



# Clearing the Air

Report #3  
Air Quality Trends  
in Greater Sudbury  
2008-2014

June 2016





## **ABOUT CLEARING THE AIR**

Clearing the Air was prepared by Clean Air Sudbury, a non-profit community group focused on community air quality issues in Greater Sudbury.

Clearing the Air conveys the highlights of Air Quality Trends in the City of Greater Sudbury between 2008 and 2014. This full version of the report is technical in nature and prepared for Clean Air Sudbury by Potvin Air Management Consulting in May 2016. A summary report may be found in both French and English on Clean Air Sudbury's website.

This report was developed as a tool to improve community awareness of air quality issues and engage the public in activities to further improve the quality of the air in Greater Sudbury.

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*View of Ramsey Lake from Science North, Greater Sudbury*



## KEY FINDINGS

- Improvements in overall air quality over the period 2008 to 2014 continued to be realized in Greater Sudbury. These are consistent with improved air quality across Ontario as a result of initiatives by governments and industry to reduce air emissions and ground-level concentrations of airborne pollutants.
- The air quality in Greater Sudbury, determined from measurements at the Air Quality Index station, was better or similar than that measured at selected cities in southern and northern Ontario for sulphur dioxide (SO<sub>2</sub>), nitrogen dioxide (NO<sub>2</sub>), ground-level ozone (O<sub>3</sub>) and respirable particulate (PM<sub>2.5</sub>).
- The annual average concentrations of SO<sub>2</sub> in Greater Sudbury, as measured by the extensive Vale and Glencore monitoring network, continued to decrease during the period 2008 to 2014. The annual and daily (24-hour) means were well below the applicable limits. The annual frequency of exceedances of the 1-hour Ambient Air Quality Criterion (AAQC) decreased during the reporting period; the improvements were more significant when comparing the results from 1998 to 2007. Further improvements are expected over time as governments and industry continue to work together to achieve additional reductions in SO<sub>2</sub> emissions from smelter operations.
- Greater Sudbury experienced two ground-level O<sub>3</sub> episodes and one PM<sub>2.5</sub> episode during the period 2008 to 2014. The O<sub>3</sub> episodes resulted from transboundary flows from the United States south of the Great Lakes. The PM<sub>2.5</sub> episode was caused by forest fire emissions from northern Manitoba.
- In 2013 and 2014, Greater Sudbury met the recently adopted Canadian Ambient Air Quality Standards (CAAQS) for O<sub>3</sub> and PM<sub>2.5</sub> scheduled for implementation in 2015.
- The annual average concentrations of particulate matter in the three size fractions (Total Suspended Particulate, Inhalable Particulate (PM<sub>10</sub>) and fine (respirable) particulate (PM<sub>2.5</sub>), from measurements taken at the Vale, Glencore and Ministry of the Environment and Climate Change stations were well below the applicable limit. Although there were exceedances of the 24-hour AAQC, the overall frequency of exceedance was less than 1% of the samples.
- Some metals in the TSP fraction, notably nickel, cobalt and cadmium, exceeded the applicable regulatory limits. The overall frequency of exceedance was less than 1%. The majority of the exceedances occurred at stations closest to smelter operations. Vale and Glencore continue to implement mitigation measures to further reduce smelter process metals emissions, improve materials handling and equipment maintenance operating procedures. This is in keeping with the Mining Technical Standard being developed by the Ministry and the mining sector to minimize metals emissions from designated mine sites.

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## 1. INTRODUCTION

This report provides a summary of the results of ambient air quality monitoring programs undertaken by the Ontario Ministry of the Environment and Climate Change (hereafter the Ministry), Glencore Limited Sudbury Integrated Nickel Operations Smelter (hereafter Glencore) and Vale Canada Limited (hereafter Vale) in Greater Sudbury from 2008 to 2014. It updates the data presented in earlier reports<sup>1,2</sup> released in 2004 and 2009 which provided an historical overview of air quality data collected in the Greater Sudbury area from 1953 to 2007. This report, and future reports, are intended to track changes in air quality in Greater Sudbury, and are planned to be updated roughly every five years.

The results presented in this report, as executed in the earlier reports, are compared to those of other urban centers in Ontario, namely Windsor, Toronto, Hamilton, Ottawa, Sault Ste. Marie and Thunder Bay for the period 2008 to 2014. For some air quality parameters, the results are also compared with those from North Bay, Sarnia and Parry Sound. The major urban centres in the south have a long history of air quality measurements and are deemed typical of air quality in the south. The cities in the north cover the Thunder Bay – North Bay corridor. Sarnia was included since, like Greater Sudbury, it has industrial emissions of sulphur dioxide. Parry Sound was also added to the list since it is located between the southern and northern cities and is impacted by transboundary air flows leading to smog episodes that can reach the cities in the north. The AQI stations selected are located in downtown environments to enable reasonable data comparisons.

The report provides the following information: the air contaminants monitored; their sources, effects, emission trends and provincial limits; the link between air quality and meteorology; updates to the Local Air Quality Air Pollution Regulation (Regulation 419/05) and Ontario Regulation 194/05 and progress on actions taken and future plans to further reduce smelter emissions in Greater Sudbury.

The report also provides an overview of the changes that have occurred since 2007 in the provincial and local air quality monitoring and reporting programs, including the introduction of Canadian Ambient Air Quality Standards (CAAQS) and the Federal Air Quality Health Index (AQHI). As with previous reports, this report provides a baseline of information to stakeholders and decision makers for discussions on possible future actions to further improve air quality in Greater Sudbury.

### 1.1 Background and Recent Changes to Regulations and Abatement Programs

#### 1.1.1 Ontario Regulation 419/05

In November 2005, the Ministry promulgated a new air regulation under the province's Environmental Protection Act (EPA). This new regulation replaced and revoked Regulation 346 of the Revised Regulations of Ontario, 1990 (General – Air Pollution).

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<sup>1</sup> Air Quality Trends in The City of Greater Sudbury, Ontario, 1953 - 2002

<sup>2</sup> Air Quality Trends in The City of Greater Sudbury, Ontario, 1998 - 2007

Regulation 419/05 is the primary regulatory tool for assessing industrial air emissions. It contains air standards (under Schedules 2 and 3) and guidelines (under Sections 19 and 20) for contaminants that are intended to protect local air quality and are legal requirements which emitters in Ontario must meet. The standards are primarily used for the issuance of Environmental Compliance Approvals by the Ministry which emitters must have to operate and release air emissions to protect local air quality. The regulation includes:

- Setting new air standards and guidelines for pollutants, including carcinogens and toxins that could pose a threat to human health
- Achieving a better picture of industrial emissions through updated technology (updated mathematical dispersion models)
- Introducing a faster, risk-based approach to implementing new air standards
- Better compliance and enforcement tools

Prohibition to Regulation 419/05 is any offence with a monitored or modelled exceedance of a standard. This is accompanied by the need to notify the Ministry as soon as practicable of possible contraventions.

The regulation specifies implementation dates for phasing-in the various industrial sector schedules and associated standards and guidelines. The standards comprise Schedules with half-hour, 24-hour and other averaging periods. The air quality guidelines also have averaging periods of a half-hour, 24-hour and other averaging periods. Schedule 6 lists Upper Risk Thresholds (URTs) with averaging periods of a half-hour and 24-hours for substances deemed to have a more serious health risk. An upper risk threshold (URT) is set above the air standard. It can be used to manage risks during the phase-in period of an air standard and is also used during the evaluation of requests for site-specific standards. Upper Risk Thresholds are not standards. URTs are concentrations, which if exceeded anywhere off-property, require timely actions (i.e. immediate notification to the Ministry in writing, and submission within 3 months of an Emission Summary and Dispersion Modelling (ESDM) report for the contaminant that exceeded the URT.

The Ontario Regulation 419/05 Schedule 3 air standards became effective in 2010 for the mining and smelting sector. The phase-in periods are such that by year 2020 all targeted industrial sectors will be subject to the new standards, guidelines and URTs and will be required to have their emissions assessed with the newer United States Environmental Protection Agency (USEPA) air dispersion models when applying for Environmental Compliance Approvals.

The regulation allows a new type of approval for an alternative standard, based on site-specific technology or optionally on economic considerations. A site-specific standard is derived from the maximum ambient ground level concentration at the facility property boundary estimated from mathematical model calculations. If an alternative standard is approved, it is deemed to be the standard for that contaminant for that facility for the purposes of the regulation. The approval process for an alternative standard requires a detailed review of the request by the Ministry, an action plan and public consultation. If granted, the alternative standard is for a specified time period to allow time for the facility to comply with the standards in the new legislation.

To promote the effective implementation of new or updated Ministry air standards and reduce regulatory burden, the Ministry's air regulation gives industry flexible options for complying with the regulation:

- Meet the air standards by the specified phase-in date; or
- Request a Site-Specific Standard (altered standard); or
- Register under a Technical Standard (sector based, if available)

The Ministry, in concert with the mining sector, is currently developing a Mining Technical Standard to address metals emissions, such as nickel, from designated mine sites. The Technical Standard is to propose a set of requirements to ensure that the best applicable methods/practices are used to minimize metals emissions from fugitive sources such as storage piles, materials handling areas, paved/unpaved roads and tailings, and from ore processing activities such as milling, smelting and refining. The Technical Standard will include technology specifications, operational practices, reporting and record keeping. The Technical Standard is expected to be published by the Ministry in 2017, following the Ministry's consultation/comment protocol requirements.

Vale and Glencore cannot presently meet all Regulation 419/05 Schedule 3 air standards unless their production is reduced to uneconomical levels. The Ministry has issued site-specific air standard approvals for smelter facilities operated by Vale (sulphur dioxide, nickel and cobalt) and Glencore (sulphur dioxide, nickel and cadmium). The approvals also specify measured levels in the community of these contaminants above which trigger actions by the emitters. The actions include an analysis of the cause of the exceedance and an action plan, with an implementation date, to further minimize the likelihood of measurements above the trigger levels. The measured/trigger levels have applicable implementation dates to allow time for the smelter facilities to comply with the standards in Ontario Regulation 419/05, such that at the expiry date of the approval the facilities have to meet the standards in Schedule 3 of the regulation. The approvals require Vale and Glencore to submit to the Ministry annual written reports of measures taken each calendar year to implement the action plans, including a description of each measure taken, the date of their implementation and proposed dates for the implementation of new measures to be taken.

There are a number of standards for metals in Total Suspended Particulate (TSP) matter (e.g. nickel, arsenic, chromium, cadmium, manganese) that are on the Ministry's list for review and update. Ontario introduced new or updated air standards for 18 high priority contaminants of concern to human health, effective February 1, 2013. These air quality standards are based on the best available science about the health and environmental toxicology of these contaminants. Of relevance to the Greater Sudbury smelter facilities is a new 24-hour standard for cadmium of  $0.025 \mu\text{g}/\text{m}^3$ , effective February 1, 2013. The previous standard was  $0.25 \mu\text{g}/\text{m}^3$ . The Ministry will be introducing new standards for chromium, manganese and nickel, effective July 1, 2016.

### 1.1.2 Regulation 194/05

Ontario's Plan for Clean Air, as announced by the Minister of the Environment and Climate Change in August 2005 also included the promulgation of Regulation 194/05 – Industry Emission Reduction Plan, which stipulates sector and facility emission budgets for oxides of nitrogen (NO<sub>x</sub>) and sulphur dioxide (SO<sub>2</sub>) across the province, as well as emission intensity rates. Regulation 194/05 also allows the acquisition and retirement of emission allowances and credits and describes the procedures or manner under which allowances and credits can be used. In addition, the regulation describes the monitoring and reporting requirements for SO<sub>2</sub> emissions in the base metal smelting sector.

The regulation requires the reporting of annual SO<sub>2</sub> emissions by March 31 of each year. Verification Orders issued to both smelter facilities in Greater Sudbury in 1990 by the Ministry require annual audits of SO<sub>2</sub> emissions by a third party.

For smelter facilities in Greater Sudbury, the annual SO<sub>2</sub> emissions stipulated by the regulation are shown in Table 1. The actual combined smelter emissions from 2008 to 2014 are illustrated in Figure 2.

Facility	Annual SO <sub>2</sub> Emissions (tonnes/year)			
	2006	2007- 2009	2010 -2014	2015 and after
Vale	265,000	175,000	175,000	66,000
Glencore	66,000	66,000	66,000	25,000
Total	331,000	241,000	241,000	91,000

**TABLE 1: ANNUAL SO<sub>2</sub> EMISSIONS LIMITS FOR SMELTERS IN GREATER SUDBURY**

### 1.1.3 Ambient Air Quality Criteria

Regulation 337 under the EPA listed the Ambient Air Quality Criteria (AAQCs) developed by the Ministry as a component of its standard setting process. This regulation was revoked in August 2007 and replaced with a list of AAQCs.

AAQCs are effect-based levels in air, with variable averaging times (e.g., 24-hour, 1-hour and 10 minutes) appropriate for the effect that it is intended to protect against. The effects considered may be based on health, odour, vegetation, soiling, visibility, corrosion or other effects. If a contaminant has multiple AAQCs, all of them must be used for assessment purposes since each represents a different type of effect linked to a particular averaging period. The AAQCs are set at levels below which adverse health and/or environmental effects are not expected. Most of the standards and guidelines identified in Regulation 419/05 are based on AAQCs developed via the Ministry's standard setting process.

The term "ambient" implies that these levels reflect general air quality independent of location. AAQCs are most commonly used in environmental assessments, special studies using ambient air monitoring data, and the assessments of general air quality in a community. The AAQCs should be used for assessing general air quality and the potential for causing an adverse effect. Because AAQCs represent desirable levels in ambient air, there are no associated phase-in periods or compliance requirements.

The air quality parameters that are discussed in this report for the smelting sector for the period 2008 to 2014 are assessed against the applicable AAQCs, standards or guidelines which are more restrictive than the measured/trigger levels listed in the site-specific air standard approvals. Most of these approvals were issued after 2014. The only exception is the site-specific approval for cadmium for the Glencore smelter which became effective in 2013.

In 2012, the Ministry issued new and stricter AAQCs for manganese, nickel and chromium in particulate matter as indicated in sections 4.4.2 and 4.4.3.

#### 1.1.4 Canada Wide Standards for Ozone and PM<sub>2.5</sub>

In 2000, the Canadian Council of Ministers of the Environment (CCME) developed a Canada Wide Standard (CWS) for ozone (O<sub>3</sub>) and respirable particulate (PM<sub>2.5</sub>) as a result of their adverse effects on human health and the environment. As referenced in the *Guidance Document on Achievement Determination*<sup>3</sup>, the CWS for O<sub>3</sub> is 65 ppb, eight-hour running average time, based on the 4th highest annual ambient measurement averaged over three consecutive years. The CWS for PM<sub>2.5</sub> is 30 µg/m<sup>3</sup>, 24-hour averaging time, based on the 98th percentile annual ambient measurement, and averaged over three consecutive years. Jurisdictions were required to meet both standards by 2010 and commence reporting on their achievement by 2011. In the interim, comprehensive reporting on progress toward meeting the CWS for O<sub>3</sub> and PM<sub>2.5</sub> commenced in 2006. A progress report covering the period 2006 to 2012 is provided in this document. Sault Sainte Marie and North Bay have not been designated to meet the CWSs since they are below the population reporting threshold of 100,000. Compliance information for PM<sub>2.5</sub> in Greater Sudbury became available in 2007.

#### 1.1.5 Canadian Ambient Air Quality Standards

In May of 2013 the federal government published the Canadian Ambient Air Quality Standards (CAAQS) as non-binding objectives under the Canadian Environmental Protection Act (CEPA). The CAAQSs were developed under the auspices of the CCME as outdoor air quality targets that “set the bar” for air quality actions across the country.

The CAAQSs replaced the existing CWS for ozone and PM<sub>2.5</sub> in 2013 by setting stricter targets, and introducing an annual standard for PM<sub>2.5</sub>. An annual standard helps protect human health from long-term or chronic exposure to fine particles. The purpose of the CAAQSs is to drive continuous improvement in ambient air quality. Air quality will be measured against these new standards for the first time in 2015 to determine management levels for air zones. Table 2 shows the standards for the 2015 target date for achieving the CAAQSs.

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<sup>3</sup> Canadian Council of Ministers of the Environment, 2002. *Guidance Document on Achievement Determination: Canada-Wide Standards for Particulate Matter and Ozone*

Standard	Ozone (8 h)	PM <sub>2.5</sub> (24 h)	PM <sub>2.5</sub> (Annual)
CAAQS	63 ppb <sup>(1)</sup>	28 ug/m <sup>3</sup> <sup>(2)</sup>	10 ug/m <sup>3</sup> <sup>(3)</sup>
CWS <sup>(4)</sup>	65 ppb <sup>(1)</sup>	30 ug/m <sup>3</sup> <sup>(2)</sup>	No standard

**TABLE 2: CANADIAN AMBIENT AIR QUALITY STANDARDS**

(1) based on the annual 4<sup>th</sup> highest daily maximum eight-hour running average, averaged over three consecutive years.

(2) based on the 98<sup>th</sup> percentile measurement annually, averaged over three consecutive years.

(3) based on the annual mean averaged over three consecutive years.

(4) replaced in 2013 by the CAAQS.

### 1.1.6 Transfer of Air Quality Monitoring Responsibilities to Emitters

Under a province-wide initiative, the Ministry began to transfer its air quality monitoring responsibilities to emitters in 2003. This is in keeping with the ‘polluter pay’ principle and monitoring requirements/approaches used for a number of years in the province’s water quality monitoring programs. It is important to note that this transfer of responsibilities does not apply to the Ministry’s provincial Air Quality Index (AQI) monitoring network which it continues to operate and maintain. This initiative is limited to air quality monitoring programs aimed at determining the impact of industrial emissions on local air quality and with the requirements of Regulation 419/05.

Under this initiative, Vale, in partnership with Glencore, are collectively responsible for the operation and maintenance of the Greater Sudbury air quality monitoring network, most of which is performed by third parties. In 2014, this network comprised 18 SO<sub>2</sub> monitoring stations. Vale is also required to measure SO<sub>2</sub> concentrations in the community from April 1<sup>st</sup> to October 31<sup>st</sup> with a mobile SO<sub>2</sub> analyzer mounted in a vehicle. This mobile monitoring program is not within the scope of this report and its results are not reported here. Both companies are also required to measure ambient concentrations of particulate matter and a number of metals in particulate matter at a number of locations in Greater Sudbury. In 2014, Vale was responsible for the operation of 8 particulate sampling stations in and around the Town of Copper Cliff and the west end of the City of Greater Sudbury, whereas Glencore operated 2 particulate sampling stations in the Town of Falconbridge. The Vale sampling program reflects its larger scale of operations (smelter and refinery) and the larger community that can be potentially affected by its emissions.

To ensure that network operators follow acceptable monitoring procedures for data integrity and accuracy, the Ministry developed a document<sup>4</sup> that outlines the Standard Operating Procedures (SOPs) and data handling and reporting requirements that must be followed for acceptance of the data. In addition, the Ministry continues to provide oversight of air quality monitoring activities by performing performance audits.

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<sup>4</sup> Operations Manual for Air Quality Monitoring in Ontario, March 2008

Since 2008, through a collaborative effort between Science North, Vale, Glencore and Bestech, real-time average SO<sub>2</sub> ground level concentrations measured at the monitoring stations in Greater Sudbury are provided as a public display at Science North and on a website operated and maintained by Bestech, the SO<sub>2</sub> network operator. The web site also provides the current wind speed and direction from meteorological towers located in the City of Greater Sudbury and in the Town of Falconbridge. The web site address is [www.sciencenorth.bestech.com](http://www.sciencenorth.bestech.com).

In addition, Vale and Glencore each have websites providing daily SO<sub>2</sub> dispersion forecasts, quarterly and annual monitoring reports for SO<sub>2</sub> and particulate matter and metals in particulate matter, environmental management system and community involvement reports and other related environmental reports. Their web site addresses are as follows: [www.sudburyino.ca/en/environment](http://www.sudburyino.ca/en/environment) and [www.vale.com/canada/EN/aboutvale//communities/environment/sudbury-environment](http://www.vale.com/canada/EN/aboutvale//communities/environment/sudbury-environment).

### 1.1.7 Air Emissions Reduction Programs

#### *Vale*

Following completion of Vale's fluid bed roasters (FBR) sulphur dioxide abatement project, which captured and treated the emissions from its Copper Cliff matte processing fluid bed roaster off-gases in 2006, Vale began development of its Clean AER (Atmospheric Emissions Reduction) project to capture emissions from its bulk converters at the Copper Cliff smelter and reduce secondary and material handling emissions. In January 2013, a decision was made to modify the Sudbury Operations flowsheet and move to a single-furnace operation at the smelter. This necessitated a reshaping of the Clean AER project plan, and will result in further emission reductions than contemplated in the original plan.

Upon completion of the project, relative to 2016 levels, Vale will achieve:

- an 85% reduction in sulphur dioxide emissions (150kt to 20-25 kt annually)
- a 40% reduction in particulate and metals emissions
- a 40% reduction in greenhouse gas emissions

Stepwise reductions will occur as project items are completed. As of the end of 2015, the project was 55% complete.

In addition, to further improve air quality and reduce metal and particulate emissions, Vale has a \$70 million suite of projects underway at the Copper Cliff nickel refinery. The projects will replace or upgrade old baghouses with new high efficiency baghouses, replace the process electrostatic precipitators with a large baghouse, and capture secondary emissions. These projects are planned to be completed by the end of 2016.

#### *Glencore*

In 2001 and 2004, Glencore Sudbury Integrated Nickel Operations (Glencore), in developing the Smelter Environmental Management System (ISO 14001), conducted an inventory of particulate emission sources from its plants and surroundings. As a follow-up to this exercise, higher priority areas being

addressed include improving efficiencies of existing emission control systems (baghouses and electrostatic precipitators) and improving monitoring and inspection processes.

Significant work is also underway to examine emissions from the Smelter's converter aisle in order to find ways to improve the collection of particulates (and associated metals) and SO<sub>2</sub>. As well, control efforts are also being directed toward reducing particulate emissions from various outdoor activities and company property surrounding the Smelter operations. Glencore continues to conduct ambient air quality monitoring in the community of Falconbridge to assess its emission reduction efforts.

The following represent a list of areas of continuous improvement:

- Baghouses (dust capture system): Improvements to equipment, maintenance and inspections;
- Electrostatic precipitators (smelter emissions capture system): Improvements in cells, maintenance programs, stack opacity monitoring, and operator training;
- Site and Roadways: Comprehensive dust reduction programs, including annual paving, road maintenance / cleaning, and application of dust suppressants;
- Material Handling: Implementation of best management practices; and
- Re-greening/reclamation: Implementation of re-greening programs to reduce blowing dust from exposed land surfaces.

Mathematical modeling of the emissions has also been initiated as part of an over-all site investigation, in order to establish priority metals and to evaluate potential impacts within the community of Falconbridge. This work is conducted in association with the ambient air quality monitoring program that has been in place in the community of Falconbridge for a number of years.

### 1.1.8 Environment Canada Air Contaminants Emission Estimates

Environment Canada periodically estimated emissions of the common air contaminants for geographical areas with reportable emissions. These estimates are no longer provided. The latest ones for Greater Sudbury are dated 2005<sup>5</sup> and were presented in the 1998-2007 Sudbury Air Quality Trends Report<sup>6</sup>. These included emissions of particulate matter, SO<sub>2</sub>, carbon monoxide (CO), nitrogen oxides (NO<sub>x</sub>) and volatile organic compounds (VOCs). The geographic area was determined with the 'Forward Sortation Area' (FSA) method which used the following postal codes: P3A, P3C, P3E, P3G, P3L, P3N, P3P and P3Y. The estimates methodology was documented earlier<sup>7</sup>.

The percentage contributions of the emission estimates for the major source categories for 2005 are shown in Table 3. Although these estimates are outdated, the dominant source categories are likely unchanged. For particulate matter (TSP, PM<sub>10</sub> and PM<sub>2.5</sub>) the industrial sector is probably still contributing the largest fraction followed by open sources such as agricultural operations, construction,

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<sup>5</sup> 2005 Criteria Air Contaminant (CAC) inventory, April 2007, Pollution Data Division, Science and Technology Branch, Environment Canada

<sup>6</sup> Air Quality Trends In The City of Greater Sudbury, Ontario, 1998 - 2007, May 2009

<sup>7</sup> 2005 Criteria Air Contaminant (CAC) inventory, April 2007, Pollution Data Division, Science and Technology Branch, Environment Canada

landfill sites, mine tailings, and paved/unpaved roads. Transportation, fuel combustion and miscellaneous sources are believed to account for the remainder.

Source category	TSP	PM <sub>10</sub>	PM <sub>2.5</sub>	SO <sub>x</sub>	NO <sub>x</sub>	CO	VOC
Industrial	68.0	62.3	72.0	99.7	24.3	24.5	12.9
Fuel combustion	1.7	5.1	10.0	0.1	4.7	11.6	10.3
Transportation	1.3	4.2	7.9	0.2	71.0	63.6	32.2
Incineration	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	0.1	< 0.1
Miscellaneous	0.2	0.6	1.2	< 0.1	< 0.1	0.1	40.0
Open sources	28.7	27.8	8.9	< 0.1	< 0.1	0.2	4.6

**TABLE 3: ENVIRONMENT CANADA EMISSION ESTIMATES (% CONTRIBUTIONS) FOR GREATER SUDBURY (2005)**

Most of the SO<sub>x</sub> emissions, as SO<sub>2</sub>, can still be attributed to industrial sources which in Greater Sudbury the Glencore and Vale smelters are the largest sources. Transportation and fuel combustion account for the rest.

Transportation sources are estimated to be responsible for the largest fraction of nitrogen oxide (NO<sub>x</sub>) emissions, followed by the industrial sector and fuel combustion.

For CO, transportation sources, industrial emissions and fuel combustion sources are estimated to account for most of the emissions. Together, incineration, miscellaneous and open sources are responsible for a small fraction of CO emissions.

Miscellaneous sources (general solvent use, fuel marketing, surface coatings, printing) are believed to account for a substantial fraction of VOC emissions, followed by transportation, industrial and fuel combustion sources. Open sources, such as agriculture and landfill sites, contribute to the remainder.

It is important to note that there is no data at this time to provide updated numerical percentage emission contributions from the source categories in Greater Sudbury. However, it is likely that the order of the dominant source categories is unchanged from 2005.

## 2. AIR QUALITY INDEX, SMOG ADVISORIES AND THE FEDERAL AIR QUALITY HEALTH INDEX

### 2.1 Ontario Air Quality Index (AQI)

In May 1988, the Ministry launched its Air Quality Index (AQI) system, partly adopted from the Canadian Air Quality Index and the U.S. EPA Pollutant Standards Index.

The AQI provides the public with real-time air quality information from 40 AQI sites located in 33 urban centers and 7 rural areas in the province. The index is based on hourly average readings for the following air pollutants that have adverse effects on human health and the environment: SO<sub>2</sub>, O<sub>3</sub>, NO<sub>2</sub>, total reduced sulphur (TRS) compounds, carbon monoxide (CO), and fine particulate matter (PM<sub>2.5</sub>). At the end of each hour, the concentration of each pollutant measured at each site is converted into a number ranging from zero upwards using a common scale or index. The calculated number for each pollutant is a sub-index value. At a given air monitoring site, the highest sub-index value for any given hour becomes the reporting AQI for that hour. The index is a relative scale, in that the lower the index, the better the air quality. Index values between 0 and 15 are very good, 16-31 good, 32-49 moderate, 50-99 poor, and 100+ are very poor. The index values, their corresponding air quality categories and potential health and environmental effects are shown in Table 4.

Computed AQI values and air quality forecasts are released to the public and news media at set times each day. The public can access the index values by calling the Ministry's air quality information Integrated Voice Response (IVR). (To access an English recording, call 1-800-387-7768, or in Toronto, call 416-246-0411. For a French recording, call 1-800-221-8852.) The AQI values can also be obtained from the Ministry's website at [www.airqualityontario.com](http://www.airqualityontario.com). Air quality forecasts, based on regional meteorological conditions and current pollution levels in Ontario and bordering U.S. states, are also provided daily on this website.

From 2008 to 2014, the AQI described the air quality in Greater Sudbury as being very good (AQI from 0 to 15) to good (AQI from 16 to 31) from 95.5% to 97.6% of the time. This is an improvement over the 1998 to 2007 average of 94.1% for very good to good air quality. The air quality was never in the very poor range (AQI > 99) and was determined to be moderate to poor (AQI from 32 to 99) for 3.4% of the time compared to an average of 5.6% from 1998 to 2007. The air quality was described as poor ≤ 0.1% of the time.

From 2008 to 2014, the Greater Sudbury AQI station recorded a total of six days with at least 1 hour with an AQI value > 49 (poor category). Three days resulted from elevated ozone concentrations and three days from elevated PM<sub>2.5</sub> concentrations.

