Air Quality in the Capital Regional District 2008

Prepared for:

Capital Regional District
Environmental Services Department
625 Fisgard Street
Victoria, BC V8W 2S6

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EXECUTIVE SUMMARY

Air quality is monitored in the Capital Regional District (CRD) to assess the impact of solid waste burning and ambient air quality and to track trends in air quality. The monitoring is conducted under the long term monitoring program (LTMP), which is a partnership between the CRD and the British Columbia Ministry of the Environment (MoE), Royal Roads University and Environment Canada. SENES Consultants Limited (SENES) was contracted to provide an analysis and summary report of the monitoring data collected in 2008, including analysis of supporting meteorological information that was available over the same time period.

In 2008, there were six air quality stations in the CRD that measured either gaseous contaminants and/or fine particulate matter. One station, on Saturna Island, is managed by Environment Canada, and records only gaseous pollutants. In addition, there are three 'Hi-Vol' sites that measure fine particulate matter only.

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 to 10 microns (PM_{10}) and particulate matter smaller than or equal to 2.5 microns ($PM_{2.5}$).

Data collection at some stations was less successful for 2008 than in previous years (e.g., in 2006), hampering some data analysis for the annual report. However, data acquisition was better in comparison to 2007. Data were missing at all six monitoring sites for the following periods:

Monitoring Location	CO	NO/NO_2	SO_2	O_3	$PM_{2.5}$
Victoria Topaz		Dec 9	Feb 5; Mar 4; Apr 21; Dec 4	Apr 7-8; May 30	Jan 27-Feb 9; Apr 17-May 13; Jun 3-12; Jul 4-14; Nov 4-13
Royal Roads		May 18,19; Apr 7		Mar 19; Apr 19-21; Jun 27-Jul 2; Jul 9,10	May 20; Nov 14-Dec 3
Stellys	Aug 4- Sep 7	Mar 6-7; Apr 7-10,17,18; May 26-31; Jun 1-11, 13-17; Aug 4-Sep8; Oct 16		Feb 22; Aug 4 - Sep 7; Dec 12	Jan 1-Apr 30; Jun 13-17; Jul 18, 29-31; Aug 4-Sep 8
Christopher Point	Feb 21- Dec 31	Feb 14; May 18-21	May 18-21; Sep 5	Sep 19, 28; Oct 27	May 18-21
Langford	Feb 3; Oct 13-15	Feb 3-4; Jun 18; Sep 30; Oct 1;Oct 12-14	Oct 1, Oct 12-14	Oct 12-14	Feb 3-4; Jun 4-9; Jul 29; Sep 30; Oct 1,Oct 12-14
Saturna Island			N/A	Jan 1-8	

N/A – not available

Note that both ozone and sulphur dioxide data were collected by Environment Canada at the Saturna Island monitoring site, but sulphur dioxide had not yet been released for use at the time that this report was initially being prepared.

A primary focus of the annual air quality report is to assess the annual monitoring data with a set of CRD ambient air quality guidelines that were developed in 2004. In addition, comparisons to provincial and federal objectives and standards were made. Further temporal and spatial analyses were completed to examine trends in community air concentrations and to establish potential links between ambient concentrations and emission sources.

For the vast majority of the time in 2008, air quality remained relatively good in the CRD. The CRD guideline for PM_{10} was exceeded once at the Keating Elementary School station and once at the Braefoot Elementary School station on a different day, the $PM_{2.5}$ guideline was exceeded once at the Victoria Topaz site. The CRD ozone guideline was also exceeded once at Saturna Island.

- The exceedence of the PM_{10} guideline of 50 $\mu g/m^3$ occurred at the Keating monitoring station on April 6th of the year, with a 24-hour average concentration of 59 $\mu g/m^3$. Concentrations recorded at each of the other PM_{10} monitoring stations in the CRD on that date were much lower, indicating that the higher PM_{10} concentration at Keating was not experienced throughout a large portion of the CRD. The likely cause of the high concentration at the Keating site on this date could not be determined. The exceedence occurred on a Sunday, which does not correspond to the allowable days for open burning activity in this community.

- The exceedence of the PM_{10} guideline of 50 $\mu g/m^3$ occurred at the Braefoot monitoring station on August 16th of the year, with a 24-hour average concentration of 70 $\mu g/m^3$. Concentrations recorded at each of the other PM_{10} monitoring stations in the CRD on that date were much lower, indicating that the higher PM_{10} concentration at Braefoot was not experienced throughout a large portion of the CRD. Although the exceedence in 2008 mirrors a similar occurrence of elevated PM_{10} levels on April 12, 2007, the likely cause of the high concentration at the Braefoot site on either date could not be determined. Neither date corresponds to allowed burn dates for open burning in Saanich.

- The CRD guideline for $PM_{2.5}$ of 25 $\mu g/m^3$ was exceeded once at the Victoria Topaz site on January 25th with a 24-hour average concentration of 29.4 $\mu g/m^3$, based on the sequential Dichotomous (Dichot) sampler. However, the co-located continuous TEOM sampler recorded a $PM_{2.5}$ concentration on that date of only 14.1 $\mu g/m^3$, less than half of the Dichot sampler. TEOM samplers are recognized to have some loss of sample in colder seasons, and it is likely that the Dichot sampler provided a more reliable sample of $PM_{2.5}$ concentration on that date, and that the CRD guideline was indeed exceeded. However, the guideline was not exceeded at any other location in the CRD on that date, or at any location in the CRD during the remainder of 2008.

- The maximum 8-hour average ozone concentration at Saturna Island of 136.3 $\mu g/m^3$ on May 17th exceeded the CRD guideline value of 120 $\mu g/m^3$. Although the peak springtime ozone concentrations at Saturna Island have been previously documented by Environment Canada and been attributed to the influence of background ozone levels, the pattern of increased ozone concentrations in the afternoon hours of May 17th also suggests the influence of photochemical production of O_3 on this occasion, and is similar to an event that occurred on May 30, 2007. While the onset of the ozone episode on May 17th was similar at all of the other CRD ozone monitoring stations except Christopher Point, the levels at Saturna Island peaked at a higher concentration and persisted at higher levels than at the other stations well into the evening hours at Saturna Island, once again mirroring the episode that occurred on May 30, 2007.

Due to the limited temporal and spatial extent of exposure to the $PM_{10,}$ $PM_{2.5}$ and ozone exceedences, related health effects for community members could not be determined with confidence.

A statistical tool was developed for the CRD in 2006 for the purpose of assessing trends in air quality concentrations over a period of five or more years. The tool assesses whether a statistically significant trend (increase or decrease) in annual mean and 98th percentile concentrations exists over the period. In addition, a trend in the proportion of measurements above the applicable CRD guideline is assessed. There were no statistically significant trends found for NO_2 or respirable particulate matter ($PM_{2.5}$) concentrations for any of the monitoring locations. The exceptions were for CO and SO_2 monitoring data at Victoria Topaz over the period 1998-2008, and SO_2 for the period 1998-2007 and O_3 at Saturna Island for the period 1998-2008, for which trends were determined to be as follows:

- an outlier value of higher than expected mean SO_2 concentration on an overall longer term trend towards lower annual mean concentrations of SO_2 at Topaz;
- a decrease of 9%/year in annual 98th percentile concentrations of SO_2 at Topaz;
- a decrease of 4%/year in the annual 98th percentile concentration of CO at Topaz;
- a decrease of 5%/year in annual mean concentrations of SO_2 at Saturna Island;
- a decrease of 12%/year in annual 98th percentile concentrations of SO_2 at Saturna Island; and,

- an increase of 22%/year in the annual frequency of O_3 values over the CRD guideline at Saturna Island.

It should be noted that the 22%/year increase in ozone concentrations above the CRD guideline at Saturna Island still only represents a low frequency of occurrence of one 8-hour average episode per year. Nevertheless, the trend analysis suggests that the frequency of guideline exceedences is increasing.

In summary, ambient concentrations of the common air contaminants monitored in the CRD remain relatively low compared with all provincial and federal guidelines objectives and standards, and the CRD was in attainment of the Canada Wide Standards (CWS) for ground level ozone and $PM_{2.5}$ in 2008 based on the available data. Overall, the majority of CAC show no upward or downward trends over time, with the exception of decreasing trends (1998 to 2007) for sulphur dioxide at the Victoria Topaz and Saturna Island sites as well as a small decrease in carbon monoxide at the Topaz site only. On the other hand, the frequency with which ground-level ozone exceeds the CRD guideline value at Saturna Island appears to be increasing and may lead to the station's also exceeding the CWS value in the near future.

As part of the analysis for the 2008 annual report on air quality in the CRD, a statistical analysis was completed to determine:

- what contribution, if any, backyard burning makes to the total ambient air quality levels of $PM_{2.5}$ in the CRD; and,
- what contribution, if any, emissions of SO_2, NO_x and $PM_{2.5}$ from cruise ships docking at Ogden Point make to the observed levels of these contaminants at the Victoria Topaz monitoring site.

The analysis of $PM_{2.5}$ concentrations in relation to backyard burning is a repeat of an analysis that was first completed using the 2004 monitoring data. The analysis of the 2004 data strongly indicated that air quality in the CRD was degraded in those communities that allow burning, in the more active months of Fall and Spring. The same analysis performed on sampling data in Victoria indicated 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. Since 2004, a number of communities have either eliminated or reduced the times when backyard burning is permitted to occur.

The analyses of the $PM_{2.5}$ monitoring data in Langford and in Central Saanich (Stellys) support the overall conclusion that open burning contributes to statistically higher concentrations of $PM_{2.5}$ in Langford. The data suggest that hourly averaged concentrations are 7.6 $\mu g/m^3$ higher on burn days (95% confidence level), while 24-hour average concentrations are 1.9 $\mu g/m^3$ higher on burn days (99% confidence level). The analyses of the Stellys $PM_{2.5}$ monitoring data is more difficult to interpret in that there may be confounding factors that affect the ability to statistically determine the impact of open burning on air quality in Central Saanich. It could be very difficult to remove the confounding factors present in the Stellys analyses to determine if burning contributes to higher air concentrations. However, the confounding may be due to meteorological conditions and may not appear in future years, such that subsequent analyses in future years may be more successful in identifying the effect of open burning on air quality in Central Saanich.

The analysis of hourly averaged ambient air quality concentrations of SO_2, NO_2 and $PM_{2.5}$ at the Victoria Topaz monitoring station in relation to the cruise ship operations at Ogden Point indicates that the emission of SO_2 from cruise ships unequivocally has the greatest effect on ambient concentrations of this contaminant at the Topaz site. The emission of NO_x and $PM_{2.5}$ is more difficult to discern but is more clearly evident for NO_2 and $PM_{2.5}$ concentrations on weekend days when background concentrations from other sources of these two contaminants are lower.

The analysis of the 2008 monitoring data at the Topaz site supports the results of the James Bay Air Quality Study (JBAQS) dispersion modelling analysis that was completed for the cruise ship operations in 2007, but suggests that the JBAQS may have underestimated maximum SO_2 and $PM_{2.5}$ impacts from cruise ships by about a factor of three (3). The underestimation of SO_2 and $PM_{2.5}$ impacts in the JBAQS may reflect differences in meteorology between 2007 and 2008, but underestimation of SO_2 and $PM_{2.5}$ emissions also cannot be ruled out. The possible implication of this is that SO_2 concentrations in the vicinity of Ogden Point may be much higher than was estimated in the JBAQS, and may be high enough in the James Bay community to be of concern for human health impacts in that area.

1.0 INTRODUCTION

The Capital Regional District (CRD) has been in partnership with the B.C. Ministry of Environment and others in conducting an ambient air quality monitoring program in the CRD area since 1996. One of the goals of the Long Term Monitoring Program (LTMP) is 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 possibly 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.

Meteorological data is collected to support the LTMP at some stations. In addition, other meteorological stations in the CRD are used to characterize weather and climate in the region, or to assess local winds for industrial or other purposes. As well, the University of Victoria facilitates the operation of a school-based weather network that includes data from up to 74 individual stations[1].

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.

The CRD monitoring network is designed to characterize the air quality in the region and to support the initiatives described above. Air quality monitoring locations are chosen to capture air concentrations that are representative of either larger geographic areas, or ‘areas of interest’ where higher contaminant air concentrations are suspected, or other reasons. Local topography and the location(s) of pollutant sources can indicate how well a monitoring location represents an area. In most cases, a monitoring location should not be overly influenced by a single emission source. With the advent of the Canada Wide Standards (CWS) for ozone and particulate matter, to be implemented by 2010, ‘community-oriented’ monitoring sites are necessary. These sites are described as locations where people live, work and play[2].

In addition to the standard data analysis of the 2008 monitoring data, SENES was requested to provide as to whether any patterns are apparent in the data that indicate an influence from solid

[1] See http://www.victoriaweather.ca/.

waste burning and/or cruise ship emissions on ambient air quality in the CRD. The analysis of the particulate matter ($PM_{2.5}$) data follows from a previous analysis completed for the 2004 monitoring data set (SENES 2005).[3]

1.1 MONITORING STATIONS

In 2008, air contaminants were sampled at six air quality monitoring stations in the Capital Regional District (CRD). Each station sampled all or some of the common air contaminants (CACs), namely: carbon monoxide (CO), nitrogen oxide (NO), nitrogen dioxide (NO_2), sulphur dioxide (SO_2), ground-level ozone (O_3) and particulate matter (PM). There are two sub-fractions of particulate matter sampled; $PM_{2.5}$ (particles with a diameter of less than or equal to 2.5 microns) as respirable PM, and PM_{10} (particles with less than or equal to 10 microns) as inhalable PM.

All of the air quality and meteorological stations in the CRD are included in Table 1.1. The contaminants and meteorological parameters monitored at each location are also listed. Their locations are indicated in Figure 1.1.

In 2008, a network review (SENES 2008)[4] was conducted and recommendations made as to the number and location of regional air quality monitoring stations. The results of the review were implemented at the end of 2008. The Victoria Topaz station has the longest record of continuous data capture of all the CRD stations. It is operated as part of the National Air Pollution Surveillance program (NAPS). Victoria Topaz, Christopher Point and Langford record all of the common air contaminants, however monitoring at Christopher Point was due to be discontinued after December 2008 as the funding from Environment Canada for the Georgia Basin Ecosystem Initiative ended. Royal Roads University collects particulate matter in the form of $PM_{2.5}$, nitrogen oxides and ground level ozone. Royal Roads University was discontinued from the monitoring network at the end of 2008. The monitor at Stellys Cross Roads in Central Saanich records all CACs except SO_2. Data from these stations were made available by the B.C. Ministry of Environment.

The Saturna Island monitoring station is part of the Canadian Air and Precipitation Monitoring (CAPMON) network of primarily rural monitoring stations. Both ozone and sulphur dioxide data collected by Environment Canada at the Saturna Island monitoring site had not yet been released for use at the time that this report was initially being prepared. The ozone data was

[2] Canadian Council of Ministers for the Environment, 2000. Guidance Document on Achievement Determination: Canada Wide Standards for Particulate Matter and Ozone. www.ccme.ca.
[3] SENES Consultants Limited 2005. Air Quality in the Capital Regional District 2004. Prepared for the CRD Environmental Services Department, Victoria, B.C.
[4] SENES Consultants Limited 2008. Capital Regional District Air Quality Monitoring Review. Prepared for the Capital Regional District, Environmental Services Department, November 2008.

subsequently provided in time for its inclusion in the final report, but the delay in obtaining data from Environment Canada has been a chronic problem for the preparation of annual air quality monitoring reports for the CRD in previous years, and part of the analysis for the 2008 report was to provide recommendations to address this issue in future reports. There are two potential options open to the CRD, namely:

1) delay issuing the annual air quality reports until the Saturna Island ozone data become available, which would likely result in the reports being made available to the general public only after the end of the year following the year in which the data were collected (e.g., the annual report for 2008 would be issued in early 2010 rather than before the end of 2009); or,
2) include the Saturna Island ozone sampling data as an appendix to the annual air quality report every 3rd or 4th year as the data become available.

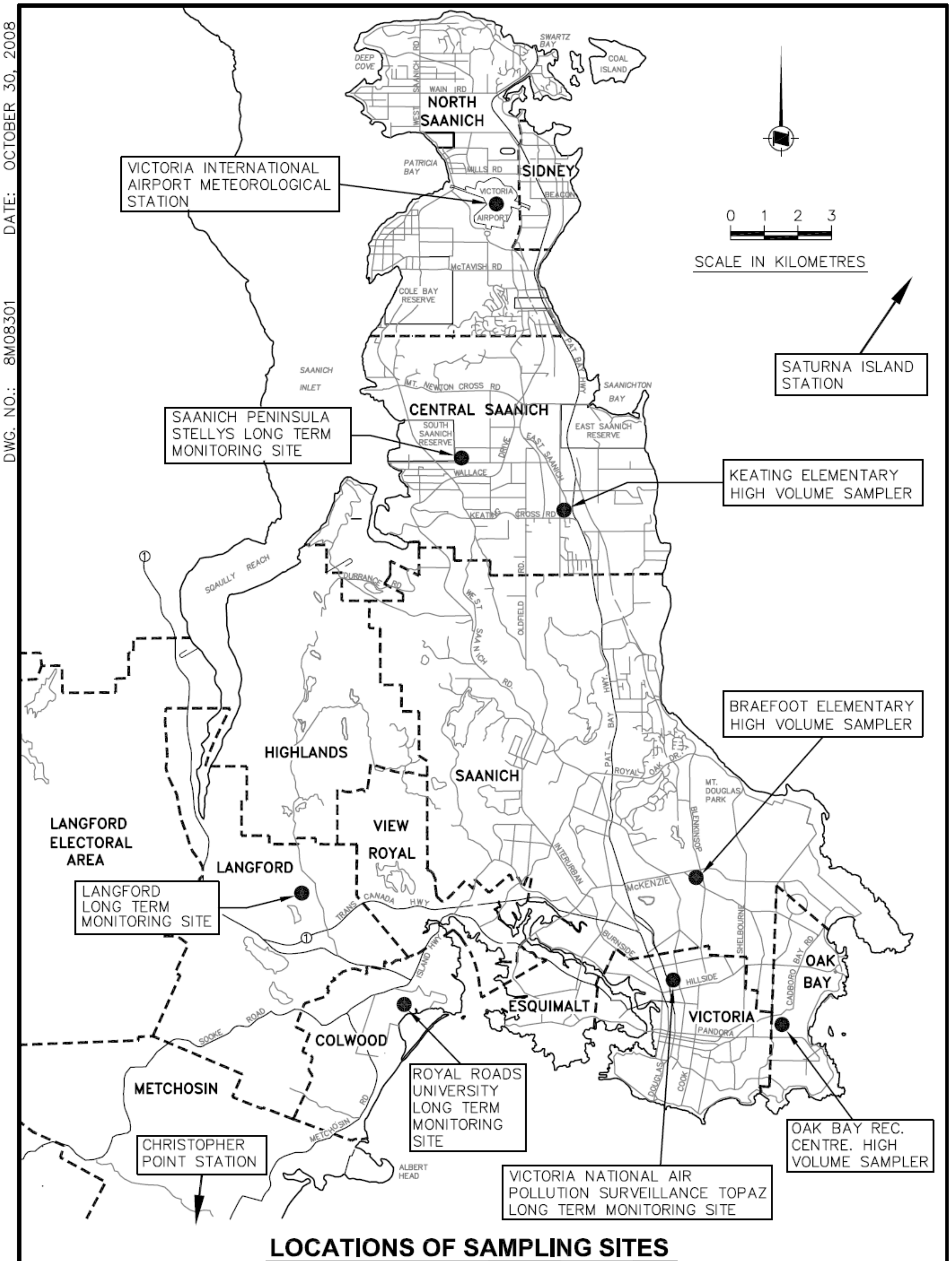
Option #2 is already the case for the SO_2 data used for trend analysis because it typically is not available for more 2-3 years after it has been collected. A similar approach could be followed for the ozone data as well.

There are three high volume sampler (Hi-Vol) equipped stations that collect PM_{10} data in the CRD at the Oak Bay Recreational Centre, and at the Braefoot and Keating Elementary Schools. These also were discontinued at the end of 2008. In addition, beginning in 2007, a Partisol sampler was installed at Langford to sample $PM_{2.5}$ as a check against the continuous $PM_{2.5}$ sampler data (see Section 4.3 of this report). The Hi-Vol (PM_{10}) sampler at Stellys was replaced by a Partisol sampler for the 2008 monitoring program. Measurements are collected on a one-in-six day cycle. This type of sampling technique requires PM to be collected on filters which are sent to a laboratory for measurement.

Table 1.1
Air Quality Monitoring Stations in the Capital Regional District, 2008

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	Dichot $PM_{2.5}$ /PM_{10} $PM_{2.5}$ (Partisol) $PM_{2.5}$ (C-TEOM)	WS, WD, T, RH
Royal Roads University	Long Term Monitoring Site	NO, NO_2, & O_3	PM_{10} (S-Hi-Vol) $PM_{2.5}$ (C-TEOM)	WS, WD, T, RH
Stellys, Saanich Peninsula[3]	Long Term Monitoring Site	CO, NO, NO_2 & O_3	PM_{10} (Partisol) $PM_{2.5}$ (C-TEOM)	WS, WD
Christopher Point[4]	Long Term Monitoring Site	CO, SO_2 NO, NO_2 & O_3	$PM_{2.5}$ (C-TEOM)	WS, WD, T, RH, others
Langford[2]	Long Term Monitoring Site	CO, NO, NO_2 SO_2 & O_3	$PM_{2.5}$ (Partisol) PM_{10} (S-Hi-Vol) $PM_{2.5}$ (C-TEOM)	WS, WD
Saturna Island	CAPMoN[5] Site	SO_2 & O_3		WS, WD
Oak Bay Recreational Centre[6]	PM sampling site (Hi-Vol)		PM_{10} (S-Hi-Vol)	
Braefoot Elementary School[7]	PM sampling site (Hi-Vol)		PM_{10} (S-Hi-Vol)	
Keating Elementary School[8]	PM sampling site (Hi-Vol)		PM_{10} (S-Hi-Vol)	
Victoria International Airport	Environment Canada meteorological station			WS, WD, T, RH, others

Notes:
WS – wind speed; WD – wind direction; T – temperature; RH – relative humidity
S-Hi-Vol - sequential sampling using a High Volume sampler
Dichot - 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 and was moved in August 2005
3- Station began operating in August, 2003
4- Station began operation in September 2005
5- Canadian Air and Precipitation Monitoring Network
6- Particulate matter sampling site since October 1996
7- Particulate matter sampling site since November 1999
8- Particulate matter sampling site since November 1999



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 more stringent than the national criteria. There is a growing awareness that there may need to be an update of existing national and provincial air quality objectives and guidelines in Canada. Updated guidelines are under discussion at the federal/provincial government levels. The current provincial objective level for PM_{10} was established in 1995, and the provincial and national objectives for CO, SO_2 and NO_2 have not been reviewed since the mid-1970's. Consequently, the existing provincial and national objectives for these pollutants may not reflect the current knowledge and understanding of the health effects of these air pollutants.

The CWS reflect a more recent federal initiative to update ambient air quality criteria, in particular for air contaminants that may have higher potential to adversely affect human or environmental health. The CWS are expressed as standards to be achieved by 2010. However, the CWS also has requirements beyond the numeric targets for O_3 and $PM_{2.5}$. These requirements are identified as *keeping clean areas clean* and *continuous improvement*, which are meant as guidance for those areas that are already in attainment of the CWS. The concept of keeping clean areas clean has been described [5] 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.

Although management of air quality rests with senior government, the CRD established a set of ambient air quality guidelines for each of the CACs in 2004. These guidelines assist with reporting air quality data. The upper-bound guidelines are protective of human and environmental health and are equal to or lower (more stringent) than applicable provincial or federal ambient air quality objectives or standards. Any exceedences of the CRD guidelines are identified and investigated each year.

The CRD guidelines are specified in Table 1.2. Analysis of ambient monitoring data in the following sections specifically addresses the CRD guidelines. In addition, adherence to the CWS is discussed for $PM_{2.5}$ and ozone. Appendix B provides a discussion of all relevant

[5] 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.

provincial and federal objectives, including a compliance analysis of CRD ambient CAC concentrations.

Table 1.2
Air Quality Guidelines for the Capital Regional District

Averaging Period	Guideline Concentration (µg/m^3)					
	NO_2	**SO_2**	**CO**	**O_3**	**PM_{10}**	**$PM_{2.5}$**
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 METEOROLOGY IN THE CRD

Meteorological data were collected at eight monitoring stations in the CRD during 2008. Each station is identified in Table 2.1 below, along with the general parameters collected each hour. The data were collected from the MoE data archives, with the exception of Saturna Island (not available from Environment Canada at the time of report preparation) and the Hartland Landfill (this station does not submit data to the MoE archives).

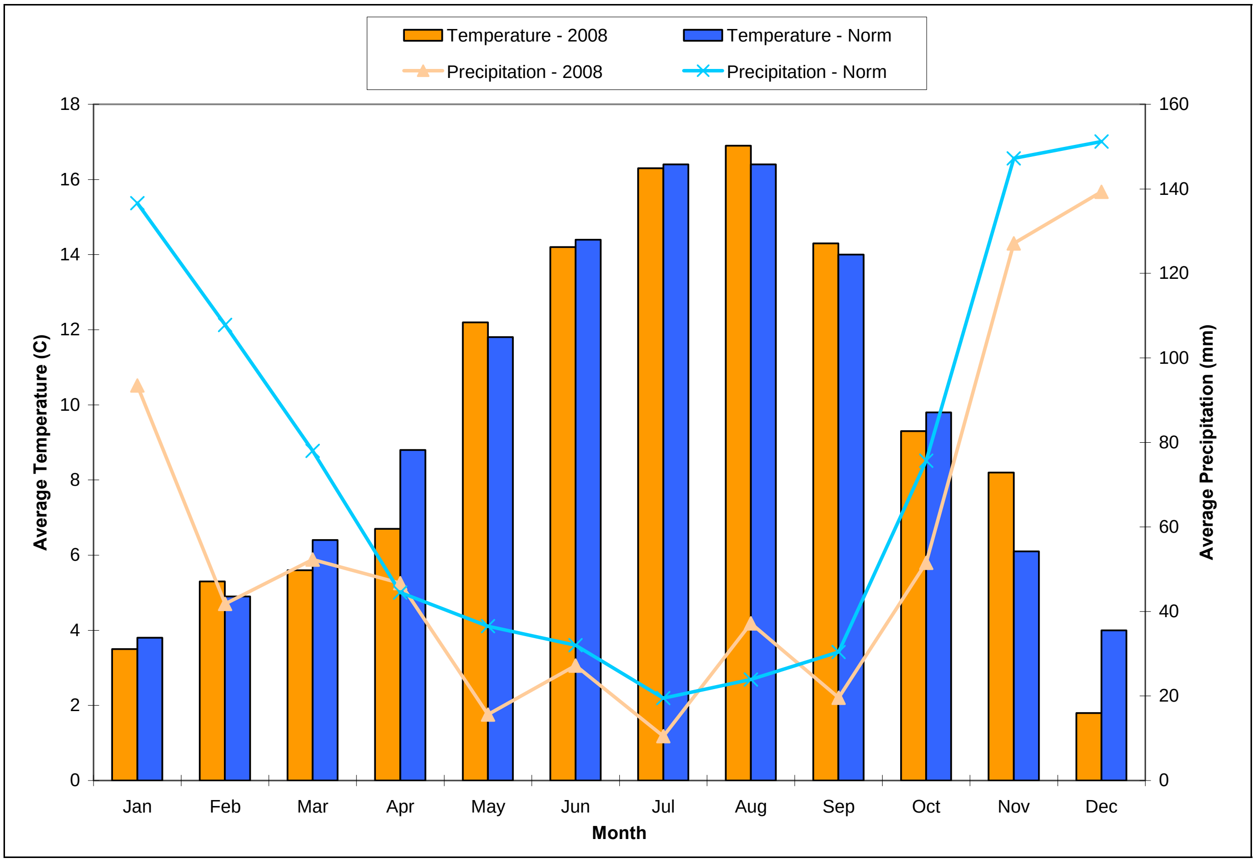
Table 2.1
Meteorological Stations in the CRD

STATION	OPERATION*	METEOROLOGICAL DATA COLLECTED**	WIND CAPTURE RATE (%)
Royal Roads University (Colwood)	Royal Roads University	WS, WD, T	99.4
Victoria Topaz	MoE, EC NAPS	WS, WD, T, RH	99.7
Stellys	MoE	WS, WD, T	93.5
Christopher Point	MoE	WS, WD, T, RH, P, Rad	100
Langford Lakewood Elementary School	MoE	WS, WD, T	99.2
Victoria Airport	EC	WS, WD, T, RH, Precip, P, Cloud, Ceil	100

* EC = Environment Canada, CAPMoN = Canadian Air and Precipitation Monitoring Network, NAPS = National Air Pollution Surveillance.
** WS = wind speed, WD = wind direction, T = dry bulb temperature, RH = relative humidity, Precip = precipitation (rain+snow) amounts, P = pressure, Rad = radiation, Cloud = cloud cover, Ceil = ceiling.

The monthly average temperatures and monthly total precipitation levels for 2008 are compared to the climate norm (1971 – 2000) in Figure 2.1. Average temperatures were comparable to the norm throughout most of the year with the exception of November, which had a mean temperature about 2 degrees higher than the norm, and December and April, which experienced temperatures roughly 2 degrees lower than the norm. With the exception of April and August, precipitation was lower than the norm throughout 2008, particularly from January to March.

Figure 2.1
2008 Monthly Average Temperature and Precipitation at the Victoria Airport



A wind rose diagram shows the frequency of wind direction (direction ***from*** which the wind blows) and wind speed at a station. Wind rose diagrams are included in Appendix A for the six stations with available data for 2008 (Royal Roads, Topaz, Stellys, Christopher Point, Langford and Victoria Airport).

3.0 GASEOUS POLLUTANTS

The gaseous air contaminants that are sampled at the monitoring stations in the CRD are carbon monoxide (CO), nitric oxide (NO), nitrogen dioxide (NO_2), sulphur dioxide (SO_2), and ozone (O_3). Ambient air concentrations are measured by gas samplers that take a representative volume of the ambient air every few seconds. However, the complete, continuous record for each of the gases tends to be highly variable and difficult to interpret with respect to both emission sources and health or environmental effects. Because of this, the data records are re-averaged to produce 1-hour average concentrations, which are recorded and archived. From these 1-hour averages, further analysis allows determination of 8-hour, 24-hour, monthly and annual average concentration amounts.

The gas samplers automatically recalibrate frequently to ensure accuracy. Occasionally, due to recalibration, hourly concentrations can be missed. For each pollutant, the percent of missing data is recorded. For monitoring sites administered by the B.C. Ministry of Environment, gaseous pollutants recorded in parts per billion (ppb) or parts per million (ppm) are converted by the Ministry to micrograms per cubic metre ($\mu g/m^3$) at 20^0C and 1 atmosphere (atm). Conversely, CAPMoN ozone data for Saturna Island recorded by Environment Canada are reported in ppb at 0^0C and 1 atm. In this report, the Saturna Island ozone data have been converted to $\mu g/m^3$ by multiplying ppb by a factor 2, without accounting for hourly differences in temperature and pressure because these were not available for the report.

A statistical analysis was conducted on each station's datasets. The mean, maximum, minimum, standard deviation and percentile concentrations were calculated to determine the variability among stations and the variability in concentration amounts throughout the year in 2008. The 98^{th} percentile concentration represents the value that is only exceeded 2% of the time during the year.

The data obtained for each sampling location were analysed to obtain 1-hour, 8-hour, 24-hour, annual average concentrations and appropriate percentile distributions for comparison with CRD ambient air quality guidelines and provincial and federal objectives and standards, as well as for trend analysis. Where there were missing data in the record, analysis was limited to only those periods when there was more than 80% data capture (e.g., at least 18 hours of data for a 24-hour average and 6 hours of data for an 8-hour average). Similarly, for comparisons of month-to-month variability in concentrations, only those months with at least 80% data capture[6] in each

[6] Note that the Canadian Council of Ministers of the Environment (CCME) considers an annual $PM_{2.5}$ data set to be complete if at least 75% of the scheduled sampling in each quarter of the year have valid data. For ozone, the CCME, the requirement is that an ozone monitoring day must have valid data for 75% of possible hours in a day (i.e., 18 out of 24 hours) to compute a valid 8-hour average, and that the annual data set must have valid monitoring days for at least 75% of the days from April through September.

month were considered. For pollutants where there was less than 80% data capture for the year, no trend analysis is presented because a representative analysis cannot be produced when 20% of the data are missing.

3.1 CARBON MONOXIDE (CO)

Carbon monoxide is produced by both natural and anthropogenic sources (e.g., automobile emissions, home heating). Natural sources include volcanic eruptions, forest fires and the decomposition of organic materials. Human emissions of CO are primarily caused by the incomplete combustion of fossil fuels. CO is an odourless, colourless, tasteless gas.

In 2008, CO data was collected at Victoria Topaz, Stellys, Langford and Christopher Point. Data at Christopher Point was missing from February 21st to December 31st. The CO monitor at Christopher Point was not calibrated after February 8th subsequently failed an audit completed by the Ministry of Environment on July 30th, and was removed from service on September 25th. All data collected after February 21st was judged to be invalid. Due to the limited amount of data at Christopher Point, it was not included in any of the CO data analyses presented in this report. CO data was also missing at Stellys from August 4th to September 7th because the entire site was shut down for upgrading the trailer and air conditioning.

The hourly concentrations of CO are summarized in Table 3.1. Eight-hour sequential average concentrations of CO for Topaz, Stellys, Langford and Christopher Point, are summarized in Table 3.2. There were no exceedences of the CRD 8-hour guideline of 5500 µg/m³ in 2008, and generally values were well below the guideline level.

Table 3.1
Hourly Averaged CO Concentrations in the CRD

Percentile Values						Max	Min	Mean	Std. Dev.	Missing Values
5	25	50	75	98	99	µg/m³	µg/m³	µg/m³	µg/m³	% of Total Hours
Victoria Topaz										
100	400	700	900	1700	2100	4000	0	688.4	398.7	5%
Stellys										
100	200	200	400	700	800	1600	0	282.9	170.8	14%
Christopher Point										
300	600	1000	1100	1200	1300	1300	200	863.7	295.8	87%
Langford										
0	100	100	200	600	800	2200	0	158.1	159.1	6%

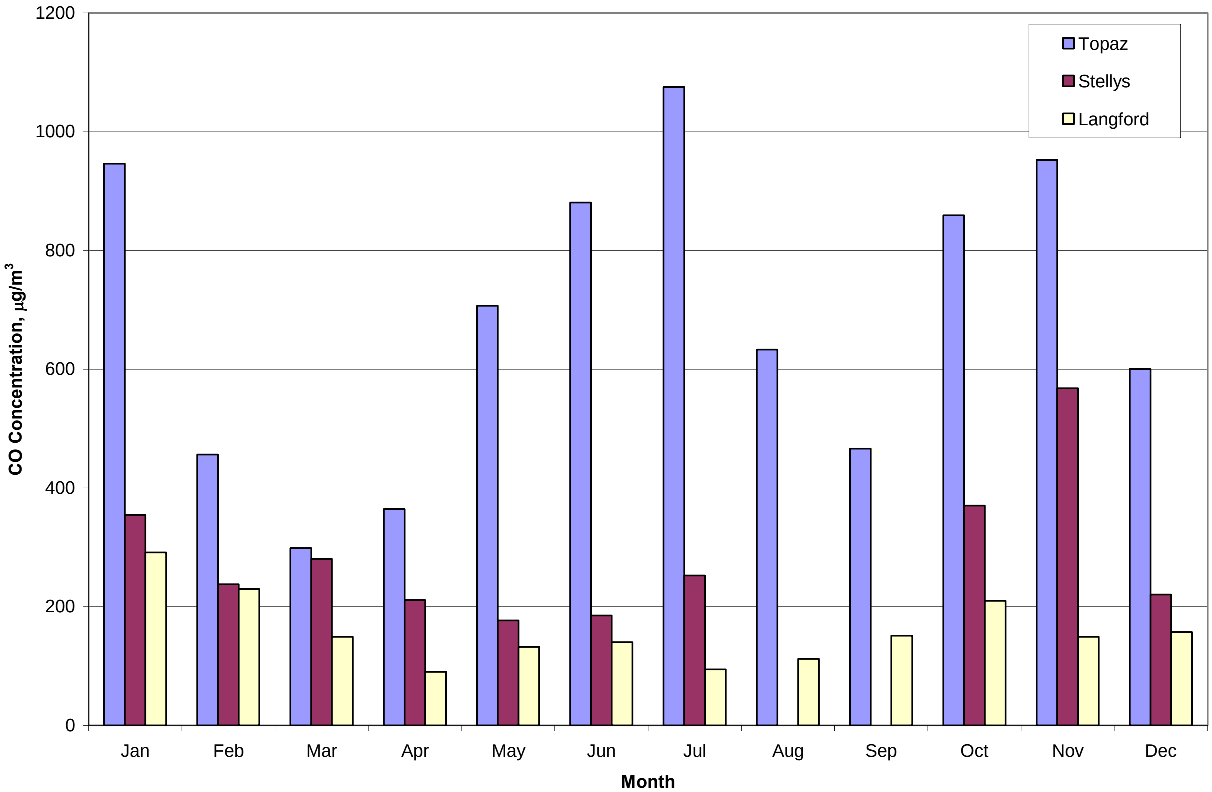
Table 3.2
8-Hour Sequentially Average CO Concentrations in the CRD[a]

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											
175	414.3	700.0	914.3	1434.0	1564.0	2671.4	0	688.0	344.0	0%	0.8%
Stellys											
100	175	242.9	357.1	672.6	727.1	912.5	0	283.2	150.6	0%	10%
Christopher Point											
300	585.7	1000	1100	1212.5	1226.7	1250	200	863.9	294.2	0%	86%
Langford											
12.5	100	125	212.5	427	478.5	671.4	0	157.9	107.1	0%	2%

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

Figure 3.1 shows the mean monthly 8-hour average carbon monoxide concentrations at Stellys, Langford and Victoria Topaz. Christopher Point was not included in the figure due to the large amount of missing data. Concentrations at Topaz were consistently higher than CO concentrations at both Langford and Stellys stations. This is likely because of the Topaz station's location in close proximity to Blanshard Street and therefore, larger amounts of traffic. CO concentrations at Langford station were the lowest throughout 2008. As with 2007, concentrations at Topaz were highest in July. Data at Langford and Stellys showed no significant monthly pattern.

Figure 3.1
Mean Monthly 8-Hour Average CO Concentrations at Langford, Stellys and Victoria Topaz



The average diurnal patterns of CO concentrations at Victoria Topaz during the warmer (April to October) and cooler (November to March) months are shown in Figure 3.2. Rush hour traffic emissions in the morning in all months of the year (warm and cool months) are indicated by the peak concentrations at approximately 8:00 am PST in cooler months, and 7:00 am PST in warmer months (the difference in time of day for the peak value is due to daylight savings time). This morning peak in concentrations can be accounted for by the increase in vehicle emissions during this time of day combined with a lower mixing layer in the atmosphere. A more gradual increase in CO concentrations observed in the late evening in hours is due to a lowering of the atmospheric mixing height towards the end of the day.

CO concentrations are typically elevated during the cooler months than the warmer months because the decrease in the depth of the mixed layer is, on average, more pronounced in the winter than in the summer, and because residential heating contributes to increased CO emissions at night during cooler months. This was certainly the case at both Stellys and Langford. However, as indicated in Figure 3.1, the 8-hour average CO concentrations at the Topaz site were also elevated during the months of May through August. Such elevated CO concentrations were not present at Topaz during these months in previous years (e.g., 2005 or 2007; 2006 had missing CO data during this period). The reason for the elevated CO concentrations during the summer months at Topaz could not be determined.

Additionally, Figure 3.3 and Figure 3.4 show the diurnal pattern of CO concentrations at Langford and Stellys, respectively. The data show a similar diurnal variation to Victoria Topaz; however, the CO concentrations at both Langford and Stellys are much lower than concentrations at Victoria Topaz. As previously mentioned, this is likely a result of the Topaz station being located in close proximity to Blanshard Street.

Figure 3.2
Average Diurnal CO Pattern for Victoria Topaz During Cold Months (November – March) and Warm Months (April – October)

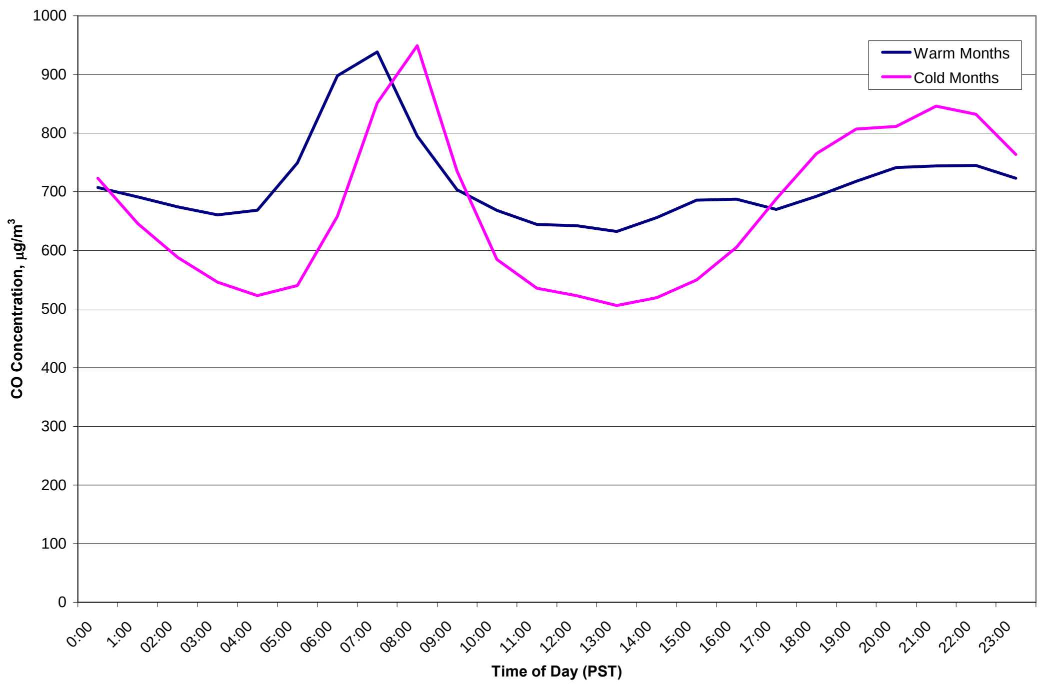


Figure 3.3
Average Diurnal CO Pattern for Langford During Cold Months (November – March) and Warm Months (April – October)

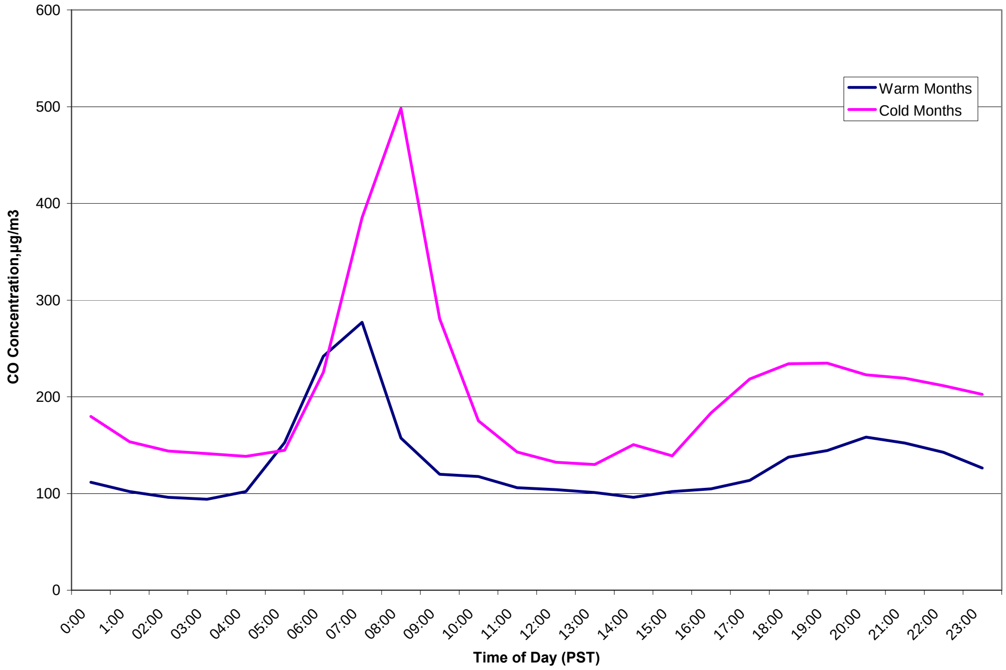
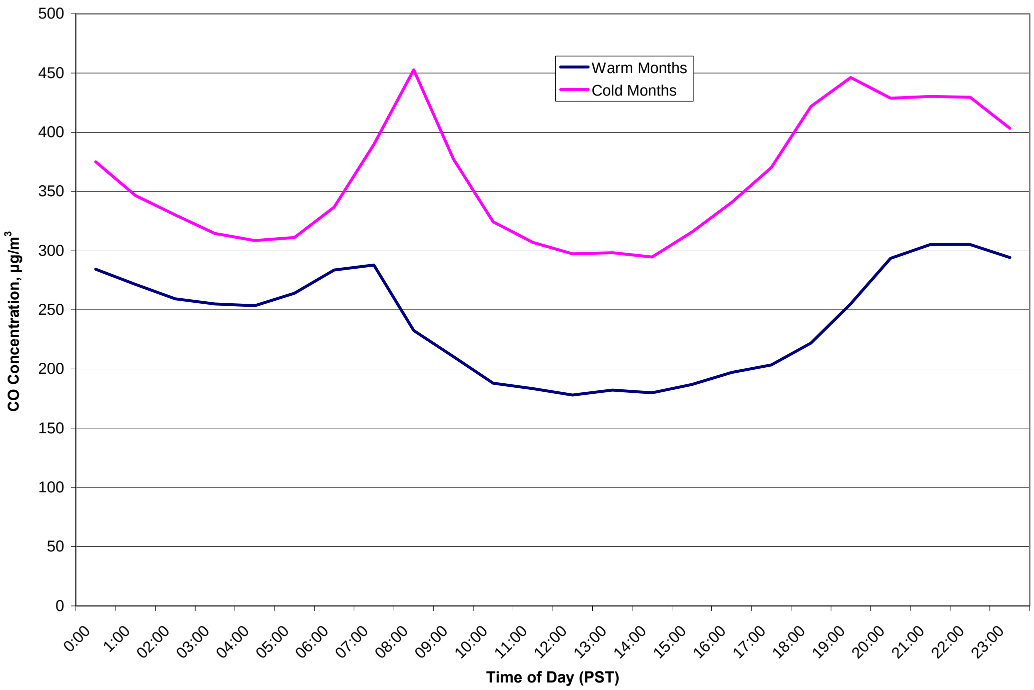


Figure 3.4
Average Diurnal CO Pattern for Stellys During Cold Months (November – March) and Warm Months (April – October)



3.2 NITROGEN OXIDES

The reaction of nitrogen with oxygen results in the production of nitrogen oxides (NO_x). NO_x can be produced through biological or atmospheric processes, but monitoring of NO_x in urban areas is generally associated with concerns about emissions from combustion processes. In particular, monitoring is generally conducted for two oxides of nitrogen: nitric oxide (NO) and nitrogen dioxide (NO_2). NO and NO_2 are released in significant quantities during combustion and have been identified as important pollutants in the lower atmosphere because they are ozone precursors and can contribute to the formation of secondary fine particles as nitrates.

