Cowichan Valley Regional District Air Quality Study

FINAL

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Table of Contents

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

Executive Summary

The BC Ministry of Environment engaged Stantec Consulting Inc. to analyze the meteorological and air quality datasets from the Cowichan Valley Regional District (CVRD) on Vancouver Island, British Columbia (BC). The study considered the 11-year period 2003 through 2013. The purpose of this study was to consolidate the most recent air quality information for the CVRD in support of future airshed management efforts. Statistical summaries, graphics, and case studies were used to characterize patterns in the observed air quality conditions.

It's well known that local meteorological conditions strongly influence air quality by enhancing or inhibiting the dispersion of air contaminants. The inclusion of a meteorological analysis is crucial to any air quality study. The primary meteorological stations included in this study were the Crofton Met, North Cowichan, and Duncan Cairnsmore stations. Climatological summaries were also obtained from four Environment Canada weather observing stations in the CVRD. Average temperatures showed little variation among the stations, however, the monthly average precipitation amounts increased with the station elevation. Precipitation totals in the study area peak in late fall to early winter, and then diminish through July and August. Occasional dry periods in winter are associated with stable high pressure systems. These atmospheric features are also important in terms of air quality as episodes of high particulate concentrations were associated with periods of air stagnation in winter.

Air quality datasets from four monitoring stations in the CVRD were analyzed. These include Crofton Substation, Crofton Escarpment Way, Duncan Deykin Avenue, and Duncan Cairnsmore. The Crofton Substation and Duncan Deykin Avenue stations were operational prior to 2003. Observations at Crofton Escarpment Way and Duncan Cairnsmore stations began in October 2008 and July 2009, respectively.

The five substances that were measured and analyzed are: sulphur dioxide (SO_2), nitrogen dioxide (NO_2), particulate matter (PM), total reduced sulphur (TRS), and ozone (O_3). Particulate matter is further categorized by diameter into inhalable (PM_{10}) and respirable ($PM_{2.5}$) fractions. These substances are known collectively as criteria air contaminants (CACs). Air quality is determined by a comparison of the measured CAC concentrations with the national and provincial ambient air quality objectives (AAQO).

A diurnal pattern was found for SO_2 concentrations in which average values peaked in late morning and decreased through the night. This pattern was likely due to shoreline fumigation after the onset of onshore (easterly) wind flow. No hebdomadal (day of week) pattern was apparent for SO_2.

A diurnal pattern was found for NO_2 concentrations as well. The diurnal pattern for NO_2 showed two peaks, one in the morning and one in the evening, corresponding to times of peak motor vehicle traffic. A hebdomadal pattern was found for NO_2, with lower concentrations on

weekends than during the week. There were no exceedances of national or provincial AAQO for SO_2 and NO_2.

Inhalable particulate matter was measured at Crofton Substation and Duncan Deykin Avenue. At Crofton Substation, there was just one day when the 24-hour average PM_{10} concentration exceeded the BC AAQO. There were no exceedances of the provincial objective at Duncan Deykin Avenue from 2003 to 2010. At Crofton substation, there is minimal seasonal trend with slightly higher concentrations in the spring and summer compared to the fall and winter. At Duncan Deykin Avenue, there were higher concentrations in the late fall and early winter due to activities such as space heating and open burning.

The Duncan Cairnsmore monitoring station had the highest $PM_{2.5}$ readings, with exceedances of the BC AAQO for both the annual and 24-hour averaging periods. Exceedance of the 24-hour objective occurred during one or more days during six of the 12 months, to a maximum of 21 days out of a year. Duncan Cairnsmore was also the only station to show a clear seasonal trend in the 24-hour average $PM_{2.5}$ concentrations, with low values in summer and relatively high values in winter. There was a bimodal peak in the diurnal pattern of $PM_{2.5}$, with maxima in the morning and evening.

These $PM_{2.5}$ patterns are likely attributable to the influence of winter time emissions from space heating, including woodstoves. However, it was also found that exceedance of the AAQO for the 24-hour averaging period can also occur in summer from forest fire smoke of distant origins. Diurnal trend analysis of $PM_{2.5}$ suggests that increased emissions from space heating are a stronger factor to diurnal enhancements of $PM_{2.5}$ than motor vehicle traffic. Hebdomadal trend analysis of $PM_{2.5}$ shows there are higher concentrations on the weekends during the fall through spring. This could be attributed to space heating and open burning on the weekends when more people are at home.

Exceedances of the $PM_{2.5}$ objectives were sporadic with exceedances having a greater frequency in winter. The study revealed that the exceedances were episodic and not systemic in nature. The Crofton Substation, Crofton Escarpment Way, and Duncan Deykin Avenue stations had very few exceedances of the 24-hour AAQO for $PM_{2.5}$ while Duncan Cairnsmore had a greater frequency in winter. The meteorological data analysis revealed that these sporadic exceedances may be due to long range transport from forest fires located in other regions (summer), local burning and space heating (winter).

Total reduced sulphur exhibited low average concentrations with short-term peaks that exceeded the most stringent BC AAQO for the 1-hour and 24-hour averaging periods. These episodes of higher TRS concentration are most likely associated with emissions from the Pulp Mill in Crofton. Exceedance of the TRS AAQO for the 24-hour averaging period occurred up to 30% of the time on an annual basis at Crofton Substation which is 250 m south of the Pulp Mill, but only up to 1.5% of the time at Duncan Deykin Avenue which is more than 8 km away from the Pulp Mill. The meteorological data analysis revealed that these sporadic exceedances may be due to the Crofton Mill emissions.

Ozone was measured at the Duncan Cairnsmore station starting in mid-2009. Ozone is more prevalent during summertime high pressure systems, as its formation is dependent on sunlight and warm temperatures. Average monthly concentrations exhibited a springtime peak, but the highest 1-hour average concentrations occurred in August. A well-defined diurnal cycle in O_3 concentration with a late afternoon maximum was observed for all seasons, indicating some local photochemical production – entirely consistent with the small urban setting. Analysis of two high-concentration episodes found these patterns were associated with periods of hot, sunny weather not usually observed in the region. Analysis of O_3 into regimes suggests that transport of O_3 from the Lower Fraser Valley (or most distant sources) is not an important factor. There were no exceedances of the national AAQO for O_3.

Episodes of high CAC concentrations in the CVRD were primarily associated with tranquil meteorological conditions, which often featured temperature inversions (temperature increasing with height). Temperature inversions are mainly a night time phenomena, but in winter they can persist well into the day when a high pressure system persists over the CVRD. This situation allows for an accumulation of CACs near the surface, which is especially evident in the NO_2 and $PM_{2.5}$ data. The datasets analyzed for this study conformed well to these conceptual models of air quality meteorology. The fact that, for most of any given year, the CVRD experiences relatively active weather patterns is beneficial to the region's air quality. The findings of the meteorological analysis show that the episodes of degraded air quality are influenced by the meteorological conditions.

The air quality data analyses indicate that the results varied considerably by substance and location during the study period. There were no exceedances of the SO_2, NO_2 and O_3 applicable objectives. Exceedances of the $PM_{2.5}$ and TRS objectives were sporadic with the $PM_{2.5}$ exceedances having a greater frequency in winter. The system wide data analysis revealed that the exceedances were episodic and not systemic in nature. The meteorological data analysis revealed that these sporadic exceedances may be due to long range transport from forest fires located in other regions (summer), local burning and space heating (winter), and (for TRS) Crofton Mill emissions. With respect to applicable objectives the overall air quality is relatively good in the summer, except for episodes of high TRS concentrations. It often becomes degraded in the winter in the higher populated areas due to episodes of high $PM_{2.5}$ concentrations.

Abbreviations

AT	Air temperature
BAM	Beta Attenuation Mass Monitor
BC	British Columbia
BC AAQO	British Columbia Ambient Air Quality Objective
BC MOE	British Columbia Ministry of Environment
˚C	Degrees Celsius
CAAQS	Canadian Ambient Air Quality Standard
CAC	Criteria Air Contaminant
CCNS	Canadian Climate Normals Station
CVRD	Cowichan Valley Regional District
H_2S	Hydrogen sulphide
km	Kilometre
LST	Local Standard Time
m	Metre
m/s	Metre per second
mm	Millimetre
NAAQO	National Ambient Air Quality Objective
NO	Nitric oxide
NO_2	Nitrogen dioxide
NO_X	Oxides of nitrogen
O_3	Ozone

PM	Particulate matter
PM_{10}	Inhalable Particulate Matter. Particulate matter with diameters less than 10 micrometres.
$PM_{2.5}$	Respirable Particulate Matter. Particulate matter with diameters less than 2.5 micrometres.
ppb	Parts per billion
RH	Relative humidity
SO_2	Sulphur dioxide
TEOM	Tapered Element Oscillating Microbalance
TRS	Total reduced sulphur
US EPA	United States Environmental Protection Agency
UTC	Coordinated Universal Time
UV	Ultraviolet
VOC	Volatile organic compound
WHO	World Health Organization
WD	Wind direction
WS	Wind speed
$\mu g/m^3$	Micrograms per metre cubed
µm	Micrometres

Glossary

Airshed: A geographical area, such as a valley, that contains a volume of air in which substances emitted from different sources in the area mix and disperse.

Air Pollutant: A substance in the air that is harmful to human health, the environment, and/or materials. Pollutants can be in a gaseous, liquid droplet, or sold particle form. The substance has to be at a specific concentration to be considered a pollutant.

Ambient Air: Outdoor, open air.

Ambient Air Quality Objectives: Quantitative guidelines for pollutant concentrations set by a government agency in order to protect human health and assist air quality planning.

Bimodal: A distribution with two different modes or peaks.

Canadian Ambient Air Quality Standards: National air quality objectives for fine particulate matter and ground-level ozone.

Climate normals: Long term means of climate variables such as temperature and precipitation based on 30-year datasets, updated every ten years.

Criteria Air Contaminant: A substance for which ambient air quality objectives or standards have been established.

Diurnal: Daily; occurring in a 24-hour period.

Episodic: Occurring occasionally and at irregular intervals.

Emissions source: A point or area from which substances enter the atmosphere. An industrial smokestack is an example of a point source. Wood smoke emissions from residential space heating in a community would be an area source.

Exceedance: Relating to air quality objectives, an exceedance is an occurrence of an ambient concentration that is higher than the objective for the applicable averaging period.

Hebdomadal: Weekly, or relating to days of the week.

Inversion: An atmospheric phenomenon where the air temperature increases with height above the ground, rather that decreasing with height, which is more common.

Mean value: Average value.

Median value: Numerical value that separates the lower and upper halves of a dataset (the 50th percentile).

Meteorological model: A numerical computer program that simulates atmospheric dynamics and physics to diagnose or predict the weather for a defined area.

Mixed layer: Also called mixing layer or planetary boundary layer, the mixed layer is the portion of air near the earth's surface where turbulence causes various constituents, including pollutants, to become well-mixed. The depth of the mixed layer varies with meteorological conditions.

North Pacific High: A semi-permanent high pressure system located in the northern portion of the Pacific Ocean.

Percentile: A value below which a given percentage of values in a dataset occur. For example, the 98th percentile value is the value at which 98% of observations in a dataset are lower.

Photochemical reaction: A chemical reaction involving absorption of energy in the form of light.

Secondary pollutant: A pollutant formed through chemical reactions with other substances in the atmosphere. This can involve a phase change, such as when particles are formed in reactions involving gaseous substances.

Sporadic: Occurring at irregular intervals.

Synoptic scale: A scale of weather features that corresponds to that of a typical weather map showing high and low pressure systems and fronts.

Systemic: Something that is spread throughout, system or group wide. Refers to something that is occurring frequently and at regular intervals

Temperature inversion: A meteorological situation in which air temperature increases with height rather than the more normal situation of temperature decreasing with height above the earth's surface.

1.0 INTRODUCTION

This report contains results from analysis of meteorological and air quality datasets for the Cowichan Valley Regional District (CVRD) on Vancouver Island, British Columbia (BC). The study period is the years 2003 through 2013. Data from four air quality monitoring stations and three meteorological stations with hourly observations were analyzed for patterns and trends. An additional five weather stations were included for evaluation of longer term climatological conditions in the CVRD.

Background information about the regions physical setting and the meteorological and air quality datasets is included in Sections 1 and 2 of the report respectively. Results are presented in Section 3, first for meteorology and then for air quality datasets. Conclusions and recommendations follow in Section 4. Supplemental meteorological and air quality datasets are included in both tabular and graphic form in Appendix A (meteorological data) and Appendix B (air quality data).

1.1 PHYSICAL SETTING

The CVRD covers a large portion of southern Vancouver Island between the Nanaimo and Alberni-Clayoquot Regional Districts to the north and the Capital Regional District to the south, with a total area of approximately 3,500 square kilometres (km). Most of the northern and western portions of the CVRD consist of undeveloped mountainous land and numerous large lakes. The CVRD contains various watersheds. The Nanaimo River watershed grouping is to the north, then the Chemainus River watershed with Crofton is at its terminus. The Cowichan Valley is defined by the Cowichan River watershed, which drains Cowichan Lake southeastward to the Salish Sea at Cowichan Bay. The relatively broad portion of this valley near the coast is the most densely settled part of the CVRD, centred on the city of Duncan. To the south of the Cowichan River watershed is the Shawnigan Lake and Mill Bay area. These areas are not as densely settled as the area surrounding Duncan but are quickly growing.

The air quality and meteorological monitoring network in the CVRD is focused around the more densely settled areas of the Cowichan and Chemainus valleys. The Cowichan Lake valley and the upper Cowichan River are quite narrow, with mountains reaching above 1,000 metres (m) on both sides. The lower valley around Duncan is more gently undulating, but with hills and small mountains on almost every side; only the southeast quadrant is open to Cowichan Bay. This complex topography has a major effect on local meteorological patterns (e.g., wind flows, temperature inversions, and precipitation), which in turn affects ambient air quality conditions in the valley.

The Cowichan Valley can be considered a distinct airshed in that emissions from one part of the valley can affect other areas through wind transport and other meteorological processes. This air quality study therefore focusses on the most densely populated area of the Cowichan Valley airshed, which is also where the air quality monitoring stations are located.

2.0 DATASETS

Climate and air quality datasets were obtained from various sources within the provincial and federal governments. There are five substances that were measured and analyzed. These substances are sulphur dioxide (SO_2), nitrogen dioxide (NO_2), particulate matter (PM), total reduced sulphur (TRS), and ozone (O_3). Particulate matter is further categorized by size into inhalable (PM_{10}) and respirable ($PM_{2.5}$) fractions. These are known collectively as criteria air contaminants (CACs). These parameters measured are summarized in Table 2-1. The datasets of these parameters are described below. There are other CACs, namely carbon monoxide, formaldehyde, lead, and total suspended particulate matter, which have not been monitored in the CVRD.

Table 2-1 Ambient Air Monitoring and Canadian Climate Normals Stations in the CVRD

Station Name	Meteorological Variable					Air Quality Parameter							
	WS	WD	AT	RH	PCPT	SO_2	NO	NO_2	NO_x	PM_{10}	$PM_{2.5}$	TRS	O_3
Crofton Met	✓	✓	✓	✓									
Crofton Substation						✓	✓	✓		✓	✓	✓	
Crofton Escarpment Way						✓	✓	✓			✓		
North Cowichan Met (CCNS)	✓	✓	✓	✓	✓								
Duncan Deykin Avenue										✓	✓	✓	
Duncan Cairnsmore	✓	✓	✓	✓			✓	✓	✓		✓		✓
Lake Cowichan (CCNS)			✓		✓								
Cowichan Lake Forestry (CCNS)			✓		✓								

Table 2-1 Ambient Air Monitoring and Canadian Climate Normals Stations in the CVRD

Station Name	Meteorological Variable					Air Quality Parameter							
	WS	WD	AT	RH	PCPT	SO_2	NO	NO_2	NO_X	PM_{10}	$PM_{2.5}$	TRS	O_3
Duncan Kelvin Creek (CCNS)			✓		✓								
Shawnigan Lake (CCNS)			✓		✓								

NOTES:
WS = wind speed; WD = wind direction; AT = air temperature; RH = relative humidity, PCPT = precipitation.
CCNS = Canadian Climate Normals Station.

2.1 CLIMATE DATA

Climate is a measure of the average pattern of variation in temperature, humidity, atmospheric pressure, wind, precipitation, and other meteorological variables in a given region over long periods of time. Climate is different from weather, in that weather only describes the short-term conditions of these variables in a given region.

A quantitative overview of the climate of the study area was obtained from Canadian Climate Normals data compiled by Environment Canada (2014a). Datasets were available from five Canadian Climate Normals Stations in the CVRD. Locations of these stations are listed in Table 2-2 and are shown in Figure 2-1. Climate "normals" are based on 30-year averages of the aforementioned meteorological variables. The North Cowichan normals dataset contains precipitation information only, while the other four stations listed in Table 2-2 have temperature and precipitation data. Environment Canada updates the climate normals every ten years; the latest dataset is based on the 1981–2010 period.

Table 2-2 Canadian Climate Normals Stations in the CVRD

Station Name	Latitude (degrees north)	Longitude (degrees west)	Elevation (m)
North Cowichan	48.82	123.72	46
Cowichan Lake Forestry	48.82	124.13	177
Lake Cowichan	48.83	124.05	171
Shawnigan Lake	48.65	123.63	159
Duncan Kelvin Creek	48.73	123.73	103

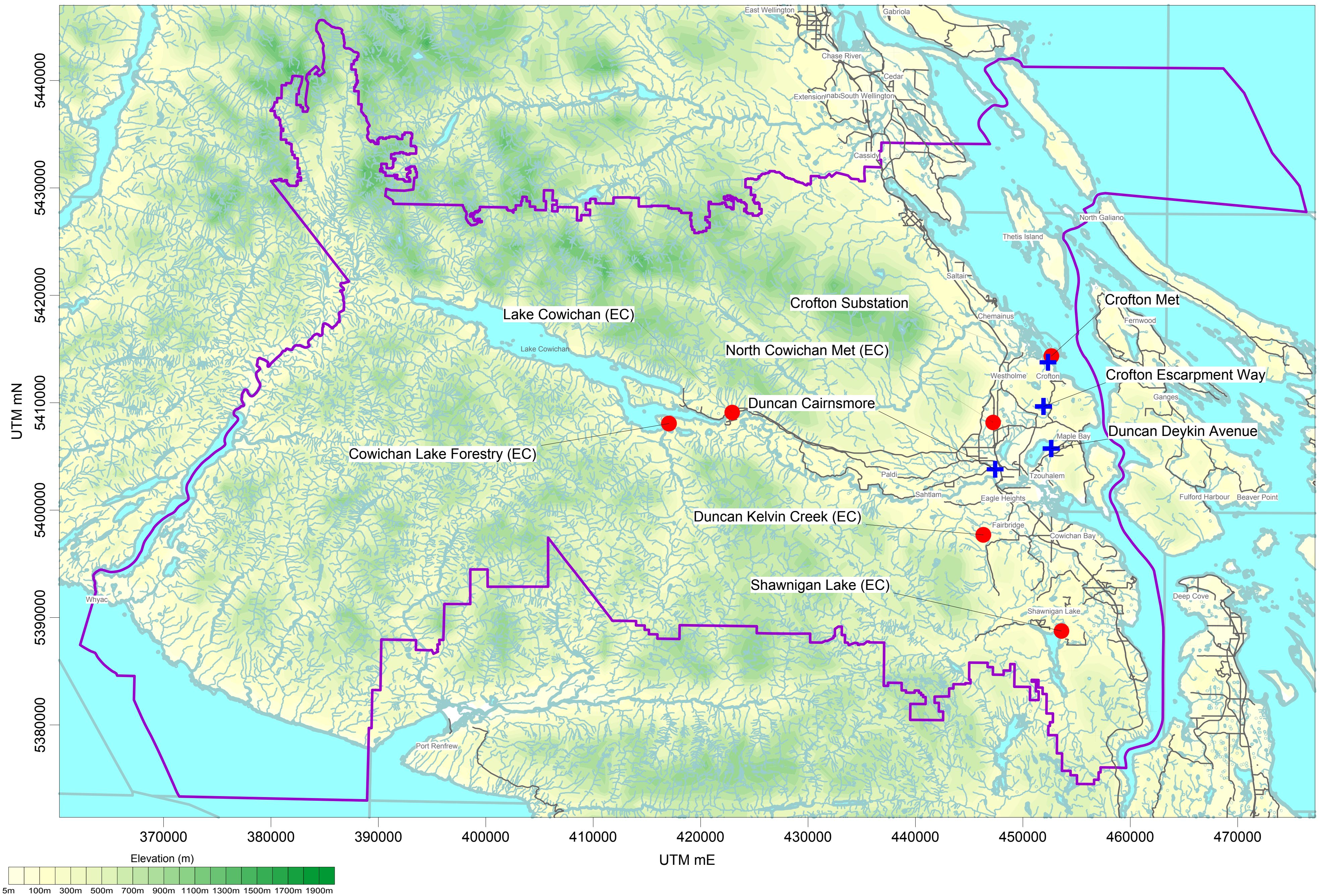
Although the North Cowichan site has normals data for precipitation only, a newer meteorological station that records hourly temperature, humidity, pressure, and wind data has operated at the same location since November 2007 (Environment Canada 2014b). Hourly temperature and wind data were obtained from this station for the climate summary (see Section 3.1).

Meteorological data were also available from two stations in the CVRD that are part of the BC air quality monitoring network (BC MOE 2014a). The Crofton Met station is located at the Crofton pulp mill near the Crofton Substation air quality monitoring station, and the Duncan Cairnsmore station has both air quality and meteorological instruments. The three stations with hourly meteorological data are listed in Table 2-3 with their respective periods of available data. The station locations are shown in Figure 2-1. See Section 3.1.2 for results of data analysis for the 2003–2013 study period.

Table 2-3 Hourly Meteorological Data in the CVRD

Station Name	Period of Available Data
North Cowichan	November 27, 2007–Present
Crofton Met	October 10, 1991–Present
Duncan Cairnsmore	October 8, 2009–Present

Historical meteorological observations from airport locations were used in the analysis of air CAC episodes (Section 3.2.5 and Section 3.2.7). These observations were obtained from a web site of the Meteorology Department at Plymouth State University (Plymouth State, 2014).



Stantec

C·V·R·D

Legend

- CVRD Boundary
- Major Road
- Water Body
- Water Course
- Meteorological Stations
- Air Quality Stations

Cowichan Valley Regional District Meteorological and Air Quality Stations

PROJECTION	UTM	DRAWN BY	KW
DATUM	NAD 83 - ZONE 10	CHECKED BY	JS
DATE	2014-Nov-17	FIGURE NO.	2-1

2.2 AIR QUALITY DATA

The following substances are monitored in the CVRD and are considered CACs because national and/or provincial ambient air quality objectives have been defined for these substances due to their potential to affect human and environmental health.

Locations where the various CACs have been measured in the CVRD are provided in Table 2-4 and Figure 2-1.

2.2.1 Sulphur Dioxide

Sulphur dioxide (SO_2) is a colourless gas that is produced in combustion processes by the oxidation of sulphur compounds in fuel. At high enough concentrations, SO_2 can have adverse effects on plant and animal health, particularly with respect to respiratory systems. Sulphur dioxide can also be further oxidized and combine with water to form the sulphuric acid component of "acid rain."

Anthropogenic (human-caused) emissions make up approximately 95% of total global atmospheric SO_2 emissions. The oxidation of reduced sulphur compounds emitted by the ocean surface accounts for most biogenic emissions, and volcanic activity accounts for much of the remainder (Wayne 1991).

Ambient concentration data for SO_2 are available from the Crofton Substation and Crofton Escarpment Way monitoring stations. Most of the SO_2 emissions in the CVRD originate from the Crofton Mill, a pulp and paper mill operated by Catalyst Paper Corporation (Levelton 2014).

