
Part A

Soil Investigation: Main Document

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1.0 Introduction

The ministry's report entitled *Soil Investigation and Human Health Risk Assessment for the Rodney Street Community, Port Colborne: March 2002*, has two parts. **Part A** describes the results of an extensive soil sampling program in the Rodney Street community of Port Colborne. **Part B** is a human health risk assessment that characterizes the potential risk associated with the elevated soil metal levels, and where warranted, establishes a soil intervention level intended to mitigate the potential health risks. For the purpose of Part A and Part B of this report, the Rodney Street community in Port Colborne is defined as the residential area bounded by the Welland Canal to the west, the International Nickel Company Limited (Inco) refinery to the east, the south side of Louis Street to the north and both sides of Rodney Street to the south. This area is also sometimes referred to as the Eastside community.

1.1 Objectives of Part A

- 1) to determine the extent and severity of soil metal and arsenic contamination in the Rodney Street community of Port Colborne;
- 2) to characterize soil metal and arsenic contamination in the Rodney Street community;
- 3) to determine the source(s) of the soil metal and arsenic contamination in the Rodney Street community; and
- 4) to determine the mechanism(s) of soil metal and arsenic contamination in the Rodney Street community.

2.0 Scope of the Study

The objective of the (Part A) sampling program was to obtain soil chemical data that is representative of the over-all metal levels of the sampled residential yards in the Rodney Street community and would therefore be indicative of the environmental exposure that a community resident would receive from long term use of the property. This representative soil data was required for the human health risk assessment (Part B of this report). The risk assessment process integrates the soil chemical data with other relevant data to determine what the over-all exposure would be for people using the property for a lifetime. The scope of the sampling program was not to exhaustively characterize the soil metal status of all possible sample sites on every yard of every residential property, rather it was to collect soil data that was representative of each sampled property. The sampling program is described in more detail in Section 5.0 of Part A.

The soil sampling conducted by the ministry in the Rodney Street community is not necessarily the only sampling that would be conducted to characterize the contaminant status of a particular property. If the soil metal levels on a property exceed the risk-based soil intervention level

determined by the ministry's health risk assessment in Part B of this report, the ministry may order the source of the contamination to conduct additional or more detailed sampling as part of a remediation strategy for the property. This sampling would be conducted according to the ministry's *Guideline for Use at Contaminated Sites in Ontario* (MOE 1997a).

3.0 Background

The ministry has been conducting environmental investigations in the Port Colborne area since the early 1970s. What led the ministry to conduct the intensive soil investigation in the Rodney Street community is explained in Section 3.3.

The Rodney Street community is one of the oldest residential areas in Port Colborne. Archival photographs show that the current road system in the Rodney Street community was in place in 1917. The Port Colborne municipal tax records obtained from the City of Port Colborne indicate that the date of home construction in this community ranges for the late 1800s to the 1970s, with about 40% of the homes built before 1920, about 54% of the homes built between 1920 and 1950, and roughly 6% of the homes built after 1950.

Historically, the Rodney Street community was situated between two large industries; Inco's nickel refinery situated to the east of Davis Street, and the Algoma Steel/Canada Furnace Company (Algoma) iron ore blast furnace situated west of the south end of Welland Street. Although metal deposition patterns in the Port Colborne area are strongly influenced by the predominant west-southwesterly winds, in the Rodney Street community the industries were so close that emissions from both facilities impacted the community. The histories of these two sources and a summary of their processes and possible emissions are briefly summarized in the following two Sections. The source of the information in Sections 3.1 and 3.2 regarding the operational histories of these two industries is largely derived from JWEL (2001a,b,c).

3.1 International Nickel Company Limited

From 1918 to 1984, the International Nickel Company Limited (Inco) operated a nickel refinery in the city of Port Colborne. Over this period of time, five operating periods are distinguishable, based on a report prepared for Inco (JWEL 2001c).

The first operating period from 1918 to 1930 was based on the Orford Process and electro-refining. The Orford Process separated the copper and nickel components of copper-nickel matte (impure copper-nickel sulphide) that was shipped to Port Colborne from Inco's facility in Copper Cliff. Once separated, the copper sulphide was oxidized to create SO₂ and blister copper and the nickel sulphide was roasted and reduced to create nickel oxide and fine refined nickel.

In the second operating period from 1931 to 1938, the Orford Process was discontinued and transferred to the Inco facility in Copper Cliff and nickel sulphide was shipped to the Port

Colborne facility for refining to produce nickel oxide. The crude oxide was further processed through a series of reverberatory-type anode furnaces that reduced the nickel oxide at high temperature to impure nickel metal. The impure nickel then went through electro-refining to produce nickel. The residue from the electro-refining was further processed to extract platinum, palladium, rhodium, ruthenium and iridium.

In the third operating period from 1939 to 1959, nickel sulphide concentrate was brought directly to the refinery where it initially went through a sintering process to aggregate fine particles and drive off the sulphur. Some of the sinter was sold and the rest was refined on site through the reverberatory-type anode furnaces. It was then further refined through a sulfate-chloride electrolyte process to produce nickel, cobalt oxide and residue. As in the second operating period, platinum, palladium, rhodium, ruthenium and iridium were extracted from the residue.

In the fourth operating period from 1960 to 1979, both nickel sulfide concentrate and nickel oxide concentrate were processed at the refinery. The nickel sulfide concentrate went directly to the anode casting, which produced a matte that was further processed by electro-refining. Along with nickel and cobalt oxide, sulphur was produced by the electro-refining process. The precious metals continued to be extracted from the electro-refining residue. In the 1960s, a Cortrell electrostatic precipitator was installed.

In the fifth operating period from 1980 to 1990, electro cobalt refining started in 1983 and the nickel refinery was shut down in 1984.

Emissions were not monitored over the operational life of the Inco refinery and so actual emissions are unknown. However, it has been estimated that approximately 18,000 tonnes of nickel was emitted by Inco over the operational life of the refinery (JWEL 2001c). Over 58% of the nickel released from the refinery was released prior to 1938 and over 97% of the total nickel emissions occurred before 1960. The highest rate of estimated annual nickel emissions, and likely the period during which the greatest amount of nickel deposition occurred, was 1939 to 1959 during which an estimated 11,466 tonnes of nickel was released to the surrounding environment (JWEL 2001c). Figure 1 illustrates the estimated nickel emissions from Inco during the six operating process time periods.

3.2 Algoma / Canada Furnace Company

The only other large industry known to historically operate in the vicinity of the Rodney Street community that had the potential to impact soil quality across the community was the Algoma iron smelter. This smelter operated from 1913 to 1977 and was originally owned by the Canadian Furnace Company Limited. In 1950, the site was purchased by Algoma Steel Corporation Limited and operated as the Canada Furnace Division of Algoma until the facility was closed in 1977. The smelter was subsequently demolished. In this report this iron industry is referred to as Algoma.

Algoma, which was located on the east side of the Welland canal bordering on the southwest corner of the Rodney Street community, had two blast furnaces at the Port Colborne facility. The iron ore or sinter, limestone and coke for the blast furnaces were shipped to Port Colborne and stored in open stockpiles next to the facility (JWEL 2001c). Initially, the ore (if not already sintered) was sintered in a single Greenawalt sintering plant. The sinter was loaded into the top of the blast furnaces along with coke (the reducing and thermal agent) and limestone (for fluxing of the gangue (rock/other minerals in the ore) material). A blast of hot air was introduced at the bottom of the furnace to burn the coke and thus heat, reduce, and melt the sinter and limestone as it descends to the bottom of the furnace. As the coke burns it releases carbon dioxide. Some of the carbon dioxide reacts with coke particles to create carbon monoxide (an endothermic reaction). The carbon monoxide reduces the iron oxides to iron. The molten iron and slag was collected at the bottom of the furnace and periodically poured (tapped) into iron ingots referred to as “pigs”.

The waste gas from a blast furnace contains carbon monoxide plus particulate. The particulate was removed and the waste gas was used as fuel for heating the five stoves that Algoma used to heat the air for the two blast furnaces. Emissions from Algoma may have included arsenic, iron, magnesium, possibly beryllium, boron, manganese, calcium, phosphorous, sulphur, silicon, plus substantial particulates (dust).

3.3 Ontario Ministry of the Environment Investigations

Between the years 1972 and 1999, the Ontario Ministry of the Environment (MOE, or the ministry) conducted numerous investigations to document the impact of Inco’s emissions on soil and vegetation in and around Port Colborne. These investigations concluded that emissions from over half a century of nickel refining had resulted in elevated levels of heavy metals in soil in various locations throughout the Port Colborne area. Nickel, copper and cobalt concentrations in surface soil (0 - 5 cm depth) were elevated in residential communities adjacent to Inco and for a considerable distance downwind (east-northeasterly) of the refinery to levels which could or did cause injury to vegetation (phytotoxicity). Generally, the observed vegetation impacts were to farm crops east of Inco and to silver maple trees east of the canal and south of Highway 3. Silver maple is a species of tree that is particularly sensitive to many pollutants, including nickel.

With the benefit of hindsight (MOE soil quality guidelines were not available prior to 1996), it is apparent that the levels of nickel, copper and cobalt identified in soil over a large area of Port Colborne as a result of these early MOE investigations are consistently and substantially elevated above MOE effects-based soil guidelines for phytotoxicity published in Table A of the MOE’s Guideline (MOE 1997a). By contrast, the soil arsenic, zinc and selenium levels found in those investigations exceed normal Ontario Table F (MOE 1997A) background ranges in a few areas, and even less frequently exceed Table A effects-based guidelines for phytotoxicity (zinc) and effects on grazing animals (selenium). The soil arsenic levels in these early investigations very rarely exceeded the Table F background guidelines. Very occasional exceedences of the Table A

guideline for arsenic occurred in agricultural soil on farms immediately east of Inco. A more detailed description of the MOE soil guidelines, how they are intended to be used in the remediation of contaminated sites, and how the ministry uses them in environmental investigations, is provided in Section 4.0.

The MOE Table A effects-based guidelines for nickel, copper, cobalt, arsenic and zinc are all based on phytotoxicity (injury to vegetation). The Table A criterion for selenium is based on the protection of grazing animals. Numerous MOE studies conducted on Port Colborne farms in the 1970s and 1980s documented toxicity to agricultural crops as a result of ambient air SO₂ fumigations and heavy metal soil contamination (MOE 1977, MOE 1978b, Ontario Ministry of the Environment and Agriculture Canada 1980, MOE 1981; Ontario Ministry of the Environment and Ontario Ministry of Agriculture and Food 1983). Up to 1991, the highest soil nickel concentration that could be proven to exist through repeat sampling in the Port Colborne area was 9,750 µg/g (MOE 1994b). Higher soil nickel levels were very occasionally encountered at a few sample sites close to Inco, however, when the sites were re-sampled these high levels could not be validated. A human health risk assessment using this maximum soil nickel level (9,750 µg/g) was jointly published by the MOE and Regional Niagara Public Health Department in 1997. It was concluded that based on a multi-media assessment of potential risks, *no adverse health effects are anticipated to result from exposure to nickel, copper or cobalt in soils in the Port Colborne area* (MOE 1997d).

Additional extensive soil sampling was conducted by the MOE in the City of Port Colborne and the surrounding area in 1998 and 1999 and demonstrated that soil nickel concentrations exceed the MOE Table F soil background-based guideline of 43 µg/g up to 28 km downwind of the refinery, covering a 345 km² area of the Niagara peninsula (MOE 2000a, MOE 2000b). Furthermore, soil nickel levels exceeded the MOE Table A effects-based guideline of 200 µg/g for phytotoxicity for a distance of up to 3 km downwind of Inco over an area of almost 29 km². In addition, copper and cobalt also exceed their corresponding effects-based Table A soil guidelines in smaller areas of the community, mainly immediately east, north, and northeast of the refinery. The derivation and significance of MOE guidelines are described in Section 4.0.

MOE surface soil sampling conducted in 1991 in the vicinity of the Rodney Street community immediately west and northwest of Inco found that soil nickel concentrations in the general area ranged from about 2,000 µg/g to about 4,000 µg/g (MOE 1994a). However, this soil sampling was incidental to a study of general phytotoxicity impacts to agricultural areas of Port Colborne focussing on areas where earlier work had indicated both high soil concentrations and vegetation impacts. No properties on Rodney Street itself were sampled in these early ministry investigations. As a result, very few surface soil samples were collected and little depth sampling (deeper than 5 cm) was done in this part of Port Colborne (the highest soil nickel concentration at 5 - 10 cm was 2,750 µg/g). Concentrations in this range were confirmed by repeated sampling over several years, and so were believed by the ministry to represent soil metal levels in urban areas of Port Colborne.

During a public information forum held in January 2000 at the Port Colborne city hall, a resident of Rodney Street requested that the ministry sample soil on his property. MOE Phytotoxicology scientists sampled the front and back yards of the property in June 2000. Analysis of the soil samples revealed that soil nickel concentrations at depth (10 - 15 cm) were much higher (~14,000 µg/g) than previously believed to be present in this part of Port Colborne. In addition, soil copper, cobalt, arsenic, lead and zinc concentrations at depth also exceeded their respective MOE Table A effects-based guidelines. MOE human health toxicologists conducted a screening level risk assessment on the new soil data and determined that the health-based nickel reference dose was exceeded for the maximum nickel concentration found in the front yard of this Rodney Street property. The human health reference dose calculations incorporate considerable safety factors, and although an exceedence of the nickel reference dose does not mean that an adverse health effect will occur, it does trigger the need for further investigation.

As a result of the findings for the single Rodney Street property, the Medical Officer of Health requested additional sampling of residential properties on Rodney Street. This additional sampling of front and back yards was completed October 3 and 4, 2000. The results showed a wide variance in soil nickel concentrations from one property to the next, and in some cases between yards on the same property. The highest soil nickel concentration was 17,000 µg/g, but several properties were substantially above the 2,000 µg/g to 4,000 µg/g nickel range that was anticipated for this area of Port Colborne, based on the ministry's 1998 and 1999 studies (MOE 2000a, MOE 2000b). On some properties the nickel concentrations were highest in the surface soil and lower at depth, while on other properties the reverse was observed. Properties with higher soil metal levels were sometimes adjacent to properties with much lower metal concentrations. Soil nickel concentrations tended to be higher in the front yards of Rodney Street properties than the back yards. This may reflect re-entrainment of contaminated dust along the roads or snow plowing and piling of dust-contaminated snow. In addition to unexpectedly high nickel, copper, and cobalt levels, the soil zinc, arsenic and in some cases lead concentrations, were also elevated on some properties and were inconsistent with levels previously observed elsewhere in the Port Colborne area. While collecting soil from the Rodney Street properties it was observed that some areas of some yards had considerable non-soil material, such as concrete, brick, and wood rubble, metal pieces, and what appeared to be cinders, slag and possibly ash. This suggested that some areas of what is now Rodney Street may have historically received fill, possibly residential refuse, or industrial process waste.

In an open letter to the residents of Port Colborne (December, 2000) concerning nickel, copper and cobalt in surface soil in and around Port Colborne, Inco stated that, "*Inco no longer refines nickel in Port Colborne, but we do acknowledge these metal levels are the result of Inco's historic operations in Port Colborne*" (Inco 2000).

