Air Quality in the Capital Regional District 2004

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EXECUTIVE SUMMARY

Air quality is monitored in the Capital Regional District (CRD) to assess ambient air quality and to track trends. Air quality monitoring in the CRD is conducted under the long term monitoring program (LTMP), which is a partnership between the CRD and the British Columbia Ministry of the Environment (BC Environment), Royal Roads University and Environment Canada. This report provides a summary and analysis of the air quality monitoring data from the stations operating within the CRD during 2004. This report also includes an evaluation of solid waste burning activities during the year and their impact on air quality. In addition, an analysis of the meteorological data (winds, temperatures, precipitation) collected in the CRD over the same period is provided.

There are four Long Term Monitoring Program (LTMP) stations in the CRD. In addition, there are three 'Hi-Vol' stations that measure fine particulate matter only. Finally, there is one station on Saturna Island that is managed by Environment Canada.

Ambient air concentrations of six air contaminants, collectively referred to as common air contaminants (CACs), are sampled on a frequent basis at the monitoring stations. The six CACs are carbon monoxide (CO), nitrogen dioxide (NO_2), sulphur dioxide (SO_2), ground-level ozone (O_3), particulate matter smaller than or equal to10 microns (PM_{10}) and particulate matter smaller than or equal to 2.5 microns ($PM_{2.5}$). Of the six CACs, five are sampled on a continuous basis, providing hourly air concentrations at one or more locations in the CRD. In contrast, air concentrations of PM_{10} are sampled sequentially on a one-in-six-day cycle.

To assess the 2004 ambient air quality data, comparisons were made to CRD air quality guidelines, as well as provincial and federal standards and objectives. Particular attention was made to any exceedence of an applicable guideline or standard. In addition, other types of analyses were made to establish links between ambient concentrations and causal factors within the CRD member communities. In some cases, consideration of meteorological data helped establish the environmental factors related to higher- or lower-than-average concentrations.

Ambient air concentrations of CACs remain relatively low when compared to the set of CRD air quality guidelines established in 2004, and all relevant provincial and federal air quality objectives/standards. However, there were three exceedences of the CRD 24-hour particulate matter (PM) guidelines. A PM_{10} exceedence occurred on June 20th at the Victoria Topaz station and a second PM_{10} exceedence occurred in Central Saanich (Stellys) on the 7th of September. In both cases, relatively low concentrations were recorded at the other PM monitoring stations, indicating that the exceedence-level concentrations were localized and not experienced by the other communities in the CRD. Further analysis suggests that fugitive dust sources, rather than combustion activity, were primarily responsible for the high PM_{10} concentrations. The third PM exceedence was for respirable particulate matter ($PM_{2.5}$), which occurred on November 5th in the community of Langford. This was the first allowed day (by municipal bylaw) for residents to burn yard and household waste materials.

Exceedence of the CRD PM guidelines has implications regarding health effects for community members. Recent health research has established that higher ambient concentrations can lead to measureable effects in a community, such as an increased frequency of hospital visits. However, research studies typically involve a longer period of time than one day. Also complicating matters is the difficulty in determining what portion of community members in the CRD were exposed to concentrations indicated by an individual air sampler. In the case of the PM_{10} exceedences, the spatial degree of community exposure to elevated concentrations was localized, but highly uncertain in extent. However, it is very likely that just a small fraction of community members in both cases were exposed to the relatively high concentrations. $PM_{2.5}$ air concentrations tend to be more uniformly distributed than for PM_{10}, but the spatial degree of community exposure to the exceedence level concentration of $PM_{2.5}$ is also uncertain. Due to the limited temporal, and uncertain spatial extent of community exposure to PM concentrations above the CRD guideline values, related health effects cannot be determined within a suitable degree of confidence.

For the first time, full annual datasets of continuous $PM_{2.5}$ monitoring data for several communities in the CRD was available to facilitate an investigation of solid waste burning. An analysis of $PM_{2.5}$ concentrations was conducted for the three CRD communities that have continuous $PM_{2.5}$ monitoring and allow solid waste (‘backyard’) burning on scheduled days of a limited burn season. A fourth community with continuous $PM_{2.5}$ monitoring that does not allow solid waste burning was also analyzed, for comparison purposes. The differences between average $PM_{2.5}$ concentrations on allowed burn days and on non-burn days were determined. In each case, the allowed burn days were identified from municipal bylaws. It was discovered that a statistically significant increase in $PM_{2.5}$ concentrations exists on allowed burn days for each of the three communities, although the increase is not present in all months of the permitted burn season. Comments from the Fire Chiefs of the three communities suggest that solid waste burning tends to occur during the Fall (November) and Spring (April and May) much more than during the other allowed months. This analysis supports a conclusion that solid waste (backyard) burning contributed to the exceedence experienced on November 5, 2004 in Langford. $PM_{2.5}$ concentrations at the three other $PM_{2.5}$ monitoring stations were much lower on the same day, indicating that the exposure of the general public to elevated fine particulate concentrations was limited to the Langford area.

The solid waste burning analysis strongly indicates that air quality is degraded in those communities that allow burning, in the more active months of Fall and Spring. It should be noted that these conclusions are representative of the air volumes surrounding the individual air quality stations for the three communities analyzed. It should be expected that more localized effects (i.e., at the neighbourhood or street level close to the sources of waste burning) could be higher. The same analysis performed on sampling data in Victoria indicates that improvements in air quality, with respect to suspended fine particulate matter, can be anticipated in those communities that reduce or eliminate solid waste (backyard) burning.

The analyses of ambient air quality concentrations over the year show that there are diurnal patterns indicative of traffic and home heating activities in the CRD. For CO, NO_2, SO_2 and respirable particulate matter ($PM_{2.5}$), hourly air concentrations experience peaks during the morning rush hour and late afternoon traffic increase. During cooler months, these air contaminants tend to remain relatively high during the evenings, coinciding with increased consumption of heating fuels. Seasonal patterns were also noted for some air contaminants. An obvious increase in ground level ozone tends to occur in the Spring, which is likely due to changes in background (i.e., natural) concentrations. Carbon monoxide and $PM_{2.5}$ concentrations were relatively low during the summer months and increased substantially during the Fall and early Winter, again indicating the influence of home heating emissions, although changes in atmospheric conditions also influence the diurnal patterns in each season.

Other comparisons were made to assess compliance with the Canada Wide Standards (CWS) for respirable particulate matter ($PM_{2.5}$) and ground-level ozone (O_3). These standards are to be implemented by 2010. A 2004 comparison value of 12.8 $\mu g/m^3$ (24-hour average) was determined for $PM_{2.5}$, which is well below the standard of 30$\mu g/m^3$. A 2004 comparison value of 109.5 $\mu g/m^3$ was determined for O_3, which also is well below the federal standard of 127.6 $\mu g/m^3$. For the vast majority of the time, air quality remains relatively good in the CRD.

1.0 INTRODUCTION

The Capital Regional District (CRD) has been in partnership with B.C. Ministry of Environment (formerly the Ministry of Water, Land and Air Protection – MWLAP) and others in conducting an ambient air quality monitoring program in the CRD area since 1996. One of the initial goals of the Long Term Monitoring Program (LTMP), was to investigate the contribution of solid waste burning to regional particulate matter (PM) air concentrations. It is also recognized that solid waste burning releases many other air contaminants, including common air contaminants (CACs) and toxic compounds. All CACs are monitored under the LTMP. An additional goal of the LTMP was to establish a reliable baseline of air quality data for all CACs to enable trend analysis. The CRD has committed to reporting on the air quality data collected within the monitoring network.

Air Quality data are collected and analysed for several reasons, including the following:

- to provide information on air quality to the public;
- to conduct long-term trend analysis;
- to fulfill Federal reporting requirements (re: Canada Wide Standards); and,
- to compare ambient concentrations to air quality objectives.

Air quality monitoring locations are chosen to capture air concentrations that are representative of either larger geographic areas, or 'hot spots' where higher contaminant air concentrations are suspected. Local topography and the location(s) of pollutant sources can indicate how well a monitoring location represents an area. With the advent of the Canada Wide Standards (CWS) for ozone and particulate matter, to be implemented by 2010, 'community-oriented' monitoring sites are to be used. These sites are described as locations where people live, work and play[1]. The CRD monitoring network is designed to adequately characterize the air quality in the region, and to support the initiatives described above.

1.1 AIR QUALITY MONITORING

Air quality is monitored at four sites in the CRD, under the LTMP. The program monitors air concentrations of carbon monoxide (CO), sulphur dioxide (SO_2), nitrogen dioxide (NO_2), ground-level ozone (O_3) and particulate matter (PM) at the locations listed in Table 1.1.

[1] Canadian Council of Ministers for the Environment, 2000. Guidance Document on Achievement Determination: Canada Wide Standards for Particulate Matter and Ozone. www.ccme.ca.

NO_2 measurements are supplemented by nitric oxide (NO) measurements, which are automatically determined by the gas sensor used. In addition, PM concentrations are recorded as two different fractions: particulate matter below 2.5 microns in diameter ($PM_{2.5}$) and particulate matter below 10 microns (PM_{10}). Meteorological observations are also collected at several of the monitoring stations.

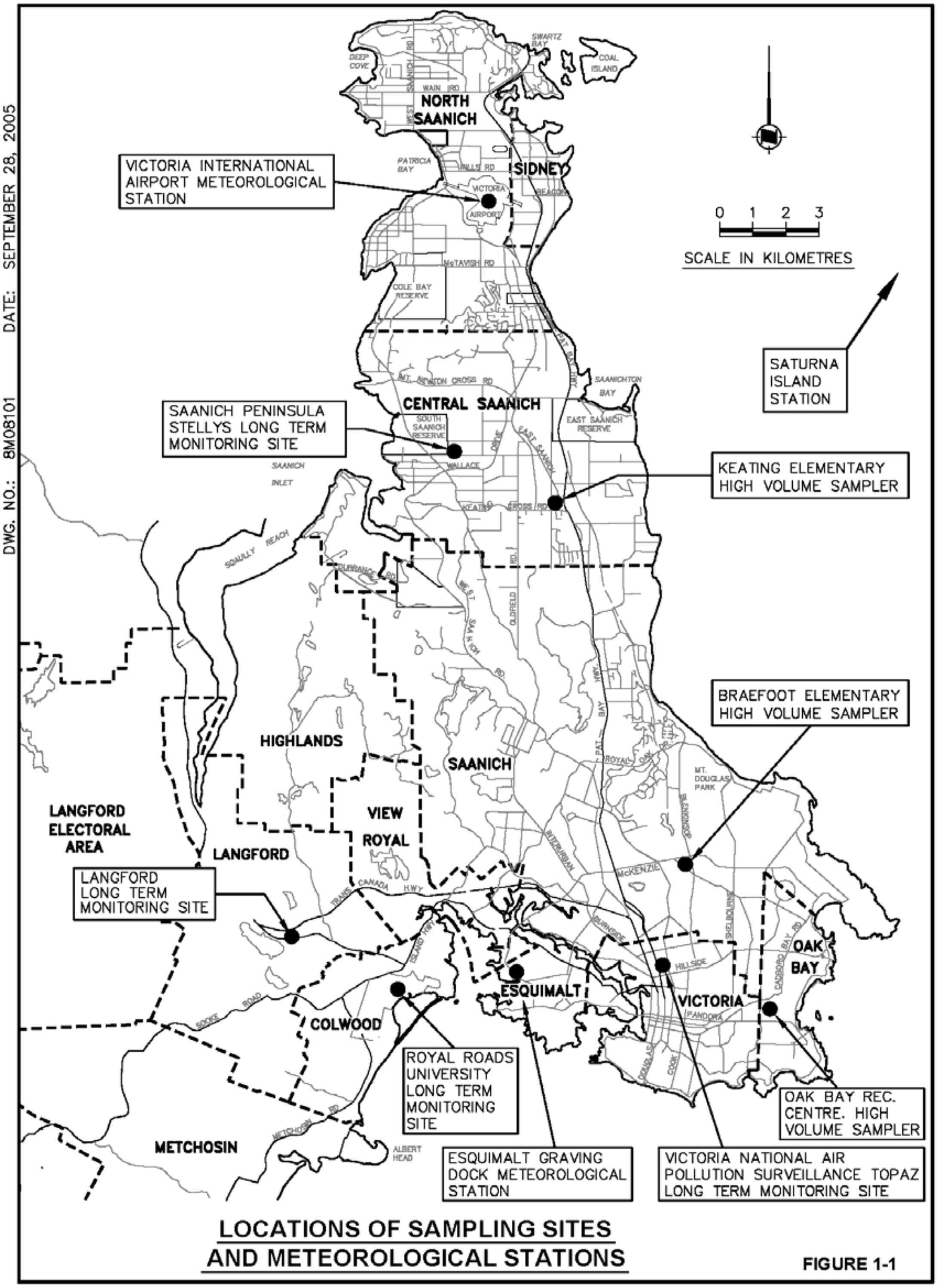
The Victoria Topaz station is part of the The National Air Pollution Surveillance (NAPS) program and samples air concentrations for all of the CACs described above. The station at Royal Roads University measures the same air pollutants with the exception of SO_2, the Stellys Saanich Peninsula (Stellys) station records O_3 and PM (both PM_{10} and $PM_{2.5}$), and Langford station monitors $PM_{2.5}$. The data from these four stations were made available by B.C. Ministry of Environment. Meteorological and ground-level ozone data were also available from a Saturna Island station. This station is part of the Canadian Air and Monitoring (CAPMoN) network of primarily rural air quality stations. The CAPMoN data were made available by Environment Canada. Finally, there are three additional air quality stations that record air concentrations of PM_{10}.

Table 1.1 Air Quality Monitoring Stations in the Capital Regional District, 2004

Monitoring Location	Type of Site	Parameters Monitored		
		Gaseous	**Particulate Matter**	**Meteorology**
Victoria, Topaz Avenue	NAPS[1] Long Term Monitoring Site	CO, NO, NO_2 SO_2 & O_3	PM_{10} (S-Hi-Vol) PM_{10} & $PM_{2.5}$ (Dicot) $PM_{2.5}$ (C-TEOM)	WS, WD, T, RH
Royal Roads University	Long Term Monitoring Site	CO, NO, NO_2, SO_2 & O_3	$PM_{2.5}$ (C-TEOM)	WS, WD, T, RH
Langford Dogwood School[2]	Long Term Monitoring Site		$PM_{2.5}$ (C-TEOM) PM_{10} (S-Hi-Vol)	WS, WD
Stellys, Saanich Peninsula[3]	Long Term Monitoring Site	O_3	PM_{10} (Partisol) $PM_{2.5}$ (C-TEOM)	WS, WD
Saturna Island	CAPMoN[4] Site	O_3		WS, WD
Oak Bay Recreational Centre[5]	Site of special interest (Hi-Vol)		PM_{10} (S-Hi-Vol)	
Braefoot Elementary School[6]	Site of special interest (Hi-Vol)		PM_{10} (S-Hi-Vol)	
Keating Elementary School	Site of special interest (Hi-Vol)		PM_{10} (S-Hi-Vol)	

Notes:

WS – wind speed; WD – wind direction; T – temperature; RH – relative humidity
Hi-Vol - sequential sampling using a High Volume sampler
Dicot - sequential sampling using a dichotomous sampler
Partisol – sequential sampling using constant air flow Partisol sampler
C-TEOM – continuous sampling using Tapered Element Oscillating Microbalance samplers
1- National Air Pollution Surveillance 2- Station began operating in November, 2002
3- Station began operating in August, 2003 4- Canadian Air and Precipitation Monitoring Network
5- Special area of interest since October 1996 6- Special area of interest since November 1995



LOCATIONS OF SAMPLING SITES AND METEOROLOGICAL STATIONS

FIGURE 1-1

1.2 CRD AIR QUALITY GUIDELINES

The Canada Wide Standards (CWS) include regulatory air quality criteria for ground-level ozone and fine particulates ($PM_{2.5}$). In addition, there are National Ambient Air Quality Objectives (NAAQOs) for other CACs. However, jurisdictions within British Columbia have the flexibility to define ambient air quality guidelines that are below the national criteria. There is a growing awareness of the need to update existing national and provincial air quality objectives and guidelines in Canada. The current objective level for PM_{10} was established in 1995, and the objectives for CO, SO_2 and NO_2 have not been reviewed since the mid-1970's. The existing provincial and national objectives may not reflect the current knowledge and understanding of the health effects of these air pollutants.

CWS has requirements that go beyond numeric targets for O_3 and $PM_{2.5}$. The provisions for *keeping clean areas clean* and *continuous improvement* suggest that air quality management is equally as important for those regions that currently meet the numerical standards as for those that may not. According to a recent discussion paper[2], the concept of keeping clean areas clean can be described as a framework on managing ambient concentrations of particulate matter and ozone below the CWS to minimize any increase in ambient concentrations and, ideally, maintain or reduce ambient concentrations.

CRD-specific air quality guidelines are listed in Table 1.2. The CRD guidelines are equal to, or lower than all existing federal and provincial air quality objectives and standards. This report provides an analysis and assessment of ambient air quality concentrations in the CRD with a focus on the CRD guidelines. Appendix B provides a discussion of all relevant provincial and federal air quality objectives.

The Canada Wide Standards are currently set at 127.6 µg/m³ (fourth highest eight-hour daily maximum concentration), and 30 µg/m³ (98^{th} percentile, averaged over three consecutive years), for ozone and $PM_{2.5}$, respectively[3].

[2] Schutte, A, and I. Liepa 2003. *Continuous Improvement and Keeping Clean Areas Clean: An Issues Paper*. Prepared for the Air Pollution Prevention Directorate, Transboundary Air Issues Branch, Environmental Protection Service, Environment Canada and the Canadian Council of Ministers of the Environment by Levelton Engineering Limited, Richmond, BC.
[3] Canadian Council of Ministers for the Environment, 2000. Guidance Document on Achievement Determination: Canada Wide Standards for Particulate Matter and Ozone. www.ccme.ca.

Table 1.2
Air Quality Guidelines for the Capital Regional District

Category/Averaging Time	Pollutant Concentration (in µg/m³)					
	NO_2	SO_2	CO	O_3	PM_{10}	$PM_{2.5}$
Upper-bound Guideline						
1-hour	200					
8-hour			5500	120		
24-hour		125			50	25

note: all averaging periods are sequential, with the exception of O_3, which uses rolling averages

2.0 Meteorological Monitoring

Meteorological data are available from seven monitoring stations in the CRD, although most collect wind data only. The station at Victoria Airport is operated by Environment Canada and collects a full climatological dataset that can be used to characterize the region. Tables A.1 and A.2 in Appendix A present a summary of monthly mean temperatures and precipitation amounts for 2004 and for the climate norm, respectively. In general, 2004 was slightly warmer than the 30 year norm, more noticeably in the summer months. The annual precipitation amount was similar to the norm, with wetter than usual conditions in the late summer and drier than usual in the spring and early summer. Table 2.1 summarizes the information collected at each of the seven monitoring stations, and the capture rate for wind data. The location of each station can be viewed in Figure 1-1.

Table 2.1
Meteorological Stations in the CRD

STATION	OPERATION*	MET. DATA COLLECTED**	WIND CAPTURE RATE (%)
Langford Dogwood School	BC Environment	ws, wdir,	99.6
Royal Roads University (Colwood)	Royal Roads University	ws, wdir, temp	84.1
Esquimalt Graving Dock	BC Environment	ws, wdir, rh	33.9
Victoria Topaz	BC Environment, EC NAPS	ws, wdir, temp, rh	97.3
Stellys, Saanich Peninsula	BC Environment	ws, wdir, temp	99.2
Victoria Airport	EC	ws, wdir, temp, rh, precip, cloud, (more)	100
Saturna Island	EC CAPMoN	ws, wdir	98.1

* EC = Environment Canada, CAPMoN = Canadian Air and Precipitation Monitoring Network, NAPS = National Air Pollution Surveillance.
** ws = wind speed, wdir = wind direction, temp = dry bulb temperature, rh = relative humidity, precip = precipitation (rain+snow) amounts, cloud = cloud cover.

A full annual dataset of wind data was collected at Stellys, Saanich Peninsula (Stellys) and Langford for the first time during 2004. A new station, Esquimalt Graving Dock (Esquimalt) began collecting data in August of the year. Wind rose (WR) diagrams, which show the frequency of wind direction (the direction ***from*** which the wind blows) and wind speed experienced at a location, were created for each of the six stations with a complete or near-complete annual dataset (Victoria Topaz, Langford, Royal Roads University, Stellys, Victoria Airport and Saturna Island) and are presented in Appendix A as Figures A.2 to A.7. Of the six stations, Langford, Royal Roads and Victoria Topaz are relatively near to each other in the south end of Greater Victoria. Stellys is approximately 16 km north of this location, and the Victoria Airport is an additional 8 km north of Stellys. The Saturna Island station is maintained by Environment Canada as part of the Canadian Air and Precipitation Monitoring (CAPMoN) network and is located to the northeast of Victoria, in the Strait of Georgia.

Each of the meteorological stations collected a high percentage of possible hourly wind data for the year with the exception of Royal Roads University, which attained an 84.1% data capture. The WR diagrams show that Victoria Topaz and Langford experience a very similar annual distribution of winds by direction. The fact that the Royal Roads station is situated relatively near and in between the Topaz and Langford stations, yet measures differing wind directions indicates that this station may be significantly influenced by local terrain features. The Esquimalt station is also in the south portion of Greater Victoria. An analysis of the Esquimalt station winds over the relatively short collecting period during the fall and early winter show similar trends to those observed at Topaz and Langford, but not Royal Roads. This comparison is displayed in Figure A.8. These comparisons indicate that the Royal Roads wind data are not representative of areas in the CRD beyond the immediate vicinity of the University. Further, it is not clear why this station records such a high frequency of northerly winds. An analysis of the siting characteristics of this station is recommended before data from the station is used for any research or planning projects in the CRD.

In general, the surface station wind data indicate that in the southern portion of the CRD, southwest and north/northeast winds are most common. In the case of Langford area, higher wind speeds are more likely to originate from the southwest. Further north, the annual wind pattern favours easterly and westerly winds (as evidenced by the Stellys dataset) and near the Victoria Airport this east-west bias becomes much more pronounced. Winds over Saturna Island are much stronger in magnitude than at any of the other meteorological stations. These data suggest that there is considerable variability in the winds experienced in different regions within the CRD.

The mean monthly wind direction for the communities in the CRD can change substantially. Wind direction data from the Stellys, Topaz, Langford and Victoria meteorological stations were used to determine the frequency of north, east, south and west winds by month for the region as a whole. The Royal Roads and Saturna stations were not used, as these data may not provide a good indication of the winds experienced in areas where a majority of the CRD residents live and work. The distribution of wind direction by month is shown in Figure A.9. This Figure shows that there is an obvious shift in prevailing wind direction during December to February, when the frequency of northerly winds increases substantially. During the summer months, northerly winds are relatively infrequent and southerly winds are more likely to occur[4].

[4] Further discussion of prevailing winds and their causes for this general area can be found in the book *The Wind Came from All Ways* (Owen S. Lange), available from Environment Canada.

3.0 GASEOUS POLLUTANTS

The Victoria Topaz Air Monitoring Station is located several kilometres from the coast in proximity to a major traffic artery (Blanshard St.) and is representative of the urban environment in greater Victoria. Victoria Topaz captures data for all gaseous pollutants of interest to the CRD, including carbon monoxide (CO), nitrogen oxides (NO and NO_2), sulphur dioxide (SO_2) and ground-level ozone (O_3). The Topaz station (and others) also monitors fine particulate matter (PM), which is addressed in Chapter 3. The Royal Roads University monitoring station records NO, NO_2, O_3 and, beginning in 2004, CO and SO_2 data. Stellys and the Canadian Air and Precipitation Monitoring Network (CAPMoN) station at Saturna Island record O_3.

Gas samplers take a measurement of the ambient air concentrations every several seconds. These values are then used to produce 1-hour averages, which can be re-averaged to produce 8-hour or 24-hour average concentrations. The samplers are designed to automatically re-calibrate themselves at relatively frequent intervals, which causes them to periodically 'miss' an hourly measurement.

3.1 CARBON MONOXIDE (CO)

Carbon monoxide is produced by both natural and anthropogenic sources. Natural sources include volcanic eruptions, forest fires and the decomposition of materials. Human emissions of CO are primarily caused by the incomplete combustion of fossil fuels. CO is a colourless, odourless and tasteless gas.

Carbon monoxide is an air contaminant of concern due to its ability to impair oxygen transport in blood. Hourly CO concentrations are available from both the Victoria Topaz and Royal Roads University monitoring station, although Royal Roads did not collect a full annual dataset. The hourly concentrations are summarised in Table 3.1.1.

Table 3.1.1 Hourly CO Concentrations at Victoria Topaz

Percentile Values						Max µg/m^3	Min µg/m^3	Mean µg/m^3	Std. Dev. µg/m^3	Missing Values % of Total Hours
5	25	50	75	98	99					
Victoria Topaz										
100	300	600	800	2200	2900	6100	0	671	530	5.1
Royal Roads University										
n/a	n/a	n/a	n/a	n/a	n/a	2300	0	635	n/a	60.0

Eight-hour sequential average concentrations for the two air quality stations are provided in Table 3.1.2. There were no exceedences of the CRD 8-hour guideline of 5500 µg/m³ in 2004.

Table 3.1.2 8-Hour Sequential Mean of CO at Victoria Topaz

Percentile Values						Max µg/m³	Min µg/m³	Mean µg/m³	Std. Dev. µg/m³	Percent of 8-h Averages > CRD Guideline (5500 µg/m³)	Missing Values[a] % of Total 8-h Averages
5	25	50	75	98	99						
Victoria Topaz											
129	343	625	863	1838	2063	3325	0	671	382	0.0	1.0
Royal Roads University											
n/a	n/a	n/a	n/a	n/a	n/a	1613	50	637	n/a	0.0	59.0

Figure 3.1.1 shows the maximum and mean sequential 8-hour concentrations by month for 2004. Mean and maximum concentrations tend to be higher during the cooler months. This may be due to a combination of human and natural activities. CO is liberated from the decomposition of leaves and other material during the fall. In addition, use of fossil fuels tends to increase during cooler months as residents heat their homes.