2.2.2 Nitrogen Dioxide

Oxides of nitrogen (NO_X) are produced in most combustion processes and are almost entirely made up of nitric oxide (NO) and nitrogen dioxide (NO_2). Nitrogen dioxide is an orange to reddish gas that is corrosive and can be toxic at high concentrations.

Anthropogenic emissions make up approximately 93% of total global atmospheric NO_2 emissions. The largest anthropogenic contributor to atmospheric NO_X is the combustion of fuels such as gas, oil, and coal. Forest fires, lightning, and anaerobic processes in soil account for nearly all biogenic emissions (Wayne 1991).

Ambient air quality objectives (AAQO) exist for NO_2 but not for NO or NO_X. Ambient concentration data for both NO and NO_2 are available from the Crofton Substation, Crofton Escarpment Way, and Duncan Cairnsmore stations. At Duncan Cairnsmore, NO_X is also recorded. In an emissions inventory for the CVRD based on 2011 data, mobile sources (motor vehicles, marine vessels, off-road equipment, etc.) accounted for a majority of the NO_X emissions (Levelton 2014).

2.2.3 Particulate Matter

Particulate matter (PM) consists of airborne solid particles and liquid droplets, and is classified by the size of the particles. The PM size classes are referenced to particle diameters in micrometres (µm). Inhalable particulate matter (PM_{10}) consists of particles with diameters less than or equal to 10 µm. Respirable particulate matter ($PM_{2.5}$) consists of particles with diameters less than or equal to 2.5 µm.

Inhalation of fine PM can lead to respiratory problems, particularly for persons with existing conditions such as asthma. Both anthropogenic and natural processes can be major sources of atmospheric PM. Industrial emissions, motor vehicles, marine vessels, and space heating are examples of anthropogenic sources, while forest fires, pollen, and windblown dust are common and natural sources of PM.

Ambient concentration data for $PM_{2.5}$ are available from the Crofton Substation, Crofton Escarpment Way, Duncan Deykin Avenue, and Duncan Cairnsmore monitoring stations. The Crofton Substation and Duncan Deykin Avenue stations also monitored PM_{10} concentrations until 2010. In 2011, area sources accounted for a majority of $PM_{2.5}$ and PM_{10} emissions in the CVRD. The most significant area source of PM was open burning, followed by space heating (Levelton 2014). Space heating produces PM through combustion of heating fuels including natural gas, oil, and wood.

2.2.4 Total Reduced Sulphur

Total reduced sulphur (TRS) is the name for a group of gaseous sulphur compounds consisting mostly of dimethyl disulphide, dimethyl sulphide, methyl mercaptan, and hydrogen sulphide (H_2S). These gases, especially methyl mercaptan and H_2S, are known for their pungent “rotten eggs” odour. Industrial sources of TRS include pulp mills and oil refineries. Natural sources include marshes and bogs (BC MOE 2013a).

Ambient concentration data for TRS are available from the Crofton Substation, Crofton Escarpment Way, and Duncan Deykin Avenue monitoring stations. Concurrent monitoring of the H_2S component of TRS was done at Crofton Substation from 2005 to 2010. Although TRS was not explicitly part of the CVRD emissions inventory (Levelton 2014), it can be assumed that, like SO_2, the vast majority of TRS emissions in the area come from the Crofton Mill.

2.2.5 Ozone

Although ozone (O_3) in the stratosphere has the beneficial property of absorbing harmful ultraviolet radiation, ground-level O_3 is considered a CAC because of its adverse effects on humans, vegetation, and materials. The main risk for humans is ozone’s potential to irritate, and even damage, the respiratory system.

Ground-level O_3 is considered a secondary pollutant because it is produced by chemical reactions of precursor substances, mainly NO_X and volatile organic compounds (VOCs) in the presence of sunlight. Therefore, high concentrations of O_3 tend to be found downwind of the sources of these precursor substances. However chemical reactions with NO and NO_2 act to destroy O_3 and lower the ambient concentrations at night (BC MOE 2013).

The only monitoring station in the CVRD that measures O_3 is Duncan Cairnsmore, where monitoring commenced in late July 2009. Regarding the precursor substances, the CVRD emissions inventory revealed that mobile sources accounted for a majority of the NO_X emissions and VOCs came from a variety of sources including solvent use, space heating, open burning, and motor vehicle exhaust (Levelton 2014).Air Quality Data Availability

Ambient air quality data were obtained from four monitoring stations in the CVRD. The stations and their measured parameters are listed in Table 2-4. Hourly averaged data from the 2003–2013 study period were downloaded from the BC Ministry of Environment (BC MOE) air data archive website (BC MOE 2014a). The Crofton Substation and Duncan Deykin stations were partially operational through the entire 11-year study period. Data collection commenced in October 2008 at Crofton Escarpment Way, while the Duncan Cairnsmore station has been operational since late July 2009. At each station, measurement of specific CACs began (and sometimes ended) at different times, depending on various factors such as monitoring priorities, funding, and instrument performance. See the results in Section 3.2 and the time series graphs in Appendix B for dates of when particular datasets began and ended.

Table 2-4 Ambient Air Quality Monitoring Stations in the CVRD

Station Name	Latitude (degrees north)	Longitude (degrees west)	Elevation (m)	Period of Available Data
Crofton Substation	48.88	123.65	40	August 19, 1994–Present
Crofton Escarpment Way	48.83	123.66	142	October 9, 2008–February 3, 2014
Duncan Deykin Avenue	48.80	123.65	20	January 11, 1998–Present
Duncan Cairnsmore	48.79	123.72	32	July 28, 2009–Present

2.3 DATA PROCESSING AND QUALITY CONTROL

Meteorological and air quality datasets were organized and processed using Microsoft Excel. An inventory of available data was performed and then time series graphs showing all data for each station and substance were made; this provided a first look at the datasets and helped identify any suspect data points. Time series graphs for the air quality parameters are included in Appendix B.

Datasets through 2013 that have been posted on the BC air data archive website have already gone through quality assurance reviews (BC MOE 2014a). Only the NO_X data from Duncan Cairnsmore and temperature data from Crofton Met were found to have some spurious values. The NO_X dataset contained several hundred negative values, which were deleted prior to preparation of the time series graph shown in Appendix B. For the Crofton Met temperatures, the time series graph indicated that at times readings lower than -20°C were recorded, a very unlikely event at that location. Closer inspection of the data showed that the anomalously low temperature values were surrounded by readings well above freezing. A search was performed on the dataset for all values below −5°C and professional judgment was used to determine which observations should be deleted prior to calculation of averages. No such issues were found with the Duncan Cairnsmore or North Cowichan meteorological data.

Annual average concentrations of CACs were calculated only for years in which data completeness was at least 75% for the substance of interest, i.e., less than 25% of the expected data points were missing. However, partial years of data were included in calculations of monthly statistics, diurnal patterns, and hebdomadal patterns.

Calculation of averages, medians, and percentiles as well as the grouping of datasets by month, hour of day, day and night, etc. were done through the use of Visual Basic macros within Microsoft Excel that were developed specifically for this project. Figures that display the results were made using Grapher 11, a program by Golden Software.

3.0 RESULTS

Results of the data analysis are presented in this section. The meteorological data analyses are presented first, followed by the air quality results. Discussion of the results, including possible explanations for identified patterns, is interspersed throughout the results presentation.

3.1 CLIMATE

The CVRD is part of the South Coast region of BC, which has a modified version of the Mediterranean climate, featuring a well-defined dry season in summer and cool, wet conditions for much of the remainder of the year. The seasonal variation in precipitation is due to seasonal shifts of the North Pacific High, which occupies its more northerly position in summer, thus deflecting storm systems toward the North Coast and Alaska. In fall, the North Pacific High shifts southward and the westerly jet stream strengthens, ushering lows and fronts across Vancouver Island and into the southern BC mainland. The waters of the Pacific Ocean moderate the air temperatures of the South Coast, resulting in a much smaller annual temperature range than that of continental regions east of the Coast Mountains.

3.1.1 Climate Normals

Climate normals data were obtained from five stations in the CVRD (see Section 2.1). Monthly mean temperature and precipitation values are shown in Figure 3-1 and Figure 3-2, respectively.

Monthly mean temperatures at the Cowichan Lake Forestry, Duncan Kelvin Creek, Shawnigan Lake, and Lake Cowichan stations (Figure 3-1) are very similar. For most months of the year, Duncan Kelvin Creek is slightly warmer than the other stations, likely due to its lower elevation. The monthly average temperatures range from about 3°C in December to about 18°C in August. Annual mean temperatures are all approximately 10°C.

Monthly mean precipitation amounts are considerably higher at the Cowichan Lake Forestry and Lake Cowichan stations as compared to the three stations at lower elevations in the CVRD (Figure 3-2). The lowest normal precipitation amounts are at the North Cowichan climate station, which is also the lowest of the five stations. At Cowichan Lake, the surrounding mountainous terrain enhances precipitation through orographic lifting of moist air masses. The mean annual precipitation (including rainfall and water equivalent of snowfall) at the Cowichan Lake Forestry site is 2,207 millimetres (mm), which is nearly double the annual amount at North Cowichan (1,153 mm).

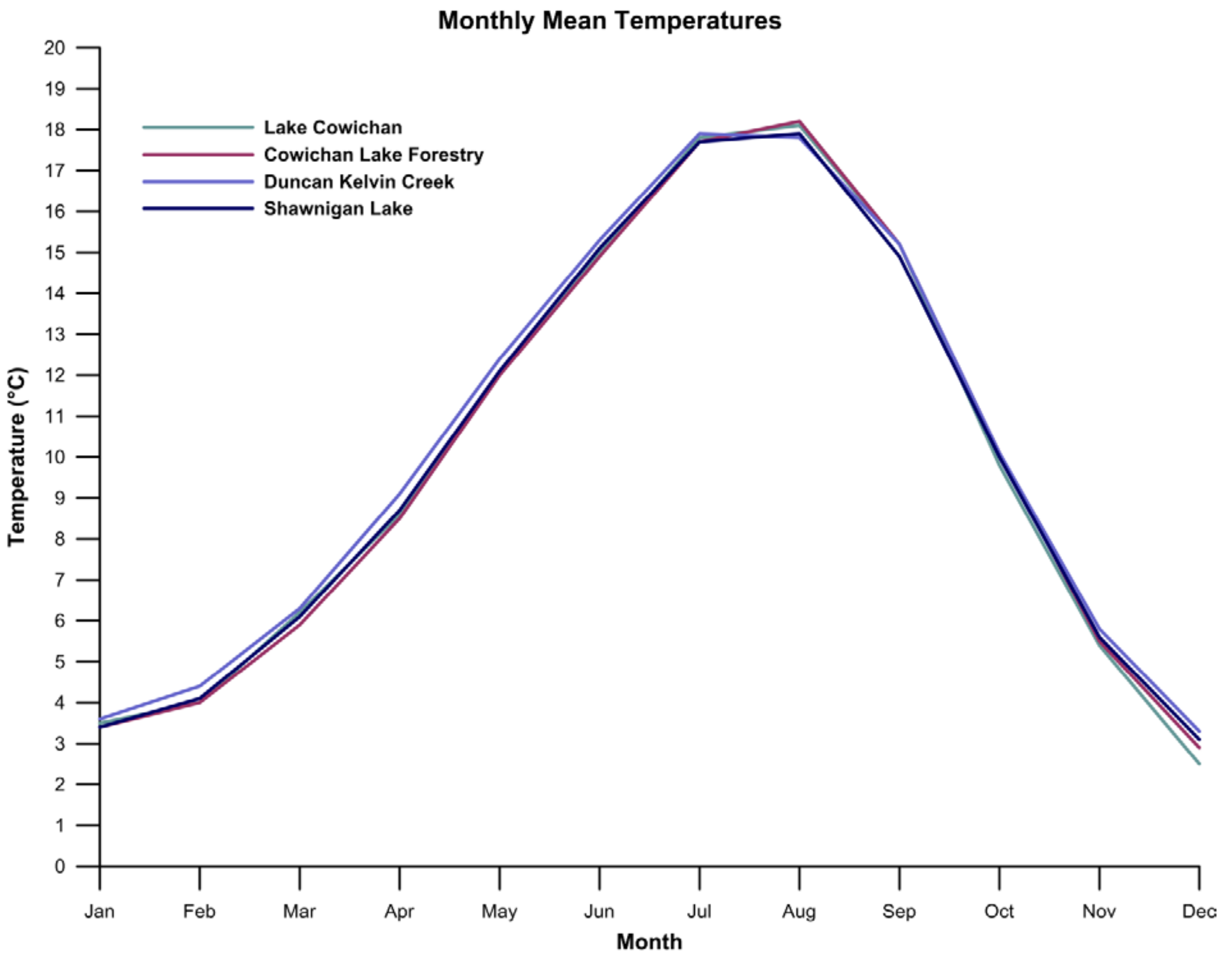


Figure 3-1 Monthly Mean Temperatures Based on 1981–2010 Climate Normals

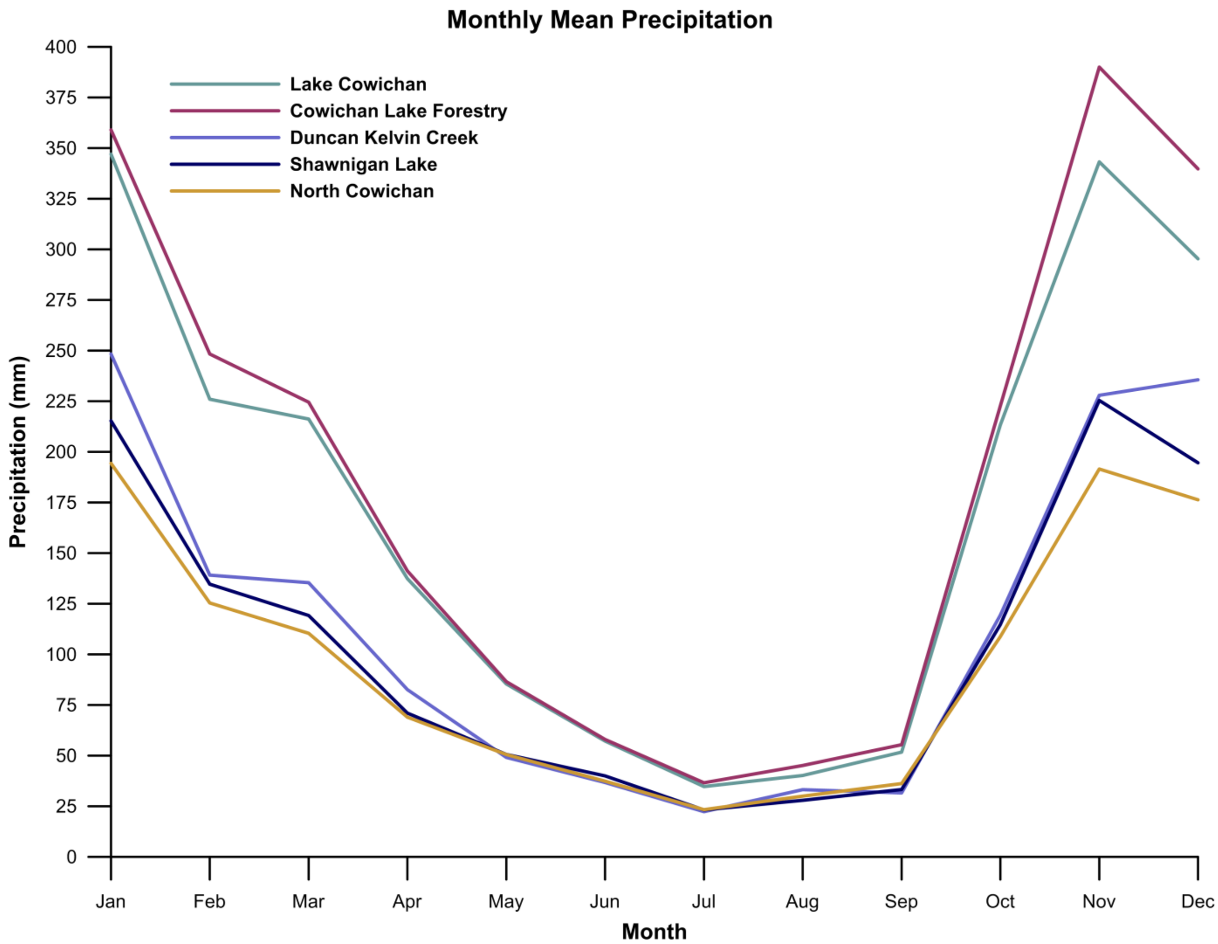


Figure 3-2 Monthly Mean Precipitation Based on 1981–2010 Climate Normals

The strong seasonality to precipitation in the CVRD is apparent in Figure 3-2. The summer dry season is centred on July, when all five stations have normal precipitation amounts well below 50 mm. A pronounced increase in monthly precipitation occurs from September to October. On average, November is the wettest month of the year at the Cowichan Lake Forestry and Shawnigan Lake stations, while January is the wettest month at Duncan Kelvin Creek, North Cowichan, and Lake Cowichan. The highest monthly average precipitation amount in the dataset is 390 mm at the Cowichan Lake Forestry station in November. Monthly precipitation amounts decline gradually from January to July.

3.1.2 Recent Meteorological Data

Hourly meteorological data were analyzed from the three stations listed in Table 2-3.

3.1.2.1 Temperature

Quality control checks on the hourly temperature data revealed some invalid readings from the Crofton Met station (e.g., -40°C) that were discarded prior to calculation of averages and extremes. Meteorological data collection at the Duncan Cairnsmore station commenced in October 2009. Therefore, only the last four complete years of the study period (2010–2013) are available for comparison to the other stations.

Monthly temperatures in Table 3-1 are 2010–2013 averages for each of the three stations. Average summertime temperatures were quite similar at the three stations, but in winter the differences were larger, with relatively mild readings recorded at Crofton Met and colder readings at North Cowichan. Closer inspection of the hourly datasets revealed that overnight low temperatures were often considerably colder at North Cowichan in all seasons. This is likely due to the sheltered valley location of the North Cowichan station, which in light wind situations favours formation of nocturnal temperature inversions and pooling of cold air that drains off surrounding hillsides. Although the North Cowichan station is only 8 km inland from the Crofton Met station, the data indicate a slightly more continental temperature pattern at North Cowichan. For most of the year, the Duncan Cairnsmore temperatures were in between those of the other two stations, but in summer the Cairnsmore station had the highest average temperatures.

Table 3-1 2010–2013 Monthly Mean Temperatures in the CVRD

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
	°C												
Crofton Met	5.5	6.0	7.4	9.2	12.5	15.0	18.3	18.7	16.0	11.1	6.5	5.2	11.0
North Cowichan	2.7	3.8	5.5	7.9	11.6	14.9	18.3	18.4	15.2	9.4	4.8	3.1	9.6
Duncan Cairnsmore	4.0	4.8	6.4	8.6	12.4	15.5	18.8	19.1	15.6	9.9	5.2	3.2	10.3

For a comparison of recent temperature data to long-term means, data from the three stations were plotted with monthly means from the nearest Canadian Climate Normals Station, which is the Duncan Kelvin Creek climate station.

Figure 3-3 shows monthly mean temperatures from each year of the 2010–2013 period at Crofton Met. Monthly normal temperatures from Duncan Kelvin Creek are represented by a thick black line. The Crofton Met temperatures generally were quite similar to the Duncan Kelvin Creek normals, but with some notable exceptions: the first three months of 2010 were considerably warmer than normal; the spring of 2011 was colder than normal; and 2013 was warmer than normal through a majority of the year. These departures from normal are within typical inter-annual climate variability that is attributable to shifts in the jet stream due to large scale factors such as the El Niño Southern Oscillation.

Figure 3-4 shows monthly mean temperatures from each year of the 2010–2013 period at North Cowichan. Temperatures were generally a bit cooler at North Cowichan than the Duncan Kelvin Creek normals. However, the warm anomaly of 2013 noted in the Crofton Met data also occurred at North Cowichan, as did the cold anomaly in the first half of 2011.

Figure 3-5 shows monthly mean temperatures from each year of the 2010–2013 period at Duncan Cairnsmore. Temperatures at the Cairnsmore site were generally a bit warmer than the Duncan Kelvin Creek normals, especially in 2013. The warm anomaly at the beginning of 2010 and the cold anomaly in the spring of 2011 are also present in the Cairnsmore data.

