

**SUDBURY AREA RISK ASSESSMENT**

**CHAPTER 3.0  
HISTORICAL REVIEW OF AIR EMISSIONS FROM THE SMELTING OPERATIONS**

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### **3.0 HISTORICAL REVIEW OF AIR EMISSIONS FROM THE SMELTING OPERATIONS**

#### **3.1 Introduction**

The Chemicals of Concern (COC) for the study are found naturally in the ores mined from the Sudbury Basin, with measurable levels ranging from considerably less than 0.1% in some cases (arsenic, cobalt, lead, and selenium) to greater than 1% for nickel and copper. Atmospheric emissions are considered the primary source of metals to Sudbury soils. This chapter will present information about past and present air emissions of the COC from the major sources. Factors contributing to emissions include significant changes to facilities and emission sources, changes in production levels, and addition and closure of facilities. Changes in operations of the major emissions sources over the lifetime of nickel and copper mining, milling, smelting and refining in Sudbury will be discussed in this chapter, as these factors have had considerable influence in dispersion and subsequent deposition into the surrounding communities.

Available air quality data will be reviewed to determine temporal and spatial trends, including the results of extensive dustfall monitoring undertaken in the Sudbury area for over 25 years. A relationship will be explored between emissions of the COC and subsequent concentrations measured in soils, based on dustfall patterns observed in the available data. One source of data reviewed in the following sections is an internal Vale Inco document authored by D. Bouillon (2003). Some of the data provided in that report represent estimates (calculations based on specific assumptions and generalizations) where actual measured data were not available. However, the order of magnitude of the estimated emissions is considered to be consistent with a smelter facility such as Vale Inco.

#### **3.2 Historical Review of Smelting in Sudbury**

##### **3.2.1 The Beginning of Sudbury Smelting**

As described in the previous chapter, the extraction of copper and nickel ores from the Sudbury basin started in the late 1880s. Past production and resources exceed 1,548 million tonnes of ore at approximately 1.2% Ni, 1.1% Cu and 0.4 g/t Platinum Group Metals (PGM). It has been estimated that this has resulted in the production of 8.5 million tonnes of nickel and 8.4 million tonnes of copper over the years. Total ore reserves are estimated at 1.6 billion tonnes (Patterson, 2001).

Nickel smelting began on December 22, 1888 when Canadian Copper started up a Herrshoff water jacket blast furnace to treat the calcine from the roast yard. It is estimated that between 80 and 100 tonnes of calcine were treated daily. The matte produced by the furnace contained about 50% copper and nickel.

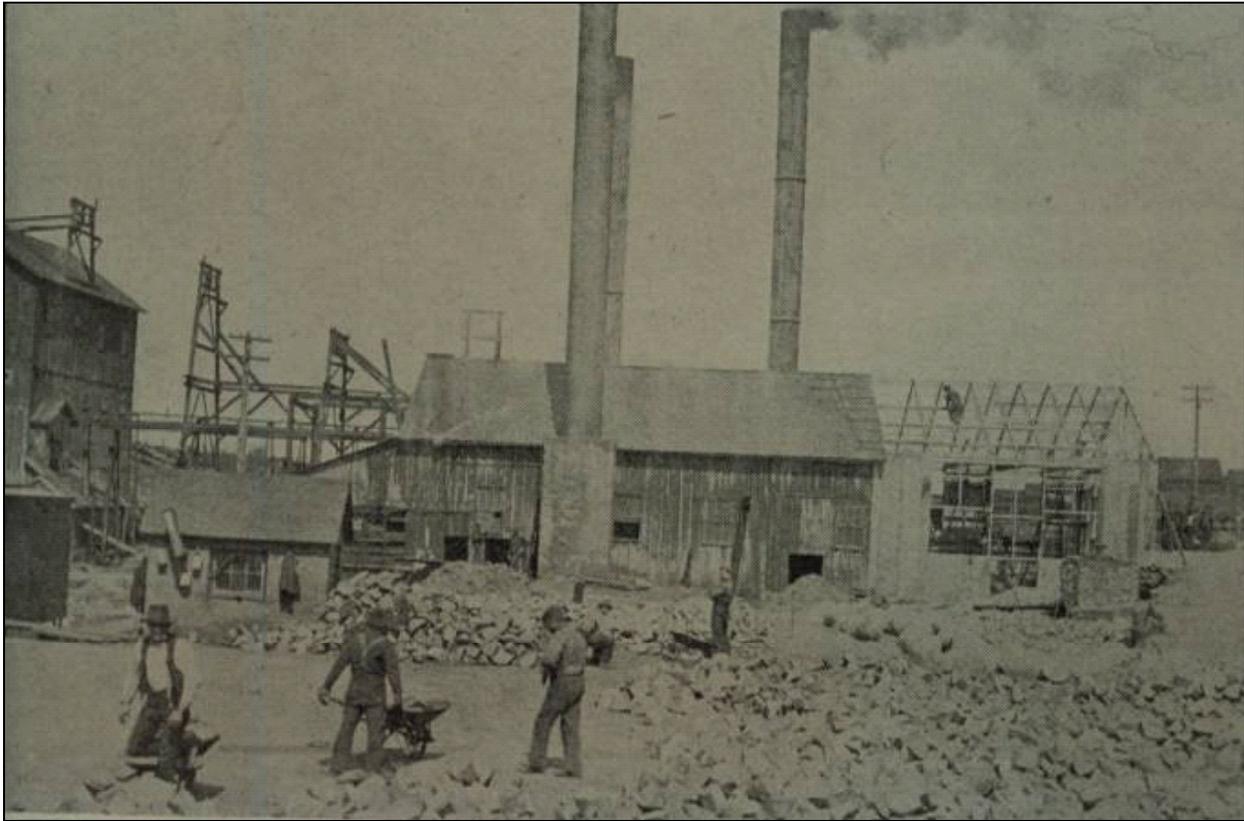
Total production in 1889 was 8,450 tonnes of matte containing 22.4% copper and 14.3% nickel. This was twice as much nickel as the rest of the world produced in 1888.

The second major smelter in Sudbury commenced operation when the Mond Nickel Company installed blast furnaces and converters in Coniston in 1913. The first matte from the Xstrata Nickel Smelter was produced in February, 1930.

### **3.2.2 Changes in the Industry**

The pyrometallurgical technologies of roasting, smelting, and converting have been used in Sudbury from the late 1800s to today to separate and concentrate the matte to the point at which the metals can be separated by final refining. Sulphur dioxide (SO<sub>2</sub>) has been one of the key pollutants associated with ore smelting in Sudbury, and total emissions to the atmosphere during the period from 1930 to 1982 have been estimated to be in the order of 94,000,000 tonnes. Similar historical totals for the COC for the Sudbury Soils Study (arsenic, cobalt, copper, lead, nickel and selenium) are not readily available, but it has been estimated that up to 70 to 80% of the copper and nickel emitted from the smelters has been deposited within the Sudbury area (within a 40 km radius of the smelters).

Current stack particulate loadings are significantly lower than historical emissions (from original operations until the 1950s), with the development and implementation of highly efficient dust removal technologies. With improvements in dust capture, the MOE stated, “the evidence suggests that there should be a significant reduction in metal deposition in the Sudbury area of at least 90% for copper and nickel...” (MOE, 1982).



**Figure 3-1 The early years of smelting at Sudbury. (Photo used in presentation given by Dr. David Pearson, July, 2002)**

### 3.2.3 Roast Yards

Production of feed for the Copper Cliff blast furnaces was carried out in open roast yards (Figure 3-2) until 1929. The ore was stockpiled, ignited using wood as fuel, and left to burn for extended periods of time. During roasting, about 50 to 70% of the sulphur associated with the pyrrhotite was preferentially oxidized using air or oxygen and carried away in the exhaust gases as  $\text{SO}_2$ . The iron was converted from a sulphide to an iron oxide. Very little of the nickel and copper sulphides were oxidized during roasting.

Air pollutants from roast yards were emitted relatively close to the ground and metals and particulate matter would not have been carried as far as emissions from tall stacks. Ground-level concentrations of particulate matter in the air around the roast yards would have been substantial by today's standards. Eleven roast yards operated in Sudbury over the period from 1888 to 1929 (Laroche, Sirois and McIlveen, 1979). The roast yards were operated for as brief a time as one year, or as long as seventeen years. The most significant roast yards were Copper Cliff No. 1, Copper Cliff No. 3, O'Donnell, Victoria No. 2 and

Coniston. All of the former yards are located on property that is now or was formerly owned by Vale Inco. The open burning precluded any form of air pollution control.

The ore added to the roast yards consisted of various layers of coarse and fine ore piled to a height of about 13 feet. The roasting reaction is exothermic; therefore, the wood was only necessary to raise the temperature to the ignition point, after which, the reaction was self-sustaining. There had to be enough porosity in the pile to allow sufficient air to pass through the mass, which enabled the sulphide in the ores to be oxidized to SO<sub>2</sub>.

Once the ore was raised to roasting temperatures by the wood fire, oxidation of the pyrrhotite generated sufficient heat energy to allow the roast to continue until the sulphur in the ore had been reduced from approximately 25% to 7%. Approximately six months were required for a pile to be completely roasted.

The reaction took place under very low rates of oxidation; therefore, the localized air velocities would have been fairly low. This suggests that the distance that the non-volatile particulate emissions traveled from roast yards would likely have been limited. However, it is likely that the temperature in parts of the roast heap was above the vapourization temperature, allowing part of the semi-volatile metals including arsenic (particularly oxidic compounds), lead and selenium to be released into the air. Between 1890 and 1930, 28,040,068 tonnes of ore were smelted, releasing about 8.4 million tonnes of sulphur dioxide (Laroche *et al.*, 1979). The quantities of particulate emitted are unknown.

In 1930, the blast furnaces and roast yards were replaced with multi-hearth roasters and reverberatory furnaces for smelting.



**Figure 3-2 A roast yard. (Photo used in presentation given by Dr. David Pearson, July, 2002)**

### **3.2.4 The Advent of Ore Concentrate**

As the demand for nickel increased, lower grade ores (lower percentage of nickel and copper) were mined. Higher amounts of metals could be produced from the same smelting process if the ore was milled into a powdered concentrate before being processed. To produce a concentrate, the ore was ground to fine slurry in rod or ball mills. Magnetic separation and/or froth flotation was used to separate the tails (waste containing little metal value) from the valuable minerals. The concentrate was fed to the smelters and the tailings were disposed of in piles or under water in ponds.

Ores containing from 1.0 to 2.5% nickel could produce concentrates containing from 6 to 10% nickel. The Copper Cliff Mill produced a nickel concentrate containing 5% nickel and a copper concentrate containing 30% copper and 1% nickel. The Levack mill produced two concentrates; a nickel concentrate containing 9% nickel and 1% copper and a copper concentrate containing 30% copper and 1% nickel (Boldt, 1967).

Sulphur dioxide and particulate matter are the principal air contaminants generated during roasting of concentrates. According to the US EPA AP-42 (1995), the uncontrolled particulate emission factor for a Multi-Hearth Roaster (MHR) was 22 kg/tonne of concentrated ore handled by the smelter. However, settling chambers were generally installed to reduce particulate emissions. The chronology of the installation of particulate removal devices on the Vale Inco MHRs is not available.

The following section provides a brief description of the smelting processes at each of the three historical smelters.

### **3.2.5 Smelting at Copper Cliff**

Smelting is a term used to describe a set of complex reactions that occur in a furnace in which sufficient heat is added to raise the temperature to melt the constituents. Flux is also added to mix with the impurities in the ores such as magnesium, alumina, and silicates. The impurities form a slag that floats on the surface of the pool inside the furnace, and the metals partition into a matte. This matte is heavier and is tapped from the bottom layer of the furnace from a matte tap hole. The slag is skimmed off in a separate slag tap hole that is at a higher elevation. The iron oxide produced during roasting partitions to the slag.

At Copper Cliff during the period from 1890 to 1929, smelting took place in blast furnaces. A new smelter close to the original site began operations in 1929 with reverberatory furnaces. According to Boldt (1967), the advantage of the reverberatory furnace was that the “unit would smelt material of a fine particle size such as concentrates from flotation plants without blowing much of it from the furnace in exhaust gases”.

By 1965, the Inco Copper Cliff Smelter consisted of two blast furnaces, 42 multi-hearth roasters (the roasting plant is divided into seven batteries of six multiple hearth roasters, with each battery superimposed over a reverberatory furnace), seven reverberatory furnaces, two oxygen flash smelting furnaces for copper concentrates, and 24 converters, with two of the latter treating copper matte. Electrostatic precipitators were used to control emissions from the roasters and converters.

Vale Inco replaced the multi-hearth roaster with a fluid bed roaster at No. 1 reverberatory furnace in 1976. A highly concentrated SO<sub>2</sub> stream was produced that could be tied into plants that converted the SO<sub>2</sub> to sulphuric acid or liquid SO<sub>2</sub>. The installation of the particulate control devices on the roasting operation contributed to the reduction in particulate matter (PM – particles of three size fractions, including respirable particulate matter less than 2.5 microns in diameter (PM<sub>2.5</sub>); respirable particulate matter less than 10 microns in diameter (PM<sub>10</sub>); and total suspended particulate matter less than 44

microns in diameter (TSP)) emissions after 1970, from 25,000 tonnes/year in 1940 to 15,000 tonnes/year in 1972.

In 1994, the reverberatory furnaces were shut down in favour of flash furnaces, which combine roasting and smelting in one unit and produce an off-gas containing a smaller volume and a higher percentage of sulphur dioxide that has been economically processed to produce sulphuric acid. The flash furnaces also include highly effective control for particulate and metals emissions.

### **3.2.6 Sintering at Coniston**

At Coniston, sintering was used to roast concentrates over the period from 1918 to 1972. The feed to a sinter plant consisted of concentrates that were blended with recycled sinter fines and other process materials. The bed was ignited on the surface with gas burners, and the flame front moved from the top to the bottom of the bed. A continuous series of individual pallets conveyed the bed over a series of windboxes, through which air was drawn from the surface of the bed down through the pallets into the windbox below the pallets. The sintered product was discharged at the end of the strand as it passed over a breaker. Crushing, screening, and cooling produced a coarse feed to the blast furnace. Fine material was cooled and recycled back through the process.

Emissions from the sintering process arose from the handling of hot, dry, final sintered product; as well as the wind box gases that contained considerable PM, metals, and SO<sub>2</sub>. According to the US EPA AP-42 (1995), the discharge of calcine from a roaster can generate 1.36 kilograms of particulate matter per tonne of concentrated ore processed, if not controlled. This 1.36 factor would have been typical for the discharge from roasters and sinter plants while being conveyed to the smelting furnaces.

In 1972, the Coniston smelter was shut down and the concentrates were diverted to the Copper Cliff smelter, which by then was equipped with a 381-metre stack. As a result, SO<sub>2</sub> and metal ground-level concentrations around Coniston were reduced.

### **3.2.7 Smelting at town of Falconbridge**

Xstrata Nickel added a concentrator and a sinter plant in 1933 to treat lower grade ores. The sinter plant/blast furnace smelting process used at Falconbridge over the period from 1933 to 1978 was very similar to the operation at the Coniston Smelter. The sinter plant produced an agglomerate, or coarser material that had sufficient porosity to be processed in a blast furnace. In 1947, the sinter plant produced a waste gas volume of 170,000 cfm at 95°C containing 1% SO<sub>2</sub> (Jackson, 1992).

The original exhaust stack used for the blast furnace and converters at Falconbridge in 1930 was 175 feet high and 12 feet in diameter. In 1936, a 304-foot stack was added to handle the blast furnace and converter gases, and the sinter plant was tied into the 175-foot stack. The 304-foot (or 93 meter) stack is still used today to disperse exhaust gases from the electric furnace, converter aisle, and acid plant tail gas. From 1965 to 1978, a 450-foot stack was used to better disperse the sinter plant emissions. The 450-foot stack still stands, but is not currently being used.

From 1932 to 1978, Xstrata Nickel used blast furnaces to smelt the sinter. A Cottrell precipitator was installed at Falconbridge in 1955 to clean the off-gases from the blast furnaces and converters. In 1978, Xstrata Nickel shut down the blast furnaces and switched to fluidized beds for roasting which fed into submerged arc electric furnaces for smelting. The No. 2 electric furnace still in operation at Falconbridge currently produces an off-gas that contains about 1.0% SO<sub>2</sub> that is too low to be converted to sulphuric acid in an acid plant.

In 1954, the grade of the concentrate produced by the Xstrata Nickel Mill and fed to the smelter contained 4% nickel, and by 1978, the grade had been increased to 10% nickel; the tonnes of concentrate that had to be roasted, smelted, and converted to produce a tonne of matte at 50% nickel had been reduced by more than one-half over the period.

A comparison of published emission factors for various smelting processes is presented in Table 3.1.

**Table 3.1 Published Emission Factors for Primary Copper Smelters (US EPA, 1995a)**

| Configuration  | Process | Particulate (kg/tonne concentrated ore produced) | Emission Factor Rating* | Sulphur Dioxide (kg/tonne concentrated ore produced) | Emission Factor Rating | References   |
|--|---------|--|-------------------------|--|------------------------|--|
| Reverberatory furnace (RF) followed by converter (C) (SCC 3-03-005-23)                                   | RF      | 25   | B                       | 160  | B                      | Laroche <i>et al.</i> , 1979; Pearson, 2002; MOE, 1982; Boldt, 1967; US EPA, 1995a; Jackson, 1992.                         |
|  | C       | 18   | B                       | 370  | B                      | Bouillon, 2003; Chan, 1982; Oztvacic and McDonald, 1982; Chan <i>et al.</i> , 1982; US EPA, 2003; MOE, 1979                |
| Multiple hearth roaster (MHR) followed by reverberatory furnace (RF) and converter (C) (SCC 3-03-005-29) | MHR     | 22   | B                       | 140  | B                      | Laroche <i>et al.</i> , 1979; Pearson, 2002; MOE, 1979; Oztvacic, 1982   |
|  | RF      | 25   | B                       | 90   | B                      | Laroche <i>et al.</i> , 1979; Pearson, 2002; MOE, 1982; Boldt, 1967; US EPA, 1995a; Hatch, 2004; Canadian Geographic, 2000 |
|  | C       | 18   | B                       | 300  | B                      | US EPA, 1995a; Chan, 1982; Oztvacic, 1982; Chan <i>et al.</i> , 1982   |
| Fluid bed roaster (FBR) followed by reverberatory furnace (RF) and converter (C) (SCC 3-03-005-25)       | FBR     | ND   | ND                      | 180  | B                      | Bell and Orford, 1986  |
|  | RF      | 25   | B                       | 90   | B                      | —  |
|  | C       | 18   | B                       | 270  | B                      | —  |
| Concentrate dryer (CD) followed by electric furnace (EF) and converter (C) (SCC 3-03-005-27)             | CD      | 5  | B                       | 0.5  | B                      | MOE, 2001; Potvin and Balsillie, 1976  |
|  | EF      | 50   | B                       | 120  | B                      | MOE, 1979  |

**Table 3.1 Published Emission Factors for Primary Copper Smelters (US EPA, 1995a)**

| Configuration  | Process | Particulate (kg/tonne concentrated ore produced) | Emission Factor Rating* | Sulphur Dioxide (kg/tonne concentrated ore produced) | Emission Factor Rating | References   |
|--|---------|--|-------------------------|--|------------------------|--|
|  | C       | 18   | B                       | 410  | B                      | US EPA, 1995a; Chan, 1982; Ozavic and McDonald, 1982; Chan <i>et al.</i> , 1982; MOE, 1979 |
| Fluid bed roaster (FBR) followed by electric furnace (EF) and converter (C) (SCC 3-03-005-30)                  | FBR     | ND   | ND                      | 180  | B                      | Bell and Orford, 1986  |
|  | EF      | 50   | B                       | 45   | B                      | MOE, 1979; Potvin, 2004  |
|  | C       | 18   | B                       | 300  | B                      | LeBourdais, 1953   |
| Concentrate Dryer (CD) followed by flash furnace (FF), cleaning furnace (SS) and converter © (SCC 3-03-005-26) | CD      | 5  | B                       | 0.5  | B                      | MOE, 2001; Potvin and Blasillie, 1976  |
|  | FF      | 70   | B                       | 410  | B                      | Earth Tech Canada Inc., 2002   |
|  | SS      | 5  | B                       | 0.5  | B                      | Potvin and Blasillie, 1976   |
|  | C       | ND   | ND                      | 120  | B                      | Potvin and Blasillie, 1976   |
| MOE 2001 Concentrate dryer (CD) followed by Noranda reactors (NR) and converter (C)                            | CD      | 5  | B                       | 0.5  | B                      | MOE, 2001; Potvin and Blasillie, 1976  |
|  | NR      | ND   | ND                      | ND   | ND                     | -  |
|  | C       | ND   | ND                      | ND   | ND                     | -  |

\* Each AP-42 emission factor is given a rating from A through E, with A being the best. A factor's rating is a general indication of the reliability, or robustness, of that factor. This rating is assigned based on the estimated reliability of the tests used to develop the factor, and on both the amount and the representative characteristics of those data (US EPA, 1995b).