Figure 3.1.2 provides the average diurnal pattern of hourly CO concentrations during warm and cool months of 2004 for Victoria Topaz. An increase in concentration that roughly coincides with the morning increase in traffic volumes is evident for all months of the year. During cooler months only, an increase during the late afternoon and evening is likely caused by the combustion of fuels for home heating, exacerbated to some degree by the rapid cooling of the earth's surface and an accompanied reduction in ability of the atmosphere to disperse ground-level emissions.

A comparison of CRD CO concentrations to provincial and federal objectives is provided in Appendix B.

[a] An 8-hour average concentration was determined for every interval having 6 or more valid hours of data.

Figure 3.1.1 Maximum and mean 8-Hour CO Concentrations by Month at Victoria Topaz

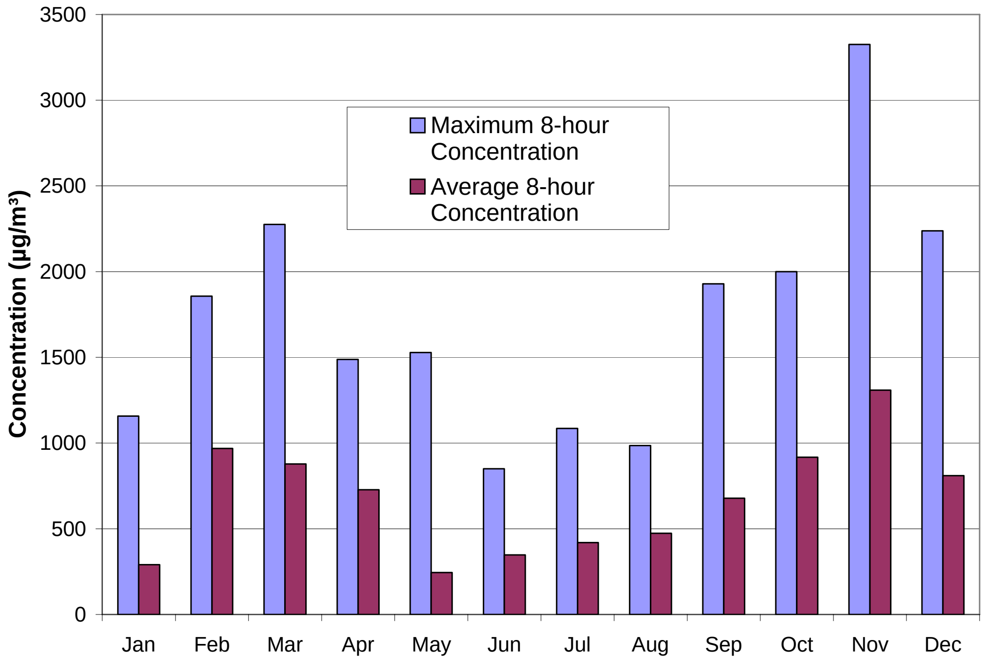
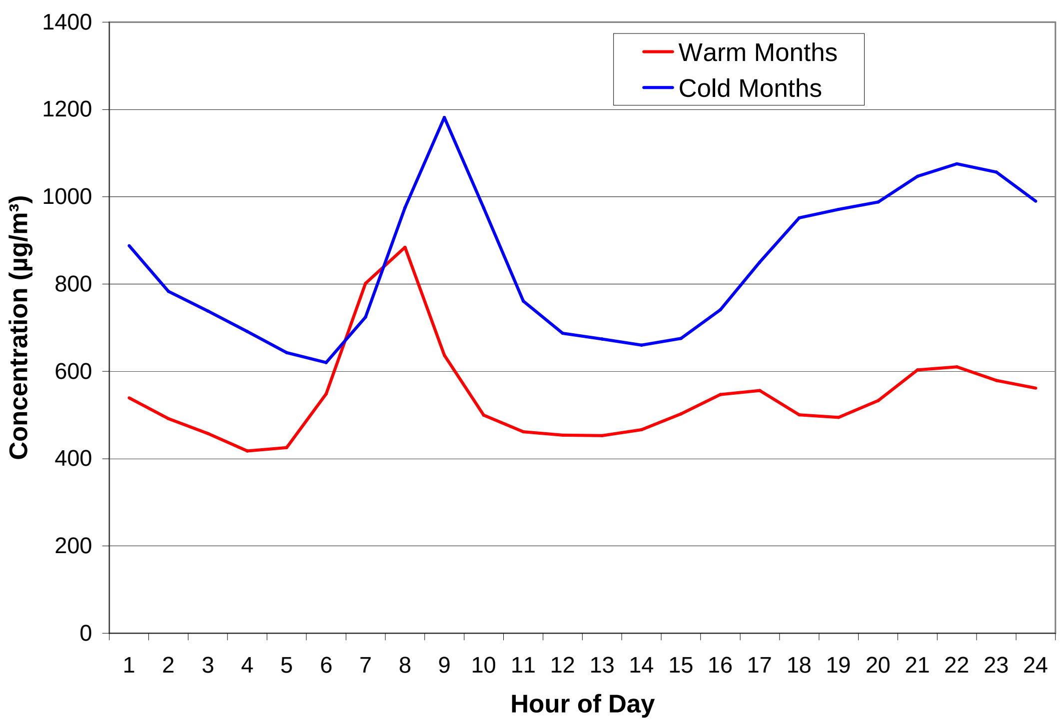


Figure 3.1.2 Average Diurnal CO Pattern for Victoria Topaz During Cold Months (November - March) and Warm Months (April – October)



3.2 NITROGEN OXIDES (NO AND NO_2)

Due to the fact that NO and NO_2 easily convert from one form to the other in photochemical reactions, they are commonly referred to collectively as 'NO_x'. Nitric oxide (NO) is colourless, odourless and tasteless, and not considered toxic at the concentrations found in the lower atmosphere. Nitrogen dioxide (NO_2) has an orangey-red colour and irritating odour at high enough concentrations. Ambient concentrations of NO_2 can at times be high enough in the lower atmosphere to warrant concern. Nitrogen dioxide is corrosive due to its high potential for oxidation and can cause a reduction in visibility in its role as a smog-forming constituent.

Nitric oxide is produced naturally from biological processes in soil and water and anthropogenically from the combustion of fuels. Although nitrogen dioxide can be formed from similar reactions, most results from the direct oxidation of NO. As such, peak NO_2 concentrations during the day tend to lag NO maximums by up to several hours. Both NO and NO_2 are involved in a complex set of reactions involving ozone.

NO and NO_2 data were collected at the Victoria Topaz and Royal Roads University air quality stations during 2004. Hourly concentrations of NO2 are summarised in Table 3.2.1 and 24-hour (sequential) concentrations are presented in Table 3.2.2. There were no exceedences of the CRD 1-hour guideline of 200 µg/m³. Concentrations experienced at Victoria Topaz are considerably higher than at Royal Roads, likely due to the proximity of the Topaz station to a major traffic artery.

Table 3.2.1 Hourly NO_2 Concentrations in the CRD

Percentile Values						Max µg/m³	Min µg/m³	Mean µg/m³	Std. Dev. µg/m³	Percent of 1-h Averages > CRD Guideline (200 µg/m³)	Missing Values % of Total Hours
5	25	50	75	98	99						
Victoria Topaz											
3.8	9.6	17.2	26.8	55.5	61.2	99.4	0.0	19.9	13.3	0.0	31.0
Royal Roads University											
0.0	1.9	5.7	11.5	30.7	36.3	55.5	0.0	8.0	8.4	0.0	32.7

note: statistical measures in Table 3.2.1 may not be representative of other years, due to missing data in both annual datasets.

Table 3.2.2 24-Hour Sequential Mean NO_2 Concentrations in the CRD

Percentile Values 5	25	50	75	98	99	Max µg/m³	Min µg/m³	Mean µg/m³	Std. Dev. µg/m³	Missing Values[b] % of Total 24-h Averages
Victoria Topaz										
8.9	14.6	19.4	24.9	36.0	39.2	50.7	1.0	19.9	7.5	29.0
Royal Roads University										
1.2	3.7	6.7	11.2	23.6	25.0	29.7	0.2	8.0	5.6	30.9

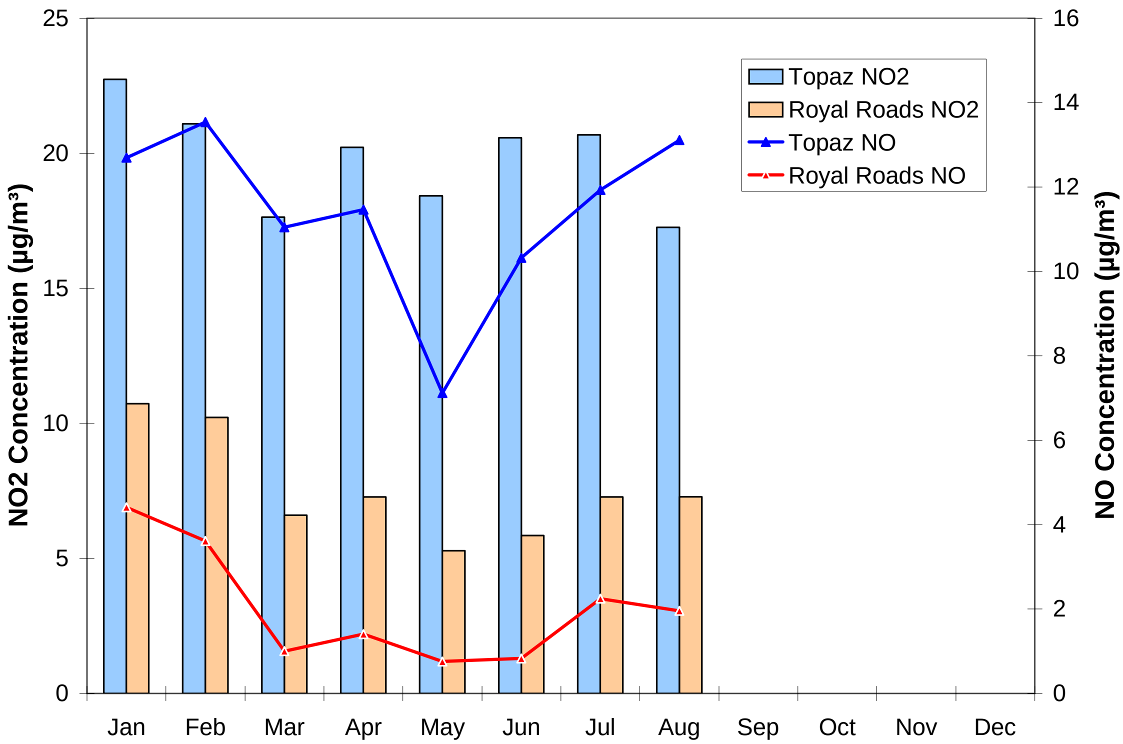
note: statistical measures in Table 3.2.2 may not be representative of other years, due to missing data in both annual datasets.

A significant amount of data is missing from the annual NO/NO_2 datasets for the two stations. This is due to the fact that instrument audits for both stations failed in December of 2004, making the preceding two months of data unreliable[5].

Monthly average NO and NO_2 concentrations are illustrated in Figure 3.2.1 for the two air quality stations. NO concentrations decline in the spring and early summer for each station, with NO_2 concentrations following the same trend at Royal Roads University, but not at Victoria Topaz (for that portion of the year for which data is available). Production of NO_2 from the oxidation of NO depends on ambient concentrations of NO, but also on the amount of solar insolation (sunshine), which varies by month. Ambient levels of ground-level ozone are also a factor.

[b] A 24-hour average concentration was determined for any day having 18 or more valid hours of data.
[5] Personal communication with Karen Kneier, B.C. Environment, June 21, 2005.

Figure 3.2.1 Average 24-Hour NO and NO_2 Concentrations by Month at Victoria Topaz and Royal Roads University



Figures 3.2.2a and 3.2.2b show the average diurnal pattern of hourly NO and NO_2 concentrations during warmer and cooler months respectively, at Victoria Topaz. Each has an NO/NO_2 peak that coincides with increased traffic volumes in the morning. During cooler months, a second maximum for both NO and NO_2 is evident later in the day, which may be due in part to emissions from home space heating.

Figure 3.2.2a Average NO and NO_2 Diurnal Patterns for Victoria Topaz during Warmer Months (May - October)

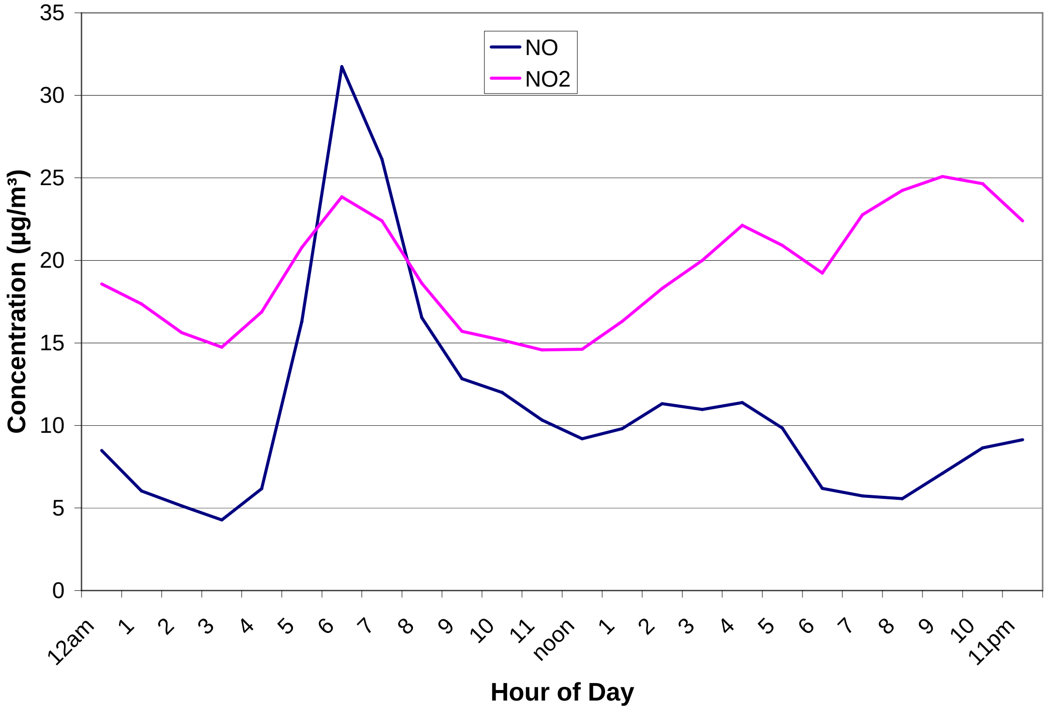
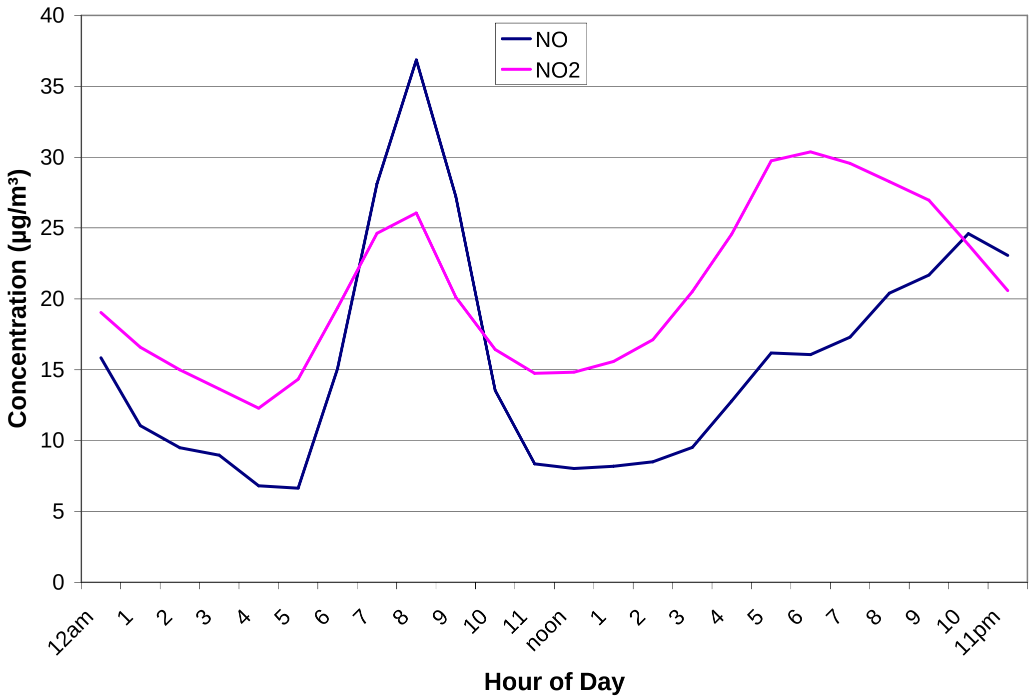


Figure 3.2.2b Average NO and NO_2 Diurnal Patterns for Victoria Topaz During Cooler Months (November – April)



A comparison of CRD NO_2 concentrations to provincial and federal objectives is provided in Appendix B.

3.3 SULPHUR DIOXIDE (SO_2)

Sulphur oxides are produced when sulphur-bearing fossil fuels are combusted. Only sulphur dioxide (SO_2) is found in appreciable amounts in the troposphere, and has ambient air quality objectives. The oxidation of SO_2 leads to the production of sulphates (a component of ambient particulate matter) and sulphuric acid in the atmosphere. Sulphur dioxide is a colourless gas, which has an unpleasant taste and odour at high enough concentrations. Background concentrations of SO_2 in the atmosphere tend to be very low; as such, elevated concentrations within urban settings can usually be attributed to anthropogenic activities such as industrial or residential consumption of fossil fuels.

SO_2 sampling occurred at the Victoria Topaz and Royal Roads air quality stations during 2004. However, the Royal Roads dataset is representative only of the period from July 28 to the end of the year. Table 3.3.1 shows the 1-hour and annual average concentrations for the two stations. The Royal Roads values do not include percentile concentrations, as the period of data collection for this station is too short to properly determine these amounts. The 24-hour average concentrations are shown in Table 3.3.2. There were no exceedences of the CRD guideline of 125 µg/m³.

Table 3.3.1 Hourly SO_2 Concentrations at Victoria Topaz

Percentile Values						Max µg/m³	Min µg/m³	Mean µg/m³	Std. Dev. µg/m³	Missing Values
5	25	50	75	98	99					% of Total Hours
Victoria Topaz										
0	0	0	3	13	19	136	0	2.4	5.2	5.1
Royal Roads University										
n/a	n/a	n/a	n/a	n/a	n/a	24	0	0.8	n/a	64.3

Table 3.3.2 24-Hour Sequential Mean SO_2 Concentrations at Victoria Topaz

Percentile Values						Max $\mu g/m^3$	Min $\mu g/m^3$	Mean $\mu g/m^3$	Std. Dev. $\mu g/m^3$	Percent of 24-h Averages > CRD Guideline (125 $\mu g/m^3$)	Missing Values[b]
5	**25**	**50**	**75**	**98**	**99**						**% of Total 24-h Averages**
Victoria Topaz											
0.1	0.8	1.7	3.4	7.8	11.4	20.5	0.0	2.4	2.4	0.0	1.4
Royal Roads University											
n/a	n/a	n/a	n/a	n/a	n/a	3.5	0.0	0.8	n/a	0.0	59.0

Monthly 24-hour average SO_2 concentrations are presented for the Victoria Topaz station in Figure 3.3.1. Although average 24-hour concentrations remain quite low each month, maximum concentrations increase substantially during the summer and early fall.

Figure 3.3.2 provides the average diurnal pattern of SO_2 concentrations during warmer and cooler months of the year. For both profiles, a peak is evident that coincides with the morning increase in traffic volumes in the CRD. A secondary peak is also evident during both warmer and cooler months of the year. During the late afternoon, ambient SO_2 concentrations tend to increase for all months of the year, which then decrease again in the evening during warm months but remain relatively high through much of the evening during cooler months.

[b] A 24-hour Concentration was determined for every day having 18 or more valid hours of data.

Figure 3.3.1 Average and Maximum SO_2 Concentrations by Month at Victoria Topaz

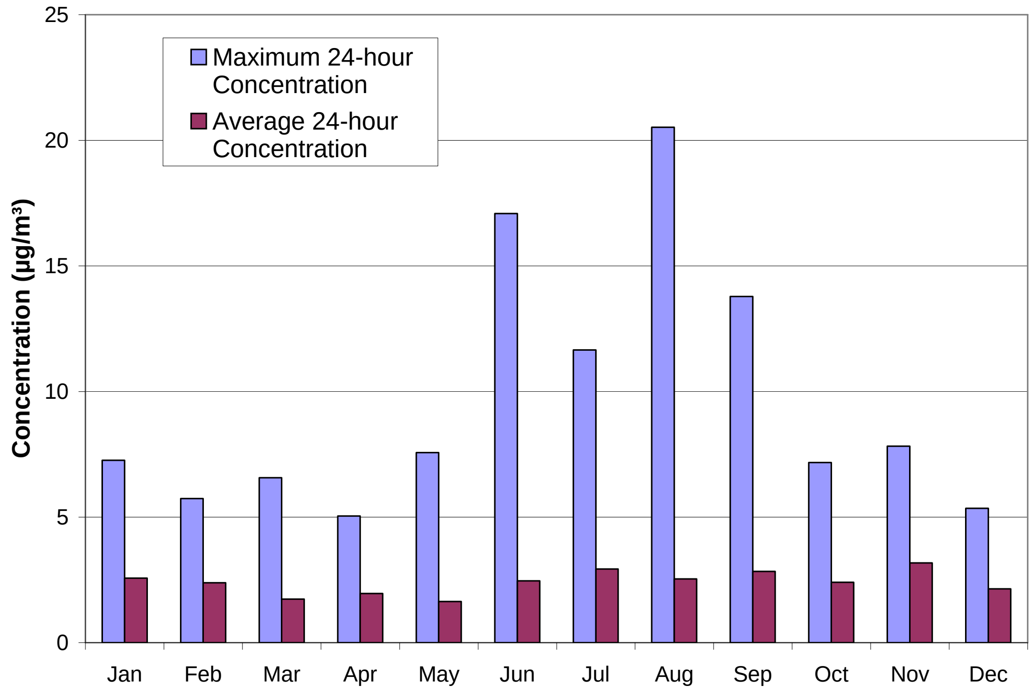
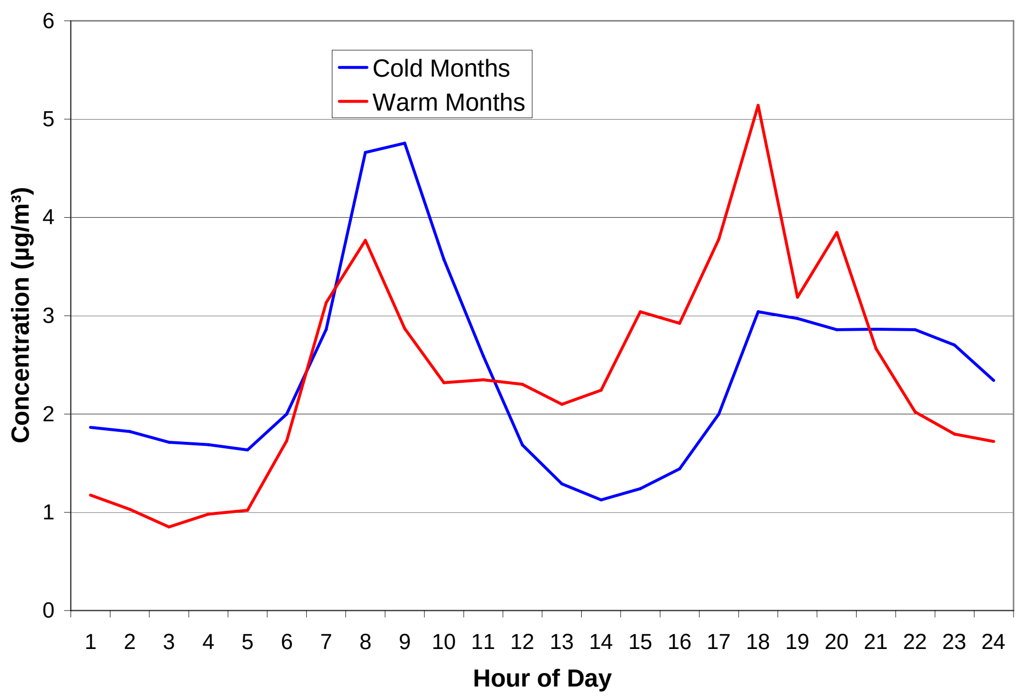


Figure 3.3.2 Average SO_2 Concentrations at Victoria Topaz by Hour of Day



Comparison of CRD SO_2 concentrations to provincial and federal objectives is provided in Appendix B.

3.4 GROUND-LEVEL OZONE (O_3)

Ozone is a photochemical oxidant that is formed in the atmosphere from chemical reactions involing NO_x, ultraviolet radiation (sunlight), oxygen and hydrocarbons. In the lower troposphere, ozone is considered to be harmful to vegetation and animal/human life at high enough concentrations. Due to its nature, ground-level ozone is termed a secondary pollutant, since it is caused by the reaction of primary pollutants.

Ground-level ozone is considered to be a regional air contaminant, since the chemical reactions that produce the gas may occur at significant distances from the areas where the primary pollutants are released. For this reason, high ground-level ozone concentrations can be experienced in rural areas or even in areas considered pristine. Also worth noting, the intrusion of stratospheric ozone, which beneficially acts to absorb ultraviolet radiation in the upper atmosphere, can cause concentrations in the lower troposphere to dramatically rise. Currently, it is widely believed that springtime weather conditions favour this effect. Variations in weather patterns from year to year can have a large effect on community concentrations.

Hydrocarbons (also referred to as volatile organic compounds – VOCs) and nitrogen oxides are the significant precursor pollutants that cause ground-level ozone. There are many compounds within the hydrocarbon family, including benzene, aldehydes, propane and acetone. Hydrocarbon releases are caused by both natural (i.e., vegetation, trees) and anthropogenic sources. In particular, man-made sources include transportation (fuel combustion, fuel filling activities), petroleum refining and chemical and solvent use. Due to the involvement of sunlight in the ozone causing reactions, sunny (high pressure), warm weather favours ground-level ozone production.

The formation of ozone depends on a rather complex set of reactions that are sensitive to relative concentrations of pollutant precursors. In particular, ozone can be ‘scavenged’ by destructive reactions with NO_x. It can therefore be common to observe a decrease in ground-level ozone concentrations during periods of peak NO_x emissions in urban areas.