Index	Category	Carbon Monoxide (CO)	Nitrogen Dioxide (NO <sub>2</sub> )	TRS Compounds	Sulphur Dioxide (SO <sub>2</sub> )	Fine Particulate Matter (PM2.5)	Ozone (O <sub>3</sub> )
0-15	Very Good	No known harmful effects	No known harmful effects	No known harmful effects	No known harmful effects	Sensitive population may want to exercise caution	No known harmful effects
16-31	Good	No known harmful effects	Slight Odour	Slight Odour	Some vegetation injury with ozone	Sensitive population may want to exercise caution	No known harmful effects
32-49	Moderate	No noticeable impairment	Odour	Odour	Damages some vegetation	People with respiratory disease at some risk	Respiratory irritation in sensitive people; some risk for people with heart & lung disorders; damages very sensitive plants
50-99	Poor	Increased symptoms for smokers with heart disease	Air smells and looks brown; some effect on asthmatics	Strong odour	Odorous; increasing vegetation damage	People with respiratory disease should limit prolonged exertion; general population at some risk	Sensitive people may experience irritation when breathing and possible lung damage; greater risk for people with heart/lung disorders; damages some plants
100-over	Very poor	Increased symptoms in non-smokers with heart disease; blurred vision	Increased sensitivity for people with bronchitis and asthma	Severe odour; some people may have nausea and headaches	Increased sensitivity for people with bronchitis and asthma; more vegetation damage	Serious respiratory effects even during light physical activity; people with heart disease, the elderly and children at high risk; increased risk for general population	Serious respiratory effects even during light activity; people with heart/lung disease at high risk; more vegetation damage

**TABLE 4: AIR QUALITY INDEX POLLUTANTS AND THEIR POTENTIAL IMPACTS**

## Comparison with Other Cities

Figure 1 depicts the composite percentage number of hours with AQI values > 31 (moderate to very poor air quality) for selected cities in the province. For the period 2008 to 2014, Windsor, Hamilton, Toronto and Parry Sound recorded the greatest percentage of hours (all individually less than 10%). Ottawa and Thunder Bay had the lowest composite percentages. Greater Sudbury had slightly smaller percentages than Sault Ste. Marie and North Bay. Its ranking is very similar to the one reported for the period 1998 to 2007.

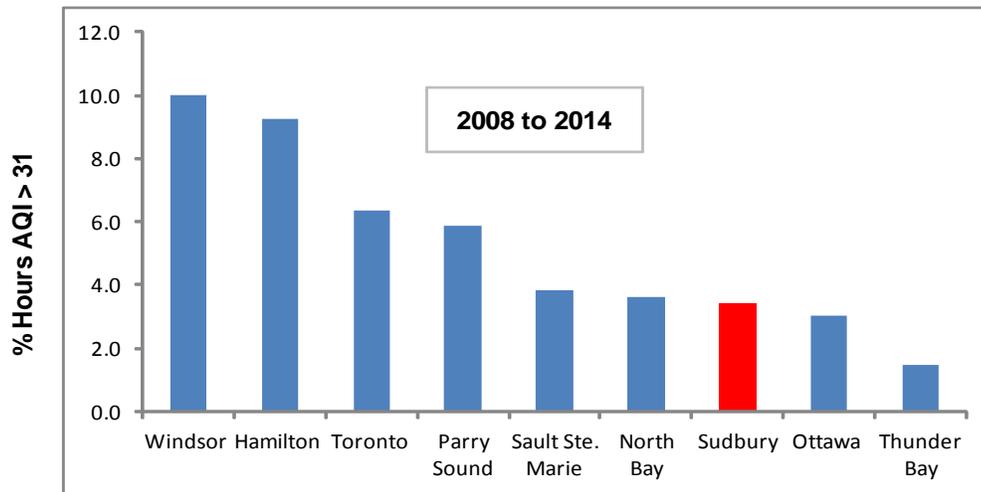


FIGURE 1: PERCENTAGE NO. OF HOURS WITH AQI > 31 IN SELECTED CITIES (2008-2014)

## 2.2 Smog Advisories

Smog advisories are issued to the public in advance when AQI values are expected to be in the poor category due to elevated, widespread and persistent levels, generally 3 or more hours in duration. Smog advisories are typically issued for elevated levels of  $O_3$  and/or  $PM_{2.5}$  but can be issued for other pollutants. Smog advisories are usually issued 24 hours in advance. However, if elevated smog conditions occur suddenly, and weather conditions conducive to elevated smog levels are expected to continue for several hours, a smog advisory is issued effective immediately. Note that a smog advisory is a forecast and does not necessarily mean elevated smog is a certainty since it is based on weather forecasts.

Smog advisories are issued via the Ministry's web site, and through email notification as per the Smog Alert Network. (To receive a direct email notification of a smog advisory, visit the Ministry web site and subscribe to the Smog Alert Network).

The Smog Alert program provides Ontarians with improved reporting through comprehensive and timely air quality readings and forecasts, and includes the following:

- A public website, [www.airqualityontario.com](http://www.airqualityontario.com), where current AQI readings, smog forecasts and other air quality information are available;
- A two-level air quality forecast that provides a three-day outlook known as a smog watch, in addition to the current 24-hour smog advisory;
- A Smog Watch is called when there is a 50 per cent chance that elevated smog levels are forecast within the next three days;
- A Smog Advisory is called when there is a strong likelihood that elevated smog levels are forecast within the next 24-hours;
- If widespread, poor AQI readings occur, and weather conditions conducive to the persistence of such levels are expected to continue for several hours, then a smog advisory is issued immediately;
- Toll-free numbers by which anyone at any time can get updated information on air quality (1-800-387-7768 in English and 1-800-221-8852 in French).

Near real-time and historic pollutant concentration data and index values are available to the public (24 hours per day, 7 days a week) from across the province on the Ministry's web site. The public can also access index values via the Interactive Voice Response (IVR) system. (To access an English recording, call 1-800-387-7768, or in Toronto, call 416-246-0411. For a French recording, call 1-800-221-8852). The Ministry's web site also provides daily air quality forecasts, based on regional meteorological conditions and current pollution levels in Ontario and bordering U.S. states.

For the period 2008 to 2014, the Ministry issued 1 smog advisory, covering 1 day, in 2009 and 2 advisories, covering 4 days in 2012 for Greater Sudbury and vicinity. 2014 was the first time since the start of the program in 1993 that no smog advisories were issued in Ontario. This can be attributed to reductions in both emissions and pollutant concentrations, along with a relatively cool summer.

## 2.3 Federal Air Quality Health Index (AQHI)

In September 2006, Health Canada proposed the AQHI, an air quality health index that derives a value based on the cumulative health effects of three pollutants: O<sub>3</sub>, PM<sub>2.5</sub> and NO<sub>2</sub>. Along with the assistance of Environment Canada and all provinces, the AQHI informs the public about health risks associated with air quality and encourages them to make their own decisions and behaviour modifications depending on how they are individually affected by air quality. In 2007, the Ministry began participating in the development of the national AQHI by providing Environment Canada with air quality data for a pilot program taking place in the Greater Toronto Area (GTA) including

Burlington, Oakville, Mississauga, Brampton, Newmarket, Toronto and Oshawa. This pilot program was then expanded over the years to include Windsor, London, Hamilton, St. Catharines, Peterborough, Kingston, Ottawa, Barrie, Dorset and Sault Ste. Marie.

In 2014, the Ministry established an AQHI Steering Committee, which includes representatives from the Ministry of Health and Long-Term Care (MOHLTC) and the federal government (Health Canada and Environment Canada), to determine the best path forward for reporting air quality in the province. The Ministry replaced the AQI with the AQHI across Ontario in June 2015.

For more information on the federal AQHI, please visit: [www.airhealth.ca](http://www.airhealth.ca).

### 3. METEOROLOGY AND AIR QUALITY

Weather has a major influence on air quality. The dispersion and behaviour of air contaminants is directly affected by wind, temperature, precipitation, sunshine and the stability condition of the atmosphere. Once released in the atmosphere, air contaminants and precursor substances follow the air currents and undergo chemical transformations and removal/dispersion depending on prevailing meteorological conditions. These conditions also have a significant influence on the speed or the rate at which these processes occur.

Generally, the concentration of air pollutants will decrease with increasing wind speed and vice-versa. Air pollution episodes typically occur when winds are stagnant or light since the atmosphere is unable to quickly disperse the pollutants, causing them to build up and lead to elevated ground-level concentrations. Wind direction determines which areas near or downwind of a source will be affected. Wind directions have seasonal patterns. For example in many areas of the province, including Greater Sudbury, winds typically originate from the south-southwest, the southwest and the west during the late spring and summer months. During the colder seasons, the winds in the Greater Sudbury area generally blow from the northwest, north and northeast. Knowledge of the frequency distribution of wind directions in an area, typically represented in a wind rose diagram, is very important in identifying more appropriate sites for new sources of air pollutants near populated areas and in determining the pollution controls or strategies required. The wind rose diagram shown in Appendix I is for the wind data collected at the Sudbury airport for the period 1996 to 2000. Wind rose diagrams remain fairly unchanged from year-to-year and are often provided on a 'multi-year' basis.

Ambient temperature plays an important role in the rate of transformation of certain air contaminants. For example, chemical reactions in the atmosphere are enhanced by warmer temperatures. Hence the formation of secondary pollutants, such as ground-level ozone, is greater in warmer climates. A critical factor affecting the behaviour of air contaminants is the stability condition of the atmosphere. This is driven by the temperature of the air as a function of altitude. This 'temperature profile' dictates whether the air is stable, i.e. very little vertical movement, or unstable, i.e. with significant vertical movement which is the case with updrafts and downdrafts. Air pollutants released in unstable air can reach ground-level due to downdrafts, even if released from elevated stacks. Air temperature normally drops with increasing altitude. Under certain conditions, however, the opposite occurs over a short range of altitudes and for short time periods, leading to so-called 'temperature inversions.' These often trap air pollutants near ground level resulting in short-term air pollution episodes or fumigations.

Precipitation, in the form of rainfall and snowfall, effectively washes out air pollutants from the atmosphere. Typically, wet summers result in better air quality due to the dual beneficial effect of precipitation and lower temperatures. This cleansing of the air, however, leads to the wet deposition of contaminants to the ground and to area lakes and streams, some of which can become acidified.

The influence of meteorology on air quality in Greater Sudbury is best exemplified with O<sub>3</sub> and SO<sub>2</sub>. Ground-level O<sub>3</sub> is formed when its precursors (VOCs and NO<sub>x</sub>) react in sunlight and high ambient

temperatures. Widespread elevated O<sub>3</sub> episodes typically occur in late spring and summer under high-pressure systems. On such days, air masses generally reach southern Ontario from the southwest, having crossed large industrial and urban areas of the eastern and mid-western U.S. These areas are potential sources of ozone and its precursors. From time to time, these ozone-laden air masses, pushed by westerly and south-westerly winds, reach the southern section of northeastern Ontario and cause elevated ground-level ozone concentrations along the Sault Sainte Marie -North Bay corridor. Air quality advisories are often issued during this type of weather.

In Greater Sudbury, SO<sub>2</sub> episodes or 'fumigations' occur when SO<sub>2</sub> emitted at significant heights from smelter stacks impinges at ground level. This 'looping plume' phenomenon typically occurs under sunny conditions from late spring to early fall - from late morning to mid-afternoon - when the air is most unstable and mixes down to the ground entraining parcels of SO<sub>2</sub> gas released from the stacks and also to a much lesser degree from smelter building roof vents. This phenomenon is aggravated under light winds or stagnant conditions. Short- term fumigations can also occur when the SO<sub>2</sub> plume is released below a temperature inversion, effectively preventing its upward dispersion. This can result in an accumulation of SO<sub>2</sub> gas which is forced to mix down to the ground at elevated concentrations under the light wind conditions. From fall through to spring atmospheric dispersion conditions are most favourable. During this period, incidences of SO<sub>2</sub> fumigations in Greater Sudbury are typically very low and average SO<sub>2</sub> concentrations are at very low background levels.

## 4. AIR QUALITY TRENDS AND PROVINCIAL PERSPECTIVE

Brief descriptions of the principle of operation of the analyzers and samplers used to measure the concentration of the air pollutants discussed in this report are provided in Appendices A to H.

### 4.1 Sulphur Dioxide

Sulphur dioxide (SO<sub>2</sub>) is a colourless gas released during the combustion of sulphur-bearing substances and smells like burnt matches. It can be transformed to sulphur trioxide (SO<sub>3</sub>), which in the presence of water vapour readily becomes sulphuric acid (H<sub>2</sub>SO<sub>4</sub>) mist. Sulphur dioxide can also be oxidized to form acid aerosols. SO<sub>2</sub> is a precursor to sulphates (SO<sub>4</sub>), which are significant components of fine particulate matter (PM<sub>2.5</sub>) in the atmosphere.

According to emission estimates compiled by the Ministry in its annual air quality in Ontario reports, and from National Pollutant Release Inventory (NPRI) data, the largest fraction of the SO<sub>2</sub> annually emitted in Ontario comes from smelters in northern Ontario, other industrial sources and electricity utilities. Of these, smelter emissions typically comprise the largest fraction. Between 2008 and 2013, the smelters in Greater Sudbury accounted for 40% to 68% of provincial annual emissions.<sup>8</sup>

There is growing scientific evidence that exposure to high levels of SO<sub>2</sub> can result in breathing problems, respiratory illness, changes in the lung's defences and worsening respiratory and cardiovascular disease. People with asthma, chronic lung disease or heart disease are believed to be the most sensitive to SO<sub>2</sub>. Under certain climatic conditions, it can damage trees and crops. SO<sub>2</sub> and NO<sub>2</sub> are the main precursors of acidic deposition (mostly acid rain), which results in the acidification of sensitive lakes and streams, accelerates the corrosion of buildings and contributes to reduced visibility. SO<sub>2</sub> also causes the formation of microscopic acid aerosols which have health implications.

#### 4.1.2 Smelter Emissions and Abatement Efforts

The history of SO<sub>2</sub> abatement efforts and programs by the provincial government and industry is well documented<sup>9</sup> <sup>10</sup>. Abatement efforts and strategies have focused on sulphur removal before smelting through rejection of the high sulphur iron minerals from the copper/nickel concentrates at the ore processing stage, the containment of sulphur through the production of sulphuric acid and liquid SO<sub>2</sub>, and roasting/smelting process improvements to increase the efficiency of sulphur

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<sup>8</sup> Air Quality in Ontario, 2014 Report (PIBS 9920e), Ontario Ministry of the Environment and Climate Change

<sup>9</sup> Ontario/Canada Task Force. 1982. *Report of the Ontario/Canada Task Force for the Development and Evaluation of Air Pollution Abatement Options for Inco Limited and Falconbridge Nickel Mines Limited in the Regional Municipality of Sudbury, Ontario*. Intergovernmental Task Force Report. Toronto, Ontario.

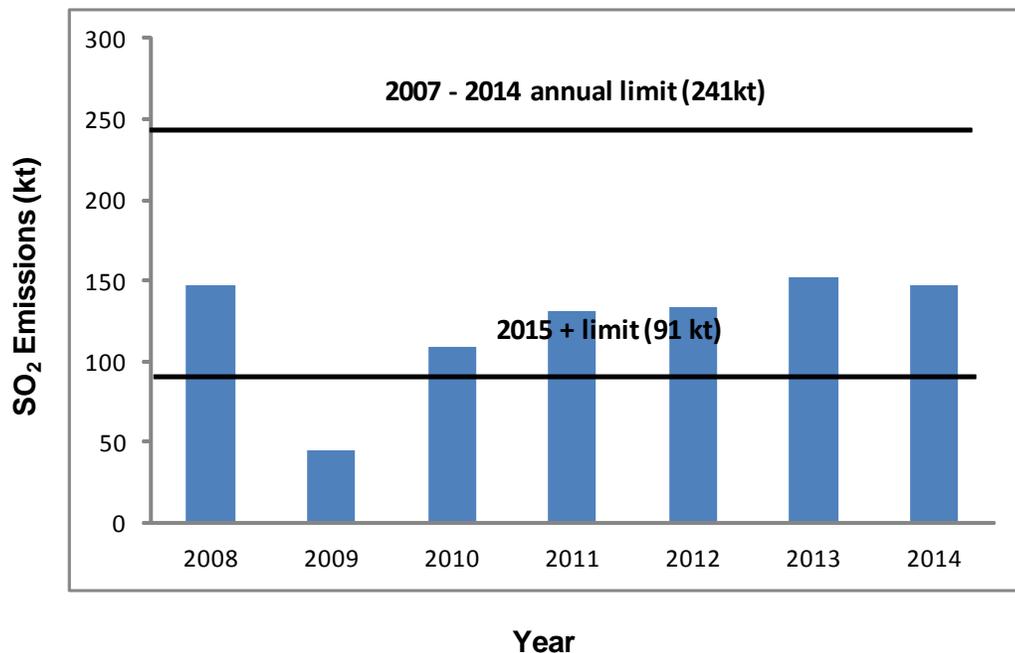
<sup>10</sup> *Restoration and Recovery of an Industrial Region, Progress in Restoring the Smelter - Damaged Landscapes near Sudbury, Canada*. 1995. Edited by John M. Gunn. Springer-Verlag New York Inc.

containment and production of these by-products. The on-going efforts and programs to reduce emissions were summarized earlier in section 1.1.7.

The trends in emissions of SO<sub>2</sub> from the 1960s to 2007 were documented in the 1998 to 2007 report<sup>11</sup>. When comparing the first and last 5 years from the 1960s to 2007, annual average smelter emissions in Greater Sudbury decreased by about 93%.

The annual smelter SO<sub>2</sub> emission trend for the period 2008 to 2014 is shown in Figure 2. Except for the lower emissions due to a production shutdown (2009) and partial operations (2010) at the Vale facilities, the total emissions from smelter operations in Greater Sudbury were fairly stable ranging from 131 kilotonnes (kt) to 148 kt. These values were well below the 2007 to 2014 O. Reg. 194/05 limit of 241 kt.

O. Reg. 194/05 requires additional emission reductions from the Vale and Glencore smelters, such that starting in 2015 the collective annual emission limit will be 91 kt, a decrease of over 62% below the 2007 to 2014 limit. The regulation provides the opportunity for the acquisition and retirement of emission allowances and credits, so that emitters can use trading to meet their emission limits with allowances and credits. The Ministry has indicated that Vale and Glencore will be able to use their allowances and credits to meet their annual limits.



**FIGURE 2: SO<sub>2</sub> EMISSIONS FROM GREATER SUDBURY AREA SMELTERS (2008 TO 2014)**

<sup>11</sup> Air Quality Trends In The City of Greater Sudbury, Ontario, 1998-2007

### 4.1.3 Supplementary Control Program

In spite of very substantial reductions in annual emissions, with their current smelting processes and associated emission levels, the Vale and Glencore smelters cannot meet at all times, with normal production levels, the provincial hourly SO<sub>2</sub> ambient air quality criterion. This is due to the 'looping plume' phenomenon, described earlier in section 3.0, which often results in short-term fumigations at ground level. The strategy consists of the timely reduction of SO<sub>2</sub> stack emissions through production curtailments during periods of poor atmospheric dispersion conditions. Weather forecasting and dispersion modelling are critical components of this strategy in order to determine when and how much to reduce production in order to meet the applicable hourly SO<sub>2</sub> limits. This program was initiated in Greater Sudbury in the late 1970s.

Consistent with the previous air quality trends reports, the applicable SO<sub>2</sub> limits in this report are the provincial AAQCs (20 ppb for the annual mean, 100 ppb for the daily (24-hour) mean and 250 ppb for the hourly mean) with health and vegetation impacts as limiting effects.

### 4.1.4 Monitoring Program

The previous air quality trends reports provide a detailed account of the history and evolution of the SO<sub>2</sub> monitoring programs in Greater Sudbury going back to 1953. The size and configuration of the monitoring network evolved with the significant changes in smelter emission intensities and characteristics that occurred over seven decades. The network of monitoring stations also experienced significant technological changes such as the development of better monitoring methods and the continuous monitoring and reporting of measured SO<sub>2</sub> levels in the communities. Another significant achievement was the use, in 'real-time', of these measurements by smelter operators to adjust smelter operations and emissions in order to comply with the Ministry hourly control limit.

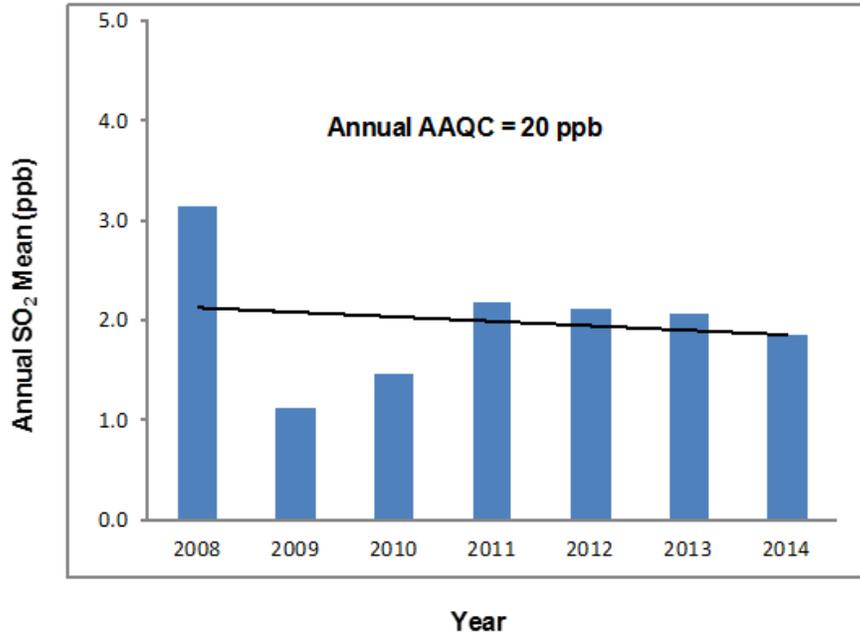
In 2008, the community SO<sub>2</sub> monitoring network operated and maintained for Vale and Glencore by a third party (Bestech) comprised 17 stations. In November 2012, a new station was put into operation on Union Street in the Town of Copper Cliff, bringing the total to 18 stations which is the current (2016) size of the network. The only other change was the relocation of the Mikkola station in December 2009 from the Jessie Hamilton Public School to the nearby Kinsmen Sports Complex on Mikkola road in the Town of Lively. The aerial photo in Appendix J shows the locations of the monitoring stations in Greater Sudbury in 2014.

As part of the provincial AQI network, the Ministry (Environmental Monitoring and Reporting Branch) operates and maintains a monitoring station in Greater Sudbury. This station was relocated to the Ramsey Lake site from Science North in 2005. In 2013, the Ramsey Lake station was relocated near the Provincial Courthouse on Elm Street in downtown Greater Sudbury.

#### 4.1.5 Results (2008 to 2014)

##### *Comparison with Annual AAQC (Community Network)*

All 18 stations in the community network had annual SO<sub>2</sub> means very much below the annual AAQC of 20 ppb. The AAQC was last exceeded in 1976 at the Skead station. During the period 2008 to 2014, the highest annual means (4.6 ppb) were recorded in 2008 at the Skead and Spruce Street stations. Figure 3 shows the composite annual mean SO<sub>2</sub> concentrations for all sites that were in operation throughout the years for the period 2008 to 2014. The composite means were lower in 2009 and 2010 coinciding with the production shutdown in 2009 and partial operations in 2010 at the Vale facilities. The composite means show a small downward trend across the network. The highest composite means (2.6 to 3.0 ppb) were obtained at the Copper Cliff, Spruce Street, Skead, Parkinson and Union Street (based only on 2013 and 2014 data) stations. The Rayside, Hanmer and Wahnapiatae stations recorded the lowest composite means (< 1.5 ppb).



**FIGURE 3: COMPOSITE MEAN SO<sub>2</sub> CONCENTRATIONS IN GREATER SUDBURY (2008 TO 2014)**

The Skead station has the longest SO<sub>2</sub> monitoring record dating back to the 1950s. Located northeast of the Greater Sudbury basin, it is located downwind of both smelters with prevailing south and southwest winds during the seasons with a higher probability of ground-level SO<sub>2</sub> impact. It has consistently recorded most of the highest SO<sub>2</sub> annual means. Figure 4 illustrates the decreasing trend in the SO<sub>2</sub> composite annual means for the 7-year periods 1994 to 2000, 2001 to 2007 and 2008 to 2014 for that station. The composite means are well below the annual AAQC of 20 ppb. These results illustrate the notable reductions over time in the annual SO<sub>2</sub> concentrations deemed to be typical in the Greater Sudbury basin.

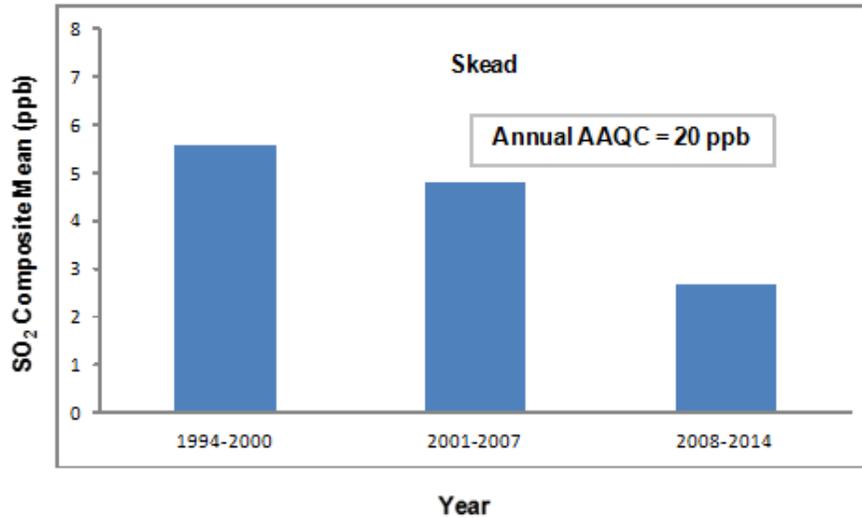


FIGURE 4: COMPOSITE MEAN SO<sub>2</sub> CONCENTRATIONS FOR THE SKEAD STATION

*Comparison with 24-hour AAQC (Community Network)*

During the period 2008 to 2014, the daily (24-hour) AAQC of 100 ppb was not exceeded at any of the stations. Table 5 illustrates by year and station the maximum daily SO<sub>2</sub> concentrations measured.

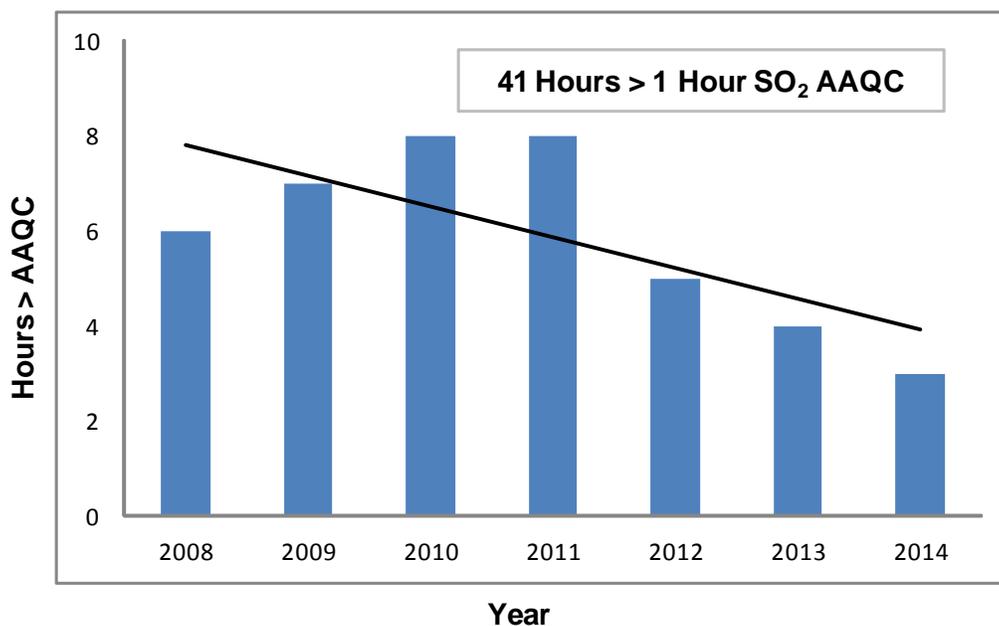
Year	Station	Maximum Daily Concentration (ppb)
2008	Skead	43
2009	Sunderland	34
2010	Kinsmen	35
2011	Kinsmen	43
2012	Sunderland	73
2013	Kinsmen	52
2014	New Sudbury	48

TABLE 5: MAXIMUM DAILY SO<sub>2</sub> CONCENTRATIONS (2008 TO 2014)

The maximum value is 73 ppb which was recorded in 2012 at the Sunderland station which is located a few kilometres west of the Town of Falconbridge. Exceedances of the daily AAQC are rare events, the most recent ones dating back to 1998 (Copper Cliff and Skead) and 2006 (Copper Cliff, Kelly Lake and Science North).