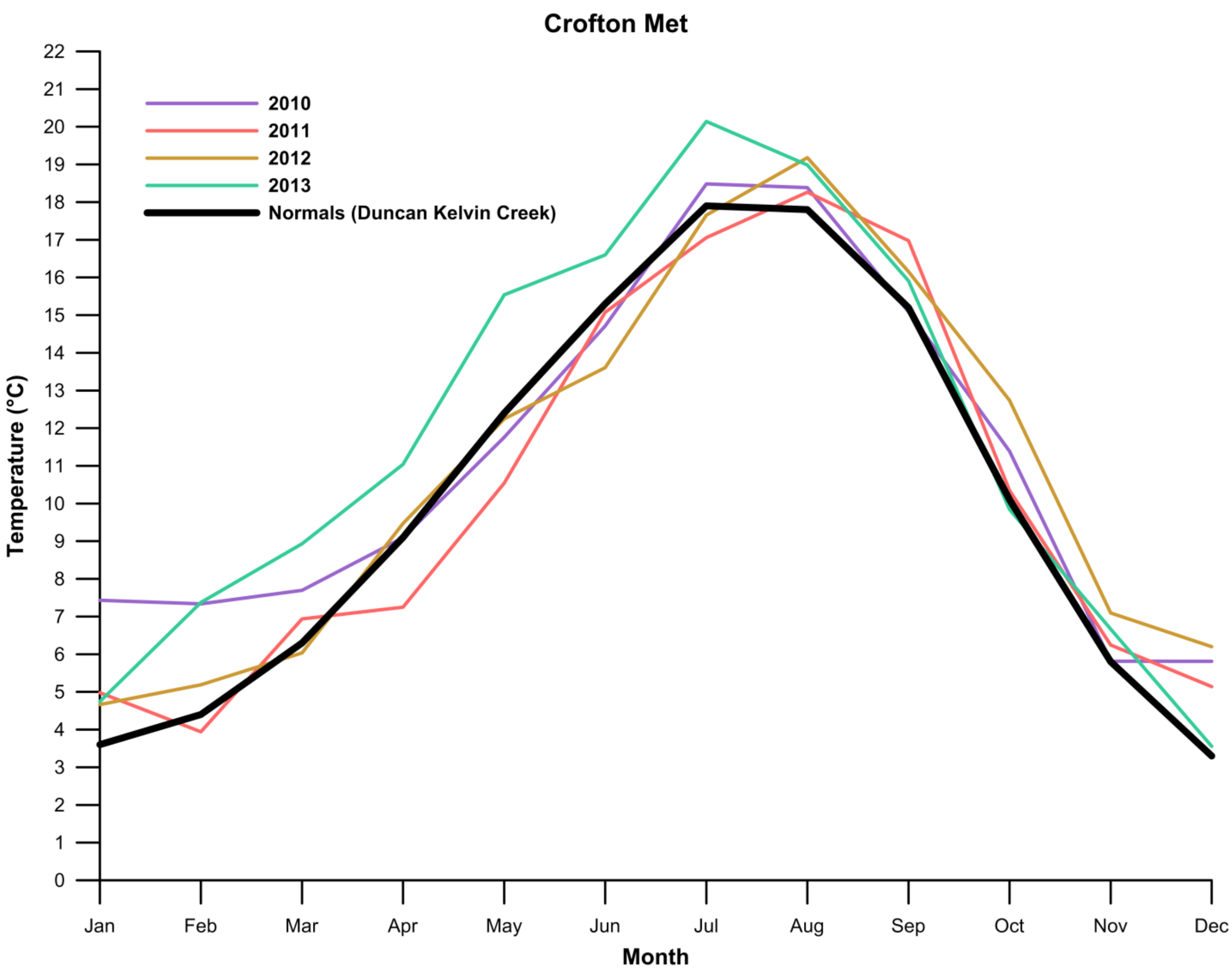


Figure 3-3 Monthly Mean Temperatures at Crofton Met Compared to Climate Normals

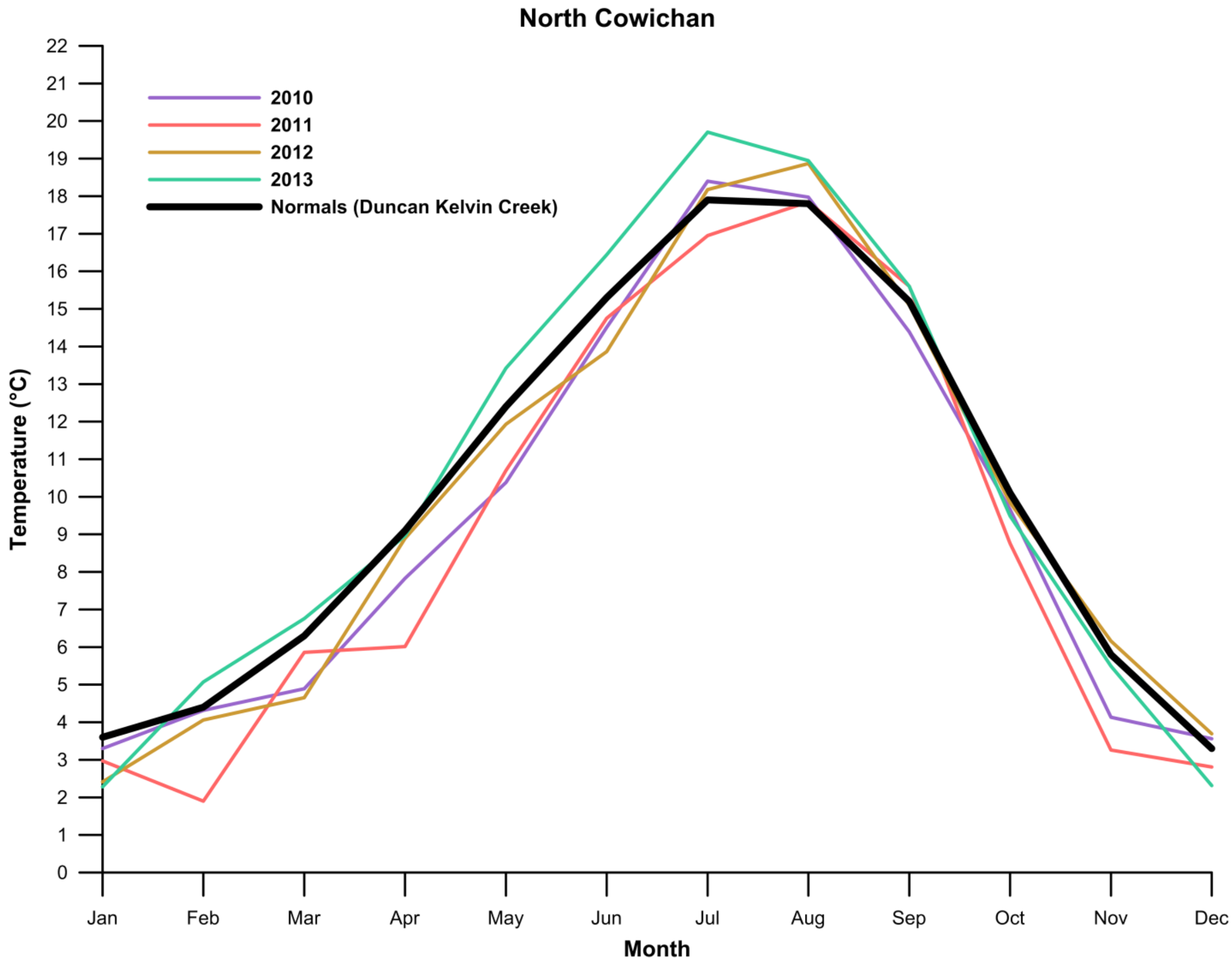


Figure 3-4 Monthly Mean Temperatures at North Cowichan Compared to Climate Normals

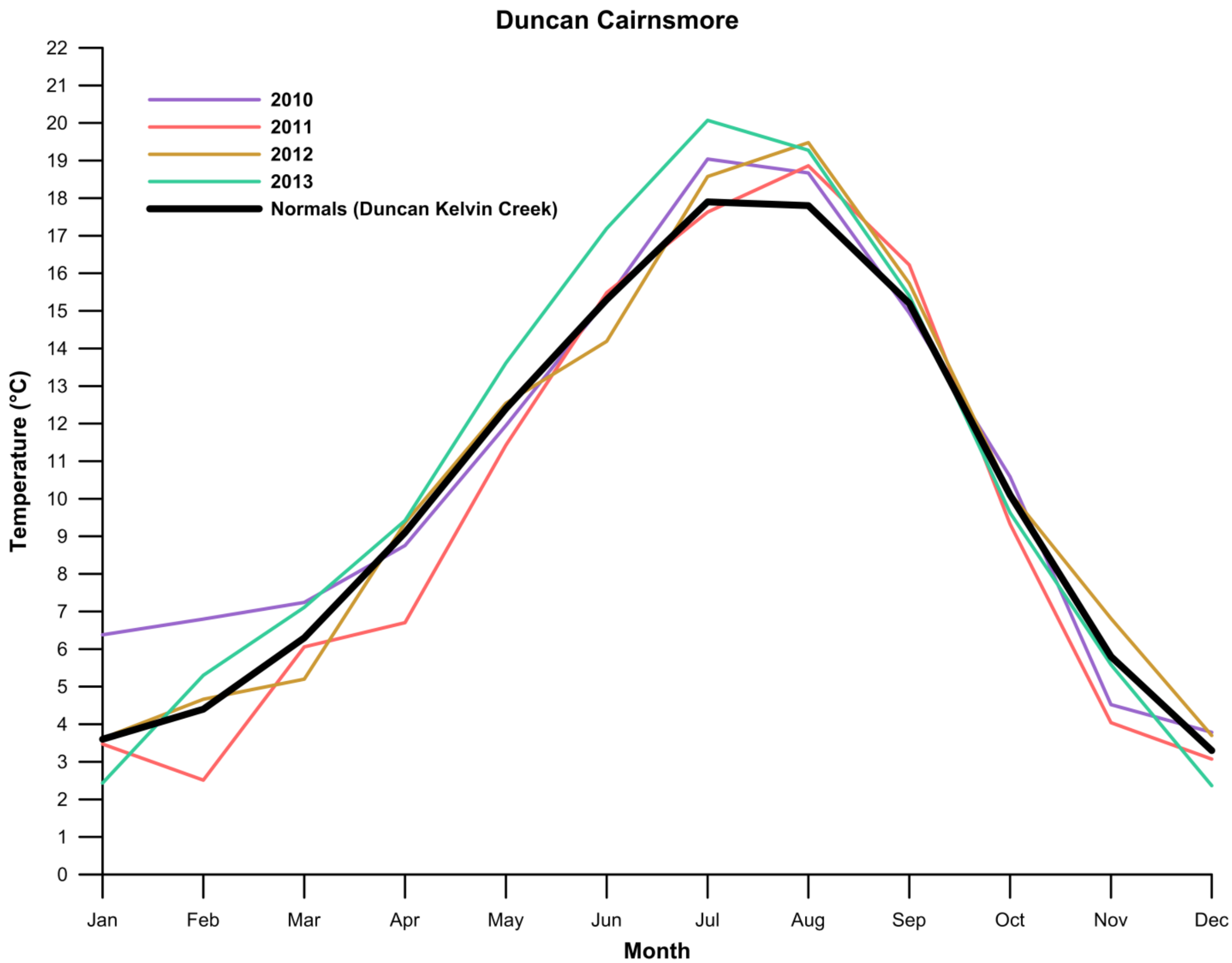


Figure 3-5 Monthly Mean Temperatures at Duncan Cairnsmore Compared to Climate Normals

3.1.2.2 Precipitation

Precipitation is not measured at the Crofton Met or Duncan Cairnsmore monitoring stations. The Environment Canada station at North Cowichan has daily precipitation data starting from December 2007 (Environment Canada 2014b). Monthly precipitation totals for the years 2008–2013 are shown in Table 3-2.

Table 3-2 2008–2013 Monthly Total Precipitation at North Cowichan

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
2008	145.5	42.4	46.5	41.8	22.5	39.5	19.3	41.0	26.7	62.7	126.1	152.4	63.9
2009	73.8	41.9	76.1	39.1	52.9	12.5	8.7	16.5	64.6	168.1	301.2	61.3[A]	77.8
2010	217.0	100.0	100.2	66.1	4.3[A]	0.5[A]	0.0[A]	33.1	78.9	81.3	158.7	193.8[A]	104.4
2011	151.1[A]	98.1	133.0	53.3	82.9	8.1	17.2	7.8	70.1	60.7	163.6	73.7	69.9
2012	80.0[A]	99.0	101.3	57.2	28.8	39.6	17.2	2.3	0.0[A]	106.7[A]	167.6	201.3	79.4
2013	94.3	56.0	90.4	54.2	63.3	44.1	0.0	46.4	110.7	17.5	85.6	80.1	61.9
Normal	194.3	125.4	110.4	69.0	50.5	37.4	23.3	30.0	36.2	108.8	191.5	176.3	88.8

NOTE:
[A] Denotes more than three days of missing data during the month.

The North Cowichan precipitation dataset has considerable missing data for some months, leading to totals that are erroneously low. Months with more than three days of missing data are flagged in Table 3-2. Months with considerably more precipitation than normal included: October 2009 (168.1 mm), November 2009 (301.2 mm), September 2010 (78.9 mm), and May 2011 (82.9 mm). Exceptionally dry months included August 2012 (2.3 mm) and July 2013 (0.0 mm).

3.1.2.3 Wind

Wind patterns can be determined from the stations that have hourly data, which are Crofton Met, Duncan Cairnsmore, and North Cowichan. The wind data record for the Duncan Cairnsmore station began in late 2009; therefore the years 2010–2013 were selected for analysis. At North Cowichan, the available full years of data were 2008–2013. This six-year period was selected for wind analysis at both North Cowichan and Crofton Met.

Wind roses are a graphic means of depicting wind speed and direction frequencies. The orientation of a wind rose petal indicates the direction from which the wind blows, and the length of the petal indicates the frequency of occurrence of that direction class. The colours represent wind speed classes, as defined in the legend. Due to the seasonal nature of meteorological patterns, it is useful to separate wind datasets by season for display in the wind rose format. Thus, the datasets have been divided into spring (March, April, and May), summer (June, July, and August), fall (September, October, and November), and winter (December, January, and February) periods.

3.1.2.3.1 Crofton Met

Seasonal wind roses for the Croton Met station are shown in Figure 3-6. Wind speeds are given in metres per second (m/s). Calm conditions are defined by hourly wind speeds less than 0.5 m/s, which is at or below the starting threshold of many anemometers. On an annual basis, the Croton Met station had calm conditions only 0.02% of the time. This very low percentage of calms can be attributed to the exposure of the wind instrument, which is atop a 10 m tower that is mounted on a 24 m high building. The station's location right on the coast also makes for good wind exposure and often higher wind speeds compared to inland valley locations.

The spring wind rose for Crofton Met is very similar to the annual wind rose (not shown). This is because spring is a transition season that features synoptic scale storms systems as well as more local thermally driven patterns, such as land-sea breezes, that are typical of summer. Winds were common from all quadrants during the spring, but the highest frequencies were for the southeast and southwest winds.

In summer, winds with a westerly component were less frequent at Crofton, and the prevailing wind direction was from the east. This can be explained by sea breezes from the east to southeast being common in summer and storm systems being much less common than during the other seasons.

In fall and winter, winds from the southeast and northwest quadrants dominated at Crofton. This is the main “storm season” when winds tend to be from the southeast as a front approaches and from the west to northwest after the frontal passage. Winds from the northeast and southwest were relatively rare during the winter.

The wind data were further divided by day and night periods for analysis of diurnal patterns. Day and night hours were based on the sunrise and sunset times of the 15th of each month, available from the National Research Council Canada (2014). Seasonal wind roses separated into day and night periods are included in Appendix A. For Crofton Met, both the spring and summer seasons show directional shifts from day to night, with more easterly (onshore) flow by day and more westerly (offshore) flow at night. The diurnal pattern is best defined in summer when the largest temperature contrasts between the land and the water occur.

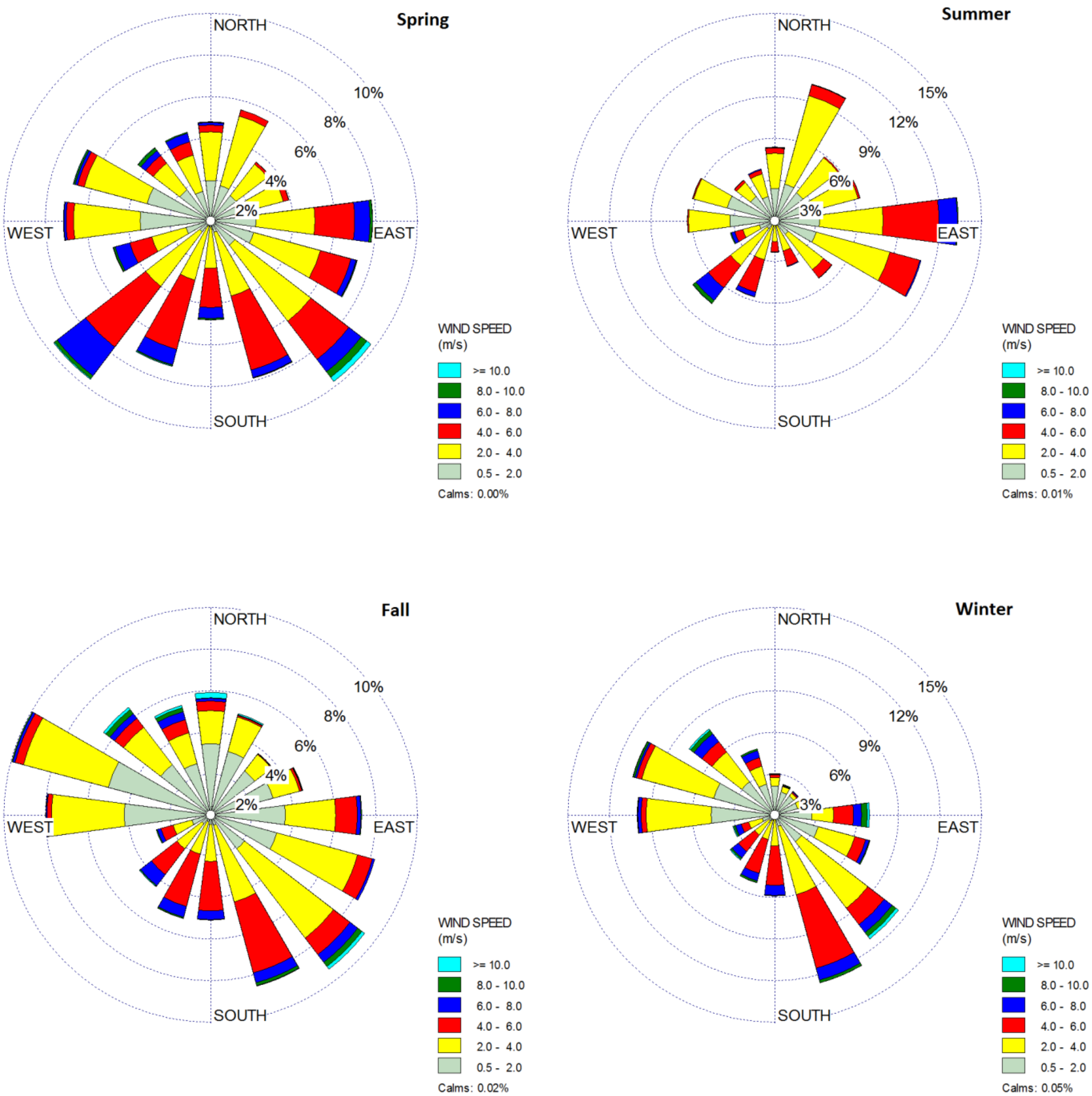


Figure 3-6 Seasonal Wind Roses for the Crofton Met Station Based on 2008–2013 Hourly Data

3.1.2.3.2 Duncan Cairnsmore

Seasonal wind roses for the Duncan Cairnsmore station are shown in Figure 3-7. On an annual basis, the Duncan Cairnsmore station had calm conditions 18% of the time. Average wind speeds were considerably lower than at Crofton and directions were less variable, demonstrating different wind conditions in the Cowichan Valley as compared to the coast. The additional height of the Crofton Met sensor (on the roof of a building) also accounts for some of the wind speed difference.

In spring, the prevailing wind direction at Duncan Cairnsmore was from the west. Winds from the southwest and southeast were also common. In summer, the southeast winds were more frequent, presumably due to daytime sea breezes coming from Cowichan Bay. The fall and winter wind roses resemble the springtime pattern, with mostly west to southwest and southeast winds. Cool air draining down the Cowichan Valley likely accounts for a good portion of the west winds. This is confirmed by the nighttime wind roses in Appendix A, which show that west winds dominated at night in all seasons. The summertime diurnal wind pattern is well-defined at Duncan Cairnsmore, with a prevailing southeast wind by day and west winds at night.

3.1.2.3.3 North Cowichan

Seasonal wind roses for the North Cowichan station are shown in Figure 3-8. On an annual basis, the North Cowichan station had calm conditions 24% of the time, indicating a relatively sheltered location in the valley. The prevailing flow was along a north-south axis in all seasons, reflecting the influence of topography on wind direction. Clearly, the valley between North Cowichan and the Crofton/Chemainus area channels the wind flow much of the time at this station.

Calm winds were least frequent in spring (17%) and most frequent in winter (29%) at North Cowichan. Calms were much more common at night than during the day, ranging from 30% of the overnight observations in spring to 47% in summer. This suggests that surface-based nocturnal temperature inversions are relatively common in this location. This is a stable pattern that occurs in the lower atmosphere when cold air accumulates at the surface and temperatures increase with height. The stable temperature profile acts to dampen vertical air movements, causing substances to remain trapped in a shallow layer near the surface. Clear nights with light winds favour the formation of strong temperature inversions.

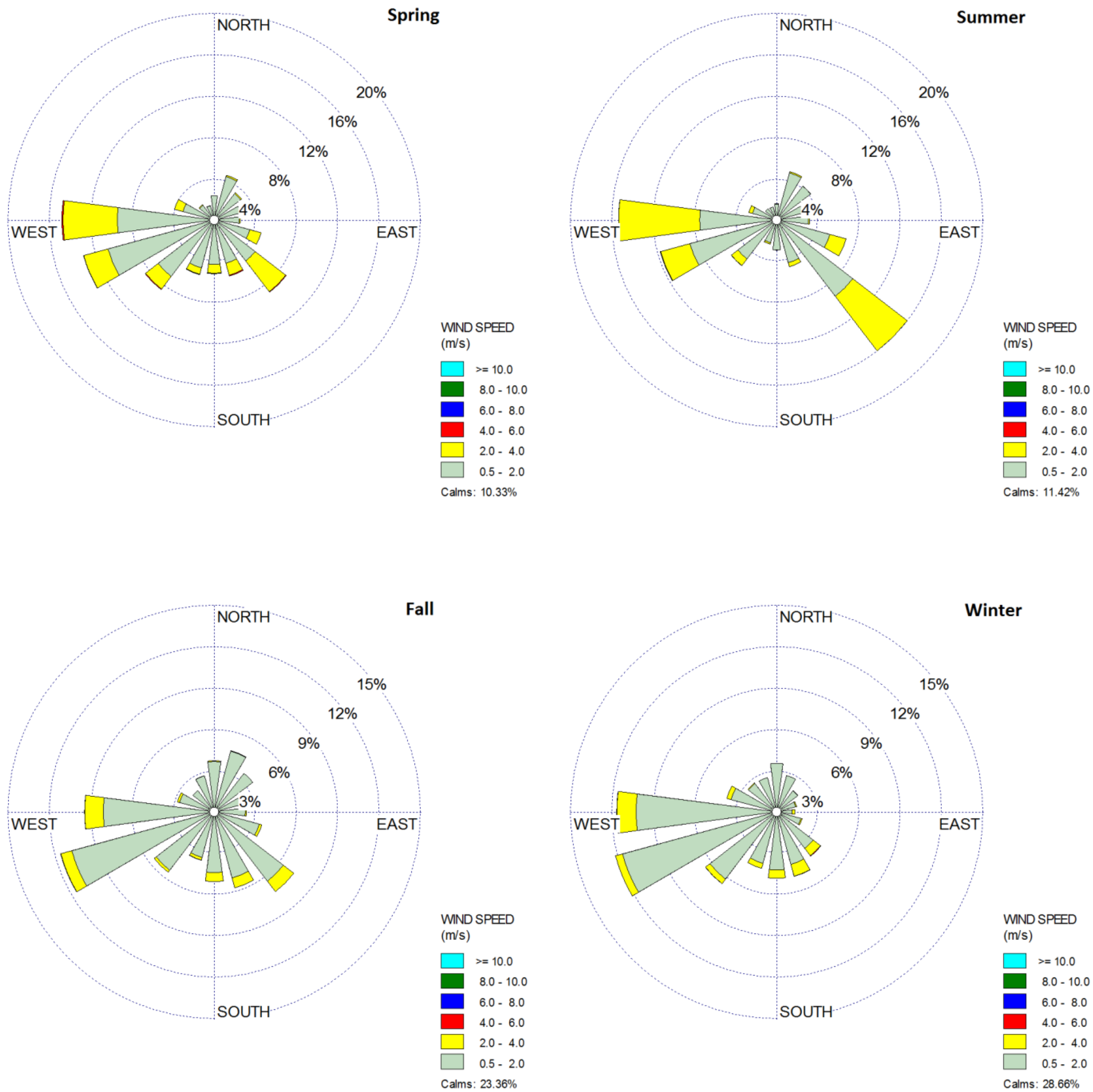


Figure 3-7 Seasonal Wind Roses for the Duncan Cairnsmore Station Based on 2010–2013 Hourly Data

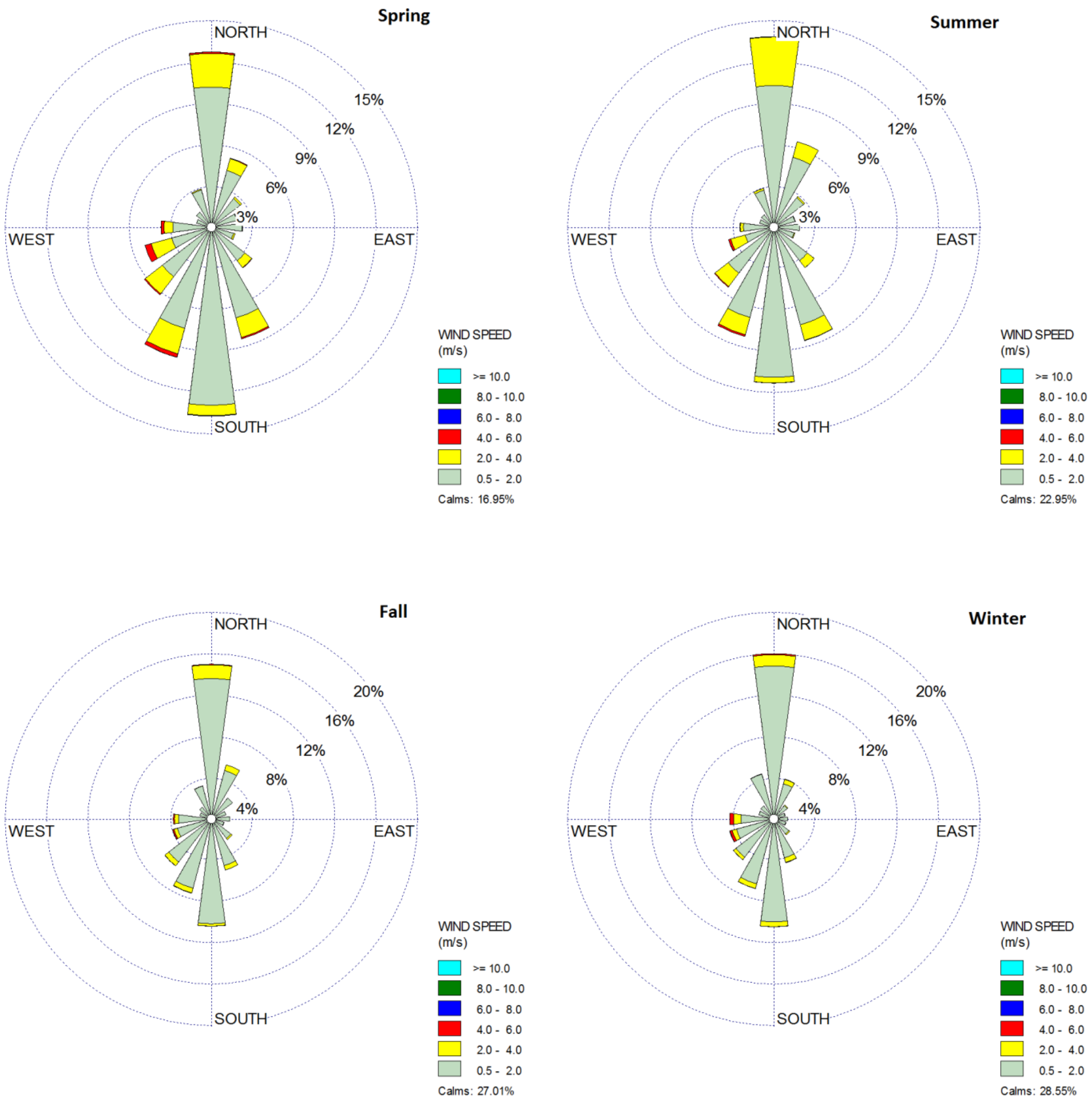


Figure 3-8 Seasonal Wind Roses for the North Cowichan Station Based on 2008–2013 Hourly Data

3.2 AIR QUALITY

The air quality data analysis results are organized by substance in the following sections. Results are expressed as average concentrations for the time period in question, e.g., 1-hour, 24-hour, and annual averages. For the gasses (SO_2, NO, NO_2, NO_X, and TRS), concentrations are given in parts per billion (ppb). Particulate concentrations (PM_{10} and $PM_{2.5}$) are given in micrograms per cubic metre (µg/m^3).

