# Air Quality in the Capital Regional District 2002

Prepared for:

**Capital Regional District**
Environmental Services Department
524 Yates Street
Victoria, BC  V8W 2S6

Prepared by:

**SENES Consultants Limited**
1275 West 6th Avenue, Suite 300
Vancouver, BC  V6H 1A6

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# EXECUTIVE SUMMARY

The air quality monitoring program conducted in the Capital Regional District (CRD) is a result of a partnership of the CRD with the British Columbia Ministry of Water, Land and Air Protection (MWLAP). The 2002 monitoring data collected from continuous and sequential monitoring stations throughout the district were analyzed and compared against Provincial and Federal ambient air quality objectives, and Health Reference Levels. Concentrations of carbon monoxide (CO), nitrogen dioxide ($NO_2$), ground-level ozone ($O_3$), sulphur dioxide ($SO_2$), inhalable particulate matter ($PM_{10}$) and respirable particulate matter ($PM_{2.5}$) were assessed. Analysis included looking at spatial and temporal trends to determine source-receptor relationships, especially in the case of an exceedence of an applicable air quality objective. Meteorological data were also analyzed to determine the influence of wind, temperature and precipitation patterns on ambient air concentrations.

Although standards for ground level ozone and $PM_{2.5}$ have recently been revised (new Canada Wide Standards), standards for the other criteria contaminants monitored in the CRD may not reflect the current understanding of related health effects and need to be revisited in the near future. Furthermore, part of the CWS setting process defines the need for continuous improvement and keeping clean areas clean in those areas that currently meet the CWS for $PM_{2.5}$ and ozone. Under this principle, jurisdictions such as the CRD have the flexibility to define ambient air quality targets that are below the numeric values of the CWS in order to minimize human health and visibility impacts. The CRD has already initiated a process to develop air quality targets that could be used as benchmarks for evaluating trends in pollutant concentrations and for public reporting on air quality within the CRD.

Analysis of the 2002 ambient data shows that air quality in the CRD remains good relative to other urban areas in North America. Concentrations of gaseous pollutants are generally low throughout the entire year. It is only on very rare occasions that particulate matter concentrations climb above the Provincial Objective of 50 µg/m³ for a 24-hour average of $PM_{10}$. The much more stringent Health Reference Levels for $PM_{10}$ and $PM_{2.5}$ continue to be exceeded for a small percentage of the year. These levels represent the minimum concentration at which a statistically measurable health effect has been established.

Carbon monoxide measurements from the Victoria Topaz monitoring station yielded a maximum 1-hour concentration of 6800 µg/m³ and a maximum 8-hour concentration of 3525 µg/m³. Both maximums are below all Federal and Provincial objectives.

Nitric oxide (NO) and nitrogen dioxide ($NO_2$), collectively designated $NO_x$, were monitored at the Victoria Topaz and the Royal Roads University monitoring stations. Maximum 1-hour $NO_2$ concentrations of 86.1 µg/m³ and 66.0 µg/m³, and maximum 24-hour $NO_2$ concentrations of 38.9

μg/m³ and 34.3 μg/m³ were determined, with annual mean values of 19.9 μg/m³ and 13.9 μg/m³ respectively. These values are all well below Federal objectives. There are no Provincial objectives for $NO_2$.

Ground-level ozone was monitored at the Victoria Topaz station, the Royal Roads station and a station situated on Saturna Island. Ozone concentrations were of a similar magnitude to the previous year, with 8-hour concentrations well below the Canada Wide Standard (CWS) for ozone. Maximum 1-hour concentrations at the three sites were 115.7, 131.7 and 149.0 μg/m³ respectively, which are above the Federal Maximum Desirable level but below the Maximum Acceptable level. The Federal Maximum Acceptable 24-hour concentration of 50 μg/m³ was exceeded 18.9, 31.4 and 62.4 % of the time, but this objective is known to be higher than the natural background ozone levels, even in remote locations of Canada.

A limited dataset for $NO_x$ and ground level ozone was available from the Royal Roads monitoring station in 2002. As there is significant interest in these criteria pollutants, it is suggested that either an effort be made to increase the percentage of valid data captured from the station in the future, or that the air contaminants be monitored elsewhere in the CRD in addition to the Royal Roads site.

Sulphur dioxide measurements from the Victoria Topaz station were used to determine a maximum hourly concentration of 61 μg/m³ and a maximum 24-hour concentration of 12.4 μg/m³. The annual arithmetic mean was 3.0 μg/m³. These concentrations are well below all applicable Federal and Provincial air quality objectives. Although $SO_2$ concentrations in other parts of the CRD are not likely to be high, it is not know if the Victoria Topaz concentrations are representative of the region. It would be helpful to either monitor $SO_2$ at another permanent location, or to monitor $SO_2$ for short time periods at two or more locations selected in the CRD. Either approach would generate a better understanding of $SO_2$ concentrations in the area.

Particulate matter concentrations were also generally low relative to the Federal and Provincial standards. Sequential $PM_{10}$ (Hi-Vol) monitoring data from the Victoria Topaz, Keating Elementary School, Braefoot Elementary School and the Oak Bay Recreational Centre monitoring stations were used to determine mean annual 24-hour concentrations of 19.6, 14.7, 13.8, and 13.7 μg/m³ respectively. Although these values are not high, each represents a small increase from 2001. One exceedence of the Provincial standard of 50 μg/m³ was recorded in October at Victoria Topaz. The TEOM sampler at Colwood Municipal Hall, which was moved to Langford in October of 2002, also recorded one exceedence of the 24-hour $PM_{10}$ objective. Analysis of the TEOM data showed that this exceedence was a brief dust event during the afternoon of April 22 with a maximum hourly concentration of 411 μg/m³. The event was caused by dry conditions and elevated wind speeds, and was likely not representative of other areas in the CRD. The $PM_{10}$ Health Reference Level of 25 μg/m³ was exceeded 23% of the time at Victoria Topaz and by smaller amounts at the other monitoring locations. This is an increase over the frequency of 2001 Health Reference exceedences.

$PM_{2.5}$ concentrations at all monitoring sites were low in comparison to the CWS 3-year objective of 30 µg/m³ (98th percentile). Mean 24-hour concentrations at the three TEOM sites (Victoria Topaz, Royal Roads University, and Colwood Municipal Hall) were 7.1, 5.1, and 5.2 µg/m³. The new $PM_{2.5}$ TEOM site in Langford began collecting data in November, yet still experienced the highest 24-hour average of all monitoring stations in 2002. This indicates that relatively high concentrations may be experienced at this location in the future. The mean value from the sequential sampler (Dicot) at Victoria Topaz was 7.3 µg/m³. Exceedences of the 24-hour Health Reference Level of 15 µg/m³ occurred 10.2 % of the time as determined by the dichotomous sampler at Victoria Topaz, and by a smaller percentage determined from the three TEOM sites (not including Langford). This is an increase over 2001 Health Reference Level exceedences. $PM_{2.5}$ concentrations were observed to increase significantly during the fall and winter months. The addition of space heating to the other sources of particulate matter in the CRD is suggested at the most likely cause.

Temporal patterns in $PM_{2.5}$ data were similar at the different monitoring stations that operated for the duration of 2002. However, particulate matter concentrations were significantly higher at Victoria Topaz, mainly due to the Topaz site being in the city core, in proximity to Blanshard Street (a major traffic corridor). Temporal patterns were observed in the CO and NO data that implied combustion was the major source of these air contaminants. It was noted that trends of $PM_{2.5}$, CO and NO were similar and likely related to the same (combustion) sources. The correlation of these contaminants was also noted in the 2001 Air Quality Report for the CRD. The simultaneous measurement of CO, NO and $PM_{2.5}$ is recommended at the new Langford monitoring station, to help determine whether combustion or some other activity is primarily responsible for higher $PM_{2.5}$ concentrations.

A baseline for air quality has not yet been established for the CRD. Historical data produced from the Long Term Monitoring Plan is essential to the eventual establishment of this baseline. Continuation of monitoring at present levels is recommended, with consideration towards extending the monitoring of gaseous pollutants.

# 1.0 INTRODUCTION

Air quality data collected in the Capital Regional District (CRD) during 2002 were analyzed for this report. Ambient air concentrations were determined to facilitate comparison to Federal and Provincial air quality objectives. For 2002, data were available from eight sites within the CRD. The air contaminants measured at these sites and the meteorological data that were available are summarized in Table 1.1.

**Table 1.1 Air Quality Monitoring Stations in the Capital Regional District**

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

Notes:

WS – wind speed; WD – wind direction; T – temperature; RH – relative humidity

S-Hi-Vol – sequential sampling using High Volume samplers

S-Dicot – sequential sampling using a dichotomous samplers

C-TEOM – continuous sampling using Tapered Element Oscillating Microbalance samplers

1- Station moved to Langford in October 2002; 2- Station began operating in November, 2002;

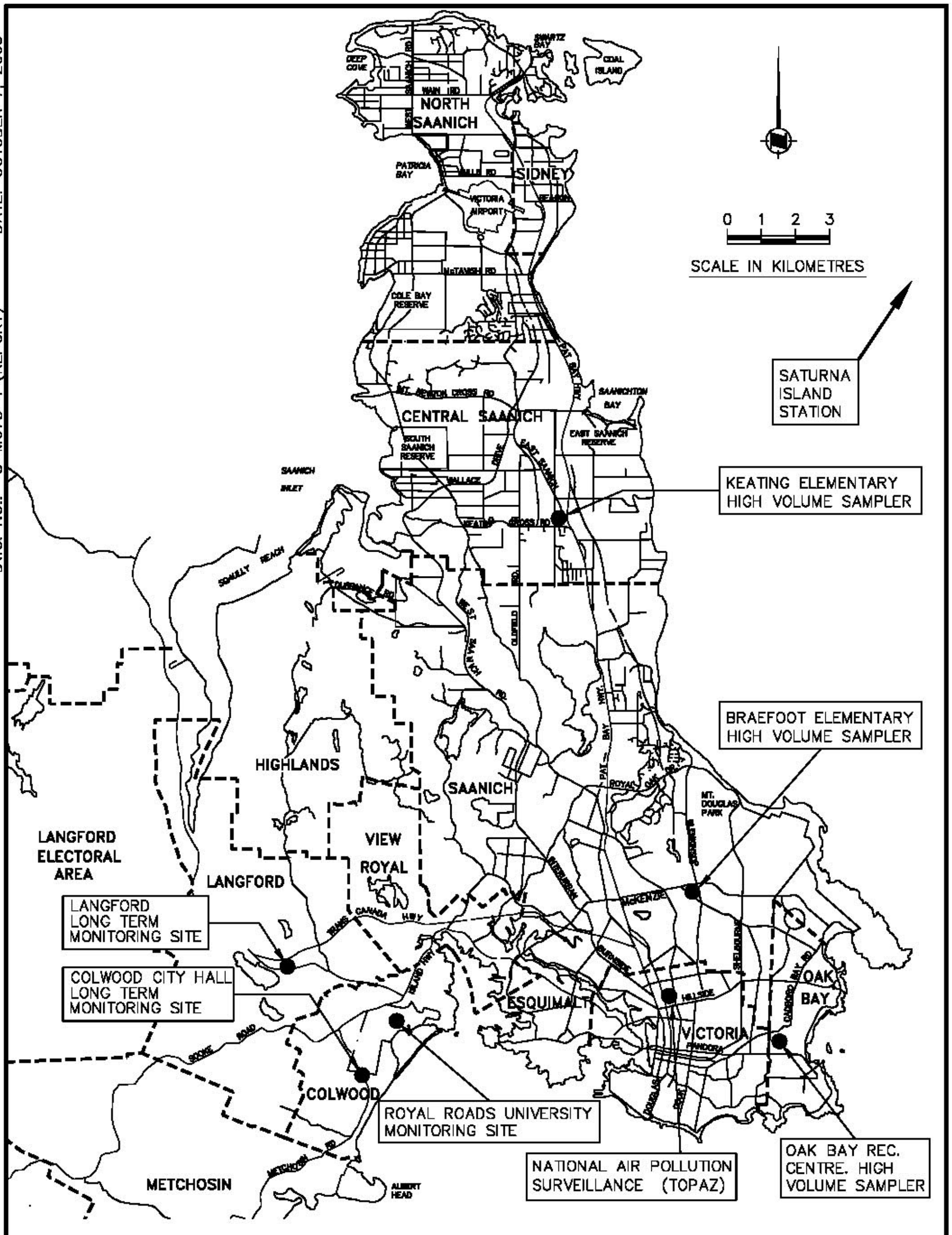
3- Canadian Air and Precipitation Monitoring Network;

4- Special area of interest since October 1996; 5- Special area of interest since November 1995;

Gaseous air pollutants are monitored by a National Air Pollution Surveillance (NAPS) station at Victoria Topaz, including carbon monoxide (CO), nitrogen oxides ($NO_x$), sulphur dioxide ($SO_2$), and ground-level ozone ($O_3$). The Royal Roads site monitored $O_3$ and $NO_x$, but not for the entire year. Ground-level ozone, $NO_x$, and $SO_2$ are also monitored at the Canadian Air and Precipitation Monitoring (CAPMoN) station on nearby Saturna Island. Ozone data from this station were provided by Environment Canada.

Particulate matter is measured at 7 of the 8 monitoring sites in the CRD. Three different sampling instruments were used to determine inhalable particulate matter ($PM_{10}$) concentrations and respirable particulate matter ($PM_{2.5}$) concentrations. The differences between the three types of sampling instruments are described in chapter 4. The Colwood Municipal Hall monitoring station, which measures both $PM_{10}$ and $PM_{2.5}$, was moved North to a location in Langford during 2002, and therefore data from the Colwood station stopped being collected in October. The locations of the 7 monitoring stations are depicted in Figure 1-1.

The ambient air monitoring programs conducted within the CRD to date have not provided suitable data that could be used for long term trend analysis. Only the monitoring data from the Victoria NAPS site provide any data for such an objective. However, the relocation of the NAPS station in 1998 limits the value of any long term trend analysis for this station. For this reason, the analysis presented in this report has been confined to data collected in 2002.




**2002 LOCATIONS OF SAMPLING SITES FOR THE CRD LONG TERM MONITORING PROGRAM**

**FIGURE 1-1**

### 1.1 AIR QUALITY OBJECTIVES

The Canadian National Ambient Air Quality Objectives (NAAQO) is a three-tiered system that monitoring data are compared to. Each level has a specific concentration for an individual air contaminant. The three levels are:

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

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

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

Some of the effects of air contaminants above or below the three Federal objective levels are summarized in Table 1.2.

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. In the case of the Bulkley Valley, the levels are interpreted in the same manner as the Federal objectives, but use simplified descriptions[1]. 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.

More recently, a set of Canada Wide Standards (CWS) was developed for $PM_{2.5}$ and ground-level ozone (and other pollutants). These standards are based on three continuous years of monitoring data, and are to be achieved by the target date of 2010.

All Federal and Provincial air quality criteria are presented in Table 1.3.

