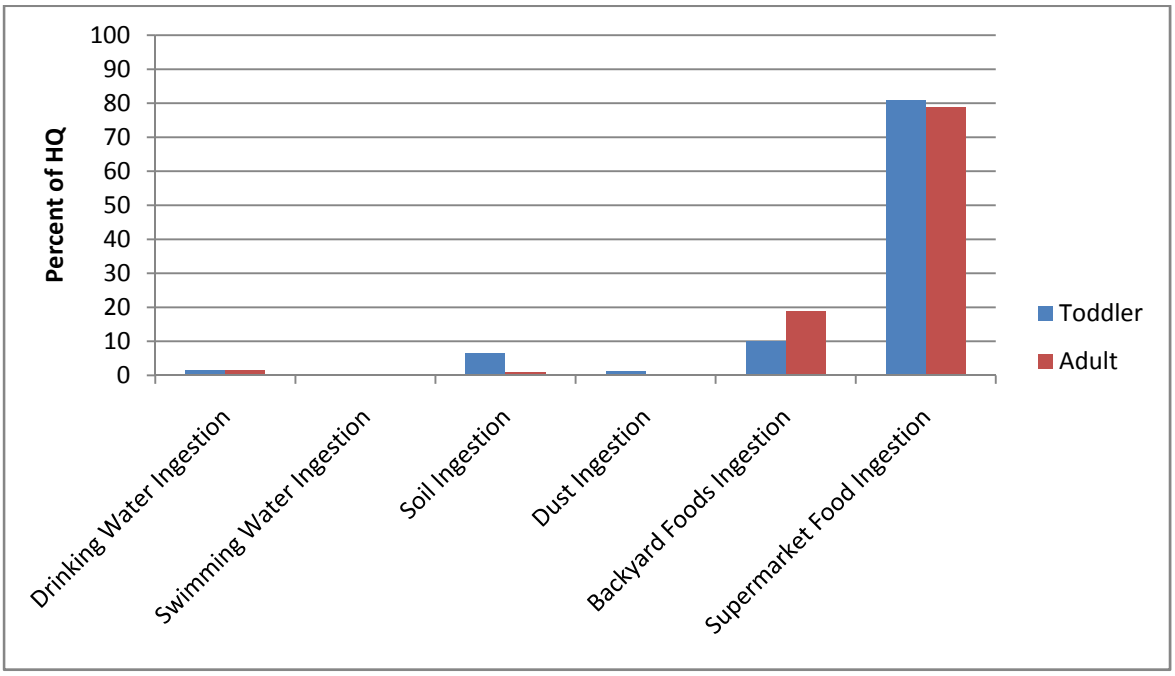
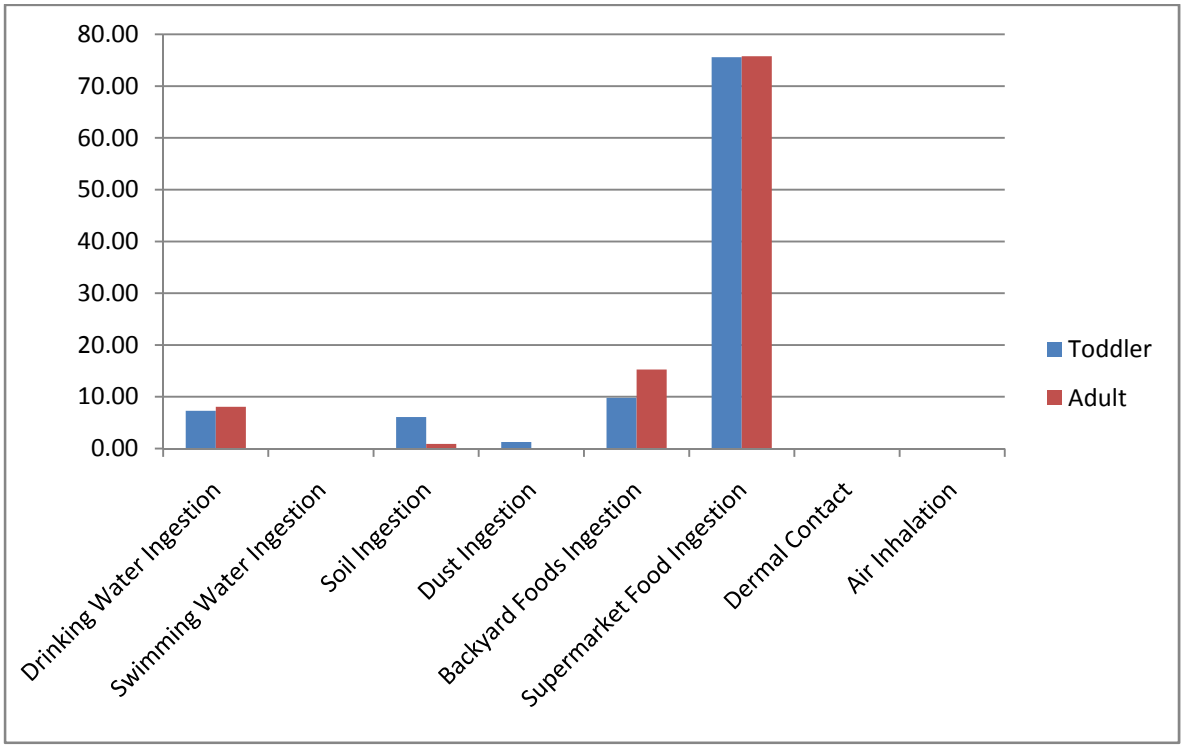


Figure 6-2: Percent Contribution of Ingestion Pathways to Total Nickel Ingestion HQ, Zone D Farm Clay



Examining the graphs, supermarket food ingestion is clearly the dominant contributing pathway to the nickel ingestion HQ for both zones and receptors shown. Backyard produce consumption also contributes significantly to the nickel ingestion HQ. Soil ingestion and drinking water consumption constituted the third greatest contributors to the nickel ingestion HQ for Zone B and Zone D farm clay toddlers, respectively.

Concentrations of nickel in Port Colborne soils contribute only a minor amount to the overall potential risk to Port Colborne residents. To put this into context, the HQ for nickel ingestion and dermal exposure for a toddler receptor in the Niagara Region is 0.3, while the maximum HQ for a toddler in Port Colborne is 0.4; the net effects of exposure to nickel in soil from the historical Inco Refinery emissions result in a slight increase in the HQ for the toddler receptor. In summary, **based on the conservative scenario and exposure pathway assumptions adopted in this HHRA, human health risks from exposure to nickel in Port Colborne are below the MOE's benchmark HQ of one (MOE 1996).**

6.2.2 Copper

6.2.2.1 Inhalation

Copper is assessed as a non-carcinogen; the HQ based on the total exposure was estimated, see Table 6-6.

Table 6-6: Hazard Quotient for Inhalation Exposure to Copper

Zone	Receptor	
	Toddler	Adult
A - Residential	0.0004	0.03
B - Residential	0.2	0.1
C - Residential	0.0004	0.02
D - Farm	0.0004	0.0004
D - Residential	0.0004	0.02
E1 – City	0.0002	0.02
E2 - Background	0.0002	0.0002
F - Background	0.005	0.005

Note:
For detailed examples of exposure and risk calculations, see Volume III, Appendix 6.

The highest HQ estimated for copper inhalation pathways was 0.2 for the Zone B toddler—well below the acceptable benchmark of one; therefore, there is no elevated human health risk indicated from the inhalation of copper in Port Colborne.

6.2.2.2 Ingestion and Dermal Contact

The ingestion and dermal dose of copper by Port Colborne residents was found to be indistinguishable from regional background (Zone F) dose via the same pathways. Since copper ingestion and dermal dose are assessed for non-carcinogenic effects, the total dose was used to estimate the HQ. For the estimated HQs for ingestion and dermal dose of copper, see Table 6-7.

Table 6-7: Hazard Quotient for Ingestion [a] and Dermal [b] Dose of Copper

Zone	Receptor		
	Infant	Toddler	Adult
A - Residential	0.5	0.4	0.1
B - Residential	0.6	0.4	0.1
C - Residential	0.5	0.4	0.1
D - Farm, Clay	0.6	0.4	0.1
D – Farm, Organic	0.6	0.4	0.1
D - Residential	0.6	0.5	0.2
E1 - City	0.5	0.4	0.1
E2 - Background	0.5	0.4	0.1
F - Background	0.5	0.4	0.1

Note:
For detailed examples of exposure and risk calculations, see Volume III, Appendix 6.

The highest estimated HQ was 0.6 for the infants in Zone B and D (resident and farm, regardless of soil type). This HQ value is below the MOE acceptable benchmark of one.

See Figures 6-3 and 6-4 for the percent contribution of each individual ingestion pathway to the total copper ingestion HQ.

Figure 6-3: Percent Contribution of Ingestion Pathways to Total Copper Ingestion HQ, Zone B

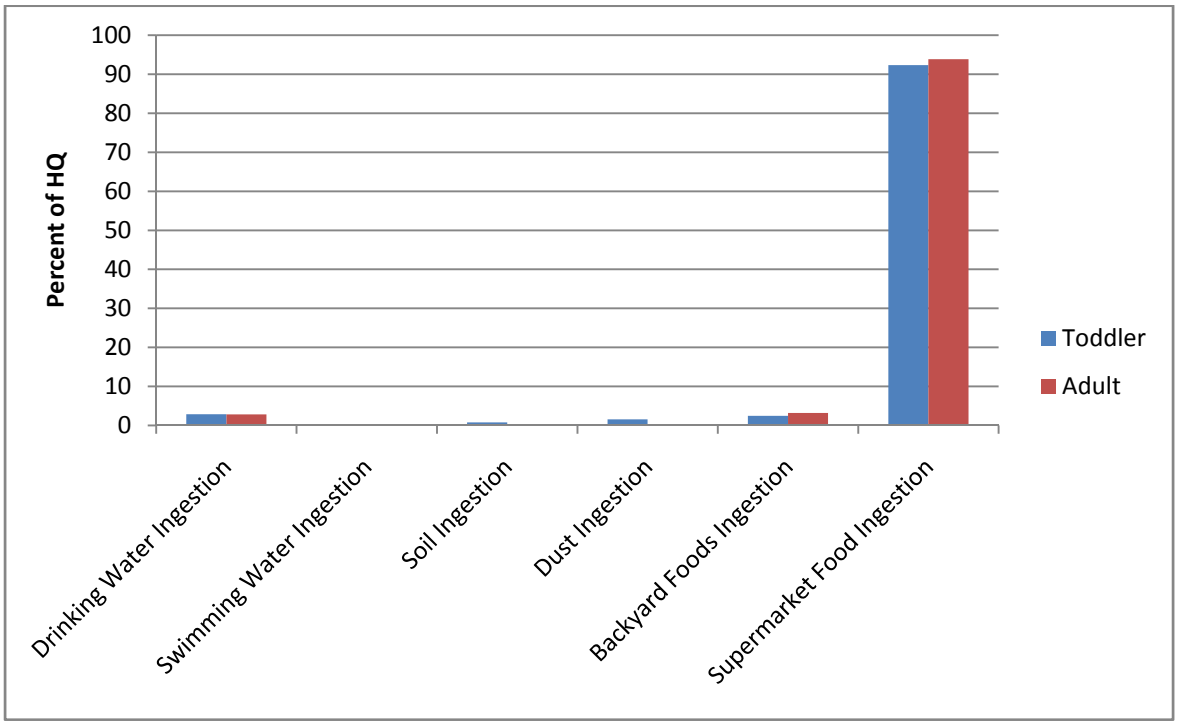
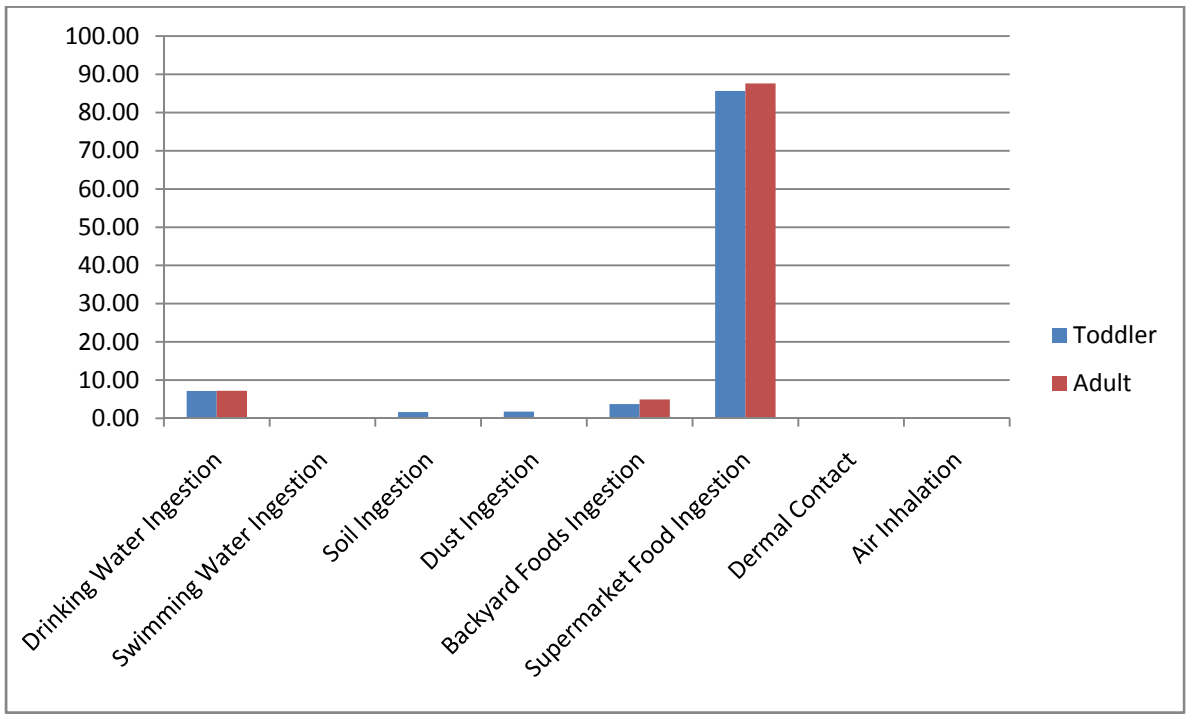


Figure 6-4: Percent Contribution of Ingestion Pathways to Total Copper Ingestion HQ, Zone D Farm Clay



As shown in Figures 6-3 and 6-4, supermarket food ingestion is the dominant pathway contributing to the copper ingestion HQ in both Zones B and D and for both the toddler and adult receptors. For the toddler receptor in both Zones B and D farm clay, the next greatest source contributing to the total ingestion HQ is drinking water ingestion, followed by consumption of backyard produce.

Results for copper indicate that the risks from ingestion and dermal doses for residents in Port Colborne are similar to background receptors. Similar to the background receptor, the majority of risk arising from copper intake is the result of dietary intake of supermarket foods, with HQs below the acceptable risk benchmark. This indicates that **soils impacted by historic emissions from the Inco Refinery do not contribute significantly to an overall risk from copper through the ingestion and dermal dose pathways.**

6.2.3 Cobalt

6.2.3.1 Inhalation

Based on the exposure assessment, inhalation exposure to cobalt in Port Colborne was determined to be similar to background (Zone F) exposure, except in Zones D and E, where exposure was estimated to be significantly less than that in Zone F. The inhalation exposure of cobalt is assessed as a non-carcinogenic effect; the HQs were estimated based on total inhalation exposure (see Table 6-8).

Table 6-8: Hazard Quotient for Inhalation Exposure to Cobalt

Zone	Receptor	
	Toddler	Adult
A - Residential	0.01	0.01
B - Residential	0.02	0.02
C - Residential	0.02	0.02
D - Farm	0.007	0.007
D - Residential	0.007	0.008
E1 - City	0.003	0.005
E2 - Background	0.003	0.003
F - Background	0.01	0.01

Note:
For detailed examples of exposure and risk calculations, see Volume III, Appendix 6.

A maximum HQ of 0.02 was estimated for the Zone B and Zone C receptors. This HQ value is well below the acceptable benchmark of one. No elevated human health risk above the MOE benchmark is indicated for inhalation of cobalt in Port Colborne.

6.2.3.2 Ingestion and Dermal Contact

Similar to the inhalation of cobalt, the ingestion and dermal dose of cobalt is assessed as a non-carcinogenic dose-response. Results from the exposure assessment indicated that except for Zone D farm receptors, exposure to cobalt via ingestion and dermal contact in Port Colborne is similar to the background dose. The HQ based on the total dose was estimated, see Table 6-9.

Table 6-9: Hazard Quotient for Ingestion [a] and Dermal [b] Dose of Cobalt

Zone	Receptor		
	Infant	Toddler	Adult
A - Residential	0.03	0.03	0.008
B - Residential	0.03	0.03	0.008
C - Residential	0.03	0.03	0.008
D - Farm, Clay	0.03	0.04	0.01
D – Farm, Organic	0.03	0.04	0.01
D - Residential	0.03	0.03	0.008
E1 - City	0.03	0.03	0.008
E2 - Background	0.03	0.03	0.008
F - Background	0.03	0.03	0.008

Note:
For detailed examples of exposure and risk calculations, see Volume III, Appendix 6.

The highest HQ of 0.04 was estimated for the toddler receptor in Zone D farm areas. This value is well below the acceptable benchmark of one.

See Figures 6-5 and 6-6 for the percent contribution of each individual ingestion pathway to the total cobalt ingestion HQ.

Figure 6-5: Percent Contribution of Ingestion Pathways to Total Cobalt Ingestion HQ, Zone B

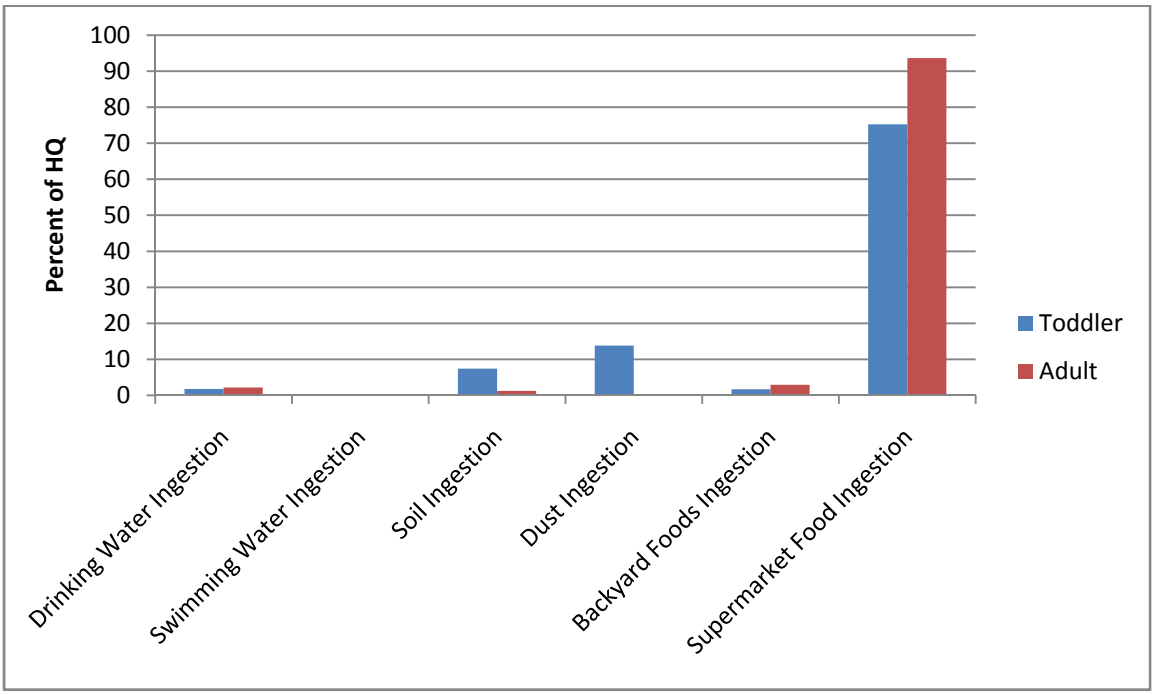
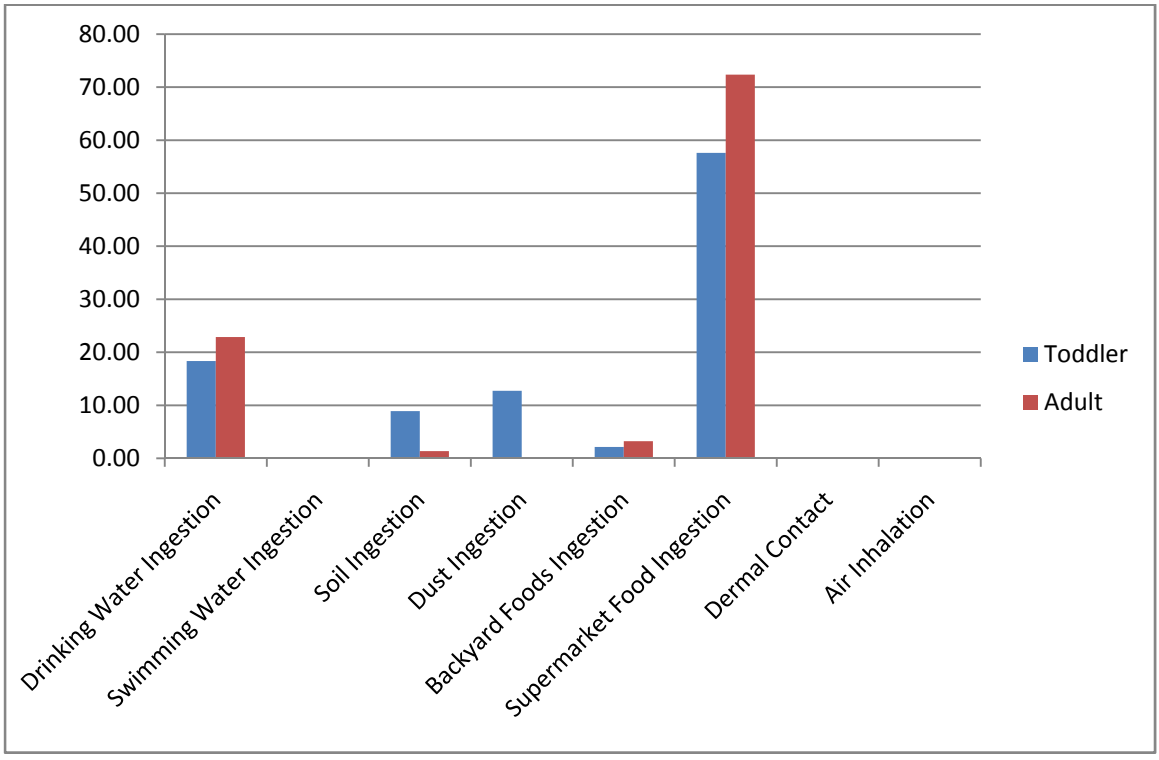


Figure 6-6: Percent Contribution of Ingestion Pathways to Total Cobalt Ingestion HQ, Zone D Farm Clay



Supermarket food ingestion is the primary pathway contributing to the total cobalt ingestion HQ for both toddler and adult receptors in Zones B and D farm clay. For the toddler receptor in Zone B, the next greatest contributing sources to the cobalt ingestion HQ were dust ingestion, followed by soil ingestion. For the toddler in Zone D farm clay, the second and third greatest contributing sources to the HQ were drinking water and dust ingestion, respectively. For the adult receptors in both zones, drinking water and backyard produce consumption were dominant contributing pathways, after supermarket foods, to the total cobalt ingestion HQ. **All of the HQs estimated for cobalt ingestion and dermal exposure were well below the threshold effects benchmark of one.**

6.2.4 Arsenic

6.2.4.1 Inhalation

See Table 6-1010 for arsenic concentrations measured in air to background concentrations and applicable MOE Ambient Air Quality Criteria (AAQC). In general, the MOE established the AAQC to "protect human health and the environment (terrestrial vegetation and wildlife)" (MOE 2001b). For arsenic, although the AAQC is not based solely on protection of human health, the value was selected by the MOE as representing an acceptable level of health protection for arsenic. Since the measured arsenic concentrations in both ambient and indoor air are all well below the MOE AAQC, no unacceptable risk is present based on MOE guidance.

All of the maximum measured air concentrations fall within the range of typical Ontario ambient air concentrations of arsenic and no incremental (*i.e.*, above background) health risk is indicated.

Table 6-10: Comparison of Arsenic Concentrations in Air to AAQC and Background Concentrations

Air Quality Parameter		Arsenic Concentration ($\mu g/m^3$)
Maximum Measured 24 hour Ambient Air Concentrations out of 40 TSP, 40 PM_{10} and 58 $PM_{2.5}$ samples	TSP	0.01
	PM_{10}	0.01
	$PM_{2.5}$	0.01
Maximum Measured 24 hour Indoor Air Concentrations out of 30 TSP and 30 PM_{10} samples	TSP	0.01
	PM_{10}	0.01
Typical 24 hour Ontario Air Concentrations (PM_{10}) from Environment Canada (MOE 2002)	Minimum	0.0003
	Maximum	0.02
	Average	0.002
Maximum Measured 24-hour Ambient Air Concentrations out of 236 TSP, 238 PM_{10}, and 233 $PM_{2.5}$ samples (MOE, 2001-2006)	TSP	0.029
	PM_{10}	0.022
	$PM_{2.5}$	0.020
24 hour AAQC (not specific to size fraction)		0.3

Note:
TSP – Total suspended particulate
PM_{10} – Fine, respirable dust particles in air
$PM_{2.5}$ – Very fine, respirable dust particles in air that may reach the deepest parts of the lungs

6.2.4.2 Oral and Dermal

The arsenic dataset contained a large number of samples in a variety of media with concentrations below the lowest-achievable limits of detection obtained at the time of chemical analysis. When the impact of these non-detects on the overall dataset reliability was examined, along with the dataset of some media with detectable arsenic, the resulting oral and dermal exposure estimates were found to have an uncertainty of roughly an order of magnitude associated with them—far greater than the computed differences between zones. This uncertainty was concluded from this to be far too great to be able to reliably estimate exposures or risks from arsenic.

