Whitehorse Air Quality Monitoring Study

November 2015 – April 2017

Prepared by the Government of Yukon in partnership with Health Canada and City of Whitehorse

June 13, 2018

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Executive summary

A collaborative air quality monitoring study took place in Whitehorse neighbourhoods from November 2015 to April 2017 to inform government and the public about ambient air pollution levels throughout the City of Whitehorse. This contributes to determining the relative air quality impact on the **environment** and public health. Exposure to air pollution like wood smoke can have adverse impacts on human health and can be linked to cardiovascular and respiratory issues.

The study data show exceedances of national and local ambient air quality standards for fine particulate matter, providing reasonable estimates of air quality during the winter months. The standards are health-based air quality objectives developed by Environment and Climate Change Canada. The standards reflect exposure for long term (annual average) and short term (24-hour average), both of which can cause health problems.

There are two factors that suggest that detected pollution is due to residential wood smoke:

1. There is a clear trending pattern of pollution throughout the day, which peaks in morning and evening with a smaller peak midday at some sites (when wood stoves are typically lit during cold weather); and
2. The highest concentrations occur during very cold periods. Inversions at many sites may cause trapping of polluted air, which was measured as increasing concentrations over consecutive cold days. There was no significant summer wildfire smoke during the monitoring period.

As topography and proximity to emission sources both affect the air quality in a given neighborhood, the study team selected these Whitehorse neighborhoods for study:

- Kopper King Trailer Park
- Range Road (NorthlandTrailer Park, Takhini South)
- Porter Creek (Jack Hulland School)
- Takhini (Geological Survey)
- Hillcrest/McIntryre (Elijah Smith School)
- Hidden Valley
- Riverdale (Vanier School)
- Copper Ridge
- Downtown Whitehorse (412 Steele Street, Yukon Environment's national air quality monitoring station)

Study results clearly demonstrate that there was short term exceedances at four separate sites: Kopper King, Hidden Valley, Takhini Trailer Park and Vanier School in Riverdale. There was also long term exceedances at the Kopper King site. These exceedances primarily occurred during long stints of cold winter weather. Many sites had higher pollution levels than were being recorded at the downtown air quality monitoring station – demonstrating that this station, which is the source for the Air Quality Health Index, does not represent air quality throughout Whitehorse.

The measurements represent the concentration of air pollution during the monitoring period, so do not represent future air quality in those areas, particularly if changes to wood burning practices, transportation fuel, population density or other sources occur.

Limitations of this study include:

1. The monitoring equipment measured particulate matter based only on size (≤2.5ug/m3), not on source. The main source of pollution during winter months in Whitehorse is residential wood burning, not transportation related sources. Although monitors were situated a reasonable distance from known point sources (chimneys, major roads, idling areas), there may have been areas where transportation or other sources affected the results. Additional monitoring would be required to determine all contributing sources.

2. Fluctuations in measurements at different sites was expected, based on unique topography, meteorology, wood burning equipment, age and efficiency of homes, population density and burning practices.

3. The study period does not necessarily reflect typical cold winter temperatures that we have seen in the past. Therefore the study period does not necessarily reflect future colder winter seasons which would likely see higher measurements.

Participating agencies include: Health Canada, Office of the Chief Medical Officer of Health, City of Whitehorse and Yukon Departments of Environment, Health & Social Services, Energy Mines & Resources, and Community Services.

Introduction

Yukon people have come to expect a healthy natural environment. It is the responsibility of Yukon Government to protect public health and the environment, as identified in Yukon's Environment Act and Public Health Act.

At present the only full-time air quality monitoring in the Yukon is a National Air Pollution Surveillance Program (NAPS) station located in downtown Whitehorse. The station monitors concentrations of a number of pollutants including Nitric Oxide, Nitrogen Oxides, Ozone and particulate matter smaller than 2.5 microns ($PM_{2.5}$). Since 2016, station data have also been used to calculate an Air Quality Health Index (AQHI) which provides public health messages based on air quality. The station location, widespread use of wood for heating and varied topography within the city limits - led Whitehorse to be chosen as the area for the study to help determine whether NAPS data, and hence the AQHI, fairly represented the air quality within the City of Whitehorse.

In 2015, as a follow-up to AQHI implementation, Government of Yukon approached Health Canada seeking support to undertake an air quality study in the territory. Wood burning for heat remains widespread and associated emissions, combined with summer forest fires, likely lead to periods of poor air quality. Health Canada's expertise with similar studies in other Canadian jurisdictions would aid in monitoring air quality in specific Whitehorse neighbourhoods, allowing the Government to determine existing health impacts, additional monitoring needs and potential mitigative measures.

Objectives

The Whitehorse Air Quality Monitoring Study (WAQMS) had four objectives:

- Characterize spatial variations in ambient air quality throughout Whitehorse, using the $PM_{2.5}$ concentration as a proxy for overall air quality.
- Obtain a better understanding of air quality throughout Whitehorse and consequently determine potential associated health and environmental impacts that may require mitigative measures.
- Develop a foundation for comparing the downtown AQHI to other areas of Whitehorse.
- Present results in a format suitable for subsequent use in education and awareness campaigns, government programs, and development of policy or legislation as required.

Background

Whitehorse Population and Neighborhoods

As of March 31, 2017 the estimated population of the City of Whitehorse is 26,778. The municipal boundary of the city encompasses approximately 416 square kilometres and includes large tracts of park land and low-density country residential neighborhoods. Whitehorse is bisected by the Yukon River and has a downtown core immediately adjacent to the river with other neighborhoods at varying elevations up the valley wall.

The geography of Whitehorse is such that individual neighborhoods may be expected to have differing air quality based on population density, age of homes, elevation and surrounding topography. The layout of neighborhoods, monitoring sites and estimated population is shown in Figure 1.

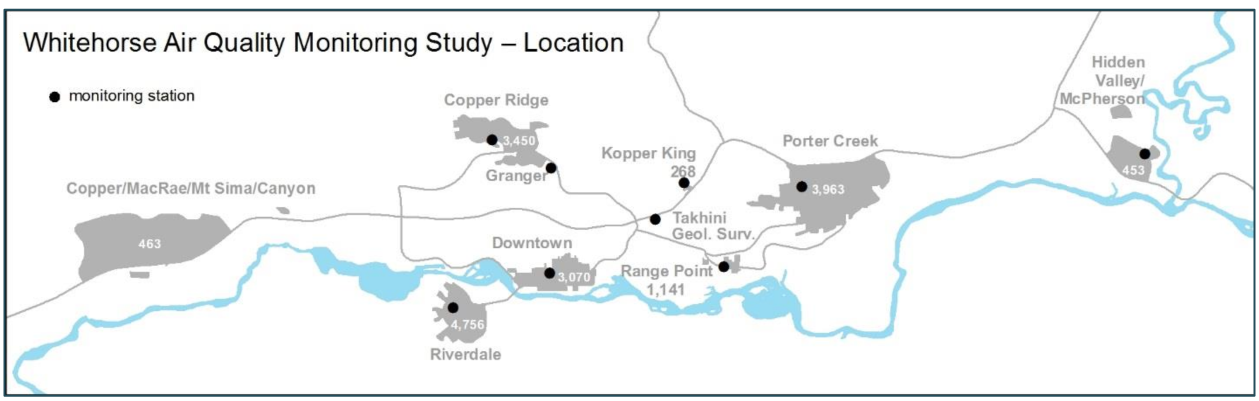

Figure 1. Whitehorse Neighbourhoods: Locations of monitors with related population estimates as of March 2017. Excludes population from 'undefined within city limits', 'PO Box' and 'inconsistent information'. From Yukon Bureau of Statistics Population Report, first quarter 2017. http://www.eco.gov.yk.ca/stats/pdf/populationMar_2017.pdf.