The Federal air quality objectives for ground-level ozone are considered to be outdated, and are commonly exceeded in many urban and rural locations throughout Canada. The Canada Wide Standard for ozone is based on more up-to-date scientific, health and environmental information.

Ozone monitoring data was captured at the Victoria Topaz, Royal Roads University, Stellys and Saturna Island monitoring stations, although the Royal Roads dataset is missing the period from January 22nd to March 10th. A full annual dataset is available for the Stellys station for the first time. Table 3.4.1 presents a summary of the hour-average ozone concentrations for the four stations during 2004.

Table 3.4.1 Hourly Ozone Concentrations in the CRD

Percentile Values						Max $\mu g/m^3$	Min $\mu g/m^3$	Mean $\mu g/m^3$	Std. Dev. $\mu g/m^3$	Missing Values
5	**25**	**50**	**75**	**98**	**99**					**% of Total Hours**
Victoria Topaz										
0.0	12.0	33.9	53.9	83.8	89.8	115.7	0.0	35.0	24.9	5.8
Royal Roads University										
2.0	18.0	39.9	59.9	93.8	96.5	121.7	0.0	40.3	26.6	17.0
Stellys										
0.0	14.0	37.9	59.9	93.8	100.8	135.7	0.0	38.2	27.1	4.7
Saturna Island										
13.7	33.3	47.0	60.8	92.1	100.0	137.2	2.0	47.2	20.7	0.8

Table 3.4.2 shows the 8-hour rolling average concentrations at the 4 monitoring sites. The 8-hour averages are used to determine compliance with both the CRD guideline (120 $\mu g/m^3$) and the CWS. Percentile and maximum ozone concentrations are lower in 2004 than those determined for 2003, for all four stations.[6] There are no exceedences of the CRD guideline for 2004.

[6] SENES Consultants Ltd., 2004. *Air Quality in the Capital Regional District, 2003.* Prepared for the Capital Regional District.

Table 3.4.2 8-Hour Rolling Average Ozone Concentrations in the CRD

Percentile Values						Max $\mu g/m^3$	Min $\mu g/m^3$	Mean $\mu g/m^3$	Std. Dev. $\mu g/m^3$	Number of 8-h Averages > CRD Guideline (120 µg/m³)	Missing Values[a]
5	25	50	75	98	99						% of Total Hours
Victoria Topaz											
2.3	17.1	33.7	51.9	79.8	82.6	106.0	0.0	35.0	21.9	0	2.4
Royal Roads University											
3.1	20.7	39.9	58.6	88.8	92.3	111.4	0.0	40.4	24.1	0	14.1
Stellys											
2.8	18.0	36.9	55.6	88.5	93.9	113.7	0.0	38.1	24.1	0	1.2
Saturna Island											
16.3	34.3	46.8	59.8	87.0	94.9	117.1	2.0	47.2	19.0	0	0.9

It should be noted that although the 98th percentile 8-hour concentration experienced at Saturna Island is lower than in previous years, the concentrations at Royal Roads and Stellys are not equally diminished. In addition, the 98th percentile values at these two stations are higher than the Saturna value, which has not been noted in the past (although Stellys has only been in operation for one full year). The current assumption that the Saturna Island monitoring station consistently experiences the highest ground-level ozone concentrations for the monitoring stations within the CRD should be re-considered in 2005.

Table 3.4.3 presents an analysis of the daily maximum 8-hour ground-level ozone concentrations at Saturna Island for 2004 and the previous two years. This comparison is done for CWS compliance, which requires that the annual 4th highest, daily maximum concentration averaged over three consecutive years does not exceed 65 parts per billion (which is equivalent to 127.6 µg/m³). CWS guidelines state that a monitoring station representative of the highest metropolitan ozone concentrations be used to demonstrate compliance. Over the past several years (with the exception of 2004), the Saturna Island station has recorded the highest ozone concentrations in the CRD and therefore can be used to produce a conservative determination of CWS compliance. The CWS for ground-level ozone is to be implemented by 2010.

[a] An 8-hour average concentration was calculated for each interval having 6 or more hours of valid data.

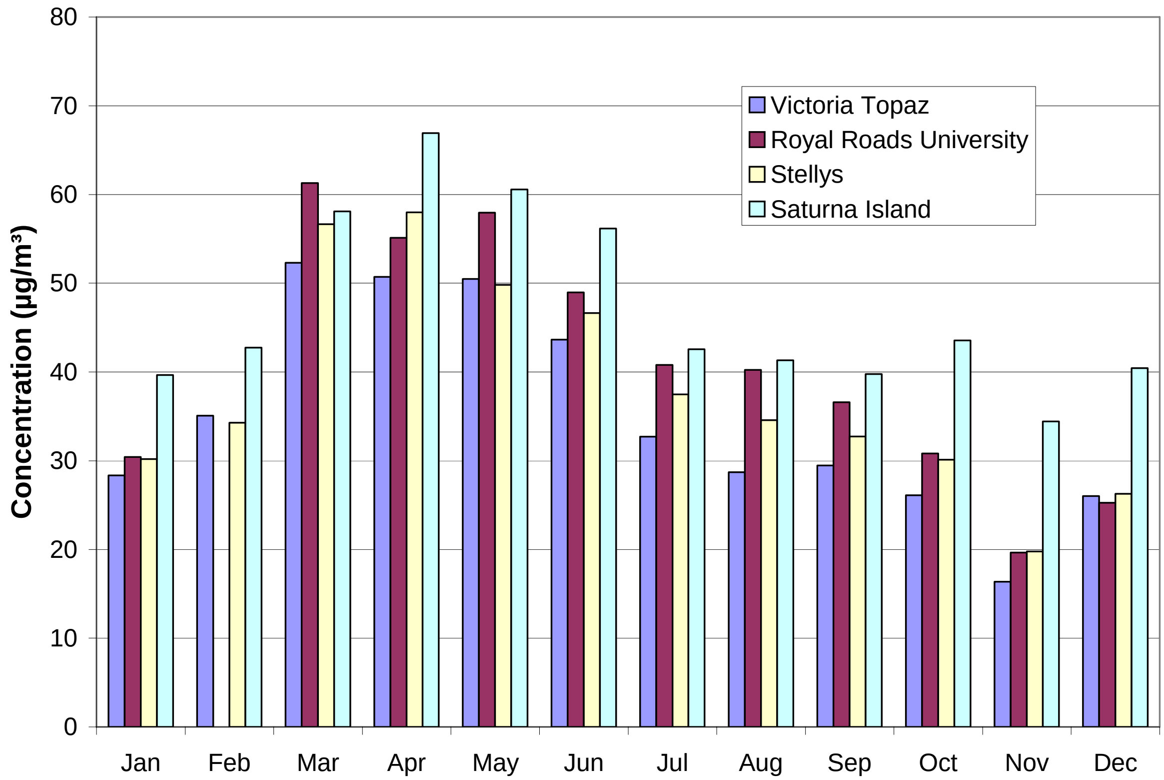
Table 3.4.3 8-Hour Rolling Mean Ozone Concentrations at Saturna Island, 2001-2003

Year	% 8-Hour Concentrations Missing	Mean 8-Hour Concentration (μg/m^3)	Maximum 8-Hour Concentration (μg/m^3)	4th Highest Daily Maximum 8-Hour Concentration (μg/m^3)
2002	1.9	55.9	116.9	115.4
2003	1.2	58.4	139.4	115.4
2004	0.9	47.2	117.1	109.5

The 4th highest, daily maximum 8-hour concentration of ground level ozone for the CRD in 2004 is 109.5 μg/m^3, which is below the CWS.

Monthly average 8-hour ozone concentrations are shown in Figure 3.4.1. With the exception of February, the Saturna Island average concentrations are consistently higher than those from the other three stations. As with previous years, ground-level ozone concentrations are highest during the spring months.

Figure 3.4.1 Monthly Average 8-Hour Ozone Concentrations at Victoria Topaz, Royal Roads University, Stellys and Saturna Island



* All data is missing for February at Royal Roads University station.

Figures 3.4.2a and 3.4.2b provide the average diurnal ozone concentrations during cool and warm months of the year respectively. Saturna Island shows a smaller degree of variation in each graph, due to its remote location removed from urban emission sources that likely affect the other three stations. The concentrations at Victoria Topaz show a short-lived trough (decrease) in the early morning that may be due to ozone scavenging caused by relatively high NO_x concentrations associated with morning traffic.

Comparison of CRD ground-level ozone concentrations to provincial and federal objectives is provided in Appendix B.

Figure 3.4.2a Average Diurnal Ozone Pattern During Cooler Months (November-March)

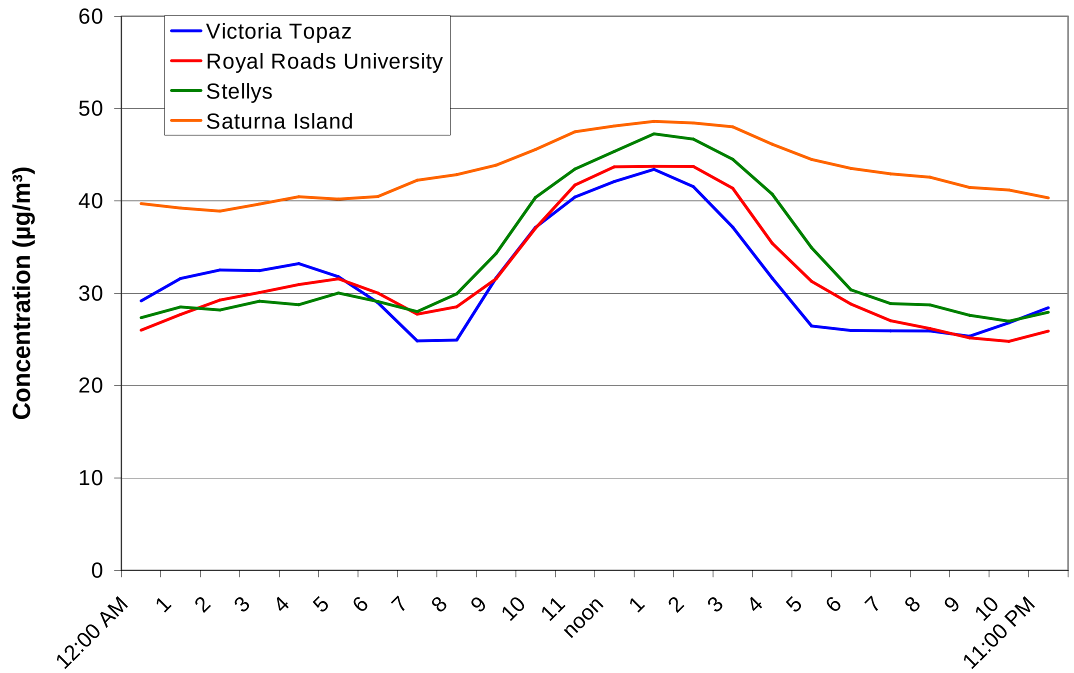
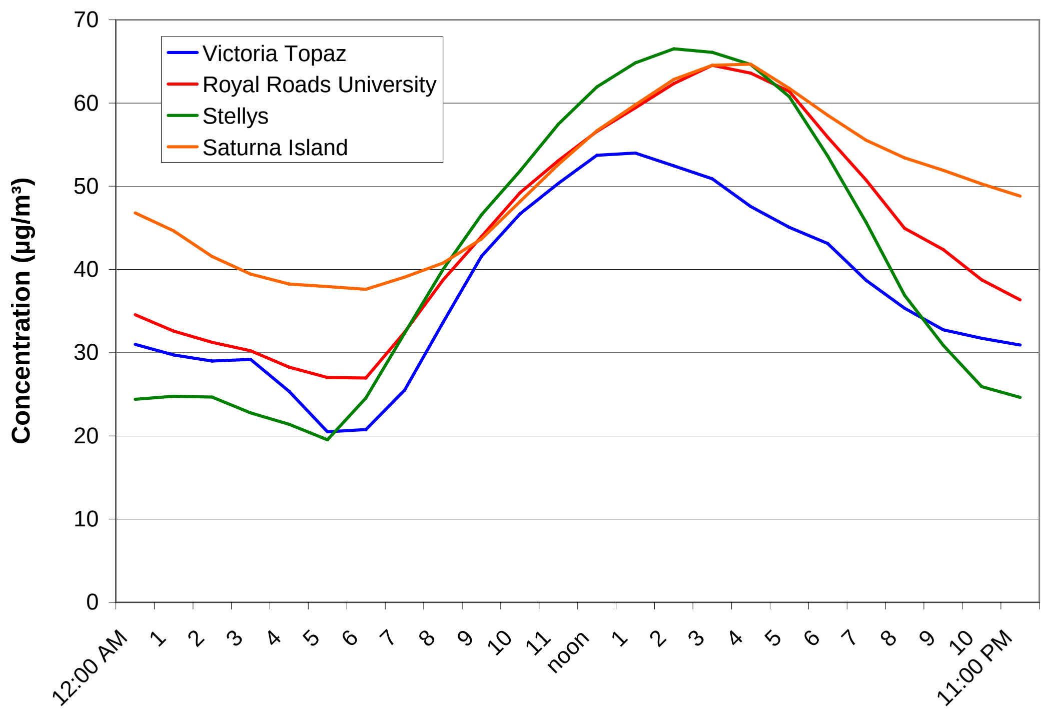


Figure 3.4.2b Average Diurnal Ozone Pattern During Warmer Months (April-October)



4.0 PARTICULATE MATTER

Particulate matter (PM) is released to the air through both natural and anthropogenic activities. Ambient PM is measured in the CRD as both 'inhalable' particulate matter, which is the fraction of atmospheric particles with diameters of 10 micrometres (µm) or less and 'respirable' particulate matter, which have diameters of 2.5 µm or less. These fractions are denoted as PM_{10} and $PM_{2.5}$ respectively. Natural sources of PM include road dust, sand, wind blown soil, marine aerosol (salt) and others. Anthropogenic contributions of PM emissions are largely due to combustion sources. Currently, there is a significant interest in community levels of $PM_{2.5}$, as health research has indicated the smaller size range of suspended particles can have negative effects on human health at concentrations typically observed in urban areas. In particular, exposure to $PM_{2.5}$ can aggravate pulmonary and cardiovascular disease, increase the occurrence of asthmatic attacks and increase the occurrence of premature mortality. Nationally, this knowledge is reflected in the Canada Wide Standards (CWS), which includes a standard for $PM_{2.5}$ amongst other atmospheric contaminants of concern.

Suspended atmospheric particles can be both solid and liquid in form and can remain suspended for periods ranging from several seconds up to several months. Primary PM describes matter emitted directly to the atmosphere, whereas secondary PM describes solid or liquid particles that are formed in the atmosphere from the chemical reactions of other compounds. An additional adverse effect that can be attributed to ambient PM concentrations is the reduction of visibility.

Four different ambient PM sampling (measuring) devices are currently used in the CRD. Tapered Element Oscillating Microbalance (TEOM) samplers are used to collect air concentrations of $PM_{2.5}$ that are recorded as hourly averaged concentrations. These samplers run continuously, with periodic maintenance depending on how quickly the sampling filter reaches capacity. Sequential high volume (Hi-Vol) samplers are used to determine 24-hour concentrations of PM_{10} on a cycle of one in every six days. One Partisol sampler is used to collect PM_{10} sequentially like the Hi-Vols, but utilizes a low-volume of airflow for sample collection. The fourth sampler type is a dichotomous (Dicot) sampler, which produces 24-hour concentrations of both PM_{10} and $PM_{2.5}$ on the same one-in-six day rotation cycle. The three types of sequential samplers collect particulate matter on a filter, from midnight of one day to midnight of the next. Once a collection period has ended, the filter is analyzed in a lab to determine the 24-hour concentration. Dicot data was not available to include in the analysis of 2004 monitoring data, although these data were available in previous years.

It should be noted that each type of sampling instrument has its own bias, in that measured amounts may be over- or under-estimated by a small amount simply due to the process the instrument uses to determine an ambient concentration. This means that two co-located PM_{10} or $PM_{2.5}$ samplers may produce ambient PM concentrations that differ. In addition, each PM sampler may be influenced by positional bias that exists due to the location of the air quality station within the community.

There may be sufficient PM data collected in the CRD during 2004 to enable a determination of the contribution of solid waste burning to ambient PM levels. This is a non-trivial initiative that requires both quantitative (i.e., monitoring data, burning bylaw requirements) and qualitative (i.e., knowledge of resident burning behaviours) information. The CRD began this investigation by commissioning a study that focussed on municipal bylaws, the issue of permits, resident complaints and the composition of emissions that involve burning solid waste[7]. The results of this initial investigation were used to support the analyses presented in this report.

4.1 INHALABLE PARTICULATE MATTER (PM_{10})

Hi-Vol PM_{10} data for 2004 are summarised in Table 4.1.1. Some variation in mean and percentile concentrations from year-to-year should be expected, due to changes in the 6-day rotation cycle (i.e., a monitoring day can fall on a period of particularly poor dispersion conditions during one year but not on another). Annual maximum concentrations for Topaz and Royal Roads University stations are much higher than concentrations recorded in 2003[8].

[7] Envirochem Services Inc., 2005. Investigation of Municipal Burning Bylaws and Air Contaminants Released from Burning Solid Waste (DRAFT). Prepared for Scientific Programs, Capital Regional District.
[8] SENES Consultants Ltd., 2004. *Air Quality in the Capital Regional District 2003.* Prepared for the Capital Regional District.

Table 4.1.1 Hi-Vol Sequential 24-Hour Mean PM_{10} Concentrations

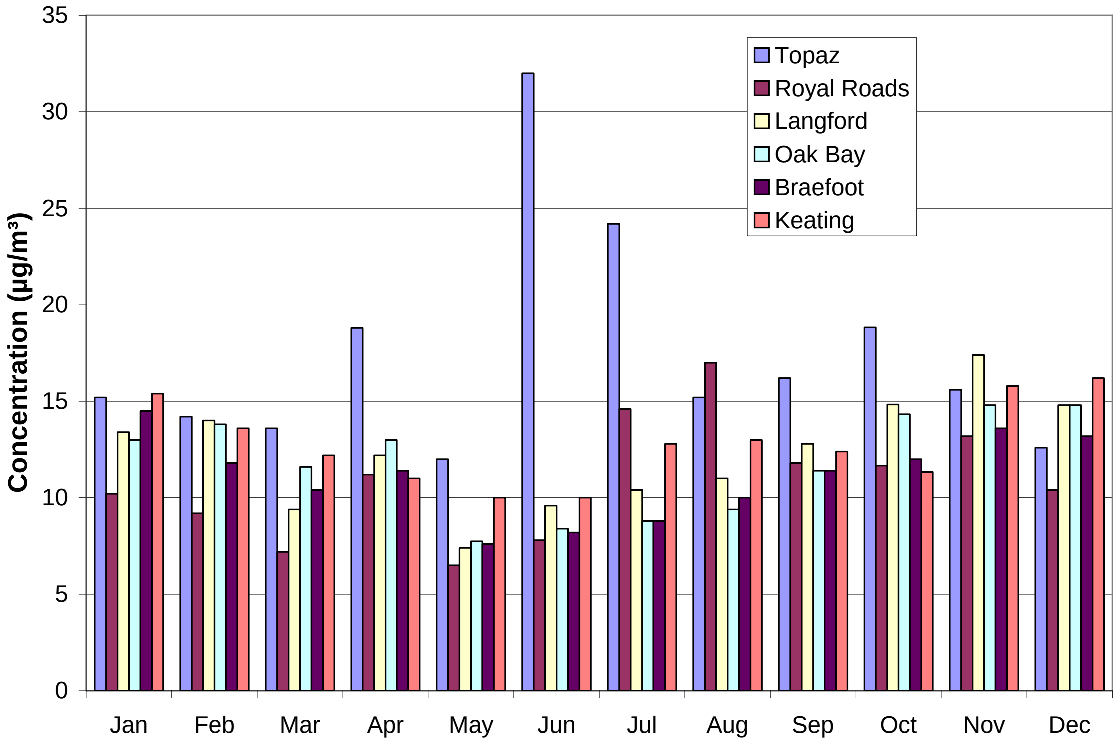
Statistic	Topaz	Royal Roads	Langford	Oak Bay	Braefoot	Keating
Mean (µg/m³)	17.4	11.0	12.3	11.8	11.0	12.8
Std. Dev. (µg/m³)	11.9	7.0	6.1	4.7	3.9	4.9
Maximum (µg/m³)	91	46	38	22	21	24
98th percentile (µg/m³)	40.0	34.6	23.0	21.8	19.0	23.6
# > CRD Guideline (50 µg/m³)	1	0	0	0	0	0
# of Samples	61	60	60	59	60	60
Percent Missing (%)	0.0	1.6	1.6	3.3	1.6	1.6

One exceedence of the CRD PM_{10} Guideline value of 50 µg/m³ (24-hour average) was recorded at Victoria Topaz on June 20th. Recorded concentrations at the five other stations were relatively low on the same day, suggesting that the exceedence was caused by a nearby source. Winds were light during the morning and moderate during the afternoon and evening of June 20th, according to wind measurements at the Topaz meteorological station. The general wind direction throughout the day was southerly to south-southwesterly, indicating that the source(s) of the elevated particulate matter concentrations were likely to the south of the station. The $PM_{2.5}$ monitor at Topaz did not measure correspondingly high levels of respirable particulate matter. This indicates that the high PM concentration on June 20th was mostly of the coarser fraction of fine particulate, which is usually associated with dust from roads or due to construction (or other) activities.

Health research has shown that there are adverse health effects associated with higher ambient particulate levels in a community. In most cases, previous studies involve analysis of PM concentrations over a greater period of time than 24 hours. Due to the limited temporal and spatial extent of the exceedence-level PM concentration experienced on June 20th, associated health effects can not be determined within a suitable degree of confidence.

Monthly average 24-hour PM_{10} concentrations are provided for the six monitoring stations in Figure 4.1.1. The average levels were relatively consistent for most of the year, with a noticeable decrease in the early summer months. An exception is evident for Victoria Topaz, which received the highest average concentrations during June and July. June and July were relatively dry months, which can lead to an increased amount of particulate matter available for re-suspension. This same pattern in PM_{10} concentrations was described in the 2003 air quality report.

Figure 4.1.1 Monthly Average 24-Hour PM_{10} Concentrations for Hi-Vol Samplers



Partisol PM_{10} concentrations for the Stellys, Saanich Peninsula (Stellys) station are summarised in Table 4.1.2. The Partisol data are collected on the same 6-day cycle as that used for the Hi-Vol samplers summarised in Table 4.1.1. In contrast to 2003, a full annual dataset was collected for 2004. Measured concentrations were not high in general, although there was one exceedence of the CRD PM_{10} Guideline of 50 µg/m³ (24-hour average). The exceedence occurred on the 7th of September, which experienced generally light and variable winds with clear skies in the morning that gradually changed to overcast by the afternoon. The high PM concentrations were not experienced at any of the other PM_{10} stations within the CRD.

Table 4.1.2 Partisol Sequential 24-Hour Mean PM_{10} Concentrations (Stellys)

Statistic	PM_{10}
Mean (μg/m^3)	11.3
Std. Dev. (μg/m^3)	11.2
Maximum (μg/m^3)	84.3
98th percentile (μg/m^3)	27.9
# > CRD Guideling (50 μg/m^3)	1
# of Samples	56
Percent Missing (%)	8.2

Similar to the PM_{10} exceedence experienced at the Victoria Topaz station, the health effects related to the relatively high concentration recorded on September 7th at Stellys cannot be clearly defined.

4.2 Respirable Particulate Matter ($PM_{2.5}$)

4.2.1 TEOM Sampling Results

Hourly averaged $PM_{2.5}$ concentrations for the four TEOM sites are summarised in Table 4.2.1. Each station captured a high percentage of possible data over the year. Stellys, which is situated in the rural setting of Central Saanich, experienced the highest mean concentration for the year, but the lowest maximum value. In contrast, the station at Royal Roads University had the lowest mean concentration but the highest maximum value.

Table 4.2.1 Hourly $PM_{2.5}$ Concentrations at

Percentile Values						Max μg/m^3	Min μg/m^3	Mean μg/m^3	Std. Dev. μg/m^3	Missing Values (%)
5	25	50	75	98	99					
Victoria Topaz										
0	2	4	7	22	27	74	0	5.6	5.8	2.0
Royal Roads University										
0	1	3	6	15	17	95	0	4.3	4.2	2.9
Langford Dogwood School										
0	2	4	7	21	25	68	0	5.7	5.3	1.0
Stellys										
1	4	7	10	21	25	57	0	7.6	5.1	2.1

Table 4.2.2 summarizes the sequential 24-hour averaged concentrations determined at the four TEOM sites. Although average concentrations experienced at the stations are similar to those from 2003[9], the annual maximum 24-hour concentration at Victoria Topaz and Royal Roads are considerably lower (Langford and Stellys did not have a complete annual dataset for 2003, and therefore no similar comparison can be made).

Table 4.2.2 24-Hour Sequential Mean $PM_{2.5}$ Concentrations in the CRD

Percentile Values						Max µg/m³	Min µg/m³	Mean µg/m³	Std. Dev. µg/m³	Percent of 24-h Averages > CRD Guideline (25µg/m³)	Missing Values[b] % of Total 24-h Averages
5	25	50	75	98	99						
Victoria Topaz											
1.8	3.0	5.0	7.1	15.5	17.4	19.0	0.5	5.6	3.4	0.0	1.9
Royal Roads University											
1.3	2.5	3.8	5.7	11.2	11.9	13.5	0.1	4.3	3.0	0.0	2.5
Langford Dogwood School											
1.7	3.3	4.9	7.3	14.2	15.8	25.8	0.7	5.7	3.5	0.3	1.4
Stellys											
3.7	5.3	7.0	9.6	14.3	16.4	19.5	2.3	7.6	3.8	0.0	1.6

There was one exceedence of the CRD 24-hour guideline of 25 µg/m³, and this occurred at Langford Dogwood school on Friday November 5th. This is the first day during the fall that the Municipality of Langford allows open and backyard (barrel) burning. As such, burning activities may be partly responsible for the exceedence. This is discussed in further detail in Section 4.3.