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

**Table 1.2:**
**National Ambient Air Quality Objectives**
**and Their Relationship to Some Health and Environmental Effects**
(Source: Environment Canada 1991)[2]

| **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.**

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

## Table 1.3 Air Quality Objectives and Standards

## For Contaminants[1] Monitored in the CRD

| Contaminant | Averaging Period | Canada Maximum Desirable | Canada Maximum Acceptable | BC Level A | BC Level B | BC Level C |
|---|---|---|---|---|---|---|
| Carbon Monoxide | 1-hour | 15000 | 35000 | 14300 | 28000 | 35000 |
| | 8-hour | 6000 | 15000 | 5500 | 11000 | 14300 |
| Nitrogen Dioxide | 1-hour | | 400 | | | |
| | 24-hour | | 200 | | | |
| | Annual Arithmetic Mean | 60 | 100 | | | |
| Ozone | 1-hour | 100 | 160 | | | |
| | 24-hour | 30 | 50 | | | |
| | Annual Arithmetic Mean | | 30 | | | |
| 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 |
| **Ambient Air Quality Objectives Established in 1995** | | | | | | |
| $PM_{10}$ | 24- hour | | | 50 | | |
| **Canada-Wide Standards Established in June 2000** | | | | | | |
| Ozone | 8-hour | 127.6[2] | | | | |
| $PM_{2.5}$ | 24-hour | 30[3] | | | | |
| **Health Reference Levels** | | | | | | |
| $PM_{10}$ | 24- hour | 25 | | | | |
| $PM_{2.5}$ | 24- hour | 15 | | | | |

Notes:
[1] All units in µg/m$^3$
[2] Achievement by 2010, based on the 4$^{th}$ highest measurement annually, averaged over 3 consecutive years.
[3] Achievement by 2010, based on the 98$^{th}$ percentile ambient measurement annually, averaged over 3 consecutive years.

It should be noted that there is a growing awareness of the need to update the existing air quality objectives and guidelines. Although the Canada-Wide Standards setting process has addressed the need to update ambient air quality criteria for ground-level ozone and fine particles ($PM_{2.5}$), the current objective level for $PM_{10}$ was established in 1995, and the objectives for CO, $SO_2$ and $NO_2$ have not been reviewed since the mid-1970's. The existing standards may not reflect the current knowledge and understanding of the health effects of these air pollutants.

Furthermore, apart from the numerical standards for particulate matter and ozone, the CWS setting process has a requirement for continuous improvement and keeping clean areas clean for those areas where existing ambient concentrations of $PM_{2.5}$ and ozone fall below the numerical standards. According to a recent discussion paper[3], the concept of keeping clean areas clean can be described as a framework on managing ambient concentrations of particulate matter and ozone below the CWS to minimize any increase in ambient concentrations and, ideally, maintain or reduce ambient concentrations.

The overriding principle of keeping clean areas clean is to minimize human health and visibility impacts. Under the CWS setting process, jurisdictions have the flexibility to define ambient air quality management targets that are below the numeric values of the CWS for $PM_{2.5}$ and ozone. In the absence of a national guidance document on the implementation of continuous improvement and keeping clean areas clean, the CRD may wish to consider establishing alternative ambient air quality target levels for use in trend analysis and reporting.

[3] 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.

# 2.0 METEOROLOGICAL MONITORING

Several meteorological stations in the Capital Regional District were operating in 2002. Data from three of these stations were obtained to develop an understanding of the climatic conditions and variations in the CRD during the year. To help in this regard, a monthly climate summary was also obtained from the Environment Canada website, which added precipitation information to the wind and temperature data from the three meteorological stations. Meteorological data from the Colwood Municipal Hall was not used, since the site did not operate for the whole year.

In general, the climate summary for Victoria International Airport, Table A.1 (Appendix A), shows that 2002 was a drier year than normal. The total annual rainfall of 660.4 mm was below the average of 841.4 mm. The summer and fall months were particularly dry, with each month having a total precipitation far below normal. The greatest difference occurred in October, which had a total rainfall of 14.2 mm, as compared to the climate normal of 75.6 mm. Monthly average temperatures, however, were similar to the long-term averages.

The wind rose diagrams presented for the three monitoring locations were constructed with calm conditions defined as those times with wind speeds less than 1 m/s. Although wind direction is indicated for measured speeds below 1 m/s, accuracy in direction measurement is known to deteriorate under these conditions. Average wind speeds were calculated using all wind speed measurements.

## 2.1 VICTORIA TOPAZ

The Victoria Topaz station is located at 923 Topaz Avenue, near downtown Victoria, and is jointly run by the Provincial and Federal governments as part of the National Air Pollutant Surveillance (NAPS) program. This station is located several kilometres from the coast and characterizes the urban environment in Victoria.

Wind speed, wind direction, temperature and relative humidity were monitored for the duration of 2002. The wind rose diagram for Victoria Topaz is presented in Figure A.1 (Appendix A).

Wind speeds experienced at this location were generally light, with an average of 2.8 m/s, and calm conditions reported 11% of the time. Southwesterly winds were most frequent during the year, with a significant portion from the north/north-northeast as well. Winds from the northwest tended to be very light, with an average wind speed of only 1.3 m/s.

## 2.2 ROYAL ROADS UNIVERSITY

The Royal Roads University station is located on the Cobourg Peninsula, near Esquimalt Lagoon. The site is operated by the University, which collected wind speed, wind direction and temperature data for the duration of 2002. Figure A.2 (Appendix A) presents the wind rose diagram for the station.

Although just 8 km from the Victoria Topaz station, measured winds at the Royal Roads site were considerably different. The location is characterized by a high percentage (23%) of light winds from the north-northwest, along with a high percentage of calms (20%). The average wind speed for the year was 2.6 m/s. Winds from the west tended to be higher in speed than those from other directions.

SENES suggests that there may be a concern with the siting and/or operation of the Royal Roads station. Based on anecdotal comments from CRD and WLAP staff, the station has good exposure to the south. Being located close to a land-sea boundary (to the south), it should be expected that average wind speeds would be higher than a station further inland (Topaz), which wasn't supported in the data. Also, the high frequency of north-northwesterly flow may be influenced by nearby structures and/or terrain.

### 2.3 SATURNA ISLAND

The meteorological station on Saturna Island is a Canadian Air and Precipitation Monitoring site (CAPMoN) operated by Environment Canada. A full year of wind speed and wind direction data was available for analysis. This location is northeast of Victoria, out in the Strait of Georgia. The wind rose diagram for the station is presented in Figure A.3 (Appendix A).

The average wind speed at the Saturna station (4.5 m/s) was significantly higher than those at the other two stations. Winds were most frequently from a southwesterly direction, as was the case for the Victoria Topaz location. The next most frequent direction of origin was northwest. Winds were not as frequent from the south and east, but tended to be higher in speed.

# 3.0 GASEOUS POLLUTANTS

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

## 3.1 CARBON MONOXIDE (CO)

Carbon monoxide is a colourless, odourless gas that is produced primarily from the incomplete combustion of fossil fuels. As such, most of the CO in the Capital Regional District is caused by motor vehicles and both industrial and residential burning.

Ambient CO concentrations were sampled at the Victoria Topaz monitoring station with a total of 8158 hours of valid data (6.9% missing) in 2002. Table 3.1.1 summarizes the 1-hour average concentrations for the period. The annual mean of 458 µg/m³ was a little higher than that determined for 2001[4] (405 µgm³). No exceedences of the B.C. Level A 1-hour ambient air quality objective of 14,300 µg/m³ were recorded.

**Table 3.1.1 Hourly CO Concentrations at Victoria Topaz**

| Percentile Values | | | | | | Max µg/m³ | Min µg/m³ | Mean µg/m³ | Std. Dev. µg/m³ | Percent of 1-h Averages > 14300µg/m³ | Missing Values % of Total Hours |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 5 | 25 | 50 | 75 | 98 | 99 | | | | | | |
| 0 | 100 | 300 | 600 | 2400 | 3000 | 6800 | 0 | 458 | 596 | 0.0 | 6.9 |

The 8-hour average concentrations for this site are summarized in Table 3.1.2. No exceedences of the 8-hour Provincial Level A objective of 5,500 µg/m³ were determined.

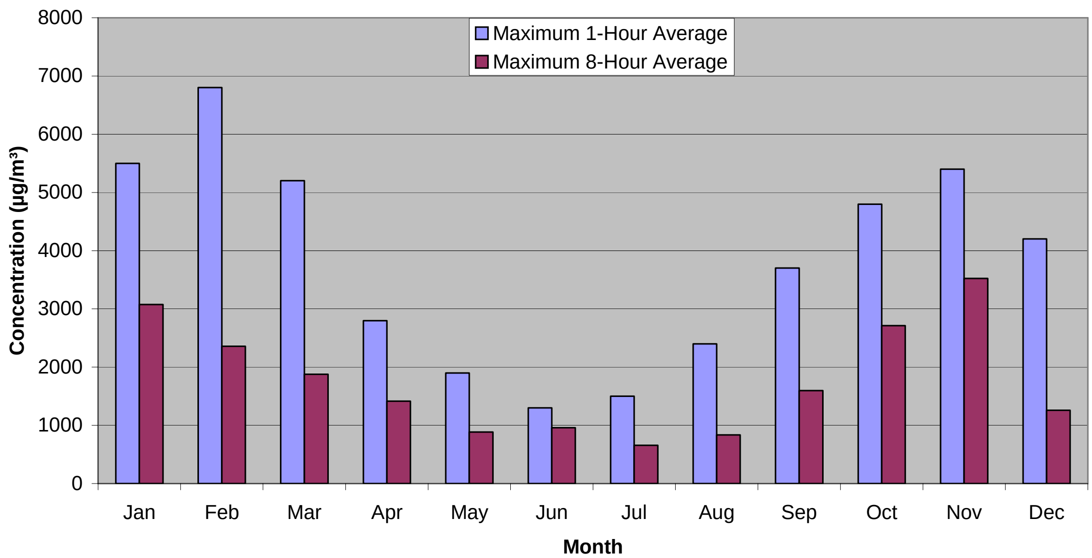
**Table 3.1.2 8-Hour Sequential Mean of CO at Victoria Topaz**

| Percentile Values | | | | | | Max µg/m³ | Min µg/m³ | Mean µg/m³ | Std. Dev. µg/m³ | Percent of 8-h Averages > 5500 µg/m³ | Missing Values[a] % of Total 8-h Averages |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 5 | 25 | 50 | 75 | 98 | 99 | | | | | | |
| 29 | 163 | 325 | 613 | 1763 | 2159 | 3525 | 0 | 459 | 449 | 0.0 | 2.3 |

[4] SENES Consultants Ltd., 2002. *2001 Report on Air Quality in the Capital Regional District.*
[a] An 8-hour average concentration was determined for every interval having 6 or more valid hours of data.

Figure 3.1.1 shows the maximum hourly and 8-hourly CO concentrations by month. A clear pattern of greater concentrations during the cooler months of the year is evident. Some of the increase in the fall months is due to natural decomposition of vegetation. In addition, fleet averaged CO emissions from light-duty gasoline powered automobiles may increase by over 50% in winter compared with summertime emissions[5]. The burning of fossil fuels for space heating is another significant source of CO in the area throughout the winter.

**Figure 3.1.1 Maximum 1-Hour and 8-Hour CO Concentrations by Month at Victoria Topaz**




The diurnal pattern of carbon monoxide in many urban areas is strongly associated with the workday transportation cycle. In the CRD, the average diurnal pattern for CO during cooler months (Figure 3.1.2a) and warmer months (Figure 3.1.2b) both show an early morning peak due to higher vehicular traffic activity at this time. A secondary peak during the evening hours is clearly delineated during the cooler months and is likely due to space heating. There is a smaller increase in levels late in the day for the warmer months as well, which is probably due to meteorological influences such as lowering of the mixing height[6].

[5] Calculation using the transportation emission model MOBILE 5C with a speed of 50 km/h.
[6] Mixing height refers to the maximum vertical distance through which pollutants emitted from ground level are able to travel, and mix with surrounding air.

**Figure 3.1.2a Average Diurnal CO Pattern for Victoria Topaz During Cooler Months (November - March)**

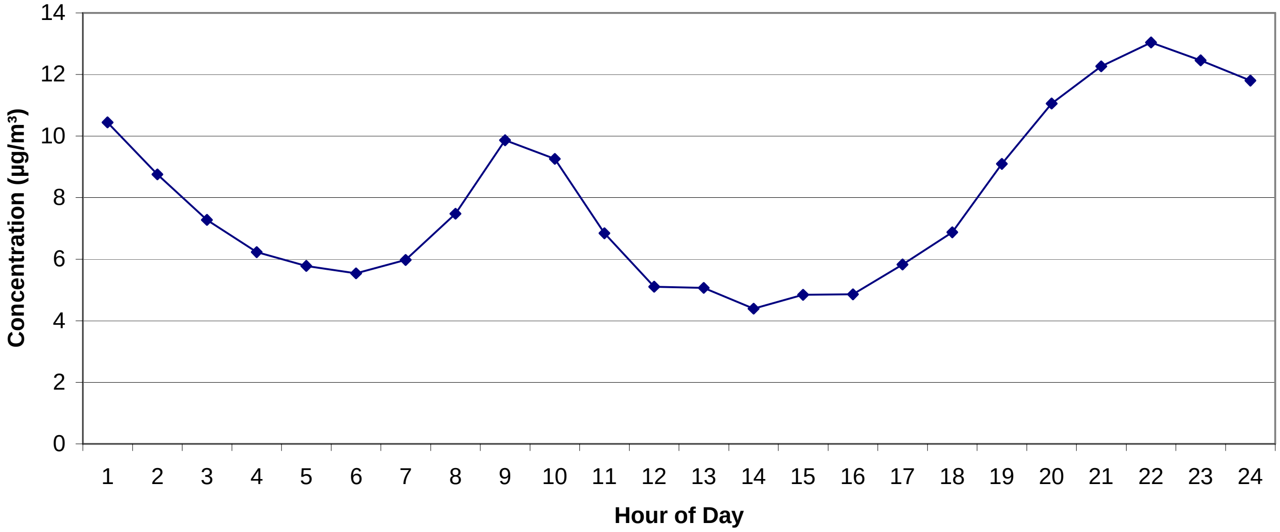
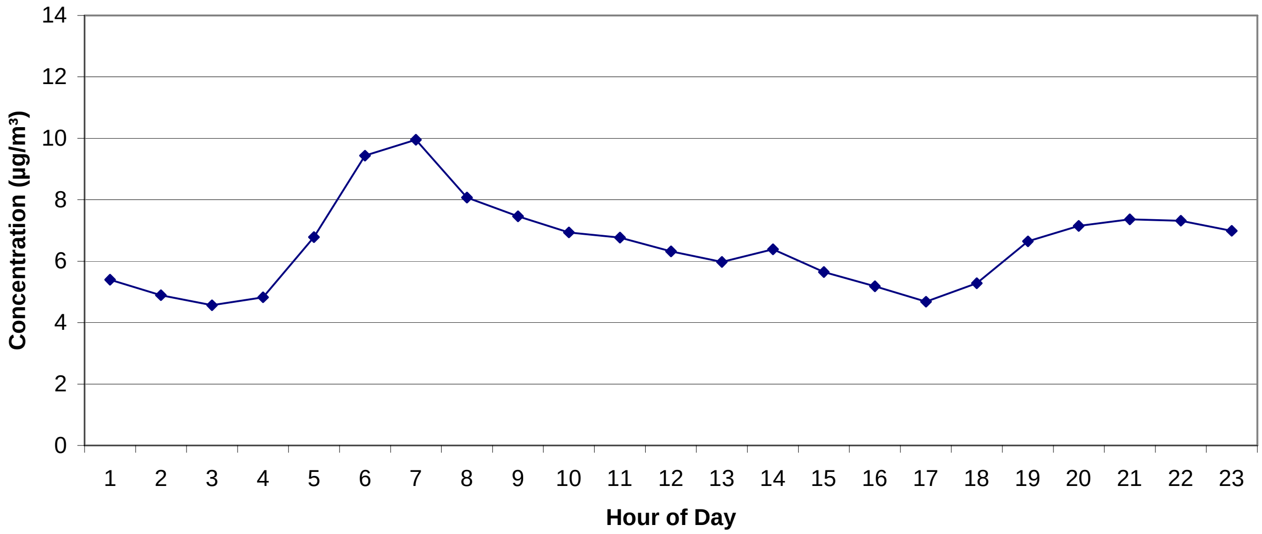