### Comparison with 1-hour AAQC (Community Network)

The 1-hour criterion (250 ppb) calculated 'on-the-hour' was exceeded a total of 41 hours during the period 2008 to 2014. This is substantially less than the total number of exceedances (353 hours) from 1998 to 2007 reported earlier<sup>12</sup>. The 41 hours represent approximately less than 0.016% of the hours monitored. The Parkinson, Edison, Mikkola/Kinsmen and New Sudbury stations recorded the highest frequency of exceedances with a combined total of 24 hours. There were no exceedances at the Hanmer, Coniston, Science North, Rayside, Algonquin and Wahnapiatae stations. Figure 5 shows the annual distribution of exceedances for the community network. The greatest number occurred in 2010 and 2011, with 8 exceedances in each year. The lowest number (3 hours) was recorded in 2014. The annual distribution in Figure 5 shows a downward trend in exceedances across the network from 2008 to 2014.



**FIGURE 5: EXCEEDANCES OF THE 1-HOUR SO<sub>2</sub> AAQC IN GREATER SUDBURY**

Of the 41 hours above the 1-hour AAQC, the stations in and around the Town of Falconbridge (Parkinson, Edison, Sunderland and Wahnapiatae) recorded a total of 16 hours, compared to a total of 32 hours from 2001 to 2007. There were no exceedances at these stations in 2013 and 2014.

The trend in the exceedance frequency of the 1-hour AAQC back to 1994 for the Skead station, the station with the largest data base, is illustrated in Figure 6. Seven year periods are compared. For the period 1994 to 2000, 62 exceedances were recorded, compared to 12 from 2001 to 2007 and 3 from 2008 to 2014. The improvements are indeed significant.

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<sup>12</sup> Air Quality Trends In The City of Greater Sudbury, Ontario, 1998-2007

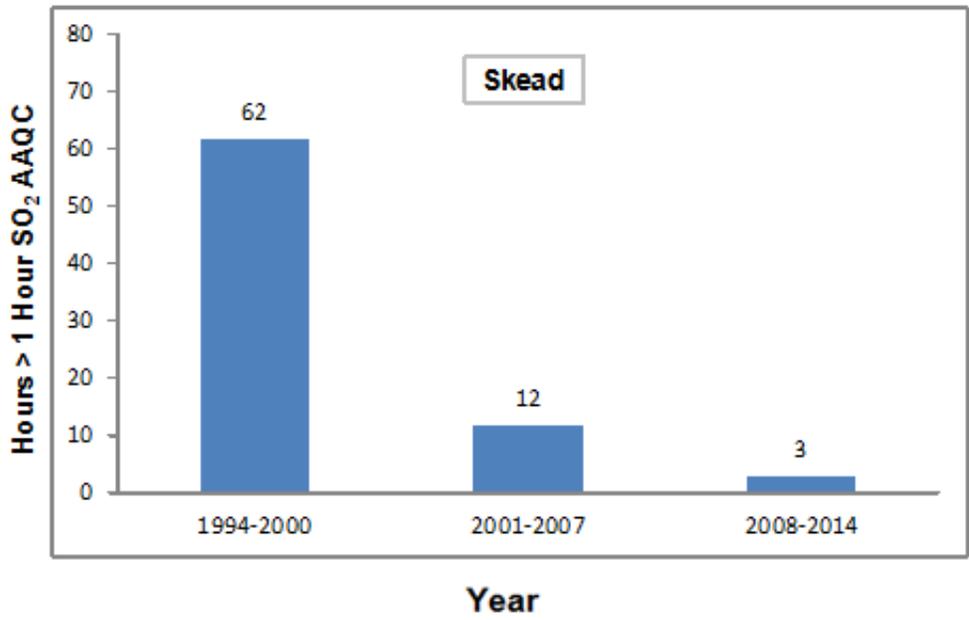


FIGURE 6: EXCEEDANCES OF THE 1-HOUR SO<sub>2</sub> AAQC AT THE SKEAD STATION

*Maximum 1-Hour Concentrations (Community Network)*

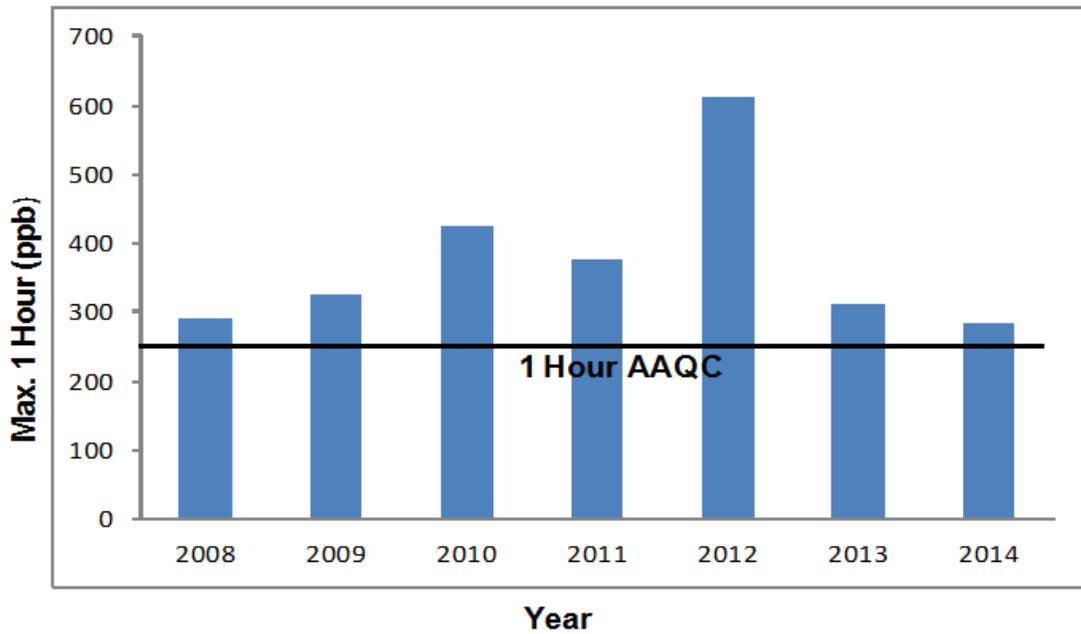


FIGURE 7: MAXIMUM 1-HOUR SO<sub>2</sub> CONCENTRATIONS IN THE SO<sub>2</sub> MONITORING NETWORK IN GREATER SUDBURY (2008 – 2014)

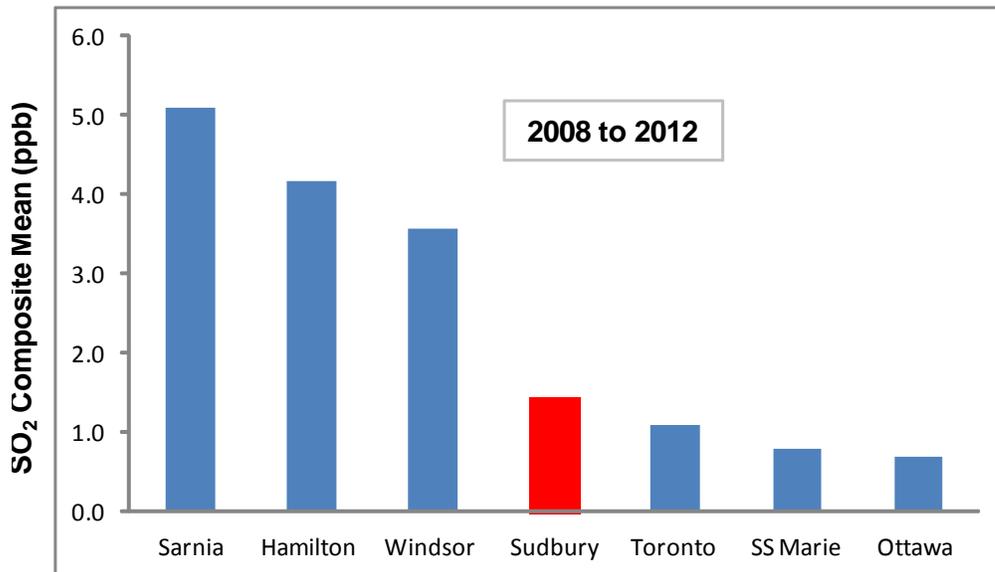
The annual maximum 1-hour readings recorded in the network of 18 stations ranged from 286 ppb in 2014 (New Sudbury) to 612 ppb in 2012 (Skead). The annual distribution is shown in Figure 7. This figure shows that the 1-hour AAQC was exceeded at least once every year.

### *Comparisons with Other Cities in Ontario (AQI network)*

With the relocation of the Greater Sudbury AQI station from Ramsey Lake (station 77219) to a downtown location (station 77233) on Elm Street in 2013, the comparisons with other cities in the province is based on the periods 2008 to 2012 and 2013 to 2014. These comparisons are more appropriate in attempting to compare results between downtown locations for the same time periods. The cities selected for comparison are Windsor Downtown (station 12008), Hamilton Downtown (station 29000), Toronto Downtown (station 31103), Ottawa Downtown (station 51001), Sault Saint Marie (station 71078), Greater Sudbury (station 77219/77233) and Sarnia (station 14064). It should be noted that the Toronto station was relocated in 2011 from a downtown location (Bay Street/Wellesley Street West) to Resources Road (station 35125) off the 401 Highway in the western part of Toronto.

#### **2008 to 2012**

The composite annual SO<sub>2</sub> concentrations for the period 2008 to 2012 are shown in Figure 8. Sarnia recorded the highest mean (5.1 ppb) and Ottawa the lowest at 0.7 ppb. Greater Sudbury ranked fourth with a mean of 1.4 ppb, behind Sarnia, Hamilton and Windsor. Greater Sudbury's ranking in the middle of the group is similar to the one reported for the periods 1990 to 2002 and 1998 to 2007.



**FIGURE 8: COMPOSITE SO<sub>2</sub> MEANS IN SELECTED ONTARIO CITIES (2008 TO 2012)**

### 2013 to 2014

The composite annual SO<sub>2</sub> concentrations for the period 2013 to 2014 are shown in Figure 9. For this period, Hamilton recorded the highest mean (5.0 ppb), followed by Sarnia (3.7 ppb) and Greater Sudbury (2.6 ppb). Ottawa had again the lowest mean (0.3 ppb).

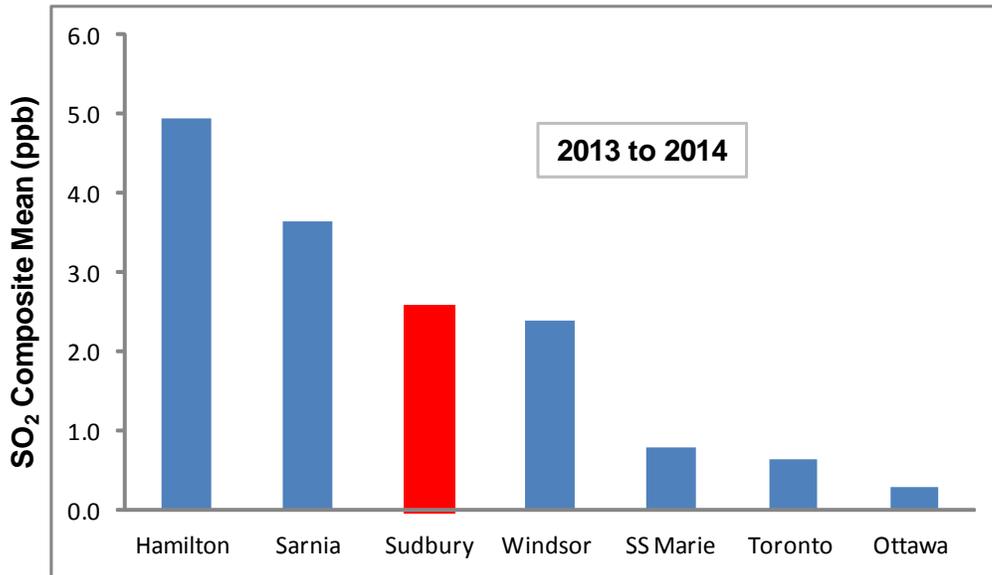


FIGURE 9: COMPOSITE SO<sub>2</sub> MEANS IN SELECTED ONTARIO CITIES (2013 TO 2014)

The change in Greater Sudbury's ranking from fourth to third reflects the increase in the composite SO<sub>2</sub> mean from 1.4 ppb (2008 to 2012) to 2.6 ppb (2013 to 2014). This may be explained by the relocation of the station to a downtown location in 2013, and/or normal production/SO<sub>2</sub> emissions in 2013 and 2014 compared to lower emissions in 2009 and 2010 from Vale's facilities. Windsor recorded a decrease in its composite means (from 3.6 ppb to 2.4 ppb), essentially the same as the mean for Greater Sudbury (2.6 ppb). The decrease in the means for Toronto, from 1.1 ppb to 0.7 ppb likely reflects the relocation of the station as described above to a site with lower SO<sub>2</sub> concentrations.

It is interesting to note that the combined average annual SO<sub>2</sub> concentration for all 18 stations in the Greater Sudbury community network was 2.0 ppb for the 2008 to 2014 period. This is less than the composite means over that period for Sarnia, Hamilton and Windsor.

Greater Sudbury was the only city, with the exception of Sarnia in 2008 (five exceedances), which recorded exceedances of the 1-hour AAQC during the period 2008 to 2014. During that period, the AAQC at the Greater Sudbury AQI station was exceeded twice in 2010 (maximum of 372 ppb) and once in 2014 (297 ppb). This is a notable improvement over the period 1998 to 2007 when the Greater Sudbury AQI station, located at Science North and Ramsey Lake recorded a total of 20

exceedances of the 1-hour AAQC. The Greater Sudbury AQI station had no exceedances of the 24-hour AAQC for the period 2008 to 2014, compared to 2 exceedances for the period 1998 to 2007.

## 4.2 Nitrogen Dioxide (NO<sub>2</sub>)

Nitrogen dioxide is a reddish-brown gas with a pungent odour, which transforms in the atmosphere to form gaseous nitric acid and nitrates. It plays a major role in atmospheric reactions that produce ground-level ozone, a major component of smog. Nitrogen dioxide also reacts in the air and contributes to the formation of PM<sub>2.5</sub><sup>13</sup>. All combustion in air produces NO<sub>x</sub>, of which NO<sub>2</sub> is a component. The other component is nitric oxide (NO). Major sources of NO<sub>x</sub> emissions include the transportation sector, industrial processes and utilities.

Nitrogen dioxide can irritate the lungs and lower their resistance to respiratory infection. People with asthma and bronchitis have increased sensitivity to NO<sub>2</sub>. Nitrogen dioxide chemically transforms into nitric acid in the atmosphere and, when deposited, contributes to the acidification of lakes and soils in Ontario. Nitric acid can also corrode metals, fade fabrics, degrade rubber, and damage trees and crops.

The NO<sub>x</sub> emission trend in Ontario since 2004 indicates a decrease of over 40%<sup>14</sup>. Ontario's emissions trading regulations on sulphur dioxide and nitrogen oxides (O. Reg. 397/01 and O. Reg. 194/05) have contributed to the reduction in nitrogen oxides emissions in recent years. Nitrogen oxides emissions from on-road vehicles have also decreased due to the phase-in of new vehicles having more stringent emission standards. The implementation of the Ontario Drive Clean program in southern Ontario in 1999 has also helped further reduce the NO<sub>x</sub> emissions from light duty gasoline vehicles.

From the NPRI data set, the total NO<sub>x</sub> emissions from Sudbury area smelters, except for lower values in 2009 and 2010 during the labour disruption at the Vale facilities, show no obvious trends from 2008 to 2014. Emissions from the transportation sector in Greater Sudbury may have decreased over the same period due to stricter emission standards for new vehicles. There is no data at this time to support this, so it not possible to draw conclusions on NO<sub>x</sub> emission trends in Greater Sudbury for the period in question.

### 4.2.1 Monitoring Program

Outdoor concentrations of nitrogen oxides (NO<sub>x</sub>) were not being measured at the Ramsey Lake site in Greater Sudbury. A NO<sub>x</sub> analyzer was included in the station instrumentation when the AQI

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<sup>13</sup> Seinfeld, J.H. and S.N. Pandis. 2006. Atmospheric chemistry and physics: From air pollution to climate change. (2nd ed.) New Jersey: John Wiley & Sons Inc.

<sup>14</sup> NPRI, 2014. National Pollutant Release Inventory (NPRI) Downloadable Datasets. Environment Canada.

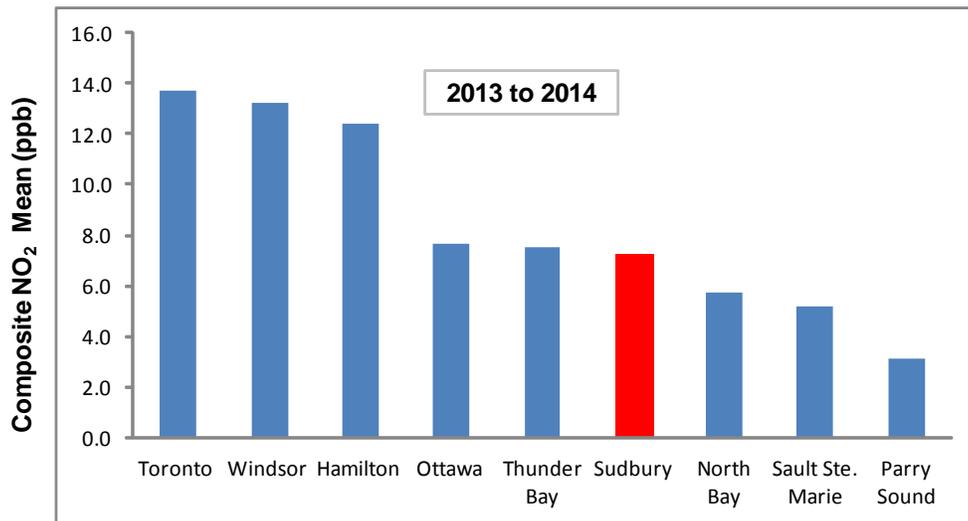
station was relocated to the Elm Street site in 2013. NO<sub>x</sub> comprises the sum of nitric oxide (NO) and NO<sub>2</sub>.

There are no AAQC criteria for NO<sub>x</sub> and NO. However, NO<sub>2</sub> has a 1-hour (200 parts per billion-ppb) and 24-hour (100 ppb) provincial criteria and has been added as a pollutant in the Federal Air Quality Health Index which is been reported since June 2015.

#### 4.2.2 Results (2013 to 2014)

In 2013 and 2014, there were no exceedances of the provincial criteria at the Elm Street site as well as in the other cities used for the comparison. In Greater Sudbury, the maximum 1-hour concentration was 63 ppb, well below the 1-hour criterion of 200 ppb, and the maximum 24-hour concentration was 32 ppb, well below the 24-hour criterion of 100 ppb.

The 2013-2014 composite mean concentration was 7.3 ppb. Figure 10 provides a comparison of the NO<sub>2</sub> composite means for the selected cities in the province.



**FIGURE 10: COMPOSITE NO<sub>2</sub> MEANS FOR SELECTED CITIES**

The highest composite means were recorded in Toronto, Windsor and Hamilton. Greater Sudbury was in the middle of the group with Ottawa and Thunder Bay, followed by North Bay and Sault Sainte Marie. Parry Sound had the lowest composite mean. The concentrations of NO<sub>2</sub> are expected to be higher in locations with higher vehicle traffic levels and also depend on the separation distance of the monitoring stations to traffic corridors.

### 4.3 Ground-Level Ozone (O<sub>3</sub>)

Ground-level ozone is a gas formed when nitrogen oxides (NO<sub>x</sub>) and volatile organic compounds (VOCs) react in the presence of sunlight. While ozone at ground level is a significant environmental and health concern, the naturally occurring ozone in the stratosphere, 10 to 40 kilometers above the earth's surface, is beneficial as it shields the earth from harmful ultraviolet radiation.

Ozone is a colourless, odourless gas at typical ambient concentrations, and is a major component of smog. Ozone is not generally emitted directly into the atmosphere; the formation and transport of ozone is strongly dependent on meteorological conditions and emissions of chemical precursors, particularly NO<sub>x</sub> and VOCs. According to emission estimates compiled by the Ministry in its annual air quality in Ontario reports, and from NPRI data, the largest sources of VOC emissions in Ontario are transportation, solvent use and printing/surface coating operations, whereas the largest source of NO<sub>x</sub> emissions is transportation. The largest source categories for NO<sub>x</sub> and VOC emissions in Greater Sudbury are believed to be the ones shown in Table 3 (transportation, industry, fuel combustion for NO<sub>x</sub> and VOCs, and miscellaneous sources for VOCs). Changing weather patterns contribute to differences in ozone concentrations hour-to-hour, day-to-day, season-to-season, and year-to-year. In Ontario, the highest concentrations of ground-level ozone are typically recorded on hot and sunny days from mainly May to September, between noon and early evening.

Ozone irritates the respiratory tract and eyes. Exposure to ozone in sensitive people can result in chest tightness, coughing and wheezing. Children who are active outdoors during the summer, when ozone levels are highest, are particularly at risk. Individuals with pre-existing respiratory disorders, such as asthma and chronic obstructive pulmonary disease (COPD), are also at risk. Ozone is associated with increased hospital admissions and premature deaths. Ozone also causes many losses in agricultural crops each year in Ontario, with visible leaf damage in many crops, garden plants and trees, especially during the summer months.

The Ministry has estimated that during widespread smog episodes, the U.S. contribution to O<sub>3</sub> excluding background levels can be as much as 90% in Ontario cities and towns on the northern shore of Lake Erie, the eastern shore of Lake Huron and in the extreme southwest near the U.S. border<sup>15</sup>. Every urban airshed that emits O<sub>3</sub> precursors will produce its own 'background' O<sub>3</sub>, an amount dependent on the levels of precursor emissions and meteorological conditions. In addition, since local emissions of NO<sub>x</sub> are known to remove O<sub>3</sub>, it has been demonstrated that O<sub>3</sub> levels are higher in rural areas and downwind of urban centres<sup>16</sup>. The amount of locally produced ground-level O<sub>3</sub> in the Greater Sudbury airshed has not been quantified and is unknown at this time. However, as in most urban centres in the province, a significant proportion of the O<sub>3</sub> measured during smog episodes in Greater Sudbury, or ozone episode days, is imported from long-range transport sources.

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<sup>15</sup> Transboundary Air Pollution in Ontario, June 2005, Ontario Ministry of the Environment and Climate Change

<sup>16</sup> Air Quality in Ontario, 2013 Report (PIBS 9795e), Ontario Ministry of the Environment and Climate Change

### 4.3.1 Monitoring Program

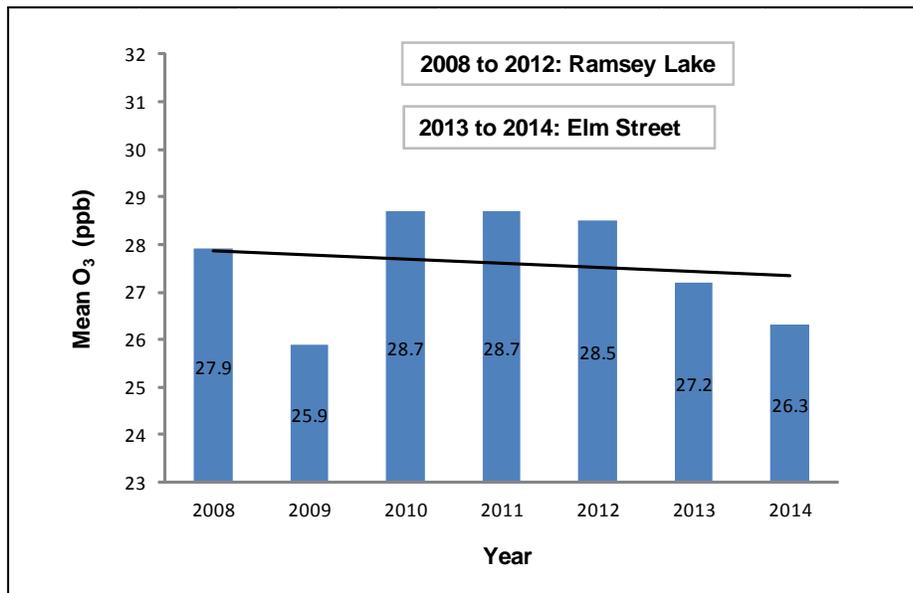
From 2008 to 2012, monitoring of ground-level O<sub>3</sub> was performed at the Ramsey Lake location and from 2013 on Elm Street in downtown Greater Sudbury.

### 4.3.2 Results (2008 to 2014)

#### *Comparison with Annual Mean Concentrations*

Annual mean concentrations in Greater Sudbury showed year-to-year variability from 25.9 ppb (2009) to 28.7 ppb (2010 and 2011) as shown in Figure 11. The Ministry's provincial network of 40 sites recorded a lower composite mean in 2009 which indicates a province wide phenomenon that year.<sup>17</sup> The slightly lower means for Greater Sudbury in 2013 and 2014 may result from the relocation to an urban site off Elm Street in 2013.

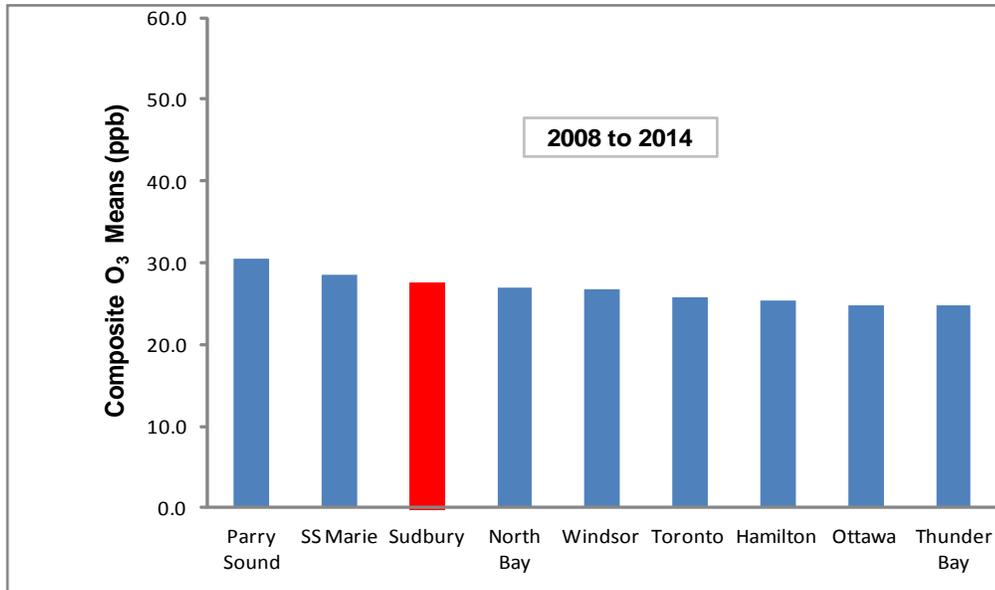
Generally, ozone concentrations are lower in urban areas because ozone is depleted by reacting with nitric oxide (NO) emitted by vehicles and other local combustion sources. Overall, there appears to be a small downward trend in the annual ozone means for Greater Sudbury for this time period.



**FIGURE 11: MEAN O<sub>3</sub> CONCENTRATIONS IN GREATER SUDBURY (2008 TO 2014)**

<sup>17</sup> Air Quality in Ontario, 2014 Report (PIBS 9920e), Ontario Ministry of the Environment and Climate Change

Figure 12 shows the composite annual ozone means for selected cities in Ontario for the period 2008 to 2014. The highest mean was recorded in Parry Sound, a transboundary-influenced site on the eastern shore of Georgian Bay. Province wide, the highest means are typically recorded in the southwest on the northern shore of Lake Erie. The lowest means were in the larger urban centres (Windsor, Toronto, Hamilton and Ottawa), probably due to the depletion of ozone by its reaction with NO<sub>x</sub> emissions from vehicles and other local combustion sources. Thunder Bay had the lowest composite mean since it historically has the least transboundary influence of the selected cities.