Poor atmospheric dispersion conditions likely played a role in the $PM_{2.5}$ exceedence in Langford, since concentrations at the other three TEOM sites on November 5th were also relatively high (but still well below the CRD guideline). These 24-hour measurements were 15.5, 9.9 and 14.3 µg/m³ at Victoria Topaz, Royal Roads University and Stellys, respectively. The Langford meteorological station shows that winds were very light throughout the day. In addition, the Victoria Airport station shows that the skies were completely overcast during the morning and afternoon. These meteorological conditions would tend to suppress both mechanical and convective mixing of the atmosphere, causing poor dispersion conditions.

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[9] SENES Consultants Ltd., 2004. Air Quality in the Capital Regional District 2003. Prepared for the Environmental Services Department, Capital Regional District.
[b] A 24-hour average was determined for every day having 18 or more valid hours of data.

In general, the Langford TEOM measured higher hourly $PM_{2.5}$ concentrations beginning at 8:00 a.m. and continuing until 7:00 p.m. that night. The maximum hourly concentration during the day was 66 µg/m³. The degree of exposure for the general public in Langford to elevated $PM_{2.5}$ concentrations is difficult to ascertain, as some residents would be away from the area for work purposes, and some residents would be indoors during much of the day. Due to the meteorological conditions during the evening, residential emissions would also have been a contributing factor.

Adverse health effects related to the $PM_{2.5}$ exceedence are uncertain, due to lack of information regarding community exposure and the short time interval that the particulate levels were relatively high. However, $PM_{2.5}$ tends to be more well-mixed than the coarser fraction of particulate matter (PM_{10}) and as such a greater portion of the community may have been exposed to the high $PM_{2.5}$ concentrations than was the case for the two PM_{10} exceedences. An assessment of the actual health effects that may have occurred on November 5th in Langford is not possible at this time.

Compliance with the CWS for $PM_{2.5}$ (30 µg/m³, 24-hour average) is determined by calculating the arithmetic mean of continuous 24-hour $PM_{2.5}$ concentrations each midnight-to-midnight period during the year from monitoring sites that meet the "neighbourhood" or "urban" criteria as defined in the CWS Guidance Document on Achievement Determination[10]. It should be noted that the Stellys station likely does not meet this criteria, as it is situated in a rural setting. Therefore, data from the Victoria Topaz, Royal Roads University and Langford stations alone were used to determine CWS compliance for 2004. The distribution of mean 24-hour concentrations is analysed to determine the 98th percentile. To achieve compliance with the CWS, the three-year (consecutive) average of the 98th percentile values must be below the standard of 30 µg/m³. For 2004, the 98th percentile $PM_{2.5}$ concentration for the CRD is 12.8 µg/m³. Currently, a three-year average cannot be determined using these four stations, as Langford did not collect data during 2002. However, given the relatively low value of 12.8 µg/m³ for 2004, and the generally low levels of $PM_{2.5}$ recorded in previous years at Victoria Topaz and Royal Roads, it is unlikely that the CWS would have been exceeded on a 3-year average basis.

Monthly average $PM_{2.5}$ concentrations are displayed in Figure 4.2.1 for the four TEOM sites. With the exception of Stellys, there is a pattern of higher average concentrations during the fall and early winter months for 2004. This is not unusual, as increased particulate emissions due to home heating can occur during colder months. Ambient concentrations at Stellys are clearly higher than those at the other stations for 10 of the 12 months of the year.

[10] Canadian Council of Ministers for the Environment, 2000. Guidance Document on Achievement Determination: Canada Wide Standards for Particulate Matter and Ozone. www.ccme.ca.

Figure 4.2.1 Average 24-Hour $PM_{2.5}$ Concentrations by Month from TEOM Samplers

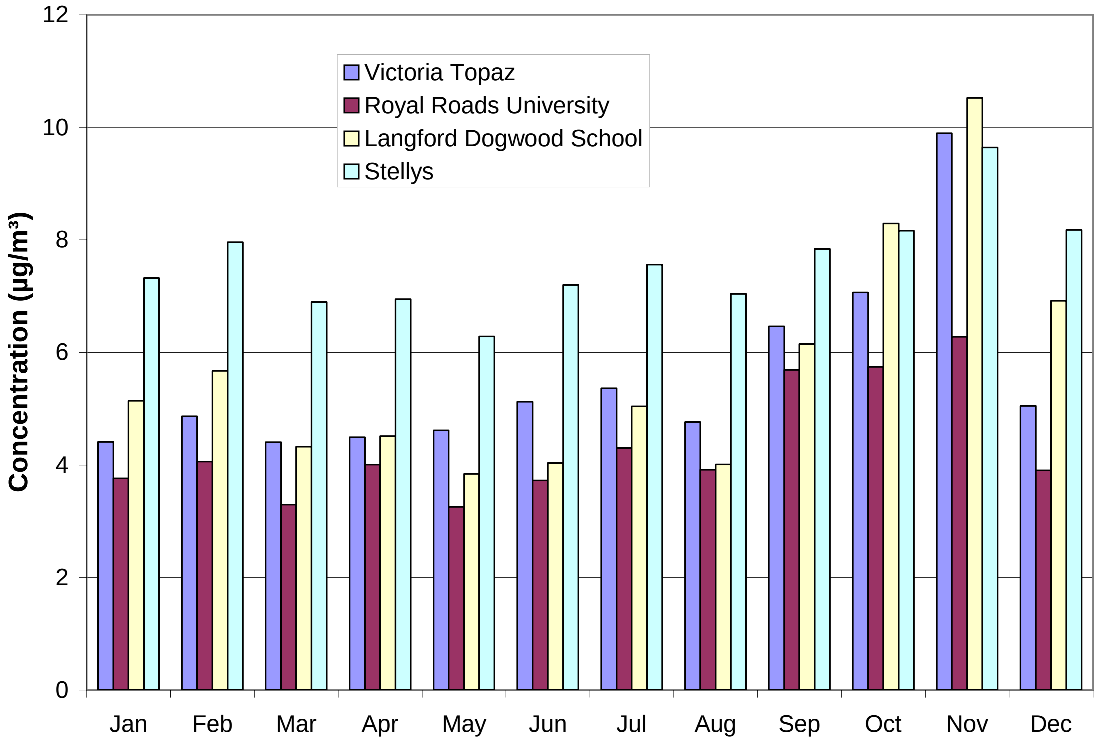


Figure 4.2.2a shows the average diurnal pattern of hourly $PM_{2.5}$ concentrations at the four monitoring station locations during cooler months. Each diurnal profile contains a peak that coincides with the morning rush hour and a second, larger peak that begins with the afternoon increase in traffic and extends into the evening. The second peak is likely due to a combination of traffic emissions and emissions due to space heating of homes. Also a contributing factor, the atmospheric mixing height[11] tends to decrease as temperatures cool in the evening, leading to greater persistence of contaminants in the ambient air.

[11] The mixing height refers to the depth of the atmosphere through which emitted pollutants are mixed through dispersion processes. Solar heating of the ground tends to increase the mixing height, whereas surface cooling tends to decrease it.

Figure 4.2.2a Average Diurnal $PM_{2.5}$ Pattern During Cooler Months at TEOM Sites (November – March)

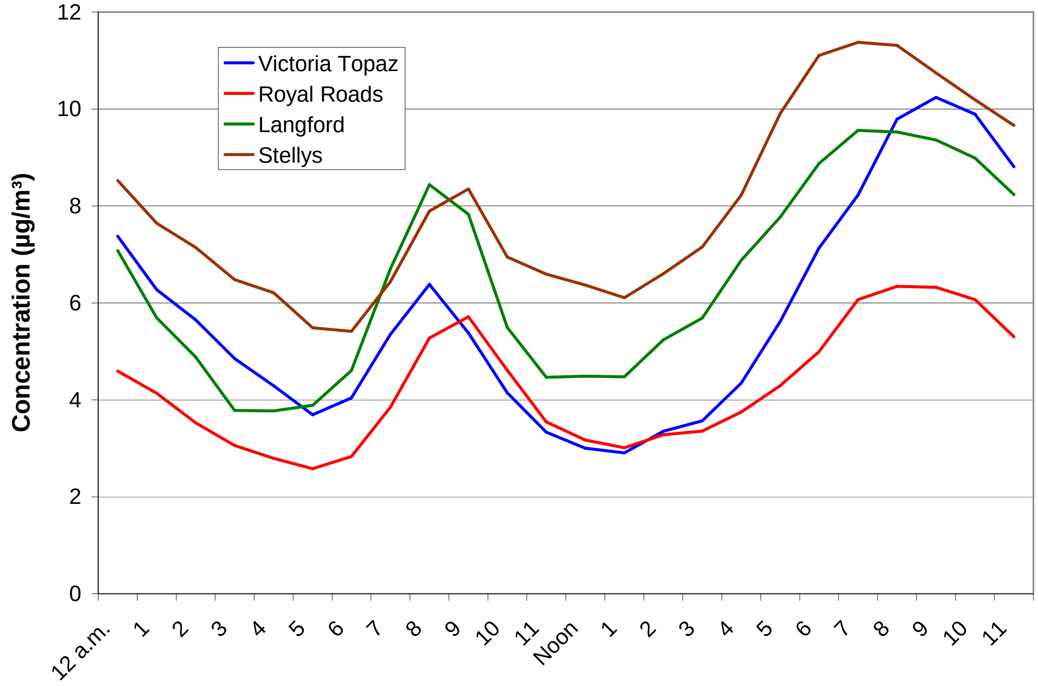


Figure 4.2.2b Average Diurnal $PM_{2.5}$ Pattern During Warmer Months at TEOM Sites (April - October)

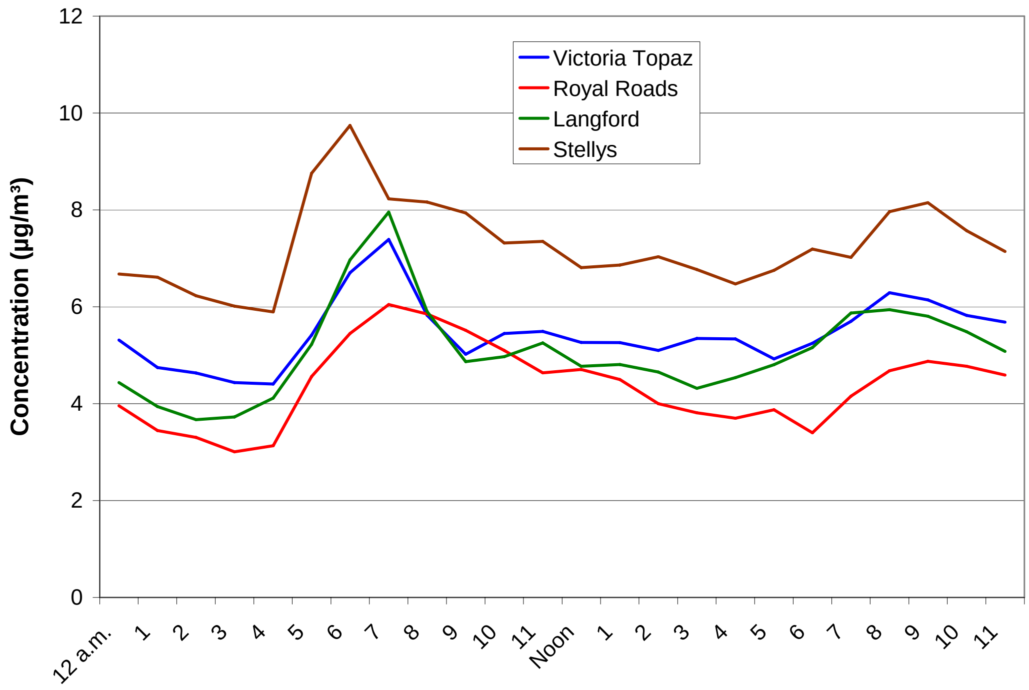


Figure 4.2.2b shows the average diurnal pattern of hourly $PM_{2.5}$ concentrations at the four monitoring station locations during warmer months. The four profiles show an early morning increase in concentrations that coincides with the morning rush hour, but the afternoon peak is much smaller than during cooler months. This suggests that space heating is a significant contributor to ambient $PM_{2.5}$ during cooler months.

4.3 SOLID WASTE BURNING AND AMBIENT PM

For the first time, full annual datasets of continuous $PM_{2.5}$ monitoring data for several communities in the CRD was available to allow a comprehensive investigation of solid waste burning. In keeping with one of the main goals of the Long Term Monitoring Plan, an assessment was performed to determine whether the occurrence of solid waste burning in the CRD has a measureable effect on ambient concentrations of particulate matter recorded at the monitoring stations.

The burning of solid waste produces a number of air contaminants. However, it is the emission of particulate matter specifically that is commonly considered a related concern. This is due to the fact that the amounts of PM released from such burning are relatively high in relation to the burning of other materials (i.e., fossil fuels) and in comparison to ambient air quality objectives. It remains very difficult to accurately estimate actual amounts of PM released during solid waste burning, as the amounts depend strongly on both the material consumed and combustion temperatures. Solid waste burning by residents of the CRD occurs in barrels or in piles, and is largely made up of yard waste (i.e., leaves and branches from trees) and to a smaller degree household waste. For those communities with beach access, beach fires are also included within this source type. Wood burning in residential fireplaces may also be considered solid waste burning, however there are no data available to assess the amounts and times when burning of this nature occurs and the inclusion of fireplace burning is beyond the scope of this report. For the purposes of this analysis, solid waste burning refers strictly to combustion of yard and household waste and to woody debris in the case of beach fires.

A draft version of *Investigation of Municipal Burning Bylaws and Air Contaminants Released from Burning Solid Waste* (July 2005) was made available to SENES for use in determining whether any trend(s) in ambient PM data are related to solid waste burning activities for the municipalities within the CRD. In general, SENES found that data from both Langford and Colwood are very useful, as these municipalities allow burning on specific and relatively infrequent days, have continuous $PM_{2.5}$ monitoring within the community, and keep a record of burning permits issued and resident complaints against burning activities. The same form of records are kept for Central Saanich, although there are many more allowed burning days in the municipal burning bylaw for this community.

There are four communities within the CRD that contain a *continuous* PM monitoring station. These are Victoria, Colwood, Langford and Central Saanich. There are other communities that have PM monitoring, but only on a *sequential* basis. Sequential monitoring data are not valuable for trend analyses of interest to this initiative, as ambient monitoring data may not have been collected on an allowed burning day. Table 4.3.1 was prepared for the earlier *Investigation of Municipal Burning Bylaws* report and is reproduced here directly from that document. This table presents a summary of the municipal burning bylaws for the communities within the CRD. The summary shows that solid waste burning is not allowed in the municipality of Victoria, but is allowed (on specific days) in Langford, Colwood and Central Saanich. $PM_{2.5}$ monitoring data for Victoria has value since it will allow an investigation of whether differences found for the other three communities may have resulted from activities or influences other than solid-waste burning.

Fire permit and complaint data for Central Saanich were obtained from the Fire Chief of that community. It was found that this information is not useful for an assessment of solid waste burning. In most cases, there is no connection between the date of issue of a permit for solid waste burning and the date when the actual burning takes place (if in fact it takes place at all). There are dates accompanying fire/smoke complaints, but there were too few complaints to allow a reasonable comparison methodology to be used. Based on comments from the Fire Chiefs of the other two communities, it was determined that the situation would be similar for Langford and Colwood. Therefore, comparisons made are based on monitoring data alone.

Similar to the burning of other materials, particulate matter emissions from solid waste burning tend to be of the smaller size fraction of suspended fine PM. In this sense, it is expected that $PM_{2.5}$ monitoring data are of more use than PM_{10} data, which include larger particulates that may be caused by the disturbance of soil or road dust. Speciated PM sampling, which provides a breakdown of the composition of collected particulate matter, can also be highly valuable to an assessment of this type. Currently, there is no speciated PM sampling that occurs within the CRD.

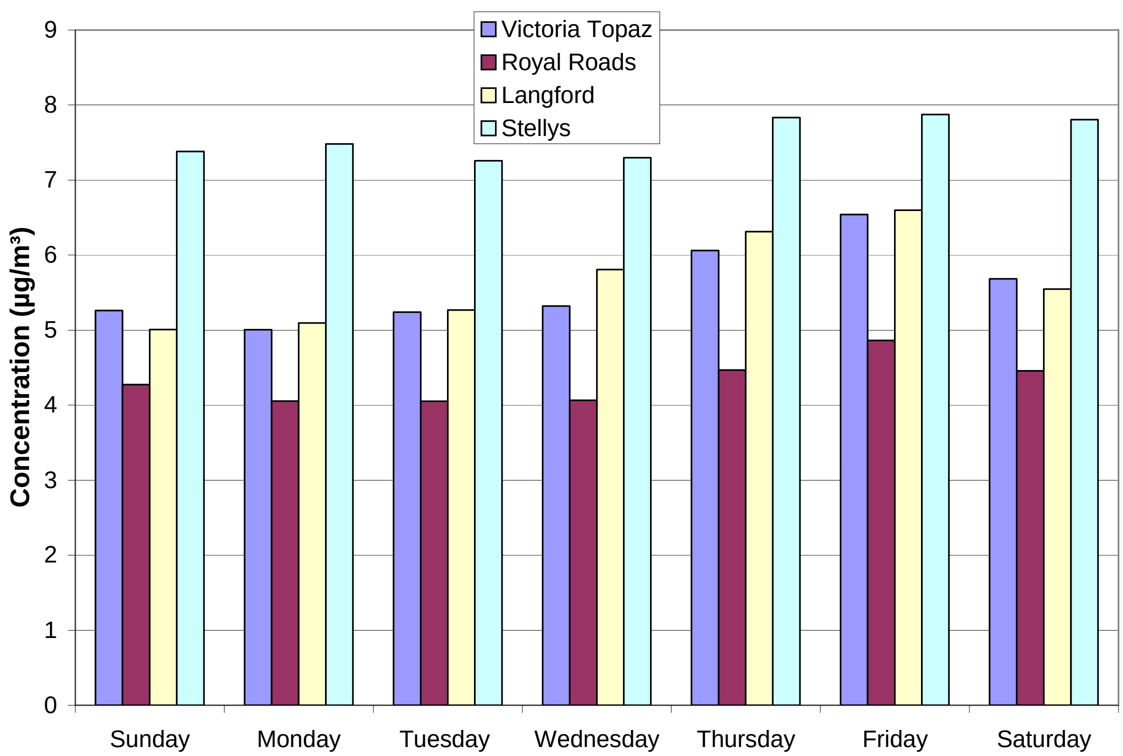
Table 4.3.1: Allowed Dates, Days, and Times for Open Burning, Incinerator Burning, and Beach Fires (From *Investigation of Municipal Burning Bylaws*, Envirochem 2005)

Municipality	Allowed Months			Allowed Days			Allowed Times			Permit Required		
	Burning Barrels	Open Burns	Beach Fires	Burning Barrels	Open Burns	Beach Fires	Burning Barrels	Open Burns	Beach Fires	Burning Barrels	Open Burns	Beach Fires
Central Saanich	Nov to Apr	All year round	All year round	Thur, Fri, and Sat	Thur, Fri, and Sat	Any day	From sunrise to sunset on Thur. & Fri. From sunrise to noon Sat.	From sunrise of Thurs. to noon of Sat.	From sunrise to 11pm.	Yes	Yes * Permit not required for <1m in diameter from Nov to May	Yes
Colwood	October to May 14th.	October to May 14th	October to May 14th	1st Fri & Sat of each allowed month	1st Fri & Sat of each allowed month	1st Fri & Sat of each allowed month	From sunrise to sunset	From sunrise to sunset	From sunrise to midnight.	No	Yes	Yes
Highlands	All year round (subject to fire hazard conditions)	All year round for Class A fires >1m: All year round for Class B fires <1m	Not Applicable; No beaches in Highlands	Any day (subject to fire hazard conditions)	Any day for Class A; Any day for Class B	Not Applicable; No beaches in Highlands	From sunrise to sunset	From sunrise to sunset	Not Applicable; No beaches in Highlands	No	Yes * Permit not required for <1m in diameter (Class B) from Oct 16th to Mar 31st	Not Applicable; No beaches in Highlands
Langford	Nov to May	Nov to May	Not Applicable; No beaches in Langford	1st consecutive Fri & Sat of each allowed month	1st consecutive Fri & Sat of each allowed month	Not Applicable; No beaches in Langford	From sunrise to sunset	From sunrise to sunset	Not Applicable; No beaches in Langford	No	No *Except for burning outside allowed times.	No beaches in Langford
Metchosin	All year round with time restrictions for certain times of the year	Nov 1st to Mar 31st	All year round	From Apr. to Oct., allowed Mon. to Sat. From Nov. to Mar., allowed any day.	Mon. to Fri.	Any day	From Apr. to Oct., allowed 8am to 6pm, Mon to Fri and 8am to noon on Sat. From Nov to Mar, allowed from sunrise to sunset.	Sunrise to sunset	Any time	No	Yes *Permit not required for <1.2m in diameter from Nov 1st to Mar 31st	No
North Saanich	All year round	All year round	All year round	Mon. to Sat.	Mon. to Sat.	Mon. to Sat.	From sunrise to sunset	From sunrise to sunset	From sunrise to sunset	No	Yes * Permit not required if <1m in dia from Oct 30th to May 15th	Yes

Municipality	Allowed Months			Allowed Days			Allowed Times			Permit Required		
	Burning Barrels	Open Burns	Beach Fires	Burning Barrels	Open Burns	Beach Fires	Burning Barrels	Open Burns	Beach Fires	Burning Barrels	Open Burns	Beach Fires
Saanich	Oct. 16th to Apr. 30th (can be banned anytime of the year due to high or extreme dry weather conditions)	Oct. 16th to Apr. 30th (can be banned anytime of the year due to high or extreme dry weather conditions)	All year round (can be banned anytime of the year due to high or extreme dry weather conditions)	Fri. and Sat.	Fri. and Sat.	Any day	From sunrise to sunset on Fri; From Sunrise to noon on Sat.	From sunrise to sunset on Fri; From sunrise to noon on Sat.	From sunrise to 11pm.	No *However, no burning allowed within Urban Containment Boundary at any time	Yes *Burning not allowed within Urban Containment Boundary at any time. ** Permit not required for <1m in diameter from Oct 16 - Apr 30	Yes
Sooke	All year round (can be banned anytime of the year due to high or extreme dry weather conditions)	All year round (can be banned anytime of the year due to high or extreme dry weather conditions)	All year round (can be banned anytime of the year due to high or extreme dry weather conditions)	Any day	Any day	Any day	From sunrise to sunset.	From sunrise to sunset.	From sunrise to sunset.	No	Yes *Permit not required for non Machine built piles.	No
View Royal	Oct. 16th to Apr. 30th	Oct. 16th to Apr. 30th	Not allowed	Mon. to Sat.	Mon. to Sat.	Not allowed	From sunrise to sunset from Mon. to Fri. From sunrise to noon on Sat.	From sunrise to sunset from Mon. to Fri. From sunrise to noon on Sat	Not allowed	No	Yes *Permit not required for <2m in dia. from Oct 16th to Apr 30st	Not allowed
Esquimalt	Not allowed	Not allowed	Not allowed	Not allowed	Not allowed	Not allowed	Not allowed	Not allowed	Not allowed	Not allowed	Not allowed	Not allowed
Oak Bay	Not allowed	Not allowed	Not allowed	Not allowed	Not allowed	Not allowed	Not allowed	Not allowed	Not allowed	Not allowed	Not allowed	Not allowed
Sidney	Not allowed	Not allowed	Not allowed	Not allowed	Not allowed	Not allowed	Not allowed	Not allowed	Not allowed	Not allowed	Not allowed	Not allowed
Victoria	Not allowed	Not allowed	Not allowed	Not allowed	Not allowed	Not allowed	Not allowed	Not allowed	Not allowed	Not allowed	Not allowed	Not allowed
Electoral Areas (Juan de Fuca, Southern Gulf Isl & Salt Spring Isl)	All year round	October to June	All year round	Any day	Any day	Any day	Any time	From sunrise to sunset	Any time	Yes	Yes	Yes

For Central Saanich, solid waste burning is allowed on Thursdays, Fridays and Saturdays (until noon only) in late fall, winter and spring months. Beach fires are allowed on any day. The bylaws for Langford and Colwood are more restrictive in that only the *first consecutive* Friday and Saturday of each month are allowed. To establish a starting point, ambient $PM_{2.5}$ monitoring data for all four stations were separated by day of the week to assess whether or not there is any general difference in daily fine particulate amounts in the CRD over a full year. The results are shown in Figure 4.3.1, which indicate that each of the three urban sites has a trend of higher $PM_{2.5}$ concentrations late in the week (particularly on Thursday and Friday). The Stellys monitoring data does not share this trend and average daily $PM_{2.5}$ concentrations tend to be fairly uniform.

Figure 4.3.1 Annual Average 24-hour $PM_{2.5}$ Concentrations by Day of the Week



To reduce the impact of potentially confounding trends in the data, the same days of the week can be compared (i.e., Fridays and Saturdays when burning is allowed can be compared with Fridays and Saturdays when burning is not allowed). There are also naturally occurring variations in $PM_{2.5}$ concentrations by month of the year. To control for this effect, only those months during which burning is allowed should be included in the analysis. One intuitive occurrence that is known to have significant influence on PM concentrations is precipitation. Unfortunately, rainfall amounts are only available from the Victoria Airport. An initial examination of $PM_{2.5}$ monitoring data showed that on days of strong precipitation (at Victoria Airport) there is a tendency for ambient particulate concentrations to be lower. However, it was determined that precipitation occurrence could not be factored into the analysis, as there is no clear methodology that can be applied to the Airport precipitation data to extrapolate amounts for the distance municipalities. Therefore, ***the monitoring data was not screened for precipitation days***.

To assess the contribution of solid waste burning to ambient particulate levels, a different strategy must be used for Central Saanich as compared to Langford and Colwood, based on the days and months that burning is allowed in this community. In general, it was expected that if a pattern were discernable in the Central Saanich (Stellys) data, it would be of smaller magnitude than that potentially for Langford and Colwood. This is simply due to the fact that there are many more allowed burning days in Central Saanich, and burning activity on an individual day may be less. Both a qualitative and a quantitative approach were used in the analyses for the three communities. The qualitative approach helps identify the patterns present in the monitoring data (1-hour and 24-hour concentrations), and the quantitative approach is used to determine whether such patterns occurred by chance or by some causal factor (presumed to be burning).