NO_2 acts mainly as an irritant affecting the mucosa of the eyes, nose, throat, and respiratory tract. Nitrogen dioxide (NO_2) has an orangey-red colour and irritating odour at high enough concentrations. NO_2 is corrosive due to its high potential for oxidation and can cause a reduction in visibility in its role as a smog-forming constituent.

In 2008, NO_x was monitored at Victoria Topaz, Royal Roads University, Stellys, Langford and Christopher Point.

3.2.1 Nitric Oxide (NO)

Table 3.3 summarizes the NO levels measured at four locations in the CRD in 2008, however most of the NO data at Christopher Point was invalidated due to a data logger issue.

As indicated in Table 3.3, the Victoria Topaz station had the greatest maximum hourly concentration and the highest hourly mean concentration of NO, while Stellys had the lowest (note that Christopher Point had a large amount of missing data and was not included in the data comparison). This is likely because of the Topaz station being located in close proximity to Blanshard Street and being influenced by traffic. There are no CRD guidelines or other regulatory criteria for NO.

Table 3.3
Hourly Averaged NO Concentrations in the CRD

Percentile Values						Max	Min	Mean	Std. Dev.	Missing Values
5	25	50	75	98	99	μg/m³	μg/m³	μg/m³	μg/m³	% of Total Hours
Victoria Topaz										
0.4	1.5	4.1	10.7	83.6	120.3	310.4	0	11.1	22.0	5%
Royal Roads University										
0.1	0.2	0.6	1.7	23.9	35.1	112.8	0	2.6	6.6	5%
Stellys										
0.4	1.1	2.2	4.2	18.6	25.3	72.8	0	3.7	4.9	20%
Christopher Point										
0	0	0	0.3	8.1	10.6	16.2	0	0.7	2.0	92%
Langford										
0.6	1.4	2.2	5	51	79.8	217.3	0.1	6.3	14.5	6%

3.2.2 Nitrogen Dioxide (NO_2)

Tables 3.4 and 3.5 provide hourly and 24-hr averaged NO_2 concentrations, respectively. There were no exceedences of the CRD 1-hour NO_2 guideline of 200 μg/m³, and values were generally well below the guideline value. Victoria Topaz experienced higher 1-hour and 24-hour average NO_2 concentrations over those measured at Langford, Stellys, Royal Roads and Christopher Point. As with the NO concentrations, the higher NO_2 levels at Topaz were likely due to the station's close proximity to a main thoroughfare. Hourly and 24-hour maximum and mean NO_2 concentrations were fairly similar between Stellys, Royal Roads and Christopher Point but were slightly higher at Langford.

Figure 3.5 shows monthly 24-hour average NO_2 levels in 2008. At all stations, NO_2 levels appear to be the lowest in the spring or early summer (i.e., April to June). Specifically, the lowest NO_2 concentrations occurred in April at Stellys, Langford and Christopher Point, and in June at Topaz and Royal Roads.

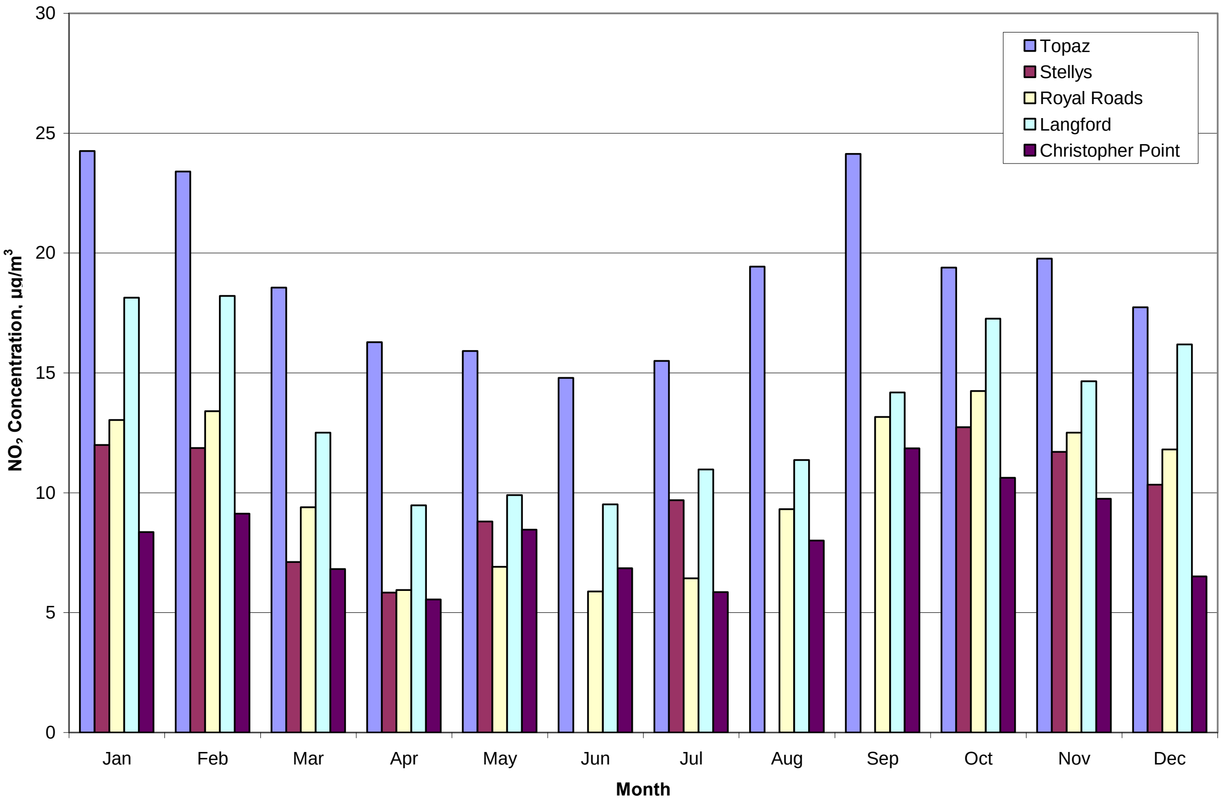
Table 3.4
Hourly Averaged NO_2 Concentrations in the CRD

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											
2.7	8.2	15.5	26.95	56	62	90.7	0	19.1	14.1	0%	5%
Royal Roads University											
1.1	3.3	7.6	14.7	33.5	38.0	55.5	0	10.1	8.8	0%	5%
Stellys											
1.3	4.4	8.2	14.3	30	33.5	59.1	0	10.2	7.7	0%	20%
Christopher Point											
1.5	2.7	5.7	11.1	28.5	31.9	56.4	0.2	8.1	7.1	0%	5%
Langford											
2.7	6.1	10.9	18.4	40.2	46.724	98.3	0	13.5	9.9	0%	6%

Table 3.5
24-Hour Sequential Averaged NO_2 Concentrations in the CRD

Percentile Values						Max µg/m³	Min µg/m³	Mean µg/m³	Std. Dev. µg/m³	Missing Values % of Total 24-h Averages
5	25	50	75	98	99					
Victoria Topaz										
6.7	12.9	18.3	23.6	39.7	41.6	44.5	2.2	19.1	8.3	0.3%
Royal Roads University										
2.4	5.2	9.6	14.0	24.3	25.2	28.6	0.9	10.2	5.9	0.8%
Stellys										
3.9	6.8	9.5	12.8	21.6	23.1	28.0	1.6	10.3	4.8	19%
Christopher Point										
2.5	4.0	6.5	11.2	20.8	24.4	27.5	1.2	8.1	5.3	1%
Langford										
4.4	8.9	12.8	17.0	28.5	28.9	38.6	2.3	13.5	6.2	2%

Figure 3.5
Mean Monthly 24-Hour Average NO_2 Concentrations at Victoria Topaz, Royal Roads, Langford and Stellys



Figures 3.6 and 3.7 show the average diurnal pattern of hourly NO_2 concentrations during the cooler and warmer months of the year at Victoria Topaz, Royal Roads University, Stellys, Langford and Christopher Point. With the exception of Christopher Point, there is a distinct concentration peak in the morning and another later in the evening in the cooler months. In the warmer periods of the year, concentrations also peak in the morning but increase more gradually to a peak in the evening hours. At Christopher Point, the data show little diurnal variation, as would be expected at a remote location.

The early morning peak at around 8:00 am PST at all sites is likely related to the morning traffic rush of commuters travelling to work or school. This peak in morning NO_2 concentrations is most pronounced at the Victoria Topaz site. The late evening peak is present for all sites but Christopher Point as well in both warm and cold months. The late evening peak occurs around 6:00 or 7:00 pm PST in the cold months and around 8:00 pm PST in the warm months.

Figure 3.6
Average Diurnal NO_2 Pattern for all Stations during Cooler Months (November-April)

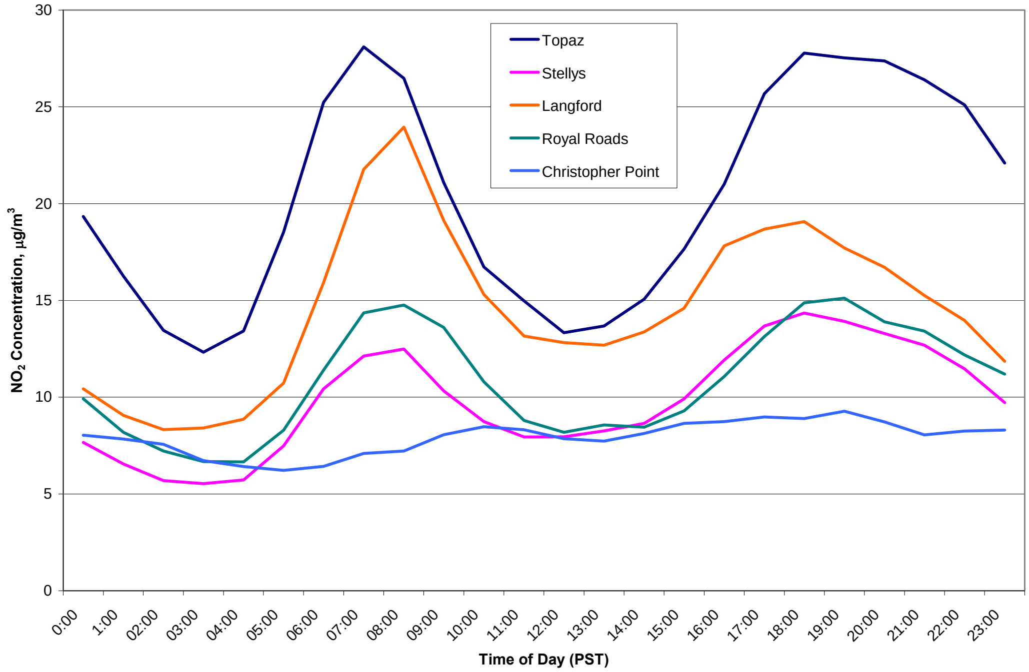
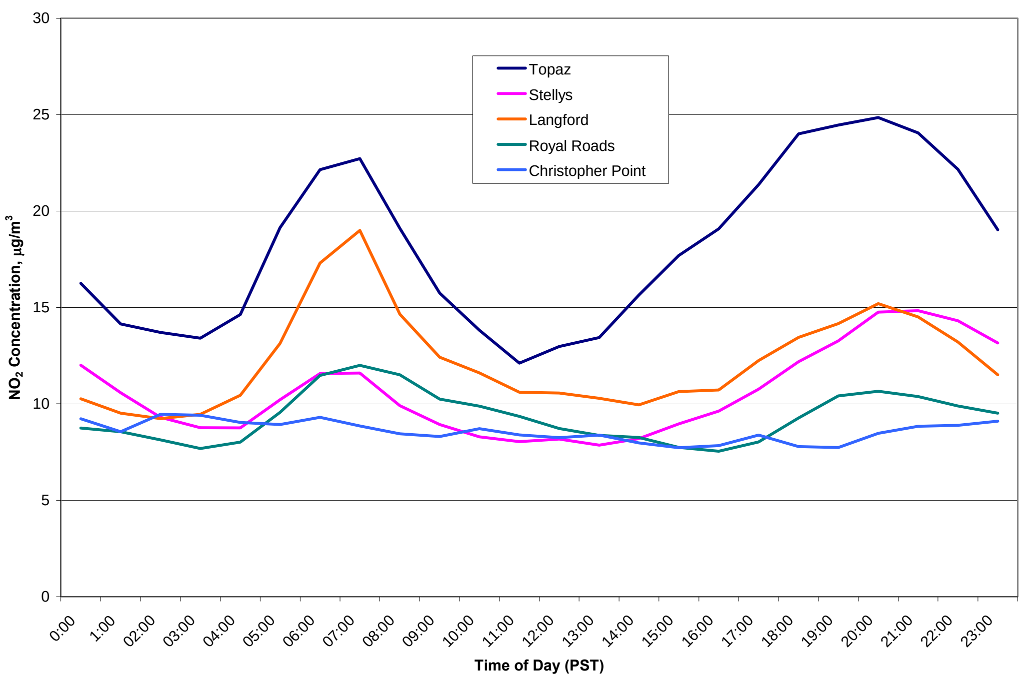


Figure 3.7
Average Diurnal NO_2 Pattern for all Stations during Warmer Months (May-October)



A more gradual increase in NO_2 concentrations in the late evening hours is due to a lowering of the atmospheric mixing height towards the end of the day. NO_2 concentrations are higher during the cooler months than the warmer months at 4 of the sites (Victoria Topaz, Stellys, Langford and Royal Roads) because the decrease in the depth of the mixed layer is, on average, more pronounced in the winter than in the summer, and because residential heating contributes to increased NO_x emissions at night during cooler months.

3.3 SULPHUR DIOXIDE (SO_2)

Sulphur oxides (SO_x) are released during the combustion of sulphur bearing fuels. Sulphur dioxide (SO_2) makes up the great majority of SO_x in the lower atmosphere. Due to a significant lowering of sulphur levels in gasoline and on-road diesel, SO_2 emissions from motor vehicles have declined considerably over the past decade. Sulphur levels in on-road diesel were reduced to 15 parts per million (ppm) in 2006 which further lowered mobile source SO_2 emissions. A similar sulphur reduction initiative for marine fuels may occur in the near future.

Sulphur dioxide is a colourless gas, with an irritating odour at sufficiently high concentrations. Emissions of SO_2 can lead to the formation of sulphuric acid (H_2SO_4) in the atmosphere. Background levels of SO_2 tend to be very low, meaning measurable concentrations are usually connected to anthropogenic activity, and occur in or near urban areas. Ambient levels of SO_2 tend to be relatively low in the CRD, due to the absence of large scale emission sources.

The major sources of emissions are fossil fuel combustion, industrial processes and geothermal activity. SO_2 can produce acid rain when it dissolves in water vapour in the atmosphere. Particulate matter ($PM_{2.5}$) concentrations in the atmosphere can also increase when sulphates combine with other compounds in the atmosphere.

Table 3.6 lists the average hourly SO_2 concentration at Christopher Point, Langford and Victoria Topaz; the three locations in the CRD network with hourly data available in 2008. Table 3.7 lists the 24-hr sequential average SO_2 concentrations at these three locations[7]. 2008 SO_2 data for Saturna Island was not available for the annual report.

Table 3.6 indicates that the Victoria Topaz station had the greatest maximum hourly concentration and the highest hourly mean concentration of SO_2, while Langford had the lowest. Table 3.7 indicates that all 24-hour average levels at all locations during 2008 were well below the CRD guideline value of 125 $\mu g/m^3$.

[7] SO_2 monitoring data at Saturna Island is only available for 24-hour averages. Although the data record dates back to 1998, the data has not been included in previous CRD annual air quality reports.

Table 3.6
Hourly Averaged SO_2 Concentrations in the CRD

Percentile Values						Max	Min	Mean	Std. Dev.	Missing Values
5	25	50	75	98	99	µg/m³	µg/m³	µg/m³	µg/m³	% of Total Hours
Victoria Topaz										
1	2	2	4	15	23.4	146	0	3.6	5.9	5%
Christopher Point										
1	1	2	3	10	13	28	0	2.7	2.5	5%
Langford										
1	1	2	2	6	7	16	0	2.0	1.3	5%

Table 3.7
24-Hour Sequentially Averaged SO_2 Concentrations

Percentile Values						Max	Min	Mean	Std. Dev.	Percent of 24-h Averages	Missing Values
5	25	50	75	98	99	µg/m³	µg/m³	µg/m³	µg/m³	> CRD Guideline (125 µg/m³)	% of Total 24-h Averages
Victoria Topaz											
1.3	2.1	2.8	4.3	11.8	16.6	24.3	0.7	3.6	2.8	0%	1.1%
Christopher Point											
1.0	1.4	2.1	3.4	7.1	8.1	11.7	0.5	2.7	1.7	0%	1.4%
Langford											
1.0	1.3	1.9	2.4	4.1	4.4	5.0	0.1	2.0	0.8	0%	1%

Figure 3.8 shows monthly averaged SO_2 concentrations at the Victoria Topaz, Langford and Christopher Point stations. The Topaz station usually had higher SO_2 concentrations than either the Langford or Christopher Point stations. As well, Topaz and Christopher Point experienced the highest SO_2 concentrations in late summer (August and September, respectively). However, given the very low concentrations of SO_2, this variability in month-to-month concentrations may not be particularly significant.

Figure 3.8: Mean Monthly 24-hour Average SO_2 Concentrations at Victoria Topaz, Langford and Christopher Point

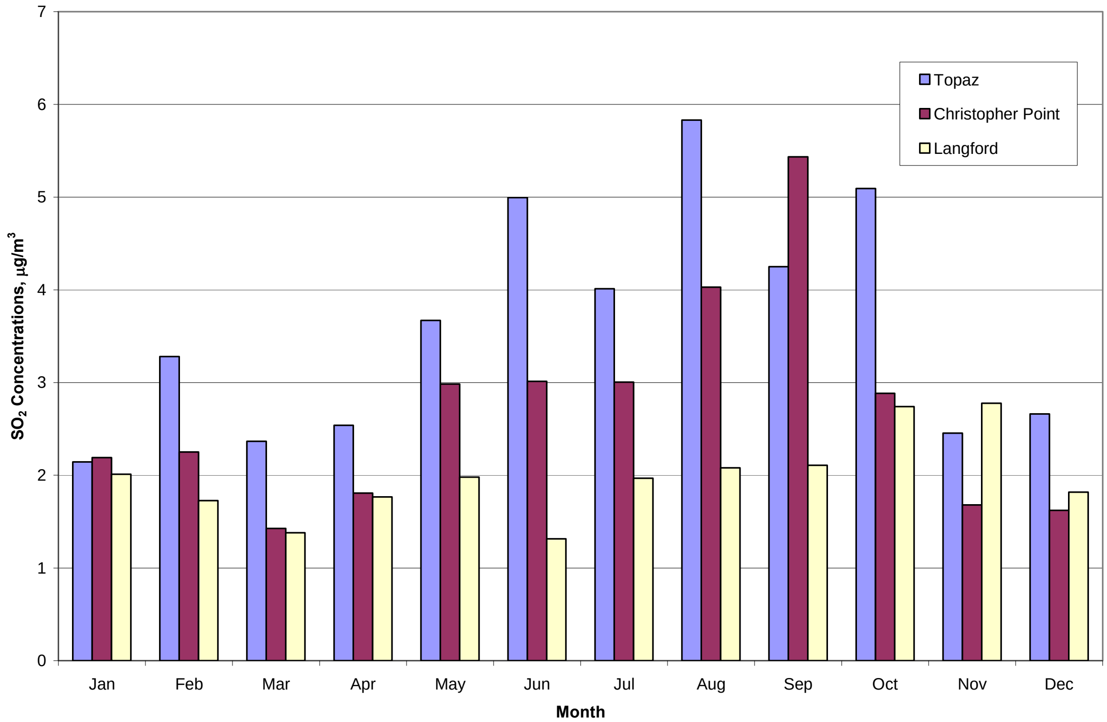
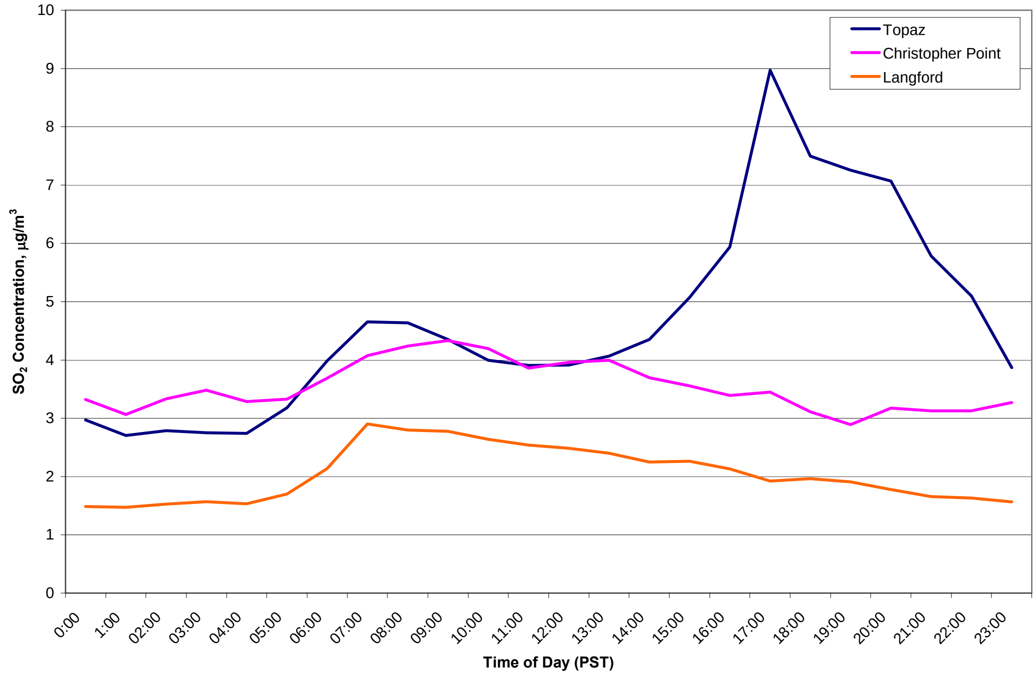


Figure 3.9 shows the average diurnal SO_2 concentrations for Victoria Topaz, Langford and Christopher Point during the cooler months (November to April), while Figure 3.10 shows the pattern for the warmer months (May to October) of the year. During the cooler months of the year, the Topaz site has a pronounced peak in SO_2 levels in the morning (8:00 am PST), and a less pronounced peak in the evening (8:00 pm PST). As discussed in Appendix D, these peaks appear to be related to SO_2 emissions from cruise ships. Langford station also has pronounced SO_2 peak in the morning (8:00 am PST), but no peak in the evening. The morning peak at Langford may be traffic related, although all diesel vehicles are currently mandated to use low sulphur fuel. It is possible that cruise ship emissions may also affect the observations at Langford, although this has not been determined.

In the warmer months of the year, the pattern is reversed at the Topaz site, with a more prominent peak in SO_2 levels in the evening (approximately 5:00 pm PST), and a lower peak in the morning (8:00 am PST). The analysis of cruise ship operations presented in Appendix D clearly shows that the summertime evening peak in SO_2 concentrations is related to cruise ship emissions. Langford station continues to show a slight peak in the morning (8:00 am PST). In comparison, the SO_2 levels at Christopher Point are more evenly distributed throughout the day in all seasons, with slightly higher levels during the midday hours in both the cold and warm months.

Figure 3.9
Average Diurnal SO_2 Pattern for Victoria Topaz, Langford and Christopher Point for the Cooler Months (November to April)

Figure 3.10
Average Diurnal SO_2 Pattern for Victoria Topaz, Langford and Christopher Point for the Warmer Months (May to October)



3.4 GROUND LEVEL OZONE (O_3)

Ozone is a photochemical oxidant that is formed in the atmosphere from chemical reactions involving NO_x, ultraviolet radiation (sunlight), oxygen and hydrocarbons (HC). Ozone is a natural component of the atmosphere, with peak concentrations experienced in the lower stratosphere. In the lower troposphere, ground level zone (O_3) is a secondary pollutant and can be formed at considerable distances from the origin(s) of the primary pollutants. Relatively high ground level concentrations can be caused by anthropogenic emissions of NO_x and HC, or by natural processes, such as stratospheric intrusion. Stratospheric intrusion involves atmospheric motions that bring ozone-rich air from very high altitudes to the surface.

Variations in weather patterns from year to year can have a large effect on community concentrations of ground level ozone. Currently, it is believed that springtime weather conditions favour the potential for stratospheric intrusion. Higher temperatures and solar insolation in the summer favour production of ozone from NO_x and HC released in urban areas. The formation of ozone depends on a rather complex set of reactions that are sensitive to relative concentrations of pollutant precursors. For example, ozone can be removed ('scavenged') by destructive reactions with NO_x. It is common in many urban areas to observe a decrease in ground-level ozone concentrations during periods of peak NO_x emissions.

The Federal air quality objectives for ground-level ozone are considered to be outdated, and the 24-hour average objective level is commonly exceeded in many urban and rural locations throughout Canada. The CWS for ozone is based on more up-to-date scientific, health and environmental information. Comparison of CRD ground-level ozone concentrations to the CRD guideline and the CWS is shown in the tables and discussion that follows. Comparison of CRD concentrations to provincial and federal objectives is provided in Appendix B.

In 2008, ozone was monitored at Victoria Topaz, Royal Roads University, Stellys, Christopher Point, Langford and Saturna Island. Hourly average ozone concentrations are summarized in Table 3.8. There is no CRD guideline value for hourly averaged ozone concentrations. The comparison of hourly maximum concentrations in 2008 to federal/provincial objectives is discussed in Appendix B.

Table 3.9 shows the 8-hour rolling average concentrations at Christopher Point, Stellys, Topaz, Langford, Royal Roads and Saturna Island. Ozone levels were below the CRD guideline value of 120 $\mu g/m^3$ (8-hour average) for all stations except for one incident on May 17th at Saturna Island. It should be noted that there was also one exceedence of the CRD guideline at Saturna Island in each of the two previous years. The ozone episode on May 17th, depicted in Figure 3.11, occurred at all of the CRD monitoring sites except at Christopher Point, but achieved its highest level at Saturna Island.

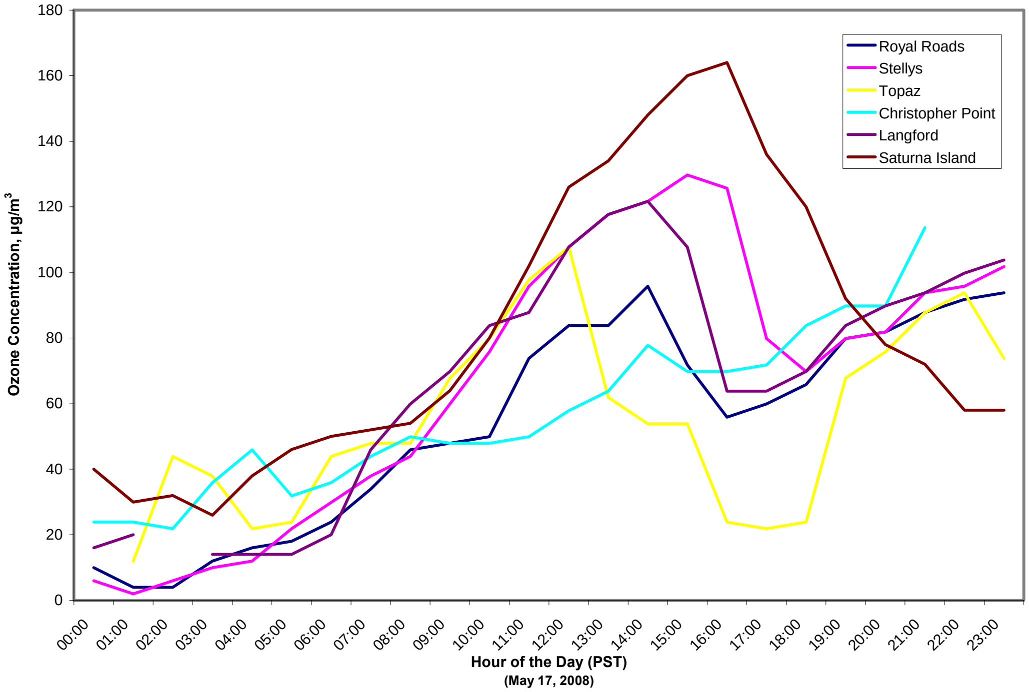
Table 3.8
Hourly Averaged Ozone Concentrations in the CRD

Percentile Values						Max	Min	Mean	Std. Dev.	Missing Values
5	25	50	75	98	99	µg/m³	µg/m³	µg/m³	µg/m³	% of Total Hours
Victoria Topaz										
0	16	37.9	57.9	87.8	93.8	113.7	0	38.1	25.3	5%
Royal Roads University										
4	23.9	43.9	65.8	93.8	98.0	199.5	0	44.9	26.1	7%
Stellys										
4	20	41.9	61.9	95.8	97.8	129.7	0	42.0	25.3	14%
Christopher Point										
18	37.9	53.9	71.8	101.8	103.8	119.7	0	55.3	23.2	5%
Langford										
0	16	37.9	59.9	93.8	97.8	121.7	0	39.6	26.9	5%
Saturna Island										
24	42	54	68	96	102	164	2	54.9	19.9	3%

Table 3.9
8-Hour Rolling Average Ozone Concentrations in the CRD

Percentile Values						Max	Min	Mean	Std. Dev.	% of 8-h Averages	Missing Values
5	25	50	75	98	99	mg/m³	mg/m³	mg/m³	mg/m³	> CRD Guideline (120 mg/m³)	% of Total 8-h Averages
Victoria Topaz											
3.4	20.2	36.7	54.9	85.1	90.4	104.8	0	38.0	22.6	0%	1.3%
Royal Roads University											
8.5	26.4	43.9	62.4	92.3	96.9	108.0	0	44.8	26.1	0%	3%
Stellys											
7.7	23.2	41.0	58.9	91.4	96.6	106.7	0	42.1	22.9	0%	10%
Christopher Point											
20.0	39.2	54.2	71.1	99.3	102.8	116.7	2.25	55.3	22.0	0%	1%
Langford											
5	19.7	37.4	57.0	91.1	95.8	107.2	0	39.7	24.0	0%	1.1%
Saturna Island											
26	42	54.3	67.8	93.8	99	136.3	2.75	54.8	18.4	0.07%	2%

Figure 3.11
Ozone Episode in the CRD May 17, 2008



The ozone concentration exceedence recorded at Saturna Island occurred on May 17th. The maximum hourly concentration recorded was 164 µg/m^3, for a maximum 8-hour average of 136.8 µg/m^3. Although the monitoring data showed simultaneous increases in ozone concentrations at other monitoring sites in the CRD at the start of the episode as indicated in Figure 3.11, elevated levels peaked higher and later than at the other stations, and persisted longer into the evening hours at Saturna Island while concentrations at the other CRD monitoring sites declined during the late afternoon hours. This ozone episode was similar to one that was reported for May 30, 2007 in the CRD annual air quality report for 2007.

This episodes in both 2007 and 2008 were instances of photochemical ozone production, rather than the product of stratospheric ozone being brought to the surface, as has been reported for elevated springtime ozone episodes in previously published studies for Saturna Island (Vingarzan and Thomson 2004)[8]. Similar increases in ozone levels were also recorded on this date in the Lower Fraser Valley, indicating that this ozone episode was regional in scale, not confined to the CRD alone.

[8] Vingarzan, R. and B. Thomson 2004. Temporal Variation in Daily Concentrations of Ozone and Acid-Related Substances at Saturna Island, British Columbia. Journal of the Air & Waste Management Association, 54:459-472.

According to Steyn[9], the strong diurnal signal in ozone all over the Lower Fraser Valley is dominated by ozone production in the morning, and then NO titration in the afternoon and through the night. This is enhanced by strong low level stability (in episode conditions) over land which isolates O_3 and NO in the lowest tens of metres, reducing ozone to low levels. In the absence of local NO emissions (as is the case on Saturna Island), and surface based inversions, O_3 will remain high through most of the night. This is observed at elevated sites in the Lower Fraser Valley, as well as on Saturna Island (elevation of the monitoring site is 178 m ASL).

Due to the limited temporal, and uncertain spatial extent of available monitoring data, community exposure to ground-level ozone concentrations above the CRD guideline value and any related health effects cannot be determined within a suitable degree of confidence.

CWS compliance requires that the annual 4th highest, daily maximum 8-hour average concentration averaged over three consecutive years does not exceed 65 parts per billion (which is equivalent to 127.6 $\mu g/m^3$). CWS guidelines state that achievement of the CWS standard should be based on data from monitoring stations that are representative of "neighbourhood" or "urban scale" exposure levels where people live, work or play. The lowest ozone concentrations in a metropolitan area may occur near the urban centre where scavenging by traffic-derived NO_x emissions can reduce ozone levels, while maximum ozone concentrations may occur downwind of the urban fringe.

Table 3.10 lists the maximum and annual 4th highest 8-hour average ozone concentrations recorded at each of the ozone monitoring locations in the CRD for the period 1998-2008. The year-to-year variations in the maximum 8-hour average ozone concentrations for the period 1998-2008 are depicted in Figure 3.12. The data indicate that maximum ozone levels at Saturna Island have consistently been above the CRD guideline value of 120 $\mu g/m^3$ over the period 2005-2008, while the levels at Royal Roads have exceeded the guideline value once during this period. The period of record at Stellys is short, but indicates that levels can approach the CRD guideline level. By comparison, the ozone levels at Victoria Topaz have never exceeded the CRD guideline at any time during this period. Data for Christopher Point and Langford were excluded from Figure 3.12 as there were only two years of available data, and monitoring at the Christopher Point site will not be continued in the future.

[9] Dr. D. Steyn, Professor, Atmospheric Science, Department of Earth and Ocean Sciences, University of British Columbia, personal communication 7 November 2008.

Figure 3.12
Maximum 8-Hour Average Ozone Levels in the CRD (1998-2008)

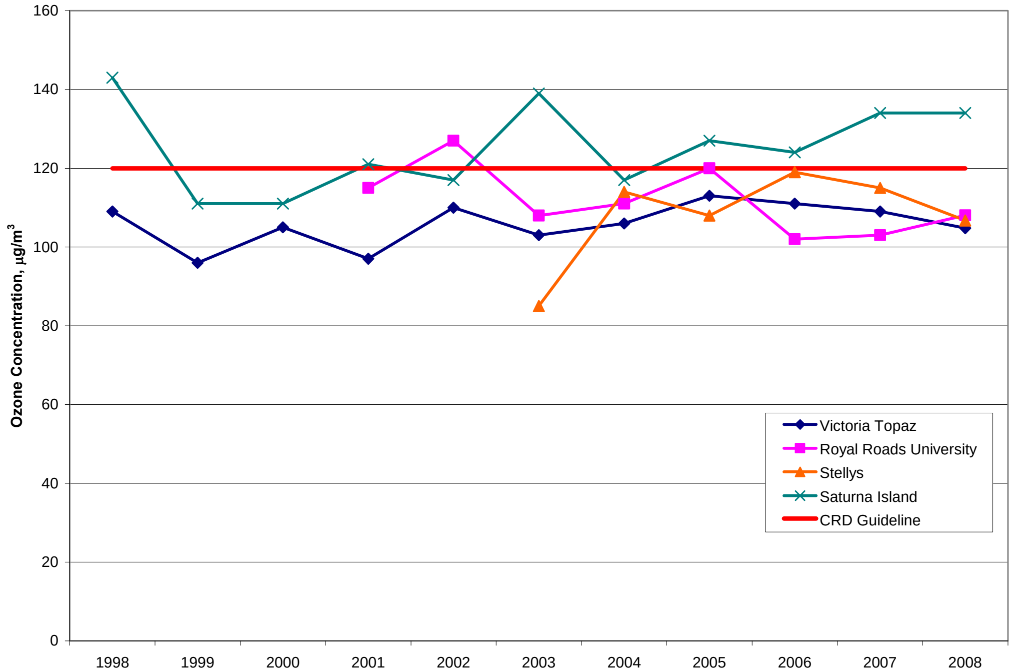


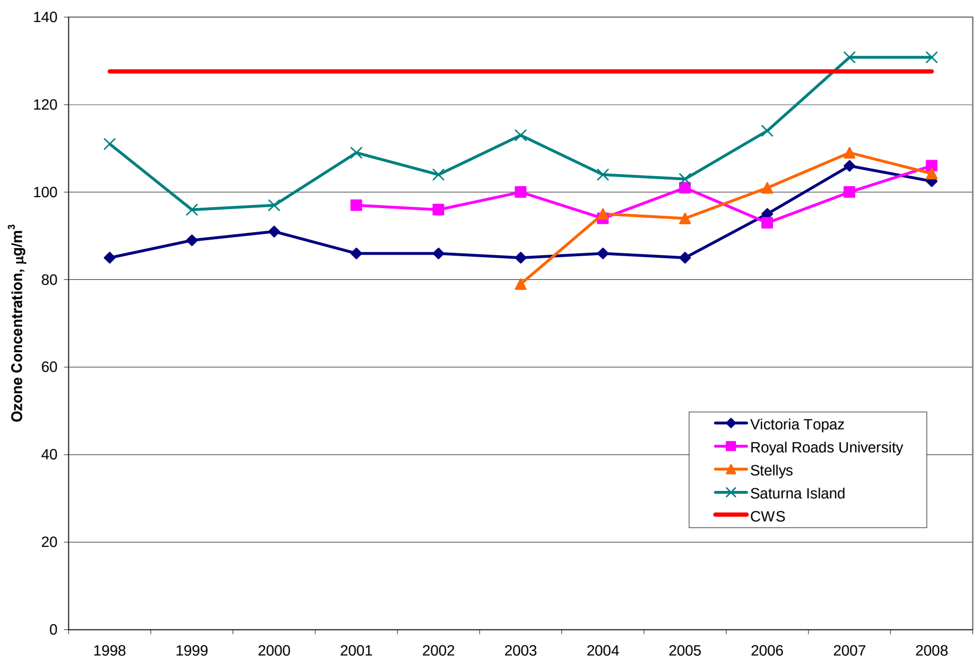
Table 3.10
Summary of 8-Hour Ozone Levels (µg/m^3) in the CRD (1998-2008)

	Victoria Topaz		Royal Roads University		Stellys		Christopher Point		Langford		Saturna Island	
	Max.	4th Highest	Max.	4th Highest	Max.	4th Highest	Max.	4th Highest	Max.	4th Highest	Max.	4th Highest
1998	109	85									143	111
1999	96	89									111	96
2000	105	91									111	97
2001	97	86	115	97							121	109
2002	110	86	127	96							117	104
2003	103	85	108	100	85[b]	79[b]					139	113
2004	106	86	111	94	114	95					117	104
2005	113	85	120	101	108	94					127	103
2006	111	95	102[a]	93[a]	119	101					124	114
2007	109	106	103	100	115	109					134	131
2008	105	103	108	106	107	104	117	115	107	105	136	129
CRD Guideline	120		120		120		120		120		120	
CWS		127.6		127.6		127.6		127.6		127.6		127.6

Notes:
a Missing data from March 2 to July 13, 2006
b Monitoring from September 16 to December 31, 2003
Max. – Maximum 8-hour average concentration for the year
4th High – 4th highest 8-hour average concentration for the year

Figure 3.13 shows the trend in the 4th highest ozone concentrations over the period 1998-2008. Data for Christopher Point and Langford were excluded from Figure 3.13 as there is only one year of existing data. The available data indicate that there is relatively little year-to-year variation in the 4th highest concentrations, especially at Victoria Topaz. Saturna Island has had the highest fluctuations, while the period of record at Stellys is still too short to make definitive conclusions. Nevertheless, the annual 4th highest ozone concentrations at all four monitoring stations are currently well below the CWS value of 127.5 μg/m^3.

Figure 3.13
4th Highest 8-Hour Average Ozone Levels in the CRD (1998-2008)



At Saturna Island in 2008, the annual 4th highest ozone concentration was 129 μg/m^3. Since the 4th highest ozone value on Saturna Island in 2007 was 131 μg/m^3, Saturna Island may exceed the CWS if the 2009 data were to also have an elevated ozone concentrations.

Previously, the Saturna Island ozone data have been used to demonstrate CWS compliance, as this station has had the highest concentrations experienced at the ozone monitoring stations in the CRD. This station is not representative of the concentrations experienced in metropolitan areas, and therefore use of the station to demonstrate compliance is conservative. Similarly, the location of the station at Christopher Point is not representative of areas where many people in the CRD are likely to be exposed. Although Langford station is located in an appropriate area, there are an insufficient number of consecutive years of data available to demonstrate CWS compliance. Instead, attainment of the CWS was based on the data collected at the Topaz, Stellys and Royal Roads sites.

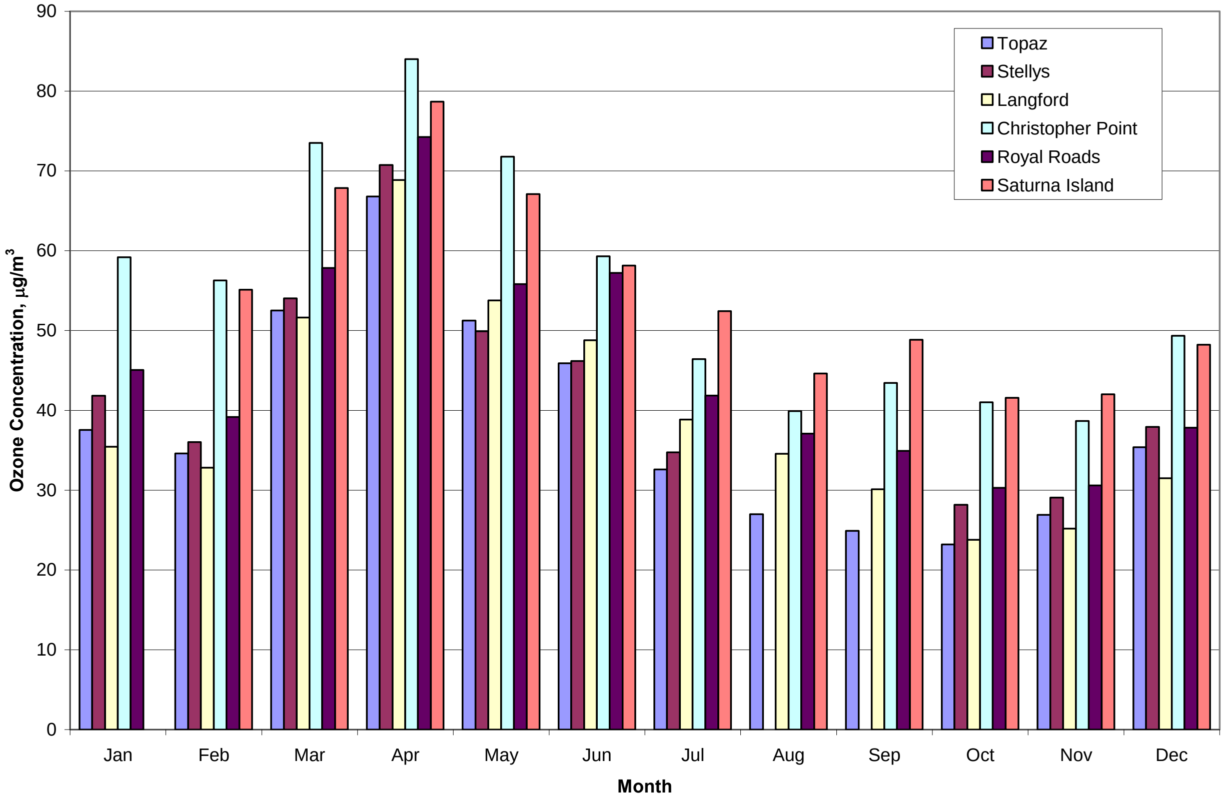
Over the three year period of 2006-2008 at Stellys, Royal Roads and Topaz, the 4th highest daily 8-hour rolling average maximum concentration did not exceed 65 parts per billion (127.5 μg/m^3) (Table 3.11). The averages over the three years for the three stations were 104.8 μg/m^3, 99.7 μg/m^3 and 101.2 μg/m^3, respectively, indicating that the CRD satisfies the CWS for ground-level ozone.

Table 3.11
4th Highest Daily Maximum 8-hour Average Ozone Concentrations at Topaz, Stellys and Royal Roads, 2006-2008

Year	**Concentration** at Stellys (μg/m^3)	**Concentration** at Royal Roads (μg/m^3)	**Concentration** at Topaz (μg/m^3)	**Concentration** at Saturna Island (μg/m^3)
2006	101	93	95	114
2007	109	100	106	130.8
2008	104	106	103	129
3-year average	104.8	99.7	101.2	124.6

Figure 3.14 shows mean monthly 8-hour average ozone concentrations for Christopher Point, Royal Roads, Topaz, Langford, and Stellys. Ozone concentrations are generally highest during the spring months of March, April and May. This is consistent with patterns observed in previous years, and the higher concentrations in March and April are generally considered to be due to stratospheric ozone being brought to the surface rather than to photochemical ozone production in the troposphere. Ozone concentrations are generally lower from September to November.