3.2.1 Ambient Air Quality Objectives

Ambient criteria for CACs include the BC Ambient Air Quality Objectives (BC AAQO), the National Ambient Air Quality Objectives (NAAQO), and the Canadian Ambient Air Quality Standards (CAAQS). To aid interpretation of the results, the most stringent of the BC AAQO, NAAQO, and CAAQS are compared to observed concentrations in the CVRD. Air quality objectives and standards are summarized in Table 3-3. The primary source for this information is the *Provincial Air Quality Objective Information Sheet* (BC MOE 2014b). At the provincial level, the most stringent objectives are the BC Level A AAQOs, where Level B and Level C represent higher concentrations. The national objectives also have three levels, which are labeled as maximum desirable, maximum acceptable, and maximum tolerable levels.

For SO_2 and NO_2, supplemental ambient air quality objectives have been used based on the guidance of the BC MOE (E. Plain, pers. comm., 2014). These objectives are shown in Table 3-4 and will also be referenced. Objectives for the 1-hour averaging period are from the United States Environmental Protection Agency (US EPA). The 1-hour objective for SO_2 references the 99th percentile of the daily 1-hour maxima and the NO_2 percentile references the 98th percentile of the daily 1-hour maxima. Objectives for 24-hour averaging period for SO_2 and annual average NO_2 concentrations are from the World Health Organization (WHO). The 24-hour and annual WHO objective for the averaging period for SO_2 and NO_2 consider the highest value within the applicable averaging period.

Table 3-3 Ambient Air Quality Objectives for Criteria Air Contaminants

Substance	Averaging Period	BC Objectives (BC AAQO)			Canada Objectives (NAAQO and CAAQS)		
		Level A	Level B	Level C	Maximum Desirable	Maximum Acceptable	Maximum Tolerable
ppb							
SO_2	1-hour	**170**	340	340	170	340	--
	3-hour	**140**	250	--	--	--	--
	24-hour	**60**	100	140	60	120	320
	Annual	**10**	20	30	12	24	--
NO_2	1-hour	--	--	--	--	**213**	532
	24-hour	--	--	--	--	**106**	160
	Annual	--	--	--	**32**	53	--
O_3	1-hour	--	--	--	--	82	--
	8-hour	--	--	--	**63**[a]	--	--
TRS	1-hour	**5**	20	--	--	--	--
	24-hour	**2**	4	--	--	--	--
µg/m³							
PM_{10}	24-hour	--	**50**	--	--	--	--
$PM_{2.5}$	24-hour	**25** [b]			28 [d]		
	Annual	**8** (6) [c]			10 [e]		

NOTES:

[a] Based on the 4th highest annual value of daily 8-hour maxima, averaged over three consecutive years.

[b] Based on the 98th percentile value for one year.

[c] The BC AAQO for $PM_{2.5}$ defines a planning goal of 6 µg/m³ (annual average) intended as a voluntary target to guide airshed planning efforts. The objective is 8 µg/m³ (BC MOE 2013b).

[d] The CAAQS for 24-hour $PM_{2.5}$ is referenced to the annual 98th percentile of daily 24-hour average concentrations, averaged over three years. This CAAQS is the standard effective in 2015 (Environment Canada 2013).

[e] The CAAQS for annual $PM_{2.5}$ is referenced to the 3-year mean of annual average concentrations. This CAAQS is the standard effective in 2015 (Environment Canada 2013).

-- No objective has been established for this category.

Values in bold identify the most stringent objectives applicable to the study area.

Table 3-4 Supplemental Ambient Air Quality Objectives for SO_2 and NO_2

Substance	Averaging Period	Supplemental Objectives	
		(ppb)	(µg/m³)
SO_2	1-hour [a]	75	200
	24-hour [b]	7.5	20
NO_2	1-hour [c]	100	188
	Annual [b]	21	40

NOTES:
All conversions between ppb and µg/m³ are referenced to standard sea level pressure and 25°C.
[a] The US EPA metric for SO_2 references the annual 99th percentile of daily 1-hour maxima, averaged over three consecutive years. This requires the extraction of the highest 1-hour value for each day followed by the calculation of the 99th percentile of those 365 values, and then averaging this value over three consecutive years (US EPA 2012).
[b] The WHO objectives consider the highest values for the applicable averaging period (WHO 2006).
[c] The US EPA metric for NO_2 references the annual 98th percentile of daily 1-hour maxima, averaged over three consecutive years. This requires the extraction of the highest 1-hour value for each day followed by the calculation of the 98th percentile of those 365 values, and then averaging this value over three consecutive years (US EPA 2012).

3.2.2 Sulphur Dioxide

Ambient concentration data for SO_2 were available from the Crofton Substation and Crofton Escarpment Way monitoring stations. Measurement of SO_2 at Crofton Substation began in February 2005 and continued through 2013. At Crofton Escarpment Way, measurements began in October 2008 and continued through 2013.

Sulphur dioxide is measured using a method based on ultraviolet (UV) fluorescence. As an air sample passes through the instrument chamber, it is exposed to UV radiation. Light emitted due to the fluorescent properties of SO_2 is measured and converted into a concentration (Jacques Whitford 2004). At Crofton Substation, the SO_2 instrument was a Teledyne API 100E analyzer, and at Crofton Escarpment Way, a Thermo Scientific 43i analyzer was used.

Annual average SO_2 concentrations were low at both stations, ranging from 0.6 ppb to 1.6 ppb at Crofton Substation, and from 0.5 ppb to 1.4 ppb at Crofton Escarpment Way. The BC Level A objective for annual average SO_2 concentrations is 10 ppb. Time series graphs of all hourly data are included in Appendix B.

Results for the 1-hour averaging period are shown in Figure 3-9 and Figure 3-10 for the Crofton Substation and Escarpment Way stations, respectively. These "box and whisker" plots summarize results by month for all years of available data. The text on the figure indicates the maximum, minimum, mean, median, 95th percentile, and 98th percentile values for the dataset. The monthly interquartile range (25th to 75th percentile) is illustrated by each box's bottom and top.

The median is represented by a line through the centre of the box. The vertical lines (whiskers) indicate the maximum and minimum 1-hour average concentrations during that month; in this case, the minimum concentrations were zero for each month.

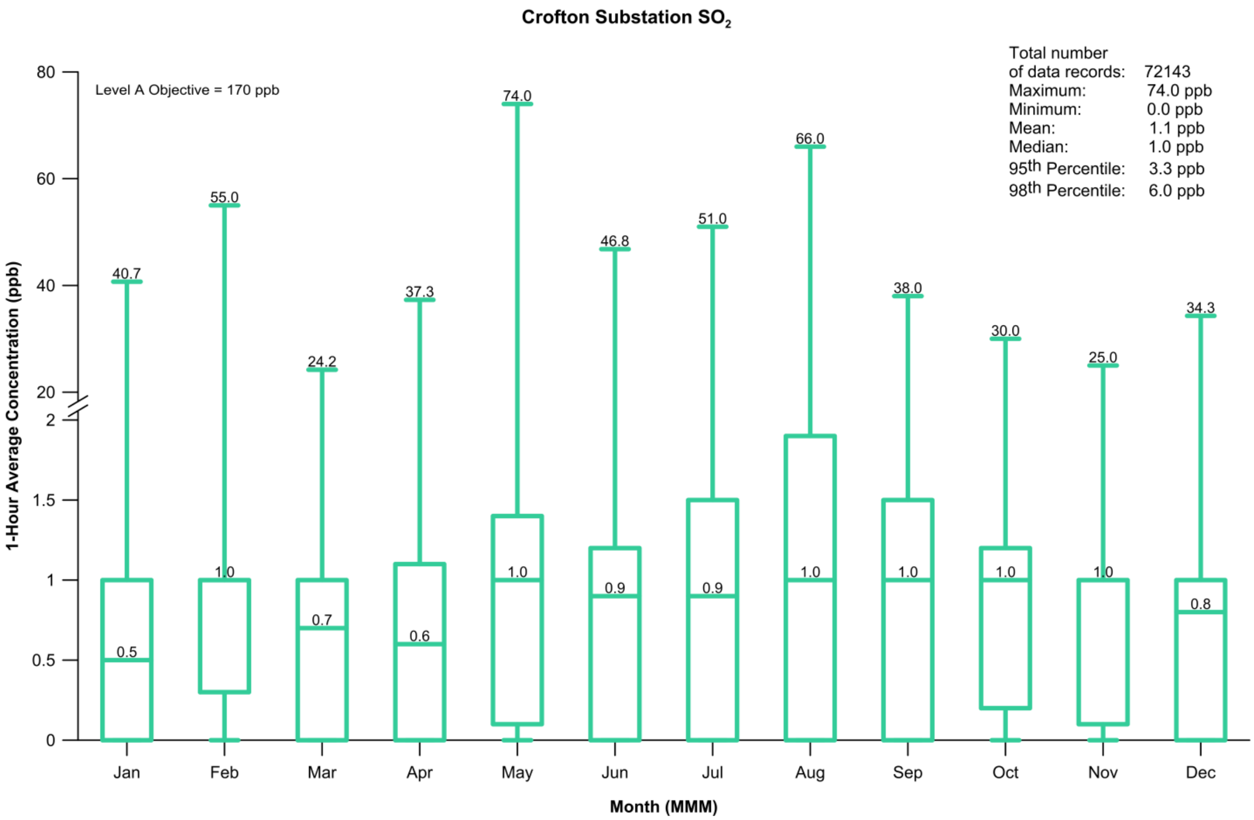


Figure 3-9 Monthly Variation of 1-Hour Average SO_2 Concentration at Crofton Substation Based on 2005–2013 Data

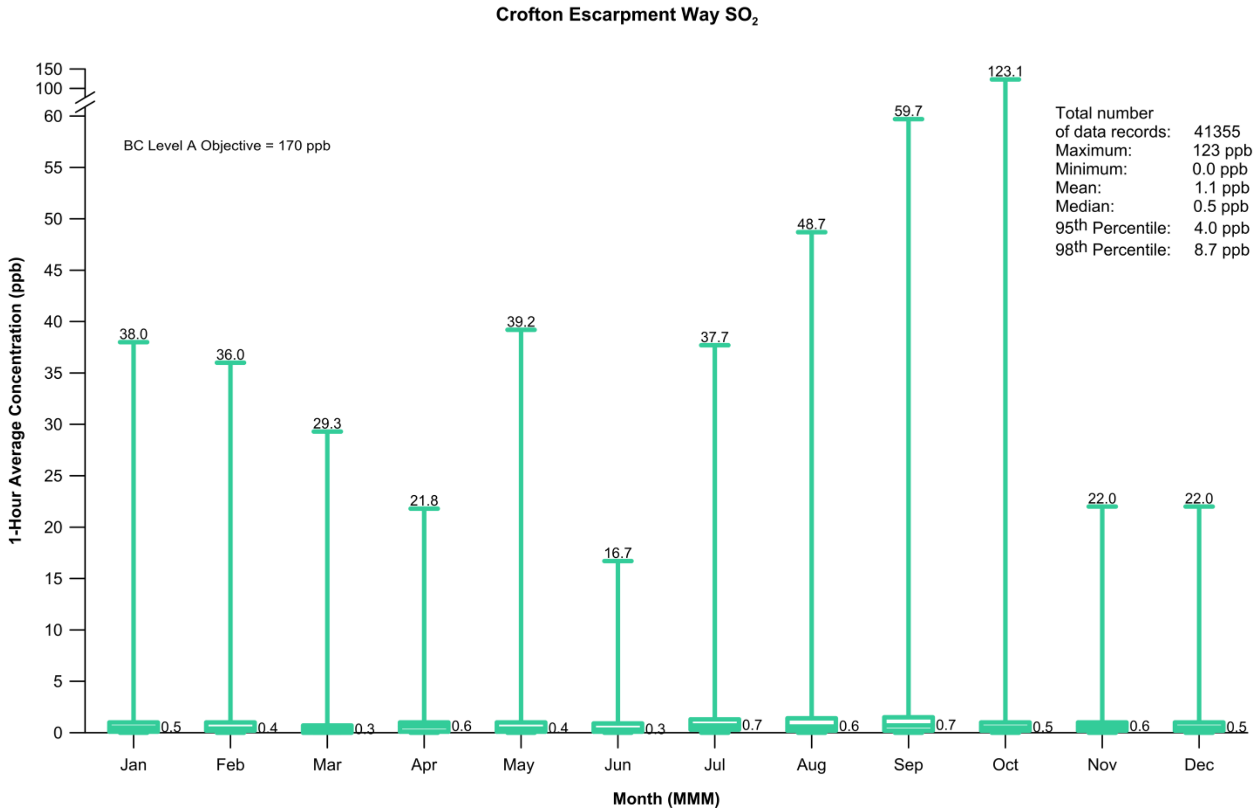


Figure 3-10 Monthly Variation of 1-Hour Average SO_2 Concentration at Crofton Escarpment Way Based on 2008–2013 Data

Figure 3-9 indicates that none of the 1-hour average SO_2 concentrations at Crofton Substation exceeded the BC Level A objective of 170 ppb. There was a slight tendency for relatively higher concentrations to occur more in late spring and summer than during other months of the year; however, there was not a well-defined seasonal pattern in the median values.

At the Escarpment Way station, monthly median values were lower than at Crofton Substation, but the overall mean was the same at 1.1 ppb. The upper percentiles and monthly maxima indicate that episodes of relatively hourly high SO_2 values were more common at the Escarpment Way station, but none of the observations exceeded the BC Level A objective. The highest values at Escarpment Way occurred in the months of September and October.

For the 24-hour averaging period, Figure 3-11 and Figure 3-12 show that concentrations were low at both stations, with the maximum values remaining well below the BC Level A objective of 60 ppb. Again, there was at most a weak seasonal pattern, with the highest median values occurring in July through September.

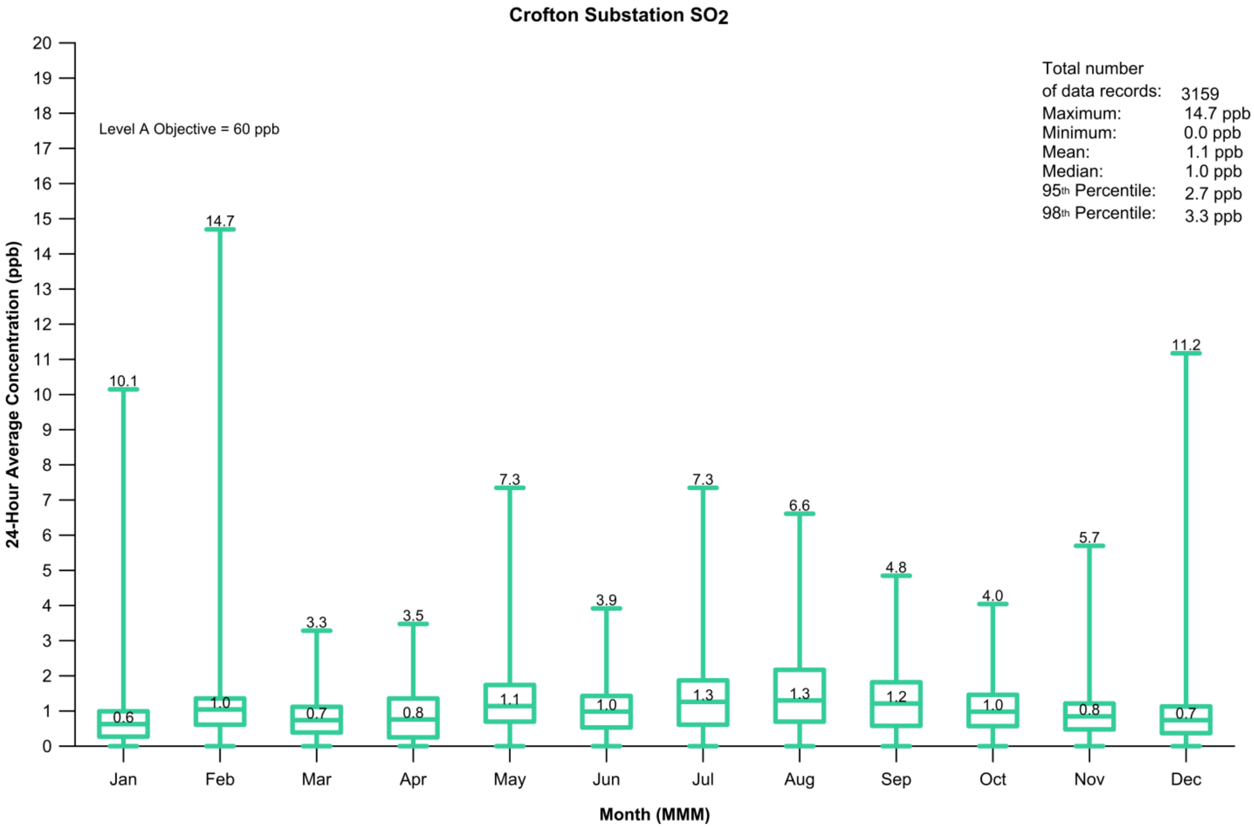


Figure 3-11 Monthly Variation of 24-Hour Average SO_2 Concentration at Crofton Substation Based on 2005–2013 Data

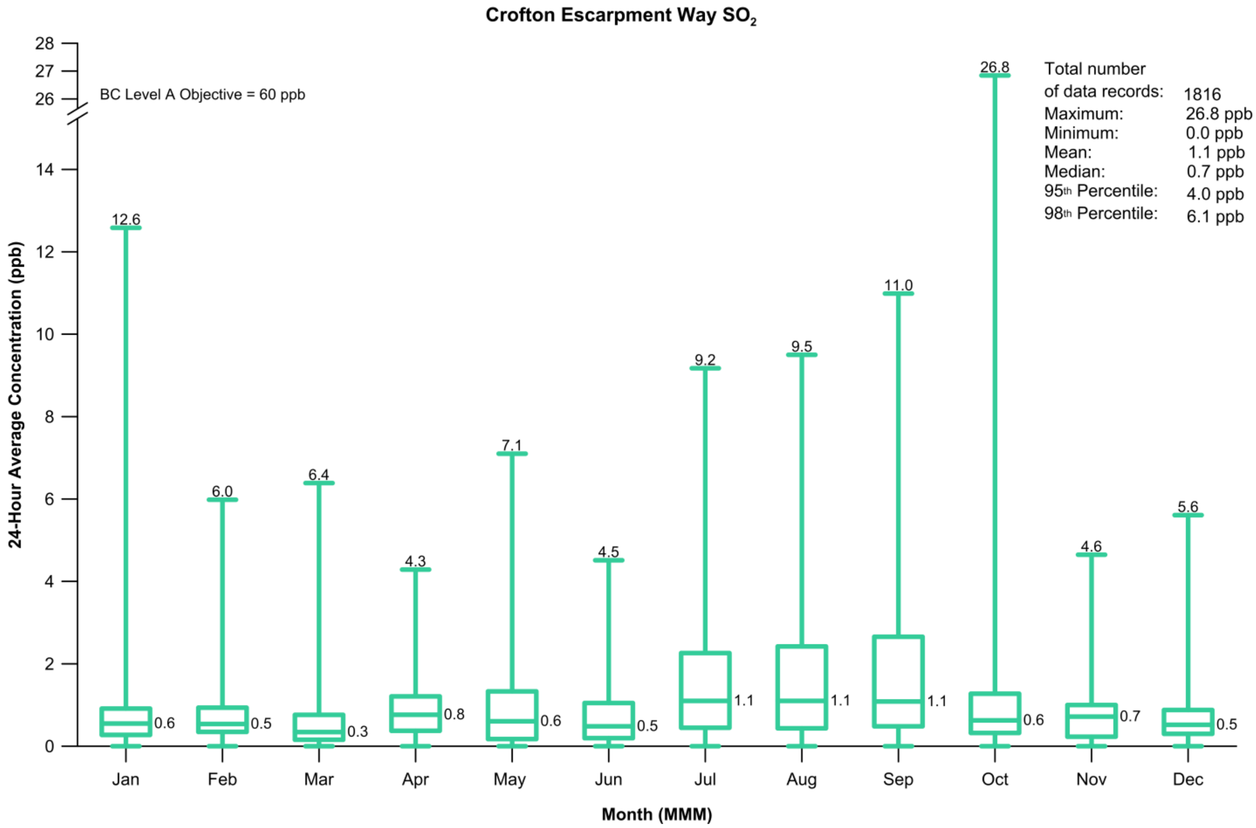


Figure 3-12 Monthly Variation of 24-Hour Average SO_2 Concentration at Crofton Escarpment Way Based on 2008–2013 Data

Tabular data showing annual means, hourly and daily percentiles, and frequencies of AAQO exceedance for SO_2 at Crofton Substation and Crofton Escarpment Way are included in Appendix B. There were no exceedances of the most stringent BC AAQO for the 1-hour, 24-hour, or annual averaging periods.

The US EPA metric for the 1-hour averaging period is based on the 99th percentile of daily maximum values averaged over three consecutive years (see Table 3-4). This metric was computed for the Crofton Substation and Crofton Escarpment Way monitoring stations for the available years. Results are presented graphically in Figure 3-13, which shows that values remained below the US EPA objective at both stations.