If the source of the unexpectedly high soil metal levels encountered on Rodney Street in October 2000 was contaminated fill then the extent of the soil contamination was anticipated to be quite limited (eg., isolated pockets, or isolated properties). If the source of the contamination was

fugitive or stack emissions from local industries then the soil concentrations would be expected to be more widespread and quite high over the general area and decrease with increasing distance from the source(s) (eg., properties beyond Rodney Street). The October 2000 Rodney Street data introduced new environmental information, in that the nickel levels were higher than anticipated and lead, arsenic, zinc, selenium and antimony were encountered above generic guidelines. Although Inco is the known source of nickel in the broader Port Colborne area, Inco may not be the source of these other contaminants.

The variability of the soil metal levels between properties made it difficult to judge the extent of the contamination. Therefore, in order to determine the extent and severity of surface soil metal contamination, all residential properties in the Rodney Street community were sampled by the ministry from November 8 to 17, 2000. In addition to the residential property sampling, soil trenches were dug at several locations in the vicinity of Rodney Street to determine if soil was contaminated at depth. Also, the City of Port Colborne requested that the MOE sample the playground located on the east side of Welland Street north of Nickel Street, as fill had been used in the construction of the berms in this park. The ministry also sampled several areas in the baseball park south of Rodney Street and west of Davis Street.

After the April, 2001 open house meeting hosted by the ministry in Port Colborne, several property owners notified the ministry that their properties, or areas on their properties, had not been sampled in the Rodney Street community-wide sampling program of November 2000. Between April and July 2001, the ministry sampled surface soil from additional residential properties. These additional properties were not sampled the previous November because access was unobtainable after repeated attempts, or they were vacant lots with obvious signs of very recent disturbance, or there was confusion about property boundaries. In at least one case, the property had been sampled in November 2000 but the owner asked that a specific section of the yard be sampled in 2001 that had not been previously sampled.

4.0 MOE Soil Guidelines

Interpretation of soil metal levels in this report is based on comparisons to the MOE *Guidelines for Use at Contaminated Sites in Ontario* (MOE 1997a). In 1996 the ministry published the soil guidelines (revised in 1997) to help owners of contaminated industrial property clean up the soil so that the property could be redeveloped for alternative uses. Although the soil guidelines were developed specifically for remediating single contaminated industrial properties, they have been used by both the ministry and the environmental consulting community to evaluate soil quality on a broader scale.

The use of the ministry's soil clean-up guidelines are voluntary, although the ministry can order property owners to follow them in order to remediate contaminated soil if the contamination has the potential to cause an off-property adverse effect, or the ministry can order the polluter to remediate if the contamination itself constitutes an off-property adverse effect.

The ministry's soil clean-up guidelines, including the SSRA approach, have been used successfully on hundreds of properties across Ontario to restore the economic and social value of previously contaminated lands.

The Table F guidelines represent background soil concentrations obtained from a MOE province-wide parkland sampling program. Soil concentrations that exceed Table F are usually indicative of a pollution source. The Table A soil guidelines are effects-based and were derived to protect both human health and the natural environment, whichever is potentially affected at the lowest concentration. Table A guidelines are not available for all chemical parameters, since for some elements there is insufficient scientific information available to establish effects-based values (i.e., strontium), or the element is considered non-toxic even at high concentrations (i.e., iron), or the element is a plant nutrient (i.e., magnesium).

An exceedence of a Table A guideline does not mean that an adverse effect will occur, it means that an effect may occur if the specific sensitive environmental receptor the guideline is intended to protect is present at the site and the soil conditions are such that the contaminant is readily bio-available (see Part A Section 5.3.3 for an explanation of plant bio-availability as it relates to ecological toxicity; Part B Appendix 5 explains bio-availability as it relates to human toxicology). For example, the nickel Table A guideline of 200 µg/g is intended to protect sensitive agricultural crops, specifically cereal grains such as oats, because these plants are injured at soil nickel levels far below most other plant species. In addition, even sensitive cereal crops will not be injured at 200 µg/g nickel unless the nickel in the soil is readily bio-available. Usually bio-availability of metals increases as: metal concentration increases; the concentration of soluble forms of the metal increase; soil pH decreases; soil cation exchange capacity decreases; soil nutrient levels decrease; soil organic matter decreases; and, soil clay content decreases/soil sand content increases.

The ministry's generic soil nickel guideline of 200 µg/g is based on eco-toxicity (injury to plants), because plants are the most sensitive environmental receptor. The ministry does not have a generic (Table A) soil nickel guideline based on human health. However, when a proponent uses the guideline to evaluate a property, the ministry has a value of 310 µg/g nickel in soil that triggers the need to conduct a human health risk assessment (MOE 1996). For example, if the soil nickel level is higher than 200 µg/g (the generic Table A guideline) but does not exceed 310 µg/g, the SSRA need only include an ecological risk assessment. If the soil nickel level is greater than 310 µg/g, the SSRA must include both an ecological risk assessment and a human health risk assessment. The 310 µg/g human health component value is neither a standard nor a guideline, it is only used as a screening level that triggers the requirement to conduct a human health risk assessment.

Regardless of the sensitivity of the soil and the presence of sensitive environmental parameters, the MOE generic soil guidelines are not used at all if a site specific risk assessment is used to evaluate the potential impact of the soil contamination and derive remedial options. The human

health risk assessment described in Part B of this report is part of a site specific risk assessment, and therefore the MOE generic soil guidelines do not apply to the Rodney Street community. However, the soil guidelines are referenced to allow comparison to background levels and evaluate the potential for adverse ecological and human health effects. For detailed information on the development and use of the ministry's soil quality guidelines, including all of the technical and rationale guideline documents, visit the ministry's soil guideline web page at <http://www.ene.gov.on.ca/envision/decomm/index.htm>.

5.0 Methods

5.1 Soil Sampling

In October 2000, sampling on 17 properties on Rodney Street was conducted to a depth of 15 cm. Since the results of this sampling showed metal levels were elevated to at least a depth of 15 cm, the sampling depth was increased to 20 cm for the soil sampling in the Rodney Street community in November 2000. Efforts were made to sample all yards on all properties in the Rodney Street community, but in some cases conditions made it impossible to collect an appropriate soil sample. For example, sampling to the 20 cm depth was not possible on every property, as occasionally stony fill was encountered. Also, some yards were covered with gravel, asphalt, or debris (e.g., vehicles, boats, car parts, construction material), which physically prevented the investigators from sampling soil. Generally, soil samples were not collected within one metre of driveways, walkways, building structures, fences and debris to reduce the likelihood of encountering local residential sources of contamination (e.g., driveway spills, eroded paint from painted surfaces). On some very small areas, this one metre buffer disqualified the area resulting in some properties not being sampled during the November 2000 investigation. At the property owner's/occupant's specific request, some of these small areas not sampled in November 2000 were sampled in April and May 2001.

Each property was assessed for sampling. A front and a back yard was usually identified, and on some properties a side yard was also included. Yards were discrete areas usually separated by physical structures such as driveways, fences, and buildings. A hand-held soil corer was utilized to collect a minimum of nine soil cores, while walking a grid, "W", or "X" pattern across the designated sampling area. Soil cores were usually collected from at least nine discrete areas of each yard sampled. Each soil core was divided into three depth intervals (0 - 5 cm, 5 - 10 cm and 10 - 20 cm) and the nine core sections for each of the three sample depths (e.g., 0 - 5 cm) were placed in one labelled polyethylene bag. The nine core sections per bag per yard are referred to as a composite soil sample.

Where only one yard was sampled using the composite single sample procedure, and soil could be obtained from all three depths, then soil would actually have been collected from a total of 27 discrete soil core sections per yard (1 yard X 9 cores X 3 depths = 27 discrete soil core sections). Duplicate sampling means the soil sampling procedure was performed twice over the same yard. A yard sampled in duplicate for which soil could be obtained from all three depths would

actually have had soil collected from a total of 54 discrete soil core sections per yard (1 yard X 9 cores X 2 replicates X 3 depths = 54 discrete soil core sections). Triplicate sampling means the soil sampling procedure was performed three times over the same yard. A yard sampled in triplicate for which soil could be obtained from all three depths would actually have had soil collected from a total of 81 discrete soil core sections per yard (1 yard X 9 cores X 3 replicates X 3 depths = 81 discrete soil core sections). Table 1 indicates how many discrete soil core sections were obtained on a property if soil was collected from all three depths and multiple yards on a property were sampled using single composite, duplicate, or triplicate sampling procedures. Assuming soil could be obtained from all three depths, the minimum number of discrete soil core sections sampled per property ranged from 27, representing 3 composite samples if only one yard was sampled, to as many as 243, representing 27 composite samples, if three yards were sampled in triplicate at all three depths. Figure 2 illustrates how a property was sampled.

The yards of all of the properties on Rodney Street sampled in October 2000 were sampled in duplicate. Of the properties in the Rodney Street community sampled in November 2000, most were sampled using single composites, while 10 percent of the properties were sampled using triplicate composites (typically two properties in each block). Properties in the Rodney Street community sampled in April and July, 2001 were composite sampled in duplicate. Duplicate and triplicate sampling was done to provide a measure of the sampling variability. Sample variability is described in Section 7.1.

5.2 Trench Sampling

Seven trenches, 2 metres long by 0.5 metre wide, were dug using a backhoe supplied by the City of Port Colborne. The trenching was done in October 2000 while the Rodney Street properties were being sampled. The purpose of the trenches was to obtain soil samples at depth to estimate how deep the contamination extended, and to observe the soil profile for signs of fill, refuse, or industrial process waste. Trenches were excavated to a depth at which contact was made with natural clay, which was about one metre in most trenches. Duplicate soil samples were removed from the sides of each trench using a trowel at three depths: 30 - 35 cm, 60 - 65 cm (which were within what appeared to be layers of coarser or discoloured soil and possibly some fill material), and 100 - 105 cm. Soil samples were placed in labelled, polyethylene bags.

The seven trenches were excavated from four areas:

- 1) Two trenches were excavated in the baseball diamond at the southwest corner of Davis Street and Rodney Street. The first trench was located on the outfield side of second base and the second trench was dug in the middle of the outfield.
- 2) Two trenches were excavated in the vacant lot situated on the south side of Rodney Street between Welland and Fares Streets. This lot was owned by Algoma from 1920 to 1992 and is currently owned by Inco. The first trench was about ten metres in from the southeast corner of

Welland and Rodney Streets, and the second trench was about ten metres in from the southwest corner of Fares and Rodney Streets.

- 3) One trench was excavated directly in front of the residence at 124 Rodney Street on the north shoulder of the road.
- 4) Two trenches were excavated on the west side of the playground located between Welland Street and Fares Street, north of Nickel Street. In addition, 0 - 5 cm, 5 - 10 cm and 10 - 15 cm duplicate soil samples were collected from eight sites along a sod-covered berm running around the north and west perimeter of the basketball court located in the same playground.

5.3 Soil Sample Preparation and Analyses

5.3.1 Metals and Hydrides

All soil samples were stored in locked vehicles while not in view of the investigators until they were delivered to the ministry's Ecological Standards and Toxicology Section for processing using standard MOE chain of custody and laboratory procedures (MOE 1993a). The samples were air dried and passed through a 2 mm sieve where vegetation and stony debris were removed, and then ground to pass through a 355 micron sieve. The fine soil fraction was transferred to the MOE Laboratory Services Branch (LSB). Because of the desire to have the analyses conducted as quickly as possible, LSB arranged to have the Rodney Street community soil samples analysed by Agat Laboratories, an accredited private environmental laboratory. LSB imposed a strict quality management regime on the private lab to ensure data integrity (refer to Section 5.4). The soil samples were analysed for the following metals: aluminum, barium, beryllium, cadmium, calcium, chromium, cobalt, copper, iron, lead, magnesium, manganese, molybdenum, nickel, strontium, vanadium and zinc. For these metals, samples at both the MOE LSB and Agat were analysed using an accredited analytical method comparable to MOE protocol E3073L1. In addition, arsenic, antimony and selenium (hydrides) were also included in the soil analysis. For the arsenic, antimony and selenium, samples at both MOE LSB and Agat were analysed using an accredited analytical method comparable to the MOE protocol E3245L1. Unless otherwise specifically identified, all the soil data in this report are reported as dry weight totals.

5.3.2 Determination of Soil pH

To assist in the interpretation of the plant bioavailability of the soil contaminant concentrations, soil pH was determined for a subset of 36 soil samples collected from across the ten blocks of the Rodney Street community. Soil pH was determined in distilled water using MOE standard protocols (MOE 1985).

5.3.3 Plant-bioavailable Soil Nickel

Between 1969 and 1979, the ministry conducted several investigations and prepared many reports on soil and vegetation chemistry in the Port Colborne area. During this time, soil was collected from urban and rural properties (typically mineral soil) and selected farm fields (both mineral soil and organic “muck” soil) to determine plant-bioavailable soil nickel concentrations using a weak ammonium acetate extraction. Ammonium acetate extraction was not done on samples collected in 2000 or 2001.

In order for the nickel in the soil to potentially cause plant injury the nickel must be dissolved in soil water so it can be taken up by plant roots. The amount of nickel dissolved in soil water depends on the chemical form of the nickel and the chemical and physical properties of the soil and is not always directly related to the amount of nickel in the soil. Therefore, higher soil nickel levels do not necessarily mean a greater risk of plant injury.

The plant-bioavailable nickel data in Part A of this report relates to soil conditions that affect the natural ecosystem, specifically vegetation. The ammonium acetate extraction used on soil is intended to simulate the leaching of nickel from the soil by natural rainfall, soil water movement, and normal soil microbial activities. The extraction process used to estimate the leaching of soil metals into the human gastrointestinal tract to evaluate the potential impact on human health from the ingestion of contaminated soil is an entirely different test and is covered in Appendix 5 of Part B of this report.

5.3.4 Nickel Speciation

Nickel can occur in various forms in the natural environment and industrial processes can produce several types of nickel. Examples of forms of nickel are nickel oxide, nickel sulphide, nickel subsulphide, nickel chloride, and metallic nickel. These various forms are often referred to as nickel species. The species of nickel in the soil can have an important impact on how available the nickel is and therefore its potential toxicity to both the natural ecosystem and human health.

Metal speciation in soil samples is non-routine, and few labs can provide quantitative results. Nickel speciation was conducted on selected soil samples from the Rodney Street community. The ministry shared processed soil composite samples from properties on Rodney Street with Inco and both organizations had qualitative tests conducted at different laboratories. Inco used their own research facility and the MOE used the Ministry of Northern Development and Mines Geoscience Laboratory in Sudbury. In addition, the ministry submitted selected soil samples for quantitative analysis to Lakefield Research in Ontario and to the Stanford Synchrotron Radiation Laboratory in California.

5.4 Data Management and Laboratory Quality Control

In order to expedite the analysis of the more than 1,500 soil samples collected from the Rodney Street community in November 2000, the MOE retained the services of Agat Laboratories, an accredited private laboratory. Agat analysed the samples collected from the Rodney Street community in November 2000. The MOE Laboratory Services Branch analysed the samples collected from the Rodney Street properties in October 2000, and the additional properties in the Rodney Street community collected from April to July, 2001. The management of the contract lab was carried out by senior scientists and managers of the MOE Laboratory Services Branch (LSB) Quality Management Unit. The contract with Agat Laboratories was established only after a thorough review of their proposal and laboratory procedures and a successful analysis of preselected test samples. The MOE analysed the first 100 soil samples from the November 2000 sampling of the Rodney Street community. These same 100 samples were then analysed by Agat Laboratories and the results compared with those obtained by the MOE LSB. This initial comparison was done by staff of the MOE LSB Quality Management Unit. The Agat Laboratory individual element results had to be within 20% of the corresponding MOE results for the same sample. Only after this first quality assurance target was met successfully were the remaining Rodney Street community samples sent to Agat Laboratories. This potential difference ($\pm 20\%$) is the analytical component of the combined sampling and analytical “error” described in Section 7.1.