Figure 3.14
Mean Monthly 8-Hour Averaged Ozone Concentrations at Christopher Point, Royal Roads, Topaz, Langford, Stellys and Saturna Island



Figures 3.15 and 3.16 show average daily ozone concentrations during the warmer and cooler months of the year for Topaz, Royal Roads, Stellys, Langford, and Christopher Point. For each station, in both the warmer and the cooler months, there is a trough in concentration levels around 5:00 or 6:00 am PST (warmer months) and 6:00 or 7:00 am PST (cooler months) and a peak in concentration levels at around 2:00 pm PST and at Topaz around 1:00 pm PST (warmer months). In the cooler months, the afternoon peak occurs at the same time as in the warmer months for Topaz, Langford and Stellys, but around 4:00 pm PST for Christopher Point and Royal Roads.

During the warmer spring and summer months (Figure 3.16), the afternoon peak in ozone levels is likely caused by increased solar insolation and warmer temperatures needed to drive the chemical transformation of NO_x and VOC to form ozone. The trough present in the morning relates to increased NO_x emissions from traffic during the morning rush hour. The higher NO_x levels chemically react with ozone, resulting in lower ozone levels. The morning trough in ozone levels in the cooler months is likely due to the same mechanism. The remainder of the diurnal variation during the cooler months results from similar ozone/NO_x interaction, with lower NO_x levels during the daytime hours (see Figures 3.6 and 3.7), and higher NO_x levels in the early morning and evening hours. Comparatively, the diurnal variation at Christopher Point, a rural station, is less pronounced during the cooler months. This suggests that ozone production in this area is more influenced by warmer temperatures and higher solar insolation and is less influenced by diurnal variations in NO_x levels.

Figure 3.15
Average Diurnal Ozone Pattern During Cooler Months (November - April)

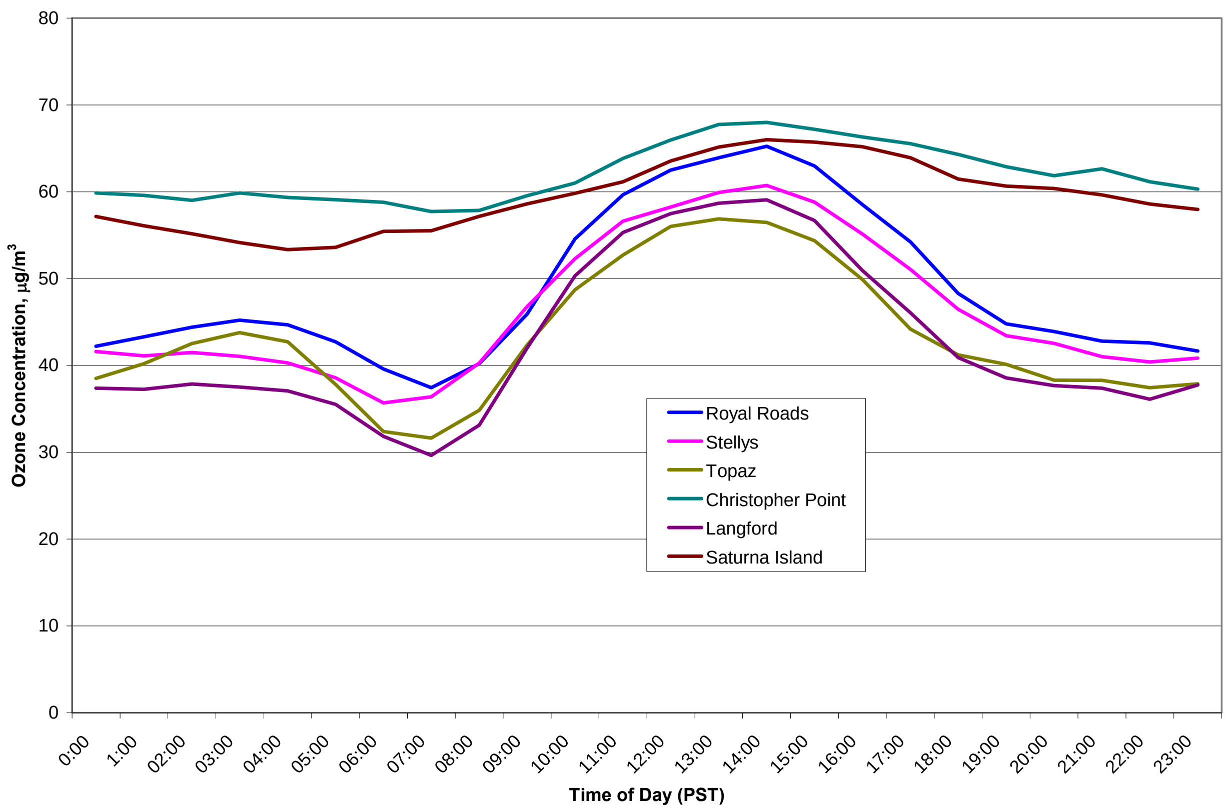
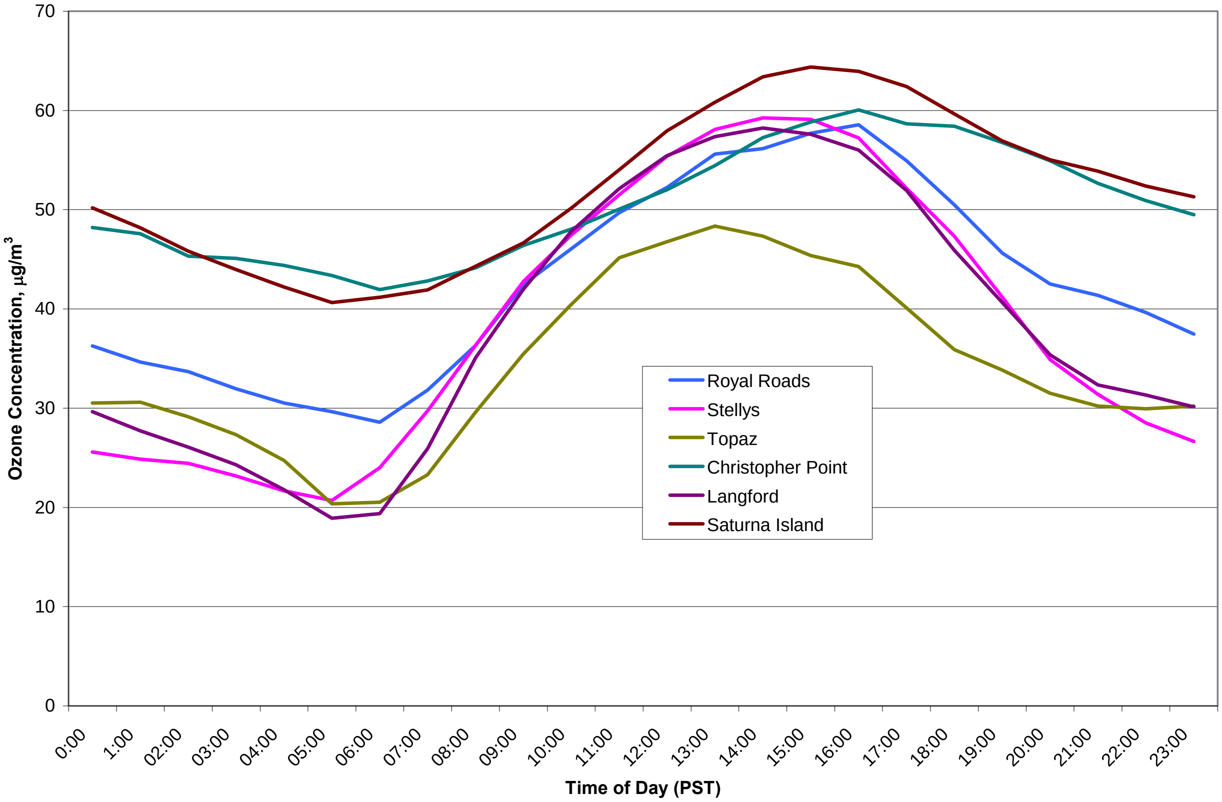


Figure 3.16
Average Diurnal Ozone Pattern During Warmer Months (May - October)



4.0 PARTICULATE MATTER

Suspended particulate matter (PM) can originate from natural sources such as dust disturbed by the action of wind, and from anthropogenic sources, such as the combustion of fuels. Fuel combustion tends to produce smaller PM, whereas dust tends to be of a larger size fraction. PM can remain suspended in air for as little as a few seconds to as long as several days or even weeks and longer. Precipitation tends to effectively remove PM from the air. Ambient PM is measured in the CRD as both 'inhalable' particulate matter, which is the fraction of suspended 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.

There is 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. For this reason, $PM_{2.5}$ is one of two common air contaminants (along with ground level ozone) with CWS criteria. Exposure to $PM_{2.5}$ can aggravate pulmonary and cardiovascular disease, increase the occurrence of asthmatic attacks and increase the risk of premature mortality. An additional adverse effect that can be related to ambient PM concentrations is the reduction of visibility.

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. Since there are few significant industrial emission sources in the CRD, much of the PM is released by motor vehicle and marine vessel exhaust, roadway emissions (dust) due to traffic activity, residential home heating and residential burning. The contribution of residential ('backyard') burning to monitored $PM_{2.5}$ concentrations in the CRD during allowed burn days was assessed in the 2004 air quality assessment[10].

In 2008, four different ambient PM sampling (measuring) devices were 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. Partisol and Dichot samplers are used to collect PM_{10} and $PM_{2.5}$ sequentially on the same schedule as the Hi-Vols, but utilize a low-volume of airflow for sample collection.

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[10] SENES Consultants Ltd, 2005. *Air Quality in the Capital Regional District 2004.* Prepared for the Capital Regional District.

The sequential Dichot sampler, is part of the National Air Pollution Surveillance (NAPS) network managed by Environment Canada, station.

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 laboratory to determine the 24-hour concentration.

It should be noted that each type of PM 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.

4.1 INHALABLE PARTICULATE MATTER (PM_{10})

Table 4.1 provides a statistical summary of 24-hour average PM_{10} concentrations at five monitoring stations that are equipped with Hi-Vol samplers: Langford, Oak Bay, Braefoot and Keating elementary schools and Royal Roads University.

Table 4.2 shows the measured 24-hr PM_{10} concentrations recorded at Stellys[11] using a Partisol sampler. The data at Stellys were collected on the same 6-day cycle as the Hi-Vol samplers.

Table 4.1
Sequentially Averaged 24-Hour Hi-Vol PM_{10} Concentrations in the CRD

Statistic	Langford	Oak Bay	Braefoot	Royal Roads	Keating
Mean (µg/m^3)	10.9	10.6	10.6	9.6	13.1
Std. Dev. (µg/m^3)	4.5	5.1	11.0	5.4	7.8
Maximum (µg/m^3)	21	33	70	30	59
98th percentile (µg/m^3)	20	47.6	47.6	47.6	47.6
# > CRD Guideline (50 µg/m^3)	0	0	1	0	1
# of Samples	61	54	56	55	55
Percent Missing (%)	0%	11%	8%	10%	10%

[11] It should be noted that the Partisol sampler at Stellys was changed from recording PM_{10} to $PM_{2.5}$ on January 6, 2009. Therefore, the 2008 sampling period is the last period during which PM_{10} data will be available for Stellys.

Table 4.2
Sequentially Averaged 24-Hour PM_{10} Concentration for Stellys

Statistic	Stellys
Mean (µg/m^3)	8.5
Std. Dev. (µg/m^3)	4.2
Maximum (µg/m^3)	25
98th percentile (µg/m^3)	18.8
# > CRD Guideline (50µg/m^3)	0
# of Samples	57
Percent Missing (%)	7%

PM_{10} data for the Dichotomous sampler at Victoria Topaz are summarised in Table 4.3. The average PM_{10} concentrations were higher at this location than at the other PM_{10} monitoring sites, with the exception of the Keating monitoring site. However, the average PM_{10} concentration at Topaz was 24% lower in 2008 than in 2007.

Table 4.3
2008 Dichot Sequential 24-Hour Mean PM_{10} (Victoria Topaz)

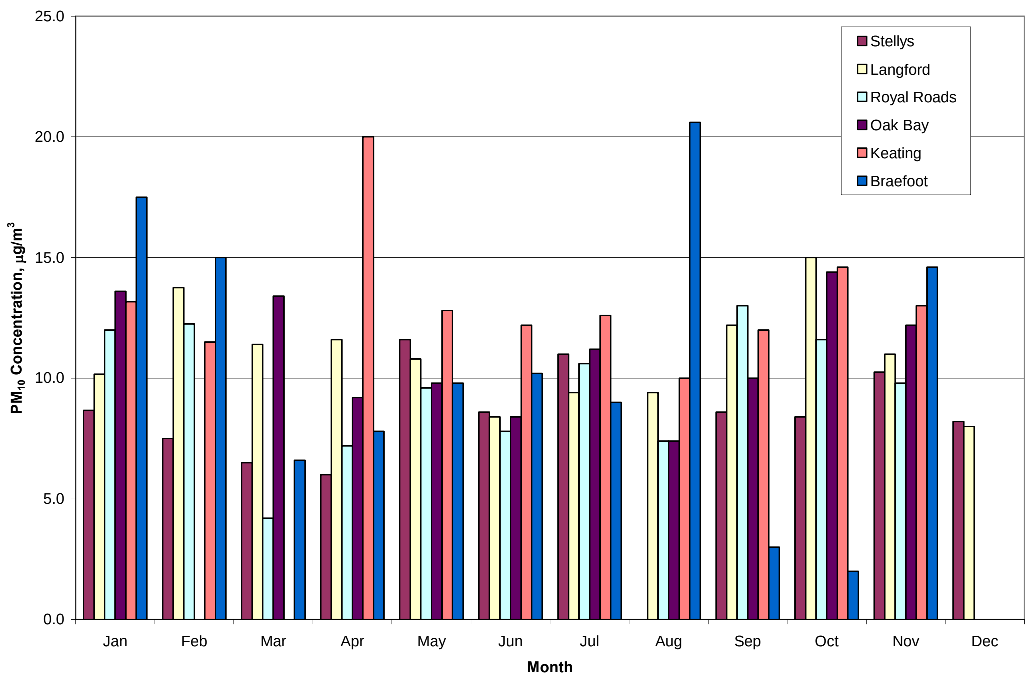
Statistic	PM_{10}
Mean (µg/m^3)	12.7
Std. Dev. (µg/m^3)	5.7
Maximum (µg/m^3)	34.9
98th percentile (µg/m^3)	27.1
# > CRD Guideline (50 µg/m^3)	0
# of Samples	58
Percent Missing (%)	5.1

During 2008, the CRD 24-hour average guideline value of 50 µg/m^3 was exceeded once at Keating Elementary School and once at Braefoot Elementary School. On April 6th, Keating recorded a 24-hour average PM_{10} concentration of 59 µg/m^3. On this date, PM_{10} levels recorded at the other monitoring locations were much lower: 3 µg/m^3 at Stellys, 3 µg/m^3 at Royal Roads, 10 µg/m^3 at Oak Bay, 4 µg/m^3 at Braefoot, and 20 µg/m^3 at Langford. On August 16th, Braefoot recorded a 24-hour average PM_{10} concentration of 70 µg/m^3. On this date, PM_{10} levels recorded at the other monitoring locations were also much lower: 11 µg/m^3 at Royal Roads, 12 µg/m^3 at Oak Bay, 17 µg/m^3 at Keating, and 18 µg/m^3 at Langford. Therefore, the elevated PM_{10} levels at both Keating and Braefoot elementary schools were not experienced in other parts of the CRD on April 6th or on August 16th, respectively.

The reason for the elevated levels at these two stations are therefore unknown, but is thought to have likely been caused by a fugitive dust source rather than due to open burning of waste nearby. April 6th was a Sunday, while April 16th was a Wednesday. Therefore, neither date corresponds to a day when burning barrels or open burning is permitted in Saanich outside of the Urban Containment Boundary[12] (i.e., Friday or Saturday; see Table 6.1, Section 6.1) or in Central Saanich (i.e., Thursday, Friday or Saturday). The elevated PM_{10} concentration at the Braefoot Elementary School station in 2008 mirrors a similar occurrence on April 12th, 2007 that was reported in the 2007 annual air quality report. That date was a Thursday, and also does not correspond to days when open burning is allowed in Saanich.

Figure 4.1 shows the monthly averaged 24-hour PM_{10} concentrations in the CRD at each of the seven monitoring sites. There was no particular pattern to the PM_{10} concentrations in 2008. Also, the difference in peak monthly averages between 2008 and 2007 was quite variable (i.e., some months were higher and some were lower). Therefore, no overall conclusions can be drawn from this distribution of monthly average PM_{10} levels.

Figure 4.1
Mean Monthly 24-Hour Average PM_{10} Concentrations in the CRD



[12] Although the Braefoot Elementary School monitoring site is located within the Urban Containment Boundary, it is close to an area outside the boundary and measured PM_{10} levels at this site could be influenced by open burning outside the boundary. Similarly, the Keating monitoring site is located within 300 metres of an agricultural area where open burning is allowed.

4.2 PARTICULATE MATTER ($PM_{2.5}$)

Table 4.4 shows the hourly averaged $PM_{2.5}$ concentrations at five TEOM-equipped monitoring stations in the CRD: Victoria Topaz, Royal Roads University, Christopher Point, Stellys and Langford. Stellys station had large amount of missing data (46%) due to ongoing problems over the past several years.[13] Topaz station also had a significant amount of missing data (20%) due to two unrelated oscillation problems with the TEOM unit which entailed extensive efforts to correct throughout the year.

There is no CRD guideline for hourly averaged $PM_{2.5}$ concentrations, nor any provincial or federal objectives or standards. However, the use of ambient air quality objectives for averaging periods shorter than 24 hours has been raised in a comprehensive review of objectives, standards and guidelines in other jurisdictions[14]. For this reason, the hourly averaged $PM_{2.5}$ values should continue to be reported for the CRD.

Table 4.4
Hourly Averaged $PM_{2.5}$ Concentrations at TEOM Sites in the CRD

Percentile Values						Max	Min	Mean	Std. Dev.	Missing Values
5	25	50	75	98	99	µg/m³	µg/m³	µg/m³	µg/m³	% of Total Hours
Victoria Topaz										
0	2	4	7	19	24	72	0	5.3	5.1	20%
Royal Roads University										
0	1	3	5	13	15	25	0	3.7	3.3	6%
Christopher Point										
0	1	3	4	10	11	21	0	3.2	2.6	2%
Stellys										
0	1	4	7	18	21	57	0	4.9	4.7	46%
Langford										
0	1	3	5	15	18	44	0	4.0	3.8	3%

Table 4.5 provides a statistical summary of the 24-hour averaged $PM_{2.5}$ concentrations at five monitoring locations. There were no exceedences of the CRD guideline of 25 µg/m³ at any of the stations.

[13] The sampling trailer was replaced in August 2008, more line conditioning capacity was added, and a new air conditioner was installed with the trailer to moderate temperature fluctuations.
[14] SENES Consultants Limited 2005. Development of Options for a New Provincial $PM_{2.5}$ Air Quality Objective. Prepared for the British Columbia Lung Association, Vancouver, BC.

Table 4.5
24-Hour Sequentially Averaged $PM_{2.5}$ Concentrations in the CRD

Percentile Values						Max μg/m³	Min μg/m³	Mean μg/m³	Std. Dev. μg/m³	Percent of 24-h Averages	Missing Values
5	25	50	75	98	99					> CRD Guideline (25 μg/m³)	% of Total 24-h Averages
Victoria Topaz											
1.7	3.2	4.6	6.6	12.6	14.2	18.4	0.9	5.3	2.9	0%	20%
Royal Roads University											
1.1	2.2	3.3	4.7	10.0	10.7	12.2	0.4	3.7	2.1	0%	6%
Christopher Point											
0.9	1.8	2.8	4.0	8.3	10.1	11.4	0.3	3.2	1.9	0%	1%
Stellys											
1.8	3.4	4.5	6.1	10.8	11.4	13.2	0.9	4.9	2.3	0%	46%
Langford											
1.1	2.2	3.5	5.3	10.3	11.0	12.4	0.3	4.0	2.3	0%	4%

$PM_{2.5}$ data for the Dichotomous sampler at Victoria Topaz are summarised in Table 4.6. The $PM_{2.5}$ concentrations were higher for the Dichotomous sampler than for the Partisol sampler at Topaz, and the CRD guideline value was exceeded on one day based on the Dichotomous sampler data, but not so for the Partisol sampler data.

Table 4.6
Sequential Dichot and Partisol 24-Hour Mean $PM_{2.5}$ Concentrations at Victoria Topaz and Langford

Statistic	Victoria Topaz		Langford
	Dichot	Partisol	Partisol
Mean (μg/m³)	6.4	5.3	4.3
Std. Dev. (μg/m³)	3.9	3.0	2.1
Maximum (μg/m³)	29.2	19.0	13
98th percentile (μg/m³)	14.2	11.8	9.8
# > CRD Guideline (50 μg/m³)	1	0	0
# of Samples	58	61	61
Percent Missing (%)	5.1	0	0

As indicated in Table 4.6, the CRD guideline for $PM_{2.5}$ of 25 $\mu g/m^3$ was exceeded once at the Victoria Topaz site on January 25th with a 24-hour average concentration of 29.4 $\mu g/m^3$, based on the sequential Dichotomous (Dichot) sampler. However, the co-located continuous TEOM sampler recorded a $PM_{2.5}$ concentration on that date of only 14.1 $\mu g/m^3$, less than half of the Dichot sampler, while the Partisol sampler concentrations was only 19 $\mu g/m^3$. TEOM samplers are recognized to have some loss of sample in colder seasons, and it is likely that the Dichot sampler provided a more reliable sample of $PM_{2.5}$ concentration on that date, and that the CRD guideline was indeed exceeded. However, the guideline was not exceeded at any other location in the CRD on that date, or at any location in the CRD during the remainder of 2008.

For the purposes of demonstrating compliance with the $PM_{2.5}$ CWS, the CCME considers an annual $PM_{2.5}$ data set to be complete if at least 75% of the scheduled sampling in each quarter of the year has valid data. Compliance with the CWS for $PM_{2.5}$ (30 $\mu g/m^3$, 24-hour average) is determined by calculating 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[15]. The consecutive three year average 98th percentile concentration must meet the CWS criteria of 30 $\mu g/m^3$. It should be noted that the Stellys station likely does not meet the siting requirement, as it is situated in a rural setting (but within 250 metres of a residential area to the west of the station). Furthermore, as has been previously noted, there was a large amount of missing data at the Stellys monitoring site in 2008. Therefore, Stellys was not included in the determination of CWS achievement. The $PM_{2.5}$ data for Langford also could not be included in the CWS determination because the data record only covers a 2-year period (February 2007 to December 2008).

Table 4.7 lists the 98th percentile $PM_{2.5}$ concentrations for 2006, 2007, and 2008 at the Victoria Topaz and Royal Roads monitoring sites. The average 98th percentile over the 3 consecutive years was 14.0 $\mu g/m^3$ for Victoria Topaz and 11.0 $\mu g/m^3$ for Royal Roads. Therefore, the CRD is currently in compliance with the CWS for respirable particulate matter.

Table 4.7: 98th Percentile $PM_{2.5}$ Concentrations for Royal Roads (2006-2008)

Station	2006 ($\mu g/m^3$)	2007 ($\mu g/m^3$)	2008 ($\mu g/m^3$)
Victoria Topaz	14	15	13 [1]
Royal Roads University	11	12 [2]	10

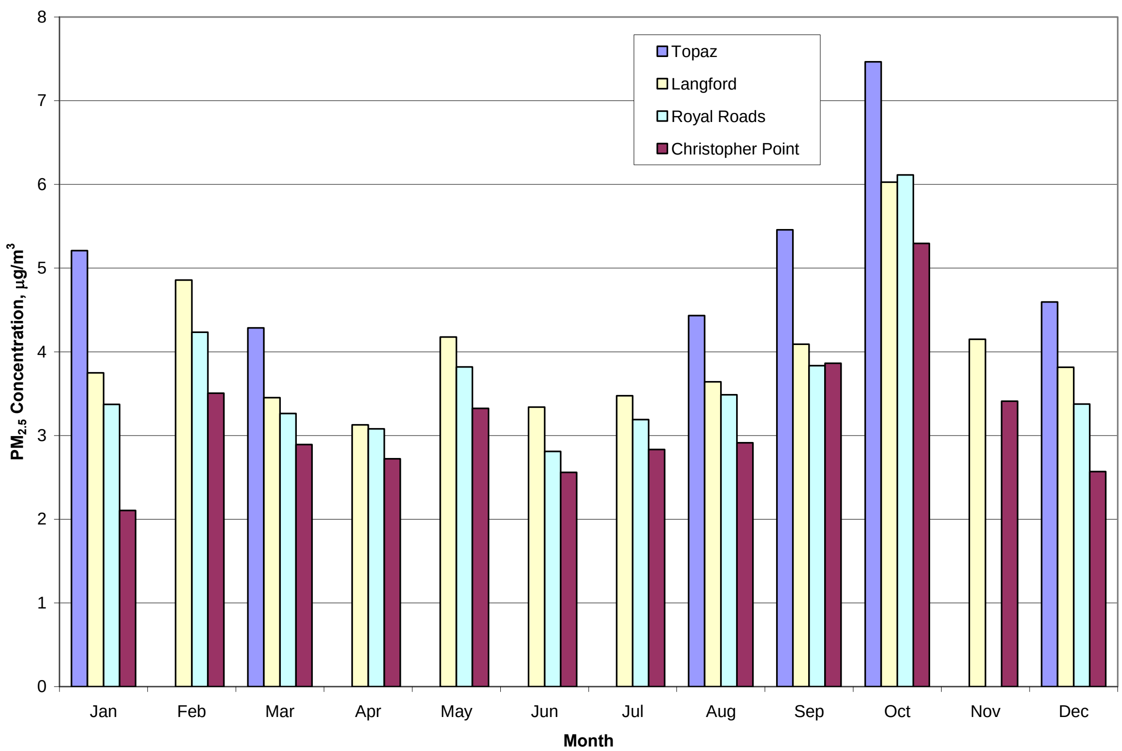
Notes:
[1] The second quarter was missing 59% of the data

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

[2] The third quarter was missing 59% of the data.

Figure 4.2 shows the monthly average $PM_{2.5}$ concentrations from the TEOM samplers at Topaz, Langford, Royal Roads and Christopher Point. The monthly concentrations for Stellys were not included in the figure as data was limited. The $PM_{2.5}$ levels at all four sites show a similar trend, with October having the highest concentrations. Also, Topaz had higher concentrations than Langford, Christopher Point and Royal Roads University for all months that data was available. This is likely due to higher traffic levels near the Topaz station (i.e., increased road dust and vehicle emissions on Blanshard Street). Although less data was available for Topaz, this result is consistent with that reported for 2007.

Figure 4.2
Mean Monthly 24-Hour Average $PM_{2.5}$ Concentrations in the CRD



Figures 4.3 and 4.4 show the monthly average diurnal $PM_{2.5}$ concentrations for the TEOM sites during the cooler (November-April) and warmer (May-October) months of the year. Data for Stellys was not included in the figures as a significant amount of data was missing. The patterns indicate pronounced morning and evening peaks in $PM_{2.5}$ concentrations at all stations during the cooler months, with Christopher Point being less significant. Open burning of waste and woodstove usage, especially in October, are the likely cause for the higher $PM_{2.5}$ concentrations at that time of year.

During the warmer months, morning peaks for all stations continue to be pronounced, whereas only Topaz shows a significant evening peak. The morning peaks are attributable to rush hour traffic as well as the breakup of morning inversion layers in the atmosphere, while the evening peaks are more likely to be associated with the re-establishment of a lower mixed layer in the atmosphere.

Figure 4.3
Average Diurnal $PM_{2.5}$ Pattern in the CRD during the Cooler Months (November – April)

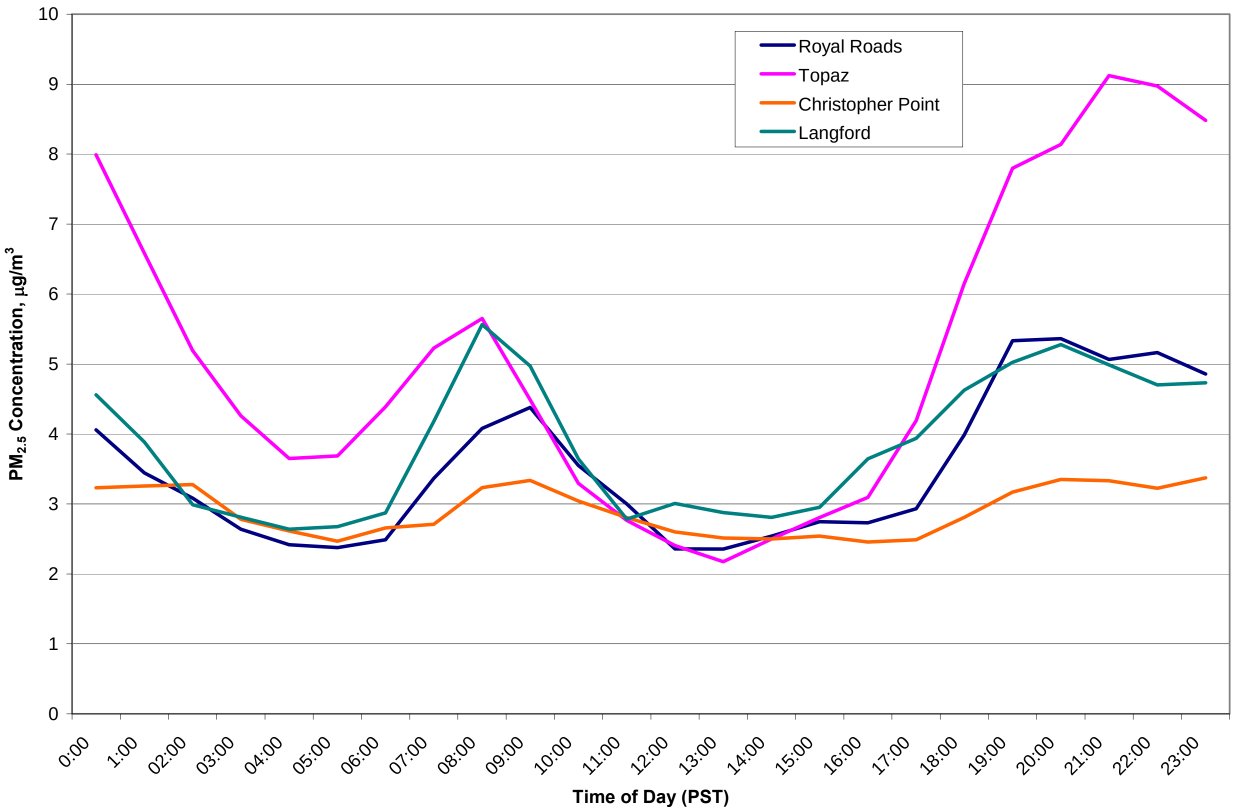
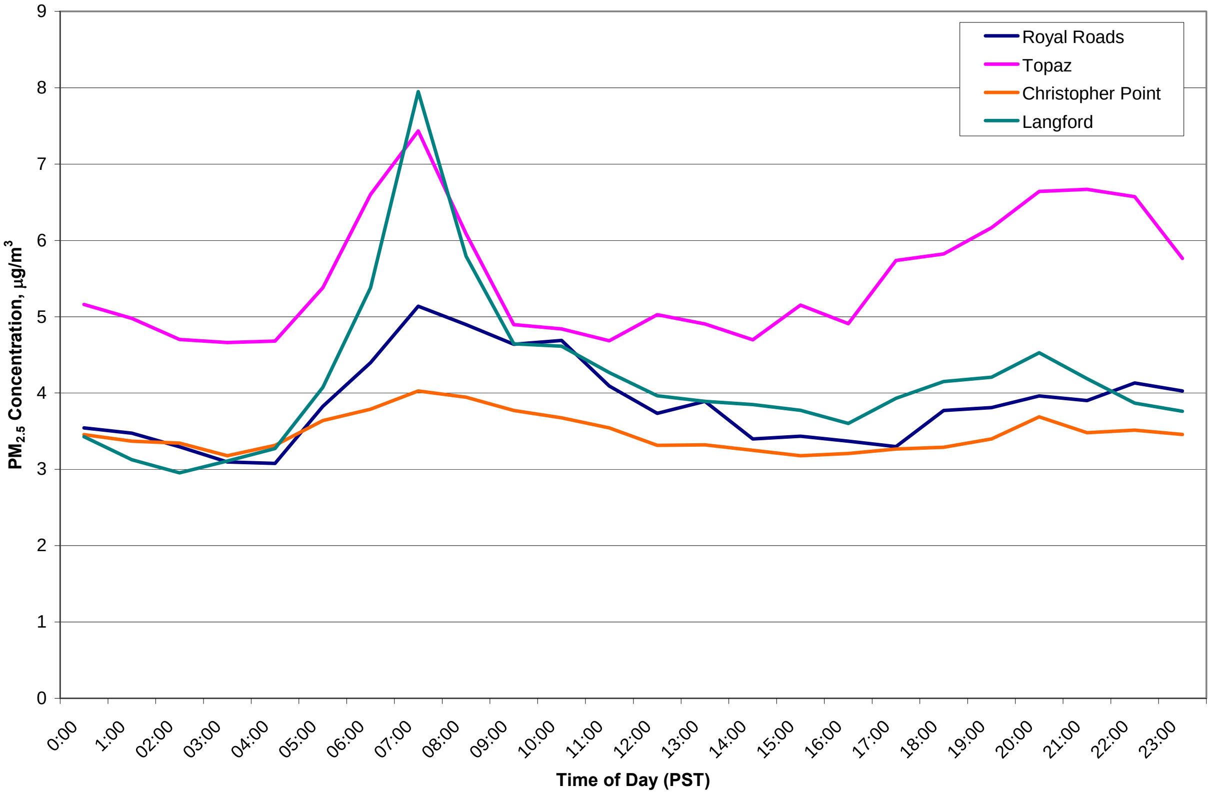


Figure 4.4
Average Diurnal $PM_{2.5}$ Pattern in the CRD during the Warmer Months (May – October)



4.3 COMPARISON BETWEEN CONTINUOUS AND SEQUENTIAL SAMPLING DATA

This section presents comparisons between continuous TEOM sampled data and sequential sampled data (i.e., Partisol and Hi-Vol samplers) at two locations (Victoria Topaz and Langford). This analysis was first performed on 2007 data as a check of data quality.

Figure 4.5 shows that the $PM_{2.5}$ data collected at Victoria Topaz using the continuous TEOM, the sequential Dichot sampler and the sequential Partisol sampler agree well most of the time. The TEOM sampler tended to record lower $PM_{2.5}$ concentrations in the colder months of the year than the other two samplers. The Dichot sampler tended to record slightly higher peak concentrations most of the time when levels exceeded 10 µg/m^3. This is much unlike 2007, when the Dichot sampler tended to give higher $PM_{2.5}$ concentrations than the TEOM, in some cases by a factor of 2-4 times. The TEOM was replaced in November 2007, but the problems persisted afterwards.

Figure 4.5
Comparison of $PM_{2.5}$ Data at Victoria Topaz

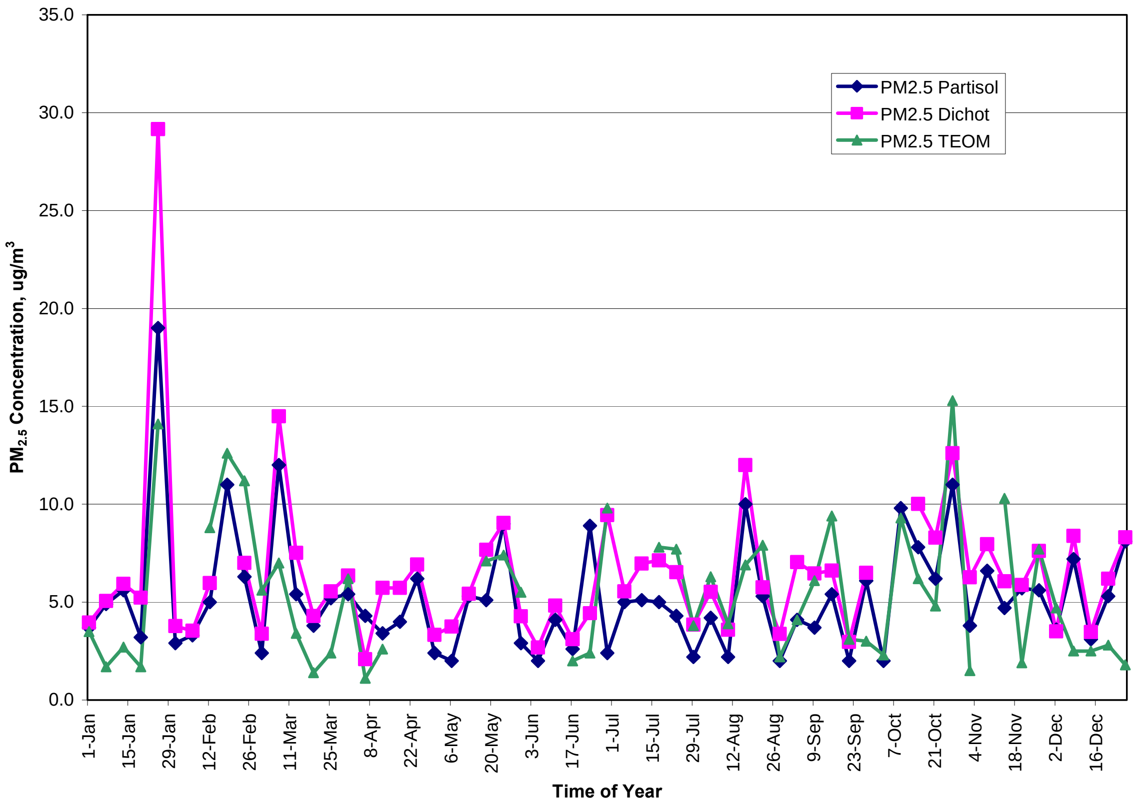
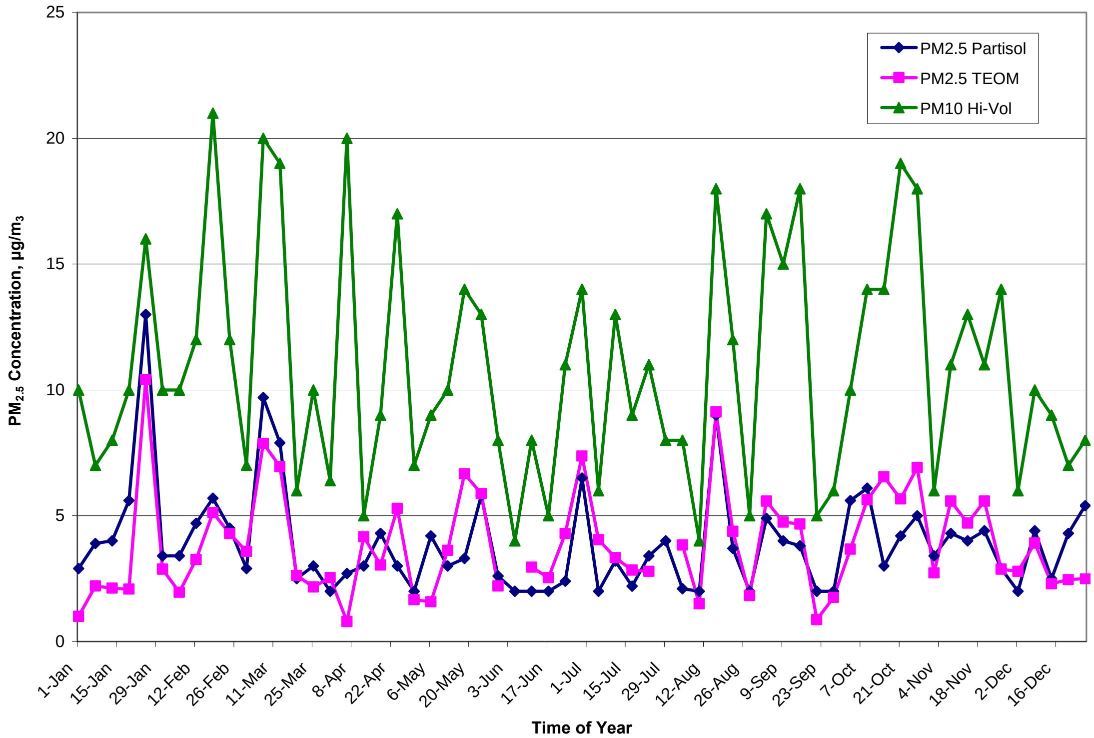


Figure 4.6 shows the comparison between Partisol and TEOM sampler $PM_{2.5}$ concentrations measured at Langford Lakewood Elementary School. The data indicate that the Partisol sampler and TEOM also have good agreement at this station, especially during July to October. Neither instrument consistently measured $PM_{2.5}$ concentrations higher (or lower) than the other. Again, this is much unlike 2007 data, which showed that the Partisol sampler consistently measured $PM_{2.5}$ concentrations higher than the TEOM.

Figure 4.6
Comparison of $PM_{2.5}$ and PM_{10} Data at Langford



5.0 AIR QUALITY TRENDS IN THE CRD

SENES developed a statistical tool in 2006 to recognize and assess significant trends in air quality monitoring data from year-to-year in the CRD. The statistical variables this tool measures are the annual mean and 98th percentile concentration. The tool also identifies the annual number of CRD guideline exceedences.

Averaging periods suitable to the CRD guideline are used for each air contaminant. There must be at least 10 years of continuous data available for each station, for small trends to be effectively assessed. If the number of continuous years of available data is limited to less than 5 years, small trends may still be recognized, but may not be considered statistically significant. However, larger trends may be identified as significant even with a data record of less than 10 years. For the trend analyses presented in this section of the report, all available data for stations with five or more years of data were used.

Victoria Topaz and Saturna Island are the only two stations that have enough continuous data for the tool to determine whether potential trends exist. Table 5.1 shows the trend analysis summary for 11 continuous years (1998-2008) at Victoria Topaz and 11 continuous years at Saturna Island. The data indicate that SO_2 concentrations at Victoria Topaz and Saturna Island have been steadily declining over this period. The decline is detectable in both the 98th percentile and the annual average concentrations, although the decline in the mean annual concentration at Saturna Island is lower (5% per year). While these trends are statistically significant, it should be noted that the absolute values of the SO_2 concentrations at both locations are relatively small.

In addition, there has been a weaker trend to lower CO concentrations at the 98th percentile level at Victoria Topaz. Also, the frequency with which O_3 levels exceed the CRD 8-hour average guideline value of 120 $\mu g/m^3$ appear to be increasing at a rate of about 22% per year at Saturna Island, although there is no trend towards increasing concentrations at either the mean or at the 98th percentile level.

It should be noted that the mean SO_2 concentration at the Victoria Topaz site in 2008 was much higher than would have been expected based on the trend in declining SO_2 concentrations in the period 2000-2007. The 2008 value represents an outlier of higher than expected mean SO_2 concentration on an overall longer term trend towards lower annual mean concentrations of SO_2 at Topaz over the longer period of record. If the 2009 levels are similar to those experienced in 2008, the trend analysis would have to be revisited as it might signal a change in the trend would have to be investigated more closely to understand its cause and what, if anything, it might indicate for future SO_2 concentrations in the CRD.

Table 5.1
Summary of Trend Analysis for Victoria Topaz and Saturna Island

Measure	CO	NO_2	SO_2	O_3	$PM_{2.5}$	PM_{10}
	Victoria Topaz (1998-2008)					
Annual mean	No Trend	No Trend	-12%/yr	No Trend	No Trend	No Trend
Annual 98th Percentile	-4%/yr	No Trend	-9%/yr	No Trend	No Trend	No Trend
	Saturna Island (1998-2007)					
Annual mean	--	--	-5%/yr	No Trend	--	--
Annual 98th Percentile	--	--	-12%/yr	No Trend	--	--
% Over CRD Guideline	--	--	--	-22%/yr	--	--

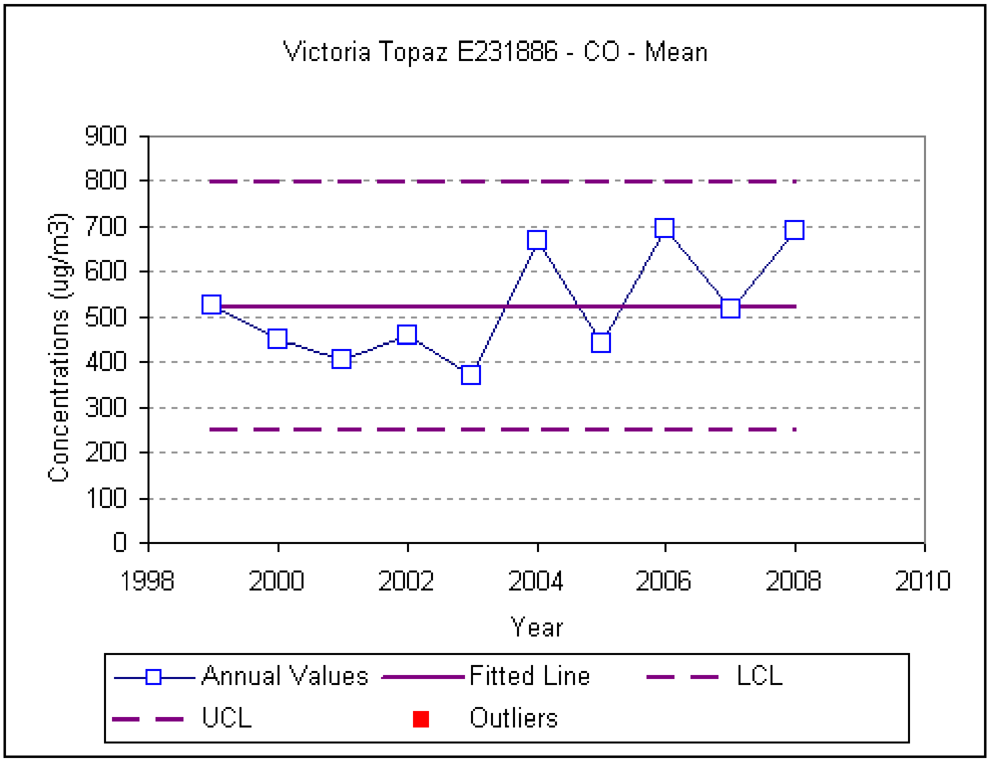
Notes: "--" denotes no data or not enough data for trend analysis.
A minimum of four years of continuous data with >80% data recovery is required to complete a trend analysis.
"No trend" indicates that no statistically significant trend can be detected at the 5% significance level.