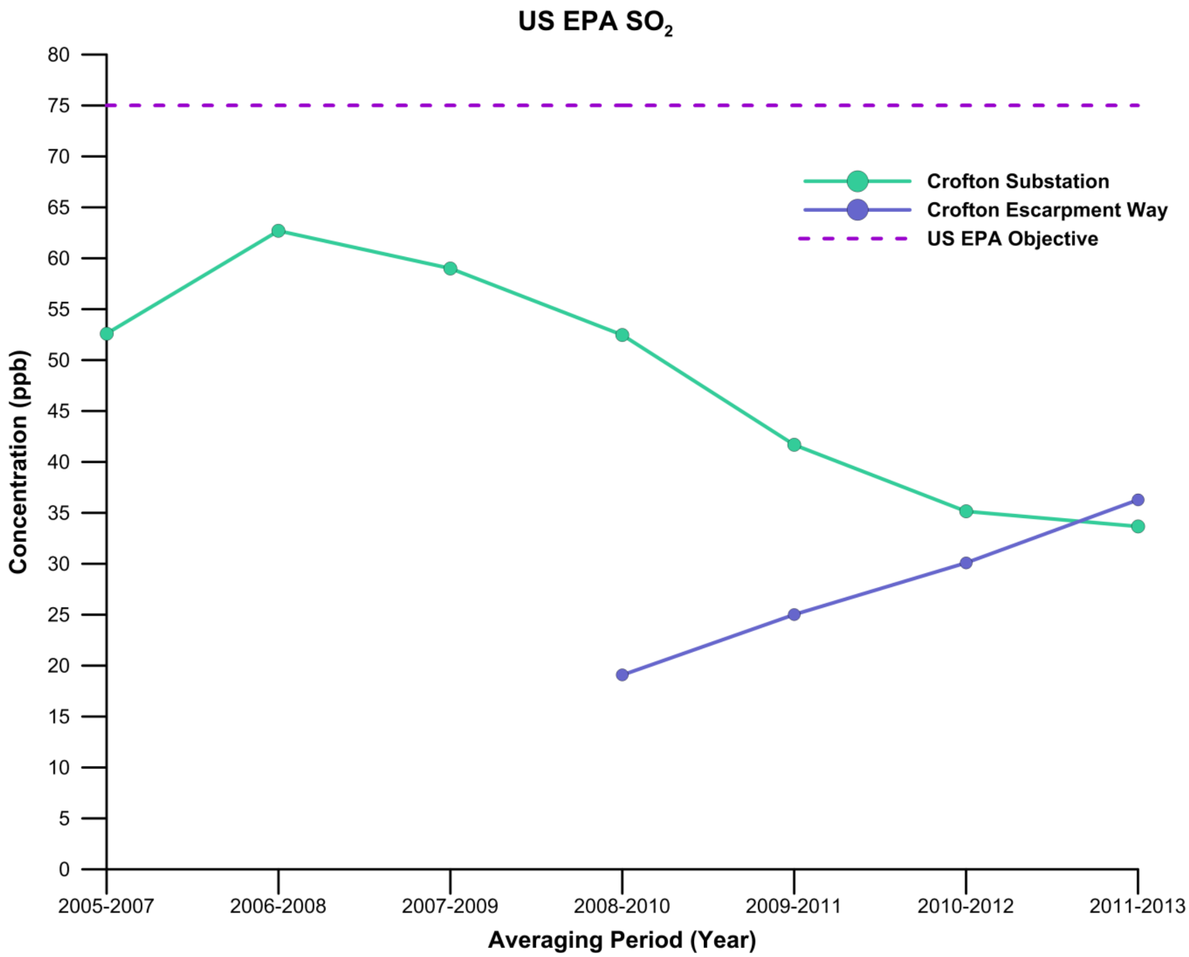


Figure 3-13 1-Hour Average SO_2 Results for the US EPA Supplemental Objective at the Crofton Substation and Crofton Escarpment Way Monitoring Stations

The WHO objective for 24-hour average SO_2 is 7.5 ppb (20 µg/m^3), which is much lower than the BC Level A objective of 60 ppb. Table 3-5 shows that, even for this stringent objective, exceedances were rare at the two Crofton monitoring stations. At Crofton Substation, there were only five days in a nine-year period when the 24-hour average SO_2 concentration exceeded the WHO objective. The Escarpment Way monitoring station had more exceedances of the 7.5 ppb objective, totalling 20 days over six years, nine of which were recorded in 2013. This tendency for the Escarpment Way station to record more episodes of relatively high SO_2 concentrations was also evident in the 1-hour data (Figure 3-10). This station is higher in elevation than the others and likely observes effects of the Crofton Mill plume.

Table 3-5 Frequency of Exceedance of the WHO 24-Hour Average SO_2 Objective

Station	Year	Number of Days > 7.5 ppb	Percent of Days > 7.5 ppb
Crofton Substation	2005	0	0
	2006	2	0.6
	2007	0	0
	2008	1	0.3
	2009	0	0
	2010	0	0
	2011	1	0.3
	2012	0	0
	2013	1	0.3
	2005–2013	5	0.2
Crofton Escarpment Way	2008	0	0
	2009	2	0.6
	2010	3	1.0
	2011	3	0.9
	2012	3	0.9
	2013	9	2.5
	2008–2013	20	1.1

3.2.2.1 Diurnal Patterns

For each station, all available SO_2 observations were grouped by time of day and then a mean value was calculated for each hour of the day, 0:00 to 23:00 local standard time (LST). The resulting diurnal trends are shown graphically in Figure 3-14 for both Crofton Substation and Crofton Escarpment Way.

The SO_2 data show a clear diurnal trend of concentration increases in the morning starting at about 6:00, with a daily maximum at 11:00, followed by gradually decreasing concentrations through the afternoon and evening hours.

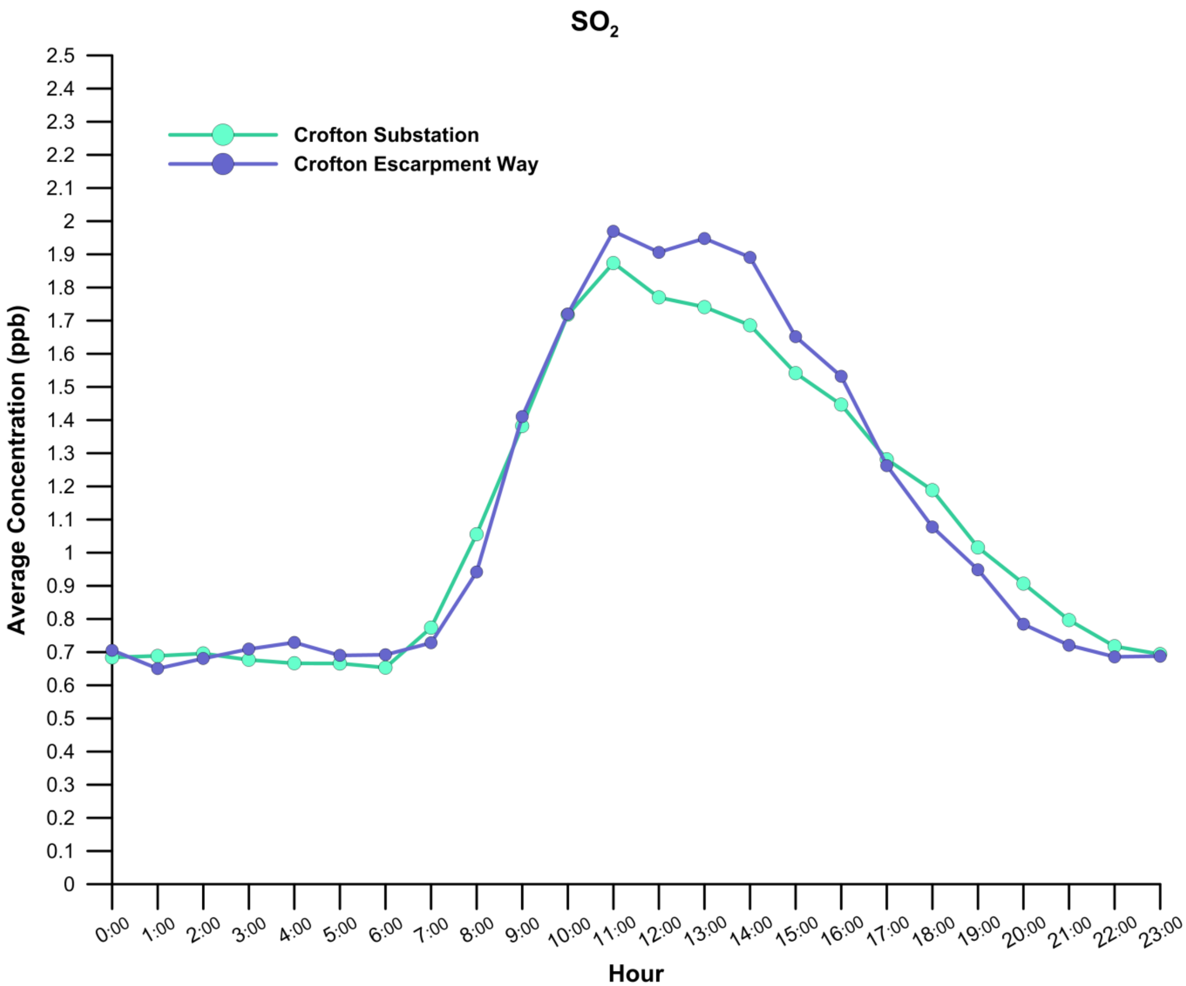


Figure 3-14 Diurnal Trends in SO_2 Concentration Based on all Available Hourly Data

Most of the CVRD emissions of SO_2 come from the Crofton Mill (Levelton 2014). Therefore, it is reasonable to assume that the diurnal pattern in SO_2 concentration is attributable to how emissions from the Pulp Mill's stacks interact with local atmospheric conditions. The rapid increase in concentration in the morning hours is likely due to fumigation. Fumigation events occur when a surface-based temperature inversion breaks up and a shallow mixed layer develops near the surface. In this situation, an elevated temperature inversion will persist at the top of the mixed layer; if this elevated inversion is just above the stack heights, then emissions from the stacks will not be able to disperse upward, and portions of the plume will be mixed downward toward the ground. The same effect can occur when a plume is carried inland by a sea breeze into more unstable air near the surface, resulting in what is known as shoreline fumigation. Fumigation events are most common in the morning and last on the order of 30 minutes (Oke 1987). The graph in Figure 3-14 implies a more gradual increase in concentrations through the morning hours because the values are averages from many days. The late morning timing of the peak suggests that shoreline fumigation after onset of a sea breeze is the most common cause of the diurnal pattern in ground-level SO_2 concentrations.

To further investigate diurnal SO_2 cycles, the hourly data were separated by season. The resulting plot for Crofton Substation is shown in Figure 3-15. The late morning peak in SO_2 concentration was most pronounced during the summer season, which is when sea breezes are most common. The other seasons had lower-amplitude cycles, with the diurnal peak shifting forward by a couple of hours from summer to winter.

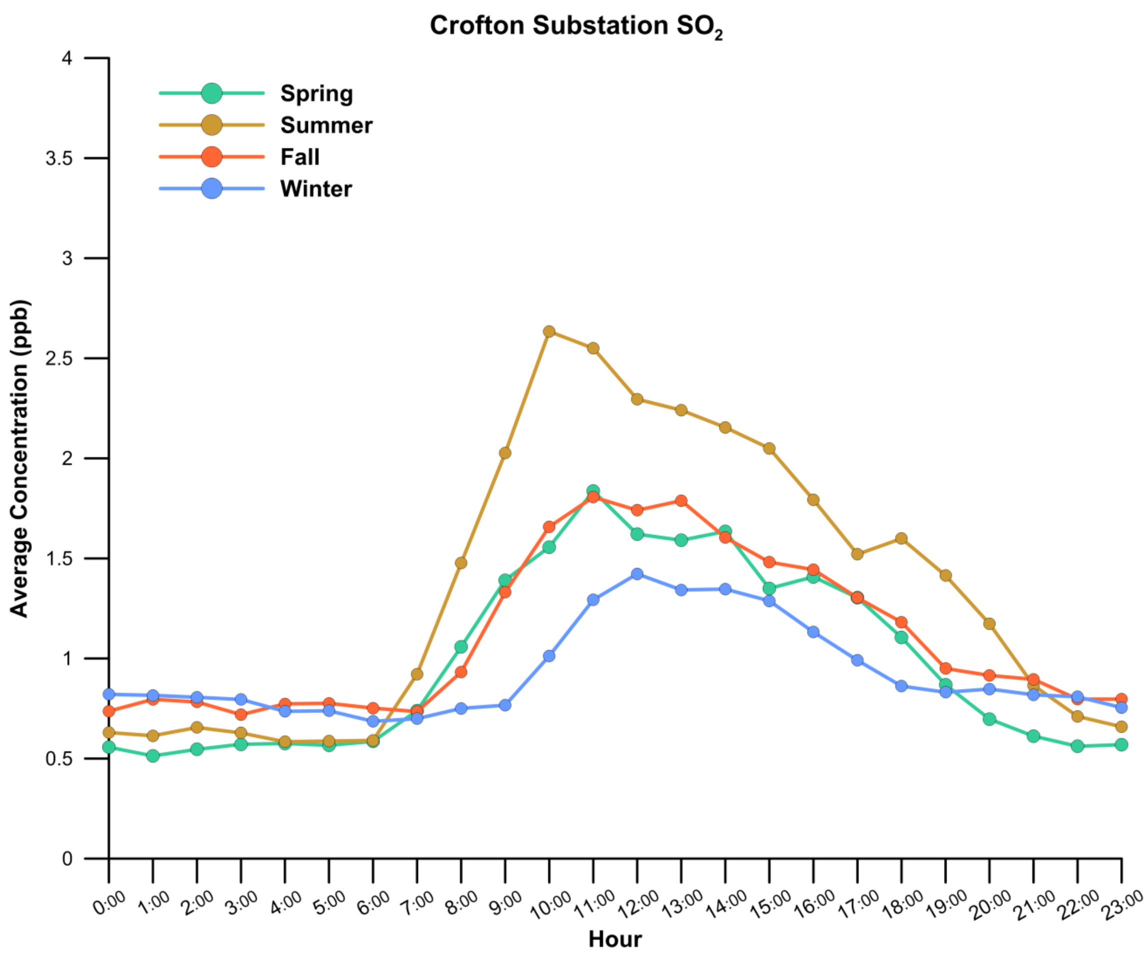


Figure 3-15 Diurnal Trends in SO_2 Concentration at Crofton Substation by Season

3.2.2.2 Hebdomadal Patterns

Variations in CAC concentrations based on day of week are usually caused by patterns of human activity that lead to variations in emission rates. For example, weekday average concentrations may be higher than weekend values if some of the industrial sources are not operational on weekends.

For analysis of hebdomadal trends, the SO_2 data were separated by day of week and then averages were calculated. Figure 3-16 shows average weekday (Monday to Friday) and weekend (Saturday and Sunday) concentrations by month for Crofton Substation. The differences were small and inconsistent, which suggests a lack of hebdomadal pattern for SO_2. Results were similar for the Escarpment Way station. This lack of hebdomadal pattern is confirmed by Figure 3-17, which shows that mean SO_2 concentrations were essentially the same for each day of the week. This reflects the fact that the Crofton Mill operations and resulting emissions are fairly consistent throughout the week whereas emissions from traffic are strongly hebdomadal.

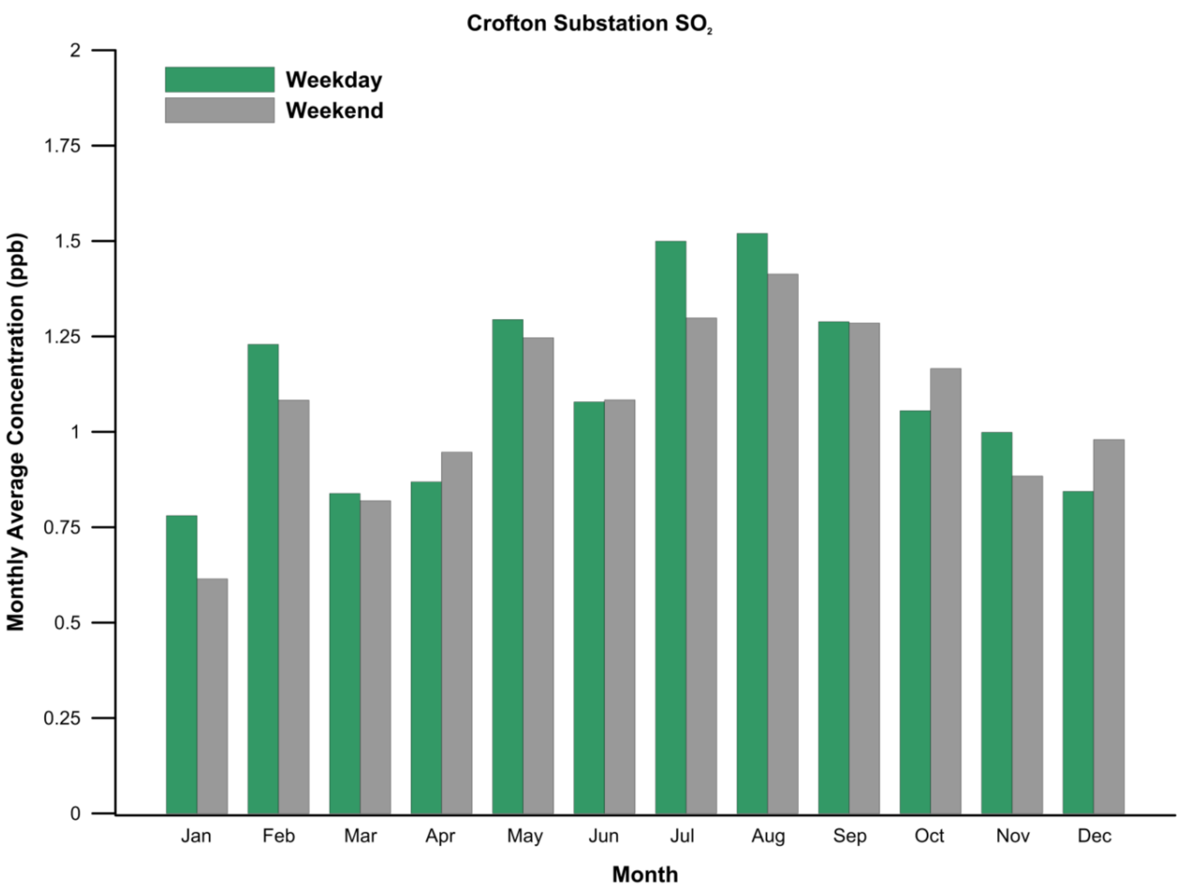


Figure 3-16 Monthly Average SO_2 Concentration for Weekdays and Weekends at Crofton Substation Based on 2005–2013 Data

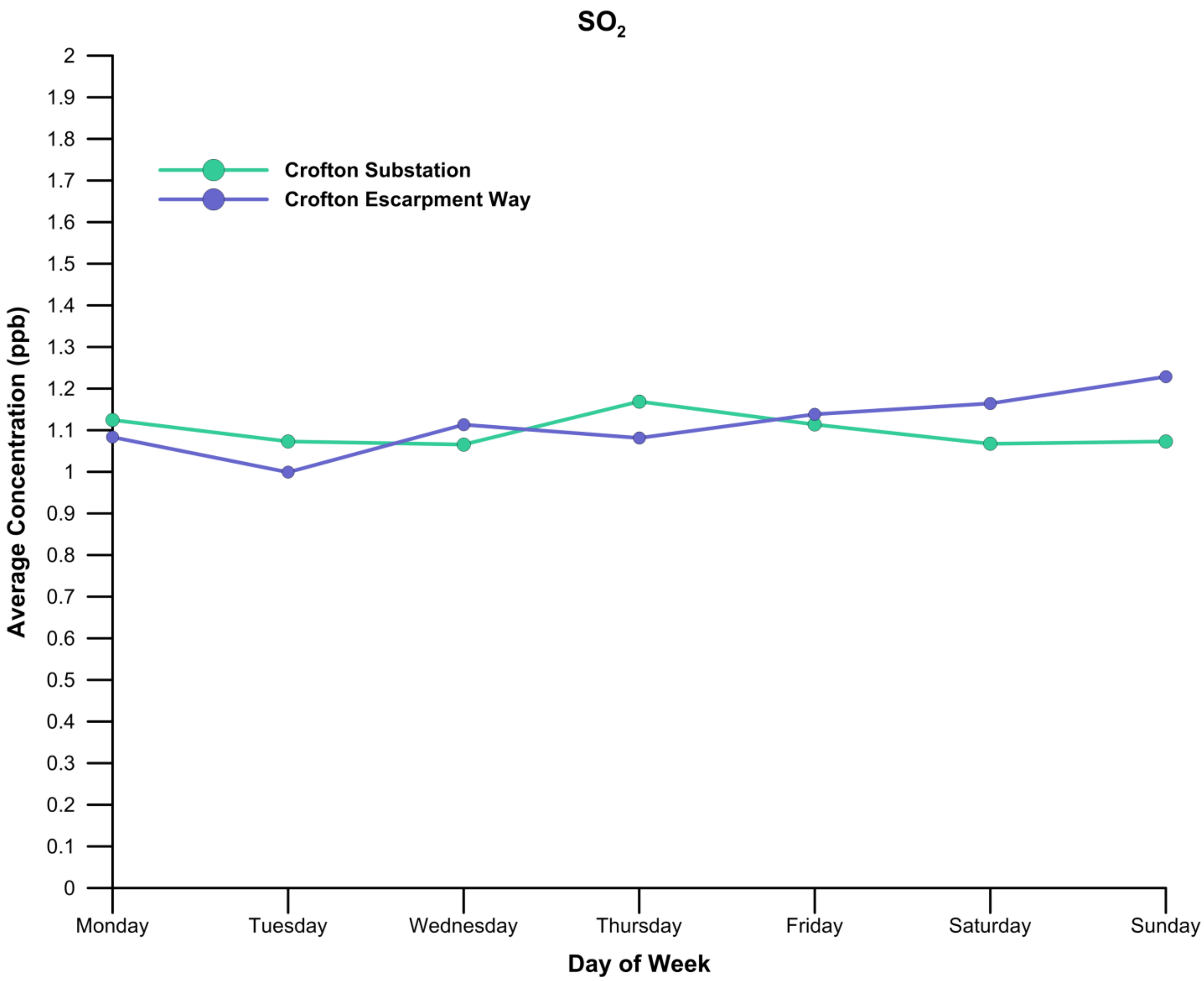


Figure 3-17 Average SO_2 Concentration by Day of Week at Crofton Substation and Crofton Escarpment Way

3.2.2.3 Pollution Roses

Pollution roses combine substance concentration information with wind direction frequency analysis. The resulting graphic is similar to a wind rose, but rather than showing wind speed classes, the various compass point wind directions are correlated with concentration ranges. Pollution roses were created for Crofton Substation air quality data using Crofton Met wind data. The result for SO_2 is shown in Figure 3-18, which indicates that enhanced SO_2 concentrations were associated mostly with winds from the north through east. This pattern is consistent with the Crofton Mill, located 250 m at 74 degrees away, being the main source of SO_2 in the area.