Geography & Climate of Whitehorse

Whitehorse is situated in southern Yukon, just north of 60° northern latitude. The community is bisected by the Yukon River running from south to north, with a valley bottom elevation of approximately 660 m and nearby peaks rising to 1800 m and above. Winter extremes as cold as -52 °C are tempered by long summer days of up to 19 hours, giving an annual average temperature of -0.1 °C. The city's location relative to the Coast Mountains keeps it shielded from much of the moisture moving inland from the Pacific Ocean, making it one of the driest communities in Canada with annual precipitation of only 262 mm split almost evenly between rainfall and snowfall. Snowfall has been recorded in every month but July, and despite its northern latitude rainfall has been recorded in every month of the year with record highs of 10°C in both December and January.

Yukon's topography is complex, with numerous mountain ranges interspersed with deep river valleys and lakes. Strong inversions are common during the winter months and prevent the dispersion of pollutants out from populated areas which are largely situated at or near valley bottom. During the summer, inversions often result from strong upper ridges which can trap not only anthropogenic pollutants but also smoke from forest fires in Alaska. Although the predominant flow is westerly, heavy smoke from fires in British Columbia, Northwest Territories and Alberta occasionally impacts the territory. While many inversions are short-lived, it is not uncommon for them to persist for periods of a week or more. This can result in pollutants becoming trapped in populated areas within the Yukon, which, when accumulated over longer periods of time, has the potential to cause adverse effects for human health and the environment.

The presence of the Yukon River and Lake Laberge to the north have a moderating effect on fall and early winter temperature, but can also cause frequent fog events during that time as they serve as a source of moisture to the otherwise cold and dry air in the valley. As with many mountain communities, inversions are a semi-permanent feature during the winter and lead to variations of as much as 15-20 C between the city's neighborhoods. These inversions contribute to both frequent fog events and incidences of poor air quality. Persistent inversions also develop periodically during the summer months under stationary ridges of high pressure, and may trap forest fire smoke from Yukon, but also from Alaska, northern British Columbia and Alberta.

The orientation of the Yukon River valley restricts wind direction to either northerly or southerly, with the latter being the predominant direction. Average speeds peak near 15 km/h in December and will frequently be stronger in the river valley than near ridge tops under the presence of inversions, where pollutants may be transported horizontally but will remain trapped in the valley. Strong, gusty winds are a common feature throughout the year.

Climate data indicate that the Whitehorse area has warmed by nearly three degrees Celsius over the past 50 years[5,6], with the majority of the warming coming during the winter months. A study of the wind and upper air data has shown that this warming has contributed to weaker, shallower inversions in recent years, and also to a slight strengthening in wind speed.

Energy

Whitehorse is distinct from many large urban centres in Canada in that natural gas is not available for heating. Predominant heating options include wood, fuel oil, propane and electricity. Due to the relatively high cost of heating, many homes use wood as either a primary or secondary heat source.

The most recent available statistics for Yukon as a whole show that[10]:

- A typical Yukon household requires approximately 25,000 kWh of heat energy annually, most often from oil or propane furnaces or boilers

- Approximately 15% of households heat with wood
- Approximately 5% of households heat with electricity
- In homes built since about 2014, up to 80% are heated with electricity and approximately one third of new builds have wood stoves installed. The average number of building permits for new residences issued per year in Yukon is approximately 350, so there are potentially about 115 wood stoves installed in new homes per year.

Homes heated exclusively with wood use approximately four to seven and half cords of wood per year, depending on the size and energy efficiency of the house, as well as occupant preferences. Many homes, and especially new builds, have wood stoves to supplement their primary heat source or for back up during electrical outages.

In recent years, the City of Whitehorse and Government of Yukon have attempted to eliminate older and inefficient wood stoves through a variety of policies and programs including mandates requiring that new stoves meet EPA efficiency standards[11], exchange programs and rebates[12] and educational campaigns which encourage burning only properly cured wood and discourage burning of waste in residential wood stoves.

Wood smoke

In the context of this study, wood smoke may be either due to emissions from home heating activities, or wildfire. Wood smoke is a mixture of fine particles and gases, some of which are considered toxic (eg. benzene, formaldehyde, acetaldehyde, acrolein and polycyclic aromatic hydrocarbons). Fine particles are associated with chronic and acute respiratory and cardiac issues, particularly for children, the elderly, and people with lung and heart conditions. Wood smoke causes concern for many Yukon residents who are subject to breathing difficulties such as asthma and Chronic Obstructive Pulmonary Disease, resulting in complaints primarily during the fall and winter months. Sources of wood smoke include indoor and outdoor residential wood stoves, outdoor wood boilers, commercial wood-fired ovens, campfires, outdoor burning due to land clearing and agricultural pest management, as well as wildfires. Residential wood burning for heating is estimated to be the largest source of harmful fine particles in the Whitehorse area during cold winter months.

Air quality monitoring in Whitehorse

The operation of the Whitehorse NAPS station was devolved to the Yukon’s Department of Environment in 1995, starting off with a single high-volume filter sampler on the roof of the current Elijah Smith Building. It moved from there to the Andrew Phillipson Law Centre, then to a heritage house on 1st Avenue, and is now currently located on Steele Street.

The site currently monitors Nitrogen Oxides, ground-level Ozone and particulate matter ($PM_{2.5}$), as the primary pollutants in Whitehorse are associated with residential and commercial heating using wood and/or fuel oil, and vehicular traffic. Smoke from forest fires are an occasional contributor to elevated particulate levels during the summer. Due to results of a 2009 study indicating under-measurement due to site location, the station was moved to its current downtown site adjacent Wood St. School in 2011.

Beginning in summer 2016, data from the NAPS site are used to calculate an Air Quality Health Index (AQHI) for Whitehorse. The AQHI is a public communication tool relating the overall concentration of particulate and concentration of particular pollutants to the health risk.

During winter 2009 a working group comprised of Environment Canada, City of Whitehorse and the Yukon Government Departments of Environment and Health & Social Services undertook a Residential Wood Combustion $PM_{2.5}$ sampling project. Two sites in Riverdale and Downtown were instrumented from January-March and samples were collected to determine both the concentration of particulate and also the origin by analyzing for levoglucosan, organic and elemental carbon, and Carbon 14.

Results showed considerable variability in derived 24-hr $PM_{2.5}$, with Riverdale having overall higher concentrations and greater contribution of wood smoke (70-80%) to the overall concentration compared to downtown. The contribution of wood smoke at the downtown site was slightly lower, presumably due to a higher contribution from vehicular traffic and heating of commercial buildings. Days with the highest $PM_{2.5}$ were associated with colder than normal temperature and light wind speed, both of which are detrimental to the dispersion of particulate from the source regions.