### 3.2.8 Converters

At all three smelters, Pierce-Smith converters are or were used. They are refractory-lined, cylindrical steel shells mounted on trunnions at either end, and rotated about the major axis for charging and pouring.

Converting is used primarily for copper and nickel matte processing, and serves to remove residual sulphur and iron in the matte from the furnaces (blast furnaces, reverberatory or electric). Converters also

have the capability of processing high-grade scrap materials. Air or oxygen-enriched air is blown through the matte, generating off-gases containing variable amounts of sulphur dioxide, volatile, and non-volatile metals (such as nickel, cobalt, copper, lead, cadmium, arsenic, lead and zinc). Slag from the converter typically has a high nickel and cobalt concentration, and can be returned to the smelting furnace for recovery of much of the metals.

During the 1930s, 40s and part of the 50s, emission controls consisted of settling chambers that would have removed about 50% of the particulate. Coarser particles were more likely to settle out than fine particulate. In the US EPA's AP-42 (1995), the fugitive emissions or the emissions from charging materials into the converter and tapping matte and slag from the converters are listed as 2.2 kilograms of PM per tonne of ore concentrated. The efficient collection of fugitive emissions at converters requires a considerable expense, for the relatively low amounts of particulate generated.

Finished Pierce-Smith converter matte typically contains 1 to 3% iron, less than 25% total sulphur, and 50% nickel. The higher-grade concentrates fed to the smelters has allowed the converter cycle times to be reduced from two days to less than eight hours. Emissions per tonne of nickel produced have been reduced proportionally.

Inco did try to make sulphuric acid from converter gas in 1925, but the process was abandoned. In 1958, the converter aisle at Copper Cliff consisted of 19 Pierce Smith converters each 35 feet long by 13 feet in diameter. The converters at Copper Cliff are a significant source of SO<sub>2</sub> from the smelter.

There were four 13-foot-diameter by 30-foot-long Pierce-Smith Converters installed at the Coniston Smelter. The gas cleaning consisted of a settling chamber.

There are four converters in use at the Xstrata Nickel smelter. The converters are a significant source of SO<sub>2</sub> from the Xstrata Nickel smelter. Converter gases have been cleaned of particulate in an electrostatic precipitator since 1955. Prior to 1955, the gases were passed through a settling chamber.

### **3.2.9 Summary of Major Events**

Tables 3.2 and 3.3 summarize major historic events relevant to air emissions for Vale Inco and Xstrata Nickel, respectively.

**Table 3.2 Summary of Major Events for Vale Inco Ltd.**

| <b>Year</b> | <b>Vale Inco Ltd.<br/>(including Copper Cliff, Mond Nickel - Coniston, &amp; Mond Nickel - Victoria)</b>  |
|-------------|---|
| <b>1886</b> | The Canadian Copper Company (predecessor to Inco Ltd.) incorporated in Ohio, under the direction of Samuel Ritchie.   |
| <b>1888</b> | <ul style="list-style-type: none"> <li>Roast yard constructed at Copper Cliff. About 80 to 100 tonnes a day of calcine was treated. Eleven roast yards (which each ran between one and seventeen years) were operated in Sudbury between 1888 and 1929.</li> <li>The Herreschoff No. 1 blast furnace was blown in at the East Smelter in Copper Cliff.</li> </ul> |
| <b>1889</b> | <ul style="list-style-type: none"> <li>Total production in 1889 was 8,450 tonnes of matte containing 22.4% copper and 14.3% nickel.</li> <li>The second Copper Cliff blast furnace was blown in. 41,000 tonnes of ore were excavated, producing 8,450 tonnes of matte.</li> <li>Roast yards were relocated further away from populated areas.</li> </ul>          |
| <b>1890</b> | Between 1890 and 1929, approximately 28,000,000 tonnes of ore were processed in Sudbury, resulting in roughly 11,000,000 tonnes of sulphur dioxide released to the atmosphere.  |
| <b>1892</b> | Copper Cliff introduction of Bessemer converters.   |
| <b>1897</b> | Copper Cliff ore begins to be pyrometallurgically processed into a matte.   |
| <b>1899</b> | Copper Cliff West smelter installed to replace the East smelter. Four blast furnaces were installed. 180' stack.  |
| <b>1901</b> | Mond Nickel starts nickel smelter in Victoria Mines, stack height 115'. Two blast furnaces and converters. Average capacity, 60,000 tonnes per year of ore.   |
| <b>1902</b> | Copper cliff East smelter shut down.  |
| <b>1903</b> | Canadian Copper Co. and Orford Copper Co. unite to form International Nickel Co.  |
| <b>1904</b> | New Copper Cliff west smelter with 210' stack.  |
| <b>1905</b> | 5 blast furnaces at new west smelter (Copper Cliff) produced 2,000 tonnes of nickel copper matte per day.   |
| <b>1909</b> | Mond Nickel Victoria plant capacity: 140,000 tonnes per year of ore.  |
| <b>1911</b> | Installation of reveratory furnace at Copper Cliff.   |
| <b>1912</b> | Installation of reveratory furnace at Copper Cliff.   |
| <b>1913</b> | <ul style="list-style-type: none"> <li>The second major smelter in Sudbury commenced operation when the Mond Nickel Company installed blast furnaces and converters in Coniston in 1913.</li> <li>Victoria smelter shut down.</li> </ul>  |
| <b>1918</b> | Coniston roast yards phased out.  |
| <b>1919</b> | Ore beinning to be pyrometallurgically processed into a matte at Coniston.  |
| <b>1925</b> | Inco tried to make sulphuric acid from converter gas in 1925, but the process was abandoned.  |
| <b>1929</b> | <ul style="list-style-type: none"> <li>Roasting of ores in open piles (roast yards) was stopped. All smelting carried out at smelters with stacks from 106 to 152 metres high.</li> <li>Inco unites with Mond Nickel.</li> <li>Reverberatory furnaces begin to replace blast furnaces at Copper Cliff.</li> </ul>   |

**Table 3.2 Summary of Major Events for Vale Inco Ltd.**

| Year | Vale Inco Ltd.<br>(including Copper Cliff, Mond Nickel - Coniston, & Mond Nickel - Victoria)   |
|------|--|
| 1950 | <ul style="list-style-type: none"> <li>Emission controls consisted of settling chambers that would have removed about 50% of the particulate (mainly larger particle sizes).</li> <li>In the period from 1900 to 1950, at all three smelters, more than 90% of the sulphur in the ore was emitted to the atmosphere.</li> </ul>                                      |
| 1952 | New 454 tonne per day oxygen flash furnace & 375 tonnes per day oxygen plant commissioned at Copper Cliff smelter. SO <sub>2</sub> produced was recovered as liquefied sulphur dioxide.  |
| 1953 | 907 tonne per day copper processed through the flash furnace, commenced construction of first unit of IORP.  |
| 1956 | Started operation of first two units of Iron Ore Recovery Plant (IORP). Capacity: 907 tonnes per day of pyrrhotite producing 235,820 tonnes per year of iron ore pellets.  |
| 1958 | <ul style="list-style-type: none"> <li>In 1958, the converter aisle at Copper Cliff consisted of 19 Pierce Smith converters each 35 foot long by 13 feet in diameter.</li> <li>Acid plant commissioned at IORP. Capacity: 363 tonnes per day H<sub>2</sub>SO<sub>4</sub>.</li> </ul>   |
| 1960 | At Coniston, four blast furnaces were on site with only one or two running in the 1960s.   |
| 1963 | Major expansion of IORP to 2,721 tonnes per day of pyrrhotite and 725,600 tonnes per year of iron ore pellets. Off-gases treated by 907 tonnes per day H <sub>2</sub> SO <sub>4</sub> acid plant.  |
| 1965 | By 1965, the Inco Copper Cliff Smelter consisted of two blast furnaces, 42 multi-hearth roasters, 7 reverberatory furnaces, two oxygen flash smelting furnaces for copper concentrates, 24 converters. Electrostatic precipitators were used to control emissions from the roasters and converters.  |
| 1967 | Third acid plant commissioned at IORP, raising capacity to 2,268 tonnes per day of H <sub>2</sub> SO <sub>4</sub> .  |
| 1968 | Expanded copper flash furnace.   |
| 1969 | Fluid bed roaster added to No. 1 reverberatory furnace with off-gases cleaned and SO <sub>2</sub> gases converted to sulphuric acid.   |
| 1970 | The installation of the particulate control devices on the roasting operation contributed to the sharp reduction in particulate matter emissions after 1970.   |
| 1972 | Coniston smelter shut down, concentrates diverted to the Copper Cliff smelter equipped with the 381-meter stack. (This superstack had just recently replaced the three lower stacks.)  |
| 1975 | Development of nickel oxygen based flash furnace technology where SO <sub>2</sub> emissions were converted to sulphuric acid.  |
| 1976 | Inco replaced the multi-hearth roaster with a fluid bed roaster at No. 1 reverberatory furnace in 1976. A highly concentrated SO <sub>2</sub> stream was produced that could be tied into plants that converted the SO <sub>2</sub> to sulphuric acid or liquid SO <sub>2</sub> .  |
| 1977 | Development of nickel oxygen based flash furnace technology where SO <sub>2</sub> emissions were converted to sulphuric acid.  |
| 1980 | <ul style="list-style-type: none"> <li>Additional precipitator capacity added to the Copper Cliff Nickel Refinery.</li> <li>A sharp transition took place during the 1980s and 1990s with the installation of acid plants at Copper Cliff to recover the SO<sub>2</sub>, and less than 10% of the sulphur in the ore is now discharged to the atmosphere.</li> </ul> |
| 1994 | <ul style="list-style-type: none"> <li>Flash furnace installed at Copper Cliff Smelter.</li> <li>In 1994, the reverberatory furnaces were shut down in favour of flash smelting furnaces.</li> </ul>   |

**Table 3.3 Summary of Major Events for Xstrata Nickel**

| Year | Xstrata Nickel   |
|------|--|
| 1928 | Nickel mines incorporated to develop ore body outlined in Falconbridge township.   |
| 1930 | <ul style="list-style-type: none"> <li>The first matte from the Falconbridge Smelter produced. Single blast furnace and two converters.</li> <li>85% of sulphur in ore released to air. Dust collection by dust chamber 80' long x 40' wide x 22' high.</li> </ul>   |
| 1933 | <ul style="list-style-type: none"> <li>Added a concentrator and a sinter plant to treat lower grade ore.</li> <li>Concentrator built to produce fine concentrate.</li> <li>Two sinter strands added to make concentrate suitable for blast furnace feed.</li> </ul>  |
| 1936 | <ul style="list-style-type: none"> <li>3<sup>rd</sup> converter added, 304' high stack added for blast furnace &amp; converter gases. Separate dust chamber for each stack.</li> <li>Production rate 327,783 tonnes of ore, 11,226,108 pounds of nickel.</li> </ul>  |
| 1937 | 3 <sup>rd</sup> sinter strand added, 438,629 tonnes of ore treated.  |
| 1942 | Two additional sinter strands added.   |
| 1943 | Additional blast furnace added.  |
| 1947 | In 1947, the sinter plant produced a waste gas volume of 170,000 cfm at 95°C containing 1% SO <sub>2</sub> .   |
| 1953 | 3 <sup>rd</sup> blast furnace, 4 <sup>th</sup> converter added.  |
| 1954 | <ul style="list-style-type: none"> <li>Sourcing of ore from west end. 3,200 tonnes per day concentrate from east end and 1,500 tonnes per day from west end.</li> <li>Pyrrhotite plant to treat pyrrhotite from east end mill was commissioned.</li> </ul>   |
| 1955 | There are four converters in use at the Falconbridge Smelter. An electrostatic precipitator was installed for cleaning gases from blast furnaces and converters but not the sinter plant.  |
| 1958 | New converter aisle added. 4 <sup>th</sup> blast furnace added, No. 5 & 6 converter added, No. 4 converter shut down. No. 2 blast furnace shut down. Converter gases cleaned in ESP.   |
| 1963 | No. 1, 2 & 3 converters shut down.   |
| 1965 | 450' stack added for dispersion of sinter plant emissions. The previous 304' stack is still used today for the electric furnace, converter aisle and acid plant tail gas.  |
| 1967 | Strathcona mine and mill started production. 6,000 tonnes per day capacity.  |
| 1970 | No. 1 blast furnace rebuilt & gases passed through cyclone & up 450' sinter stack.   |
| 1971 | 6 <sup>th</sup> sinter strand added.   |
| 1972 | <ul style="list-style-type: none"> <li>Pyrrhotite plant shut down.</li> <li>Construction starts on Smelter Environmental Improvement Project (SEIP)</li> </ul>   |
| 1978 | Sinter plant & blast furnaces shut down. The remainder of the sinter plant replaced with fluid bed roaster and electric furnace. Fluid bed roaster off-gases to be tied into acid plant. Blast furnaces shut down and switched to fluidized beds for roasting. All process gases now cleaned and the SO <sub>2</sub> , metals and particulate emission reduction is significant. |
| 1985 | No. 8 converter started up.  |

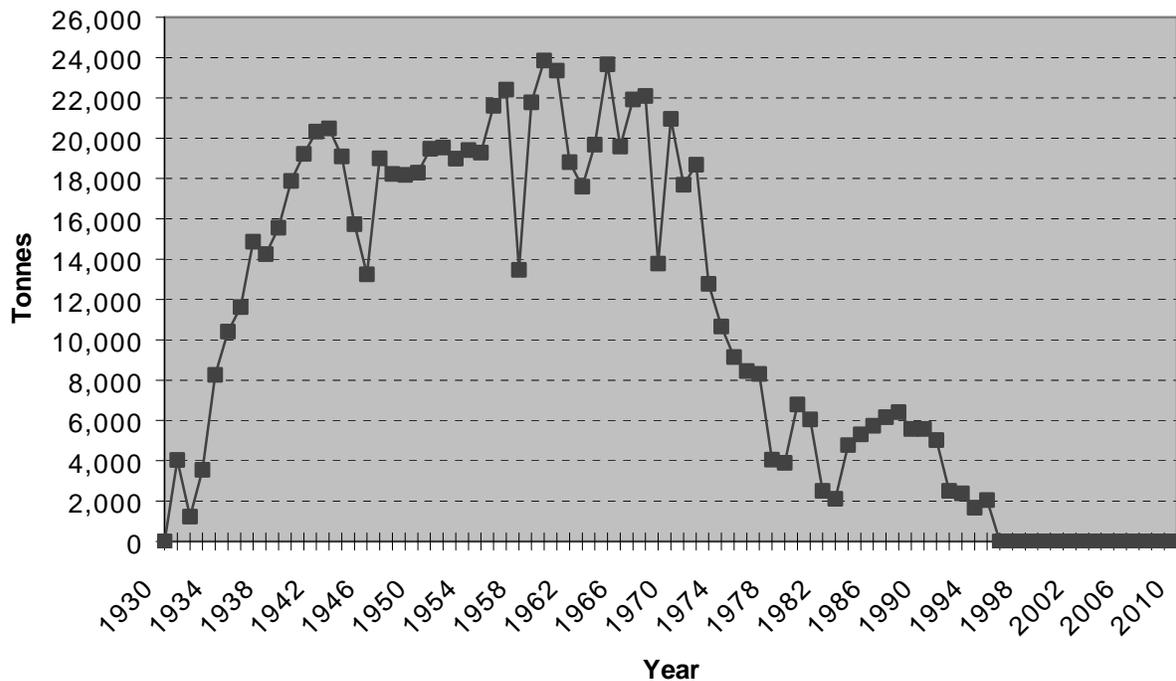
### 3.3 Emission Data

#### 3.3.1 Emissions Estimates at Copper Cliff

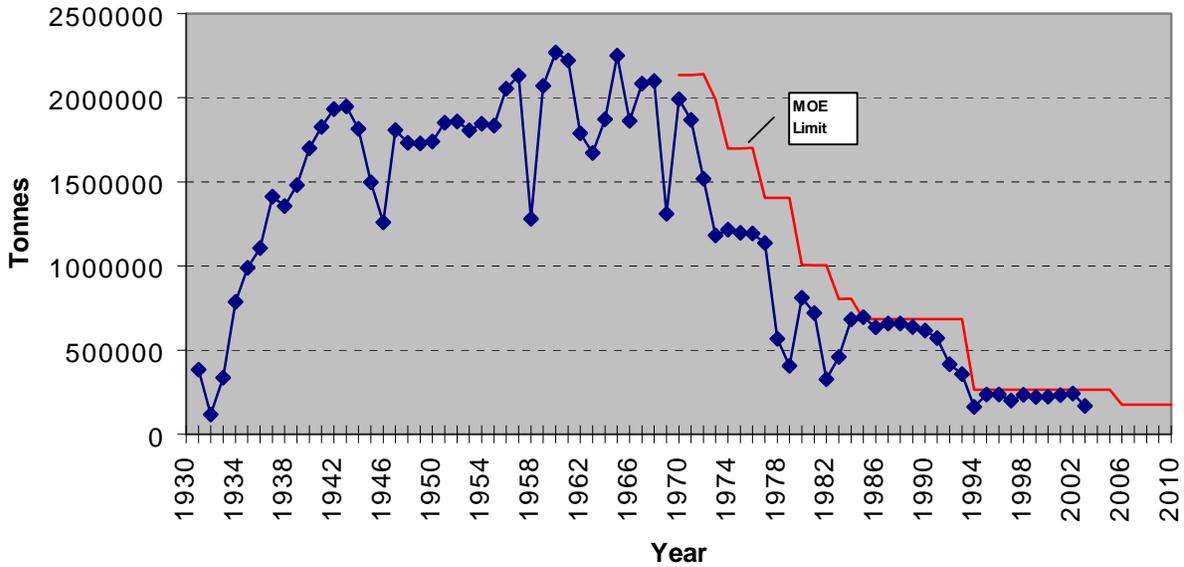
Bouillion (2003) used emission factors to develop a history of particulate emissions (PM) generated from smelting and related processes at the Copper Cliff smelter over the period from 1932 to 1996. The result is shown in Figure 3-3, which shows annual emissions of particulate matter in tonnes/year. This trend mimics that for SO<sub>2</sub> (Figure 3-4) emissions.