6.2.4.3 Historical Use of Arsenic Trioxide

To put into context potential exposures associated with arsenic, historical and current uses of arsenic were reviewed. Background concentrations of arsenic in the environment such as those used in this assessment for Zone F do not necessarily take into account all of the anthropogenic sources of arsenic that might have contributed to background levels in the Niagara Region.

Arsenic trioxide was used historically for a number of purposes, including as a healing agent to treat conditions including leukemia and amoebic dysentery and in veterinary medicine for the treatment of parasitic diseases (Ratnaike 2003; Fishbein 1981). However, the predominant use of arsenic compounds has been in agricultural and residential areas for pest control. Arsenic trioxide was used in the production of arsenical pesticides including lead arsenate, calcium arsenate, sodium arsenite and organic arsenicals (Fishbein 1981). It was also used in combination with copper acetate to create Paris Green, a widely used general insecticide and defoliant, until the introduction of synthetic insecticides such as DDT (Glenn and Puterka 2005). In Ontario, lead arsenate sprays were officially recommended for use in apple orchards as late as 1975 (Frank *et al.,* 1976 as cited by Peryea 1998). Repeated applications of high concentrations of arsenic-containing compounds have resulted in soil contamination in treated areas (Peryea 1998).

Use of arsenic as a wood preservative and in timber treatment to prevent termite damage (APVMA 2003) continues. The compound is used to produce chromated copper arsenate (CCA), a preservative for pressure treated wood products, which might be leached from treated wood in the outdoor environment by rainwater (Brooks 2005; Stilwell and Gorny 1997). There are many documented methods through which arsenic might enter into the soil from man-made products.

6.2.4.4 Findings from Studies Involving Bioassays

Three health studies for arsenic involving bioassays have been conducted in Ontario for the communities of Wawa, Deloro and Falconbridge. The findings of these studies are summarized and compared to the Port Colborne situation (see Volume III, Appendix 7, Attachment B). These three lines of evidence point to a conclusion of no elevated risks to residents of Port Colborne from exposure to arsenic in soils. For example, one of these three studied communities (*i.e.,* Falconbridge), has the same CoCs (Ni, Cu, Co, As) in soil as those found in the Port Colborne community. See Table 6-11 for a comparison of the soil arsenic concentration in the community of Port Colborne and Falconbridge as one of the three arsenic-in-urine studied communities. Since the soil arsenic concentration in Port Colborne was either the same or lower than those in soil from the arsenic-impacted community of Falconbridge and since health effects were not observed in comparison between the Falconbridge residents and residents of Hanmer (a control community comparator to Falconbridge), by extension, **no health effects from arsenic exposures are expected to residents of Port Colborne.**

Table 6-11: Comparison of Soil Arsenic Concentrations between Port Colborne and the Arsenic-in-Urine Studied Communities of Falconbridge and Hanmer

Site	Arsenic Soil Concentration (µg/g)						Inorganic Arsenic Concentration in Urine (µg/L) [b]	
	Minimum		Maximum		Mean		Mean	Median
Arsenic Impacted Community of Falconbridge [a]	2.5		620		79		7.1	6.0
Hanmer, Control Community Comparator to Falconbridge	2.5		25		3.7		7.2	6.0
Community of Port Colborne, Residential Soils Impacted by CoCs Including As, Ni, Co, Cu	Zone A	0.7	Zone A	15	Zone A	6.2	NA	NA
	Zone B	1.2	Zone B	350	Zone B	14		
	Zone C	2.2	Zone C	26	Zone C	7.2		
	Zone D	2.1	Zone D	9.6	Zone D	4.2		
	Zone E	1.3	Zone E	6.3	Zone E	3.4		

a. Other CoCs besides arsenic in these soils include nickel, cobalt and copper.

b. The inorganic arsenic species is most often associated with health effects and is used in this comparison table.

NA – Not Analyzed

6.3 Summary of Risk Characterization for Reasonable Maximum Exposure Concentrations

6.3.1 Non Cancer Risks

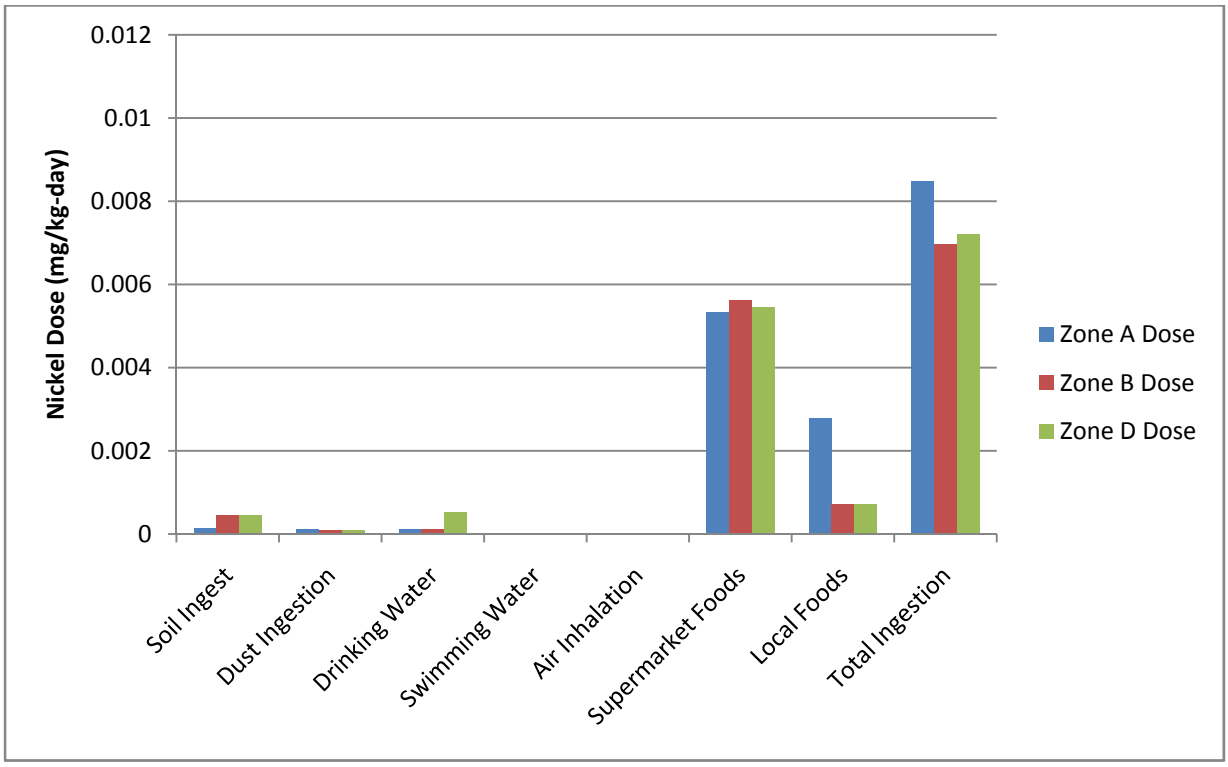
See Table 6-12 for the highest HQs estimated in Port Colborne for the RME concentration scenarios. None of the estimated HQs exceed the MOE recommended benchmark of one.

Table 6-12: Maximum Estimated Hazard Quotients

Chemical	Exposure Route	Zone of Maximum Hazard Quotient (HQ)	Life Stage	Hazard Quotient
Nickel	Inhalation	Zone B	Toddler, Adult	0.2
	Ingestion/Dermal	Zones A and D Farm Organic	Toddler	0.4
Copper	Inhalation	Zone B	Toddler	0.2
	Ingestion/Dermal	Zones B and D (all)	Infant	0.6
Cobalt	Inhalation	Zones B and C	Toddler, Adult	0.02
	Ingestion/Dermal	Zone D Farms	Toddler	0.04

Of note in Table 6-12, the toddler ingestion and dermal dose for nickel is highest in Zone A, even though soil concentrations are lower in this Zone than in Zones B, C or D. As illustrated in Figure 6-7, the higher dose to this receptor is from local foods, or more specifically garden produce.

Figure 6-7: Comparison of Nickel Dose by Ingestion Pathway for Zones A, B and D Farm Organic Toddler Receptors



6.3.2 Cancer Risks

Using Approach I, the maximum estimated risk from nickel refinery dust inhalation in Zone B (see Table 6-13) was estimated at three times the reference level of one in one million. Using Approach II, the reference level of one in one million was not exceeded for risk from inhalation of oxidic nickel, the dominant species in Port Colborne soils and ambient air. No exceedances of the target ER of one were noted for the limit value approach (Approach III), indicating that cancer risks from inhalation of oxidic nickel in Port Colborne are not elevated. For the maximum ER estimate, see Table 6-14.

Table 6-13: Maximum Estimated Incremental Lifetime Cancer Risks

Chemical	Exposure Route	Zone of Maximum ILCR	Slope Factor	ILCR
Nickel	Inhalation (Lifetime)	Zone B	Approach I: U.S. EPA Refinery Dust	3×10^{-6}
			Approach II: Oxidic Nickel (European Commission)	0.6×10^{-6}

Table 6-14: Maximum Estimated Exposure Ratio

Chemical	Exposure Route	Zone of Maximum ER	Slope Factor	ER
Nickel	Inhalation (Toddler, Adult)	Zone B	Approach III: Oxidic Nickel Limit Value (European Union)	0.03

6.3.3 Conclusion

The potential risks estimated for RMEs are considered representative of most people in Port Colborne and are within the range considered acceptable by MOE; therefore, no adverse effects to human health are expected for most people living in, working in or visiting Port Colborne.

This evaluation does not account for potential maximally exposed individuals where specific characteristics of their homes, properties or contaminants on their properties might result in exposures higher than those that are typical for most residents; however, those scenarios and specific properties representing conditions and actual properties of potential maximally exposed individuals are investigated in Chapter 7.

7.0 RISK CHARACTERIZATION FOR MAXIMALLY EXPOSED INDIVIDUALS

7.1 Introduction

In addition to the Risk Characterization for Reasonable Maximum Exposure (RME) concentrations discussed in Chapter 6, maximally exposed receptors are evaluated in this Chapter based on exposure to the highest concentrations of Chemicals of Concern (CoCs) measured in:

- Soils at all sampled depths;
- Garden produce;
- Drinking water;
- Ambient air; and,
- Indoor air.

This analysis was undertaken to assume that property specific risks do not exceed acceptable values. Note that concentrations in all media are not generally all maximized at the same time. For instance, well water use does not occur in the area of the highest soil concentrations. Although garden produce concentrations of nickel, and, to a lesser degree, cobalt, have a relationship with soil concentration, for the most part this relationship cannot be characterized sufficiently to be used in a predictive manner. In addition, produce concentrations may not be highest in the location of the highest soil concentration due to differences in CoC bioavailability associated with factors such as soil type or soil amendments. These types of interrelationships were considered in the selection of maximum exposure scenarios. Concentrations in sampled media not directly related to those that were maximized were held at RME concentrations for this analysis. Note that RME concentrations are already conservative values based variously on maxima, 75th percentiles, or upper confidence limits of mean or geometric mean values.

In the assessment of maximally exposed individuals, receptor characteristics were held to be the same as in the main Human Health Risk Assessment (HHRA) report. Variability in receptor characteristics is considered further in the Sensitivity Analysis presented in Chapter 8.

Local and regional background exposures in HHRA Zones (See Figure 3-1 for outlining the HHRA Zones) E2 Background and F, respectively, were not evaluated for maximally exposed individuals since these maximum scenarios are not considered applicable to background. Zone E1 City was also not evaluated in the maximum scenarios since Zone E1 City residents are not representative of any maximally exposed individuals.

Arsenic was not assessed for maximally exposed individuals since the oral/dermal exposures were found to have uncertainties too large to make the evaluation reliable. Also, arsenic inhalation exposures evaluated on a RME concentration basis included consideration of maximum measured arsenic concentrations in air (See Chapter 6, Section 6.2.4.1).

Five scenarios of maximally exposed individuals, exposed to maximum CoC concentrations in one or more particular sampled media and to RME CoC concentrations in all other remaining exposure media (except where noted) were selected for evaluation. These maximum exposure scenarios included:

- Maximum soil CoC concentrations;
- Maximum garden produce CoC concentrations combined with corresponding soil CoC concentrations;
- Maximum well water CoC concentrations;
- Maximum location ambient air CoC concentrations and correspondingly higher indoor air CoC concentrations;
- Maximum home indoor air CoC concentrations based on short term measurements.

7.2 Maximum Concentrations in Soil at All Sample Depths

In order to assess potential maximally exposed individuals, concentrations of nickel, copper and cobalt in soils were maximized. This approach provides an upper estimate of the level of risk for residents that may be exposed to maximum concentrations on individual properties since it also maximizes other concentrations in the community. As a result, the maximum concentrations in soil scenario is likely unrealistically conservative but provides an upper estimate of potential for exposures to soil.

For each zone, the maximum soil concentrations (Volume V, Appendix 20) for each soil type and land use were adopted. This approach is consider highly conservative as it assumes that the resident is exposed to the maximum soil CoC concentrations in all activities (*i.e.* school, work, play, home, gardening), for their entire lifetime. Maximum CoC concentrations measured at all sampled depths, as presented in Table 7-1, were used in the maximum concentrations in soil scenario.

Table 7-1: Maximum Concentrations in Soil at All Sample Depths, by Zone

Zone	Soil Type / Location	Maximum Concentration of CoCs in Soil, All Sample Depths (mg/kg) [b]		
		Nickel	Copper	Cobalt
A	Residential	1,700	210	30.
	Recreational	1,100	96	22
	Commercial	430	69	14
	Garden	320	47	9
B	Residential	17,000	2,700	260
	Recreational	9,300	720	180
	Commercial	16,000	8,400	270
	Garden	6,700	570	100
C	Residential	3,300	380	73
	Recreational	7,300	650	100
	School	590	72	17
	Garden	2,400	260	38
D	Residential	3,900	360	74
	Recreational	33,000 [a]	3,900	430
	Commercial	290	64	12
	Agricultural Soils	5,900	710	120
	Garden	2,700	360	54
	Beach	240	11	15

Note:

a. This concentration was measured in the Reuter Road woodlot during Jacques Whitford's tree study.

b. As remediation has been carried out on several properties since the sampling campaigns took place, the current maxima may be less than those presented here.

This scenario does not account for potential increased concentrations of CoCs in garden produce that may occur simultaneously in relationship to increased soil concentrations. The combination of this increase of garden produce concentrations with the maximization of all soil concentrations in the community is considered too unrealistic to be an appropriate scenario for evaluation of maximally exposed individuals. Actual measured concentrations in garden produce are considered the more reliable and appropriate measure of maximum receptor exposures. For this reason, maximum measured garden produce and their corresponding soil concentrations are evaluated in Section 7.3 and not in this maximum soil concentration scenario.

The resulting risk from CoCs based on exposure to the maximum soil concentration at all sample depths, as well as the risk based on the RME concentration, are presented in Tables 7-2 through 7-4. Results are displayed for the toddler, as the receptor having the greatest potential for exposure to soil and the adult as the longest lifestage. Age categories were defined in Chapter 3. A hazard quotient (HQ) of less than or equal to one indicates that no observable adverse human health effects are expected and is considered by the Ontario Ministry of the Environment (MOE) to be an acceptable level of risk (MOE 1996) when a multimedia exposure assessment is conducted. HQ estimation and theory is explained in detail in Chapter 6.

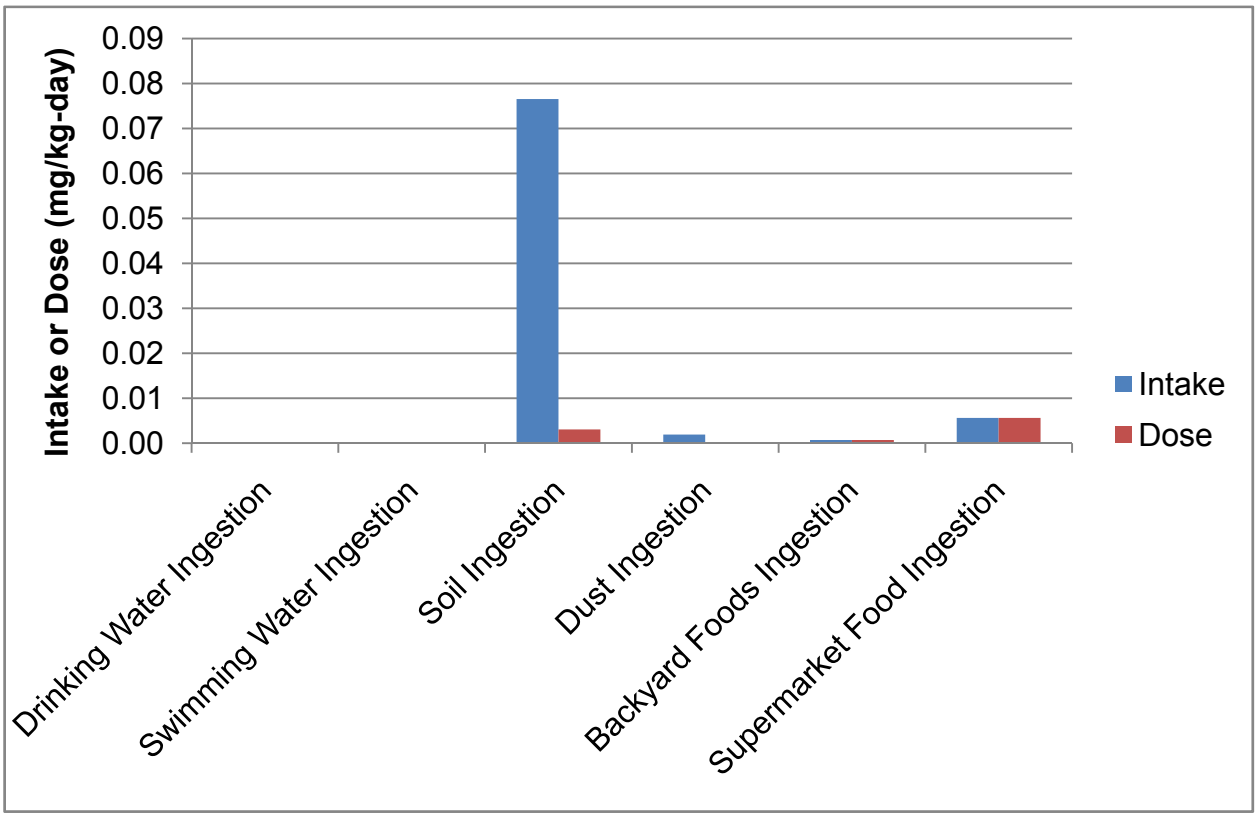
Table 7-2: Variation of Risk with Soil Nickel Concentration, Toddler and Adult

Zone	Toddler Receptor		Adult Receptor	
	HQ, Based on Maximum Soil Concentration	HQ, Based on RME Concentration	HQ, Based on Maximum Soil Concentration	HQ, Based on RME Concentration
A	0.4	0.4	0.1	0.1
B	0.5	0.3	0.1	0.1
C	0.5	0.3	0.1	0.1
D – Resident	0.4	0.3	0.1	0.1
D – Farm, Clay	0.5	0.3	0.1	0.1
D – Farm, Organic	0.5	0.4	0.1	0.1

Note:
Detailed results for all receptor age groups are summarized in Volume III, Appendix 6.

The use of maximum nickel soil concentrations had no significant effect on the ingestion/dermal HQ for the adult receptor. The reason that the change was not large is that soil is a small component of the total nickel dose after adjustment for relative oral bioavailability. Figure 7-1 displays the toddler ingestion of nickel in the various media, for this scenario without adjustment for bioavailability. Figure 7-1 also shows ingestion doses for the same exposure, but with adjustment for nickel bioavailability. As seen, the difference between the intake and dose is the greatly decreased dose of nickel from soil ingestion compared to the intake of nickel from soil ingestion.

Figure 7-1: Zone B Toddler Oral Intake (No Adjustment) and Dose (with Adjustment) of Nickel for Maximum Soil Concentration



As seen in Table 7-3, the same pattern was observed in the HQs generated using maximum soil copper concentrations. In the case of copper, relative oral bioavailability is higher than for nickel; however, the dietary intake of copper is a higher portion of total intake and the change in soil nickel ingestion is minor by comparison. HQs were compared to a benchmark of one, considered applicable by the MOE.

Table 7-3: Variation of Risk with Soil Copper Concentration, Toddler and Adult

Zone	Toddler Receptor		Adult Receptor	
	HQ, Based on Maximum Soil Concentration	HQ, Based on RME Concentration	HQ, Based on Maximum Soil Concentration	HQ, Based on RME Concentration
A	0.4	0.4	0.1	0.1
B	0.4	0.4	0.1	0.1
C	0.4	0.4	0.1	0.1
D – Resident	0.5	0.5	0.2	0.2
D – Farm, Clay	0.4	0.4	0.1	0.1
D – Farm, Organic	0.4	0.4	0.1	0.1

Table 7-4 for cobalt shows a slight increase in the ingestion/ dermal HQs of both the adult and toddler receptor using maximum soil cobalt concentrations. The HQs estimated are still well below the MOE benchmark of one.

Table 7-4: Variation of Risk with Soil Cobalt Concentration, Toddler and Adult

Zone	Toddler Receptor		Adult Receptor	
	HQ, Based on Maximum Soil Concentration	HQ, Based on RME Concentration	HQ, Based on Maximum Soil Concentration	HQ, Based on RME Concentration
A	0.03	0.03	0.008	0.008
B	0.05	0.03	0.009	0.008
C	0.04	0.03	0.008	0.008
D – Resident	0.04	0.03	0.009	0.008
D – Farm, Clay	0.05	0.04	0.01	0.01
D – Farm, Organic	0.05	0.04	0.01	0.01

The results of the maximum concentrations in soil scenario analysis indicate minimal variation in the HQ observed when maximum soil concentrations were adopted for all soil types. This indicates that exposure pathways other than ingestion and dermal exposure to soil govern the potential human health risks associated with nickel, copper and cobalt in Port Colborne. **Although concentrations of CoCs in soils from Port Colborne may be elevated, they contribute only a minimal amount to the total intake from all exposure pathways.**

7.3 Maximum Garden Produce Concentrations

The sensitivity of the ingestion/dermal HQ to maximum garden produce CoC concentrations was examined. The absolute maximum fruit and vegetable concentrations as measured in the garden produce sampling program for each zone (See Volume V, Appendix 17) were adopted for Zones A through D Farm receptors. Only organic soils were evaluated in Zone D as these have higher CoC concentrations. Organic and clay soils were not differentiated for the evaluations of maximums. The higher of the two soil types for Zone D farm was selected for each CoC for this scenario. The maximum garden produce concentrations scenario was seen as a highly conservative assumption as it assumes that the resident is continuously ingesting the maximum measured concentration in produce for their entire lifetime. It further assumes that the maximum fruit and vegetable concentrations both occur at the same location, though this was not generally observed in the garden produce study. To further demonstrate the conservative nature of the Risk Characterization, the maximum concentrations of CoCs in vegetables, which, in general, were measured from root vegetables, were selected for use with all vegetable types in this scenario. The resulting maximum vegetable and fruit concentrations as measured in each zone are presented in Table 7-5.

Table 7-5: Maximum Concentration of Nickel, Copper and Cobalt in Garden Vegetable and Fruit Samples

Zone	CoC	Maximum Concentration in Fruit (µg/g)	Maximum Concentration in Vegetables (µg/g)	Maximum Corresponding Garden Soil Concentration [a]
A	Co	0.017	0.054	38
	Cu	1.3	2.1	138
	Ni	2.2	4.1	2350
B	Co	0.037	0.052	37
	Cu	1.9	2.1	180
	Ni	0.95	2.5	6680
C	Co	0.037	0.054	38
	Cu	1.9	2.1	138
	Ni	0.95	4.1	2350
D	Co	0.051	0.26	14
	Cu	2.1	2.9	92
	Ni	2.7	6.4	454

Note:

a. Concentrations substituted for RME garden soil and residential soil concentrations only when higher than RME concentration values.

The resulting HQs based on exposure to the maximum garden produce concentrations of nickel, copper and cobalt, as well as the risk based on the RME concentration of these CoCs in garden produce (utilizing the MOE defined benchmark of one), are presented in Tables 7-6 to 7-8.

Table 7-6: Variation of Ingestion/ Dermal HQ for Nickel with Garden Vegetable and Fruit Concentrations, Toddler and Adult

Zone	Toddler Receptor		Adult Receptor	
	HQ, based on Maximum Garden Produce	HQ, based on RME CoC Concentration	HQ, based on Maximum Garden Produce	HQ, based on RME CoC Concentration
A	0.7	0.4	0.3	0.1
B	0.5	0.3	0.2	0.1
C	0.7	0.3	0.3	0.1
D Farm - Organic	0.8	0.4	0.3	0.1

As seen in Table 7-6, the assumption of maximum garden produce nickel concentrations combined with corresponding maximum soil nickel concentrations applied to both lawns and gardens results in HQs estimated at up to 0.8. The difference between the RME concentration analysis and the maximum garden produce concentrations scenario is lowest for Zone B, which also has the lowest estimated HQs. This is primarily due to garden produce nickel concentrations in this Zone being lower than those measured in other zones. The evidence available indicates that the lower concentrations in Zone B produce are the product of lower bioavailability of nickel in the Zone B soils. The results of the *in vivo* bioavailability testing of soils using rats indicated that the oral bioavailability of nickel (which is related to the solubility) in Zone B fill soils is approximately half that of its bioavailability in clay soils dominant in the area. The HQs estimated for this scenario are therefore considered reasonable. Since all HQs estimated for this maximum garden produce concentrations scenario are less than the MOE benchmark of one, no adverse affects on health are anticipated to receptors exposed to the highest garden produce concentrations of nickel.

Table 7-7 shows that maximum garden produce concentrations of copper do not have a significant impact on estimated risks.

Table 7-7: Variation of Ingestion/ Dermal HQ for Copper with Garden Vegetable and Fruit Concentrations, Toddler and Adult

Zone	Toddler Receptor		Adult Receptor	
	HQ, based on Maximum CoCs in Fruit	HQ, based on RME CoC Concentration	HQ, based on Maximum CoCs in Fruit	HQ, based on RME CoC Concentration
A	0.4	0.4	0.1	0.1
B	0.4	0.4	0.1	0.1
C	0.4	0.4	0.1	0.1
D Farm - Organic	0.4	0.4	0.1	0.1

Similar to copper, Table 7-8 indicates that the maximum measured cobalt concentrations in garden produce have little impact on the risk estimates. The resulting HQ values are still well below the MOE benchmark of one.