All sample submissions sent to Agat Laboratories contained at least four “check” samples which had been previously analysed as part of the original 100 samples. Each submission also contained field replicate samples, which could be used to measure repeatability of the sampling and analytical processes. The preliminary acceptance criteria were 20% for the check samples and 50% for the field replicates. The field replicates had a higher acceptance bracket because it was known from previous work in Port Colborne that between-replicate variability increased as the soil contaminant concentration increased. This is a common occurrence for non-homogeneous samples.

Data was quality assured in several ways. Data checking was performed by the manager and a senior scientist of the MOE LSB Spectroscopy Section, as well as Phytotoxicology scientists. If the results for the “check” samples and the replicate data were acceptable, then the rest of the data were checked for outliers. Outliers were determined by reviewing the ratios of elements between samples in each laboratory submission. Several sample submissions were repeated because the ratios of certain elements did not match the observed general trend. In almost all cases, repeat analysis by Agat Laboratories, and in some cases by MOE, confirmed the original result. Repeat analysis was continued until the data either matched the original “check” samples or were confirmed by MOE analysis. Generally, outliers were found to be due to the improper use of dilution factors. Outlier sample results were either re-calculated or Agat Laboratories was required to repeat the analyses. The variability in field replicates that was finally reported was much less than the 50% used as an acceptance criteria. Once all these criteria were met, the data

were released to the principal authors for use in the preparation of this report.

Agat experienced some difficulty consistently obtaining the agreed to detection limits of 0.1 µg/g for selenium and 0.4 µg/g for antimony. However, since identification of samples exceeding the ministry's effects-based guidelines of 10 µg/g for selenium and 13 µg/g for antimony was the critical factor, occasional problems obtaining the agreed upon detection limits did not jeopardize data quality.

6.0 Results

6.1 Soil Results

6.1.1 Data Tables

Differences between summary statistics given in this report and the October 2001 draft report are because the summary statistics in the current report include both the 2000 and 2001 sample data for the Rodney Street community. The analytical results for all soil samples taken from residential properties in the Rodney Street community in 2000 and 2001 are listed in Table 2 (2000) and Table 3 (2001). Table 4 lists the soil results of the trench samples collected in 2000. Tables 2 and 3 are generically coded so that individual property addresses cannot be determined. All the owners/occupants of residential properties sampled in the Rodney Street community in 2000 and 2001 have been contacted and provided with a copy of these tables and the corresponding codes to allow them to identify the data pertaining to their properties.

In addition, the 2000 and 2001 residential soil data are summarized in four tables that list the minimum, maximum, mean and median datum plus the 10th to the 90th percentiles. Table 5 summarizes the 0 to 5 cm sampling depth from all residential properties, Table 6 summarizes the 5 to 10 cm depth data, Table 7 summarizes the 10 to 20 cm depth data and Table 8 summarizes the soil data by all depths combined.

The distribution of nickel in soil in the Rodney Street community is very skewed. The maximum soil nickel level is 17,000 µg/g, which was detected in a soil sample collected in the original Rodney Street soil sampling in October 2000, confirming that these very high soil nickel levels are not wide-spread throughout the community. Only 10% of the samples had soil nickel concentrations greater than 5,592µg/g and only 20% of the samples had soil nickel concentrations greater than 3,784 µg/g (see Table 8). The average soil nickel concentration on residential properties in the Rodney Street community is 2,508 µg/g, which is consistent with the data in the 1998 and 1999 Port Colborne MOE soil investigations that predicted the soil nickel levels in this community are in the range of 2,000 µg/g to 4,000 µg/g. The residential soil data are further discussed in Section 7.

6.1.2 Soil pH

Soil results for the 36 soil samples submitted for pH determination are listed in Table 9. The pH of soil in the Rodney Street community is very consistent, ranging from 6.85 to 7.76 and averaging 7.23. This neutral pH is characteristic of fine-textured mineral soil and common in surface soil in southern Ontario. The soil pH was determined on soil samples collected (mostly from) from the 0 - 5 cm sample depth.

6.1.3 Soil Nickel Plant-Bioavailability

The plant-bioavailability of nickel in Port Colborne pH-neutral mineral soil averaged 0.22%, whereas the plant-bioavailability of nickel in acidic organic (muck) soil averaged 8.49% (MOE 1975, MOE 1977, MOE 1978b). None of the samples analysed for plant-bioavailable nickel were collected from sites where slag or other process waste was observed, and because of the distance from Inco all sites were believed to have been contaminated through atmospheric deposition. The plant-bioavailable nickel levels were much higher in the muck soil. These soils are naturally more acidic, often with a pH less than 6.0, which would place much more nickel in soil water solution and therefore increase its availability to plants. With a neutral to slightly alkali pH (the average soil pH in the Rodney Street community is 7.23) and with most of the nickel being in the form of insoluble nickel oxide, very little of the nickel in the soil in the Rodney Street community is likely to be available for uptake by plants.

These results indicate that the potential for nickel to go into solution in the soil and be available for uptake by vegetation (plant-bioavailability) is very small for the type of mineral soil that predominates in the Port Colborne area. A very low ammonium acetate soil leach is consistent with nickel being in the form of the very insoluble nickel oxide or simply elemental nickel metal. In order for nickel in the soil to injure vegetation it must be dissolved in soil water, be taken up through the roots and translocated throughout the plant. With such low plant-availability there would be very little dissolved nickel in soil water resulting in a small potential for vegetation uptake and injury. This would explain the paucity of characteristic nickel injury symptoms on vegetation throughout Port Colborne, particularly in the Rodney Street community, even though soil nickel levels far exceed the ministry's effects-based Table A nickel soil guideline. After the shutdown of the refinery in 1984, nickel injury on sensitive species of vegetation has rarely been observed in Port Colborne. This corroborates the low soil nickel plant-bioavailability results and suggests that most of the nickel injury observed on vegetation up to 1984 was likely from absorption of nickel deposited on the foliage from ambient air, and not from translocation of soluble nickel from nickel-contaminated soil. No plant injury believed to be caused by nickel toxicity was observed in the Rodney Street community during the course of sampling in 2000 and 2001.

The low soil plant-bioavailability would also explain the generally poor relationship between soil nickel levels and nickel levels in residential garden produce observed in Port Colborne. The

nickel levels in garden produce were not consistently higher from properties that had high soil nickel concentrations. In fact, a linear relationship between plant nickel levels and soil nickel levels would not be expected. Plants growing in soil with high soil nickel levels may actually have lower tissue nickel levels than plants growing in soil with moderately high nickel levels, because nickel is toxic to plants and injured plants are less physiologically active and so less able to take up compounds dissolved in soil water. The relationship between nickel levels in soil and nickel levels in garden vegetables is given in greater detail in Part B, Appendix 4 of this report.

6.2 Nickel Speciation

6.2.1 Qualitative Nickel Speciation Results and Mineralogy

Nickel concentrations reported in Tables 2 to 4 are all total concentrations, with no distinction made regarding the form (species) of the nickel. Nickel is present in the soil in various forms (e.g., nickel oxide, nickel chloride, nickel sulphide, nickel subsulphide). In this section *Qualitative* nickel speciation results are presented. *Qualitative* means that the analytical techniques used can only determine whether a particular nickel species is present in the soil and not the concentration of the nickel species. *Quantification* of nickel species in soil is given in the next section entitled *Quantitative Nickel Speciation*. *Quantitative* means both the presence and the concentration of the various nickel species in soil can be determined.

Speciation of nickel in soil is non-routine, requiring specialized laboratory equipment and specially trained technicians/scientists. This type of analysis is not routinely conducted in environmental investigations, and was not previously done on Port Colborne soil samples. In previous MOE reports pertaining to soil contamination in Port Colborne, the metal concentrations have been reported as the “total” (refer to Section 5.3.1) amount of nickel in the soil. Prior to 2000, the MOE soil studies in Port Colborne did not speciate the various metal compounds in local soil. The main issue arising from the health related concerns expressed by the community was the species of nickel present in Rodney Street community soils. Of particular concern were the relative amounts of nickel oxide in the soil, as nickel oxide is a component of nickel refinery dust. Nickel refinery dust is a mixture of nickel compounds that is a potential lung carcinogen if inhaled.

Nickel speciation was conducted on selected soil samples collected from properties on Rodney Street (not the Rodney Street community, but just properties on Rodney Street) independently by both the Ontario Ministry of Northern Development and Mines (MNDM) Geoscience Laboratory in Sudbury (MNDM 2001) and by Inco (Inco 2001a). Jacques Whitford Environmental Ltd. (JWEL) also submitted selected soil samples from across Port Colborne for metal speciation as part of their sampling program to determine the contaminants of concern for the Community Based Risk Assessment currently underway in Port Colborne (Enpar 2001).

The MNDM report concluded that nickel oxide was detected in the magnetic fraction of each sample, and that no other nickel form or species was detected in either the magnetic or non-

magnetic fractions of any of the samples. The Inco report had similar conclusions: the only forms of nickel identified in soil samples collected from Rodney Street were elemental nickel, nickel alloys (i.e., nickel-copper alloy), and nickel oxide, but specifically neither sulphidic or halide forms of nickel were detected. The results from the more recent work conducted by JWEL concurred with both the MNM and Inco reports, in that nickel oxide was the only nickel compound detected, with no evidence of either sulphate or sulphide nickel forms.

Some of the Rodney Street property soil samples examined for nickel speciation by MNM and Inco were very heterogeneous, containing up to 40% non-soil material, such as wood, construction rubble, metal, and slag. The most abundant non-soil phase was iron oxide, but included metallic iron, carbonaceous particles that could be coke or coal dust (probably coke because of the presence of gas-bubbles), and the occasional arsenic grain hosted in iron oxide and associated with copper, nickel, antimony and molybdenum. The iron oxide was often in the form of dendritic iron oxide crystals, suggesting an artificial origin. Precious metal inclusions with platinum and palladium were identified in several particles in one sample, which were alloyed with copper and hosted in nickel oxide (Inco 2001a).

The origin of the non-soil material in these samples may be inferred from its chemistry. The presence of nickel, copper, cobalt and precious metals suggests an Inco origin, because Inco's emissions are known to have included nickel, copper and cobalt, and Inco currently re-processes its waste to recover precious metals. However, the presence of quantities of manganese slag with high silicate and iron concentrations in some samples is more typical of blast furnace slag, and suggests some of the iron-based material found in soil from Rodney Street properties may have originated from Algoma.

Some areas of some of the properties in the Rodney Street Community may have received industrial fill from either Inco or Algoma, and that fill may have contributed to the elevated soil metal and arsenic levels on those properties. The current location and history of slag and related process waste on the former Algoma site is not currently known, however Inco has information of this nature for slag waste on its property. Orford slag is a waste from the Orford process used by Inco from 1918 to about 1938 to separate copper from nickel. A single Orford slag sample was examined by Inco from their on-site Orford slag pile and the results made available to the ministry (Inco 2001b). This Orford slag sample contained soda and sulphur, and had cobalt and copper levels that were about ten times higher than the average of the Rodney Street soil samples examined by Inco and the ministry. The Rodney Street soil iron levels are comparable to the slag sample and the soil nickel levels are about twice as high as in the slag sample. In addition, the nickel and copper-bearing phases present in the Orford slag are mostly sulfides, which is in contrast to the Rodney Street soil samples in which nickel oxide is the most common nickel form. These data suggest that the non-soil material collected from a few properties on Rodney Street is not primarily Orford slag from Inco. Because the non-soil or fill material does not resemble Orford slag does not mean it did not come from Inco, since it is not known when the fill was deposited in this area and Inco only used the Orford process for a portion of the refinery's

operating period. Over the operating life of the Inco refinery nickel oxide has been both a feedstock and product and so its association with wastes from Inco is not unexpected.

On Rodney Street and in the Rodney Street community, many factors have affected the soil composition and chemistry, including the possible dumping of waste materials from both Inco and Algoma, deposition of atmospheric emissions from both Algoma and Inco, domestic sources of contaminants, landscaping practices, and natural soil processes associated with soil microbial activity. Therefore, the soil chemistry of some properties in the Rodney Street community that appear to have received fill would not be expected to exactly match the chemical composition of a particular waste from any particular industrial source. Specifically, the nickel, nickel-copper alloys and nickel oxide, would be expected to have originated from Inco processes, and the manganese slag with high iron concentrations and coke-like material are more likely to have originated from Algoma processes. The qualitative speciation results and mineralogy data suggests that some soil on the from Rodney Street properties contain a mixture of waste materials from both Inco and Algoma.

6.2.2 Quantitative Nickel Speciation Results

The preceding section on qualitative nickel speciation reported that Rodney Street soil samples examined for nickel speciation for the ministry by MNDM and by Inco both confirmed the presence of nickel oxide but no other nickel species. These analyses could not quantify the concentration of nickel oxide. Therefore, the ministry contracted two additional laboratories to conduct further nickel speciation testing in an attempt to quantify the various nickel forms in the soil.

Quantification of metal speciation in soil samples is non-routine, leading edge science. The ministry sent 20 soil samples from the broader Rodney Street community to Lakefield Research in Ontario and six samples to the Stanford Synchrotron Radiation Laboratory in California. The results of these analyses are summarized in Table 10. The ministry's Laboratory Services Branch, in addition to analysing these same 20 samples for total nickel, also provided technical and scientific guidance on the speciation methods used by Lakefield and they sought independent input from the Federal government regarding Lakefield protocols.

Composite soil samples were collected from ten sites in the Rodney Street community. Each sample was split in two with half the sample processed according to standard MOE soil preparation protocols (drying, grinding and sieving) and the other half submitted as a dried unprocessed bulk sample. Sub-samples of all of these 20 samples were sent to Lakefield Laboratories for determination of total nickel and nickel species by a sequential leaching process. Sub-samples of the ten processed samples were sent to the MOE laboratory for total metal analysis. Two sub-samples of the processed samples were sent to Saint Mary's University for total metal analysis and to the Stanford laboratory for speciation analysis. Lakefield used a sequential leaching process to isolate and then quantify the various metal species groups. The

Stanford lab used SEM-XAFS (scanning electron microscope - X-ray absorption fine structure).

The Lakefield and Stanford laboratories were both able to provide quantitative estimates of speciated nickel. Lakefield identified four fractions of nickel in the processed and unprocessed samples; soluble nickel, nickel sulfide, nickel metal and nickel oxide. The processing status made no appreciable difference in the results. On average, nickel oxide comprised just over 80% (range from 54.6% to 87.7%) of the total nickel in the Rodney Street soil samples analysed by Lakefield. Lakefield found nickel metal present at 11.30%, nickel sulphide at 7.66%, and soluble nickel at 0.37% of the total nickel detected in the processed soil. By comparison, the six samples analysed by the Stanford lab averaged 89.5% nickel oxide, but this lab did not observe any other nickel species. Inco's ongoing analytical work in Port Colborne indicates that the majority of the nickel present in soil in the Rodney Street community is in the form of nickel oxide with traces of nickel metal and nickel:copper and nickel:cobalt alloys. However, Inco has not identified nickel sulphide or other nickel species in any of the Rodney Street soil samples it has examined.