**Figure 3.1.2b Average CO Diurnal Pattern for Victoria Topaz During Warmer Months (April – October)**



### 3.2 NITROGEN OXIDES (NO AND $NO_2$)

Nitric oxide (NO) and nitrogen dioxide ($NO_2$) are two forms of gaseous nitrogen that are considered pollutants in the lower troposphere. In urban settings, NO is formed by (high temperature) combustion processes, such as automobile exhaust, fossil-fuel electricity generating stations, industrial incinerators and residential space heating. Patterns in nitric oxide emissions typically are linked to work-day transportation cycles. NO is a relatively non-toxic gas, having no Provincial or Federal air quality objectives. $NO_2$ is produced by the direct oxidation of NO and by a complex balance of reactions involving other atmospheric constituents including ozone. $NO_2$ is relatively toxic and can also be corrosive at high enough concentrations. Peak $NO_2$ levels tend to follow NO peaks by several hours, due to chemical and photochemical oxidation of NO. NO and $NO_2$ are commonly designated '$NO_x$' due to their interconvertibility in photochemical reactions.

In 2002, NO and $NO_2$ sampling data were recorded from the Victoria Topaz and the Royal Roads University monitoring sites. Victoria Topaz operated for the entire year whereas Royal Roads collected data between June 19 and November 30, 2002. Tables 3.2.1 and 3.2.2 outline the statistical analysis of hourly averaged $NO_2$ concentrations at the two monitoring sites. Maximum hourly concentrations at both stations were well below the Federal Maximum Acceptable guideline of 400 µg/m³.

**Table 3.2.1 Hourly $NO_2$ Concentrations at Victoria Topaz**

| Percentile Values | | | | | | Max µg/m³ | Min µg/m³ | Mean µg/m³ | Std. Dev. µg/m³ | Percent of 1-h Averages > 400 µg/m³ | Missing Values |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 5 | 25 | 50 | 75 | 98 | 99 | | | | | | % of Total Hours |
| 1.9 | 9.6 | 17.2 | 28.7 | 53.5 | 57.4 | 86.1 | 0.0 | 19.9 | 13.4 | 0.0 | 4.3 |

**Table 3.2.2 Hourly $NO_2$ Concentrations at Royal Roads University**

| Percentile Values | | | | | | Max µg/m³ | Min µg/m³ | Mean µg/m³ | Std. Dev. µg/m³ | Percent of 1-h Averages > 400 µg/m³ | Missing Values |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 5 | 25 | 50 | 75 | 98 | 99 | | | | | | % of Total Hours |
| 0.0 | 3.8 | 11.5 | 21.0 | 42.1 | 47.8 | 66.0 | 0 | 13.9 | 12.0 | 0.0 | 59.7 |

Tables 3.2.3 and 3.2.4 present a summary of the 24-hour average concentrations for $NO_2$ in 2002. Concentrations at both sites are well below the Federal Maximum Acceptable guideline of 200 µg/m³.

**Table 3.2.3 24-Hour Sequential Mean $NO_2$ at Victoria Topaz**

| Percentile Values | | | | | | Max µg/m³ | Min µg/m³ | Mean µg/m³ | Std. Dev. µg/m³ | Percent of 24-h Averages > 200 µg/m³ | Missing Values[b] |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 5 | 25 | 50 | 75 | 98 | 99 | | | | | | % of Total 24-h Averages |
| 7.6 | 14.6 | 19.8 | 26.0 | 34.0 | 35.6 | 38.9 | 3.2 | 20.0 | 7.5 | 0.0 | 0.5 |

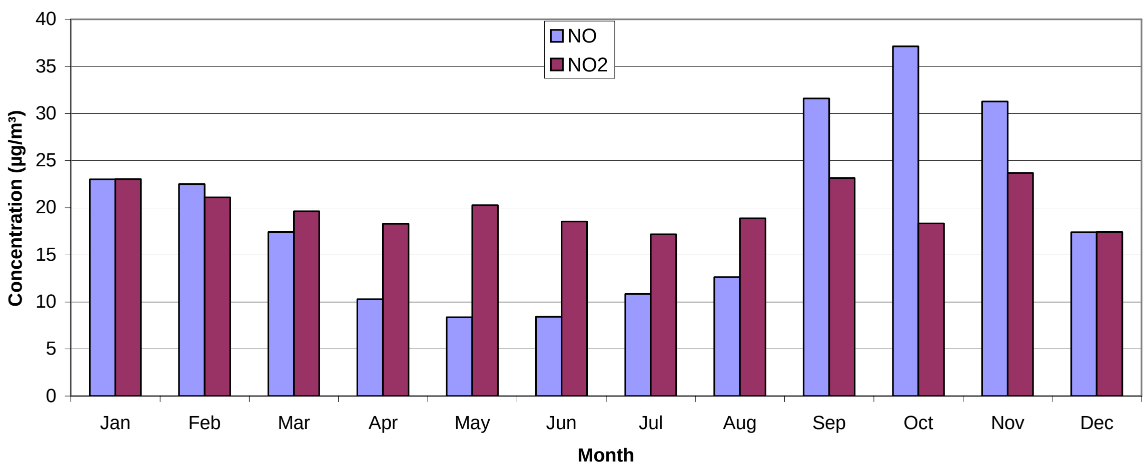
**Table 3.2.4 24-Hour Sequential Mean $NO_2$ at Royal Roads University**

| Percentile Values | | | | | | Max µg/m³ | Min µg/m³ | Mean µg/m³ | Std. Dev. µg/m³ | Percent of 24-h Averages > 200 µg/m³ | Missing Values[b] |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 5 | 25 | 50 | 75 | 98 | 99 | | | | | | % of Total 24-h Averages |
| 0.9 | 6.5 | 13.5 | 20.5 | 31.2 | 32.8 | 34.3 | 0.1 | 14.0 | 8.9 | 0.0 | 58.0 |

Figure 3.2.1 shows the average 24-hour NO and $NO_2$ concentrations by month for Victoria Topaz. Although $NO_2$ concentrations remain relatively uniform throughout the year, NO levels increase dramatically in the fall and are at a minimum in the late spring and summer months. Low NO concentrations in the spring and summer can be partly attributed to increased oxidation of NO to $NO_2$. Photochemical reactions involving NO emissions are stimulated by warmer temperatures and higher solar insolation and by increased levels of ozone. Greater conversion of NO (primarily to $NO_2$) occurs during the warmer months with relatively high ozone levels (detailed in the following section). Mixing heights tend to be higher during warmer months as well, allowing emitted NO to mix through greater volumes of air, thus reducing concentrations at ground level.

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

**Figure 3.2.1 Average 24-Hour NO and $NO_2$ Concentrations by Month at Victoria Topaz**




The increase in NO concentrations between September and November is a result of several factors. To begin with, emissions of NO increase during the fall, due to the addition of residential space heating to motor vehicle and industrial sources. Also, Table A.1 (Appendix A) shows that these months were drier than normal. Lower overnight temperatures during the fall, together with generally clear skies, would cause strong stability to develop during many evenings. Each of these months had an average wind speed less than or equal to 2 m/s. Mixing during the evenings would be strongly inhibited, causing elevated levels of NO to persist beyond the end of the work day. Finally, ozone levels are at a minimum during these months, reducing the scavenging of NO by $O_3$. Concentrations of NO decrease in December due to higher rainfall (periodically flushing the airshed of pollutants), along with greater cloud cover and wind speeds (preventing the development of strong stability).

Figures 3.2.2 and 3.2.3 show the average diurnal pattern of NO and $NO_2$ at Victoria Topaz and Royal Roads University. Both figures show a bimodal distribution of NO with peaks in the morning and evening. The morning peak at Topaz is much stronger in magnitude than at Royal Roads, due to the proximity of the Topaz site to heavier traffic at the start of the work day. At both locations, NO and $NO_2$ concentrations decrease in the late morning due to expansion of the mixed layer and increased production of ozone (see Figure 3.3.2). Concentrations of $NO_2$ are more uniform at both locations throughout the day.

**Figure 3.2.2 Average NO and $NO_2$ Diurnal Pattern for Victoria Topaz for 2002**

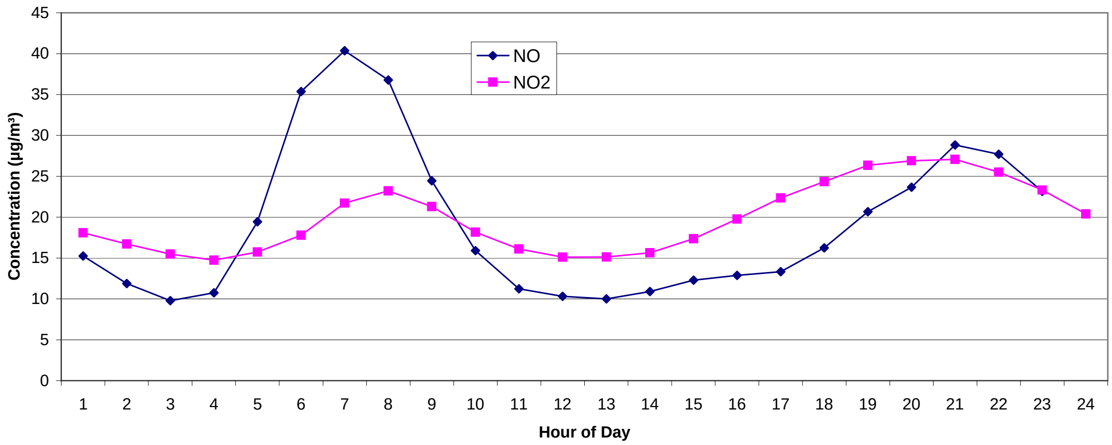



**Figure 3.2.3 Average NO and $NO_2$ Diurnal Pattern for Royal Roads University for 2002**

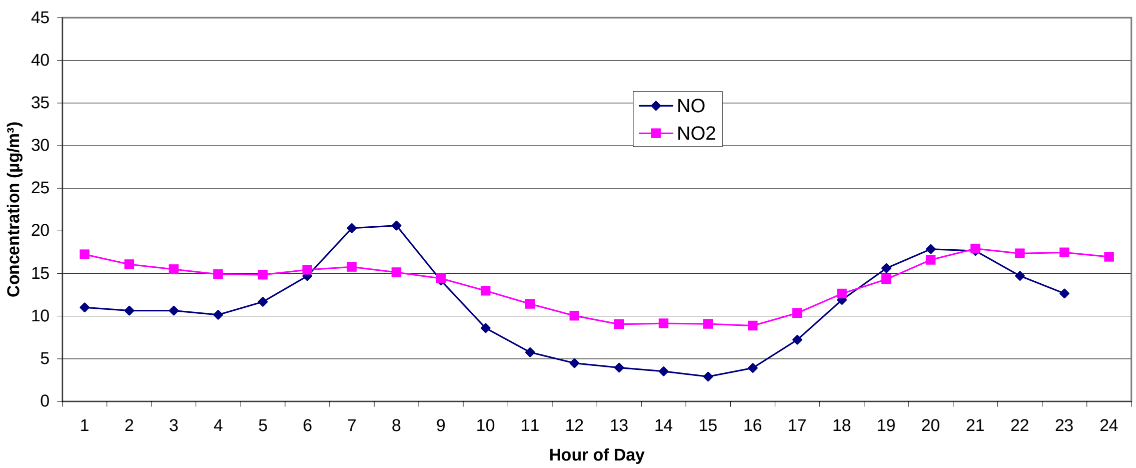
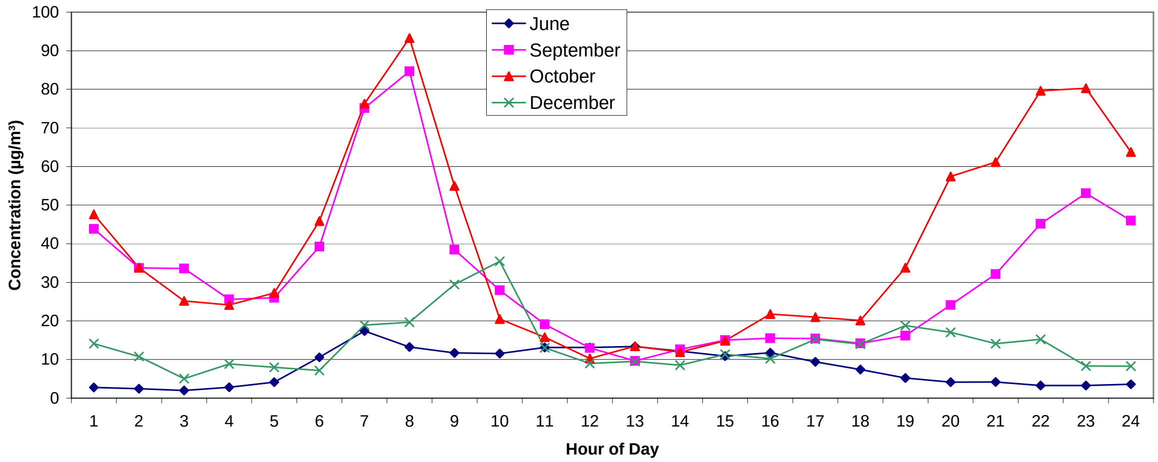



Figure 3.2.4 shows the difference in diurnal NO patterns during months with high NO concentrations (September and October) and low NO concentrations (June) at Victoria Topaz. December is also included to illustrate the pattern during a wet, winter month. The secondary peak near the end of the day entirely vanishes in June and is greatly reduced in December.

**Figure 3.2.4 Average Monthly Diurnal Patterns of NO at Victoria Topaz**




### 3.3 Ground-level Ozone ($O_3$)

Ground-level ozone is termed a secondary pollutant because it is formed from the reaction of primary pollutants and not directly released by anthropogenic activity. Background levels of ozone are naturally produced by the reaction of compounds in the lower troposphere and by intrusion of stratospheric ozone. In urban regions, anthropogenic production of ozone is largely due to emissions of nitrogen oxides ($NO_x$) and hydrocarbons (HCs). Ground-level ozone is considered a regional pollutant, because the primary pollutant precursors can be transported downwind from their origins before photochemically reacting in the production of $O_3$.