No other trends were found for CO, NO_2, O_3, $PM_{2.5}$ or PM_{10} data, although there appears to be the suggestion of a weak downward trend in mean $PM_{2.5}$ concentrations post-2002 at both Topaz and Royal Roads. Figures 5.1 to 5.13 show the annual mean and 98th percentile concentration trends for each air contaminant for the period of record at Victoria Topaz, Royal Roads, Saturna Island, Oak Bay, Braefoot and Keating. There was insufficient data to perform trend analysis for Stellys, Langford and Christopher Point. 2008 data for SO_2 were not available for Saturna Island in time for the trend analysis.

Note that the mean concentration, not including the outliers identified during the regression trend analysis, is calculated as the standard deviation of the concentrations. Upper and lower limits (UCL and LCL) are calculated based on the observed mean, standard deviation and appropriate t-statistic for the selected confidence level. Outliers or unusual values are assessed if the annual value is outside the confidence limits. Further discussion of the methodology used for trend analysis is provided in SENES (2006)[16].

[16] SENES Consultants Limited 2006. Method to Assess Presence of Annual Trend or Unusual Values in Air Quality Data. Prepared for the Capital Regional District, Environmental Services Department, Victoria, BC. http://www.crd.bc.ca/airquality/documents/trend_method.pdf

Figure 5.1
CO Trend at Victoria Topaz



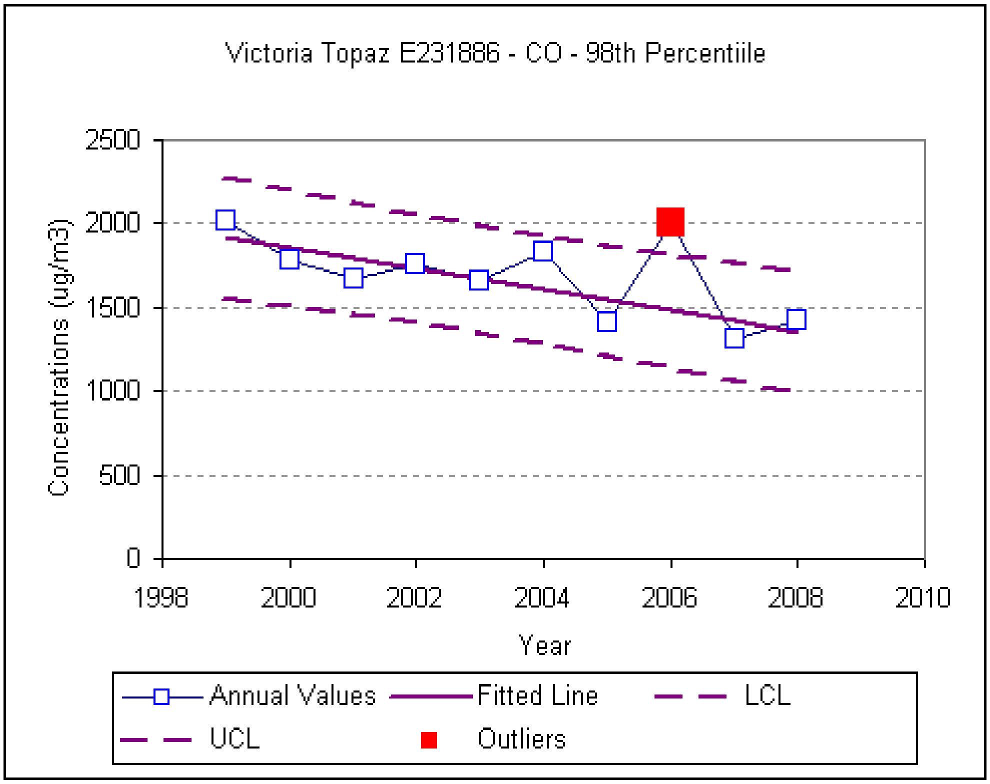
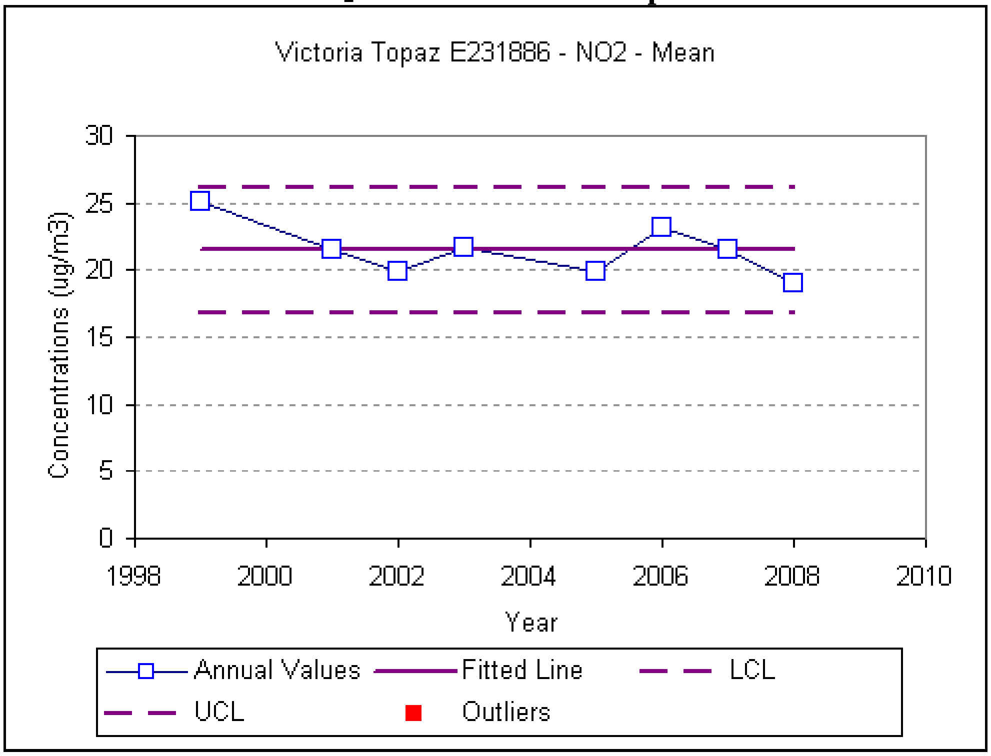


Figure 5.2
NO_2 Trend at Victoria Topaz



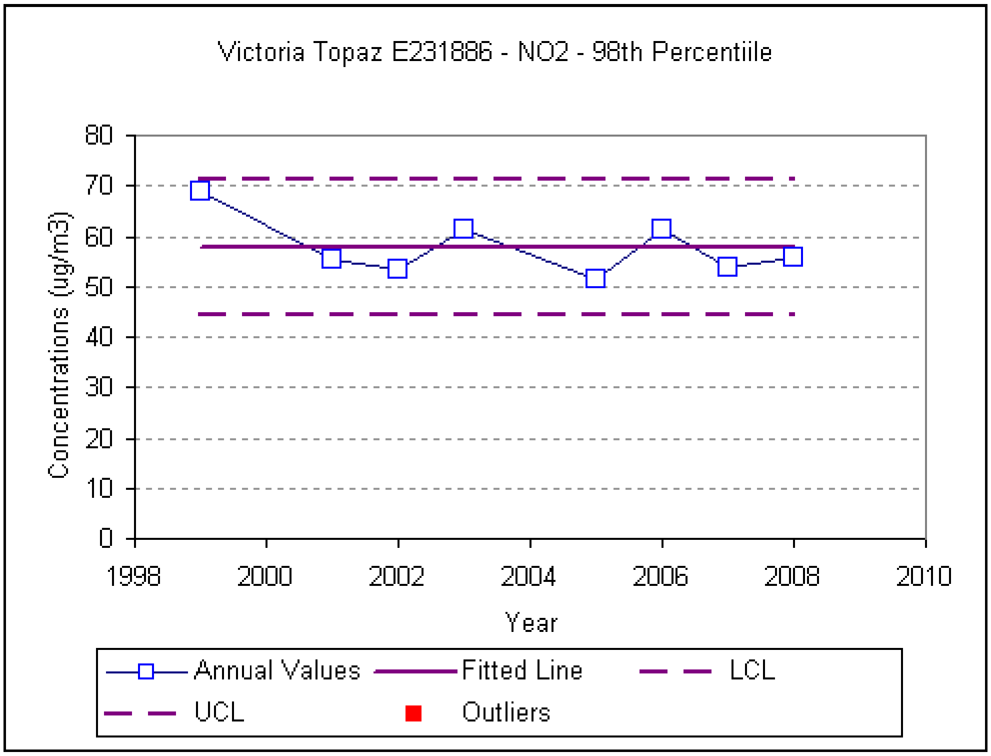
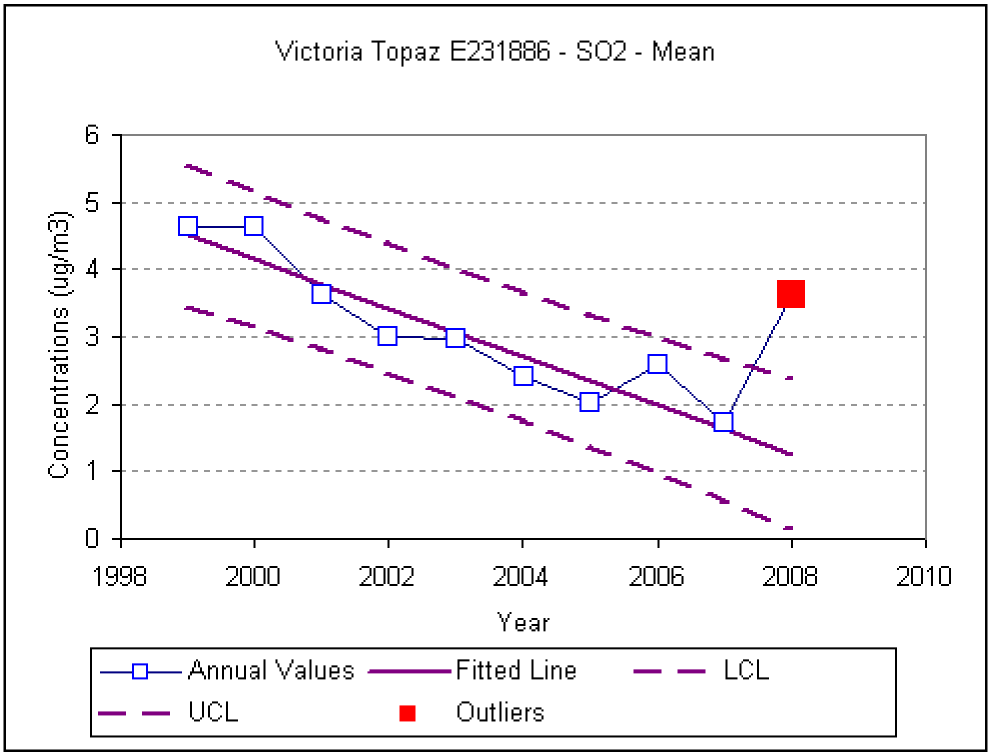


Figure 5.3
SO_2 Trend at Victoria Topaz



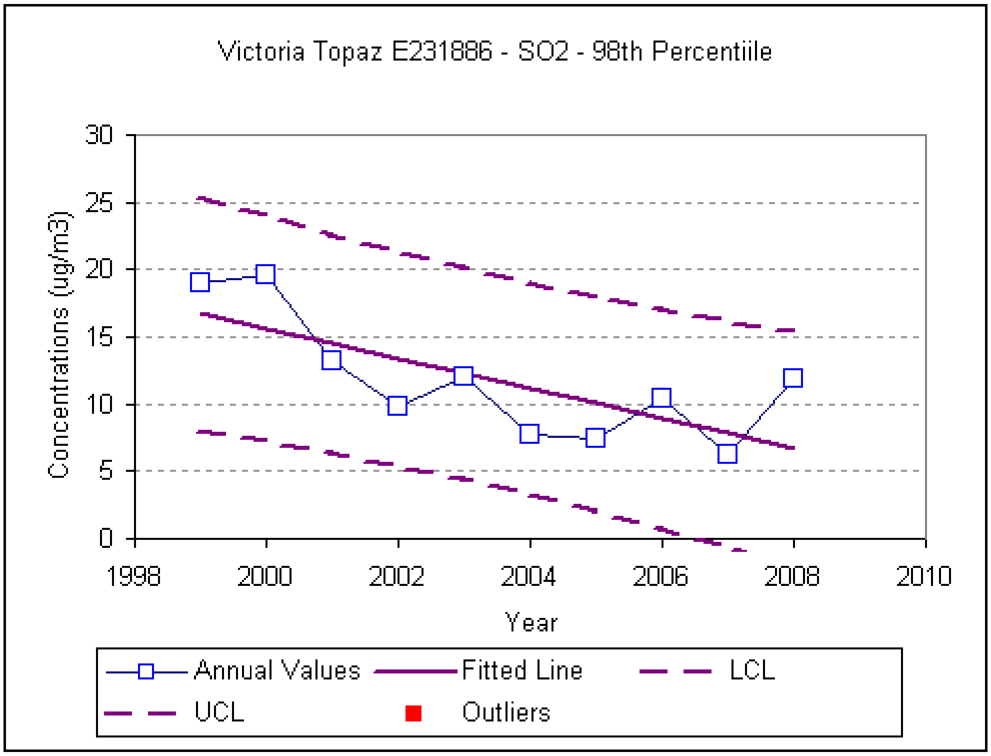
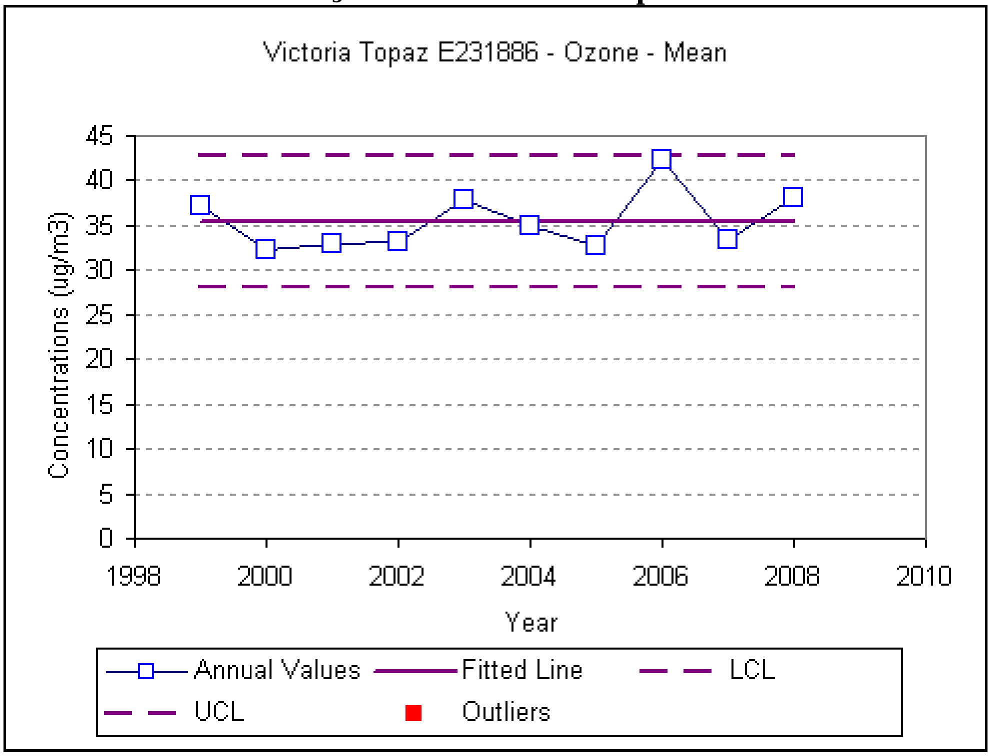


Figure 5.4
O_3 Trend at Victoria Topaz



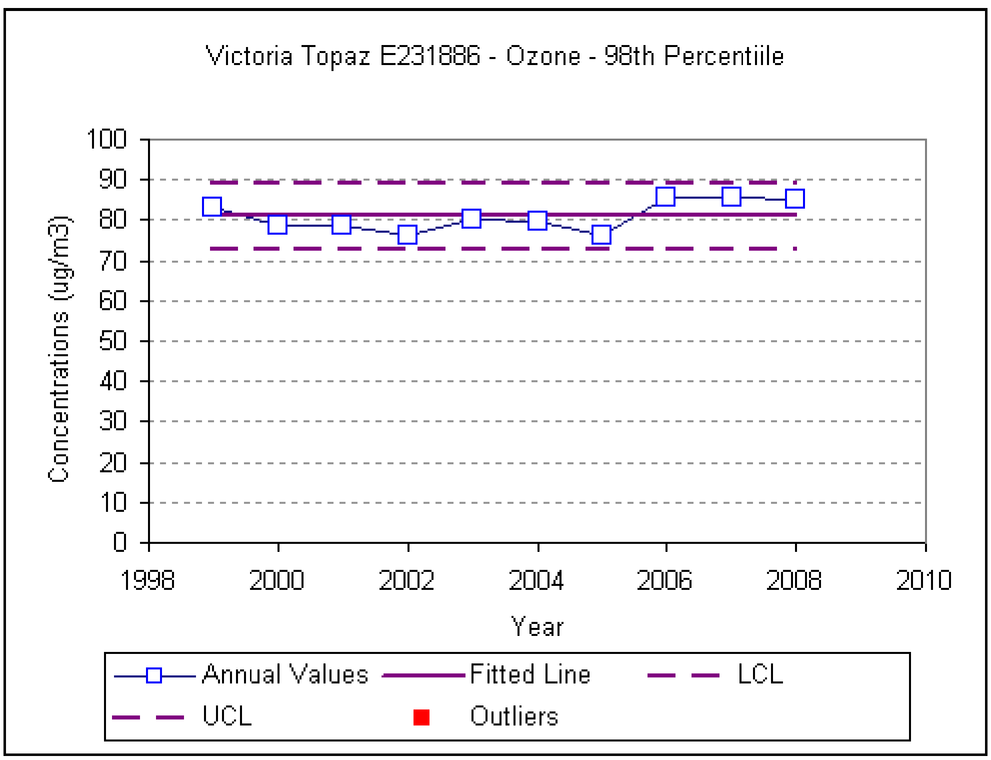
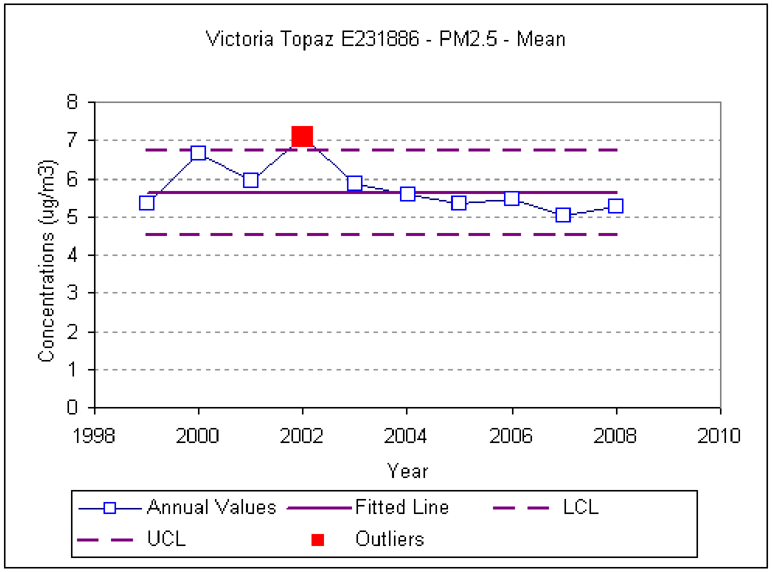
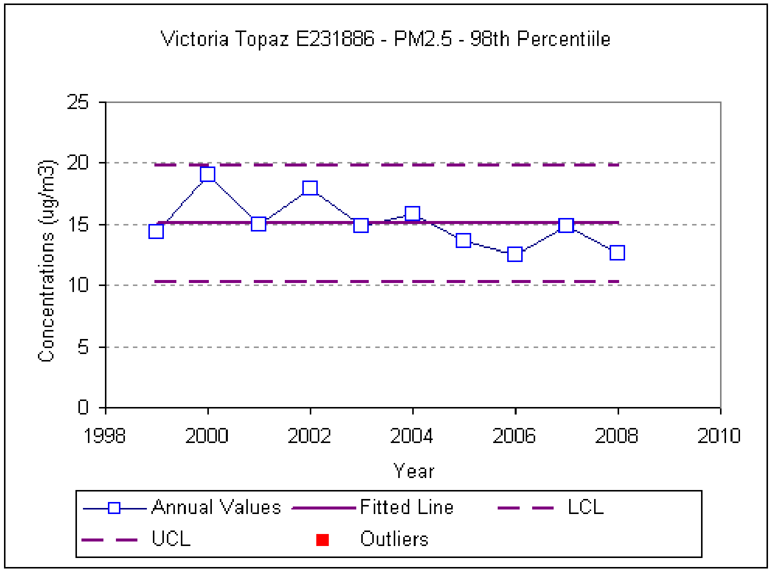


Figure 5.5
$PM_{2.5}$ Trend at Victoria Topaz





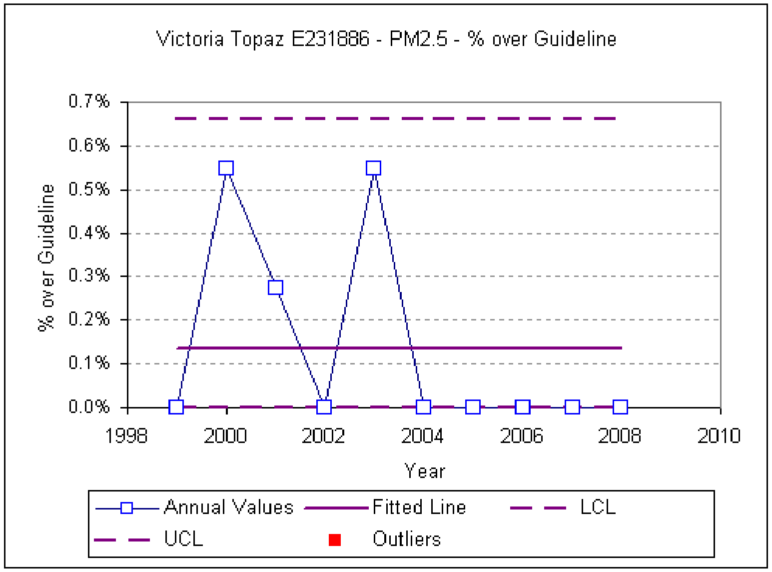
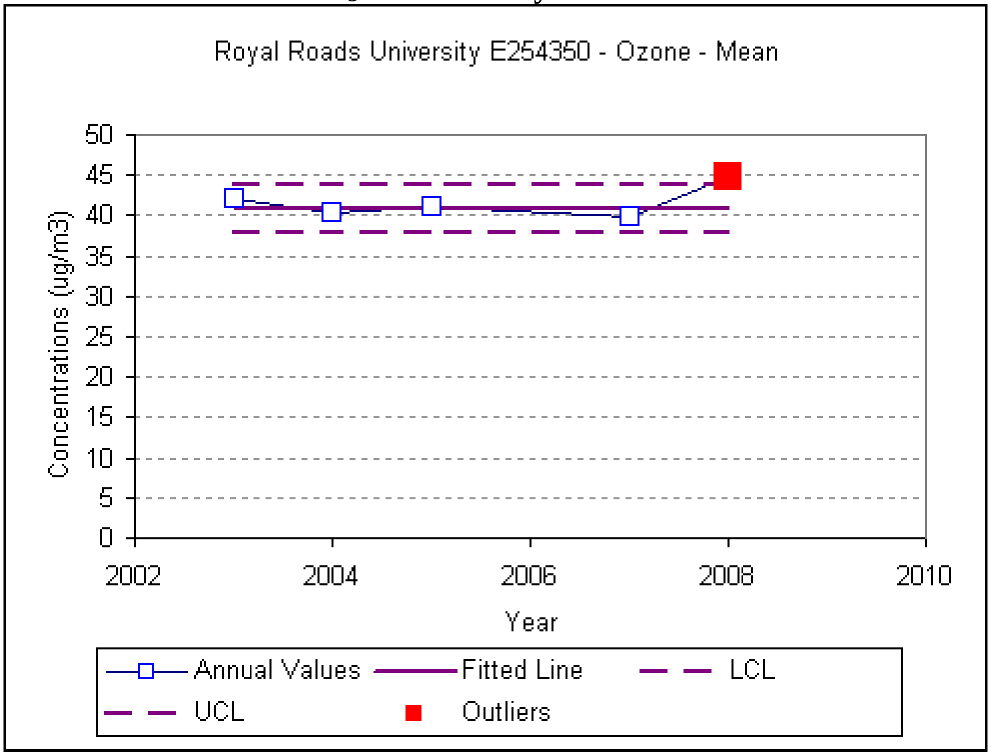


Figure 5.6
O_3 Trend at Royal Roads



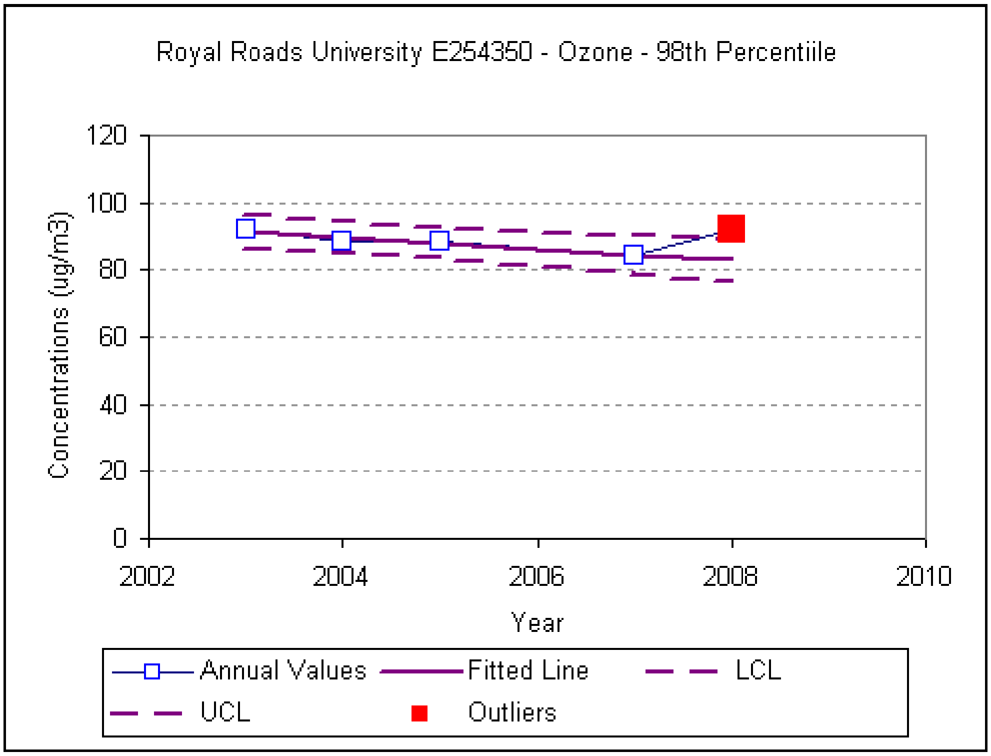


Figure 5.7
$PM_{2.5}$ Trend at Royal Roads

Figure 5.8
PM_{10} Trend at Royal Roads

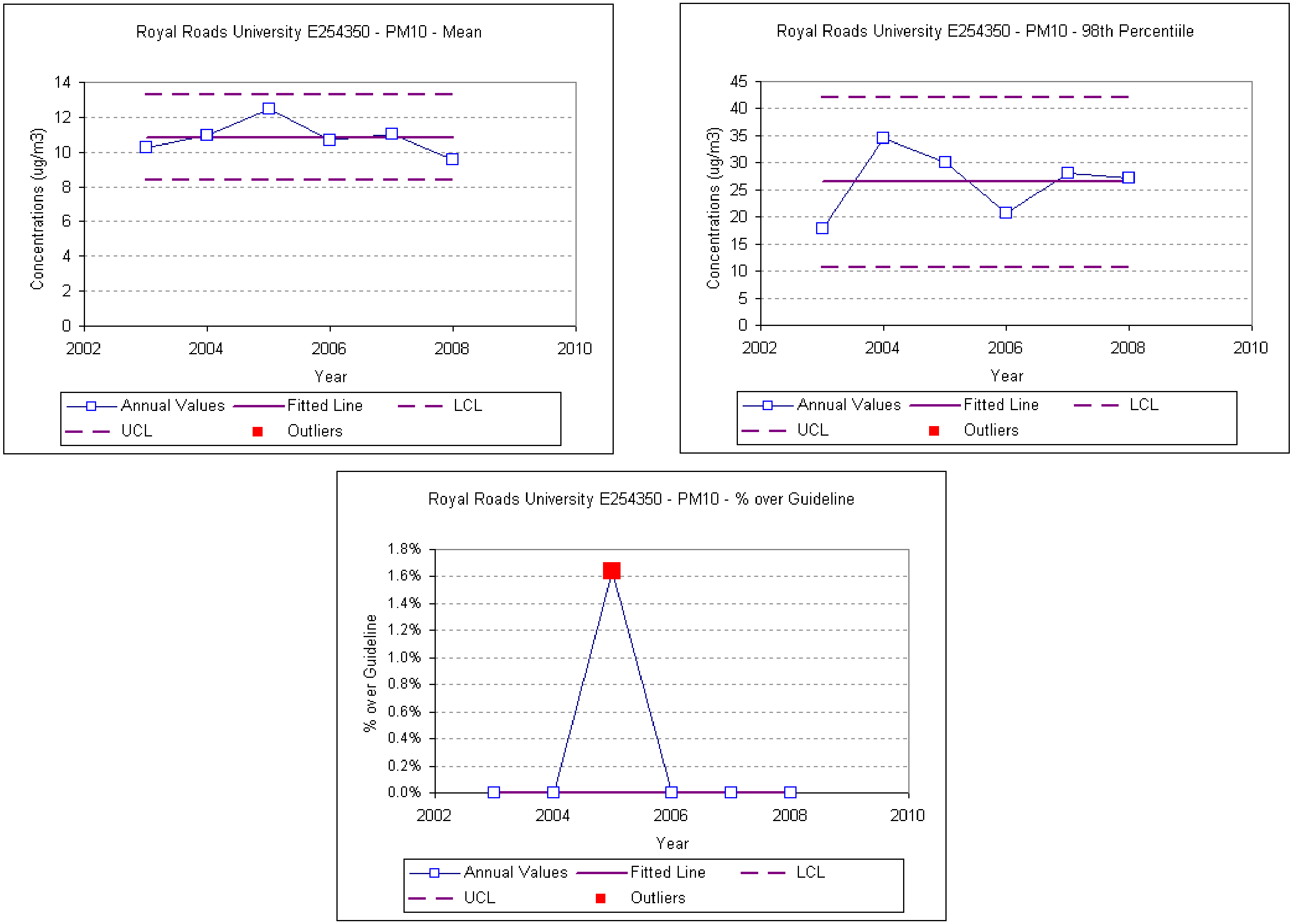
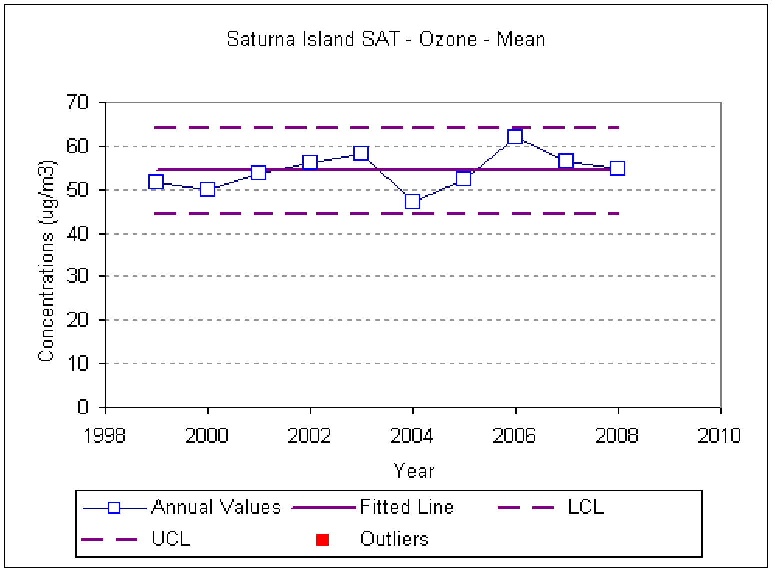
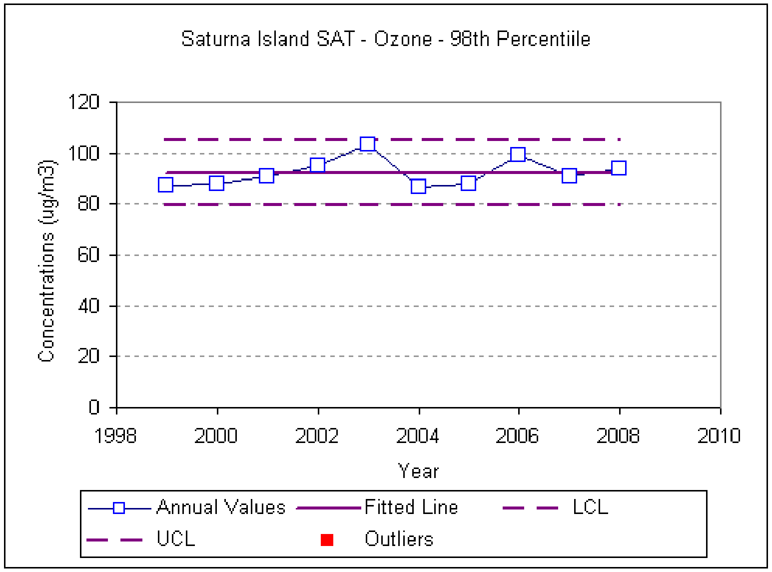


Figure 5.9
O_3 Trend at Saturna Island





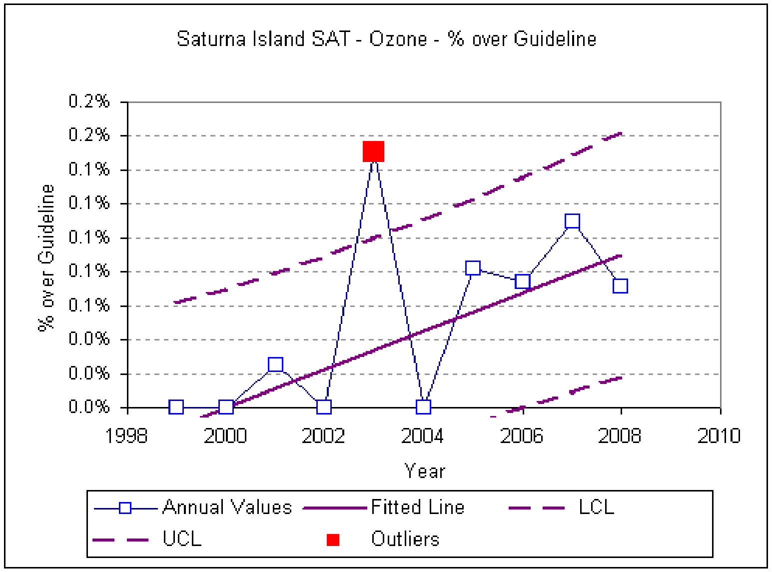
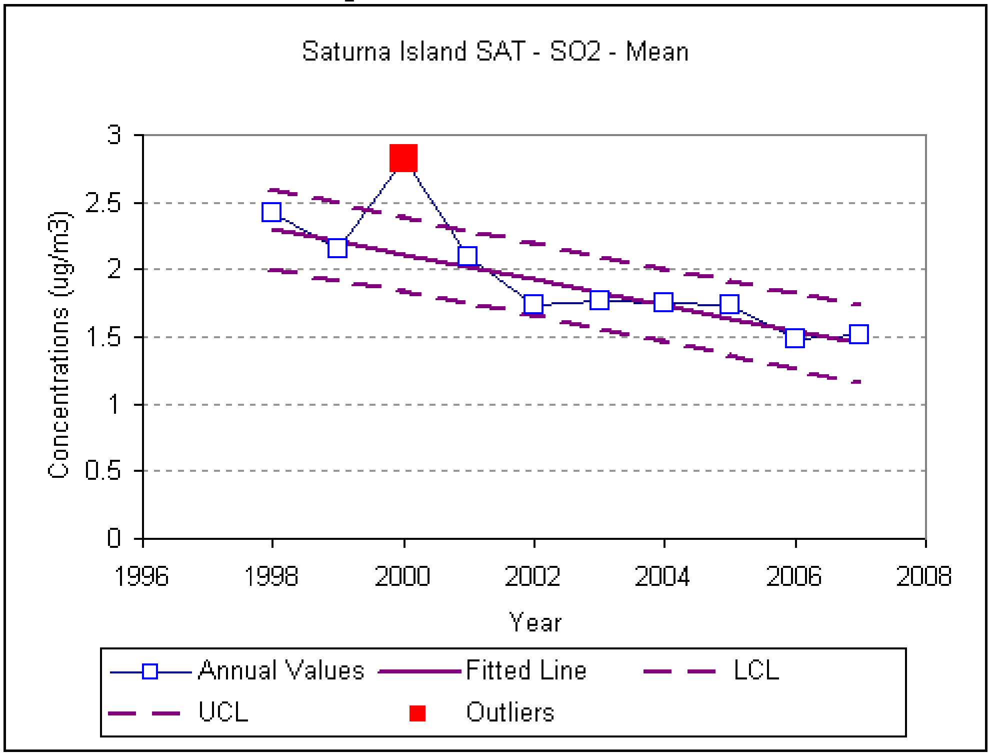


Figure 5.10
SO_2 Trend at Saturna Island



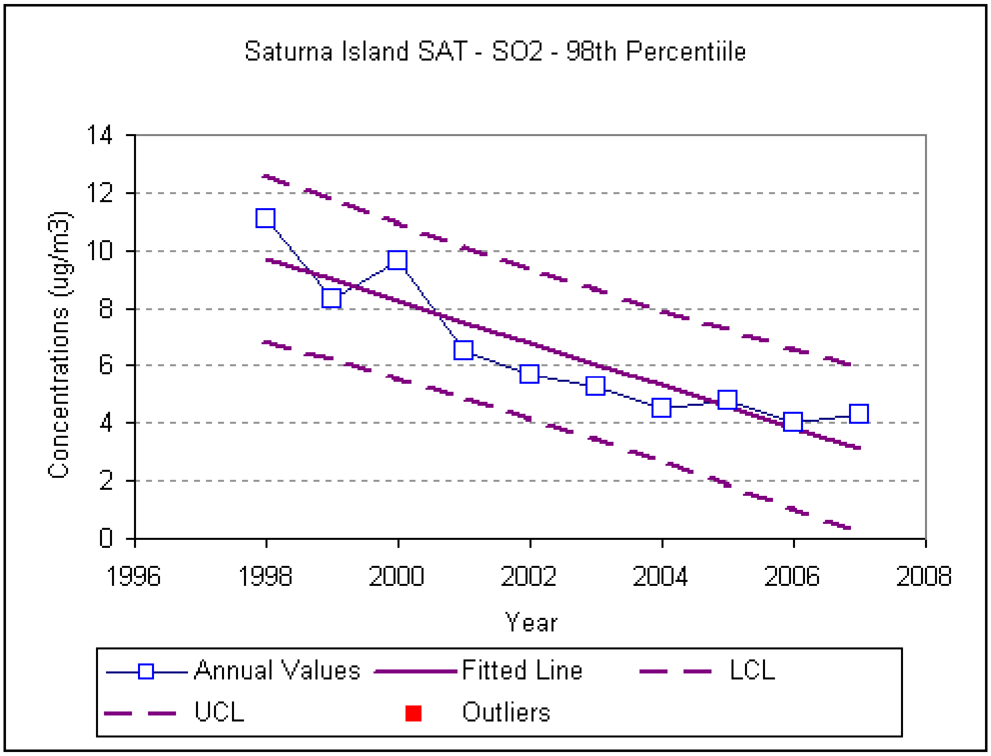
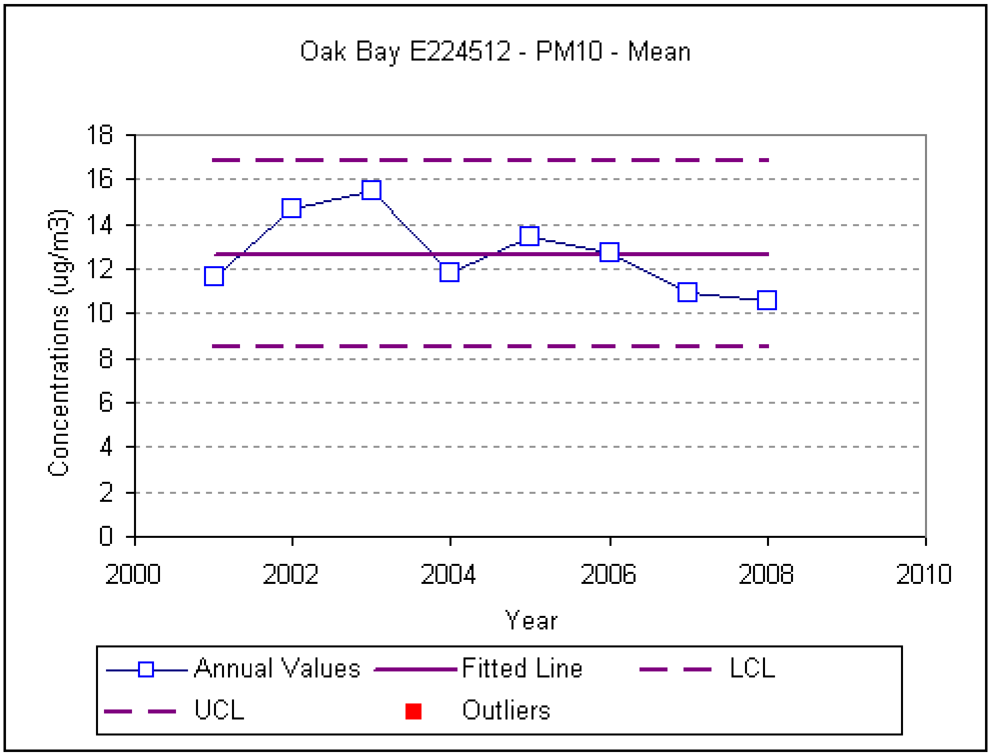


Figure 5.11
PM_{10} Trend at Oak Bay



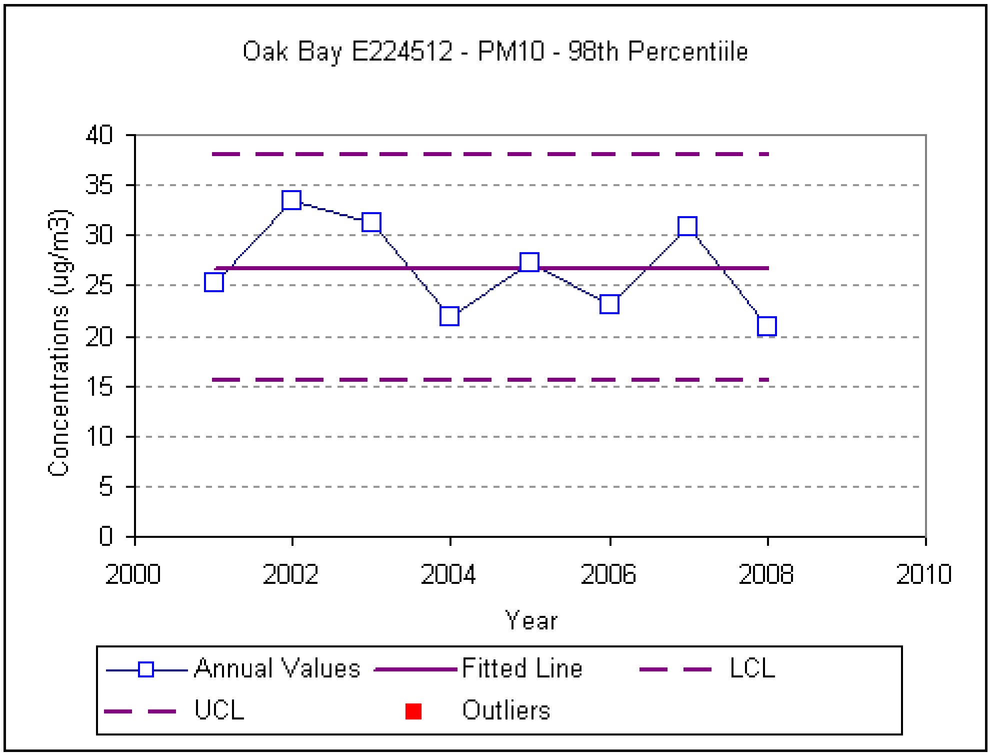
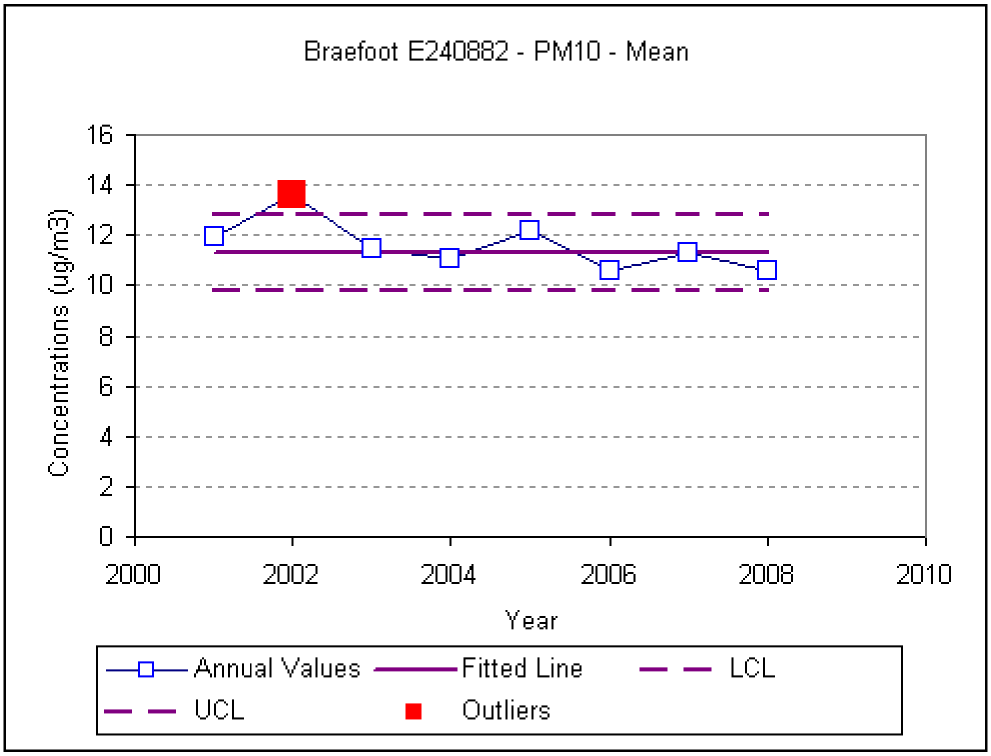