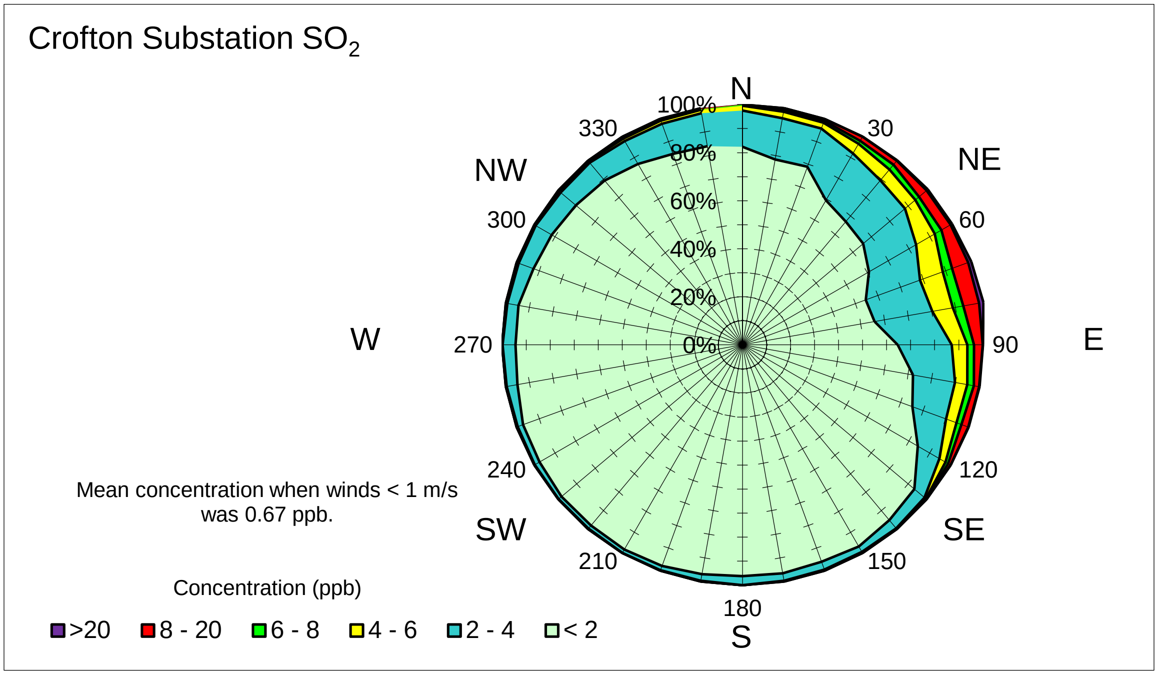


Figure 3-18 Pollution Rose for SO_2 at Crofton Substation Based on 2008–2013 Data

3.2.3 Nitrogen Dioxide

Ambient concentration data for NO and NO_2 were available from the Crofton Substation, Crofton Escarpment Way and Duncan Cairnsmore monitoring stations. At Duncan Cairnsmore, NO_X was also measured. This section focusses on NO_2 results because that is the substance for which objectives have been established. Tabular results for NO and NO_X are included in Appendix B. Measurement of NO_2 at Crofton Substation began in February 2005 and continued through 2013. At Crofton Escarpment Way, measurements began in October 2008 and continued through 2013. At Duncan Cairnsmore, NO_2 measurements began in July 2009 and continued through 2013.

Nitrogen dioxide is measured using a method based on chemiluminescence, which is the emission of light as a result of a chemical reaction. The instrument used to measure NO_2 at Crofton Substation, Crofton Escarpment Way, and Duncan Cairnsmore, was a Teledyne API 200E photolytic analyzer.

Annual average NO_2 concentrations at Crofton Substation ranged from 3.4 ppb in 2008 to 4.6 ppb in 2006 and 2007. At Crofton Escarpment Way, the annual average concentrations ranged from 2.8 ppb in 2009 to 3.8 ppb in 2010. At Duncan Cairnsmore, the annual average concentrations ranged from 4.7 ppb in 2013 to 5.7 ppb in 2010. These values are all well below the most stringent NAAQO for annual average NO_2 of 32 ppb. Only Duncan Cairnsmore showed an inter-annual trend. Figure 3-19 shows that annual mean NO_2 concentrations at Duncan Cairnsmore decreased gradually through the four-year period of 2010 to 2013. This trend may be due to increased efficiency of motor vehicle engines, resulting in less NO_X emissions per vehicle. Time series graphs of all hourly data are included in Appendix B.

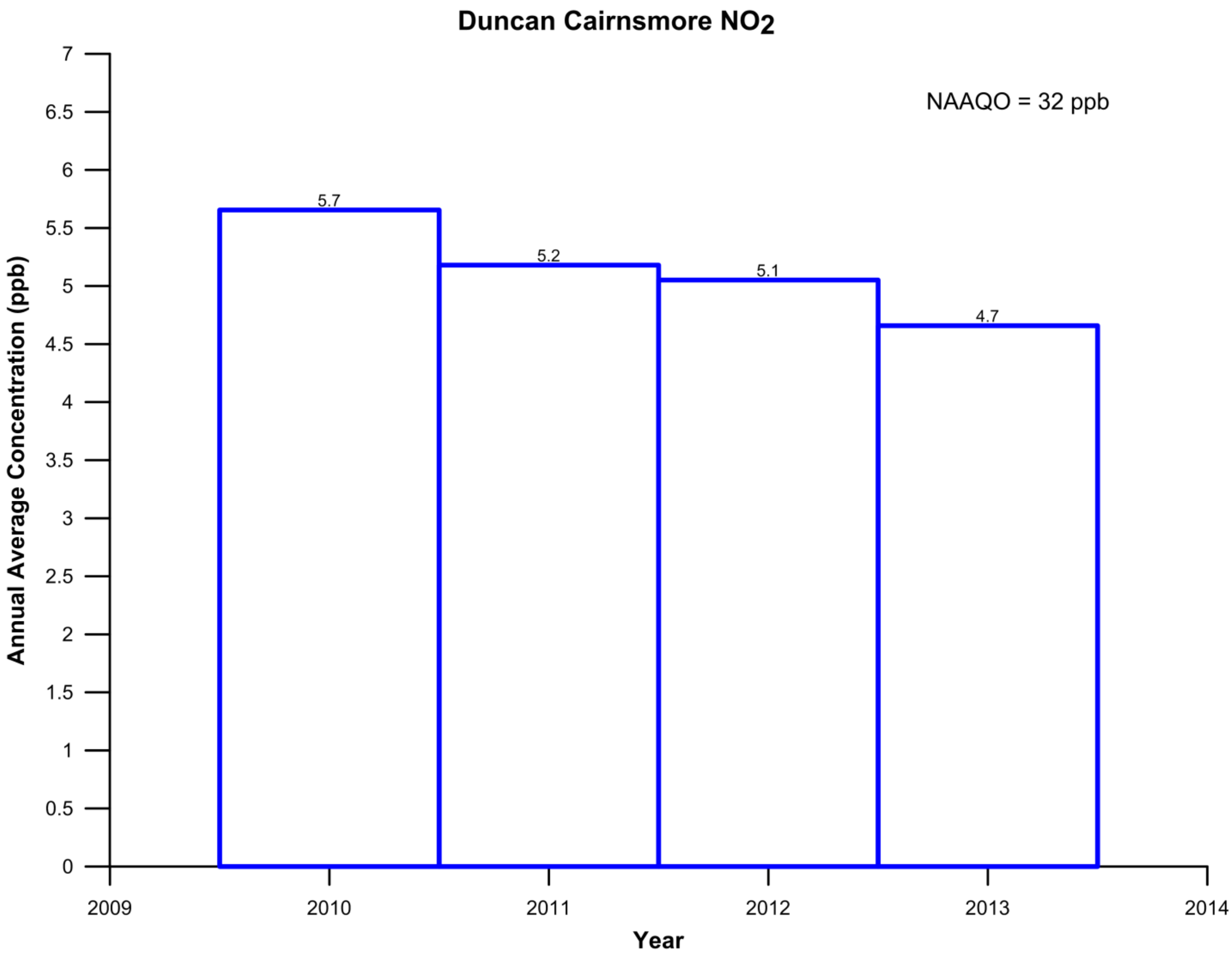


Figure 3-19 Annual Average NO_2 Concentrations at Duncan Cairnsmore for 2010–2013

Results for the 1-hour averaging period are shown in Figure 3-20, Figure 3-21, and Figure 3-22 for the Crofton Substation, Crofton Escarpment Way, and Duncan Cairnsmore stations, respectively. These box and whisker plots summarize results by month for all years of available data. Monthly median concentrations were below 5 ppb for all months at the Crofton Substation and Escarpment Way stations, while concentrations were modestly higher at Duncan Cairnsmore. Maximum hourly values remained well below the most stringent NAAQO of 213 ppb at all stations. The Duncan Cairnsmore station is within the more densely populated part of the CVRD, which likely accounts for the higher concentrations compared to the Crofton stations. Common sources of NO_X emissions, such as motor vehicles and space heating, are concentrated in the urban and suburban areas.

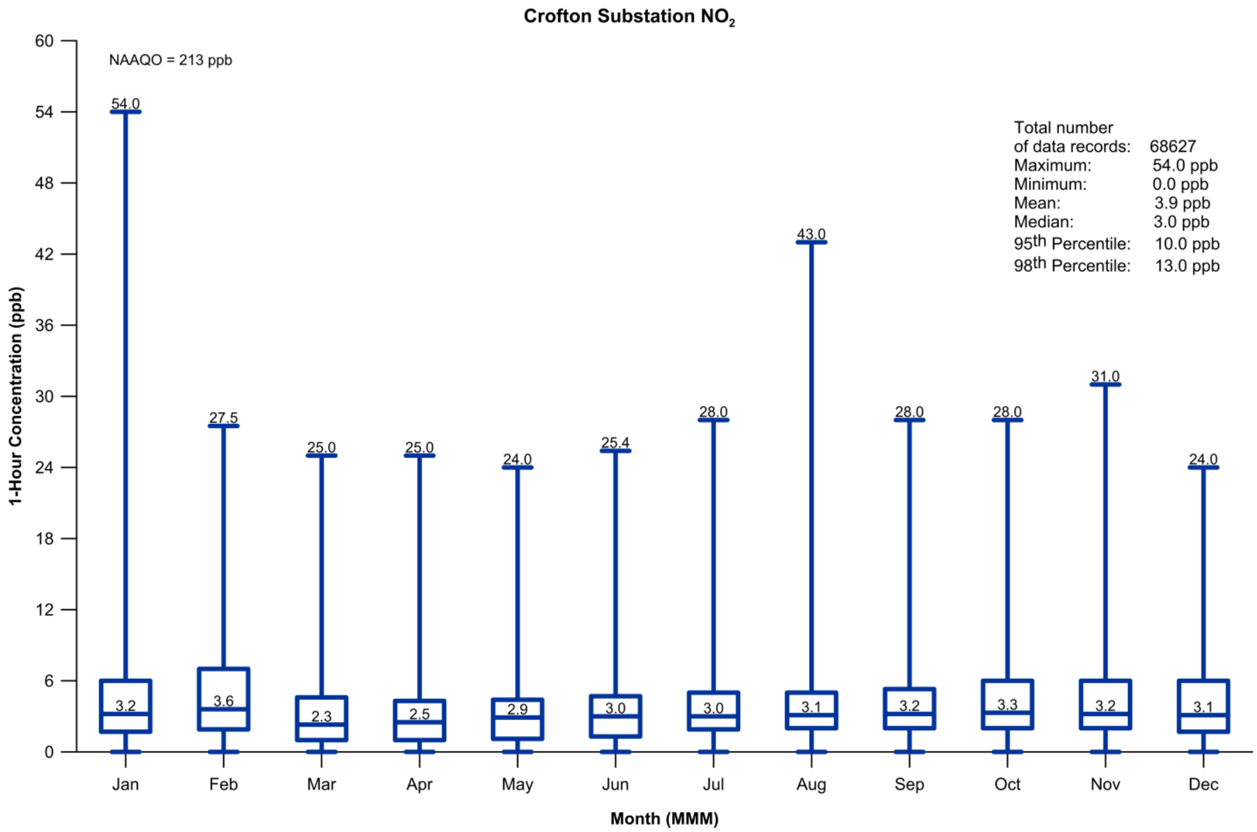


Figure 3-20 Monthly Variation of 1-Hour Average NO_2 Concentration at Crofton Substation Based on 2005–2013 Data

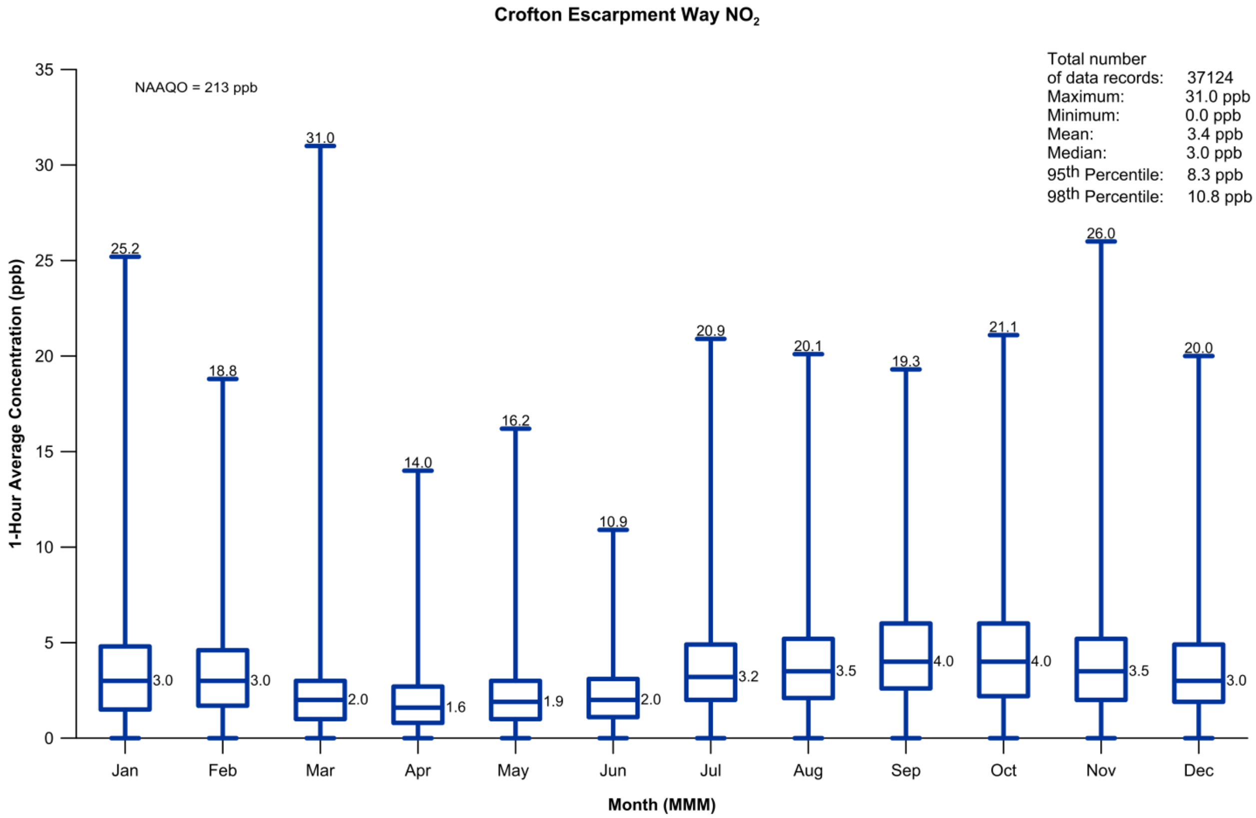


Figure 3-21 Monthly Variation of 1-Hour Average NO_2 Concentration at Crofton Escarpment Way Based on 2008–2013 Data

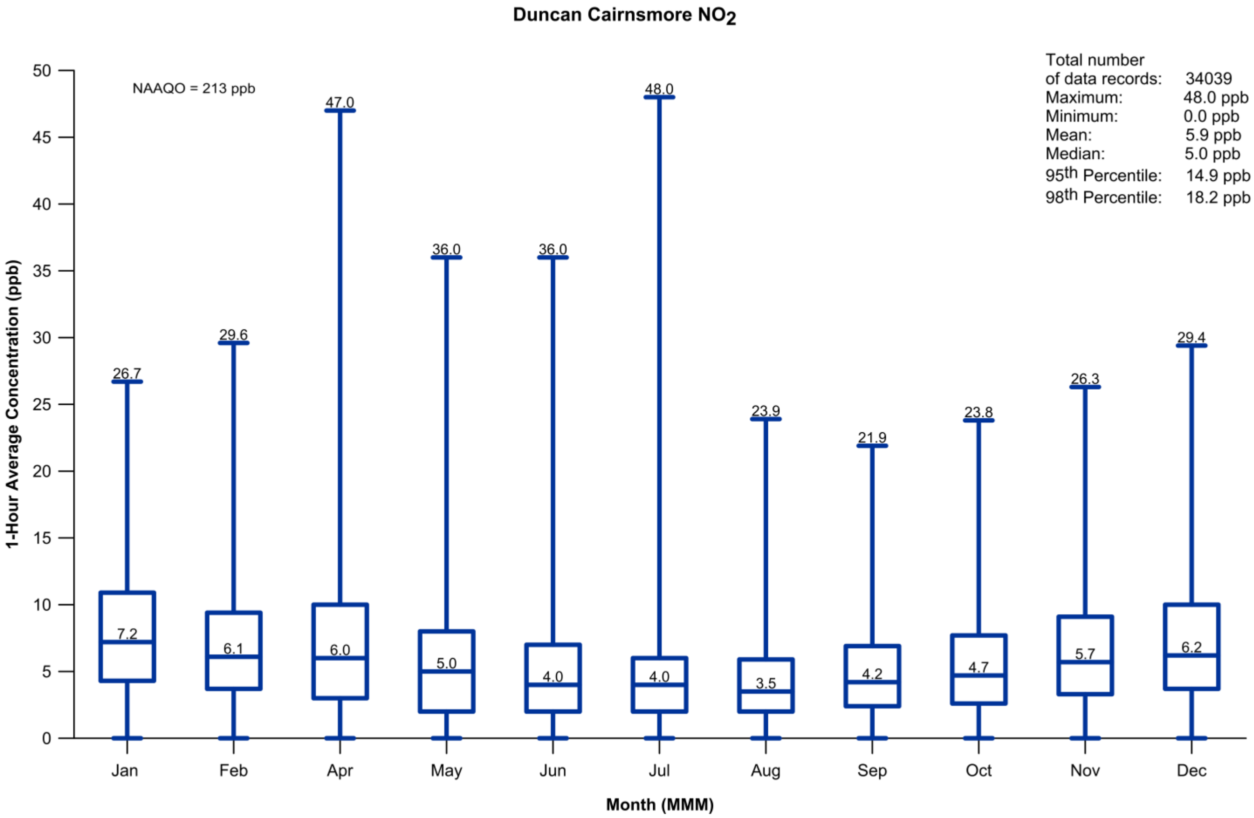


Figure 3-22 Monthly Variation of 1-Hour Average NO_2 Concentration at Duncan Cairnsmore Based on 2009–2013 Data

Box and whisker plots for the 24-hour average NO_2 data are shown in Figure 3-23, Figure 3-24, and Figure 3-25 for the Crofton Substation, Crofton Escarpment Way, and Duncan Cairnsmore stations, respectively. None of the maximum values approached the most stringent NAAQO of 106 ppb. Although Duncan Cairnsmore had higher mean and median values than the Crofton stations, maximum values were similar at all three stations.

The 1-hour and 24-hour plots for the two Crofton stations show a slight seasonal trend, with the lowest NO_2 concentrations occurring in the spring. A better-defined seasonal cycle is apparent in the Duncan Cairnsmore dataset, with a summer minimum and winter maximum in monthly median concentrations. This trend is also apparent in the Duncan Cairnsmore NO_2 and NO_X time series in Appendix B. The wintertime maximum for NO_2 in Duncan may be due to seasonal changes in emissions as well as different meteorological conditions. Vehicle emissions are likely higher in winter due to increased idling during cold weather. Emissions from space heating also peak in winter. Additionally, nocturnal temperature inversions, which tend to trap substances near the surface in the valley, persist later into the morning during the darker winter months.

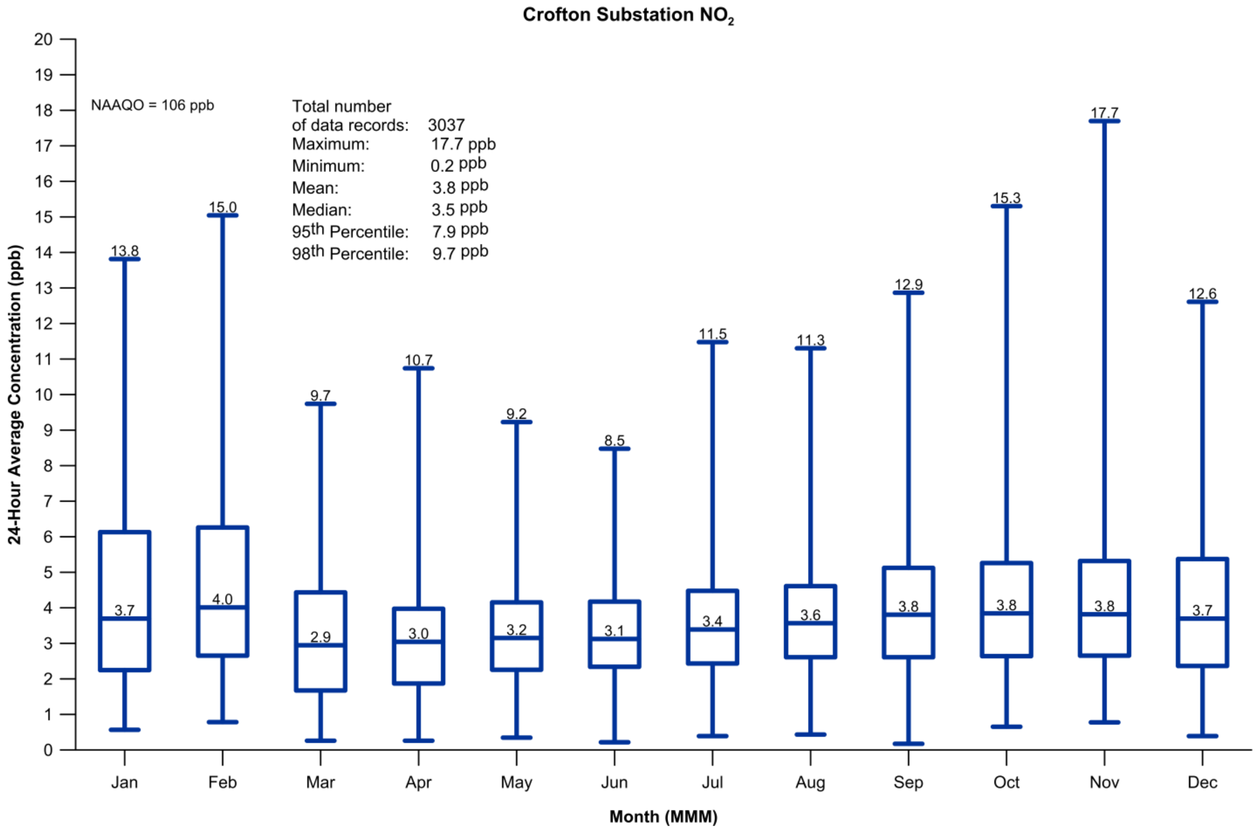


Figure 3-23 Monthly Variation of 24-Hour Average NO_2 Concentration at Crofton Substation Based on 2005–2013 Data