During 2002 ground-level ozone was recorded at Victoria Topaz, Royal Roads University and at the CAPMoN station on Saturna Island. A full year of data is available from Victoria Topaz and Saturna Island, and for the period of April 5 to December 31 for the Royal Roads site. An additional two years of ozone data (for 2000 and 2001) was used for the Saturna Island site to facilitate comparison to the Canada Wide Standard.

Hourly averaged ozone concentrations are detailed in Tables 3.3.1, 3.3.2 and 3.3.3. The annual 1-hour mean ozone concentration at the rural Saturna Island site is shown to be much higher than the mean at the two urban sites. The annual mean value for 2002 at Victoria Topaz (33.2 µg/m³) is almost identical to that determined for 2001 (33 µg/m³). The recorded maximum hourly averages for all sites are above the Federal Maximum Desirable level (100 µg/m³), but below the Federal Maximum Acceptable level (160 µg/m³).

**Table 3.3.1 Hourly Ozone Concentrations at Victoria Topaz**

| Percentile Values | | | | | | Max µg/m³ | Min µg/m³ | Mean µg/m³ | Std. Dev. µg/m³ | Percent of 1-h Averages > 100 µg/m³ | Missing Values |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 5 | 25 | 50 | 75 | 98 | 99 | | | | | | % of Total Hours |
| 0.0 | 10.0 | 31.9 | 51.9 | 79.8 | 85.8 | 115.7 | 0.0 | 33.2 | 24.6 | 0.2 | 5.7 |

**Table 3.3.2 Hourly Ozone Concentrations at Royal Roads University**

| Percentile Values | | | | | | Max µg/m³ | Min µg/m³ | Mean µg/m³ | Std. Dev. µg/m³ | Percent of 1-h Averages > 100 µg/m³ | Missing Values |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 5 | 25 | 50 | 75 | 98 | 99 | | | | | | % of Total Hours |
| 2.0 | 16.0 | 39.9 | 59.9 | 89.8 | 93.8 | 131.7 | 0.0 | 39.5 | 26.3 | 0.5 | 29.1 |

**Table 3.3.3 Hourly Ozone Concentrations at Saturna Island**

| Percentile Values | | | | | | Max µg/m³ | Min µg/m³ | Mean µg/m³ | Std. Dev. µg/m³ | Percent of 1-h Averages > 100 µg/m³ | Missing Values |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 5 | 25 | 50 | 75 | 98 | 99 | | | | | | % of Total Hours |
| 19.6 | 41.2 | 56.8 | 70.6 | 98.0 | 99.0 | 149.0 | 2.0 | 55.9 | 21.5 | 1.4 | 2.9 |

Concentrations averaged with an 8-hour time span, for the three consecutive years leading up to 2002, are indicated for Saturna Island in Table 3.3.4. The 4th highest concentration, averaged over the three years, was determined to be 103.3 µg/m³; which is below the Canada Wide Standard of 127.6 µg/m³. This parameter was not determined for the other two sites, as it would be considerably lower there.

**Table 3.3.4 8-Hour Sequential Mean Ozone at Saturna Island**

| Year | % 8-Hour Concentrations Missing | Mean 8-Hour Concentration (µg/m³) | Maximum 8-Hour Concentration (µg/m³) | 4th Highest 8-Hour Concentration (µg/m³) |
|---|---|---|---|---|
| 2000 | 0.2 | 49.7 | 106.3 | 97.3 |
| 2001 | 1.4 | 53.4 | 115.6 | 108.5 |
| 2002 | 0.4 | 55.9 | 116.9 | 104.1 |

The 24-hour average ozone concentrations are summarized in Tables 3.3.5, 3.3.6, and 3.3.7. The Federal Maximum Acceptable 24-hour concentration of 50 µg/m³ was exceeded 18.9% of the time at Victoria Topaz, 31.4% of the time at Royal Roads University (although this site didn't operate for the duration of the year) and 62.4% of the time at Saturna Island. However, it should be noted that the air quality objective for 24-hour $O_3$ concentrations is not considered relevant because natural background concentrations often exceed this objective level.

**Table 3.3.5 24-Hour Sequential Mean Ozone at Victoria Topaz**

| Percentile Values | | | | | | Max µg/m³ | Min µg/m³ | Mean µg/m³ | Std. Dev. µg/m³ | Percent of 24-h Averages > 50 µg/m³ | Missing Values[b] |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 5 | 25 | 50 | 75 | 98 | 99 | | | | | | % of Total 24-h Averages |
| 6.3 | 20.0 | 32.2 | 44.7 | 70.3 | 73.9 | 84.0 | 1.2 | 33.3 | 17.7 | 18.9 | 1.6 |

**Table 3.3.6 24-Hour Sequential Mean Ozone at Royal Roads University**

| Percentile Values | | | | | | Max µg/m³ | Min µg/m³ | Mean µg/m³ | Std. Dev. µg/m³ | Percent of 24-h Averages > 50 µg/m³ | Missing Values[b] |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 5 | 25 | 50 | 75 | 98 | 99 | | | | | | % of Total 24-h Averages |
| 6.6 | 24.4 | 41.6 | 53.1 | 72.6 | 79.9 | 90.0 | 1.6 | 39.4 | 19.0 | 31.4 | 26.0 |

**Table 3.3.7 24-Hour Sequential Mean Ozone at Saturna Island**

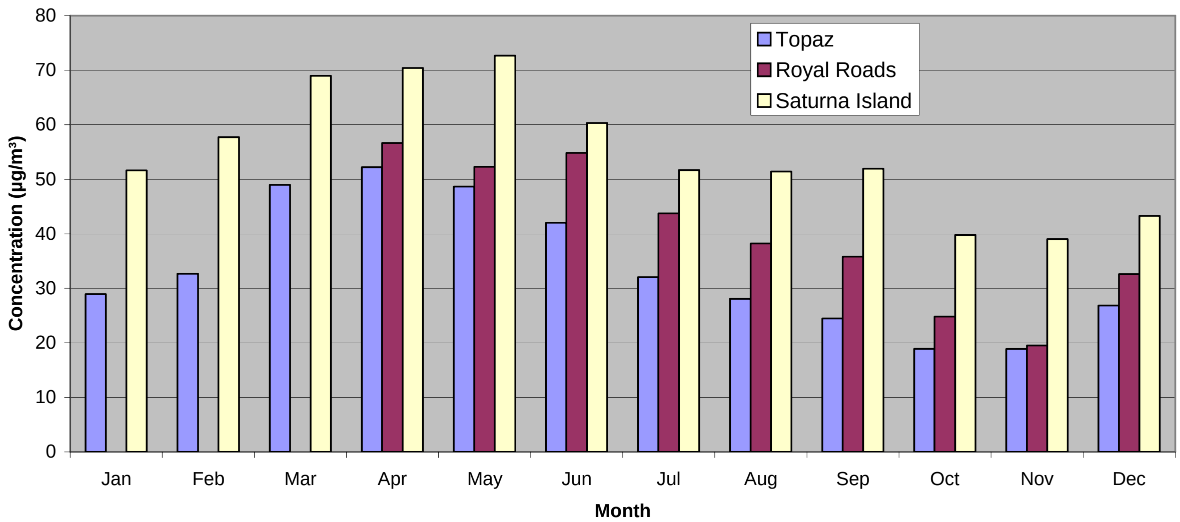
| Percentile Values | | | | | | Max µg/m³ | Min µg/m³ | Mean µg/m³ | Std. Dev. µg/m³ | Percent of 24-h Averages > 50 µg/m³ | Missing Values[b] |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 5 | 25 | 50 | 75 | 98 | 99 | | | | | | % of Total 24-h Averages |
| 24.4 | 44.0 | 54.7 | 67.0 | 86.8 | 88.3 | 93.2 | 4.8 | 54.9 | 17.0 | 62.4 | 1.6 |

Figure 3.3.1 shows the monthly average 24-hour ozone concentrations for the three sites. The ozone levels at each station follow the same general pattern, with concentrations on Saturna Island consistently the highest of the three locations. Concentrations are highest during the spring when hours of sunlight and magnitude of temperature are somewhat low for much of the time. In contrast, ozone concentrations in the Fraser Valley are typically at a maximum during

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

the warmer (summer) months[7]. This indicates that regional sources of ozone and ozone precursors may dominate over local sources in the CRD. Natural production of ozone, including contribution from tropospheric folding, likely is the dominant source during the spring.

**Figure 3.3.1 Monthly Average 24-Hour Ozone Concentrations at Victoria Topaz, Royal Roads University and Saturna Island**




Figures 3.3.2a and 3.3.2b show the average diurnal pattern of ozone concentrations during cooler and warmer months respectively. Levels are highest in the afternoon hours, when solar insolation is at a maximum. Diurnal variation is greatly reduced, especially during cooler months, at the Saturna Island site. The patterns are nearly identical for the two urban monitoring locations. At these locations, the profiles for both warmer and cooler months indicate the local effects of ozone scavenging during 6:00 am to 9:00 am and increased ozone production during the afternoon. The ozone scavenging is due to higher $NO_x$ levels (as indicated in Figures 3.2.2a and 3.2.2b), caused by morning traffic volumes, and the afternoon increase in ozone production is caused by higher solar radiation and temperature values. The second peak is higher during the warmer months due to greater sunshine and temperatures.

[7] Greater Vancouver Regional District, 2001. *Lower Fraser Valley Ambient Air Quality Report 2000*.

**Figure 3.3.2a Average Diurnal Ozone Pattern During Cooler Months (November-March)**

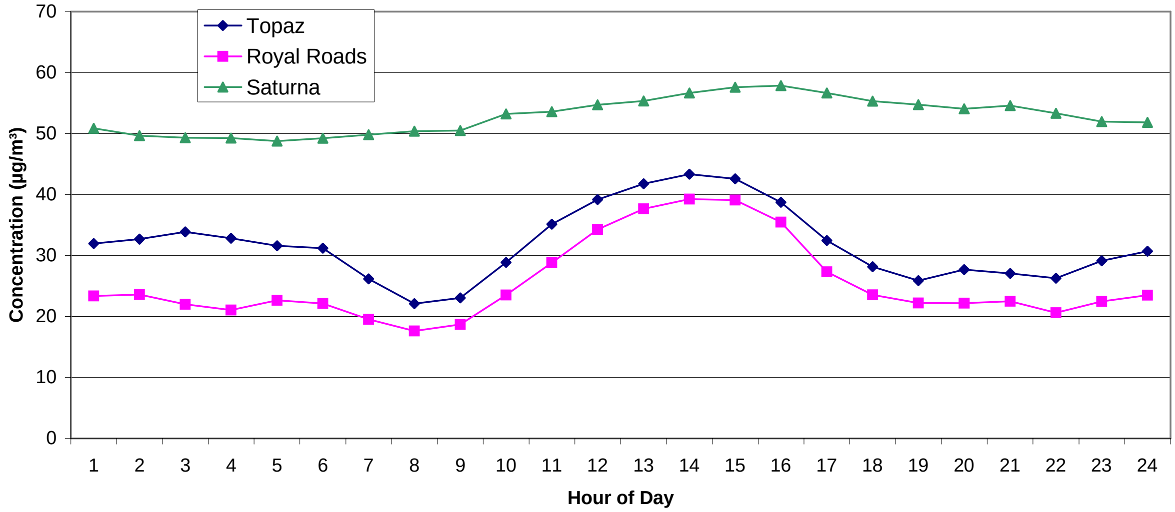
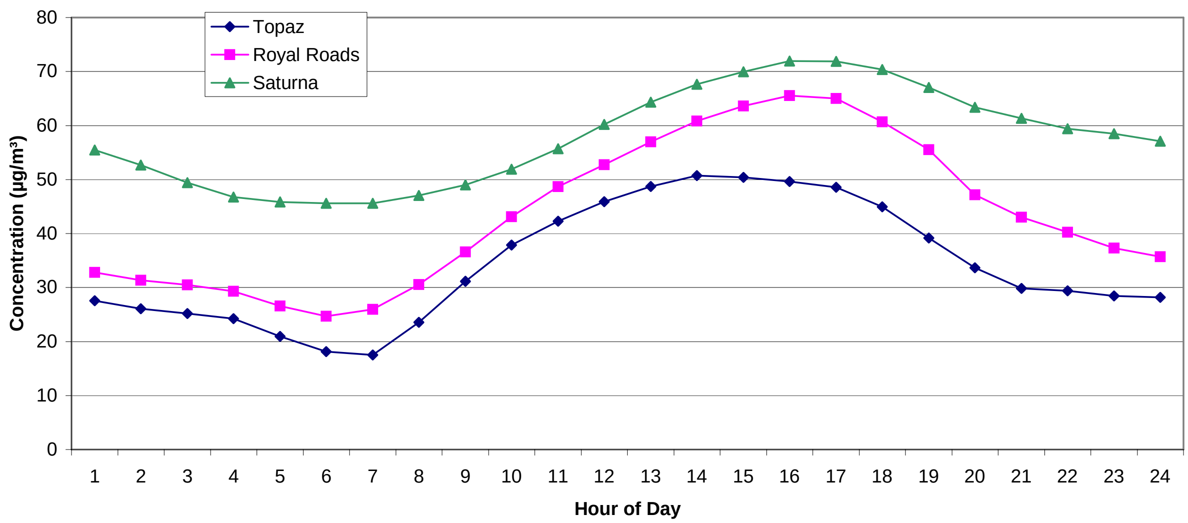



**Figure 3.3.2b Average Diurnal Ozone Pattern During Warmer Months (April-October)**



### 3.4 SULPHUR DIOXIDE ($SO_2$)

Valid sampling data for $SO_2$ was available from Victoria Topaz from January 16 until the end of the year in 2002. Table 3.4.1 shows hourly-averaged concentrations and Table 3.4.2 shows 24-hour concentrations. $SO_2$ levels were well below the Provincial Level A 1-hour objective of 450 µg/m³ and 24-hour objective of 160 µg/m³.

**Table 3.4.1 Hourly $SO_2$ Concentrations at Victoria Topaz**

| Percentile Values | | | | | | Max µg/m³ | Min µg/m³ | Mean µg/m³ | Std. Dev. µg/m³ | Percent of 1-h Averages > 450 µg/m³ | Missing Values % of Total Hours |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 5 | 25 | 50 | 75 | 98 | 99 | | | | | | |
| 0 | 0 | 3 | 3 | 16 | 21 | 61 | 0 | 3.0 | 4.65 | 0.0 | 8.4 |

**Table 3.4.2 24-Hour Sequential Mean $SO_2$ Concentrations at Victoria Topaz**

| Percentile Values | | | | | | Max µg/m³ | Min µg/m³ | Mean µg/m³ | Std. Dev. µg/m³ | Percent of 24-h Averages > 160 µg/m³ | Missing Values[b] % of Total 24-h Averages |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 5 | 25 | 50 | 75 | 98 | 99 | | | | | | |
| 0.0 | 1.0 | 2.3 | 4.2 | 9.8 | 10.7 | 12.4 | 0.0 | 3.0 | 2.5 | 0.0 | 4.7 |

The monthly average and maximum $SO_2$ concentrations at Victoria Topaz are illustrated in Figure 3.4.1, and the average diurnal pattern for both cooler and warmer months are shown in Figures 3.4.2a and 3.4.2b. Generally, $SO_2$ concentrations are higher during cooler months. The average diurnal pattern during November to March shows a morning peak at approximately 8:00 am and a smaller peak at about 9:00 pm. During April to October the same early peak is evident, but the later peak is smaller in magnitude. Although the early peak is likely due to morning traffic volumes, during all months of the year, the presence of the secondary peak during cooler months is indicative of space heating (in particular the burning of heating oil).