A sharp increase in emissions occurred in the 1930s, which was mainly related to an increase in production and the scale of the operations. The emissions levelled off in the 1940s, 50s and 60s and then declined dramatically in the 1970s and 80s, with the advent of new technologies that included acid plants for recovery of sulphur emissions and electrostatic precipitators for control of particulate matter.

The emissions shown in Figure 3-3 do not include miscellaneous PM emissions from equipment activity, periodic wind erosion events at the tailings disposal areas, *etc.* Historical emissions of these so-called fugitive dust emissions are not easily quantified and the amounts are unknown.

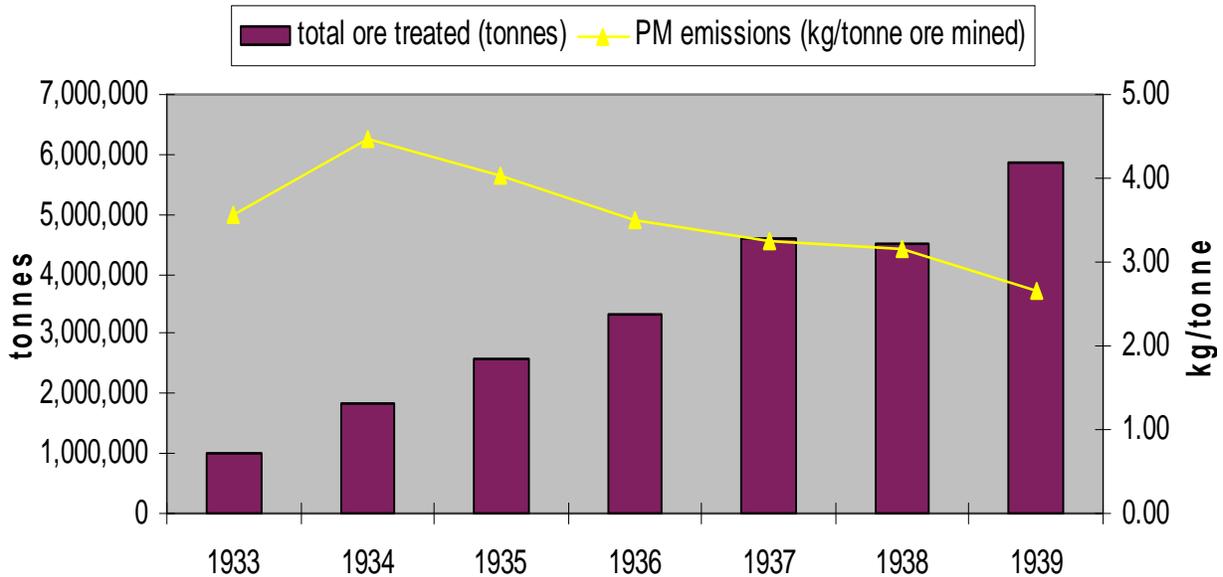


**Figure 3-3 Estimated Particulate Matter (PM) Emissions from Smelting at Copper Cliff (total tonnes per year – no data available past 1996) (after Bouillion, 2003).**



**Figure 3-4 SO<sub>2</sub> generated from the Copper Cliff smelter (Bouillon, 2003).**

Figure 3-5 shows estimated emissions data from the 1930s era. The significant increase in annual production that occurred during this period can be seen. The emission factor for PM per tonne of ore treated at the Copper Cliff Smelter was reduced from 4.48 to 2.65 kilograms of emissions per tonne of mine feed over the period from 1934 to 1939, but that reduction was more than offset by the increased production.



**Figure 3-5 Emission factor for PM per tonne of ore treated at the Copper Cliff smelter (Bouillon, 2003).**

Emissions data for individual COC at Copper Cliff are shown in Tables 3.4 and 3.5, based on data gathered in studies conducted by the Ontario Ministry of the Environment since the early 1970s. While these data show a significant declining trend in overall PM emissions during the 1970s and 80s, as in Figure 3-3, the same trend does not reveal itself clearly for the individual COC. The reason is unclear, but is partly related to gaps and approximations in the data.

Figure 3-6 shows historical Inco lead emissions as an example of COC emissions trends. The trends are similar to those shown previously for particulate matter and SO<sub>2</sub>, with a significant increase in emissions in the 1930s and declines during the 1970s and 80s. Bouillon (2003) states that emissions from the tall stacks account for over 90% of the metals emissions from Inco facilities. He calculated/extrapolated Pb:SO<sub>2</sub> ratios to be 0.000148 and 0.0001867 for the periods of 1931 to 1971 and 1972 to 1992, respectively, from information collected representing emissions from the smelter stacks before and after the installation of the superstack.

**Table 3.4 Annual Emissions of COC (Bouillon, 2003)**

| Date, Unit               | Smelter - Annual Particulate Emissions (tonnes) | Annual Nickel Emissions (tonnes) | Annual Copper Emissions (tonnes) | Annual Lead Emissions (tonnes) | Annual Arsenic Emissions (tonnes) |
|--------------------------|---|----------------------------------|----------------------------------|--------------------------------|-----------------------------------|
| 1974 Inco smelter metric | 14,870  | nd                               | nd                               | nd                             | nd                                |
| 1975 Inco smelter metric | 14,500  | nd                               | nd                               | nd                             | nd                                |
| 1976 Inco smelter metric | 15,220  | 164                              | 107                              | 56                             | nd                                |
| 1977 Inco smelter        | 14,470  | nd                               | nd                               | nd                             | nd                                |
| 1978 Inco smelter        | 8,444   | nd                               | nd                               | nd                             | nd                                |
| 1979 Inco smelter        | 6,770   | 36                               | 187                              | 80                             | 31                                |
| 1979 & 1980 Inco IORP    | nd  | 156                              | 56                               | 12                             | nd                                |
| 1980 Inco CC Smelter     | 10,644  | 319                              | 321                              | 120                            | 34                                |
| 1988 Inco                | 6,410   | 1,019                            | nd                               | nd                             | 35                                |
| 1993 Inco                | 2,381   | 334.3                            | nd                               | nd                             | 10.62                             |
| 1995 Inco                | 2,053   | 509                              | nd                               | nd                             | 9.4                               |
| 1996 Inco                | 2,473   | 222                              | nd                               | nd                             | 40.8                              |
| 1997 Inco                | 2,345   | 238                              | nd                               | nd                             | 55                                |
| 1998 Inco                | 1,981   | 190                              | nd                               | nd                             | 53                                |
| 1999 Inco                | 2,161   | 207                              | nd                               | nd                             | 68                                |
| 2000 Inco                | 2,507   | 241                              | nd                               | nd                             | 60                                |

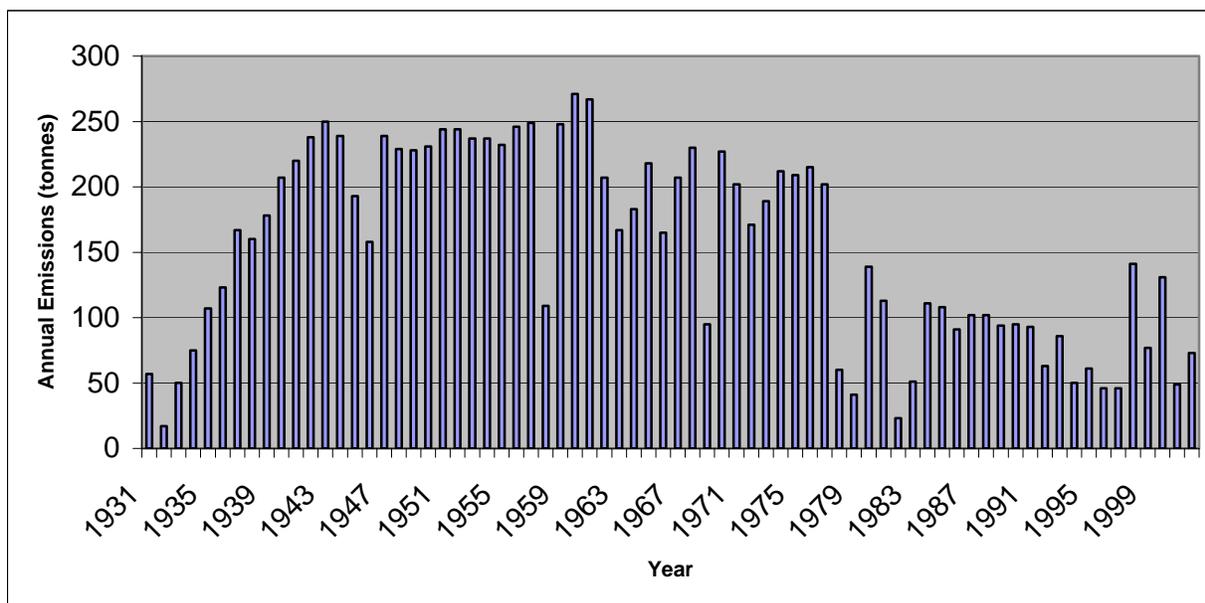
nd = no data

**Table 3.5 Emissions of COC from the Copper Cliff Smelter**

| Year | Stack | Units | As    | Cu    | Ni    | Pb    | Notes  | Reference                  |
|------|-------|-------|-------|-------|-------|-------|--|----------------------------|
| 1981 | 381 m | g/sec | 0     | 5.282 | 4.726 | 0     | Fe and Cu calculated from regression lines   | Chan, 1982                 |
| 1980 | nd    | g/sec | 2.78  | 6.116 | 5.838 | 9.452 | Fe and Cu calculated from regression lines   | Chan, 1982                 |
| 1980 | nd    | g/sec | 1.32  | 12.4  | 12.3  | 9.47  | mean of test 4 and 5                         | Ozvacic and McDonald, 1982 |
| 1979 | nd    | g/sec | nd    | 2.224 | 1.668 | nd    | Fe and Cu calculated from regression lines   | Ozvacic and McDonald, 1982 |
| 1979 | nd    | g/sec | 1.236 | 7.488 | 1.44  | 3.192 |  | Chan <i>et al.</i> , 1982  |
| 1978 | nd    | g/sec | nd    | 3.892 | 3.336 | 2.78  | Fe and Cu calculated from regression lines   | Chan <i>et al.</i> , 1982  |
| 1977 | nd    | g/sec | 2.224 | 10.29 | 9.73  | 5.004 | Fe and Cu calculated from regression lines   | Chan <i>et al.</i> , 1982  |
| 1977 | nd    | g/sec | nd    | 11.42 | 9.22  | 4.89  | obtained at south quadrant at a single point | Ozvacic and McDonald, 1982 |
| 1976 | nd    | g/sec | 4.17  | 10.84 | 10.84 | 3.336 | Fe and Cu calculated from regression lines   | Chan, 1982                 |
| 1975 | nd    | g/sec | 6.394 | 10.84 | 10.56 | 6.394 | Fe and Cu calculated from regression lines   | Chan, 1982                 |

**Table 3.5 Emissions of COC from the Copper Cliff Smelter**

| Year | Stack | Units | As    | Cu    | Ni    | Pb    | Notes                                      | Reference  |
|------|-------|-------|-------|-------|-------|-------|--|------------|
| 1974 | nd    | g/sec | 2.78  | 10.84 | 10.29 | 8.062 | Fe and Cu calculated from regression lines | Chan, 1982 |
| 1973 | nd    | g/sec | 3.058 | 8.618 | 8.062 | 5.838 | Fe and Cu calculated from regression lines | Chan, 1982 |



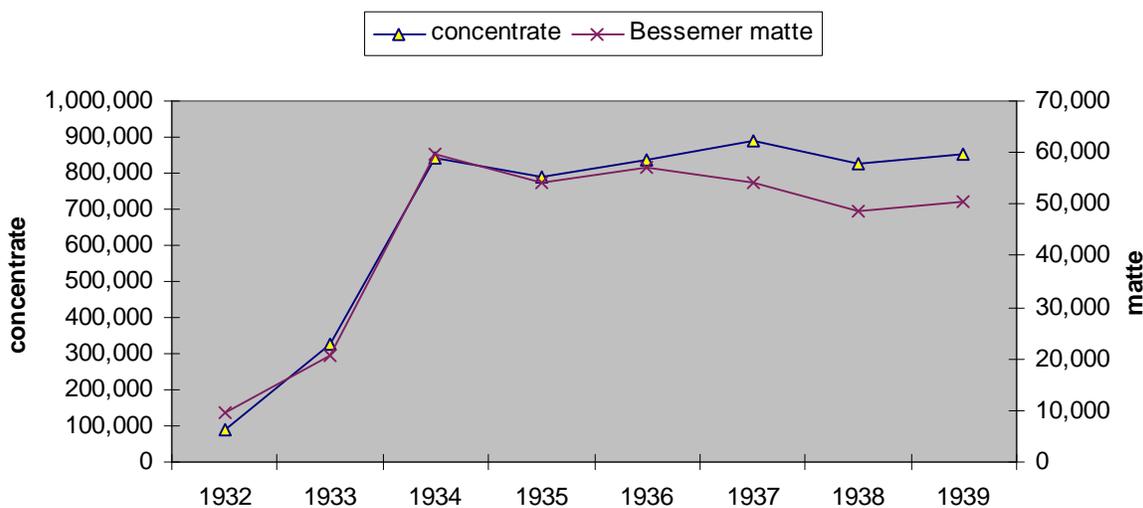
**Figure 3-6 Estimated Annual lead emissions from the Copper Cliff smelter (Bouillion, 2003).**

**3.3.2 Emissions at Coniston**

Figure 3-7 shows production data for Coniston from the 1930s. Production increased dramatically in the early 30s and then levelled off.

The estimated PM emission factor developed for Coniston by Bouillion (2003) is four kilograms of PM emitted per tonne of concentrate treated. As previously mentioned the source of the emission factors is unknown and the factors are not necessarily consistent with published generic emission factors (US EPA AP-42, 1995). Nevertheless, this factor has been used in combination with data on the average composition of the PM (Table 3.6) to illustrate historical trends. The result is shown in Figure 3-8 for the 1960s and early 1970s, *i.e.*, the period leading up to the closure of the Coniston smelting operations.

The data show a decline in emissions in the early 60s, presumably related to a decline in production at this facility. The emissions fluctuated for the remainder of the 1960s until the operations were shutdown and emissions ceased in 1972 (Figure 3-8).



**Figure 3-7 Estimated total concentrate treated and matte processed (tonnes) at Coniston.**

Table 3.6 shows that the Coniston blast furnace and converter aisle dust contained an arsenic analysis that is seven times higher and the lead about five times higher than the sinter stack PM. The sinter plant dust is partially enriched compared to the arsenic and lead in ore, while there is a significant enrichment of arsenic and lead in the blast furnace-converter dust.

The enrichment takes place when a portion of the semi-volatile arsenic and lead evaporates, and is carried into the flue gas stream as a vapour. In the colder settling chamber, some of the vapour is condensed as a very fine particulate, and either settles in the settling chamber or is carried out the stack. The arsenic and lead in the settled dust was removed and added back into the sinter plant feed. The same arsenic and lead are then evaporated again, and part of the same material is condensed and recycled around the process. A balance is created between the amount that leaves up the stack, and the amount that is removed in the settling chamber. The collection efficiency for the semi-volatile arsenic and lead in a settling chamber would, according to the EPA fact sheet (2003), have been about 10%. A possible explanation for the lower semi-volatile emission rates from the Coniston sinter plant is that the average bed temperatures in a sinter strand are much lower than in a smelting operation where the temperatures exceed 1150°C.

The Coniston smelter used essentially the same technology and gas cleaning technology as the Falconbridge sinter plant/blast furnace did from 1933 to 1955 (Falconbridge added an electrostatic precipitator for cleaning blast furnace and converter emissions in 1955. The sinter plant gases were cleaned in a settling chamber, until the strands were shut down in 1978). Inco reported the 1971 PM emission rate for Coniston at 2,741 tonnes per year (Bouillon, 2003). This was equivalent to 4.4 kilograms per tonne of concentrate treated. The US EPA’s AP-42 (1995) compilation of emission factors assumes an uncontrolled emission factor of about 65 kilograms per tonne of concentrate, or after the settling chamber about 30 kilograms per tonne of concentrate treated. The copper and nickel smelting operations used by the EPA to derive their emission factors are very similar to those at the Sudbury operations. Thus, the US EPA generic data (reported in Table 3.1 of this chapter) suggest a much higher emission rate than those reported by Bouillon (2003).