Figure 5.12
PM_{10} Trend at Braefoot



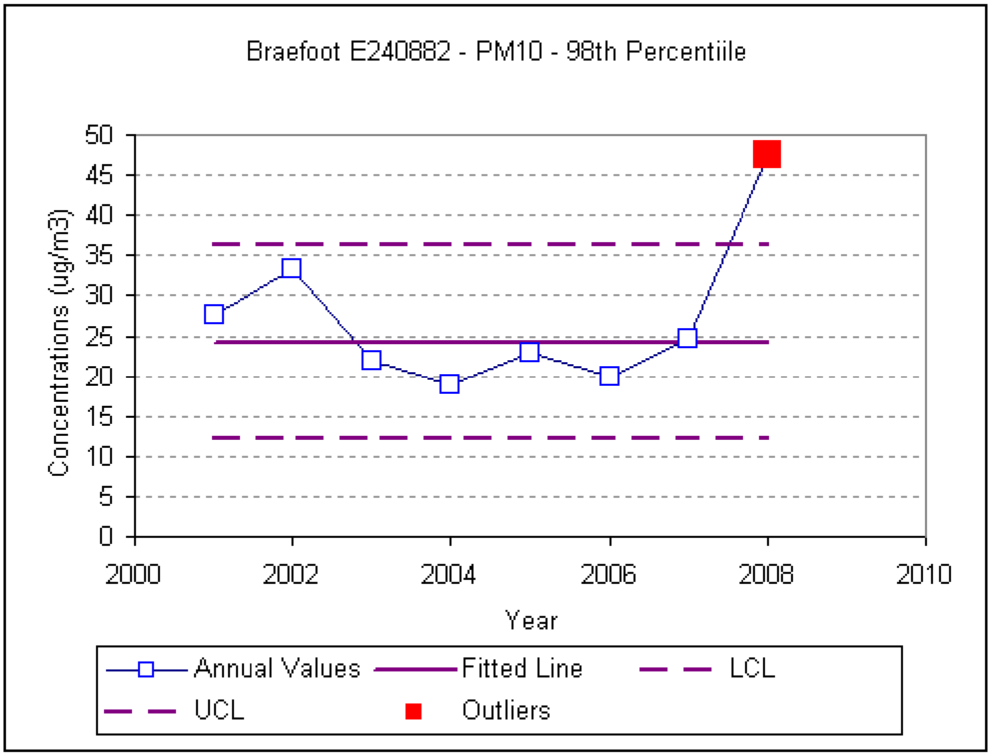
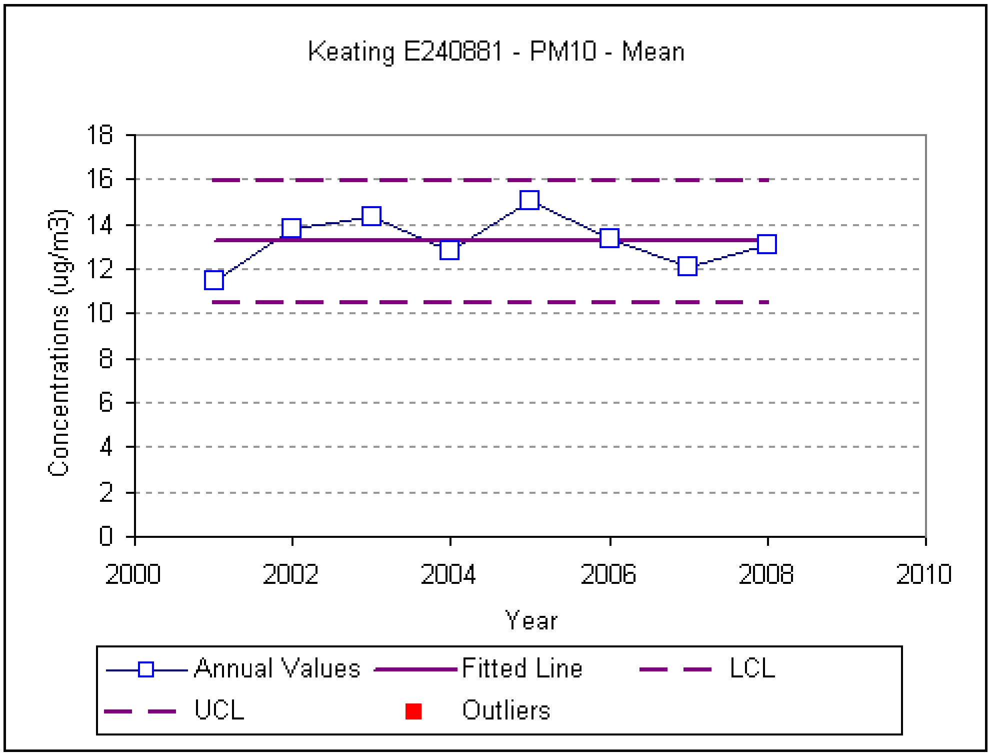
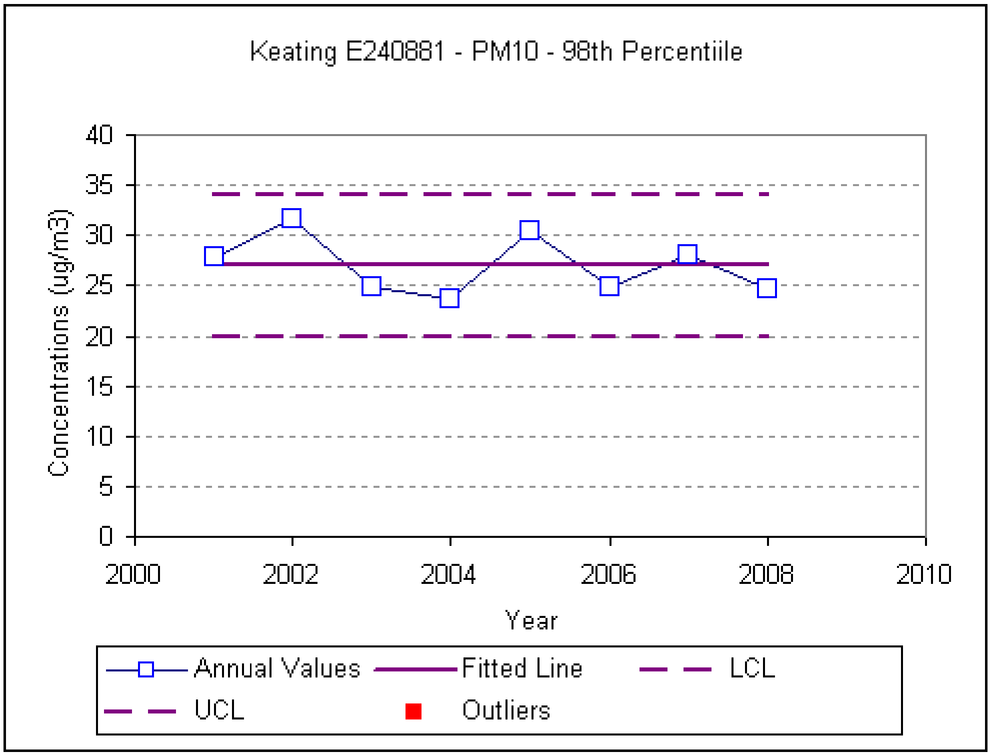


Figure 5.13
PM_{10} Trend at Keating





6.0 CONCLUSION

A summary of comparisons of maximum pollutant concentrations in 2008 to the CRD guidelines and CWS levels are provided in Table 7.1. In general terms, air quality in the CRD was good and far below any applicable guidelines or objectives for most of the time during 2008. There were two exceedences of the CRD guideline for PM_{10}, one each at Braefoot and Keating. There was one exceedence of the $PM_{2.5}$ guideline level based on the Dichot sampler at Topaz, and one exceedence of the ozone guideline value at Saturna Island. In all cases, the level of exposure to the elevated concentrations was determined to be quite small for the CRD as a whole because the exceedences were localised in the vicinity of a single monitoring location in each case. There were no exceedences of the CRD guidelines for other common air contaminants. At this time, there is no indication that the Canada Wide Standards (CWS) for respirable particulate matter ($PM_{2.5}$) will be exceeded at the implementation date (2010), but the CWS for ozone was higher than in previous years at Saturna Island in both 2007 and 2008 which could lead to levels exceeding the CWS at this station if similarly high levels were present in 2009.

Table 6.1
Summary of Maximum Pollutant Concentrations (µg/m³) in the CRD for 2008

		Air Quality Criteria		Monitoring Station								
Contaminant	Averaging Period	CWS	CRD Guideline	Victoria Topaz	Stellys	Royal Roads	Langford	Christopher Point	Oak Bay	Braefoot	Keating	Saturna Island
CO	8-hour*		5500	2671.4	912.5		671.4	1250				
NO_2	1-hour*		200	90.7	59.1	55.5	98.3	56.4				
SO_2	24-hour*		125	24.3			5.0	11.7				N/A
O_3	8-hour**		120	104.8	106.7	108.0	107.2	116.7				**136.3**
PM_{10}	24-hour*		50		25 (Partisol)	30 (Hi-Vol)	21 (Hi-Vol)		33 (Hi-Vol)	**70** (Hi-Vol)	**59** (Hi-Vol)	
$PM_{2.5}$	24-hour*		25	**29.4** (Dichot)	13.2 (TEOM)	12.2 (TEOM)	12.4 (TEOM)	11.4 (TEOM)				
Canada Wide Standards												
Ozone	8-hour**	127.6 [1]		101.2	104.8	99.7						124.6
$PM_{2.5}$	24-hour*	30 [2]		14.0		11.0						

Notes:
* Sequential averaging periods used.
** Rolling average periods used.
[1] Achievement by 2010, based on the annual 4th highest daily measurement, averaged over 3 consecutive years.
[2] Achievement by 2010, based on the 98th percentile ambient measurement annually, averaged over 3 consecutive years.
[3] Compliance determined using data from Royal Roads University.
N/A – not yet available
Values in **bold** indicate that the CRD Guideline or CWS has been exceeded.

Data collection rates were reasonably good for the year, with some exceptions. Approximately 87% of the CO and 92% of NO data were missing for the Christopher Point station. Almost 50% of the $PM_{2.5}$ monitoring data and more than 20% of the NO_x data were missing for the Stellys site. As well, about 20% of the $PM_{2.5}$ data was missing from Victoria Topaz. Overall, the amount of missing data in 2008 was much less than 2007.

Exceedences of the PM_{10} guideline of 50 $\mu g/m^3$ occurred once at the Keating monitoring station on April 6^{th} and once at the Braefoot monitoring station on August 16^{th}, with 24-hour average concentrations of 59 $\mu g/m^3$ and 70 $\mu g/m^3$, respectively. Concentrations recorded at each of the other PM_{10} monitoring stations in the CRD during both incidences were much lower, indicating that the higher PM_{10} concentrations observed at Keating and Braefoot were not experienced throughout a large portion of the CRD.

The PM_{10} exceedences appear to have been representative of localized dust in the air near the Keating and Braefoot stations. Due to the limited temporal and spatial extent of exposure to both the PM_{10} exceedences, related health effects for community members could not be determined with confidence.

In both 2006 and 2007, there was an ozone exceedence at the Saturna Island monitoring station. 2008 Saturna Exceedence

With respect to long-term trends in air quality in the CRD:

- SO_2 concentrations at the Victoria Topaz site are low and have been declining at a rate of about 12% per year over the period 1998-2007, and at about 9% per year in terms of the peak (98^{th} percentile) concentration. However, the mean SO_2 concentration in 2008 was an outlier and could represent an early indication of a change in the trend if levels remained high in 2009.
- A decline in SO_2 concentrations at the 98^{th} percentile level has also occurred at Saturna Island (12% per year) over the period 2000-2007, although the decline in the mean annual concentration has been lower than at Topaz, at a rate of 5% per year. SO_2 data for Saturna Island in 2008 were not yet available to be included in this report.
- CO concentrations at Victoria Topaz have also been declining at a rate of about 4% per year.
- The frequency with which O_3 levels exceed the CRD 8-hour average guideline value of 120 $\mu g/m^3$ appear to be increasing at a rate of about 22% including 2008 per year, although there is no trend towards increasing concentrations at either the mean or at the 98^{th} percentile levels. The rate at which the CRD ozone guideline value is exceeded at Saturna Island is low (approximately one 8-hour event per year). Nevertheless, the trend analysis suggests that the frequency of guideline exceedences is increasing. At the rate of

increase suggested by the trend analysis, the frequency of exceeding the ozone CRD guideline value could rise to two events per year in a few years.

No other statistically significant trends were identified for any of the other pollutants in the monitoring network, although in most cases the period of record is insufficient to determine such trends. There appears to be a suggestion of a very weak downward trend in $PM_{2.5}$ concentrations at both the Victoria Topaz and Royal Roads University monitoring locations, but these are not statistically significant trends to date.

Meteorological data were available from six monitoring stations in the CRD. These stations are co-located with the air quality monitoring stations, with the exception of the Victoria Airport station. Data from the Environment Canada station at Saturna Island could not be obtained in timely fashion. Wind speed and direction data were summarised for each station as wind rose diagrams in Appendix A. In addition, a climate comparison was completed using data from the Environment Canada station at the Victoria Airport.

As part of the analysis of the 2008 air quality data, specific attention was directed at identifying the influence of emissions from solid waste burning in the CRD. In 2005, an analysis of $PM_{2.5}$ concentrations during the period 2001-2004 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[17]. The solid waste burning analysis strongly indicated that air quality can be degraded in those communities that allow burning, in the more active months of Fall and Spring. The same analysis performed on sampling data in Victoria indicated that improvements in air quality, with respect to suspended fine particulate matter, could be anticipated in those communities that reduce or eliminate solid waste (backyard) burning.

The analyses of the $PM_{2.5}$ monitoring data in Langford and in Central Saanich (Stellys) support the overall conclusion that open burning contributes to statistically higher concentrations of $PM_{2.5}$ in Langford. The data suggest that hourly averaged concentrations are 7.6 $\mu g/m^3$ higher on burn days (95% confidence level), while 24-hour average concentrations are 1.9 $\mu g/m^3$ higher on burn days (99% confidence level). The analyses of the Stellys $PM_{2.5}$ monitoring data is more difficult to interpret in that there may be confounding factors that affect the ability to statistically determine the impact of open burning on air quality in Central Saanich. It could be very difficult to remove the confounding factors present in the Stellys analyses to determine if burning contributes to higher air concentrations. However, the confounding may be due to meteorological conditions and may not appear in future years, such that subsequent analyses in

[17] SENES Consultants Limited (SENES) 2005. Air Quality in the Capital Regional District 2004. Prepared for the Environmental Services Department, Capital Regional District, Victoria, BC.

future years may be more successful in identifying the effect of open burning on air quality in Central Saanich.

The analysis of hourly averaged ambient air quality concentrations of SO_2, NO_2 and $PM_{2.5}$ at the Victoria Topaz monitoring station in relation to the cruise ship operations at Ogden Point indicates that the emission of SO_2 from cruise ships unequivocally has the greatest effect on ambient concentrations of this contaminant at the Topaz site. The emission of NO_x and $PM_{2.5}$ is more difficult to discern because other sources of these two contaminants obscure the impacts of cruise ship emissions during weekdays. However, the impact of cruise ship emissions is more clearly evident for NO_2 and $PM_{2.5}$ concentrations on weekend days when background concentrations from other sources of these two contaminants are lower.

The analysis of the 2008 monitoring data at the Topaz site supports the results of the James Bay Air Quality Study (JBAQS) dispersion modelling analysis that was completed for the cruise ship operations in 2007. The 2008 monitoring data indicate that maximum hourly averaged NO_2 concentrations attributable to cruise ship emissions support the results of the JBAQS. However, the analysis of the 2008 monitoring data also suggests that the JBAQS may have underestimated maximum SO_2 and $PM_{2.5}$ impacts from cruise ships by about a factor of three (3).

The underestimation of SO_2 and $PM_{2.5}$ impacts in the JBAQS may reflect differences in meteorology between 2007 and 2008, but underestimation of SO_2 and $PM_{2.5}$ emissions also cannot be ruled out. Only a small number of cruise ships were associated with the highest observed SO_2 concentrations at the Topaz site, indicating that these vessels may emit SO_2 at higher rates than was assumed in the JBAQS. The possible implication of this is that SO_2 concentrations in the vicinity of Ogden Point may be much higher than was estimated in the JBAQS, and may be high enough in the James Bay community to be of concern for human health impacts in that area.

Appendix A: Meteorological Data

Table A.1 2008 Monthly Climate Data for Victoria International Airport[a]

	Mean Max Temp	Mean Temp	Mean Min Temp	Extreme Max Temp	Extreme Min Temp	Total Rainfall	Total Snow	Total Precip
	°C	**°C**	**°C**	**°C**	**°C**	**mm**	**cm**	**mm**
Jan	6.6	3.5	0.4	10.9	-5.3	92.9	0.6	93.5
Feb	9.3	5.3	1.2	13.1	-2.3	41.8	T	41.8
Mar	9.4	5.6	1.8	11.6	-1.7S	46.5	5.8	52.3
Apr	11.2	6.7	2.1	18.4	-2.9	34.5	12.2	46.7
May	16.8	12.2	7.6	26.6	2.5	15.6	0	15.6
Jun	19	14.2	9.3	30.6	6.3	27.2	0	27.2
Jul	21.8	16.3	10.8	26.9	7.7	10.5	0	10.5
Aug	22.2	16.9	11.6	29.9	6.7	37.2	0	37.2
Sep	19.8	14.3	8.8	26.2	3.3	19.6	0	19.6
Oct	13.1	9.3	5.4	17.1	1.1	51.5	0	51.5
Nov	11.3	8.2	5.1	15.3	-1	127.1	0	127.1
Dec	4.6	1.8	-1.1	11.4	-9.1	56.7	85.8	139.3
Sum						**561.1**	**104.4**	**662.3**

Table A.2 Climate Normals (1971-2000) for Victoria International Airport[a]

	Mean Temp	Mean Max Temp	Mean Min Temp	Extreme Max Temp	Extreme Min Temp	Rainfall	Snowfall	Precipitation
	°C	**°C**	**°C**	**°C**	**°C**	**mm**	**cm**	**mm**
Jan	3.8	6.9	0.7	15.4	-15.6	121.8	15.2	136.6
Feb	4.9	8.4	1.4	18.3	-15	98.8	9	107.8
Mar	6.4	10.5	2.3	21.4	-10	75.8	2.4	78
Apr	8.8	13.4	4.1	26.3	-3.9	44.5	0	44.5
May	11.8	16.6	6.9	31.5	-1.1	36.5	0	36.5
Jun	14.4	19.3	9.3	33.3	2.1	32	0	32
Jul	16.4	21.9	10.8	36.1	4.1	19.5	0	19.5
Aug	16.4	22	10.8	34.4	4.4	23.9	0	23.9
Sep	14	19.4	8.4	31.1	-1.1	30.4	0	30.4
Oct	9.8	14.2	5.3	27.6	-4.4	75.6	0.2	75.7
Nov	6.1	9.5	2.7	18.3	-13.3	144.4	3.3	147.2
Dec	4	6.9	1	16.1	-14.4	138.3	13.8	151.2
Sum						**841.5**	**43.9**	**883.3**

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

Figure A.1
2008 Wind Rose Diagram for Victoria International Airport

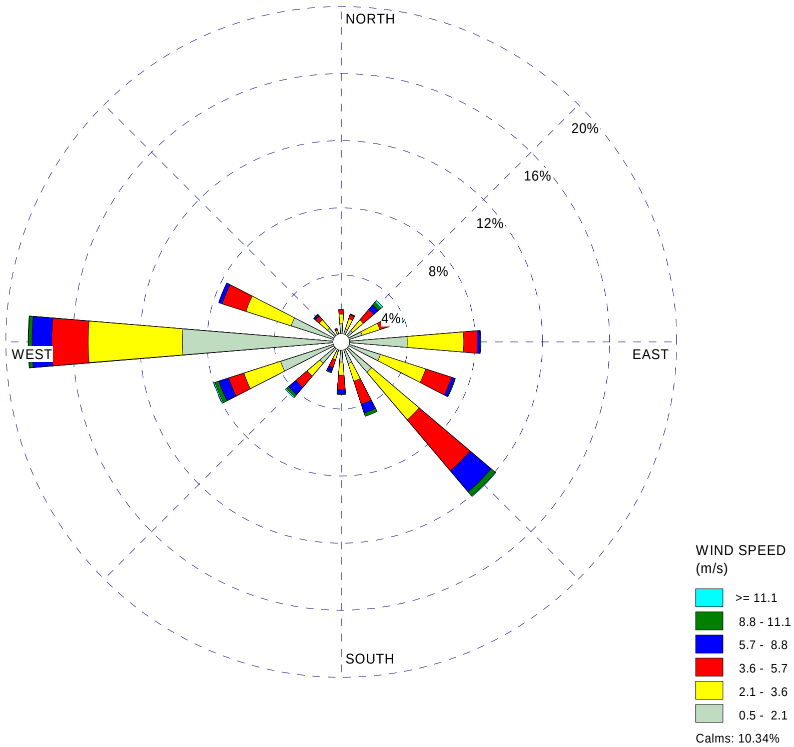


Figure A.2
2008 Wind Rose Diagram for Victoria Topaz

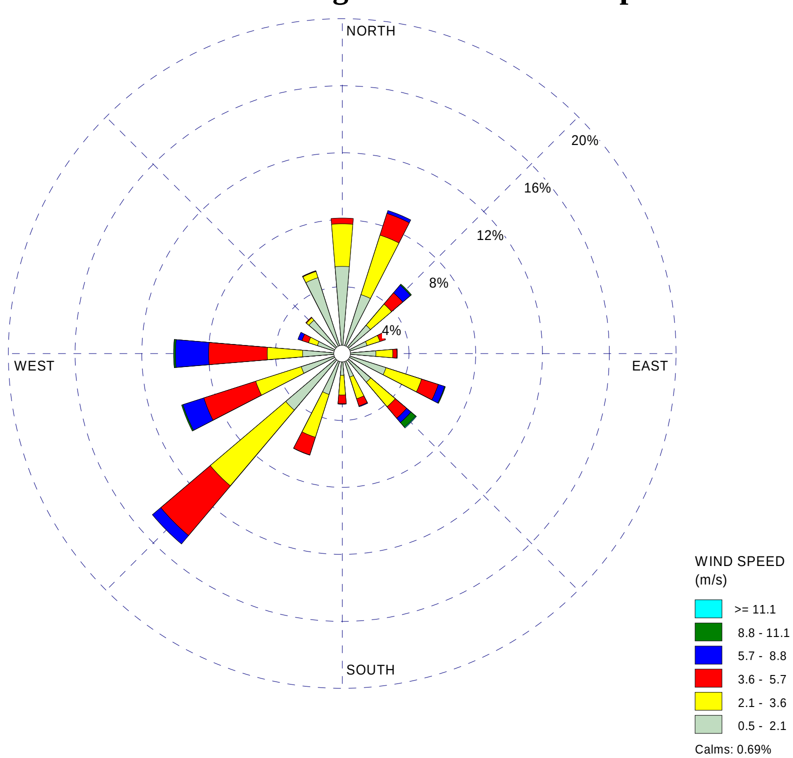


Figure A.3
2008 Wind Rose Diagram for Stellys

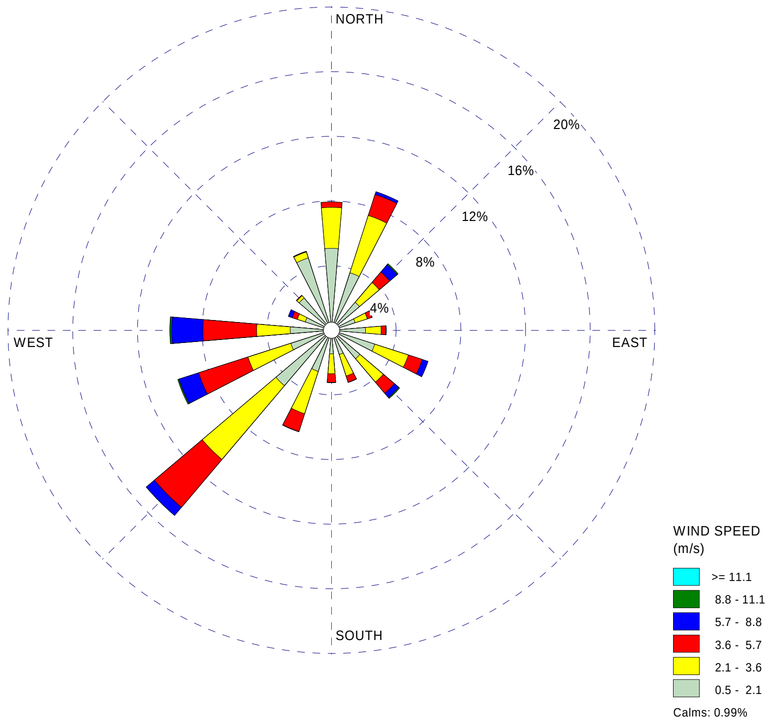


Figure A.4
2008 Wind Rose Diagram for Royal Roads University

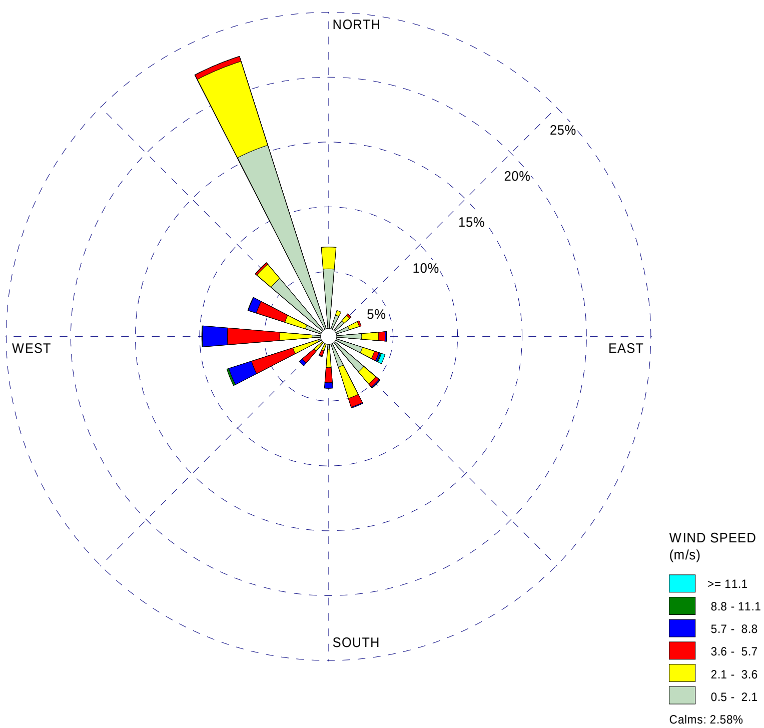


Figure A.5
2008 Wind Rose Diagram for Christopher Point[f]

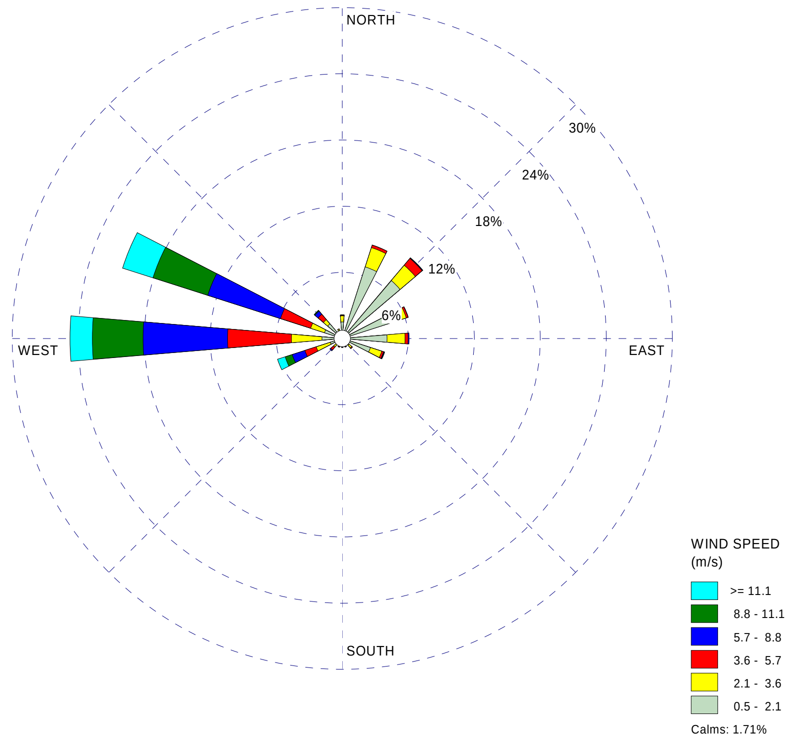
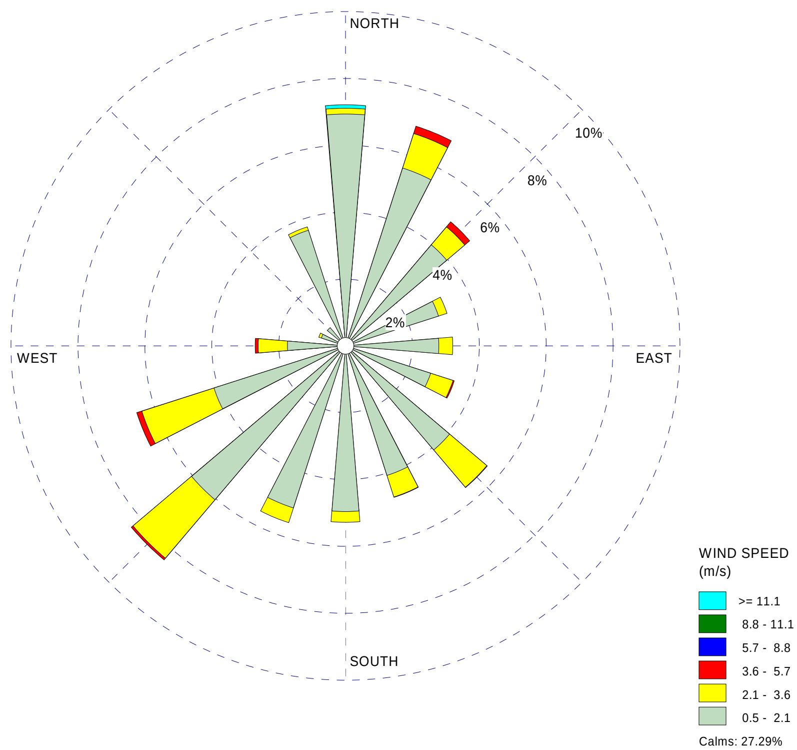


Figure A.6
2008 Wind Rose Diagram for Langford



Appendix B: Federal/Provincial Air Quality Objectives

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 summarised 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[18]. 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. Ambient air quality levels in the CRD in 2006 are compared with federal and provincial objectives in Table B.3.

[18] 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)[19]

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.**

[19] 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 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 $\mu g/m^3$

Table B.3
Comparison of Maximum Observed Pollutant Concentrations (μg/m³) in the CRD for 2008 with Provincial and Federal Objectives

Contaminant	Averaging Period	B.C. or Federal Maximum Acceptable Level	Victoria Topaz	Royal Roads	Stellys	Christopher Point	Langford	Oak Bay	Braefoot	Keating	Saturna Island
CO	1-hour	28000	4000		1600	1300	2200				
	8-hour	11000	2671.4		912.5	1250	671.4				
Nitrogen Dioxide	1-hour	400	90.7	55.5	59.1	56.4	98.3				
	24-hour	200	44.5	28.6	28.0	27.5	38.6				
	Annual	100	19.1	10.1	10.2	8.1	13.5				
Sulphur Dioxide	1-hour	900	146			28	16				
	24-hour	300	24.3			11.7	11.7				N/A
	Annual	60	3.6			2.7	2.0				
Ozone	1-hour	160	113.7	199.5	129.7	119.7	121.7				164
	24-hour	50	92.7	97.7	97.1	107.4	97.5				98.6
	Annual	50	38.1	44.9	42.0	55.3	39.6				54.9
PM_{10}	24-hour	50		30 (Hi-Vol)	25 (Partisol)		21 (Hi-Vol)	33 (Hi-Vol)	70 (Hi-Vol)	59 (Hi-Vol)	

Note: values in red indicate that the B.C. or Federal Maximum Acceptable Level has been exceeded

Appendix C: Solid Waste Burning and Air Quality in the CRD

C.1 GENERAL OVERVIEW

As part of the analysis of the 2008 air quality data, specific attention was directed at identifying the influence of emissions from solid waste burning in the CRD. In 2005, an analysis of $PM_{2.5}$ concentrations during the period 2001-2004 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[20]. 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. It was determined that a statistically significant increase in $PM_{2.5}$ concentrations existed on allowed burn days for each of the three communities, although the increase was not present in all months of the permitted burn season. The analysis supported a conclusion that solid waste (backyard) burning contributed to at least one exceedence of the $PM_{2.5}$ guideline value 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 indicated that air quality can be 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 indicated that improvements in air quality, with respect to suspended fine particulate matter, could be anticipated in those communities that reduce or eliminate solid waste (backyard) burning.

There are two communities within the CRD where continuous $PM_{2.5}$ monitoring data is available and that also have burning restrictions: these can be used to assess the relationship between ambient particulate matter air concentrations and community burning activities. Although the burn season varies by municipality, it generally consists of the fall, winter and spring months of the year for those locations where burning is allowed. The monitoring data for Central Saanich (Stellys) and Langford 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, 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. The allowed dates and days for open burning are listed in Table C.8.

[20] SENES Consultants Limited (SENES) 2005. Air Quality in the Capital Regional District 2004. Prepared for the Environmental Services Department, Capital Regional District, Victoria, BC.

Although differences may exist between $PM_{2.5}$ concentrations on burn days versus non-burn days, these differences may not be only due to the contribution from burning but instead can be the result in variation of other 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).

C.2 STATISTICAL METHODS

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, this means that only Fridays and Saturdays during months that solid waste burning was allowed were used. 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 (Stellys) 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 are potentially more confounding influences in the comparison for the community of Central Saanich (Stellys) since baseline concentrations may be different on Monday through Wednesday than on Thursdays and Fridays. Similar tests were performed on the other three locations (Topaz, Royal Roads and Christopher) to explore the potential for confounding of the analyses by other factors.

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 were 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 shows 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 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 $PM_{2.5}$ from other sources. This seasonal effect reduces the ability to detect a statistically 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).

The Wilcoxon test if designed to determine if there are differences in the median concentrations between the two sets of data. We have assessed that the mean concentrations are statistically significantly different if the medians are statistically significantly different.

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.

C.3 DISCUSSION OF RESULTS

C.3.1 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. The data include measurements from both 2007 and 2008, and it is of note there were a number of dates with missing measurements at the Stellys location over these time periods. 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 in December combined across the two years 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 19 and 13.6 µg/m^3, respectively, and the mean rank for burn days was 0.61. These statistics show that the calculated average concentration on burn days was higher than on non-burn days. Statistically significant differences were also observed for December 2008 and all burn months in 2008. When all data (2007-2008) were combined, there were statistically significant differences for February, December, the combination of April and November and, for all burn months combined. Using all data, the difference between burn days and non-burn days was 3.3 µg/m^3 based on averages of 18.1 µg/m^3 and 14.8 µg/m^3.

Table C.1
Daily Maximum 1-hour Average $PM_{2.5}$ Concentrations (µg/m³)
for Stellys (Central Saanich) in 2007-2008

Year	Month	Comparison of Average Values				Statistical Significance		
		Mean on Non-Burning Days	Mean Burning Days	Number of Non-Burning Days	Number of Burning Days	Wilcoxon (p-value)	Mean Rank	Rank Wilcoxon
2007	1	18.5	14.9	15	8	0.37	0.44	
2007	2	13.5	18.8	12	8	0.12	0.64	
2007	3	17.5	20	12	10	0.72	0.5	
2007	4	14.5	20	13	8	0.25	0.61	
2007	Apr	14.5	20	13	8	0.25	0.61	0.25
2007	All Burn	16.1	18.5	52	34	0.44	0.54	0.48
2008	11	12.8	18	12	8	0.23	0.61	
2008	12	12.1	16.5	15	8	0.10 *	0.65	
2008	Nov	12.8	18	12	8	0.23	0.61	0.23
2008	All Burn	12.4	17.3	27	16	0.04 *	0.63	0.04 *
All	1	18.5	14.9	15	8	0.37	0.44	
All	2	13.5	18.8	12	8	0.12	0.64	
All	3	17.5	20	12	10	0.72	0.5	
All	4	14.5	20	13	8	0.25	0.61	
All	11	12.8	18	12	8	0.23	0.61	
All	12	12.1	16.5	15	8	0.10 *	0.65	
All	Apr/Nov	13.6	19	25	16	0.10 *	0.61	0.09 *
All	All	14.8	18.1	79	50	0.06 *	0.57	0.07 *

Table C.2 shows the analysis of 24 hour concentrations at Stellys for data from 2007 through 2008. In most cases, the burn day average concentrations were higher than the non-burn days. There were statistically significant differences found for February 2007 and December 2008 and for all burn months. The difference was statistically significant when all data was considered. The difference in the means was 1.2 µg/m³ based on averages of 6.9 µg/m³ and 5.7 µg/m³, respectively for burn and non-burn days.

Table C.2
24-hour Average $PM_{2.5}$ Concentrations (µg/m³) for Stellys (Central Saanich) in 2004

Year	Month	Comparison of Average Values: Mean on Non-Burning Days	Mean Burning Days	Number on Non-Burning Days	Number of Burning Days	Statsitical Significance: Wilcoxon (p-value)	Mean Rank	Rank Wilcoxon
2007	1	7.8	6.7	15	8	0.48	0.45	
2007	2	5.8	8.6	12	8	0.08 *	0.64	
2007	3	6.5	7.4	12	10	0.72	0.53	
2007	4	5.9	7.7	13	8	0.37	0.57	
2007	April	5.9	7.7	13	8	0.37	0.57	0.37
2007	All Burn	6.6	7.6	52	34	0.23	0.55	0.25
2008	11	4.3	5.4	12	8	0.4	0.57	
2008	12	3.6	5.8	15	8	0.03 *	0.68	
2008	Nov	4.3	5.4	12	8	0.4	0.57	0.4
2008	All Burn	3.9	5.6	27	16	0.03 *	0.62	0.03 *
All	1	7.8	6.7	15	8	0.48	0.45	
All	2	5.8	8.6	12	8	0.08 *	0.64	
All	3	6.5	7.4	12	10	0.72	0.53	
All	4	5.9	7.7	13	8	0.37	0.57	
All	11	4.3	5.4	12	8	0.4	0.57	
All	12	3.6	5.8	15	8	0.03 *	0.68	
All	Apr:Nov	5.1	6.5	25	16	0.27	0.57	0.21
All	All Burn	5.7	6.9	79	50	0.03 *	0.57	0.03 *

Direct interpretation of the results considers that $PM_{2.5}$ concentrations on Monday-Wednesday would have a similar distribution 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 to 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. The potential for confounding is explored in a Section C.3.3.

C.3.2 Langford

There is an expectation that the effect may be more apparent at Langford compared to Central Saanich as the burning days are much more restricted in Langford so that burning occurs on fewer days. Burning is allowed on only two days of the month at Langford while burning is allowed on more than 12 days (Thursday through Saturday) in Central Saanich. The difference in concentrations between burn days and non-burn days will tend to be higher in 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 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 potentially results in a lower number of measurements in the analyses compared to Stellys, the potential for confounding by day-of-the-week is lowered since burn days on Friday and Saturdays are not compared to other days of the week. Generally, the average concentration on burn days is higher than the average concentration on non-burn days with many individual months having statistically significant differences for 1 hour maximums. Combining all burn months in 2007 and 2008, the difference in means is 7.4 μg/m^3 (from 16 and 8.6 μg/m^3) and this is also denoted as statistically significant. The differences for considering burn months are statistically significantly different for 2007 and for the combined 2007-2008 data.

Table C.4 shows the analysis of 24 hour concentrations at Langford for data from 2007 through 2008. In most cases, the burn day average concentrations were higher than the non-burn days; however, 2008 was quite unusual as four months (January, February, May, and November) had lower mean concentrations on burn days compared to non-burn days. There were statistically significant differences for many months and for all burn months where the burn days had higher average concentrations than the non-burn days. The difference was statistically significant when all data were considered and the difference in means was 1.9 μg/m^3 based on averages of 5.4 μg/m^3 and 3.5 μg/m^3, respectively for burn and non burn-days. The possible presence of confounding is discussed in a Section C.3.3.

Table C.3
Daily Maximum 1-hour Average $PM_{2.5}$ Concentrations (µg/m³) for Langford in 2007 through 2008

Year	Month	Comparison of Average Values				Statistical Significance		
		Mean on Non-Burning Days	Mean Burning Days	Number of Non-Burning Days	Number of Burning Days	Wilcoxon (p-value)	Mean Rank	Rank Wilcoxon
2007	2	7.3		4				
2007	3	6.3	9.5	8	2	0.15	0.77	
2007	4	5.7	12.5	6	2	0.04 *	0.83	
2007	5	6	16.5	6	2	0.09 *	0.83	
2007	11	9	18	7	2	0.14	0.75	
2007	12	7.9	29	7	2	0.04 *	0.85	
2007	Apr:May: Nov	7	15.7	19	6	0.00 *	0.81	0.00 *
2007	All Burn	7	17.1	38	10	0.00 *	0.81	0.00 *
2008	1	11.8	5	6	2	0.31	0.44	
2008	2	10.6	17	7	2	0.18	0.75	
2008	3	7	18.5	7	2	0.04 *	0.85	
2008	4	9.7	5	6	2	0.06 *	0.22	
2008	5	9	17.5	8	2	0.06 *	0.82	
2008	11	11.7	12	7	2	0.76	0.7	
2008	12	6.5	32	6	2	0.05 *	0.83	
2008	Apr:May: Nov	10.1	11.5	21	6	0.66	0.58	0.54
2008	All Burn	9.5	15.3	47	14	0.05 *	0.66	0.03 *
All	1	11.8	5	6	2	0.31	0.44	
All	2	9.4	17	11	2	0.11	0.75	
All	3	6.6	14	15	4	0.01 *	0.81	
All	4	7.7	8.8	12	4	0.67	0.53	
All	5	7.7	17	14	4	0.01 *	0.83	
All	11	10.4	15	14	4	0.2	0.73	
All	12	7.2	30.5	13	4	0.00 *	0.84	
All	Apr:May: Nov	8.6	13.6	40	12	0.02 *	0.69	0.01 *
All	All Burn	8.4	16	85	24	0.00 *	0.72	0.00 *

Table C.4
24-hour Average $PM_{2.5}$ Concentrations ($\mu g/m^3$) for Langford in 2007-2008

Year	Month	Comparison of Average Values				Statsitical Significance		
		Mean on Non-Burning Days	Mean Burning Days	Number on Non-Burning Days	Number of Burning Days	Wilcoxon (p-value)	Mean Rank	Rank Wilcoxon
2007	2	2.9		4				
2007	3	2.7	4.4	8	2	0.19	0.73	
2007	4	1.8	7.3	6	2	0.05 *	0.83	
2007	5	3	3.5	6	2	0.74	0.56	
2007	11	4.1	7	7	2	0.24	0.7	
2007	12	2	5.5	7	2	0.04 *	0.85	
2007	Apr:May:Nov	3	5.9	19	6	0.02 *	0.7	0.04 *
2007	All Burn	2.8	5.5	38	10	0.00 *	0.73	0.00 *
2008	1	4.8	1.7	6	2	0.32	0.33	
2008	2	4.5	3.5	7	2	0.56	0.4	
2008	3	2.3	7.8	7	2	0.04 *	0.85	
2008	4	4.5	1.7	6	2	0.10 *	0.22	
2008	5	5.3	6.4	8	2	0.3	0.68	
2008	11	4.5	3.6	7	2	0.77	0.45	
2008	12	2.5	12.4	6	2	0.05 *	0.83	
2008	Apr:May:Nov	4.8	3.9	21	6	0.48	0.45	0.64
2008	All Burn	4.1	5.3	47	14	0.52	0.54	0.5
All	1	4.8	1.7	6	2	0.32	0.33	
All	2	3.9	3.5	11	2	1	0.4	
All	3	2.5	6.1	15	4	0.01 *	0.79	
All	4	3.2	4.5	12	4	0.63	0.53	
All	5	4.3	5	14	4	0.4	0.62	
All	11	4.3	5.3	14	4	0.52	0.58	
All	12	2.3	8.9	13	4	0.00 *	0.84	
All	Apr:May:Nov	3.9	4.9	40	12	0.24	0.57	0.27
All	All Burn	3.5	5.4	85	24	0.01 *	0.62	0.01 *

C.3.3 Analysis of Potential Confounding Factors

The statistical analyses were completed for Victoria Topaz using the Langford rule to explore the potential for confounding of the Langford analysis. 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 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 may have arisen from some meteorological or emission influence other than solid waste burning.