**FIGURE 12: COMPOSITE OZONE MEANS FOR SELECTED CITIES**

Generally, cities in northern Ontario have slightly higher annual ozone means than in southern Ontario. This is believed to be due to the higher concentrations in the north during the colder months of the year. Although the summer ozone concentrations are higher in the south and have decreased slightly over time across Ontario, the net result is slightly higher annual means in the north<sup>18</sup>. On a province-wide basis, the winter ozone means are increasing. This increase is mainly attributed to the rising global background concentrations which in turn drives the increasing trend of ozone annual means<sup>19</sup>. Although the differences are not substantial, Greater Sudbury ranked third behind Parry Sound and Sault Ste. Marie. The relocation downtown of the Greater Sudbury AQI station resulted in a slightly lower composite mean (26.8 ppb) for 2013 to 2014, compared to

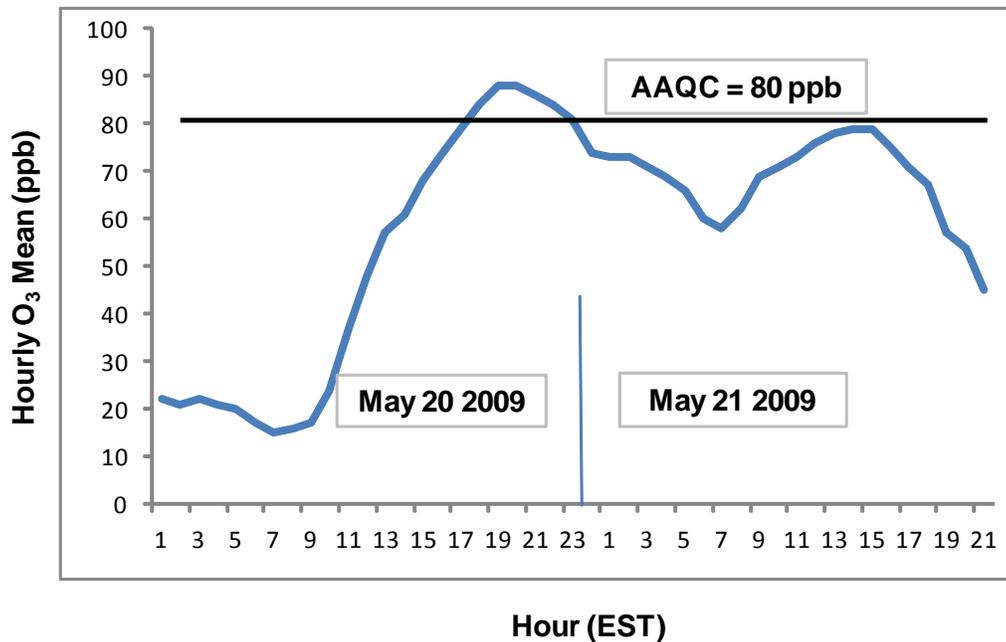
<sup>18</sup> Air Quality in Ontario, 2007 Report (PIBS 6930e), Ontario Ministry of the Environment

<sup>19</sup> Reid, N., Yap, D. and R. Bloxam. 2008. The potential role of background ozone on current and emerging air issues: *An overview. Air Quality, Atmosphere & Health*, Vol. 1, pp. 19-29.

27.9 ppb for the period 2008 to 2012 when the station was located near Ramsey Lake. The lower mean could be from the depletion of O<sub>3</sub> by NO<sub>x</sub> in the downtown environment. Greater Sudbury's ranking for 2013 to 2014 dropped to 4<sup>th</sup> from 3<sup>rd</sup>. As noted above, the differences in composite annual means between cities are small.

### *Ozone Episodes in Greater Sudbury*

From 2008 to 2014, the 1-hour AAQC for O<sub>3</sub> was exceeded in Greater Sudbury on May 20/21 in 2009 (6 hours) and on May 19/20 in 2012 (7 hours). The hourly means for the May 20/21 2009 event are illustrated in Figure 13. The May 2012 event shows a similar pattern. Parry Sound and other locations in Ontario, such as Tiverton and Grand Bend on the eastern shore of Lake Huron, also recorded exceedances on these days in May 2009. Backward trajectories of the air masses that arrived over Greater Sudbury on these days show that these events resulted from transboundary transport of ozone and its precursors from areas in the U.S. south of the Great Lakes. The backward trajectories were performed over 48 hours and are depicted in Appendices K and L. As stated in the Transboundary Air Pollution in Ontario report, elevated ozone levels in southwestern Ontario are generally attributed to the long-range transport of pollutants from the United States<sup>20</sup>.

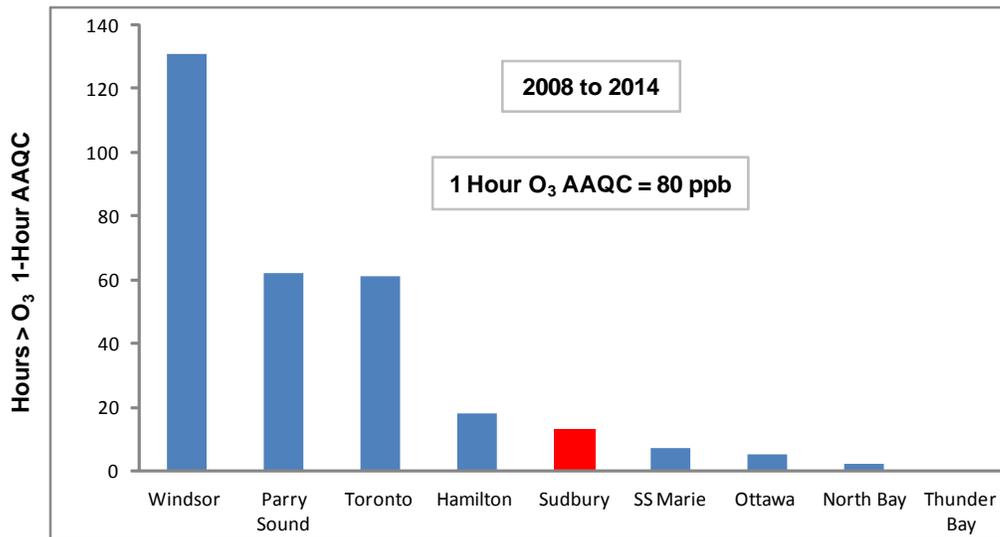


**FIGURE 13: HOURLY O<sub>3</sub> CONCENTRATIONS IN GREATER SUDBURY ON MAY 20/21 2009**

<sup>20</sup> Yap, D., Reid, N., De Brou, G. and R. Bloxam. 2005. Transboundary Air Pollution in Ontario. Ontario Ministry of the Environment.

### Comparison with Other Cities in Ontario

Although Greater Sudbury, Sault Ste. Marie and North Bay, along with Parry Sound, recorded the highest composite annual means from 2008 to 2014 for the selected cities, the larger urban centers in the south recorded a greater number of hours above the 1-hour criterion of 80 ppb. The distribution is shown in Figure 14.



**FIGURE 14: FREQUENCY OF EXCEEDANCE OF THE 1-HOUR O<sub>3</sub> AAQC IN SELECTED CITIES (2008-2014)**

Figure 14 shows that during the 7-year period covered, Windsor recorded over 130 hours with 1-hour O<sub>3</sub> concentrations greater than 80 ppb. Thunder Bay did not record any hours over that value. Greater Sudbury recorded a total of 13 hours above the 1-hour criterion, which is substantially less than the total of 108 hours recorded during the previous 7-year period (2001 to 2007). The 13 hourly exceedances all resulted from transboundary influence as noted above (6 hours in 2009 and 7 hours in 2012). The other selected cities also recorded much lower totals of exceedances from 2008 to 2014. For the group of selected cities shown in Figure 14, the number of exceedances dropped from 77 hours in 2008 to 0 hours in 2014. For the period 2008 to 2014, Greater Sudbury ranked in the middle of the group of selected cities as illustrated in Figure 14.

Table 6 summarizes the range of O<sub>3</sub> 1-hour maximum and average maximum concentrations for the selected cities. Windsor recorded the highest average at 96 ppb, followed by Toronto, Parry Sound, Hamilton, Greater Sudbury, Sault Ste. Marie, Ottawa and North Bay. Thunder Bay recorded the lowest (67 ppb) and no exceedances of the 1-hour AAQC from 2008 to 2014.

These results show that the Sault Ste. Marie-North Bay corridor and Ottawa were exposed to similar maximum 1-hour O<sub>3</sub> concentrations but lower than in the southern part of the province. It is important to emphasize that the frequency of occurrence of elevated hourly O<sub>3</sub> concentrations is much lower in the north than in the southern part of the province as illustrated in Figure 14. Under

the right meteorological conditions during the early part of the growing season, moderate to light vegetation injury caused by exposure to elevated O<sub>3</sub> can occur in Greater Sudbury on sensitive vegetation. However, the extent of vegetation injury is substantially lower than encountered in southern Ontario where injury to cash crops is typically much more significant<sup>21</sup>.

City	Maximum 1- Hr Concentration (ppb)	Average Maximum 1-Hr Concentration (ppb)
Windsor	128	96
Toronto	102	90
Parry Sound	97	85
Hamilton	92	83
Sudbury	88	77
Sault Ste. Marie	85	77
Ottawa	84	73
North Bay	82	77
Thunder Bay	74	67

**TABLE 6: MAXIMUM 1-HOUR O<sub>3</sub> CONCENTRATIONS IN SELECTED CITIES (2008 TO 2014)**

#### *Comparison with Canada Wide Standard (CWS)*

The Ministry reported<sup>22</sup> on compliance for designated sites (communities with population greater than 100,000) with the CWS for O<sub>3</sub> which is 65 ppb, eight-hour running average time, based on the 4th highest annual ambient measurement averaged over three consecutive years. (For example, the 2010 CWS consists of an average over the three-year period 2008 to 2010). For the 3 reporting years (2010, 2011 and 2012), Greater Sudbury met the CWS in 2011 but exceeded it marginally in 2010 and 2012 with a value of 66 ppb. In 2012, only 2 (Ottawa Downtown and Thunder Bay) of the 21 designated sites met the CWS.

#### *Comparison with Canadian Ambient Air Quality Standard (CAAQS)*

The CAAQS introduced in 2013 for ozone is based on the consecutive three year average of the annual 4<sup>th</sup> highest daily maximum eight-hour running average. Although this new standard will be

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<sup>21</sup> Linzon, S.N., R.G. Pearson, J.A. Donnan and F.N. Durham, 1984. *Ozone Effects on Crops in Ontario and Related Monetary Values*. Ontario Ministry of the Environment, Toronto, ARB-13-84-Phyto. 60 pp.

<sup>22</sup> Air Quality in Ontario, 2012 Report (PIBS 9598e), Ontario Ministry of the Environment and Climate Change.

used for the first time in 2015 to determine management levels for air zones, the Ministry reported on this new standard in its 2013<sup>23</sup> and 2014<sup>24</sup> annual air quality reports for 21 designated sites. In 2013, which comprises 2011 to 2013 for the averaging period, Greater Sudbury marginally exceeded the CAAQS of 63 ppb with a value of 65 ppb. Using a weight of evidence approach, the Ministry determined that Greater Sudbury (and the other 3 cities assessed with this approach) would have met the CAAQS with a value of 58 ppb if it had not been influenced by days with transboundary flow<sup>23</sup>.

In 2014, which comprises 2012 to 2014 for the averaging period, Sudbury marginally exceeded the CAAQS of 63 ppb with a value of 64 ppb. Using a weight of evidence approach, the Ministry determined that Sudbury (and the other 3 cities assessed with this approach) would have met the CAAQS with a value of 57 ppb if it had not been influenced by days with transboundary flow<sup>24</sup>.

It is important to consider the influence of transboundary flows using the weight of evidence approach for each designated monitoring station when reporting on achievement of the CAAQS.

## 4.4 Particulate Matter

Particulate matter (PM) is the general term used to describe a mixture of solid and sometimes liquid particles suspended in air. Examples of PM include smoke, fumes, dust, aerosols, fly ash and pollen. It is characterized according to size, ranging from less than 0.1 microns (1 millionth of a metre) to over 100 microns, because of the different health effects associated with particles of different aerodynamic diameters. The term Total Suspended Particulates (TSP) continues to be used to describe this particle size range. The Ministry defines suspended particulates as particles in the size range < 44 microns for the purposes of Regulation 419/05 and in the AAQC listing unless another size range is specified.

TSP has been associated mostly with soiling and visibility effects. Health effects have been associated with smaller particulate matter, i.e. particles 10 microns or less (PM<sub>10</sub>), and especially with particles 2.5 microns or less (PM<sub>2.5</sub>). These are also known as coarse or inhalable (PM<sub>10</sub>) and fine or respirable (PM<sub>2.5</sub>) particles. They can penetrate the respiratory system further than larger particles. Exposure to inhalable and especially respirable particles is reported to be associated with hospital admissions and several serious health effects, including premature mortality. People most at risk are those with asthma, cardiovascular or lung disease, as well as children and the elderly<sup>25</sup>.

Particles originate from many different stationary and mobile sources, as well as from natural sources. Industrial sources include iron and steel, pulp and paper, forestry, mining and smelting, aggregates, cement, and construction. In urban air sheds, motor vehicle exhaust, residential wood combustion and road dust are major sources of PM. Natural sources include wind-blown soil,

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<sup>23</sup> Air Quality in Ontario, 2013 Report (PIBS 9795e), Ontario Ministry of the Environment and Climate Change.

<sup>24</sup> Air Quality in Ontario, 2014 Report (PIBS 9920e), Ontario Ministry of the Environment and Climate Change.

<sup>25</sup> Air Quality in Ontario, 2013 Report (PIBS 9795e), Ontario Ministry of the Environment and Climate Change.

pollen, forest fires, ocean spray and volcanic activity. Fine particulate matter may be emitted directly to the atmosphere (primary emissions) through fuel combustion (e.g. motor vehicles, smelters, power plants, industrial facilities, residential fireplaces and wood stoves, agricultural burning and forest fires) or formed indirectly in the atmosphere through a series of complex chemical reactions.

During periods of elevated concentrations of PM<sub>2.5</sub> in Ontario, notwithstanding forest fires, it is estimated that there are significant contributions from the U.S., specifically affecting border communities. Like ozone, PM<sub>2.5</sub> can be transported many hundreds of kilometres from its point of origin. From emission inventories prior to 2005, neighbouring U.S. states release approximately 28 times as much primary fine particulate matter as does Ontario, mainly from on-road transportation and point sources such as industry<sup>26</sup>.

As discussed earlier in section 1.1.8 (Table 3), the largest source categories for particulate matter emissions in Greater Sudbury are believed to be industrial and open sources (TSP and PM<sub>10</sub>), and industrial, fuel combustion, open sources and transportation (PM<sub>2.5</sub>).

Particulate matter emitted from the smelter facilities in Greater Sudbury contains metals such as copper, nickel, cadmium and cobalt some of which have provincial limits based on health effects.

### *New PM<sub>2.5</sub> Measurement Technology in Ontario*

In 2002, Ontario became the first province in Canada to report hourly PM<sub>2.5</sub> concentrations to the public under the AQI program utilizing Tapered Element Oscillating Microbalance (TEOM) instruments that provided continuous particulate matter (PM) monitoring. Continuous PM monitoring is essential for reporting hourly ambient concentrations. The TEOM was the most innovative method at the time for continuous real-time PM<sub>2.5</sub> monitoring<sup>27</sup>, and continues to be used by many jurisdictions across North America.

Over the last decade, continuous PM<sub>2.5</sub> monitoring technologies have evolved dramatically to address the technical issues associated with cold weather PM<sub>2.5</sub> measurements. After extensive evaluations of new PM<sub>2.5</sub> monitors, it was determined that Ontario's TEOM instruments did not perform as well as these new PM<sub>2.5</sub> monitors, particularly during the winter. Ontario selected the Synchronized Hybrid Ambient Real-time Particulate (SHARP) 5030 to replace the aging TEOM monitors deployed in the AQI network. As part of a national initiative funded by Environment Canada, Ontario deployed the SHARP 5030 monitors in 2012 across the ambient air monitoring network for testing. In January 2013, Ontario commenced public reporting with the new SHARP 5030 instruments. The SHARP 5030 reports higher PM<sub>2.5</sub> concentrations than the TEOM during cold

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<sup>26</sup> Transboundary Air Pollution in Ontario, June 2005, Ontario Ministry of the Environment

<sup>27</sup> Patashnick, H. and E.G. Rupprecht. 1991. *Continuous PM-10 Measurements Using the Tapered Element Oscillating Microbalance*. Journal of the Air & Waste Management Association, Vol. 41, pp. 1079-1083.

weather due to the improved performance of the SHARP 5030<sup>28</sup>. This has resulted in an increase in Ontario's PM<sub>2.5</sub> annual mean in 2013. This is not an indication that the air quality has changed; only that the measurement is more accurate.

The Ministry collocated TEOM and SHARP monitors at a sub-set of the air monitoring network to continue reporting annual trends and work towards making the new PM<sub>2.5</sub> measurements comparable to historical data. Seven sites were selected to be representative of Ontario's PM<sub>2.5</sub> network, taking into consideration the differences in air quality across the province. The 10-year PM<sub>2.5</sub> trend for these sites, using TEOM technology, shows a decrease of PM<sub>2.5</sub> levels. For the period of 2005 to 2014 a decrease of 31 per cent was observed. Additionally Ontario developed corrections for historical TEOM measurements, for the fall and winter seasons, for the purpose of making them more agreeable to SHARP measurements through a multiple linear regression analysis. This analysis, using collocated TEOM and SHARP instruments, showed that on average annual SHARP measurements were 25 per cent higher than TEOM measurements<sup>29</sup>.

With more accurate but higher reported PM<sub>2.5</sub> values that come with the implementation of SHARP instruments, achievement of PM<sub>2.5</sub> reference levels and standards is more challenging.

#### 4.4.1 Respirable Particulate (PM<sub>2.5</sub>)

##### *Provincial Monitoring Program*

In 2002, the Ministry started to report fine particulate matter in the AQI network obtained from measurements of respirable particulate (PM<sub>2.5</sub>) using a Tapered Element Oscillating Microbalance (TEOM) instrument at 30°C with a Sample Equilibration System (SES) to measure concentrations on an hourly basis. As described earlier, in January 2013 the Ministry started reporting PM<sub>2.5</sub> measurements with a SHARP 5030 instrument. At the Greater Sudbury AQI station on Ramsey Lake, PM<sub>2.5</sub> concentrations were measured with a TEOM from 2004 to 2012 and with the SHARP 5030 instrument as of January 2013 at the Elm Street location. The results are presented in Table 7.

##### *Results (2008 to 2014)*

From 2008 to 2012, the annual means ranged from 3.4 µg/m<sup>3</sup> to 4.1 µg/m<sup>3</sup> from measurements at the Ramsey Lake station. The means rose in 2013 and 2014 (5.7 and 6.0 µg/m<sup>3</sup> respectively) at the Elm Street location. This increase of over 30% is attributed to the change in measurement technology (from TEOM to SHARP) and possibly due to the change in monitoring location. The 24-

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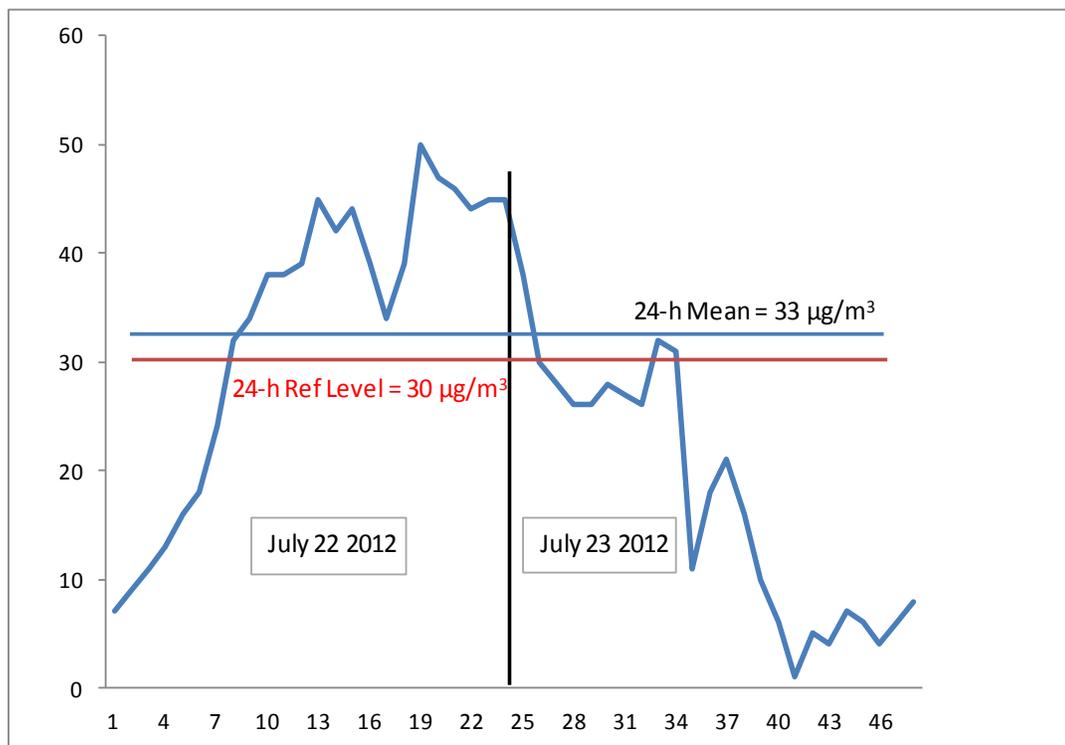
<sup>28</sup> Sofowote, U., Su, Y., Bitzos, M.M., and Munoz, A. 2014. *Improving the Correlations of Ambient TEOM PM<sub>2.5</sub> Data and SHARP 5030 FEM in Ontario: a Multiple Linear Regression Analysis*. Journal of the Air & Waste Management Association, 64:1, 104-114.

<sup>29</sup> Sofowote, U., Su, Y., Bitzos, M.M., and Munoz, A. 2014. *Improving the Correlations of Ambient TEOM PM<sub>2.5</sub> Data and SHARP 5030 FEM in Ontario: a Multiple Linear Regression Analysis*. Journal of the Air & Waste Management Association, 64:1, 104-114.

hour reference level of  $30 \mu\text{g}/\text{m}^3$  was exceeded once. The event occurred on July 22<sup>nd</sup> and 23<sup>rd</sup> 2012 as illustrated in Figure 15.

Year	Mean ( $\mu\text{g}/\text{m}^3$ )	Max 1-Hour ( $\mu\text{g}/\text{m}^3$ )	Max 24-Hour ( $\mu\text{g}/\text{m}^3$ )	No. of Times Above 24-Hour Reference Level ( $30 \mu\text{g}/\text{m}^3$ )
2008	4.1	42	23	0
2009	3.4	27	13	0
2010	3.6	31	16	0
2011	4.0	38	22	0
2012	4.0	50	33	1
2013	5.7	50	24	0
2014	6.0	60	24	0

**TABLE 7: PM<sub>2.5</sub> RESULTS FROM THE RAMSEY LAKE (2008 TO 2012) AND ELM STREET (2013 AND 2014) STATIONS IN GREATER SUDBURY**



**FIGURE 15: PM<sub>2.5</sub> MEASUREMENTS AT THE GREATER SUDBURY RAMSEY LAKE AQI STATION ON JULY 22 AND JULY 23 2012**

The 54-hour backward trajectory, illustrated in the Figure in Appendix M, shows that the air mass arriving in the Greater Sudbury area during that time period passed through northern Manitoba which was experiencing forest fires at the time. The PM<sub>2.5</sub> 24-hour maximum concentration in 2012 for the 40 AQI sites in the province was 36 µg/m<sup>3</sup> (in Parry Sound). It was recorded on July 22 also due to forest fire smoke that originated in northern Manitoba and travelled over 600 kilometres<sup>30</sup>.

### Comparison with the CWS and Other Cities in Ontario

The Ministry reported<sup>30</sup> on compliance with the CWS for PM<sub>2.5</sub> (30 µg/m<sup>3</sup>) which is based on the 98th percentile of the daily average for 21 designated sites across Ontario. (For example, the 2010 CWS consists of an average over the three-year period 2008 to 2010). Since 2006 when it started reporting on the progress to meet the CWS, the CWS was never exceeded at the Ramsey Lake station. During the period 2006 to 2012, the CWS metric for PM<sub>2.5</sub> decreased about 45%. The change over time is illustrated in Figure 16.

A similar trend is noted for the 21 designated sites across Ontario<sup>30</sup>. This change over the same period was attributed by the Ministry to reductions in provincial PM<sub>2.5</sub> emissions from industrial processes, including the elimination of coal-fired electricity generation stations, and from the transportation sector with the phase-in of new vehicles/engines having more stringent emission standards.

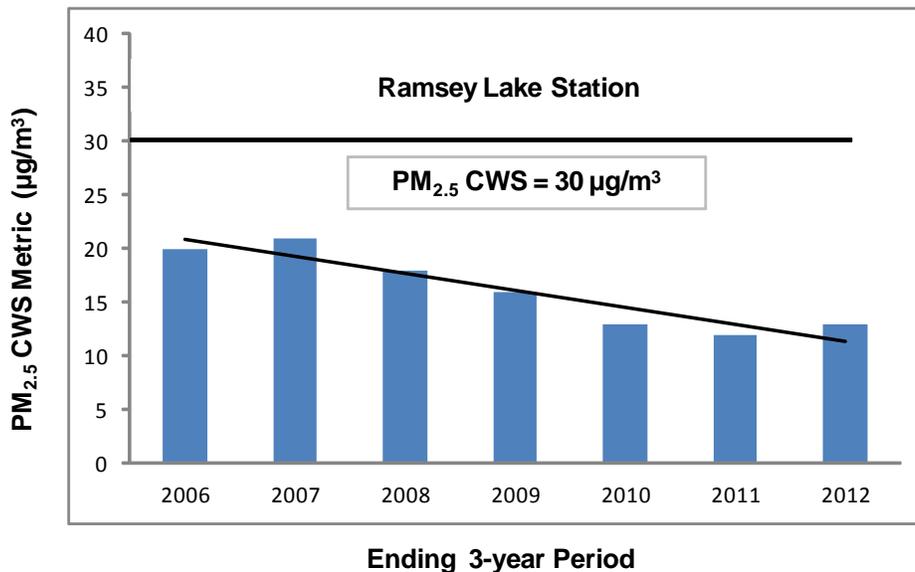


FIGURE 16: PM<sub>2.5</sub> CWS METRIC FOR THE GREATER SUDBURY RAMSEY LAKE AQI STATION

<sup>30</sup> Air Quality in Ontario, 2012 Report (PIBS 9598e), Ontario Ministry of the Environment and Climate Change.

Table 8 summarizes the 24-hour reference level PM<sub>2.5</sub> results (not the CWS standard as defined above) for 2008 to 2012 for the cities compared in this report. This reference level is used as a guide for decision making by monitoring agencies and to assess short terms impacts of PM<sub>2.5</sub>. The highest composite means were recorded in Hamilton, Windsor, Toronto and Ottawa. Hamilton had the highest frequency of exceedance of the reference level. The Greater Sudbury Ramsey Lake station had the lowest composite mean as shown in Table 8 and in Figure 17.

Table 9 summarizes the 24-hour reference level PM<sub>2.5</sub> results for 2013-2014 for the cities compared. The reference level for that period is 28 µg/m<sup>3</sup> with the replacement of the CWS with the CAAQS. The measurements were taken with the SHARP 5030 instrument. The means are higher for all the sites and is attributed to the change in measurement technology (from TEOM to SHARP).

The ranking is similar to the one for 2008-2012 with the higher means and exceedance frequency of the reference level recorded at the Hamilton, Windsor, Toronto and Ottawa sites. However, Greater Sudbury's ranking changed from 9<sup>th</sup> to 6<sup>th</sup> likely due to the relocation of the station from Ramsey Lake to Elm Street. Figure 18 shows the rankings for 2013-2014.