The analytical procedures employed by the Lakefield and Stanford labs are very different, and at this time there is not a weight of evidence to suggest that one process is more accurate or more reliable than the other. In this case there are three labs (Inco, Enpar and Stanford), all using Scanning Electron Microscopy technology, that detected only nickel oxide, and one lab (Lakefield) that detected traces of other nickel species in addition to nickel oxide. All labs concur that nickel oxide is the most abundant nickel species present in the soil. Therefore, the conclusions to be drawn from the new nickel speciation tests reaffirm the position originally stated by the ministry that the majority of the nickel in the soil in the Rodney Street community is in the form of nickel oxide. Considering the uncertainty associated, at this time, with this leading edge analytical technology, the presence of nickel species other than nickel oxide in trace concentrations in soil in Port Colborne is speculative until it can be confirmed with repeat analysis of samples from multiple locations using different laboratories.

Table 11 summarizes data from a 1978 report of analyses of Port Colborne refinery dusts (MOE 1978a). This report provides elemental analysis of dust samples collected from the Cottrell Precipitator, the Cobalt Multiclone Stack, the Tumblast Stack, and the Submerged Combustion Evaporator Stack. It must be noted that these data reflect results from one sample from each of the precipitator or stacks collected on a single day and therefore may not be representative of emissions from Inco over its operating life. As mentioned in this 1978 report, the data from an onsite Cottrell Precipitator captured dust from the Anode Reverb Furnaces during charging, smelting, and on-stream periods of operation, and so should reflect the particulates present in stack and fugitive emissions at the time of sampling in 1978. The precipitator dust was 38.7% nickel, 10.5% lead, 7.6% copper, 7.1% sulphur, 0.66% cobalt, 0.61% iron, 0.38% arsenic and 0.14% zinc. The main nickel component was reported as nickel oxide and the main lead component was reported as lead sulphate. In addition, "minor phases" (not quantified) of hydrated nickel and copper sulphate were identified. Therefore, most of the nickel in precipitator dust, and so likely in the stack and fugitive emissions at the time of sampling in 1978, was nickel

oxide.

It is important to note that the MOE Table A effects-based guideline for nickel was developed for the total nickel concentration in the soil and is not based on nickel oxide; i.e., it is a nickel guideline, not a nickel oxide guideline. The ministry does not have a nickel oxide guideline for soil, nor is the ministry aware of a nickel oxide soil guideline for any other environmental agency.

7.0 Discussion

7.1 Sample Variability and Data Confidence

Section 5.1 discussed the strategy used to sample the properties in the Rodney Street community. The sample strategy used in the Rodney Street community was appropriate for its intended purpose, which was to collect information on soil contaminant levels that reflect representative environmental exposures to people using the property. All sampling strategies, no matter how thorough, have inherent variability because they can only estimate, not measure, the soil chemical concentrations. The term used to identify this inherent variability is “sampling error”. It is a statistical term used to identify uncertainty, it does not imply the data are wrong.

Statistical analysis was carried out on the replicated samples collected from the two properties on each block that were sampled in triplicate (single samples were collected from all other properties in the Rodney Street community and the properties on Rodney Street were sampled in duplicate). Within-site sampling and analytical variability was acceptable for all elements excluding antimony and selenium, in that the standard deviation of the replicates was less than 20% of the mean value for the property. The standard deviations of the replicate samples for antimony and selenium, expressed as percentages of the mean concentration, were 24.2% and 24.6%, respectively. The concentrations of both antimony and selenium are naturally very low in soil, usually less than 0.2 µg/g. The high variability between sample replicates for these two elements was related to the difficulty that the contract laboratory had in consistently obtaining detection limits that were in the 0.2 µg/g range. A low detection limit for these elements was not a selection criteria for the contract lab, and since the concern was not to miss high soil levels, the problem of detection limit consistency did not jeopardize data quality.

7.2 Soil Results for Residential Properties

Summary statistics presented in this section for soil results from residential properties are based on samples collected in both 2000 and 2001. Summary statistics given in the October 2001 draft document are slightly different because they were based on only the 2000 sampling results.

MOE Table A effects-based generic criteria (residential/parkland land uses - medium/fine textured soils) were exceeded in soil on one or more of the residential properties in the Rodney Street community for the following ten elements: antimony, arsenic, beryllium, cadmium, cobalt,

copper, lead, nickel, selenium and zinc. The Table A guideline (refer to Part A Section 4.0) for lead, antimony and beryllium are based on human health. These are intended for generic clean-up or as a trigger for a detailed human health risk assessment. The criterion for selenium is based on the protection of grazing animals. The criteria for arsenic, cadmium, cobalt, copper, nickel and zinc are based on ecological protection, specifically plant growth. Soil nickel concentrations exceed the Table A effects-based generic criterion of 200 µg/g on almost all of the properties in the Rodney Street community. It was evident from the condition of the few properties that did not exceed the nickel guideline that they had undergone extensive landscaping, so the contaminated soil had either been buried below the 20 cm sampling depth, or been removed and replaced with clean soil.

Elevated soil nickel levels were expected in the Rodney Street community, since the contaminant contour maps prepared for the 1998 and 1999 MOE Port Colborne soil investigations indicated that soil nickel concentrations in the area could range up to 5,000 µg/g. Similarly, soil cobalt and copper concentrations were expected to be high, and about 70% of the properties in the Rodney Street community exceeded the Table A effects-based criteria for these two elements (Table 12). A high percentage (approximately 70%) of the properties sampled in this investigation also had soil lead levels above the Table A effects-based criterion. Soil beryllium levels on almost 50% of the properties exceeded the Table A effects-based criterion. The effects-based criteria for arsenic and zinc were exceeded on about 50% and 40% of the properties, respectively. Table A guideline exceedences were rare for antimony, cadmium, and selenium, occurring on only three properties (about 2 %) for antimony, and one property each (less than 1%) for cadmium and selenium.

7.3 Contaminant Contour Maps

7.3.1 Map Preparations and Precautions

To illustrate the spatial distribution of soil contamination in the Rodney Street community, contaminant contour maps were created for selected elements using Surfer™ and ArcView™ computer mapping programmes. Because of the technical complexities associated with creating contour maps from a very large data base, and because no spatial pattern was evident for some elements, maps were created only for the elements of specific interest and those that exceeded the MOE Table A effects-based guidelines for which the guideline rationale was health-based. Zinc was excluded, because with few exceptions, the exceedences of the Table A effects-based criteria were marginal, and the rationale for the guideline is not health-based. Iron was included because it is a potential emission from both Inco and Algoma, even though environmentally it is essentially a benign contaminant, a spatial pattern may assist in contaminant source allocation. Therefore, maps were prepared for the following ten elements: antimony, arsenic, beryllium, cadmium, cobalt, copper, lead, nickel, selenium and iron (Maps 1 - 30). A separate contaminant contour map was produced for each of the three sampling depths (0 - 5 cm, 5 - 10 cm and 10 - 20 cm) for each element. All the soil data collected in both 2000 and 2001 from the Rodney Street community, excluding the trench samples, was included in the contaminant contour maps. Therefore, the contour maps in this report may appear slightly different than the contour maps in

the October 2001 draft report, which were created using only the 2000 soil data.

Two software packages were used to generate the maps. The data analysis and creation of the concentration contours were produced using Surfer™ (Version 7.0 for Windows 95/NT, by Golden Software Inc.). The output from Surfer™ was then imported into ArcView™ GIS (Version 3.2, by Environmental Systems Research Institute Inc.) and combined with base maps to produce the final maps. Details concerning the process used to generate the maps are provided in Part A Soil Contour Maps and Figures.

These maps are statistical approximations of the spatial distribution of the different contaminants. Soil concentrations are only known with certainty at those sites for which soil was actually sampled and chemically analysed. The contours produced by the program are significantly affected by the spatial distribution of the sampling sites, the accuracy of the position information of the sampling sites, and the program options used to generate the contours. The accuracy of the contours diminishes at the edges of the map and in large areas where there are no or very few sample sites. In this case, the sampling density was almost uniform across the community inside Welland, Rodney, Davis and Louis Streets, therefore the contours should accurately reflect the residential soil conditions for the purposes used in the report. The contours may be less accurate in the area south of Rodney Street in the vicinity of the vacant lot to the southwest and the baseball park to the southeast because the density of the sampling was much lower in these two areas than elsewhere in the community. In addition, contours indicating high metal concentrations at the edge of the map (e.g., Map 24) give the impression that the area of high contamination extends beyond the edges of the map, which may not be the case because there were no sample sites on the other side of the streets at the east, north, and west map edges or beyond the vacant lot and ball park at the south end of the maps.

These maps are very helpful tools for identifying spatial trends, particularly for very large data sets. Although useful and reasonably accurate, particularly with a high sampling density as used in this study, the contour maps are still only estimates of soil concentrations based on a statistical model. The actual soil concentration is known with certainty only at the sites where the samples were collected. Therefore, the maps by themselves should not be used to “prove” a contaminant source, but should be considered relative to all available data to assist with determination of source allocation.

7.3.2 Soil Contaminant Patterns

It is evident from the contaminant contour maps, and the data in Tables 2 to 4, that soil contamination in the Rodney Street community, although extensive for some elements, tends to be patchy. Properties with much lower soil contaminant levels were often encountered between properties with much higher concentrations. Conversely, occasionally single properties with significantly elevated concentrations of some elements were surrounded by properties with much lower contaminant levels. The mechanism for the observed patchwork pattern of contamination

is related to the interaction between atmospheric deposition, placement of contaminated fill and property specific landscaping and construction activities.

Atmospheric deposition, either from fugitive or stack emissions, would result in a decreasing soil contamination gradient relative to increasing distance from the source. Fugitive emissions can be considered a series of small point sources from vents, windows, doors or other openings in the refinery or other buildings. Fugitive emissions can be a significant component of the total emissions, but they are difficult to quantify. The particulates from fugitive sources would be carried by wind currents a short distance into the surrounding community and would not necessarily be deposited evenly due to wind currents eddying around structures like trees and buildings. Particulates emitted from the stack drop out of the plume as their weight overcomes the buoying effect of the hot rising gases. Depending on the wind speed, particle size, and stack gas temperature and velocity, the particles in stack emissions can travel considerable distances before they reach the ground. For both fugitive and stack emissions, the larger denser particles will tend to be deposited closest to the source and the finer particles will tend to be carried the greatest distance. Because it is so close to both Inco and Algoma, the Rodney Street community would tend to get more deposition of larger, denser particles and be affected more by fugitive emissions than more distant areas, which would be impacted relatively more by stack emissions.

Atmospheric deposition by both stack and fugitive emissions was not constant over the operating life of Inco and Algoma. Releases to the local environment, particularly through fugitive emissions, were much greater in the early years of operation at both Inco and Algoma. An estimated 97% of the total nickel emitted from Inco was released before 1959 (Figure 1) and about 75% of the total amount of iron released from Algoma was emitted before 1959 (JWEL 2001c). Subsequent to the cessation of emissions (Inco ceased operations in 1984 and Algoma in 1977) and over time through property landscaping or redevelopment, on some properties the contaminated soil would be either diluted by coverage with clean soil or removed and replaced by clean soil. Landscaping need not be elaborate to substantially alter the surface soil (top few cm) contaminant levels. Simply filling low spots in a lawn with topsoil or re-sodding can add enough clean soil to dilute the residual surficial contamination. The contamination status of undisturbed/unlandscaped properties would remain relatively unchanged in the years since the sources closed, to create the soil contamination patchwork pattern that was observed across the Rodney Street community.

With time, even on undisturbed properties, soil contamination deposited on the surface can work its way downwards into the lower soil horizons where it is subject to further mixing and redistribution both up and down by normal soil processes (ants, earthworms, water movement, etc.). Also, industrial process waste could have been used to fill low areas, and since the waste is usually aggregate in nature, some residents may have deliberately brought it onto their property to improve drainage around homes or structures, or as construction material. Atmospheric deposition over the decades would add to the general contaminant levels on properties that did not receive fill material.

Regardless of the patchiness, some overall contaminant contour gradients and patterns are evident. The most consistent are nickel, copper, cobalt, arsenic and selenium. The concentrations of these five elements tended to be highest in the easterly and southeasterly areas of the Rodney Street community, adjacent to the Inco refinery. The patterns of nickel (Maps 22 - 24), copper (Maps 16 - 18) and cobalt (Maps 13 - 15) soil contamination were particularly similar, with the higher concentrations restricted to properties along Rodney, Davis and Mitchell Streets. The maximum soil nickel level was 17,000 µg/g detected in the 5 - 10 cm depth of a property on Rodney Street. The maximum soil copper concentration was 2,720 µg/g in a sample from the 10 - 20 cm depth of a Mitchell Street property. The highest soil cobalt concentration, also from a Mitchell Street property, was 262 µg/g in the 5 - 10 cm soil profile. Although properties with high nickel levels also had elevated copper and cobalt concentrations, the maxima for these elements did not occur on the same property.

The patterns of soil arsenic (Maps 4 - 6) and soil selenium (Maps 25 - 27) contamination were similar. The contours are driven by the elevated arsenic and selenium levels in soil on properties along Rodney Street, with the remaining contaminated properties tending to be scattered in the eastern part of the community on properties along Mitchell Street, and a few on Davis Street. Unlike nickel, copper, and cobalt, which exceed their respective Table A effects-based guidelines on the majority of properties in the Rodney Street community, the extent of arsenic and selenium contamination was much more restricted, with concentrations that were proportionately much lower. The maximum soil arsenic concentration was 350 µg/g in the 0 to 5 cm depth from a property on Rodney Street. However, most soil arsenic levels were much less, with 70% of the soil samples collected in the Rodney Street community being below the Table A effects-based guideline of 20 µg/g and about 60% of the soil samples collected being within normal arsenic background concentrations (Table 8). The property with the highest soil arsenic level was not the property with the highest soil nickel level.

Although a soil selenium gradient toward Inco was evident, only one property had selenium levels that exceeded the Table A effects-based guideline, with a maximum concentration of 19.4 µg/g in soil collected from the 5 - 10 cm depth of a property on Mitchell Street. Soil selenium levels are naturally low and therefore any elevation above background is noticeable, a fact that allowed for a contaminant gradient to be evident.

Even though soil beryllium levels exceeded the Table A effects-based guideline of 1.2 µg/g on about 47% of the properties in the Rodney Street community, unlike the other nine elements for which maps were constructed, the beryllium contaminant contour maps (Maps 7 - 9) did not indicate a consistent spatial pattern. There was a weak trend of generally slightly higher levels toward the west side of the community, but the highest individual levels occurred toward the east and northeast. The highest soil beryllium level was 4.6 µg/g, which was detected in the 10 - 20 cm depth at a property on Mitchell Street. Like the other metals, soil beryllium levels tended to be slightly higher at depth.