Statistical analyses were performed with several different groupings. The differences in average $PM_{2.5}$ concentrations on burning versus non-burning days were analyzed by individual month and for all of the months during the allowed burn season. Due to anecdotal information[12] that solid waste burning tends to occur much more frequently on the first and last allowed months of the burn season (i.e., in the Fall month and in the Spring month(s) only), a third grouping was used using the 2 or 3 months that burning is much more likely to occur. For Central Saanich these months are November and April, and for Colwood and Langford the months are November, April and May. There is greater statistical power when analyzing a larger dataset over a smaller one. In effect, this means that even if there is no statistically significant difference resolved for an individual month, there may be statistical significance when two or more months are considered together.

4.3.1 Central Saanich

The allowable 'burn season' for residents in Central Saanich is from October 31st to April 30th, on Thursdays, Fridays and Saturdays until noon. An exception is made for beach fires, which can occur on any day of the week. It was explained to SENES that burning during other months can actually occur, but only with the possession of a special permit. Such a permit is authorized only in the case of a significant problem, such as the contamination of feed by

[12] Comments from the Fire Chiefs for Central Saanich, Langford and Colwood.

noxious weeds[13]. The *Investigation of Municipal Burning Bylaws* report[14] states that a permit is 'generally' required for both open burning and burning in an incinerator (which would include a barrel with some sort of screen for sparks). For fires smaller than 3 by 3 by 3 feet, no permit is required.

The Stellys, Saanich Peninsula monitoring station is situated near a major paved road and surrounded by farmland in general. However, there is a First Nations reserve (South Saanich Reserve) a short distance away and also a Fair Grounds, which has some areas under gravel. A major confounding problem in comparing ambient air concentrations on burn days versus non-burn days for this community is the fact that the reserve is not subjected to municipal bylaws. This means that burning can, and likely does[15], occur on any day of the week.

With Stellys monitoring data, it is not possible to adequately deal with the differences in ambient PM data by day of the week, since burning occurs on ***all*** Thursdays, Fridays and Saturdays of the burn season, with the exception of a fire ban in effect. However, the day of week differences are much smaller for this community (Figure 4.3.1). Figure 4.3.2 shows the average maximum daily 1-hour and 24-hour concentrations during months of the burn season in Central Saanich. Only the weekdays (Monday to Friday) are included. The concentrations on the allowed burn days each month (in red) are compared to the concentrations on the non-burn days each month (in blue).

[13] Personal communication with Ron French, Central Saanich Fire Chief. July 21, 2005.
[14] Envirochem Services Inc., 2005. Investigation of Municipal Burning Bylaws and Air Contaminants Released from Burning Solid Waste (DRAFT). Prepared for Scientific Programs, Capital Regional District.
[15] Personal communication with Ron French, July 21, 2005.

Figure 4.3.2 Average $PM_{2.5}$ Concentrations on Allowable Burn Days Versus Non-burn Days at Stellys Monitoring Station in 2004 (Weekdays only)

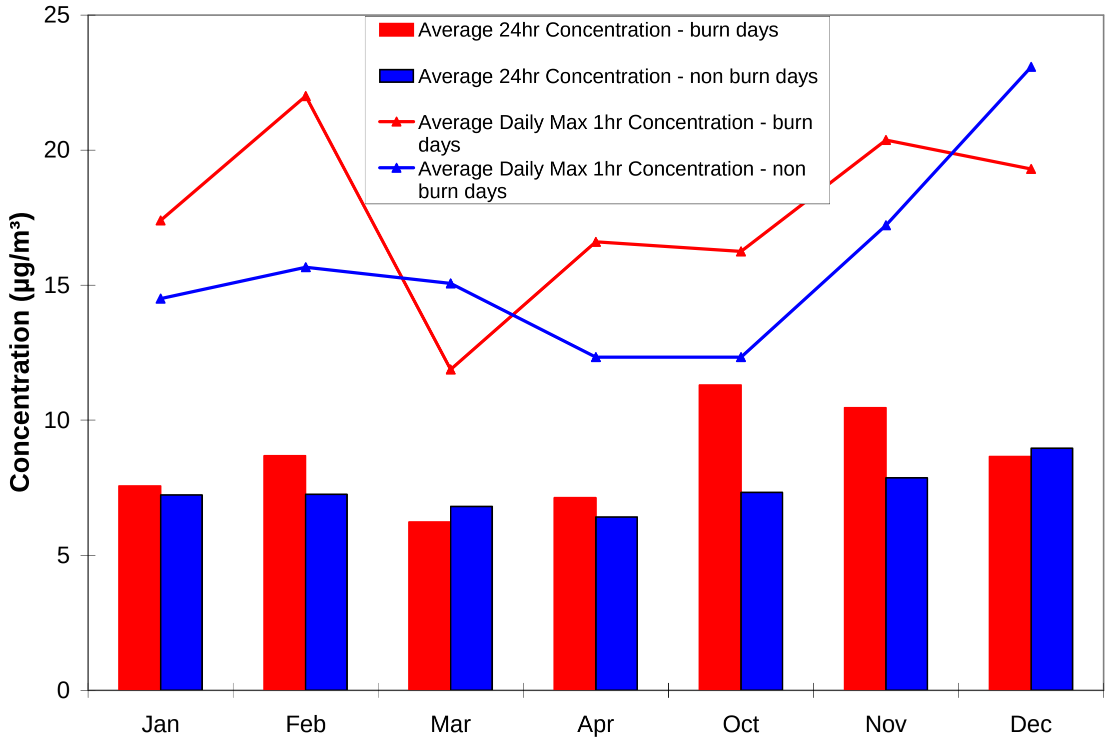


Figure 4.3.2 shows that allowable burn days have higher average maximum 1-hour and 24-hour concentrations during some of the months of the burn season. The appreciable differences occurred during the months of October and November in 2004. The Fire Chief for the municipality confirmed that the fall months tend to have much higher burning activity than the other months during the allowed fire season, and that this was the case for 2004. It should be noted that October is not actually within the allowed months of the burn season (with the exception of October 31). However, during this month there are some residents that apply for, and receive, a special permit to burn.

A statistical analysis was performed on the Stellys monitoring data to assess whether or not differences in allowed burn versus non-burn days for ambient $PM_{2.5}$ concentrations are statistically significant. This analysis is described in Appendix C, Tables C.1 and C.2, along with additional explanation of the tests performed. The differences in average maximum daily 1-hour and 24-hour concentrations were shown ***not*** to be statistically significant on any individual month, or when the entire burning season of 2004 is considered. However, when combining the two months when burning tends to occur more frequently (November and April), the average daily maximum1-hour and 24-hour $PM_{2.5}$ concentrations ***are*** significantly higher on allowed burn days.

4.3.2 Langford

Residents of Langford do not need a permit to burn solid waste unless burning is to occur outside of allowed dates and times. It is estimated that half of the total solid waste burning occurs in barrels and half in piles[16]. There are no beaches within the community for potential beach fires to occur. The Municipal Burning Bylaw states that allowed times are from sunrise to sunset on the first consecutive Friday and Saturday of the month from November to May. These allowed burning days are far fewer in number than for Central Saanich, indicating that greater amounts of household and yard waste may be burned on allowable days. Also worth noting, Langford is an urban community, whereas Central Saanich is a rural community.

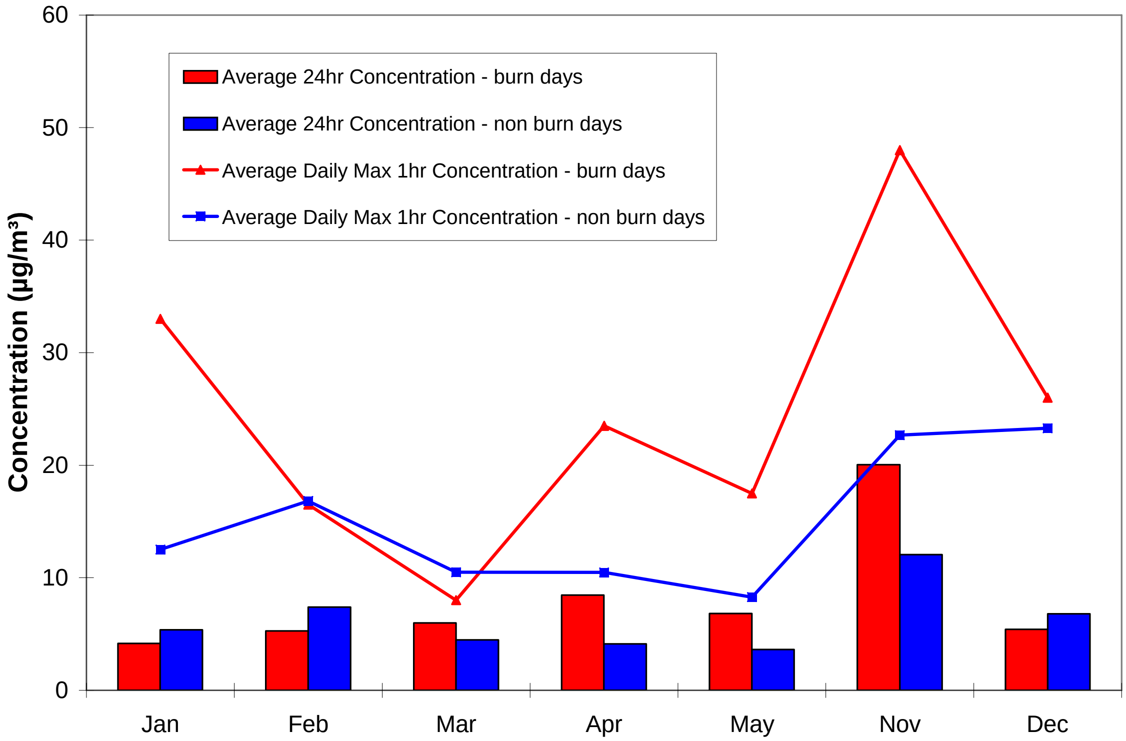
The Langford $PM_{2.5}$ monitor is situated at the Langford Dogwood School, which is reasonably central to the municipality, within a residential neighbourhood and less than a kilometre from the Trans Canada Highway. SENES is unaware of any additional solid waste burning activities not on the schedule prescribed by the burning bylaw within this community (i.e., such as the case with Central Saanich).

Figure 4.3.3 shows the average 24-hour and average daily maximum 1-hour concentrations during Fridays and Saturdays for each month solid waste burning is allowed in Langford. By removing other days of the week, the effect of potentially confounding effects that lead to different $PM_{2.5}$ concentration amounts by day of week (as indicated in Figure 4.3.1) is minimized.

The concentrations on the two allowed burn days each month (in red) are compared to the concentrations on the non-burn days each month (in blue). The Fridays and Saturdays that are non-burn days number from 6 to 8 each month, whereas there are always 2 corresponding burn days. There is a rather large difference in both the average daily maximum 1-hour and 24-hour concentrations during November, April and May, when burn days experience higher $PM_{2.5}$ concentrations at Langford Dogwood School compared with non-burn days. For other months, the differences are smaller, and concentrations are actually lower on burn days for January, February and December.

[16] Personal communication with Bob Beckett, Langford Fire Chief. July 13, 2005. There is no beach access within Langford.

Figure 4.3.3 Average $PM_{2.5}$ Concentrations on Allowable Burn Days Versus Non-burn Days at Langford Monitoring Station in 2004 (Fridays and Saturdays only)



It is reasonable to expect that sizeable emissions of particulate matter due to solid waste burning occurred during November and May, as compared to the other months. At these times, there may be appreciable amounts of household and yard waste that have accumulated over the summer and fall, and over the winter, respectively. The Langford Fire Chief verified this general trend and that burning activities are particularly high during the first Friday and Saturday in November[17]. In fact, the highest 1-hour and 24-hour $PM_{2.5}$ concentration of the year occurred on November 5th for the Langford monitoring station. November 5th was a Friday and therefore the first allowed burn day following the summer and fall of 2004. In addition, November 5th experienced the only exceedence of the CRD 24-hour $PM_{2.5}$ ambient air quality guideline of 2004, for any of the areas in the CRD that have continuous PM monitoring stations.

Significance testing was conducted on the differences between average maximum daily1-hour and 24-hour concentrations on allowed burn days versus non-burn days, and this is shown in Appendix C, Table C.3 and C.4, respectively. Statistically significant differences exist for the average maximum daily 1-hour concentrations when including all of the months of the allowed burn season in the comparison datasets. Significant differences ***do not*** exist during most months

[17] Personal communication with R. Bennet, July 13 2005.

of the burn season when considered in isolation. This is not surprising, as solid waste burning is not as likely to occur during some of the allowed burning months in this community. In addition, the average daily maximum 1-hour concentrations are statistically significantly higher on burn days when just November, April and May are considered together.

Table C.4 shows that there is no statistically significant difference in average 24-hour concentrations on burn days versus non-burn days, when the entire burn season is included in the comparison datasets. However, when considering just those months that are likely to have a large amount of solid waste burning occurring (November, April, May), there ***is*** a statistically significant difference in average 24-hour concentrations.

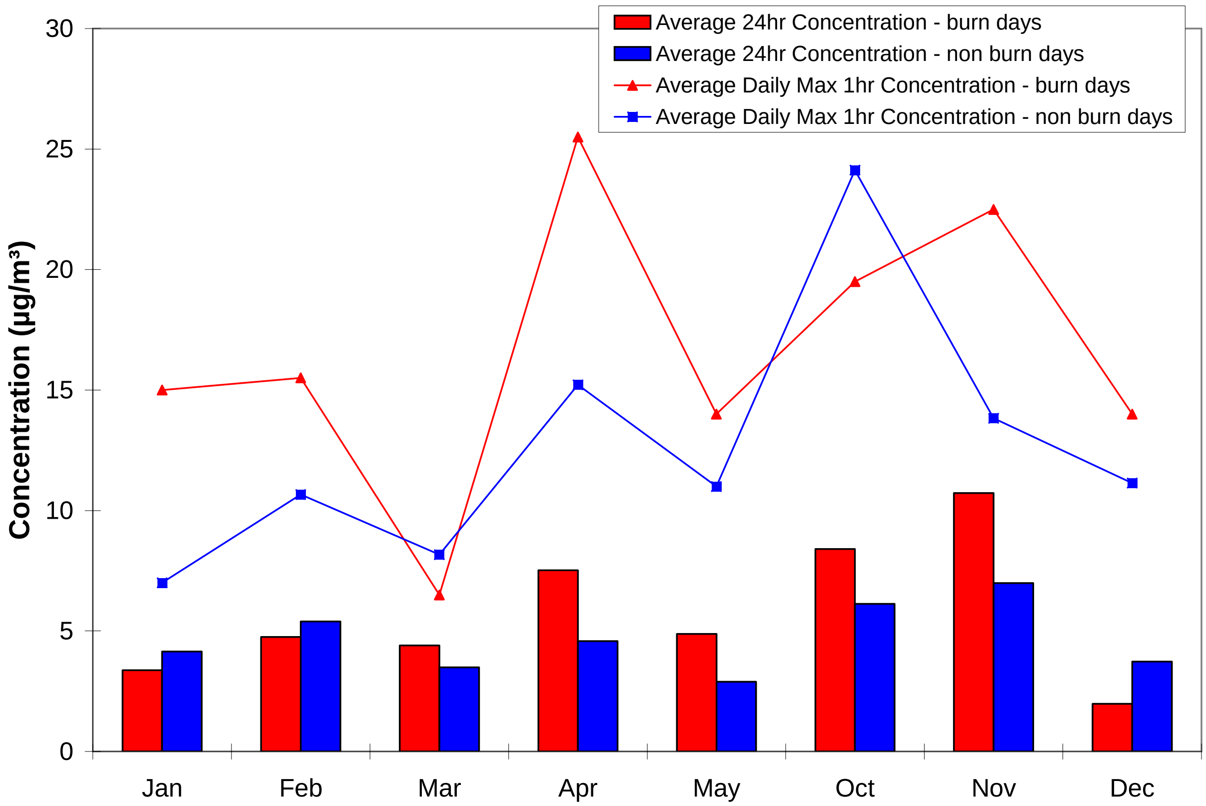
4.3.3 Colwood

Colwood has a similar solid waste burning bylaw to that of Langford, with only the first consecutive Friday and Saturday of a month in the burn season being allowed. A difference is that the burn season includes the month of October in addition to the months Langford allows. Colwood generally experiences lower $PM_{2.5}$ concentrations (as measured at the Royal Roads University monitoring station) than Langford, primarily because of its location by the coast. However, since Colwood also allows relatively few burn days, it is likely that any existing patterns in the monitoring data related to solid waste burning can be discerned. Colwood has a successful chipping program that the community residents are able to access (without cost) as an alternative to burning woody debris[18]. This program likely reduces the impact of solid waste burning on ambient $PM_{2.5}$ concentrations at the Royal Roads University monitoring station.

A similar trend in the $PM_{2.5}$ monitoring data for Colwood (Royal Roads station) to that discovered for Langford is evident in Figure 4.3.4. Although $PM_{2.5}$ concentrations are generally lower than those experienced in Langford, 24-hour concentrations on Fridays and Saturdays that allow solid waste burning tend to be higher than on Fridays and Saturdays that do not allow burning, noticeably for the months of April, May, October and November.

[18] Personal communication with R. Cameron, August 11, 2005.

Figure 4.3.4 Average $PM_{2.5}$ Concentrations on Allowable Burn Days Versus Non-burn Days at Royal Roads Monitoring Station in 2004 (Fridays and Saturdays only)



$PM_{2.5}$ monitoring data at the Royal Roads monitoring station are available for a period extending from January 2001 to the end of 2004. This full period was used to test for statistical significance in the differences between concentrations on allowable burn and non-burn days. This decision was made to provide an understanding of the variability in burn/non-burn PM concentrations that may exist due to differences in meteorological conditions from year to year.

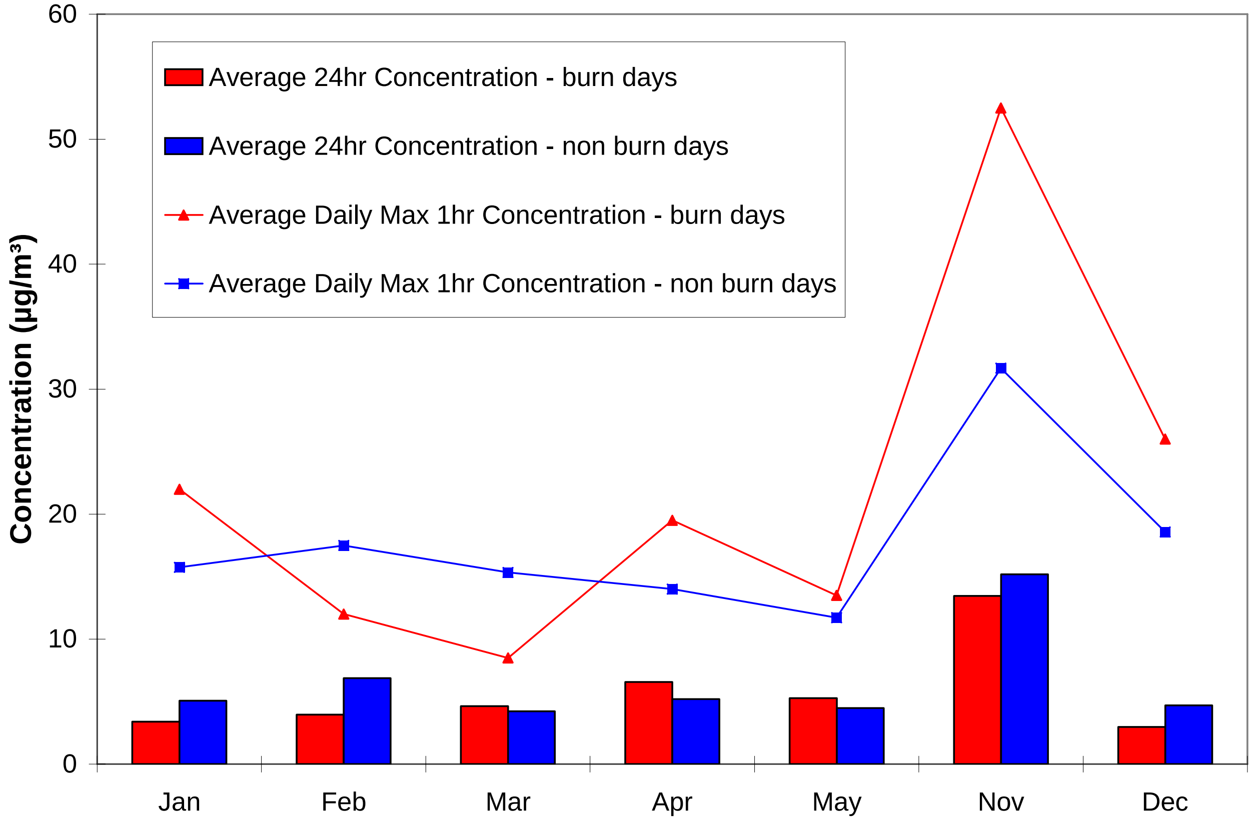
Statistical significance testing was performed on the Royal Roads $PM_{2.5}$ dataset, with the same approach that was used for Langford, with data from each individual year between 2001-2004 and with 4 consecutive years (2001-2004) of data. When considering the entire burn season over 4 continuous years, average maximum daily 1-hour and 24-hour concentrations are statistically significantly higher on burn days compared to non-burn (Friday and Saturday) days. These results are shown in Tables C.5 and C.6 in Appendix C.

It is evident that there is great variability in particulate matter air concentrations on burn versus non-burn Fridays and Saturdays from year to year, shown in Tables C.7 and C.8. In particular, during 2003, differences were relatively small and not statistically significant (with the exception of one individual month). This is not surprising, since both precipitation amounts and prevailing wind direction in Colwood have a large influence on particulate matter concentrations recorded at the Royal Roads site. During times with an ocean breeze (i.e., winds approaching from the ocean) it is very unlikely that the Royal Roads University would experience relatively high ambient particulate matter concentrations, regardless of burning or industrial activity within the community.

4.3.4 Victoria

The municipality of Victoria does not allow solid waste burning during any months of the year. The same qualitative analysis was performed on the continuous $PM_{2.5}$ monitoring data from this community as that conducted for Langford and Colwood. A similar strategy to that used with Central Saanich was not considered appropriate, since the Victoria station location can be classified as urban, similar to the Langford and Colwood stations. If similar trends are evident in the Victoria monitoring data to those observed for Langford and Colwood, one of two possibilities must be considered: 1) burning activities in Langford and Colwood influence $PM_{2.5}$ concentrations in Victoria; or, 2) higher concentrations on allowed burn days in Langford and Colwood may be caused by some other influence besides solid waste burning. Figure 4.3.4 shows that average 24-hour $PM_{2.5}$ concentrations on allowed burn days (for Langford and Colwood) are not noticeably different than concentrations on non-burn days (either higher or lower in magnitude). This is the same trend for maximum daily 1-hour concentrations, with the exception of concentrations in November, when the average maximum daily 1-hour concentration on Langford/Colwood burn days was substantially higher.

Figure 4.3.4 Average $PM_{2.5}$ Concentrations on Allowable Langford and Colwood Burn Days Versus Non-burn Days at Victoria Topaz Monitoring Station in 2004 (Fridays and Saturdays only)



Tables C.9 and C.10 in Appendix C show the results of statistical tests performed on the Victoria monitoring data, using the same strategy used for Langford and Colwood. The average daily maximum 1-hour and 24-hour concentrations on days that burning is allowed in Langford and Colwood are not statistically significantly different than concentrations on non-burn days. There is one exception during the month of February, although the statistically significant difference is that concentrations are lower, not higher on allowable burn days.

4.3.5 Summary

Both average daily maximum 1-hour and 24-hour $PM_{2.5}$ concentrations were found to be higher on days allowing solid waste (backyard, and to a lesser degree beach) burning over days when burning is not allowed for three municipalities of the CRD, although this general pattern was not evident during all months of the allowed burn season in 2004. The association of higher concentrations on burn days is most pronounced for Langford, which also tended to have the highest degree of statistical significance associated with burn and non-burn day $PM_{2.5}$ concentrations. There are three communities in the CRD that allow solid waste burning and have continuous $PM_{2.5}$ monitoring. The specific municipal bylaws that govern when burning may take place in each community were used in the qualitative and quantitative assessments. The reader is directed to Appendix C for a more detailed account of the statistical tests performed on the monitoring data.

Based on comments from the Fire Chiefs of the three communities, the burning bylaws are infringed upon and burning does take place on days that are not allowed. The degree to which bylaw enforcement and response occurs differs by municipality and this may be partly responsible for trends to be more evident in one community over another.

The community of Colwood was found to be a particularly useful case study, since continuous monitoring data exists for a longer period in this community. An expanded dataset for Colwood was used in the statistical tests, which included the years 2001 – 2004. When considering all months of the burn season over four years, the average $PM_{2.5}$ daily maximum 1-hour and 24-hour concentrations were found to be statistically significantly higher on allowed burn days. Variations in concentrations over each individual year highlight the fact that differences in air concentrations for burn/non-burn days may be lessened or removed entirely due to natural changes in meteorological conditions (i.e., precipitation).

The quantitative assessments imply that the higher $PM_{2.5}$ concentrations that were experienced on allowable burn days for some of the months of the burn season in Langford, Colwood and Central Saanich did not occur by chance. Further, the results of a similar assessment on a community that does not allow solid waste burning (Victoria) implies that solid waste burning was likely the cause of the increased $PM_{2.5}$ concentrations in Langford and Colwood. Therefore, on average, similar trends should be expected in Langford, Colwood and Central Saanich in future years if the current municipal burning bylaws continue to be in effect.

5.0 CONCLUSION

For the majority of the time during 2004, ambient air concentrations of common air contaminants were well below the CRD air quality guidelines. The exceptions were three exceedences of the CRD guidelines for particulate matter. Air quality levels were below the Canada Wide Standards for particulate matter and ground-level ozone. These comparisons are summarized in Table 5.1 for all of the monitoring stations that were in operation during 2004.

A $PM_{2.5}$ exceedence occurred on November 5^{th} in Langford as measured by the continuous TEOM monitor. A PM_{10} exceedence was recorded at Victoria Topaz on June 20^{th} and a second PM_{10} exceedence was recorded at Stellys, Saanich Peninsula (Stellys) on September 7^{th}. The PM_{10} exceedences were determined with a Hi-Vol and a Partisol sequential sampler, respectively.