One final finding of the study was that the NAPS station, at the time situated adjacent to the Yukon River, showed consistently lower $PM_{2.5}$ measurements than the Downtown study site. Stronger wind and better dispersion along the channel of the river were the likely causes, and this prompted the NAPS station to be moved to the Downtown sampling site in 2011.

Study design

Nine instruments (ES-642 Nephelometers) were deployed to monitoring sites for the study period (WAQMS monitoring instruments). As topography and proximity to emission sources both affect the air quality in a given neighborhood, the study team conducted a prioritization exercise for all Whitehorse neighborhoods. Criteria considered were:

- Prevalence of wood as a primary heat source
- Overall age of homes, taken as a proxy for heating efficiency
- Local knowledge of neighborhoods known to have frequent smoky conditions
- Local topography that would contribute to poor dispersion
- Availability and security of a site with AC power.

Following the exercise, eight sites were identified with the ninth instrument deployed adjacent to the NAPS station's national standard instrument (BAM 1020) as a baseline measurement. The selected sites are shown in Figure 2. Instruments were located either on secure roof tops no higher than one story or in fenced areas to protect against theft and vandalism.

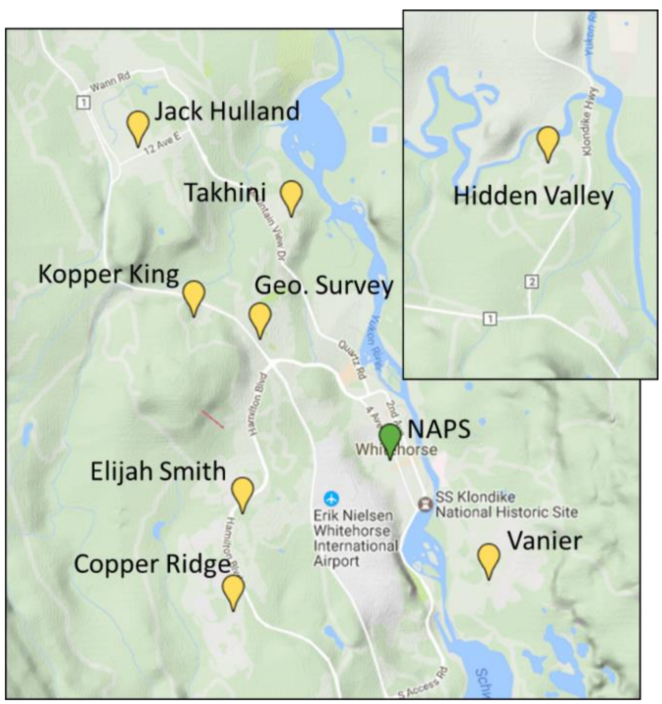

Figure 2. Sampling locations for WAQMS

Sites were equipped with cellular modems, enabling remote monitoring by Health Canada. Data collection began in November 2015 and was concluded in April 2017. The original study design was for only one year however the first winter was well above normal temperature therefore collection was extended for an additional winter season.

All sites included one WAQMS monitoring instrument, which recorded the following parameters in one minute intervals:

- $PM_{2.5}$
- Air Temperature
- Relative Humidity
- Wind Direction
- Wind Speed

Meteorological data from WAQMS sites were collected as hourly means of all samples from that hour. The analysis also used data from several other sources in Whitehorse: Whitehorse Airport (CYXY) and Whitehorse Auto (VXY), approximately 3.5 km NNW, report data once per hour at the top of the hour; The Whitehorse Upper Air Station, co-located with VXY, launches radiosondes twice daily just prior to 1200 and 0000 UTC. The difference in sampling procedures means that direct comparison between these and WAQMS sites may lead to slightly varying results, but the conclusions in this report remain valid.

Site	**Air Temperature**	**Relative Humidity**	**Wind Speed**	**Wind Direction**
WAQMS	Average of all samples that hour	Average of all samples that hour	Average of all samples that hour	Average of all samples that hour
Whitehorse Airport (CYXY)	2-minute average from xx:58 to xx:60 each hour	2-minute average from xx:58 to xx:60 each hour	10-minute average from xx:50 to xx:60 each hour	10-minute average from xx:50 to xx:60 each hour
Whitehorse Auto (VXY)	2-minute average from xx:58 to xx:60 each hour	2-minute average from xx:58 to xx:60 each hour	10-minute average from xx:50 to xx:60 each hour	10-minute average from xx:50 to xx:60 each hour
Upper Air (surface values)	Single sample at launch time, approx. 1100 and 2300 UTC	Single sample at launch time, approx. 1100 and 2300 UTC	Single sample at launch time, approx. 1100 and 2300 UTC	Single sample at launch time, approx. 1100 and 2300 UTC

Table 1. Meteorological data analysis summary

Sites were visited approximately once per month, where a visual survey was conducted for any physical damage, and the cyclone cleaned of any accumulated particulate matter. Site visits were also scheduled in cases where Health Canada's remote monitoring detected missing or suspect data.

Results

Site reliability

WAQMS monitoring instruments performed well for the majority of the study. Some missing or suspect data were noted, with the site, dates, issue and corrective action noted in Table 2. Overall the sites were reliable throughout the study period. Missing data during the summer season were replaced with those from the nearest station for the purpose of analysis. Missing or suspect data during the winter heating season were removed or left missing as stations showed substantial geographical variation in $PM_{2.5}$ and there was no reliable method to estimate missing values.

Site	Date Range	Issue	Action
Vanier	30 June – 2 Oct 2016	Loss of AC power	Data substituted with data from NAPS station for analysis
Vanier	25 Feb 2017	Flow rate over-reported	Data removed
Jack Hulland	16 June – 14 July 2016	Loss of AC power	Replaced with data from Takhini
Geological Survey	Feb 2016	Missing data	none
Hidden Valley	Feb 2016	Missing data	none
NAPS	Feb 2016	Missing data	none

Table 2. Summary of missing or suspect data during the study period.