Table C.5, with maximum 1-hour average concentrations, shows that some months have statistically significant differences between Langford burn and non-burn days. For the entire grouped data, the statistical significance is almost reached and the mean 1-hour average maximum concentration on burn days is higher than the mean concentration on non-burn days. Table C.6 shows a similar pattern for 24-hour average concentrations. The all data means for burn days are higher than the means for the non-burn days, and this is statistically significant.

The pattern observed with the Victoria Topaz data is surprising and suggests that there may be a confounding factor in the assessment of the effect of waste burning days in Langford. The effect of Langford burning on Topaz concentrations is expected to be minimal and there seems to be little reason that the emissions of other sources may be higher on the first weekend in each of the burn months. There may be potential for meteorological confounding such as differences in wind direction or precipitation on the burn days compared to the non-burn days in Langford.

Table C.5
Daily Maximum 1-hour Average $PM_{2.5}$ Concentrations (µg/m³)
for Victoria Topaz During 2007-2008

Year	Month	Comparison of Average Values				Statistical Significance		
		Mean on Non-Burning Days	Mean Burning Days	Number of Non-Burning Days	Number of Burning Days	Wilcoxon (p-value)	Mean Rank	Rank Wilcoxon
2007	1	23.2	14	6	2	0.31	0.33	
2007	2	8.8	47.5	6	2	0.04 *	0.83	
2007	3	10.5	11.5	8	2	0.79	0.55	
2007	4	7.8	23	6	2	0.04 *	0.83	
2007	5	11	8.5	6	2	0.5	0.39	
2007	11	20.1	20	7	2	0.56	0.6	
2007	12	9.1	34	7	2	0.14	0.75	
2007	Apr:May:Nov	13.4	17.2	19	6	0.2	0.61	0.41
2007	All Burn	12.9	22.6	46	14	0.01 *	0.61	0.12
2008	1	23.3	6	6	2	0.09 *	0.22	
2008	2	16.7		6				
2008	3	11.7	19.5	7	2	0.14	0.75	
2008	4	11	8.5	2	2	1	0.5	
2008	5	15.3		6				
2008	11	14		7				
2008	12	10.2	18.5	6	2	0.18	0.72	
2008	Apr:May:Nov	14.1	8.5	15	2	0.37	0.5	0.88
2008	All Burn	14.9	13.1	40	8	0.81	0.55	0.63
All	1	23.3	10	12	4	0.09 *	0.28	
All	2	12.8	47.5	12	2	0.03 *	0.83	
All	3	11.1	15.5	15	4	0.16	0.65	
All	4	8.6	15.8	8	4	0.17	0.67	
All	5	13.2	8.5	12	2	0.27	0.39	
All	11	17.1	20	14	2	0.43	0.6	
All	12	9.6	26.3	13	4	0.06 *	0.74	
All	Apr:May:Nov	13.7	15	34	8	0.58	0.58	0.5
All	All Burn	13.8	19.2	86	22	0.08 *	0.59	0.12

Table C.6
24-hour Average $PM_{2.5}$ Concentrations (µg/m³) for Victoria Topaz During 2004

Year	Month	Comparison of Average Values: Mean on Non-Burning Days	Mean Burning Days	Number on Non-Burning Days	Number of Burning Days	Statsitical Significance: Wilcoxon (p-value)	Mean Rank	Rank Wilcoxon
2007	1	7.6	3.9	6	2	0.32	0.33	
2007	2	3.6	17.1	6	2	0.05 *	0.83	
2007	3	3.9	4.6	8	2	0.43	0.64	
2007	4	3.3	11.8	6	2	0.04 *	0.83	
2007	5	4.5	3.3	6	2	0.5	0.39	
2007	11	8	7.3	7	2	0.77	0.55	
2007	12	3.1	9.2	7	2	0.24	0.7	
2007	Apr:May: Nov	5.4	7.5	19	6	0.19	0.59	0.36
2007	All Burn	4.9	8.2	46	14	0.03 *	0.61	0.08 *
2008	1	7.5	1.6	6	2	0.18	0.28	
2008	2	6.4		6				
2008	3	3.4	7.9	7	2	0.04 *	0.85	
2008	4	5	2.2	2	2	0.12	0.3	
2008	5	7.4		6				
2008	11	5.3		7				
2008	12	3.4	10.6	6	2	0.05 *	0.83	
2008	Apr:May: Nov	6.1	2.2	15	2	0.07 *	0.3	0.23
2008	All Burn	5.5	5.6	40	8	0.88	0.57	0.4
All	1	7.6	2.7	12	4	0.11	0.31	
All	2	5	17.1	12	2	0.03 *	0.83	
All	3	3.7	6.3	15	4	0.02 *	0.74	
All	4	3.7	7	8	4	0.5	0.57	
All	5	6	3.3	12	2	0.2	0.39	
All	11	6.7	7.3	14	2	0.53	0.55	
All	12	3.3	9.9	13	4	0.03 *	0.77	
All	Apr:May: Nov	5.7	6.2	34	8	0.92	0.52	0.87
All	All Burn	5.1	7.2	86	22	0.11	0.59	0.05 *

The statistical analyses were completed for Victoria Topaz using the Langford rule to explore the potential for confounding of the Langford analysis. 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 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 may have arisen from some meteorological or emission influence other than solid waste burning.

Table C.5, with maximum 1-hour average concentrations, shows that some months have statistically significant differences between Langford burn and non-burn days. For the entire grouped data, the statistical significance is almost reached and the mean 1-hour average maximum concentration on burn days is higher than the mean concentration on non-burn days. Table C.6 shows a similar pattern for 24-hour average concentrations. The all data means for burn days are higher than the means for the non-burn days, and this is statistically significant.

The pattern observed with the Victoria Topaz data is surprising and suggests that there may be a confounding factor in the assessment of the effect of waste burning days in Langford. The effect of Langford burning on Topaz concentrations is expected to be minimal and there seems to be little reason that the emissions of other sources may be higher on the first weekend in each of the burn months. There may be potential for meteorological confounding such as differences in wind direction or precipitation on the burn days compared to the non-burn days in Langford.

C.4 CONCLUSIONS

Table C.7 summarizes the calculated difference in average concentrations between burn and non-burn days for all months. Results are shown for the two locations with allowable burn days along with the same rule applied to the other locations to investigate the potential for confounding. The table indicates that there is potential for confounding as applying either the Langford or Saanich burn rule to other locations results in higher concentrations on the burn days compared to non-burn days and in some cases this difference is statistically significant. The confounding seems to be most pronounced for the comparisons of Thursday and Friday against Monday, Tuesday and Wednesday for the Central Saanich burn rule. All four locations, other than Stellys, show higher average concentrations on the Central Saanich burn days compared to the Central Saanich non-burn days. In some cases at Royal Roads and Topaz, the statistical significance of the difference is higher than at Stellys. The level of confounding at Stellys cannot be assessed using the other location since it is unlikely that the day-of-week pattern in emissions, other than burning, is the same in all these areas. The reason for this apparent confounding is unclear and it is possible that some local confounding may also be present at Stellys. Without the removal of confounding, there is limited evidence of higher $PM_{2.5}$ on burn days at the Stellys monitoring location.

Table C.7: Summary of Differences (μg/m³) in Average $PM_{2.5}$ Concentrations Between Burn Days and Non-burn Days for All Burn Months

Location	24-hour Average	Maximum 1-hour Average
Langford Rule for Burn Days		
Langford	1.9 **	7.6 **
Christopher Point	1.1	2.5
Royal Roads	2.1	5.7 *
Stellys	4.3 *	6.8
Topaz	2.1 *	5.4
Central Saanich Rule for Burn Days		
Stellys	1.2 *	3.3 *
Christopher Point	0.6 *	1 *
Langford	0.7 *	0.9 *
Royal Roads	1 **	2.7 **
Topaz	1.5 **	3.4 **

Notes:

* statistically significant at 95% level
** statistically significant at 99% level

The Langford analyses indicate statistically significant increases at the 99% (one-sided) level for both 24-hour and maximum 1-hour averages. There is some evidence of confounding at the other locations since the difference in concentrations between Langford burn and non-burn days are consistently positive and some of the differences are statistically significant, but not as statistically significant as at the Langford station. The presence of confounding is unusual since the burn and non-burn comparisons have been completed for the same days of the week. There is potentially meteorological confounding present where the burn days may have been drier or the winds consistently from a different direction compared to the non-burn days. Since the Langford data are more statistically significant, it is expected that there is a difference associated with burn days above confounding that might be present. Previous analyses were conducted in 2004 and the confounding with Topaz was minimal where the differences were slightly negative and not statistically significant.

These analyses support the conclusion that open burning contributes to $PM_{2.5}$ concentrations in Langford, but that there may be confounding that affects the analyses of Stellys data. It could be very difficult to remove the confounding present in the Stellys analyses to determine if burning contributes to higher air concentrations. The confounding may be meteorological conditions and may not appear in future years, such that subsequent analyses in future years may be more successful in identifying the effect of open burning on air quality in Central Saanich.

Table C.8: Allowed Dates, Days, and Times for Open Burning, Incinerator Burning, and Beach Fires

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	Not Allowed	Not Allowed	Not Allowed	Not Allowed	Not Allowed	Not Allowed	Not Allowed	Not Allowed	Not Allowed	Not Allowed	Not Allowed	Not Allowed
Highlands	All year round (subject to fire hazard conditions)	All year round	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	Yes	Yes *no permit required from Oct 15 to Apr 1 for Class B fires	Not Applicable No beaches in Highlands
Langford	Nov to May 15	Nov to May 15	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	All year round with time restrictions for certain times of the year	All year round	Any day	Any day	Any day	Sunrise to sunset	Sunrise to sunset	Extinguished by midnight	No	No	No
North Saanich	Nov 1 to May 15	Nov 1 to May 15	All year round	1st and 3rd consecutive Thurs. Fri. Sat of each allowed month	1st and 3rd consecutive Thurs. Fri. Sat of each allowed month	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
Saanich	Oct. 16th to Apr. 30th (can be banned	Oct. 16th to Apr. 30th (can be banned	All year round (can be banned anytime of	Fri. and Sat.	Fri. and Sat.	Any day	From sunrise to sunset on Fri; From Sunrise to	From sunrise to sunset on Fri; From sunrise to	From sunrise to 11pm.	No *However, no burning allowed	Yes *Burning not allowed within Urban	Yes

Appendix D: 2008 Cruise Ship Emissions and Air Quality in the CRD

D.1 GENERAL OVERVIEW

In 2006, researchers at the University of Victoria were approached by the Vancouver Island Health Authority (VIHA) with a request from the James Bay Neighbourhood Association (JBNA) to investigate air quality and possible related health risks in the area in relation to emissions from cruise vessels, passenger and vehicle ferries, diesel bus traffic, float planes and helicopters operating in the area. The James Bay Air Quality Study (JBAQS) Phase II[21], which was completed in December 2008, used atmospheric dispersion modelling to determine the relative contribution of individual source groups to the air quality in the James Bay community during the 2007 summer cruise ship sailing season. As part of the analysis of the 2008 air quality data, specific attention was directed at identifying the influence of emissions from cruise ships operating out of Ogden Point in the Port of Victoria.

The JBAQS estimated that the maximum 1-hour average SO_2 concentration in the James Bay community due to cruise ship and ferry emissions alone was 151 $\mu g/m^3$. The highest maximum predicted 1-hour average SO_2 concentration in the modelling domain due to emissions from these sources was 257 $\mu g/m^3$. The maximum predicted 1-hour average SO_2 concentrations were well below the BC Level A and Canadian Maximum Desirable objective of 450 $\mu g/m^3$. The maximum 24-hour average SO_2 concentration in the James Bay Community was predicted to be 40 $\mu g/m^3$, including 33 $\mu g/m^3$ from cruise ships and ferries and 7 $\mu g/m^3$ from other background sources. This estimated 24-hour average concentration was well below the guideline level of 125 $\mu g/m^3$ established by the CRD for air quality reporting purposes, as well as below the BC Level A and Canadian Maximum Desirable objectives f 160 $\mu g/m^3$ and 150 $\mu g/m^3$, respectively. However, the maximum predicted 24-hour average SO_2 concentration exceeded the World Health Organization's (WHO) guideline value of 20 $\mu g/m^3$ for 24-hour average concentrations.[22]

For other contaminants, the JBAQS determined that, although the emissions from cruise ships and ferries make significant contributions to the air quality in the James Bay community, these emissions would generally not be expected to exceed either the CRD, BC Level A, Canadian or WHO objectives/guidelines or standards for NO_2, PM_{10} or $PM_{2.5}$ concentrations. The analysis indicated that the CRD and WHO guidelines for NO_2 might be slightly exceeded on rare occasions, but that otherwise all ambient air quality criteria for these three contaminants would be met.

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[21] James Bay Air Quality Study Team 2008. James Bay Air Quality Study: Phase II – Report on the Results of CALPUFF Air Quality Dispersion Modelling 2007. Prepared by the University of Victoria, Spatial Sciences Research Laboratory and SENES Consultants Limited for the Vancouver Island Health Authority, Victoria, BC.
[22] World Health Organization 2006. *WHO Air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide. Global Update 2005. Summary Risk Assessment.*

The maximum predicted concentrations and relevant ambient air quality criteria for each contaminant are summarized in Table D.1.

Table D.1
Summary of JBAQS Phase II Dispersion Modelling Results

Contaminant	JBAQS Maximum Predicted Concentrations ($\mu g/m^3$)			Ambient Air Quality Criteria ($\mu g/m^3$)			
	Cruise Ships /Ferries	Background	Total	CRD Guideline	BC Level A	Canadian Maximum Acceptable	WHO Guideline
SO_2 (1-h)	257	13	270	-	450	900	-
SO_2 (24-h)	33	7	40	125	160	300	20
NO_2 (1-h)	153	51	204	200	-	400	200
NO_2 (24-h)	17	36	53	-	-	200	-
PM_{10} (1-h)	20	19	39	-	-	-	-
PM_{10} (24-h)	4	14	18	50	50	-	50
$PM_{2.5}$ (1-h)	30	16	46	-	-	-	-
$PM_{2.5}$ (24-h)	4	12	16	25	25	30[a]	25

[a] 98th percentile averaged over 3 consecutive years, achievement by 2010

Based on the dispersion modelling analysis, the JBAQS concluded that cruise ships were the most influential source of emissions to air quality in the James Bay community, and that the WHO guideline for 24-hour averaged SO_2 concentrations may be exceeded in the community about 3% of the time, as well as in a limited portion of the Songhees north of Laurel Point in the Victoria Harbour, and in downtown Victoria.

As a quality assurance exercise, the JBAQS compared the model predicted concentration at the Victoria Topaz station with observed contaminant concentration levels. The maximum modelled 1-hour average contaminant concentrations were lower at the Topaz site than those actually measured, as summarized below:

Contaminant	Maximum Predicted Concentration ($\mu g/m^3$)	Maximum Observed Concentration ($\mu g/m^3$)
SO_2	48	88
NO_2	60	77
$PM_{2.5}$	5	69

The maximum modelled 24-hour average concentrations of these contaminants at the Topaz site were significantly lower than the maximum observed concentrations, indicating that other sources may contribute to the ambient concentrations recorded at the Topaz monitoring site.

Of particular interest to the current analysis presented in the following section is the ratio of the maximum predicted 1-hour average SO_2 concentration of 257 µg/m^3 near the cruise ship berths at Ogden Point and the maximum predicted SO_2 concentration of 48 µg/m^3 at the Victoria Topaz site. The ratio of 5.35 represents the difference in concentrations between the two locations that could be attributed solely to the emissions from cruise ships. As will be discussed in the following section, the analysis of the SO_2 monitoring data at Victoria Topaz in relation to cruise ship sailing schedules suggests that the JBAQS modelling analysis may have underestimated the relative contribution of cruise ship emissions to the SO_2 concentrations recorded at the Topaz site in 2008 by about a factor of 3.0. On the other hand, the analysis of the 2008 monitoring data at the Topaz site supports the JBAQS results with respect to $PM_{2.5}$ but suggests that the maximum predicted NO_2 concentrations may have been overestimated.

D.2 2008 CRUISE SHIP ANALYSIS

There were a total of 201 cruise ship sailings from Ogden Point during the 2008 season, between April 3rd and October 14th. The median arrival/departure times for cruise ships were 17:36 and 23:35, with a median stay at the Ogden Point dockside of 6.15 hours. The earliest vessel arrival time in 2008 was at 5:37 in the morning, and the latest departure time was 24 minutes after midnight. The schedule of cruise ship arrivals/departures is attached at the end of Appendix D.

D.2.1 SO_2 Concentrations at Topaz

The median arrival/departure times for the cruise ships coincide with the period of highest observed 1-hour average SO_2 concentrations at the Victoria Topaz monitoring station (see Figure 3.10, Section 3.3) in 2008. For example, Figure D.1 shows the probability frequency distributions for all hours between April 1st and October 30th when cruise ships were docked at Ogden Point versus hours when there where no ships docked, regardless of wind direction as measured at the Victoria Topaz site. It is immediately obvious that, even without considering wind direction or time of day as separate variables, SO_2 concentrations measured at the Victoria Topaz site are generally higher when cruise ships are docked at Ogden Point than when there are no cruise ships in the harbour, and the highest observed 1-hour average SO_2 concentration of 146 µg/m^3 corresponds to a period when cruise ships were present. The latter concentration is 2.7 times higher than the highest concentration of 54 µg/m^3 recorded when there were no cruise ships docked at Ogden Point.

Figure D.1
Comparison of Hourly Averaged SO_2 Concentrations
Victoria Topaz: April 1 – October 15, 2008

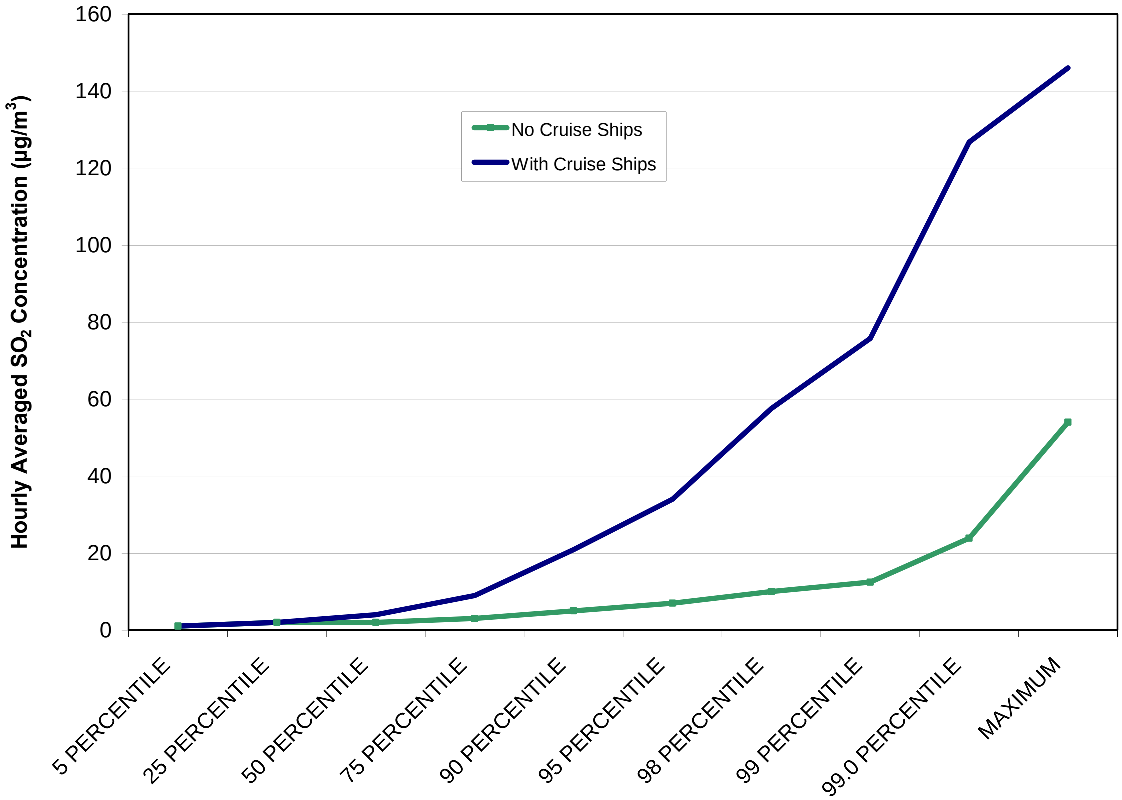


Figure D.2 shows that the hourly averaged SO_2 concentrations at the Topaz site are highest when the cruise ships are docked at Ogden Point and winds are blowing from the southwest ($\pm 22.5^0$), placing the Topaz site directly downwind of Ogden Point. For all other wind directions, SO_2 concentrations at Topaz remain generally somewhat higher from the 75^{th} through 99^{th} percentile levels when cruise ships are docked at Ogden Point than when they are absent.

Figure D.3 shows the 1-hour average SO_2 concentrations at Victoria Topaz for all hours when cruise ships were docked at Ogden Point with wind direction at the Topaz site. Clearly, the highest SO_2 concentrations are recorded with winds from 190^0 to 240^0, roughly SSW to WSW, essentially when the monitoring station is downwind of Ogden Point.

Figure D.2: Comparison of Hourly Averaged SO_2 Concentrations Segregated by Wind Direction
Victoria Topaz: April 1 – October 15, 2008

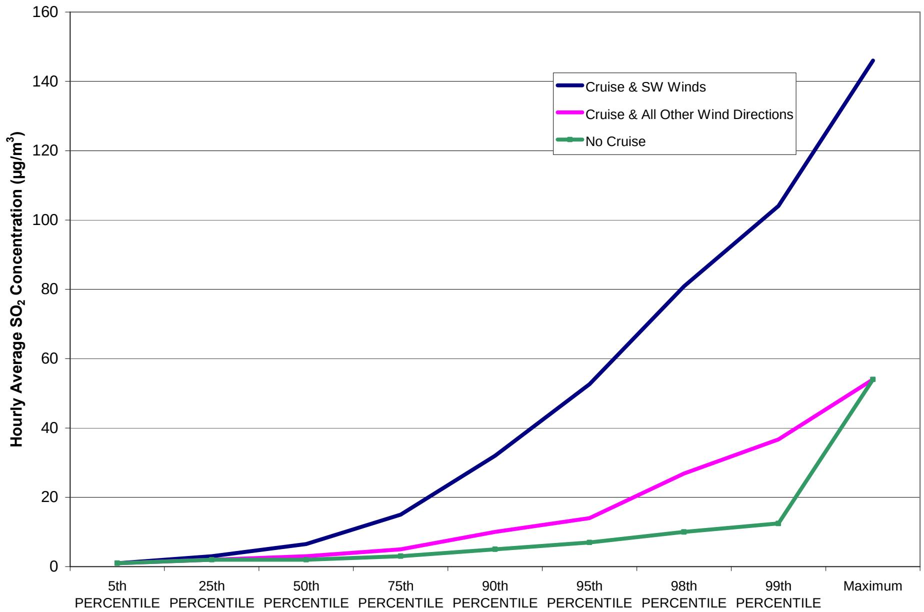
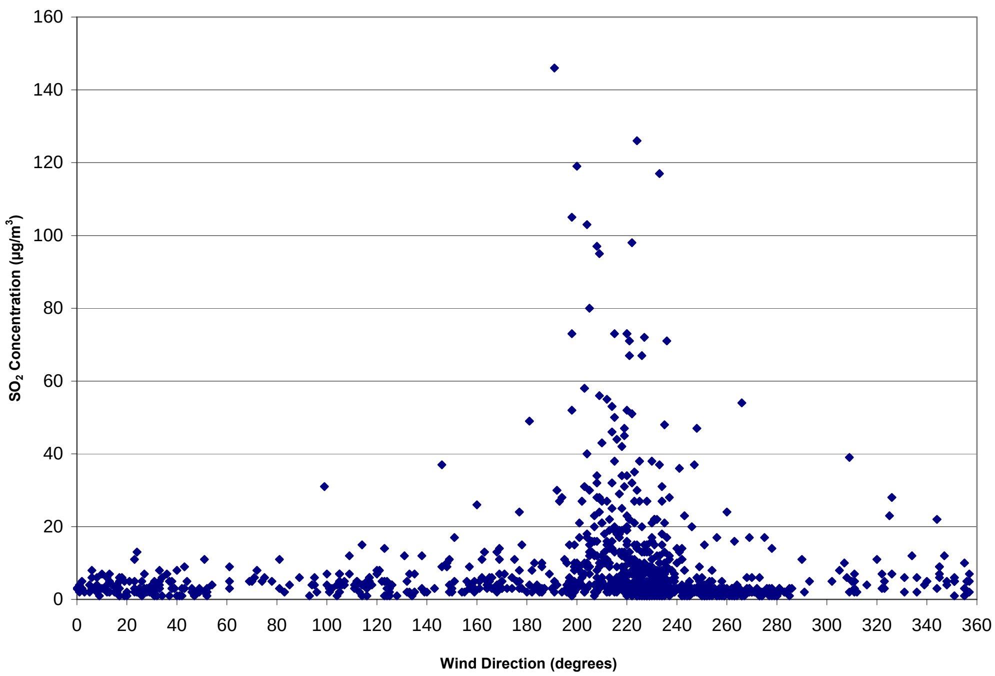


Figure D.3: Comparison of Hourly Averaged SO_2 Concentrations at Victoria Topaz and Wind Direction
During Hours when Cruise Ships are at Ogden Point



Since there were fewer cruise ship sailings in both April and October, the analysis was repeated using only the data for the period May through September in order to remove any potential bias of an inordinate number of days without cruise ships. Figure D.4 shows the probability frequency distributions for that period, while Figures D.5 and D.6 show the distributions segregated for weekdays (Monday through Friday) and weekend days (Saturdays and Sundays) separately. All three figures show that hourly averaged SO_2 concentrations recorded at the Topaz site are higher when cruise ships are docked at Ogden Point than when they are not.

Figure D.4
Comparison of Hourly Averaged SO_2 Concentrations
Segregated by Wind Direction
Victoria Topaz: May – September, 2008

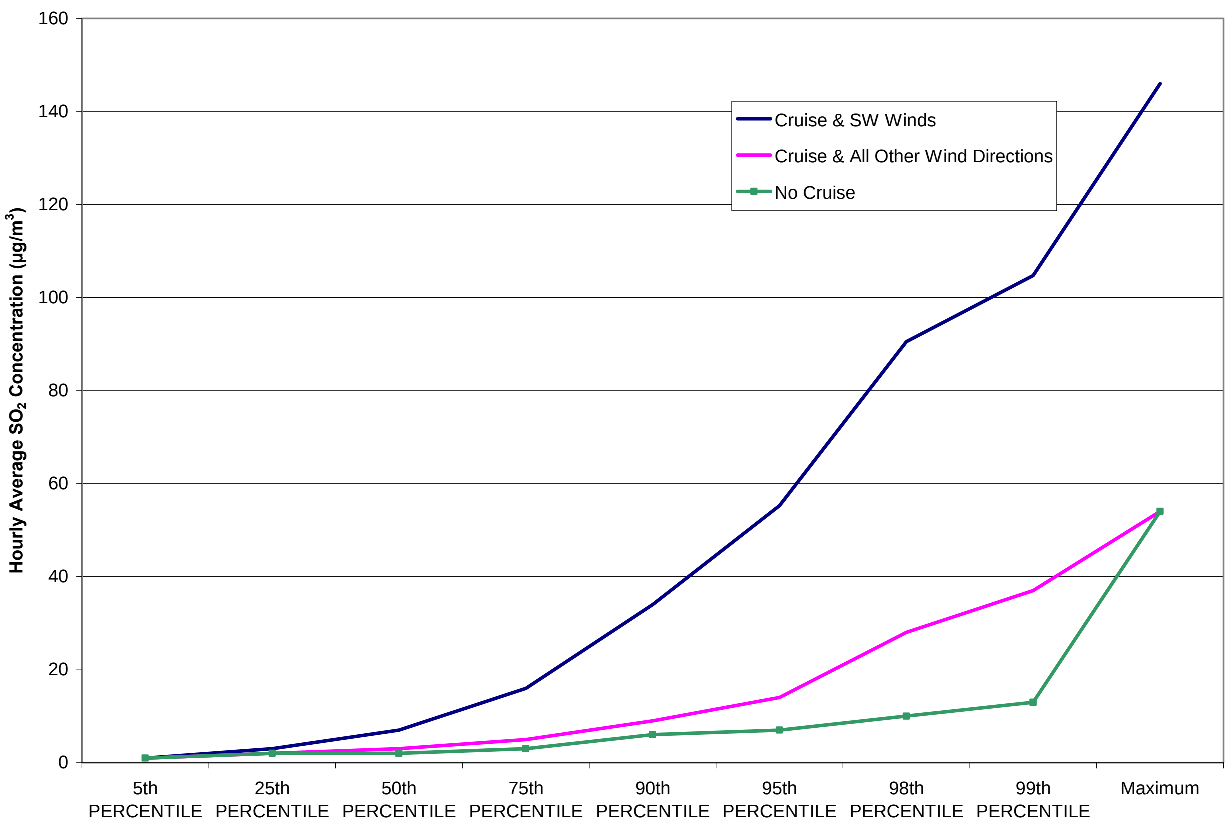


Figure D.5: Comparison of Weekday Hourly Averaged SO_2 Concentrations Segregated by Wind Direction for Victoria Topaz: May – September, 2008

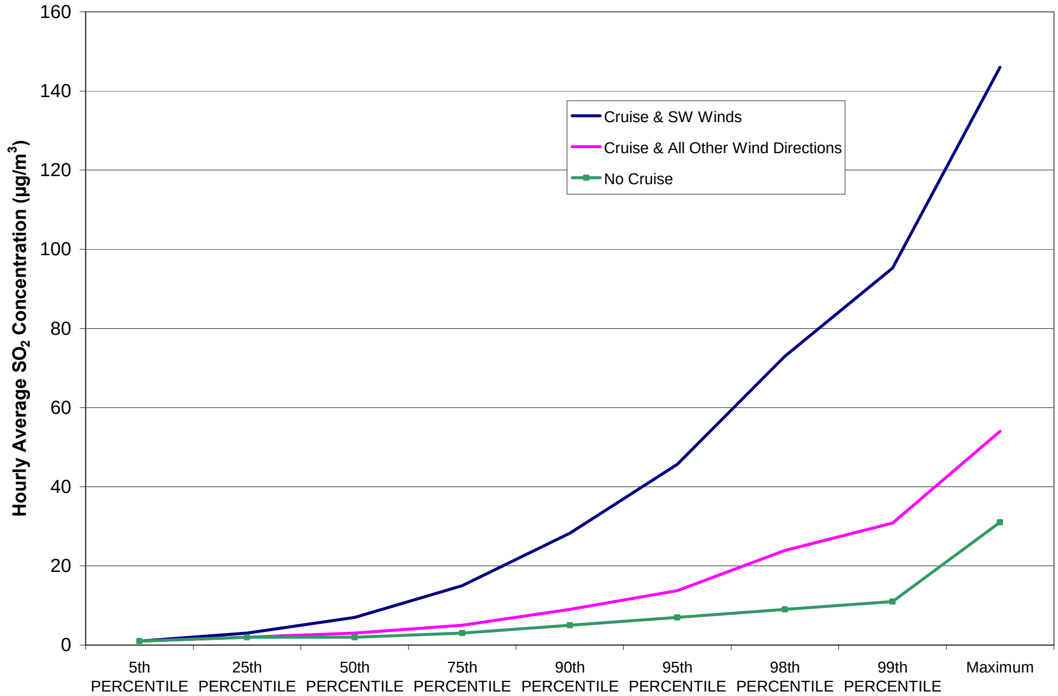


Figure D.6: Comparison of Weekend Hourly Averaged SO_2 Concentrations Segregated by Wind Direction for Victoria Topaz: May – September, 2008

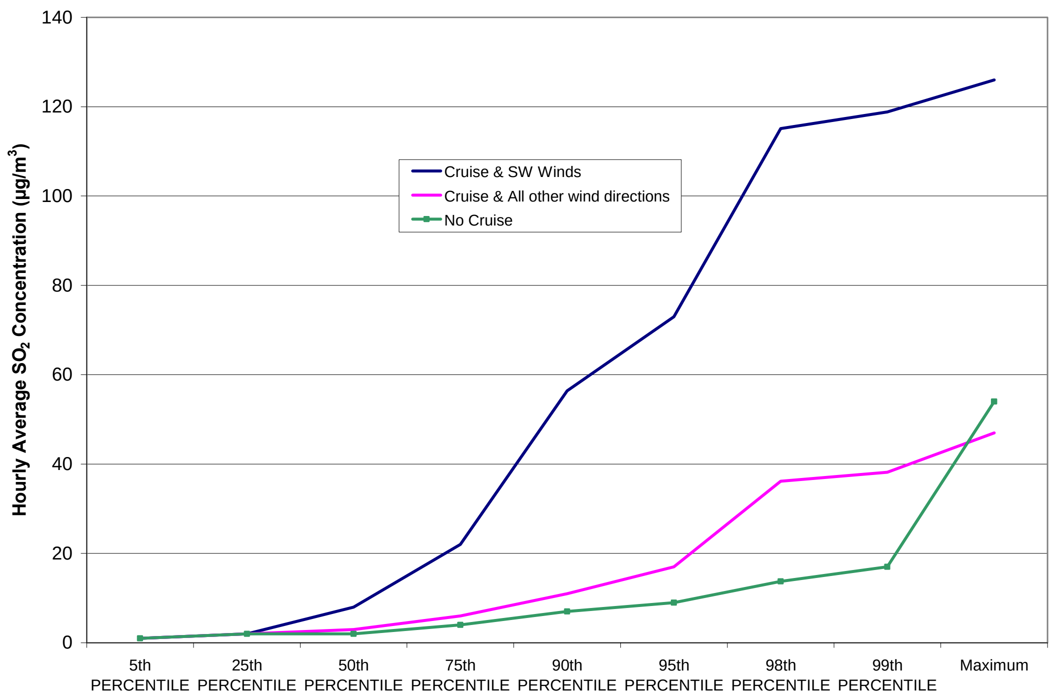


Figure D.7 provides a plot of the diurnal variation in hourly averaged SO_2 concentrations at Victoria Topaz for hours when cruise ships are docked at Ogden Point and winds are blowing from the SW, for hours when cruise ships are docked at Ogden Point and winds are blowing from other directions, and for hours when there are no cruise ships docked at Ogden Point.

Figure D.7
Diurnal Variation in Average SO_2 Concentrations
Segregated by Wind Direction
Victoria Topaz: April 1 – October 15, 2008

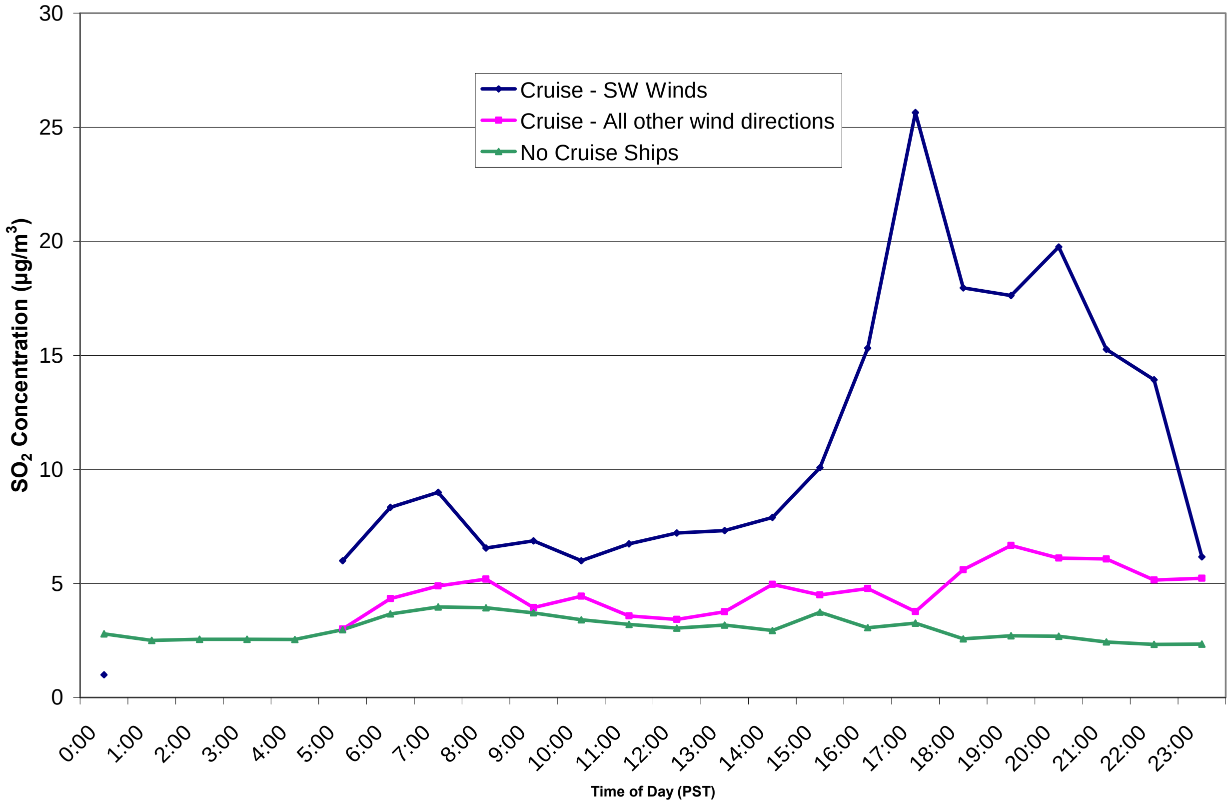


Figure D.7 shows that average SO_2 concentrations at the Topaz site are always highest when cruise ships are docked at Ogden Point and winds are from the SW, regardless of the time of day. Average SO_2 concentrations are also slightly higher at Topaz for all other wind directions when cruise ships are docked at Ogden Point. There is very little variation in average SO_2 concentrations over the day when cruise ships are absent from the port, and the diurnal pattern of SO_2 concentrations at Topaz during these periods resembles the diurnal variation observed at Langford and at Christopher Point (see Figure 3.10, Section 3.3). Figures D.8, D.9 and D.10 show that the same basic pattern exists for the period May-September, and for weekdays and weekends alike.

Figure D.8
Diurnal Variation in Average SO_2 Concentrations
Segregated by Wind Direction
Victoria Topaz: May - September, 2008

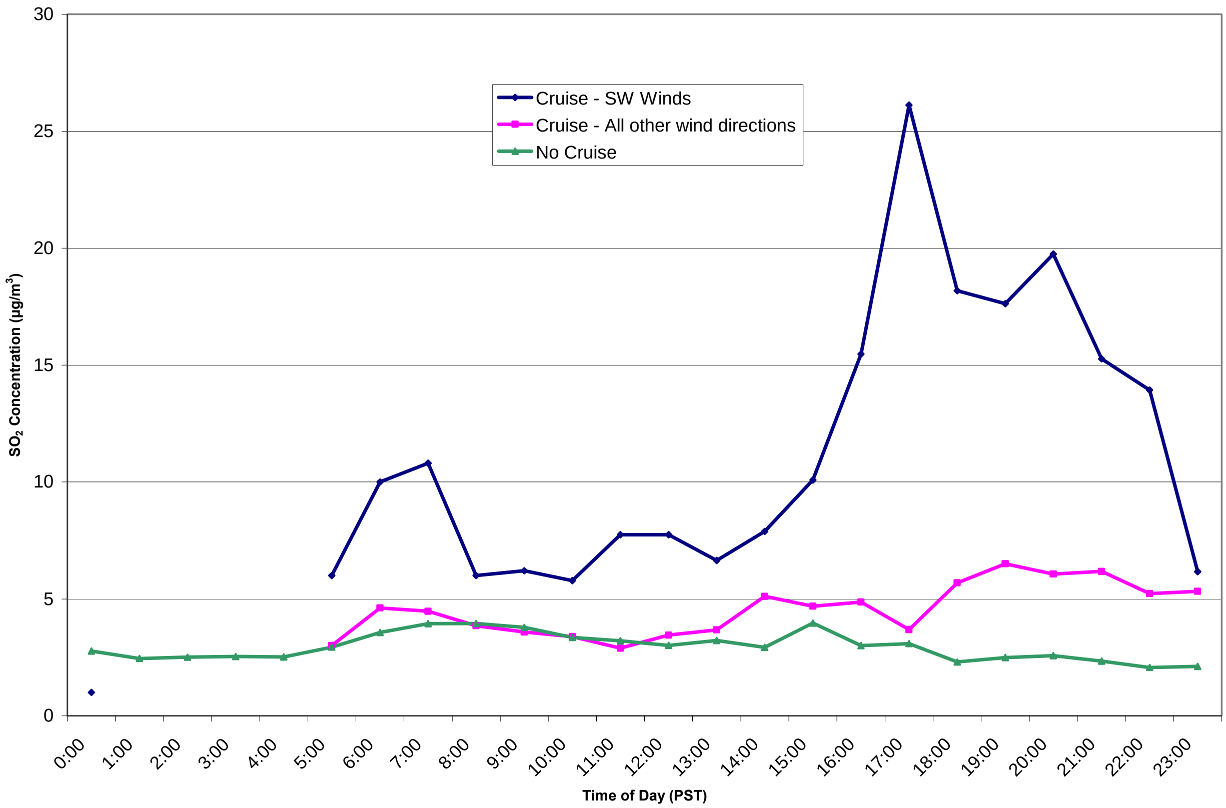


Figure D.9: Diurnal Weekday Variation in Average SO_2 Concentrations Segregated by Wind Direction at Victoria Topaz: May - September, 2008

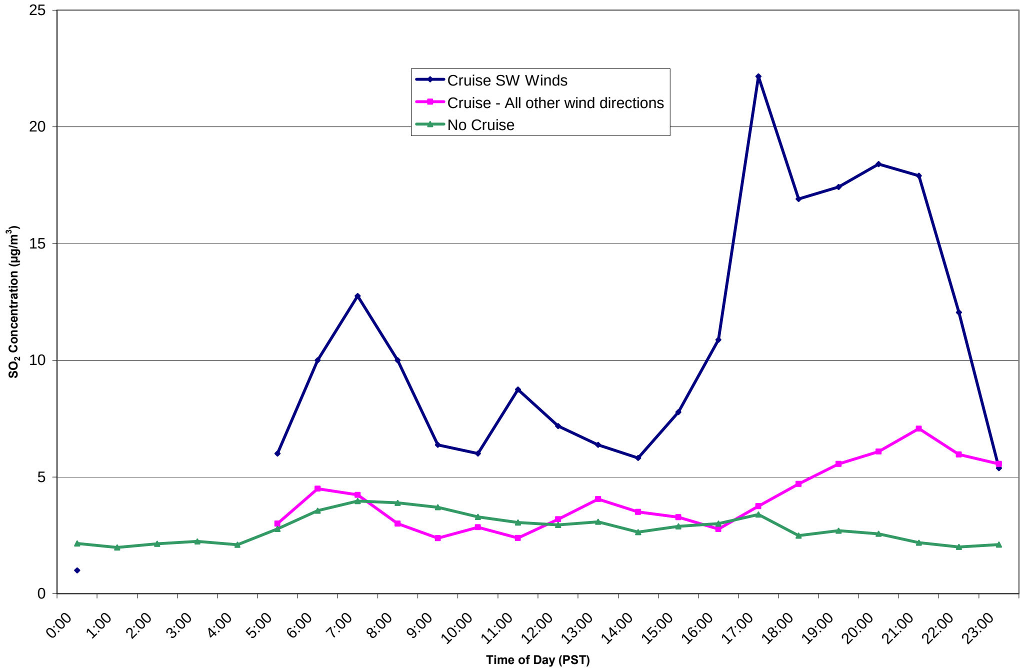
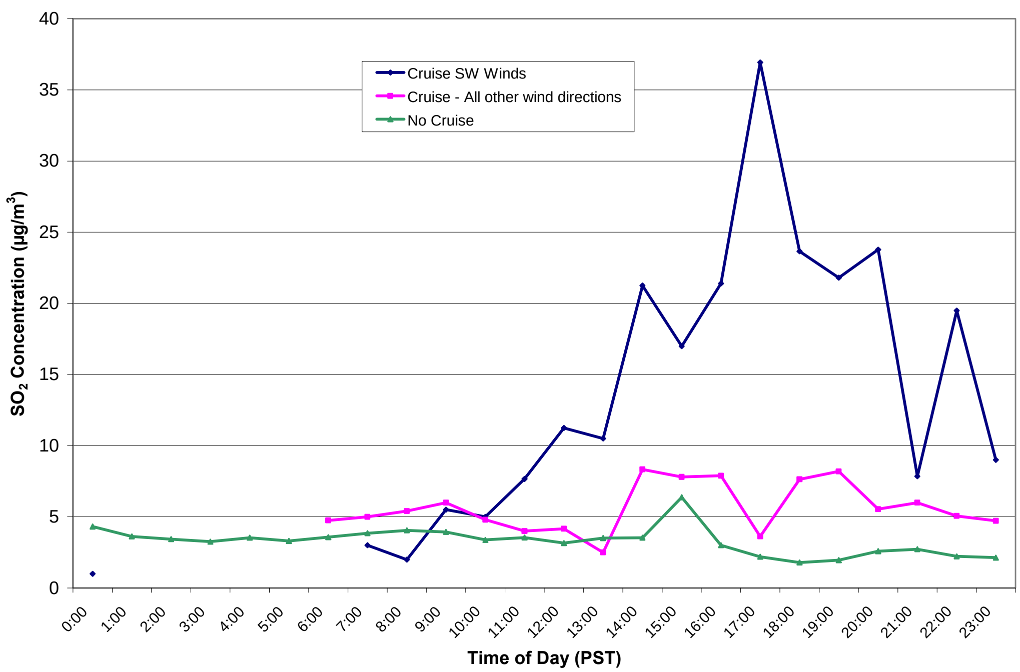


Figure D.10: Diurnal Weekend Variation in Average SO_2 Concentrations Segregated by Wind Direction at Victoria Topaz: May - September, 2008



D.2.2 NO_x Concentrations at Topaz

Cruise ships were also identified as a major source of NO_x emissions in the JBAQS. Since most of the NO_x emissions (90-95%) from diesel engines are composed of NO, it would be reasonable to expect that NO concentrations at the Victoria Topaz monitoring site would reflect some impact from cruise ship emissions.