Table 7-8: Variation of Ingestion/ Dermal HQ for Cobalt with Garden Vegetable and Fruit Concentrations, Toddler and Adult

Zone	Toddler Receptor		Adult Receptor	
	HQ, based on Maximum CoCs in Fruit	HQ, based on RME CoC Concentration	HQ, based on Maximum CoCs in Fruit	HQ, based on RME CoC Concentration
A	0.04	0.03	0.01	0.008
B	0.03	0.03	0.009	0.008
C	0.04	0.03	0.01	0.008
D Farm - Organic	0.06	0.04	0.02	0.01

Since all HQs estimated for this maximum garden produce concentrations scenario are less than the MOE benchmark of one, no adverse affects on health are anticipated to receptors exposed to the highest garden produce concentrations of nickel, copper or cobalt..

7.4 Maximum Drinking Water Concentrations

The effects on the ingestion/ dermal HQs as a result of the concentrations of CoCs in drinking water were examined. Zones A, B, C, and E are areas which are serviced by a municipal drinking water system; variation in municipal concentration is not considered significant and is not addressed in this maximum drinking water concentrations scenario analysis. The focus of this maximum drinking water concentrations scenario analysis is on concentrations of CoCs in drinking water samples collected from drilled wells and dug wells and their impact on the HQs estimated for receptors in Zone D. The maximum concentration of CoCs as measured in drilled and dug wells in Port Colborne are presented in Table 7-9.

Table 7-9: Maximum Concentration of Nickel, Copper and Cobalt in Drinking Water in Drilled and Dug Wells in Zone D

Medium	Maximum Concentration of Chemicals of Potential Concern in Drinking Water from Drilled and Dug Wells (mg/L)		
	Cobalt	Copper	Nickel
Drilled Wells	0.035	0.76	0.076
Dug Wells	0.0012	0.84	0.017

The resulting HQs based on exposures estimated for the maximum drinking water concentrations of nickel, copper, and cobalt for the Zone D receptors, as well as the risk based on the RME concentrations of CoCs (utilizing the MOE defined benchmark of one), are presented in Tables 7-10 to 7-12.

Table 7-10: Variation of Ingestion/ Dermal HQ for Nickel with Drinking Water Concentration, Toddler and Adult

Zone	Toddler Receptor		Adult Receptor	
	HQ, Based on Maximum Drinking Water CoC Concentrations	HQ, Based on RME CoC Concentration	HQ, Based on Maximum Drinking Water CoC Concentrations	HQ, Based on RME CoC Concentration
D – Residential	0.4[a]	0.3	0.1[a]	0.1
D – Farm Clay	0.6[b]	0.3	0.2[b]	0.1
D – Farm Organic	0.6[b]	0.4	0.2[b]	0.1

Notes:

a. Based on maximum dug well nickel concentrations

b. Based on maximum drilled well nickel concentrations

Tables 7-10 and 7-11 reveal that the well water concentrations may have a significant impact on the estimated HQs for nickel and copper; however, the estimated HQ values are below the MOE benchmark of one, indicating that no adverse affects to human health are expected under this maximum drinking water concentrations scenario.

Table 7-11 : Variation of Ingestion/ Dermal HQ for Copper with Drinking Water Concentration, Toddler and Adult

Zone	Toddler Receptor		Adult Receptor	
	HQ, based on Maximum Drinking Water CoC Concentrations	HQ, based on RME CoC Concentration	HQ, based on Maximum Drinking Water CoC Concentrations	HQ, based on RME CoC Concentration
D – Residential	0.8[a]	0.5	0.3[a]	0.2
D – Farm Clay	0.8[b]	0.4	0.2[b]	0.1
D – Farm Organic	0.8[b]	0.4	0.2[b]	0.1

Notes:
a. Based on maximum dug well copper concentrations
b. Based on maximum drilled well copper concentrations

Cobalt HQs are also affected by drinking water concentrations as shown in Table 7-12; however, the resulting values are still well below the MOE benchmark of one.

Table 7-12: Variation of Ingestion/ Dermal HQ for Cobalt with Drinking Water Concentration, Toddler and Adult

Zone	Toddler Receptor		Adult Receptor	
	HQ, based on Maximum Drinking Water CoC Concentrations	HQ, based on RME CoC Concentration	HQ, based on Maximum Drinking Water CoC Concentrations	HQ, based on RME CoC Concentration
D – Residential	0.04[a]	0.03	0.009[a]	0.008
D – Farm Clay	0.1[b]	0.04	0.04[b]	0.01
D – Farm Organic	0.1[b]	0.04	0.04[b]	0.01

Notes:
a. Based on maximum dug well cobalt concentrations
b. Based on maximum drilled well cobalt concentrations

Since all estimated HQs are less than one, the results indicate that no elevated risks to human health are expected based on the results of the maximum well water scenario.

7.4.1 Home with Highest Nickel in Well Water

Results of the maximum worst case scenarios evaluated for drinking water concentrations and garden produce concentrations suggest that if concentrations in both of these media were maximized at the same time, the total hazard quotient to the Zone D farm area toddler would be representative of maximum exposure. For this assessment, one home was selected as having a measured well water nickel concentration above all other homes measured. Of note for this particular home was the condition of the well reported by MOE as not meeting proper well construction standards and thus a candidate for well contamination. This home is therefore expected to be atypical, and similar conditions are unlikely to be found at other homes.

Well and tap water from this home (MOE site) were only sampled by the MOE, but no samples of soil or garden produce were collected by the MOE. A nearby home (Site 526) was sampled for both soil and produce. For the maximum worst case evaluation, the maximum of the measured drinking water concentrations at this home (MOE site), and the maximum concentrations of each of garden fruits, vegetables and soil from the nearby residence (Site 526) were selected, as summarized in Table 7-13. Review of well water and garden produce concentrations indicated that the combination of these parameters selected for this home was expected to result in the highest potential exposure to residents.

Table 7-13: Home with Highest Nickel Concentrations in Well Water

Medium	Selected Nickel Concentrations	
	Value	Units
Well Water	.076	mg/L
Fruits	0.076	mg/kg
Vegetables	0.88	mg/kg
Soil	302	mg/kg

The resulting toddler hazard quotient for this home (MOE site) with the maximum concentration is 0.6, indicating that no effects to the most sensitive receptor at this home using maximum concentrations are expected.

7.5 Maximum Ambient Air Concentration

As part of the Risk Characterization for maximally exposed individuals, the effects on the inhalation HQ as a result of varying air concentrations of CoCs in different locations in the community were examined. More specifically, maximum concentrations of the CoCs in ambient air were used instead of the RME concentrations in the HHRA calculations in order to determine the effect on the risk estimates. As the selected RME ambient air concentrations of the CoCs in Zone B were already considered to be maxima, Zone B was excluded from the maximum ambient air concentrations scenario. Instead, Zone B ambient air concentrations were used to represent the maximum ambient air CoC concentrations in Zones A, C, and D, and exposures and risks were estimated based on this approach. The ambient air concentrations selected for use in the maximum ambient air concentrations scenario are presented in Table 7-14.

Table 7-14: Maximum Concentrations of Nickel, Copper, and Cobalt in Ambient Air

Zone	Selected Maximum Concentrations ($\mu g/m^3$)		
	Nickel	Copper	Cobalt
A	0.022	0.51	0.0026
B	0.022 [a]	0.51 [a]	0.0026 [a]
C	0.022	0.51	0.0026
D	0.022	0.51	0.0026

Note:
a. Zone B concentrations used to represent maximum for Zones A, C, and D.

Note that receptors were assumed to be exposed to these maximum concentrations from Zone B everywhere in the other Zones of Port Colborne. If a receptor lives in Zone A, for example, but goes to the beach in Zone D and works in Zone B, these maximum concentrations from Zone B were assumed to be present in all three locations.

Since indoor air concentrations were evaluated as being proportional to ambient air, these were also increased accordingly for this maximum ambient air concentrations scenario. The resulting nickel inhalation cancer risks (Total Lifetime Cancer Risk, (TLCR), Incremental Lifetime Cancer Risk, (ILCR), and Exposure Ratio (ER)), are shown in Tables 7-15 through 7-17, for each of the three approaches.

Table 7-15: Maximum Ambient Air Nickel Inhalation Cancer Risk, Approach I: U.S. EPA Refinery Dust Unit Risk

Zone	TLCRs		ILCRs	
	Based on RME Concs.	Based on Maximum Concs.	Based on RME Concs.	Based on Maximum Concs.
A – Residential	2×10^{-6}	4×10^{-6}	2×10^{-6}	3×10^{-6}
C – Residential	2×10^{-6}	4×10^{-6}	2×10^{-6}	3×10^{-6}
D – Farm	1×10^{-6}	4×10^{-6}	0.9×10^{-6}	4×10^{-6}
D – Residential	1×10^{-6}	4×10^{-6}	1×10^{-6}	3×10^{-6}

Table 7-16: Maximum Ambient Air Nickel Inhalation Cancer Risk, Approach II: European Union, Oxidic Nickel Unit Risk

Zone	TLCRs		ILCRs	
	Based on RME Concs.	Based on Maximum Concs.	Based on RME Concs.	Based on Maximum Concs.
A – Residential	0.3×10^{-6}	0.6×10^{-6}	0.3×10^{-6}	0.5×10^{-6}
C – Residential	0.4×10^{-6}	0.6×10^{-6}	0.3×10^{-6}	0.5×10^{-6}
D – Farm	0.2×10^{-6}	0.6×10^{-6}	0.2×10^{-6}	0.6×10^{-6}
D – Residential	0.2×10^{-6}	0.6×10^{-6}	0.2×10^{-6}	0.5×10^{-6}

Table 7-17: Maximum Ambient Air Nickel Inhalation Cancer Risk, Approach III: European Commission, Nickel Refinery Dust Limit Value

Zone	Exposure Ratio Approach III: European Commission Nickel Refinery Dust Limit Value					
	Infant		Toddler		Adult	
	Based on RME Concs.	Based on Maximum Concs.	Based on RME Concs.	Based on Maximum Concs.	Based on RME Concs.	Based on Maximum Concs.
A – Residential	0.01	0.02	0.01	0.02	0.01	0.02
C – Residential	0.01	0.02	0.02	0.02	0.02	0.02
D – Farm	0.007	0.02	0.008	0.03	0.008	0.03
D – Residential	0.007	0.02	0.008	0.03	0.01	0.02

Although ILCRs estimated using the highly conservative Approach I unit risk for nickel refinery dust slightly exceed one in one million, risks estimated based on Approaches II and III are below the applicable thresholds, indicating that cancer from nickel inhalation is not expected.

Nickel inhalation HQs are shown in Table 7-18, based on nickel as nickel sulphate. Although these are generally higher than the HQs estimated for the RME concentrations scenario, all HQs are well below the benchmark of one.

Table 7-18: Variation of the Inhalation HQ for Nickel with Ambient Air Concentrations, based on Nickel Sulphate

Zone	Toddler Receptor		Adult Receptor	
	HQ, Based on RME Concs.	HQ, Based on Maximum Concs.	HQ, Based on RME Concs.	HQ, Based on Maximum Concs.
A	0.07	0.2	0.09	0.2
C	0.1	0.2	0.1	0.2
D – Farm	0.06	0.2	0.06	0.2
D – Resident	0.06	0.2	0.07	0.2

Tables 7-19 and 7-20 show comparisons of HQs for copper and cobalt, respectively, for maximum and RME concentrations. All resulting HQs are well below the target benchmark of one.

Table 7-19: Variation of the Inhalation HQ for Copper with Ambient Air Concentrations

Zone	Toddler Receptor		Adult Receptor	
	HQ, Based on RME Concs.	HQ, Based on Maximum Concs.	HQ, Based on RME Concs.	HQ, Based on Maximum Concs.
A	4×10^{-4}	0.1	0.03	0.1
C	4×10^{-4}	0.1	0.02	0.1
D – Farm	4×10^{-4}	0.2	4×10^{-4}	0.2
D – Resident	4×10^{-4}	0.2	0.02	0.1

Table 7-20: Variation of the Inhalation HQ of Cobalt with Ambient Air Concentrations

Zone	Toddler Receptor		Adult Receptor	
	HQ, Based on RME Concs.	HQ, Based on Maximum Concs.	HQ, Based on RME Concs.	HQ, Based on Maximum Concs.
A	0.01	0.02	0.01	0.02
C	0.02	0.02	0.02	0.02
D – Farm	0.007	0.02	0.007	0.02
D – Resident	0.007	0.02	0.008	0.02

In summary, the results of the assessment of maximum ambient air concentrations indicates that inhalation health risks associated with the highest evaluated maximum ambient air concentrations (*i.e.* highest location) are not expected.

7.6 Maximum Indoor Air Concentrations

The effects on the HQ as a result of the maximum concentrations of CoCs in indoor air were examined. The indoor air nickel concentrations adopted for the maximum indoor air concentrations scenario analysis are presented in Table 7-21. Scenarios in which only the maximum copper and cobalt concentrations were used were run for Zones A through D. In addition, for Zone B multiple nickel concentrations were adopted in different scenarios to see the variation in risk associated with the nickel concentration in particulate matter with a diameter of less than 10 µm (PM10), as measured in Port Colborne.

7.6.1 Nickel

Three scenarios were run for the highest indoor air nickel concentrations measured in Port Colborne. The three highest indoor air nickel concentrations were input into the exposure spreadsheets. Note that the highest concentration selected, from home IAS 102, was a statistical outlier relative to the study population. No other home sampled from the entire study population showed a concentration in the same order of magnitude as IAS 102. Zone B was conservatively chosen as the base case for comparison due to survey results indicating that Zone B residents spend more time in Port Colborne than residents of Zones A, C, D, and E.

Table 7-21: Maximum Concentration of Nickel in Indoor Air PM_{10} Samples Measured in Port Colborne

Zone	CoC	Maximum Concentration (µg/m^3)
B, Maximum Value	Nickel	0.15 [1]
B, Second Highest Value	Nickel	0.023 [2]
B, Third Highest Value	Nickel	0.0082 [3]

Note:
1. Average of 2 24-hour samples from home IAS 102
2. Average of 2 24-hour samples
3. Single 24 hour sample

In examining the effects of the maximum indoor air concentration of CoCs on the HQ, the maximum concentration measured in Port Colborne was adopted for all zones as opposed to HHRA Zone specific maximum concentrations. This differed from the other approaches adopted in this Chapter and can be interpreted as being more conservative. The resulting HQs, lifetime cancer risk and ERs, based on the maximum concentrations of nickel in indoor air as well as the RME concentrations are presented in Table 7-22 through 7-25.

Table 7-22: Variation of the Inhalation HQ for Nickel with Indoor Air Concentrations, Infant, Toddler, and Adult

Zone	HQ, Based on Maximum Concs.			HQ, Based on RME Concs.		
	Infant	Toddler	Adult	Infant	Toddler	Adult
B, Maximum Value	1	1	1	0.2	0.2	0.2
B, Second Highest Value	0.3	0.2	0.3	0.2	0.2	0.2
B, Third Highest Value	0.1	0.2	0.1	0.2	0.2	0.2

For the home with the maximum indoor air nickel concentration, the highest HQ for nickel sulphate exposure is one. Speciation of nickel in indoor air in this home indicated that the indoor air in this home was made up of less than one-quarter soluble nickel. Additionally, the predominant form of nickel in soils around this home is oxidic. Oxidic nickel is known to be much less potent in causing non-cancer effects than nickel sulphate when inhaled. The use of the nickel sulphate toxicity reference value to compute the HQ of one therefore most likely overstates potential risks by a significant factor. Given the magnitude of conservatism built into the HQ value of one, the maximum indoor air concentrations scenario for the house with the highest measured indoor air concentrations was concluded to result in conditions at which no elevated inhalation health risk would be expected.

Table 7-23: Maximum Indoor Air Nickel Inhalation Cancer Risk, Approach I: U.S. EPA Nickel Refinery Dust Unit Risk

Zone	TLCRs		ILCRs	
	Based on RME Concs.	Based on Maximum Concs.	Based on RME Concs.	Based on Maximum Concs.
B, Maximum Value	4×10^{-6}	30×10^{-6}	3×10^{-6}	30×10^{-6}
B, Second Highest Value		5×10^{-6}		5×10^{-6}
B, Third Highest Value		3×10^{-6}		3×10^{-6}

Table 7-24: Maximum Indoor Air Nickel Inhalation Cancer Risk, Approach II: European Union, Oxidic Nickel Unit Risk

Zone	TLCRs		ILCRs	
	Based on RME Concs.	Based on Maximum Concs.	Based on RME Concs.	Based on Maximum Concs.
B, Maximum Value	0.6×10^{-6}	4×10^{-6}	0.6×10^{-6}	4×10^{-6}
B, Second Highest Value		0.9×10^{-6}		0.8×10^{-6}
B, Third Highest Value		0.5×10^{-6}		0.4×10^{-6}

Although the analysis in Approach I (Table 7-23), which assumes the composition of indoor air dust is nickel refinery dust, indicates a potential risk that may be elevated above the MOE benchmark of one in one million incremental lifetime cancer risk, the analysis in Approach II (Table 7-24), which assumes the composition of indoor air dust is oxidic nickel, indicates that potential risks do not exceed the benchmark for the second and third highest homes evaluated. The ILCR exceeds the benchmark under Approach II in the home with the maximum indoor air nickel concentration.

Table 7-25: Maximum Indoor Air Nickel Inhalation Cancer Risk, Approach III: European Commission, Nickel Refinery Dust Limit Value

Zone	ER, Based on Maximum Concs.			ER, Based on RME Concs.		
	Infant	Toddler	Adult	Infant	Toddler	Adult
B, Maximum Value	0.02	0.02	0.02	0.02	0.03	0.03
B, Second Highest Value	0.04	0.04	0.04	0.02	0.03	0.03
B, Third Highest Value	0.02	0.02	0.02	0.02	0.03	0.03

Use of the maximum measured indoor air concentrations resulted in an estimated exposure ratio well below the benchmark of one (Table 7-25). Although some potential for risk is shown for the cancer unit risk Approaches I and II, **the threshold approach indicates that the concentrations are well below the minimum concentration required for a cancer risk to exist. Since the selected Approach III limit value is based on nickel refinery dust, which is lower than the applicable limit value for oxidic nickel (See Volume III, Appendix 7), the Approach III results (see Table 7-25) are broadly applicable to the species of nickel in indoor air that may have resulted from resuspension of nickel refinery dust historically deposited in walls or attics.**

Based on the evaluation performed, the evidence was concluded to be sufficient to indicate that potential risks associated with nickel inhalation are very low. There is unlikely to be an elevated risk from nickel inhalation, even for residents of the home with the maximum measured indoor air nickel concentration.

7.6.2 Copper and Cobalt

Maximum indoor air concentrations of copper and cobalt were selected and applied to zones A, B, C and D. Table 7-26 summarizes copper and cobalt concentrations chosen for the maximum scenario analysis.

Table 7-26: Maximum Indoor Air Concentrations of Copper and Cobalt

Zone	CoC	Maximum Concentration (µg/m^3)
A, B, C, D	Copper	0.045
	Cobalt	0.0067

Table 7-27 summarizes the variation of HQs for copper with indoor air concentrations.

Table 7-27: Variation of Inhalation HQ for Copper with Indoor Air Concentrations, Infant, Toddler and Adult

Zone	Receptor					
	Infant		Toddler		Adult	
	HQ, Based on Maximum Concs.	HQ Based on RME Concs.	HQ, Based on Maximum Concs.	HQ Based on RME Concs.	HQ, Based on Maximum Concs.	HQ Based on RME Concs.
A	0.02	3×10^{-4}	0.01	4×10^{-4}	0.04	0.03
B	0.04	0.1	0.1	0.02	0.07	0.1
C	0.02	4×10^{-4}	0.01	4×10^{-4}	0.03	0.02
D – Resident	0.02	3×10^{-4}	0.01	4×10^{-4}	0.03	0.02
D – Farm	0.02	3×10^{-4}	0.01	4×10^{-4}	0.01	4×10^{-4}

Table 7-28 summarizes the variation of HQs for cobalt with indoor air concentrations. All resulting HQs in both Tables 7-27 and 7-28 can be seen to be well below the benchmark of one.

Table 7-28: Variation of Inhalation HQ for Cobalt with Indoor Air Concentrations, Infant, Toddler and Adult

Zone	Receptor					
	Infant		Toddler		Adult	
	HQ, Based on Maximum Concs.	HQ Based on RME Concs.	HQ, Based on Maximum Concs.	HQ Based on RME Concs.	HQ, Based on Maximum Concs.	HQ Based on RME Concs.
A	0.06	0.01	0.05	0.01	0.04	0.01
B	0.06	0.02	0.05	0.02	0.06	0.02
C	0.06	0.02	0.06	0.02	0.05	0.02
D – Resident	0.06	0.006	0.04	0.007	0.04	0.008
D – Farm, Clay	0.06	0.006	0.04	0.007	0.04	0.007
D – Farm, Organic	0.06	0.006	0.04	0.007	0.04	0.007

Since HQs are below the applicable benchmark of one, no adverse health effects from copper or cobalt are expected to residents of the homes with maximum measured indoor air concentrations.

7.7 Conclusions

This chapter has shown that under maximum CoC concentration scenarios, property-specific CoC levels did not exceed benchmarks for acceptable risk as defined by applicable MOE guidelines and therefore no adverse affects on human health are expected. One home showed concentrations of nickel levels measured in indoor air that resulted in a nickel inhalation hazard quotient equal to one. The hazard quotient is based on soluble nickel, which is the most toxic non-cancer species by inhalation, but is not the dominant species in Port Colborne. The risks were thus concluded to be very low and not expected to result in a health risk even to maximally exposed individuals.

The results of the assessment of maximumally exposed individuals are considered further in Chapter 9 for selection of the approach used to develop Risk-Based Soil Concentrations. Additional factors that may affect the outcome of the assessment, but were not specifically evaluated as maximum scenarios, are considered further in the Sensitivity Analysis that follows in Chapter 8.

8.0 SENSITIVITY ANALYSIS

8.1 Background

Risk assessment is a very powerful decision-making tool; however, there are a number of potential sensitivities and uncertainties inherent in the analysis. Generally, these sensitivities and uncertainties are addressed by making multiple conservative assumptions, or by using site-specific values in the analysis. That is, a generally accepted principle is that the results of a risk assessment will overstate the risks, and that the results will be conservative. Although there may be a large amount of information and a large number of input parameters to a quantitative risk assessment, usually there are only a few parameters that substantially influence the total estimated risk. More important than how uncertain any one factor or parameter is, is how sensitive the results are to the uncertainty in that factor or parameter. The Sensitivity Analysis therefore attempts to answer the question,

> *Does the uncertainty in a particular parameter or factor impact the results and conclusions of the assessment?*

In order to have confidence in the conclusions of a risk assessment, there must be:

i) a high level of certainty; or,
ii) an acceptable and reasonable level of conservatism (*i.e.*, an over-statement of risk); or,
iii) an appreciation of the bounds on the final result.

The Exposure Assessment conducted as part of the Port Colborne Community Based Risk Assessment was based on:

i) measured values and site observations where available;
ii) peer-reviewed and/or government-recommended literature values where available; and
iii) conservative assumptions for certain parameters, where required.

Where applicable, site-specific environmental parameters and community specific characteristics were used. The use of Port Colborne-specific environmental parameters provides a greater degree of confidence in the resulting risk assessment, as the risks estimated are governed by the chemical and physical conditions of the Study Area. In general, default values are typically more conservative than field-measured values and community-specific parameters; therefore, the use of Port Colborne-specific environmental parameters, although less conservative in some instances, reflects the actual conditions present in Port Colborne.

The uncertainty associated with environmental parameters varies according to the nature of the parameter, the quantity and quality of the data, and the nature and magnitude of the variability associated with the parameter.

A principal assumption is that the community-specific parameters, that is soil, groundwater, air, produce, and other media characteristics, are constant within each Zone in the Study Area. Although the study Zones are likely to be heterogeneous in nature, utilizing Reasonable Maximum Exposure (RME) and upper bound concentrations for Zone conditions effectively simplifies the required inputs, and is an accepted approach for risk assessment. Deviation is expected to occur throughout each Zone of the Study Area; however, the maximum scenarios evaluated bracket the upper end of the range of variability. Acute exposure to the maximum soil concentration may occur; however, continuous exposure to the maximum concentration is not expected and, therefore, use of the maximum concentrations for all parameters is not considered to be a reasonable scenario.

Uncertainties associated with the estimation of the toxicological effects of a chemical are inherent in the risk assessment process. For instance, when assessing the toxicity of a chemical, it is not ethical to experiment on human receptors. As a result, toxicologists must rely on animal data, toxicological models and epidemiological studies to estimate the effect of a chemical. In addition, the availability of toxicological data is often limited because of the vast number of chemicals potentially present in the environment and the high costs associated with conducting these studies.

To compensate for such shortcomings and the related uncertainties, a number of uncertainty factors are typically built into the derivation of doses, below which no adverse health effects are expected. Use of multiple uncertainty factors (by as much as 1,000 fold) results in a conservative estimate of risk. Repetitive use of uncertainty factors is often the single largest contributor to conservatism in the risk assessment process.

In this assessment, a deterministic evaluation was carried out for RME concentrations and for maximally exposed receptors in order to derive an upper estimate of the potential exposure to a given Chemical of Concern (CoC). The deterministic evaluation allows the verification of calculations and methods by reviewers, making the assessment clear and transparent. Detailed calculations provided in Volume III, Appendix 6 correspond to the deterministic values presented in this report.

In the current assessment of sensitivity and uncertainty, a deterministic approach has been used to perform a sensitivity analysis of input parameters and assumptions to understand the potential impact that each has on the estimation of risks. A deterministic assessment provides more conservative estimates of risk permitting the impact of uncertainty in individual parameters to be more easily estimated and understood.

In the sensitivity and uncertainty estimation, both uncertainty and inherent variability in parameters and assumptions are considered. Both of these are examined more closely in the sections that follow.