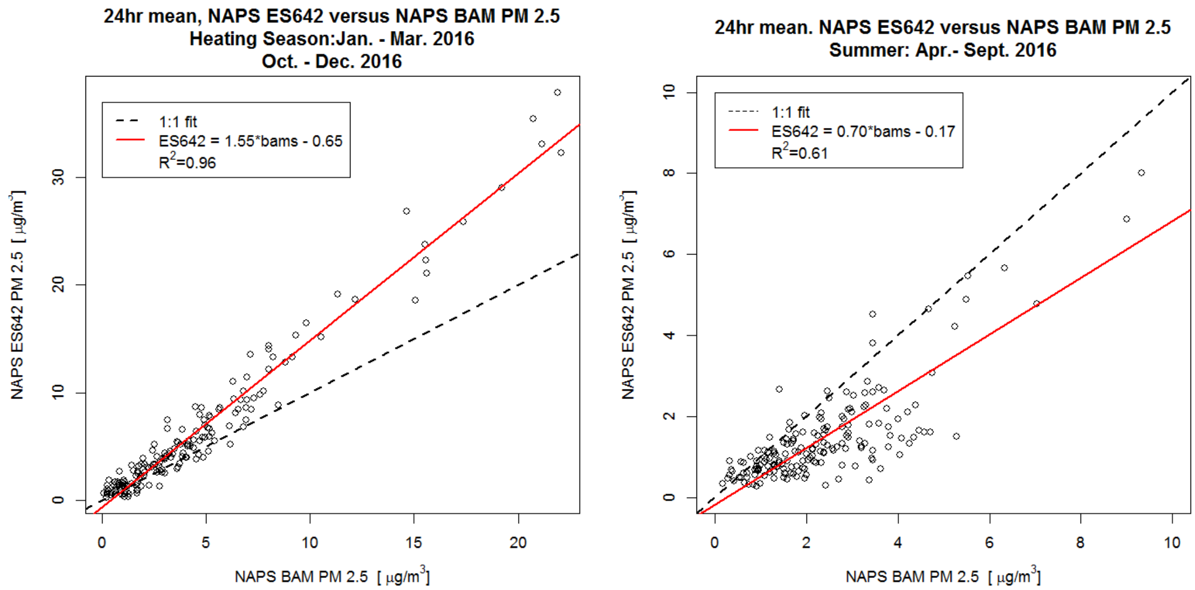

Figure 3. Linear regression between WAQMS ES-642 and BAM at the downtown naps station using 24hr mean readings, 2016 calendar year. Data show that the ES-642 reports higher values than the BAMS during the winter heating season while the opposite is true during the summer.

Both Figure 3 and Figure 4 show the WAQMS monitoring instruments over-predicting by a factor of approximately 1.5 relative to the national standard instrument during the winter heating season, while readings for the summer months have the WAQMS instrument under-predicting by a factor of 0.6 to 0.7 relative to the national standard instrument. The linear fit for summer months is relatively poor in both Figure 3 and Figure 4, but $PM_{2.5}$ readings are also relatively low.

In order to conduct further analysis, data from all WAQMS monitoring instruments were adjusted using the linear regressions shown in Figure 3. This adjustment should not be considered to be a correction, rather it is an effort to compare measurements from two different instruments, of which the national standard instrument is subject to more stringent standards for calibration and is used throughout Canada to monitor fine particulate concentrations. Both adjusted and unadjusted data are used throughout the remainder of this report, and are noted as such.

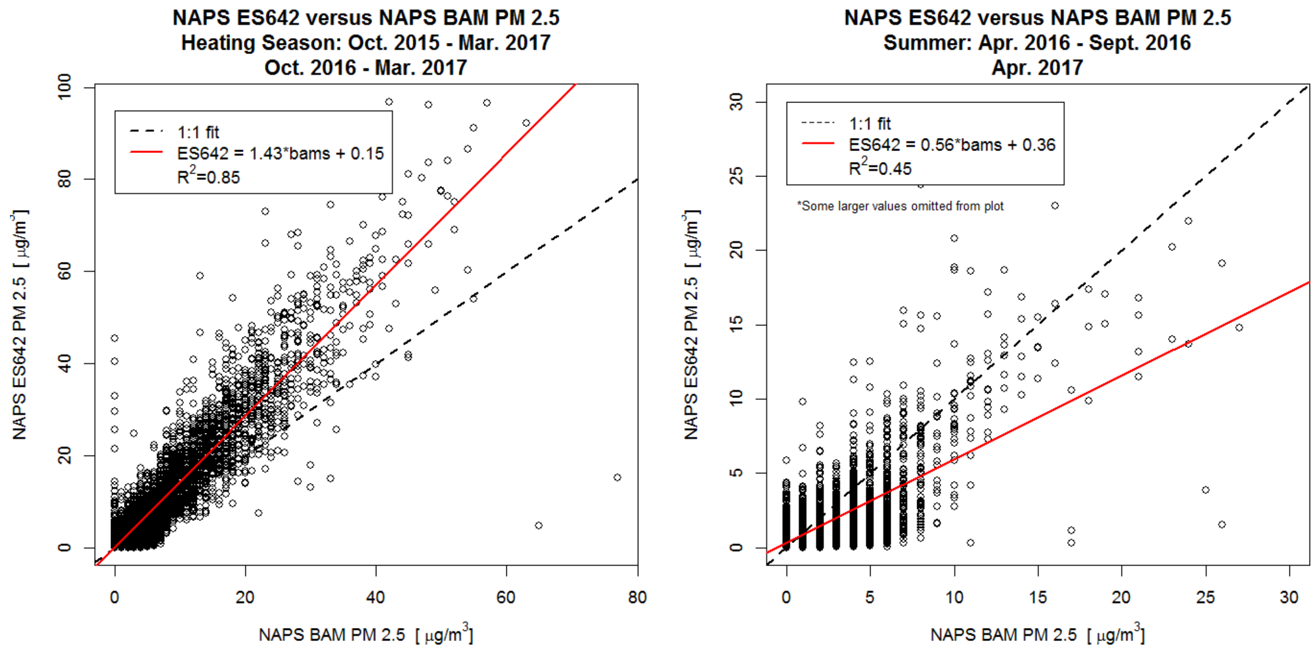

Figure 4. LINEAR REGRESSION BETWEEN WAQMS ES-642 AND BAM AT THE DOWNTOWN NAPS STATION using hourly readings. While linear regression gives slightly different best-fits than in Figure 3, the es-642 shows higher values than the BAMS instrument during the winter, and lower than the BAMS during the summer. It should be noted that the BAMS only reports to the nearest integer.

The full time series of unadjusted hourly data from all eight stations along with the national standard instrument are shown in Figure 5. Data from the full measurement period spanning November 2015 through April 2017 are shown. Overall higher concentrations of $PM_{2.5}$ can be seen at all stations during the winter months, with peak concentrations varying by site. Both the WAQMS monitoring instrument and the national standard instrument located at the NAPS site along with the Geological Survey tend to have lower peak hourly readings, while Kopper King, Vanier, Hidden Valley and Range Road have peak values of 3-4 times the former sites. Kopper King is also notable for the incidence of high peak values during the summer months.

Before delving more into specific geographic and temporal trends, it is instructive to examine the meteorology during the measurement period. Air quality at a specific site is primarily a function of topography, emission sources and meteorology, while topography is a constant. Both the emissions and meteorological conditions can vary substantially, and emissions from heating are dependent to some extent on the mean temperature during a given period.

As only one summer period was included in the study period, and air quality is generally much better due to fewer emissions from heating activities as well as fewer and weaker inversions, it will be ignored and will be assumed to be representative of 'normal' summer conditions at all sites.

Winter air quality is heavily dependent on temperature and the presence of inversions. All sites in the study area are subject to frequent inversions of varying strength during the winter months, which tend to trap particulate close to the surface. Mean air temperature is a useful proxy of the prevalence and strength of winter time inversion, with colder temperatures indicative of more persistent and strong inversions.

Figure 5 compares the January – March period for 2016 and 2017 and shows the latter half of the 2017 heating season to be generally colder with a pronounced difference in March, which in 2017 was accompanied by a strong and persistent inversion throughout the study area.