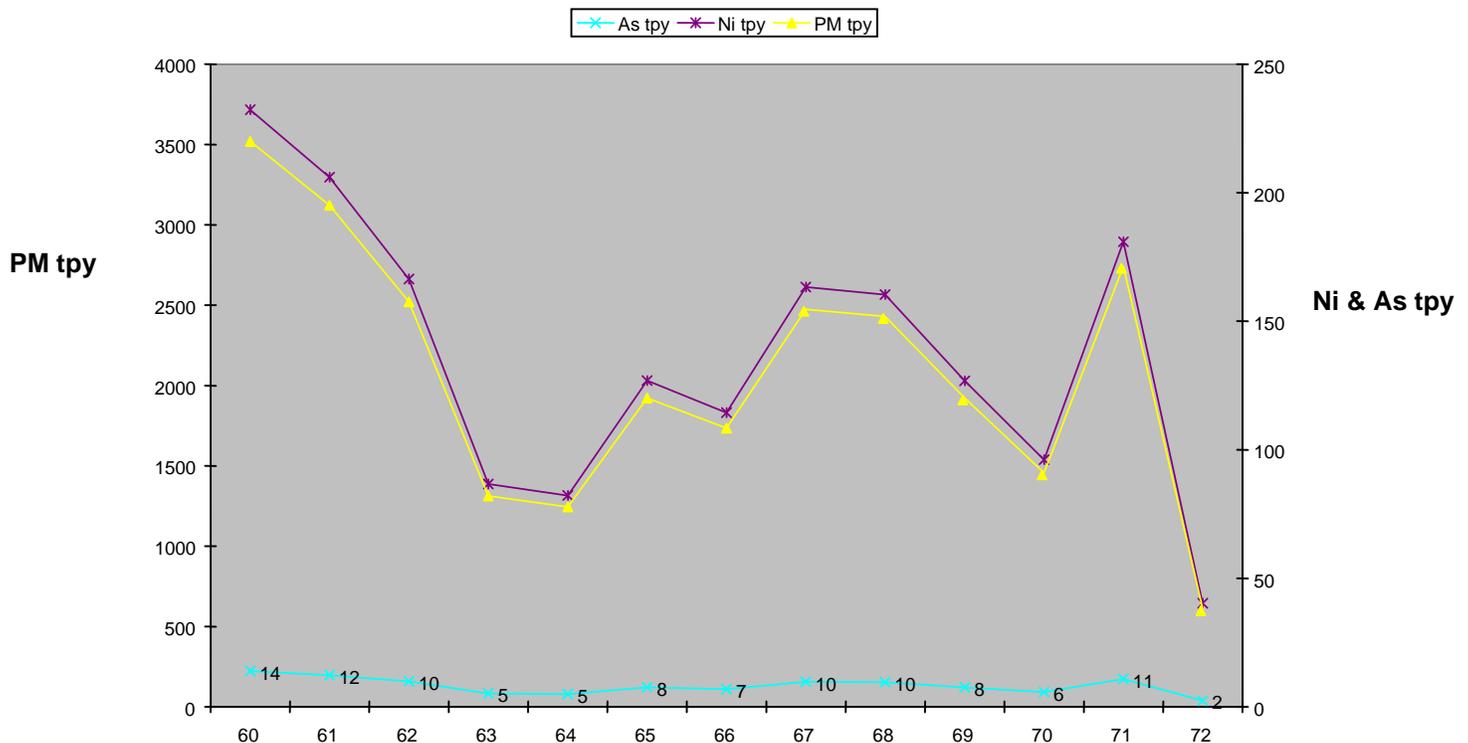
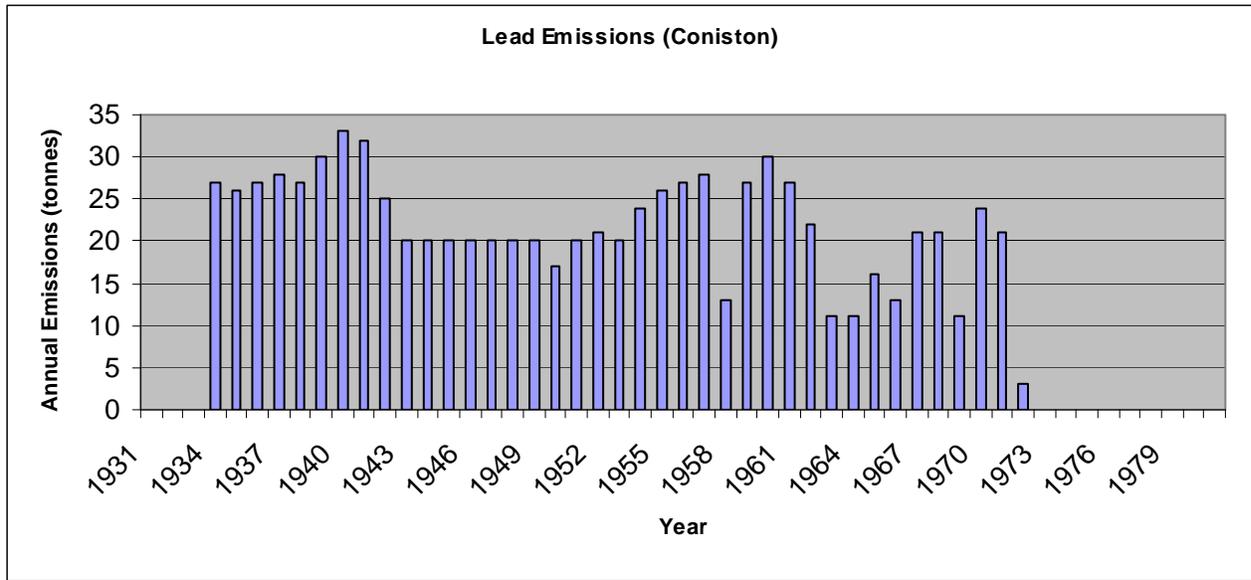


Figure 3-8 Estimated Annual Coniston PM, nickel and arsenic emission rates (tonnes per year)

**Table 3.6 Coniston Dust Analysis (%) (comparison with IORP and Copper Cliff Smelter emissions).**

|         | Coniston Sinter Settling Chamber | Coniston Smelter Settling Chamber | IORP Flue Stack | 1971 CC, Copper Stack | 1971, CC Nickel Stack | 1971, CC Orford Stack |
|---------|----------------------------------|-----------------------------------|-----------------|-----------------------|-----------------------|-----------------------|
| As, %   | 0.09                             | 0.7                               | 0.001           | 0.09                  | 0.03                  | 0.09                  |
| Bi, %   | 0.012                            | 0.09                              | 0.0004          | 0.043                 | 0.012                 | 0.016                 |
| Cd, %   | 0.012                            | 0.041                             | <0.001          | 0.035                 | 0.019                 | 0.009                 |
| Cr, %   | 0.007                            | 0.003                             | 0.013           | 0.003                 | 0.013                 | 0.44                  |
| Co, %   | 0.19                             | 0.18                              | 0.01            | 0.13                  | 0.09                  | 0.13                  |
| Cu, %   | 1.7                              | 1.5                               | 0.08            | 15.7                  | 2.2                   | 12.6                  |
| Ge, %   | 0.0008                           | 0.003                             | <0.0005         | <0.0005               | 0.002                 | 0.002                 |
| In, %   | 0.001                            | 0.001                             | 0.001           | 0.002                 | 0.001                 | 0.001                 |
| Fe, %   | 24.4                             | 23.8                              | 58.3            | 20.9                  | 24.1                  | 17.6                  |
| Pb, %   | 0.11                             | 0.5                               | 0.004           | 0.5                   | 0.25                  | 0.2                   |
| Mn, %   | 0.027                            | 0.024                             | 0.024           | 0.021                 | 0.034                 | 0.067                 |
| Hg, %   | 0.00002                          | 0.00002                           | 0.0004          | 0.00015               | 0.00035               |                       |
| Mo, %   | 0.001                            | 0.001                             | 0.002           | 0.002                 | 0.001                 | 0.008                 |
| Ni, %   | 6.6                              | 6.6                               | 0.74            | 8.3                   | 2.5                   | 8.6                   |
| Se, %   | 0.022                            | 0.051                             | 0.021           | 0.033                 | 0.021                 | 0.062                 |
| Ag, %   | 0.0008                           | 0.0009                            | 0.0004          | 0.006                 | 0.0017                | 0.004                 |
| Sr, %   | 0.02                             | 0.01                              | 0.002           | 0.002                 | 0.02                  | 0.02                  |
| Te, %   | 0.014                            | 0.024                             | <0.001          | 0.027                 | 0.01                  | 0.016                 |
| Sn, %   | 0.015                            | 0.045                             | <0.0005         | 0.01                  | 0.006                 | 0.024                 |
| V, %    | 0.007                            | 0.005                             | 0.006           | 0.003                 | 0.01                  | 0.007                 |
| Zn, %   | 0.27                             | 0.2                               | 0.01            | 0.29                  | 0.16                  | 0.17                  |
| Zr, %   | <0.01                            | <0.01                             | <0.01           | <0.01                 | <0.01                 | <0.01                 |
| Pd, ppm | 3.1                              | 2.8                               | 0.44            | 9.7                   | 2.8                   | 11.1                  |
| Pt, ppm | 1.7                              | 1.5                               | 0.25            | 1.7                   | 0.9                   | 3.6                   |
| Au, ppm | 0.5                              | 0.5                               | <0.1            | 2.1                   | 0.5                   | 1                     |
| Rh, ppm | 0.48                             | 0.41                              | <0.1            | 0.38                  | 0.17                  | 0.72                  |

Figure 3-9 shows predicted historical lead emissions for the Coniston smelting operations. The emissions peaked in the 1930s and early 40s, dropped off somewhat in the 40s and early 50s, and then peaked again in the late 1950s. As shown previously for arsenic and nickel, the emissions dropped dramatically in the early 60s and then fluctuated until plant closure in 1972.



**Figure 3-9 Predicted Annual lead emissions from Coniston (Bouillon, 2003).**

**3.3.3 Emissions at Falconbridge**

There were three phases for particulate emissions at Falconbridge: (1) from 1930 to 1955 when gas cleaning of process gases consisted of settling chambers; (2) from 1955 to 1978, when an electrostatic precipitator was installed for cleaning gases from blast furnaces and converters but not the sinter plant; and (3) in 1978, when the sinter plant and blast furnaces were shut down and replaced with a fluid bed roaster electric furnace process. By 1978, all process gases were cleaned and the SO<sub>2</sub>, metals and particulate emission reduction was significant. This section will develop estimated emissions from those three periods using available data.

Due to the processing of the east range ores over the period from 1930 to 1982, the emissions of arsenic from the Xstrata Nickel Smelter are of interest. An internal Xstrata Nickel memo (Falconbridge, 1987) indicated that the partitioning of the arsenic was as shown in Table 3.7.

**Table 3.7 Arsenic mass balance, Falconbridge Smelter. (Falconbridge, 1987)**

|                | 1973           | 1975           | 1976           |
|----------------|----------------|----------------|----------------|
|                | % distribution | % distribution | % distribution |
| Cast matte     | 48             | 38.9           | 41.6           |
| Dump slag      | 5              | 6.1            | 6.6            |
| Sinter Stack   | 21             | 18.7           | 41.8           |
| Smelter Stack  | 3              | 1              | 2.3            |
| StockPile dust |                | 6.8            | 3.3            |
| Unaccounted    | 23             | 28.5           | 4.4            |

Approximately 50% of the arsenic stayed with the matte and slag, and from 20 to 40% was emitted up the stack. High proportion of arsenic in the stack is due to the fact that the collection efficiency of submicron sized particles of semi-volatile metals such as arsenic in the settling chambers is low, as opposed to the higher efficiency for cobalt, nickel and copper. A US EPA Fact Sheet (2003) indicates that “the Collection efficiency for PM less than or equal to 10  $\mu\text{m}$  in aerodynamic diameter ( $\text{PM}_{10}$ ) is typically less than 10%”. Certainly a higher percentage of semi-volatile metals in the ores was emitted than the percentage of non volatile emissions. For low-volatile species such as nickel, cobalt and copper, most of the particles are about the size of the milled particle, and in general, greater than 2.5 microns in size (MOE, 1979). According to EPA, the efficiency of the settling chambers was about 50% for these coarse particulates.

A 1959 Falconbridge memorandum (Falconbridge, 1987), reported on the gas sampling trial from sinter machine No. 5 (Table 3.8). The report documented a trial using a 24 inch cyclone to clean the gases from the No. 5 machine flue. The dust concentration in the flue was reported at 51  $\text{mg}/\text{m}^3$  (normal conditions). The daily total PM content in the main flue that could be recovered in cyclones was reported at seven tonnes per day. A sinter production rate at the time was estimated at about 1,300 tonnes per day. An emission factor for sintering at Falconbridge of five kilograms of emission per tonne of concentrate treated can be assumed from the data.

**Table 3.8 Analysis of Falconbridge Sinter Plant Main Flue Dust, 1959**

|                  |       |
|------------------|-------|
| Ni               | 6.77% |
| Cu               | 4.69% |
| Fe               | 34.2% |
| Co               | 0.31% |
| S                | 27.4% |
| S. elem.         | 2.0%  |
| SiO <sub>2</sub> | 9.6%  |
| As               | 0.5%  |
| Pb               | 0.33% |

Source: Falconbridge Ltd.

A settling chamber was installed ahead of the sinter plant stack, and a settling chamber was also installed ahead of the combined blast furnace, converter stack. Jackson (1992) indicated that the quantity of dust recovered from flues and dust chambers increased from 2.5 to 5.7% of the tonnage of ore and concentrate smelted over the period from 1933 to 1954 (prior to the installation of the electrostatic precipitator). This was the combined value for sinter plants, blast furnaces and converters. The same article quotes that in August 1947 the production of 23,039 tonnes of sinter was accompanied by the recovery of 2,036 tonnes of dust in 2,540 hours of operations. This value is equivalent to 8.8%, so the sinter plant was most likely the highest source of particulate emissions at the plant. Assuming a collection efficiency for the settling chamber of 50%, 8.8% of the dust was removed and up to 8.8% was emitted. The particulate emission factor for the blast furnaces, sinter plant and converters was from 25 to about 50 kilograms of emissions per tonne, and about 88 kilograms of emissions per tonne of concentrate treated for the sinter plant.

A stack sampling study was carried out at Falconbridge by the MOE at the sinter plant stack and reported (MOE, 1979). The report documents the emissions from the June 1977 sampling of the 450-foot sinter plant stack at 2.31 tonnes per day (693 tonnes per year) of iron, 0.44 tonnes per day (132 tonnes per year) of arsenic, 0.38 tonnes per day (114 tonnes per year) of copper, 0.27 tonnes per day (81 tonnes per year) of nickel. Per Table 3.9, the particulate emissions from the sinter plant are reported at 12,000 tonnes per year, which were reduced to 865 tonnes per year in 1979 with the shutdown of the sinter plant. The emissions of the semi-volatile arsenic exceeded the emission of nickel and copper, which were at a much higher content in the materials being processed. Therefore, for the period before 1978, emissions of arsenic from the Xstrata Nickel Smelter sinter plant likely exceeded 100 tonnes per year.

**Table 3.9 Xstrata Nickel Smelter Particulate and Metal Stack Emissions (Ontario Ministry of Environment, 1982).**

|                     | Smelter, Annual Particulate Emissions (tonnes) | Annual Nickel Emissions (tonnes) | Annual Copper Emissions (tonnes) | Annual Cobalt Emissions (tonnes) | Annual Lead Emissions (tonnes) | Annual Arsenic Emissions (tonnes) |
|---------------------|--|----------------------------------|----------------------------------|----------------------------------|--------------------------------|-----------------------------------|
| <b>1973</b>         | 12,820   | 80                               | 100                              |                                  |                                | 132                               |
| <b>1979 to 1981</b> | 865  | 10                               | 11                               |                                  | 13                             | 6                                 |
| <b>1988</b>         | 1,066  | 20                               |                                  |                                  |                                | 12                                |

The emissions from the Xstrata Nickel stack were measured in 1979 and the results reported by Ozvacic and MacDonald (1982). The particulate emissions were identified at  $27 \pm 10.3$  grams per second. Using a figure of 300 operating days per year, the 1979 yearly emissions are estimated at 700 tonnes per year of particulate, 72 tonnes per year of iron, nine tonnes per year of copper, seven tonnes per year of nickel, 13.7 tonnes per year of lead, and 6.9 tonnes per year of arsenic. The shutdown of the sinter plant in 1979 led to a significant reduction in particulate, SO<sub>2</sub>, and metal emissions from Xstrata Nickel .

More recently, a Minor Element Balance completed for the Xstrata Nickel Smelter in 2003 demonstrates that the collection efficiency in the Cottrell precipitator for non-volatile metals, nickel, copper, and cobalt is about 99%, while the collection efficiency for semi-volatile metals such as lead and cadmium is about 95% (Hatch, 2004).

The Xstrata Nickel smelter historical SO<sub>2</sub> emissions are shown in Figure 3-10. This figure shows a similar trend to that shown previously for Vale Inco, with significant declines occurring in the 1970s. Further declines have continued to the present day.

Emissions of COC for the 1980s and 90s are shown in both tabular form and graphically (Table 3.10 and Figure 3-11). More recent emissions data were not obtained for this report. Figure 3-11 shows significant decreases in all the COC in the late 1980s, and a return to somewhat higher values for some of the COC (except arsenic, selenium and cobalt) in the late 1990s.



Kilo tonnes Sulphur Dioxide Emitted

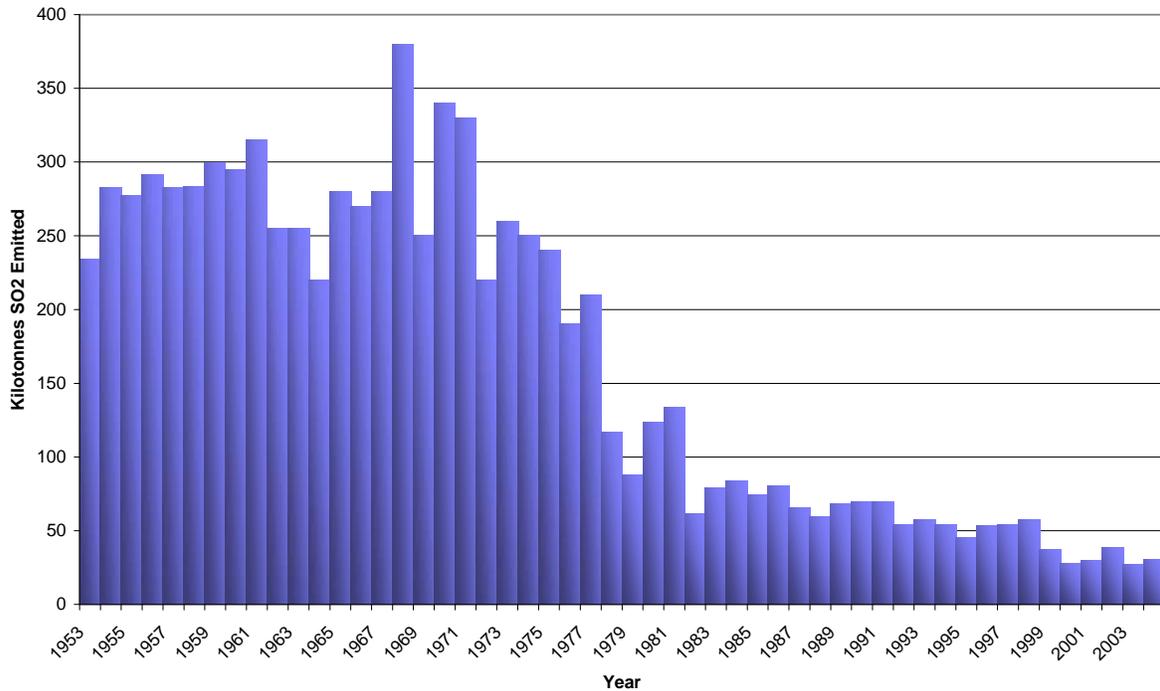


Figure 3-10 Xstrata Nickel smelter annual SO<sub>2</sub> emissions.