8.2 Sensitivity in Site Characterization and Problem Formulation

In the Site Characterization and Problem Formulation, potential sources of uncertainty include the definition of the Study Area, characterization of CoCs in local environmental media and selection of concentrations for use in the quantitative estimation. The data used in the assessment and the potential impact of assumptions on the risk conclusions are reviewed in Table 8-1.

Table 8-1: Sensitivity Analysis for Site Characterization and Problem Formulation

Risk Analysis Study Factor/Assumption	Justification	Analysis Likely to Over/Under Estimate Risk?	Uncertainty Likely to Change Risk Conclusions?
General			
Identification of Study Area	The Study Area was identified based on soil concentrations exceeding Ontario Ministry of the Environment (MOE) guidelines (1997). Frequency of measurements of concentrations of the CoCs in various media in the Study Area are more concentrated towards areas of higher soil concentrations of CoCs. Although some of the areas more distant from the source may exceed MOE generic soil guidelines, these are expected to have lower CoC concentrations than the areas where most samples were taken.	Overestimate	No
Changes in future land use – commercial/industrial	Concentrations of the CoCs measured in soil (excluding fill) on commercial and industrial properties (other than the Vale Inco (Inco) property) are less than the maximum concentrations measured for other land uses (*e.g.*, woodlots) in Port Colborne.	Overestimate	No
Changes in future land use – residential	The change of residential areas in Port Colborne to land uses other than agricultural would not be expected to increase human exposure and for some land uses, exposures would decrease. Change of land use from residential to agricultural is considered highly improbable and requires a record of site condition.	No / Overestimate	No
Changes in future land use – agricultural	Change of agricultural areas to other land uses would not be expected to increase potential exposures. Exposures would decrease for commercial/industrial land use.	No / Overestimate	No
Changes in future land use – schools	Schools were evaluated in each Zone except Zone B; however, the evaluation for the toddler in Zone B is more conservative than the evaluation for a school child. This life stage thus indicates that a risk above the benchmark value is not expected in this Zone of highest concentrations; therefore, excess risk would not be expected if a change of school locations occurred.	No / Overestimate	No

Table 8-1: Sensitivity Analysis for Site Characterization and Problem Formulation

Risk Analysis Study Factor/Assumption	Justification	Analysis Likely to Over/Under Estimate Risk?	Uncertainty Likely to Change Risk Conclusions?
Changes in future land use – recreational	The highest soil concentrations of CoCs measured in the woodlots were used to estimate recreational risks. No risks above the applicable benchmark values were seen for the highest recreational concentrations. **Residential development of the Reuter Road woodlot would increase exposures and may lead to higher risks.** Concentrations in other recreational areas are less than those found in current residential locations and change of these land uses would not affect the conclusions of the risk assessment	Underestimate for highest locations in Reuter Road woodlot only	**Yes**
Changes in future land use – Inco property	Direct exposure to soils and other media at the Inco Refinery were not estimated as part of the current assessment and change in land use for the Inco Refinery that would allow public access to areas not currently accessible would require further evaluation and a certificate of property use.	Unknown	Unknown: Further evaluation would be required
Selection of study zones	The study zones were selected in a manner designed to reduce uncertainties by grouping similar exposure factors. The more (smaller) study zones are selected, the more refined the results would become; however, practical limitations on data collection limit the effectiveness of using more zones.	No	No
Receptor selection	Receptors were selected for all age groups.	No	No
Lifetime Exposure Duration	A lifetime of 70 years was chosen for this assessment as a conservative alternative to the recommendation by Health Canada (2004) of 75 years. The 70 year lifetime factors in exposure to carcinogenic CoCs from all 70 years of life as opposed to only 56 as in Health Canada's recommendation. Including infant, toddler, child and teen exposure to assess carcinogenicity is more conservative because these receptors, especially the toddler, are considered the most sensitive to exposure to CoCs.	Overestimate	No

Table 8-1: Sensitivity Analysis for Site Characterization and Problem Formulation

Risk Analysis Study Factor/Assumption	Justification	Analysis Likely to Over/Under Estimate Risk?	Uncertainty Likely to Change Risk Conclusions?
Areas of exposure for each receptor	Receptors were assumed to work, go to school and visit parks in the reasonable zones of exposure where the higher exposures are likely to occur compared to other potential zones that were also considered reasonable, where lower exposures may be expected.	Overestimate	No
School Zone	Children living in Zones B, C and D may attend elementary school in either Zone C or D. Although they were evaluated as attending school in Zone C, maximum concentrations of CoCs are higher in Zone D. Attendance at elementary school in Zone D was selected for further evaluation.	See Section 8.5.1	See Section 8.5.1
Exposure to toddlers at daycare	Toddler receptors were assumed to go to daycare in the same zone as that in which their homes were located. This is considered reasonable, as even the Zone B toddler, the receptor assumed as exposed to the highest concentrations, showed no risk to CoCs from the Zone.	No	No
Variability in soil concentrations	Soil samples have been more concentrated in the areas of higher concentrations, creating a bias. Samples have also been collected in grid patterns across the Study Area. Higher concentrations have been noted in woodlots; however, particular attention was given to woodlot sampling for the natural environment investigations, again creating bias by concentrating sampling in areas of higher concentrations. Potential to miss local high concentrations always exists; however, the soil characterization database is considered adequate for the purposes of this assessment and is unlikely to have missed concentrations significantly different from those measured.	Overestimate	No

Table 8-1: Sensitivity Analysis for Site Characterization and Problem Formulation

Risk Analysis Study Factor/Assumption	Justification	Analysis Likely to Over/Under Estimate Risk?	Uncertainty Likely to Change Risk Conclusions?
Speciation of CoCs in soils	Results of the speciation of nickel in Port Colborne soils suggest oxidic nickel is the predominant nickel form in soil. Results of all fourteen soil speciation analyses conducted by Jacques Whitford are consistent with results of the MOE samples (MOE 2002). Arsenic was not speciated in Port Colborne soils; however, speciation work conducted in other communities in Ontario has indicated that the predominant form of arsenic in soils is inorganic. In the current assessment, 100% of the arsenic in soil was assumed to be inorganic.	No	No
Selected concentrations in soil	Given the extensive soil sampling campaigns that have taken place in Port Colborne, the soils of the Port Colborne areas are considered well-characterized, with relatively few uncertainties. Although it has been shown that concentrations in layers below the surface sometimes differ markedly from those in the surface (0 to 5 cm) layer, this fact is not expected to change the conclusions of the Human Health Risk Assessment (HHRA) because most receptors would not be exposed frequently to layers of soil below the surface. This expectation is also supported by one of the maximally exposed receptor scenarios presented in Chapter 7.0, which examined the effects of using maximum full-depth soil concentrations in the exposure calculations.	No	No

Table 8-1: Sensitivity Analysis for Site Characterization and Problem Formulation

Risk Analysis Study Factor/Assumption	Justification	Analysis Likely to Over/Under Estimate Risk?	Uncertainty Likely to Change Risk Conclusions?
Soil type	Most soils found in the area are clay, organic or sandy soils. Although fill soils are found extensively throughout Zone B, these reflect the soil types found elsewhere in the community. In the residential areas, soils, and particularly garden soils, were found to be heavily amended. As a result, soil characteristics and bioavailability could not be predicted based on native soil type or un-amended soil type. Since the garden produce survey noted that garden soils were dominated by amendments and not readily classifiable, distinguishing by soil type was not practical. In rural areas, the distinction between clay, organic and sandy soils was clearer, so these were evaluated separately. In all cases, bioavailability estimates were based on pooled values so as to not underestimate bioavailability in any soil type. Garden produce was pooled by Zone for the same reason. For soils, Zone D data were evaluated separately for the various soil types since concentrations differed significantly between these areas of soil types.	Over estimate	No
Future groundwater migration north and east of the Inco property	The hydrogeological review indicates that groundwater is not expected to flow up-gradient in the direction of off-site properties to the north or east of the Inco property.	No	No
Groundwater migration West and Southwest of the Inco property	Migration of groundwater off-site to the West and Southwest of the Inco property has occurred in the past. A groundwater extraction system is currently controlling off-site migration in this direction.	No	No
Use of municipally supplied water for drinking in Zone E	Zone E residents are considered to be either "city" residents (Zone E1) or "background" (Zone E2) residents. In either case they are assumed to consume municipally supplied drinking water as opposed to well water. This is considered a suitable approach for Zone E, as consumption of well water has been assessed in three scenarios in Zone D, Zone D Farm Clay Soils, Zone D Farm Organic Soils, and Zone D Residents Only. Nevertheless, exposure of Zone E residents to well water has been quantitatively estimated as part of this Sensitivity Analysis, and results of this evaluation can be found in Section 8.5.2.	Review further (See Section 8.5.2)	Review further (See Section 8.5.2)

Table 8-1: Sensitivity Analysis for Site Characterization and Problem Formulation

Risk Analysis Study Factor/Assumption	Justification	Analysis Likely to Over/Under Estimate Risk?	Uncertainty Likely to Change Risk Conclusions?
Use of well water for drinking	Consumption of well water for drinking has been estimated for Zone D, which is considered to be beyond the municipal water distribution system. Wells within the boundaries of the water distribution system have not been quantitatively estimated. Immediately west and south-west of the Inco property, the potential exists for concentrations in groundwater higher than in other parts of Port Colborne. As this area is serviced by the municipal water distribution system, use of groundwater in this area for human consumption is considered highly improbable.	No	No
Use of cistern water for drinking	Maximum concentrations of CoCs measured in cistern samples are less than maxima measured in dug well samples that were considered in the quantitative estimation. All concentrations measured also meet the applicable drinking water objectives.	Overestimate	No
Current concentrations in residential well water	Approximately one in three wells in Port Colborne was sampled, yielding a good representation of well types, construction techniques, well depths, ages, *etc.* The database of well water information is thus considered adequate to characterize well water quality in the Study Area.	No	No
Residential well water concentrations below detection limit	For arsenic, 81% of samples had concentrations below the analytical detection limit. For cobalt, nickel and copper, the number of concentrations below the detection limit was lower, at 59, 30 and 19%, respectively. Detected concentrations of arsenic were generally within or close to the range of the analytical detection limits, so the uncertainty associated with concentrations below the analytical detection limits is high for arsenic. For other CoCs, concentrations were measured well above the analytical detection limits, so the degree of uncertainty is low. **For arsenic, an assumption of concentrations equal to ½ the detection limit when not detected may significantly overestimate exposures.**	Arsenic: overestimate Nickel, copper, cobalt: No	**Arsenic: yes** Nickel, copper, cobalt: No

Table 8-1: Sensitivity Analysis for Site Characterization and Problem Formulation

Risk Analysis Study Factor/Assumption	Justification	Analysis Likely to Over/Under Estimate Risk?	Uncertainty Likely to Change Risk Conclusions?
Surface water concentrations	Although limited surface water sampling was conducted, the Lake Erie near-shore environment is dynamic and concentrations near-shore are more likely impacted by overall quality of the water in Lake Erie. Because of the size of this water body, significant variability in concentrations is not expected.	No	No
Concentrations in municipal drinking water	The data on concentrations of CoCs in municipally distributed water covers a significant number of years and is considered adequate to characterize municipal water quality with a high degree of confidence.	No	No
Selected concentrations in municipal water	A significant database of information was reviewed in this assessment and is considered to correctly characterize the municipal water.	No	No
Selected concentrations in well water	All measured concentrations in well water meet the applicable guidelines and standards. Although considerable variability exists in the well water concentrations, hazard quotients were estimated for maximum concentrations measured in well water. Hazard quotients for nickel, copper and cobalt were all less than 1 for all receptors.	No	No
Selected concentrations in surface water	Surface water is not a significant contributor to total dose and uncertainty in the selection of surface water concentrations would therefore not affect the assessment results. Despite the fact that Jacques Whitford only obtained 3 samples of surface water, Lake Erie was considered to be sufficiently well-mixed that the samples taken were representative of concentrations along the entire shoreline in the Port Colborne area. The use of the maximum analyzed concentrations as RMEs is therefore not expected to underestimate risks.	No	No

Table 8-1: Sensitivity Analysis for Site Characterization and Problem Formulation

Risk Analysis Study Factor/Assumption	Justification	Analysis Likely to Over/Under Estimate Risk?	Uncertainty Likely to Change Risk Conclusions?
Ambient air concentrations	Ambient air samples were collected as a part of two Jacques Whitford studies. Samples collected during 2001, which was an uncharacteristically dry and hot summer, were used in this assessment since resuspension would be higher than at some other times due to lack of snow cover and the dryness of the season. Long term monitoring data collected by MOE were also used in the assessment. These were collected in the Rodney Street ball diamond, a location indicated by the assessment as yielding the highest ambient air concentrations in the community. As a conservative assumption, the minimum CoC concentrations from field blanks were used to background correct the individual samples taken during the ambient air sampling program. Through this method, any error in estimating ambient air concentrations would have tended towards overestimation.	No / Overestimate	No
Particle sizes measured during ambient air sampling	The ambient air sampling campaign conducted by Jacques Whitford measured air samples in the Total Suspended Particulate (TSP), PM_{10},(fine particulate matter in air, less than 10 µm diameter) and $PM_{2.5}$ (very fine particulate matter in air, less than 2.5 µm in diameter) size ranges at three of the sampling locations, as well as the Control Site. Samplers at the other three sites measured $PM_{2.5}$ only. As such, a broad spectrum of particle sizes was measured by Jacques Whitford. It should be noted, however, that only modeled air concentrations and ambient air concentrations measured by the MOE were used in the exposure calculations for the HHRA. Any uncertainty or variability in particle sizes in Jacques Whitford's measurements is therefore not expected to change the conclusions of the HHRA.	No	No
Farming and ambient air concentrations	The farming study demonstrated that measured concentrations of CoCs in ambient air under worst case tilling conditions were below 24 hour Ambient Air Quality Criteria (AAQC). Tilling operations were also considered in the modelling of ambient air concentrations that farmers and other receptors would be exposed to.	No	No

Table 8-1: Sensitivity Analysis for Site Characterization and Problem Formulation

Risk Analysis Study Factor/Assumption	Justification	Analysis Likely to Over/Under Estimate Risk?	Uncertainty Likely to Change Risk Conclusions?
Indoor dust – filters, field blanks and travel blanks	There are no applicable guidelines for sampling of particulates in indoor air. As a result, Jacques Whitford opted to use Mixed Cellulose Ester (MCE) filters to measure the concentration of CoCs in PM_{10} and TSP from suspended indoor dust. MCE was chosen due to the ability to embed particulate matter within the matrix of the filter as well as the homogeneous nature of the material (*i.e.,* manufactured using non-naturally occurring materials). Both factors serve not to underestimate the risk. All dust samples collected as part of the indoor dust sampling program were background corrected. As a conservative assumption, the minimum CoC concentrations from field blanks were used to background correct.	No / Overestimate	No
Ambient data used to establish indoor air quality	The 24 hour samples of indoor air are considered to be like a snap shot in time and are not considered sufficient to directly estimate long-term (chronic) indoor air concentrations. The ambient air monitoring data provides a more robust, long-term data set for the evaluation and is therefore considered more applicable, with adjustment for the difference between indoor and ambient air.	No	No
Use of 24 hour indoor air concentrations to evaluate maximum scenario long term exposures	The use of one or two 24 hours samples to represent long term average concentrations in indoor air has a high degree of uncertainty associated with it. This is only one line of evidence used. Long term ambient monitoring data was also used to estimate indoor air concentrations. Since these data were obtained from the MOE sampler in the Rodney St. Ball park, which is considered a location for the maximum concentrations of CoCs in ambient air, the resulting estimation of indoor air concentrations is also a maximum and may be more representative of long term indoor air concentrations. Since the conclusions of the two lines of evidence agree, the use of the 24 hour data was concluded to not affect the conclusions of the assessment.	Unknown	No

Table 8-1: Sensitivity Analysis for Site Characterization and Problem Formulation

Risk Analysis Study Factor/Assumption	Justification	Analysis Likely to Over/Under Estimate Risk?	Uncertainty Likely to Change Risk Conclusions?
Indoor air quality – selection of ratio	The results of the indoor air monitoring were used to approximate a relationship between indoor and ambient air for use in the evaluation of indoor air exposures and risks. The method is consistent with standard methods for evaluating indoor air exposures. The ratio of 0.6 derived is greater than the ratio of 0.5 often selected for this parameter and is greater than the highest estimate of the ratio using three data sets for the derivation. The ratio is thus considered a reasonable upper estimate of the ratio of the concentrations of indoor air to ambient air.	Overestimate	No
Indoor dust CoC concentrations	A total of 132 hard surface and 69 soft surface dust samples were collected. Large variabilities in CoC mass loadings were observed; however, this is expected for this type of sampling. Since a large number of samples (201) were collected in 30 homes, surface dust is considered to be adequately characterized for the purposes of this assessment.	No	No
Selected concentrations in dust	Exposure to dust was found to be a relatively minor pathway and uncertainty associated with natural variability of these concentrations, whether in one home or between many homes, will thus not significantly impact the dose estimation.	No	No
Attic dust CoC concentrations	Only twelve samples of attic dust were collected since many homes did not have accessible attics. Measured concentrations varied about one to three orders of magnitude. Although not a robust data set, the data are considered adequate to bracket the reasonable range of concentrations that would be anticipated in attics in the community.	No	No
CoCs in garden produce	A total of 301 garden produce samples were collected and analyzed for CoCs. Although samples in some parts of Port Colborne were more scarce than in other areas, the overall database is comprehensive and is considered adequate to characterize CoCs in garden produce in the Study Area.	No	No

Table 8-1: Sensitivity Analysis for Site Characterization and Problem Formulation

Risk Analysis Study Factor/Assumption	Justification	Analysis Likely to Over/Under Estimate Risk?	Uncertainty Likely to Change Risk Conclusions?
Garden produce arsenic concentrations below detection limit	For arsenic, 96% of vegetables sampled and 100% of fruits sampled had concentrations below the analytical detection limit. Detected concentrations of arsenic were generally within or close to the range of the analytical detection limits, so the uncertainty associated with concentrations below the analytical detection limits is high. **An assumption of concentrations equal to one half the detection limit when not detected may significantly overestimate exposures.**	Overestimate	**Yes**
Selected concentrations in garden produce	A large natural variability exists in concentrations of CoCs in garden produce. Each produce sample is unique; however, long term average concentrations need to be considered in evaluating chronic health risks. Few trends could be identified in the data to relate CoC concentrations directly to soil concentrations indicating that the variability between collected specimens is greater than other factors (see Volume V, Appendix 17). The values selected for the characterization of RME concentrations in garden produce are believed to be representative of RME concentrations that a receptor may be exposed to in the long term. Because of the high degree of variability between concentrations in different types of produce, maximum garden produce concentrations are expected to significantly overestimate risks. The use of these concentrations in selecting Risk Based Soil Concentrations (RBSCs) is also highly conservative.	No - RME concentration scenario; Overestimate, maximum concentration scenario	No
Dry weather impact on produce concentrations	The summer of 2001 was an unusually dry summer. This lead to generally smaller produce size and lower moisture contents which would tend to increase garden produce concentrations. The resulting garden produce data may be interpreted as conservative or may be representative of typical concentrations in the future should dryer weather continue due to global climate change patterns. Although apparently yielding conservative data, the dry summer was interpreted as potentially reflective of long term average conditions.	No	No

Table 8-1: Sensitivity Analysis for Site Characterization and Problem Formulation

Risk Analysis Study Factor/Assumption	Justification	Analysis Likely to Over/Under Estimate Risk?	Uncertainty Likely to Change Risk Conclusions?
Selected concentrations in garden produce – Zone B fruits	Since only one fruit sample was obtained in Zone B, samples from Zone C were combined with samples from Zone B in estimating a RME and maximum fruit concentration for Zone B receptor exposures. Since soil CoC concentrations in Zone B are generally higher than in Zone C, this is not conservative; however, the use of RME concentrations is conservative. The difference between the two zones is thus not expected to be large enough to significantly impact the results.	No	No
Selected concentrations in garden produce – Zone A vegetables	Since no vegetable samples were obtained in Zone A, samples from Zones B and C were combined in estimating a RME and maximum vegetable concentrations for Zone A receptors. These Zones were selected since the concentrations of CoCs in Zone A fruit samples were of the same order of magnitude as fruit samples in Zones B and C. This approach is expected to overestimate exposures from this pathway to Zone A receptors.	Overestimate	No
CoCs in cows' milk	The only samples of cows' milk that were obtained were from near the edge of the Study Area since no dairy cattle were identified elsewhere in the Study Area. The CoCs are not known to biomagnify in milk and CoCs other than copper were not detected so this is not considered a significant deficiency.	No	No
CoCs in local eggs	Samples of 13 eggs were obtained from four locations in the Study Area. Very little variability between the samples was noted and the available data are thus considered an adequate characterization of CoC concentrations in eggs in the Study Area. Given that local egg ingestion did not contribute significantly to Zone D receptors' exposures, factors such as the locations where the laying hens were kept and whether the chickens were free range or penned would not be expected to affect the conclusions of the HHRA.	No	No

Table 8-1: Sensitivity Analysis for Site Characterization and Problem Formulation

Risk Analysis Study Factor/Assumption	Justification	Analysis Likely to Over/Under Estimate Risk?	Uncertainty Likely to Change Risk Conclusions?
CoCs in local chickens	One chicken sample from a short distance outside the Study Area was obtained and analyzed. The chicken was raised as an egg laying hen, is not a meat source and thus this sample is not considered representative. Since no chickens raised for consumption of meat could be identified in the Study Area, and since the CoCs are known to not biomagnify, this is not considered a significant deficiency.	No	No
CoCs in local wine	Only one sample of local wine was collected. The results of analysis were compared to one sample and its replicate from the local supermarket study. Concentrations of arsenic were similar in the two samples. Concentrations of copper and cobalt were lower in the local wine sample. The nickel concentration was roughly three times higher in the local sample compared to the supermarket sample. Since only one sample of wine was collected locally, the data are insufficient to conclude whether there is any difference in local wines compared to non-local wines.	Unknown	No
Exclusion of local cows' milk exposure pathway	In the milk samples collected, arsenic, cobalt and nickel were not detected and copper was measured at lower concentrations than in 2% milk from the supermarket. Local milk was therefore not considered to contribute significantly to health risk, and the pathway was excluded. As such, any uncertainties and variabilities in CoC concentrations in local milk would not affect the conclusions of the risk assessment.	No	No
Exclusion of local chickens exposure pathway	As a conservative check, the concentrations of CoCs measured in the flesh of the one chicken sample were compared to concentrations in other poultry measured in the supermarket study. Concentrations of cobalt in this chicken were lower than the average in other poultry samples. Concentrations of arsenic, copper and nickel were somewhat higher. Assuming that all poultry consumed was at these concentrations, the dietary intake of these CoCs would not increase by more than 1%. Given that the one chicken sample is not considered representative, no overestimation of risks is indicated.	No	No

Table 8-1: Sensitivity Analysis for Site Characterization and Problem Formulation

Risk Analysis Study Factor/Assumption	Justification	Analysis Likely to Over/Under Estimate Risk?	Uncertainty Likely to Change Risk Conclusions?
Exclusion of local eggs pathway for Zones A, B, C and E	This exposure pathway was evaluated for Zone D receptors and did not contribute significantly to exposures, so this pathway was not expected to contribute significantly to exposures in any of the other Zones. Concentrations of arsenic and nickel in local eggs were less than in supermarket eggs; concentrations of copper were almost the same. Only cobalt was significantly higher in local eggs. Since hazard quotients estimated for cobalt ingestion were well below the applicable MOE benchmark of one, consumption of local eggs by these receptors would not impact the conclusions.	Overestimate for nickel and arsenic; Underestimate for cobalt; No effect for copper	No
Exclusion of local maple syrup exposure pathway	The concentrations of arsenic in maple syrup collected in Port Colborne are lower than supermarket maple syrup concentrations measured. Maple syrup accounts for 0.3% of the typical diet (USDA, 2000). The CoC concentrations in maple syrup collected in Port Colborne are higher than supermarket maple syrup concentrations measured for nickel, copper and cobalt. If residents were assumed to obtain all of their maple syrup from Port Colborne, this would increase the CoC intake to the child (the age group that consumed the most maple syrup as a fraction of total diet) by 2.6% for cobalt, 0.6% for copper and 1.2% for nickel. Such increases in CoC intake would not change the assessment conclusions.	Overestimate for arsenic; Underestimate for nickel, copper, and cobalt	No
CoCs in local fish	The number of perch caught locally is considered representative. Concentrations of CoCs in other species may vary, naturally or otherwise, from those harvested; however, the fish harvested are those most commonly consumed locally.	No	No

Table 8-1: Sensitivity Analysis for Site Characterization and Problem Formulation

Risk Analysis Study Factor/Assumption	Justification	Analysis Likely to Over/Under Estimate Risk?	Uncertainty Likely to Change Risk Conclusions?
CoCs in local game	Limited samples of local game were obtained; however, the CoCs are known to not biomagnify in meat and this pathway is not a major component of the local diet. Variability of CoC concentrations across individuals and species is therefore not expected to make a difference to the conclusions of the risk assessment. This reasoning also applies to other factors potentially affecting CoC concentrations in game, such as the home ranges of the animals in question, and these factors were also not expected to change the conclusions of the HHRA. Nickel, copper, and cobalt tend to concentrate in organ tissue, therefore, liver from two rabbits harvested locally provides a reasonable measurement of CoCs in organ tissue, despite the small sample size.	No	No
Exclusion of local fish exposure pathway	Evaluation of potential exposure to anglers was considered further in Section 8.5.3.	See Section 8.5.3	See Section 8.5.3
Exclusion of local game exposure pathway	Evaluation of potential exposure to hunters was considered further in Section 8.5.3.	See Section 8.5.3	See Section 8.5.3
CoCs in supermarket foods	Natural variability is a factor in accurately estimating concentrations in supermarket foods. In this study, foods were selected from every food group in order to characterize the full diet. Foods were selected with consideration for a range of packaging materials and from a variety of local sources to try to capture a range of variability.	No	No
Source of dietary intake rates and food concentrations	These uncertainties are discussed in detail in Volume V, Appendix 19, Section 5.3. The data selected based on the Northeastern United States are expected to provide a reasonable estimate of dietary intake rates in the Study Area.	No	No

