

Air Quality in Prince George

Summary Report

June 2016

Prepared for:

PRINCE GEORGE AIR IMPROVEMENT ROUNDTABLE

BRITISH COLUMBIA MINISTRY OF ENVIRONMENT

ENVIRONMENTAL PROTECTION DIVISION

MONITORING, ASSESSMENT AND STEWARDSHIP

Contents

Introduction 1
Monitoring Stations 1
Influence of Meteorology and Topography 2
Pollutant Sources and Health Effects 2
Data Completion Criteria 3
Trends 4
$PM_{2.5}$ 4
Wildfire Smoke 6
Monitor Exchange 7
PM_{10} 9
TRS 11
SO_2 13
Analysis and Discussion 17
Conclusions 20
Bibliography 21

Introduction

This report presents an overview of trends in ambient air quality within the Prince George Airshed. Pollutants of concern include $PM_{2.5}$[1], PM_{10}[2], TRS[3], SO_2[4], NO_2[5] and O_3[6]. Air Quality Objectives (AQOs) for each pollutant are provided below (Table 1).

Table 1: Air Quality Objectives for the six pollutants of interest

Pollutant	Averaging period	Objective
$PM_{2.5}$	24-hour[a]	25 µg/m^3
	Annual	8 µg/m^3
PM_{10}	24-hour	50 µg/m^3
TRS	1-hour[*]	20 ppb
	24-hour[*]	4 ppb
SO_2	1-hour[b]	75 ppb
NO_2	1-hour[c]	100 ppb
	Annual	32 ppb
O_3	1-hour[d]	82 ppb
	8-hour[e]	63 ppb

[a] 98th percentile of daily means for the year
[b] 99th percentile of daily 1-hour maximums for one year (interim objectives)
[c] 98th percentile of daily 1-hour maximums for one year (interim objectives)
[d] For advisory purposes – no percentile for annual reporting (interim objectives)
[e] Mean over three consecutive years of the 4th highest daily maximum 8 hour running average for each year. (CAAQS)
[*] Pollutant Control Objective for the Forest Products Industry

Monitoring Stations

Air quality monitoring in Prince George consists of one core site that measures all six pollutants and seven other sites that measure one to three of the aforementioned pollutants. Figure 1 shows the layout of the air quality stations in Prince George and the pollutants monitored. Plaza 400 (Site No. 0450307) is the core site maintained and operated by the Ministry of Environment. Exploration Place (Site No. E293670) and Marsulex (Site No. E270963) are permittee sites, and the rest, i.e., Gladstone (Site No. 0450270), Lakewood (Site No. 0450324), Corrections Centre (Site No. 0450322), CBC Transmitter (Site No. E209179), and BC Rail (Site No. E224013) are operated under collaboration between the Ministry of Environment, industry and the community through a stakeholder consortium called the Monitoring Working Group (MWG). In addition to air quality monitors, there are also several meteorological stations that provide valuable wind speed and direction, temperature, and humidity data. Three of these stations are collocated with air quality monitors at Plaza 400, Gladstone, and Exploration Place. The other two are located at Northwood and PG Pulp.

[1] $PM_{2.5}$: particulate matter with aerodynamic diameters less than or equal to 2.5 micrometers.
[2] PM_{10}: particulate matter with aerodynamic diameters less than or equal to 10 micrometers.
[3] TRS: total reduced sulphur
[4] SO_2: sulphur dioxide
[5] NO_2: nitrogen dioxide
[6] O_3: ozone



Figure 1. Map showing the locations and details of continuous air quality monitoring stations in Prince George for $PM_{2.5}$, PM_{10}, SO_2, TRS, O_3, and NO_2.

Influence of Meteorology and Topography

The city centre is located in a bowl shaped river valley, surrounded by steep ridge lines. As a result, Prince George, like many other interior communities in BC, is susceptible to high levels of air pollution during temperature inversions, when a stable layer of cooler air is capped by a layer of warmer air. Such conditions are often associated with light or calm winds and can persist for hours or days, resulting in stagnation of the air mass and a temporary buildup of pollutants in the valley. Temperature inversions can form at any time of year, but most commonly occur during winter months.

Pollutant Sources and Health Effects

Sources of $PM_{2.5}$ include, but are not limited to industry, wood stoves, motor vehicles and wildfires. $PM_{2.5}$ has a broad range of adverse health effects, predominantly affecting the respiratory and cardiovascular systems. Research has identified that both short-term and long-term $PM_{2.5}$ exposures are associated with adverse health effects [1, 2].

PM_{10} is composed of both fire particulates ($PM_{2.5}$) and more coarse material including winter traction material, dust from unpaved roads and dirt services surfaces, as well as emissions from wood processing industries. Elevated PM_{10} concentrations generally occur during late winter and early spring, when loose winter traction material becomes exposed on road surfaces. However, in dry summer conditions, PM_{10} concentrations can become elevated from lofting of dust, such as through suspension by mechanical activities like farming and construction, or due to

wildfires. While measurements of PM_{10} include $PM_{2.5}$, it is important to note that the primary source drivers causing PM_{10} exceedances are not necessarily the same as those causing $PM_{2.5}$ exceedances [3].

TRS includes any of four sulphur-containing compounds (dimethyl disulphide, dimethyl sulphide, methyl mercaptan and hydrogen sulphide), but SO2 is not included. TRS has a distinctive odour similar to rotten eggs and can be emitted from both natural and anthropogenic sources. Industrial sources include the steel industry, petroleum refineries, sewage treatment facilities and the pulp and paper industry. Natural sources include swamps, bogs, and marshes. TRS is classified as a nuisance pollutant at low concentrations with no known health impacts but it has an offensive odour, which can be detected by the human nose at low concentrations. At elevated TRS concentrations, sensitive individuals may experience headaches and nausea [4].

SO_2 has a pungent odour and can adversely affect both human health and the environment at high concentrations. Major sources of SO_2 include petroleum refineries, pulp and paper mills, and transportation particularly railway and shipping. Minor sources include residential and commercial space heating. At high concentrations, SO_2 can cause serious respiratory illnesses such as bronchoconstriction and asthma [5].

NO_2 is an important pollutant in urban areas. NO_2 belongs to a group of nitrogen-containing gases called nitrogen oxides (NO_x) which includes NO_2 and nitrogen oxide (NO). NO_x is produced from high temperature combustion of fossil fuels in vehicles, power plants and other industrial processes. Natural sources are limited and include wildfires and lightning. NO_x is primarily emitted as NO but is quickly converted into NO_2 in the atmosphere. NO_2 has negative health impacts from direct exposure and from being a $PM_{2.5}$ precursor. NO_2 is known to irritate the lungs, decrease lung function, cause inflammation of the airway and contribute to acid deposition in the environment [1, 6]. The provincial air quality objectives for NO_2 are 32 ppb for the annual mean and 100 ppb for the 98^{th} percentile of daily 1-hour maximums for one year.There have been no exceedances of the provincial guideline for NO_2 in Prince George over the period monitored. In 2014 the annual mean was 9.8 ppb. As such, NO_2 will not be further discussed in this report.

Ground-level ozone (O_3) is considered a secondary pollutant as it is not directly emitted into the lower atmosphere. It is produced through photochemical reactions involving NO_x, volatile organic compounds (VOCs) and the presence of sunlight. Sources of both NO_x and VOCs include industrial facilities, motor vehicle exhaust and chemical solvents. O_3 can have harmful impacts on both the environment (e.g. by damaging plant tissue) and human health [1] [7]. The provincial objective for O_3 is 63 ppb for the mean over three consecutive years of the 4^{th} highest daily maximum 8 hour running average for each year. There is also a 1 hour averaging period used for advisory purposes only. There has been a total of four O_3 advisories in Prince George – two in 1998 and two in 2001. There have been no further O_3 events and concentrations have remained well below the objectives. As such, ozone will not be further discussed in this report.

Data Completion Criteria

The Ministry of Environment requires at least 75% data availability in order for a data set to be considered valid. Valid daily averages (midnight to midnight) require at least 18 hourly measurements. When considering seasonal variability, annual data sets of $PM_{2.5}$ and PM_{10} require at least 75% of calendar days for each quarter to be valid in order for that year's data to be considered a valid data set.

Trends

Data trends for the Prince George airshed are presented using line graphs and bar graphs; the data presented are validated values from the various air quality monitors across Prince George with >75% data capture. Time series plots of the annual mean values are presented to provide a historical analysis of how pollutant concentrations have changed in Prince George over the span of monitoring. Although time series graphs are useful representation of the changes in pollutant concentrations over time, it is important to note that the annual mean values can be influenced by both large and small extreme events. Bar graphs of exceedance events have been included to provide information on the frequency of extreme occurrences through the monitoring history. Also included is a time series plot of daily mean values in 2014 for selected pollutants to provide more information on seasonal variations throughout the year.

$PM_{2.5}$

$PM_{2.5}$ is continuously monitored at Plaza 400 and Gladstone stations. The Plaza 400 site located downtown is in close proximity to industrial sources that are located in the northeast area of the city, while the Gladstone site is located in the southern region in a more residential area. The provincial objectives for $PM_{2.5}$ are 25 µg/m^3 - for the 98th percentile of one year's daily means and 8 µg/m^3 for the full annual mean. Annual mean values from 2006-2012 are 10-20% higher at Plaza 400 than at Gladstone. In 2013 and 2014, annual mean values at Plaza 400 were >40% higher than the 2012 mean.