Location	Composite Mean (µg/m <sup>3</sup> )	Maximum 1-Hour (µg/m <sup>3</sup> )	Maximum 24-Hour (µg/m <sup>3</sup> )	No. of Times Above 24-Hour Reference Level (30 µg/m <sup>3</sup> )
Hamilton	7.9	102	37	13
Windsor	7.6	81	34	4
Toronto	6.2	45	35	2
Ottawa	4.8	117	45	1
Parry Sound	4.5	86	36	1
Sault Ste. Marie	4.3	86	29	0
Thunder Bay	4.2	84	52	1
North Bay	4.1	59	25	0
Sudbury	3.8	50	33	1

**TABLE 8: REFERENCE LEVEL PM<sub>2.5</sub> (TEOM) RESULTS FOR SELECTED CITIES (2008 TO 2012)**

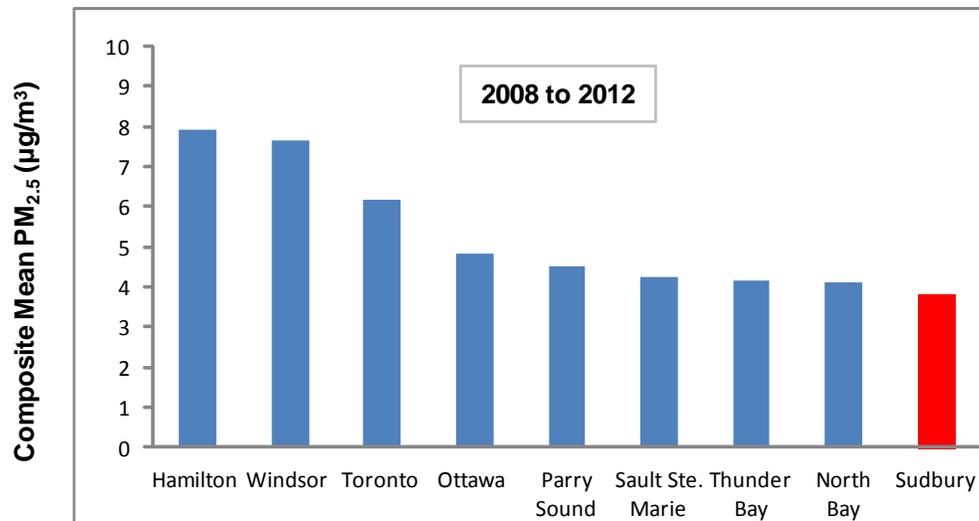
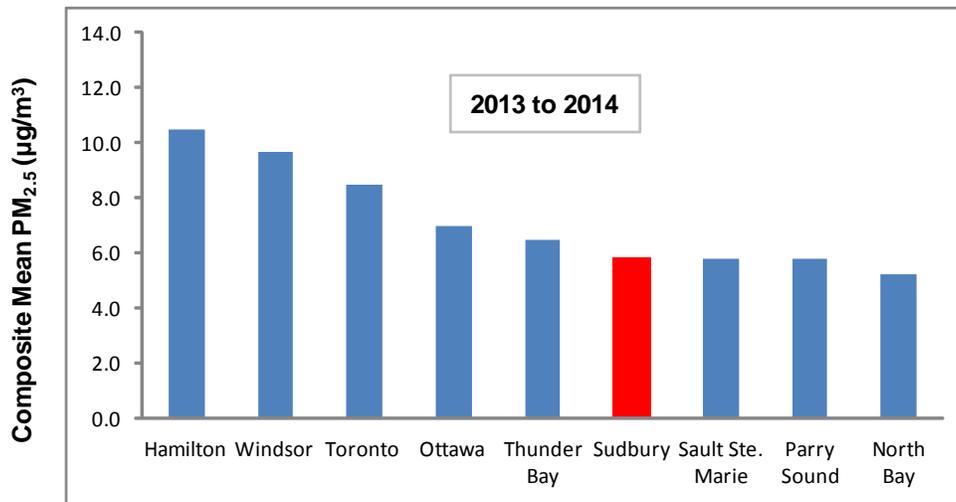


FIGURE 17: PM<sub>2.5</sub> COMPOSITE MEANS (TEOM) FOR SELECTED CITIES (2008-2012)

Location	Composite Mean (µg/m <sup>3</sup> )	Maximum 1-Hour (µg/m <sup>3</sup> )	Maximum 24-Hour (µg/m <sup>3</sup> )	No. of Times Above 24-Hour Reference Level (28 µg/m <sup>3</sup> )
Hamilton	10.5	78	45	9
Windsor	9.7	71	29	2
Toronto	8.5	75	33	5
Ottawa	7.0	80	42	2
Thunder Bay	6.5	48	21	0
Sudbury	5.9	60	24	0
Sault Ste. Marie	5.8	51	18	0
Parry Sound	5.8	52	25	0
North Bay	5.3	43	18	0

TABLE 9: REFERENCE LEVEL PM<sub>2.5</sub> (SHARP 5030) FOR SELECTED CITIES (2013-2014)



**FIGURE 18: PM<sub>2.5</sub> COMPOSITE MEANS (SHARP 5030) FOR SELECTED CITIES (2013-2014)**

*Comparison with the CAAQS and Other Cities in Ontario*

The 24-hour CAAQS introduced in 2013 for PM<sub>2.5</sub> is based on the consecutive three year average of the annual 4<sup>th</sup> highest daily maximum eight-hour running average. An annual standard for PM<sub>2.5</sub> was also introduced in 2013. The annual standard of 10 µg/m<sup>3</sup> is based on the annual mean averaged over three consecutive years. Although these new standards will be used for the first time in 2015 to determine management levels for air zones, the Ministry reported on this new standard in its 2013<sup>31</sup> and 2014<sup>32</sup> annual air quality reports for 21 designated sites. In 2013 and 2014 (which comprises 2011 to 2013 and 2012 to 2014 for the averaging periods respectively), Greater Sudbury had a 24-hour CAAQS metric value of 14 µg/m<sup>3</sup> in both years. This value is considerably less than the CAAQS of 28 µg/m<sup>3</sup>. All 21 designated sites across the province met the CAAQS in both periods. Of the 21 designated sites, Greater Sudbury, as well as Thunder Bay, had the lowest 24-hour CAAQS metric value.

The 2013 (2011-2013) and 2014 (2012-2014) annual PM<sub>2.5</sub> CAAQS metric values for Greater Sudbury were 4.5 µg/m<sup>3</sup> and 5.2 µg/m<sup>3</sup> respectively, which are less than the annual CAAQS of 10 µg/m<sup>3</sup>. Of the 21 designated sites, Greater Sudbury had the lowest annual CAAQS metric values.

Outdoor concentrations of PM<sub>2.5</sub>, as well as ozone, can be influenced by emission sources outside the control of sources in the province such as transboundary flows and events such as forest fires.

<sup>31</sup> Air Quality in Ontario, 2013 Report (PIBS 9795e), Ontario Ministry of the Environment and Climate Change.

<sup>32</sup> Air Quality in Ontario, 2014 Report (PIBS 9920e), Ontario Ministry of the Environment and Climate Change.

#### *Community Air Monitoring Program (Vale)*

From 2008 to 2012, Vale measured 24-hour PM<sub>2.5</sub> concentrations with a Partisol FRM Model 2000 sampler at the Dynamic Earth and Norite Street stations. Their locations are shown in the aerial photo in Appendix N. Particulate samples were collected on 47 mm Teflon filters which were sent to a laboratory to determine the collected weight and hence the concentration of dust in µg/m<sup>3</sup>. Sampling was terminated in 2012 due to instrumentation failures.

The 2008 to 2012 composite mean PM<sub>2.5</sub> concentration at the Dynamic Earth station was 5.8 µg/m<sup>3</sup>, slightly higher than at Norite Street (5.4 µg/m<sup>3</sup>). The maximum 24-hour concentrations ranged from 20.9 to 46.2 µg/m<sup>3</sup> at the Dynamic Earth station, and from 19.8 to 30.9 µg/m<sup>3</sup> at Norite Street. There were 2 exceedances of the reference level of 30 µg/m<sup>3</sup> at Dynamic Earth from 515 samples, and 1 exceedance at Norite Street from 503 samples. The exceedances were recorded in 2010 and are suspect since the elevated PM<sub>2.5</sub> values were higher than the concurrent PM<sub>10</sub> and TSP concentrations.

#### 4.4.2 Inhalable Particulate (PM<sub>10</sub>)

#### *Community Air Monitoring Program (Vale)*

From 2008 to 2014, PM<sub>10</sub> monitoring was performed at the following Vale stations: Dynamic Earth, Delki Dozzi Park, Spruce Street and in Copper Cliff (Norite Street, Venice Street, Copper Cliff Creek and Union Street). Their locations are shown in the aerial photo in Appendix N. High volume air samplers with quartz filters were used to collect 24-hour samples. The Dynamic Earth and Norite Street samples operated throughout the 2008 to 2014 period. The Venice Street sampler was commissioned in January 2009. The Copper Cliff Creek, Spruce Street and Delki Dozzi Park samplers began collecting samples in December 2011 until the end of June 2013.

Sampling Period	Station	Number of Samples	Composite Mean (µg/m <sup>3</sup> )	Maximum (µg/m <sup>3</sup> )	Number > AAQC
2008-2014	Dynamic Earth	701	14.3	88	3
2008-2014	Norite Street	713	11.0	39	0
2009-2014	Venice Street	352	13.2	48	0
2012-2014	Copper Cliff Creek	247	12.0	41	0
2012-2013	Delki Dozzi Park	169	11.0	35	0
2012-2013	Spruce Street	172	9.5	28	0
2013-2014	Union Street	133	11.0	30	0
	Total	2487			3

**TABLE 10: PM<sub>10</sub> SAMPLING RESULTS FOR VALE STATIONS (2008-2014)**

The Union Street sampler was activated in November 2012. From 2008 to July 2013, samples were collected at all sites every 3<sup>rd</sup> day, and thereafter every 6<sup>th</sup> day. Table 10 summarizes the sampling periods and locations as well as the PM<sub>10</sub> sampling results for full years of data. The Dynamic Earth station had the highest PM<sub>10</sub> composite mean with 14.3 µg/m<sup>3</sup> and the highest 24-hour concentration at 88 µg/m<sup>3</sup> (2014). It was the only station to record exceedances of the 24-hour interim PM<sub>10</sub> AAQC of 50 µg/m<sup>3</sup>. The 2014 exceedance was due to particulate emissions from a road construction project near the station. The 3 exceedances were recorded from a total of 2487 samples.

All samples were analyzed for the following metals: arsenic, cadmium, chromium, cobalt, copper, iron, lead, manganese, nickel, selenium, sulphur, vanadium and zinc. The majority of the results for arsenic, cadmium, chromium, selenium and vanadium were below the method detection limit. In 2012, the Ministry introduced AAQCs for manganese (24-hour average) and nickel (24-hour and annual averages) in PM<sub>10</sub>. The stations in the Vale network are deemed to be “fence line sampling stations” and are subject to the regulatory requirements imposed by the Ministry. There are no applicable standards or guidelines in Regulation 419/05 for metals in PM<sub>10</sub>.

By way of example for metals in PM<sub>10</sub>, Table 10 presents the annual and composite means for nickel and copper for Dynamic Earth, Norite Street and Venice Street (the stations with a complete data base for the period 2009 to 2014). The Venice Street station recorded the highest composite means for nickel and copper, followed by Dynamic Earth and Norite. The Venice Street station is located approximately 250 m west northwest of the Vale smelter complex tall stack, and within about 50 m of the smelter yard property boundary fence. The other stations are further removed from the Vale operations. The composite mean copper concentrations were higher than those of nickel for the three stations. The copper results from high volume particulate samplers need to be interpreted with caution since the vacuum motors with brushes commonly used with these samplers are known to emit copper particles. This has the potential to add artifact copper to the true outdoor concentrations.

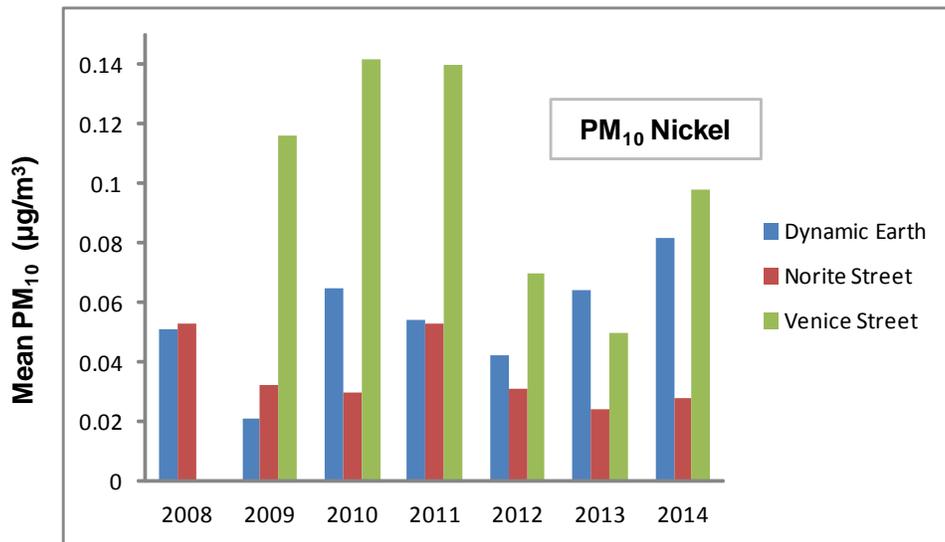
Year	Dynamic Earth		Norite Street		Venice Street	
	Ni (µg/m <sup>3</sup> )	Cu (µg/m <sup>3</sup> )	Ni (µg/m <sup>3</sup> )	Cu (µg/m <sup>3</sup> )	Ni (µg/m <sup>3</sup> )	Cu (µg/m <sup>3</sup> )
2009	0.02	0.04	0.03	0.07	0.12	0.77
2010	0.06	0.12	0.03	0.05	0.14	0.35
2011	0.05	0.09	0.05	0.08	0.14	0.20
2012	0.04	0.05	0.03	0.03	0.07	0.08
2013	0.06	0.04	0.02	0.03	0.05	0.07
2014	0.08	0.06	0.03	0.03	0.10	0.10
Mean	0.055	0.068	0.033	0.049	0.103	0.24

**TABLE 11: PM<sub>10</sub> NICKEL AND COPPER SAMPLING RESULTS FOR THE DYNAMIC EARTH, NORITE STREET AND VENICE STREET STATIONS (2009-2014)**

Vale changed to brushless high volume motors in June 2010 such that the copper results from that point forward are believed to be representative of the true ambient concentrations. Figure 19 illustrates the annual mean PM<sub>10</sub> nickel concentrations for the Dynamic Earth, Norite Street and Venice Street stations over the period 2008 to 2014. (The Venice Street station was commissioned in 2009). The annual means show considerable year-to-year variability at all stations.

The Venice Street station recorded the highest nickel PM<sub>10</sub> annual means of all the stations listed in Table 11. Dynamic Earth had its lowest mean in 2009, coinciding with Vale’s production shutdown, and its highest mean in 2014. A few elevated 24-hour nickel concentrations at the Dynamic Earth station were largely responsible for the higher means in 2010, 2013 and 2014. Norite Street had its highest nickel annual means in 2008 and 2011 again as a result of a few elevated values.

Venice Street also recorded its highest means when a few elevated 24-hour values (> 0.8 µg/m<sup>3</sup>) were measured in 2009, 2010, 2011 and 2014. It is important to note that a few elevated values in a year can significantly increase the annual mean. For all the sites listed in Table 11, the highest 24-hour PM<sub>10</sub> nickel concentration was measured at the Dynamic Earth station in 2010 with a value of 3.6 µg/m<sup>3</sup>.



**FIGURE 19: ANNUAL MEAN PM<sub>10</sub> NICKEL CONCENTRATIONS FOR THE DYNAMIC EARTH, NORITE STREET AND VENICE STREET STATIONS (2008 TO 2014)**

Figure 20 illustrates the annual mean PM<sub>10</sub> copper concentrations for the Dynamic Earth, Norite Street and Venice Street stations over the period 2008 to 2014. The highest annual copper means for Dynamic Earth and Norite Street were recorded in 2008. Thereafter, the means were variable but tended to be lower as of 2012. The 2009 copper mean for the Venice Street station was significantly higher partly as a result of an unusually elevated 24-hour value of 7.1 µg/m<sup>3</sup>. Thereafter, the annual means exhibited a downward trend and were comparable to those of the other stations in 2012, 2013 and 2014.

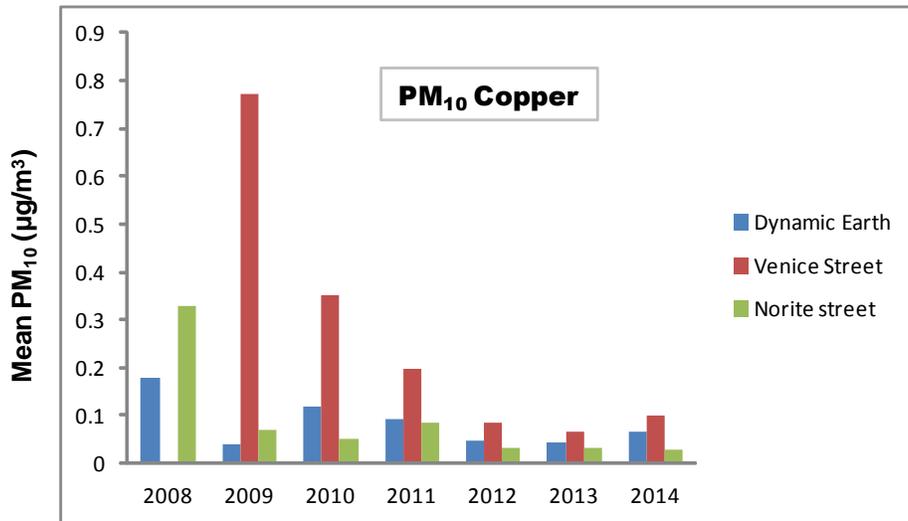


FIGURE 20: ANNUAL MEAN PM<sub>10</sub> COPPER CONCENTRATIONS FOR THE DYNAMIC EARTH, NORITE STREET AND VENICE STREET STATIONS (2008 TO 2014)

*Community Air Monitoring Program (Ministry)*

The Ministry measures 24-hour PM<sub>10</sub> concentrations on the roof of the Federal building on Lisgar Street in downtown Greater Sudbury with a high volume particulate sampler using motors with brushes. The particulate samples are collected on quartz filters which are analyzed at the Ministry's laboratory for dust and metals concentrations. The filters were analyzed for cadmium, chromium, copper, iron, nickel, lead, manganese, zinc and vanadium.

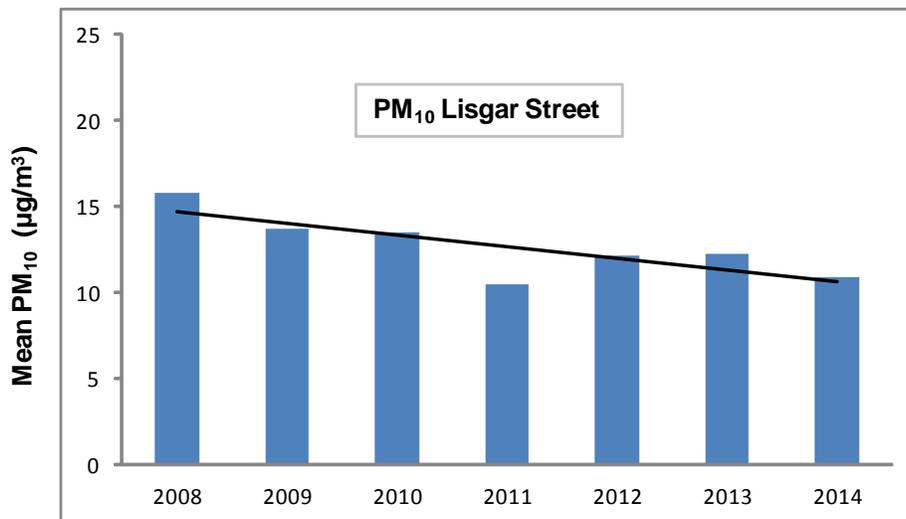


FIGURE 21: ANNUAL MEAN PM<sub>10</sub> CONCENTRATIONS FOR THE MINISTRY LISGAR STREET STATION (2008 TO 2014)

From 2008 to 2014, 334 samples were collected with a composite mean of 12.7  $\mu\text{g}/\text{m}^3$ . This mean is comparable to some of the means in Table 9 for the Vale stations. Figure 21 illustrates a downward trend in the annual  $\text{PM}_{10}$  means at the Lisgar Street station. There was only one exceedance of the interim 24-hour AAQC of 50  $\mu\text{g}/\text{m}^3$ . It was recorded in 2008 at a concentration of 56  $\mu\text{g}/\text{m}^3$ .

As shown in Table 12, the composite means for metals in  $\text{PM}_{10}$  were low, in some instances just above the method detection limits. There were no exceedances of the 24-hour AAQCs for nickel and manganese published by the Ministry in 2012.

<b>Lisgar Street Monitoring Results for Metals in <math>\text{PM}_{10}</math> (2008 - 2014)</b> (results expressed in $\mu\text{g}/\text{m}^3$ )									
	Cd	Cr	Cu	Fe	Ni	Pb	Mn	Zn	V
Composite Mean	0.001	0.002	0.030	0.37	0.016	0.007	0.006	0.072	0.004
Max. Concentration	0.005	0.018	0.29	2.50	0.26	0.06	0.140	0.260	0.19
AAQC (24h)					0.1		0.20		
No. > AAQC (24h)					0		0		

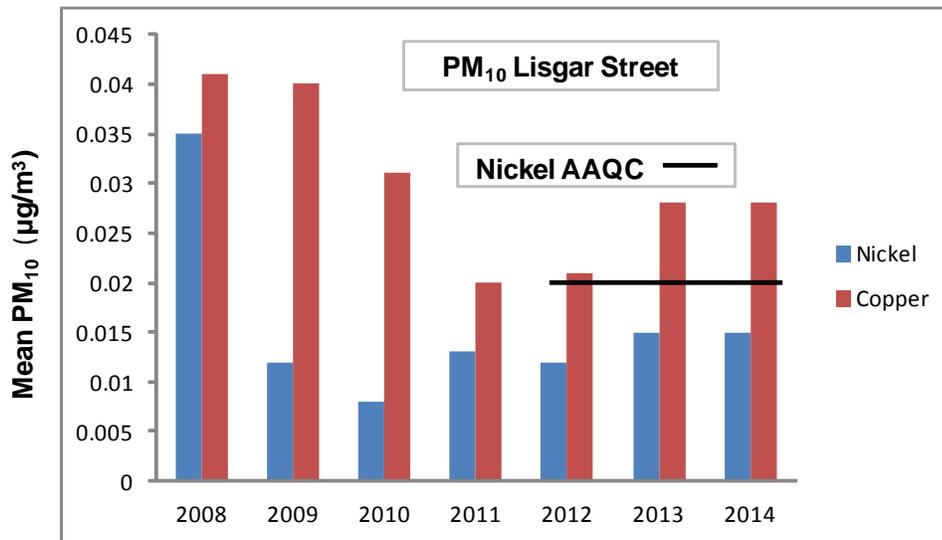
**TABLE 12: METALS IN  $\text{PM}_{10}$  SAMPLING RESULTS FOR THE MINISTRY LISGAR STREET STATION (2008-2014)**

Figure 22 illustrates the annual  $\text{PM}_{10}$  nickel and copper concentrations for the 2008 to 2014 period. The 2008 mean for nickel was much higher than the means in other years. A maximum value of 0.26  $\mu\text{g}/\text{m}^3$  in 2008, compared to maximum values less than 0.09  $\mu\text{g}/\text{m}^3$  in the other years resulted in a higher arithmetic mean for 2008. For the other years, the means ranged from a low of 0.008  $\mu\text{g}/\text{m}^3$  in 2010 to 0.015  $\mu\text{g}/\text{m}^3$  in 2013 and 2014. As stated earlier, for the period 2012 to 2014 there were no exceedances of the 24-hour AAQC for nickel of 0.1  $\mu\text{g}/\text{m}^3$  introduced by the Ministry in 2012.

Figure 22 shows that the mean  $\text{PM}_{10}$  nickel concentrations met the annual mean AAQC of 0.02  $\mu\text{g}/\text{m}^3$  introduced by the Ministry in 2012.

The results for copper were substantially higher than those of nickel and generally followed a similar trend. Higher copper to nickel concentrations were also noted for the Vale stations. The lower means for nickel in 2009 and 2010 at the Lisgar Street station possibly reflect lower emissions from Vale's operations as a result of a production shutdown and partial operations in 2009 and 2010 respectively. The possible impact of Vale's lower emissions in 2009 and 2010 is not as evident for copper, with the lowest means recorded in 2011 and 2012. The copper results from high volume particulate samplers using motors with brushes need to be interpreted with caution as explained earlier. This has the potential to add artifact copper to the true outdoor concentrations.

Except for iron, the other metals had much lower concentrations than nickel and copper and were variable year-to-year. There is no AAQC, guideline or standard for copper in  $\text{PM}_{10}$ .



**FIGURE 22: ANNUAL MEAN PM<sub>10</sub> NI AND CU CONCENTRATIONS FOR THE MOECC LISGAR STREET STATION (2008 TO 2014)**

#### 4.4.3 Total Suspended Particulate (TSP)

##### *Community Air Monitoring Program (Vale)*

From 2008 to 2014, TSP monitoring was performed at the following Vale stations: Dynamic Earth, Power Street, Delki Dozzi Park, Spruce Street and in Copper Cliff (Norite Street, Venice Street, Copper Cliff Creek and Union Street). Their locations are shown in the aerial photo in Appendix N. High Volume air samplers with quartz filters were used to collect 24-hour samples. The Dynamic Earth and Norite Street stations operated throughout the 2008 to 2014 period. The Power Street and Venice Street sampler was commissioned in January 2009. The Copper Cliff Creek, Spruce Street and Delki Dozzi Park samplers began collecting samples in December 2011. The Union Street sampler was activated in November 2012. From 2008 to 2014, TSP samples were collected at all sites every 3<sup>rd</sup> day.

Table 13 summarizes the TSP sampling results for the Vale stations for the period 2008 to 2014. (Geometric means are used for TSP since the annual AAQC is calculated as a geometric mean (60 µg/m<sup>3</sup>)). The Dynamic Earth station had the highest annual composite geometric mean (23.0 µg/m<sup>3</sup>) as well as the highest annual mean (28 µg/m<sup>3</sup> obtained in 2014) of all the stations. It also had the highest 24-hour TSP concentration at 396 µg/m<sup>3</sup>. This maximum value was recorded in July 2014 during a road construction project near the station.

Four of the six exceedances of the 24-hour standard of 120 µg/m<sup>3</sup> occurred in 2014 and resulted from road traffic/construction sources.

Period	Station	No of Samples	Composite Geometric Mean ( $\mu\text{g}/\text{m}^3$ )	Max. 24h Value ( $\mu\text{g}/\text{m}^3$ )	Number >24h Standard
2008-2014	Dynamic Earth	827	23.0	396	6
2008-2014	Norite Street	823	12.6	76	0
2009-2014	Venice Street	699	17.5	235	2
2009-2014	Power Street	710	20.2	245	6
2012-2014	Copper Cliff Creek	358	14.3	85	0
2012-2014	Delki Dozzi Park	362	15.7	145	1
2012-2014	Spruce Street	350	14.7	108	0
2013-2014	Union Street	239	13.0	57	0
	Total	4368			15

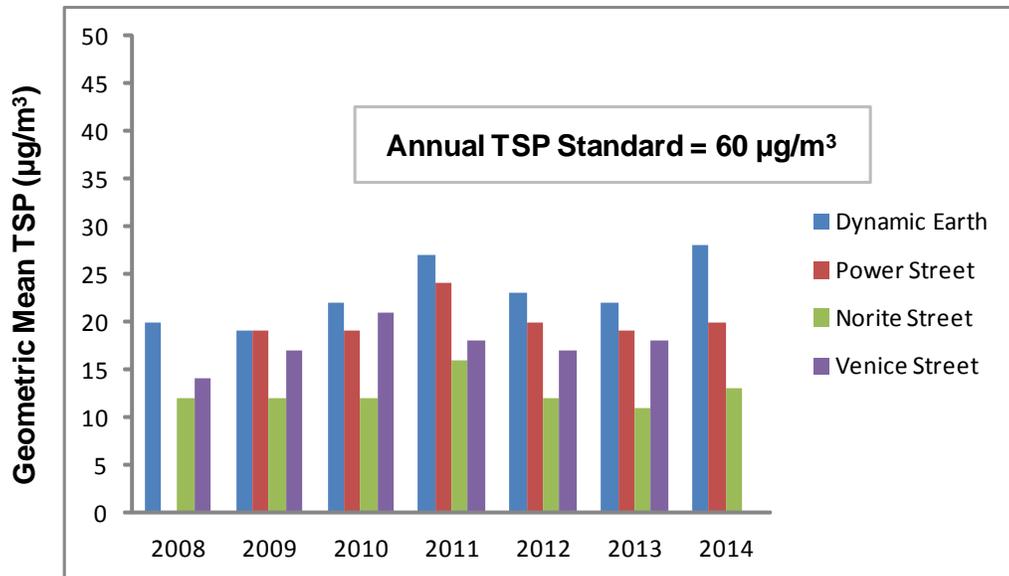
**TABLE 13: TSP SAMPLING RESULTS FOR THE VALE STATIONS (2008-2014)**

The Power Street station recorded the next highest composite mean ( $20.2 \mu\text{g}/\text{m}^3$ ) and a total of 6 exceedances of the 24-hour standard. Four of these resulted from a combination of high winds (May 2009) and emissions from a picket line fire (December 2009 and March 2010) located near the station. Investigations of the other exceedances revealed that they were not related to Vale's operations.