Past research studies have shown that there are demonstrable health effects associated with higher levels of ambient particulate matter in a community. The relatively short duration of the three PM exceedences in the CRD during 2004, and the uncertainty of community exposure to the high concentrations in each case prohibits an assessment of the potential related health effects at this time.

Data collection rates for the year were high at each of the air quality monitoring stations, with the exception of NO/NO_2 data collection at Victoria Topaz and Royal Roads University. For these two stations, the NO_x samplers failed an audit during late December, which resulted in the removal of collected data from the provincial archives from early September to late December for the two stations. These are the only stations that collect NO_x data in the CRD, and therefore comparison of ambient NO_2 concentrations to CRD and provincial/federal guidelines is limited for 2004. This is not a problematic issue, as NO_2 concentrations from previous years in the CRD have been well below all appropriate guidelines and objectives.

The Royal Roads University station began collecting CO and SO_2 data in July for the first time. There are now two monitoring stations within the CRD that collect ambient data for these two air contaminants.

There are seven meteorological stations within the CRD that collect data that can be used to support the air quality monitoring program. Data from the Hartland Landfill were not used in this report, but should be considered in future years. Wind speed and direction data were summarised for each station and an aggregate summary was determined to show the seasonal differences in wind flow. In addition, a climate comparison was completed using data from the Environment Canada station at the Victoria Airport, which shows that 2004 had a relatively warm spring and summer, with an annual precipitation very similar to the climate norm.

Significant differences were noted between the mean Royal Roads wind directions and those from nearby meteorological stations. It is recommended that an analysis of the Royal Roads station, in terms of equipment maintenance, siting and nearby terrain influences, be conducted in the future.

Achievement of the Canada Wide Standard for particulate matter was assessed. The 98th percentile 24-hour $PM_{2.5}$ concentration for 2004 was 12.8 µg/m^3, which is very close in magnitude to that determined for 2003. This value is representative of the 'community based' CRD $PM_{2.5}$ monitoring sites and is well below the CWS of 30 µg/m^3. In addition, compliance with the Canada Wide Standard for ground-level ozone (to be implemented in 2010) was demonstrated with a 4th highest annual daily maximum 8-hour concentration of 109.5 µg/m^3 for 2004. This value was determined using the Saturna Island monitoring data, which tends to record the highest ozone concentrations of the four monitoring locations within the CRD. It was noted that Saturna did not experience the highest 98th percentile 8-hour averaged concentration in 2004. Some attention to this issue is warranted in 2005; in particular, the choice of Saturna Island data for determining compliance with the CWS may have to be re-assessed.

Table 5.1
Summary of Maximum Pollutant Concentrations (µg/m³) in the CRD for 2004

		Air Quality Criteria		**Monitoring Station**							
Contaminant	Averaging Period	CWS	CRD Guideline	Victoria Topaz	Royal Roads	Langford	Stellys	Oak Bay	Braefoot	Keating	Saturna Island
Carbon Monoxide	8-hour[*]		5500	3325							
Nitrogen Dioxide	1-hour[*]		200	99.4[1]	55.5[1]						
Sulphur Dioxide	24-hour[*]		125	20.5							
Ground-level Ozone	8-hour[**]		120	106.0	111.4[2]		113.7				117.1
PM_{10}	24-hour[*]		50	91 (HiVol)	46 (HiVol)	38 (HiVol)	84.3 (Partisol)	22 (HiVol)	21 (HiVol)	24 (HiVol)	
$PM_{2.5}$	24-hour[*]		25	19.5 (TEOM)	13.5 (TEOM)	25.8 (TEOM)	19.5 (TEOM)				
Canada-Wide Standards											
Ozone	8-hour[**]	127.6[3]									114.6
$PM_{2.5}$	24-hour[*]	30[4]		12.8[5]							

Notes:
[*] Sequential averaging periods used.
[**] Rolling average periods used.
[1] Partial record: January 1 – September 6, December 15 – December 31, 2004.
[2] Partial record: January 1 – January 21, March 11 – December 31, 2004.
[3] Achievement by 2010, based on the annual 4th highest daily measurement, averaged over 3 consecutive years.
[4] Achievement by 2010, based on the 98th percentile ambient measurement annually, averaged over 3 consecutive years.
[5] Value determined for 2004 only; data does not exist to determine a three year average.

A comparison and statistical analysis were conducted to determine patterns in the continuous PM monitoring data that may reflect an influence of solid waste burning in the CRD. In each of the communities of Central Saanich, Langford and Colwood, air concentrations were determined to be higher on burn days than non-burn days and the differences were determined to be statistically significant over a portion or portions of the allowed burn season. This implies that the higher $PM_{2.5}$ concentrations that were recorded on allowed burn days during some months of the burn season did not occur by chance (less than a 5% likelihood). An expanded analysis was possible for Colwood, since continuous PM monitoring data exists for a four-year period (2001-2004). Over this extended period the same pattern of higher $PM_{2.5}$ concentrations exists, and is statistically significant.

The magnitude of increase in the level of fine particulate concentrations on allowed burn days varies for the three communities. The resolved increase for Central Saanich was relatively small, due in part to the fact that there are many more allowed burn days in this community than in the other two. In addition, there is a First Nations reserve within the community that is not regulated by the municipal burning bylaw. A statistically significant increase in $PM_{2.5}$ concentrations was found only when considering the two months that burning is much more likely to occur (the first and last allowed months of the burn season). This increase is likely, but not certainly, due to solid waste burning activities.

$PM_{2.5}$ concentrations were statistically significantly higher in Langford on allowed Friday/Saturday burn days than on Fridays/Saturdays that do not fall on burn days over a reduced portion of the burn season of 2004 (April, May and November in combination). In addition, statistically significant increases were noted on individual months in isolation. Four continuous years of $PM_{2.5}$ monitoring data were available to analyze for the Colwood municipality (Royal Roads University monitoring station). When considering the entire burn season over 4 years, a statistically significant increase in fine particulate matter concentrations on allowed burn days was determined. Considerable variation was noted when performing the tests on individual years. These tests highlight the possibility that meteorological patterns may reduce or even remove altogether the differences in $PM_{2.5}$ concentrations on allowable burn and non-burn days in any given year. In effect, the resolved differences found in the 2004 monitoring data were made possible by 'favourable' precipitation patterns – there likely was little precipitation during days on which a large amount of solid waste burning occurred, resulting in an increased loading of particulate matter to the airshed.

On November 5th, the CRD $PM_{2.5}$ guideline of 25 µg/m³ (24-hour average) was exceeded at the Langford monitoring station. The recorded air concentration of 25.8 µg/m³ occurred on the first day of the allowed 'burn season' when residents are permitted to conduct backyard burning. The solid waste burning analysis conducted as part of this year's Air Quality Report supports a conclusion that backyard burning contributed to the exceedence experienced on November 5, 2004. $PM_{2.5}$ concentrations at the three other monitoring stations were much lower on the same day, indicating that the exposure of the general public to elevated fine particulate matter concentrations was limited to the Langford area.

Long term monitoring data provides the information needed to determine trends in air quality for the CRD. In addition, the monitoring program allows assessment of different community and industrial activities and their potential relationships with concentrations of air contaminants within the individual communities of the region. It is therefore recommended that air quality monitoring continue in the CRD at its present level.

Appendix A: Meteorological Data

Table A.1 2004 Monthly Climate Data for Victoria[d]

	Mean Max Temp	Mean Temp	Mean Min Temp	Extr Max Temp	Extr Min Temp	Total Rain	Total Snow	Total Precip
	°C	°C	°C	°C	°C	mm	cm	mm
Jan	6.7	4.3	1.8	11.9	-6.5	89.9	25	112.9
Feb	9.7	5.9	2	12.1	-1.5	50.4	1.6	52
Mar	12.6	8.1	3.6	20.8	-0.3	56	0	56
Apr	16.7	10.8	4.9	25	1.2	4.2	0	4.2
May	18.3	13.1	7.8	22.8	4.7	30.4	0	30.4
Jun	22.3	16.2	10.2	32.3	6.8	23.4	0	23.4
Jul	24.6	18.5	12.5	34.4	9.6	13.5	0	13.5
Aug	23.3	18.1	12.8	31.3	10.6	98.5	0	98.5
Sep	18.3	13.9	9.4	23.5	5.9	71.3	0	71.3
Oct	14.5	10.7	6.9	21.9	0.2	107.3	0	107.3
Nov	9.8	6.9	3.9	13.8	-1.6	116.9	0	116.9
Dec	8.7	6	3.2	13.6	-1.9	164.2	T	0
Sum						**826**	**26.6**	**850.6**

Notes: T = trace amount

Table A.2 Climate Norm (1971 – 2000) for Victoria[d]

	Mean Max Temp	Mean Temp	Mean Min Temp	Extr Max Temp	Extr Min Temp	Total Rain	Total Snow	Total Precip
	°C	°C	°C	°C	°C	mm	cm	mm
Jan	6.9	3.8	0.7			121.8	15.2	136.6
Feb	8.4	4.9	1.4			98.8	9.0	107.8
Mar	10.5	6.4	2.3			75.8	2.4	78.0
Apr	13.4	8.8	4.1			44.5	0.0	44.5
May	16.6	11.8	6.9			36.5	0.0	36.5
Jun	19.3	14.4	9.3			32.0	0.0	32.0
Jul	21.9	16.4	10.8			19.5	0.0	19.5
Aug	22.0	16.4	10.8			23.9	0.0	23.9
Sep	19.4	14.0	8.4			30.4	0.0	30.4
Oct	14.2	9.8	5.3			75.6	0.2	75.7
Nov	9.5	6.1	2.7			144.4	3.3	147.2
Dec	6.9	4.0	1.0			138.3	13.8	151.2
Sum						**841.50**	**43.7**	**883.3**

[d] Sourced from Environment Canada, http://www.climate.weatheroffice.ec.gc.ca/climateData/