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

**Figure 3.4.1 Average and Maximum $SO_2$ Concentrations by Month at Victoria Topaz**

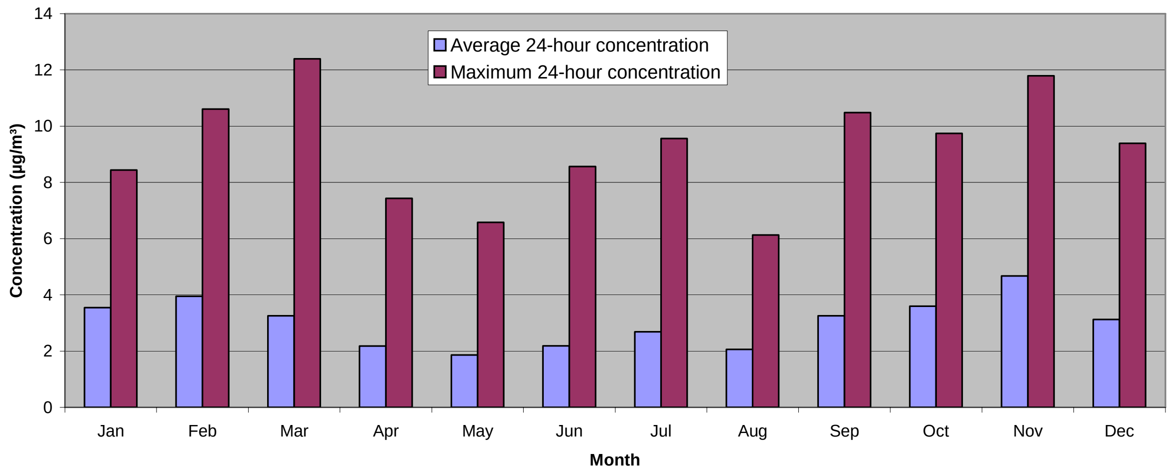



**Figure 3.4.2a Average $SO_2$ Diurnal Pattern for Victoria Topaz During Cooler Months (November-March)**

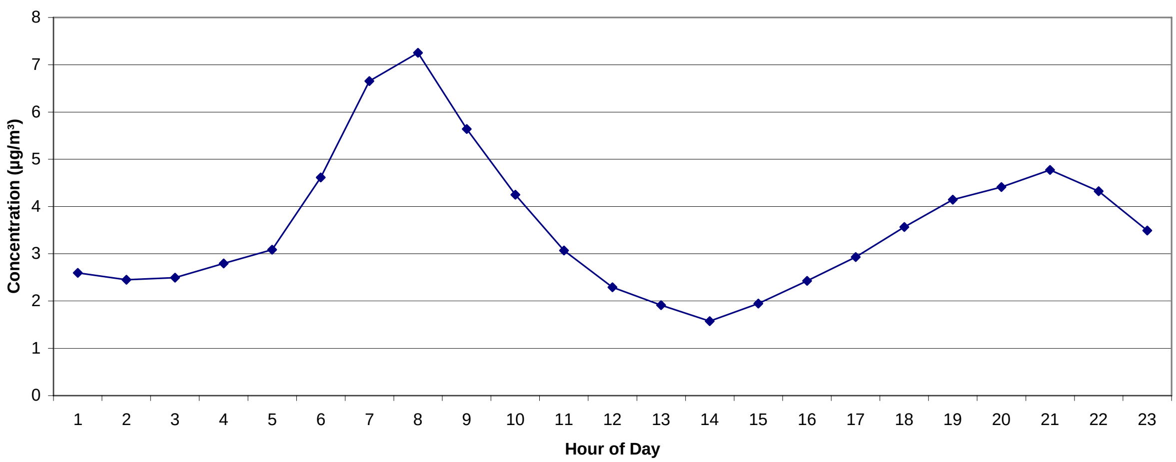
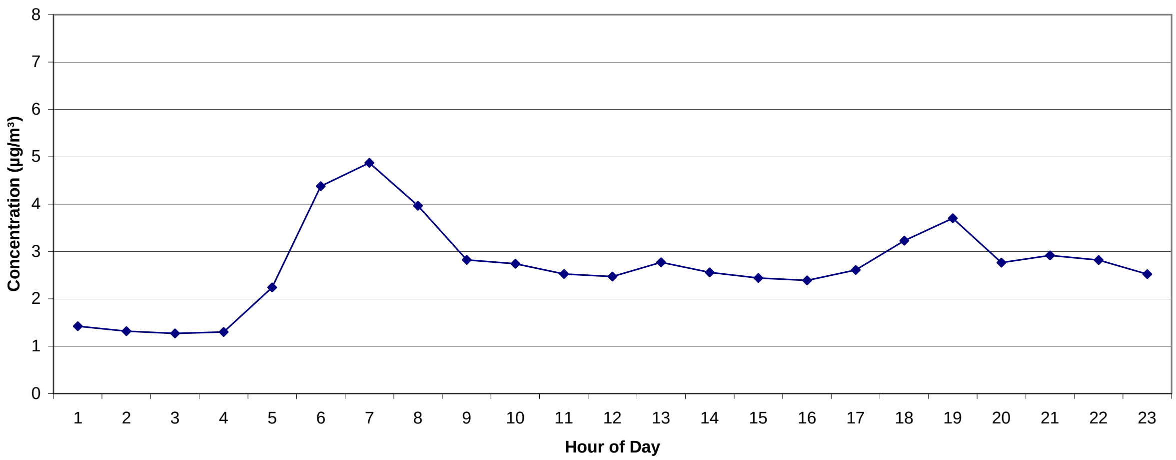


**Figure 3.4.2b Average $SO_2$ Concentrations at Victoria Topaz During Warmer Months (April-October)**




## 3.5 SUMMARY OF GASEOUS POLLUTANTS

The 2001 CRD Air Quality Report[8] compared local concentrations of gaseous pollutants to those reported in other urban areas in Canada and the United States during 1987 to 1998. At this time, air quality conditions in the CRD were determined to be relatively good. In general, monitoring data from 2002 contained similar concentration levels to 2001. The small differences can be attributed to variations in meteorological conditions that normally occur from year to year. This shows that the concentrations of gaseous air contaminants in the CRD remains relatively low compared to other areas in North America.

[8] SENES Consultants Ltd., 2002. *2001 Report on Air Quality in the Capital Regional District.*

# 4.0 PARTICULATE MATTER

Particulate matter (PM) is a term used for both solid and liquid particles of small size in the atmosphere. Primary PM is that which is directly emitted to the atmosphere, and secondary PM represents the fraction that is chemically formed from other pollutants. Particulate matter varies considerably in size. Total Suspended Particulate (TSP) describes all particles with diameters less than 30 µm in length, $PM_{10}$ describes all particles with diameters less than 10 µm in length and $PM_{2.5}$ describes all particles with diameters less than 2.5 µm in length. Particulate matter can be produced by both natural sources such as soil erosion and anthropogenic sources such as fossil fuel burning. Natural production of suspended particulate tends to be of a greater diameter than anthropogenic production. Currently, $PM_{10}$ is considered the *inhalable* fraction and $PM_{2.5}$ the *respirable* fraction of TSP.

Both $PM_{10}$ and $PM_{2.5}$ were sampled in the Capital Regional District during 2002. Unlike the situation with a gaseous pollutant, particulate matter concentrations were recorded using different sampling instruments. Tapered Element Oscillating Microbalance (TEOM) samplers were used to collect hourly averaged concentrations, which were also re-averaged to produce 24-hour concentrations. These samplers run continuously, with scheduled maintenance every week or two (depending on the ambient air concentrations). Sequential high volume (Hi-Vol) samplers and a dichotomous (Dicot) sampler were used to produce 24-hour concentrations once every 6 days. The latter two sampler types 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 to determine the 24-hour concentration.

For $PM_{10}$, Hi-Vol samplers were used at the Victoria Topaz, Keating Elementary School, Oak Bay Recreational Center and the Braefoot Elementary School monitoring sites to obtain 24-hour averages once every 6 days. One TEOM sampler was used to collect hourly averaged concentrations at Colwood Municipal Hall, although this sampler was in operation for a reduced period of January 1 to October 4, 2002. The monitoring station at Victoria Topaz also had a Dicot sampler operating for the full year, which collected data on the same 6-day cycle as the Hi-Vol samplers.

For $PM_{2.5}$, TEOM samplers collected data at Victoria Topaz, Royal Roads University and Colwood Municipal Hall (although for the same reduced period indicated previously). The Dicot sampler at Victoria Topaz determined $PM_{2.5}$ concentrations in addition to $PM_{10}$ levels.

## 4.1 INHALABLE PARTICULATE MATTER ($PM_{10}$)

### 4.1.1 Sequential $PM_{10}$ Sampling Results (Hi-Vol and Dicot)

Tables 4.1 and 4.2 show the summary statistics for all sequential $PM_{10}$ monitoring stations in the Capital Regional District. The higher mean and maximum concentrations at Victoria Topaz may be due to the proximity of a major traffic artery. Of the 4 monitoring locations, only Victoria Topaz had any 24-hour concentrations that exceeded the Provincial $PM_{10}$ objective of 50 µg/m³. This exceedence occurred just once, on October 17, 2002 with a Hi-Vol measurement of 92 µg/m³ and a Dicot measurement of 66.8 µg/m³. Previous analysis of 2001 Hi-Vol and Dicot sampled data determined that the Hi-Vol sampler generally measures higher $PM_{10}$ concentrations than the Dicot sampler under the same ambient conditions[9]. This same trend was evident from analysis of the 2002 data.

On October 17, concentrations at the other sites were much lower (24 µg/m³ or less). It was also noted that wind speeds during this day at Victoria Topaz were very low. Further, $PM_{2.5}$ hourly concentrations at Victoria Topaz (see next section) increased to as high as 50 µg/m³, a trend that was not matched at the Royal Roads $PM_{2.5}$ site. This evidence suggests that the exceedence was caused by sources in the proximity of the monitoring site, such as unusually high volumes of traffic or increased industrial burning.

**Table 4.1 Hi-Vol 24-Hour Sequential Mean $PM_{10}$ Concentrations**

| Statistic | Victoria - Topaz | Oak Bay | Keating | Braefoot |
|---|---|---|---|---|
| Mean (µg/m³) | 19.6 | 14.7 | 13.8 | 13.7 |
| Std. Dev. (µg/m³) | 13.2 | 8.2 | 6.9 | 7.9 |
| Maximum (µg/m³) | 92 | 46 | 34 | 49 |
| 98th percentile (µg/m³) | 44.8 | 33.5 | 31.7 | 33.3 |
| # of Samples[c] | 57 | 60 | 60 | 60 |
| Percent Missing (%) | 6.6 | 1.6 | 1.6 | 1.6 |
| # > 25 µg/m³ | 13 | 7 | 3 | 5 |
| # > 50 µg/m³ | 1 | 0 | 0 | 0 |

[9] SENES Consultants Ltd., 2002. *2001 Report on Air Quality in the Capital Regional District.*

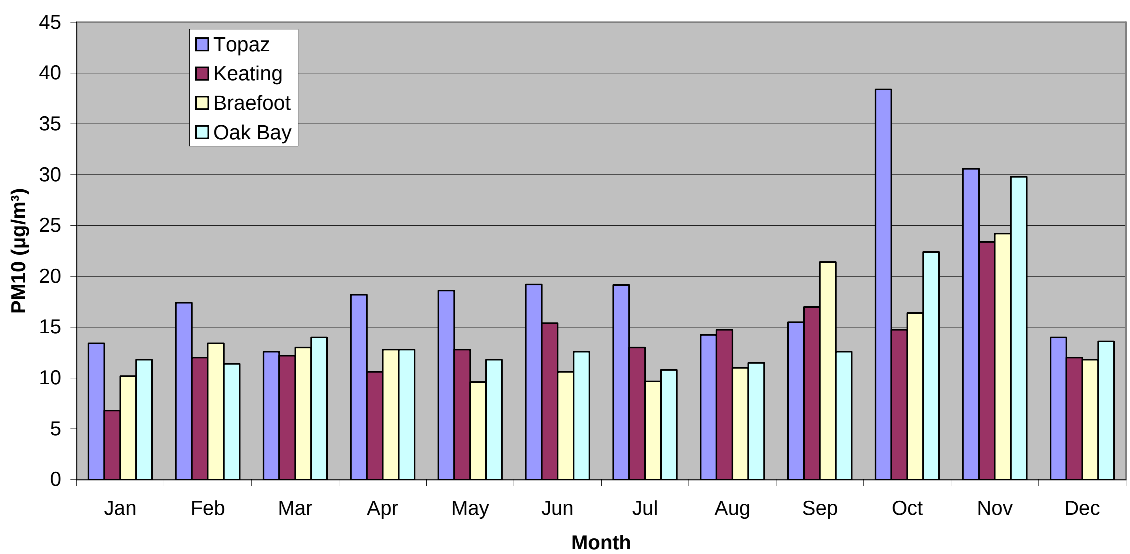
[c] A combined total of 5 values marked as 'mos' (mark on surface) and 1 value marked as 'mnc' (margin not clear) were used in this analysis.

**Table 4.2 Dicot 24-Hour Sequential Mean $PM_{10}$ Concentrations at Victoria Topaz**

| Statistic | $PM_{10}$ |
|---|---|
| Mean ($\mu g/m^3$) | 16.0 |
| Std. Dev. ($\mu g/m^3$) | 10.3 |
| Maximum ($\mu g/m^3$) | 66.8 |
| $98^{th}$ percentile ($\mu g/m^3$) | 39.1 |
| # > 25 $\mu g/m^3$ | 6 |
| # > 50 $\mu g/m^3$ | 1 |
| # of Samples | 59 |
| Percent Missing (%) | 3.3 |

Figure 4.1 shows the average 24-hourly $PM_{10}$ concentrations by month for the 4 Hi-Vol monitoring sites. Concentrations remain relatively uniform throughout the year until fall when they increase at all sites. Victoria Topaz experienced higher average 24-hour concentrations than the other locations for most of the year.