Changes to the monitoring technology in 2013 are responsible for part of the discrepancy between annual means at Plaza 400 and Gladstone stations. In 2013, $PM_{2.5}$ monitoring at Plaza 400 transitioned from a TEOM Series 1400a (Rupprecht and Patashnick Co. Inc., NY, USA) to a SHARP Model 5030 (Thermo, MA, USA). Studies conducted in BC show that $PM_{2.5}$ annual mean concentrations measured using the SHARP instrument are 10% - 40% higher than TEOM measurements. The reported increases are primarily related to winter $PM_{2.5}$ concentrations where SHARP monitors provide a more complete measurement than the TEOM monitors [8].

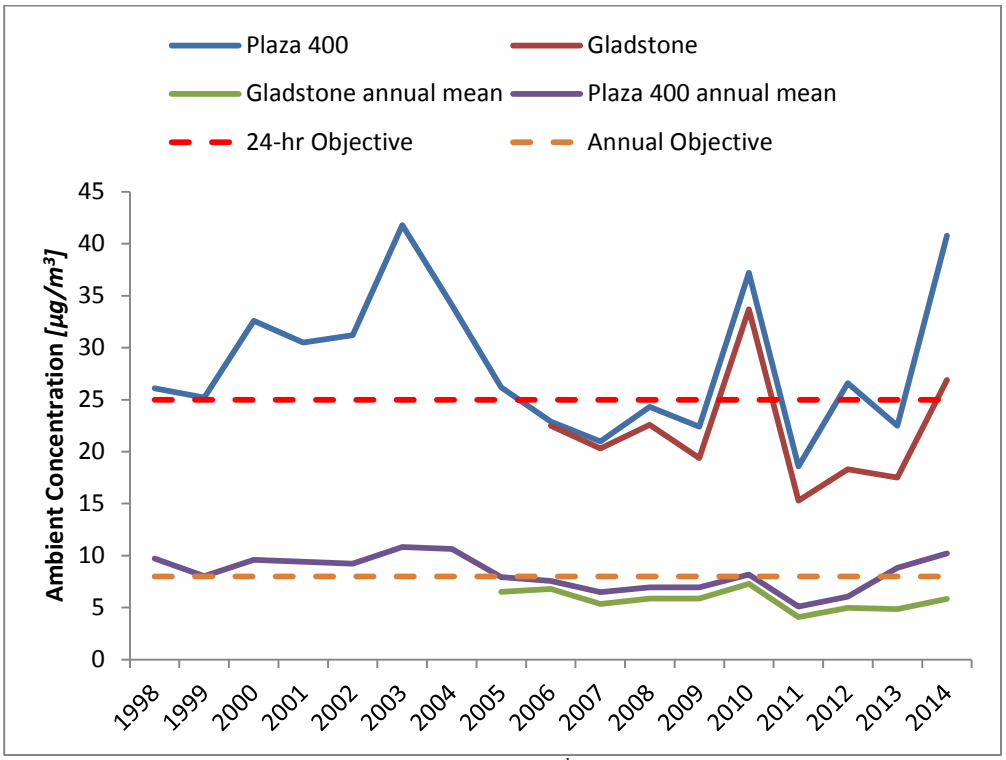


Figure 2. $PM_{2.5}$ concentrations for Prince George, annual 98th percentiles and annual mean concentrations. Data completeness not met by Gladstone in 2007

Annual mean values from the full period of sampling (1998 – 2014) demonstrate a general downwards trend over time for $PM_{2.5,}$ with the exception of 2010, which had high reported concentrations that reflect a highly active forest fire season. In addition, there have been elevated concentration levels reported at both monitoring sites (Plaza 400 and Gladstone) in 2014. Figure 3 reports the number of exceedances reported at the two $PM_{2.5}$ monitoring sites in Prince George. Plaza 400 has reported more exceedances for all years excluding 2006.

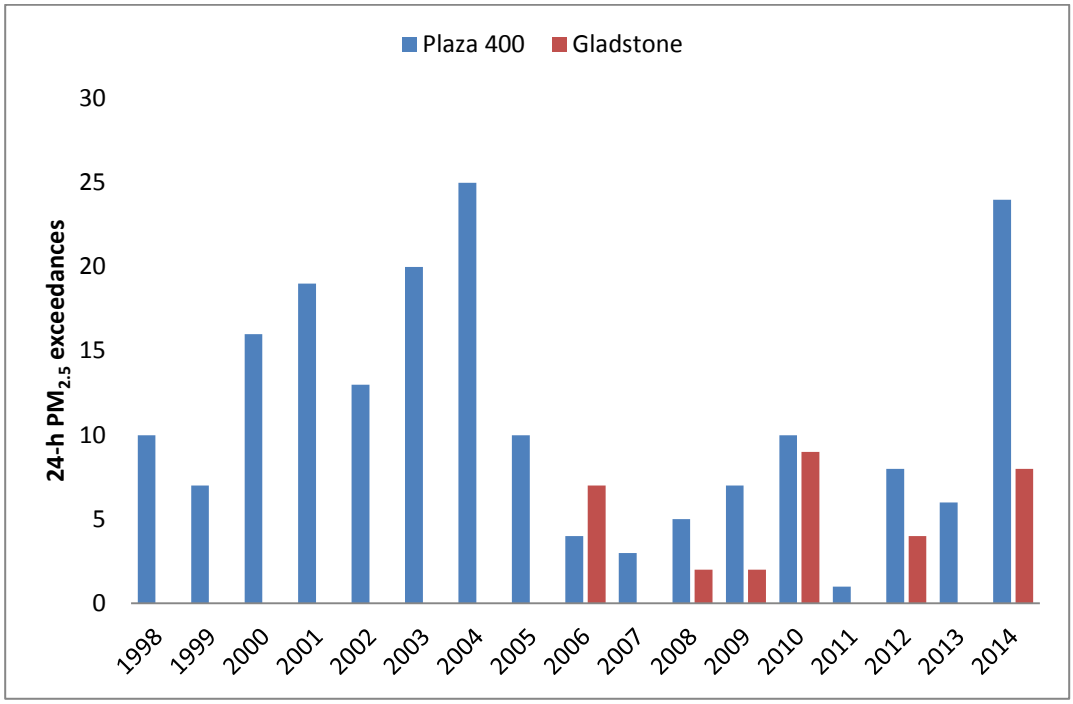


Figure 3. Number of $PM_{2.5}$ exceedances in Prince George. Data completeness not met by Gladstone in 2007.

In 2014, 24 exceedances of the numerical 24-hour Provincial $PM_{2.5}$ objective were observed at Plaza 400 (Figure 3). The majority of these exceedances (58%) occurred from July-September as a result of wildfires (Figure 4), including the Chelaslie River wildfire that burned an unprecedented 1331 km^2 of the Entiako Provincial Park just 200 km southwest of the station. The remaining exceedances generally occurred during late winter periods when meteorological conditions can create stagnant conditions and wood burning appliances and other sources emit particulates that become trapped in the local air.

Seasonal variations in $PM_{2.5}$ concentrations are evident in the 2014 time series of both sites (Figure 4). The plot identifies the summer exceedances linked to wildfires and the winter events linked to meteorological conditions. The majority of exceedances occurred between July and September with other exceedance events occurring in November and February.