Figure D.11 provides probability frequency distributions of NO concentrations at the Topaz site for the period from May through September showing the differences between weekday hourly averages when the station was downwind of Ogden Point with cruise ships at dockside versus hours when cruise ships were in port with winds from other directions and for hours when cruise ships were not present. The plot shows that there was little discernible difference in the NO concentrations on weekdays whether cruise ships were in port or not, and certainly the highest NO concentrations were not attributable to cruise ship emissions.

However, Figure D.12 shows the same analysis for weekend days, indicating that days when cruise ship are in port produce much higher NO concentrations at the Topaz site. Figure D.12 indicates that maximum NO concentrations at Topaz were up to 75 $\mu g/m^3$ higher when ships were in port than on weekend days when cruise ships were absent from Ogden Point. The reason why the differences are not as great on weekdays is likely due to the higher emissions from motor vehicles on Blanshard Street near the Topaz site on weekdays versus weekend days.

Figure D.11: Weekday Probability Frequency Distributions of NO Concentrations Segregated by Wind Direction at Victoria Topaz: May - September, 2008

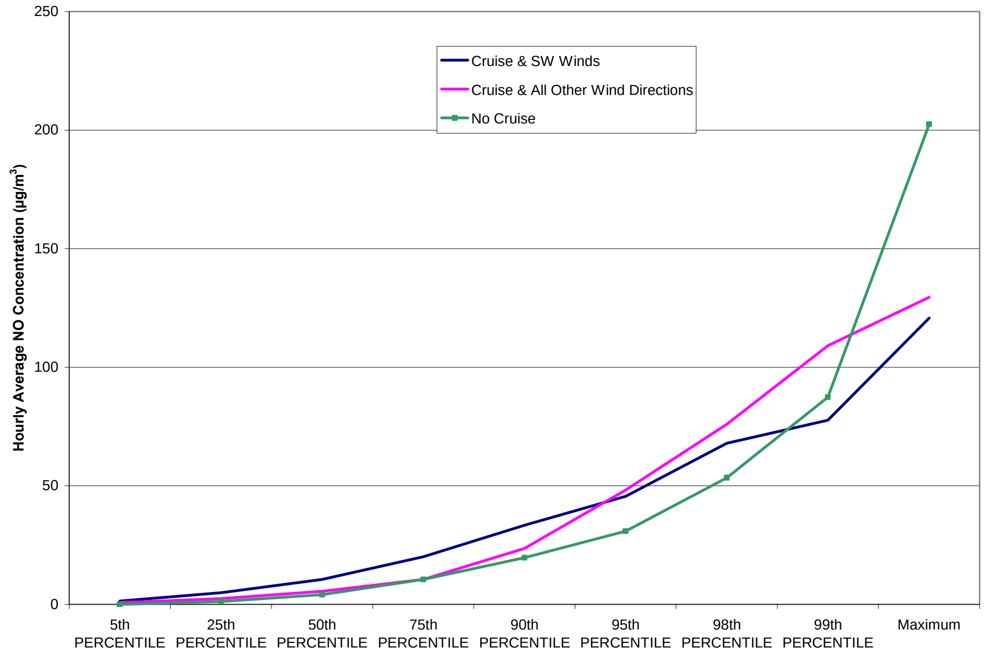
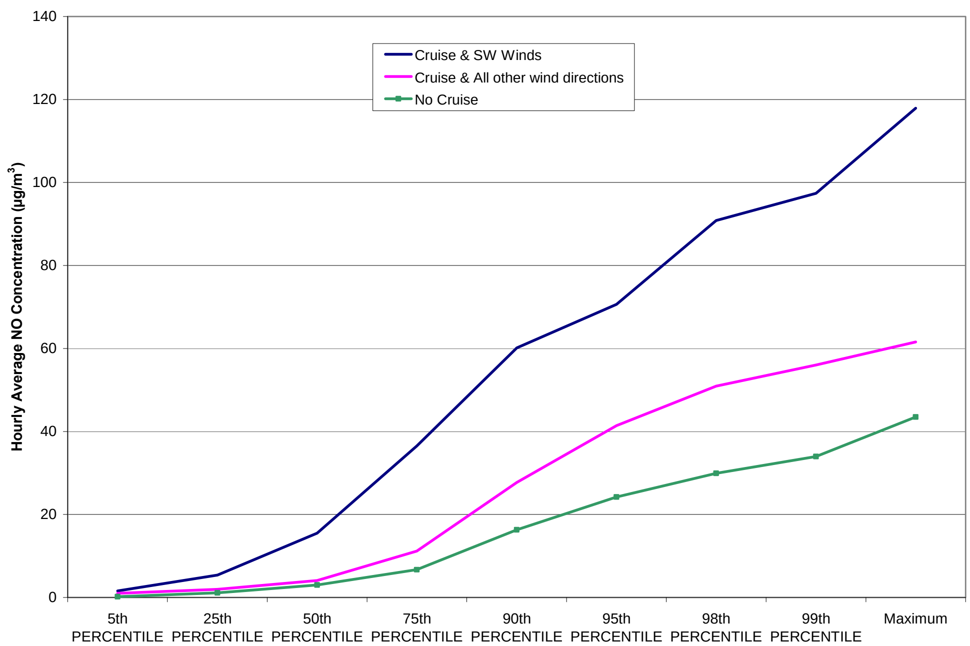


Figure D.12: Weekend Probability Frequency Distributions of NO Concentrations Segregated by Wind Direction at Victoria Topaz: May - September, 2008



By comparison, Figures D.13 and D.14 show that NO_2 concentrations at Topaz were generally higher with cruise ships in port on both weekdays and weekends. The magnitude of the differences on weekend days were not as great as for NO concentrations since NO_2 emissions are much lower than NO emissions, and only a portion of the NO emitted by the cruise ships would have been converted to NO_2 by the time the emission plumes reach the Topaz site. Nevertheless, the data do indicate that cruise ship NO_x emissions have a measurable impact on both NO and NO_2 concentrations at the Topaz monitoring site, approximately 4 km downwind from Ogden Point.

Figures D.15 and D.16 show the diurnal distribution of average NO concentrations on weekdays and weekends, respectively. Similarly, Figures D.17 and D.18 show the diurnal distribution of average NO_2 concentrations on weekdays and weekends, respectively. The data indicate that NO concentrations are generally higher at the Topaz site on weekdays when cruise chips are in port and winds are from the SW (Figure D.17) than when cruise ships are not in port, and that NO concentrations are always higher on weekend days when cruise ships are in port than when they are not. The magnitude of the elevated NO concentrations varies with time of day, but is generally about 10-15 $\mu g/m^3$ higher on weekdays, and can be 25 to 30 $\mu g/m^3$ higher in the evening hours on weekend days (Figure D.16). NO_2 concentrations at Topaz are always higher under these conditions, although the magnitude of the difference is generally less than 15 $\mu g/m^3$ (Figures D.17 and D.18). The difference can be greater than 30 $\mu g/m^3$ during some hours if one disregards the wind direction and just considers weekend days when cruise ships are in port and days when they are not (Figure D.19). In fact, the significance of cruise ship emissions is more clearly shown in Figures D.19 through D.22 in terms of the simple presence or absence of cruise ships from the port.

Figure D.13: Weekday Probability Frequency Distributions of NO_2 Concentrations Segregated by Wind Direction at Victoria Topaz: May - September, 2008

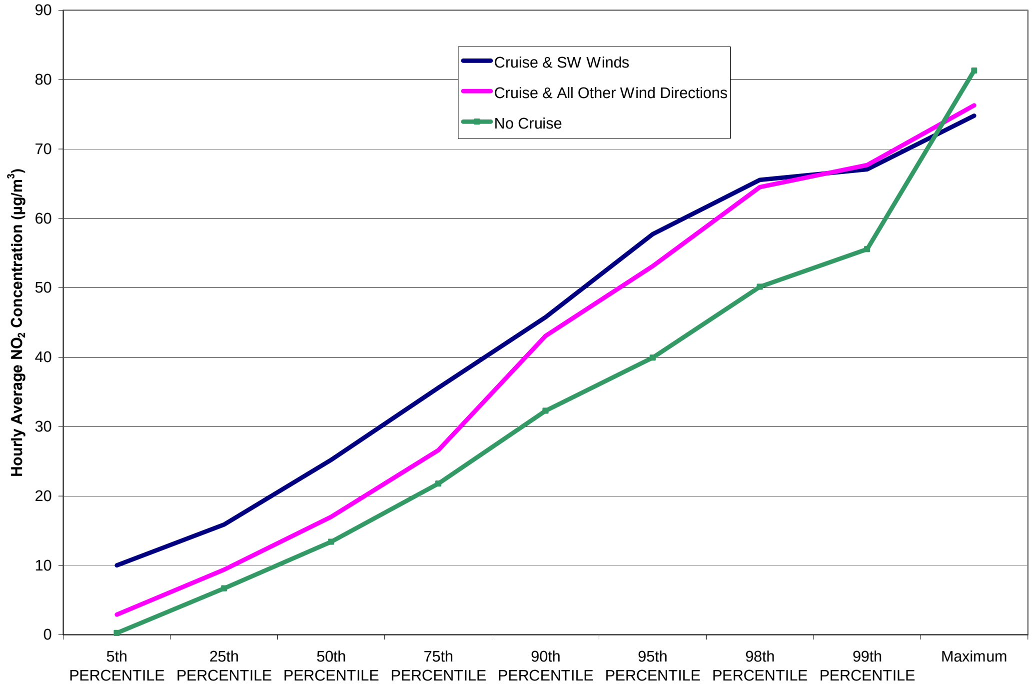


Figure D.14: Weekend Probability Frequency Distributions of NO_2 Concentrations Segregated by Wind Direction at Victoria Topaz: May - September, 2008

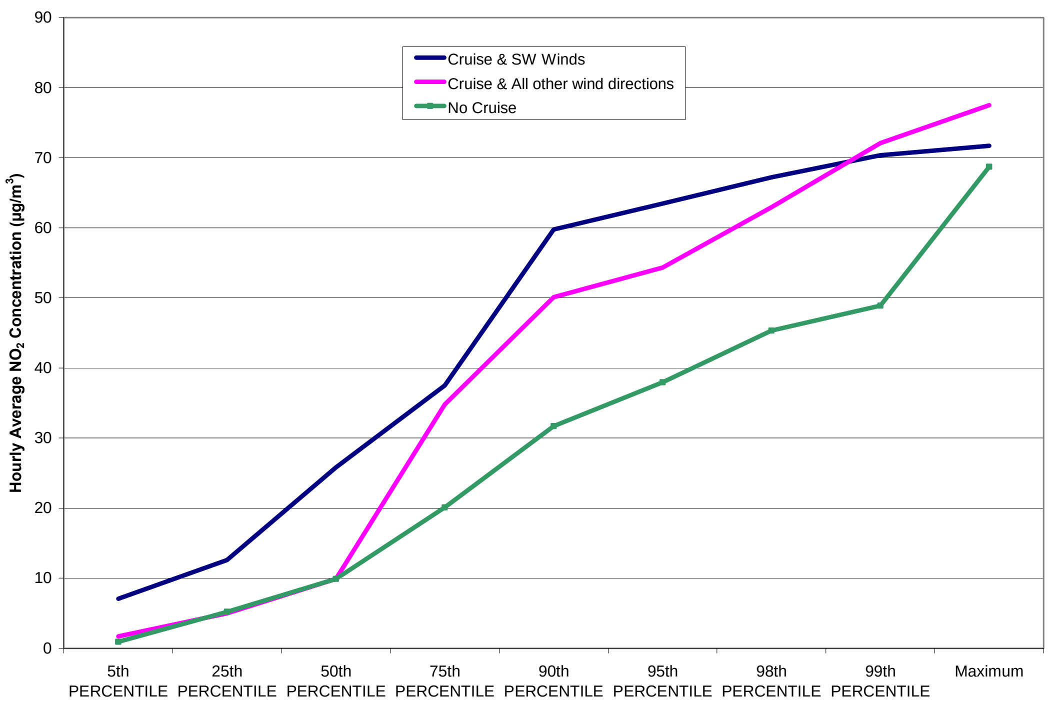


Figure D.15: Diurnal Weekday Variation in Average NO Concentrations Segregated by Wind Direction at Victoria Topaz: May - September, 2008

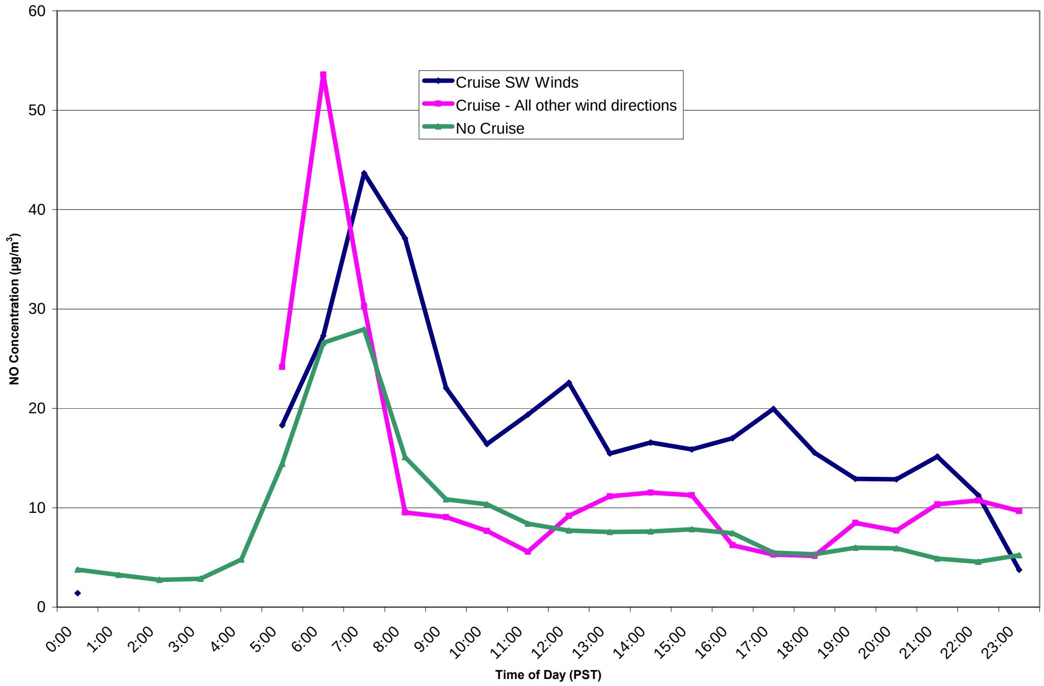


Figure D.16: Diurnal Weekend Variation in Average NO Concentrations Segregated by Wind Direction at Victoria Topaz: May - September, 2008

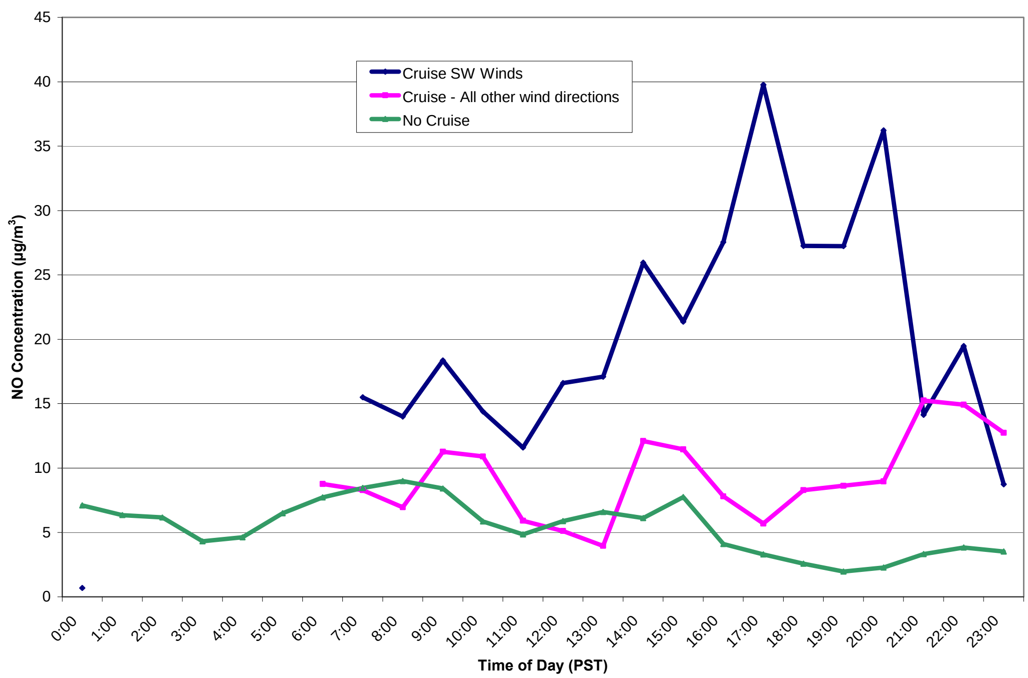


Figure D.17: Diurnal Weekday Variation in Average NO_2 Concentrations Segregated by Wind Direction at Victoria Topaz: May - September, 2008

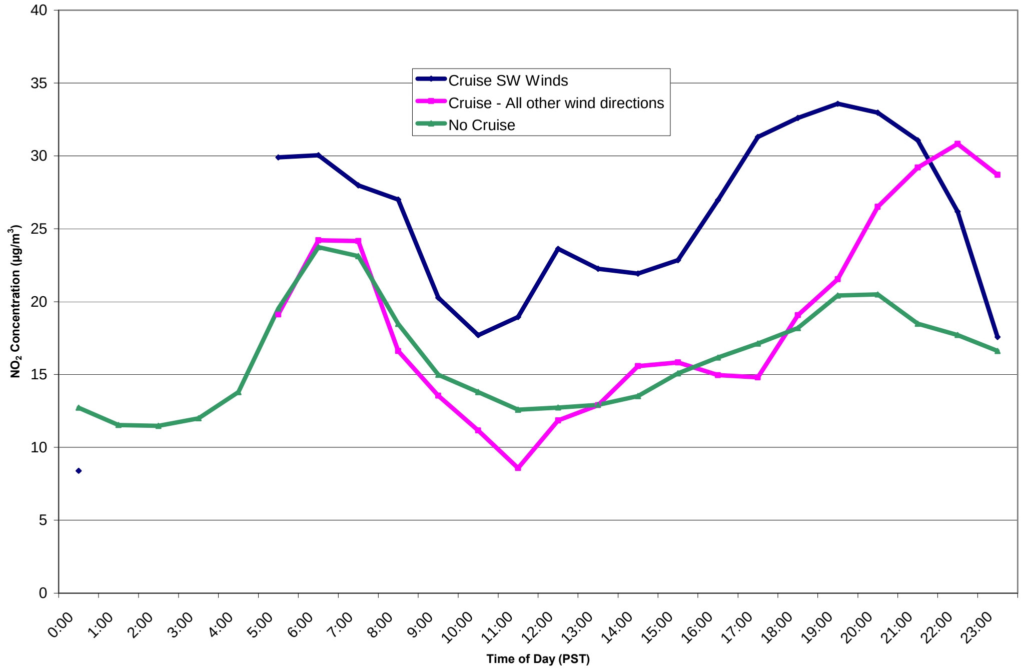


Figure D.18: Diurnal Weekend Variation in Average NO_2 Concentrations Segregated by Wind Direction at Victoria Topaz: May - September, 2008

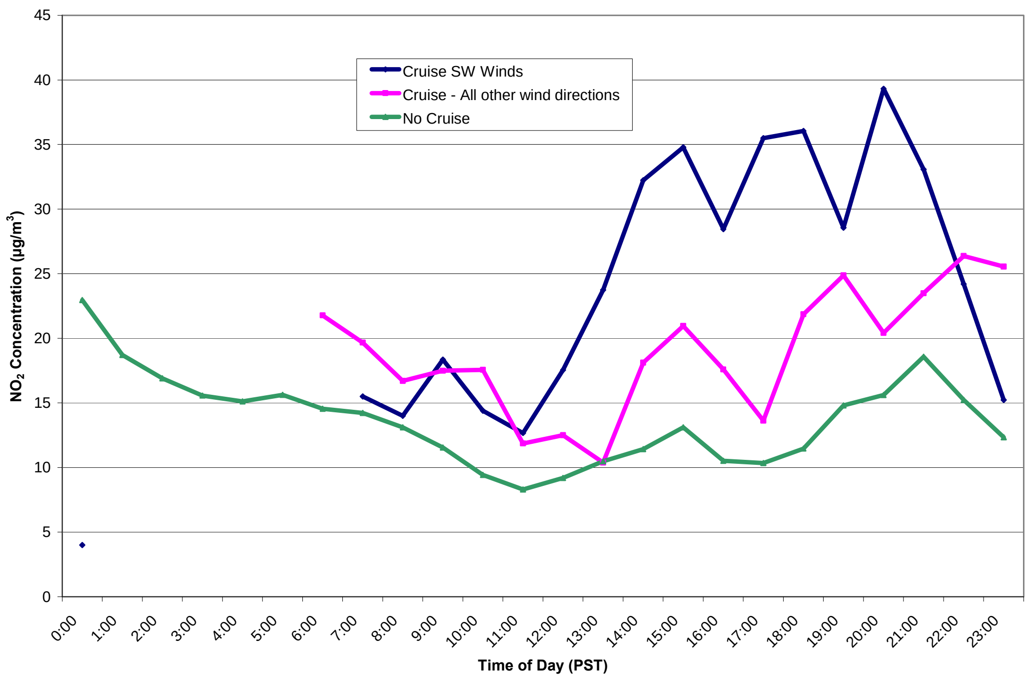


Figure D.19: Diurnal Weekday Variation in Average NO Concentrations

Segregated by Presence/Absence of Cruise Ships: May - September, 2008

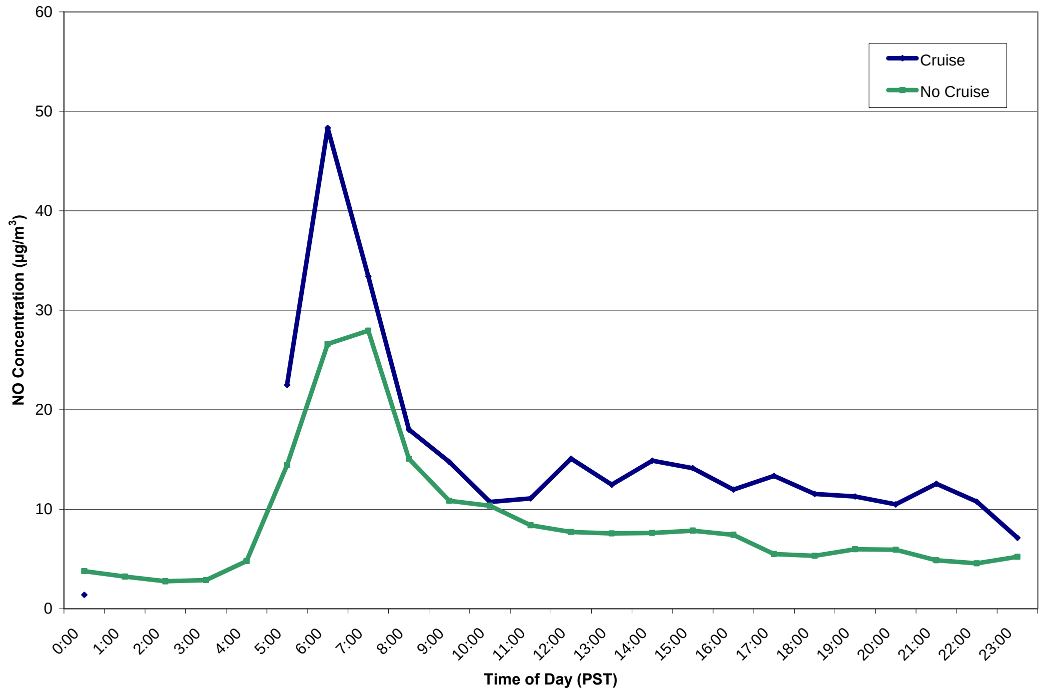


Figure D.20: Diurnal Weekend Variation in Average NO Concentrations Segregated by Presence/Absence of Cruise Ships: May - September, 2008

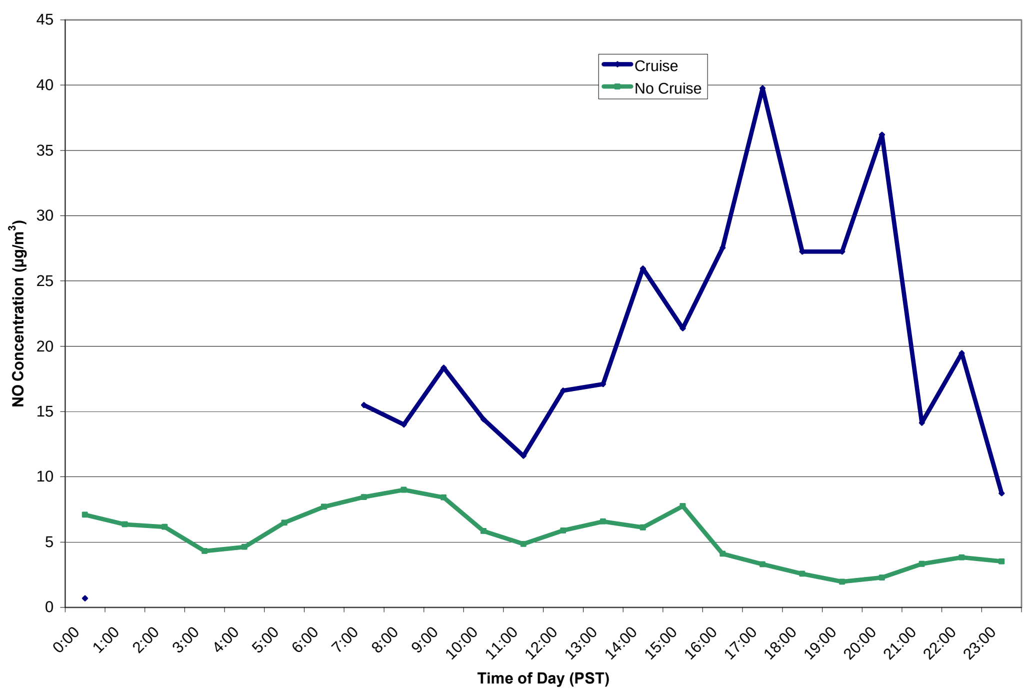


Figure D.21: Diurnal Weekday Variation in Average NO_2 Concentrations Segregated by Presence/Absence of Cruise Ships: May - September, 2008

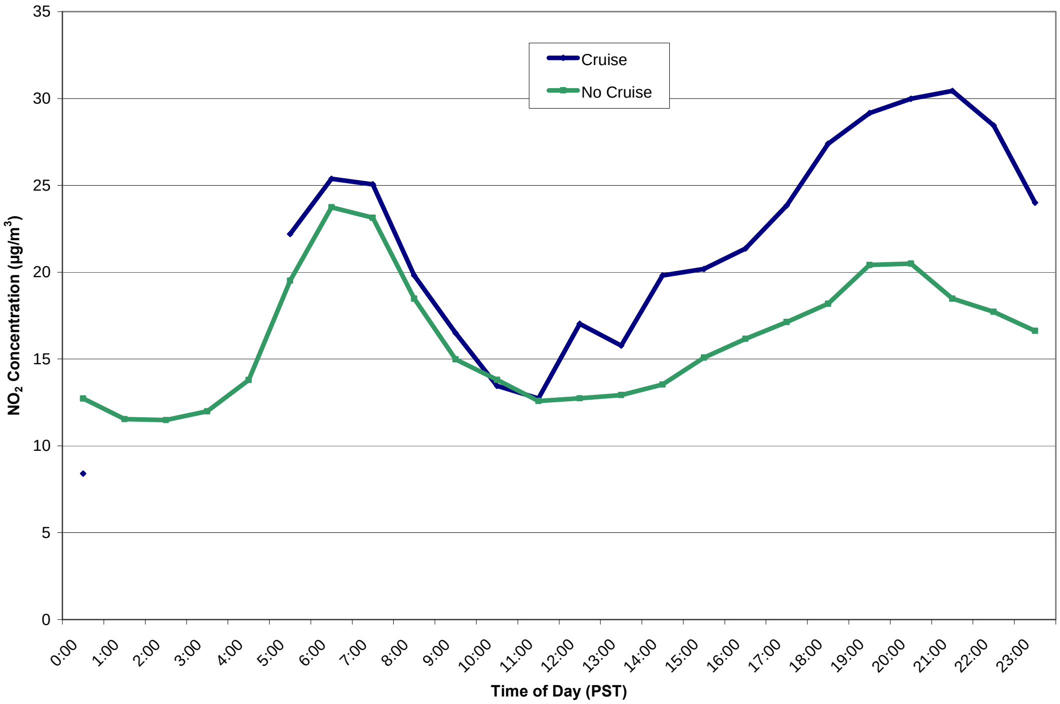
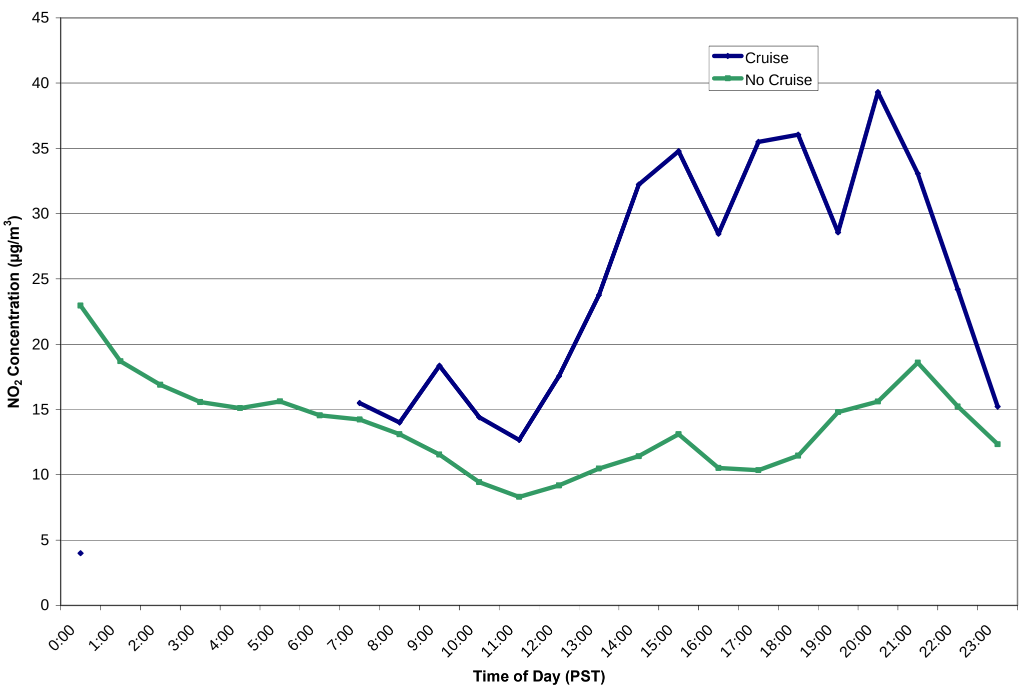


Figure D.22: Diurnal Weekend Variation in Average NO_2 Concentrations Segregated by Presence/Absence of Cruise Ships: May - September, 2008



D.2.3 $PM_{2.5}$ Concentrations at Topaz

Figure D.23 indicates that, as with the NO concentrations, there is little difference at the Topaz monitoring site for hourly averaged $PM_{2.5}$ concentrations measured on weekdays with or without cruise ships in port. The highest hourly averaged $PM_{2.5}$ concentrations occurred when cruise ships were not in port, indicating that other sources of $PM_{2.5}$ have a greater impact on ambient concentrations at the Topaz site during weekdays. However, Figure D.24 indicates that the average $PM_{2.5}$ levels on weekend days can be up to 5 $\mu g/m^3$ higher when the cruise ships are in port and the winds are from the SW.

Figures D.25 and D.26 show that the diurnal differences in measured $PM_{2.5}$ concentrations at Topaz are not particularly clear for weekdays when cruise ships are in port and winds are from the SW, but the pattern is much more readily apparent on weekend days, when hourly $PM_{2.5}$ concentrations at Topaz can be 6-7 $\mu g/m^3$ higher during the mid-afternoon hours. The data in Figures D.23 and D.25 show that other sources contributed to the $PM_{2.5}$ levels recorded at Topaz on weekdays, but the effect of cruise ships was greater on weekend days when the contributions from other background sources are lower. This pattern is most easily discerned on Figure D.28 when the analysis is conducted simply for the hours when ships are in port versus hours when they are not.

Figure D.23: Weekday Probability Frequency Distributions of $PM_{2.5}$ Concentrations Segregated by Wind Direction at Victoria Topaz: May - September, 2008

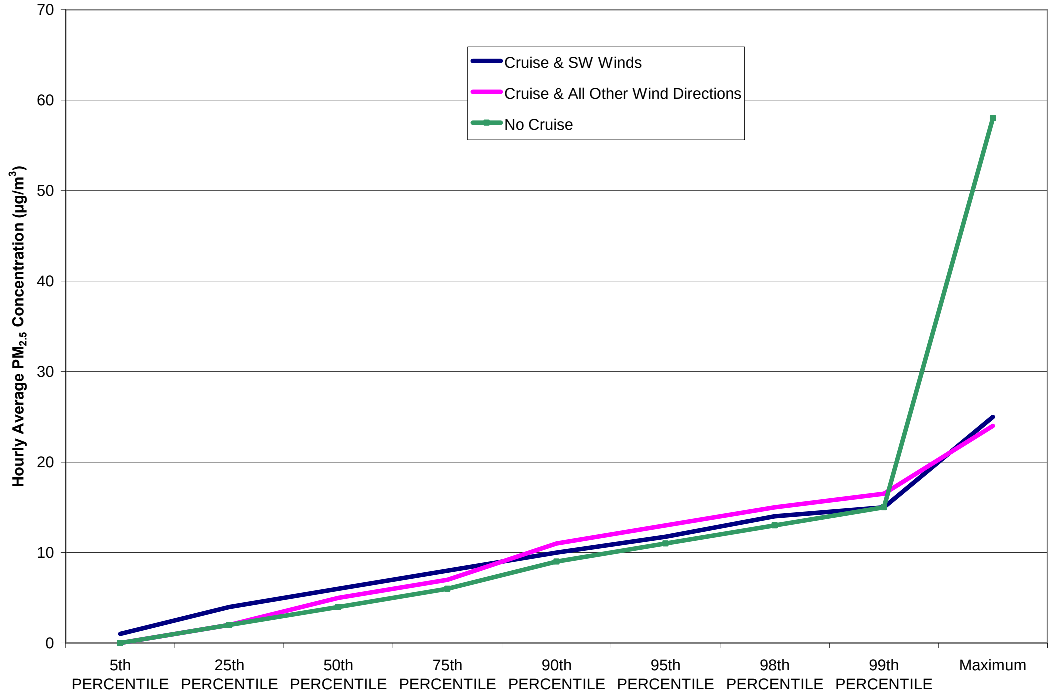


Figure D.24: Weekend Probability Frequency Distributions of $PM_{2.5}$ Concentrations Segregated by Wind Direction at Victoria Topaz: May - September, 2008

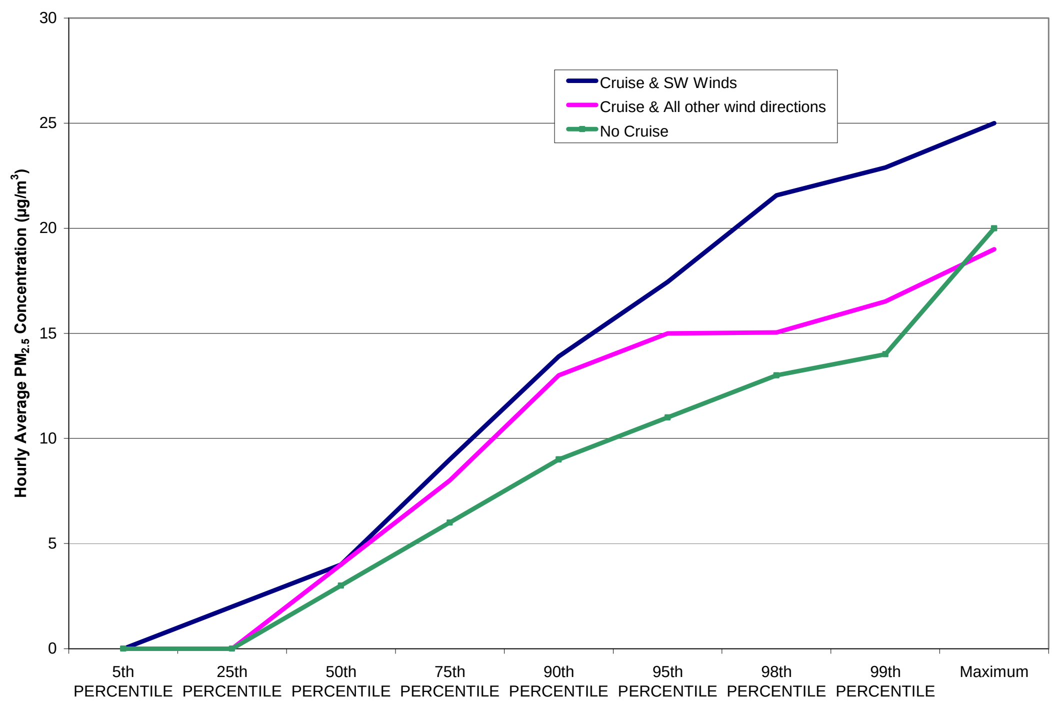


Figure D.25: Diurnal Weekday Variation in Average $PM_{2.5}$ Concentrations Segregated by Wind Direction at Victoria Topaz: May - September, 2008

Figure D.26: Diurnal Weekend Variation in Average $PM_{2.5}$ Concentrations Segregated by Wind Direction at Victoria Topaz: May - September, 2008

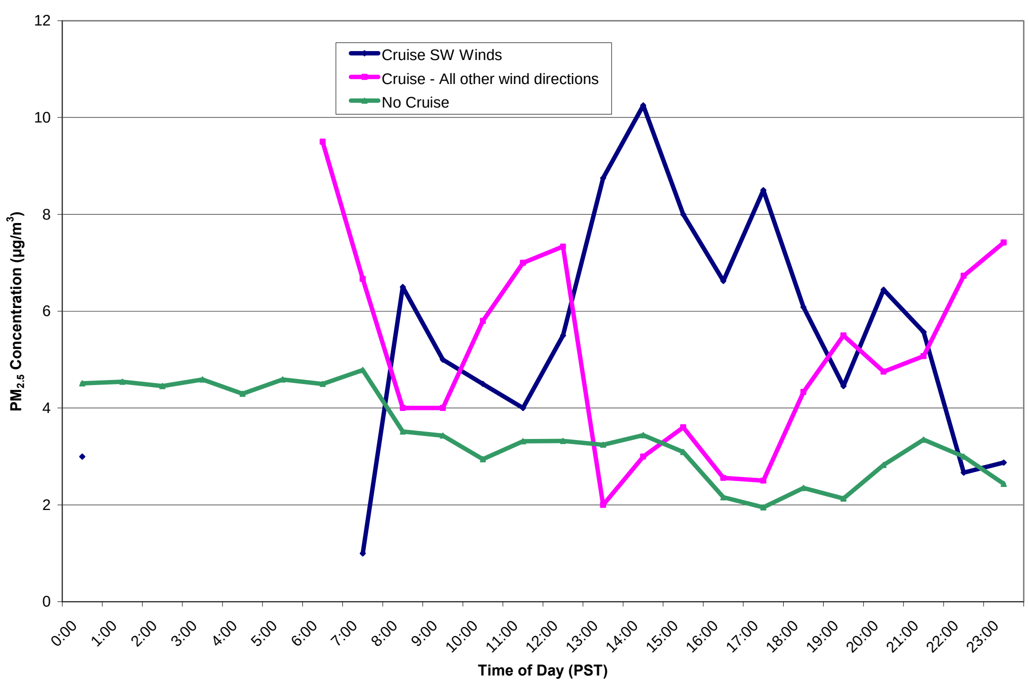


Figure D.27: Diurnal Weekday Variation in Average $PM_{2.5}$ Concentrations Segregated by Presence/Absence of Cruise Ships: May - September, 2008

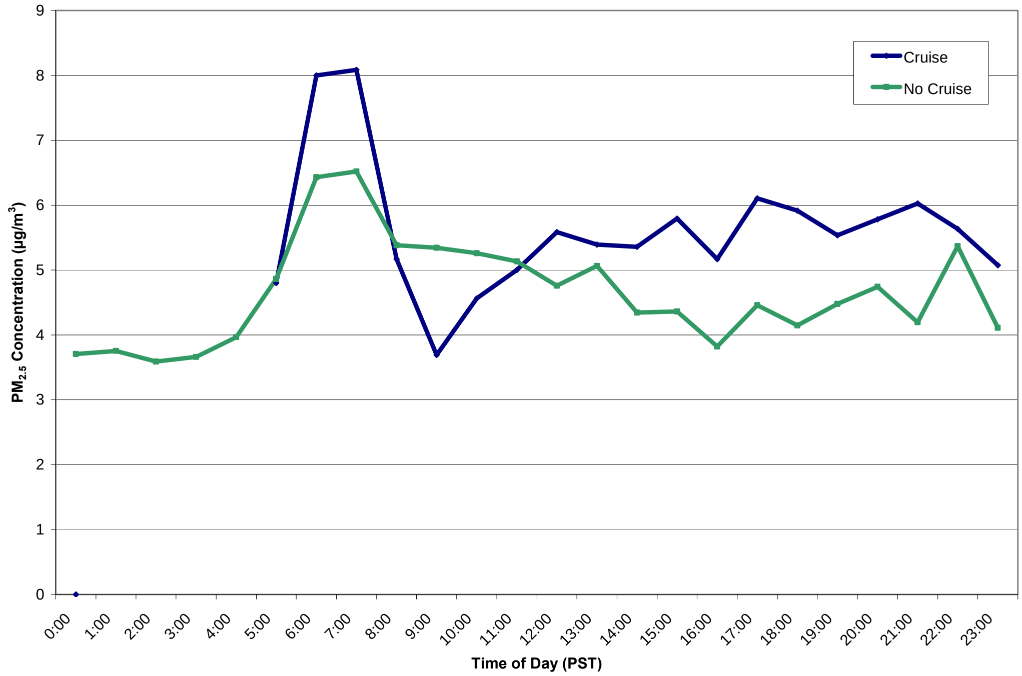
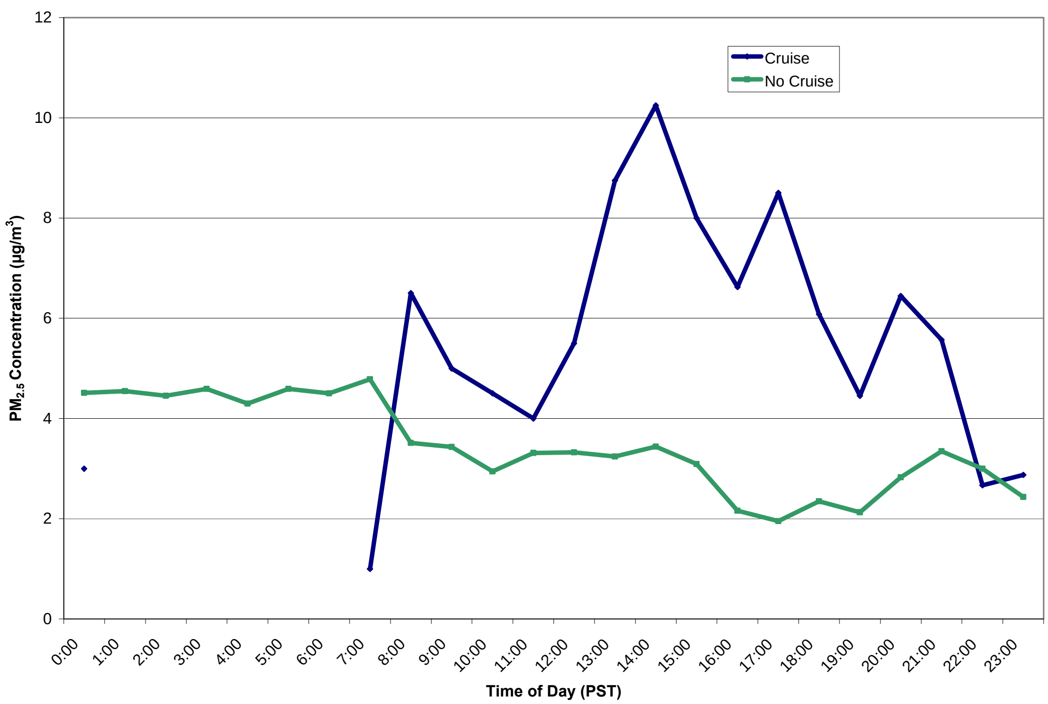


Figure D.28: Diurnal Weekend Variation in Average $PM_{2.5}$ Concentrations Segregated by Presence/Absence of Cruise Ships: May - September, 2008



D.2.4 Specific Examples of Cruise Ship Impacts at Topaz

Over the period April 3rd to October 14th, there were a total of 104 days when there was at least one cruise ship call at Ogden Point in 2008. On 12 of those days, the highest hourly averaged SO_2 concentrations recorded at the Victoria Topaz monitoring site exceeded 60 µg/m^3. The highest and second highest recorded concentrations were 146 µg/m^3 and 126 µg/m^3, respectively. Figures D.29 and D.30 provide plots of hourly averaged SO_2, NO_2 and $PM_{2.5}$ concentrations at the Topaz monitoring station for those two days. The figures are used to illustrate the impact of cruise ship emissions on the observed concentrations of these contaminants over a 24-hour period.

Figure D.29 shows that the highest hourly averaged SO_2 concentration of 146 µg/m^3, which was recorded on Friday, August 15th, 2008, was almost entirely attributable to emissions from cruise ships at Ogden Point. On that date, two cruise vessels arrived at Ogden Point at 18:12 and 18:50 hours, both departing at 23:33 and 23:45 hours, respectively. During this period, SO_2 concentrations at Topaz rose sharply in the hour before the vessels docked (i.e., as the vessels were arriving in port) from a pre-arrivals level of between 3 and 15 µg/m^3 to a peak of 146 µg/m^3 in the hour when the ships arrived at dockside, declining quickly after docking and subsiding back to pre-docking levels after vessel departure. Therefore, the estimated contribution of SO_2 from cruise ships is in the order of $\geq$130 µg/m^3. This level of impact is approximately 2.7 times higher than was estimated as the maximum impact from cruise ship emissions (i.e., 48 µg/m^3) in the JBAQS.