**Figure 4.1 Monthly Average 24-Hour $PM_{10}$ Concentrations for Hi-Vol Samplers**



### 4.1.2 Continuous $PM_{10}$ Sampling Results (TEOM)

Tables 4.3 and 4.4 show the 1-hour and 24-hour $PM_{10}$ concentrations from the TEOM sampler at Colwood Municipal Hall. Data were collected between January 1 and October 4, 2002. The maximum 1-hour concentration of 411 µg/m³ and maximum 24-hour concentration of 94.9 µg/m³ occurred on April 22. This day was the only occasion during the monitoring period that the Provincial 24-hour $PM_{10}$ objective of 50 µg/m³ was exceeded at the site. Elevated concentrations did not persist beyond mid-afternoon; so this was a brief, and probably localized event. $PM_{2.5}$ concentrations (detailed in the following section) during the same hours were not high, indicating that combustion was not a primary source of this exceedence. On this day the winds at the nearby Royal Roads meteorological station were recorded with an average wind speed of 5.8 m/s from the west. The relatively high wind speeds, reaching as high as 9.3 m/s, likely were a contributing factor to the elevated concentrations of $PM_{10}$ at the Colwood site, and may be related to the proximity of the monitoring station to the public works yard and abandoned gravel pit. During the monitoring period, the 24-hour Health Reference Level of 25 µg/m³ was exceeded 12.7 % of the time.

**Table 4.3 Hourly TEOM $PM_{10}$ Concentrations at Colwood Municipal Hall**

| Percentile Values | | | | | | Max µg/m³ | Min µg/m³ | Mean µg/m³ | Std. Dev. µg/m³ | Missing Values | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 5 | 25 | 50 | 75 | 98 | 99 | | | | | # of Hours | % of Total Hours |
| 3 | 7 | 12 | 18 | 52 | 69 | 411 | 0 | 15.2 | 16.7 | 2273 | 25.9 |

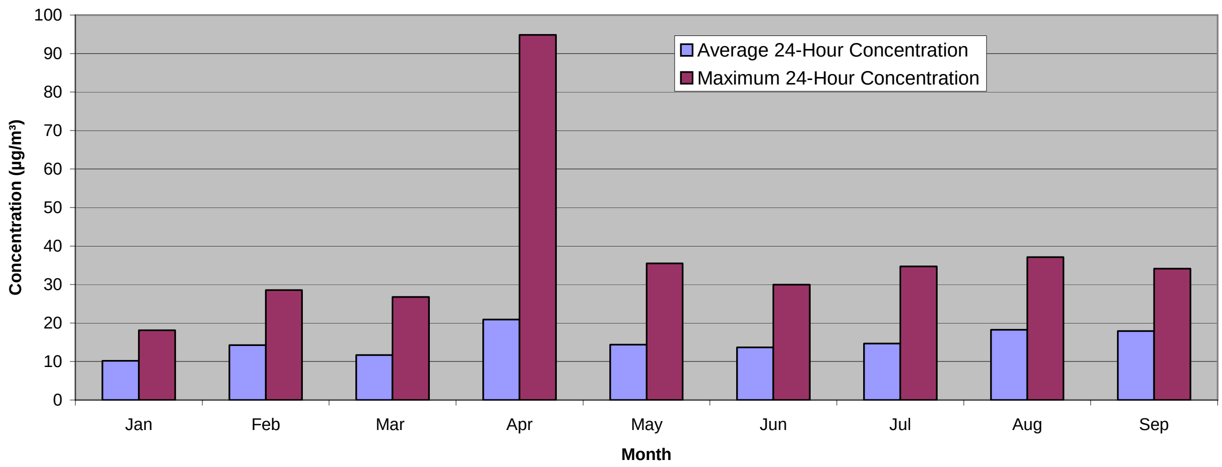
**Table 4.4 24-Hour Sequential Mean TEOM $PM_{10}$ Concentrations at Colwood Municipal Hall**

| Percentile Values | | | | | | Max µg/m³ | Min µg/m³ | Mean µg/m³ | Std. Dev. µg/m³ | Percent of 24-h Averages > 25 µg/m³ | Missing Values[b] |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 5 | 25 | 50 | 75 | 98 | 99 | | | | | | % of Total 24-h Averages |
| 6.5 | 9.4 | 13.5 | 18.8 | 34.1 | 35.9 | 94.9 | 2.1 | 15.1 | 8.6 | 12.7 | 26.0 |

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

Monthly average 24-hour concentrations did not stray far from the mean of 15.1 µg/m³ for the nine months the Colwood sampler was operating. Aside from the exceedence of April 22, $PM_{10}$ concentrations in April were similar to those in August and September. Since average concentrations at the Hi-Vol sites were highest in October and November, when the Colwood station wasn't operating, it is possible that higher $PM_{10}$ concentrations were also experienced at the Colwood site during these times. Figure 4.2 shows the average and maximum monthly 24-hour $PM_{10}$ concentrations from the TEOM measurements.

**Figure 4.2 Average and Maximum 24-Hour $PM_{10}$ Concentrations by Month from the TEOM Sampler at Colwood Municipal Hall**




Figures 4.3a and 4.3b show the average diurnal pattern of $PM_{10}$ concentrations during cooler and warmer months. Average concentrations are higher during warmer months. Concentrations peak during the end of the day during cooler months, whereas the peak occurs mid-day for warmer months. This implies that space heating is a source of $PM_{10}$ when temperatures are cool, and that wind blown dust, stirred up by traffic and higher afternoon wind speeds, is a significant source of $PM_{10}$ during the warmer months of the year.

**Figure 4.3a Average Diurnal Pattern of $PM_{10}$ Concentrations at Colwood Municipal Hall During Cooler Months (January-March)**

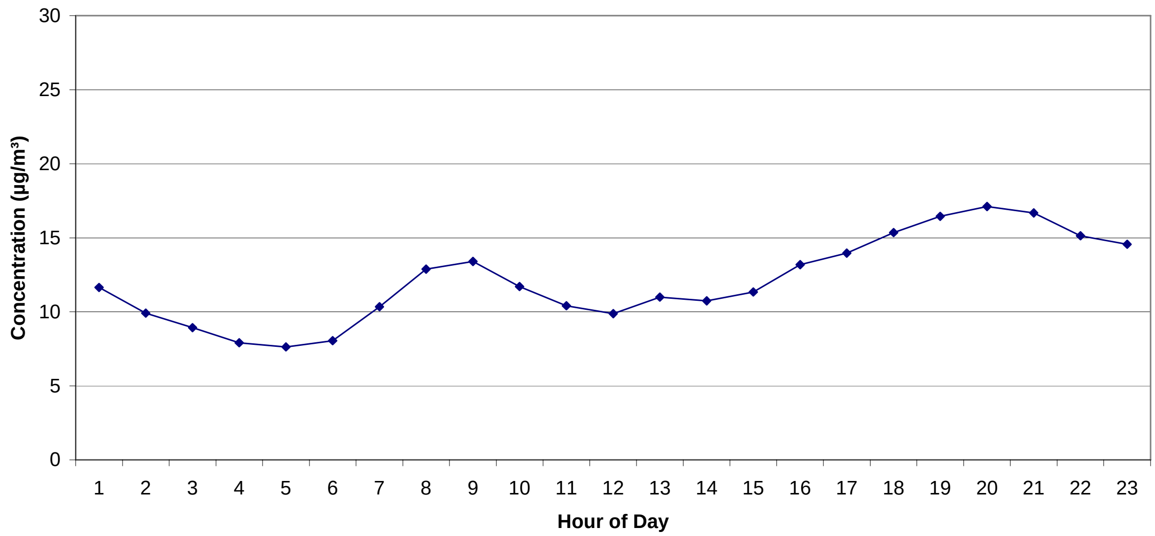
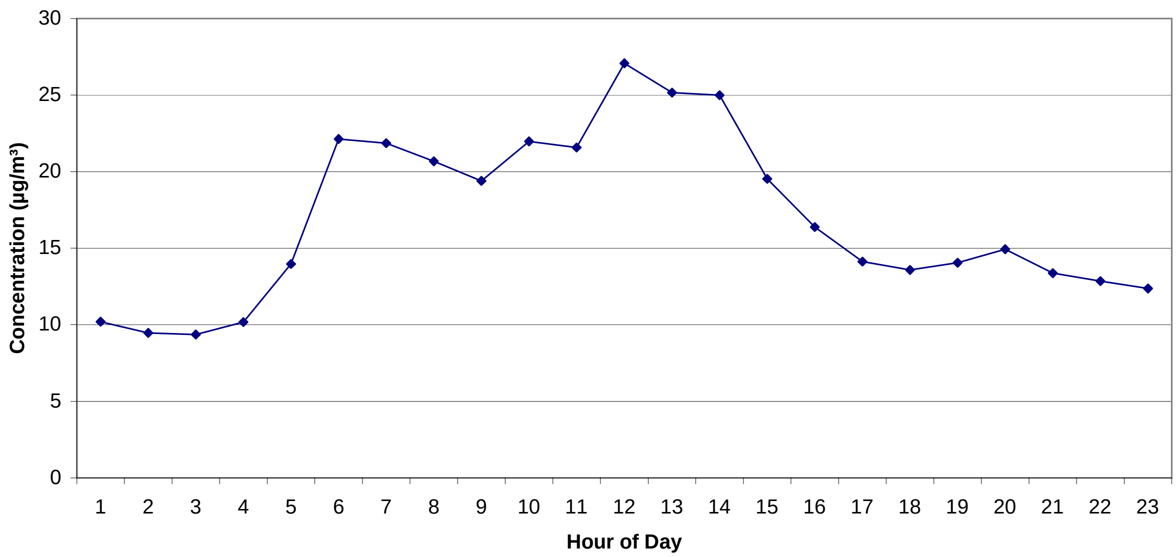



**Figure 4.3b Average Diurnal Pattern of $PM_{10}$ Concentrations at Colwood Municipal Hall During Warmer Months (April-September)**



## 4.2 RESPIRABLE PARTICULATE MATTER ($PM_{2.5}$)

### 4.2.1 Sequential $PM_{2.5}$ Sampling Results (Dicot)

Table 4.5 shows the 24-hour Dicot concentrations at Victoria Topaz for 2002. Although the maximum 24-hour concentration for the year is 34.3 µg/m³, which occurred on November 2nd, the 98th percentile value is 21.2 µg/m³, which is well below the Canada Wide Standard (CWS) of 30 µg/m³. The health reference level of 15 µg/m³ was exceeded 10.2 % of the time.

**Table 4.5 24-Hour Sequential Mean $PM_{2.5}$ Concentrations from the Dicot Sampler at Victoria Topaz**

| Statistic | $PM_{2.5}$ |
|---|---|
| Mean (µg/m$^3$) | 7.3 |
| Std. Dev. (µg/m$^3$) | 5.8 |
| Maximum (µg/m$^3$) | 34.3 |
| 98th percentile (µg/m$^3$) | 21.2 |
| # > 15 µg/m$^3$ | 6 |
| # > 30 µg/m$^3$ | 1 |
| # of Samples | 59 |
| Percent Missing (%) | 3.3 |

### 4.2.2 Continuous $PM_{2.5}$ Sampling Results (TEOM)

Tables 4.6, 4.7, 4.8, and 4.9 summarize the 1-hour average $PM_{2.5}$ concentrations at the 4 TEOM sites in the Capital Regional District. Monitoring at the Colwood station was terminated in October and moved to Langford, which began operation in November. The maximum values for the four locations occurred at different times of the year: November 2nd for Topaz, September 28th for Royal Roads University, March 2nd for Colwood Municipal Hall, and November 30th for Langford Dogwood School. Although the Victoria Topaz site experiences higher $PM_{2.5}$ concentrations overall, the maximum hourly concentrations are higher at the Royal Roads and Colwood stations.

**Table 4.6 Hourly $PM_{2.5}$ Concentrations at Victoria Topaz**

| Percentile Values | | | | | | Max µg/m³ | Min µg/m³ | Mean µg/m³ | Std. Dev. µg/m³ | Missing Values | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 5 | 25 | 50 | 75 | 98 | 99 | | | | | # of Hours | % of Total Hours |
| 0 | 3 | 5 | 9 | 28 | 37 | 71 | 0 | 7.1 | 7.1 | 184 | 2.1 |

**Table 4.7 Hourly $PM_{2.5}$ Concentrations at Royal Roads University**

| Percentile Values | | | | | | Max µg/m³ | Min µg/m³ | Mean µg/m³ | Std. Dev. µg/m³ | Missing Values | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 5 | 25 | 50 | 75 | 98 | 99 | | | | | # of Hours | % of Total Hours |
| 0 | 2 | 4 | 7 | 17 | 21 | 90 | 0 | 5.1 | 4.5 | 27 | 0.3 |

**Table 4.8 Hourly $PM_{2.5}$ Concentrations at Colwood Municipal Hall**

| Percentile Values | | | | | | Max µg/m³ | Min µg/m³ | Mean µg/m³ | Std. Dev. µg/m³ | Missing Values | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 5 | 25 | 50 | 75 | 98 | 99 | | | | | # of Hours | % of Total Hours |
| 0 | 2 | 4 | 7 | 19 | 24 | 80 | 0 | 5.2 | 5.0 | 2266 | 25.9 |

**Table 4.9 Hourly $PM_{2.5}$ Concentrations at Langford Dogwood School**

| Percentile Values | | | | | | Max µg/m³ | Min µg/m³ | Mean µg/m³ | Std. Dev. µg/m³ | Missing Values | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 5 | 25 | 50 | 75 | 98 | 99 | | | | | # of Hours | % of Total Hours |
| 0 | 3 | 7 | 12 | 34 | 39 | 64 | 0 | 8.9 | 8.7 | 7566 | 86.4 |

Tables 4.10, 4.11, 4.12, and 4.13 present the statistics for 24-hour concentrations at the TEOM sites for 2002. Emphasis should not be placed on statistics determined for the Langford station, as it was operating for a short period in 2002. However, the maximum 24-hour concentration at this site is higher than at the three other TEOM locations; indicating that relatively high $PM_{2.5}$ concentrations may be experienced here at other times of the year.

At each station, the 98$^{th}$ percentile concentration is far below the Canada Wide Standard. At Victoria Topaz, the Health Reference Level was exceeded 5.6% of the time; about one-half the measure determined by the Dicot sampler at the same location. This, and the fact that the maximum TEOM value at the site (23.8 µg/m³) is much lower than the same-day Dicot value of 34.3 µg/m³ shows that the Dicot sampler generally determines higher 24-hour concentrations than the TEOM sampler. Victoria Topaz, being situated in a greater population density area, experiences higher 24-hour $PM_{2.5}$ concentrations than either the Royal Roads or Colwood areas.