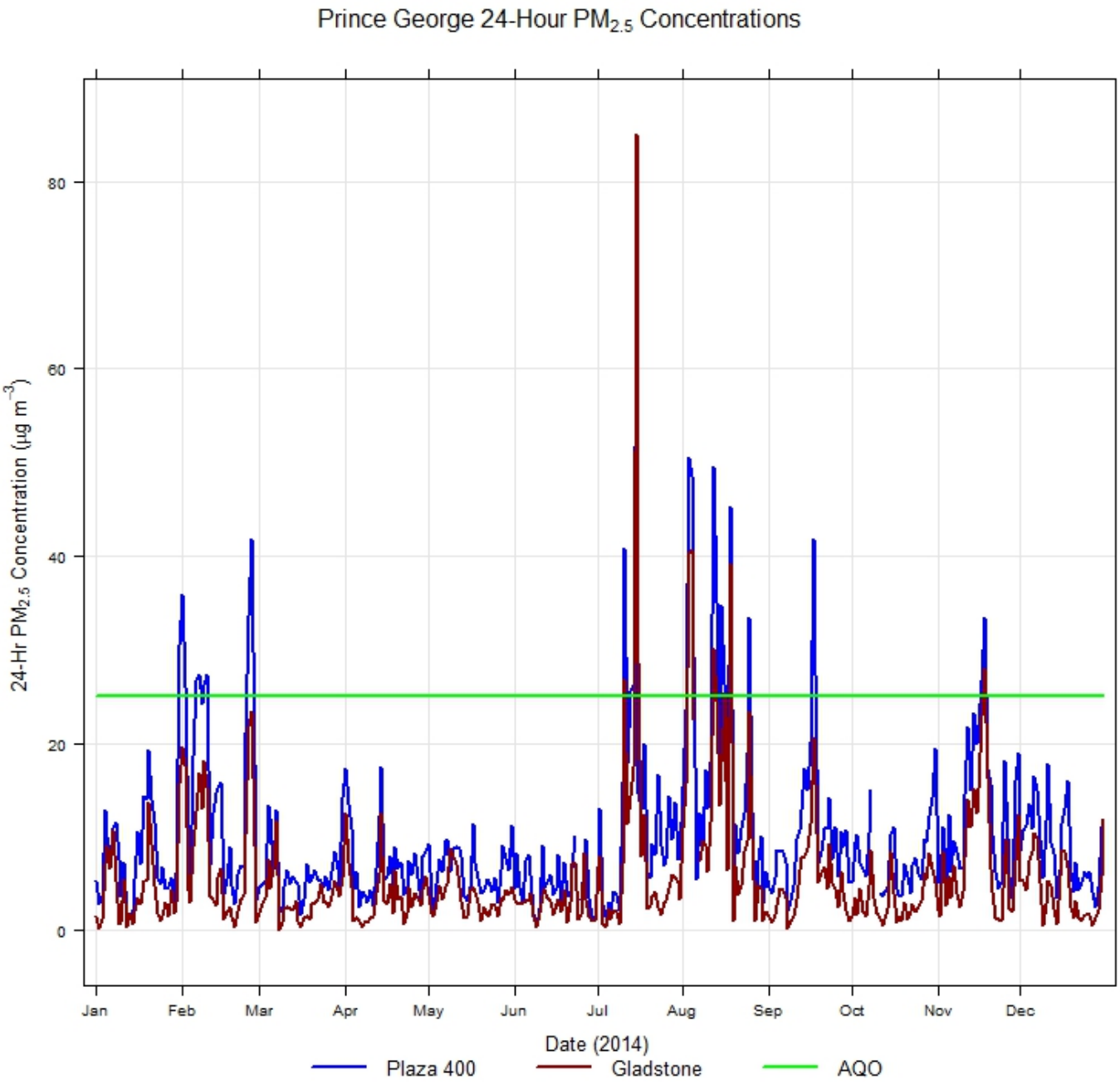


Figure 4. Time series plot of daily $PM_{2.5}$ concentrations in 2014

Wildfire Smoke

Smoke from wildfires can result in a significant deterioration in air quality; sometimes for extended periods of time. In 2014, wildfire smoke advisories were issued in both July and August. Wildfire smoke is typically the primary cause of $PM_{2.5}$ exceedances in Prince George over the summer. Due to the unpredictable nature of wildfire events, they cannot be effectively managed at the community level. PM concentrations excluding wildfire smoke were estimated for 2014 in order to determine the impact of wildfires on the overall trend of $PM_{2.5}$ during this high activity year and provide a more accurate evaluation of progress made as a result of the airshed planning process. This was done by not including days in July, August and September (the three months with the greatest wildfire activity) with $PM_{2.5}$ values greater than 20 $\mu g/m^3$. There is no standard method for removing the effect of wildfires from data-sets,

but this simple method has been found to work well for interior communities in this province. The estimated influence of forest fires on both 24 hour and annual mean PM concentrations at Plaza 400 and Gladstone in 2014 can be seen below in Figure 5. The applicable AQOs are a 24-hour mean of 25 µg/m^3 and an annual mean of 8 µg/m^3.

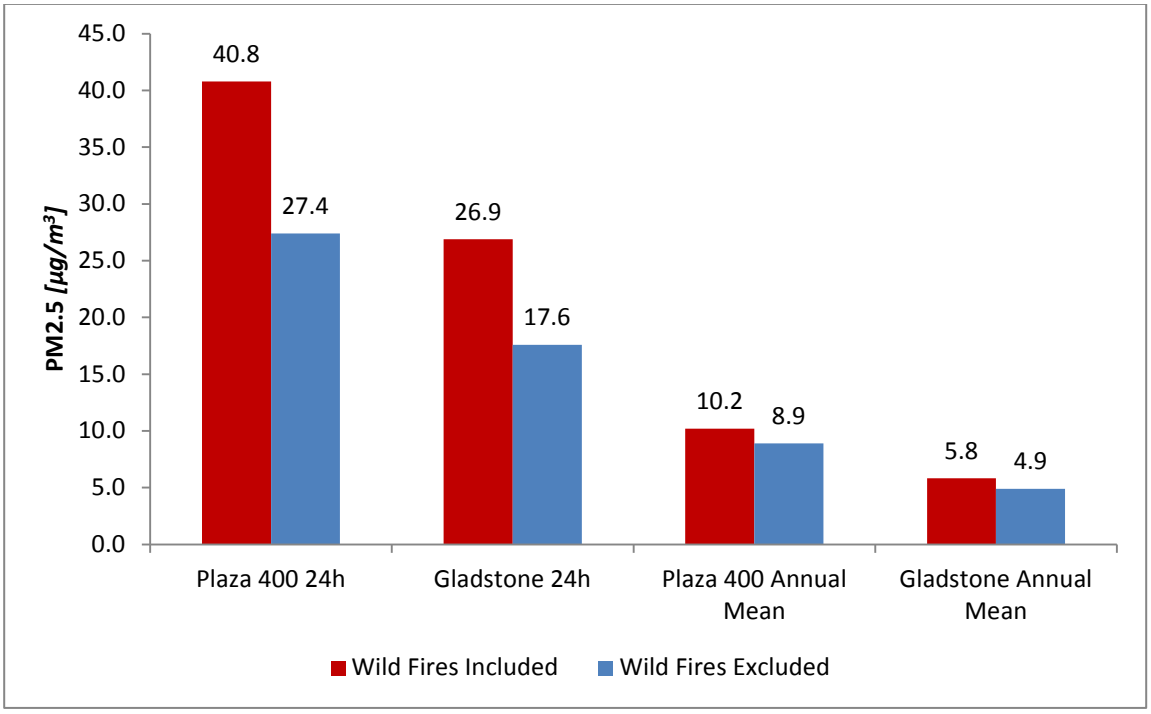


Figure 5. Estimated impact of wildfires on $PM_{2.5}$ concentrations in Prince George in 2014

Monitor Exchange

The upgrade from the older TEOM monitoring system to the more modern SHARP instrument has also had an impact on the $PM_{2.5}$ concentrations reported for 2014. Figure 6 presents the trends of $PM_{2.5}$ for both the TEOM monitor and SHARP monitor at the Plaza 400 station in 2014. The SHARP sampler clearly trends higher than the TEOM monitor, particularly in the winter when there are colder temperatures. While both samplers are approved methods for monitoring $PM_{2.5}$ in Canada, the newer SHARP sampler provides a more complete picture of $PM_{2.5}$ in many parts of the country including Prince George. In Prince George there is approximately 35% difference between the TEOM and SHARP monitoring systems.

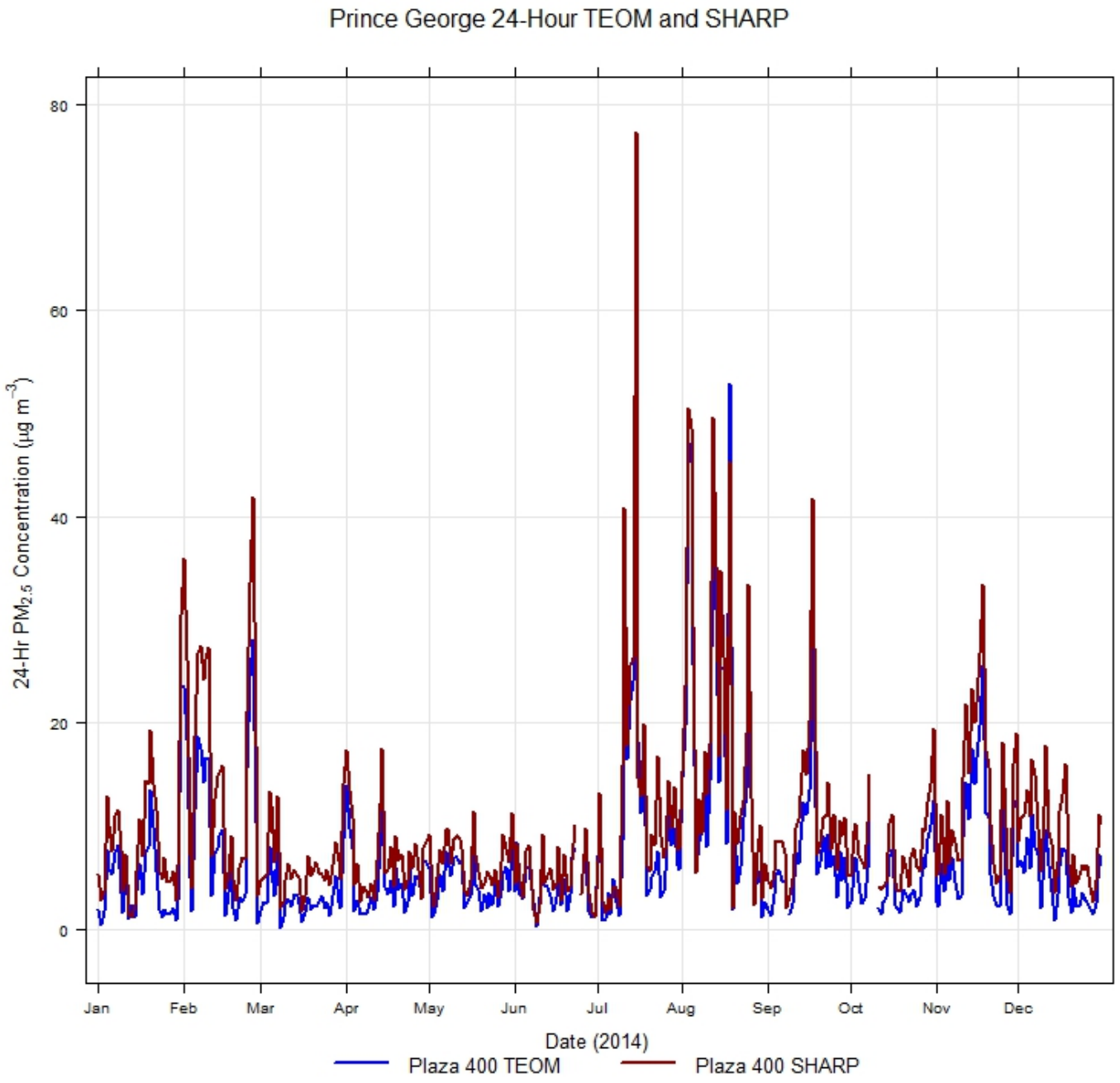


Figure 6. Comparison of $PM_{2.5}$ results from TEOM and SHARP instruments at Plaza 400 for 2014

PM_{10}

PM_{10} monitoring in Prince George is performed at three sites using TEOM 1400a analyzers. The provincial objective for PM_{10} is 50 µg/m^3 for the maximum daily (24-hour) mean for the year. Historical trends across the sites (from 1994 to 2014) are reported in Figure 7 and demonstrate a slight downwards trend in PM_{10} concentrations over time, with the concentrations levelling off in recent years at all sampling sites. In the historical data, values at all three sites in 2006 were slightly elevated, particularly in relation to the years that follow. Figure 8 reports on the number of exceedances recorded for each sampling site in the PM_{10} monitoring network. Exceedances were highest at the BC Rail site, located in a heavy industrial facility, and lowest at Gladstone, a residential monitoring site. In 2014, the highest PM_{10} mean values and number of exceedances were recorded in August at the Plaza 400 and BC Rail sites, coinciding with significant wildfires that also increased $PM_{2.5}$ concentrations (Figure 9). There were, however, several exceedances throughout the year; BC Rail Warehouse reported the highest number.