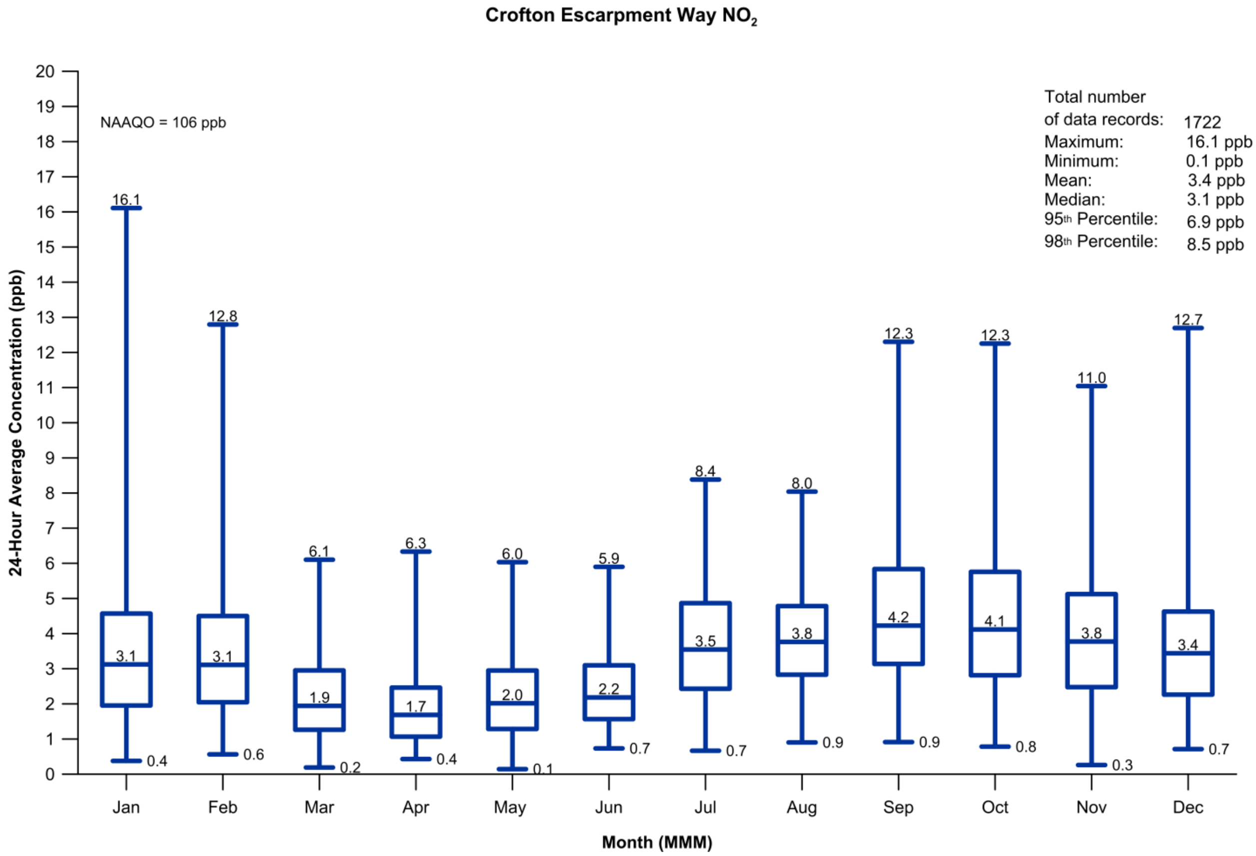


Figure 3-24 Monthly Variation of 24-Hour Average NO_2 Concentration at Crofton Escarpment Way Based on 2008–2013 Data

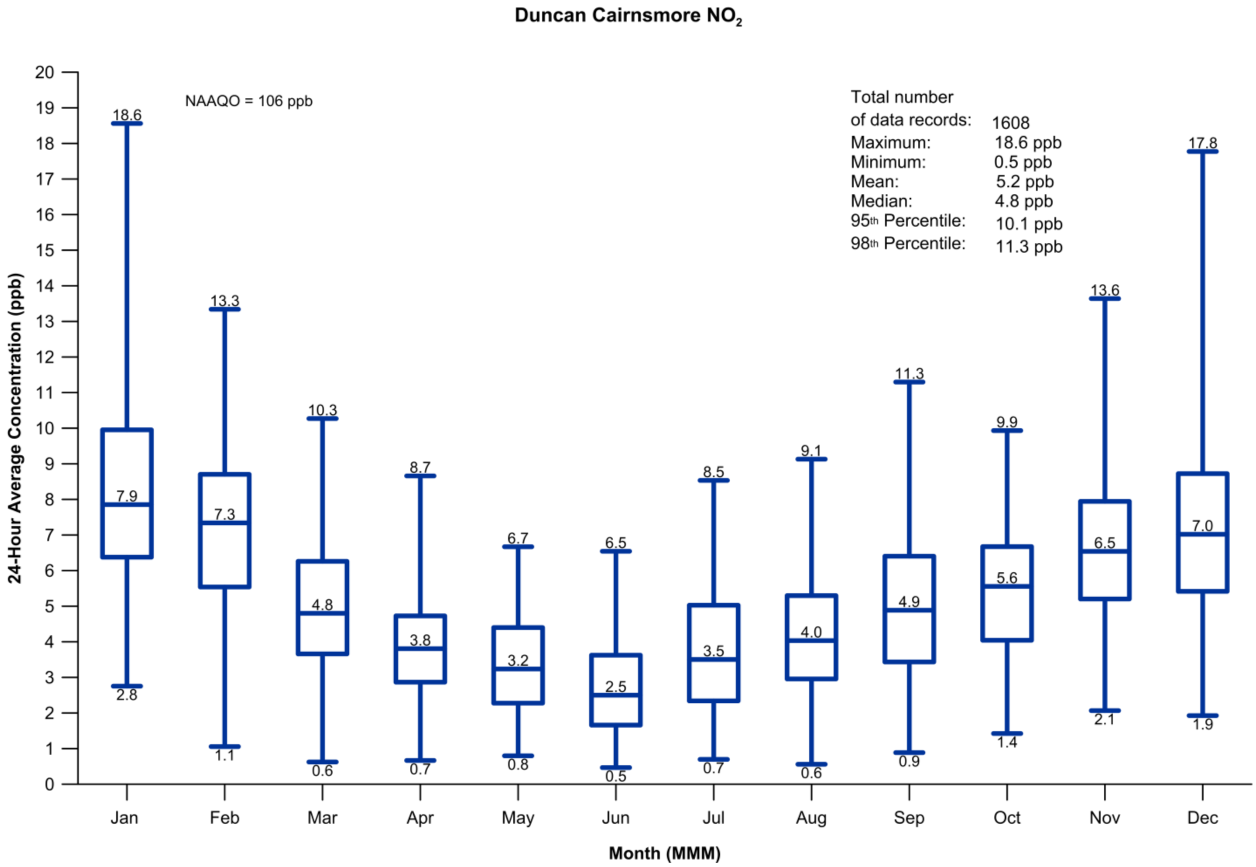


Figure 3-25 Monthly Variation of 24-Hour Average NO_2 Concentration at Duncan Cairnsmore Based on 2009–2013 Data

Tabular data showing annual means, hourly and daily percentiles, and frequencies of AAQO exceedance for NO_2 at Crofton Substation, Crofton Escarpment Way, and Duncan Cairnsmore are included in Appendix B. There were no exceedances of the most stringent NAAQO for the 1-hour, 24-hour, or annual averaging periods. There were also no exceedances of the WHO annual average NO_2 objective of 21 ppb (40 µg/m^3).

The US EPA metric for the 1-hour averaging is based on the 98th percentile of daily maximum values averaged over three consecutive years (see Table 3-4). This metric was computed for the three stations with NO_2 data for the available years. Results are presented graphically in Figure 3-26, which shows that values remained below the US EPA objective at all three stations.

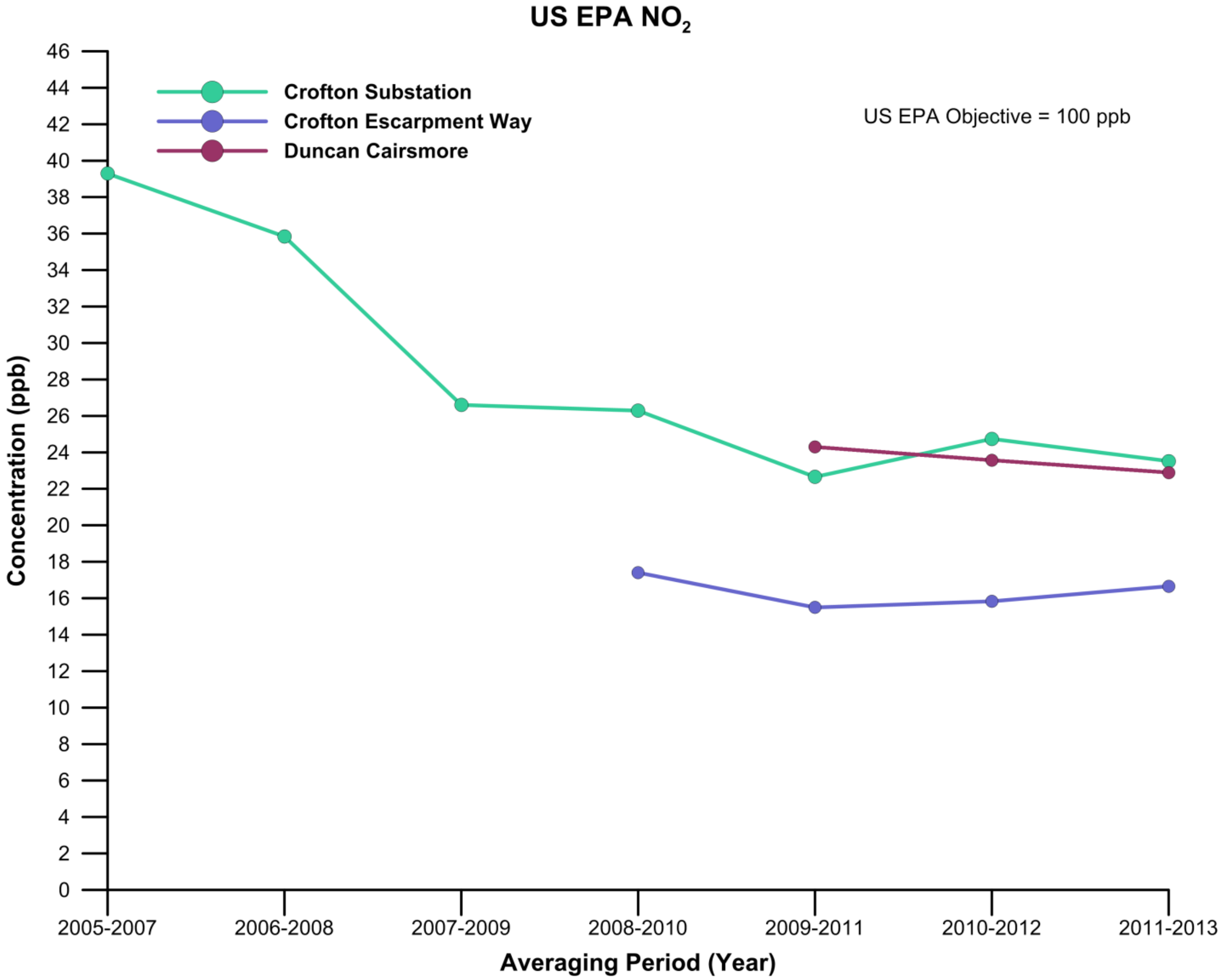


Figure 3-26 1-Hour Average NO_2 Results for the US EPA Supplemental Objective at the Crofton Substation, Crofton Escarpment Way, and Duncan Cairnsmore Monitoring Stations

3.2.3.1 Diurnal Patterns

Diurnal trends in average hourly concentration are shown in Figure 3-27 for the three stations with NO_2 data. Crofton Substation and Duncan Cairnsmore had bimodal peaks in morning and early evening, while the Crofton Escarpment Way station had no discernable diurnal pattern. As mobile sources such as motor vehicles are the primary sources of NO_X in the CVRD, it can be assumed that the twice-daily NO_2 peaks are caused by the morning and evening “rush hour” traffic. The peaks are more clearly defined at Duncan Cairnsmore due to the more urban location of that station. The station at Escarpment Way is much less affected by motor vehicle emissions due to its elevated location (142 m above sea level) in a much less densely settled area.

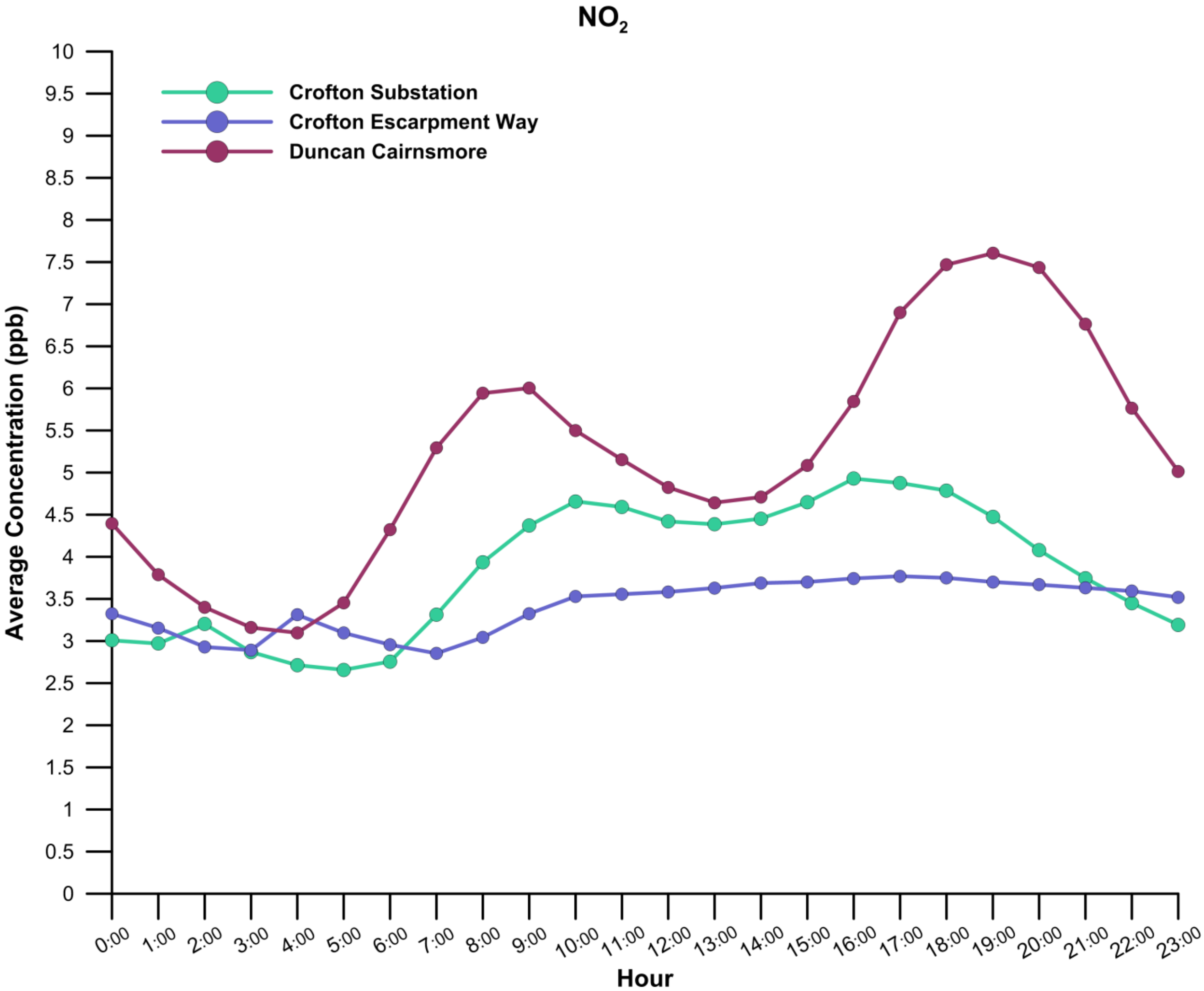


Figure 3-27 Diurnal Trends in NO_2 Concentration Based on all Available Hourly Data

3.2.3.2 Hebdomadal Patterns

The notion that variations in NO_2 concentration are largely due to variable emissions from mobile sources is supported by a hebdomadal pattern that is evident in Figure 3-28 and Figure 3-29. Average NO_2 concentrations (Figure 3-28) were higher during the week than on the weekends. This was the case at all three stations, but it was best-defined at Duncan Cairnsmore, where the average daily concentrations ranged from 4.1 ppb on Sunday to 5.9 ppb on Friday (Figure 3-29). This hebdomadal pattern can be explained by emissions from motor vehicles and other mobile sources being higher during the business week than on weekends.

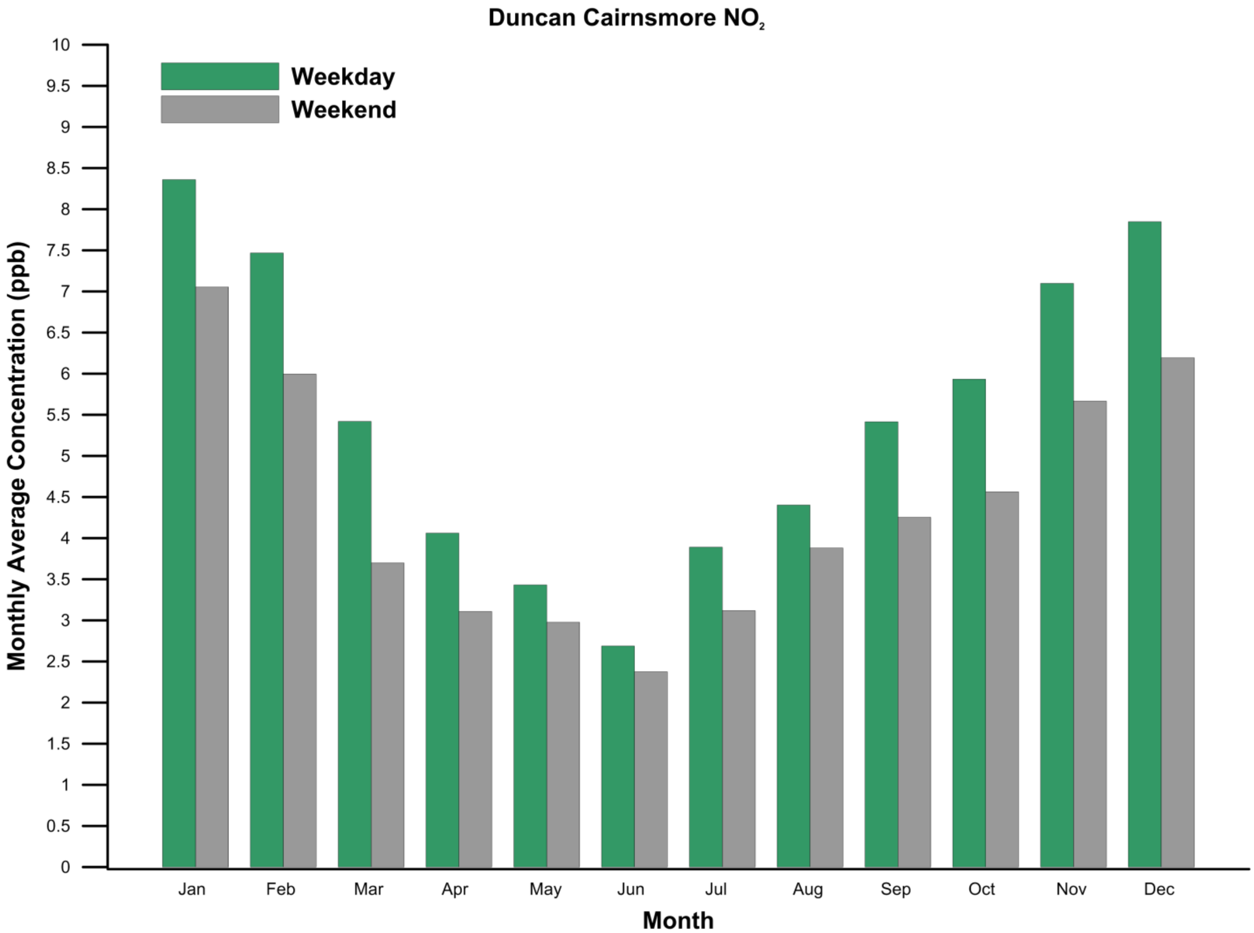


Figure 3-28 Monthly Average NO_2 Concentration for Weekdays and Weekends at Duncan Cairnsmore Based on 2009–2013 Data

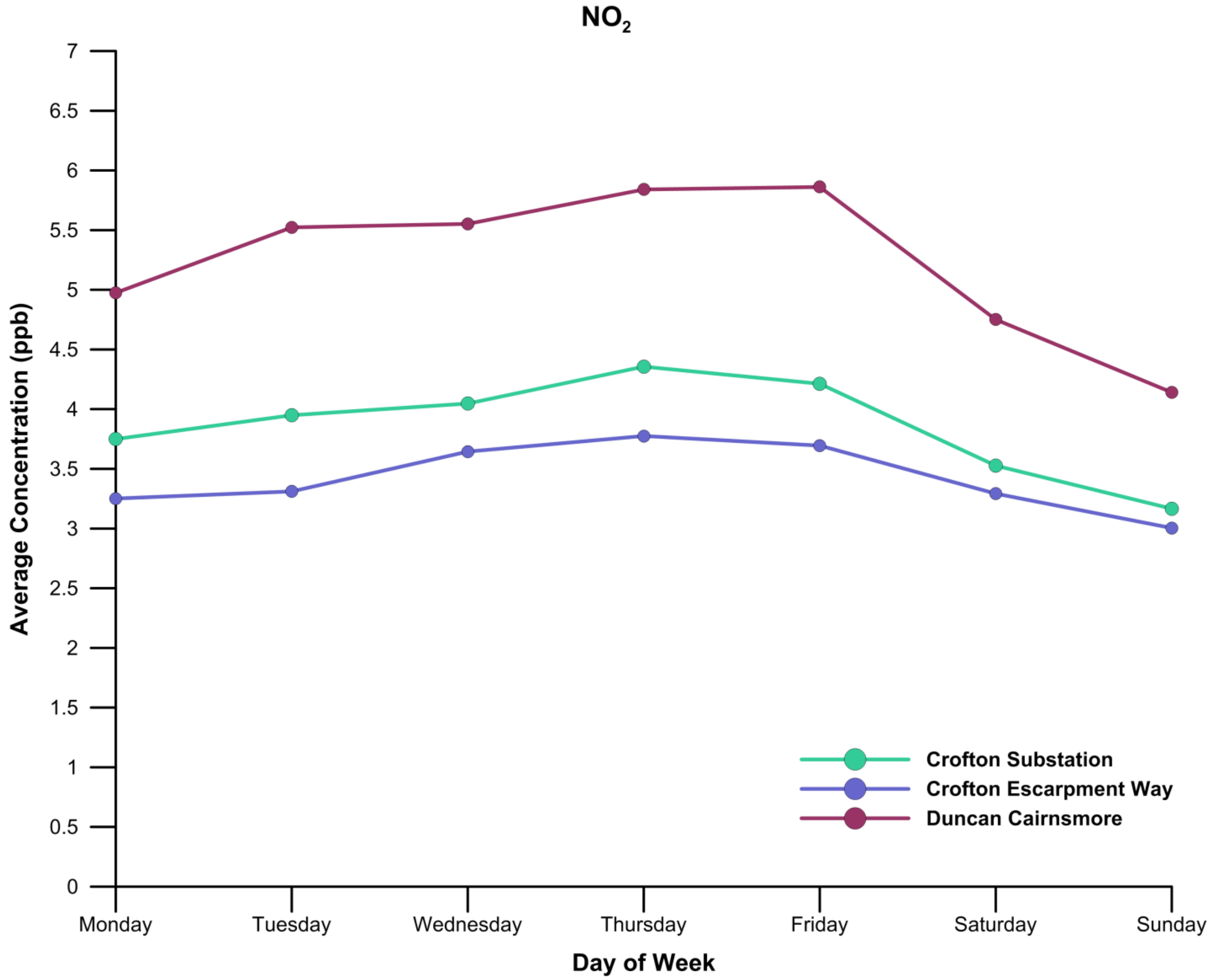


Figure 3-29 Average NO_2 Concentration by Day of Week at Crofton Substation, Crofton Escarpment Way, and Duncan Cairnsmore

3.2.3.3 Pollution Roses

Pollution roses for the locations with both NO_2 and hourly wind data are shown in Figure 3-30 and Figure 3-31 for Crofton Substation and Duncan Cairnsmore, respectively. The pollution rose for Crofton Substation NO_2 shows much less directional dependence than for SO_2, indicating more diverse sources (motor vehicles, space heating, etc.). The Duncan Cairnsmore pollution rose also does not show strong directional dependence for NO_2 levels, except that the highest values were mostly associated with winds from the northwest. This may be due to industrial NO_2 sources immediately northwest of the Cairnsmore monitoring station.