**Table 4.10 24-Hour Sequential Mean $PM_{2.5}$ Concentrations at Victoria Topaz**

| Percentile Values | | | | | | Max µg/m³ | Min µg/m³ | Mean µg/m³ | Std. Dev. µg/m³ | Percent of 24-h Averages > 15µg/m³ | Missing Values[b] % of Total 24-h Averages |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 5 | 25 | 50 | 75 | 98 | 99 | | | | | | |
| 2.1 | 4.0 | 6.2 | 9.1 | 18.0 | 21.9 | 23.8 | 0.5 | 7.1 | 4.2 | 5.6 | 1.6 |

**Table 4.11 24-Hour Sequential Mean $PM_{2.5}$ Concentrations at Royal Roads University**

| Percentile Values | | | | | | Max µg/m³ | Min µg/m³ | Mean µg/m³ | Std. Dev. µg/m³ | Percent of 24-h Averages > 15µg/m³ | Missing Values[b] % of Total 24-h Averages |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 5 | 25 | 50 | 75 | 98 | 99 | | | | | | |
| 1.3 | 2.8 | 4.4 | 6.5 | 14.4 | 16.5 | 18.6 | 0.4 | 5.1 | 3.1 | 1.9 | 0.0 |

**Table 4.12 24-Hour Sequential Mean $PM_{2.5}$ Concentrations at Colwood Municipal Hall**

| Percentile Values | | | | | | Max µg/m³ | Min µg/m³ | Mean µg/m³ | Std. Dev. µg/m³ | Percent of 24-h Averages > 15µg/m³ | Missing Values[b] % of Total 24-h Averages |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 5 | 25 | 50 | 75 | 98 | 99 | | | | | | |
| 1.4 | 2.7 | 4.8 | 7.0 | 12.8 | 14.7 | 19.7 | 0.6 | 5.2 | 3.1 | 1.1 | 25.8 |

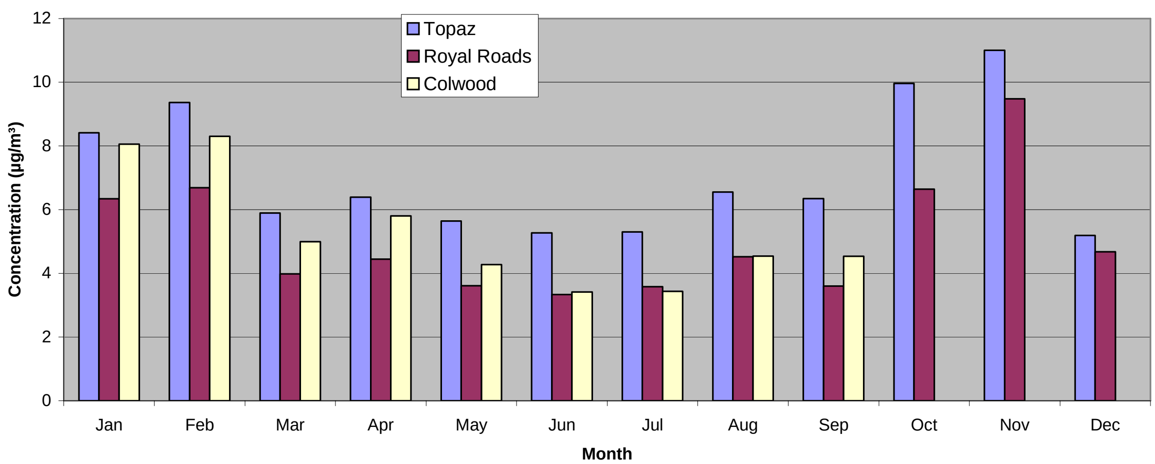
**Table 4.12 24-Hour Sequential Mean $PM_{2.5}$ Concentrations at Langford Dogwood School**

| Percentile Values | | | | | | Max µg/m³ | Min µg/m³ | Mean µg/m³ | Std. Dev. µg/m³ | Percent of 24-h Averages > 15µg/m³ | Missing Values[b] % of Total 24-h Averages |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 5 | 25 | 50 | 75 | 98 | 99 | | | | | | |
| 2.9 | 4.4 | 7.1 | 12.9 | 23.6 | 25.2 | 26.7 | 1.9 | 9.0 | 5.9 | 14.0 | 86.3 |

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

Figure 4.4 presents monthly average 24-hour $PM_{2.5}$ concentrations from 3 TEOM sites. Concentrations are higher during cooler months, due in part to space heating. $PM_{10}$ levels also followed this general pattern (see Figure 4.1). As previously discussed in section 3.2, the Environment Canada climate archives show that September was drier than normal and that October was much drier than normal. A return to normal precipitation later in November and December likely is responsible for decreased ambient concentrations (due to particulate scavenging). A relatively high average wind speed of 3.5 m/s during December, as measured by the Victoria Topaz meteorological station, may also be somewhat responsible for the reduction in $PM_{2.5}$ levels by allowing an increased flushing of particulate from the CRD airshed.

**Figure 4.4 Average 24-Hour $PM_{2.5}$ Concentrations by Month from TEOM Samplers**




Figures 4.5a and 4.5b further indicate the contribution of space heating to ambient $PM_{2.5}$ levels during the late fall and winter. The highest concentrations were experienced during the evening hours for those months with cooler temperatures. The early morning peak for both profiles is due to traffic at the beginning of the work day. The similarity of the diurnal patterns for the three monitoring sites shows that $PM_{2.5}$ is typically well-mixed in the Capital Regional District, with concentrations a little higher in more populated areas.

**Figure 4.5a Average Diurnal $PM_{2.5}$ Pattern During Cooler Months at TEOM Sites (November – March)**

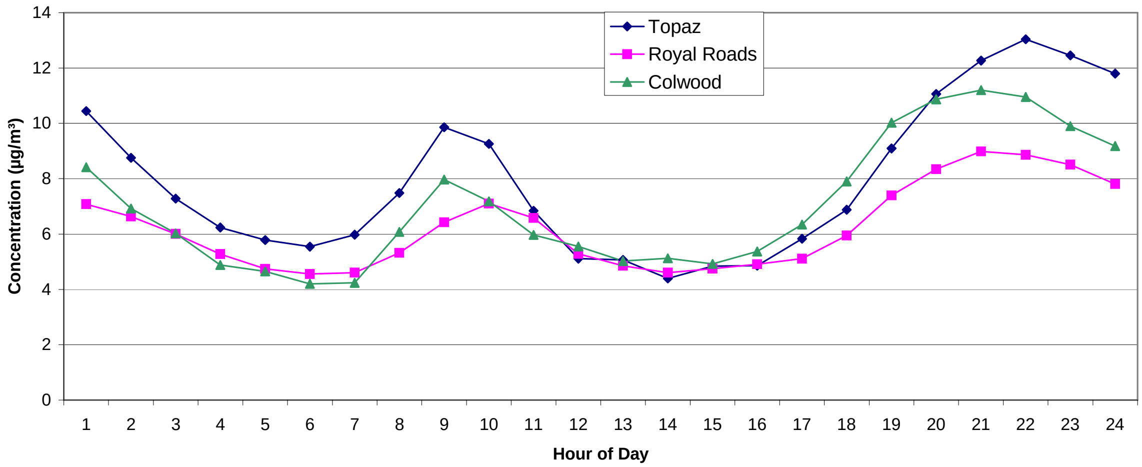
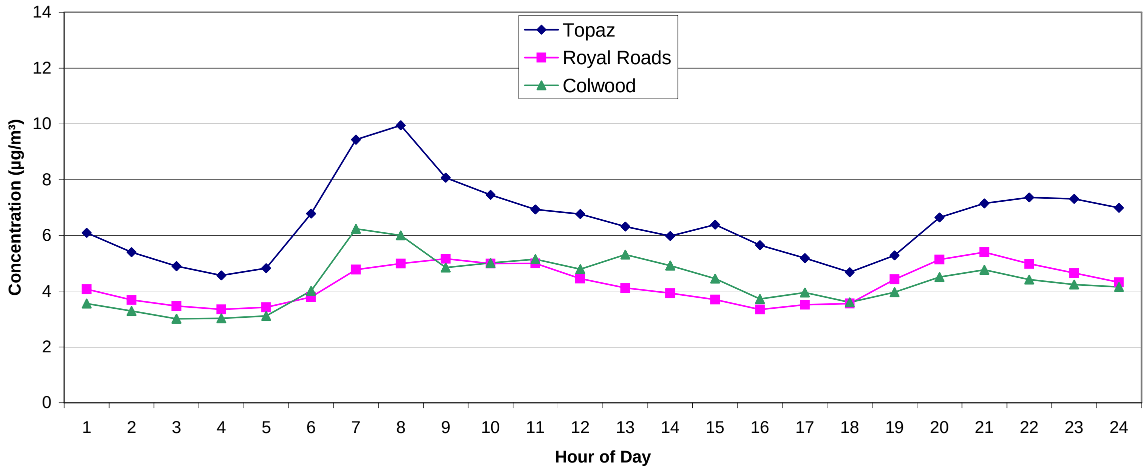



**Figure 4.5b Average Diurnal $PM_{2.5}$ Pattern During Warmer Months at TEOM Sites (April – October)**



### 4.3 SUMMARY OF PARTICULATE MATTER

The analysis of 2001 particulate matter data in the CRD[10] determined that there was an inverse relationship between the ratio of $PM_{2.5}$ to $PM_{10}$ and ambient temperature. The fact that smaller particulate was a larger portion of PM during cooler months implied that burning (for space heating) was a greater source of emissions during these times. The significant contribution of residential and commercial space heating to ambient PM concentrations (in particular $PM_{2.5}$) was verified by the 2002 monitoring data.

Although 2002 PM concentrations were generally higher than those determined for 2001, the levels were relatively low when compared to a sampling of PM data from other areas, completed for the 2001 CRD air quality report (ibid). The small increases over 2001 concentrations were due to drier conditions and other natural variations in weather patterns. Ambient PM air quality during 2002 continued to be relatively good in the CRD.

[10] SENES Consultants Ltd., 2002. *2001 Report on Air Quality in the Capital Regional District.*

# 5.0 CONCLUSION

Levels of air contaminants determined from the CRD's ambient air monitoring network in 2002 continue to be relatively low compared to other urban areas in North America, and when compared against Provincial and Federal ambient air quality objectives. Table 5.1 presents a summary of the air quality determined from the Capital Regional District's ambient monitoring program in 2002.

Meteorological data collected in the CRD is helpful in determining source-receptor relationships for the different air contaminants. Patterns in the data captured from the Royal Roads site indicate that there may be a problem with this station; in particular its representativeness to surrounding areas. It is suggested that the Royal Roads meteorological site be checked to ensure that it is both operating correctly and is not strongly influenced by topographical features and/or structures in proximity to the tower.

With the exception of ozone, concentrations of the gaseous pollutants were well below all air quality objectives. The 24-hour Federal Maximum Acceptable concentration for ozone was exceeded at all three monitoring locations, but this guideline is not considered relevant, since background ozone concentrations at rural locations often exceed this amount. The highest measured 24-hour ozone concentrations were experienced at the Saturna Island site; however, analysis of the last three years of data from this location show that it is in no danger of exceeding the Canada Wide Standard for ozone, which is to be implemented by 2010. A significant amount of $NO_x$ and ozone data from the Royal Roads monitoring station was not available for 2002. It is recommended that either an effort be made to increase the percentage of valid data available from this station in the future, or that these contaminants be measured elsewhere in the CRD.

Particulate matter concentrations were generally low. The 98$^{th}$ percentile $PM_{2.5}$ concentrations were significantly below the Canada Wide Standard at all monitoring sites. There were two measured exceedences of the 24-hour $PM_{10}$ Provincial objective of 50 µg/m$^3$. One of the exceedences was determined at the Victoria Topaz site from both of the Hi-Vol and Dicot samplers. The second exceedence occurred at the Colwood Municipal Hall (measured with a TEOM sampler). The Colwood exceedence can be attributed to re-entrainment of dust. The cause(s) of the exceedence at Victoria Topaz is more difficult to determine. Increased traffic at a nearby traffic corridor may have been a contributing factor. Evidence suggests that both cases were localized and not experienced throughout the CRD.

Concentrations of particulate matter continue to be significantly higher at the Victoria Topaz station compared to the other monitoring sites, likely due to its location in the core of the city, and the proximity of the high traffic corridor (Blanshard Street). Although the Langford station operated for just a short period at the end of 2002, data collected at this site indicate that relatively high concentrations of $PM_{2.5}$ may be experienced there in the future. Simultaneous measurement of CO, $NO_x$ and $PM_{2.5}$ at this location would help to determine whether higher $PM_{2.5}$ levels are related to combustion sources or to some other types of activities.

The more stringent 24-hour PM Health Reference Levels were exceeded at all monitoring stations for both $PM_{2.5}$ and $PM_{10}$. These objectives represent the minimum levels at which measurable health effects have been determined. The $PM_{10}$ Health Reference Level of 25 µg/m³ was exceeded up to 23% of the time (indicated by the Hi-Vol sampler at Victoria Topaz) and the $PM_{2.5}$ Health Reference Level of 15 µg/m³ was exceeded up to 10.2% of the time (indicated by the Dicot sampler at Victoria Topaz). This is an increase over the frequency of Health Reference Level exceedences determined for 2001 monitoring data.

Analysis of the 2002 data indicates that combustion is the primary source of $PM_{2.5}$ in the CRD. Although traffic activity was indicated to cause peak concentrations during the day, the increase of concentrations during evening hours in the cold season was determined to be caused by space heating, although meteorological conditions also play a significant role. Examination of temporal trends also indicated that space heating was the cause of higher CO and $NO_x$ during the same cooler period. Although concentrations of gaseous pollutants (such as CO, $NO_2$ and $SO_2$) are consistently low in the CRD, the correlation of CO and $NO_x$ with $PM_{2.5}$ can be useful in illuminating source-receptor relationships in $PM_{2.5}$ data.

$SO_2$ concentrations in 2002 were low compared to Provincial and Federal standards. However, it is not certain that the monitored levels at Victoria Topaz are representative of other areas in the CRD. It would be useful to either monitor $SO_2$ at another location in the CRD, or to conduct a study wherein a temporary monitor is placed at two or more different locations for short time periods, to compare levels with those measured at the Victoria Topaz site.

Long term monitoring provides the data that is needed to establish baseline concentrations for an area. A baseline has not yet been established for the CRD, and therefore continuation of the Long Term Monitoring Plan is vitally important. Although ambient concentrations of the gaseous pollutants are currently considered low, Provincial and/or Federal standards for these contaminants are outdated and need to be revised. It is therefore recommended that air quality monitoring in the CRD continue at the present level, with some consideration applied to increasing the amount of data currently generated for the gaseous contaminants.