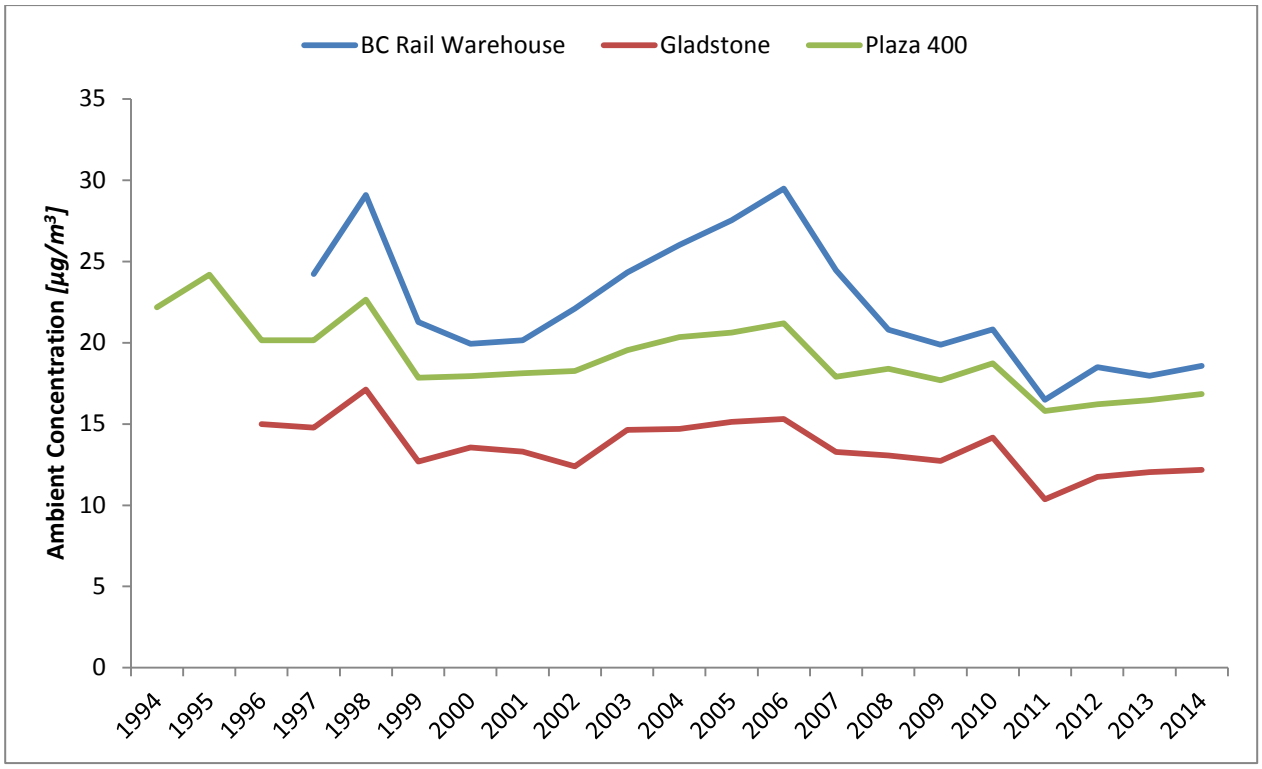


Figure 7. Annual concentrations of PM_{10} for sample sites in the Prince George region

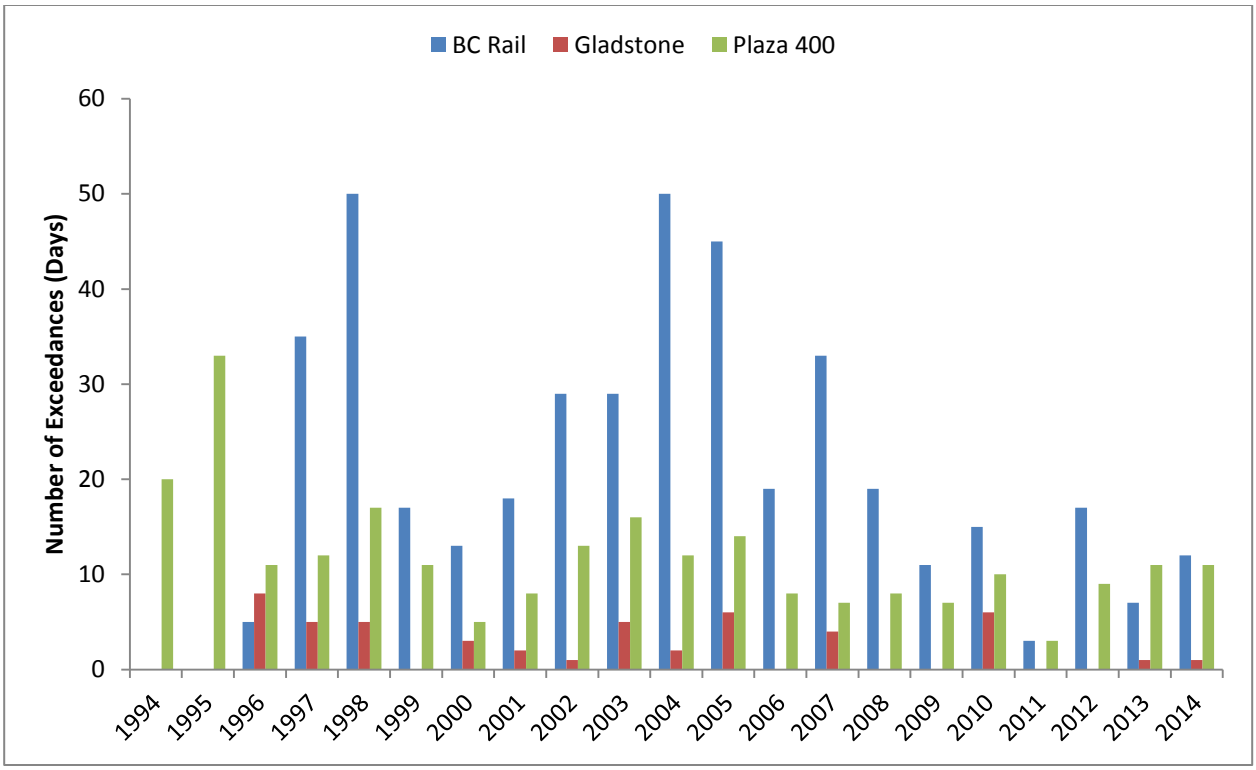


Figure 8. Number of PM_{10} exceedance days.