Table 8-1: Sensitivity Analysis for Site Characterization and Problem Formulation

Risk Analysis Study Factor/Assumption	Justification	Analysis Likely to Over/Under Estimate Risk?	Uncertainty Likely to Change Risk Conclusions?
Effects of cooking food in stainless steel pans	Cooking in nickel containing pots is a source of potential impact on exposures through food. Some limited studies have been conducted into this including a pilot study conducted as part of this assessment. New stainless steel pans are known to leach nickel during first use but this quickly diminishes. A short term increase in dietary intake from new pans could occur. This can be estimated to contribute about 0.02% of the toddlers dietary intake. In the pilot cooking study, cooking was found to increase some concentrations of CoCs and decrease others based on a number of factors. No increase in nickel concentrations was seen for any foods cooked in stainless steel compared to those cooked in a ceramic pan. The contribution from cooking was concluded to be negligible.	No	No
Nickel – Ingestion/ Dermal Exposure			
Speciation of nickel in water	Nickel in water has been evaluated as soluble nickel. Particulate nickel of lower solubilities such as oxidic nickel would be less bioavailable.	Overestimate	No
Nickel in local maple syrup	A total of 23 sap and two maple syrup samples were collected from seven woodlots in Port Colborne. This is considered a reasonable representation of the woodlots in the Study Area. Comparing sap to syrup concentrations indicates a greater variability in nickel concentrations in sap than seen in syrup. Comparing ratios of CoCs in syrup and sap suggests that nickel concentrations in syrup may be higher than those measured in supermarket syrup. Since this is a very minor contribution to dietary intake, the difference is not expected to impact estimated risks.	No	No
Effect of Method Detection Limit (MDL) in supermarket data on dietary intake of nickel	Volume V, Appendix 19 presents a quantitative sensitivity analysis of assumed nickel concentrations below the method detection limit. Concentrations were assumed to be equal to zero, equal to one half of the MDL and equal to the MDL. The resulting dietary intakes estimated varied by 3% for nickel. The impact of this uncertainty on the results of the assessment was concluded to be very small.	No	No

Table 8-1: Sensitivity Analysis for Site Characterization and Problem Formulation

Risk Analysis Study Factor/Assumption	Justification	Analysis Likely to Over/Under Estimate Risk?	Uncertainty Likely to Change Risk Conclusions?
Surface dust nickel speciation	Speciation of nickel in surface dust was not conducted. Speciation of nickel in both soil and attic dust indicated that the dominant form of nickel is oxidic; therefore, there is no reason to suggest that nickel in surface dust would not be of a similar composition.	No	No
Attic dust nickel speciation	Two attic dust samples were speciated for nickel compounds. The results suggest oxidic nickel compounds are the predominant nickel form in attic dust. Although only two samples were analyzed in this manner, the results are reasonably consistent with what is anticipated.	No	No
Consumer product contributions of nickel to exposures	Primary sources of consumer product nickel exposures include stainless steel pots and cooking utensils and nickel containing jewellery. As noted above, the contribution from stainless steel to chronic exposures is negligible. Nickel containing jewellery can cause dermatitis from direct contact. Nickel can absorb into the skin tissue from this type of exposure but absorption into the blood stream is a very small (negligible) fraction of this exposure. Most of the absorbed nickel remains in the skin layers. The contribution of nickel from consumer products was concluded to be negligible compared to other exposure media. Further discussion is provided in Section 8.5.4.	See Section 8.5.4	See Section 8.5.4
Nickel – Inhalation Exposure			
Selected nickel concentrations in ambient air	The analysis utilizes the highest year of 5 years of sampling data (July 6, 2001 toMarch 30, 2006) from the MOE sampler located in the Rodney Street ball park. Ambient air monitoring and modelling indicated that the location presents a spatial maximum for ambient air nickel concentrations. Since a maximum year was selected, the data are considered sufficient to characterize a reasonable maximum exposure concentration scenario for maximally exposed receptors.	No	No

Table 8-1: Sensitivity Analysis for Site Characterization and Problem Formulation

Risk Analysis Study Factor/Assumption	Justification	Analysis Likely to Over/Under Estimate Risk?	Uncertainty Likely to Change Risk Conclusions?
Indoor air quality – Nickel	The results of the power calculation for nickel measured met the target of less than 50% error on the mean at a 95% confidence level. The indoor air quality data collected is thus considered adequate for characterizing 24 hour indoor air exposures.	No	No
Copper – Ingestion/ Oral Exposure			
Impact of aging plumbing on copper concentrations in drinking water	Many of the homes at which tap water samples were collected are older homes with copper plumbing. Unfiltered drinking water samples were collected and included in the data evaluated within the HHRA; therefore the effects of aging plumbing have been considered in the estimation of risks. In some homes, higher concentrations may occur, increasing exposures to specific residents. The maximum copper concentrations measured in tap water in the Study Area would not yield a hazard quotient greater than 1.	No	No
Effect of Method Detection Limit (MDL) in supermarket data on dietary intake of copper	Volume V, Appendix 19 presents a quantitative sensitivity analysis of assumed copper concentrations below the method detection limit. Concentrations were assumed to be equal to zero, equal to one half of the MDL and equal to the MDL. The resulting dietary intakes estimated varied by 0% for copper. The impact of this uncertainty on the results of the assessment was concluded to be very small.	No	No
Copper – Inhalation Exposure			
Indoor air quality – Copper	The results of the power calculation for copper measured met the target of less than 50% error on the mean at a 95% confidence level. The indoor air quality data collected is thus considered adequate for characterizing 24 hour indoor air exposures.	No	No

Table 8-1: Sensitivity Analysis for Site Characterization and Problem Formulation

Risk Analysis Study Factor/Assumption	Justification	Analysis Likely to Over/Under Estimate Risk?	Uncertainty Likely to Change Risk Conclusions?
Cobalt – Ingestion/ Dermal Exposure			
Effect of Method Detection Limit (MDL) in supermarket data on dietary intake of cobalt	Volume V, Appendix 19 presents a quantitative sensitivity analysis of assumed cobalt concentrations below the method detection limit. Concentrations were assumed to be equal to zero, equal to one half of the MDL and equal to the MDL. The resulting dietary intakes estimated varied by 6% for cobalt. The impact of this uncertainty on the results of the assessment was concluded to be very small.	No	No
Cobalt – Inhalation Exposure			
Indoor air quality – Cobalt	The results of the power calculation for cobalt measured met the target of less than 50% error on the mean at a 95% confidence level. The indoor air quality data collected is thus considered adequate for characterizing 24 hour indoor air exposures.	No	No
Arsenic – Ingestion/ Dermal Exposure			
Historic arsenic use	Historically, arsenic trioxide was applied to soils as a pesticide in both residential and agricultural settings. More recently, it has been used as a preservative for pressure-treated wood and, studies have shown, is capable of being leached into soils from treated wood pieces.	Overestimate	No
Speciation of arsenic in well water	Canadian Environmental Protection Act (CEPA) arsenic report (CEPA 1993) indicates that most arsenic in well water is inorganic.	No	No
Speciation of arsenic in drinking water and surface water	CEPA (1993) indicates that approximately 80% of arsenic in surface water is inorganic. Although somewhat conservative, this assumption is not expected to significantly overestimate risks	No	No

Table 8-1: Sensitivity Analysis for Site Characterization and Problem Formulation

Risk Analysis Study Factor/Assumption	Justification	Analysis Likely to Over/Under Estimate Risk?	Uncertainty Likely to Change Risk Conclusions?
Local fish and game arsenic concentrations below detection limit	All but one of 24 perch samples and all of the hare flesh samples had concentrations below the analytical detection limit. The detected concentrations of arsenic in perch was only 50% higher than the analytical detection limit. The uncertainty associated with concentrations below the analytical detection limit is high. **An assumption of concentrations equal to ½ the detection limit when not detected may significantly overestimate exposures.**	Overestimate	**Yes**
Arsenic in rabbit liver	One sample of rabbit liver was analyzed. The laboratory reported a relatively high concentration of arsenic in this sample and also noted on the laboratory report that this was likely due to the presence of buckshot in the liver sample. The sample results were concluded to have been contaminated and were therefore not used in the assessment. Since the sample results for arsenic were discarded, there is no impact on the results of the assessment.	No	No
Effect of Method Detection Limit (MDL) in supermarket data on dietary intake of arsenic	Volume V, Appendix 19 presents a quantitative sensitivity analysis of assumed arsenic concentrations below the method detection limit. Concentrations were assumed to be equal to zero, equal to one half of the MDL and equal to the MDL. The resulting dietary intakes estimated varied by roughly an order of magnitude for the toddler and a large degree for other receptors, indicating **a high degree of uncertainty in the dietary intake estimate for arsenic.**	Overestimate	**Yes**
Speciation of arsenic in foods	The literature indicates that **a significant portion of the arsenic in foods is in the organic form and would thus be less toxic.**	Overestimate	**Yes**
Arsenic – Inhalation Exposure			
Speciation of arsenic in ambient air	Arsenic was not speciated in Port Colborne ambient air samples. In the current assessment, 100% of the arsenic in air was assumed to be inorganic. Although this may be somewhat conservative and overestimate risks, the overestimation is not expected to be significantly or impact the conclusions of the risk assessment.	Overestimate	No

Table 8-1: Sensitivity Analysis for Site Characterization and Problem Formulation

Risk Analysis Study Factor/Assumption	Justification	Analysis Likely to Over/Under Estimate Risk?	Uncertainty Likely to Change Risk Conclusions?
Indoor air quality – arsenic	The results of the power calculation for arsenic in indoor air exceed the target of less than 50% error on the mean at a 95% confidence level, with a calculated error of 61%. The confidence in the results is lower than the target level. The slight exceedance of the target error is not expected to substantially affect the results.	No	No
Speciation of arsenic in indoor air	Arsenic was not speciated in indoor air samples obtained from Port Colborne. In the current assessment, 100% of the arsenic in air was assumed to be inorganic. Although this will underestimate risks, the underestimation is not expected to be significant and will not affect the conclusions of the assessment.	Overestimate	No

Note:

Detailed Sensitivity Analysis calculations can be found in Volume III, Appendix 6.

8.3 Sensitivity in Toxicity Assessment

Uncertainties in the selection of dose-response data are one of the largest sources of uncertainty in any human health risk assessment.

8.3.1 Non-Cancer Toxicity Reference Values for Threshold Effects

Reference Doses (RfDs), Limit Values, and other threshold toxicity reference values are derived using Uncertainty Factors (UFs). Use of multiple uncertainty factors provides a degree of conservatism in extrapolating estimates of adverse effects. For example, human toxicity data for CoCs are often not available; in such cases, an extrapolation of human toxicity from animal studies may be used, and an uncertainty factor may then be applied to account for extrapolating results to humans.

The toxicology of each chemical is also dependent on the route of exposure. For some chemicals, the route of administration can have a distinct effect on the adverse outcomes that occur; therefore, when the toxicological effects of a chemical differ between the routes of exposure, inhalation and ingestion exposures are usually assessed separately.

In the HHRA, toxicity reference values used for the CoCs include uncertainty factors of up to 100 times and the potential risks to receptors are thus likely to be overestimated due to this fact alone.

8.3.2 Slope Factors and Unit Risk Factors

In the context of carcinogenic risks to human receptors, toxicity reference values may be based on a threshold approach or a non-threshold approach. For the latter case, carcinogenic potencies of chemicals known to cause cancer can be expressed as slope factors or as unit risks. A slope factor is an upper-bound estimate of the increase in carcinogenic risk due to lifetime exposure to a chemical. A unit risk, on the other hand, is the upper bound of the increase in carcinogenic risk estimated for continuous lifetime exposure to a chemical at a concentration of 1 µg/L in water, or 1 $\mu g/m^3$ in air. Unit risks are used to estimate an upper bound probability of an individual developing cancer as a result of inhalation exposure to a particular level of a potential carcinogen, while slope factors are used to estimate the upper bound probability of the same event due to ingestion or dermal exposure to a potential carcinogen.

8.3.3 Combined Effects of Lead

The MOE (2002) noted that elevated levels of lead are found in the Rodney Street area of the community. Although lead is not a CoC in the current assessment, available information was reviewed regarding combined effects of lead on effects associated with the CoCs. Two interaction profiles by ATSDR (2004 b and c) were identified with information on effects of lead on the toxicity of arsenic and copper, respectively. Their findings are summarized in Table 8-2.

Table 8-2: Summary of Combined Effects

Type of Toxicity	Effect of Lead on Toxicity of Arsenic [1]	Effect of Lead on Toxicity of Copper [2]
Neurological	Greater than additive	Additive
Dermal	Indeterminate	Not Applicable
Renal	Less than additive	Not Applicable
Cardiovascular	Indeterminate	Not Applicable
Hematological	Less than additive	Additive
Hepatic	Not Applicable	Additive

Note:

1 Source: ATSDR 2004b
2 Source: ATSDR 2004c

The effects of potential concern for additive or greater than additive concern are therefore neurological effects for arsenic and neurological, hematological or hepatic effects for copper.

For arsenic, carcinogenic effects were not identified as an endpoint relevant to combined effects. The conclusions regarding arsenic toxicity are based on comparison of exposure concentrations and corresponding results of biomonitoring studies. Since elevated levels of arsenic (i.e. above levels in background communities) were not seen in biomonitoring results at similar or higher exposure concentrations, there is no basis to conclude that lead would impact potential effects associated with arsenic exposures.

For copper, the highest hazard quotient estimated in the maximum exposure scenarios was 0.3. This leaves considerable room for additive effects associated with potential lead exposures before the benchmark of one is reached.

The potential for combined effects of lead on the toxicity of the CoCs was concluded to not be a significant concern.

8.3.4 Summary

Table 8-3 summarizes the major sources of uncertainty in the Toxicity Assessment and the potential for these uncertainties to impact on the results and conclusions of the assessment.

Table 8-3: Sensitivity Analysis for Toxicity Assessment

Risk Analysis Study Factor/Assumption	Justification	Analysis Likely to Over/Under Estimate Risk?	Uncertainty Likely to Change Risk Conclusions?
General			
Cancer slope factors and unit risks	The slope factor is an upper-bound estimate of the increase in carcinogenic risk due to lifetime exposure to a chemical. The unit risk is the upper bound of the increase in carcinogenic risk estimated for continuous lifetime exposure to a chemical at a concentration of 1 µg/L in water, or 1 µg/m^3 in air. Unit risks are used to estimate an upper bound probability of an individual developing cancer as a result of exposure to a particular level of a potential carcinogen. Cancer slope factors and unit risks are based on the assumption of a linear low-dose response. This is considered conservative and, in some cases, the mechanisms of carcinogenicity indicate that a threshold type response exists. In such cases, **the actual risk may be zero at concentrations below the threshold value even though the linear extrapolation predicts a risk.**	Over estimate.	**Yes**
Dermal absorption rates	Scant information is available on dermal absorption of the CoCs and, in particular, the form of the CoCs found in Port Colborne soils. Available absorption rates are based on soluble salts of the CoC compounds and are expected to overestimate absorption.	Overestimate	No
Nickel – Ingestion/ Dermal Exposure			
Nickel oral RfD	In order to derive a nickel oral RfD, the Working Group (2007) applied an uncertainty factor of 100 to the No Observed Adverse Effects Level (NOAEL) to account for inter-species (factor of 10) and intra-species variabilities (factor of 10).	Overestimate	No
Nickel contact dermatitis	Contact dermatitis to nickel in soils is not well understood and large uncertainties exist in this area. In the case of Port Colborne soils, the chemical form of nickel is known with some degree of certainty and general conclusions, at best, regarding potential for contact dermatitis can be drawn as a result. The potential for nickel contact dermatitis was selected for further evaluation (See Section 8.5.5)	See Section 8.5.5	See Section 8.5.5

Table 8-3: Sensitivity Analysis for Toxicity Assessment

Risk Analysis Study Factor/Assumption	Justification	Analysis Likely to Over/Under Estimate Risk?	Uncertainty Likely to Change Risk Conclusions?
Oral Bioavailability of nickel in soils	A weight of evidence approach was used in this assessment to reduce uncertainties. This, combined with the use of data based on both Port Colborne soils in animal testing and human literature data, yields a satisfactory level of uncertainty.	No.	No.
Oral Bioavailability of CoCs in House Dust	The adjustments for relative oral bioavailability of the CoCs in soil were applied to house dust. The primary source of CoCs in house dust is expected to be outdoor soil. Bioavailability and bioaccessibility testing was conducted using soil sieved to < 250 µm particle size fraction. Based on a review of house dust particle size fraction data (Lewis *et al*. 1999), house dust was concluded to be of a similar size fraction to the soil size fraction used in the analyses. Although there is a degree of uncertainty associated with this assumption, the uncertainty was concluded to be relatively small and unlikely to affect the conclusions of the assessment.	Uncertain.	No.
Oral Bioavailability of nickel in foods	The RfD for nickel is based on a study of soluble nickel sulphate administered by gavage (Springborn 2000). The bioavailability of nickel has been shown to decrease when in food. The bioavailability of nickel in both supermarket foods and garden produce can be expected to be somewhat less than that administered in the Springborm study. Nickel in supermarket foods and natural produce is chemically bound in the food as opposed to the nickel in the RfD where soluble nickel was not administered with food. Since no fasting occurred in the toxicity study, the bioavailability associated with the nickel administered in those studies cannot be estimated with any reliability, but is likely less, and possibly considerably less than for the selected Toxicity Reference Value (TRV).	Overestimate.	No.
Nickel – Inhalation Exposure			
Nickel species for inhalation Minimal Risk Level (MRL)	The Agency for Toxic Substances Disease Registry (ATSDR) MRL is based on the soluble nickel species nickel sulphate. **Nickel sulphate is noted to be the most toxic nickel species by non-carcinogenic inhalation effects, more so than nickel oxide which is the dominant nickel form in Port Colborne soils.**	Overestimate	**Yes**

Table 8-3: Sensitivity Analysis for Toxicity Assessment

Risk Analysis Study Factor/Assumption	Justification	Analysis Likely to Over/Under Estimate Risk?	Uncertainty Likely to Change Risk Conclusions?
Nickel inhalation MRL uncertainty factors	The ATSDR (2005) MRL for nickel sulphate includes uncertainty factors of 10 for human variability and 3 for interspecies variability.	Overestimate	No
Nickel inhalation unit risk: Approach I, nickel refinery dust unit risk	The use of the United States Environmental Protection Agency (U.S. EPA 2003) refinery dust unit risk provides a highly conservative estimate of risks that overestimates the true risks by an order of magnitude or more. This unit risk is based specifically on nickel refinery dust which is not found in the environment. The refinery dust basis is noted by the U.S. EPA to have been approximately 50% sulphidic nickel, a more potent inhalation carcinogen than other nickel species in refinery dust. Oxidic nickel accounts for the bulk of nickel emissions from the refinery and has been established to be the dominant nickel species in Port Colborne soils. Since the value is also based on epidemiological data, a higher rate of smoking than found in the general population at the present time may have also led to higher lung cancer risk estimates due to potentially greater than additive effects from smoking. Since epidemiological data indicates a threshold below which lung cancer is not seen, the **Approach I nickel refinery dust unit risk will significantly overstate risks below the threshold of effects.**	Overestimate	**Yes**
Arsenic as a confounder in nickel inhalation unit risk	Arsenic was a contaminant in materials used in the nickel refining processes in Clydach, Wales and Kristiansand, Norway. Because arsenic is a powerful carcinogen causing lung cancer, this may have significantly impacted the data that the U.S. EPA estimated from nickel refinery dust and led to **a significant overestimation of unit risks.**	Overestimate	**Yes**
Nickel inhalation unit risk: Approach II, oxidic nickel unit risk	The European Union unit risk (Lepicard *et al*, 1997) is based on a non-threshold approach for oxidic nickel although the mechanisms of nickel inhalation carcinogenicity indicates a threshold response. **At exposures below the threshold, risks will be overstated.**	Overestimate	**Yes**

Table 8-3: Sensitivity Analysis for Toxicity Assessment

Risk Analysis Study Factor/Assumption	Justification	Analysis Likely to Over/Under Estimate Risk?	Uncertainty Likely to Change Risk Conclusions?
Nickel air speciation and characterization of nickel in air, Approach II, oxidic nickel	Speciation of soil samples clearly indicates that oxidic nickel is the dominant nickel form. Other sources of nickel to ambient air may contribute soluble nickel; however, sulphidic nickel, and particularly nickel subsulphide, are not expected to be present in ambient air in Port Colborne in significant quantities. Note that Inco no longer emits significant quantities of any form of nickel in Port Colborne.	No	No
Nickel Threshold for Carcinogenic Risks, Approach III, nickel refinery dust limit value	The selected limit value (European Commission, 2001; Lewis and Caldwell, 1999) includes uncertainty factors of 10 for use of a Lowest Observed Adverse Effect Level (LOAEL) and 5 for human variability. The value is less than (*i.e.* more conservative) than that estimated for oxidic nickel (See Volume III, Appendix 7), the dominant form of nickel in Port Colborne soils and therefore will overstate potential risks. Since the value is based on epidemiological data, a higher rate of smoking than found in the general population at the present time may have also led to higher lung cancer risk estimates due to potentially greater than additive effects from smoking. The increase in lung cancer risk from smoking is likely to have made the limit value lower (*i.e.* more conservative).	Overestimate	No

Table 8-3: Sensitivity Analysis for Toxicity Assessment

Risk Analysis Study Factor/Assumption	Justification	Analysis Likely to Over/Under Estimate Risk?	Uncertainty Likely to Change Risk Conclusions?
Nickel air speciation	Good agreement was obtained for speciation of nickel in soils, clearly indicating that the main constituent of the nickel contamination in surface soil is oxidic nickel compounds. Since the focus of this study is current environmental conditions attributable to Inco, and Inco no longer emits significant quantities of nickel in any form in Port Colborne, the primary source of nickel from Inco is resuspension from soil which is known to be primarily oxidic nickel. Therefore, oxidic nickel compounds are considered appropriate for assessment of current nickel inhalation risks attributable to historic emissions from Inco in Port Colborne. Other unrelated ambient sources (*e.g.* coal fired generating stations) may be significant sources of soluble nickel compounds in ambient air in the community; however, this is largely unknown and is not the focus of the current assessment. Nonetheless, a TRV for soluble nickel inhalation (*i.e.,* ATSDR 2005 MRL) has been evaluated to characterize this uncertainty. There is also some potential for other forms of nickel to be present in undisturbed dust entrained in walls and attics of homes. Limited speciation results leave a large uncertainty associated with this. Since exposure to such dust is likely to be short term (*e.g.* during renovation or infrequent attic access), oxidic nickel is expected to be the appropriate species for evaluation.	No	No
Copper – Ingestion/ Dermal Exposure			
Copper oral UL	The tolerable upper limit is the highest level of daily intake of a nutrient (over a lifetime) likely not to result in an adverse health effect to almost all individuals. The tolerable upper limits (UL) for copper were based on a NOAEL.	No	No
Oral Bioavailability of copper in soils	Although a weight of evidence approach was used, the data available are limited to *in vitro* (acid extract) test results which have a high degree of uncertainty associated with them. The nature of the tests make them inherently conservative.	Overestimate	No

Table 8-3: Sensitivity Analysis for Toxicity Assessment

Risk Analysis Study Factor/Assumption	Justification	Analysis Likely to Over/Under Estimate Risk?	Uncertainty Likely to Change Risk Conclusions?
Copper – Inhalation Exposure			
Copper inhalation Reference Exposure Level (REL)	The copper REL was derived from the American Conference of Governmental Industrial Hygenists (ACGIH 1992) Threshold Limit Value (TLV) by dividing by a factor of 420. This factor is made up of a conversion from a 40 hour work week (4.2), a factor to protect sensitive individuals (10) and a factor to account for the deficiency of using a TLV rather than a no observable adverse effects level (NOAEL) (10).	Overestimate	No
Cobalt – Ingestion/ Dermal Exposure			
Oral Bioavailability of cobalt in soils	Although a weight of evidence approach was used, the data available are limited to *in vitro* (acid extract) test results which have a high degree of uncertainty associated with them. The nature of the tests make them inherently conservative.	Overestimate	No
Cobalt contact dermatitis	Cobalt and cobalt oxides are insoluble (ATSDR, 2001), hence the low aqueous extraction rate of less than 1% seen for Port Colborne soils. An aqueous concentration of between 0.01% and 0.1% (Allenby and Basketter, 1989) is required to elicit an allergic reaction and because of the insolubility of forms of cobalt anticipated in Port Colborne soils, allergic dermatitis from soil contact is considered unlikely.	No	No
Cobalt oral RfD	This value is based on the upper range of the average intake of cobalt in the diet of children.	No	No
Cobalt – Inhalation Exposure			
Cobalt inhalation MRL	ATSDR (2001) derived a Minimal Risk Level (MRL) for chronic inhalation of cobalt based on a No Observable Adverse Effects Level (NOAEL) to workers. Exposures were weighted to convert from occupational exposure and an uncertainty factor of 10 was applied for human variability.	Overestimate	No

Table 8-3: Sensitivity Analysis for Toxicity Assessment

Risk Analysis Study Factor/Assumption	Justification	Analysis Likely to Over/Under Estimate Risk?	Uncertainty Likely to Change Risk Conclusions?
Arsenic – Ingestion/ Dermal			
Oral Bioavailability of arsenic in soils	Although a weight of evidence approach was used, the data available are limited to *in vitro* (acid extract) test results which have a moderate degree of uncertainty associated with them. The nature of the tests make them inherently conservative.	Overestimate	No
Arsenic oral RfD	The RfD was developed based on the NOAEL of 8×10^{-4} mg/kg-d (estimated from the NOAEL of 0.009 mg/L) of arsenic divided by an uncertainty factor of 3. The uncertainty factor of 3 was to account for both the lack of data to preclude reproductive toxicity as a critical effect and to account for some uncertainty in whether the NOAEL of the critical study accounts for all sensitive individuals. Since arsenic risks were evaluated qualitatively, the oral RfD does not affect the estimates of risk.	No	No

Note:

Detailed sensitivity calculations can be found in Volume III, Appendix 6.