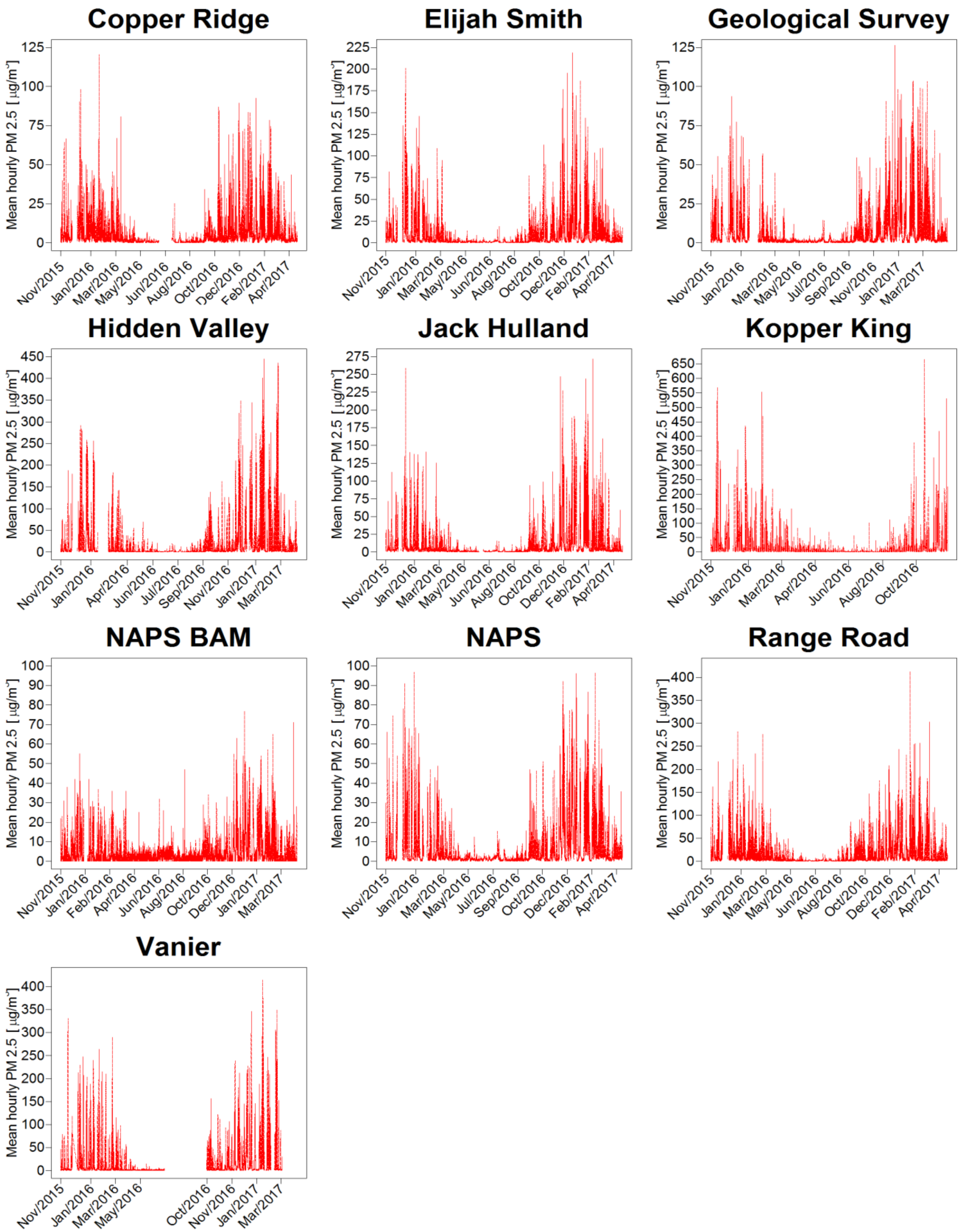

Figure 5. Hourly $PM_{2.5}$ data from all stations for the period November 2015 to April 2017. The vertical scales differs substantially between sites, depending on peak readings.

This difference can be quantified somewhat by comparing the diurnal trend of temperature and $PM_{2.5}$. Figure 6 shows this trend at Vanier and Hidden Valley for January – March 2016 and 2017. Both sites are at low elevation and are subject to cold air pooling and poor air quality during strong inversions. Both sites are also sheltered with low wind speed, all of which work together to trap particulate close to the surface.

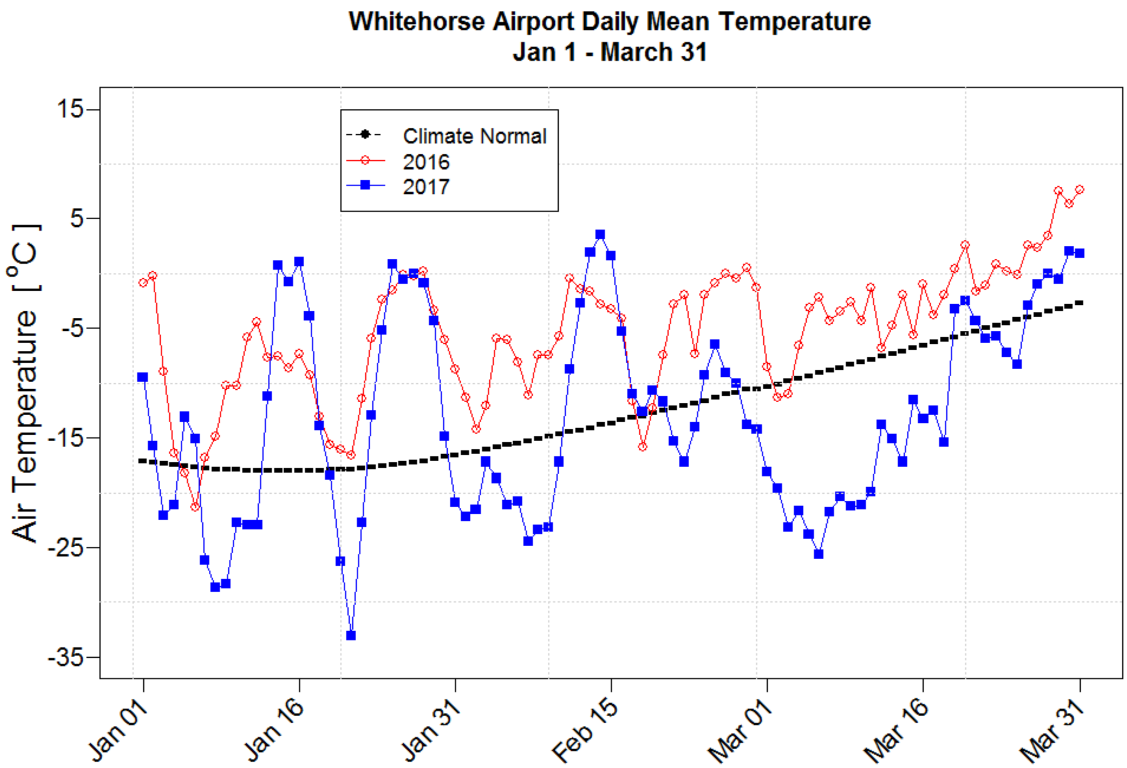

Figure 6. Mean daily temperature at Whitehorse airport for Jan. - Mar. 2016 and 2017, compared with the climatological mean. The winter of 2017 was generally colder than 2016, with an especially pronounced difference in early march.