## Table 5.1 Summary of Maximum Pollutant Concentrations (μg/m³) in the CRD for 2002

| | | **Air Quality Standard** | | **Monitoring Station** | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Contaminant | Averaging Period | B.C. or Federal Maximum Acceptable Level | Health Reference Level | Victoria Topaz | Royal Roads | Saturna Island | Oak Bay | Braefoot | Keating | Colwood | Langford |
| Carbon Monoxide | 1-hour | 28000 | | 6800 | | | | | | | |
| Nitrogen Dioxide | 1-hour | 400 | | 86.1 | 66.0 | | | | | | |
| | 24-hour | 200 | | 38.9 | 34.3 | | | | | | |
| | Annual | 100 | | 19.9 | 13.9 | | | | | | |
| Ozone | 1-hour | 160 | | 115.7 | 131.7[1] | 149.0 | | | | | |
| | 24-hour | 50 | | 84.0 | 90.0[1] | 93.2 | | | | | |
| | Annual | 50 | | 33.2 | | 55.9 | | | | | |
| Sulphur Dioxide | 1-hour | 900 | | 61 | | | | | | | |
| | 24-hour | 300 | | 12.4 | | | | | | | |
| | Annual | 60 | | 3.0 | | | | | | | |
| $PM_{10}$ | 24-hour | 50 | 25 | 92 (HiVol) 66.8 (Dicot) | | | 46 (HiVol) | 49 (HiVol) | 34 (HiVol) | 94.9 (TEOM) | |
| $PM_{2.5}$ | 24-hour | | 15 | 23.8 | 18.6 | 19.7 | | | | | 26.7[2] |
| **Canada-Wide Standards** | | | | | | | | | | | |
| Ozone | 8-hour | 127.6[3] | | | | 103.3 | | | | | |
| $PM_{2.5}$ | 24-hour | 30[4] | | 18.0[5] (TEOM) 21.2[5] (Dicot) | 14.4[5] (TEOM) | | | | | | |

Notes:
1 Partial record: April 5 – December 31, 2002
2 Partial record: November 12 – December 31, 2002.
3 Achievement by 2010, based on the 4th highest measurement annually, averaged over 3 consecutive years.
4 Achievement by 2010, based on the 98th percentile ambient measurement annually, averaged over 3 consecutive years.
5 Average for 2002 only, not averaged over 3 years.

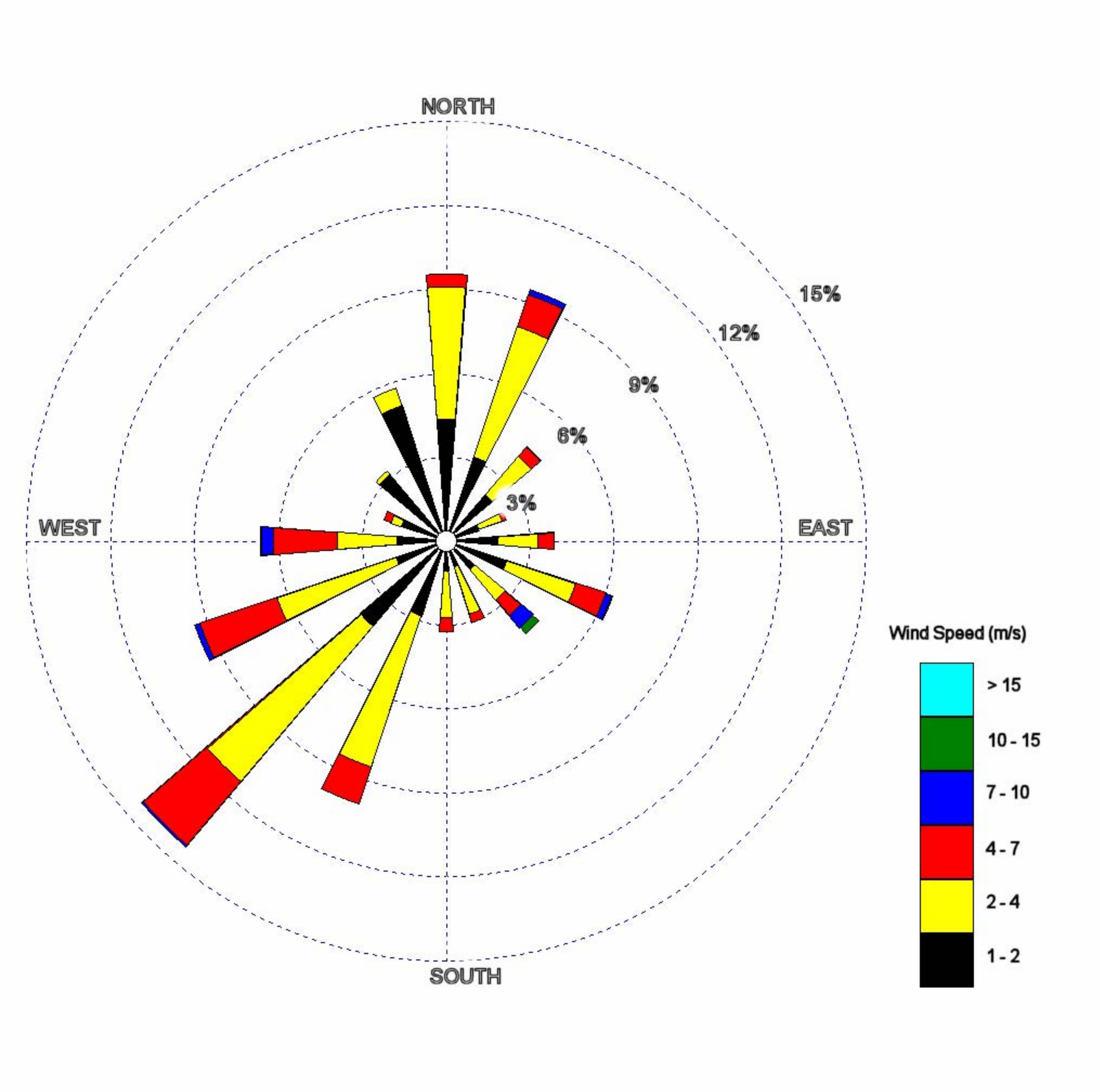
# Appendix A: Meteorological Data

**Table A.1 2002 Monthly Climate Data for Victoria[d]**

| MONTH | Mean Max Temp °C | Mean Temp °C | Mean Min Temp °C | Total Rain mm | Total Snow cm | Total Precip mm | Dir of Max Gust 10's Deg | Spd of Max Gust km/h |
|---|---|---|---|---|---|---|---|---|
| Jan | 7.9 | 4.9 | 1.8 | 137.6 | 18.2 | 155.8 | 16 | 44 |
| Feb | 8.6 | 4.7 | 0.7 | 123.6 | 0.2 | 123.8 | 24 | 63 |
| Mar | 8.6 | 4.8 | 1.1 | 84.8 | 21.2 | 104.4 | 15S | 59S |
| Apr | 13.2 | 8.6 | 3.9 | 51.9 | 0 | 51.9 | 24 | 74 |
| May | 15.9 | 10.9 | 6 | 23.6 | 0 | 23.6 | 24 | 50 |
| Jun | 21 | 15.5 | 10 | 19.8 | 0 | 19.8 | 26 | 59 |
| Jul | 22.8 | 17 | 11.2 | 6.6 | 0 | 6.6 | 12 | 37 |
| Aug | 22.7 | 16.7 | 10.6 | 3.4 | 0 | 3.4 | 13 | 37 |
| Sep | 20.5 | 14.5 | 8.5 | 11.9 | 0 | 11.9 | 27S | 35S |
| Oct | 14 | 9.4 | 4.8 | 14.2 | 0 | 14.2 | 4 | 50 |
| Nov | 11.7 | 8 | 4.3 | 68.9 | 0 | 68.9 | 15 | 54 |
| Dec | 8.3 | 5.7 | 3 | 114.1 | 3 | 117.1 | 14S | 78S |

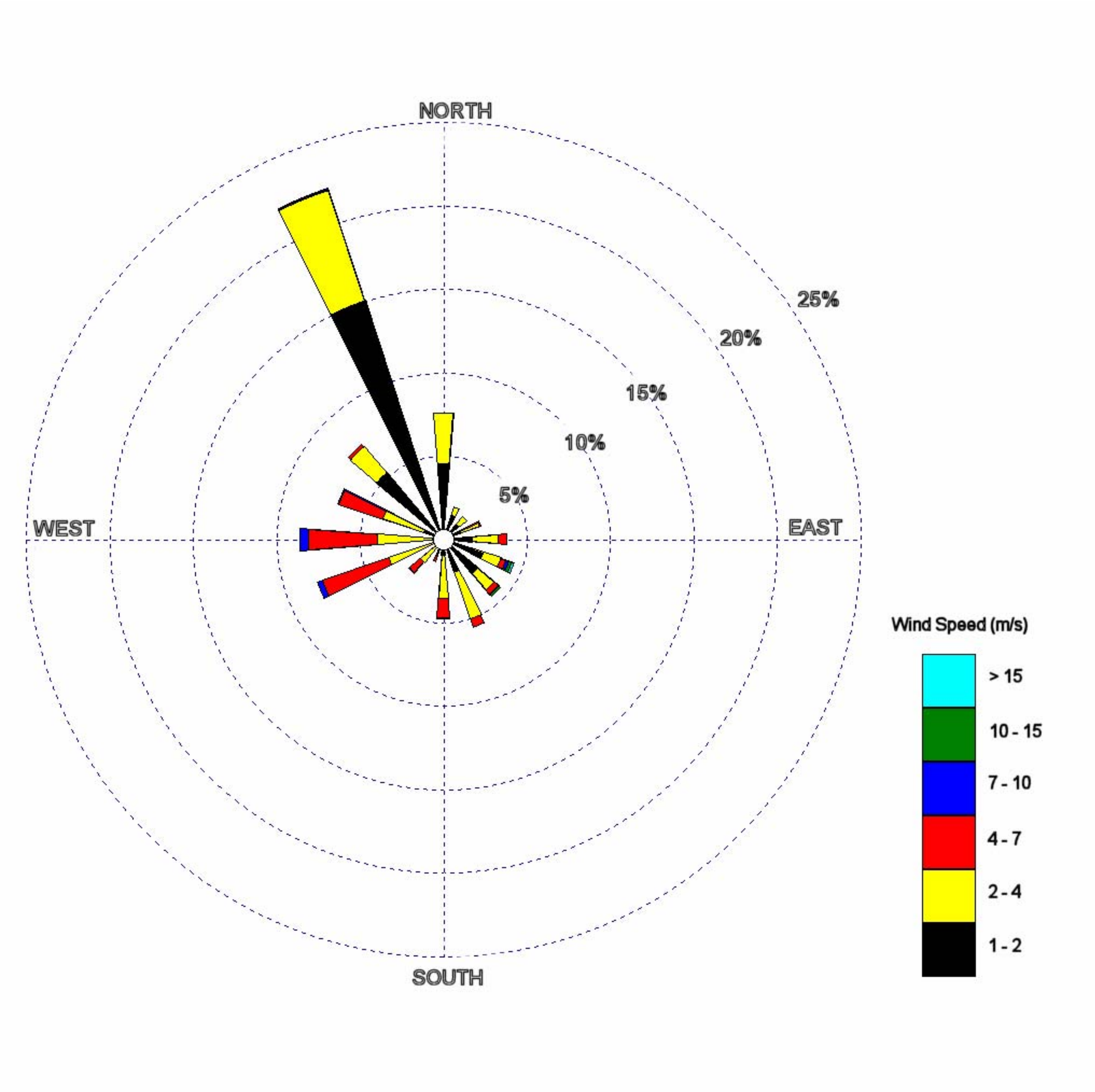
[d] Sourced from Environment Canada, http://www.climate.weatheroffice.ec.gc.ca/climateData/

**Figure A.1 2002 Wind Rose Diagram for Victoria Topaz**



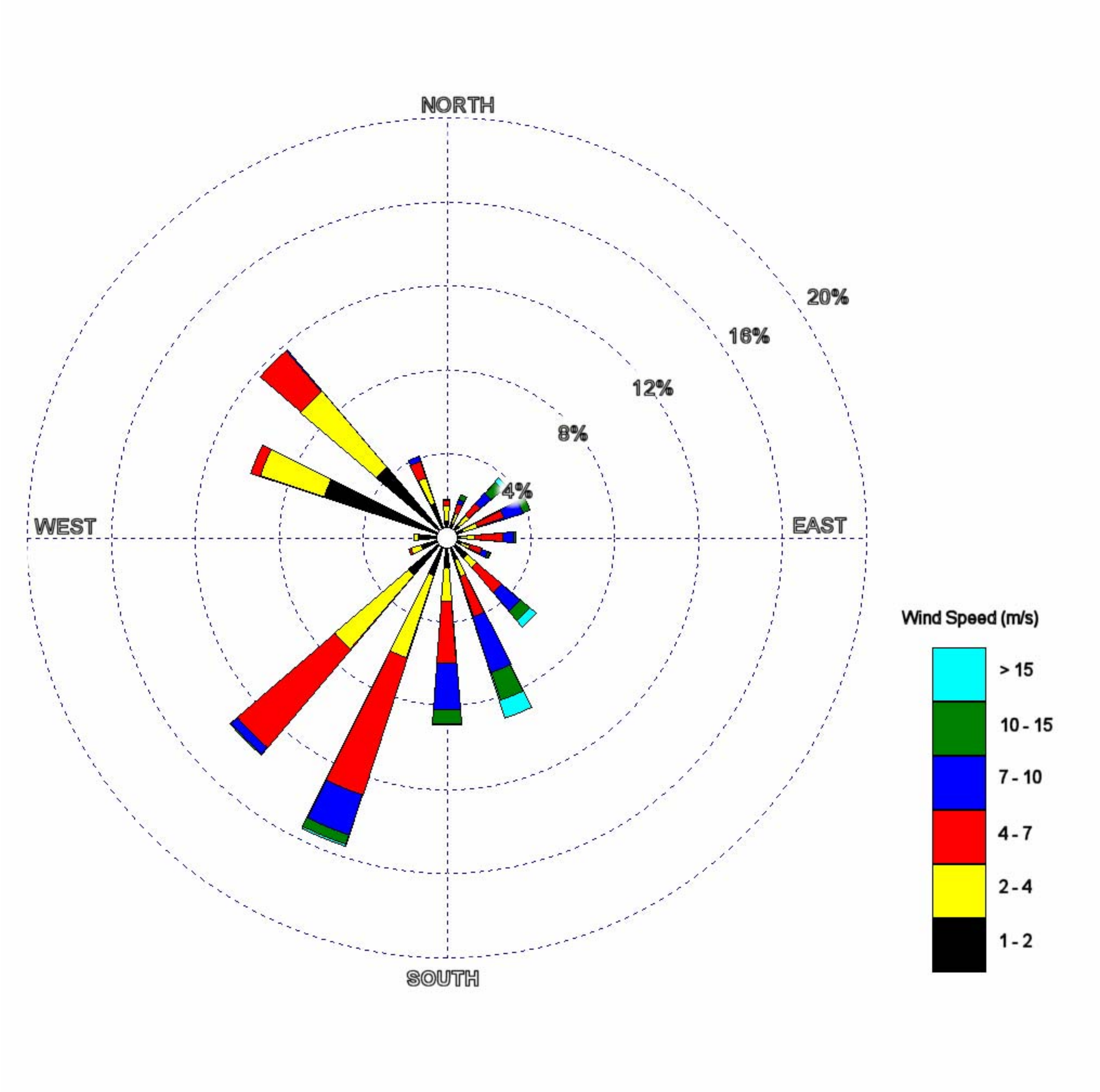

| | |
|---|---|
| Average Wind Speed: | 2.8 m/s |
| Calms: | 11.0 % |

**Figure A.2 2002 Wind Rose Diagram for Royal Roads University**




| | |
|---|---|
| Average Wind Speed: | 2.6 m/s |
| Calms: | 20.0% |

**Figure A.3 2002 Wind Rose Diagram for Saturna Island**




Average Wind Speed: 4.5 m/s
Calms: 3.9%