8.4 Sensitivity in Exposure Assessment

In order to check the accuracy of the exposure calculations based on the equations detailed in Volume III, Appendix 2, a third party peer review of the calculation spreadsheet of the equations was undertaken. SENES Consultants Limited (SENES) staff specializing in statistics and risk analysis undertook a check of every cell of the spreadsheets. Their review is detailed in Volume VI, Appendix 28. Subsequent to the initial review, some modifications to the spreadsheet were made and the verification was repeated, thereby ensuring that the equation coding was correctly implemented.

In the HHRA, a comprehensive survey of residents in the community was undertaken in order to reduce uncertainties in the receptor characterization. Whenever possible, Port Colborne specific receptor characteristics were used in the evaluation of exposures and risks. These characteristics were also compared to literature values to ensure reasonableness (see Volume III, Appendix 3).

Table 8-4 presents a summary of further uncertainties in the assessment of exposure in this HHRA.

Table 8-4: Sensitivity Analysis for Exposure Assessment

Risk Analysis Study Factor/Assumption	Justification	Analysis Likely to Over/Under Estimate Risk?	Uncertainty Likely to Change Risk Conclusions?
Exposure duration	A 70 year lifetime in Port Colborne is considered highly conservative given the general mobility of people in Southern Ontario. This is even conservative based on the Port Colborne resident survey results	Overestimate	No
Outdoor workers	Except for farmers, receptors were assumed to work indoors. This may underestimate potential exposure to outdoor workers such as landscapers. An outdoor worker was selected for further evaluation in Section 8.5.6.	See Section 8.5.6	See Section 8.5.6
Body weight	This is based on Canadian data and is considered representative for Port Colborne residents.	No	No
Exposure skin surface area	Conservative assumptions were made in the selection of values from the literature.	Overestimate	No
Inhalation rate	Inhalation rates are based on literature data available and are considered representative. Inhalation of dust has little effect on ingestion/dermal exposures. When inhalation toxicity is based on exposure concentrations, risks are not particularly sensitive to inhalation rates. The estimated inhalation exposure varies with change in inhalation rates over the course of the day(i.e. active and non-active compared to average). Only the ratio affects the results and the data used are considered the most applicable to this analysis.	No	No
Soil intake rates	Soil intake rates from the literature are considered upper ranges of normal intake. These do not consider abnormal (pica) behaviour which is atypical and not considered within the scope of evaluating RME concentration scenarios. The selected values are considered quite conservative. Pica behaviour is considered further in Section 8.5.7.	See Section 8.5.7	See Section 8.5.7

Table 8-4: Sensitivity Analysis for Exposure Assessment

Risk Analysis Study Factor/Assumption	Justification	Analysis Likely to Over/Under Estimate Risk?	Uncertainty Likely to Change Risk Conclusions?
Dust ingestion rates	In the current assessment, soil ingestion rates were used that did not differentiate between soil and dust. In addition, hand to mouth activity for infants and toddlers was used to evaluate exposure to house dust. This results in double counting of intakes for toddlers; however, the magnitude of the impact has a large associated uncertainty. Hand to mouth event frequencies have been based on recent U.S. EPA guidance and are significantly higher than earlier guidance values. This may indicate a significant double counting. Since elevated risks were not indicated by the results of the assessment, the conclusions were deemed to not be impacted.	Overestimate	No
Skin soil adherence rate, hand-to mouth frequency, surface water ingestion rate	These values are based on the available literature and are considered best estimates. The exposures involved are minor for this study and the impact of uncertainties in these factors is therefore small.	No	No
Drinking water ingestion rate	The drinking water ingestion rates are based on the resident survey and are high compared to applicable literature values. These values are thus considered conservative.	Overestimate	No
Infant drinking water ingestion rate	The resident survey obtained data on only a few infants. The reported drinking water rates were unrealistic and, due to the small sample size, these were not used. Literature infant formula consumption rates were used to estimate water intake.	No	No
Time-activity factors	Detailed results of the resident survey were used to minimize uncertainties in these factors. The results are “average” factors which may well reflect actual activity patterns of, for instance, workers versus non-workers.	No	No
Vacation Time – Receptors in Zones A, C, D and E are assumed to spend 1 to 2 weeks of vacation outside of Port Colborne.	The results are based upon the resident survey administered by Jacques Whitford. The time-activity pattern adopted is a conservative assumption since residents are also assumed to spend their entire lifetime in Port Colborne, less vacation time (1 week for Zones C, D, E; 2 weeks for Zone A.	No	No

Table 8-4: Sensitivity Analysis for Exposure Assessment

Risk Analysis Study Factor/Assumption	Justification	Analysis Likely to Over/Under Estimate Risk?	Uncertainty Likely to Change Risk Conclusions?
Vacation Time – Receptors in Zone B are assumed to spend 1 week of vacation in Port Colborne.	The results are based upon resident survey administered by Jacques Whitford. The time-activity pattern adopted is highly conservative.	Overestimate	No
Vacation Location – Receptors in Zone C are assumed to vacation outside Port Colborne	61% of survey respondents in Zone C indicated that they vacation away from Port Colborne, but 39% of respondents in that Zone indicated that they do not. This source of uncertainty is likely to underestimate risks to Zone C receptors, but since the Zone C receptors were only assumed to spend one week out of 52 outside Port Colborne (or 7 days out of 365), the magnitude of the underestimation is not considered to be significant enough to affect the conclusions of the HHRA.	Underestimate	No
Dietary intake	Dietary intakes based on the Northeastern United States as used in this evaluation are considered appropriate and reasonable. Further discussion of this issue can be found in Volume V, Appendix 19, Section 5.3.	No	No
Infant diet	The infant was evaluated as consuming infant formula or breast milk exclusively to the age of 6 months. Although this is consistent with the recommendations of many physicians and health agencies, other foods are often introduced before this age. The intent of the evaluation as conducted is to capture the life-stage when formula or breast milk is the primary source of nourishment; however, this does exclude some small portion of the average infant diet, mostly from 4 to 6 months of age, where infants consume other foods. This consumption is captured for the toddler and the omission of these foods from the evaluation of the infant is not considered significant to the results of this assessment.	No	No
Exclusion of evaluation of drinking water from cisterns	Concentrations of the CoCs in cisterns were found to be less than in well water.	Overestimate	No
Fraction of produce from gardens	These fractions are based on the resident survey and are considered representative for the produce items grown locally.	No	No

Table 8-4: Sensitivity Analysis for Exposure Assessment

Risk Analysis Study Factor/Assumption	Justification	Analysis Likely to Over/Under Estimate Risk?	Uncertainty Likely to Change Risk Conclusions?
Fraction of eggs obtained locally	These fractions are based on the resident survey and are considered representative. Furthermore, receptors in Zone D were conservatively assumed to consume locally produced eggs only.	No	No
Consumption of local beef	No cattle farms were identified in Port Colborne. A review of the source of beef for local butchers and supermarkets, as presented in Volume II, Appendix 1.13, indicates that beef is obtained from areas outside of Port Colborne. A number of small farms in the past and currently have raised cattle for the purposes of dairy production. There is no evidence that suggest CoC concentrations in cattle grazed in Zone D of Port Colborne would differ from other areas in Ontario.	No	No
Ambient air modelling	The ambient air modelling was conducted using CalPUFF in order to reduce uncertainties inherent in the application of point measurements of air concentrations to long term average exposures. Although considerable natural variability and uncertainty in the model exists, these are considered less than the initial uncertainties in applying available ambient air monitoring from several fixed sampling locations to the risk assessment that used modelled results to generate CoC concentrations at numerous grid nodes throughout the Port Colborne Study Area. The model results were also calibrated based on available monitoring results.	No	No
Occasional attic exposure to resuspended dust	Exposure to attic dust has not been evaluated in the RME or maximum concentration scenarios. Since this may underestimate risks, potential exposures to attic dust are evaluated further in Section 8.5.78	See Section 8.5.8	See Section 8.5.8

Table 8-4: Sensitivity Analysis for Exposure Assessment

Risk Analysis Study Factor/Assumption	Justification	Analysis Likely to Over/Under Estimate Risk?	Uncertainty Likely to Change Risk Conclusions?
Occasional exposure to resuspended dust during renovation activities	Home renovations are considered likely to disturb and resuspend some dust collected behind walls or other normally-inaccessible areas. As described in Volume II, Appendix 1.17, however, airborne dust concentrations during renovations were not measured for the HHRA due to a lack of volunteers. Should renovations disturb dust in walls, the exposure concentrations may be fairly high; however, the exposure duration would be relatively short. If dust concentrations are significant, workers would be expected to follow reasonable health and safety measures appropriate to an area under construction such as use of dust masks.The evaluation conducted for exposure to attic dust in Section 8.5.8 is considered an appropriate approximation of potential risks that may result from home renovations. Post renovation and clean-up, the potential for exposures in the home would be expected to decrease as a result of removal of the dust source. Since the evaluation of the attic scenario did not indicate a health risk, no elevated risk is expected from home renovations.	Underestimate	No
Nursing infant exposures	A large degree of uncertainty exists in the estimation of the transfer of the CoCs to breast milk. Because of the large degree of uncertainty, these exposures were selected for further evaluation in the Sensitivity Analysis (See Section 8.5.9).	See Section 8.5.9	See Section 8.5.9
Equations and calculations	The Exposure Assessment is based on standard equations for exposure pathways and rates. The outcome of the analysis is dictated by the input values selected, the ability of the equations to accurately characterize exposure mechanisms, and the proper coding of the equations. Because the results of the assessment had initially differed significantly from earlier results of the MOE (2002) assessment, further verification that the equations were correctly implemented and are able to produce the same results as the MOE study produced was selected for further assessment (See Section 8.5.10)	See Section 8.5.10	See Section 8.5.10

8.5 Sensitivity in Risk Characterization

Potential uncertainties in the Risk Characterization are driven by the input data and evaluations of the previous steps in the assessment. Based on these inherent uncertainties in the assessment, and particularly in the toxicity reference values, the quantitative estimations of risk are not considered accurate beyond one significant digit even though the input data may have more significant digits. Natural variability, particularly variability between individuals, as well as the uncertainties inherent in all aspects of development of the estimates of risk, result in hazard quotients and risks designed to provide an indication of whether a risk may exist. The estimated risks reported to one significant digit may also have uncertainty factors built into toxicity reference values in some assessments, which can add up to three hundred times greater levels of additional protection to members of the community. For this reason, a hazard quotient greater than one, or a risk estimate greater than a certain level, does not necessarily indicate an unacceptable risk; whereas, a hazard quotient or risk estimate less than one or a cancer risk level of one in one million does indicate an acceptable level of risk, according to the MOE (MOE 1996).

Interactions between the CoCs and toxicologically similar efforts were not identified in this assessment (see Chapter 6 of Volume III, Appendix 7). Further discussion of uncertainty on combined toxicologically independent effects of the CoCs is provided in Section 8.5.11.

Based on the Sensitivity Analysis performed, some scenarios and sensitivity factors were selected for further evaluation of whether or not they would affect the assessment results and conclusions. The selected sensitivity factors are as follows:

1. Attendance at elementary school in Zone D
2. Consumption of well water in Zone E
3. Local hunter/angler
4. Exposure to CoCs through consumer products
5. Nickel contact dermatitis
6. Outdoor worker
7. Soil pica behaviour in children
8. Attic Dust
9. Nursing Infant exposures
10. Assessment verification
11. Combined toxicologically independent effects

Evaluation of each of the above selected factors is detailed in the sections that follow.

8.5.1 Attendance at Elementary School in Zone D

Children residing in Zones B, C or D may attend elementary school in Zone C or D. Since measured maximum soil concentrations at Zone D school properties are higher than those for Zone C schools, the maximum soil concentration scenario (See Chapter 7) was evaluated for the child receptor attending school in Zone D. Since the highest HQs for this receptor were for residents of the Zone D farming area, the Zone D farm child was evaluated. Selected school soil concentrations are shown in Table 8-5.

Table 8-5: Sensitivity Ingestion Hazard Quotients to Maximum Soil Concentrations and Zone D Elementary School for Zone D Farm Child Receptor

CoC	Zone D Maximum School Soil Concentration (µg/g)	Ingestion HQ (Child Attending School in Zone D)	Zone C Maximum School Soil Concentration (µg/g)	Ingestion HQ (Child Attending School in Zone C)
Nickel	2,600	0.02	590	0.02
Copper	310	0.2	72	0.3
Cobalt	44	0.2	17	0.2

Note
HQ – Hazard Quotient

As seen in Table 8-5, the HQs for the Zone D child attending school in Zone D only differ for copper when compared to HQs for the same receptor attending school in Zone C. Since all estimated HQ values are below the applicable MOE benchmark of one, no health risks are expected for this scenario.

8.5.2 Consumption of Well Water in Zone E

One assumption made during the Exposure Assessment was that Zone E1 (City) receptors obtained their drinking water from municipal sources. The exposure of these receptors to concentrations of CoCs in well water was selected for further assessment as a source of uncertainty. In order to estimate risks based on this scenario, Zone E1 (City) toddler receptors were exposed to the maximum measured CoC concentrations observed in wells in Zone E, as presented in Volume V, Appendix 15. For copper, which was not detected in the three drilled well water samples collected in Zone E, a value of half of the method detection limit (MDL) was utilized as the selected concentration. The results of this analysis are presented in Table 8-6.

Table 8-6: Sensitivity Ingestion Hazard Quotients to Drinking Water Source of Zone E1 (City) Toddler Receptor

CoC	Zone E Well Water Concentration (µg/L)	Ingestion HQ (Receptors Consuming Well Water)	Municipal Water Concentration (µg/L)	Ingestion HQ (Receptors Consuming Municipal Water)
Nickel	0.002	0.3	0.0016	0.3
Copper	0.10	0.4	0.022	0.4
Cobalt	5×10^{-5}	0.03	0.00017	0.03

Note
HQ – Hazard Quotient

As demonstrated in Table 8-6, the source of drinking water for Zone E1 (City) residents did not cause a significant difference to toddler ingestion Hazard Quotients (HQs). Indeed, no HQ value differed between the two scenarios. From this observation, it can be concluded that no elevated health risks are estimated for those Zone E residents who obtain their drinking water from wells in Zone E.

8.5.3 Local Angler/Hunter Scenario

The local angler/hunter scenario evaluates the risk posed to a Port Colborne resident who may consume locally hunted game and locally-caught fish rather than meat or fish from the supermarket. The local angler/hunter was evaluated as an adult receptor that resides in Zone D agricultural lands on organic soils. The angler/hunter is assumed to consume fish and meat solely from local sources. Intake rates in the scenario are based upon Food Basket Questionnaire results (Volume III, Appendix 5). The fish intake rate was based upon the 75th percentile of values reported in the quadrant with the highest 75th percentile value of reported intake rate of local fish. This consumption rate selected was 44 kg/year based on Quadrant One respondents. The game intake rate was estimated by summing the 75th percentiles of the intake rates reported by those residents that consume venison, rabbit, duck and turkey. Therefore, a game consumption rate of 43 kg/year was utilized in the scenario. Food Basket Questionnaire results were utilized in the scenario as the intake rates reported by residents exceeded those recommended by the U.S. EPA (1997) for game consumption and fish consumption by anglers. The total selected fish plus game consumption for this hypothetical receptor was slightly higher than the total fish and meat consumption selected for evaluation of other adult receptors. These rates were thus considered as a highly conservative sensitivity scenario. The likelihood of any one individual consuming fish and game from each of these reported groupings at these rates and from local sources only, to the extent that they do not eat any supermarket meat or fish or game from outside the Study Area, is considered highly unlikely.

CoC concentrations were altered in the scenario to reflect local CoC levels in game and fish. The local angler/hunter was assumed to consume the maximum CoC concentrations measured in local meat. The maximum values were used as only four samples were available. The angler/hunter was assumed to be exposed to the Upper Confidence Limit of the Mean (UCLM) CoC concentrations measured in fish, as this measure was greater than the 75th percentile. Adjusting organ meat concentrations to reflect local samples was considered, however, due to sample contamination by buckshot, this adjustment was not considered appropriate. The scenario constructed in this way is considered to be a very conservative estimate of risk posed to any Port Colborne resident who may consume local game or fish as any portion of their diet. The sensitivity to risk posed to the local angler/hunter is summarized in Table 8-7.

Table 8-7: Hazard Quotients for Local Angler/Hunter Scenario

CoC	RME Concentration Scenario Zone D Farm, Organic		Local Angler/Hunter Scenario Zone D Farm, Organic	
	Ingestion Dose (mg/kg-day)	Ingestion HQ	Ingestion Dose (mg/kg-day)	Ingestion HQ
Nickel	0.0021	0.1	0.0026	0.1
Copper	0.017	0.1	0.031	0.2
Cobalt	0.00020	0.01	0.00038	0.02

The HQs for cobalt, copper and nickel are well below the MOE benchmark of one and, therefore, no risk is to the local angler/hunter is expected. Arsenic was not evaluated in this scenario due to the large number of samples below the detection limit.

8.5.4 Exposure to CoCs through Consumer Products

The use of consumer products is another pathway through which the general public may be exposed to chemicals. Dominant exposure routes would be associated with nickel in food preparation products (*e.g.,* pots and pans), prolonged contact with jewellery or other nickel containing items through direct contact, or through inhalation of nickel that may become airborne as a result of use of a product. The U.S. EPA, Health Canada and the MOE do not have guidelines for assessing risk associated with exposure from consumer products.

Increased nickel levels in food may originate from cooking utensils. The literature (see Volume V, Appendix 19) indicates that larger amounts of nickel may be leached from new (*i.e.,* during first two or three uses, decreasing significantly with subsequent use) stainless steel utensils during cooking than from older, more heavily-used utensils. Because concentrations leached to foods drops rapidly after first use, these exposures were concluded to be very small and not contribute significantly to long term exposures. In addition, Jacques Whitford conducted its own cooked food screening study, which indicated that leaching of nickel into cooked foods from older nickel containing cookware was negligible. See Attachment D of Volume V, Appendix 19 for details.

Exposure to nickel-containing jewellery is a relatively common occurrence. Nickel in jewellery can be absorbed into the skin layers. Nickel is not well absorbed through this route of exposure, and typically does not reach the bloodstream in significant concentrations. The contribution to exposures from jewellery is therefore not significant compared to other sources of exposure.

Overall, the contribution of consumer products to nickel exposures was concluded to not significantly impact exposures or risks and would therefore not impact the conclusions of the assessment.

8.5.5 Nickel Contact Dermatitis

The skin's acid mantle is formed by sebum (an oily secretion) and sweat which form a natural barrier with a pH of about 4 to 5.5. This mildly acidic layer cannot be assumed to be comparable to the high acid environment of the stomach or the stomach phase of the bioaccessibility test. Nonetheless, the highly conservative stomach phase bioaccessible values have been used in the following estimate of maximum loading of nickel to skin, which is considered to be overly conservative. As detailed in Volume III, Appendix 8, the corresponding bioaccessibility was estimated at 21%.

The highest soil nickel concentration that has been measured in Port Colborne is 33,000 mg/kg. As an extreme worst case, this soil concentration was combined with the soil adherence factor used in the assessment for a farmer of 0.1 mg soil/cm^2 skin. The product of the soil concentration, adherence factor and bioaccessibility is 0.7 µg Ni/cm^2. This is an extreme maximum estimate of potential soluble nickel loading to the skin from soil exposure at the maximum concentration.

This estimated concentration can be compared to the lowest reported concentrations in the literature resulting in a dermatological response. Menne (1994) concluded that a nickel dermatitis reaction was unlikely for a skin loading of 15 µg Ni/cm^2 for non-occluded (*i.e,.* not broken) skin. Menne (1994) also observed that a nickel dermatitis reaction was unlikely for a skin loading of <0.1 to 1 µg/cm^2 for occluded skin. Since the estimated maximum soluble nickel skin loading is in the range of loadings at which a dermatitis reaction is unlikely, and since an extreme maximum case has been evaluated, a dermatological response to nickel in Port Colborne soils was concluded to be highly improbable for nickel-sensitized individuals.

8.5.6 Outdoor Worker Scenario

The outdoor worker scenario attempts to characterize the risk from exposure to CoCs by someone working outside all day on non-snow days, such as a landscaper. The outdoor worker, considered to be an adult receptor, is assumed to spend 40 hours per week outdoors in the Zone of highest soil nickel concentrations, namely Zone B. This is a conservative estimate of the potential exposure to all outdoor workers in Port Colborne. The outdoor worker Exposure Assessment used the same RME concentrations for CoCs in all media as the regular CBRA receptors. The resulting dermal/ingestion and inhalation risks are presented in Tables 8-8 through 8-10.

Table 8-8: Sensitivity of Ingestion/Dermal Hazard Quotients to an Outdoor Worker Scenario

CoC	RME Concentration Scenario (Indoor Worker) Zone B		Outdoor Worker Scenario Zone B	
	Ingestion/Dermal Dose (mg/kg-day)	Ingestion/Dermal HQ	Ingestion/Dermal Dose (mg/kg-day)	Ingestion/Dermal HQ
Nickel	0.0021	0.1	0.0021	0.1
Copper	0.017	0.1	0.017	0.1
Cobalt	0.00016	0.008	0.00017	0.008

Table 8-9: Sensitivity of Inhalation Hazard Quotients to an Outdoor Worker Scenario

CoC	RME Concentration Scenario (Indoor Worker) Zone B		Outdoor Worker Scenario Zone B	
	Inhalation Exposure (mg/m^3)	Inhalation HQ	Inhalation Exposure (mg/m^3)	Inhalation HQ
Nickel	1.5E-05	0.2	1.7E-05	0.2
Copper	3.5E-04	0.1	4.0E-04	0.2
Cobalt	1.8E-06	0.02	2.0E-06	0.02

Table 8-10: Sensitivity of Nickel Inhalation Cancer Risks to an Outdoor Worker Scenario

Approach to Risk Estimation	ILCR or ER Indoor Worker	ILCR or ER Outdoor Worker
Approach I, Nickel Refinery Dust ILCR	3×10^{-6}	4×10^{-6}
Approach II, Oxidic Nickel ILCR	0.5×10^{-6}	0.6×10^{-6}
Approach III, Nickel Refinery Dust ER	0.03	0.03

Note:
ILCR – Incremental Lifetime Cancer Risk
ER – Exposure

The outdoor worker scenario shows that no significant difference in risk is present between residents working outdoors compared to indoors. The results of the sensitivity analysis for an outdoor worker indicate that although a slight increase in incremental lifetime cancer risks is shown for nickel inhalation, the overall increase is minor. The total body burden associated with nickel, copper, and cobalt exposure remains relatively unchanged indicating that the change in worker scenario does not affect the total amount of exposure relative to other sources (*e.g.,* dietary intake).

8.5.7 Soil Pica Behaviour in Children

The exposure calculations for the Risk Characterization for RME concentrations were developed with the specific goal of assessing risk to the overall community. From the standpoint of incidental soil ingestion, this approach entails the use of a reasonable maximum soil ingestion rate, and the usual selection for this rate is an upper estimate of typical child behaviour. Should a child who exhibits soil pica behaviour (deliberate ingestion of soil) be present in the community, the selected soil ingestion rate may not adequately represent this child's average soil intake. In order to investigate this issue, a soil pica child was assessed further.

The U.S. EPA distinguishes between pica and soil pica; the former is defined by the U.S. EPA as "the repeated eating of non-nutritive substances" (Feldman 1986, cited in U.S. EPA 1997), while the latter is limited to the repeated eating of soil. While pica appears to be relatively common among children – according to Sayetta (1986, cited in U.S. EPA 1997), pica behaviour occurs in approximately half of children aged between one and three years – the U.S. EPA has suggested, despite limited information on the subject, that soil pica appears to be less common in children. Soil pica behaviour has also been noted in pregnant women, and deliberate ingestion of clays (also known as geophagia) is a cultural practice in many regions of the world.

In terms of quantification of soil ingestion rates relevant to soil pica, the U.S. EPA (1997) recommends an upper percentile value of 400 mg/day. In addition, for a soil pica child, a mean soil intake of 10 g/day (10,000 mg/day) was recommended for use in acute exposure assessments only. The 400 mg/day value is recommended for long term studies because a pica child does not typically ingest soil deliberately on a day to day basis, but rather exhibits this behaviour infrequently. The value of 10 g/day was also derived from observations of only one child in a study of 64 children (Calabrese et al. 1991, cited in U.S. EPA 1997), and no confirmatory evidence outside of this one child was available to substantiate the value.

Outside these recommendations, a range of values has been used in risk assessments conducted by the U.S. EPA and other agencies. In a human health risk assessment for dioxins (U.S. EPA 1984, cited in U.S. EPA 1997), the U.S. EPA used 5 g/day as an estimate of the amount of soil ingested by a soil pica child. The Center for Disease Control (CDC) used a value of 10 g/day to represent this quantity in an assessment of potential exposures to dioxins (Kimbrough *et al.* 1984, cited in U.S. EPA 1997).

In order to gather professional and scientific opinions on the subject of soil pica, the Agency for Toxic Substances Disease Registry (ATSDR) conducted a Soil-Pica Workshop in June 2000. One of the conclusions of the Workshop appearing in its summary report prepared by the Eastern Research Group (ERG) was that for the present time, the ATSDR should continue to use 5,000 mg/day (that is, 5 g/day) as an estimate of the amount of soil ingested by a soil pica child (ERG 2001). The ERG report is careful to note that this conclusion does not represent ATSDR policy, and the recorded discussions at the Workshop indicated that the ATSDR validate the use of this number (ERG 2001).

For the purposes of the Port Colborne HHRA, the U.S. EPA (1997) upper percentile estimate of 400 mg/day was chosen as the representative soil ingestion rate relevant to soil pica behaviour. The toddler was chosen as the most sensitive receptor in terms of soil ingestion, and a quantitative analysis for a toddler exhibiting this soil pica behaviour was thus performed. All other characteristics of the toddler receptor remained the same as in the Risk Characterization for RME concentrations, and all media concentrations were kept at their RME levels. The results of the resulting soil pica toddler analysis are presented in Table 8-11.