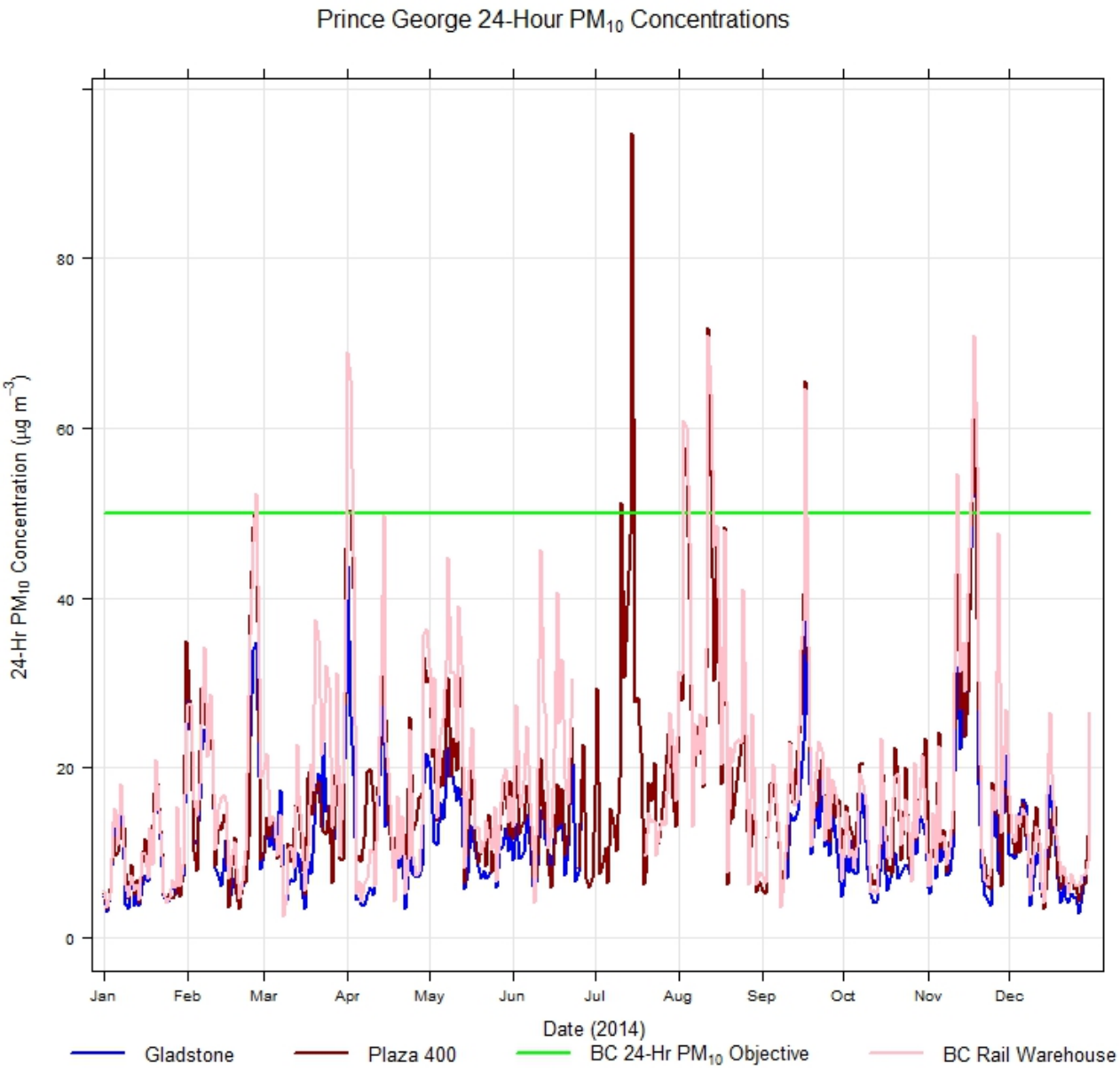


Figure 9. Daily PM_{10} concentrations for the Prince George region.

TRS

There are four TRS samplers located in the Prince George airshed. They are located at Plaza 400, Lakewood Jr. School, Exploration Place and the Regional Correction Centre. There are no provincial air quality objectives for TRS; however the pollution control objectives (PCOs) for the forest products industry, established in 1977 and repealed in 2006, have been retained for reference purposes. The PCOs for TRS are categorized into two levels with two time metrics: Level A –"desirable goal for all discharges", with 5 ppb for 1 hour measurements and 2 ppb for 24-hr measurements and Level B, "an acceptable interim objective", is 20 ppb for hourly averages and 4 ppb for daily measurements.

Annual trends for Plaza 400 measurements are reported in Figure 10. Daily mean values for 2014 are reported in Figure 11. There is a long record of concentrations at three of the four sites, while the Exploration Place is a new monitoring station and does not have an extensive data record. In 2013, the site was rebuilt and did not achieve data completeness requirements. An artificial value has been introduced by taking the mean between 2012 and 2014 to provide a better picture of data available for 2014. The Lakewood sampling site has historically trended below the other three sampling sites. Figure 10 demonstrates that TRS concentrations have been relatively constant until 2011 when there was a sharp drop in concentration. From 2012 to 2014, there have been elevated annual mean concentrations at all sampling sites.

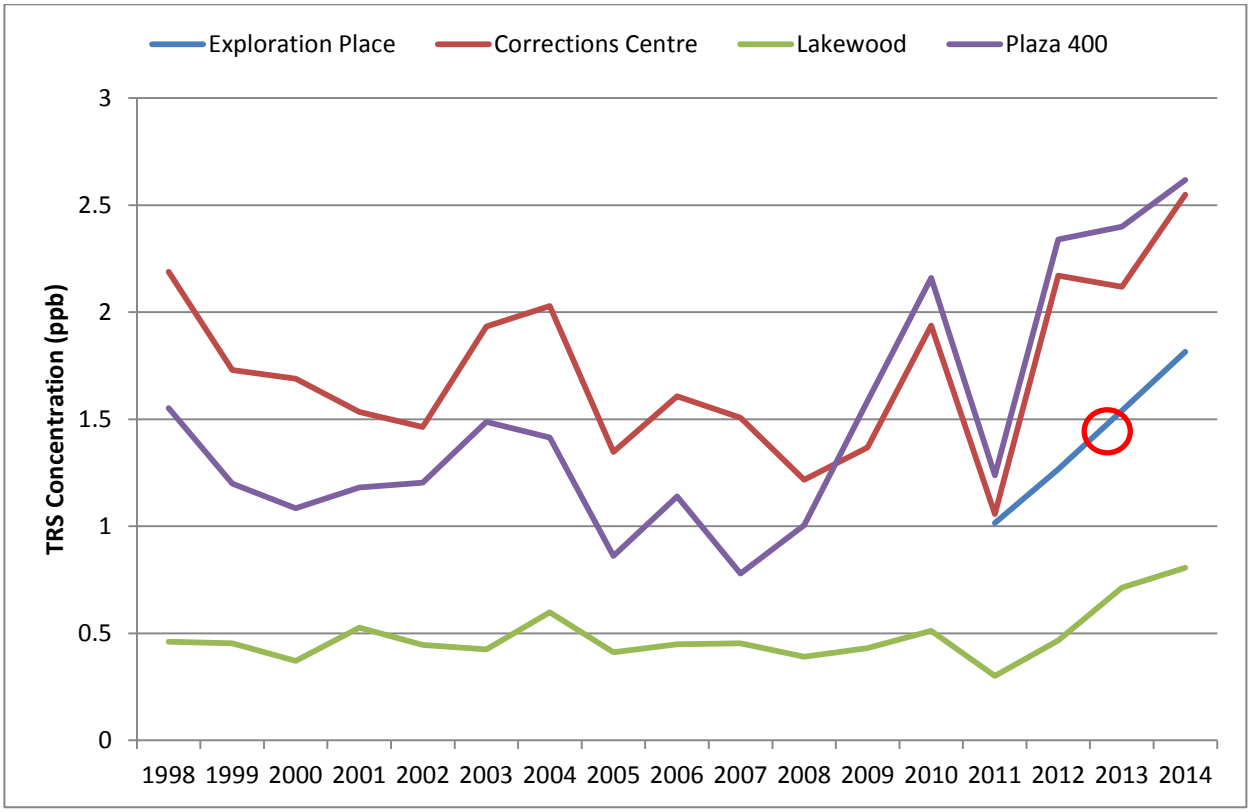


Figure 10. Annual means for TRS sampling in Prince George. Data completeness was not met by Exploration in 2013. The circled value has been artificially introduced to display the 2014 data.

Figure 11 shows the variation in TRS concentrations during 2014 for all available monitoring data with reference to the rescinded PCO values. As previously noted in the long-term monitoring - Lakewood trends below the remaining three sampling sites. There is significant variation between days, with the greatest variation in the winter months. There are two peaks of interest – early August and late September. Variation between the sites can again be seen with Lakewood generally reporting much lower concentrations than the other three sampling sites.