Data from both years show relatively good dispersion of particulate during the early afternoon, but 2017 is notable for much higher overnight concentrations and cooler temperatures during both the daytime and overnight periods.

The diurnal trends for January-March 2016 and 2016 for all stations are shown in Figure 8. The Hidden Valley and Vanier sites show the most difference year-to-year, but other sites do show elevated concentrations in 2017 versus 2016, especially during the overnight period. As noted previously, Kopper King is notable for relatively poor dispersion during the daytime hours. This may be due to a combination of the topography, which is bowl-shaped and tends to shelter the site from any wind, as well as emissions from an adjacent commercial area and vehicular traffic on the Alaska Highway.

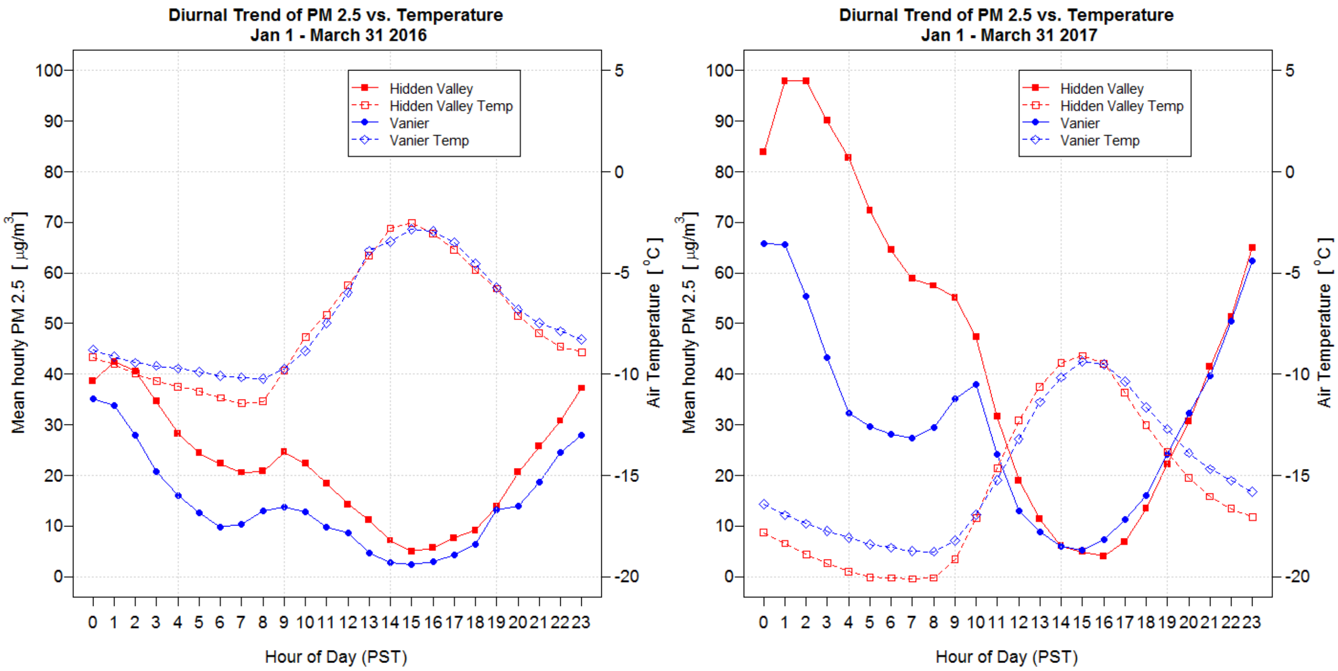

Figure 7. Mean diurnal temperature versus $PM_{2.5}$ at two sites heavily influenced by inversions, Jan. – March. 2016 and 2017. The former was relatively warm with fewer inversions while the 2017 was colder with more frequent and stronger inversions which both increase emissions from heating and trap particulate close to the surface.

Unfortunately, the Kopper King site had to be removed prior to January 2017 and no year-to-year comparison is possible.

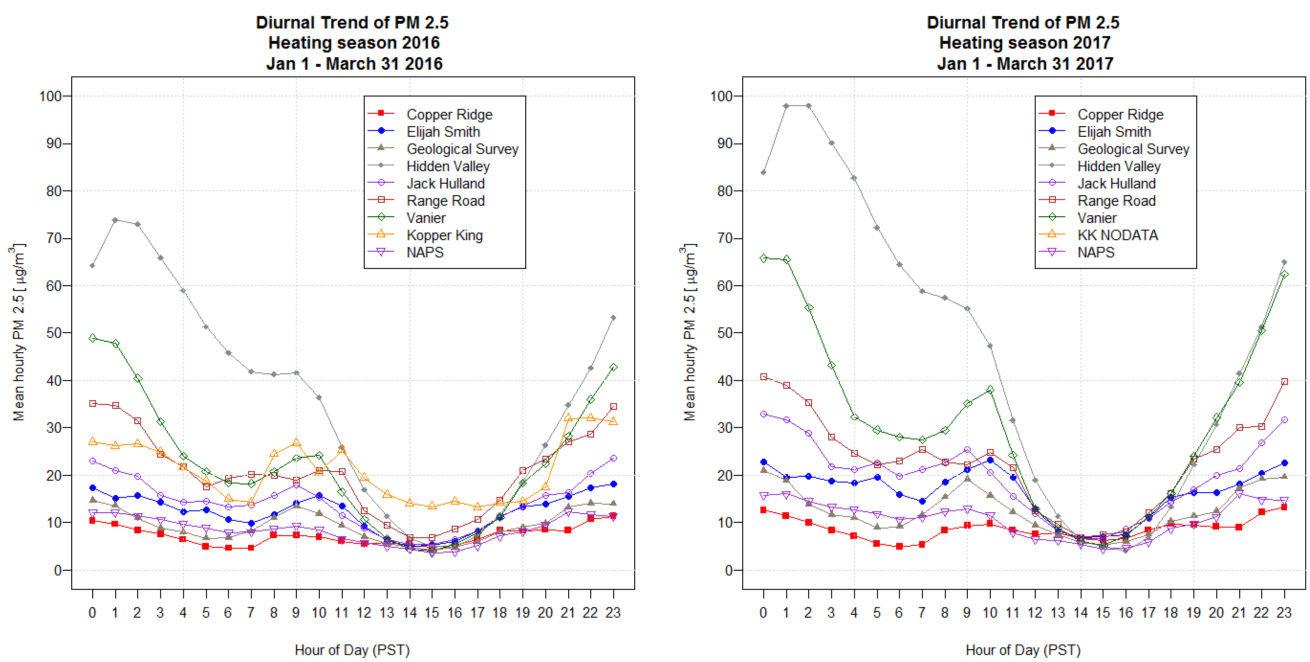

Figure 8. Diurnal trends in $PM_{2.5}$ for all sites, Jan. - March 2016 and 2017.