Table 8-11: Sensitivity of Inhalation Hazard Quotients to a Pica Toddler Scenario

CoC	RME Concentration Scenario (Toddler) Zone B		Soil Pica Toddler Scenario Zone B	
	Ingestion Dose (mg/kg-day)	Ingestion HQ	Ingestion Dose (mg/kg-day)	Ingestion HQ
Nickel	7.0E-03	0.3	8.3E-03	0.4
Copper	5.2E-02	0.4	5.4E-02	0.4
Cobalt	6.2E-04	0.03	7.6E-04	0.04

As demonstrated in Table 8-11, use of an elevated soil ingestion rate to represent soil pica behaviour did not lead to significant differences in risk estimates. All hazard quotients are below the MOE benchmark of one, indicating that no adverse health effects are expected.

8.5.8 Attic Dust

Exposures of Port Colborne residents to attic dust were assessed as part of the Sensitivity Analysis. In particular, resuspension of settled dust and inhalation during periodic use of the attic was assessed. Re-entrainment of attic dust to indoor air space outside of the attic was previously taken into account in measurements of indoor air concentrations. In the residential areas of concern, attics tend to be either renovated living space or limited access such as crawl spaces and ceiling openings, accessed by ladder, to spaces used for long term storage or not used. Since the concern in this Sensitivity Analysis is specifically attics that are not frequently accessed, small children were concluded to be unlikely to frequent them.

The re-suspension of household dust has been studied in literature. The U.S. Nuclear Regulatory Commission (U.S. NRC 2002) has provided a review document of resuspension rates of household dust measured in literature associated with various daily household activities. In reviewing the document, the exposure equation from U.S. NRC (2002) was adopted and the source of the resuspension rates reviewed and is presented in Volume III, Appendix 2.

Details of the equation and input parameters are also presented in Volume III, Appendix 2. In this scenario, the adult receptor was assumed to be potentially exposed for 50 years at a rate of 12 hours per year. Although some individuals may be exposed with greater frequency, the increased traffic through the attic would be expected to decrease dust CoC concentrations. With no new source of attic dust (i.e., no continuing emissions from the Inco Refinery), concentrations would decrease over time and exposures would not be expected to be higher than those estimated for the less frequent exposure over a longer time frame.

The principal variable in the exposure equation governing the dose is the Resuspension Factor (RF). The U.S. NRC (2002) recommends a RF of 9.6 x 10^{-7} m^{-1} based upon a 90th percentile of a log normal fit of the mean RFs of 5 sites. This is based upon a limited data set that was considered applicable for a decommissioning facility. Fish *et al*., (1964, cited in U.S. NRC 2002) measured a RF value of 0.00019 m^{-1} based upon 10 minutes of vigorous activity (including sweeping) in room with no exhaust or fans for freshly dispersed particles in a test room. Given that the physical conditions in the Fish *et al*., study is similar to what is expected in an attic, the conservative use of fresh dust in comparison to aged dust and the conservative (*i.e.,* high) level of activity applied in the test room, the results of this latter study were adopted in the HHRA. The results of this analysis are thus considered highly conservative as this level of activity would serve to rapidly reduce the amount of dust remaining in the attic, thereby decreasing long-term exposures.

The maximum concentration of the 12 attic swipe samples (*e.g.,* 43,705 µg/m^2 for nickel) was used in this sensitivity assessment, as presented in Tables 8-12 and 8-13. Given that the source of nickel (*i.e.,* refinery) impact in attics no longer exists, cleaning would reduce the nickel dust concentration that is present in the attic. As a result, application of a maximum concentration of an un-disturbed attic over an exposure period of 50 years with an RF based upon cleaning would produce highly conservative results.

Table 8-12: Sensitivity of the Hazard Quotient to Attic Exposures for Zone B Resident

CoC	Attic Concentration (µg/m^2)	Resuspended Attic Dust Concentration (µg/m3)	Inhalation HQ excluding Attic	Inhalation HQ with Attic
Nickel	44,000	8.3	0.2	0.3
Copper	7,200	1.4	0.1	0.1
Cobalt	690	0.13	0.02	0.02
Arsenic	820	0.16	NA	NA

Note:
NA – Not Applicable

Table 8-13: Sensitivity of Incremental Lifetime Cancer Risks for Attic Dust Inhalation Exposures to Zone B Resident

Approach to Risk Estimation	ILCR or ER Excluding Attic	ILCR or ER Including Attic
Approach I, Nickel Refinery Dust ILCR	3×10^{-6}	6×10^{-6}
Approach II, Oxidic Nickel ILCR	0.6×10^{-6}	0.9×10^{-6}
Approach III, Nickel Refinery Dust ER	0.03	0.04
Arsenic ILCR	Nil	Nil

The results of the attic dust sensitivity analysis indicate that periodic use of the attic does not significantly change the risk estimates for Zone B residents. The hazard quotients for all three of the CoCs, for which this analysis was performed, were still all less than the MOE benchmark of one when attic exposures were factored in, as was the exposure ratio for carcinogenic effects due to nickel inhalation.

Note that dermal and ingestion exposures of the adult resident to attic dust were not quantitatively assessed. This approach was considered reasonable as attic grab-sample concentrations (Volume IV, Appendix 13) were lower in nickel, copper, and cobalt than the maximum concentrations of the respective CoCs in soils.

8.5.9 Nursing Infant Exposures

A literature review of concentrations of the four CoCs in breast milk was undertaken and is summarized in Attachment C to Volume III, Appendix 7. Transfer factors to human breast milk with which to conduct a quantitative evaluation of these potential infant exposures were not identified. As such, a quantitative evaluation cannot be undertaken. Literature indicates that the rate of transfer of nickel, cobalt and arsenic to breast milk is small. This small rate of transfer would be expected to result in relatively low exposures to infants compared to the mother. Since the assessment did not indicate risks to any of the receptors evaluated, no adverse affects to nursing infants is expected.

For copper, the literature indicated that strict homeostatic controls of copper uptake are responsible for a lack of correlation of copper intakes to concentrations in breast milk. Since these are not correlated, exposure to the mother would not result in increased infant exposures via breast milk and no adverse affects to the infant would be expected.

8.5.10 Assessment Verification

Another method to demonstrate the accuracy of the human health calculations adopted as part of the HHRA was to use the same key assumptions made by the MOE in the *Soil Investigation and Human Health Risk Assessment for Rodney Street Community, Port Colborne* (2002) report for nickel using the Jacques Whitford spreadsheets to reproduce the MOE assessment. To that end, the changes incorporated into the HHRA spreadsheets in this example calculation included the following:

- Bioavailability for all soils changed to value of 19% used by MOE;
- Soil nickel concentration changed to value of 9,061 mg/kg for all soil types (value computed by MOE for an HQ of one);
- Soil intake rates for infant and child changed to match MOE values;
- Sleep inhalation rates changed to match MOE values;
- Average inhalation rates changed to match MOE values;
- Drinking water ingestion rates changed to match MOE values;
- Soil adherence to skin factors changed to match MOE values;
- Total skin surface areas changed to match MOE values;
- Fractions of local vegetables in diet changed to match MOE values;
- Fractions of local fruit changed to match MOE values;
- Time outdoors changed to match MOE values; and
- Supermarket intakes of nickel changed to match MOE values.

All other assumptions, such as other media concentrations of nickel in, for example, surface water, drinking water, and dust were held constant as followed in Jacques Whitford's assessment. The resulting estimated risk values are presented in Table 8-14.

Table 8-14: Ingestion/Dermal Hazard Quotients for Nickel

Parameter	RME Concentration Approach in Jacques Whitford's Assessment		MOE Simulation		MOE Results
	Nickel Dose (mg/kg-day)	Nickel HQ	Nickel Dose (mg/kg-day)	Nickel HQ	Nickel HQ
Infant	0.0016	0.08	0.015	0.7	-
Toddler	0.0070	0.3	0.021	1	1.0
Child	0.0039	0.2	0.012	0.6	-
Teen	0.0024	0.1	0.0059	0.3	-
Adult	0.0021	0.1	0.0050	0.2	-

The result of the MOE simulation was an HQ of one. This compares well to the MOE hazard quotient of one for the same soil nickel concentration and demonstrates not only that the spreadsheet calculations as used by Jacques Whitford in this assessment have been correctly implemented, but also demonstrates that the parameters adjusted include those, to which the calculations are most sensitive.

Note that the results displayed in Table 8-14 are strictly for the purposes of MOE simulation and verification that Jacques Whitford's calculation spreadsheets and the assessment using the Jacques Whitford spreadsheets correctly computes dose and hazard quotients from a given set of input values. Since the inputs used to generate Table 8-14 do not reflect the more precise results of analyses performed for the current risk assessment, as compared to those used earlier by the MOE (2002), the MOE simulation outputs do not reflect estimates of dose or risk for the current assessment.

8.5.11 Combined Toxicologically Independent Effects

For the combination of independent effects, the methodology used was the addition of responses (See Figure 4-1). In the human health risk assessment the ratio of dose of TRV (*i.e.,* Hazard Quotients) for humans is representative of risk or responses, with a ratio greater than 1 indicating a potential response and a ratio less than 1 indicating no potential response. In the summing of responses based on the independence of effects, ratios for component chemicals of less than one indicate no response. An example adapted from the U.S. EPA (2000) is presented in Table 8-15.

Table 8-15: Example of Risk Summation for Independent Effects

Chemical	Exposure	TRV	HQ	Response Measure [a]
A	13	16	0.8	No
B	7	8	0.9	No
C	22	24	0.9	No
Mixture Risk			0	No

Notes:
a. Response =No since HQ<1

Zero response measure is used to indicate a hazard quotient below one (*i.e.,* sub-threshold risk) or a small enough exposure or dose compared to a toxicological reference value, to be considered safe.

The results of the Risk Characterization presented in Chapters 6 and 7 indicated that no health effects or responses were anticipated, and summation of the responses therefore yields a result of zero or no response. As indicated in the example (Table 8-15), the response associated with the mixture is zero, based on addition of toxicologically independent effects.

8.6 Summary

The overall confidence in the Risk Characterization is high. The risks to residents of Port Colborne are not underestimated. The HHRA, using community-specific data, scientifically defendable and regulatory-accepted data from the literature, and a rigorous Sensitivity Analysis, indicates that concentrations of CoCs known to be present in Port Colborne soils do not present an unacceptable risk to human health as defined by applicable MOE guidelines.

The parameters to which the risk estimates were found to be most sensitive to in the Sensitivity Analysis were considered further in the selection of the approach used to select Risk-Based Soil Concentrations in the next chapter.

9.0 RISK-BASED SOIL CONCENTRATIONS

The Risk-Based Soil Concentration (RBSC) for a Chemical of Concern (CoC) is an estimate of the concentration of that CoC in soil that is expected to be protective of human health for worst case exposure of sensitive receptors. The toddler was shown to be the most sensitive life stage for soil ingestion and dermal pathways in the Human Health Risk Assessment (HHRA) assessment; therefore, the RBSCs were estimated for toddlers in the community and would be protective of all other life stages as well. Infants had higher Hazard Quotients (HQs) for copper, but this was not due to direct soil contact.

In some cases, inhalation risks are greater for life stages other than the toddler; however, RBSCs are developed only based on oral and dermal exposure pathways. The relationship between soil concentrations and ambient and indoor air concentrations is complex and the use of inhalation pathways to derive RBSCs was not possible. The assessment found that the highest levels of ambient and indoor air concentrations across the community are acceptable for human health. In addition, current concentrations of nickel in soil in Port Colborne are considered safe for human health inhalation up to the maximum measured soil CoC concentrations currently existing in the community.

The general approach to RBSC estimation was essentially the reverse of the exposure and risk estimation process (see Chapters 5 and 6). Specifically, soil concentrations were selected that resulted in a calculated HQ value equivalent to the MOE benchmark HQ of one. Garden produce concentrations were set at the maximum measured concentrations. Soil concentration was then varied while holding other parameters at their selected values until the target HQ was reached. The assumptions and framework of this methodology were very conservative, therefore, the resulting soil concentrations, *i.e.,* the RBSCs, would be protective of human health under worst-case land use and for sensitive receptors.

9.1 Derivation of RBSCs

Direct and indirect exposure pathways, as well as background exposures, were built into the HHRA calculations (see Volume III, Appendix 6), making the relationships between CoC concentrations in soil and estimated HQs not straightforward. Only doses obtained through direct soil to receptor exposure pathways, such as soil ingestion and soil dermal contact, would vary with changes in soil concentrations in the RBSC estimation process. Other pathways, such as ingestion of backyard garden produce, would be affected by a change in soil CoC concentrations—fruits or vegetables grown in soil higher in CoCs would naturally be expected to contain higher concentrations of CoCs themselves. Since no direct relationships between soil concentrations and garden produce concentrations were quantified in the HHRA assessment

(see Volume V, Appendix 17), the dependence of garden produce CoC concentrations on soil CoC concentrations was taken into account using maximum observed concentrations (as opposed to Reasonable Maximum Exposure (RME) concentrations) for garden fruit and vegetable concentrations. Specifically, the maximum observed backyard fruit and vegetable CoC concentrations in each Zone were used in the RBSC calculation for that Zone. For other exposure pathways (*e.g.,* drinking water ingestion and indoor dust exposure), for which direct relationships between soil CoC concentrations and risk are not reasonably quantifiable, doses and exposures were considered as constants in the calculation of site specific concentrations with a target HQ of one. This is considered reasonable since pathways such as drinking water ingestion are based on actual measured concentrations.

Another assumption made in the RBSC estimation process was contrary to the assumptions of the exposure and risk calculations (see Chapters 5 and 6), receptors were assumed to be exposed to the same CoC concentrations in soil everywhere in the community, regardless of land use. In the results (see Chapters 5 and 6), land use-specific concentrations of CoCs were used as inputs into the spreadsheets, but because the RBSCs are designed to be applied across the Port Colborne community, derivation of a single CoC soil concentration was considered the most appropriate strategy.

9.1.1 Nickel

For each Zone, all soil concentrations were started at the same value, which was varied until a target HQ of one was obtained for the toddler life stage, based on the reference dose of 0.02 mg/kg-day. For the resulting soil nickel concentration for each of the zones considered in this assessment, see Table 9-1.

Table 9-1: Risk-Based Soil Concentrations for Nickel

Zone	Receptor	Estimated Nickel RBSC (mg/kg)	Full Depth: Zone Maximum Measured Concentrations (mg/kg)
A	Toddler	30,000	1,700
B	Toddler	60,000	17,000
C	Toddler	30,000	7,300
D Farm (Clay and Organic)	Toddler	20,000	33,000 [a]
D Residential	Toddler	40,000	
E1 City	Toddler	70,000	1,100
E2 Background	Toddler	70,000	

Note:

a. Maximum is for Recreational land use and was measured in the Reuter Road woodlot

For detailed derivations of these estimates, see Volume III, Appendix 6.

See Volume III, Appendix 6 for the estimates of HQs based on the concentrations presented in Table 9-1. The variations in RBSCs between the zones are attributed to exposures from backyard gardens. The fact that the Zone D Farm RBSC was lowest is due to the consumption of a larger amount of garden produce in the diet, both in terms of fraction of total consumption of fruits and vegetables and magnitude of concentrations in those fruits and vegetables. The Zone D farm receptor was assumed (based on the results of the resident survey) to consume about 50% more fruits and vegetables grown in their backyard gardens than residents in Zone B. More significantly, the maximum measured concentrations in vegetables and fruits in Zone D were over two and one half times greater than the maximum concentrations measured in Zone B. The combined result is a higher intake of nickel in the local fruits and vegetables portion of the diet by about six times. This has a noticeable impact on the estimated RBSC values. Even if the Zone D maximum soil nickel concentrations were assumed to possibly occur in Zone B, the lower fraction of the diet from backyards in Zone B due to the simple constraints based on city yard size, would not impact on the Zone D farm receptor being the more sensitive of the two.

This derivation indicates that, regardless of soil type and land use, nickel concentrations of less than 20,000 mg/kg are protective of human health in Port Colborne. Note that the computed value has been rounded down to 20,000 mg/kg based on the number of significant digits in the reference dose.

Concentrations higher than the RBSC value of 20,000 have been found only in Vale Inco Ltd. (Inco) owned woodlots in Zone D. These woodlots are adjacent to the Inco lands and not accessible to the public. See Figure 2-4 for locations depicted as numbers 2 and 3. The Reuter Road woodlot is delineated on Figure 2-4 as the green shaded area where these numbers are indicated. Direct and prolonged exposure to these soils by toddlers is considered highly unlikely, since they are not currently residential. This localized area would not be considered suitable for residential development unless concentrations were reduced.

9.1.2 Copper

The highest estimated HQ for ingestion and dermal exposure to copper was for the infant. Since the infant exposure, however, is almost exclusively due to ingestion of infant formula and not soil, the infant was not considered the most conservative receptor for the derivation of RBSCs.

Typically, the most sensitive life stage for exposure to chemicals in soil is the toddler because toddlers have the greatest tendency to ingest soil and have low body masses. For this reason, RBSCs for copper based on a target HQ of one were developed based on the toddler.

For each zone, all soil concentrations were given one value, which was varied until a target HQ of one was obtained for the toddler life stage, based on the Toxicity Reference Value (TRV) of 0.13 mg/kg-day. For the copper soil concentrations corresponding to target HQs of one for the toddler receptor, see Table 9-2.

Table 9-2: Risk-Based Soil Concentrations for Copper

Zone	Receptor	Estimated Copper RBSC (mg/kg)	Full Depth: Zone Maximum Measured Concentrations (mg/kg)
A	Toddler	43,000	210
B	Toddler	40,000	8,400
C	Toddler	41,000	650
D Farm (Clay and Organic)	Toddler	39,000	3,900
D Residential	Toddler	35,000	
E1 City	Toddler	42,000	140
E2 Background	Toddler	42,000	

Note:
For detailed derivations of these estimates, see Volume III, Appendix 6.

See Volume III, Appendix 6, for the estimates of HQs based on the concentrations presented in Table 9-2. The two lowest RBSC values are for the residential and farm areas of Zone D. This difference is due to a higher concentration of copper in drinking water in this Zone. Zone D residential receptors were evaluated as obtaining their drinking water from dug wells, where the selected RME concentration for copper was 0.20 mg/L. Zone D farm receptors, which had the next lowest estimated RBSC, were assumed to obtain their drinking water from drilled wells, where the selected RME concentration was 0.059 mg/L for copper. The copper RME concentration selected for municipal water, the source of drinking water for Zones A, B and C was 0.022 mg/L.

The highest RBSC estimated for copper is an order of magnitude higher than the highest measured copper soil concentration measured in the community. A RBSC for copper is therefore not required and there are no health risks expected based on the highest concentrations of copper in soil present in Port Colborne.

9.1.3 Cobalt

The toddler receptor was selected for the derivation of a conservative concentration of cobalt in soils for a target HQ of one.

For each zone, all soil concentrations were given one value, which was varied until a target HQ of one was obtained for the toddler life stage based on the TRV of 0.02 mg/kg-day. For the resulting cobalt soil concentrations, see Table 9-3.

Table 9-3: Risk-Based Soil Concentrations for Cobalt

Zone	Receptor	Estimated Cobalt RBSC (mg/kg)	Full Depth: Zone Maximum Measured Concentrations (mg/kg)
A	Toddler	10,000	30
B	Toddler	10,000	270
C	Toddler	10,000	100
D Farm (Clay and Organic)	Toddler	10,000	430
D Residential	Toddler	10,000	
E1 City	Toddler	10,000	27
E2 Background	Toddler	10,000	

Note:

For detailed derivations of these estimates, see Volume III, Appendix 6.

See Volume III, Appendix 6, displays the estimates of HQs based on these concentrations. The RBSCs estimated for cobalt were approximately two orders of magnitude higher than the highest concentrations of cobalt measured in soils in Port Colborne. A RBSC for cobalt in soil is therefore not required and the concentrations of cobalt present in Port Colborne soils, up to the maximum concentration are considered protective of human health.

9.1.4 Arsenic

As stated (see Chapter 6), quantitative human health risks were not estimated for arsenic in Port Colborne soils. The qualitative Risk Characterization concluded that no elevated human health risks were indicated by the presence of arsenic in Port Colborne soils. The concentrations of arsenic currently present in Port Colborne soil are deemed to be protective of human health in the community and, therefore, no RBSC was derived for arsenic.

9.2 Selected RBSCs

See Table 9-4 for a list of the derived RBSCs. The concentrations are estimated levels of concentrations of CoCs in soil that are expected to be protective of human health for a worst case exposure of sensitive receptors.

Exposures to arsenic could not be reliably quantified, therefore, arsenic concentrations in soil with HQs of one or incremental risks of one in one million were not derived.

Table 9-4: Risk-Based Soil Concentrations (RBSCs) Selected

CoC	Receptor	Risk-Based Soil Concentration (mg/kg)
Nickel	Toddler	20,000
Copper	Toddler	Above maximum soil concentration; RBSC not required
Cobalt	Toddler	Above maximum soil concentration; RBSC not required
Arsenic	Toddler	No health risk; RBSC not required

The nickel RBSC of 20,000 mg/kg differs from the intervention level of 8,000 mg/kg set by the MOE (2002). There are two dominant factors that cause this difference. The first is the re-evaluation of the intake of nickel from supermarket foods. In the current study, actual foods from local supermarkets, farmers markets and shops were analyzed for nickel content in a comprehensive study of dietary nickel. The second factor is the fraction of nickel in Port

Colborne soils that after ingestion is absorbed into the blood. In the current study, a weight of evidence approach weighted several methods of analyzing this factor including the results of live animal tests using actual soils from Port Colborne, literature studies documenting absorption in humans and animals, studies of nickel speciation in Port Colborne soils, and laboratory methods of measuring nickel solubility in various media including acids. The result was a lower estimate of dietary nickel intake from supermarket foods and a lower absorption of nickel from ingested soils, yielding an overall increase in the RBSC over the previous intervention level.

9.3 Sensitivity Analysis

Since a pica child is the receptor with the highest potential exposure to soil, a sensitivity analysis was conducted to ensure that the selected RBSC concentrations are protective of this child.

Since the analysis performed indicated that RBSCs for cobalt and copper were not required, the sensitivity analysis considered maximum measured concentrations of these CoCs in soil, as shown in Tables 9-2 and 9-3. The Zone B and the Zone D residential toddlers were selected for evaluation since these receptors correspond to the highest soil concentrations of cobalt and copper and the lowest estimated RBSC values. The RBSC scenarios evaluated as detailed in Section 9.2 were re-evaluated for these receptors using maximum measured soil concentrations applied to all land uses, and the pica child long term average soil intake of 400 mg/day, as discussed previously in Section 8.5.6. The resulting hazard quotients are summarized in Table 9-5.

Table 9-5: Results of Sensitivity Analysis for Cobalt and Copper Maximum Measured Soil Concentrations

Receptor	Maximum Full Depth Measured Soil Concentration		Ingestion/Dermal Hazard Quotient	
	Copper (mg/kg)	Cobalt (mg/kg)	Copper	Cobalt
Zone B toddler	8400 [a]	270 [a]	0.9	0.1
Zone D residential toddler	3900 [b]	430 [b]	0.7	0.2

Notes:

a. This concentration was measured in commercial soil from the specified Zone.

b. This concentration was measured in recreational soil from the specified Zone.

Since the hazard quotients for cobalt and copper are all less than 1, the maximum concentrations are considered protective of a pica child.

For nickel, the selected RBSC value was evaluated using the pica child soil intake and maximum home scenarios based on the following:

1. Home with highest garden produce nickel concentrations; and,

2. Home with highest well water nickel concentrations.

The scenario of the home evaluated for the highest measured well water concentrations was detailed previously in Section 7.4.1. The selected parameter values are shown in Table 9-6.

Table 9-6: Nickel Parameters Selected for Highest Well Water Nickel Scenario

Parameter	Value	Units
Vegetable concentration (Site 526)	0.88	mg/kg
Fruit concentration (Site 526)	0.076	mg/kg
Soil concentration (RBSC)	20,000	mg/kg
Drinking water concentration (MOE Site)	0.076	mg/L
Soil ingestion rate	400	mg/day

Garden produce Sites 1 and 13 were selected as being the homes with the highest fruit and vegetable concentrations, based on the average of all fruit or all vegetables samples collected at each home. An average concentration was selected since evaluating only the maximum concentration, in combination with evaluation of a pica child would be an extreme, unrealistic scenario. More than one type of fruit or vegetable would typically be consumed from a garden. Since fruit samples were not collected at the home with the highest average vegetable concentrations, data from these two highest homes were combined into a single maximum home scenario.

Multiple drinking water samples were collected at both homes, which had the same maximum measured concentration of nickel in drinking water. The selected input parameters for the sensitivity analysis of nickel for the maximum home garden scenario are summarized in Table 9-7.

Table 9-7: Nickel Parameters Selected for Maximum Home Garden Scenario

Parameter	Value	Units
Vegetable concentration (Site 1)	2.6	mg/kg
Fruit concentration (Site 13)	1.3	mg/kg
Soil concentration (RBSC)	20,000	mg/kg
Drinking water concentration (Sites 1 and 13)	0.004	mg/L
Soil ingestion rate	400	mg/day

Results of both nickel sensitivity analyses are shown in Table 9-8. Since hazard quotients from the sensitivity analysis scenarios did not exceed 1, the selected RBSC value of 20,000 mg/kg was concluded to be protective.

Table 9-8: Results of Sensitivity Analysis for Nickel

Scenario	Ingestion/Dermal Hazard Quotient
Max. garden produce	1
Home with highest well water nickel	1

9.4 Summary

No RBSCs were found to be required for arsenic, cobalt or copper. The maximum concentrations found in the community are considered protective of human health. An RBSC of 20,000 mg/kg was established for nickel in soils as protective of human health, including receptors with the greatest potential for exposure. The highest nickel soil concentrations in the Reuter Road woodlot were identified as exceeding the RBSC for nickel. These soils in the woodlot were concluded to not pose a risk to human health under the current land use. woodlot would not be considered suitable for residential development unless concentrations were reduced.

10.0 SUMMARY

The Chemicals of Concern CoCs for this Community Based Risk Assessment (CBRA) were identified in an earlier Jacques Whitford report (Jacques Whitford 2001d) as nickel, copper, cobalt and arsenic (Jacques Whitford, 2001d).