Table 3.10 Metal emission rates from Falconbridge Smelter primary stack (tonnes per year)

|    | 1988  | 1989  | 1990 | 1991  | 1992  | 1993  | 1994 | 1995  | 1996  | 1997  | 1998  | 1999 | 2000 |
|----|-------|-------|------|-------|-------|-------|------|-------|-------|-------|-------|------|------|
| As | 11.73 | 2.91  | 1.77 | 0.58  | 0.99  | 0.21  | 0.07 | 0.28  | 0.08  | 0.12  | 0.08  | 0.34 | 0.17 |
| Cd | 2.66  | 1.82  | 1.82 | 2.14  | 3.33  | 3.98  | 2.28 | 3.53  | 2.76  | 3.79  | 2.74  | 2.60 | 1.52 |
| Cr | 1.20  | 0.97  | 0.90 | 1.00  | 1.26  | 1.06  | 0.94 | 0.89  | 0.85  | 0.82  | 0.88  | 0.09 | 0.11 |
| Co | 1.55  | 1.09  | 0.99 | 1.16  | 1.36  | 1.74  | 1.56 | 1.76  | 1.72  | 1.27  | 1.16  | 0.38 | 0.28 |
| Cu | 12.32 | 5.81  | 1.96 | 5.29  | 10.13 | 6.13  | 4.51 | 7.10  | 7.58  | 9.20  | 8.29  | 5.55 | 3.79 |
| Pb | 17.24 | 6.37  | 5.68 | 8.88  | 12.59 | 18.01 | 8.21 | 10.20 | 8.03  | 11.97 | 9.15  | 7.00 | 5.26 |
| Ni | 20.42 | 6.30  | 3.79 | 5.37  | 8.31  | 7.08  | 5.28 | 8.46  | 8.96  | 11.64 | 11.43 | 7.04 | 5.30 |
| Zn | 32.50 | 15.49 | 8.70 | 19.02 | 10.15 | 13.38 | 8.01 | 10.32 | 10.16 | 7.64  | 8.11  | 9.68 | 5.04 |

Source: Multi-pollutant Emission Reduction Analysis Foundation (MERAf) for the Base Metals Smelting Sector

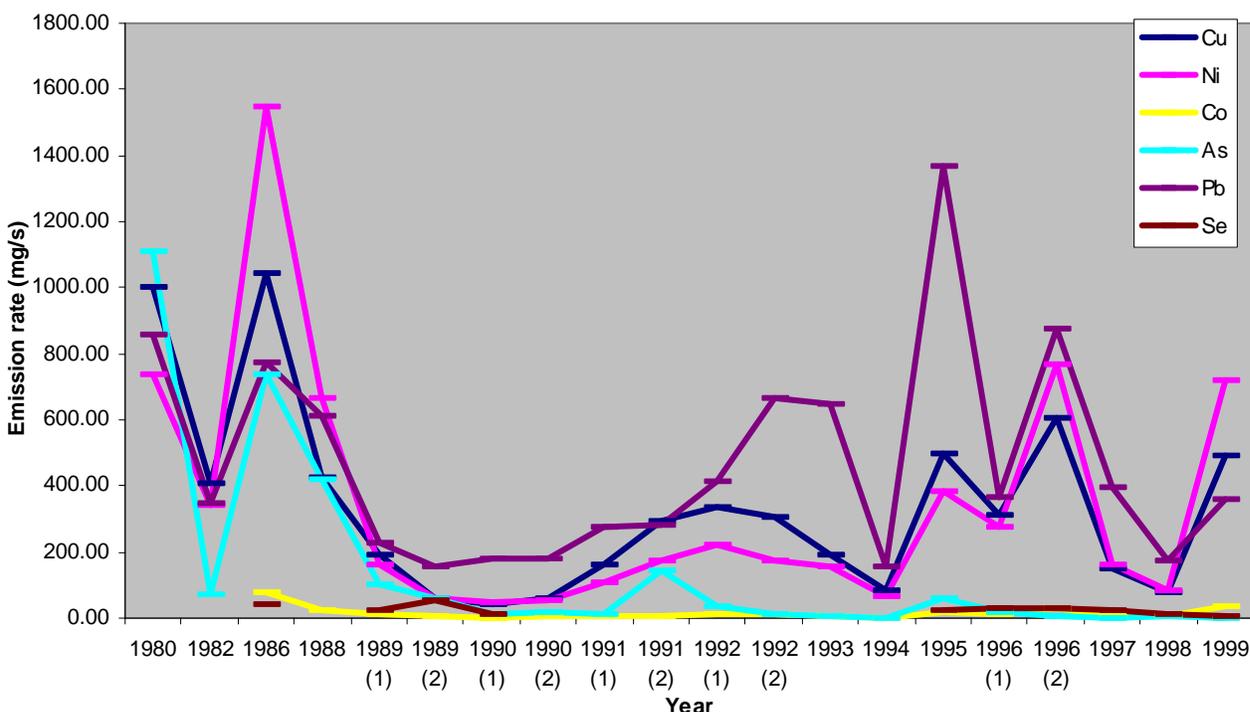


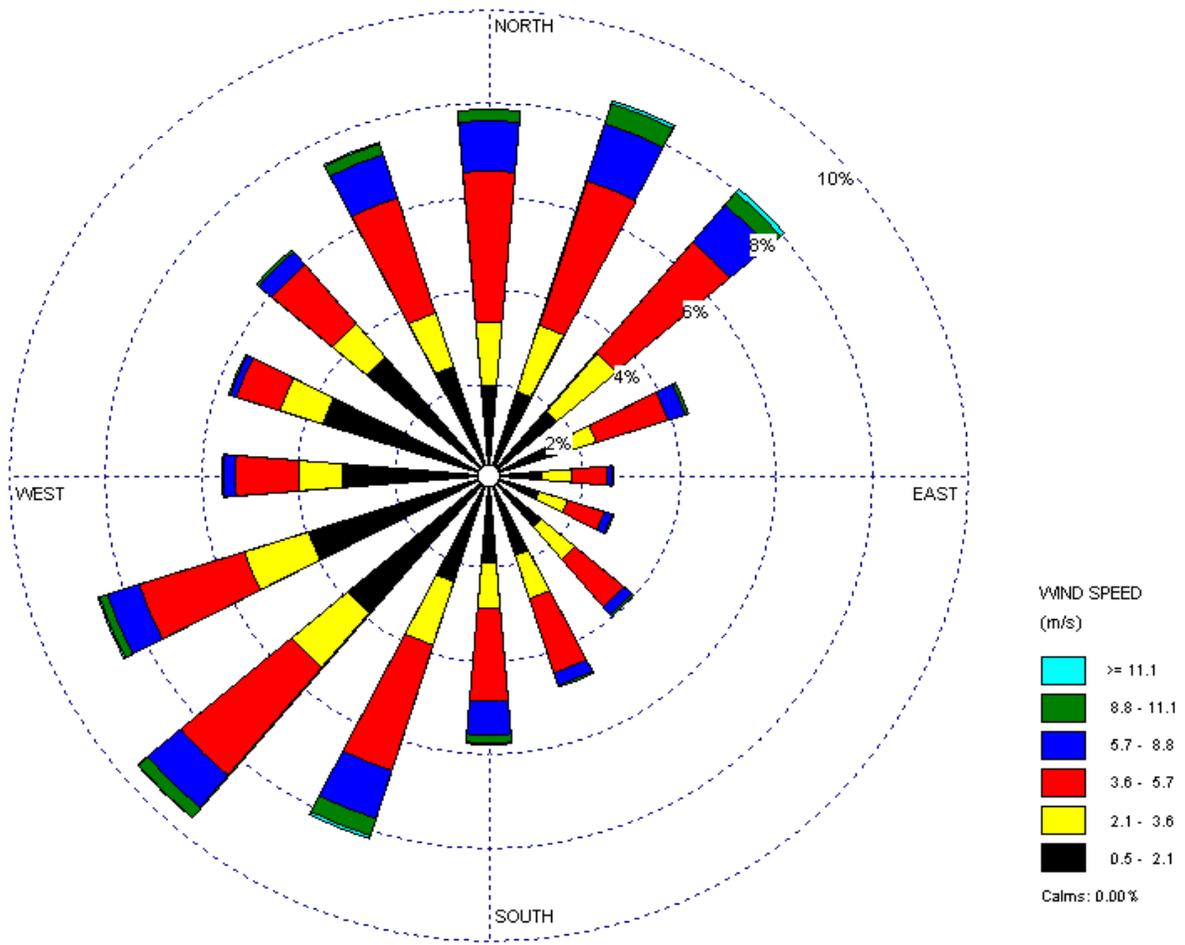
Figure 3-11 Emission rates for Chemicals of Concern (COC) at Xstrata Nickel smelter.

### 3.4 Dispersion of Emissions

#### 3.4.1 Wind Climate and Predicted Dispersion Patterns

Section 3.3 provided a discussion of the emissions of COC, particulate matter and SO<sub>2</sub> from the smelting and mining operations in Sudbury over the years. These emissions were (and continue to be) dispersed into the communities surrounding the facilities as a function of the local meteorological conditions and the source characteristics. For example, emissions from the Vale Inco superstack may travel tens of kilometers before being deposited to the ground, whereas emissions from low-level sources at all facilities will more likely be deposited in the soils of the immediately surrounding area around each facility.

Figure 3-12 provides a wind distribution “rose” for the Sudbury area, showing a compilation of wind directions and wind speeds measured in the period from 1996 to 2000 (inclusive) at the Sudbury Airport. From this diagram, it is evident that winds from all directions are experienced over the course of time, but that the winds are most frequently from southwesterly and north/northeasterly directions.



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Winds from the east are least frequently experienced. Longer term climate data for this area for the years 1971 to 2000 indicate the predominance of winds from the southwest and north. The dominant wind direction by month is summarized in Table 3.11.

**Table 3.11 Historical Wind Characteristics**

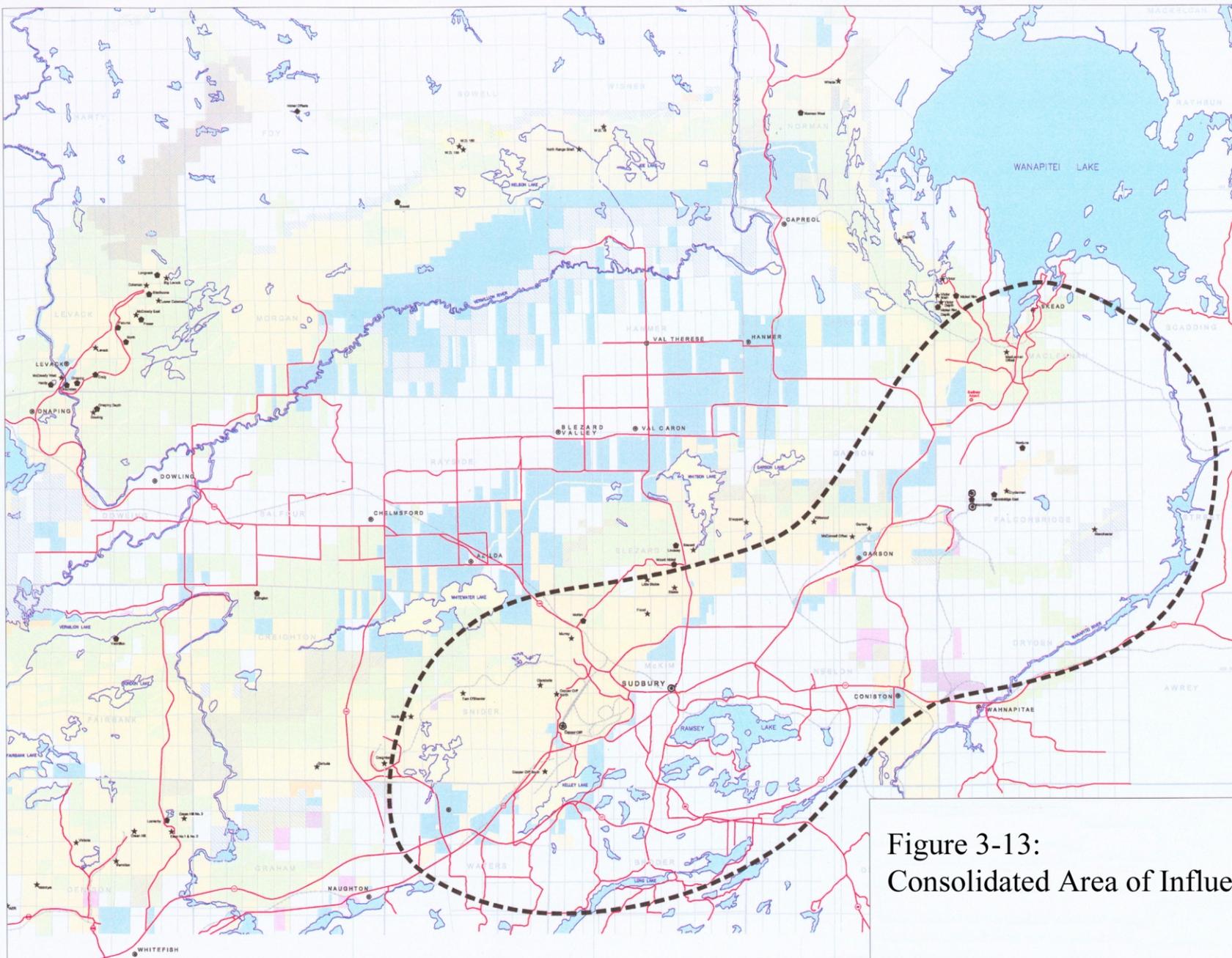
|                   | Jan  | Feb  | Mar  | Apr  | May  | Jun  | Jul  | Aug  | Sep  | Oct  | Nov  | Dec  | Year |
|-------------------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| Speed (km/h)      | 16.6 | 16.1 | 17.2 | 17.4 | 15.9 | 14.8 | 13.5 | 13.2 | 14.6 | 16.0 | 16.7 | 16.0 | 15.7 |
| Predom. Direction | SW   | N    | N    | N    | N    | SW   | SW   | SW   | S    | S    | SW   | NW   | SW   |

The wind and other meteorological factors have determined the fate of the emissions from the smelters and other operations since the time that operations began at Vale Inco and Xstrata Nickel, and thus it would be expected that the communities to the northeast and southwest of the smelting and other facilities would have experienced higher concentrations and subsequent fallout (deposition) of dust and the COC than other areas in Sudbury.

One of the major considerations in designing the air-monitoring program for the Sudbury Soils Study (October 2003 to September 2004) was locating monitoring stations to ensure adequate representation of populated areas in the City of Greater Sudbury expected to be influenced by current smelting operations. A preliminary dispersion modeling study was undertaken, based on very basic, current information for the Copper Cliff and Falconbridge smelters for arsenic, cobalt, copper and nickel. These were the original chemicals of concern when the study began. Figure 3-13 shows the combined area of influence of the two major smelters. The overall pattern compares well to a map printed in Canadian Geographic (Lees, 2000), based on information provided by Dr. Peter Beckett of Laurentian University to the Land Reclamation Program of the City of Greater Sudbury (Figure 3-14). This figure shows the semi-barren lands as viewed from a satellite, if consideration of past influence of the old Coniston smelter is considered. This preliminary information was used to help place the air monitors subsequently used in the air monitoring program.

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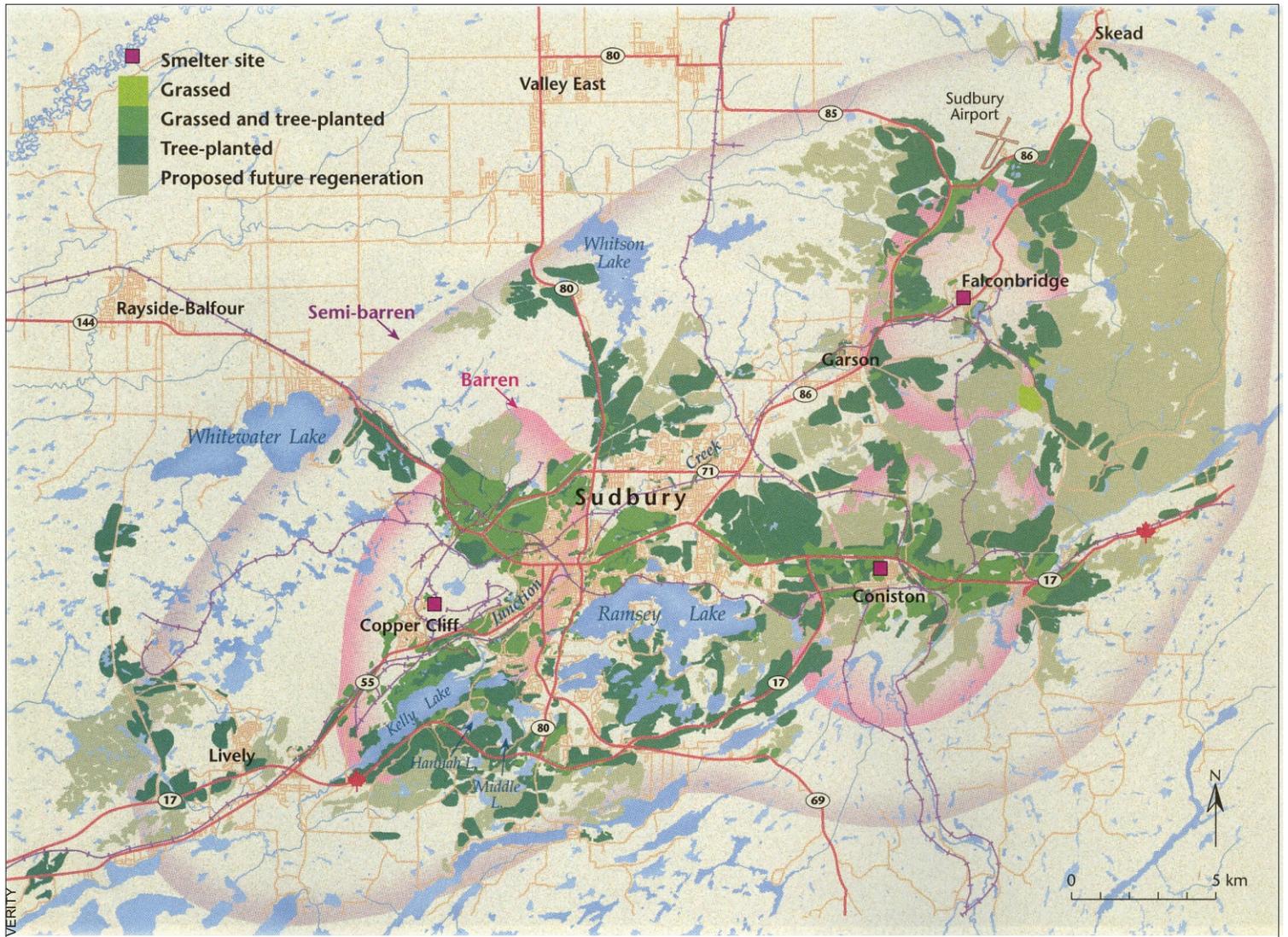
DRAFT FOR DISCUSSION  
PURPOSES ONLY



- LEGEND**
- Municipality
  - ⊖ Major Highway
  - Local Road
  - ⋯ Railway
  - ▭ Township
  - ★ Inco Deposits
  - Falconbridge Deposits
  - ◆ Other Deposits
  - ◆ Sudbury Igneous Complex
- — — Combined Predominant Area of Influence of INCO/Falconbridge Facility Emissions (based on modelled results - As, Co, Cu, Ni, 24-hr, annual)

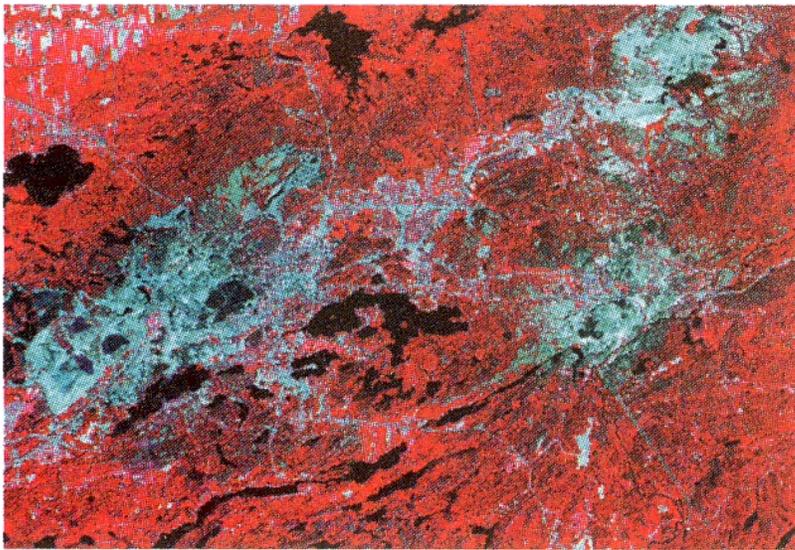
Figure 3-13:  
Consolidated Area of Influence

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CANADA CENTRE FOR REMOTE SENSING; DALE SEMPSEY/LAURENTIAN UNIVERSITY

STEVE FICK/CANADIAN GEOGRAPHIC; SOURCES: GUY GIONET/REGIONAL MUNICIPALITY OF SUDBURY



The scars on the land around Sudbury catch the eye on remote-sensing imagery (LEFT), where forests are red, lakes are black and bare land is blue-grey. Mapping the work (ABOVE) reveals how, parcel by parcel, the face of the region is changing.