It should be noted that winds during the period between the hours of vessel arrival and departure (i.e., 17:00 hours and midnight) were light and variable, ranging from 0.4 to 1.8 m/s and varying from 181 to 266 degrees. The decline in SO_2 concentrations after the ships docked may simply be due to a shift in the direction of the exhaust plume relative to the Topaz site.

Figure D.29 also indicates that $PM_{2.5}$ concentrations rose steeply on August 15th with the arrival of two cruise ships, in parallel with increased SO_2 concentrations, and declined afterwards, also in conjunction with the decline in SO_2 concentrations. The fact that the variation in the two pollutant levels mirrored each other during the period from 16:00 (when the two ships were approaching Ogden Point), to 20:00 indicates that the two contaminants were emitted by the same source. However, it is also worth noting that a peak in $PM_{2.5}$ concentration occurred in the morning hours that was of a similar magnitude to the peak coinciding with the arrival of cruise ships in the afternoon. Clearly, other sources were responsible for the morning peak in $PM_{2.5}$ concentrations.

The change in $PM_{2.5}$ concentrations on August 15th (Figure D.29) from pre-cruise ship arrival of about 8 µg/m^3 to the peak concentration of 25 µg/m^3 suggests that the contribution of cruise ship emissions to ambient $PM_{2.5}$ concentrations at the Topaz site was about 17 µg/m^3. This is more than 3 times the maximum estimated impact of 5 µg/m^3 for $PM_{2.5}$ emissions that was estimated for the Topaz site in the JBAQS dispersion modelling analysis. The factor 3 underestimate between modelled and observed $PM_{2.5}$ concentrations is similar to the factor 2.7 underestimate in SO_2 impacts discussed above.

With respect to NO_2 concentrations, Figure D.29 shows that there was also an increase in NO_2 concentrations in conjunction with the rise in SO_2 and $PM_{2.5}$ levels, but the increase was not as large as for the other two contaminants. Since NO_2 is mainly a secondary pollutant which is formed as the plume is carried downwind, the increase in NO_2 concentrations observed at Topaz would depend on the atmospheric conditions (i.e., temperature, available sunlight, levels of ozone, and hydroxyl radicals) present at the time to drive the chemical reactions needed to convert the NO to NO_2 between the exhaust from the cruise ships and the transport of the plume to the Topaz site.

Based on the change in NO_2 concentration from 33.7 µg/m^3 at 16:00 to 66.9 µg/m^3 at 18:00, the estimated contribution of NO_2 from cruise ships to total observed NO_2 at Topaz is about 33 µg/m^3. This is only slightly more than half of the maximum estimated impact of cruise ship emissions (i.e., 60 µg/m^3) determined through dispersion modelling in the JBAQS for the 2007 cruise ship season. Since the JBAQS had to estimate how much of the NO emitted by the cruise ships would be converted to NO_2 by the time the exhaust plume reached the Topaz monitoring site, and the analysis used a single conversion rate for all hours of the day, it is not surprising that the JBAQS may have overestimated impacts on any particular day.

Figure D.30 provides a second example for the second highest 1-hour average SO_2 concentration recorded at Victoria Topaz in 2008 on Saturday, June 28th. On that date, three cruise ships docked at Ogden Point at 16:35, 17:35 and 18:15 hours. Wind direction during vessel arrival was from the NNE to the NNW, swinging to the SW by 19:00 hours, when the SO_2 concentration at Victoria Topaz peaked at 126 µg/m^3, a time when the Topaz site would have been directly downwind of Ogden Point. Winds were very light (0.6 to 1.6 m/s) and variable during the time the vessels were in port, changing direction from the SW to the S and then back to the N by the time the vessels left port. As a result, there were only a couple of hours (19:00 and 20:00) when SO_2 concentrations were particularly elevated at the Topaz site because the monitoring site would not have remained directly downwind of Ogden Pont for most of the time when the ships were in port.

As with the previous example for August 15th, $PM_{2.5}$ and SO_2 concentrations peaked concurrently on June 28th after the arrival of three cruise ships only when the wind shifted to where the Topaz site was downwind of Ogden Point and then dropped when the winds shifted the plume away from the Topaz site. However, in contrast to the August 15th example, NO_2

concentrations also rose sharply in parallel with the SO_2 and $PM_{2.5}$ concentrations. The NO_2 concentration rose from a low of 3.8 µg/m^3 at 16:00 to a peak of 70.6 µg/m^3 at 20:00 for a total increase of 66.8 µg/m^3. The latter value is almost identical to the maximum predicted impact of 60 µg/m^3 estimated by the JBAQS for cruise ship emissions.

Therefore, based on the analysis presented in Figures D.29 and D.30, the observational data at the Topaz monitoring site suggests that the JBAQS underestimated maximum impacts from cruise ship emissions at this location by a factor of about 3 for both SO_2 and $PM_{2.5}$ emissions, but was pretty accurate with respect to maximum NO_2 impacts. The underestimation of both SO_2 and $PM_{2.5}$ impacts from cruise ships at the Topaz site raises concerns about the JBAQS modelling results in the vicinity of Ogden Point. The factor 3 differences may be explained by differences between the meteorological conditions in 2007 versus 2008, but this would need to be verified by a comparative analysis of cruise ship emissions modelling for both years. However, the possibility that emissions of these two contaminants from cruise ships were underestimated in the JBAQS cannot be ruled out.

Table D.1 lists the total number of vessel calls by each cruise ship during the 2008 season, as well as the total number of days when SO_2 concentrations at the Topaz site exceeded 60 µg/m^3 that were associated with each vessels presence in port. Table D.2 lists the dates on which the hourly average SO_2 readings exceeded 60 µg/m^3, and the vessels that made calls at Ogden Point on each of those days. Of the 24 vessels that called at the port, only five ships were associated with multiple dates on which the SO_2 readings were high. All five ships made frequent calls at the port, so their odds of being in port on days when the meteorological conditions were suitable for producing higher readings at the Topaz site were higher than for vessels that made less frequent calls. Nevertheless, there were other cruise ships that also made frequent calls at Ogden Point which were not associated with any days with elevated SO_2 concentrations at Topaz. The higher frequency of elevated SO_2 readings in association with a few vessels suggests that one or more of these five vessels is a high emitter of SO_2 compared to other vessels calling at Ogden Point, and that these higher vessels emit higher levels of both SO_2 and $PM_{2.5}$ than was assumed in the JBAQS dispersion modelling analysis.

Perhaps of greater concern is the factor 5 difference between predicted and observed SO_2 concentrations reported in the JBAQS modelling analysis between concentrations at Ogden Point and at Topaz. If this factor difference were to hold true for the impact of cruise ship emissions in 2008, the 130 µg/m^3 impact level at the Topaz site would translate into an hourly averaged SO_2 concentration at Ogden Point of about 650 µg/m^3. This concentration would exceed the BC Level A ambient air quality objective of 450 µg/m^3, and would also exceed the WHO 10-minute average guideline level of 500 µg/m^3 (WHO 2006). It suggests that SO_2 concentrations in the vicinity of Ogden Point may be much higher than was estimated in the JBAQS, and may be high enough in the James Bay community to be of concern for human health impacts in that area.

Figure D.29
Observed SO_2, NO_2 & $PM_{2.5}$ Concentrations at Victoria Topaz, August 15, 2008

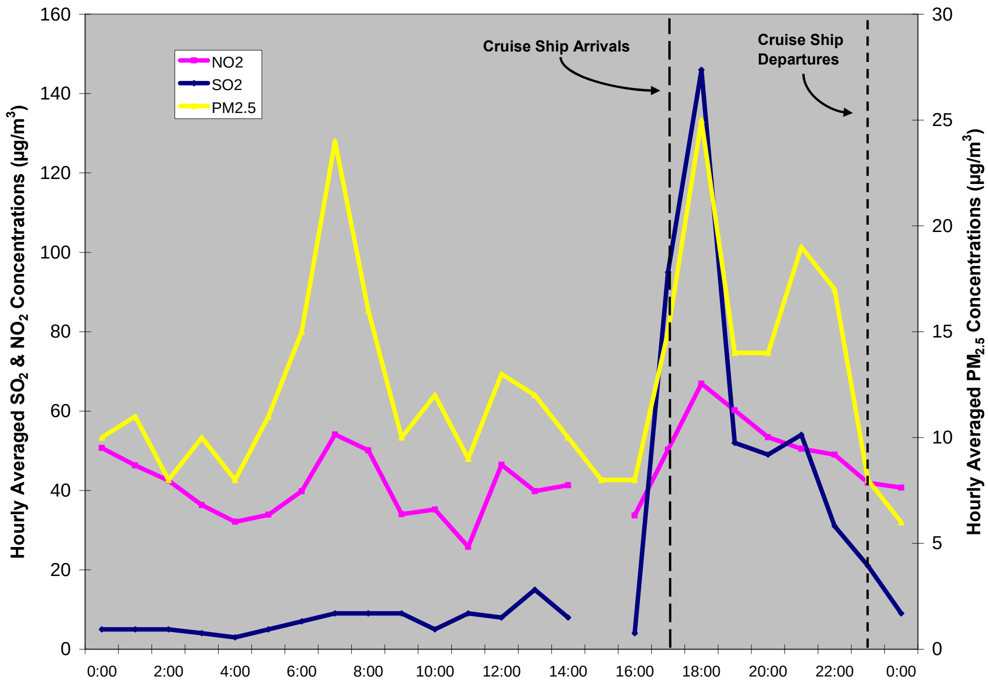


Figure D.30
Observed SO_2, NO_2 & $PM_{2.5}$ Concentrations at Victoria Topaz, June 28, 2008

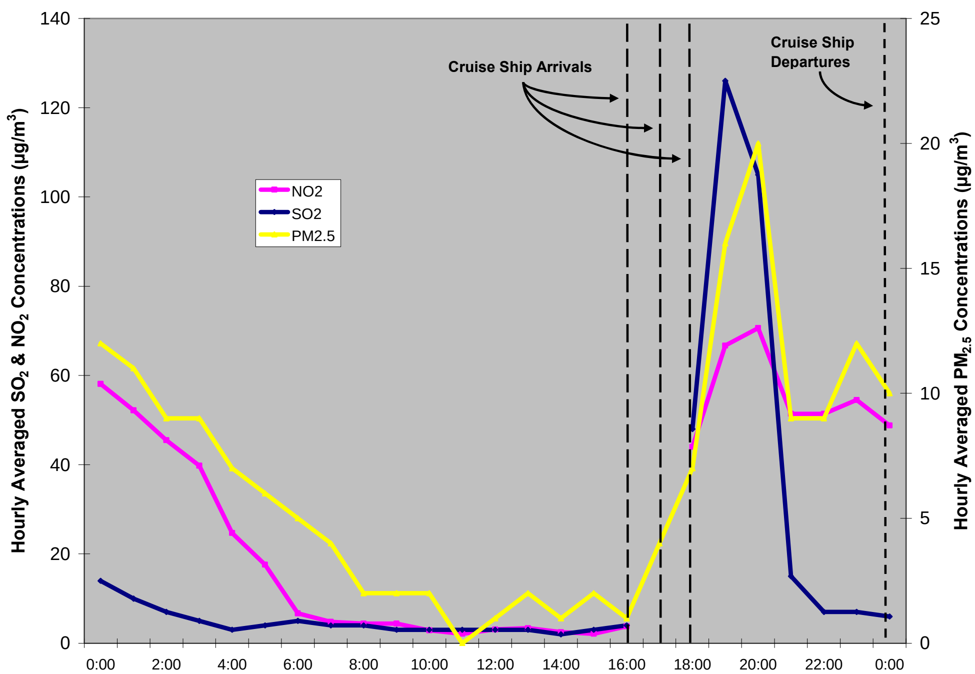


Table D.2
Summary of Cruise Ship Calls at Ogden Point

Cruise Ship Name	Total No. of Vessel Calls at Ogden Point in 2008	Total No. of Vessel Calls Associated with Elevated SO_2 Concentrations at Topaz
Celebrity Infinity	21	
Celebrity Mercury	13	
Celebrity Millennium	2	1
Dawn Princess	14	1
Golden Princess	18	5
Star Princess	20	8
Sun Princess	1	1
Tahitian Princess	7	
Oosterdam	23	5
Westerdam	21	6
Amsterdam	19	
Veendam	2	
Voledam	2	1
Zaandam	2	
Ryndam	2	
Statendam	1	
Norwegian Pearl	16	6
Norwegian Sun	2	
Norwegian Star	1	
Silver Shadow	9	1
Seven Seas Mariner	2	
Serenade of the Seas	1	
Radiance of the Seas	1	
Rhapsody of the Seas	1	
Total No. of Vessel Calls	201	

Table D.3
Vessel Calls Associated with Elevated SO_2 Concentrations at Victoria Topaz

Date	Maximum Hourly SO_2 Concentration at Topaz ($\mu g/m^3$)	Vessels Calling at Ogden Point									
		Celebrity Millennium	Voledam	Westerdam	Norwegian Pearl	Star Princess	Silver Shadow	Oosterdam	Golden Princess	Dawn Princess	Sun Princess
17-May	67	x	x	x	x	x					
14-Jun	117			x	x	x					
20-Jun	73						x	x	x		
21-Jun	119			x	x	x					
28-Jun	126			x	x	x					
4-Jul	80							x	x	x	
11-Jul	71							x	x		
12-Jul	98			x	x	x					
18-Jul	103					x		x	x		
26-Jul	73			x	x	x					
12-Aug	97										x
15-Aug	146					x		x	x		

D.3 CONCLUSIONS

The analysis of hourly averaged ambient air quality concentrations of SO_2, NO_2 and $PM_{2.5}$ at the Victoria Topaz monitoring station in relation to the cruise ship operations at Ogden Point indicates that the emission of SO_2 from cruise ships unequivocally has the greatest effect on ambient concentrations of this contaminant at the Topaz site. The emission of NO_x and $PM_{2.5}$ is more difficult to discern but is more clearly evident for NO_2 and $PM_{2.5}$ concentrations on weekend days when background concentrations from other sources of these two contaminants are lower.

The analysis of the 2008 monitoring data at the Topaz site supports the results of the James Bay Air Quality Study (JBAQS) dispersion modelling analysis that was completed for the cruise ship operations in 2007, but suggests that the JBAQS may have underestimated maximum SO_2 and $PM_{2.5}$ impacts from cruise ships by about a factor of three (3). The underestimation of SO_2 and $PM_{2.5}$ impacts in the JBAQS may reflect differences in meteorology between 2007 and 2008, but underestimation of SO_2 and $PM_{2.5}$ emissions also cannot be ruled out. The possible implication of this is that SO_2 concentrations in the vicinity of Ogden Point may be much higher than was estimated in the JBAQS, and may be high enough in the James Bay community to be of concern for human health impacts in that area.

Attachment A

2008 Cruise Ship Schedule at Ogden Point

Western Stevedoring

P. O. Box 1442, 189 Dallas Road,
Victoria, BC V8W 2X2
Phone: (250) 386-1321 Fax: (250) 386-2734
As Agents / Managers for the Greater Victoria Harbour Authority

2008 CRUISE SHIP SCHEDULE - VICTORIA, BC / OGDEN POINT

	DATE		VESSEL	FROM	ARR	DEP	TO	# PASS	CRUISE LINE	LGTH
1	Apr 03	Thu	CELEBRITY MERCURY	Vancouver	6:40	14:02	San Francisco	1,870	Celebrity Cruise Line	866 '
2	Apr 10	Thu	CELEBRITY MERCURY	Vancouver	6:34	14:22	San Francisco	1,870	Celebrity Cruise Line	866 '
3	Apr 17	Thu	CELEBRITY MERCURY	Vancouver	6:10	14:15	San Francisco	1,870	Celebrity Cruise Line	866 '
4	Apr 21	Mon	ZAANDAM	San Diego	14:33	23:50	Vancouver	1,440	Holland America Line	777 '
5	Apr 25	Fri	CELEBRITY MERCURY	Vancouver	6:20	14:09	San Francisco	1,870	Celebrity Cruise Line	866 '
6	Apr 29	Tue	VOLENDAM	San Diego	14:25	23:55	Vancouver	1,440	Holland America Line	777 '
7	Apr 30	Wed	CELEBRITY INFINITY	San Francisco	7:37	16:59	Nanaimo	2,000	Celebrity Cruise Line	965 '
8	May 01	Thu	CELEBRITY MERCURY	Astoria	6:49	16:48	Prince Rupert	1,870	Celebrity Cruise Line	866 '
9	May 01	Thu	OOSTERDAM	Vancouver	7:40	16:55	Astoria	1,840	Holland America Line	951 '
10	May 01	Thu	VEENDAM	San Diego	14:48	23:50	Vancouver	1,250	Holland America Line	720 '
11	May 06	Tue	RYNDAM	San Diego	19:28	23:59	Vancouver	1,250	Holland America Line	720 '
12	May 07	Wed	SERENADE OF THE SEAS	Seattle	7:35	17:55	Ketchikan	2,500	Royal Caribbean Int'l	962 '
13	May 08	Thu	NORWEGIAN SUN	San Francisco	9:15	18:05	Vancouver	1,900	Norwegian Cruise Line	853 '
14	May 08	Thu	GOLDEN PRINCESS	San Francisco	10:55	17:06	Vancouver	2,600	Princess Cruise Lines	951 '
15	May 09	Fri	OOSTERDAM	Ketchikan	17:54	23:36	Seattle	1,840	Holland America Line	951 '
16	May 10	Sat	ZAANDAM	Astoria	7:35	16:24	Vancouver	1,440	Holland America Line	777 '
17	May 10	Sat	WESTERDAM	San Diego	15:18	0:03	Seattle	1,916	Holland America Line	936 '
18	May 10	Sat	STAR PRINCESS	Skagway	18:28	23:36	Seattle	2,600	Princess Cruise Lines	951 '
19	May 10	Sat	NORWEGIAN PEARL	Ketchikan	17:35	23:47	Seattle	2,400	Norwegian Cruise Line	971 '
20	May 14	Wed	AMSTERDAM	Los Angeles	7:35	23:57	Vancouver	1,380	Holland America Line	780 '
21	May 15	Thu	DAWN PRINCESS	Skagway	5:46	14:07	San Francisco	1,950	Princess Cruise Lines	856 '
22	May 15	Thu	CELEBRITY INFINITY	Juneau	16:20	23:23	Seattle	2,000	Celebrity Cruise Line	965 '
23	May 16	Fri	OOSTERDAM	Ketchikan	18:30	23:46	Seattle	1,840	Holland America Line	951 '
24	May 16	Fri	GOLDEN PRINCESS	Ketchikan	19:00	0:01	Seattle	2,600	Princess Cruise Lines	951 '
25	May 17	Sat	CELEBRITY MILLENNIUM	Vancouver	6:15	16:00	San Francisco	2,034	Celebrity Cruise Line	965 '
26	May 17	Sat	VOLENDAM	Astoria	7:18	16:25	Vancouver	1,440	Holland America Line	777 '
27	May 17	Sat	STAR PRINCESS	Skagway	17:15	0:05	Seattle	2,600	Princess Cruise Lines	951 '
28	May 17	Sat	WESTERDAM	Ketchikan	17:50	23:40	Seattle	1,916	Holland America Line	936 '
29	May 17	Sat	NORWEGIAN PEARL	Ketchikan	17:45	23:43	Seattle	2,400	Norwegian Cruise Line	971 '
30	May 19	Mon	DAWN PRINCESS	San Francisco	10:21	16:57	Ketchikan	1,950	Princess Cruise Lines	856 '
31	May 22	Thu	AMSTERDAM	Ketchikan	17:40	23:38	Seattle	1,380	Holland America Line	780 '
32	May 22	Thu	CELEBRITY INFINITY	Ketchikan	18:32	23:56	Seattle	2,000	Celebrity Cruise Line	965 '
33	May 23	Fri	OOSTERDAM	Ketchikan	17:55	23:42	Seattle	1,840	Holland America Line	951 '
34	May 23	Fri	GOLDEN PRINCESS	Ketchikan	18:30	23:57	Seattle	2,600	Princess Cruise Lines	951 '
35	May 24	Sat	STAR PRINCESS	Skagway	16:25	23:55	Seattle	2,600	Princess Cruise Lines	951 '
36	May 24	Sat	NORWEGIAN PEARL	Ketchikan	17:25	23:45	Seattle	2,400	Norwegian Cruise Line	971 '
37	May 24	Sat	WESTERDAM	Ketchikan	18:05	23:38	Seattle	1,916	Holland America Line	936 '
38	May 28	Wed	SEVEN SEAS MARINER	Vancouver	7:05	18:04	Ketchikan	700	Regent Seven Seas	709 '
39	May 29	Thu	AMSTERDAM	Ketchikan	17:45	23:30	Seattle	1,380	Holland America Line	780 '
40	May 29	Thu	CELEBRITY INFINITY	Ketchikan	18:38	23:51	Seattle	2,000	Celebrity Cruise Line	965 '
41	May 30	Fri	OOSTERDAM	Ketchikan	17:50	23:41	Seattle	1,840	Holland America Line	951 '
42	May 30	Fri	GOLDEN PRINCESS	Ketchikan	18:35	23:53	Seattle	2,600	Princess Cruise Lines	951 '
43	May 31	Sat	STAR PRINCESS	Skagway	16:44	0:08	Seattle	2,600	Princess Cruise Lines	951 '
44	May 31	Sat	WESTERDAM	Ketchikan	17:57	23:52	Seattle	1,916	Holland America Line	936 '
45	May 31	Sat	NORWEGIAN PEARL	Ketchikan	17:40	23:39	Seattle	2,400	Norwegian Cruise Line	971 '
46	Jun 04	Wed	DAWN PRINCESS	Skagway	7:22	15:20	San Francisco	1,950	Princess Cruise Lines	856 '
47	Jun 04	Wed	SILVER SHADOW	San Francisco	11:30	18:42	Ketchikan	350	Silversea	600 '
48	Jun 05	Thu	AMSTERDAM	Ketchikan	18:41	23:26	Seattle	1,380	Holland America Line	780 '
49	Jun 05	Thu	CELEBRITY INFINITY	Ketchikan	19:17	0:10	Seattle	2,000	Celebrity Cruise Line	965 '
50	Jun 06	Fri	OOSTERDAM	Ketchikan	17:45	23:44	Seattle	1,840	Holland America Line	951 '

Arrival and Departure dates and times are subject to change without notice. **Updated: Thursday, April 24, 2008** **Page 1 of 5**

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As Agents / Managers for the Greater Victoria Harbour Authority

2008 CRUISE SHIP SCHEDULE - VICTORIA, BC / OGDEN POINT

	DATE		VESSEL	FROM	ARR	DEP	TO	# PASS	CRUISE LINE	LGTH
51	Jun 06	Fri	GOLDEN PRINCESS	Ketchikan	18:29	23:57	Seattle	2,600	Princess Cruise Lines	951'
52	Jun 07	Sat	STAR PRINCESS	Skagway	16:40	0:10	Seattle	2,600	Princess Cruise Lines	951'
53	Jun 07	Sat	WESTERDAM	Ketchikan	17:55	23:36	Seattle	1,916	Holland America Line	936'
54	Jun 07	Sat	NORWEGIAN PEARL	Ketchikan	17:54	23:49	Seattle	2,400	Norwegian Cruise Line	971'
55	Jun 08	Sun	DAWN PRINCESS	San Francisco	11:50	18:53	Ketchikan	1,950	Princess Cruise Lines	856'
56	Jun 11	Wed	TAHITIAN PRINCESS	Sitka	13:46	23:52	Vancouver	680	Princess Cruise Lines	592'
57	Jun 12	Thu	AMSTERDAM	Ketchikan	17:45	23:25	Seattle	1,380	Holland America Line	780'
58	Jun 12	Thu	CELEBRITY INFINITY	Ketchikan	18:26	23:50	Seattle	2,000	Celebrity Cruise Line	965'
59	Jun 13	Fri	OOSTERDAM	Vessel Did Not Arrive at Ogden Point					Holland America Line	951'
60	Jun 13	Fri	GOLDEN PRINCESS	Vessel Did Not Arrive at Ogden Point					Princess Cruise Lines	951'
61	Jun 14	Sat	STAR PRINCESS	Skagway	16:20	0:10	Seattle	2,600	Princess Cruise Lines	951'
62	Jun 14	Sat	WESTERDAM	Ketchikan	17:50	23:35	Seattle	1,916	Holland America Line	936'
63	Jun 14	Sat	NORWEGIAN PEARL	Ketchikan	17:40	23:50	Seattle	2,400	Norwegian Cruise Line	971'
64	Jun 19	Thu	AMSTERDAM	Ketchikan	18:15	23:23	Seattle	1,380	Holland America Line	780'
65	Jun 19	Thu	CELEBRITY INFINITY	Ketchikan	18:55	23:47	Seattle	2,000	Celebrity Cruise Line	965'
66	Jun 20	Fri	SILVER SHADOW	Wrangell	10:00	0:04	Vancouver	350	Silversea	600'
67	Jun 20	Fri	OOSTERDAM	Ketchikan	17:50	23:40	Seattle	1,840	Holland America Line	951'
68	Jun 20	Fri	GOLDEN PRINCESS	Ketchikan	18:27	23:53	Seattle	2,600	Princess Cruise Lines	951'
69	Jun 21	Sat	STAR PRINCESS	Skagway	15:50	23:59	Seattle	2,600	Princess Cruise Lines	951'
70	Jun 21	Sat	WESTERDAM	Ketchikan	17:44	23:33	Seattle	1,916	Holland America Line	936'
71	Jun 21	Sat	NORWEGIAN PEARL	Ketchikan	17:38	23:45	Seattle	2,400	Norwegian Cruise Line	971'
72	Jun 24	Tue	DAWN PRINCESS	Skagway	6:06	14:11	San Francisco	1,950	Princess Cruise Lines	856'
73	Jun 25	Wed	TAHITIAN PRINCESS	Sitka	14:25	23:53	Vancouver	680	Princess Cruise Lines	592'
74	Jun 26	Thu	AMSTERDAM	Ketchikan	18:42	23:30	Seattle	1,380	Holland America Line	780'
75	Jun 26	Thu	CELEBRITY INFINITY	Ketchikan	20:02	0:21	Seattle	2,000	Celebrity Cruise Line	965'
76	Jun 27	Fri	OOSTERDAM	Ketchikan	18:30	23:44	Seattle	1,840	Holland America Line	951'
77	Jun 27	Fri	GOLDEN PRINCESS	Ketchikan	19:08	23:56	Seattle	2,600	Princess Cruise Lines	951'
78	Jun 28	Sat	STAR PRINCESS	Skagway	16:35	0:10	Seattle	2,600	Princess Cruise Lines	951'
79	Jun 28	Sat	NORWEGIAN PEARL	Ketchikan	17:35	23:50	Seattle	2,400	Norwegian Cruise Line	971'
80	Jun 28	Sat	WESTERDAM	Ketchikan	18:15	23:52	Seattle	1,916	Holland America Line	936'
81	Jul 03	Thu	SILVER SHADOW	San Francisco	12:08	18:23	Ketchikan	350	Silversea	600'
82	Jul 03	Thu	AMSTERDAM	Ketchikan	17:50	23:24	Seattle	1,380	Holland America Line	780'
83	Jul 03	Thu	CELEBRITY INFINITY	Ketchikan	20:25	0:24	Seattle	2,000	Celebrity Cruise Line	965'
84	Jul 04	Fri	DAWN PRINCESS	Skagway	5:43	14:14	San Francisco	1,950	Princess Cruise Lines	856'
85	Jul 04	Fri	OOSTERDAM	Ketchikan	18:20	23:41	Seattle	1,840	Holland America Line	951'
86	Jul 04	Fri	GOLDEN PRINCESS	Ketchikan	19:10	23:56	Seattle	2,600	Princess Cruise Lines	951'
87	Jul 05	Sat	STAR PRINCESS	Skagway	16:53	23:55	Seattle	2,600	Princess Cruise Lines	951'
88	Jul 05	Sat	WESTERDAM	Ketchikan	18:02	23:37	Seattle	1,916	Holland America Line	936'
89	Jul 05	Sat	NORWEGIAN PEARL	Ketchikan	17:36	0:05	Seattle	2,400	Norwegian Cruise Line	971'
90	Jul 09	Wed	TAHITIAN PRINCESS	Sitka	14:18	23:48	Vancouver	680	Princess Cruise Lines	592'
91	Jul 10	Thu	AMSTERDAM	Ketchikan	19:08	23:52	Seattle	1,380	Holland America Line	780'
92	Jul 10	Thu	CELEBRITY INFINITY	Ketchikan	18:38	0:06	Seattle	2,000	Celebrity Cruise Line	965'
93	Jul 11	Fri	OOSTERDAM	Ketchikan	18:33	23:42	Seattle	1,840	Holland America Line	951'
94	Jul 11	Fri	GOLDEN PRINCESS	Ketchikan	17:58	23:53	Seattle	2,600	Princess Cruise Lines	951'
95	Jul 12	Sat	STAR PRINCESS	Skagway	16:20	0:05	Seattle	2,600	Princess Cruise Lines	951'
96	Jul 12	Sat	NORWEGIAN PEARL	Ketchikan	17:32	23:50	Seattle	2,400	Norwegian Cruise Line	971'
97	Jul 12	Sat	WESTERDAM	Ketchikan	17:50	23:37	Seattle	1,916	Holland America Line	936'
98	Jul 14	Mon	DAWN PRINCESS	Skagway	5:45	14:11	San Francisco	1,950	Princess Cruise Lines	856'
99	Jul 15Tue		SILVER SHADOW	San Francisco	12:00	18:36	Sitka	350	Silversea	600'
100	Jul 17	Thu	AMSTERDAM	Ketchikan	17:34	23:21	Seattle	1,380	Holland America Line	780'

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2008 CRUISE SHIP SCHEDULE - VICTORIA, BC / OGDEN POINT

	DATE		VESSEL	FROM	ARR	DEP	TO	# PASS	CRUISE LINE	LGTH
101	Jul 17	Thu	CELEBRITY INFINITY	Ketchikan	18:34	23:55	Seattle	2,000	Celebrity Cruise Line	965 '
102	Jul 18	Fri	OOSTERDAM	Ketchikan	17:53	23:36	Seattle	1,840	Holland America Line	951 '
103	Jul 18	Fri	GOLDEN PRINCESS	Ketchikan	18:32	23:49	Seattle	2,600	Princess Cruise Lines	951 '
104	Jul 19	Sat	STAR PRINCESS	Skagway	16:22	23:53	Seattle	2,600	Princess Cruise Lines	951 '
105	Jul 19	Sat	NORWEGIAN PEARL	Ketchikan	17:30	0:12	Seattle	2,400	Norwegian Cruise Line	971 '
106	Jul 19	Sat	WESTERDAM	Ketchikan	17:52	23:40	Seattle	1,916	Holland America Line	936 '
107	Jul 23	Wed	TAHITIAN PRINCESS	Sitka	14:32	23:51	Vancouver	680	Princess Cruise Lines	592 '
108	Jul 24	Thu	DAWN PRINCESS	Skagway	5:53	14:05	San Francisco	1,950	Princess Cruise Lines	856 '
109	Jul 24	Thu	AMSTERDAM	Ketchikan	17:37	23:29	Seattle	1,380	Holland America Line	780 '
110	Jul 24	Thu	CELEBRITY INFINITY	Ketchikan	18:38	23:59	Seattle	2,000	Celebrity Cruise Line	965 '
111	Jul 25	Fri	OOSTERDAM	Ketchikan	17:55	23:41	Seattle	1,840	Holland America Line	951 '
112	Jul 25	Fri	GOLDEN PRINCESS	Vessel Did Not Arrive at Ogden Point					Princess Cruise Lines	951 '
113	Jul 26	Sat	STAR PRINCESS	Skagway	16:31	23:53	Seattle	2,600	Princess Cruise Lines	951 '
114	Jul 26	Sat	NORWEGIAN PEARL	Ketchikan	17:40	0:10	Seattle	2,400	Norwegian Cruise Line	971 '
115	Jul 26	Sat	WESTERDAM	Ketchikan	18:07	23:51	Seattle	1,916	Holland America Line	936 '
116	Jul 28	Mon	DAWN PRINCESS	San Francisco	10:47	18:47	Ketchikan	1,950	Princess Cruise Lines	856 '
117	Jul 31	Thu	SILVER SHADOW	Juneau	12:30	0:12	Vancouver	360	Silversea	600 '
118	Jul 31	Thu	AMSTERDAM	Ketchikan	18:59	23:31	Seattle	1,380	Holland America Line	780 '
119	Jul 31	Thu	CELEBRITY INFINITY	Ketchikan	19:17	23:57	Seattle	2,000	Celebrity Cruise Line	965 '
120	Aug 01	Fri	OOSTERDAM	Ketchikan	17:46	23:36	Seattle	1,840	Holland America Line	951 '
121	Aug 01	Fri	GOLDEN PRINCESS	Ketchikan	18:32	23:48	Seattle	2,600	Princess Cruise Lines	951 '
122	Aug 02	Sat	STAR PRINCESS	Skagway	16:21	23:40	Seattle	2,600	Princess Cruise Lines	951 '
123	Aug 02	Sat	WESTERDAM	Ketchikan	17:58	23:51	Seattle	1,916	Holland America Line	936 '
124	Aug 02	Sat	NORWEGIAN PEARL	Ketchikan	17:30	0:10	Seattle	2,400	Norwegian Cruise Line	971 '
125	Aug 06	Wed	TAHITIAN PRINCESS	Sitka	14:21	23:44	Vancouver	680	Princess Cruise Lines	592 '
126	Aug 07	Thu	AMSTERDAM	Ketchikan	17:59	23:20	Seattle	1,380	Holland America Line	780 '
127	Aug 07	Thu	CELEBRITY INFINITY	Ketchikan	18:35	23:56	Seattle	2,000	Celebrity Cruise Line	965 '
128	Aug 08	Fri	OOSTERDAM	Ketchikan	17:53	23:36	Seattle	1,840	Holland America Line	951 '
129	Aug 08	Fri	GOLDEN PRINCESS	Ketchikan	18:57	23:53	Seattle	2,600	Princess Cruise Lines	951 '
130	Aug 09	Sat	SILVER SHADOW	Sitka	12:41	17:55	Vancouver	350	Silversea	600 '
131	Aug 09	Sat	STAR PRINCESS	Skagway	16:25	23:59	Seattle	2,600	Princess Cruise Lines	951 '
132	Aug 09	Sat	WESTERDAM	Ketchikan	18:49	23:44	Seattle	1,916	Holland America Line	936 '
133	Aug 09	Sat	NORWEGIAN PEARL	Ketchikan	17:26	23:35	Seattle	2,400	Norwegian Cruise Line	971 '
134	Aug 12	Tue	SUN PRINCESS	San Francisco	11:20	23:57	Vancouver	1,950	Princess Cruise Lines	856 '
135	Aug 13	Wed	DAWN PRINCESS	Skagway	5:46	14:36	San Francisco	1,950	Princess Cruise Lines	856 '
136	Aug 14	Thu	AMSTERDAM	Ketchikan	18:18	23:01	Seattle	1,380	Holland America Line	780 '
137	Aug 14	Thu	CELEBRITY INFINITY	Ketchikan	18:47	23:48	Seattle	2,000	Celebrity Cruise Line	965 '
138	Aug 15	Fri	OOSTERDAM	Ketchikan	18:12	23:33	Seattle	1,840	Holland America Line	951 '
139	Aug 15	Fri	GOLDEN PRINCESS	Ketchikan	18:50	23:45	Seattle	2,600	Princess Cruise Lines	951 '
140	Aug 16	Sat	STAR PRINCESS	Skagway	16:28	0:02	Seattle	2,600	Princess Cruise Lines	951 '
141	Aug 16	Sat	NORWEGIAN PEARL	Ketchikan	17:29	23:40	Seattle	2,400	Norwegian Cruise Line	971 '
142	Aug 16	Sat	WESTERDAM	Ketchikan	19:00	23:47	Seattle	1,916	Holland America Line	936 '
143	Aug 17	Sun	DAWN PRINCESS	San Francisco	11:31	19:04	Ketchikan	1,950	Princess Cruise Lines	856 '
144	Aug 20	Wed	TAHITIAN PRINCESS	Vessel Did Not Arrive at Ogden Point					Princess Cruise Lines	592 '
145	Aug 21	Thu	AMSTERDAM	Ketchikan	18:08	22:53	Seattle	1,380	Holland America Line	780 '
146	Aug 21	Thu	CELEBRITY INFINITY	Ketchikan	18:49	23:42	Seattle	2,000	Celebrity Cruise Line	965 '
147	Aug 22	Fri	OOSTERDAM	Ketchikan	18:27	23:35	Seattle	1,840	Holland America Line	951 '
148	Aug 22	Fri	GOLDEN PRINCESS	Ketchikan	19:04	23:49	Seattle	2,600	Princess Cruise Lines	951 '
149	Aug 23	Sat	STAR PRINCESS	Skagway	16:30	0:02	Seattle	2,600	Princess Cruise Lines	951 '
150	Aug 23	Sat	NORWEGIAN PEARL	Ketchikan	20:16	23:50	Seattle	2,400	Norwegian Cruise Line	971 '

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2008 CRUISE SHIP SCHEDULE - VICTORIA, BC / OGDEN POINT

	DATE		VESSEL	FROM	ARR	DEP	TO	# PASS	CRUISE LINE	LGTH
151	Aug 23	Sat	WESTERDAM	Ketchikan	18:47	23:39	Seattle	1,916	Holland America Line	936'
152	Aug 26	Tue	SILVER SHADOW	Wrangell	12:30	23:51	Vancouver	350	Silversea	600'
153	Aug 28	Thu	AMSTERDAM	Ketchikan	18:45	23:11	Seattle	1,380	Holland America Line	780'
154	Aug 28	Thu	CELEBRITY INFINITY	Ketchikan	19:08	23:46	Seattle	2,000	Celebrity Cruise Line	965'
155	Aug 29	Fri	OOSTERDAM	Ketchikan	17:52	23:40	Seattle	1,840	Holland America Line	951'
156	Aug 29	Fri	GOLDEN PRINCESS	Vessel Did Not Arrive at Ogden Point					Princess Cruise Lines	951'
157	Aug 30	Sat	STAR PRINCESS	Skagway	16:22	23:38	Seattle	2,600	Princess Cruise Lines	951'
158	Aug 30	Sat	NORWEGIAN PEARL	Vessel Did Not Arrive at Ogden Point					Norwegian Cruise Line	971'
159	Aug 30	Sat	WESTERDAM	Ketchikan	18:26	23:38	Seattle	1,916	Holland America Line	936'
160	Sep 02	Tue	DAWN PRINCESS	Sitka	5:37	14:09	San Francisco	1,950	Princess Cruise Lines	856'
161	Sep 03	Wed	TAHITIAN PRINCESS	Sitka	14:30	23:46	Vancouver	680	Princess Cruise Lines	592'
162	Sep 04	Thu	SILVER SHADOW	Sitka	12:09	0:06	Vancouver	350	Silversea	600'
163	Sep 04	Thu	AMSTERDAM	Ketchikan	18:10	23:33	Seattle	1,380	Holland America Line	780'
164	Sep 04	Thu	CELEBRITY INFINITY	Ketchikan	18:40	23:46	Seattle	2,000	Celebrity Cruise Line	965'
165	Sep 05	Fri	OOSTERDAM	Ketchikan	17:55	23:30	Seattle	1,840	Holland America Line	951'
166	Sep 05	Fri	GOLDEN PRINCESS	Ketchikan	18:25	23:42	Seattle	2,600	Princess Cruise Lines	951'
167	Sep 06	Sat	STAR PRINCESS	Skagway	16:35	23:49	Seattle	2,600	Princess Cruise Lines	951'
168	Sep 06	Sat	WESTERDAM	Ketchikan	18:22	23:37	Seattle	1,916	Holland America Line	936'
169	Sep 06	Sat	NORWEGIAN PEARL	Vessel Did Not Arrive at Ogden Point					Norwegian Cruise Line	971'
170	Sep 11	Thu	SEVEN SEAS MARINER	Vancouver	6:18	15:47	Ketchikan	700	Regent Seven Seas	709'
171	Sep 11	Thu	AMSTERDAM	Ketchikan	18:20	22:55	Seattle	1,380	Holland America Line	780'
172	Sep 11	Thu	CELEBRITY INFINITY	Ketchikan	18:57	23:42	Seattle	2,000	Celebrity Cruise Line	965'
173	Sep 12	Fri	DAWN PRINCESS	Juneau	5:48	14:09	San Francisco	1,950	Princess Cruise Lines	856'
174	Sep 12	Fri	SILVER SHADOW	Ketchikan	11:17	17:41	San Francisco	350	Silversea	600'
175	Sep 12	Fri	OOSTERDAM	Ketchikan	17:41	23:33	Seattle	1,840	Holland America Line	951'
176	Sep 12	Fri	GOLDEN PRINCESS	Ketchikan	18:30	23:49	Seattle	2,600	Princess Cruise Lines	951'
177	Sep 13	Sat	RADIANCE OF THE SEAS	Vancouver	6:28	16:21	Juneau	2,500	Royal Caribbean Int'l	962'
178	Sep 13	Sat	STAR PRINCESS	Skagway	16:28	23:45	Seattle	2,600	Princess Cruise Lines	951'
179	Sep 13	Sat	WESTERDAM	Ketchikan	18:40	23:36	Seattle	1,916	Holland America Line	936'
180	Sep 13	Sat	NORWEGIAN PEARL	Vessel Did Not Arrive at Ogden Point					Norwegian Cruise Line	971'
181	Sep 16	Tue	DAWN PRINCESS	San Francisco	11:13	18:50	Juneau	1,950	Princess Cruise Lines	856'
182	Sep 17	Wed	TAHITIAN PRINCESS	Sitka	14:28	0:01	Vancouver	680	Princess Cruise Lines	592'
183	Sep 18	Thu	AMSTERDAM	Ketchikan	18:06	22:51	Seattle	1,380	Holland America Line	780'
184	Sep 18	Thu	CELEBRITY INFINITY	Ketchikan	18:30	23:39	Vancouver	2,000	Celebrity Cruise Line	965'
185	Sep 19	Fri	NORWEGIAN SUN	Juneau	11:55	18:30	San Francisco	1,900	Norwegian Cruise Line	853'
186	Sep 19	Fri	OOSTERDAM	Ketchikan	17:47	23:36	Seattle	1,840	Holland America Line	951'
187	Sep 19	Fri	GOLDEN PRINCESS	Ketchikan	18:18	23:49	Seattle	2,600	Princess Cruise Lines	951'
188	Sep 20	Sat	RHAPSODY OF THE SEAS	Vancouver	6:35	16:02	Astoria	2,000	Royal Caribbean Int'l	915'
189	Sep 20	Sat	CELEBRITY INFINITY	Seattle	7:00	17:15	Prince Rupert	2,000	Celebrity Cruise Line	965'
190	Sep 20	Sat	STAR PRINCESS	Skagway	16:44	23:30	Seattle	2,600	Princess Cruise Lines	951'
191	Sep 20	Sat	NORWEGIAN PEARL	Vessel Did Not Arrive at Ogden Point					Norwegian Cruise Line	971'
192	Sep 20	Sat	WESTERDAM	Ketchikan	18:08	23:38	Seattle	1,916	Holland America Line	936'
193	Sep 21	Sun	STATENDAM	Vancouver	7:35	14:12	San Francisco	1,270	Holland America Line	719'
194	Sep 21	Sun	CELEBRITY MILLENNIUM	Seattle	7:14	17:07	Vancouver	2,034	Celebrity Cruise Line	965'
195	Sep 21	Sun	CELEBRITY MERCURY	Sitka	9:54	18:06	Seattle	1,870	Celebrity Cruise Line	866'
196	Sep 22	Mon	SAPPHIRE PRINCESS	Vessel Did Not Arrive at Ogden Point					Princess Cruise Lines	951'
197	Sep 22	Mon	ZAANDAM	Vessel Did Not Arrive at Ogden Point					Holland America Line	777'
198	Sep 22	Mon	NORWEGIAN STAR	Vancouver	7:39	17:02	Astoria	2,200	Norwegian Cruise Line	971'
199	Sep 24	Wed	CELEBRITY MERCURY	Nanaimo	7:44	17:55	Seattle	1,870	Celebrity Cruise Line	866'
200	Sep 25	Thu	RYNDAM	Vancouver	6:30	12:47	San Diego	1,250	Holland America Line	720'

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2008 CRUISE SHIP SCHEDULE - VICTORIA, BC / OGDEN POINT

	DATE		VESSEL	FROM	ARR	DEP	TO	# PASS	CRUISE LINE	LGTH
201	Sep 26	Fri	OOSTERDAM	Ketchikan	17:42	23:34	Seattle	1,840	Holland America Line	951'
202	Sep 26	Fri	GOLDEN PRINCESS	Ketchikan	18:23	0:06	Seattle	2,600	Princess Cruise Lines	951'
203	Sep 27	Sat	VEENDAM	Vancouver	6:46	13:37	San Diego	1,250	Holland America Line	720'
204	Sep 27	Sat	CELEBRITY MERCURY	Seattle	7:33	18:03	Nanaimo	1,870	Celebrity Cruise Line	866'
205	Sep 27	Sat	WESTERDAM	Ketchikan	18:45	23:07	Seattle	1,916	Holland America Line	936'
206	Sep 28	Sun	OOSTERDAM	Seattle	7:23	16:52	Astoria	1,840	Holland America Line	951'
207	Oct 01	Wed	OOSTERDAM	Vancouver	6:40	15:57	San Diego	1,840	Holland America Line	951'
208	Oct 01	Wed	CELEBRITY MERCURY	Nanaimo	7:49	18:22	Seattle	1,870	Celebrity Cruise Line	866'
209	Oct 04	Sat	CELEBRITY MERCURY	Seattle	7:25	18:05	Nanaimo	1,870	Celebrity Cruise Line	866'
210	Oct 08	Wed	CELEBRITY MERCURY	Nanaimo	7:24	18:08	Seattle	1,870	Celebrity Cruise Line	866'
211	Oct 11	Sat	CELEBRITY MERCURY	Seattle	7:35	18:14	Nanaimo	1,870	Celebrity Cruise Line	866'
212	Oct 14	Tue	CELEBRITY MERCURY	Vancouver	7:25	18:09	Seattle	1.870	Celebrity Cruise Line	866'