Figure A.1
Monthly Temperatures at Victoria Airport

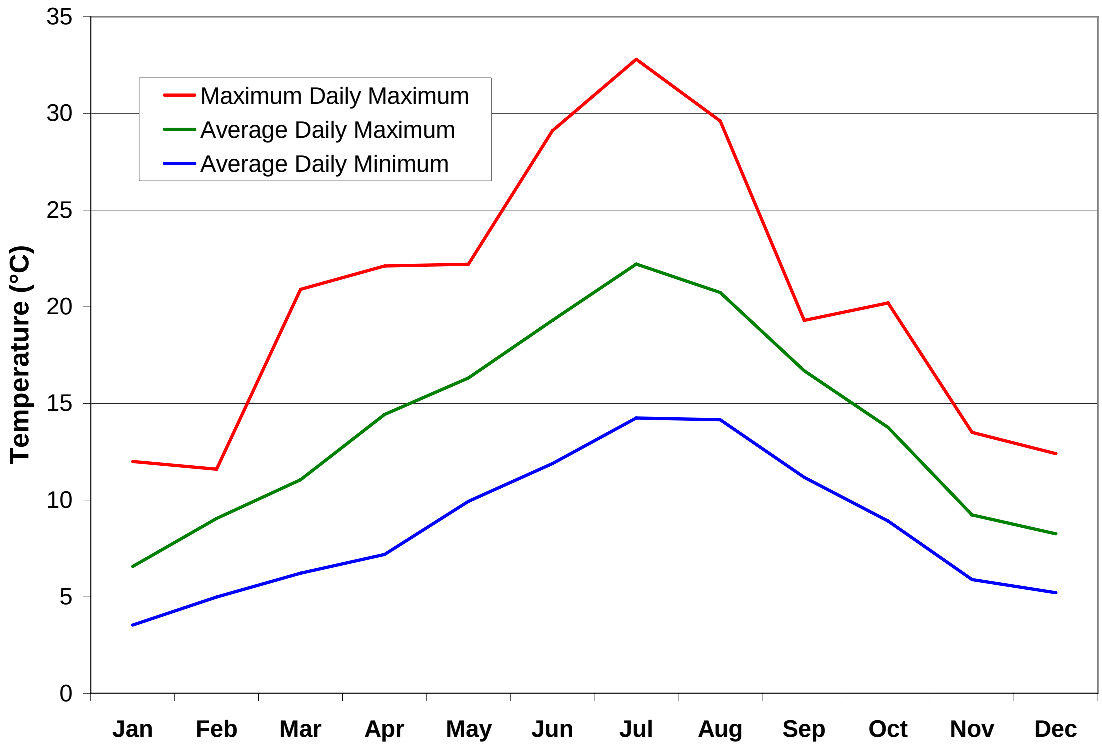


Figure A.2
2004 Wind Rose Diagram for Victoria Topaz

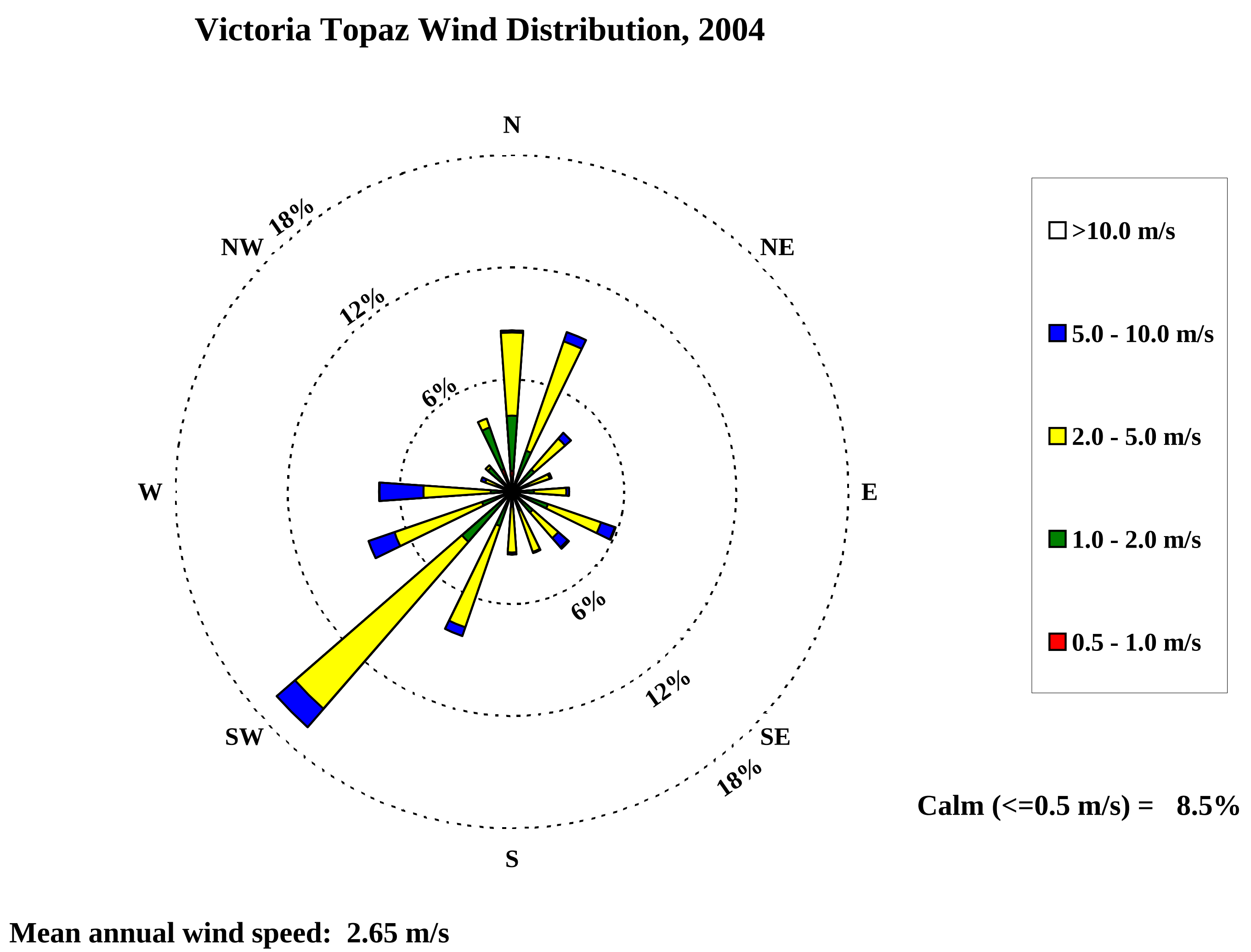


Figure A.3
2004 Wind Rose Diagram for Langford

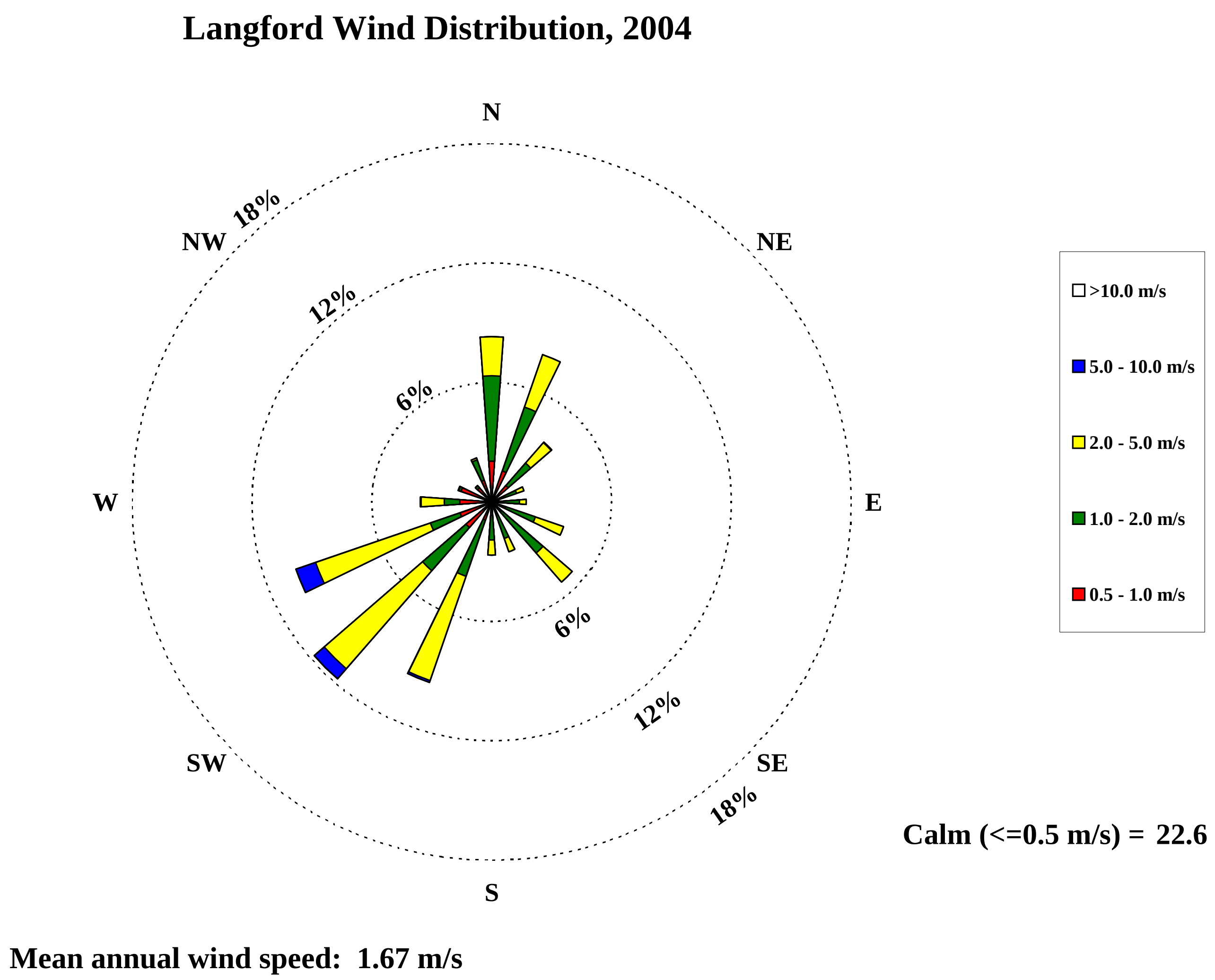


Figure A.4
2004 Wind Rose Diagram for Royal Roads University

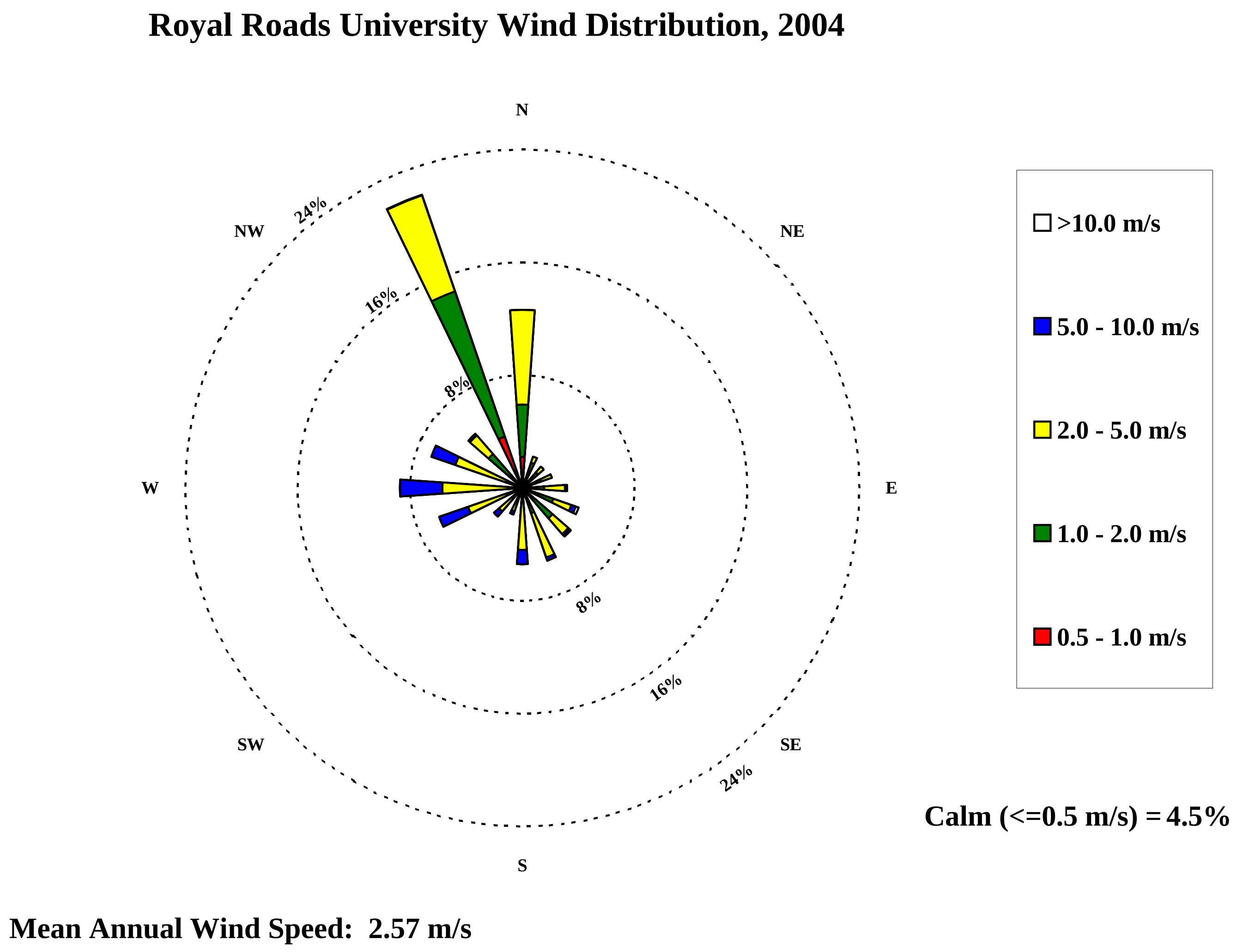


Figure A.5
2004 Wind Rose Diagram for Stellys, Saanich Peninsula

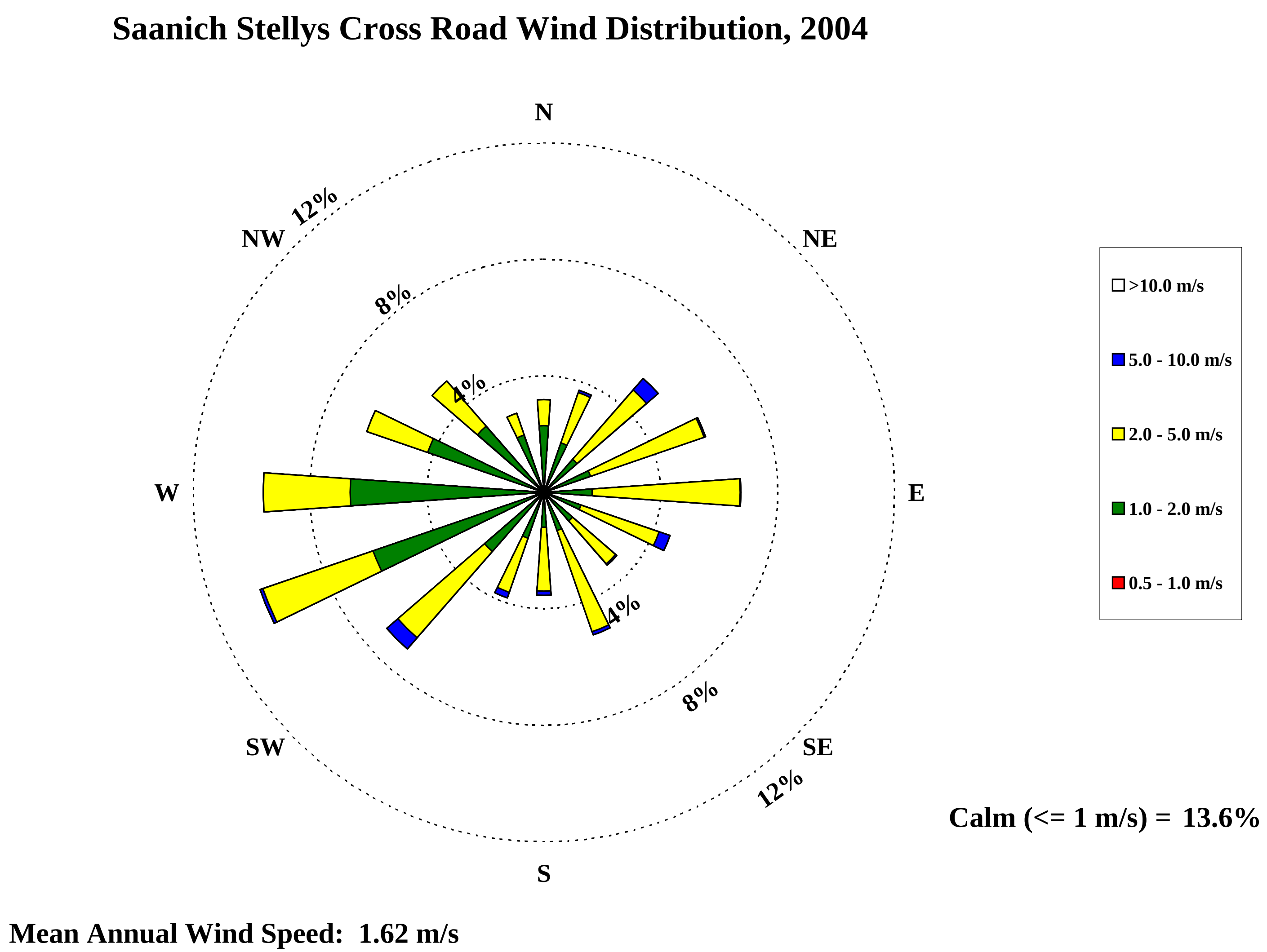


Figure A.6
2004 Wind Rose Diagram for Victoria Airport

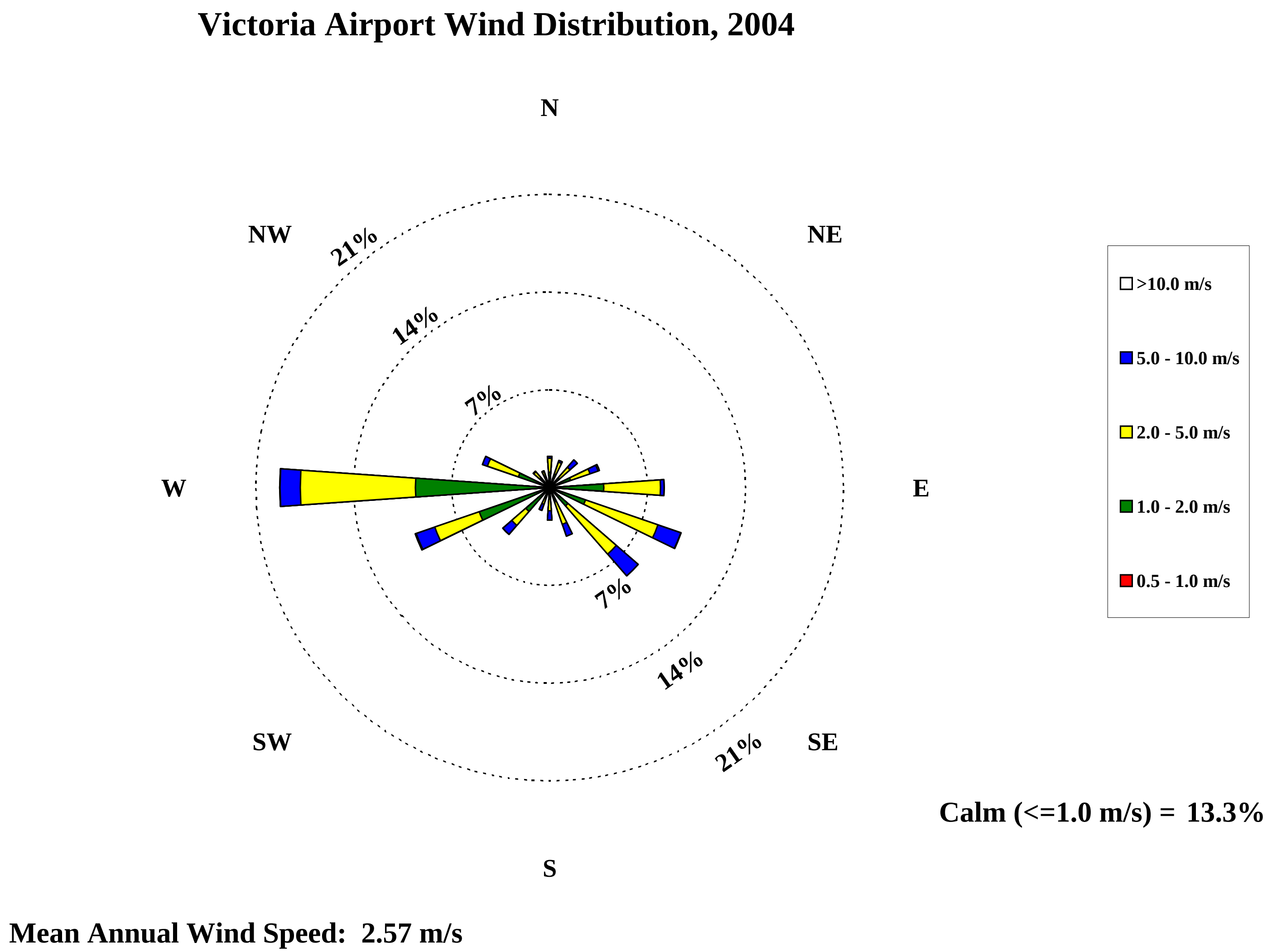
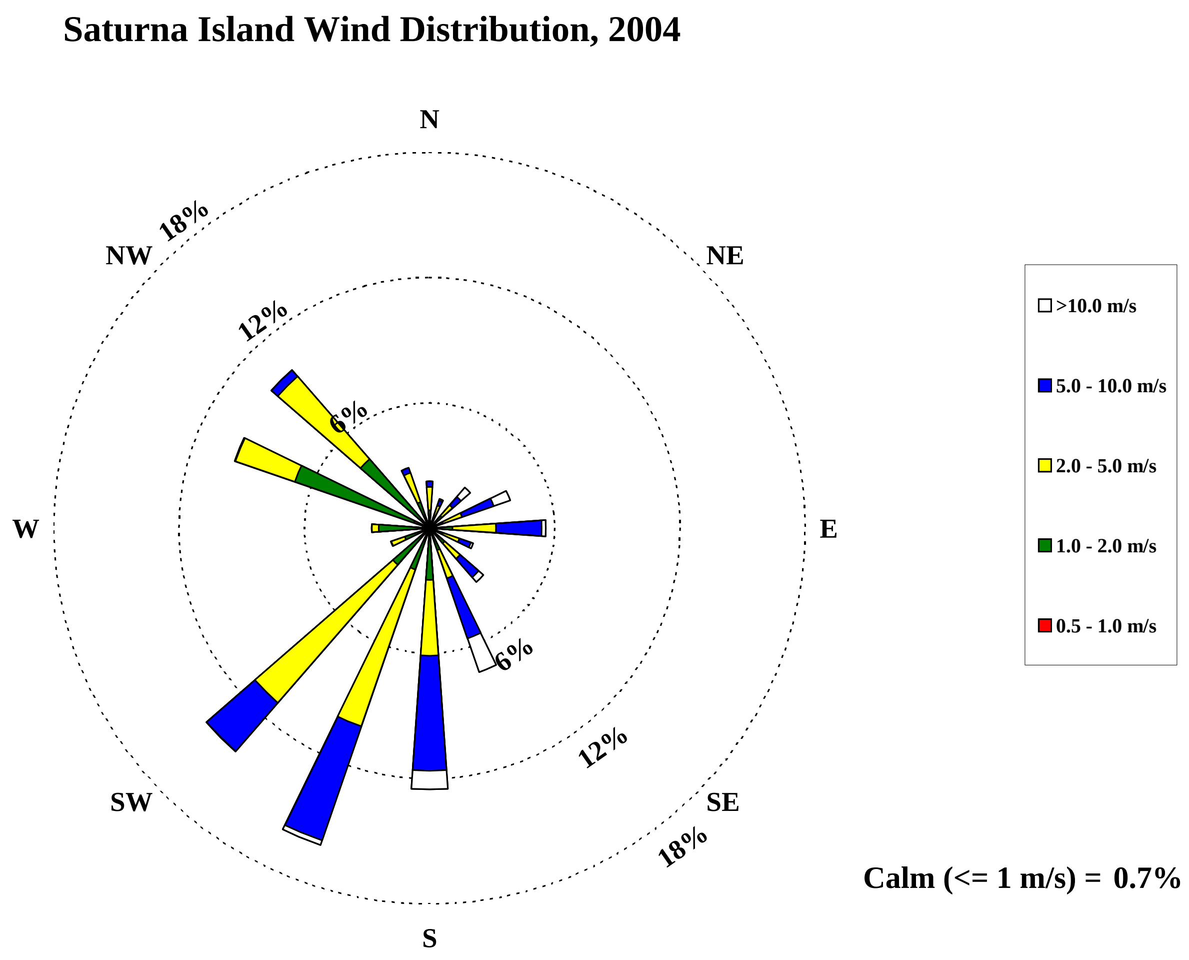


Figure A.7
2004 Wind Rose Diagram for Saturna Island



Mean Annual Wind Speed: 4.1 m/s

Figure A.8
Wind Comparison for Stations in the South of the CRD (September – December 2004)

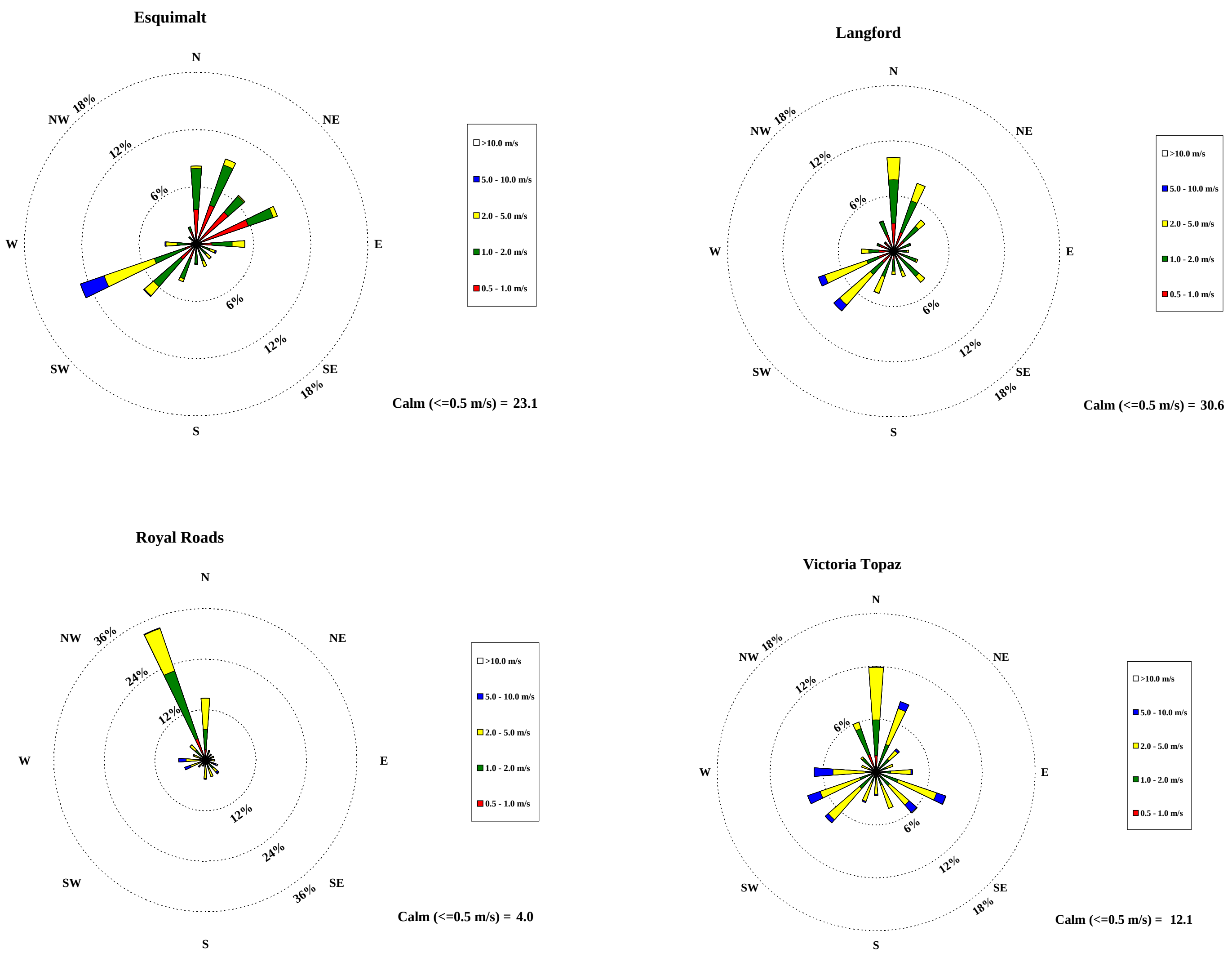
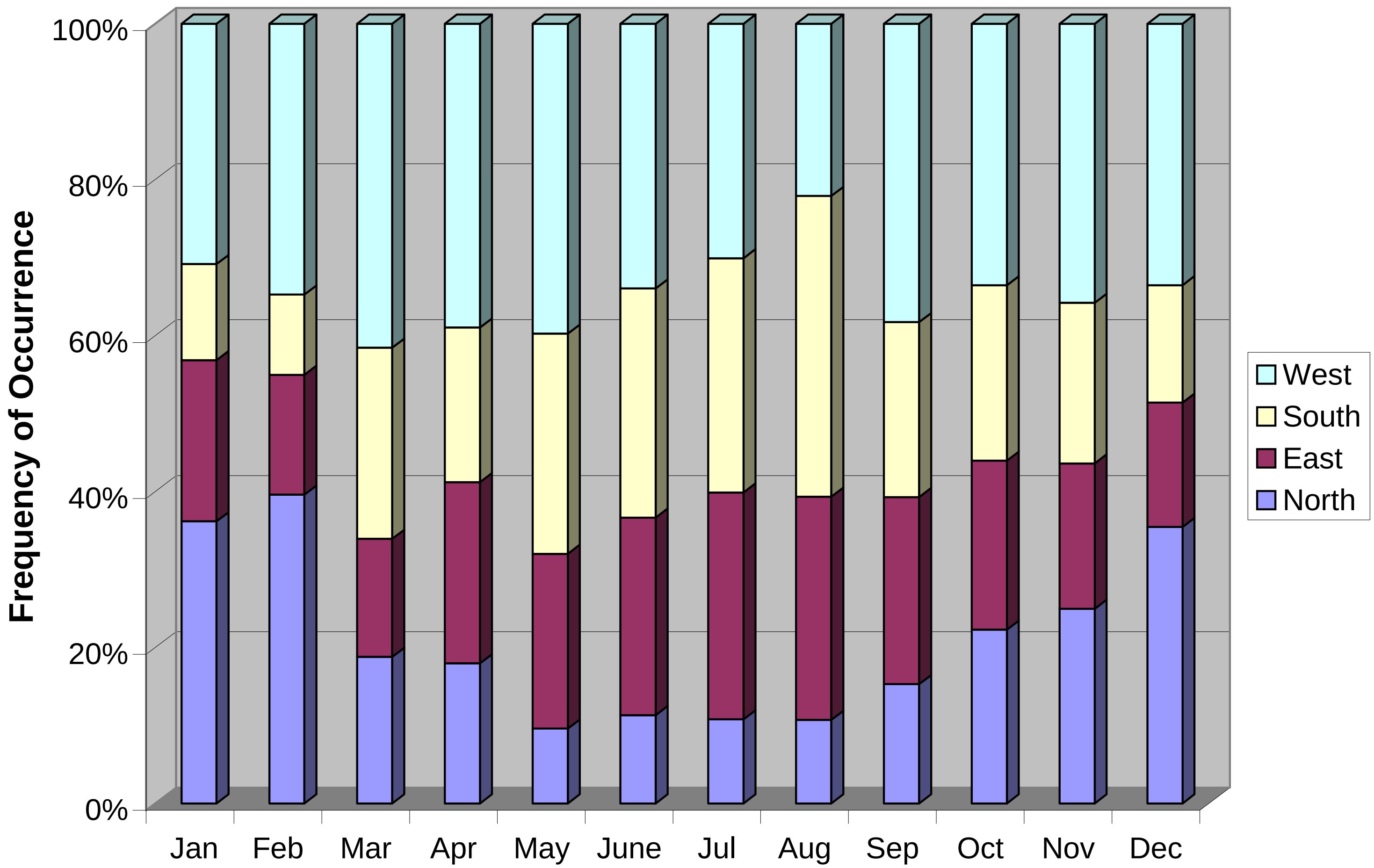


Figure A.9
Frequency of Wind Direction for Meteorological Stations in the CRD



note: convention used is direction the wind blows *from*.

Appendix B: Federal/Provincial Air Quality Objectives

B.1 FEDERAL AND PROVINCIAL OBJECTIVES AND STANDARDS

The Canadian National Ambient Air Quality Objectives (NAAQO) is a three-tiered system. Each level has a specific concentration for an individual air contaminant, with one or more averaging periods used. The three levels are:

- The **Maximum Tolerable Level**, representing a time-averaged concentration, above which immediate action is necessary to protect the health of the general population.

- The **Maximum Acceptable Level**, representing a time-averaged concentration suitable to protect human health, animals, soils, water, vegetation, materials and visibility against the effects of air pollution.

- The **Maximum Desirable Level**, representing a time-averaged concentration that is a long term goal for air quality and also provides a benchmark for preserving air quality in the least polluted parts of the country.

Some of the effects of air contaminants above or below the three Federal objective levels are summarized in Table B.1.

British Columbia also has air quality criteria for ambient air concentrations defined at three levels. However, there are no consistent or official definitions for these objectives. For example, in the case of the Bulkley Valley, the levels have been interpreted in the same manner as the Federal objectives, but use simplified descriptions[19]. These levels are:

- **Level A;** below this level, air quality is ‘good’. It represents the maximum desirable concentration.

- **Level B;** below this level (but above Level A), air quality is ‘fair’. It represents the maximum acceptable concentration.

- **Level C;** below this level (but above Level B), air quality is ‘poor’. Above this level, air quality is ‘very poor’. It represents the maximum tolerable concentration.

All federal and provincial air quality criteria are presented in Table B.2.

[19] Johnson, D., *Bulkley Valley Air Quality Management Plan*. February 1999. http://wlapwww.gov.bc.ca/ske/skeair/reports/BVAQMP1999.pdf

Table B.1:
National Ambient Air Quality Objectives
and Their Relationship to Some Health and Environmental Effects
(Source: Environment Canada 1991)[20]

POLLUTANT	GOOD RANGE (0-MAX. DESIRABLE)	FAIR RANGE (MAX. DESIRABLE-MAX. ACCEPTABLE)	POOR RANGE (MAX. ACCEPTABLE - MAX. TOLERABLE)	VERY POOR RANGE* (OVER THE MAX. TOLERABLE)
Sulphur Dioxide (SO_2)	no effects	increasing injury to species of vegetation	odorous; increasing vegetation damage and sensitivity	increasing sensitivity of patients with asthma and bronchitis
Total Suspended Particulate (TSP)	no effects	decreasing visibility	decreased visibility; evident soiling	increasing sensitivity of patients with asthma and bronchitis
Ground-Level Ozone (O_3)	no effects	increasing injury to some species of vegetation	decreasing performance by some athletes exercising heavily	light exercise produces effect in some patients with chronic pulmonary disease
Carbon Monoxide (CO)	no effects	no detectable impairment but blood chemistry changing	increasing cardiovascular symptoms in smokers with heart disease	increasing cardiovascular symptoms in non-smokers with heart disease; some visual impairment
Nitrogen Dioxide (NO_2)	no effects	odorous	odour and atmospheric discoloration; increasing bronchial reactivity in asthmatics	increasing sensitivity of patients with asthma and bronchitis

***The upper limit of the very poor range is not defined. At extremely high levels of any of these pollutants, symptoms would be worse than those listed.**

[20] Environment Canada 1991. *The State of Canada's Environment.* Government of Canada, Ministry of Supply and Services, Ottawa.

Table B.2 Federal and Provincial Air Quality Objectives

For Contaminants[1] Monitored in the CRD

Contaminant	Averaging Period	Canada Maximum Desirable	Canada Maximum Acceptable	BC Level A	BC Level B	BC Level C
Carbon Monoxide	1-hour	15000	35000	14300	28000	35000
	8-hour	6000	15000	5500	11000	14300
Nitrogen Dioxide	1-hour		400			
	24-hour		200			
	Annual Arithmetic Mean	60	100			
Sulphur Dioxide	1-hour	450	900	450	900	900 -1300
	24-hour	150	300	160	260	360
	Annual Arithmetic Mean	30	60	25	50	80
Ozone	1-hour	100	160			
	24-hour	30	50			
	Annual Arithmetic Mean		30			
Ambient Air Quality Objectives Established in 1995						
PM_{10}	24- hour			50		

Notes:
[1] All units in µg/m^3

B.2 COMPARISON OF CRD LEVELS TO FEDERAL AND PROVINCIAL OBJECTIVES

Table B.3 provides a summary of CRD air quality concentrations at averaging times corresponding to provincial and/or federal ambient objectives. Comparisons to CRD guidelines, and the Canada Wide Standards can be found in the main body of this report. The ozone data analyzed in section 3.4 is re-averaged here (Table B.3) to provide 24-hour concentrations, necessary for comparison to the federal objectives.

There were two exceedence-level concentrations of particulate matter experienced during the year. These were PM_{10} exceedences of the provincial 24-hour objective of 50 µg/m³. There were numerous exceedences of the federal National Ambient Air Quality Objective (NAAQO) for 24-hour concentrations of ground-level ozone. However, the federal ozone objectives were set in the mid 1970's and are known to be outdated. These objectives are commonly exceeded at several rural monitoring sites in Canada. The more current Canada Wide Standard for ozone (8-hour average) was not exceeded at any ozone monitoring station in the CRD (see Section 3.4).

Sequential 24-hour ozone concentrations for the four monitoring stations are shown in Table 3.4.4.

Table B.3 24-Hour Sequential Mean Ozone Concentrations in the CRD

Percentile Values						Max µg/m³	Min µg/m³	Mean µg/m³	Std. Dev. µg/m³	Missing Values[b]
5	25	50	75	98	99					% of Total 24-h Averages
Victoria Topaz										
7.0	22.1	33.1	47.8	70.0	74.6	82.5	0.3	34.9	18.0	2.5
Royal Roads University										
8.0	27.0	41.5	53.7	78.1	82.8	92.4	1.7	40.6	19.7	14.2
Stellys										
6.4	24.2	38.8	51.3	75.3	79.5	83.2	1.0	38.2	18.8	0.8
Saturna Island										
20.2	35.4	47.2	57.8	77.1	81.9	95.3	4.1	47.1	16.4	0.8

[b] A 24-hour average concentration was determined for every day having 18 or more valid hours of data.

Table B.3
Comparison of Maximum Pollutant Concentrations (μg/m³) in the CRD for 2003 to Provincial and Federal Objectives

		Air Quality Criteria	Monitoring Station							
Contaminant	Averaging Period*	B.C. or Federal Maximum Acceptable Level	Victoria Topaz	Royal Roads	Langford	Stellys	Oak Bay	Braefoot	Keating	Saturna Island
Carbon Monoxide	1-hour	28000	6100							
	8-hour	11000	3325							
Nitrogen Dioxide	1-hour	400	99.4[1]	55.5[1]						
	24-hour	200	50.7[1]	29.7[1]						
	Annual	100	19.7[1]	8.0[1]						
Sulphur Dioxide	1-hour	900	136	24[3]						
	24-hour	300	20.5	3.5[3]						
	Annual	60	2.4	0.8[3]						
Ozone	1-hour	160	115.7	121.7[2]		135.7				137.2
	24-hour	50	82.5	92.4[2]		83.2				95.3
	Annual	50	35.0	40.3[2]		38.2				47.2
PM_{10}	24-hour	50	91 (HiVol)	46 (HiVol)	38 (HiVol)	84.3 (Partisol)	22 (HiVol)	21 (HiVol)	24 (HiVol)	

Notes:
* Type of averaging period (i.e., rolling or sequential) is not specified. SENES has assumed sequential averaging for each.
1 Partial record: January 1 – September 6, December 15 – December 31, 2004.
2 Partial record: January 1 – January 21, March 11 – December 31, 2004.
3 Partial record: July 28 – December 31, 2004.

APPENDIX C: Statistical Tests on $PM_{2.5}$ Data

There are four communities within the CRD that collect continuous $PM_{2.5}$ monitoring data that can be used to assess the relationship between ambient particulate matter air concentrations and community burning activities. Of these four, three communities have a municipal solid waste burning bylaw that restricts burning activities to specific days during the 'burn season'. Although the burn season varies by municipality, it generally consists of the fall, winter and spring months of the year. The monitoring data for Central Saanich (Stellys), Langford and Colwood (Royal Roads University) were analyzed for statistically significant differences in the average maximum daily 1-hour and 24-hour $PM_{2.5}$ concentrations on burn days compared to non-burn days. For Langford and Colwood, the first consecutive Friday and Saturday of each month of the burn season are allowable burn days. For Central Saanich, each Thursday, Friday and Saturday (until noon) are allowable burn days.

Although differences may exist between $PM_{2.5}$ concentrations on burn days versus non-burn days, these differences may not be due to a contribution from burning but instead to a variation in emissions, meteorology or other factors that coincide with the allowable burn schedule. A statistical significance test can be used to determine whether the differences in concentrations from two different datasets (burn or non-burn air concentrations) are unlikely to have occurred by chance alone; however, a statistical test can not prove that the burning caused the differences in particulate levels since there is potential for confounding with the actual cause(s).

SENES applied the Wilcoxon signed rank test to examine differences in average $PM_{2.5}$ concentrations experienced on allowed solid waste burn days and days when burning was not allowed. To reduce the potential influence of other residential emission activities, the same days of the week were used as much as possible in the tests. For Langford and Colwood, this means that only Fridays and Saturdays during months that solid waste burning was allowed were included. In effect, Fridays and Saturdays that fell on allowed burn days were compared against Fridays and Saturdays that fell on days when burning was not allowed. This approach was not possible for Central Saanich since burning in that community was allowed on every Thursday, Friday and Saturday (until noon) of the month. Therefore, an alternative methodology was used that compares burn days versus non-burn days during weekdays only (Thursdays and Fridays as burn days versus Mondays-Wednesdays as non-burn days during the burn season). This means that there potentially are more confounding influences in the comparison for the community of Central Saanich since baseline concentrations may be different on Monday through Wednesday than on Thursdays and Fridays. The fourth community with continuous $PM_{2.5}$ monitoring is Victoria, but solid waste burning is not allowed in this community. A similar test to that performed on Langford and Colwood (i.e., Fridays and Saturdays) was performed on the Victoria monitoring data to validate an assumption that any patterns found in the Langford or Colwood datasets are not due to effects such as meteorological differences.