**Figure 3-14: Images from Canadian Geographic Article (2000)**

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3.4.2 Historical Dustfall

Data for total dustfall and nickel and copper concentrations in the dustfall from 14 stations in the Sudbury area are presented in Figures 3-15, 3-16, and 3-17 for the years 1961 to 1985, respectively. These data all show significant declines in dustfall occurring during the early to mid-1970s, more-or-less consistent with the advent of the superstack at Vale Inco and the emission reductions at both Vale Inco and Xstrata Nickel achieved during that period.

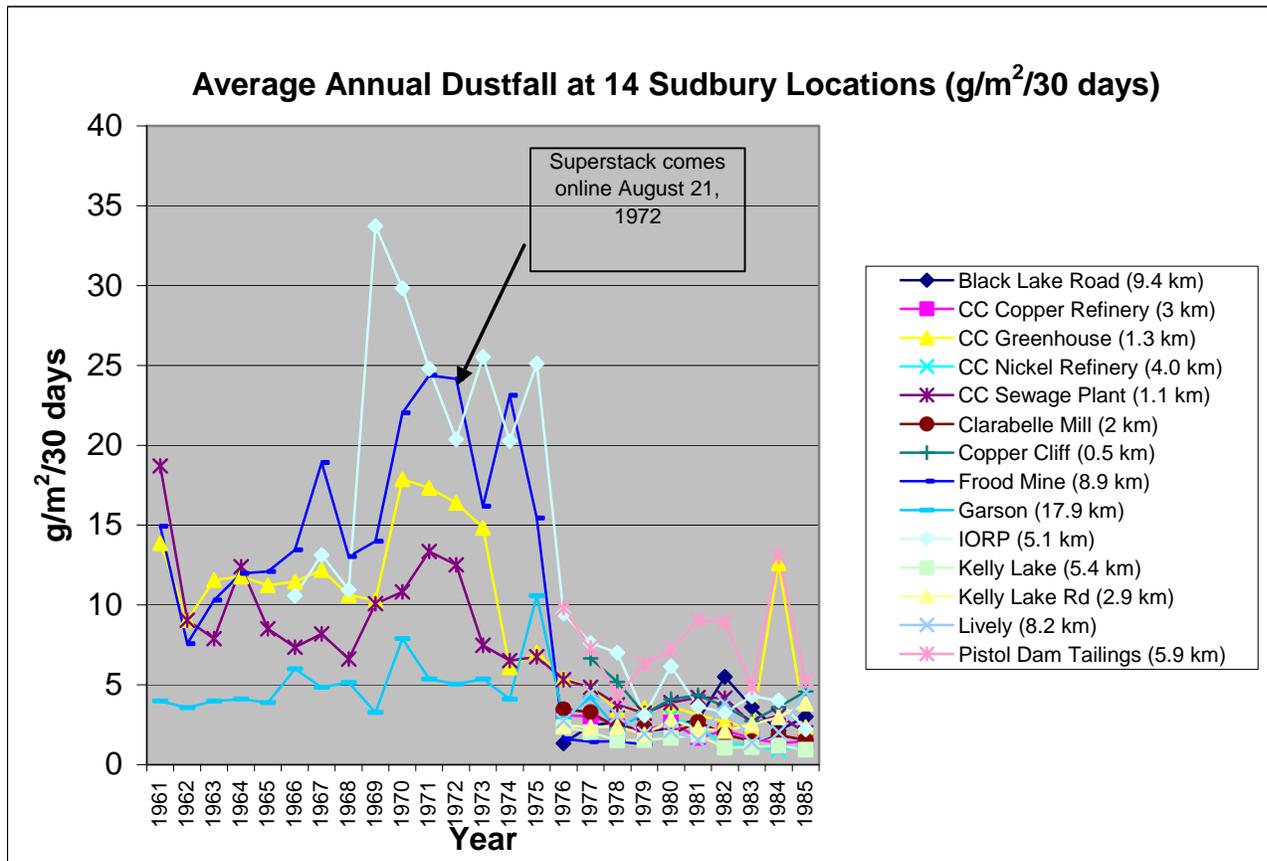


Figure 3-15 Average Annual Dustfall in Sudbury. (Bell and Orford, 1986)

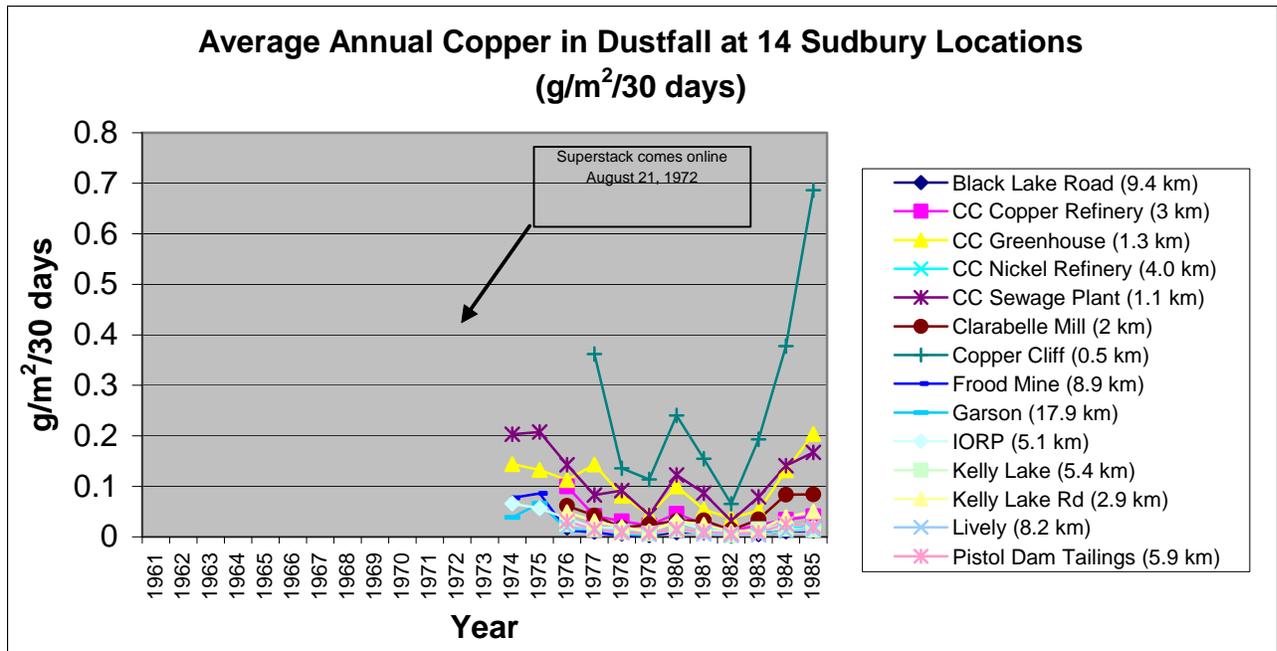


Figure 3-16 Average Annual Copper in Dustfall in Sudbury. (Bell and Orford, 1986)

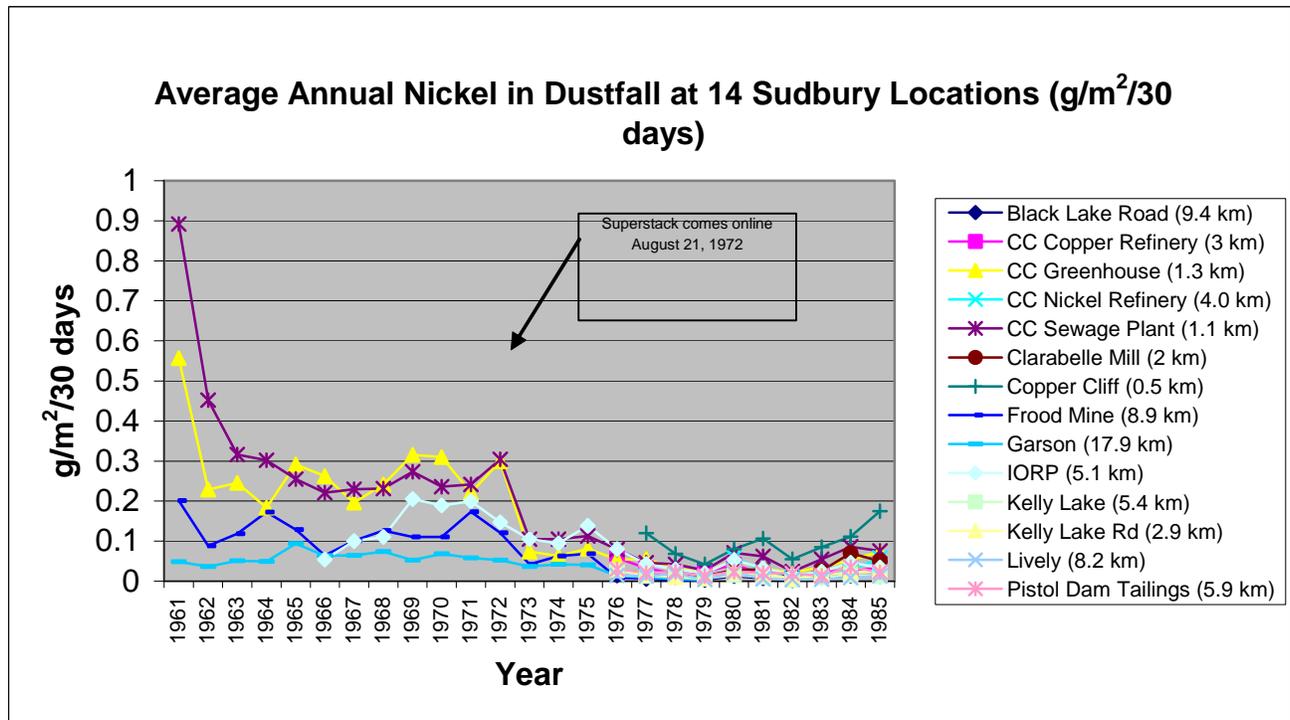


Figure 3-17 Average Annual Nickel in Dustfall in Sudbury. (Bell and Orford, 1986)

Figure 3-18 shows a closer look at average and maximum 30-day total dustfall levels for monitoring sites near Copper Cliff. Significantly lower levels were observed after 1976 at all stations. It turns out that this decrease in dustfall levels is not related just to the operation of the superstack and related smelter emission control programs, which came on-line in 1972, but can also be partly attributed to the initiation of an intensive dust suppressant spraying program instigated in 1976 (Bell and Orford, 1986). This observation emphasizes an important contribution to local dustfall from fugitive sources, including tailings areas. The MOE Ambient Air Quality Criteria for dustfall (soiling) of 7 g/m<sup>2</sup>/30 days (MOE, 2005) was exceeded at most of the stations before 1976, and only infrequently after that time.

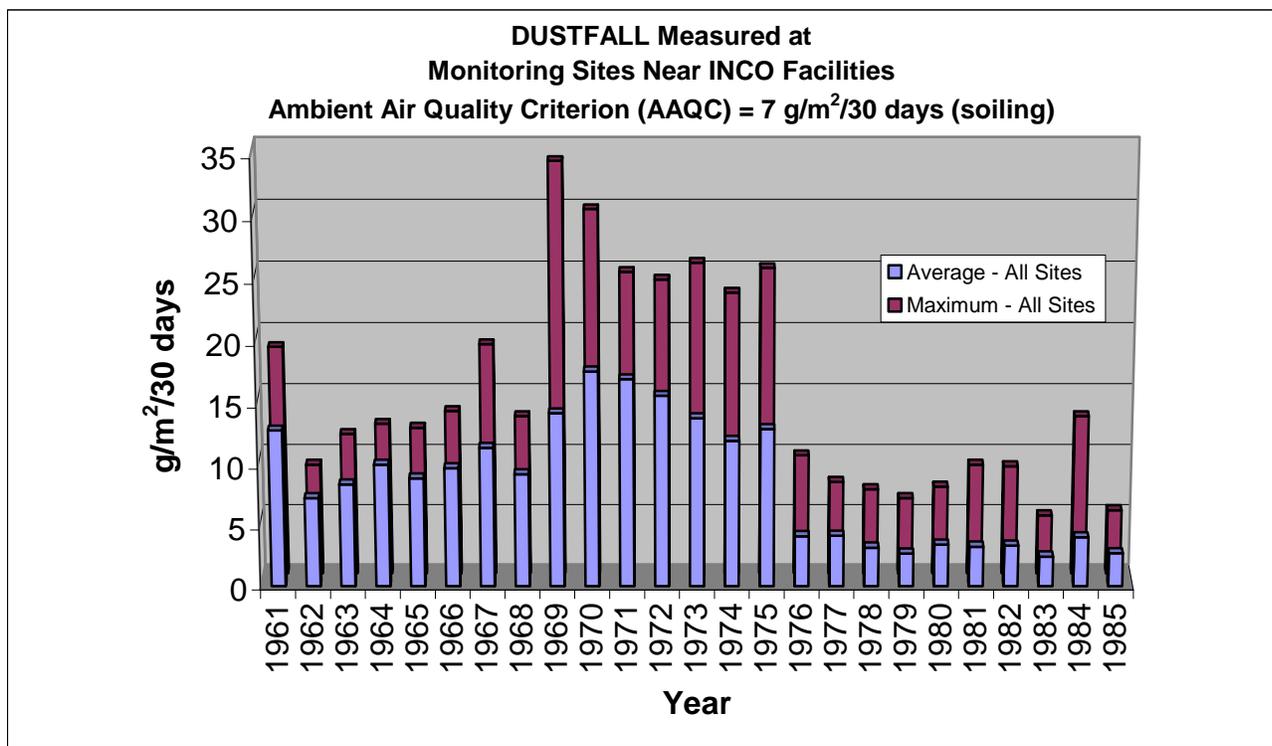
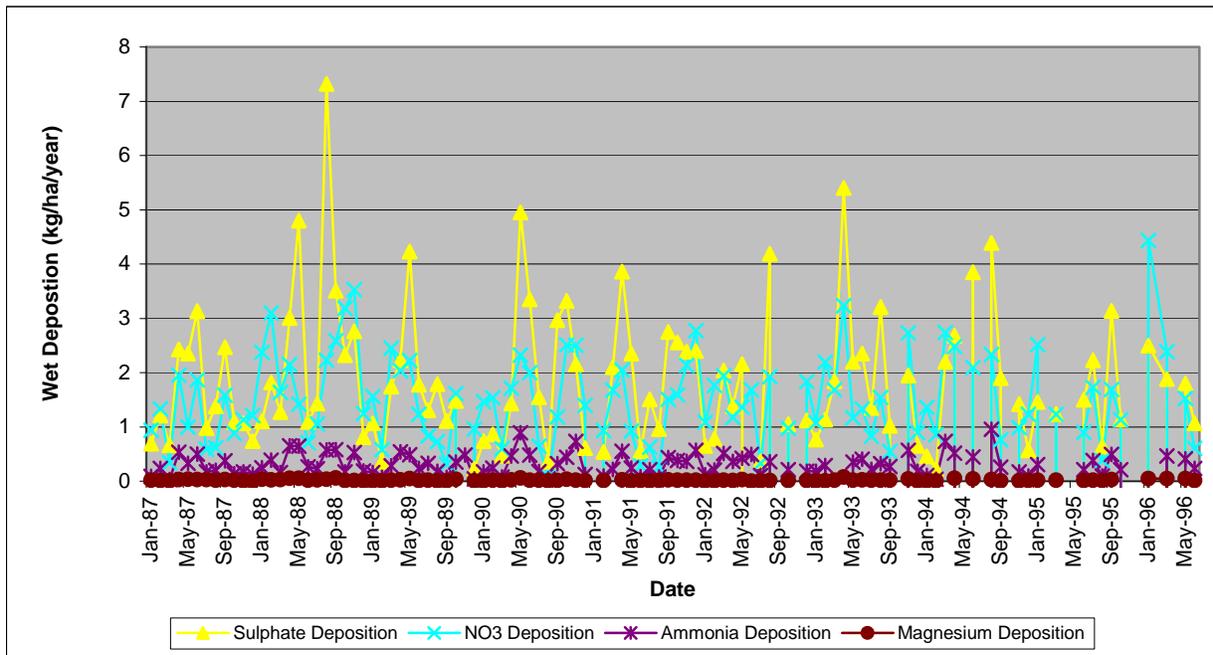


Figure 3-18 Average 30-day total dustfall levels. (Bell and Orford, 1986)

Unlike total dustfall, nickel concentrations in the dustfall did decrease after the superstack, as can be seen in Figure 3-17 indicating that most of the nickel in the dustfall came from process sources rather than fugitive dust.

**3.4.3 Wet Deposition**

Wet deposition data for select substances were provided by Environment Canada for a number of sites in the Sudbury area for the 1980s and 90s. Selected sites are presented in Figures 3-19 to 3-21. These data did not include analysis for metals, but the levels of COC are expected to follow similar spatial and temporal patterns to those for the SO<sub>2</sub>. These data represent the period after the significant changes of the 1970s, and thus do not show any significant trends.