The contaminant contour maps for lead (Maps 19 - 21), and to a lesser degree for cadmium (Maps 10 - 12) and antimony (Maps 1 - 3), did not illustrate a consistent spatial pattern relative to either Inco or Algoma or orient to specific streets, but rather identified numerous apparently random “hot spots”. Soil lead levels exceeded the MOE Table A effects-based guideline of 200 µg/g on about 73% of the properties, whereas cadmium and antimony exceeded the MOE guidelines only on about 1% of the properties (Table 12). Even though the three elements appeared to be spatially related to each other (same general patterns on the contour maps) the soil lead concentrations were far higher than either the cadmium or antimony levels and the maximum concentrations did not occur on the same properties. For example, the maximum soil lead level was 1,800 µg/g, which occurred on a property on Mitchell Street. The maximum soil antimony level was 91 µg/g, encountered on a Louis Street property. The maximum soil cadmium concentration was 35 µg/g, which occurred on a Davis Street property. Like the other metals, these elements tended to be slightly higher at depth.

The soil iron concentrations in the Rodney Street community are quite variable and in some areas are substantially elevated. The mean iron concentration was 29,706 µg/g, which is within a normal range for Ontario, but the maximum iron level was 140,000 µg/g. The pattern of iron distribution in soil (Maps 28 - 30) most closely resembles the nickel pattern, with the highest concentrations occurring toward the south and east, obviously centred on the homes on Rodney Street east of Fares Street. Although both Algoma and Inco were potential iron sources, Algoma was a pig iron blast furnace, which are characteristically “dusty” operations. The Inco ore mined in Sudbury was iron-based (Pyrrhotite, Pentlandite, Chalcopyrite, Pyrite, Magnetite, Bornite) and some of the iron would have remained in the matte refined at Port Colborne. JWEL (2001c) estimated the total iron emissions from Algoma at just over 8,900 tonnes, compared to an estimated 111 tonnes of iron from Inco (Table 13).

7.4 Statistical Analysis of Chemical Relationships

The concentrations of some of the chemicals in soil tended to be slightly higher in the lower sample depths. Table 14 summarizes the Rodney Street community 2000 and 2001 soil concentrations by sample depth and lists the upper and lower 95% confidence limits around the mean values. These data clearly illustrate that the difference between depths is statistically significant for many elements.

Results of Pearson Product Correlation tests on the soil data for each depth and all depths combined for all chemicals are summarized in Tables 15, 15.1, 15.2 and 15.3. Due to the very large number of degrees of freedom (1,500 plus) all *r* values greater than 0.088 are significantly correlated at the 95% level, and *r* values greater than 0.115 are significant at 99%. Statistical tests are one tool that can be used to evaluate these data. The *r* values provide a measure of the strength of relationship between the elements, with the higher the *r* value the stronger the correlation. Negative *r* values indicate an inverse relationship (i.e., one soil concentration increases as the other decreases). Similar Pearson Product correlation tables were prepared for

each of the three sample depths: Table 15.1 (0 - 5 cm), Table 15.2 (5 - 10 cm) and Table 15.3 (10 - 20 cm). Since the Rodney Street community is very close to two historic industrial sources, and both sources are towards the south end of the community, atmospheric deposition from both sources could contaminate the community and the contaminants may appear through statistical testing to be spatially correlated even though the contaminants originated from different sources. Relational statistics are a useful tool for evaluating source allocation, but like the contaminant contour maps they should not be used in isolation.

Nickel, copper and cobalt contamination in surface soil in the broader Port Colborne community is associated with Inco emissions. Of these three elements, nickel can be considered a “signature” contaminant for Inco, since the Port Colborne facility was a nickel refinery and elevated nickel concentrations have been found over an extensive area around the refinery and there is a consistent soil nickel concentration gradient relative to distance and direction from Inco. Elements in soil that are highly statistically correlated with nickel are likely to be related to Inco emissions. Similarly, iron can be considered a signature contaminant for Algoma, because the Port Colborne operation was a pig iron blast furnace and emitted large quantities of iron. Elements in soil that are highly statistically correlated with iron are likely to be related to Algoma emissions. Some elements may have been emitted from both Inco and Algoma. Using the common sense approach that nickel is from Inco and iron is from Algoma, if the element has a higher correlation coefficient with nickel then Inco is probably the principal source, if it has a higher r value with iron then Algoma is probably the principal source.

Soil nickel concentrations in the Rodney Street community are very highly correlated with soil cobalt ($r=0.929$), copper ($r=0.878$), iron ($r=0.798$), selenium ($r=0.764$), zinc ($r=0.733$) levels, and highly correlated with soil arsenic ($r=0.629$) levels, suggesting that these elements are associated with Inco emissions. The high statistical correlation is corroborated by the contaminant contour maps which strongly imply a spatial relationship relative to Inco and between nickel, copper, cobalt, and to a lesser extent arsenic, selenium and iron (zinc was not mapped).

Previous MOE soil sampling in the Port Colborne area identified elevated soil nickel, copper and cobalt levels as having originated from Inco (MOE 2001a, MOE 2001b). However zinc, arsenic, selenium and iron levels in soil in areas other than the Rodney Street community have not been shown to be consistently elevated above MOE guidelines, suggesting additional or other sources than Inco may have contributed to these levels in the Rodney Street community. Arsenic levels in soil in the Inco regional plume zone are spatially and statistically related to nickel levels in soil, even though the soil arsenic levels are generally not elevated above either the MOE generic Table A or Table F guidelines. In the MOE report on re-sampling of soil at Humberstone School, the relationship between soil arsenic and soil nickel levels was so consistent that soil arsenic levels could be predicted by soil nickel levels to within a few parts per million (MOE 2001a). The relationship between soil arsenic and soil nickel levels in the Rodney Street community, although statistically highly correlated, is not quite as predictive (less consistent) as in the wider Port Colborne area downwind of the Inco stack. This suggests there may be a secondary arsenic

source in the Rodney Street community.

Figure 3 illustrates arsenic concentrations in surface soil across the regional Port Colborne area. This map was not prepared for the 1998 MOE reports because the soil samples were not analysed for arsenic, as the arsenic concentrations in soil collected during the MOE studies through the 1970s and 1980s indicated that arsenic levels rarely exceeded background. Archived 1998 and 1999 MOE samples were analysed by JWEL as part of the CBRA program and Figure 3 was created using the same Surfer and ArcView settings as the 1998/1999 MOE regional soil contour maps. MOE 2000 and 2001 Rodney Street community soil arsenic data were not used to create Figure 3. Figure 3 clearly illustrates that, even though the concentrations are below the MOE generic soil guideline of 20 µg/g, there is an arsenic plume downwind of Inco that is remarkably similar to the contours of nickel in surface soil. Figure 3 also illustrates that in the Rodney Street community there appears to be a secondary arsenic plume originating in the vicinity of Algoma and extending well into the Rodney Street community.

Soil iron levels are highly correlated (greater than 0.6) with cobalt, nickel, arsenic, copper, selenium and zinc. With the exception of arsenic, the coefficients of correlation are slightly lower between iron and these metals than they are between these metals and nickel, suggesting a somewhat stronger/more consistent relationship with Inco than Algoma. In the Rodney Street community, the correlation between iron and arsenic ($r=0.636$) is marginally greater than between nickel and arsenic ($r=0.629$), reaffirming the apparent spatial relationship in Figure 3 that suggests Algoma was an arsenic source in the Rodney Street community.

Soil lead levels are highly correlated with zinc ($r=0.753$) and barium ($r=0.724$). These three elements are common components of lead-based paint. Also, the historic use of leaded gasoline has substantially added to the soil lead levels in all urban areas. Even though lead was likely emitted from Inco (lead made up about 10% of a single precipitator dust sample collected in 1978 (MOE 1978a)) the complete lack of a soil lead spatial pattern relative to either Inco or Algoma, suggests that the lead in the soil in the Rodney Street community is associated with general urban and domestic residential sources (lead based exterior paint, disposal of battery and automotive parts, pesticide use, and leaded gasoline). Any lead deposited in the Rodney Street community by Inco or Algoma cannot be distinguished from general urban and residential sources.

7.5 Results of Trench Samples

The results of chemical analysis of soil samples removed from the walls of the various trenches are summarized in Table 4. All seven of the trenches contained some non-soil or fill-like material, which included construction debris, brick pieces, metal and in some cases possibly coal, coal ash, cinders and slag. Some trenches had much more of this material than others. Natural undisturbed clay was encountered at about one metre in all trenches. The main contaminants in the trench soil are nickel, copper, cobalt, zinc, iron and to a lesser degree lead, arsenic and

beryllium. The iron concentrations are quite elevated in some trench samples, ranging almost to 17% (168,000 µg/g at 60 cm depth from the trench on the shoulder of Rodney Street). In addition to iron enriched fill, these high iron levels in soil samples from some of the trenches may also be from oxidized metal debris observed in some soil layers.

The two trenches from the baseball park at the south end of Rodney Street were contaminated with nickel to the bottom of the trench, a depth of about one metre, with concentrations ranging from 304 µg/g to 6,680 µg/g. The maximum arsenic level was 33.1 µg/g, the maximum copper level was 524 µg/g, and the maximum cobalt concentration was 88.8 µg/g. The nickel, copper, cobalt and arsenic levels all tended to be higher at depth. Most other elements, notably lead, were quite low, at least relative to elsewhere in the Rodney Street community.

The trench excavated on the shoulder of Rodney Street, and the two trenches excavated in the vacant lot south of Rodney Street between Fares and Welland Streets, were similar to each other and different from the baseball park trenches in that the maximum contaminant levels tended to be closer to the surface. For example, in the trench at the shoulder of the road near 124 Rodney Street, the soil nickel levels ranged from 8,900 µg/g to 9,730 µg/g to a depth of approximately 35 cm and then decreased to 204 µg/g at a depth of approximately 60 cm. Similarly, the arsenic concentrations ranged from 30.7 µg/g to 43.1 µg/g in the top 65 cm, then fell to background below this depth. The contaminant levels in the trenches from the vacant field tended to be lower than in the Rodney Street and baseball park trenches. Unlike the baseball park trenches, which had high nickel levels at all depths, the trench on the shoulder of Rodney Street and both trenches in the vacant field had the highest metal levels near the surface, with the layer of nickel contamination abruptly ending between 30 and 60 cms.

The two trenches excavated in the parkette on the east side of Welland Street tended to have lower soil contaminant levels than the other trenches. Although nickel levels were elevated to the bottom in the west trench, all other contaminants were confined to the top 65 cm. Similarly, in the east trench all the contamination was confined to the top 65 cm, falling to virtually background levels below this depth. By comparison, the soil from the two sodded berms located on the perimeter of the parkette's basketball court was much cleaner than the trenches. Only a few samples exceeded the MOE Table F background-based guidelines, and only a single sample exceeded the Table A effects-based guideline for beryllium.

Soil contamination was deepest in the baseball park. Based on the depth of metal contamination and the physical appearance of the trench faces, it is clear that the ball park had received at least one metre of metal-contaminated fill. Anecdotal accounts obtained from community residents during the MOE's April open house suggested that most of the area of what is now the baseball park had been filled. Judging by the presence of debris in the other trenches, it was evident these areas had also received some fill material, although metal contamination was mostly confined to the upper 30 - 60 cm. This suggests that outside of the baseball park, metal-contaminated material may have been used more as top dressing rather than as fill, perhaps to level the ground

in preparation for or subsequent to building. It is also possible that, outside of the obvious deep fill in the baseball park, the bulk of the soil metal contamination in the area of the trenches in the vacant field south of Rodney Street is from atmospheric deposition because the contamination is largely confined to the near surface layer and this area is very close to and directly between both the Inco refinery and the Algoma foundry. If this is the case, and most of the soil metal levels in the broader Rodney Street community are also related to atmospheric deposition, then the soil contamination in the Rodney Street community can be expected to extend to at least 30 cm in depth. However, the only way to confidently characterize the extent of soil contamination at depth is to conduct bore hole or trench sampling at multiple locations throughout the community.

As part of the ongoing environmental sampling for the CBRA, JWEL conducted some test pit sampling across the community in 2001. Two of these test pits (front yard 106 Rodney Street and front yard 91 Rodney Street) were clearly on residential properties. Evidence of slag was detected in the top 40 cm of lawn soil at these two Rodney Street residences, indicating at least a portion of these properties may have been top-dressed or levelled with fill (JWEL 2001b). In both of these test pits the soil nickel levels were highest at about 10 cm and the greatest concentration gradient was between 15 and 30 cm, where the nickel levels fell rapidly from many thousands of ppm to hundreds of ppm or lower. This is consistent with the limited trench sampling conducted by the ministry, corroborating the conclusion that the elevated soil metal and arsenic levels in the Rodney Street community are not likely to be deeper than about 30 cm, unless specific properties have received abundant fill material.

7.6 Contaminant Movement in Soil

If the amount of atmospheric metal deposition were constant and ongoing, the upper most soil layer would have the highest metal concentration because the rate of accumulation at the surface exceeds the rate of downward movement. Fugitive and stack emissions from Inco in the early years of operation, particularly before the 152 m stack was constructed in 1935 (there were two 91 m stacks in place from 1918), would have caused higher levels of atmospheric metal loading and subsequent deposition closer to Inco, particularly in the Rodney Street community, and resulted in the rapid accumulation of metals in surface soil. The pattern of slightly higher soil metal levels on front yards may reflect the influence of re-entrainment by vehicles, surface runoff and/or contaminated snow from the roads plowed onto the shoulders or narrow front yards. With no change in production levels at the refinery the impact of stack emissions and fugitive emissions on the Rodney Street community would have been reduced after the tall stack was constructed. However, Figure 1 indicates that in the period 1939-1959, the amount of nickel emitted increased over four fold, and therefore the rate of deposition in the Rodney Street community may not have decreased at all. With a reduction in production and further reductions in emissions, eventually the rate of accumulation in the surface soil fell below the rate of downward movement resulting in a slow but consistent downward migration of the metal contamination out of the top five cm of the surface soil and into the near-surface and sub-surface soil layers between 10 and 30 cm in depth.

A downward movement of metals from the surface to subsurface soil layers after the cessation of nickel deposition in Port Colborne is consistent with the pattern observed in soil lead levels in Toronto. In the 1970s lead from leaded gasoline combustion was ubiquitous in the Toronto airshed, resulting in high ambient air lead levels and subsequent deposition and accumulation of lead in surface soil. In 1971 the MOE established a baseline soil sampling network throughout Toronto and determined that the soil lead levels were highest at the surface and decreased quickly with depth. The ratio of lead in the 0 - 5 cm surface soil compared to the 10 - 15 cm soil depth was 1.6:1. Leaded gasoline was phased out in the early 1980s resulting in substantial reductions in ambient air lead levels and a virtual cessation of lead deposition to soil. A repeat sampling of the same sites in 1991 showed that with the elimination of lead deposition from the air, the lead had moved down into the soil so that it was consistently higher at depth than near the surface. The ratio of lead in 0 - 5 cm soil compared to 10 - 15 cm soil changed from 1.6:1 in 1971 to 0.6:1 in 1991.