The other stations had composite geometric means ranging from  $17.5 \mu\text{g}/\text{m}^3$  (Venice Street) to Norite Street ( $12.6 \mu\text{g}/\text{m}^3$ ).

For the network, a total of 15 exceedances of the 24-hour TSP standard were measured from a total of 4368 samples or 0.3% of the samples. The annual AAQC was not exceeded at any station.

Figure 23 shows the trends in the annual TSP means for the four stations with the largest data set (Dynamic Earth, Power Street, Norite Street and Venice Street) from 2008 to 2014. Except for 2009, the annual means were always higher at Dynamic Earth. Three of the four stations recorded their highest means in 2011. Dynamic Earth recorded a mean in 2014 similar to that of 2011 ( $28$  and  $27 \mu\text{g}/\text{m}^3$  respectively). Its lowest means occurred in 2008 and 2009. Otherwise, the annual mean TSP concentrations varied very little and were consistently much lower than the annual standard.



**FIGURE 23: ANNUAL MEAN TSP CONCENTRATIONS FOR THE DYNAMIC EARTH, POWER STREET, NORITE STREET AND VENICE STREET STATIONS (2008 TO 2014)**

All samples were analyzed for the following metals: arsenic, cadmium, cobalt, chromium, copper, iron, lead, manganese, nickel, selenium, vanadium, zinc, sulphur and sulphate (from a calculation assuming all sulphur is in the form of sulphate). Statistical summaries of the 24-hour results are shown in Tables 14 to 21. Many elements from this list are often reported as lower than their method detection limit. These include arsenic, cadmium, cobalt, chromium, selenium and vanadium. Their means are very conservative since from 50% to over 90% of the results are below the method detection limit. For this reason, the results for selenium and vanadium are not reported here. There are no AAQCs for sulphur and sulphate and their results are not reported here. Tables 14 to 21 list the Reg. 419 limits. The O. Reg. 419 limits are standards and guidelines that have to be met.

The metallic iron (total) results have been expressed as ferric oxide ( $\text{Fe}_2\text{O}_3$ ). Iron is not present as metallic iron. A portion of the metallic iron is assumed to be oxidized. Therefore, the iron results are conservatively compared to the  $\text{Fe}_2\text{O}_3$  Schedule 3 standard for information purposes only. The remainder of the iron is present in various mineral and amorphous forms (e.g. slag, concentrate, etc.).

The standard for lead (Pb) was changed from  $2.0 \mu\text{g}/\text{m}^3$  to  $0.5 \mu\text{g}/\text{m}^3$  in 2010. The standard for cadmium was changed from  $0.25 \mu\text{g}/\text{m}^3$  to  $0.025 \mu\text{g}/\text{m}^3$  in 2013.

The arsenic guideline of  $0.3 \mu\text{g}/\text{m}^3$  was exceeded only once, with a value of  $0.43 \mu\text{g}/\text{m}^3$ . It was recorded at the Power Street station in September 2009. The Vale facilities were not operating at that time. The filter was observed to be very dark (black) and had a wood smoke odour. The fire from the picket line on Power Street near the sampling station was deemed to be the likely source.

Lumber is known to be treated with a chromated copper arsenate preservative. Traces of Cr, Cu and Pb were also found in this TSP sample.

The cadmium standard of  $0.025 \mu\text{g}/\text{m}^3$  was exceeded only once, with a value of  $0.074 \mu\text{g}/\text{m}^3$ . It was recorded at the Spruce Street station in June 2012.

There were no exceedances of the chromium (metallic, divalent and trivalent) guideline of  $1.5 \mu\text{g}/\text{m}^3$ .

The cobalt guideline of  $0.1 \mu\text{g}/\text{m}^3$  was exceeded once at the Dynamic Earth and Power Street stations, and for 8 samples at the Venice Street station. There were no exceedances (shown as 0 within brackets in Tables 14 to 21) of the trigger action level of  $1.2 \mu\text{g}/\text{m}^3$  as a condition of the site-specific standard issued to Vale in 2012.

There were no exceedances of the copper standard of  $50 \mu\text{g}/\text{m}^3$ .

The ferric oxide standard of  $25 \mu\text{g}/\text{m}^3$  was exceeded twice at Dynamic Earth, and 6 times each at Power Street and Venice Street. The exceedances at Venice Street often coincided with elevated concentrations of nickel and cobalt. As indicated earlier, the Venice Street station is located approximately 250 m west northwest of the Vale smelter complex tall stack, and within about 50 m of the Smelter yard property boundary fence. The other stations are further removed from the Vale operations.

The maximum 24-hour nickel result of  $13.6 \mu\text{g}/\text{m}^3$  was recorded in December 2010 at the Dynamic Earth station. An analysis of this exceedance suggested that wind-blown particulate from the material handling area northeast of the Vale smelter was the likely cause. The nickel standard ( $2.0 \mu\text{g}/\text{m}^3$ ) was exceeded for 19 samples (from a total of 699 samples) at the Venice Street station, and for 2 samples each at the Dynamic Earth (from 837 samples) and Union Street (from 239 samples) stations. There was 1 exceedance (shown as 1 within brackets for Dynamic Earth in Table 14) and 2 exceedances (shown as 2 within brackets for Venice Street in Table 16) of the trigger action level of  $3.0 \mu\text{g}/\text{m}^3$  as a condition of the site-specific standard issued to Vale in 2012.

The standard for lead ( $0.5 \mu\text{g}/\text{m}^3$ ) was exceeded only once with a value of  $0.62 \mu\text{g}/\text{m}^3$ . It was recorded at the Power Street station (May 2010). The sample filter was very dark (black) with wood fibers and wood particles on its surface. It also had a wood smoke odour. Close proximity of emissions from the striking picketers' fire near the sampling location are believed to have caused this exceedance. Scanning electron microscope (SEM) analysis results indicated the presence of lead oxide particles, consistent with paint, which most likely originated from the picketer's fire. In addition, the Vale smelter was not operating on the sampling day due to a failure of the fluid bed dryer stack.

There were no exceedances of the manganese guideline ( $2.5 \mu\text{g}/\text{m}^3$ ) for all TSP samples collected at the Vale stations during the period 2008 to 2014.

<b>Dynamic Earth Monitoring Results for Metals in TSP (2008 - 2014)</b> (results expressed in $\mu\text{g}/\text{m}^3$ )										
	<b>As</b>	<b>Cd</b>	<b>Cr</b>	<b>Co</b>	<b>Cu</b>	<b>Fe (Fe<sub>2</sub>O<sub>3</sub>)</b>	<b>Pb</b>	<b>Ni</b>	<b>Mn</b>	<b>Zn</b>
Composite Mean	< 0.004	0.001	0.004	0.008	0.21	2.3	0.009	0.16	0.009	0.022
Max. Concentration	0.147	0.005	0.153	0.306	18.3	36.6	0.247	13.6	0.120	0.058
O. Reg 419 Limit	0.3	0.025	1.5	0.1	50	25	0.5	2	2.5	120
No. > Reg 419 Limit	0	0	0	1 (0)	0	2	0	2 (1)	0	0

( ): Exceedances of trigger action levels in site-specific approvals issued in 2012

**TABLE 14: TSP METALS RESULTS FOR THE DYNAMIC EARTH STATION (2008-2014)**

<b>Norite Street Monitoring Results for Metals in TSP (2008 - 2014)</b> (results expressed in $\mu\text{g}/\text{m}^3$ )										
	<b>As</b>	<b>Cd</b>	<b>Cr</b>	<b>Co</b>	<b>Cu</b>	<b>Fe (Fe<sub>2</sub>O<sub>3</sub>)</b>	<b>Pb</b>	<b>Ni</b>	<b>Mn</b>	<b>Zn</b>
Composite Mean	< 0.004	0.001	0.002	0.004	0.71	1.1	0.006	0.10	0.004	0.015
Max. Concentration	0.048	0.004	0.024	0.042	1.66	9.4	0.072	1.71	0.032	0.167
O. Reg 419 Limit	0.3	0.025	1.5	0.1	50	25	0.5	2	2.5	120
No. > Reg 419 Limit	0	0	0	0(0)	0	0	0	0 (0)	0	0

( ): Exceedances of trigger action levels in site-specific approvals issued in 2012

**TABLE 15: TSP METALS RESULTS FOR THE NORITE STREET STATION (2008-2014)**

<b>Venice Street Monitoring Results for Metals in TSP (2009 - 2014)</b> (results expressed in $\mu\text{g}/\text{m}^3$ )										
	<b>As</b>	<b>Cd</b>	<b>Cr</b>	<b>Co</b>	<b>Cu</b>	<b>Fe (Fe<sub>2</sub>O<sub>3</sub>)</b>	<b>Pb</b>	<b>Ni</b>	<b>Mn</b>	<b>Zn</b>
Composite Mean	< 0.004	0.001	0.006	0.013	0.44	2.7	0.012	0.36	0.007	0.023
Max. Concentration	0.096	0.020	0.112	0.222	16.9	35.5	0.277	4.6	0.040	0.555
O. Reg 419 Limit	0.3	0.025	1.5	0.1	50	25	0.5	2	2.5	120
No. > Reg 419 Limit	0	0	0	8 (0)	0	6	0	19 (2)	0	0

( ): Exceedances of trigger action levels in site-specific approvals issued in 2012

**TABLE 16: TSP METALS RESULTS FOR THE VENICE STREET STATION (2009-2014)**

<b>Power Street Monitoring Results for Metals in TSP (2009 - 2014)</b> (results expressed in $\mu\text{g}/\text{m}^3$ )										
	<b>As</b>	<b>Cd</b>	<b>Cr</b>	<b>Co</b>	<b>Cu</b>	<b>Fe (Fe<sub>2</sub>O<sub>3</sub>)</b>	<b>Pb</b>	<b>Ni</b>	<b>Mn</b>	<b>Zn</b>
Composite Mean	< 0.004	0.001	0.003	0.006	0.14	1.6	0.010	0.12	0.001	0.025
Max. Concentration	0.433	0.005	0.049	0.186	3.50	16.9	0.619	1.27	0.274	0.705
O. Reg 419 Limit	0.3	0.025	1.5	0.1	50	25	0.5	2	2.5	120
No. > Reg 419 Limit	1	0	0	1 (0)	0	6	1	0 (0)	0	0

( ): Exceedances of trigger action levels in site-specific approvals issued in 2012

**TABLE 17: TSP METALS RESULTS FOR THE POWER STREET STATION (2009-2014)**

<b>Copper Cliff Creek Monitoring Results for Metals in TSP (2012 - 2014)</b> (results expressed in $\mu\text{g}/\text{m}^3$ )										
	<b>As</b>	<b>Cd</b>	<b>Cr</b>	<b>Co</b>	<b>Cu</b>	<b>Fe (Fe<sub>2</sub>O<sub>3</sub>)</b>	<b>Pb</b>	<b>Ni</b>	<b>Mn</b>	<b>Zn</b>
Composite Mean	< 0.004	0.001	0.002	0.004	0.14	0.8	0.007	0.13	0.005	0.015
Max. Concentration	0.066	0.006	0.018	0.053	1.56	6.8	0.144	1.60	0.036	0.142
O. Reg 419 Limit	0.3	0.025	1.5	0.1	50	25	0.5	2	2.5	120
No. > Reg 419 Limit	0	0	0	0 (0)	0	0	0	0 (0)	0	0

( ): Exceedances of trigger action levels in site-specific approvals issued in 2012

**TABLE 18: TSP METALS RESULT FOR THE COPPER CLIFF CREEK STATION (2009-2014)**

<b>Delki Dozzi Park Monitoring Results for Metals in TSP (2012 - 2014)</b> (results expressed in $\mu\text{g}/\text{m}^3$ )										
	<b>As</b>	<b>Cd</b>	<b>Cr</b>	<b>Co</b>	<b>Cu</b>	<b>Fe (Fe<sub>2</sub>O<sub>3</sub>)</b>	<b>Pb</b>	<b>Ni</b>	<b>Mn</b>	<b>Zn</b>
Composite Mean	< 0.004	0.001	0.001	0.003	0.06	0.8	0.006	0.07	0.005	0.017
Max. Concentration	0.011	0.004	0.015	0.054	0.57	11.8	0.131	1.87	0.059	0.154
O. Reg 419 Limit	0.3	0.025	1.5	0.1	50	25	0.5	2	2.5	120
No. > Reg 419 Limit	0	0	0	0 (0)	0	0	0	0 (0)	0	0

( ): Exceedances of trigger action levels in site-specific approvals issued in 2012

**TABLE 19: TSP METALS RESULTS FOR THE DELKI DOZZI PARK STATION (2012-2014)**

<b>Spruce Street Monitoring Results for Metals in TSP (2012 - 2014)</b> (results expressed in $\mu\text{g}/\text{m}^3$ )										
	<b>As</b>	<b>Cd</b>	<b>Cr</b>	<b>Co</b>	<b>Cu</b>	<b>Fe (Fe<sub>2</sub>O<sub>3</sub>)</b>	<b>Pb</b>	<b>Ni</b>	<b>Mn</b>	<b>Zn</b>
Composite Mean	< 0.004	0.001	0.002	0.005	0.10	1.0	0.007	0.10	0.004	0.018
Max. Concentration	0.074	0.074	0.149	0.058	1.55	12.4	0.151	1.39	0.169	0.373
O. Reg 419 Limit	0.3	0.025	1.5	0.1	50	25	0.5	2	2.5	120
No. > Reg 419 Limit	0	1	0	0 (0)	0	0	0	0 (0)	0	0

( ): Exceedances of trigger action levels in site-specific approvals issued in 2012

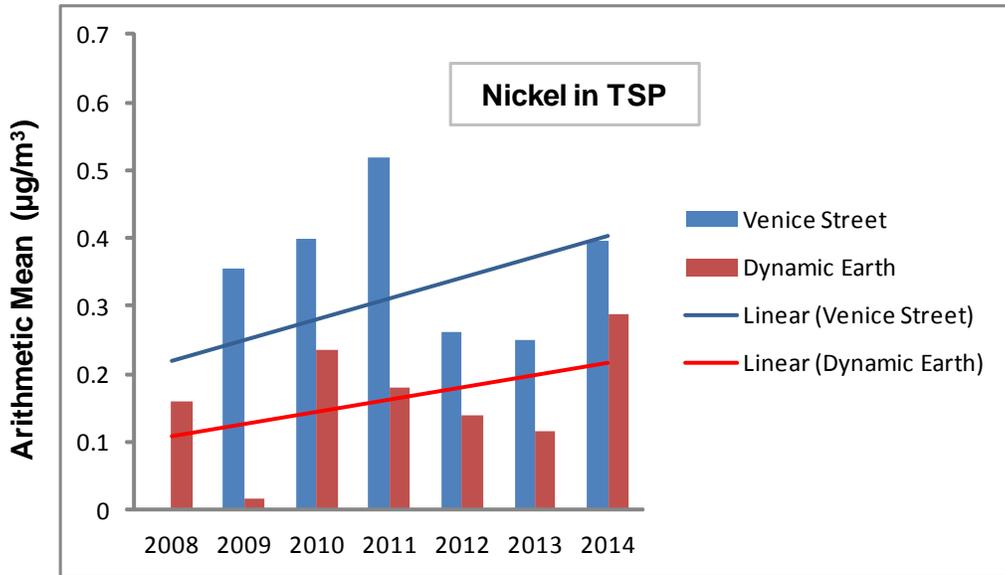
**TABLE 20: TSP METALS RESULTS FOR THE SPRUCE STREET STATION (2012-2014)**

<b>Union Street Monitoring Results for Metals in TSP (2013 - 2014)</b> (results expressed in $\mu\text{g}/\text{m}^3$ )										
	<b>As</b>	<b>Cd</b>	<b>Cr</b>	<b>Co</b>	<b>Cu</b>	<b>Fe (Fe<sub>2</sub>O<sub>3</sub>)</b>	<b>Pb</b>	<b>Ni</b>	<b>Mn</b>	<b>Zn</b>
Composite Mean	< 0.004	0.001	0.002	0.004	0.15	0.70	0.007	0.20	0.004	0.013
Max. Concentration	0.056	0.004	0.024	0.037	1.50	5.8	0.072	2.80	0.021	0.152
O. Reg 419 Limit	0.3	0.025	1.5	0.1	50	25	0.5	2	2.5	120
No. > Reg 419 Limit	0	0	0	0 (0)	0	0	0	2 (0)	0	0

( ): Exceedances of trigger action levels in site-specific approvals issued in 2012

**TABLE 21: TSP METALS RESULTS FOR THE UNION STREET STATION (2013-2014)**

As an example of trends with metals in TSP, Figure 24 illustrates the annual arithmetic mean concentrations of nickel at the Venice Street and Dynamic Earth stations, both with the highest nickel means of the Vale stations.

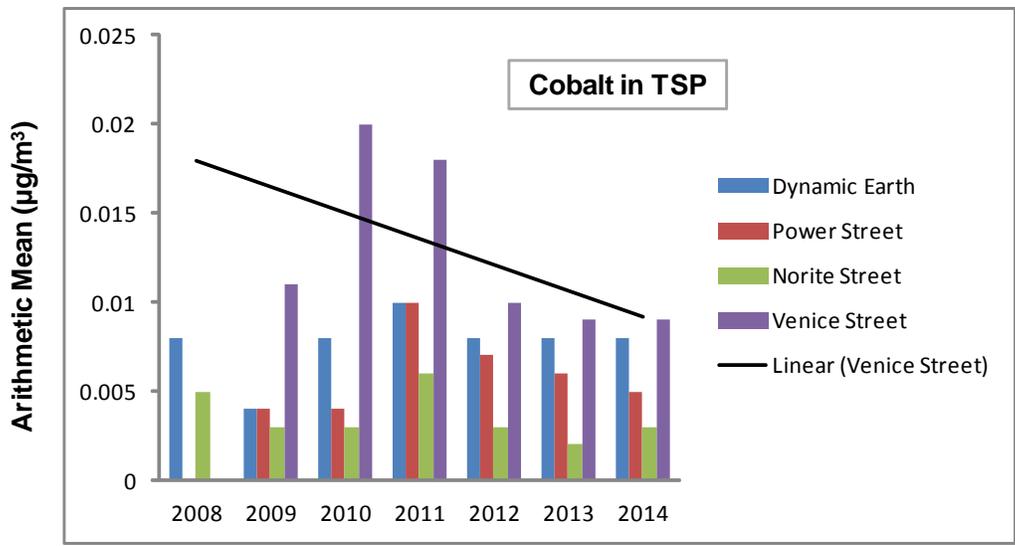


**FIGURE 24: ANNUAL MEAN NI CONCENTRATIONS IN TSP FOR THE VENICE STREET AND DYNAMIC EARTH STATIONS (2008 TO 2014)**

The highest means in every year were obtained at the Venice Street station. The results showed noticeable year-to-year variability at both locations. The means at Venice Street trended up from 2009 to 2011, were at their lowest in 2012 and 2013 and increased in 2014 to its 2010 level. The magnitude of the annual means coincided with the occurrence of the exceedances. The lowest means occurred in 2012 and 2013 when only one of the 19 exceedances were recorded.

At Dynamic Earth, the lowest mean was recorded in 2009, coinciding with the shutdown at Vale's operations. From 2011 to 2014, the means for both stations followed a similar pattern. It is important to repeat that the annual arithmetic means can significantly increase with a few elevated values, possibly resulting in substantial year-to-year variability. Figure 24 also illustrates the upward trend, in part as a result of the higher means in 2014.

The annual trends for cobalt in TSP are illustrated in Figure 25 for the Dynamic Earth, Power Street, Norite Street and Venice Street stations. The results showed noticeable year-to-year variability for all locations. The highest means were recorded in 2011 at most stations and in 2010 at Venice Street. In every year, the Venice Street station recorded the highest mean. Figure 25 shows a noticeable downward trend for the Venice Street station. Although not shown in the figure, the other locations did not show noticeable annual trends over the period 2008 to 2014.



**FIGURE 25: ANNUAL MEAN CO CONCENTRATIONS IN TSP FOR THE AND DYNAMIC EARTH, POWER STREET, NORITE STREET AND VENICE STREET STATIONS (2008 TO 2014)**

*Community Air Monitoring Program (Glencore)*

From 2008 to 2014, TSP monitoring was performed at the Edison and Pumphouse stations near the Glencore smelter site in the Town of Falconbridge. Their locations are shown in the aerial photo in Appendix M. The Edison station is located near the smelter property main gate, approximately 0.5 km from the smelter complex. The Pumhouse station is located about 0.75 km southwest of the smelter complex and just east of Boucher Lake. High Volume air samplers with glass fiber and quartz filters (as of 2010) were used to collect 24-hour samples every 3<sup>rd</sup> day. Motors with brushes were used in the samplers.

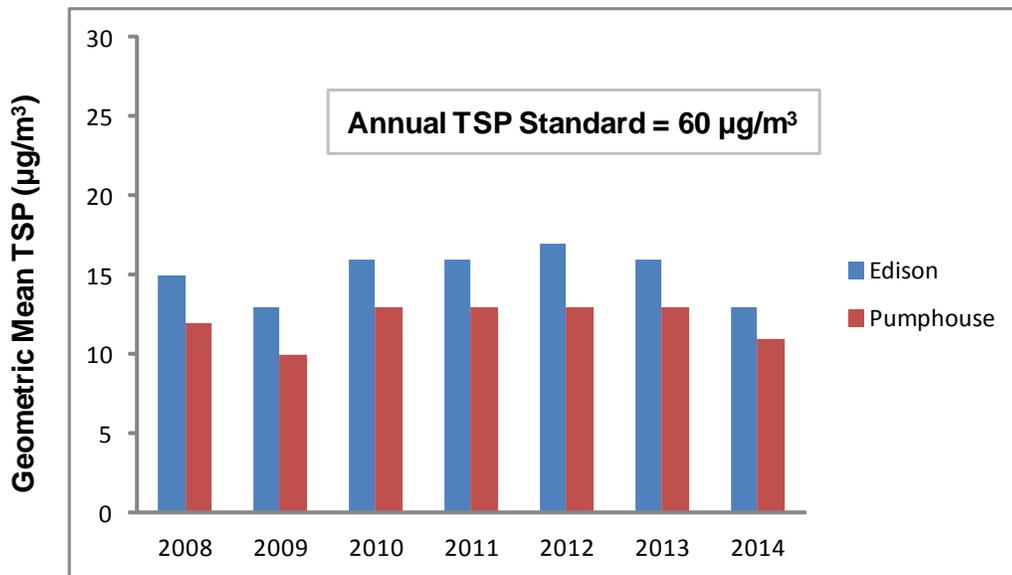
Table 22 summarizes the TSP sampling results for these stations for the period 2008 to 2014. Geometric means are used for TSP since the annual standard is calculated as a geometric mean (60 µg/m<sup>3</sup>).

Station (Glencore)	No. of Samples	Composite Geometric Mean (µg/m <sup>3</sup> )	Max. 24h Value (µg/m <sup>3</sup> )	Number >24h Standard
Edison	820	15.1	389	3
Pumphouse	815	12.1	155	1

**TABLE 22: TSP SAMPLING RESULTS FOR THE GLENCORE STATIONS (2008-2014)**

The Edison station had a composite TSP annual mean of 15.1  $\mu\text{g}/\text{m}^3$ , compared to the composite mean of 12.1  $\mu\text{g}/\text{m}^3$  for the Pumphouse station. The 24-hour standard of 120  $\mu\text{g}/\text{m}^3$  was exceeded on 3 occasions at the Edison station and once at the Pumphouse station. The exceedances at the Edison site were explained as follows: road work and pipe repairs near the station (April 2012); municipal road repairs near the station (August and September 2013). The exceedance at the Pumphouse station occurred in June 2014 and was attributed to pine pollen.

Figure 26 illustrates the annual geometric means for both stations for the period 2008 to 2014. The maximum annual geometric mean for the Edison station was 17  $\mu\text{g}/\text{m}^3$  and 13  $\mu\text{g}/\text{m}^3$  for the Pumphouse station. These are substantially lower than annual standard of 60  $\mu\text{g}/\text{m}^3$ . The annual means were slightly higher at the Edison station for all years. The trend in the annual means was similar for both stations with the lowest means recorded in 2009 and 2014 and the slightly higher means from 2010 to 2013.



**FIGURE 26: ANNUAL MEAN TSP CONCENTRATIONS FOR THE EDISON AND PUMPHOUSE STATIONS (2008 TO 2014)**

All samples were analyzed for the following metals: arsenic, cadmium, cobalt, chromium, copper, iron, lead, nickel, vanadium, sulphur and sulphate (from a calculation assuming all sulphur is in the form of sulphate). Statistical summaries of the results are shown in Tables 23 and 24. Many elements from this list are often reported as lower than their method detection limit. These include arsenic, cadmium, cobalt, chromium, and vanadium. Their annual means are very conservative since from 50% to over 90% of the results are below the method detection limit. For this reason, the results for vanadium are not reported here. There are no limits for sulphur and sulphate and their results are not reported here as well. For the period covered in this report, there are no regulatory annual limits for metals in TSP.

The iron (total) results have been expressed as ferric oxide ( $\text{Fe}_2\text{O}_3$ ) for the reasons provided earlier, since iron is not present as metallic iron. A portion of the metallic iron is assumed to be oxidized. Therefore, the iron results are conservatively compared to the  $\text{Fe}_2\text{O}_3$  Schedule 3 standard for information purposes only.

The standard for lead (Pb) was changed from  $2.0 \mu\text{g}/\text{m}^3$  to  $0.5 \mu\text{g}/\text{m}^3$  in 2010. The standard for cadmium was changed from  $0.25 \mu\text{g}/\text{m}^3$  to a trigger action level of  $0.17 \mu\text{g}/\text{m}^3$  in the site-specific approval issued to Glencore (then Xstrata Nickel Canada) in 2013.

Tables 23 and 24 show that the composite means for cadmium and lead were slightly higher at the Pumphouse station. The means for the other metals were higher at the Edison station.

The Edison station recorded exceedances of the applicable limits for cadmium (3), cobalt (5), iron expressed as ferric oxide (3) and nickel (3). The 3 cadmium exceedances resulted from cleaning operations of a dust collector (Cottrell) during a shutdown in 2012, materials handling emissions in 2013 and a power outage in 2014 affecting the electric furnace fans. Four of the five cobalt exceedances and the three nickel exceedances resulted from a combination of sources such as materials handling and fugitive emissions from the smelter site. The other exceedance was attributed to an off-site source. Two of three iron (ferric oxide) exceedances occurred during an extensive municipal road and sewer repair project near the station. The other exceedance was attributed to an off-site source. The frequency of exceedances was less than 0.5% of the samples collected.

The Pumphouse station recorded exceedances of the applicable limits for cadmium (1) and cobalt (2). The cadmium exceedance occurred in 2014 during a power outage affecting the electric furnace fans. The two cobalt exceedances resulted from a combination of sources such as materials handling and fugitive emissions from the smelter site. The frequency of exceedances was approximately 0.1% of the samples collected.

As a result of these exceedances, Glencore has implemented mitigation measures to improve its materials handling and equipment maintenance operating procedures.

Edison Monitoring Results for Metals in TSP (2008 - 2014) (results expressed in $\mu\text{g}/\text{m}^3$ )								
	As	Cd	Cr	Co	Cu	Fe ( $\text{Fe}_2\text{O}_3$ )	Pb	Ni
Composite Mean	< 0.004	0.009	0.017	0.013	0.21	2.6	0.019	0.13
Max. Concentration	0.139	0.395	0.227	0.407	3.15	37.4	0.402	2.32
O. Reg 419 Limit	0.3	0.25 (0.17) <sup>1</sup>	1.5	0.1	50	25	0.5	2
No. > O. Reg 419 Limit	0	3	0	5	0	3	0	3

**TABLE 23: TSP METALS RESULTS FOR THE EDISON STATION (2008-2014)**

<sup>1</sup> Cadmium site-specific standard effective 2013

Pumphouse Monitoring Results for Metals in TSP (2008 - 2014) (results expressed in $\mu\text{g}/\text{m}^3$ )								
	As	Cd	Cr	Co	Cu	Fe ( $\text{Fe}_2\text{O}_3$ )	Pb	Ni
Composite Mean	< 0.004	0.013	0.007	0.009	0.14	2.0	0.026	0.11
Max. Concentration	0.018	0.320	0.119	0.276	2.63	22.9	0.448	1.58
O. Reg 419 Limit	0.3	0.25 (0.17) <sup>1</sup>	1.5	0.1	50	25	0.5	2
No. > O. Reg 419 Limit	0	1	0	2	0	0	0	0

**TABLE 24: TSP METALS RESULTS FOR THE PUMPHOUSE STATION (2008-2014)**

<sup>1</sup> Cadmium site-specific standard effective 2013

Figures 27 to 30 illustrate the trends in the annual means for cobalt, cadmium, nickel and copper for both stations. The cobalt and cadmium results show a downward trend.