The Wilcoxon signed rank test was selected to determine whether there were statistically significant differences in average concentrations between the burn and non-burn days. The test uses the rank-ordering of $PM_{2.5}$ concentrations for two datasets that are being compared, rather than the direct comparison of concentration values. The Wilcoxon test is a well-known example of a non-parametric statistical test, which does not require as many assumptions of the datasets being compared, as are necessary for parametric (also known as conventional) tests. For example, a parametric test of differences in mean concentrations requires an assumption that the datasets are normally distributed. A violation of this assumption can result in incorrect conclusions regarding the statistical significance of the difference. A non-parametric test is commonly chosen when violation of the parametric assumptions is possible, or even likely. For the analysis, correlation in the concentrations was considered to be negligible. In the future, the CRD may wish to do further statistical studies on the $PM_{2.5}$ monitoring data using a parametric approach, provided the assumptions can be shown to be true or if suitable data transformations can be made to the data. An alternative approach would be to use a methodology that combines both parametric and non-parametric tests.

A 95% significance level was chosen for the tests, as is common practice. This means that a difference is considered to be statistically significant at the 95% significance level if there is less than a 5% chance (probability) that a difference in average concentrations occurred by chance alone. The p-values given in the comparison tables correspond to two-sided 95% significance testing. Since the null hypothesis is that there is no difference in concentrations between burn and non-burn days and the alternate hypothesis is that concentrations are higher on burn days, one-sided significance levels are considered. One-sided p-values will typically be ½ of the p-values shown in the table (e.g. a 0.10 p-value for a two-sided test is considered equivalent to a 0.05 p-value for a one-sided test.) The asterisk show which values are considered statistically significantly different at the 5% level for a one-sided significance test; that is, that there is less than a 5% chance that the burn day average concentrations are higher than the non-burn day average concentrations by chance alone. It is also worth noting that the statistical power of the tests (ability to detect differences in the two datasets) tends to increase with a greater number of data entries (in this case, days). In effect, this means that even if there is no statistically significant difference for individual months, the difference may be statistically significant when two or more months are considered together.

Statistical analyses were performed with three different groupings of the measurement data. The $PM_{2.5}$ concentrations on burn versus non-burn days were analyzed by individual month and for all of the months during the allowed burn season grouped together. Due to anecdotal information that community burning tends to occur much more frequently on the first and last one or two allowed months of the burn season (i.e., in the Fall month and in the Spring month(s) only), a third analysis was performed grouping the 2 or 3 months that burning is much more likely to occur. For Central Saanich, the months are November and April, and for Colwood and Langford the months are November, April and May.

For the statistical tests on measurement data grouped over several months, there is a potential for differences, unrelated to burning, in the air concentrations between months of the year. For example, baseline air concentrations may be lower between months due to seasonal differences in meteorology (e.g. wind direction) or emissions of $PM_{2.5}$. This seasonal effect reduces the ability to detect a statistical ly significant difference between burn and non-burn days. In order to account (control) for a seasonal baseline variation, the concentration data were ranked within each month and the statistical test for difference was done on the ranks of the concentrations. (Note: this approach would be similar to the two-way ANOVA parametric test with factors for burn/non-burn days and for month of the year).

Finally, it must be stressed that if a difference is found to be statistically significant between concentrations on burn versus non-burn days, this does not necessarily mean that solid waste burning caused the difference. The possibility of other causal factors and chance alone must be considered. SENES has attempted to minimize the potential contribution from other external factors by selecting similar days of the week (to remove potential variation in emission sources throughout a week) and when reducing the effect of potential meteorological and emission rates differences between months when grouping multiple months of data. The potentially confounding effect of precipitation on measured $PM_{2.5}$ concentrations was not considered in the analyses. Obviously, this effect can have a dramatic influence on ambient $PM_{2.5}$ levels and could cause differences in burn versus non-burn days to be either enhanced or reduced. However, there was insufficient information available about the spatial variation and timing of precipitation events in the CRD municipalities to account for precipitation effects on $PM_{2.5}$ concentrations.

CENTRAL SAANICH (STELLYS):

Tables C.1 and C.2 present the results of statistical comparisons between daily maximum 1-hour and 24-hour concentrations experienced at the Stellys monitoring station during the burn season. To quantify the observed difference in concentrations, the mean concentration amounts on burn days and non-burn days are included, as are the mean rank of concentrations on burn days. Mean ranks exceeding 0.50 indicate that concentrations tend to be higher on burn days compared to non-burn days. For example, the average 1-hour maximum concentration on burn days in April and November was statistically significantly higher than the average 1-hour maximum concentration on non-burn days in those months. The average of measured concentrations for burn and non-burn days was 18.3 and 15.0 µg/m³, respectively, and the mean rank for burn days was 0.62. These statistics show that the calculated average concentration on burn days was higher than on non-burn days.

C.1

Daily Maximum 1-hour $PM_{2.5}$ Concentrations (μg/m³) for Stellys (Central Saanich) in 2004

Month	Comparison of Average Values				Statistical Significance		
	Mean on Non-burning Days	Mean on Burning Days	Number of Non-burning Days	Number of Burning Days	Wilcoxon p-value	Mean Rank	Rank Wilcoxin
January	14.5	17.4	12	10	0.29	0.58	
February	15.7	22	12	8	0.11	0.65	
March	15.1	11.9	15	8	0.13	0.44	
April	12.3	16.6	12	10	0.10 *	0.64	
November	17.2	20.4	14	8	0.34	0.59	
December	23.1	19.3	13	10	0.66	0.49	
April and November only	15	18.3	26	18		0.62	0.05 *
All Burning Months	16.4	17.9	78	54		0.56	0.17

C.2

24-hour $PM_{2.5}$ Concentrations (μg/m³) for Stellys (Central Saanich) in 2004

Month	Comparison of Average Values				Statistical Significance		
	Mean on Non-burning Days	Mean on Burning Days	Number of Non-burning Days	Number of Burning Days	Wilcoxon p-value	Mean Rank	Rank Wilcoxin
January	7.2	7.6	12	10	0.84	0.51	
February	7.3	8.7	12	8	0.23	0.6	
March	6.8	6.2	15	8	0.7	0.47	
April	6.4	7.1	12	10	0.34	0.57	
November	7.9	10.5	14	8	0.17	0.61	
December	9	8.7	13	10	0.98	0.5	
April and November only	7.2	8.6	26	18		0.58	0.10 *
All Burning Months	7.4	8.1	78	54		0.54	0.19

Both the average daily maximum 1-hour and 24-hour $PM_{2.5}$ concentrations at Stellys were found to be statistically significantly higher during burn days, but only when the months of April and November are considered together. When including all months of the burn season, the calculated differences in average $PM_{2.5}$ concentrations of 0.7 for 24-hour and 1.5 for maximum 1-hour were not statistically significantly different.

It is implied in the analyses of Stellys data that the $PM_{2.5}$ concentrations on Monday-Wednesday would be similarly distributed as the PM concentrations on Thursdays and Fridays if no burning were allowed on any days. If emissions of $PM_{2.5}$ from other sources were higher on Thursdays and Fridays (e.g., possibly more automobile traffic) than on Monday-Wednesday, this would be a confounding factor in analyses and could contribute to the finding that average $PM_{2.5}$ concentrations were higher on burn days than on non-burn days.

LANGFORD:

Tables C.3 and C.4 present the results of statistical comparisons between daily maximum 1-hour and 24-hour concentrations experienced at the Langford $PM_{2.5}$ monitoring station during the burn season. The analyses compare measurements from the 1st Friday and Saturday of the month against the measurements on other Fridays and Saturdays of the month. While this results in a lower number of measurements in the analyses compared to Stellys, the potential for confounding by day-of-the-week is lowered. Average daily maximum 1-hour and 24-hour concentrations are statistically significantly higher when considering the months of April, May and November together. In addition, the average daily maximum 1-hour concentrations are statistically significantly higher when all months of the burn season are included in the analysis. This was not the case for the average 24-hour concentrations.

C.3
Daily Maximum 1-hour $PM_{2.5}$ Concentrations (μg/m³) for Langford in 2004

Month	Comparison of Average Values				Statistical Significance		
	Mean on Non-burning Days	Mean on Burning Days	Number of Non-burning Days	Number of Burning Days	Wilcoxon p-value	Mean Rank	Rank Wilcoxin
January	13.9	21.5	8	2	0.09 *	0.82	
February	17.2	23.5	6	2	0.4	0.67	
March	10.8	16	6	2	0.4	0.67	
April	10.4	26.5	7	2	0.04 *	0.85	
May	7.7	18	7	2	0.46	0.65	
November	25.2	45.5	6	2	0.31	0.67	
December	16.3	16.5	7	2	0.88	0.55	
April, May and November only	13.9	30	20	6		0.72	0.02 *
All Burning Months	14.3	23.9	47	14		0.7	0.00 *

C.4
24-hour $PM_{2.5}$ Concentrations (µg/m³) for Langford in 2004

Month	Comparison of Average Values				Statistical Significance		
	Mean on Non-burning Days	Mean on Burning Days	Number of Non-burning Days	Number of Burning Days	Wilcoxon p-value	Mean Rank	Rank Wilcoxin
January	5.4	4.2	8	2	0.43	0.36	
February	7.4	5.3	6	2	0.18	0.28	
March	4.5	6	6	2	0.32	0.67	
April	4.7	8.5	7	2	0.04 *	0.85	
May	3.6	6.8	7	2	0.77	0.55	
November	12	20	6	2	0.10 *	0.78	
December	6.8	5.4	7	2	0.56	0.4	
April, May and November only	6.5	11.8	20	6		0.73	0.02 *
All Burning Months	6.2	8	47	14		0.56	0.41

COLWOOD (ROYAL ROADS UNIVERSITY):

Continuous monitoring data exists for the Colwood $PM_{2.5}$ community monitoring station for the complete years of 2001 to 2004. The current municipal burning bylaw has been in effect during the entire period (i.e., solid waste burning is allowed on the first Friday and Saturday of an eligible month within the burn season). Considering all months of the burn season over four continuous years, a statistically significant difference is evident between average daily maximum 1-hour $PM_{2.5}$ concentrations and average 24-hour concentrations for Fridays and Saturdays that fall on allowable burn days and those that do not. On an individual month basis, only March and November show statistically significantly higher concentrations (both average daily maximum 1-hour and 24-hour) on burn days.

Comparisons for the individual years between 2001 and 2004 are shown in Tables C.7 and C.8. When considering the mean concentrations for all months and for the grouping of April, May and November, there is a general pattern of higher average concentration on burn days compared to non-burn days with exception of average 24-hour concentrations in 2003. Not all differences were statistically significant. The variation in the concentrations and the statistical significance levels is likely to be due, in part, to the variation in meteorological conditions (e.g. differences in precipitation or typical wind directions and speed).

C.5
Daily Maximum 1-hour $PM_{2.5}$ Concentrations for Colwood (Royal Roads University) 2001 - 2004

Month	Comparison of Average Values				Statistical Significance		
	Mean on Non-burning Days	Mean on Burning Days	Number of Non-burning Days	Number of Burning Days	Wilcoxon p-value	Mean Rank	Rank Wilcoxin
January	12.9	10	26	8	0.64	0.48	
February	12.8	16.8	24	8	0.62	0.56	
March	9.6	15.5	29	8	0.05 *	0.71	
April	9.4	16.8	25	8	0.58	0.55	
May	10	9.3	28	8	0.52	0.53	
October	14.8	21.4	27	8	0.4	0.61	
November	17.7	27.5	28	8	0.05 *	0.68	
December	8.8	15.5	26	8	0.17	0.6	
April, May and November only	12.5	17.8	81	24		0.59	0.13
All Burning	12	16.6	213	64		0.59	0.01 *

C.6
24-hour $PM_{2.5}$ Concentrations for Colwood (Royal Roads University) 2001 - 2004

Month	Comparison of Average Values				Statistical Significance		
	Mean on Non-burning Days	Mean on Burning Days	Number of Non-burning Days	Number of Burning Days	Wilcoxon p-value	Mean Rank	Rank Wilcoxin
January	5.6	5.1	26	8	0.76	0.47	
February	5.2	6.3	24	8	0.29	0.58	
March	4.1	5.8	29	8	0.09 *	0.65	
April	4.4	4	25	8	0.74	0.47	
May	4.3	3.8	28	8	0.51	0.44	
October	6	6.4	27	8	0.29	0.57	
November	8	11.6	28	8	0.04 *	0.7	
December	3.6	5.3	26	8	0.5	0.59	
April, May and November only	5.6	6.5	81	24		0.53	0.42
All Burning	5.2	6	213	64		0.56	0.04 *

C.7

Daily Maximum 1-hour $PM_{2.5}$ Concentrations for Colwood (Royal Roads University) for Individual Years Between 2001 – 2004

2001

Month	Comparison of Average Values				Statistical Significance		
	Mean on Non-burning Days	Mean on Burning Days	Number of Non-burning Days	Number of Burning Days	Wilcoxon p-value	Mean Rank	Rank Wilcoxin
January	17.3	10.5	6	2	0.18	0.28	
February	10.8	7.5	6	2	0.23	0.39	
March	10	15	8	2	0.06 *	0.91	
April	8	7.5	6	2	0.87	0.5	
May	11.7	9.5	6	2	0.73	0.5	
October	10.2	22.5	6	2	0.61	0.61	
November	13.9	34.5	7	2	0.08 *	0.8	
December	7.1	12	7	2	0.88	0.55	
April, May and November only	11.3	17.2	19	6		0.6	0.44
All Burning	11.1	14.9	52	16		0.57	0.41

2002

Month	Comparison of Average Values				Statistical Significance		
	Mean on Non-burning Days	Mean on Burning Days	Number of Non-burning Days	Number of Burning Days	Wilcoxon p-value	Mean Rank	Rank Wilcoxin
January	10.3	12	6	2	0.24	0.72	
February	13.7	14.5	6	2	0.87	0.56	
March	9.3	27	8	2	0.06 *	0.82	
April	8	7	6	2	0.74	0.44	
May	9.7	8	7	2	0.76	0.6	
October	17.2	21.5	6	2	1	0.5	
November	20.8	42	8	2	0.05 *	0.86	
December	9.3	28.5	6	2	0.05 *	0.83	
April, May and November only	13.4	19	21	6		0.64	0.21
All Burning	12.4	20.1	53	16		0.67	0.01 *

2003

Month	Comparison of Average Values				Statistical Significance		
	Mean on Non-burning Days	Mean on Burning Days	Number of Non-burning Days	Number of Burning Days	Wilcoxon p-value	Mean Rank	Rank Wilcoxin
January	15.6	9.5	7	2	0.38	0.4	
February	13.2	27.5	6	2	0.4	0.67	
March	9.3	7.5	7	2	0.77	0.45	
April	10.3	22.5	6	2	1	0.5	
May	10.6	7	8	2	0.29	0.36	
October	13.6	9.5	7	2	0.66	0.45	
November	19	16	7	2	0.77	0.45	
December	10.2	15.5	6	2	0.4	0.67	
April, May and November only	13.3	15.2	21	6	0.86	0.44	0.45
All Burning	12.8	14.4	54	16	0.81	0.49	0.55

2004

Month	Comparison of Average Values				Statistical Significance		
	Mean on Non-burning Days	Mean on Burning Days	Number of Non-burning Days	Number of Burning Days	Wilcoxon p-value	Mean Rank	Rank Wilcoxin
January	8.7	8	7	2	1	0.5	
February	13.3	17.5	6	2	0.5	0.61	
March	10	12.5	6	2	0.49	0.67	
April	11.1	30	7	2	0.14	0.75	
May	8	12.5	7	2	0.38	0.65	
October	17.6	32	8	2	0.04 *	0.86	
November	16.5	17.5	6	2	0.61	0.61	
December	9	6	7	2	0.3	0.35	
April, May and November only	11.7	20	20	6		0.67	0.09 *
All Burning	11.8	17	54	16		0.63	0.04 *

C.8
24-hour $PM_{2.5}$ Concentrations for Colwood (Royal Roads University) for Individual Years Between 2001 – 2004

2001

Month	Comparison of Average Values				Statistical Significance		
	Mean on Non-burning Days	Mean on Burning Days	Number of Non-burning Days	Number of Burning Days	Wilcoxon p-value	Mean Rank	Rank Wilcoxin
January	6.6	4.4	6	2	0.18	0.28	
February	4	4.2	6	2	0.87	0.56	
March	4.8	4.6	8	2	0.79	0.45	
April	3.8	2.6	6	2	0.5	0.39	
May	4.6	2.8	6	2	0.32	0.33	
October	3.6	6.2	6	2	0.10 *	0.78	
November	5.8	10.8	7	2	0.24	0.7	
December	3.7	3.9	7	2	1	0.5	
April, May and November only	4.8	5.4	19	6		0.47	0.85
All Burning	4.6	4.9	52	16		0.5	0.93

2002

Month	Comparison of Average Values				Statistical Significance		
	Mean on Non-burning Days	Mean on Burning Days	Number of Non-burning Days	Number of Burning Days	Wilcoxon p-value	Mean Rank	Rank Wilcoxin
January	5.5	7	6	2	0.32	0.67	
February	6.9	6.9	6	2	0.74	0.56	
March	3.9	10.4	8	2	0.04 *	0.86	
April	4.3	2.9	6	2	0.5	0.39	
May	4.4	3.9	7	2	1	0.5	
October	9.3	5.3	6	2	0.10 *	0.22	
November	10.4	15	8	2	0.19	0.73	
December	3.6	10.5	6	2	0.05 *	0.83	
April, May and November only	6.6	7.2	21	6		0.54	0.64
All Burning	6.1	7.7	53	16		0.59	0.09 *

2003

Month	Comparison of Average Values				Statistical Significance		
	Mean on Non-burning Days	Mean on Burning Days	Number of Non-burning Days	Number of Burning Days	Wilcoxon p-value	Mean Rank	Rank Wilcoxin
January	6.3	5.7	7	2	1	0.5	
February	4.3	9.3	6	2	0.05 *	0.83	
March	4.1	3.6	7	2	0.77	0.55	
April	4.5	3	6	2	0.32	0.33	
May	5.3	3.6	8	2	0.3	0.32	
October	5	5.7	7	2	1	0.5	
November	8.3	9.9	7	2	0.24	0.7	
December	3.5	4.7	6	2	0.32	0.67	
April, May and November only	6.1	5.5	21	6		0.45	0.64
All Burning	5.2	5.7	54	16		0.55	0.4

2004

Month	Comparison of Average Values				Statistical Significance		
	Mean on Non-burning Days	Mean on Burning Days	Number of Non-burning Days	Number of Burning Days	Wilcoxon p-value	Mean Rank	Rank Wilcoxin
January	4.1	3.4	7	2	0.77	0.45	
February	5.4	4.8	6	2	0.5	0.39	
March	3.5	4.4	6	2	0.18	0.72	
April	4.8	7.5	7	2	0.14	0.75	
May	2.9	4.9	7	2	0.56	0.6	
October	6.1	8.4	8	2	0.12	0.77	
November	7	10.7	6	2	0.32	0.67	
December	3.7	2	7	2	0.38	0.35	
April, May and November only	4.8	7.7	20	6		0.67	0.07 *
All Burning	4.7	5.8	54	16		0.59	0.12

VICTORIA TOPAZ (VICTORIA):

The same methodology used for comparing $PM_{2.5}$ data for Langford was used with the 2004 $PM_{2.5}$ monitoring data from Victoria Topaz for 2004. Solid waste burning is not allowed in this community, and as such there should be no statistically significant difference evident between concentrations on Fridays and Saturdays that fall on burn days (Langford and Colwood burn days) and those that do not, assuming that the contribution from burning in nearby communities is minimal. This comparison was used to investigate whether the statistically significant differences found for Langford and Colwood may have arisen from some meteorological or emission influence other than solid waste burning. A similar comparison with the Topaz data using the Stellys schedule of allowed burning days cannot be done, as the pattern of higher $PM_{2.5}$ concentrations on Thursdays and Fridays compared to Monday-Wednesday for the Victoria monitoring data may be due to other emission influences (see Figure 3.4.1) that vary by day-of-week and are confounded with the timing of allowable burn days in Central Saanich.

Table C.9 and C.10 show that there are no statistically significant differences between Topaz $PM_{2.5}$ concentrations that fall on Langford/Colwood allowable burn days and those that do not (Fridays and Saturdays only) when considering some or all of the burn months of the season. One individual month (February) was found to have statistically significantly different concentrations, but with concentrations on non-burn days being higher, not lower, than on burn days.

The Victoria Topaz comparison strengthens the assumption that it is solid waste burning that causes average $PM_{2.5}$ air concentrations in Langford and Colwood to be higher on days when burning is allowed, rather than meteorological influences. In addition, ambient $PM_{2.5}$ concentrations monitored in Victoria are not measurably related to allowed burning activities in Langford and Colwood.

Table C.9
Daily Maximum 1-hour $PM_{2.5}$ Concentrations (µg/m³) for Victoria Topaz During 2004

Month	Comparison of Average Values				Statistical Values		
	Mean on Non-burning Days	Mean on Burning Days	Number of Non-burning Days	Number of Burning Days	Wilcoxon p-value	Mean Rank	Rank Wilcoxin
January	15.5	10	8	2	0.6	0.41	
February	18.3	8	6	2	0.05 *	0.17	
March	15.7	10.5	6	2	0.5	0.39	
April	14.3	19	7	2	0.3	0.7	
May	10.1	14	7	2	0.24	0.7	
November	45	35.5	6	2	0.32	0.33	
December	14.1	10	7	2	0.55	0.45	
April, May and November only	22.1	22.8	20	6		0.58	0.39
All Burning	18.5	15.3	47	14		0.45	0.36

Table C.10
24-hour $PM_{2.5}$ Concentrations (µg/m³) for Victoria Topaz During 2004

Month	Comparison of Average Values				Statistical Values		
	Mean on Non-burning Days	Mean on Burning Days	Number of Non-burning Days	Number of Burning Days	Wilcoxon p-value	Mean Rank	Rank Wilcoxin
January	5.1	3.4	8	2	0.43	0.36	
February	6.9	4	6	2	0.05 *	0.17	
March	4.2	4.6	6	2	0.74	0.56	
April	6.1	6.6	7	2	0.56	0.6	
May	4.5	5.3	7	2	0.38	0.65	
November	15.2	13.5	6	2	0.5	0.39	
December	4.7	3	7	2	0.14	0.25	
April, May and November only	8.3	8.4	20	6		0.55	0.58
All Burning	6.5	5.8	47	14		0.42	0.22

CONCLUSION

Table C.11 summarizes the calculated difference in average concentrations between burn and non-burn days for the two groupings of months used in the statistical analyses. The three communities that allow burning have statistically significantly higher concentrations on burn days compared to the "matched" non-burn days either for daily 24-hour concentrations or for daily maximum 1-hour concentrations, or for both measures. The association of higher concentrations is most evident for Langford, which has the largest differences in mean concentrations between burn and non-burn days and typically the highest statistical significance (i.e., lowest p-values).

Table C.11
SUMMARY OF DIFFERENCES (μg/m³) IN AVERAGE $PM_{2.5}$ CONCENTRATIONS

		Difference in Mean 24-hour Concentrations		Difference in Mean Maximum Daily 1-hour Concentrations	
	Comparison Days	Selected Months	All Burn Months	Selected Months	All Burn Months
Central Saanich (2004)	Thur-Fri vs Mon-Wed	1.4*	0.7	3.3*	2.5
Langford (2004)	1st Fri-Sat vs other Fri/Sat	5.3**	1.8	16.1**	9.6**
Colwood (2004)	1st Fri-Sat vs other Fri/Sat	2.9*	1.1	8.3*	5.2*
Colwood (2001-2004)	1st Fri-Sat vs other Fri/Sat	0.9	0.8*	5.3	4.6**
Victoria (2004) (using Langford/Colwood burning schedule)	1st Fri-Sat vs other Fri/Sat	0.1	-0.3	0.7	-3.2

Notes:
- * statistically significant at 95% level
- ** statistically significant at 99% level

The calculated differences for the community of Victoria, which does not allow solid waste burning, are small or negative for the same burning schedule as Langford and Colwood. This indicates that any contributions to ambient $PM_{2.5}$ concentrations in Victoria from burning in Langford and Colwood was likely to be small in that year and that confounding with meteorological or other factors was minimal.

The association of higher average air concentrations on burn days in Central Saanich may be due, in part, to confounding, with varying emissions from other sources on different days-of-the-week. The level of confounding cannot be assessed using the Victoria data since it is unlikely that the day-of-week pattern in emissions, other than burning, is the same in Victoria (e.g., an urban area) as it is in Saanich (e.g.,a rural area).

The differences in $PM_{2.5}$ concentrations and the statistical significance of the differences can vary from year-to-year due to unaccounted confounding factors. For example, the pattern of meteorology and other emission sources may align with designated burn days such that any apparent effect due to burning may be either masked or enhanced. The Colwood data indicate to some extent the variation from year-to-year. The calculated difference in average concentrations and the statistical significance of these differences in 2004 are higher than the corresponding statistics for the combined 2001 to 2004 period. This could indicate that the differences observed in 2004 at the Stellys and Langford monitoring locations might also be higher than the differences that would be present over a longer-term average. Regardless, the combined Colwood data from 2001 to 2004 will tend to average-out the confounding factors. The consistency over a number of years strengthens the association of higher PM concentrations and days when burning is allowed.

These analyses indicate that there is a statistically significant relationship between higher $PM_{2.5}$ concentrations and the days when solid waste burning is allowed. Note that the comparisons are only for selected days of the month; therefore the analyses can not be used to directly estimate the contribution to $PM_{2.5}$ on a monthly or annual basis. Additional years of monitoring and inclusion of other variables related to $PM_{2.5}$ concentrations in statistical analyses will aid in the isolation, or better understanding, of the potential contribution of burning to ambient $PM_{2.5}$ levels in the CRD.