With the cessation of atmospheric deposition, contaminants should no longer accumulate at the soil surface and the fact that soil contaminant levels in the Rodney Street community tend to be higher in subsurface soil layers is a further indication that the main deposition ceased many years ago and the sources of contamination are historic. However, this does not imply that over time the contaminants will continue to move downwards in the soil profile and eventually be deep enough so that they no longer pose a potential ecological or human health concern. Soil is a dynamic chemical, mechanical, and biological system, and at the microcosm scale, soil is constantly in flux. Limited MOE studies in other communities where soil has been contaminated by historic industrial air emissions have indicated that soil contaminants can move downwards through the soil by gravity and soil water percolating through soil pores, root and insect channels. In addition, soil contaminants can be brought back to the surface from a moderate depth as a result of plant uptake and tunnelling by ants, earthworms, and other soil macro and microorganisms. Earthworms alone can completely turnover the top 10 cm of soil in 100 years. The result is that over time, likely many decades, soil contaminants that originated on the surface tend to first move deeper and eventually get mixed into the top 30 or so centimetres of soil.

8.0 Soil Contamination: Source Allocation

8.1 Sources of Contamination

The elevated metals in soil in the Rodney Street community occurred by some combination of stack emissions, fugitive emissions, and aggregate process waste landfilling. Both Inco and Algoma had substantial stack emissions. Both Algoma and Inco had fugitive emissions that escaped from windows, doors, roof vents and from on-site contamination that was re-entrained and dispersed by traffic. Fugitive emissions were uncontrolled, can be as great or greater in magnitude than stack emissions, and tend to have the most significant impact on the local environment adjacent to the industry. In addition, it was not uncommon in the past for process waste to get placed locally to fill low areas or level land for subsequent building, or for employees to take aggregate-like waste for home construction projects. These three emission

pathways are not discrete and elevated soil metal levels in the Rodney Street community probably resulted from a combination of these three mechanisms.

8.1.1 Contaminant Groups

As described in Section 7.4, relational statistics are a useful tool for evaluating source allocation, but like the contaminant contour maps they should not be used in isolation. Since the Rodney Street community is literally sandwiched between two historic industrial sources, emissions from both industries impacted the community and the soil metal levels are spatially correlated even though the contaminants originated from different sources.

It is accepted that nickel is a signature contaminant for Inco. Similarly, iron can be considered a signature contaminant for Algoma because Algoma was a pig iron blast furnace and therefore certainly emitted iron. In the absence of compelling evidence that neither Inco nor Algoma emitted substantial amounts of lead, and in light of the known relationship between urban domestic residential soil lead and the historic use of leaded paint, lead could be considered a signature contaminant for urban domestic residential sources. Based on this common sense approach, three contaminant groups can logically be developed; 1) the Inco nickel group, 2) the Algoma iron group, and 3) the urban domestic residential lead group. Elements in soil that are highly statistically correlated with nickel are likely to be related to Inco emissions. Elements in soil that are highly statistically correlated with iron are likely to be related to Algoma emissions. Elements in soil that are highly correlated with lead are likely to be related to domestic, property specific, domestic residential sources.

Using this common sense grouping in combination with the correlative statistics in Table 15 the various elements can be ranked such that some confidence can be expressed as to their likely origin. It should be emphasized that for some elements it is not possible to definitively allocate them to a specific source, rather the ranking expresses the probability that it is more likely one source is the principal source and another is a secondary or contributing source. This is a grouping based on degrees of confidence rather than certainty. For example, if an element has a higher correlation coefficient with nickel then Inco is probably the principal source, if it has a higher r value with iron then Algoma is probably the principal source. Elements that are highly correlated to both nickel and iron and have very similar r values cannot be confidently allocated to either Inco or Algoma and may have been emitted by both industries.

Table 16 ranks the elements, using only those with positive r values in Table 15, relative to the three signature elements nickel, iron, and lead. Recognizing the limitations of correlative statistics where three separate sources are active in the same geographic area and some of the elements may be emitted from more than one source, all that can confidently be concluded about the source of any specific element is that the further to the right side of Table 16 it occurs the greater the likelihood that Inco, Algoma, or urban domestic residential properties are the principal sources. For example, cobalt has an r value of 0.929 for nickel, and so it is placed on

the far right side of the Inco row in Table 16. The r value between cobalt and iron is 0.760, so it is positioned to the right of centre in the Algoma row. By comparison, the r value between cobalt and lead is 0.380, so it is placed to the left side of the urban domestic residential lead row. The conclusions to be drawn are that cobalt is most likely to have been emitted by Inco, less likely to have been emitted by Algoma, and least likely to be associated with urban domestic residential sources.

Based on the relationships summarized in Table 16, the elements most likely associated with Inco, in addition to nickel, are cobalt, copper, selenium, zinc, and arsenic. The elements most likely associated with Algoma, in addition to iron, are arsenic and manganese. The relationship between nickel and arsenic ($r=0.629$) and between iron and arsenic ($r=0.636$) is too close to confidently allocate either Inco or Algoma as the principal source of elevated soil arsenic levels on some Rodney Street community properties. The Port Colborne soil arsenic map (Figure 3) and the Rodney Street community soil arsenic maps (Maps 4 to 6) clearly illustrate that both Inco and Algoma emitted arsenic. The elements most likely associated with urban domestic residential sources, in addition to lead, are barium, cadmium, antimony, chromium, and strontium.

8.2 Nickel, Copper, Cobalt, Selenium and Zinc

The soil nickel, copper and cobalt contamination documented in Port Colborne and the surrounding area in the 1998 and 1999 MOE investigations (MOE 2000a, MOE 2000b) is related to long term atmospheric deposition of Inco's stack emissions. Stack dynamics and prevailing wind patterns make the area to the northeast of Inco the zone of maximum deposition from stack emissions. The nickel:copper and nickel:cobalt soil ratios from the area to the northeast of Inco in the maximum downwind deposition area are 9.9:1 and 56:1 respectively, and are remarkably consistent to soil ratios from the average of all samples collected in the Rodney Street community in 2000 and 2001; which are 10.1:1 (nickel:copper) and 51:1 (nickel:cobalt), and the Rodney Street community trench samples, 9.5:1 (nickel:copper) and 44:1 (nickel:cobalt) (see Table 17). By comparison, the ratio of these elements in un-contaminated soil is very different. For the natural background levels in Ontario soil (Table F in the MOE *Guideline for Use at Contaminated Sites in Ontario* (MOE, 1997) and the 98th percentile and actual mean background soil values, MOE 1993) the ratios for these three elements range from 0.5:1 to 0.9:1 (nickel:copper) and from 1.8:1 to 2.4:1 (nickel:cobalt). This clearly illustrates the soil contaminant signature of Inco's Port Colborne refinery. The nickel, copper and cobalt contamination detected in the Rodney Street community is completely consistent with the soil contamination in the broader Port Colborne area downwind (to the northeast) of Inco, which is commonly accepted, and admitted by Inco, to be from atmospheric stack emissions from the nickel refinery.

Table 18 is a summary of selected soil metal levels observed by the ministry around specific types of heavy industry in Ontario. It clearly illustrates that in Ontario the only industries associated with substantially elevated soil nickel levels even remotely similar to levels found in

Port Colborne are nickel refineries and smelters, and the only other nickel operations in the province are Inco and Falconbridge in Sudbury. Specifically, elevated soil nickel levels have not been detected around foundries similar to the Port Colborne Algoma blast furnace. The only other industry where measurably elevated soil nickel levels have been detected is stainless steel manufacturing, as nickel is used in the production of stainless steel. In addition, Table 18 illustrates that soil iron levels are elevated not only around iron foundries but also nickel refining and smelting centres.

Because of the spatial distribution of selenium in soil in the Rodney Street community and the very high correlation coefficient between nickel and selenium, and because the correlation coefficient is higher between nickel and selenium than between iron and selenium, Inco is likely a more significant source of selenium than Algoma. Figure 4 is a regional-scale contour map of selenium in surface soil in the greater Port Colborne area produced in the same manner as the arsenic regional map (Figure 3). Like arsenic, the soil selenium concentrations in the greater Port Colborne area are mostly below the Table A effects-based guideline, and so selenium was not mapped in the 1998/1999 MOE Port Colborne reports. At the regional scale, the selenium pattern in soil is very similar to the “classic Inco nickel pattern”, which strongly suggests Inco is the source. Small areas of marginally higher soil selenium levels are apparent immediately adjacent to the northwest of Inco and downwind to the east of the refinery, but a small plume off of Algoma, similar to the arsenic plume in Figure 3, is not evident for selenium, indicating that Algoma is not principal source of elevated soil selenium levels on some properties in the Rodney Street community.

The elevated concentrations of zinc in soil on some properties in the Rodney Street community are believed to have originated principally from Inco. Zinc was detected in Inco refinery dust (Table 11) and so it was likely emitted by the refinery. However, like arsenic, the statistical correlation between nickel and zinc in soil ($r=0.733$) is very similar to the relationship between iron and zinc ($r=0.677$), making it difficult to confidently allocate a primary source. Based on the statistics and the spacial distribution of soil zinc levels on some properties, Algoma may be a secondary, contributing source of zinc. In addition, there are many potential domestic sources of zinc, such as paint, galvanized fences, roofs and eaves troughs.

The spatial distribution of the nickel, copper, cobalt, selenium and zinc soil contamination is consistent with the principal source to the south and east of the Rodney Street community, as the soil concentrations are higher on Rodney Street, Davis Street and Mitchell Street.

8.3 Arsenic

Of the various soil contaminants, arsenic is one of the most difficult to confidently attribute to a specific source in the Rodney Street community. Arsenic is strongly correlated to both nickel and iron, with the correlation coefficient being slightly higher with nickel. However, the property with the highest soil arsenic level is not the property with the maximum nickel concentration, and

there are several properties with elevated soil arsenic and disproportionately elevated soil nickel levels (i.e., five properties with soil arsenic concentrations between 75 and 150 µg/g and a soil nickel level less than 2,000 µg/g).

Figure 3 suggests there is an arsenic plume associated with Algoma in the vicinity of the Rodney Street community, but the same figure clearly indicates Inco is an arsenic source affecting the greater Port Colborne area. This is corroborated by the 1978 data that identified arsenic in Inco refinery dust at a concentration of 0.38% (MOE 1978a).

Arsenic is frequently associated with iron ore bodies and iron mineralization. Substantially elevated soil arsenic levels are associated with Algoma iron ore sintering operations in Wawa (see Table 18). The Port Colborne Algoma blast furnace used Wawa ore for part of its operating history. Therefore, both Algoma and Inco were sources of arsenic to the Rodney Street community and the data available to date is insufficient to confidently apportion their relative contributions.

8.4 Iron

The emissions of iron from Algoma over its operating life are estimated to have exceeded 8,900 tonnes compared to an estimated 111 tonnes of iron released from Inco (JWEL 2001c, see Table 13). Therefore, there is little doubt that Algoma is the principal source of the very high soil iron levels encountered on some properties in the Rodney Street community. Unlike nickel, the background concentration of iron in soil is quite high (OTR₉₈ of 33,000 µg/g for old urban parkland, MOE 1993c). Although pre-Algoma background iron concentrations in the Rodney Street community are unknown, the average soil iron concentration at the Port Colborne schools was determined to be 17,443 µg/g (median of 17,500 µg/g, MOE 2000c). This is about 9,000 µg/g lower than the average soil iron concentration in surface soils (0 to 5 cm) in the Rodney Street community of 26,252 µg/g (median of 24,800 µg/g). Since the soil type is similar, the “normal” soil iron level in Rodney Street community should be similar to the schools. Therefore, it is not unreasonable to assume that the difference in average soil iron levels between the schools and the Rodney Street community, about 9,000 µg/g, is at least in part the result of deposition of Algoma iron particulate emissions. Nevertheless, iron levels across a large part of the Rodney Street community are still within the normal range of background concentrations for Ontario soils. For example, the soil iron 80th percentile for the Rodney Street community is 35,500 µg/g compared to the 98th percentile of the provincial background of 33,000 µg/g (OTR₉₈, MOE 1993c).

The soil iron contour maps (Maps 28 - 30) show varying iron concentrations in the Rodney Street community but there is no obvious gradient relative to either Algoma or Inco. The very high iron concentrations on the south side of Rodney Street are considerably above the general loading in the Rodney Street community. This area is closest to and directly downwind of Algoma so atmospheric deposition would have been greatest in this vicinity. However, because the iron

levels are so high (up to 140,000 µg/g, or 14%) it is likely that some of the iron is from Algoma fill.

Even though the soil iron levels are very high on some properties they are not expected to have any adverse ecological or health effects, because iron is a plant macro-nutrient (required in large concentrations) and is an essential requirement for human health.

8.5 Antimony

Antimony in soil in the Rodney Street community was not spatially or consistently statistically associated with nickel or iron in soil. Neither Inco nor Algoma are believed to have had significant antimony emissions. Only three properties in the Rodney Street community had soil antimony levels above the MOE Table A effects-based guideline. On these few properties the elevated soil antimony levels are spatially correlated with high soil lead concentrations. Antimony is commonly alloyed with lead as a hardening agent, and was used extensively in battery manufacture, particularly automotive lead acid batteries. Phytotoxicology investigations around secondary lead smelters that used lead acid batteries in their feed stock and around battery manufacturers, routinely identified soil lead and antimony contamination. The soil lead and soil antimony Rodney Street community contaminant contour maps illustrate a very consistent spatial relationship between these two elements (compare antimony Map 3 with lead Map 21). The antimony contamination on these three properties is likely associated with lead batteries.

8.6 Beryllium

Although the average soil beryllium concentration in the Rodney Street community was 1.0 µg/g, which is consistent with typical Ontario background levels, a significant number of properties (47%) had soil beryllium concentrations that exceeded the Table A effects-based guideline. The source of the beryllium contamination is not known with certainty, but it could be related to slag deposited or used in the Rodney Street community, natural sources, and on one property from leaded paint.

The ministry has limited information, based on the manufacture of rockwool insulation spun from slag, that beryllium concentrations in slag can range up to 10 µg/g. Beryllium is also associated with coal ash. Anecdotal information suggests that slag was a common material for roadbed construction in the Rodney Street community. A historic photograph of the Rodney Street community shows most of the roads in place by 1917, after the start up of Algoma but before Inco began operations. Therefore, if slag was used in local road construction, Algoma slag would have been an attractive construction material. The 1917 photograph also illustrates that at that time the area that is now the Rodney Street community appeared quite flat, and so wide-scale filling is unlikely to have been necessary, although “top-dressing” or grade-levelling as previously discussed remains a possibility on some properties. In the 2000 MOE investigations, slag was observed on road shoulders, in some of the trench samples, and was occasionally

encountered while sampling the residential properties. Slag-like particles were identified in the scanning electron microscope photographs of soil samples collected from several Rodney Street properties. It is evident that slag is present in soil at the surface in some areas of the Rodney Street community, and its presence may account for the generally higher than expected soil beryllium levels.

The MOE recently became aware of circumstances where elevated concentrations of naturally occurring beryllium were found to be associated with shale deposits. In view of the suspected toxicity of the metal, the presence of numerous deposits of shale in Ontario, and a practice of using shale as fill material, in 1997 MOE Phytotoxicology scientists undertook a province wide sampling program of representative shale deposits in Ontario. Seven of the twelve shale formations sampled, or 58%, had beryllium concentrations in the shale rock and the adjacent soil overburden that exceeded the MOE Table A effects-based guideline of 1.2 µg/g (MOE 1997c).