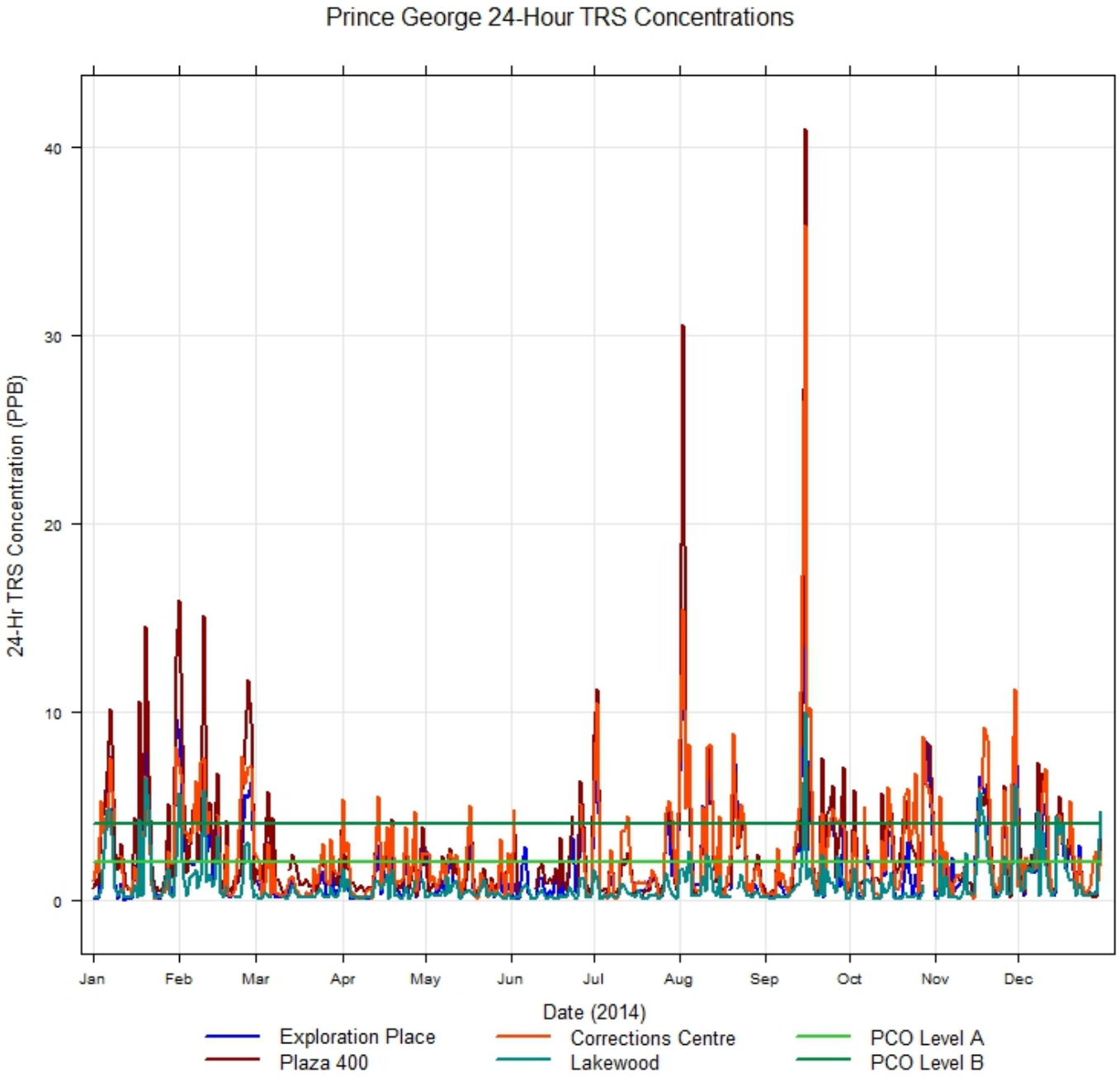


Figure 11. 24 hour concentrations of TRS for 2014. The PCO values have been included for reference.

SO_2

SO_2 is monitored at five sites in the Prince George area: Plaza 400, CBC Transmitter, Gladstone Jr. School, the Regional Correction Centre and the Marsulex Acid Plant. The Interim Provincial Air Quality Objective for SO_2 is 75 ppb for the 99th percentile of daily 1-hour maximums for one year. Trends in annual 99th percentiles of daily maximum SO_2 concentrations are provided in Figure 12. This figure demonstrates that over time there has been great variation in the concentration of SO_2 and that the concentrations are heterogeneous across the community. The Gladstone and Plaza 400 community monitors and the Marsulex Acid plant monitor have stabilized below the

Interim Air Quality Objective while the Regional Correction Centre marginally exceeds the Objective. The CBC Transmitter site is well above the Objective.

Figure 13 similarly provides the daily 1-hour maximum values for 2014. There is significant variation in concentrations both at and between sites. Once again, the CBC Transmitter site reported the highest values, most exceedance hours and most variation (Figure 14). The Corrections Centre site also reported several exceedances of the Interim Objective, but with lower frequency and concentrations than of the CBC transmitter. The remaining sites reported much lower concentrations and are more consistent with each other.

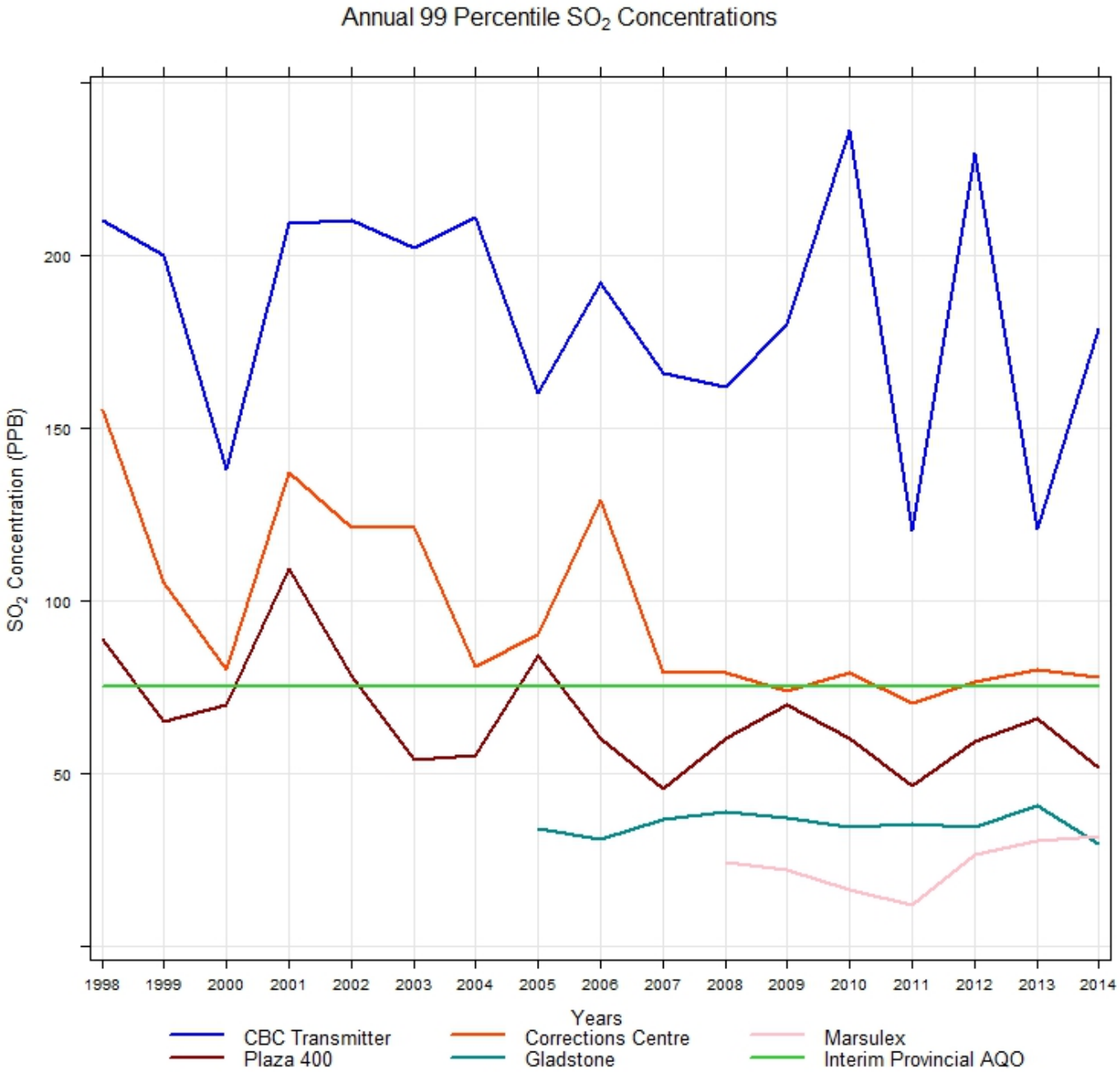


Figure 12. Annual 99th percentile of daily 1-hour maximum values of SO_2 in the Prince George area.

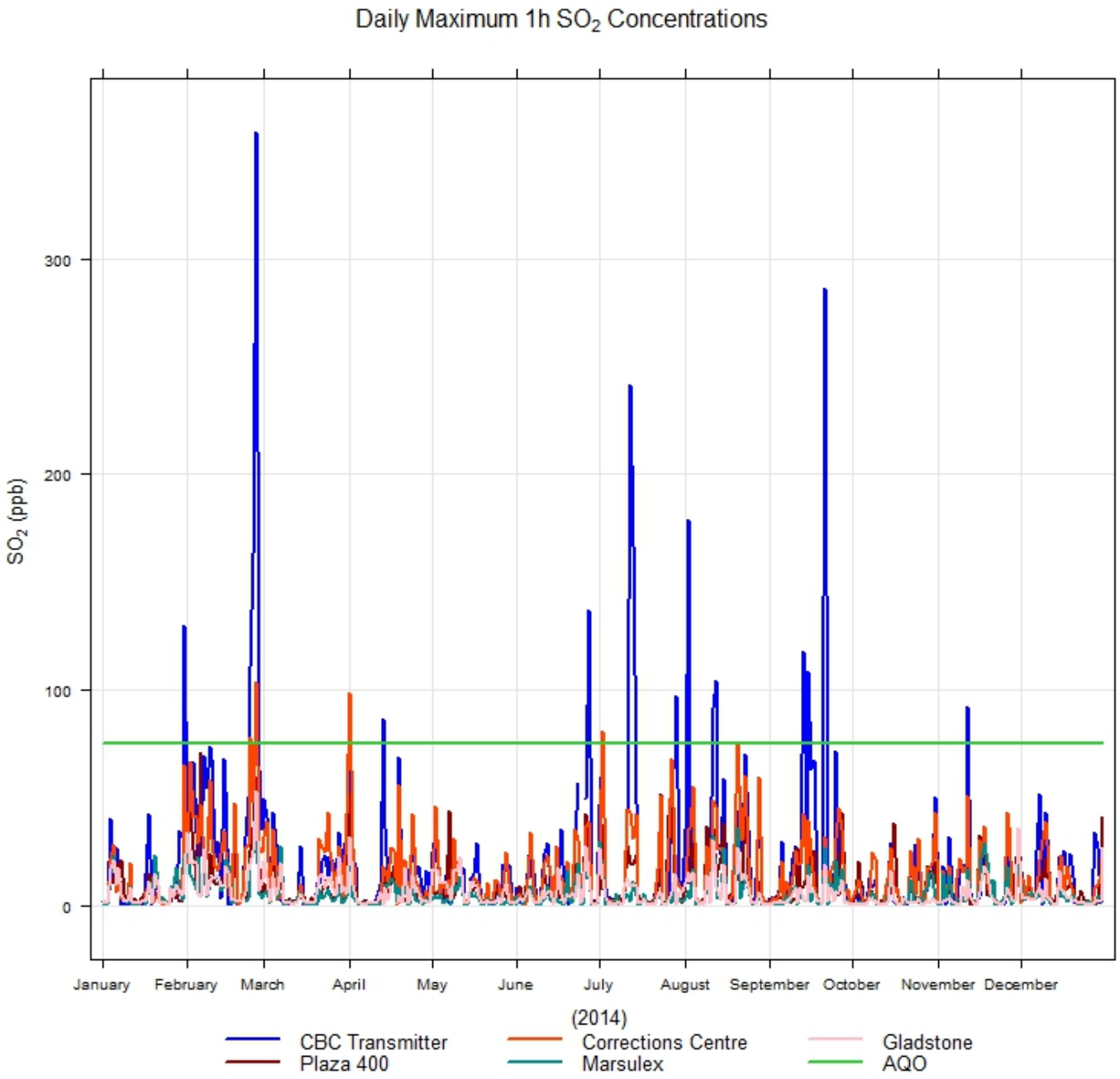


Figure 13. Daily 1-hour maximum concentrations of SO2 in Prince George.