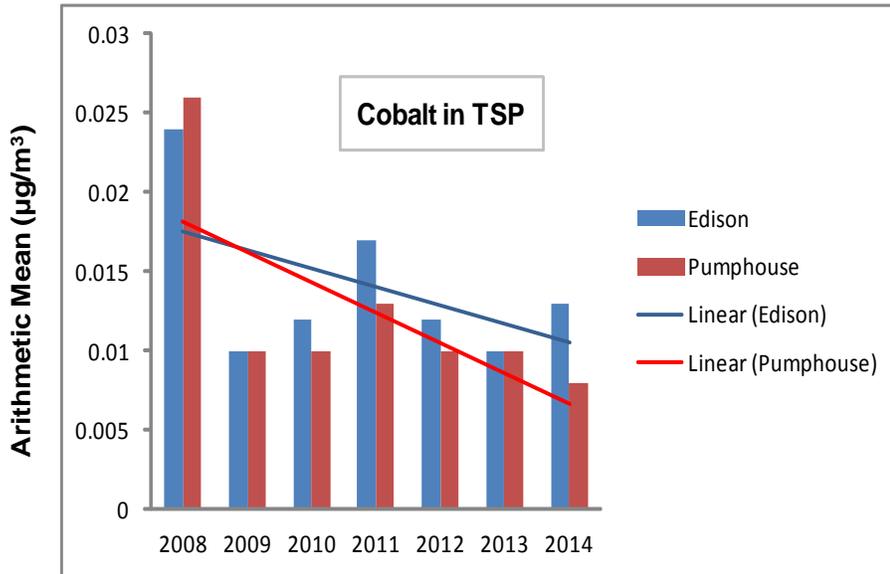


FIGURE 27: ANNUAL MEAN COBALT CONCENTRATIONS FOR THE EDISON AND PUMPHOUSE STATIONS (2008 TO 2014)

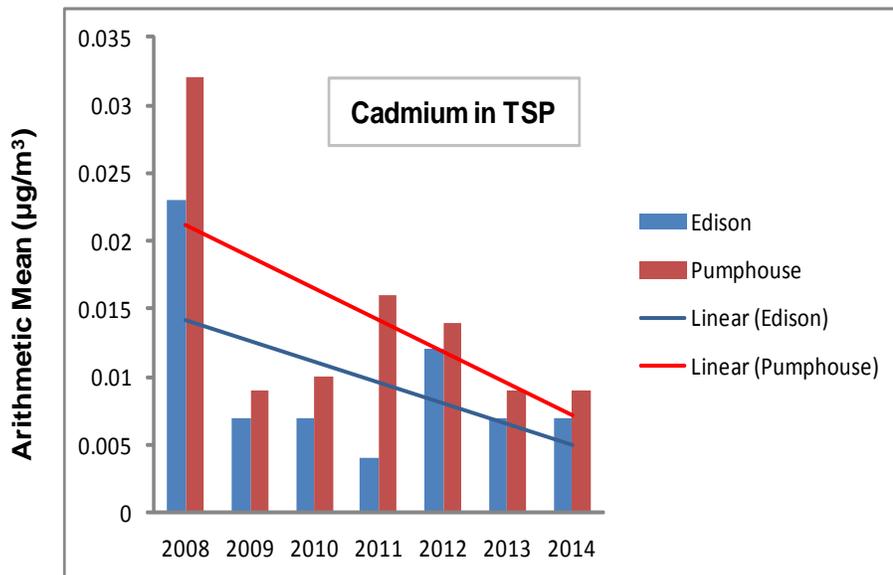


FIGURE 28: ANNUAL MEAN CADMIUM CONCENTRATIONS FOR THE EDISON AND PUMPHOUSE STATIONS (2008 TO 2014)

Nickel in TSP showed no trend at the Edison station and a very small downward trend at the Pumphouse station. Copper in TSP appears to have trended up at the Edison station and trended down at the Pumphouse station. The copper results need to be interpreted with caution as explained earlier.

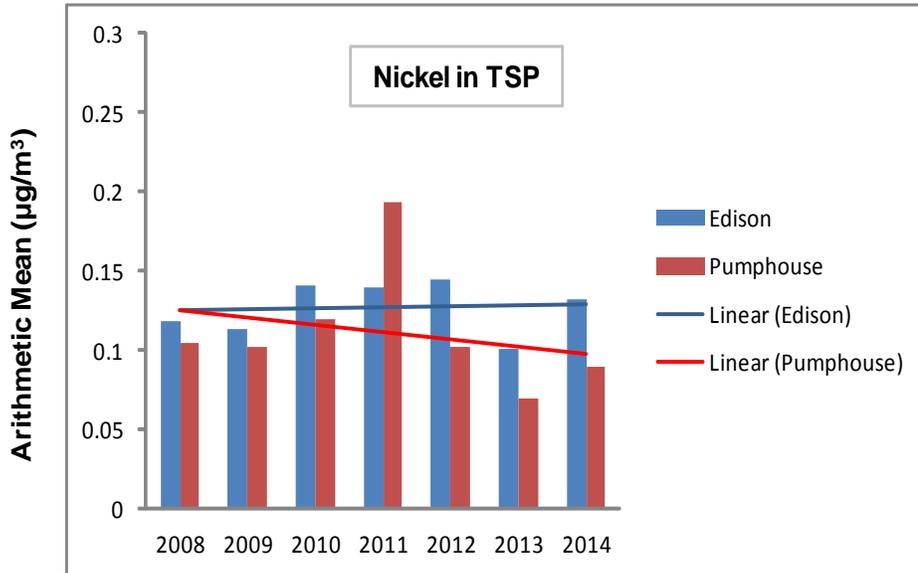


FIGURE 29: ANNUAL MEAN NICKEL CONCENTRATIONS FOR THE EDISON AND PUMPHOUSE STATIONS (2008 TO 2014)

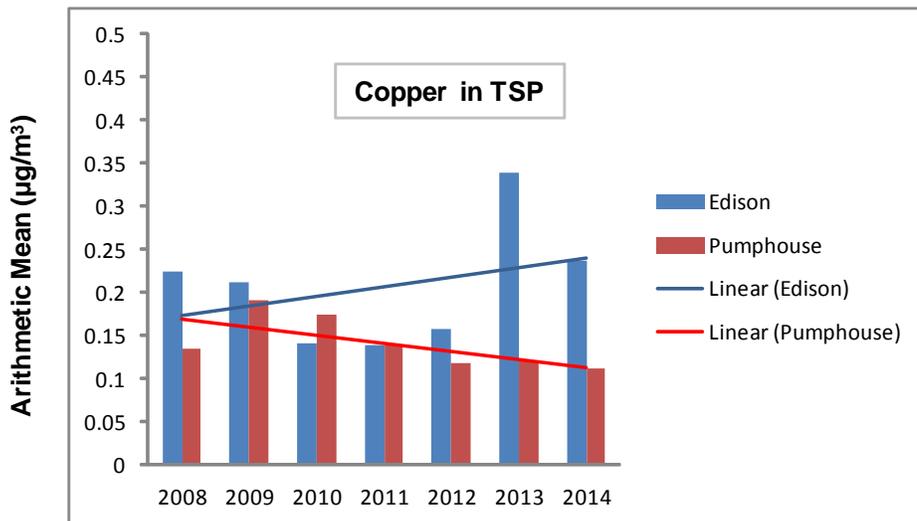


FIGURE 30: ANNUAL MEAN COPPER CONCENTRATIONS FOR THE EDISON AND PUMPHOUSE STATIONS (2008 TO 2014)

## 6. SUMMARY

Improvements in overall air quality over the period 2008 to 2014 continued to be realized in Greater Sudbury. These are consistent with improved air quality across Ontario as a result of initiatives by governments and industry to reduce emissions and ground-level concentrations of airborne pollutants. These include the replacement in 2013 of the Canada Wide Standards (CWS) for O<sub>3</sub> and PM<sub>2.5</sub> with the Canadian Ambient Air Quality Standards (CAAQS) using stricter standards, stricter federal vehicle emission standards and lower sulphur content in transportation fuels, stricter standards for some metals in particulate matter and continuous improvements by local smelter facilities to further reduce their emissions of airborne pollutants.

Future initiatives include the implementation of the Federal Air Quality Health Index (AQHI) across Ontario, which occurred in June 2015, by combining the best features of the AQI and the AQHI to report on air quality and associated health information for Ontarians, and on-going abatement programs by smelter facilities to meet government requirements.

### 6.1 Results

The results of air monitoring programs in Greater Sudbury for the period 2008 to 2014 are summarized below by air pollutant. For key pollutants measured province-wide in the AQI network, the results from the Greater Sudbury AQI station are compared with those from selected cities in Ontario.

#### 6.1.1 Air Quality Index

From 2008 to 2014, the air quality as measured at the Greater Sudbury AQI station was very good to good 96.6% of the time. This is an improvement over the 1998 to 2007 average of 94.1% for very good to good air quality. The air quality was never in the very poor range and was determined to be moderate to poor for 3.4% of the time compared to an average of 5.6% from 1998 to 2007. The air quality was described as poor  $\leq$  0.1% of the time.

Elevated ground-level O<sub>3</sub> and PM<sub>2.5</sub>, both transboundary pollutants, continued to be largely responsible for poor air quality in Greater Sudbury and across the Province. The air quality in Greater Sudbury was poor due to SO<sub>2</sub> for 2 hours in 2010 and 1 hour in 2014. Out of 9 cities selected for comparison, Greater Sudbury ranked 3<sup>rd</sup> lowest, ahead of Ottawa and Thunder Bay, for the composite mean frequency of occurrence of moderate to poor air quality.

#### 6.1.2 Sulphur Dioxide (SO<sub>2</sub>)

- The emissions from the smelters were well below their combined annual limit of 241 kilotonnes (kt), peaking at 152 kt in 2013.

- Every Vale and Glencore community SO<sub>2</sub> monitoring station had annual and daily (24 hour) means well below the provincial AAQCs. The composite annual means for the network appear to be trending down with time. The downward trend was most obvious for the Skead station from measurements back to 1994.
- The 18 community network stations recorded a total of 41 exceedances of the 1- hour provincial criterion. This is a substantial improvement over the 353 exceedances recorded during the previous 7 year period (1998 to 2007). Generally, the stations closest to the smelters recorded more exceedances. The exceedance frequency also trended down, with a maximum of 8 in 2010 and 2011 and a minimum of 3 in 2014. The downward trend was most obvious for the Skead station from measurements back to 1994.
- Compared to other cities in the province, Greater Sudbury recorded lower composite SO<sub>2</sub> annual means than Sarnia, Hamilton and Windsor for the period 2008 to 2012, and lower means than Sarnia and Hamilton for the period 2013 to 2014 after the relocation of the AQI station to a downtown site. Sarnia and Greater Sudbury were the only cities to record exceedances of the 1- hour AAQC.

### 6.1.3 Nitrogen Dioxide (NO<sub>2</sub>)

- From measurements taken at the Elm Street downtown station in 2013 and 2014, the maximum 1- hour and 24- hour NO<sub>2</sub> concentrations were much lower than the AAQCs.
- Compared to other cities in the province, Greater Sudbury had lower composite means than Toronto, Windsor and Hamilton and ranked in the middle of the group of selected cities.

### 6.1.4 Ground-Level Ozone (O<sub>3</sub>)

- In spite of year-to-year variability, the annual mean O<sub>3</sub> concentrations showed a small downward trend.
- Compared to other cities in Ontario, Greater Sudbury, together with other northern cities (Parry Sound, Sault Ste. Marie) had slightly higher composite annual means than the cities in the south. This is consistent with previous findings and is explained by higher winter and lower summer ozone concentrations in the north, and less nitric oxide from traffic emissions in the north to deplete the ozone.
- The 1-hour AAQC was exceeded a total of 13 hours due to 2 ozone episodes recorded in May 2009 and 2012. From backward air mass trajectory analyses, both episodes resulted from transboundary flow from states south of the Great Lakes. During the previous 7 year period, Greater Sudbury recorded 108 hourly exceedances.
- Greater Sudbury ranked in the middle of the group of cities compared, behind Windsor, Parry Sound, Toronto and Hamilton for the number of hours greater than the AAQC.

- For the 3 reporting years, Greater Sudbury marginally exceeded the CWS in 2010 and 2012, but was in compliance in 2011. The majority of the Ministry designated cities in the province exceeded the CWS each reporting year.
- Although the CAAQS were implemented in 2015, the Ministry reported that Greater Sudbury marginally exceeded the standard in both reporting years (2013 and 2014). Using a weight of evidence approach, the Ministry determined that the standard would have been met if the ozone concentrations had not been influenced by days with transboundary flow.

#### 6.1.5 Respirable Particulate (PM<sub>2.5</sub>)

- The 24-hour reference level (30 µg/m<sup>3</sup>) was marginally exceeded once (May 2012). A backward air mass trajectory analysis revealed that the exceedance resulted from forest fire emissions in Northern Manitoba, over 600 kilometres from Greater Sudbury. Compared to selected cities in the province, Greater Sudbury had the lowest composite mean for the 2008 to 2012 period, based on measurements with a TEOM analyzer.
- Greater Sudbury never exceeded the CWS (30 µg/m<sup>3</sup>) since it began to be reported in 2006. During the period 2006 to 2012, the CWS metric for PM<sub>2.5</sub> decreased about 45% based on measurements with a TEOM analyzer.
- The stricter 24-hour reference level (28 µg/m<sup>3</sup>), introduced in 2013 and coinciding with the replacement of the TEOM with the SHARP analyzer, was not exceeded at the Elm Street station in 2013 and 2014. Greater Sudbury had a lower composite annual PM<sub>2.5</sub> mean than Hamilton, Windsor, Toronto, Ottawa and Thunder Bay.
- Although the new CAAQSs will be used for the first time in 2015 to determine management levels for air zones, the Elm Street AQI station recorded 24-hour concentrations well below the CAAQS. Of the 21 Ministry designated sites, Sudbury, as well as Thunder Bay, had the lowest 24-hour CAAQS metric value. The Elm Street AQI station also recorded annual means well below the CAAQS. Of the 21 designated sites, Greater Sudbury had the lowest annual CAAQS metric values.
- From 2008 to 2012, Vale measured PM<sub>2.5</sub> concentrations with a low volume air sampler at 2 stations. The composite means ranged from 5.4 to 5.8 µg/m<sup>3</sup>. Three exceedances of the 24-hour reference level (30 µg/m<sup>3</sup>) were reported but are suspect since they were higher than concurrent PM<sub>10</sub> and TSP results.

#### 6.1.6 Inhalable Particulate (PM<sub>10</sub>)

- The available data from the Vale monitoring network yielded composite annual means ranging from 9.5 to 14.3 µg/m<sup>3</sup>. Three exceedances of the 24-hour interim AAQC were recorded from a total of 2487 samples.

- The station closest to the Vale smelter had the highest composite mean for nickel and copper, and a downward trend in the annual means for copper. For the period covered in this report, there are no regulatory limits for metals in PM<sub>10</sub>.
- The Ministry's PM<sub>10</sub> monitoring station on Lisgar Street in downtown Greater Sudbury had a composite mean of 12.7 µg/m<sup>3</sup> for the period 2008 to 2014, and recorded one exceedance of the 24-hour interim AAQC from of 334 samples. The annual means decreased from a high of 15.8 µg/m<sup>3</sup> to a low of 10.9 µg/m<sup>3</sup> in 2014. The data also suggests a downward trend for copper. There were no exceedances of the 24-hour AAQCs for nickel and manganese or of the annual AAQC for nickel, both effective as of 2012.

### 6.1.7 Total Suspended Particulate (TSP)

#### Vale Stations

- The composite annual geometric means for the Vale network of 8 stations varied from 23.0 to 12.6 µg/m<sup>3</sup>. There were no exceedances of the annual AAQC. The annual means for the stations with the largest data set showed year-to-year variability with no obvious trends.
- Fifteen exceedances of the 24-hour TSP standard were measured from a total of 4368 samples. More than half of the exceedances were not related to Vale's operations.
- Twenty-three samples had nickel concentrations above the 24-hour standard. Nineteen of these were recorded at the station closest to the Vale smelter facilities. That station also recorded 8 exceedances of the applicable cobalt 24-hour limit. Another station recorded an exceedance of arsenic and lead, both not related to Vale's operations. The overall exceedance rate was less than 1% of the samples collected.

#### Glencore Stations

- The composite annual geometric means for the 2 Glencore stations located in the Town of Falconbridge varied from 15.1 to 12.1 µg/m<sup>3</sup>. There were no exceedances of the annual standard. The annual means for both stations showed little year-to-year variability and no obvious trends.
- Four samples of 1635 samples exceeded the 24-hour TSP standard. They were not related to Glencore's operations.
- Seven samples had cobalt concentrations above the applicable limits, as well as 4 samples for cadmium and 3 samples for nickel. The majority of the exceedances occurred at the station closest to the Glencore smelter. The overall exceedance rate was less than 0.5%. The cobalt and cadmium annual means showed a downward trend over the period 2008 to 2014.

## 6.2 Provincial Perspective

A summary of Greater Sudbury's ranking among other cities in Ontario is presented Table 25.

Air Quality Parameter	Sudbury Ranking From Selected Cities
Sulphur Dioxide	Ranked in the middle for composite means, behind Sarnia, Hamilton and Windsor; the only city with Sarnia to record exceedances of the 1-hour AAQC
Nitrogen Dioxide	Ranked near the middle of the group with Ottawa and Thunder Bay for the composite annual means
Ground-Level O <sub>3</sub>	Highest composite annual mean behind Parry Sound and Sault Ste. Marie; ranked in the middle for 1-hour AAQC exceedances; did not meet the CWS for 2010 and 2012 like most cities in Ontario; met the proposed CAAQs for 2013 and 2014 when considering transboundary flow
Respirable Particulate	Ranked one of the lowest for composite mean just ahead of Thunder Bay; ranked in the middle for exceedances of the CWS reference level; met the CWS for 2005-2007 and ranked one of the best of 20 designated cities in Ontario for compliance with the CWS
Air Quality Index	Ranked near the bottom of the group for frequency of AQI values in the moderate to poor range (AQI > 31)

**TABLE 25: RANKING OF GREATER SUDBURY'S AIR QUALITY FROM SELECTED ONTARIO CITIES**

Comparisons with other cities for carbon monoxide and Total Reduced Sulphur could not be made since these parameters ceased to be measured in Greater Sudbury in 2004. In addition, comparisons between the selected cities for TSP and PM<sub>10</sub> could not be made since these air quality parameters are no longer measured in the provincial network.

## GLOSSARY OF TERMS

<b>Acid aerosol</b>	Dispersion of fine particles (smoke) or fine droplets (fog) in air which are acidic. Examples include fine particulate sulphate compounds and sulphuric acid mists.
<b>Acidic deposition</b>	Refers to deposition of a variety of acidic pollutants (acids or acid-forming substances such as sulphates and nitrates) on biota or land or in waters of the Earth's surface. Deposition occurs in the dry form (fine particulate) or in the wet form (rain/snow).
<b>Air Quality Index</b>	Real-time information system that provides the public with an indication of air quality in cities and towns across Ontario.
<b>AQI station</b>	Continuous monitoring station used to inform the public of air quality levels on a real-time basis; station reports on criteria pollutants.
<b>Airshed</b>	A geographical region of influence, or spatial extent of the air pollution burden.
<b>Air zones</b>	Geographical areas/regional airsheds to improve the management of air quality across Canada
<b>Ambient air</b>	Outdoor or open air.
<b>Continuous pollutant</b>	Pollutant for which a continuous record exists; effectively, pollutants that have hourly data (maximum 8,760 values per year except leap year where maximum values for the year are 8,784).
<b>Continuous station</b>	Where pollutants are measured on a real-time basis and data determined hourly (for example O <sub>3</sub> , sulphur dioxide).
<b>Criterion</b>	Maximum concentration or level (based on potential effects) of contaminant that is desirable or considered acceptable in ambient air.
<b>Daily pollutant</b>	Pollutant with a 24-hour or daily value (maximum 365 values per year), such as Total Suspended Particulate.
<b>Data telemetry system</b>	An automated data collection and transmission system which sends environmental (or other) data to a central computer for storage, analysis and reporting. The data transfer can be done within minutes (real-time) after its detection by the analyzer at the monitoring station.
<b>Detection limit</b>	Minimum concentration of a contaminant that can be determined.

<b>Exceedance</b>	Violation of the pollutant levels permitted by environmental protection limit.
<b>Fine Particulate Matter</b>	Particles smaller than about 2.5 microns in aerodynamic diameter, which arise mainly from condensation of hot vapors and chemically driven gas-to-particle conversion processes; also referred to as PM <sub>2.5</sub> . These are fine enough to penetrate deep into the lungs and have the greatest effects on health. Also known as respirable particulate matter.
<b>Fossil fuels</b>	Natural gas, petroleum, coal and any form of solid, liquid or gaseous fuel derived from such materials for the purpose of generating heat.
<b>Geometric mean</b>	Statistic of a data set calculated by taking the n <sup>th</sup> root of the product of all (n) values in a data set. Provides a better indication than the arithmetic mean of the central tendency for a small data set with extreme values. Typically used when data set is log normally distributed such as TSP.
<b>Global warming</b>	Long-term rise in the average temperature of the Earth; principally due to an increase in the buildup of carbon dioxide and other greenhouse gases.
<b>Ground-level O<sub>3</sub></b>	Colorless gas formed from chemical reactions between nitrogen oxides and hydrocarbons in the presence of sunlight near the Earth's surface.
<b>Inhalable particles</b>	Represent up to 60 per cent of the total suspended particulate matter; composed of both coarse (aerodynamic diameter of 2.6 to 10.0 microns) and fine (< 2.5 microns) particles; also referred to as PM <sub>10</sub> .
<b>Looping plume</b>	Plume released from an elevated stack which is alternately brought down to ground and lifted up due to downdrafts and updrafts in an unstable atmosphere.
<b>Micron</b>	A millionth (10 <sup>-6</sup> ) of a meter.
<b>Non-continuous station</b>	Station that measures pollutant concentration (over a 24 hour period), typically every third or every sixth day using a non-continuous sampler such as a high volume sampler.
<b>Nitrates</b>	Compounds containing the radical (NO <sub>3</sub> ) <sup>-</sup> . Most are soluble in water and when converted to nitric acid (HNO <sub>3</sub> ) can acidify sensitive aquatic ecosystems.

<b>O<sub>3</sub> episode day</b>	A day on which widespread (hundreds of kilometers) elevated O <sub>3</sub> levels (greater than 80 ppb maximum hourly concentration) occur simultaneously.
<b>Particulate matter</b>	Refers to all airborne finely divided solid or liquid material with an aerodynamic diameter smaller than 100 microns.
<b>Photochemical oxidant</b>	Air pollutants (e.g. O <sub>3</sub> ) formed by action of sunlight on oxides of nitrogen and VOCs.
<b>Photochemical reaction</b>	Chemical reaction influenced or initiated by light, particularly ultraviolet light.
<b>Photochemical smog</b>	See smog.
<b>Precursor pollutant</b>	Usually a primary pollutant which can be transformed (or enable the transformation) into secondary pollutants.
<b>Primary pollutant</b>	Pollutant emitted directly to the atmosphere.
<b>Respirable particles</b>	Particles smaller than about 2.5 microns in diameter, which arise mainly from condensation of hot vapours and chemically driven gas to particle conversion processes; also referred to as fine particulate matter and/or PM <sub>2.5</sub> . These are fine enough to penetrate deeply into the lungs and have the greatest effects on health.
<b>Secondary pollutant</b>	Pollutant formed from other pollutants in the atmosphere.
<b>Smog</b>	A concentration of smoke and fog; colloquial term used for photochemical fog, which includes O <sub>3</sub> and other contaminants; tends to be a brownish haze.
<b>Smog advisory</b>	Public is advised when elevated pollution levels are forecast due to ground-level O <sub>3</sub> .
<b>Stratosphere</b>	Atmosphere 10 to 40 kilometers above the Earth's surface.
<b>Stratospheric O<sub>3</sub></b>	O <sub>3</sub> formed in the stratosphere from the conversion of oxygen molecules by solar radiation; O <sub>3</sub> found there absorbs much ultraviolet radiation and prevents it from reaching the Earth.
<b>Sulphate</b>	A compound containing the sulphate radical (SO <sub>4</sub> ) <sup>-2</sup> . It is formed from the gradual oxidation of sulphur. When combined with moisture in the air, it is transformed to sulphuric acid (H <sub>2</sub> SO <sub>4</sub> ) which can acidify sensitive aquatic ecosystems when deposited to ground.
<b>Supplementary emission control</b>	A strategy to reduce air emissions on a short-term basis by curtailing production. The strategy relies on weather forecasting to anticipate periods of poor atmospheric dispersion conditions.

<b>Total Suspended Particles</b>	Suspended particulate matter (aerodynamic diameter less than 44 microns).
<b>Temperature inversion</b>	A rise in the air temperature with increasing altitude, usually over a short range of altitudes. Pollutants released under this inversion layer can effectively become trapped and unable to dissipate upwards, resulting in a build-up at ground level.
<b>Wind rose</b>	<p>A pictorial representation of surface wind data (direction and speed) collected from a meteorological tower over a number of years which displays the frequency distribution of wind speed classes, usually over sixteen or thirty six compass directions. A seasonal wind rose is very useful for identifying wind patterns during different times of the year.</p> <p>A typical multi-year wind rose for wind data collected in Greater Sudbury is shown in Appendix I.</p>

## ACRONYMS

<b>AAQC</b>	Ambient Air Quality Criteria	<b>PM<sub>10</sub></b>	Inhalable particulate matter (< 10 microns)
<b>AQI</b>	Air Quality Index	<b>ppb</b>	parts (of pollutant) per billion (parts of air)
<b>AQUIS</b>	Air Quality Information System (Ontario)	<b>ppm</b>	parts (of pollutant) per million (parts of air)
<b>CO</b>	Carbon monoxide	<b>PM<sub>2.5</sub></b>	Respirable particulates (< 2.5 microns)
<b>HNO<sub>3</sub></b>	Nitric acid	<b>POI</b>	Point of Impingement Standard
<b>H<sub>2</sub>SO<sub>4</sub></b>	Sulphuric acid	<b>SO<sub>2</sub></b>	Sulphur dioxide
<b>H<sub>2</sub>S</b>	Hydrogen sulphide	<b>SO<sub>3</sub></b>	Sulphur trioxide
<b>kt</b>	kilotonnes	<b>SO<sub>4</sub></b>	Sulphate
<b>MOE</b>	Ministry of Environment	<b>SP</b>	Suspended particles
<b>nm</b>	nanometres	<b>TPM</b>	Total particulate matter
<b>NO</b>	Nitric oxide	<b>TRS</b>	Total reduced sulphur
<b>NO<sub>2</sub></b>	Nitrogen dioxide	<b>TSP</b>	Total suspended particulate
<b>NO<sub>x</sub></b>	Oxides of nitrogen	<b>µg/m<sup>3</sup></b>	micrograms (of pollutant) per cubic metre (of air)
<b>NPRI</b>	National Pollutant Release Inventory (Canada)	<b>VOCs</b>	Volatile organic compounds
<b>O<sub>3</sub></b>	Ozone		

## APPENDIX A: Method for Measuring Sulphur Dioxide (SO<sub>2</sub>) in Ambient Air Using a Pulsed Fluorescent Monitor

The pulsed fluorescent sulphur dioxide (SO<sub>2</sub>) monitor operates on the principle that SO<sub>2</sub> molecules excited by ultraviolet light give off radiation.

Pulsating ultraviolet light is focused through a narrow filter into the fluorescent chamber. Here it excites SO<sub>2</sub> molecules which give off their characteristic decay radiation. A second filter allows only this radiation to fall on a photomultiplier tube. Electronic signal processing transfers the light energy impinging on the photomultiplier into a voltage which is in direct proportion to the concentration of SO<sub>2</sub> in the sample stream being analyzed.

More specifically, light in the 230 nanometre (nm) to 190 nanometre (nm) region is used because it exhibits minimal interference by air and most other molecules that are found in ambient air. The pulsed light source emits ultraviolet radiation which acts on the SO<sub>2</sub> in the sample gas producing electronically excited SO<sub>2</sub>. The electronically excited SO<sub>2</sub> can then decay back to the ground state by fluorescence. The following equation outlines the overall reaction where SO<sub>2</sub> is excited SO<sub>2</sub><sup>\*</sup>, k<sub>f</sub> is a rate constant and hv refers to the energy released by the reaction.



The fluorescent radiation impinging upon a detector is directly proportional to the concentration of SO<sub>2</sub>, thus forming the basis for this measurement technique.