**Figure 3-19 Wet Deposition at McFarlane Lake (Site ID AP1C87452A) (Source: Environment Canada)**

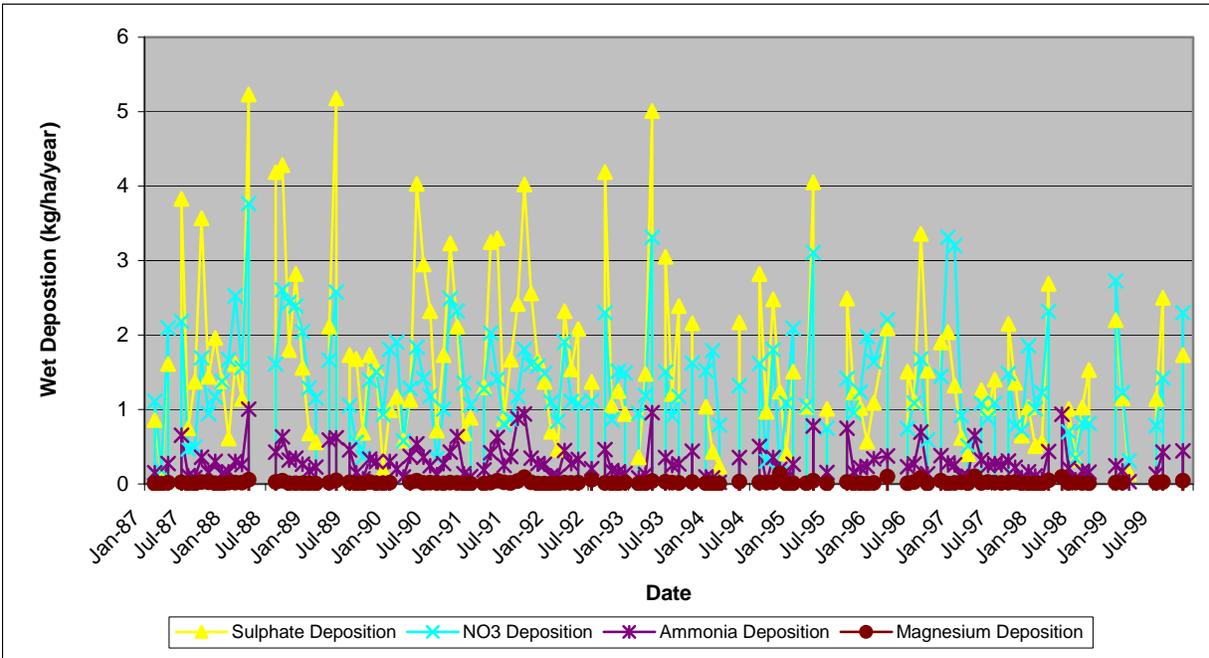


Figure 3-20 Wet Deposition at Hanmer (Site ID AP1C87551A) (Source: Environment Canada)

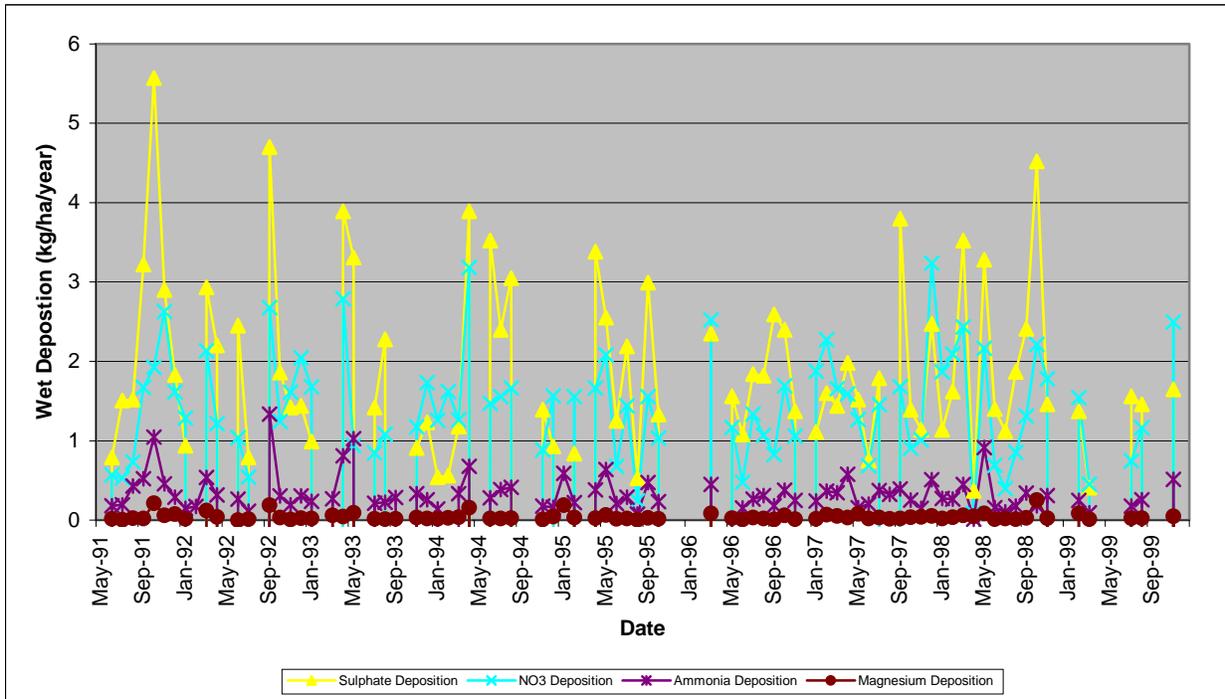


Figure 3-21 Wet Deposition at Garson (Site ID AP1C87552A) (Source: Environment Canada)

### 3.4.4 Historical Ambient Air Monitoring Data

Air quality data that define levels for most of the COC in ambient air at a number of sites in the Sudbury area are available for the time period of 1971 to the present. Table 3.12 provides a list of the Ontario MOE air quality limits for 24-hour levels of the COC in ambient air:

**Table 3.12 Ambient Air Quality Criteria (AAQC). (MOE, 2001)**

| Contaminant | 24-hour AAQC ( $\mu\text{g}/\text{m}^3$ ) * |
|-------------|---|
| Arsenic     | 0.3   |
| Cobalt      | 0.1   |
| Copper      | 50.0  |
| Lead        | 2.0   |
| Nickel      | 2.0   |
| Selenium    | 10.0  |

\* AAQCs for arsenic, cobalt, copper, lead and selenium are set for the protection of human health; AAQC for nickel is protective of vegetation.

The MOE has no criteria for longer periods (e.g., annual averages) at this time.

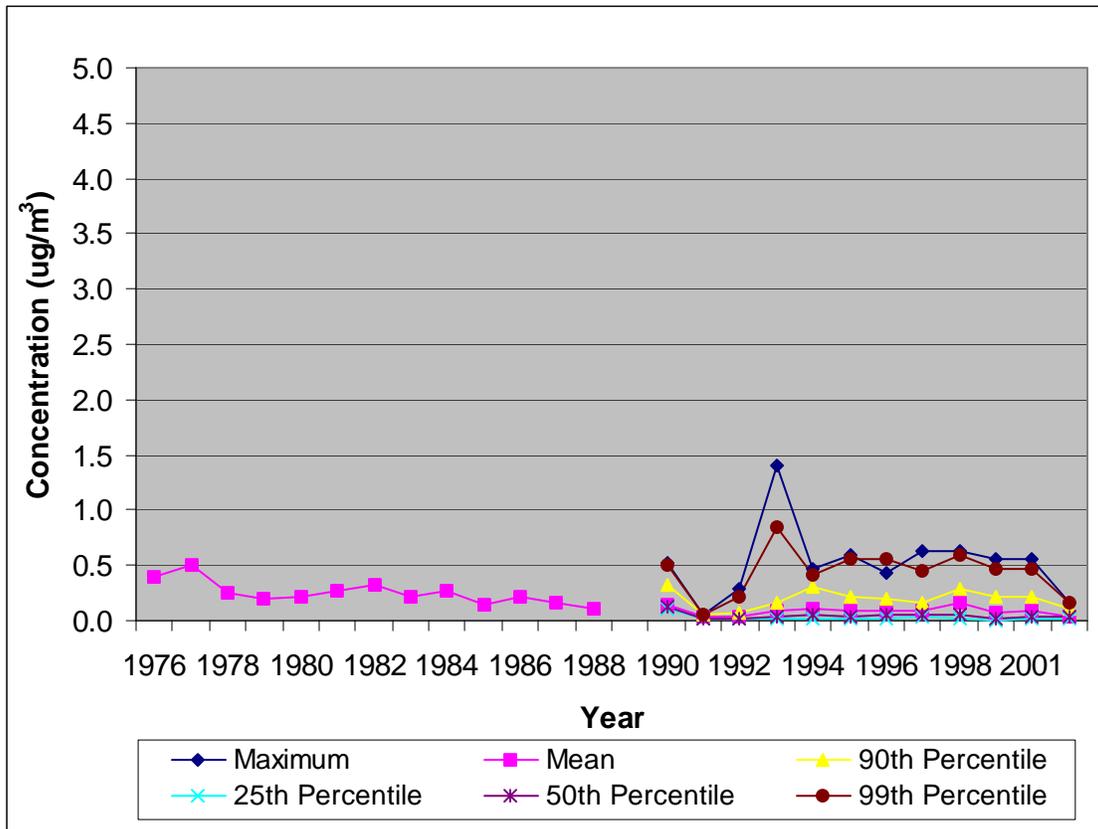
Figures 3-22–3-29 present a selection of results from ambient air monitoring of suspended particulate matter carried out by the MOE between 1971 to 2002 at the following three stations: Copper Cliff (in close proximity to the Copper Cliff smelter complex), Falconbridge (in close proximity to the Falconbridge smelter complex) and Lisgar Street (downtown Sudbury). From 1971 to 1988 mean air concentrations are reported, as these are the only data available. From 1992 to present, more detailed data are available, and are presented.

While there were gaps in the data that were available, the following general observations could be made:

- Significant declines in annual maximum concentrations of copper and nickel in the 1970s can be seen at the Copper Cliff site (Figures 3-23 and 3-27). This may have been related to the initiation of intensive use of chemical dust suppressants in 1976 as previously mentioned. There also appears to have been a gradual decline in annual average concentrations over the period from the mid-1970s to 2002. Throughout this period, the concentrations generally remained well below the provincial criteria for copper and nickel.
- At the Lisgar St. site in Sudbury, the results are lower in magnitude than those for Copper Cliff and do not show the dramatic decline in maximum concentrations during the 1970s that was

observed at Copper Cliff. Apparently, the benefits of the initiation of chemical dust suppression at Inco were greatest in the local area around Copper Cliff.

- At the Falconbridge sites, no obvious trends are observed, although there appears to have been some decline in average copper and nickel levels from the mid-1970s to the 1990s.



**Figure 3-22 Copper 24-hour Concentrations Measured in Ambient Air MOE Station 77326 Sudbury Lisgar St. (Dobrin and Potvin, 1992; Inco and Falconbridge, unpublished; MOE, 1978)**

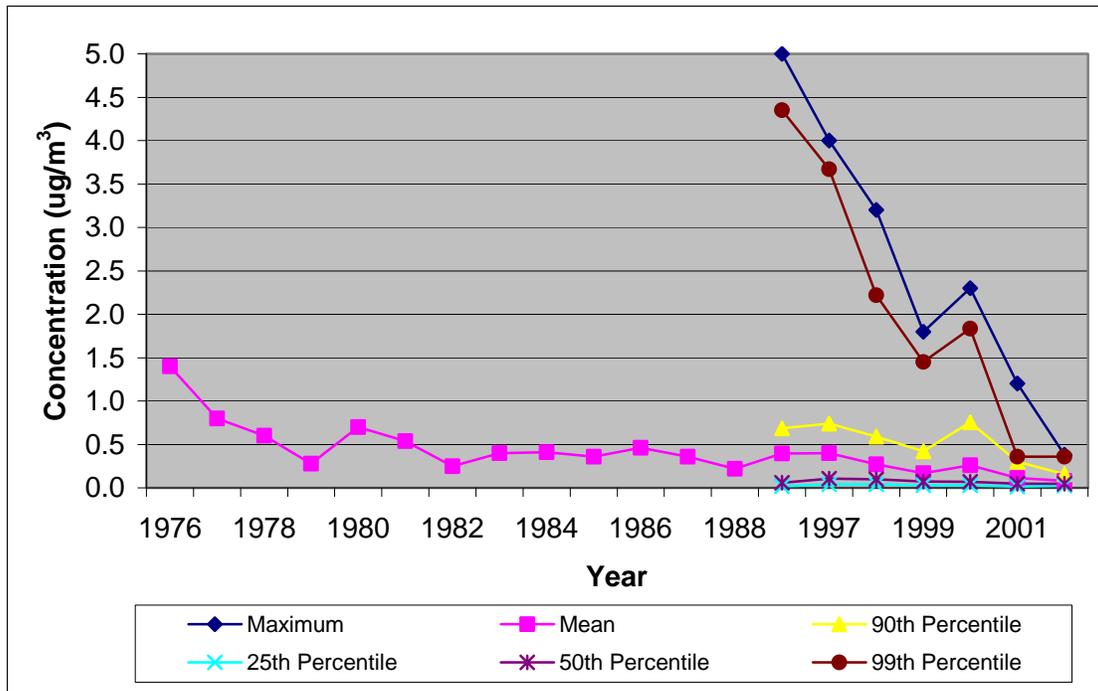


Figure 3-23 Copper 24-hour Concentrations Measured in Ambient Air MOE Station 77570 Copper Cliff (Dobrin and Potvin, 1992; Inco and Falconbridge, unpublished; MOE, 1978)

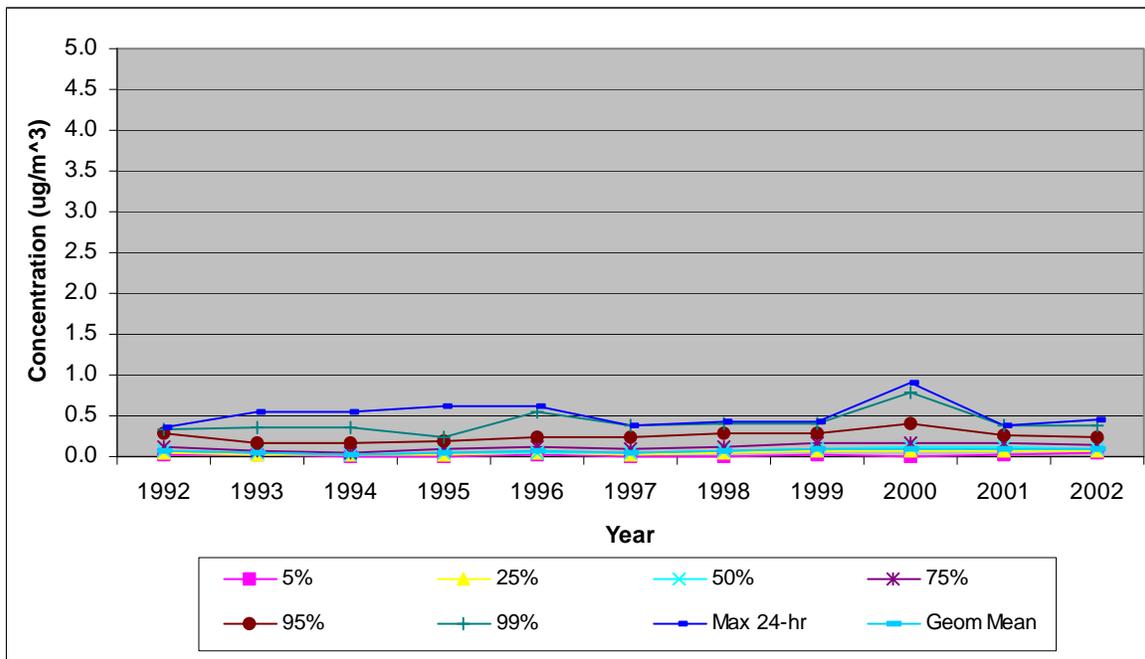
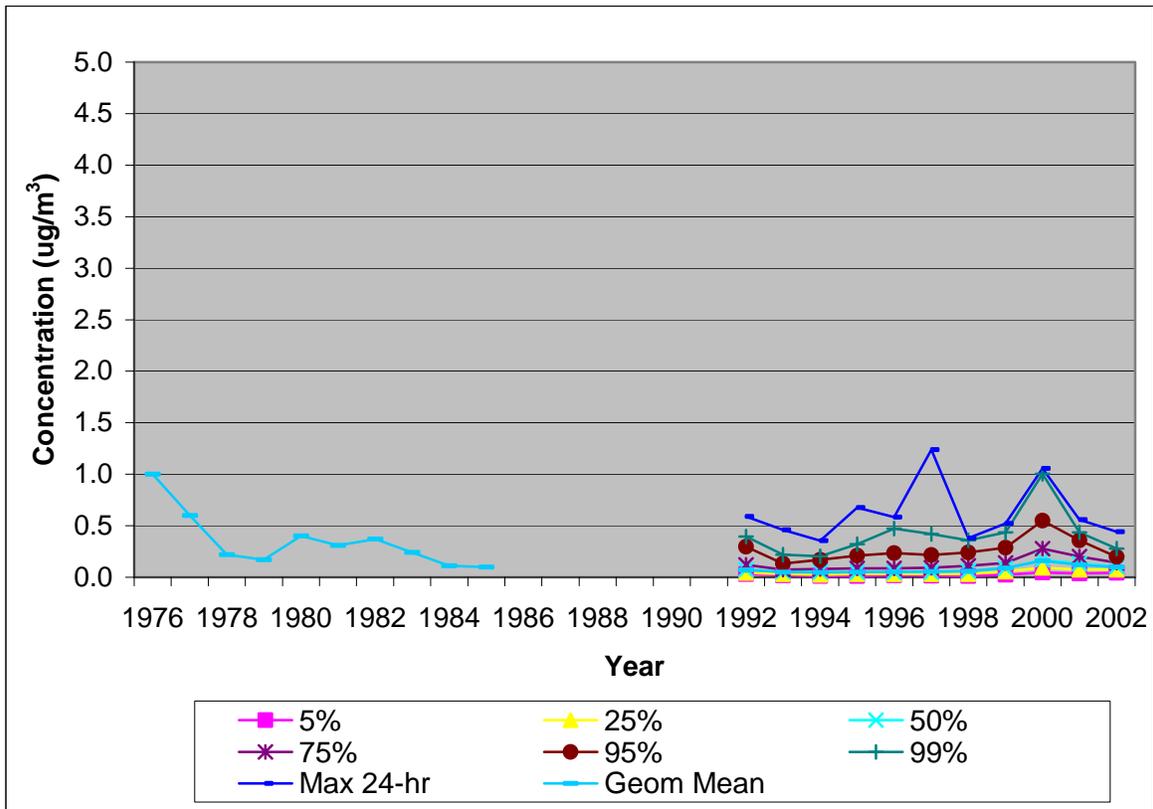
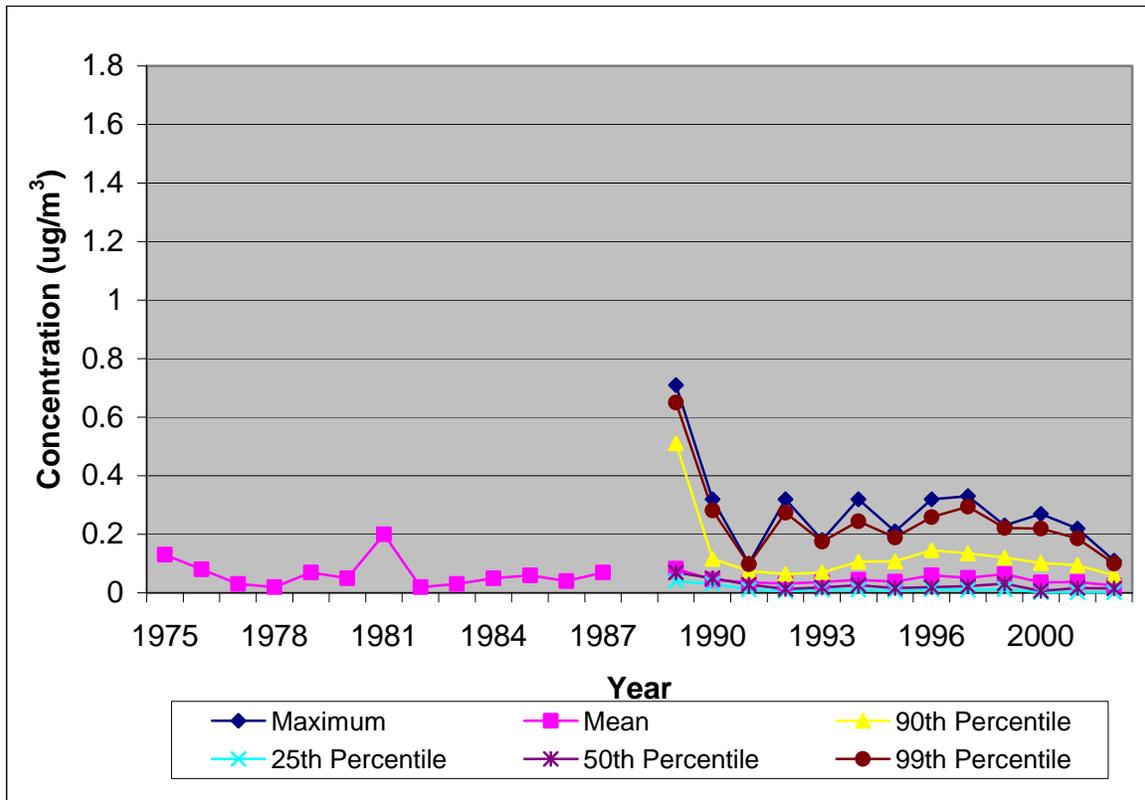