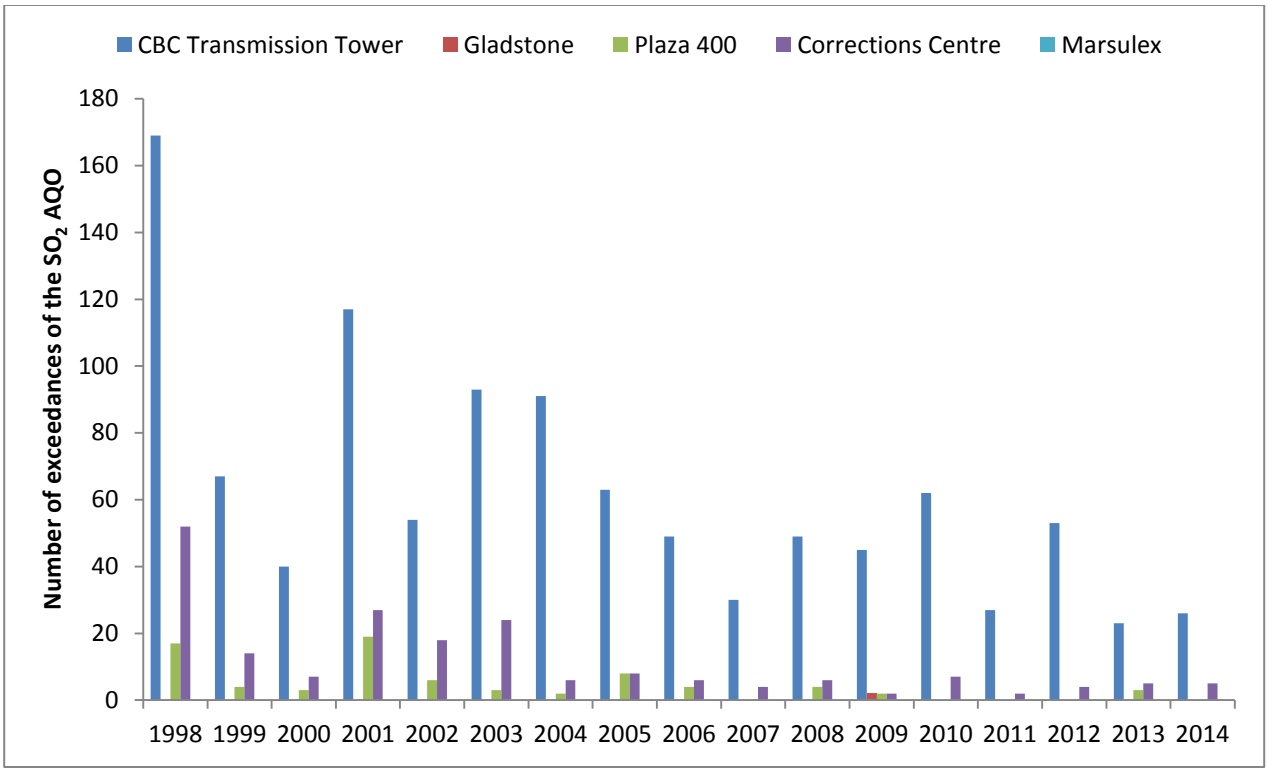


Figure 14. Number of hours above the AQO of 75 ppb.

Analysis and Discussion

Trend analysis of the ambient monitoring data from the Prince George area provides valuable understanding of how pollutant concentrations have changed over time. Of the six monitored pollutants, two (NO_2 and O_3) have not been presented or discussed in depth as their concentrations have been well below provincial objectives for many years. The remaining four pollutants are further discussed below.

Figure 2 provides both annual averages and 98th percentiles of daily concentrations of $PM_{2.5}$ and the associated provincial objectives (8 µg/m^3 and 25 µg/m^3 respectively). These values provide two different ways to look at the same information: chronic exposure using the annual mean concentration and relatively short term exposure using the 24 objective. The trends of both measurements are generally downward through the monitoring history at both sampling sites until 2013. However, particularly active wildfire seasons in 2010 and 2014 led to extreme concentrations, while a very wet year in 2011 led to a decrease in concentrations which demonstrates the impact of climatological conditions on air quality in the community. Figure 5 demonstrates that when wildfire smoke can account for up to a third of the total concentration of $PM_{2.5}$ present in ambient air in Prince George. The censoring system used to explore the relationship between $PM_{2.5}$ in Prince George is a rough method that does not account for elevated concentrations due to wildfire smoke below 20 µg/m^3 or impacts due to wildfires that occurred outside of the three targeted months (July, August and September). However, this method does work reasonably well in BC for interior communities and provides valuable information on both the possible impact of wildfires within communities, as well as giving an estimate of how much of measured $PM_{2.5}$ is likely due to local sources. This information indicates the challenge of remaining below the Provincial Air Quality Objectives for communities who are regularly exposed to wildfire smoke.

In 2014, the 24-hour and annual means at the Plaza 400 monitoring station exceeded the AQO and diverged from the Gladstone monitoring site, which reported smaller increases in 24-hour and annual concentrations over the same time period. In 2013, the Plaza 400 $PM_{2.5}$ monitoring instrument was upgraded from a TEOM to a SHARP instrument, which has been found to result in an increase of 10% to 40% in reported $PM_{2.5}$ concentrations across the province. In Prince George, there was approximately a 35% increase in concentrations from the monitor exchange. It is important to note that both monitoring systems are approved for $PM_{2.5}$ monitoring in Canada, the newer SHARP monitors are more accurate for local conditions. This monitor exchange likely accounts for much of the greater increase in $PM_{2.5}$ levels recorded at Plaza 400 in 2013 and 2014 relative to the Gladstone monitoring site, which is still using a TEOM monitor (Figure 2). Total exceedances of the provincial objective are reported by year and site in Figure 3. It is clear that in the majority of years where both sites were sampling, the Plaza 400 site reported more exceedances than Gladstone, which can be attributed to differences in local land use conditions for the majority as well as the difference in monitoring systems for 2013 and 2014.

During 2014, there were 24 exceedances of the 24 hour $PM_{2.5}$ objective reported at the Plaza 400 monitoring site and another 8 reported at the Gladstone monitoring site. Many exceedances were recorded from July to September during the active wildfire season, with 58% of exceedances at Plaza 400 and 87% of exceedances at Gladstone occurring during this time period. In particular, the Chelaslie River fire had a significant impact on $PM_{2.5}$ levels in Prince George during this time period. The remainder of the exceedances occurred during late winter, when meteorological inversions which produce stagnant conditions and limit normal dispersion of pollution are more common. Figure 4 provides trend analysis of $PM_{2.5}$ monitoring data from 2014. There is significant variation between the two sampling sites with Plaza 400 having a higher general concentration when compared to Gladstone, which is a result of both the different environments of the two monitors and the different monitoring instruments being used at those sites. There is a significant increase in $PM_{2.5}$ at Gladstone during July which is most likely related to wildfire smoke impacting on one monitoring system while not impacting on the Plaza 400 site.

Figure 5 shows that smoke from wildfires in the summer appear to contribute significantly to the total $PM_{2.5}$ concentrations for the year. Even when wildfire impacts are censored, the recorded concentrations at the Plaza 400 site still exceed the AQOs. This indicates that, while wildfires do have an impact on the pollutant load, local emissions are still significant and are likely lead to exceedances even in the absence of wildfires.

Overall, there has been a slight downward trend in $PM_{2.5}$ concentrations within Prince George since sampling began in 1997 (Figure 2). However, this trend was reversed in 2013 and 2014, most likely due to a dry year with a very active wildfire season across the province in 2014. There has been an increase in $PM_{2.5}$ at the Plaza sampling site in 2013 and 2014. However, this can be primarily attributed to the monitor upgrade, and does not necessarily indicate an increase in $PM_{2.5}$ emissions in the community, just a clearer picture of what was already occurring.

PM_{10} (particles with an aerodynamic diameter $\leq$ 10 μm) is sampled at three sites in Prince George – Plaza 400, Gladstone and the BC Rail Station. Concentrations of PM_{10} at these stations generally remained relatively constant or dropped slightly over the 15 year sampling history. However, in both 2013 and 2014, slight increases are evident (Figure 7). The slight increase is most likely related to generally dry conditions in the past two years resulting in particularly active wildfire seasons. In 2010, a highly active wildfire year, there was a much greater relative increase in the amount of $PM_{2.5}$ than PM_{10}, which suggests that the two components of PM do not necessarily have the same sources even though $PM_{2.5}$ is included in PM_{10}. PM_{10} is primarily related to road dust or dust from un-vegetated surfaces, industrial areas and construction work while $PM_{2.5}$ is more closely related to combustion.