## APPENDIX B: Method for Measuring Ground-Level O<sub>3</sub> in Ambient Air Using a Chemiluminescence Monitor

A continuous sample of ambient air is mixed with an excess of ethylene in a reaction chamber. Any O<sub>3</sub> in the sample reacts instantaneously with the ethylene emitting visible light (chemiluminescence), with peak emission at 440 nanometers (nm). The light intensity, directly proportional to the O<sub>3</sub> concentration, is measured with a photomultiplier tube whose output signal is fed to a recorder. The signal is calibrated so that O<sub>3</sub> concentrations are read directly on the recorder.

A suitable working range for field instruments is 0 – 0.5 ppm (0 – 1000 µg/m<sup>3</sup>).

The detection limit (sensitivity) for the measurement of O<sub>3</sub> by this method is 0.001 ppm (2 µg/m<sup>3</sup>).

### Interferences and Limitations

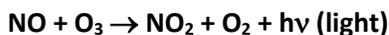
Particulate matter in the sample will scatter the emitted light, and also accumulate in the intake line and on optical surfaces. Particulate matter in the sample is removed with a suitable filter.

The reaction of O<sub>3</sub> with ethylene is not subject to interference from any of the common gaseous air pollutants.

Moisture may be a potential interferent and can be removed with a suitable drying system.

## APPENDIX C: Method for Measuring Ground-Level NO<sub>x</sub> in Ambient Air Using a Chemiluminescence Monitor

The monitor operates on the principle that nitric oxide (NO) and ozone (O<sub>3</sub>) react to produce a characteristic luminescence with an intensity linearly proportional to the NO concentration. Infrared light emission results when electronically excited NO<sub>2</sub> molecules decay to lower energy states. Specifically:



NO<sub>2</sub> must first be transformed into NO before it can be measured using the chemiluminescent reaction. NO<sub>2</sub> is converted to NO by a molybdenum NO<sub>2</sub>-to-NO converter heated to about 325 °C (an optional stainless steel converter is heated to 625 °C). The ambient air sample is drawn into the monitor through the sample bulkhead. The sample flows through a capillary, and then to the mode solenoid valve. The solenoid valve routes the sample either straight to the reaction chamber (NO mode) or through the NO<sub>2</sub>-to-NO converter and then to the reaction chamber (NO<sub>x</sub> mode). A flow sensor to the reaction chamber measures the sample flow. Dry air enters the monitor through the dry air bulkhead, passes through a flow switch, and then through a silent discharge ozonator.

The ozonator generates the ozone needed for the chemiluminescent reaction. At the reaction chamber, the ozone reacts with the NO in the sample to produce excited NO<sub>2</sub> molecules. A photomultiplier tube (PMT) housed in a thermoelectric cooler detects the luminescence generated during this reaction. From the reaction chamber, the exhaust travels through the ozone converter to the pump, and is released through the vent. The NO and NO<sub>x</sub> concentrations calculated in the NO and NO<sub>x</sub> modes are stored in memory. The difference between the concentrations is used to calculate the NO<sub>2</sub> concentration. The monitor outputs NO, NO<sub>2</sub>, and NO<sub>x</sub> concentrations to the front panel display, the analog outputs, and also makes the data available over the serial or Ethernet connection.

## APPENDIX D: Method for Measuring in Real-Time the Particulate Mass Concentrations Using a TEOM (Tapered Element Oscillating Microbalance) Monitor

The TEOM monitor is designed to measure the concentration, in real-time, of particulates with aerodynamic diameters ranging from TSP to less than PM<sub>2.5</sub> using the appropriate size-selective inlet head. It is a filter-based mass monitoring method. Monitoring in real-time is made possible through the use of an inertial mass transducer patented in the U.S. and internationally by Rupprecht & Patashnick Co. Inc.

In its most common configuration, it calculates mass concentration, mass rate and the total mass accumulation on the TEOM filter cartridge under the following conditions:

<b>Flow rate through sample inlet:</b>	<b>16.7 l/min (1 m<sup>3</sup>/hr)</b>
<b>Main flow rate to the filter:</b>	<b>3.0 l/min</b>
<b>Temperature of sample stream:</b>	<b>40°C</b>
<b>Particulate matter concentration:</b>	<b>less than 5 µg/m<sup>3</sup> to several g/m<sup>3</sup></b>

At the exit of the sample inlet, the 16.7 l/min flow is isokinetically split into a 3.0 l/min sample stream that is sent to the instrument's mass transducer and a 13.7 l/min exhaust stream. In the mass transducer, the sample air stream passes through a Teflon-coated borosilicate glass fiber filter which is weighed every two seconds. The filter sits on a glass tube whose oscillation frequency changes as the weight of the particulate collected on the filter changes this frequency. The frequency change is detected electronically and converted to a mass loading. The difference between the filter's current and initial weight gives the total mass of the collected particulate matter. These instantaneous readings of total mass are smoothed exponentially to reduce noise.

The mass concentration in µg/m<sup>3</sup> is computed by dividing the mass rate by the flow rate (corrected to USEPA standard temperature and pressure and expressed in m<sup>3</sup>/sec), and then multiplying the result by 10<sup>6</sup> to convert from g/m<sup>3</sup> to µg/m<sup>3</sup>.

Internal temperatures in the instrument are controlled to minimize the effects of changing ambient conditions. The sample stream is preheated to 40°C before entering the mass transducer so the sample filter collects particulate under low and constant relative humidity and to minimize the loss of volatile particulate components. All measurement and temperature functions are controlled by a dedicated microcontroller.

These monitors are currently used in the Ontario Air Quality Index monitoring network and have yet to be designated by the USEPA as a Class III Federal Equivalent Method (FEM).

## APPENDIX E: Method for Measuring in Real-Time the Particulate Mass Concentrations Using a SHARP 5030 Monitor

The Model 5030 is based on the principles of aerosol light scattering (nephelometer) and beta attenuation to measure precise and accurate ambient aerosol concentrations. The Model 5030 is a hybrid nephelometric/radiometric particulate mass monitor capable of providing precise, one-minute, real-time measurements with a superior detection limit. The SHARP monitor measures the mass concentration of ambient  $PM_{10}$ ,  $PM_{2.5}$ , and  $PM_{1.0}$  aerosol in real-time. The SHARP monitor incorporates a high sensitivity light scattering photometer whose output signal is continuously referenced to the time-averaged measurements of an integral beta attenuation mass sensor. This system achieves heretofore-unattained short-term precision and accuracy. The SHARP monitor incorporates advanced firmware to optimize the continuous mass calibration of the nephelometric signal, ensuring that the measured mass concentration remains independent of changes in the particle population being sampled.

The SHARP monitor incorporates a dynamic heating system (DHS) designed to maintain the relative humidity (RH) of the air passing through the filter tape of the radiometric stage well below the point at which the collected particles accrete and retain liquid water. This DHS system minimizes the internal temperature rise ensuring negligible loss of semivolatiles from the collected sample when the ambient relative humidity is below the threshold to which the heater is controlling. As the ambient RH increases above the threshold, the applied heating is optimized to maintain the RH threshold above the beta attenuation filter tape. The purpose of this heating system is specifically designed to force the continuous mass monitor to agree with the gravimetric reference method and the relative humidity conditions to which the reference filter samples are conditioned. Furthermore, sufficient flexibility is provided within the firmware to configure the heating conditions to satisfy global monitoring protocols.

## APPENDIX F: Method for Measuring Respirable Particulate (PM<sub>2.5</sub>) in Ambient Air Using a Low Volume Partisol FRM Model 2000 Sampler

The Partisol-FRM Model 2000 PM<sub>2.5</sub> air sampler is designed to conform to the U.S. EPA Federal Reference Method for fine particulate sampling. Specifically, the hardware has been designed to exceed or meet the requirements of CFR 40 Part 50 Appendix L and related drawings supplied by the U.S. EPA. It includes the following features:

- A flow rate of 1 m<sup>3</sup>/h through a single filter.
- The use of standard 47 mm sample filters with a convenient filter exchange mechanism.
- Full microprocessor control and data handling.
- Active volumetric flow control.

The Partisol-FRM Sampler contains the U.S. EPA-designed PM<sub>2.5</sub> WINS Impactor, which performs a 2.5 µm cut of the incoming particulate matter before the sample stream passes through a 47 mm filter. A modified PM<sub>10</sub> (1st stage) inlet is used at the entrance to the sampler to provide a pre-cut at a 10 µm particle size and to protect the sample path against precipitation.

## APPENDIX G: Method for Measuring Inhalable Particulate (PM<sub>10</sub>) in Ambient Air Using a High Volume Sampler

The high volume (hi-vol) sampling technique determines the mass concentration of airborne particulate by drawing a known volume of air through a pre-weighted filter medium. When equipped with a size-selective inlet head for PM<sub>10</sub>, the hi-vol sampler can be used to determine the mass concentration of inhalable particulate matter. Standard operation of the sampler requires an airflow rate of 1.14 m<sup>3</sup>/min. (40cfm) using a flow controller and the use of quartz fibre filters 8 in. by 10 in. in size. The sample is collected over a 24-hour period, midnight to midnight, every one, three or six days. The six-day operating schedule is pre-determined and is consistent throughout Canada and the United-States. This six-day sampling is considered to be representative of the average air quality over a year.

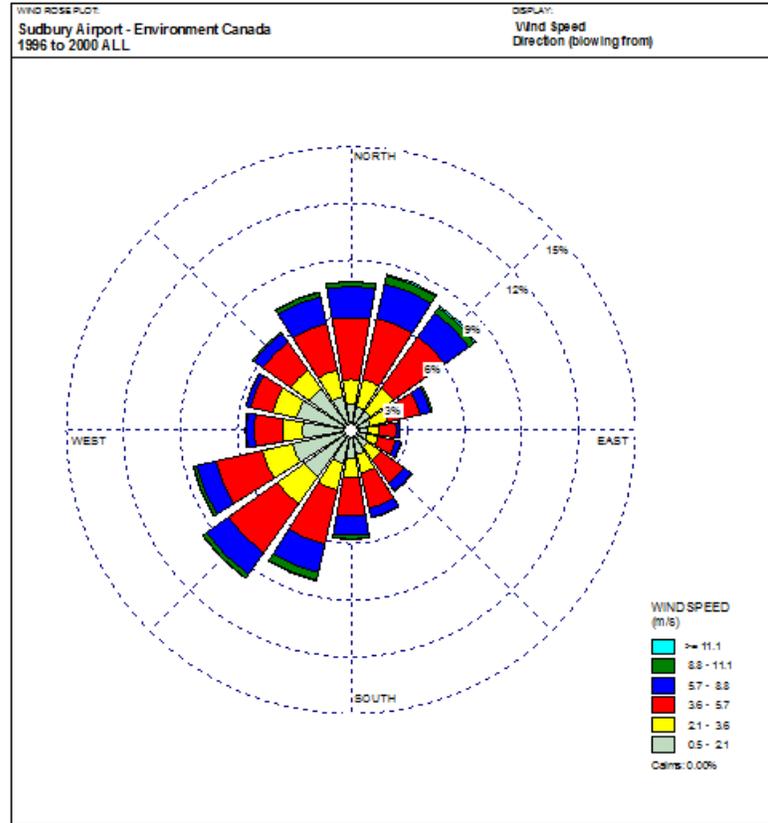
The quartz filters may also be analyzed for trace metals and a variety of compounds.

## APPENDIX H: Method for Measuring Total Suspended Particulate (TSP) in Ambient Air Using a High Volume Sampler

The high volume (hi-vol) sampling technique determines the mass concentration of suspended airborne particulate (<100 microns) by drawing a known volume of air through a pre-weighted filter medium. Standard operation of the sampler involves an airflow rate of 1.14 m<sup>3</sup>/minute (40 cfm) using a flow controller and the use of glass or quartz fibre filters. Quartz fiber filters are preferred due to their low metal content and since they provide more accurate particulate sulphate concentrations. The sample is collected over a 24-hour period, midnight to midnight, every one, three or six days. The six-day operating schedule is pre-determined and is consistent throughout Canada and the United-States. The six-day sampling schedule is considered to be statistically representative of the average air quality over a year.

High-volume samples may also be analyzed for trace metals and a variety of compounds.

APPENDIX I: Wind Rose Diagram for Wind Speed (km/hr) and Direction (degrees) was Collected at the Greater Sudbury Airport Environment Canada Station for the Period 1996-2000



**Note:** Vale provided the wind rose diagram

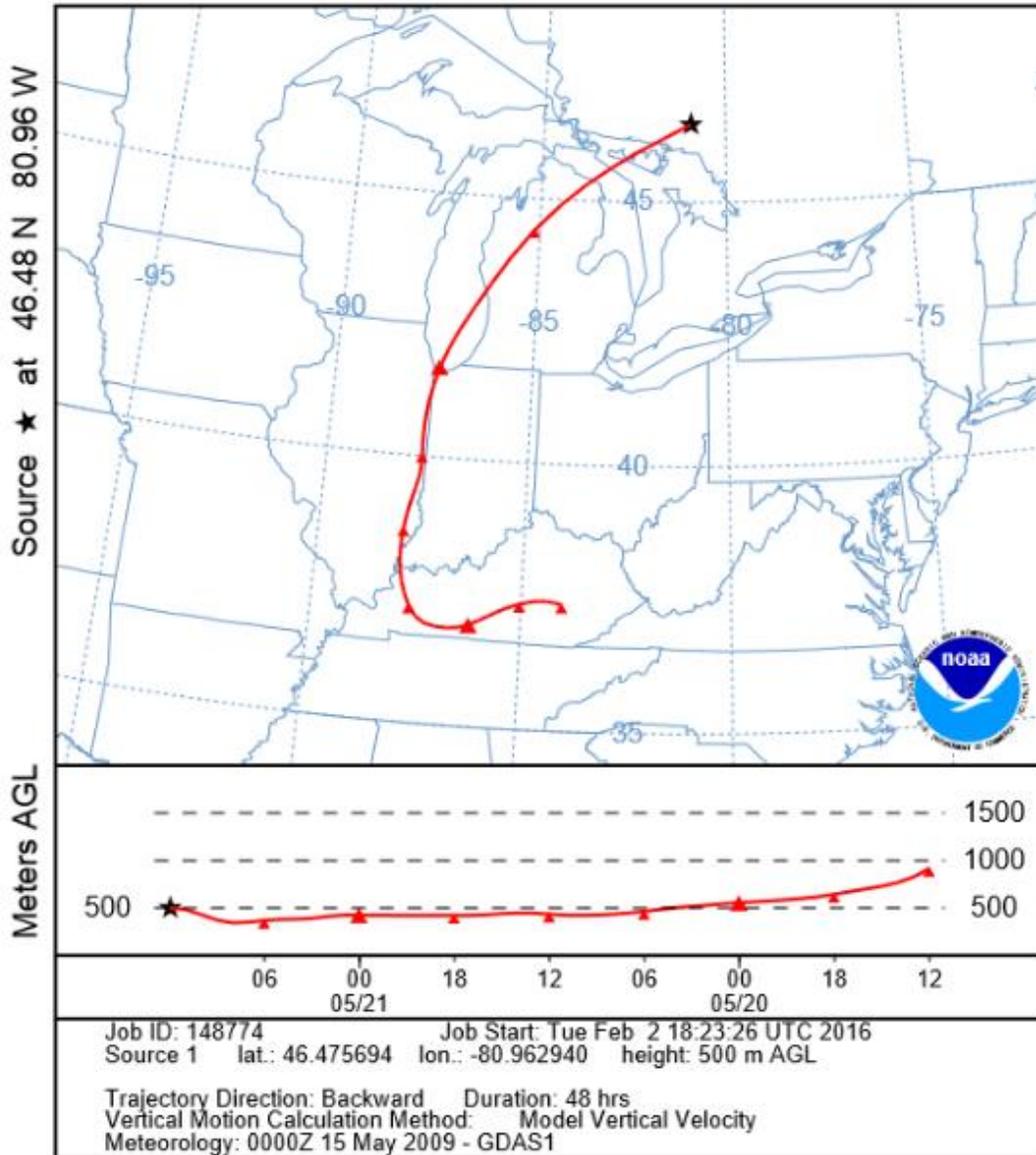
## APPENDIX J: Satellite Photo of the Greater Sudbury SO<sub>2</sub> Monitoring Station Locations



Photo taken from the Annual SO<sub>2</sub> Report Submission, SO<sub>2</sub> Monitoring Network for Sudbury, January to December 2014, prepared by AECOM

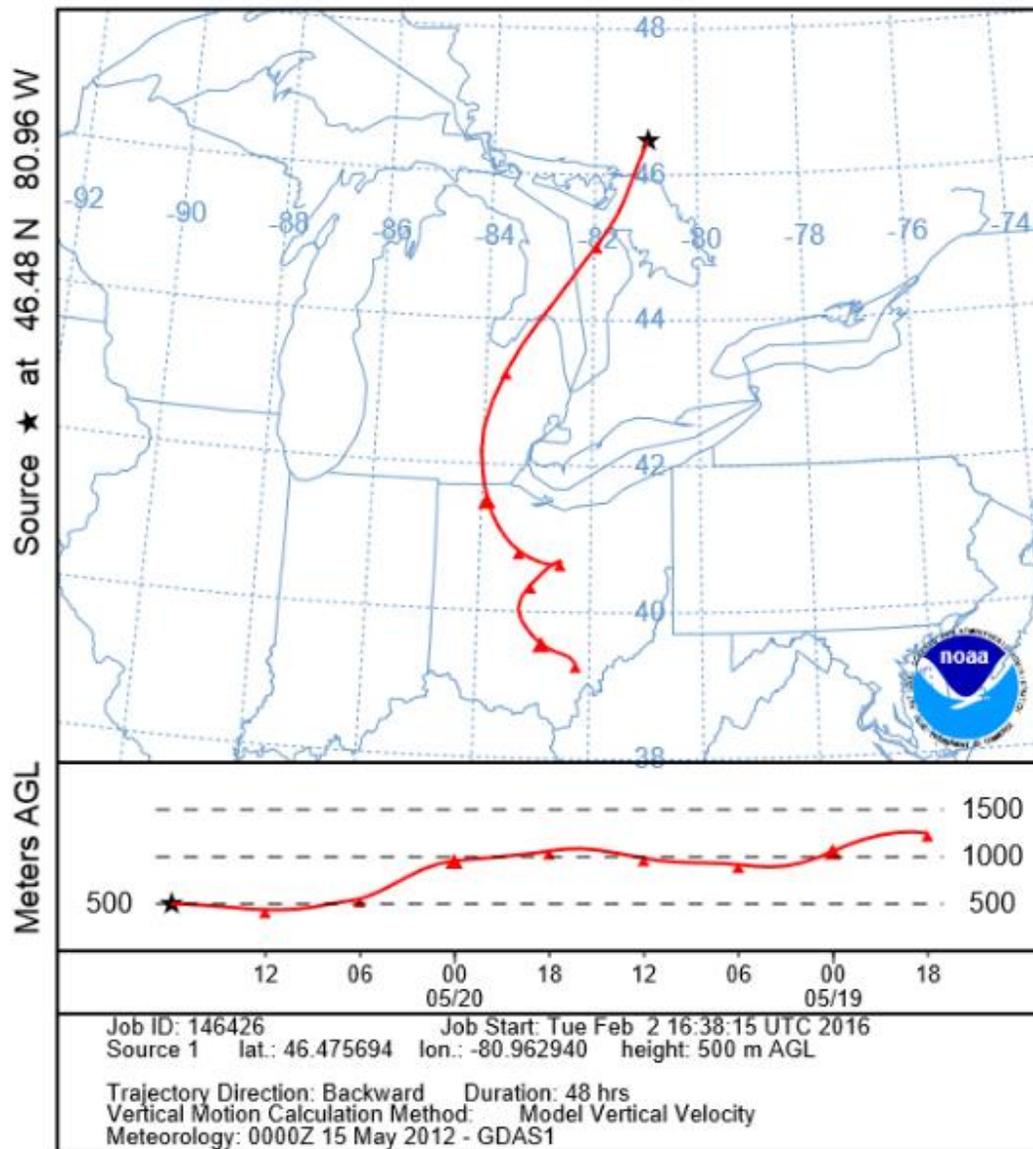
Appendix K: Backward Trajectory for the Ozone Event of May 21, 2009

NOAA HYSPLIT MODEL  
 Backward trajectory ending at 1200 UTC 21 May 09  
 GDAS Meteorological Data



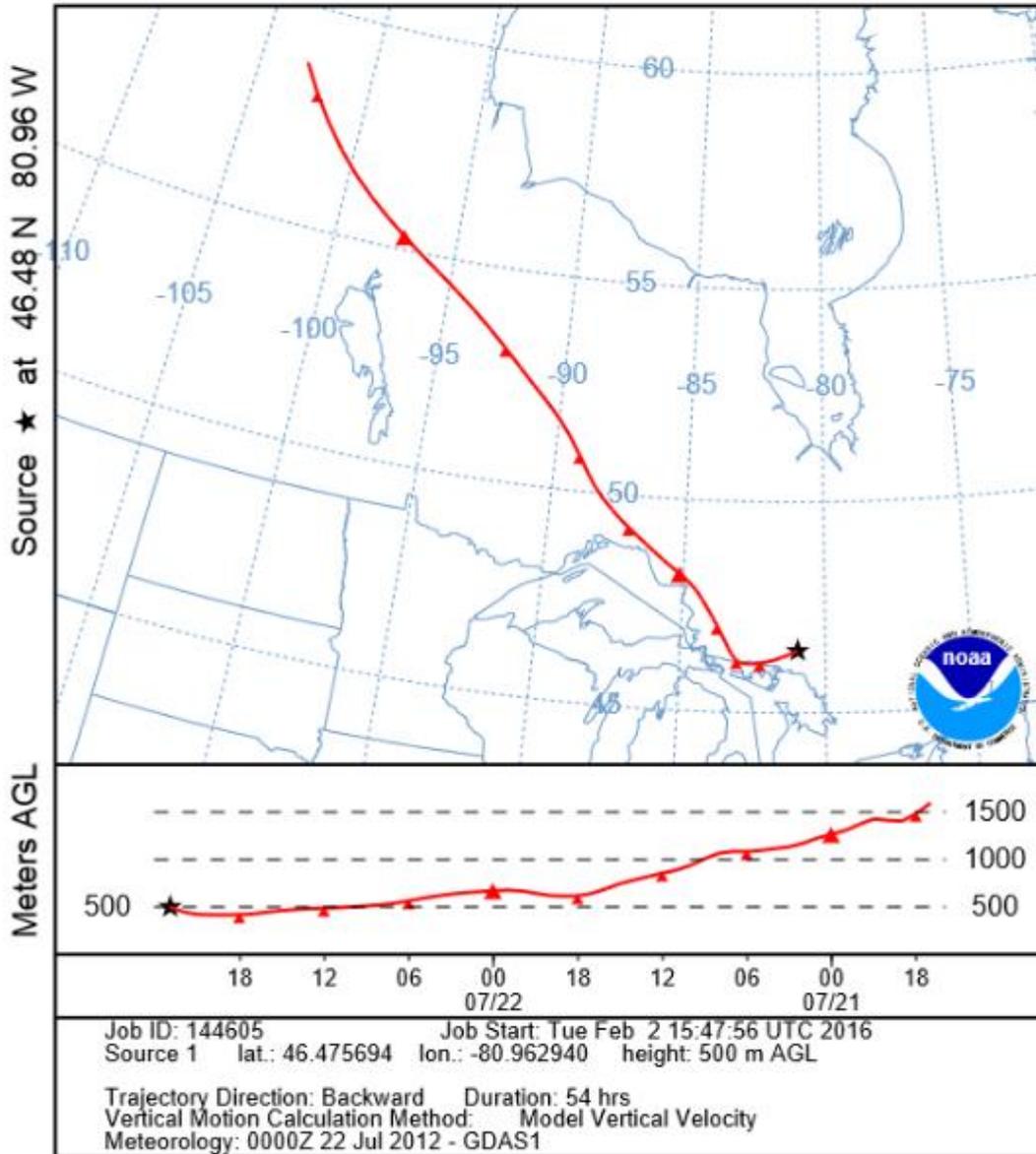
Appendix L: Backward Trajectory for the Ozone Event of May 20, 2012

NOAA HYSPLIT MODEL  
 Backward trajectory ending at 1800 UTC 20 May 12  
 GDAS Meteorological Data

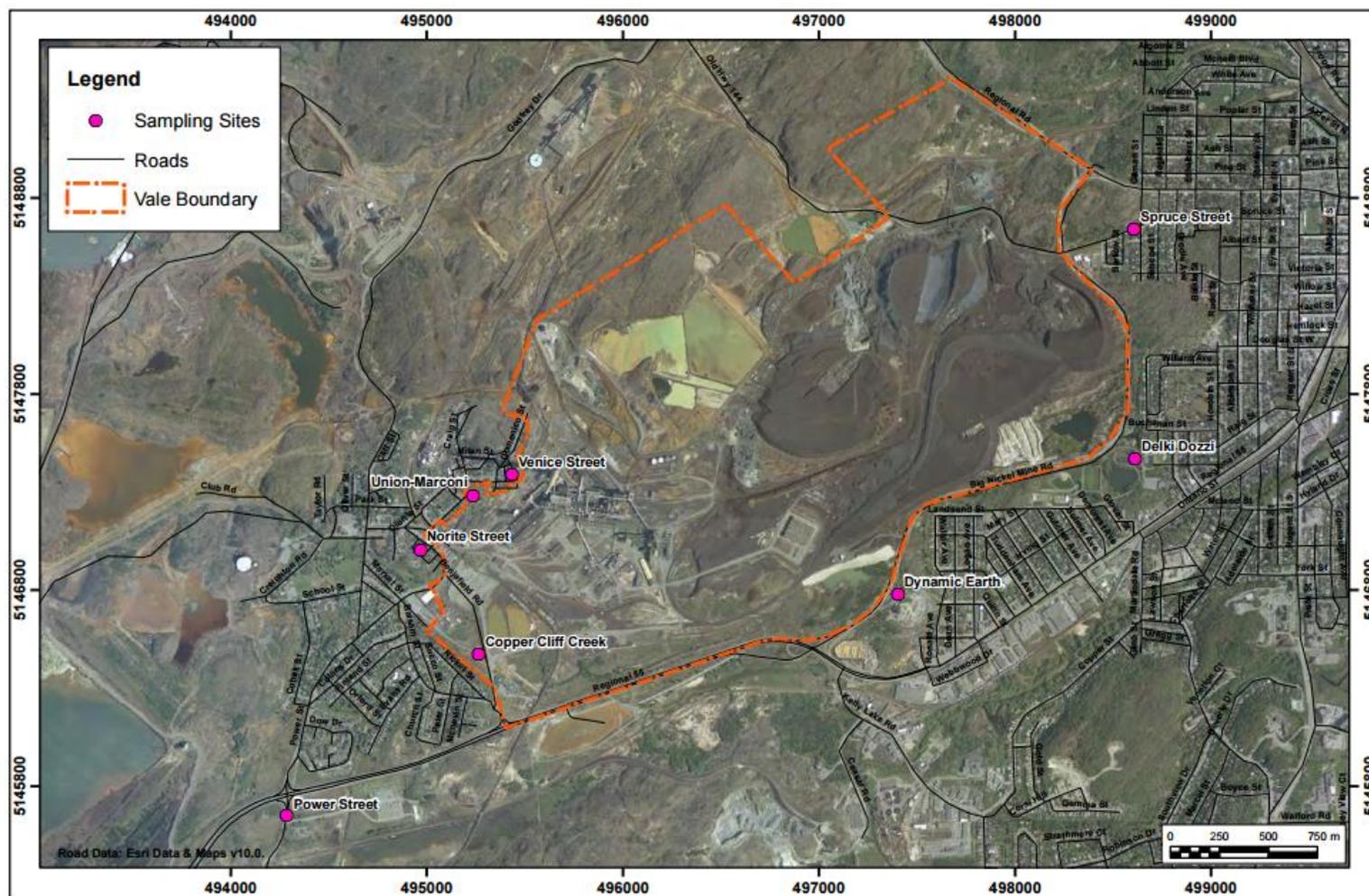


Appendix M: Backward Trajectory for the PM<sub>2.5</sub> Event of July 22, 2012

NOAA HYSPLIT MODEL  
Backward trajectory ending at 2300 UTC 22 Jul 12  
GDAS Meteorological Data



## Appendix N: Satellite Image of the Vale Particulate Monitoring Station Locations



Satellite image taken from the Vale 2014 Annual Ambient Air Quality Monitoring Report prepared by RWDI Air Inc.

## Appendix O: Satellite Image of the Glencore Particulate Monitoring Station Locations



Satellite image taken from the Air Quality Monitoring Annual Summary Report for 2014 prepared by Glencore