The remainder of this section compares data from the WAQMS sites with Canadian Air Quality Standards threshold for fine particulate. Data should be regarded as preliminary due to the short time frame of the study as well as limitations inferred by year-to-year variations in meteorological conditions as discussed above. The 'heating season' in the results above is a composite of the January – March and October – December 2016 periods, but despite the limitations is likely representative of geographical differences in $PM_{2.5}$ that could be expected during any winter heating season.

Management Level	Management Actions	Proposed Air Management Threshold Values					
		Ozone (ppb)		$PM_{2.5}$ Annual ($\mu g/m^3$)		$PM_{2.5}$ 24h ($\mu g/m^3$)	
		2015	2020	2015	2020	2015	2020
RED	Actions for Achieving Air Zone CAAQS						
Threshold		63 ppb	62 ppb	10.0 µg/m3	8.8 µg/m3	28 µg/m3	27 µg/m3
ORANGE	Actions for Preventing CAAQS Exceedance						
Threshold		56 ppb		6.4 µg/m3		19 µg/m3	
YELLOW	Actions for Preventing AQ Deterioration						
Threshold		50 ppb		4.0 µg/m3		10 µg/m3	
GREEN	Actions for Keeping Clean Areas Clean						

Figure 9. Canadian ambient air quality standards for $PM_{.5}$ and ozone.

Figure 9 shows the Canadian Ambient Air Quality Standards (CAAQS) for $PM_{2.5}$. Two standards will be used to quantify air quality and geographical distributions identified during the WAQMS study: The 2015 Annual levels include levels of 6.4 $\mu g/m^3$ and 10.0 $\mu g/m^3$ which represent thresholds actions for preventing CAAQS exceedances and actions for achieving air zone CAAQS, respectively. These levels are annual means and will minimize the impact of the high winter readings seen at most WAQMS stations, but are a valid way of comparing WAQMS data against national standards.

Figure 10 shows the annual mean $PM_{2.5}$ for all sites overlaid with the CAAQS annual thresholds. The left figure shows raw, or unadjusted data while the right figure shows data adjusted against the NAPS BAMS site using the linear regressions from Figure 3. Regardless of which data are used, four sites (Hidden Valley, Kopper King, Range Road and Vanier) exceed the 6.4 $\mu g/m^3$ threshold. The 10.0 $\mu g/m^3$ threshold is exceeded at both Hidden Valley and Kopper King in the unadjusted set, and by only Kopper King in the adjusted data set.

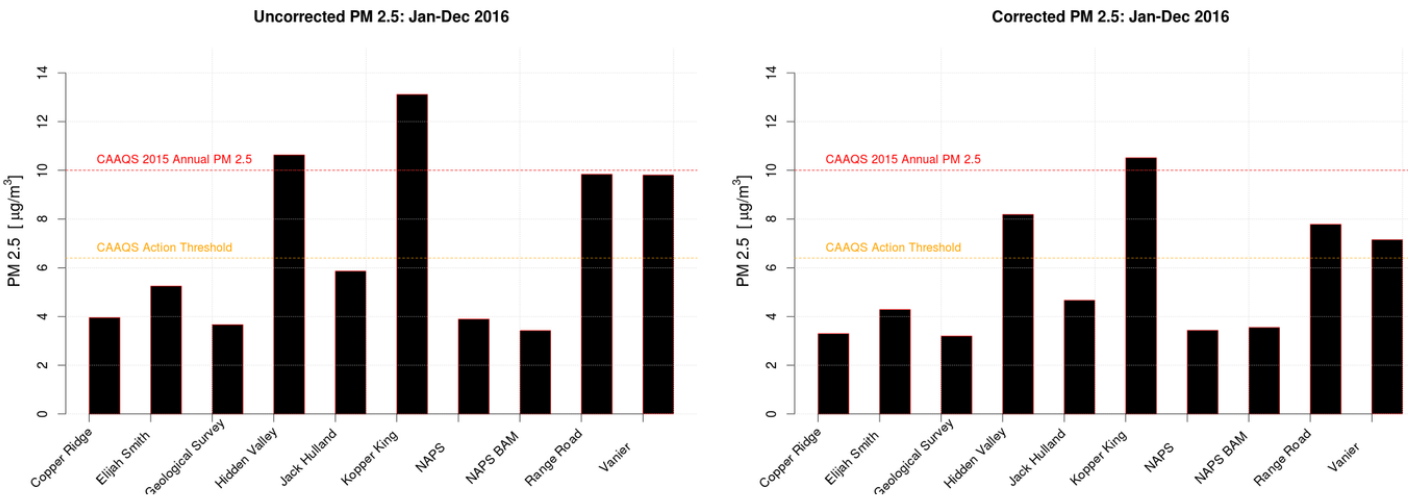

Figure 10. Annual mean $PM_{2.5}$ and CAAQS standards for all stations. The left figure shows raw data from all sites while the right-hand figure shows data adjusted against the NAPS BAMS site using regressions from Figure 3.

A second set of threshold in Figure 9 is relative to the 98^{th} percentile of 24-hour mean $PM_{2.5}$, again for the calendar year: In this case 19 $\mu g/m^3$ is the threshold for preventing CAAQS exceedances and 28 $\mu g/m^3$ is the threshold for actions for achieving air zone CAAQS. It should be noted that the values at a given site should be calculated annually, and averaged over 3 years. In this case only one full calendar year of data are available so this is not a direct comparison with national standards; nevertheless, it does reveal sites that may exceed these standards were the data available. Given the previous analysis of the relative warmth of 2016 relative to climactic normals, many sites may be expected to have higher exceedances were a longer record available.

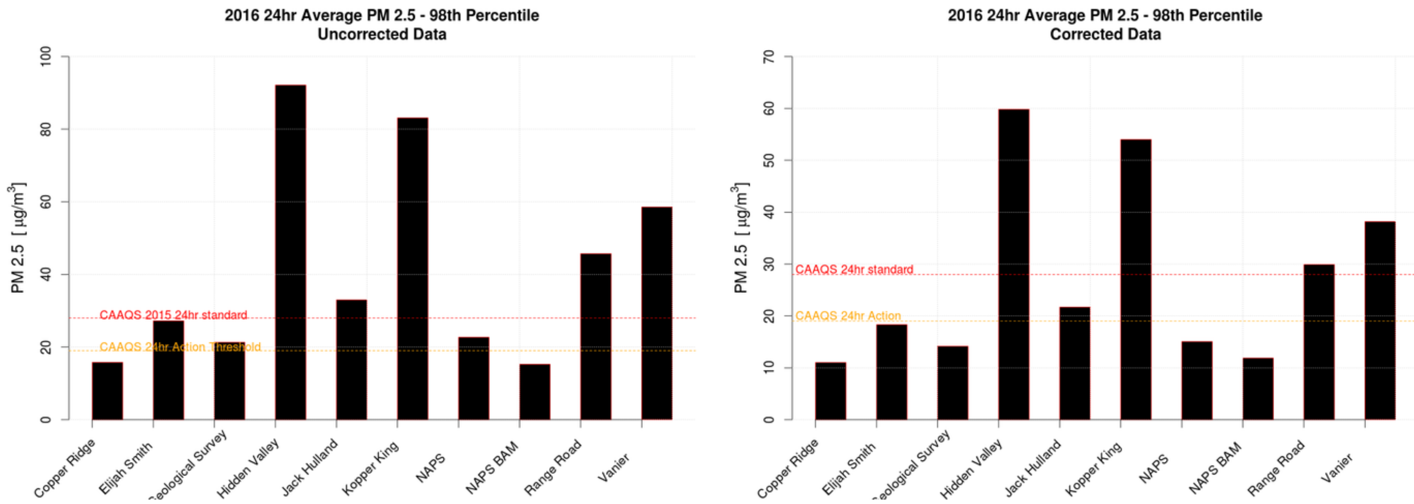

Figure 11. The 98th percentile of 24-hour mean $PM_{2.5}$ concentrations at WAQMS sites. The left-hand figure shows unadjusted data while the righthand figure shows data adjusted to the NAPS BAMS site using linear regressions from Figure 3.