For the CBRA, the definition of a CoC is a chemical found in Port Colborne soils originating from the Vale Inco Ltd. (Inco) Refinery when **all** of the following **Conditions** are met:

Condition 1) Chemicals that were historically used or generated by the Inco Refinery or its processes, and

Condition 2) Chemicals that are present at a community level at concentrations greater than Ontario Ministry of Environment (MOE) generic effects-based guidelines (MOE 1997), and

Condition 3) Chemicals whose presence in soil shows a scientific linkage to the historical operations of the Inco Refinery.

This assessment did not evaluate other chemicals from other sources that may be locally elevated in soils in some parts of Port Colborne (*e.g.*, lead) and the results of this assessment in no way imply whether an elevated risk from such other chemicals may or may not exist. The conclusions of this assessment are only applicable to the four CoCs evaluated: nickel, copper, cobalt and arsenic.

Cancer and non-cancer risks from exposure to nickel, copper and cobalt were estimated quantitatively in each Human Health Risk Assessment (HHRA) Zone. Hazard quotients (HQs), used to estimate non-cancer threshold risks, and Exposure Ratios (ERs), used to estimate cancer threshold risk, were compared to the MOE benchmark of one for acceptable threshold type risks. For non-threshold effects, Total Lifetime Cancer Risks (TLCRs) and Incremental Lifetime Cancer Risks (ILCRs) were estimated. The ILCRs were compared to the MOE benchmark of one in one million as an acceptable level of risk.

No non-cancer HQs exceeded the threshold benchmark of one for oral, dermal or inhalation exposures to nickel, copper or cobalt.

The results of this assessment indicate that nickel inhalation risks to residents of Port Colborne are very low. There is unlikely to be an elevated risk from nickel inhalation even for residents of the single home with the highest measured nickel concentrations in indoor air.

Potential risks associated with arsenic were evaluated on a qualitative basis because of the absence of detectable concentrations in foods, produce and drinking water. Oral and dermal exposures in Port Colborne were evaluated by comparison of arsenic in soils in Port Colborne to arsenic soil concentrations in other Ontario communities where health studies, in particular bioassays, were performed. Since the soil arsenic concentrations in Port Colborne are lower than those in soil in other communities where bioassays were completed, and since health effects were not observed from exposure to higher soil arsenic concentrations in those communities in which the bioassays were completed, by extension, no health risks are expected to residents of Port Colborne from soil arsenic concentrations. This conclusion is considered applicable to inhalation as well as oral and dermal exposures to arsenic since the primary source of arsenic in air is likely to be resuspension of soil.

10.1 Conclusion

The results of the assessment of conservative exposure scenarios indicate that the concentrations of nickel, copper, cobalt and arsenic in the Port Colborne environment do not pose an unacceptable risk to residents as defined by the MOE target risk levels. In a quantitative evaluation of uncertainties, arsenic oral/dermal exposures were found to have uncertainties too large to make the evaluation reliable.

A Risk-Based Soil Concentration (RBSC) was derived for nickel in soil. The evaluation determined that RBSCs were not required for copper or cobalt because the computed values were greater than the maximum measured soil concentrations. The objective of the RBSC is to derive a safe soil concentration for a worst-case exposure of sensitive receptors. This benchmark ensures that soil concentrations below this value are protective of human health. The evaluation of RBSCs for Port Colborne is summarized in Table 10-1.

Table 10-1: Evaluation of Risk-Based Soil Concentrations

CoC	Risk-Based Soil Concentration (mg/kg)
Nickel	20,000
Copper	RBSC not required
Cobalt	RBSC not required
Arsenic	RBSC not required

There are no residential areas in Port Colborne where measured soil concentrations exceed the 20,000 mg/kg nickel RBSC. Concentrations higher than the nickel RBSC were measured in two samples in the Inco owned woodlot on the east side of Reuter Road, immediately east of the Inco Refinery property. Although no risk is present to human health based on the current land use in this area (woodlot), if this woodlot was to be redeveloped for residential use, an appropriate remedial action and soil management plan for soils above the 20,000 mg/kg nickel RBSC would have to be implemented at that time.

The nickel RBSC of 20,000 mg/kg differs from the intervention level of 8,000 mg/kg set by the MOE (2002). There are two dominant factors that cause this difference. The first is the re-evaluation of the intake of nickel from supermarket foods. In the current study, actual foods from local supermarkets, farmers markets and shops were analyzed for nickel content in a comprehensive study of dietary nickel. The second factor is the fraction of nickel in Port Colborne soils that is absorbed into the blood after ingestion. In the current study, a weight-of-evidence approach weighted several methods of analyzing this factor including:

- the results of live animal tests using actual soils from Port Colborne
- literature studies documenting nickel absorption in humans and animals
- studies of nickel speciation in Port Colborne soils
- laboratory methods of measuring nickel solubility in various media including acids

The result was a lower estimate of dietary nickel intake from supermarket foods and a lower absorption of nickel from ingested soils, yielding an overall increase in the RBSC over the previous intervention level.

The third party peer reviewers of the peer review draft of the HHRA noted that:

> *"This HHRA has benefitted greatly from the extensive amount of field data collected. Considerable effort was also spent on characterizing the site-specific pathways within the community, and in determining the form and bioavailility of nickel in soil. The field data collected and studies undertaken have increased the confidence associated with the risk assessment conclusions."*

11.0 REFERENCES

ACGIH. 1992. Threshold Limit Values. Cincinnatti, OH. American Conference of Governmental and Industrial Hygienists.

Allenby, C.F. and D.A. Basketter. 1989. "Minimum eliciting patch test concentrations of cobalt." *Contact Dermatitis* **20**:185-190.

AMEC. 2001a. *Phase II Environmental Site Assessment Parcel #NP-021-B (Site #1) Vacant Lands Between Clarence & Rodney Streets Port Colborne, Ontario*. Submitted to St. Lawrence Seaway Management Corporation. AMEC & Environmental Limited.

AMEC. 2001b. *Phase II Environmental Site Assessment Parcel #NP-022-B (Site #2) Vacant Lands Between Rodney Street & East Breakwater Port Colborne, Ontario*. Submitted to St.Lawrence Seaway Management Corporation. AMEC & Environmental Limited.

AMEC. 2001c. *Environmental Investigation – Lorraine Bay Community Water Quality Concerns*. Submitted to: Members of Lorraine Bay Community. AMEC & Environmental Limited.

APVMA. Australian Pesticides and Veterinary Medicines Authority. 2003. *Arsenic Timber Treatmnets (CCA and Arsenic Trioxide). Review Scope Document.* Canberra, Australia..

ATSDR. 2001. *Toxicological Profile for Cobalt.* U.S. Department of Health and Human Services, Draft for Public Comment. Agency for Toxic Substances and Disease Registry.

ATSDR. 2004. *Toxicological Profile for Cobalt.* United States Department of Health and Human Services, Public Health Service, Agency for Toxic Substances and Disease Registry.

ATSDR. 2005. *Toxicological Profile for Nickel.* U.S. Department of Health and Human Services, Public Health Service, Agency for Toxic Substances and Disease Registry.

Brooks, W.E. 2005. Arsenic. In: *Mineral Commodity Summaries*. US Department of the Interior. US Geological Survey: Washington, DC, US.

Brun, R. 1979. "Nickel in food: the role of stainless-steel utensils". *Contact Dermatitis,* **5**:43-45.

CAPCOA. 1993. *Revised 1992 Risk Assessment Guidelines.* Air Toxics "Hot spots" Program, California Air Pollution Control Officers Association. October 1993.

CCME. 1996. *A Protocol for the Derivation of Environmental and Human Health Soil Quality Guidelines*. Canadian Council of Ministers of the Environment.

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

CEPA. 1993. *Priority substances list assessment report: Arsenic and its compounds*. Priority substances list assessment report, Environment Canada and Health Canada. Canadian Environmental Protection Act. Ottawa, Canada.

Chapman, L.J. and Putnam, D.F. 1984. The Physiography of Southern Ontario, Third Edition. Ontario Geological Survey Special Volume 2. Ontario Ministry of Natural Resources.

City of Port Colborne. 1996. Zoning By-Law 1150/97/81. Consolidation of zoning by-law 1150/97/81 (and subsequent amendments) as approved by the Ontario Municipal Board on March 19th 1984. Updated on January 13th 1992. City Planning Office.

City of Port Colborne. 2000. Municipal Drains and Drain Areas.

City of Port Colborne. 2001. Municipal assessment roles. City Planning Office.

City of Port Colborne. 2002. Maps of Port Colborne's Water Distribution System.

Dabeka, R.W. and A.D. McKenzie, 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.A.O.A.C.* Vol. **78**: 897-909.

Department of Energy Mines and Resources, Surveys and Mapping Branch. 2000. Southern Ontario Topographic Maps.

District School Board of Niagara. 2002a. Maps and school zone information. Facsimile, Apr. 9, 2002, Planning & Transportation Dept.

District School Board of Niagara. 2002b. Elementary school boundaries map, school year 2001-02. E-mail, April 8, 2002, Planning & Transportation Dept.

District School Board of Niagara. 2002c. Niagara School Board Calendar. Available at: http://www.dsbn.edu.on.ca.

Doll, R., A.; Anderson, W.C.; Cooper, I.; Cosmatos, D.L.; Cragle, D.; Easton, P.; Enterline, M.; Goldberg, L.; Metcalfe, T.; Norseth, J.; Peto, J.P.; Rigaut, R.; Roberts, S.K.; Seilkop, H.; Shannon, F.; Speizer, F.W.; Sunderman Jr., P.; Thornhill, J.S.; Warner, J.; Weglo, M.; and Wright. 1990. "Report of the International Committee on Nickel Carcinogenesis in Man." *Scand J Work Environ Health* **16**:1-82. International Committee on Nickel Carcinogenesis in Man (ICNCM).

Eastern Research Group. 2001. Summary Report for the ATSDR Soil – Pica Workshop June 2000. Prepared for The Agency for Toxic Substances and Disease Registry Division of Health Assessment and Consultation.

Enpar Technologies Incorporated. 2001. Sequential Extraction of Two Soil Samples from the Port Colborne Area. May 16, 2001.

Environment Canada Climate Normals 1971-2000: St. Catharines Station (Station ID 6137287).

EC. 2001. Ambient Air Pollution by As, Cd, and Ni Compounds. Working Group on Arsenic Cadmium and Nickel Compounds, European Commission, Director General Environment.

Finley, B.; Proctor, D.; Scott, P.; and Harrington, N. 1994. "Recommended Distributions for Exposure Factors Frequently Used in Health Risk Assessment." *Risk Analysis* **14(4)***:* 533-552.

Fishbein, L. 1981. "Sources, transport and alterations of metal compound: an overview. I. Arsenic, beryllium, cadmium, chromium and nickel." *Environmental Health Perspectives* **40:** 43-64.

Flint, GN and S. Packirisamy, 1995. "Systemic nickel: the contribution made by stainless-steel cooking utensils." Contact Dermatitis. 32: 218-224.

Flint, GN and S. Packirisamy, 1997. "Purity of food cooked in stainless steel utensils" Food Additives and Contaminants. Vol. 14, No. 2, 115-126. Glenn, D.M. and Puterka, G.J. 2005. "Particle films: a new technology for agriculture." *Horticultural Reviews* **31:** 44 p.

Glenn, D.M. and Puterka, G.J. 2005. "Particle films: a new technology for agriculture." *Horticultural Reviews* **31:** 44 p.

Health Canada. 1993. Reference Values for Canadian Populations. Prepared by the Environmental Health Directorate Working Group on Reference Values. May 1993.

Health Canada. 1994. Human Health Risk Assessment for Priority Substances. Canadian Environmental Protection Act. Ottawa, Canada.

Health Canada. 1995. Investigating Human Exposure to Contaminants in the Environment: A Handbook for Exposure Calculations. Ottawa, Canada.

Health Canada. 2004. Federal Contaminated Site Risk Assessment in Canada, Part II: Health Canada Toxicological Reference Values. Environmental Health Assessment Services, Safe Environments Programme.

Hopenhayn-Rich, C.; Smith, A.H; and Goeden, H.M. 1993. "Human studies do not support the methylation threshold hypothesis for the toxicity of inorganic arsenic." *Environ Res.* **60**:161-177.

Hostynek, J.J.; Hinz, R.S.; Lorence, C.R.; Price, M.; and Guy, R.H. 1993. "Metals and the skin." *Crit Rev Toxicol* **23**:171-235.

IOM. 2001. *Dietary Reference Intakes for Vitamin A, Vitamin K, Arsenic, Boron, Chromium, Copper, Iodine, Iron, Manganese, Molybdenum, Nickel, Silicon, Vanadium, and Zinc.* Panel on Micronutrients, Institute of Medicine, Food and Nutrition Board. Washington, D.C., National Academy Press.

Jacques Whitford. 2000. Ambient Air Monitoring in the Vicinity of Schools during Tilling Activities – Port Colborne, Ontario. Jacques Whitford Environment Limited. December 4th, 2000.

Jacques Whitford. 2001a. Potential CoC identification using soil chemical concentration data in exceedance of MOE generic guidelines. Port Colborne Community Based Risk Assessment. Jacques Whitford Environment Limited. Draft Report, November 2001.

Jacques Whitford. 2001b. Potential CoC Identification using Statistical Analysis. Port Colborne Community Based Risk Assessment. Jacques Whitford Environment Limited. Draft Report, November 2001.

Jacques Whitford. 2001c. Summary Report on Chemicals of Concern Evaluation. Jacques Whitford Environment Limited. Draft Report, November 2001.

Jacques Whitford. 2001d. CoC Identification Using Emission Inventories and Dispersion Modelling of Inco and Algoma Operations. Prepared for Inco Limited. Jacques Whitford Environment Limited. Draft Report. Revised 2003.

Jacques Whitford. 2004a. Community Based Risk Assessment Crop Studies. Prepared for Inco Limited. Jacques Whitford Environment Limited.

Jacques Whitford. 2004b. Community Based Risk Assessment Ecological Risk Assessment – Natural Environment Report. Prepared for Inco Limited. Jacques Whitford Environment Limited.

Kanerva, L.; Jolanki, R.; Estlander, T.; Alanko, K.; and Savela, A. 2000. Incidence Rates of Occupational Allergic Contact Dermatitis Caused by Metals. *American Journal of Contact Dermatitis* **11**(3): 155-160.

Lepicard S, T Schneider, P Fritsch, R Maximilien and A Deloraine. 1997. *Risk Assessment for Nickel and Nickel Compounds in the Ambient Air from Exposure by Inhalation.* Review of the European Situation. CEPN C380. Report No. 249.

Lewis, R.J. and D.J. Caldwell. 1999. *Scientific Basis for an Air Quality Standard for Nickel.* CONCAWE, Brussels. Report No. 99/53.

Lloyd GK. 1980. "Dermal absorption and conjugation of nickel in relation to the induction of allergic contact dermatitis: Preliminary results." *Academic Press* 145-148.

McLaughlin, D. and Bisessar, S. 1994. Phytotoxicology Survey Report: International Nickel Comapy Limited, Port Colborne – 1999. Standards Development Branch, Phytotoxicology Section, Ontario Ministry of Environment and Energy.

Menne, T. 1994. "Quantitative aspects of nickel dermatitis: Sensitization and eliciting threshold concentrations." *Sci Tot Environ* **148**:275-281.

MOE. 1996. *Guidance on Site Specific Risk Assessment for Use at Contaminated Sites in Ontario.* Standards Development Branch, Ontario Ministry of Environment and Energy.

MOE. 1997. *Guideline for Use at Contaminated Sites In Ontario.* Ontario Ministry of Environment and Energy. 1996. Revised February 1997.

MOE. 1998. *Assessment of Potential Health Risks of Reported Soil Levels of Nickel, Copper, Cobalt in Port Colborne and Vicinity. August 1998.*

MOE. 2000a. *Phytotoxicity Soil Investigation: Inco – Port Colborne (1998).* Ontario Ministry of Environment. January 2000.

MOE. 2000b. *Phytotoxicity Soil Investigation: Inco – Port Colborne (1999).* Ecological Standards and Toxicology Section, Standards Development Branch, Ontario Ministry of the Environment. July 2000.

MOE. 2000c. *Soil Contamination in Port Colborne Woodlots: 2000*. Ontario Ministry of the Environment. Queen's Printer for Ontario. February 2000.

MOE. 2000d. *Phytotoxicology Soil Investigation: School Yards and Beaches Port Colborne (April 2000)*. Ontario Ministry of Environment. Queen's Printer for Ontario. December 2000.

MOE. 2001a. *Ontario Drinking Water Standards*. Ontario Ministry of the Environment. Revised January 2001.

MOE. 2001b. *Summary of Point of Impingement Standards, Point of Impingement Guidelines, and Ambient Air Quality Criteria (AAQCs).* Technical Services Branch, Ontario Ministry of the Environment. September 2001.

MOE. 2002. *Soil Investigation and Human Health Risk Assessment for the Rodney Street Community, Port Colborne.* Ontario Ministry of the Environment. March 2002.

MOE. 2003. *Technical Support Document for Ontario Drinking Water Standards, Objectives and Guidelines*. Standards Development Branch, Ontario Ministry of the Environment. June 2003.

MOE. 2005. *Procedures for the Use of Risk Assessment under Part XV.1 of the Environmental Protection Act.* Standards Development Branch, Ontario Ministry of the Environment. October 2005.

New Jersey. 1992. "Subchapter 6: Derivation of Additional Numeric Cleanup Standards" In *Cleanup Standards for Contaminated Sites*. *NJAC 7:26D.* New Jersey Administrative Code.

Nickel Working Group. 2007. "Working Group on Nickel Oral Reference Dose for Non-Carcinogenic Effects." See Volume 3, Appendix 7: Attachment A.

Nielsen, G., U. Søderberg, P. Jørgensen, D. Templeton, S. Rasmussen, K. Anderson and P. Grandjean. 1999. "Absorption and retention of nickel from drinking water in relation to food intake and nickel sensitivity." *Toxicology and Applied Pharmacology*. **154**:67-75.

NPRI. 2001. "Inco, Port Colborne." Data available from Government of Canada website: *http://www.ec.gc.ca/pdb/npri/npri_home_e.cfm.* National Pollution Release Inventory.

OMAFRA. 1989. *Soil maps of the Regional Municipality of Niagara*. Ontario Ministry of Agriculture, Food and Rural Affairs.

Ontario 2004a. "Ontario Regulation 153/04". *The Ontario Gazette*. June 19, 2004.

Ontario 2004b. *Soil, Groundwater and Sediment Standards for Use Under Part XV.1 of the* Environmental Protection Act. Queen's Printer for Ontario, March 9, 2004.

Paustenbach, D.J. 2000. "The Practice of Exposure Assessment: A State-of-the-Art-Review." *J.Toxicol. Environ. Health*. Part B, **3**: 179-291.

Pennington JAT and Jones JW. 1987. Molybdenum, Nickel, Cobalt, Vanadium and Strontium in Total Diets. Journal of the American Dietetic Association **87**: 1644-1650.

Peryea, F.J. 1998. Historical use of lead arsenate insecticides, resulting soil contamination and implications for soil remediation [Online]: Proceedings of the 16th World Congress of Soil Science, Symposium 25th, Monpellier, France, 24-25 August 1998. Available at: http://natres.psu.ac.th/Link/SoilCongress/en/symt25.htm

Ratnaike, R.N. 2003. "Acute and chronic arsenic toxicity." *Postgraduate Medical Journal* **79:** 391-396.

Regional Municipality of Niagara. 2000a. Digital air photos. Flown April 26, 2000, 1:20,000 Aerial photography. Public Works Department, Operational Support Services.

Regional Municipality of Niagara. 2000b. Digital zoning maps. Flown April 26, 2000, 1:20,000 Aerial photography. Public Works Department, Operational Support Services.

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

Ruby, M.V., Schoof, R., Brattin, W., Goldale, M., Post, G., Harnois, M., Mosby, D.E., Casteel, S.W., Berti, W., Carpenter, M., Edwards, D., Cragin, D. and Chappell, W. 1999. "Advances in evaluating the oral bioavailability of inorganics in soil for use in human health risk assessment." *Environ Sci Technol,* **33(21)**: 3697-3705.

SGS Lakefield Research Limited. 2002a. Scanning Electron Microscope Examination of Air Filter Samples 01-9-11, 01-9-13 and 01-12-29. June 27, 2002.

SGS Lakefield Research Limited. 2002b. Scanning Electron Microscope Examination of Nickel Deportment in One Dust Sample and Two Air Filters, Report 1 of 2. January 14, 2002

Springborn Laboratories, Inc. 2000. An Oral (Gavage) Two-Generation Reproduction Toxicity Study in Sprague-Dawdley Rats with Nickel Sulphate Hexahydrate. Ohio Research Center. Spencerville, OH.

Stilwell, D.E. and Gorny, K.D. 1997. "Contamination of soil with copper, chromium and arsenic under decks built from pressure treated wood." *Bulletin of Environmental Contamination and Toxicology* **58:** 22-29.

Tao, SSH and Bolger PM. 1998. Dietary arsenic intakes in the United States: FDA Total Diet Study, September 1991- December 1996. Food Additives and Contaminants **16(11)**: 465-472.

USDA. 2000. "Table Set 10." In: *Results from the USDA's 1994-96 Continuing Survey of Food Intakes by Individuals and 1994-96 Diet and Health Knowledge Survey*. Food Surveys Research Group, Beltsville Human Nutrition Research Center. United States Department of Agriculture. 2002.

US DOE. 2002. "Risk Assessment Information System." Bechtel Jacobs Company LLC. United States Department of Energy. Available at: http://risk.lsd.ornl.gov/index.shtml.

US EPA. 1986. *Health Assessment Document for Nickel and Nickel Compounds.* United Stated Environmental Protection Agency.

US EPA. 1989. *Risk Assessment Guidance for Superfund, Volume I, Human Health Evaluation Manual (Part A) Interim Final.* Office of Emergency and Remedial Response, United States Environmental Protection Agency. December 1989.

US EPA. 1992. *Oral Toxicity Assessment for Cobalt*. Memorandum from Kenneth A. Poirier to Roxy Barnett. Office of Research and Development, Environmental Criteria and Assessment Office, United States Environmental Protection Agency.

US EPA. 1996. *Soil Screening Guidance: User's Guide*. Office of Solid Waste and Emergency Response, United States Environmental Protection Agency, Washington DC, July 1996.

US EPA. 1997. *Exposure Factors Handbook*. Office of Research and Development, National Center for Environmental Assessment. United States Environmental Protection Agency. August 1997.

US EPA. 1999. *Risk Assessment Guidance for Superfund, Volume 1, Human Health Evaluation Manual, Supplement to Part A: Community Involvement in Superfund Risk Assessments*. Office of Emergency and Remedial Response, United States Environmental Protection Agency. March 1999.

US EPA. 2000. *Supplementary Guidance for the Health Risk Assessment of Chemical Mixtures*. Washington D.C., U.S. Environmental Protection Agency.

US EPA. 2001a. *Risk Assessment Guidance for Superfund, Volume I: Human Health Evaluation Manual (Part E, Supplemental Guidance for Dermal Risk Assessment).* Office of Emergency and Remedial Response, Interim Review Draft. United States Environmental Protection Agency. September 2001.

US EPA. 2001b. EPA Region 4 Human Health Risk Assessment Bulletins – Supplement to RAGS. United States Environmental Protection Agency. Available at: http://www.epa.gov/Region4/waste/ots/healtbul.htm.

US EPA. 2001c. "Risk-based Concentration Table." EPA Region III. United States Environmental Protection Agency. Last revised 09/25/2001. Available at: http://www.epa.gov/reg3hwmd/risk/riskmenu.htm.

US EPA. 2002. "EPA Region III RBC Table." United States Environmental Protection Agency Region III, October 9, 2002. Available at: http://www.epa.gov/reg3hwmd/risk/rbc1002.pdf.

US EPA, 2002a. "National Primary Drinking Water Standards." United States Environmental Protection Agency, July 2002. Available at: http://www.epa.gov/safewater/mcl.html#inorganic.

US EPA. 2002b. "Child-specific exposure factors handbook." National Center for Environmental Assessment, Washington D.C. United States Environmental Protection Agency September 2002. Available at: http://www.epa.gov/ncea.

US EPA. 2002c. Arsenic, inorganic; CASRN 7440-38-2 (04/10/1998). IN: *IRIS, Integrated Risk Information System.* United States Environmental Protection Agency, Last revised December 3, 2002.

US EPA. 2002d. *Compilation of Air Pollution Emission Factors.* Volumes 1 and 2, AP-42 Fifth Edition, January, 1995 and revision for paved road emissions. U.S. Environmental Protection Agency. Dated October 2002.

US EPA. 2003. "Nickel Refinery Dust (no CASRN)". *IRIS, Integrated Risk Information System*. United States Environmental Protection Agency. Last revised 10/28/2003.

US EPA. 2004. *Risk Assessment Guidance for Superfund, Volume I: Human Health Evaluation Manual (Part E, Supplemental Guidance for Dermal Risk Assessment).* Final, Office of Emergency and Remedial Response, EPA/540/R/99/005. United States Environmental Protection Agency. July, 2004.

US EPA. 2005. *Guidelines for Carcinogen Risk Assessment.* U.S. Environmental Protection Agency, Washington, D.C., EPA/630/P-03/001F.

US EPA. 2006. *Child-Specific Exposure Factors Handbook (External Review Draft)*. U.S. Environmental Protection Agency, Washington, D.C., EPA/600/R-06/096A.

US FDA. 2000. *Total Diet Study Statistics on Element Results*, Revision 1: 1991-1998. United States Food and Drug Administration, April 25, 2000.

US NRC. 2002. *Re-evaluation of the Indoor Resuspension Factor for the Screening Analysis of the Building Occupancy Scenario for NRC's License Termination Rule.* Draft Report for Comment. US Nuclear Regulatory Commission. June, 2002.

Wahlberg, J.E. and Boman, A. 1978. "Sensitization and testing of guinea pigs with cobalt chloride." *Contact Dermatitis* **4**:128-132.

Ysart G, P Miller, M Croasdale, H Crews, P Robb, M Baxter, C L'Argy and N Harrison, 2000. "1997 UK Total Diet Study-dietary exposure to aluminium, arsenic, cadmium, chromium, copper, lead, mercury, nickel, selenium, tin and zinc." Food Additives and Contaminants. Vol. **17(9)**: 775-786.