Exceedance events for PM_{10} follow a similar pattern, occurring with decreasing frequency until 2008, after which the number of exceedances remained generally stable. The BC rail site has historically had the most exceedances, followed by Plaza 400, with Gladstone experiencing very few. In 2014, there were 10 exceedances at Plaza 400, 13 at the BC Rail Station monitoring site, and 1 at the Gladstone monitoring site. Similar to $PM_{2.5,}$ the majority of the exceedances took place during the summer, coinciding with the hot, dry weather and active wildfire seasons when there is significant dust and smoke in the atmosphere. The BC Rail Station monitoring site is located in an industrial area with large vehicles and unpaved surfaces. As such, it is not surprising to find exceedances of PM_{10} in this area during a dry spell or dry season. Plaza 400, which is located near the BC Rail Station, is affected by wind-blown dust from the rail yard that contributes to the PM_{10} levels while Gladstone is in a residential area with more vegetative cover.

Trend analysis of 2014 PM_{10} is presented in Figure 9. This figure presents daily averages of PM_{10} for all days which satisfied completion requirements. Significant variation of daily concentrations is clear at each of the sampling sites. Likewise, a strong relationship between the BC rail warehouse and Plaza 400 sites can be seen. The Gladstone site generally follows the same pattern but at much lower concentrations and .The peak concentrations are less extreme as the particulates are buffered by the surrounding land use and vegetation. The greatest number of AQO exceedances occurred during the dry season of July to September with other events in November as vegetation dies off and in February and March as snow cover disappears and exposed road grit contributes to ambient dust.

There have been overall improvements in PM_{10} concentrations since monitoring began in 1994. It is important to note that, while there is slight improvement in total concentrations, there have been decreases in the number of exceedance events within the community, particularly at the BC Rail Warehouse site. This suggests that control methods are reducing ambient concentrations to lower levels. In 2014, we can see that the majority of elevated concentrations occurred in the dryer summer, but also with increases in November – possibly due to vegetation die off, – and in early spring, most likely related to snow melt and road grit.

There have been improvements in $PM_{2.5}$ and PM_{10} concentrations and a decreasing trend in the number of exceedances. While wildfires play a significant role in ambient concentrations, particularly in the summer, there are exceedances which were not related to wildfires for both size fractions of PM and, as such, there is still room for improvement. Recommendations for improvement include: changing to CSA approved wood stoves, better wood

storage, cleaner fuels, better management of point sources, prompt clean-up of winter traction materials and dirt transported onto roads, and better dust management for unpaved and non-vegetated surfaces.

Historical trends of mean annual TRS concentrations from 1998 to 2014 are presented in Figure 10. TRS concentrations were on a slight downward trend for the first 10 years of monitoring. However, from 2008 to 2010, there was a sharp increase in TRS concentrations. Concentrations were much lower in 2011, but steadily increased at all sites from 2012 to 2014. This figure also demonstrates similarity and variability between concentrations recorded at the sampling sites. Plaza 400 and Corrections Centre sampling sites are quite similar, while Lakewood is less than half of the previous two sampling sites. Plaza 400 and the Corrections Centre monitoring sites are geographically similar and are most likely responding to the same TRS sources. The newest sampling site – Exploration Place – is also located nearby and reported similar concentrations, so it might also be affected by the same sources. Lakewood is located at a higher elevation, which could be why it is less impacted by TRS.

Daily mean concentrations of TRS from 2014 (Figure 11) seem to indicate a seasonal pattern, with the lowest concentrations occurring between March and July, and the greatest variation occurring during the colder months of October to March. There were two extreme peaks, with the first in late July, only being reported by the Plaza 400 and Corrections Centre monitoring sites, possibly indicating a local event, and a second extreme event in mid-September reported by all monitoring sites. It is possible that these events were influenced by meteorological conditions or temperature changes. The greatest variability in concentrations was in the winter. These swings in concentrations could be related to inversion events which trap pollutants near to the ground and the monitoring stations. Caution should be exercised, however, in drawing conclusions based on this data. The overall concentrations are generally low, so peaks in concentrations may be influenced by relatively extreme short term events where there is one hour in the day which has a very high value pulling up the daily average. While TRS is not considered a health risk at the concentrations observed in Prince George, it has an odour that can be an unpleasant nuisance to local residents.

Figure 12 shows the SO_2 monitoring history for Prince George using the annual 99^{th} percentile of maximum daily values relative to the AQO of 75 ppb since monitoring began in 1998. This figure identifies a strong disparity in concentrations between the different sites within the community. The Marsulex and Gladstone sampling sites are well below the AQO and are consistent between years. Plaza 400 and the Corrections Centre indicate consistent improvement of SO_2 measurements, with concentrations at both of these sites decreasing in variability and concentration, such that values at the Plaza 400 station have been below the AQO for several years while the Corrections Centre is now only slightly exceeding in some years. The final site, CBC Transmitter, has not decreased in concentration and is significantly above the applicable AQO for all monitoring years. This monitoring site, due to its elevation and location, has much greater exposure to stack emissions driven by dominant winds and was chosen because it was the location modelled to have the highest SO_2 concentrations in the community. Figure 14 shows the number of hours per year at each monitoring station that exceeded the SO_2 AQO. This figure demonstrates a significant downward trend in the amount of time that community residents were exposed to SO_2 concentrations exceeding AQOs, with the majority of the exceedances occurring at the CBC Transmission Tower, which is to be expected as previously noted. This indicates that not only has there been a long term downward trend in SO_2 concentrations, there is also a decrease in the frequency with which exceedances occur.

Figure 13 presents 1-hour daily maximum concentrations from 2014. The CBC transmitter station exhibits much higher peaks of SO_2 than the other monitoring locations. These peak events could be caused by local meteorological conditions such as changes in wind direction or short term process changes in the SO_2 sources in the region, as well as the higher elevation of the CBC transmitter site, and its position relative to the major industrial sources of SO_2.

Conclusions

Overall, there has been a consistent improvement in air pollution in the Prince George area over the last 15 years. These improvements have been driven by lowered concentrations of several key pollutants in the area including SO_2, PM_{10} and $PM_{2.5}$. There have been decreasing numbers of exceedances of these pollutants in the last three years, which is most likely due to the airshed planning process, improved pollution controls and other changes implemented by local industry.

While there have been increases in the concentration of $PM_{2.5}$ and number of exceedance days reported at the Plaza 400 site in 2013 and 2014, a portion of the increase can be attributed to the upgrade of the older TEOM to the newer SHARP instrument, which reports approximately 35% high values in Prince George. These higher values are predominantly reported in the winter when the SHARP monitoring system provides a more complete picture of cold weather emissions than the older TEOM. The remainder of the increased concentrations at the Plaza 400 site and the increased $PM_{2.5}$ concentration at the Gladstone site can be attributed to a highly active wildfire season. This report also identifies the impact of climatological conditions on local air quality, with 2010 and 2014 wildfires creating high concentrations of $PM_{2.5}$, while a very wet year in 2011 led to a decline in $PM_{2.5}$ concentrations.

Like $PM_{2.5}$, the majority of PM_{10} exceedances occurred during the summer due to wildfires and dry conditions. However, with both types of PM, there are also exceedances that occur at other times in the year that are unrelated to wildfire activity, such as PM_{10} exceedance events in the early spring related to winter traction material. The majority of PM_{10} exceedances occurred at the BC Rail Station monitoring site. This is expected due to the industrial activities taking place at the site, dry conditions and wildfire activity, occurring during late summer when conditions are dry and wildfires are active. Exceedances reported at the Plaza 400 monitoring site occurred during all seasons and were related to dry conditions and wildfires in the summer and winter traction material in the winter.

A slight increase in TRS concentrations across the community is evident over the last few years and has resulted in increased odour complaints. While not linked to any identified health impacts at the concentrations that are being monitored, it is a source of significant annoyance in the Prince George Community. SO_2 has demonstrated a significant downward trend over time with fewer exceedances in recent years.

Over the period of monitoring of air pollution in Prince George there have been improvements in air quality in the community. This is evident by decreasing concentrations of various pollutants and decreasing in the number of exceedances of provincial objectives. These air quality improvements can be attributed to the airshed management process and improvements by all the stakeholders in the Prince George Airshed. However, there are still improvements that could be made with further stakeholder engagement and effort to continue to improve air quality in Prince George.

Bibliography

[1] R. Laumbach, "Outdoor Air Pollutants and Patient Health," *American Family Physician,* vol. 81, no. 2, pp. 175-180, January 2010.

[2] A. J. Cohen, A. H. Ross, B. Ostro, K. D. Pandey, M. Krzyzanowski, N. Künzli, K. Gutschmidt, A. Pope, I. Romieu, J. M. Samet and K. Smith, "The Global burden of disease due to outdoor air pollution," *Journal of toxicology and environmental health,* vol. 68, pp. 1301-10307, 2005.

[3] World Health Organization, "Health Effects of Particulate Matter," 2013.

[4] Ontario Ministry of the Environment, "Ontario Air Standard For Total Reduced Sulphur," 2007.

[5] World Health Organization, "Air Quality Guidelines: Global Update 2005," 2005.

[6] H. H. Shin, D. Stieb, R. Burnett, G. Takahara and B. Jessiman, "Tracking national and and regional spatial-temporal mortality risk associated with NO2 Concentrations in Canada: A bayesian hierarchical two-level model," *Risk Analysis*, vol. 32, no. 3, pp. 513-530, 2011.

[7] World Health Organization, "Health risks of ozone from long-range transboundary air pollution," 2013.

[8] Environment Canada, "Preformance of Continuous PM2.5 Monitors at Canadian Monitoring Locations.," 2004.