Four sites exceed the highest threshold whether adjusted or unadjusted data are used, in the case of Hidden Valley and Kopper King by a significant margin. Most sites come close to exceeding the lower 19 µg/m³ threshold, depending on whether adjusted or unadjusted data are used.

Discussion – data analysis

The data and analyses presented in this report are the result of a 16-month campaign to measure fine particulate at eight sites within the Whitehorse city limits. Although the measurement period is limited, the results may be taken to be representative of what could be expected in terms of diurnal, seasonal and geographical variation in fine particulate concentrations.

Data from the 2016 calendar year were compared against national (CAAQS) standards for annual mean and 98th percentile 24-hour mean $PM_{2.5}$ concentrations. As the data are from a relatively warm winter with fewer and weaker inversions the exceedances shown are likely representative or possibly lower than what would be obtained from a longer measurement record.

Quality control of the data was performed by Health Canada experts. Missing or unreliable data were identified and summarized in Table 2. Once quality-controlled, all raw 1-minute readings were converted to hourly readings by averaging the raw data from 1 minute past the hour to the top of the next hour. This includes meteorological data, so direct comparisons between WAQMS sites and airport meteorological sites, which report a single 1-minute average (temperature) or 10-minute average (wind) value prior to the top of the hour, should be done with caution.

Data from the WAQMS monitoring instrument co-located with the downtown Whitehorse NAPS site were compared in an effort to relate WAQMS measurements with those from a national standard instrument. Linear regression was performed, with best fit found to be when winter/heating season was treated separately from summer/non-heating season. Linear regressions were performed between the 24hr mean readings (Figure 3) and the hourly readings (Figure 4). While the linear best-fit differs depending on the method chosen, both show that the WAQMS monitoring instrument tends to report higher values than the national standard instrument during the winter heating season when $PM_{2.5}$ is generally higher. The opposite is true during the summer, when overall lower values were observed.

Recommendations

The analyses presented here were necessarily limited in scope due to the short measurement period, but some further study may prove useful in designing future measurements campaigns or in assisting policy or public communications:

- Wind speed: The surface wind speed and its role in dispersion of particulate was not considered in this report, nor was the wind speed versus climatology examined. A closer study of observed wind speed correlations with $PM_{2.5}$ concentrations, particularly during the heating season and overnight periods, may provide useful correlations.
- Vertical structure of the atmosphere: Upper air soundings are available from the Whitehorse Upper Air station twice daily at 12 and 00 UTC, and the hourly presence and strength of inversions may be inferred to some degree by comparing temperatures at NAPS, the Whitehorse Airport and Mount Sima ski hill. In this report the presence and strength of inversions was inferred from the air temperature alone, while a closer examination of vertical structure may quantify the utility of that assumption.
- Ventilation Indices: The ventilation index is a combination of wind speed and stability in the lower atmosphere. While forecasts are available for Whitehorse, they are limited by the low topographical resolution available in weather models. A true ventilation index may only be calculated twice daily based on the upper air soundings, and will not necessarily be applicable to specific sites that may be sheltered or otherwise influenced by local topography. Nevertheless, a more rigorous comparison of model-forecast ventilation with locally observed meteorological and $PM_{2.5}$ from WAQMS sites may reveal useful correlations.
- Multiple regression forecast model: The $PM_{2.5}$ at a given site is known to be primarily a function of topography (constant), meteorology and emissions, which themselves are influenced in part by air temperature. A multiple regression model comprised of readily available hourly temperature, wind and vertical temperature structure may prove useful for forecasting $PM_{2.5}$ at WAQMS sites.

It is therefore recommended, based on the above limitations, that, Government of Yukon:

- extend this monitoring program for another two years, in order to capture accurate data that reflects seasonal variability within the City of Whitehorse;
- develop a plan for similar air quality monitoring studies to be undertaken throughout other Yukon communities to help identify any potential impact of air pollution on human health; and,
- make determined efforts to mitigate the effects of air pollution in neighbourhoods with identified risks, inlcuding, but not limited to: research, policy, programming, education, outreach, community engagement and consultation, and continued monitoring.

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Glossary

- **BAM 1020:** an insturment used at the Whitehorse NAPS station to measure $PM_{2.5}$. This national standard instrument is used throughout Canada's NAPS network.
- **CAAQS**: Canadian Ambient Air Quality Standards. Health-based air quality objectives for pollutant concentrations in outdoor air. Comprise both short-term and long term limits for fine particulate matter ($PM_{2.5}$) and ground level Ozone. Established by the Government of Canada in 2013.
- **WAQMS:** Whitehorse Air Quality Monitoring Study. A study of ground-level fine particulate ($PM_{2.5}$) undertaken from November 2015 through August 2017 in 8 neighborhoods throughout the City of Whitehorse. A partnership between the Government of Yukon, Health Canada and the City of Whitehorse.
- **Inversion**: An atmospheric condition where temperature increases with elevation, creating stable conditions which trap pollutants close to the surface. Very frequent and persistent in mountainous regions such as Whitehorse during the winter.
- **NAPS**: National Air Pollution Surveillance Program. A network of ground-based monitoring sites throughout Canada. Instrument type and analysis protocols are standardized. Various pollutants are monitored including fine particulate matter ($PM_{2.5}$). Data from NAPS sites are used to create and disseminate the Air Quality Health Index (AQHI). Data from the Whitehorse NAPS site were compared with sites deployed during WAQMS.
- **Meteorological data**: In the context of air quality monitoring, meteorological data including observations of wind direction, wind speed, air temperature and vertical air temperature profile are all variables affecting the concentration and dispersion of pollutants at the surface. Meteorological data from Environment Canada or Nav Canada sites are reported using a 1-minute average prior to the top of the hour (air temperature) or a 10-minute average preceding the top of the hour (wind speed and direction). Data measured at upper air stations ("weather balloons") are recorded twice daily at 12 UTC and 00 UTC. Data from other sites
- **National Standard Instrument:** BAM 1020, an instrument used at the Whitehorse NAPS station to measure $PM_{2.5.}$ This instrument is used throughout the Canadian NAPS network.
- **$PM_{2.5}$**: Fine particulate matter smaller than 2.5 microns. This is considered a significant threshold with respect to human health, as these fine particulate can enter the bloodstream through the lungs and may contribute to short-term (acute) or long-term (chronic) health problems.