The highest beryllium concentration found in the province wide shale study was 3.4 µg/g, detected in samples collected from the Animikie-Gunflint shale formation in the Thunder Bay area. The Queenston and Rockcliffe shale formations, closer to Port Colborne, had beryllium concentrations ranging up to 2.3 µg/g. Only two soil samples of the almost 2,000 samples collected from the Rodney Street community had beryllium levels greater than 2.3 µg/g. The marginally elevated soil beryllium levels in this community are consistent with naturally occurring beryllium in soil derived from shale, although the number of properties with beryllium concentrations higher than the provincial background was unexpected. In addition, the soil beryllium concentrations in the Rodney Street community are very highly correlated with soil aluminum levels ($r=0.804$), which implies the beryllium may be natural in origin.

The highest soil beryllium concentration detected in the Rodney Street community was 4.6 µg/g, which occurred on a property that had significantly elevated soil lead levels (877 µg/g). This property also had high arsenic, barium, nickel, cobalt, copper and zinc concentrations. Although soil lead levels and soil beryllium levels across the Rodney Street community are not highly correlated ($r=0.289$), the spatial relationship between beryllium and lead at this single property is not likely coincidental (compare beryllium Maps 7, 8 and 9 with lead Maps 19, 20 and 21). It is certain that the beryllium levels on this property are not related to Inco emissions because the statistical relationships between soil beryllium and soil nickel ($r=0.102$), soil beryllium and copper ($r=0.183$), as well as soil beryllium and cobalt ($r=0.124$) are less significant than the soil beryllium and lead relationship and there is no consistent soil beryllium contour gradient relative to Inco. In addition, beryllium and arsenic soil levels are actually inversely related (negative correlation coefficient, $r=-0.030$, i.e., as arsenic levels increase beryllium levels decrease, and vice versa). Soil beryllium levels are more highly correlated with barium ($r=0.615$) than with antimony ($r=0.097$), which suggests that the elevated lead and beryllium levels on this property are related to paint rather than batteries. Even though the high beryllium levels in soil on this property appear to be related to leaded paint, this is not the case elsewhere in the Rodney Street community. Other than this single property, there is no consistent spatial relationship between

soil beryllium and soil lead concentrations. With the exception of this one property, the marginally elevated beryllium levels in soil in the Rodney Street community are believed to be a combination of natural levels of some local shale inclusions or soil morphologically associated with local shale, surficially scattered slag, and possibly coal ash.

8.7 Lead

The MOE lead contour maps in this report (Maps 19 - 21) display no consistent spacial gradient to either Algoma or Inco. High lead levels are randomly scattered throughout the community with little or no consistent spacial similarity to the contour maps for nickel, copper, cobalt, arsenic or iron. Instead, lead levels in soil are highly correlated with barium and zinc ($r > 0.700$), both elements associated with paint. The maps do suggest that on a few properties both copper and lead levels are elevated. Copper is an antifungal agent and was used in some paint and pesticides, which may explain the lead and copper relationship on some properties.

MOE Phytotoxicology investigations in other communities have clearly linked residential soil contaminated with lead to the erosion, weathering, and/or removal of exterior leaded paint. Paint chips from flaking paint are often visible on the soil. Analysis of these chips collected from residential yards of older urban homes in Toronto showed that the paint contained up to 31%, or 310,000 $\mu\text{g/g}$, lead and 12.4%, or 124,000 $\mu\text{g/g}$, zinc (MOE 1995). The soil lead and zinc concentrations of these Toronto yards ranged up to 890 $\mu\text{g/g}$ and 445 $\mu\text{g/g}$, respectively. MOE Phytotoxicology scientists have assisted MOE District Environmental Officers and local health unit inspectors in the investigation of blood lead poisoning of very young children. In most cases the lead source is found to be either ingestion of soil contaminated with lead from flaking or eroded exterior lead-based paint, or the direct ingestion of paint chips. Lead paint chips have a particular attraction to young children because the chips can be brightly coloured so they are often clearly visible in the soil, and lead has a distinctly sweet taste.

In a recent MOE Phytotoxicology soil-blood lead investigation on a Sarnia property very similar in age and construction to many homes in the Rodney Street community, the soil lead concentration averaged 629 $\mu\text{g/g}$ across the property, 1,150 $\mu\text{g/g}$ within one metre of painted exterior house walls, and ranged from 170 $\mu\text{g/g}$ in the corner of the property away from any structures to 3,400 $\mu\text{g/g}$ adjacent to the front porch (MOE 2000d). In similar investigations of several properties in Welland the soil lead levels averaged between 237 $\mu\text{g/g}$ and 329 $\mu\text{g/g}$ generally across the properties and ranged up to 1,796 $\mu\text{g/g}$ in close proximity to painted exterior walls (MOE 2000e, MOE 2000f, MOE 2000g). The Welland homes also were very similar in age and construction to many homes in the Rodney Street community. Although not community wide studies, these recent MOE investigations in Sarnia and Welland indicate that soil lead levels like those detected in the Rodney Street community are not anomalous for older urban residential areas and can occur in the absence of a local lead source.

Lead is a ubiquitous soil contaminant in old urban environments. Historically, the use of lead additives in gasoline resulted in the release of lead in automobile exhaust and the contamination of soil near the roadways. Soil lead contamination from leaded fuel was particularly acute in urban communities because they have more roads and more cars. Lead was also a component of paint for houses, automobiles, road markings, fire hydrants, bridges and other structures. Lead leached from the paint by rain and removed from structures by peeling, flaking, scrapping, sand blasting and grinding results in the surrounding soil becoming lead contaminated. Lead-based pesticides, particularly lead-arsenate, were commonly used on fruit trees before the 1970s, which could contaminate the soil beneath the trees with both lead and arsenic. Also, very localized areas were contaminated by lead containing debris such as automobile batteries, glassware, ceramics, TV tubes, solder, fishing sinkers and lead shot. Due to the recognition of the detrimental effects of lead on human health and the natural environment the use of lead has been dramatically reduced in recent years. Lead is no longer added to gasoline or most house paint. Because older urban communities have been exposed to more domestic lead sources for a longer period of time, they tend to have substantially higher soil lead levels than younger urban, suburban, or rural communities.

Current levels of lead in soil in Port Colborne in general, and the Rodney Street community specifically, have no consistent spatial relationship relative to Inco or Algoma. Although Inco and Algoma emissions may have contributed to the overall soil lead burden in the Rodney Street community, historic vehicle emissions from the combustion of leaded gasoline and residential sources, such as weathered exterior lead-based paint, are both far more significant and known lead sources that could account entirely for the soil lead levels encountered in this study, and so any Inco or Algoma lead contributions cannot be measured above the normal urban domestic residential lead loading.

Generally, the older and more urban the community, the greater the likelihood that some properties will have elevated lead levels. The Rodney Street community is among the oldest in Port Colborne (average house age is about 78 years, based on Port Colborne municipal tax records) and therefore elevated soil lead levels on some properties expected. Soil lead levels from newer urban/suburban communities and from outlying rural residential areas in Port Colborne would not necessarily have similar soil lead levels as the Rodney Street community. Therefore, soil lead data collected from boulevards and large suburban or rural lawns around Port Colborne in earlier MOE soil investigations cannot be used to gauge normal residential soil lead burdens for the Rodney Street community.

8.7.1 Comparison of Lead Levels in the Rodney Street Community with Other Urban Communities

Generally, the older and more urban the community the greater the likelihood that some properties will have elevated soil lead levels. In the Rodney Street community of Port Colborne about 70% of the properties exceed the MOE Table A generic effects-based soil lead guideline of

200 µg/g. Also, the MOE has adapted from the US EPA lead intervention levels of 400 µg/g for children's play areas with bare soil and 1000 µg/g for all other areas to which children have regular access and the soil is sodded or covered. The average lead level of the combined 2000 and 2001 Rodney Street community residential soil is 217 µg/g and the 90th percentile is 406 µg/g.

In Toronto, the MOE has been monitoring environmental lead levels for 25 years in a community that has no known industrial source of lead pollution. In this community, which is similar to the Rodney Street community in age and style of home construction, 78% of the residential properties exceed the MOE Table A effects-based criterion and the average soil lead level is 486 µg/g. Spuriously elevated soil lead levels are an artifact of older "residential urban-core" communities. Soil lead concentrations in the 1,000 µg/g range, such as detected at a few scattered properties in the Rodney Street community, are entirely consistent with urban domestic residential lead sources and do occur in older urban communities in Ontario.

Table 19 summarizes the Rodney Street soil lead data and compares it to other communities in Ontario and American urban lead studies where there are no known industrial lead sources. The soil lead levels from these other communities are similar to, and in some cases, substantially higher than in Port Colborne. It is also apparent that soil lead levels tend to be much higher directly adjacent to exterior painted walls. In the Toronto communities the soil lead levels from older residential homes routinely averaged from 202 µg/g to 509 µg/g, the 90th percentiles were up to 930 µg/g, and soil lead levels ranged up to 3,400 µg/g (MOE 1974, MOE 1971-1991). In a survey of 1,984 urban residential properties in the United States the soil lead level adjacent to the house wall averaged three times higher than the midpoint of the adjacent yard (324 µg/g vs 105 µg/g) and the 90th percentile ranged from 243 µg/g to 633 µg/g for samples collected from the midyard compared to samples collected nearer walls. The higher lead level near the wall was concluded to be associated with weathering of exterior leaded paint (U.S. H.U.D. 2001). In a study of almost 1,000 "high risk" homes in three communities in California (risk defined by wood construction, homes greater than 50 years, weathered paint evident, and young children present, but no industrial lead sources) the average soil lead levels were 188 µg/g in Los Angeles, 234 µg/g in Sacramento, and 897 µg/g in Oakland (Sutton 1995). In a detailed study of lead contamination on a residential property caused by the removal of leaded paint by sandblasting, the soil lead levels were found to range from 360 µg/g at distances of more than about one metre from the walls being treated to 3,900 µg/g within one metre of the walls (Mielke 2001).

There is a consistent relationship between the age of the home and the likelihood of elevated soil lead levels. This has been observed in numerous MOE investigations and is supported by the published literature. In a California study approximately 85% of the residential properties built before 1920 had maximum soil lead levels greater than 500 µg/g, compared to about 11% of the homes built after 1970 (Sutton et al., 1995). Similarly, a study of urban communities in the United States found that 67% of the homes built before 1940 had maximum soil lead levels above 400 µg/g compared to only 9% built after 1960 (U.S. H.U.D. 2001). This study also found

that 26% of the properties with houses built before 1940 had maximum soil lead levels greater than 1,600 µg/g, which is in the range of the maximum soil lead level (1,800 µg/g) found in the Rodney Street community.

Soil lead levels in a California study of 933 residential properties in three communities found that the age of the housing was the best predictor of lead in soil; homes built before 1920 were 10 times more likely to have soil lead levels greater than 500 µg/g compared to post 1950 homes (Sutton et al., 1995, and see Figure 5).

Table 20 summarizes the soil lead levels of Rodney Street properties broken down by the year of house construction. In the Rodney Street community, about 40% of the houses were built before 1920, about 54% were constructed between 1920 and 1949, and only about 6% of the houses were built after 1950. The mean soil lead level was highest (260 µg/g) from the oldest group of homes and lowest (125 µg/g) from the youngest group of homes.

Lead was likely emitted from Inco since lead comprised 10.5% of a single Cottrell Precipitator dust sample collected at the Inco refinery in 1978 (MOE 1978a). However, based on data from soil samples collected in the Port Colborne area downwind to the east-northeast of Inco in the area of greatest atmospheric deposition, of those soil samples with soil nickel levels greater than 1,000 µg/g, the average soil nickel level was 2,120 µg/g and the average soil lead concentration was 98 µg/g (MOE 2000a, MOE 2000b), which gives a nickel:lead soil ratio of 21.6:1. Similarly, using the soil data from the Rodney Street community that was collected in 2000 and 2001 (excluding the trench data) the average soil nickel level was 2,508 µg/g and the average soil lead level was 217 µg/g, which gives a nickel:lead ratio of 11.6:1. Since the nickel:lead ratio of 21.6:1 for the Port Colborne area downwind of Inco is not similar at all to the nickel:lead ratio of 11.6:1 for the Rodney Street community, the lead is unlikely from the same source as the nickel contamination. Also, for the Rodney Street community soil data, since the statistical correlation between iron and lead ($r=0.377$) is even less than between nickel and lead ($r=0.426$) the lead is unlikely from the same source as the iron contamination. Furthermore, based on almost 2,000 soil samples from almost every yard of almost every property in the Rodney Street community, there is no consistent soil lead concentration gradient relative to either Inco or Algoma.

The preceding data indicate that the lead levels in soil in the Rodney Street community can be accounted for by general urban domestic residential lead sources. Although Inco and Algoma likely emitted some lead and deposition from these two industries impacted the Rodney Street community, the lead contribution from these sources is not measurable above the normal urban domestic residential lead loading.

9.0 Conclusions

9.1 General Conclusions

The average soil nickel concentration in the Rodney Street community is 2,508 µg/g and the predominant form of nickel in the soil in the Rodney Street community is nickel oxide (80% of the total nickel, on average).

Property by property sampling revealed substantial variation in both the numbers of contaminants and the soil contaminant concentrations. Of the approximately 2,000 samples collected from about 200 properties, 99% of the properties had soil nickel levels that exceeded the MOE generic Table A effects-based criterion of 200 µg/g. The maximum soil nickel level was 17,000 µg/g. In addition to nickel, the MOE Table A effects-based guidelines were exceeded for lead on approximately 73% of the properties, cobalt on 72% of the properties, copper on 66% of the properties, beryllium on 47% of the properties, arsenic on 46% of the properties, zinc on 37% of the properties, antimony on 1.5% of the properties, and selenium and cadmium on less than 1% of the properties. For many elements on most properties, the soil contaminant concentrations tended to increase with depth. If the trenches excavated in the vacant lot south of Rodney Street and the park east of Welland Street, and the test pits dug by JWEL on two Rodney Street properties are representative of the soil profiles across the community, then soil contamination on most residential properties in the Rodney Street community may extend to 30 cm, but should decrease very rapidly below that depth.

Inco is the source of soil nickel, copper, and cobalt contamination in the Rodney Street community. The elevated soil arsenic levels are a result of emissions from both Inco and Algoma. Because of the degree of spatial and statistical relationship of selenium and zinc with nickel, copper and cobalt, Inco is likely the principal source of the elevated soil zinc and selenium levels. However, there is almost as strong a relationship between iron, zinc and selenium as there is between nickel, zinc and selenium, and therefore Algoma may be a secondary or contributing source of soil selenium and zinc concentrations in the Rodney Street community.

The baseball park at the southwest corner of Rodney and Davis Streets was, at least partially, created from metal contaminated fill. Similarly, because of the long history of industry ownership of the land behind the residential properties on the south side of Rodney Street, some of these residential properties may also have been affected by fill, particularly in the back yards. Notwithstanding the possibility that isolated properties may have imported aggregate process waste for home construction projects or grading and subsequently added to the soil contaminant burden on these properties, the primary mechanism of the soil nickel, copper, cobalt, arsenic, selenium and zinc soil contamination across the broader Rodney Street community is believed to be atmospheric deposition of stack and fugitive emissions and not fill. Regardless of the mechanism of contamination (fill or atmospheric deposition) the nickel, copper and cobalt originated from Inco.