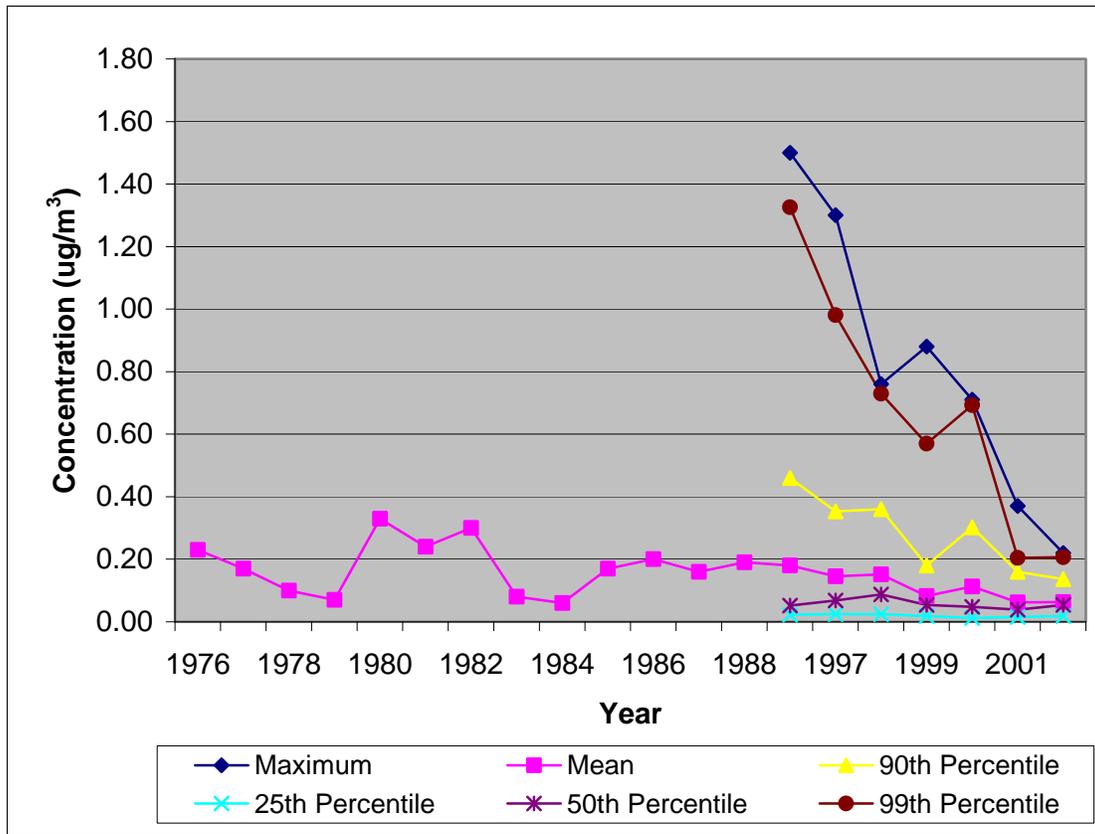
Figure 3-24 Copper 24-hr Concentrations Measured in Ambient Air Falconbridge Pumphouse Station (Inco and Falconbridge, unpublished)



**Figure 3-25 Copper 24-hr Concentrations Measured in Ambient Air Falconbridge Edison Station (Dobrin and Potvin, 1992; Inco and Falconbridge, unpublished; MOE, 1978)**



**Figure 3-26 Nickel 24-hour Concentrations Measured in Ambient Air MOE Station 77326 Sudbury Lisgar St. (Dobrin and Potvin, 1992; Inco and Falconbridge, unpublished; MOE, 1978)**



**Figure 3-27 Nickel 24-hour Concentrations Measured in Ambient Air MOE Station 77570 Copper Cliff (Dobrin and Potvin, 1992; Inco and Falconbridge, unpublished; MOE, 1978)**

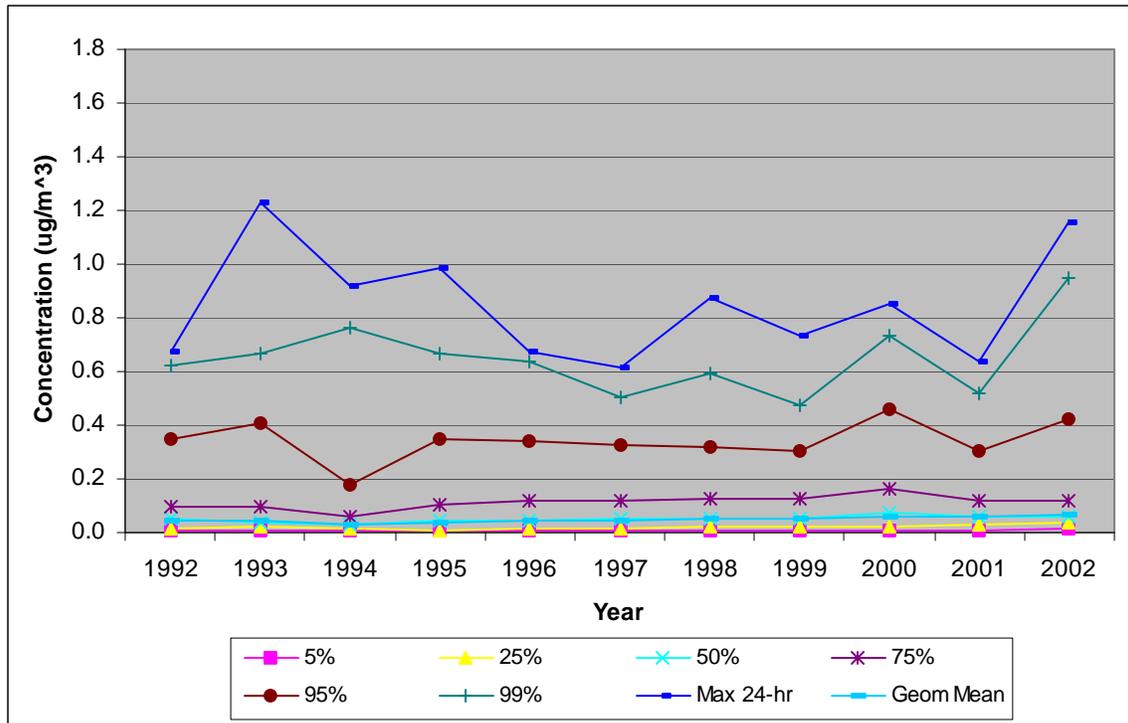
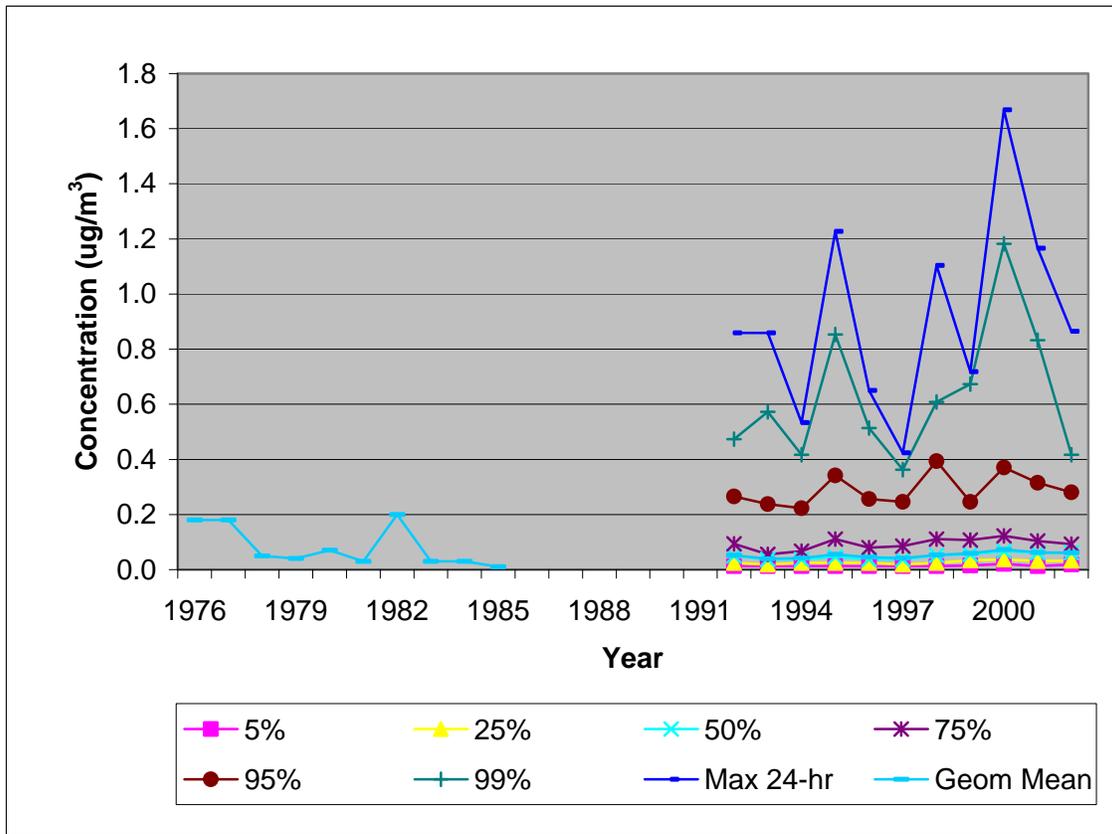


Figure 3-28 Nickel 24-hr Concentrations Measured in Ambient Air Falconbridge Pumphouse Station (Inco and Falconbridge, unpublished)



**Figure 3-29 Nickel 24-hr Concentrations Measured in Ambient Air Falconbridge Edison Station (Dobrin and Potvin, 1992; Inco and Falconbridge, unpublished; MOE, 1978)**

A selection of individual sample results plotted for the Falconbridge Pumphouse station (Figures 3-30 and 3-31) indicate the existence of a strong seasonal trend for TSP, with the highest values measured during the summer months. With respect to TSP, it is important to note that in northern Ontario, snow cover eliminates most of the ground sources of dust for several months of the year; thus a seasonal trend as appears below would likely be apparent in any northern community in our climate zone, despite any mining emission sources.

This trend is not as evident for the COC. This finding suggests that TSP concentrations are significantly affected by non-process fugitive dust sources that are more prevalent during the warmer months when higher wind speeds and drier conditions tend to occur, but the concentration of metals are non-seasonal and more related to process emissions that can occur at all times of the year.

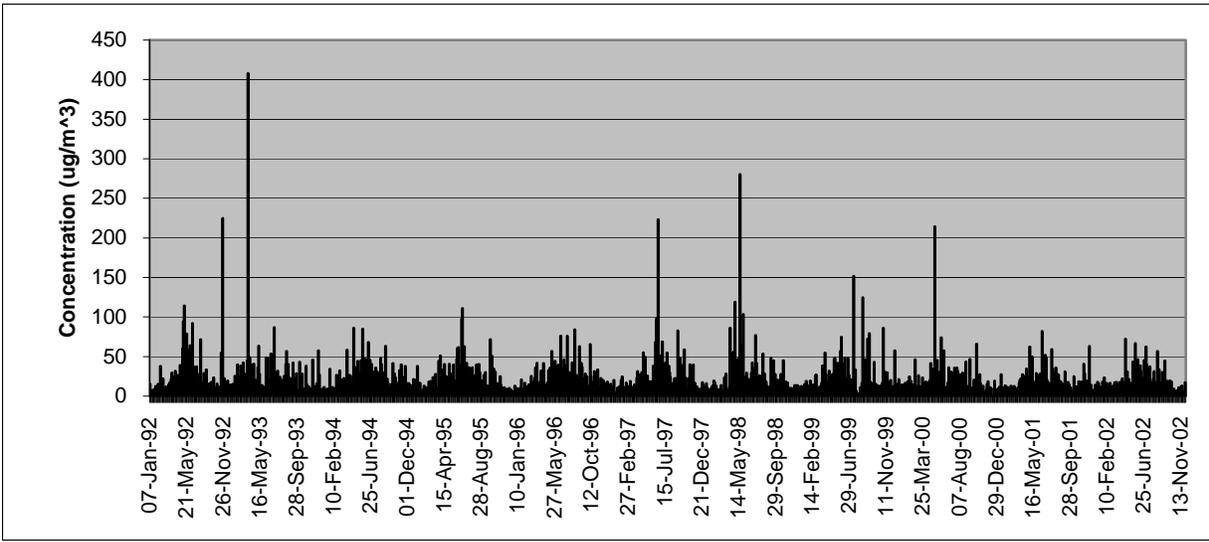
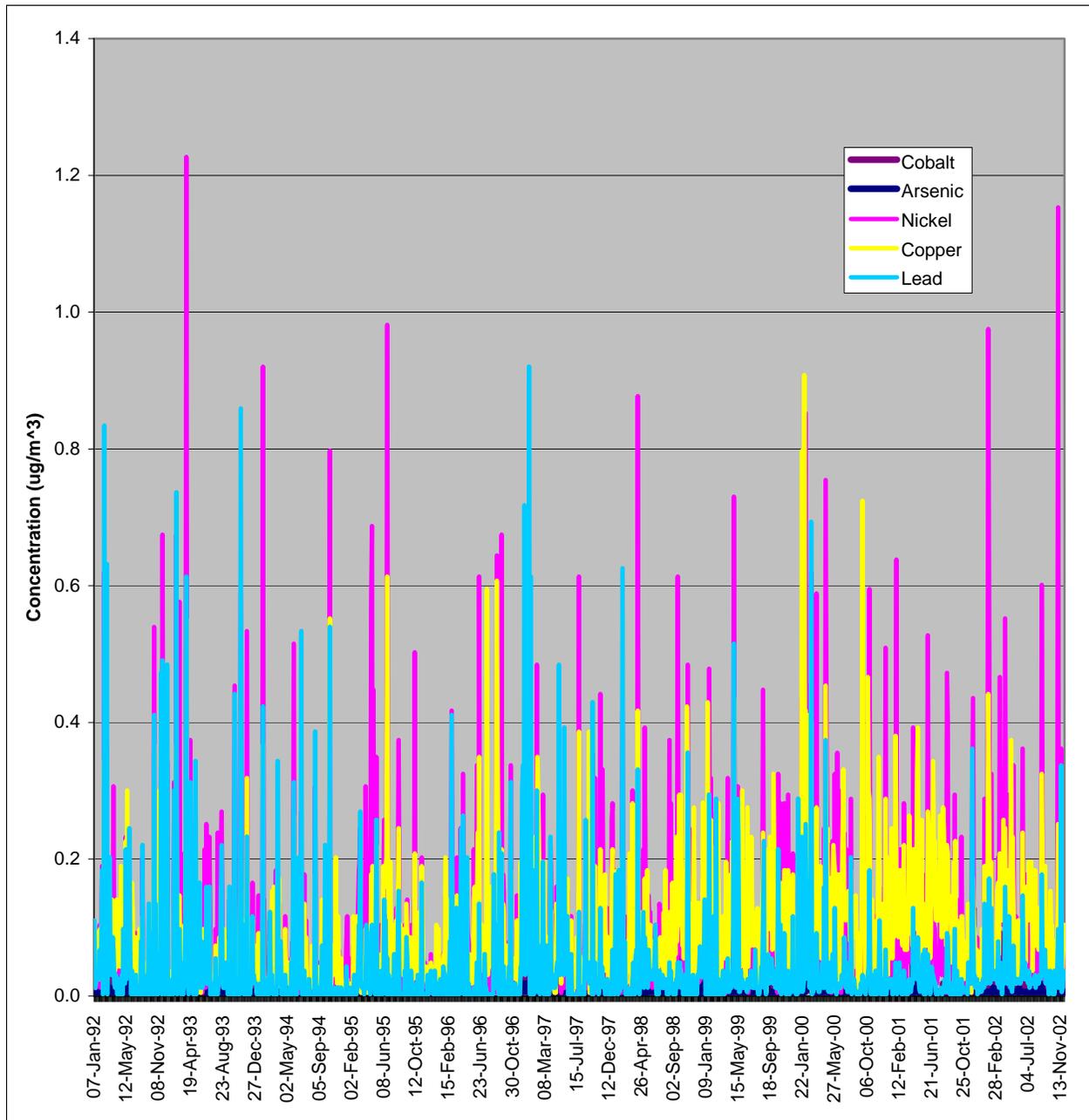


Figure 3-30 TSP 24-hour concentrations at the Falconbridge Pumphouse



**Figure 3-31 Measured COC concentrations at Falconbridge Pumphouse.**

A recent report entitled “Air Quality Trends—City of Greater Sudbury, Ontario 1953–2002” (Potvin, 2004) studied the trends in levels of TSP, SO<sub>2</sub> and PM<sub>10</sub> in the Sudbury area. TSP was first measured in the 1970s and a downward trend was observed such that “by the early to mid-1980s, mean TSP concentrations had fallen in the range of 30 to 40 µg/m<sup>3</sup> from their 50 to 60 µg/m<sup>3</sup> levels in the early

1970s” at the industrial (Copper Cliff and Falconbridge) and the downtown MOE sites (Potvin, 2004). Measurements made at Coniston in 1975 and 1976 resulted in annual mean concentrations of 36 and 40  $\mu\text{g}/\text{m}^3$ , respectively, which compares to the values measured at the other locations.

The study showed that the small number of exceedances could be attributed to tailings dust and/or wind-blown soils, often under freeze-dry conditions. The study also concluded that the installation of the superstack by Inco and further abatement measures undertaken in the early 1970s resulted in significant improvements in the air quality, such that by the early 1990s and continuing through to today, there have been few exceedances of the 24-hour criteria for particulate matter, and the annual average criterion has been met consistently.

A report, commissioned by Inco in 2002 (Earth Tech Canada Inc., 2002), reviewed available air quality data for the Sudbury area and reported the following findings:

- TSP,  $\text{PM}_{10}$ , nickel, copper and lead concentrations measured at three MOE stations over the most recent 19-year period were below their respective AAQC levels at least 95% of the time;
- The fraction of  $\text{PM}_{10}$  to TSP was found to be approximately 46%, which is expected; and,
- Generally, a higher proportion of the metals are present in the  $\text{PM}_{10}$  samples than in the TSP samples.

An extensive one-year ambient air quality monitoring study was undertaken as part of the Sudbury Soils Study for the period of October 2003 to September 2004, with results provided in Volume II – Human Health Risk Assessment (HHRA). The purpose of the study was to collect samples of ambient air in the communities located in the Sudbury Basin, and to analyze these samples for levels of COC. This has allowed the study team to better define the spatial and temporal patterns of these metals/metalloids currently in the air of these communities. Information collected during this study has been used for exposure modelling in the HHRA.

### **3.5 Concluding Comments on the Historical Review**

The historical air emissions review suggests that, for the COC as well as for SO<sub>2</sub> and particulate matter, the emissions and ambient concentrations exhibited the following trends:

- Emissions increased with rising smelter production during the 1930s and remained at relatively high levels through the 1940s and 50s.
- Annual emissions of the COC were mainly associated with the smelting process exhaust gases, *e.g.*, from the roasters, furnaces and converters. Fugitive dust sources such as the tailings disposal areas and slag heaps were lesser contributors.
- Dramatic declines in emissions and corresponding ambient concentrations occurred during the late 1960s and through the 1970s, with the implementation of new technologies that included significant pollution control on the smelter exhaust streams, taller stacks, dust suppression on tailings disposal areas, *etc.*
- Ambient levels of COC have remained at lower levels since the 1970s, with some continued declines and are now generally well within provincial criteria for these contaminants.
- The pattern of elevated metal levels in Sudbury soils can be primarily attributed to emissions prior to the mid-1970s, and not to current emissions.

**3.6 References**

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