The height of the tall stack, constructed in 1935, in conjunction with the strong southwesterly prevailing winds in the non-snow season, dispersed most of the stack emissions to the northeast of the Inco refinery after the stack was built, resulting in the soil contaminant pattern across the regional Port Colborne area documented in the 1998 and 1999 MOE soil investigations. However, fugitive emissions from the refinery, particularly in the early years of the refinery's operation, would have substantially impacted the Rodney Street community. At the MOE open house in April 2001, many anecdotal observations were offered by long time Rodney Street community residents and refinery employees about the chronically dusty conditions in the Rodney Street community and in and around the Inco refinery during the earlier years of operation. Since the community was literally sandwiched between two large industries (Inco and Algoma) that were dusty by nature, particularly in the past before the technology was available and implemented to control fugitive emissions, there is no reason to doubt the anecdotal comments about the Rodney Street community being a dusty neighbourhood.

The highest soil nickel, copper, cobalt, arsenic, selenium and zinc soil concentrations occurred on properties in the south and eastern areas of the Rodney Street community along Rodney, Mitchell and Davis Streets. Based on the contaminant contour maps it is likely that elevated soil metal levels may extend slightly further along Davis Street north of Louis Street. Further soil sampling is also warranted in the residential communities immediately adjacent to the north-northwest, north, and north-northeast of Inco.

In Ontario, the only industries associated with substantially elevated soil nickel levels even remotely similar to levels found in Port Colborne are nickel refineries and smelters, and the only other nickel refineries and smelters in the province are the Inco and Falconbridge operations in Sudbury. Elevated soil nickel levels have not been detected around foundries similar to the Algoma foundry that operated in Port Colborne to the west of the Rodney Street community.

The randomly scattered soil lead contamination observed in the Rodney Street community is primarily related to general urban domestic residential lead sources and not to Inco or Algoma emissions. The erosion and flaking of old lead-based paint from exterior structures such as house and shed walls, porches, fences, poles and playground equipment is a common source of soil lead contamination in older urban communities. The soil lead levels found in the Rodney Street community are not unusual, either in extent or concentration, relative to other similarly aged older urban communities in Ontario. On properties where the soil lead levels were elevated, the concentrations of cadmium, chromium, copper, barium and zinc sometimes were proportionately elevated. Along with lead, these elements were common pigment, anti-mildew or anti-fungal additives in old exterior paint and are frequent co-contaminants with lead in residential soil.

Antimony was another element that was highly correlated with lead on some properties, although it exceeded MOE guidelines on only three properties. Antimony is commonly alloyed with lead, particularly in lead acid batteries. Lead and antimony soil contamination is an indication that batteries may have been stored or disposed of on the property, whereas lead and barium, lead and

zinc, or lead and copper soil contamination is a signature of lead-based paint.

Although the average soil beryllium level in the Rodney Street community was comparable to the provincial soil background concentration, almost one half of the properties exceeded the MOE Table A effects-based guideline. Soil beryllium levels marginally above the guideline are not unusual, because the guideline and the upper end of the background range are the same (1.2 µg/g). Also, MOE investigations have documented that shale, and soil derived from shale, regularly exceed the guideline. In addition, slag and coal ash can have a beryllium concentration that is above the guideline, and slag is present on some properties in the Rodney Street community. Slag was believed to have been used as roadbed material. With the exception of one property where elevated beryllium levels were concurrent with high lead and other heavy metals, the marginally elevated soil beryllium concentrations across the Rodney Street community are likely related to the presence of slag and local shale deposits. Emissions from Algoma may have contributed to the generally marginally elevated soil beryllium levels in the Rodney Street community.

Recent or ongoing atmospheric deposition results in soil contaminants accumulating in the upper most soil layers and decreasing quite abruptly with depth. Where atmospheric deposition is the only source of contamination, measurably elevated soil contaminant levels are usually confined to the top 20 - 30 cm of soil. For most of the Rodney Street community, and across Port Colborne, the highest soil contaminant levels tended to occur not right at the surface but between 10 and 20 cm, and then fell rapidly to near background concentrations below about 25 - 30 cm. This pattern, which has been observed by the ministry in other communities that have been impacted by historic industrial emissions, is consistent with deposition that was much higher in the past and was much lower or abated entirely in more recent years. Test pits dug by JWEL on Inco property at undisturbed sites confirm the pattern of high levels at the surface, highest levels between 10 and 20 cm, lower levels below 20 cm, and very low (almost background) soil contaminant concentrations below about 30 cm (JWEL 2001b). Figure 1 confirms that Inco nickel emissions were substantially higher in the past (97% of the total nickel emitted was released before 1960). Algoma ceased operations in 1977 but 75% of the total amount of iron emitted by Algoma was released before 1959. Based on these data it is evident that most of the heavy metals and arsenic that are currently present in soil in the Rodney Street community, and elsewhere in the Port Colborne area, are a result of historic industrial emissions that occurred up to or before 1960. Some properties in the Rodney Street community, particularly those on the south side of Rodney Street, in addition to being impacted by atmospheric deposition also likely have received industrial process waste or fill from either or both Inco and Algoma.

Other than the properties on the south side of Rodney Street that may have received process waste or fill from either or both Inco and Algoma, the “patchwork” pattern of high and low soil contamination on neighbouring lots is likely related to fugitive emissions and property maintenance and landscaping. Adding topsoil or mulch, re-sodding, building, and cultivating gardens are landscaping practices that, over time, tend to cover or dilute contaminants that are

predominantly present in the surface soil. It also indicates that the source of the soil contamination is likely atmospheric and that with deposition abated, newly landscaped properties have not become re-contaminated to the levels of undisturbed properties.

The plant-bioavailability of nickel in soil in Port Colborne is very low, in the range of less than 1% for mineral soil (this refers to the plant bio-availability in Part A Section 5.3.3, not the human stomach leach bio-availability discussed in Part B Appendix 5). This means the nickel has a low mobility in the soil, which means it would not be readily taken up by plants. The low plant-bioavailable nickel levels account for the remarkably minor amount of nickel injury observed on species of vegetation known to be sensitive to nickel in areas of Port Colborne where the soil nickel levels are substantially above the MOE Table A ecotox-based guidelines.

9.2 Conclusions Related to the Stated Objectives

There were four specific objectives of Part A of the report stated in Section 1.0.

1) *To determine the extent and severity of soil metal and arsenic contamination in the Rodney Street community of Port Colborne.*

Although an overall spatial pattern was evident for some contaminants, particularly nickel, copper, cobalt and arsenic (see the soil contaminant contour maps) there was considerable property by property variability. Soil contamination above the 8,000 µg/g nickel intervention level on some properties in the Rodney Street community is at least 20 cm deep but is not likely to extend much deeper than 30 cm. Additional sampling is warranted north of Louis Street to find any additional properties with soil nickel levels greater than 8,000 µg/g.

2) *To characterize metal soil contamination in the Rodney Street community.*

The metal contaminants can be divided into the following three logical groups (see Table 21):

- 1) the Inco nickel group that includes nickel, cobalt, copper, selenium, zinc and arsenic;
- 2) the Algoma iron group that includes iron, arsenic, manganese, and possibly selenium and zinc; and
- 3) the urban domestic residential lead group that includes lead, zinc, barium, cadmium, antimony, chromium and strontium.

3) *To determine to the extent possible the source(s) of the soil contamination in the Rodney Street community.*

Inco is the source of the soil nickel, copper and cobalt contamination. Inco is likely the

principal source of the elevated soil zinc and selenium levels. Algoma is the principal iron and manganese source and is likely a contributor to the soil zinc and selenium levels. Both Inco and Algoma emitted arsenic and it is not possible to confidently apportion the soil arsenic levels in the Rodney Street community between these two sources. Although both Inco and Algoma likely emitted lead, their contribution cannot be measured above the general urban domestic residential lead sources. Soil lead levels in the Rodney Street community are consistent with soil lead levels in older urban communities in Ontario and the United States. The sources of the lead are numerous and property specific (i.e., lead-based paint, pesticide use, storage, maintenance, and disposal of vehicles and vehicle parts, particularly batteries, historic use of leaded gasoline). Slightly elevated soil beryllium levels are likely related to natural shale deposits with a contribution from Algoma slag and particulate emissions.

4) *To determine to the extent possible, the mechanisms(s) of soil contamination in the Rodney Street community.*

Notwithstanding the possibility that isolated properties may have imported aggregate process waste for home construction projects or grading and subsequently added to the soil contaminant burden on these properties, the predominant mechanism of soil nickel, cobalt, copper and to a lesser extent iron, selenium, arsenic and zinc contamination in the Rodney Street community is believed to be atmospheric deposition of Inco and Algoma emissions from both fugitive and stack sources. The contamination in the Rodney Street baseball park is predominantly from Inco fill with contributions from atmospheric deposition. Some of the properties on Rodney Street, particularly the back yards of the properties on the south side, likely have been influenced by shallow filling or spreading of Inco or Algoma aggregate process waste. Regardless of the mechanism(s) of contamination, Inco is the only source of the substantially elevated soil nickel concentrations in the Rodney Street community.

9.3 Calculated Soil Nickel Levels

Nickel deposition over Inco's operating life-time was estimated by JWEL (2001c) to range from approximately 5,000 g/m² in the vicinity of the Welland Canal to about 20,000 g/m² adjacent to the refinery. The Rodney Street community falls within this estimated deposition range. Table 21 calculates the resultant soil nickel concentration at various depths across the 5,000 g/m² to 20,000 g/m² range of estimated nickel deposition. If all the nickel stayed where it fell on the soil (no wash-off or leaching), at a deposition rate of 20,000 g/m² the resultant soil nickel concentration would be 266,667 µg/g if the nickel all stayed in the top 5 cm of soil. At a deposition rate of 5,000 g/m² the resultant soil nickel concentration could be 11,111 µg/g if the nickel were evenly mixed in the top 30 cm of soil. Based on JWEL (2001c), the highest soil nickel level found in the Rodney Street community of 17,000 µg/g through to a depth of 20 cm could be accounted for by a deposition rate as low as 5,000 g/m² (see Table 21). Therefore,

atmospheric deposition alone could account for all the nickel currently present in soil in the Rodney Street community.

9.4 Application of the Soil Nickel Intervention Level

In consideration of the variability inherent in sampling soil and laboratory testing, the ministry used the maximum nickel concentration found in any soil sample at any depth in the front, back or side yard, to determine if a property exceeded the soil intervention level derived from the human health risk assessment. If the maximum soil nickel concentration on the property exceeded the intervention level, the property becomes a candidate for soil remediation. Even though the maximum concentration is a worst case estimate of the overall property concentration, because of sampling and analytical variability a property owner/occupant could still have concerns that the maximum nickel concentration found on the property is an underestimate of the true (but unknown) nickel concentration. By determining the variability around the maximum measured concentration a confidence interval for any specific concentration can be calculated.

The soil data from all of the sampled properties in the Rodney Street community were statistically evaluated to determine the confidence interval around the maximum value of all the samples collected from any single property. Given the large data base and the log-normal distribution of the soil nickel levels across the Rodney Street community, the asymptotic distribution (also known as the Gumbel distribution - see Johnson and Kotz, 1995) of the maximum likelihood estimates (normal) was used to construct confidence intervals around the maximum concentration for any property. From the Human Health Risk Assessment in Part B of this report it was determined that at a soil nickel concentration of 9,061 $\mu\text{g/g}$ (refer to Part B, Section 7.1) the nickel exposures from all sources, including soil in the Rodney Street community, is less than the nickel reference dose (RfD) for all age groups including the toddler. Using the confidence intervals from the Gumbel distribution of the combined 2000 and 2001 Rodney Street residential soil data, it can be shown that, if the maximum soil nickel level of any single sample at any depth from a property is 8,139 $\mu\text{g/g}$ or less, it is 99% certain that no sample on the property would exceed 9,061 $\mu\text{g/g}$. Based on these calculations the soil intervention level is set at 8,000 $\mu\text{g/g}$ nickel.

9.5 The Effect of Remediation of Properties Above the 8,000 $\mu\text{g/g}$ Intervention Level

Properties with soil nickel concentrations at and above 8,000 $\mu\text{g/g}$ are to be remediated. Some of these properties may also have elevated levels of other metals or arsenic, which will be removed with the nickel contaminated soil during remediation. After the remediation there will be fewer properties in the Rodney Street community that exceed the MOE guidelines (Table 12). Specifically many of the properties with elevated arsenic levels in soil will be remediated as a result of the nickel clean-up. Table 22 illustrates that after remediating the nickel contaminated properties the maximum soil arsenic level in the Rodney Street community drops from 350 $\mu\text{g/g}$ to 62 $\mu\text{g/g}$ and the 90th percentile drops to 22 $\mu\text{g/g}$, which is below the MOE Table A guideline

of 25 µg/g for medium/fine textured soil. After remediation, the maximum soil arsenic level in the Rodney Street community is about 1/4 the maximum level in Port Hope, about 1/10th the maximum level in Deloro, and about 1/17th the maximum concentration of arsenic in soil in Wawa. Wawa and Deloro have undertaken health studies and a health risk assessment was conducted in Port Hope. These studies concluded:

Wawa

This study did not produce evidence that Wawa residents are at an increased risk of cancer due to exposure to arsenic (Goss Gilroy 2000).

Deloro

Estimated arsenic exposures are not measurably higher than those of typical Ontario residents (Cantox 1999).

Port Hope

Estimated intakes from contact with these soils yield risk estimates in the range generally considered negligible and below the WHO permissible intake (MOE 1991).

Conclusions Summary

- ! Inco is the source of nickel, copper, and cobalt soil contamination in the Rodney Street community.
- ! Inco is the principal source of selenium and zinc soil contamination in the Rodney Street community.
- ! Both Inco and Algoma emitted arsenic; it is not possible to confidently apportion which source contributed how much arsenic or where it was deposited in soil in the Rodney Street community.
- ! Algoma is the principal source of iron.
- ! The predominant mechanism of the soil nickel, copper, cobalt, arsenic, iron, selenium and zinc contamination in the Rodney Street community is atmospheric deposition from both stack and fugitive sources.
- ! The soil lead contamination in the Rodney Street community is typical of older urban residential communities in Ontario; the sources are domestic, numerous and property specific (e.g., paint, pesticide use, the storage, maintenance, and disposal of vehicles and vehicle parts (particularly batteries); historic use of leaded gasoline).
- ! The surficial soil contamination in the Rodney Street community is between 20 and 30 cm deep (may be deeper on the south side of Rodney Street).
- ! The mechanism of the soil contamination at depth in the baseball park at the southwest corner of Rodney and Davis Streets is industrial process waste/fill.
- ! Industrial process waste/fill has contributed to the soil contamination on some properties (particularly the back yards) on the south side of Rodney Street.
- ! Process waste/fill that is high in iron and low in nickel is from Algoma, if it is high in nickel and relatively low in iron it is from Inco, and if it has high concentrations of both iron and nickel it is likely a mix of both Algoma and Inco waste/fill.
- ! Both Inco and Algoma likely emitted lead, and some lead in soil in the Rodney Street community is probably from industrial emissions, but the contribution can not be measured above the general urban domestic residential soil lead burden.
- ! The generally elevated soil beryllium concentrations are associated with natural shale deposits and/or dust/slag probably from Algoma.
- ! Most of the surficial soil contamination in the Rodney Street community occurred earlier in Inco's and Algoma's operating history, likely before 1960.

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