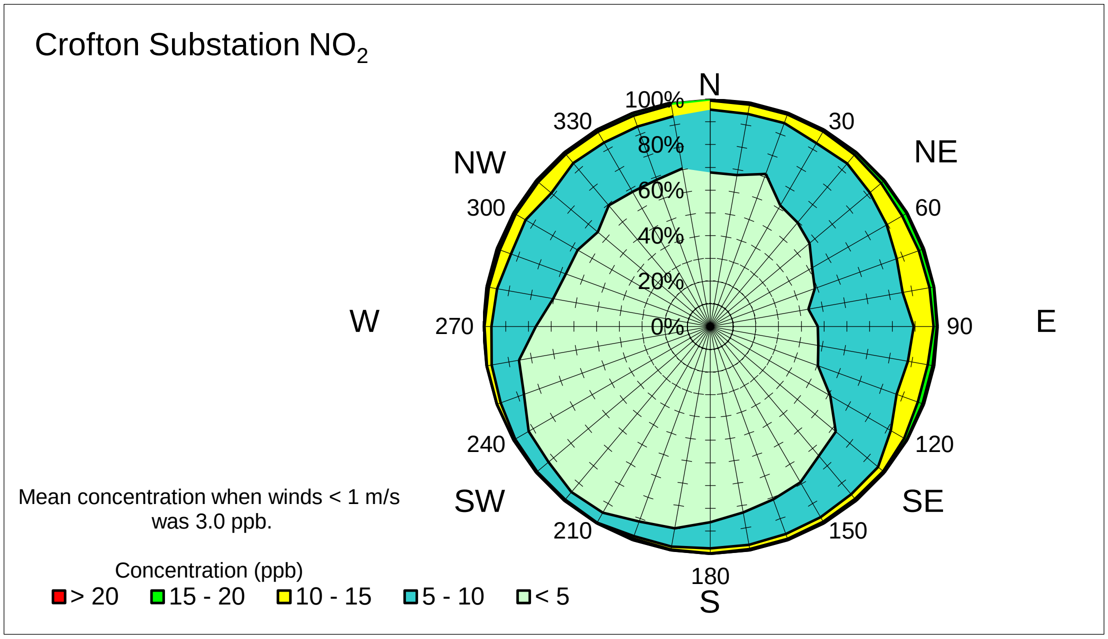


Figure 3-30 Pollution Rose for NO_2 at Crofton Substation Based on 2008–2013 Data

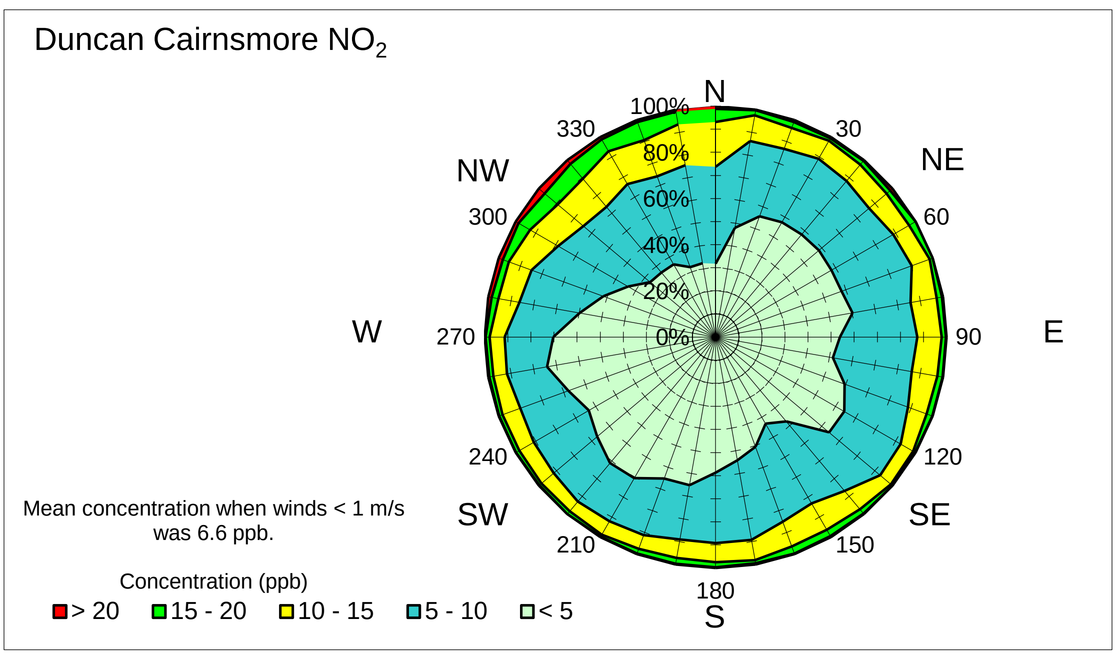


Figure 3-31 Pollution Rose for NO_2 at Duncan Cairnsmore Based on 2009–2013 Data

3.2.4 Inhalable Particulate Matter

Inhalable particulate matter (PM_{10}) was measured at Crofton Substation from February 2005 to May 2010 and at Duncan Deykin Avenue starting prior to 2003 and ending in April 2010. Continuous measurement of PM_{10} was done with a Tapered Element Oscillating Microbalance (TEOM). This instrument draws ambient air through an inlet head that controls the size of particles entering the microbalance. The particles are then collected on a filter that is mounted on the tip of a hollow glass tube (the tapered element). The oscillating frequency of the tapered element changes in proportion to the particle load on the filter (BC MOE 2013a).

Hourly time series of PM_{10} data from Crofton Substation and Duncan Deykin Avenue are included in Appendix B. The only applicable objective for PM_{10} is the BC AAQO of 50 µg/m^3 for the 24-hour averaging period. Box and whisker plots of 24-hour average PM_{10} results are shown in Figure 3-32 and Figure 3-33 for the Crofton Substation and Duncan Deykin Avenue monitoring stations, respectively. Monthly mean and median concentrations were between 9.0 and 11.0 µg/m^3 for both stations. At Crofton Substation, there was just one day (in April 2006) when the 24-hour average PM_{10} concentration exceeded the BC AAQO of 50 µg/m^3. There were no exceedances of the provincial objective at Duncan Deykin Avenue from 2003 to 2010.

The monthly box plots show little indication of seasonal patterns in the PM_{10} data. At Crofton Substation, the monthly median values were slightly higher in spring and summer as compared to late fall and winter, whereas Duncan Deykin Avenue had its highest monthly median concentrations in October and February. Sources of PM such as open burning and road dust tend to be most prevalent in spring and summer, but other common sources such as space heating (e.g., woodstoves) have their peak emissions in winter.

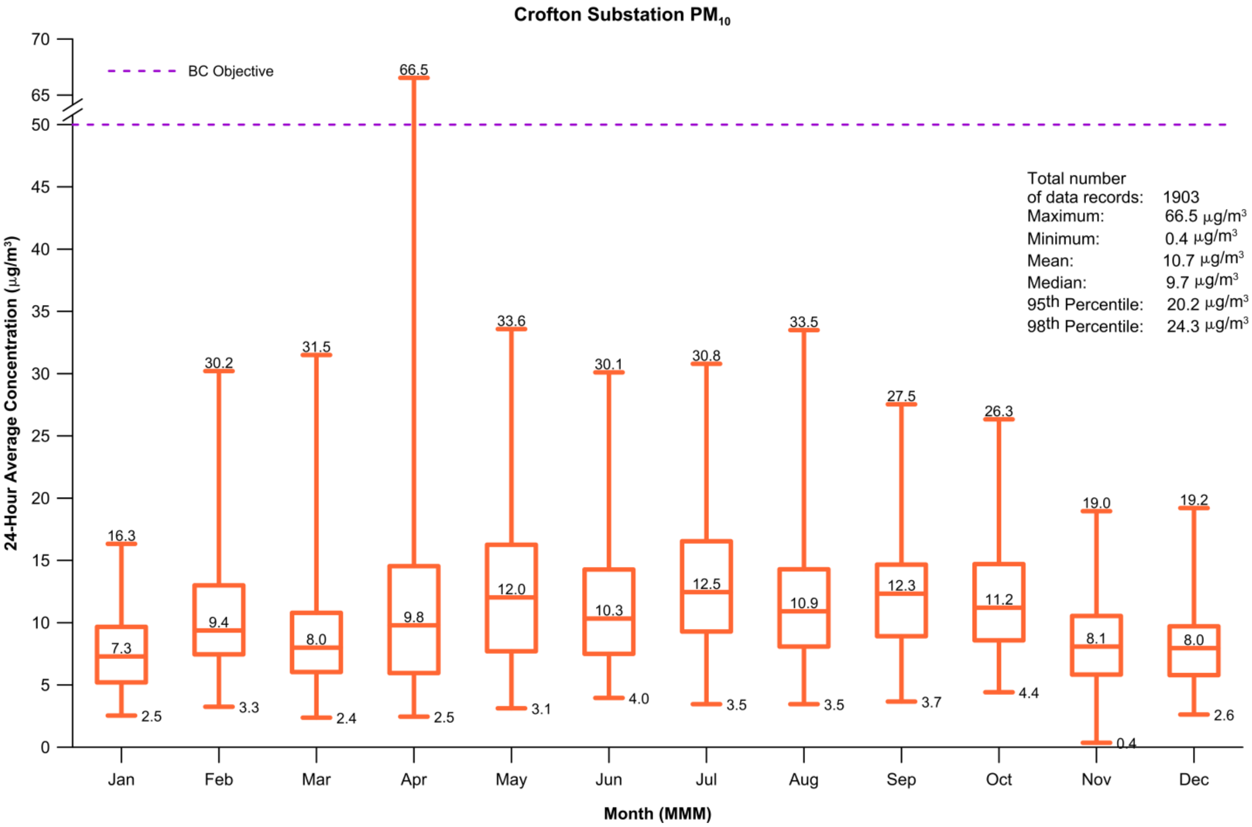


Figure 3-32 Monthly Variation of 24-Hour Average PM_{10} Concentration at Crofton Substation Based on 2005–2010 Data

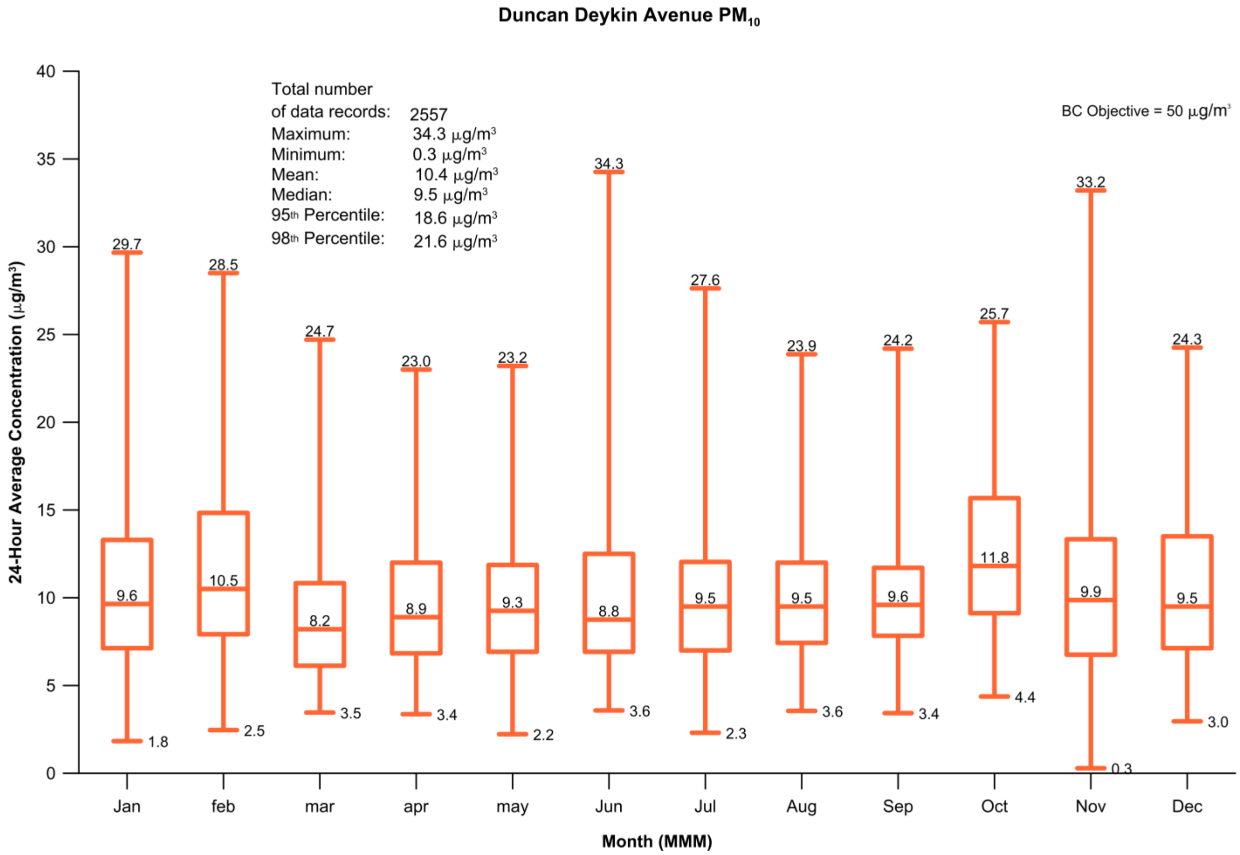


Figure 3-33 Monthly Variation of 24-Hour Average PM_{10} Concentration at Duncan Deykin Avenue Based on 2003–2010 Data

3.2.5 Respirable Particulate Matter

Respirable particulate matter ($PM_{2.5}$) was measured at all four of the air quality monitoring stations included in this study. Two types of instrument have been used to measure $PM_{2.5}$ in the CVRD, a TEOM and a BAM. The TEOM (described in subsection 3.2.4) is fitted with a size-selective inlet set to allow only $PM_{2.5}$ to the microbalance. The Beta Attenuation Mass monitor (BAM) has a constant source of beta ray transmission that is measured across a section of filter tape before and after the filter tape is exposed to air that has been drawn through a size selective inlet. The beta ray transmission is attenuated by presence of PM according to a known equation (Met One 2008). The TEOM instruments used were model 1400 AB and the BAM instruments were Met One BAM 1020 monitors. Table 3-6 shows the date ranges and instrument types used for $PM_{2.5}$ monitoring at the four stations.

Table 3-6 Measurement of $PM_{2.5}$ in the CVRD

Station Name	Start Date	End Date	Instrument
Crofton Substation	March 30, 2010	Ongoing	TEOM
Crofton Substation	November 28, 2013 [a]	Ongoing	BAM
Crofton Escarpment Way	October 9, 2008	2014	TEOM
Duncan Deykin Avenue	June 3, 2010	November 20, 2013	TEOM
Duncan Deykin Avenue	November 28, 2013 [b]	Ongoing	BAM
Duncan Cairnsmore	August 19, 2009 [c]	Ongoing	BAM

NOTES:
[a] Crofton Substation BAM had data gaps Dec 4–11 and Dec 17–31, 2013.
[b] Duncan Deykin BAM had data gaps Dec 4–12 and Dec 17–27, 2013.
[c] Duncan Cairnsmore BAM had numerous data gaps in 2009 and 2012.

Data from the BAM instruments at Crofton Substation and Duncan Deykin Avenue are not analyzed here, because only about two weeks of observations were available from each station in 2013 as the instrumentation was being switched from TEOM to BAM technology.

Studies have found that TEOM instruments under-report PM concentrations compared with newer instruments such as the BAM monitors when the air contains a considerable amount of semi-volatile PM (Environment Canada 2014c). A portion of the semi-volatile PM can be lost due to the heating of the sample that occurs in the TEOM. The under-reporting is most prevalent during the cold season.

To compare TEOM and BAM instrument output, equations have been developed to adjust concentration values from TEOM monitors to approximate what would have been reported by BAM monitors. These equations were based on studies involving co-located instruments (Environment Canada 2014c). The equations give overall increases in $PM_{2.5}$ however, more so in the cold season than the warm season. In the following $PM_{2.5}$ results, the TEOM values from Crofton Substation, Crofton Escarpment Way, and Duncan Deykin Avenue have been adjusted using the Environment Canada technique. Results from the unadjusted TEOM datasets are included in Appendix B. The BAM values are from Duncan Cairnsmore.

Ambient air quality objectives for $PM_{2.5}$ are based on 24-hour and annual averaging periods. The summary table for $PM_{2.5}$ in Appendix B indicates that the BC objective for annual average $PM_{2.5}$ (8 $\mu g/m^3$) was exceeded each year from 2009–2013 at Duncan Cairnsmore (BAM data), but was not exceeded at the other three stations. Part of the difference between Duncan Cairnsmore and the other stations can likely be attributed to the instrument differences discussed above. However, Figure 3-34 shows that annual mean concentrations at Duncan Cairnsmore were also higher than the adjusted TEOM concentrations from the other three stations. Therefore, the more urban location and relatively frequent occurrence of temperature inversions at the Duncan

Cairnsmore location may have contributed to higher $PM_{2.5}$ concentrations that are not simply an artefact of measurement techniques. No significant long-term trend in $PM_{2.5}$ concentration is apparent in the data shown in Figure 3-34.

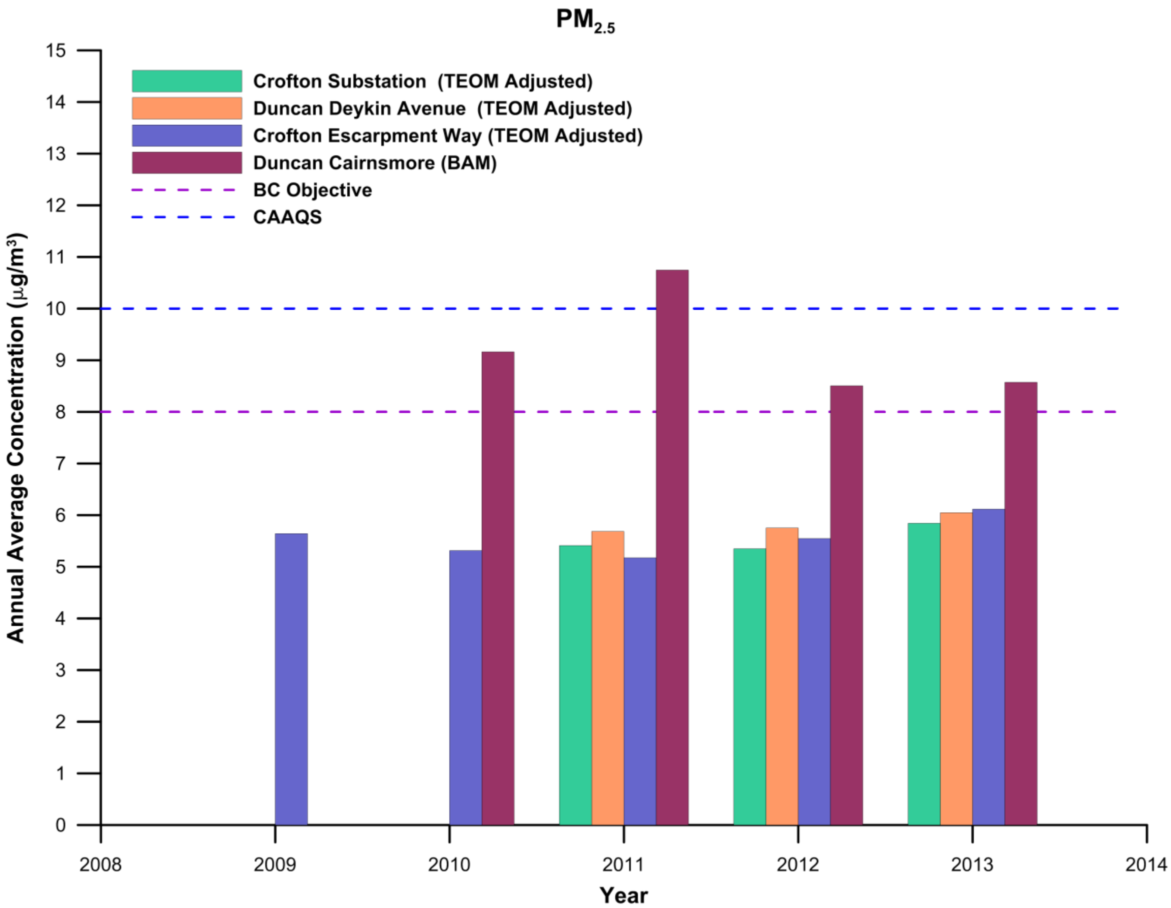


Figure 3-34 Annual Average $PM_{2.5}$ Concentrations in the CVRD

Box and whisker plots of 24-hour average $PM_{2.5}$ results are shown in Figure 3-36, Figure 3-37, Figure 3-38, and Figure 3-39 for Crofton Substation, Crofton Escarpment Way, Duncan Deykin Avenue, and Duncan Cairnsmore, respectively. Appendix B.3 (Figure B-12 to Figure B-16) contains hourly time series figures that also illustrate similar seasonal trends of $PM_{2.5}$ concentrations.

Monthly median $PM_{2.5}$ concentrations were generally low (less than 8 µg/m³) at all stations except Duncan Cairnsmore. The Crofton Substation, Crofton Escarpment Way, and Duncan Deykin Avenue stations each had just one or two instances of daily 24-hour average $PM_{2.5}$ concentrations exceeding the BC AAQO of 25 µg/m³. Exceedance of the 24-hour objective was more common at Duncan Cairnsmore, with one or more days exceeding the BC objective during six of the twelve months. Figure 3-35 is a time series of the 24 hour average $PM_{2.5}$ concentration at Duncan Cairnsmore. Table B-4 (Appendix B.3) shows the number of days in each year where exceedances occurred. The maximum number of days $PM_{2.5}$ exceeds the BC AAQO is 21 days in 2011.

Duncan Cairnsmore was also the only station to show a clear seasonal trend in the 24-hour average $PM_{2.5}$ concentrations, with low values in summer and relatively high values in winter (Figure 3-35). Figure 3-35 shows that the majority of $PM_{2.5}$ exceedances, other than the 2010 forest fire impacts, occur during the fall and winter months. The other three stations did show some indication of a maximum in fall, with peak median concentrations occurring in October, but the seasonal trend was less well-defined than at Duncan Cairnsmore.

There are several air quality bylaws in the CVRD for open and backyard burning as well as wood heating. These bylaws act to moderate when open and backyard burning can occur in the different electoral districts and municipalities. For example, some bylaws indicate that burning is allowed in certain regions between October and April depending on the municipality (BC MOE 2011, City of Duncan 2013, CVRD 2013, CVRD 2010). October is one of the more active months in terms of open burning (land clearing, forestry slash burns, and residential back-yard burning). The peak in $PM_{2.5}$ concentrations in October can be partially attributed to increases in these sources. The additional PM from woodstoves and other space heating is a likely cause of the higher wintertime concentrations observed at Duncan Cairnsmore. A similar seasonal cycle was found for NO_2 concentrations at the Cairnsmore site.

The 2010 August peak in $PM_{2.5}$ concentrations is discussed further in Section 3.2.5.4., where the analysis indicates that the August peak is due to forest fires in BC.

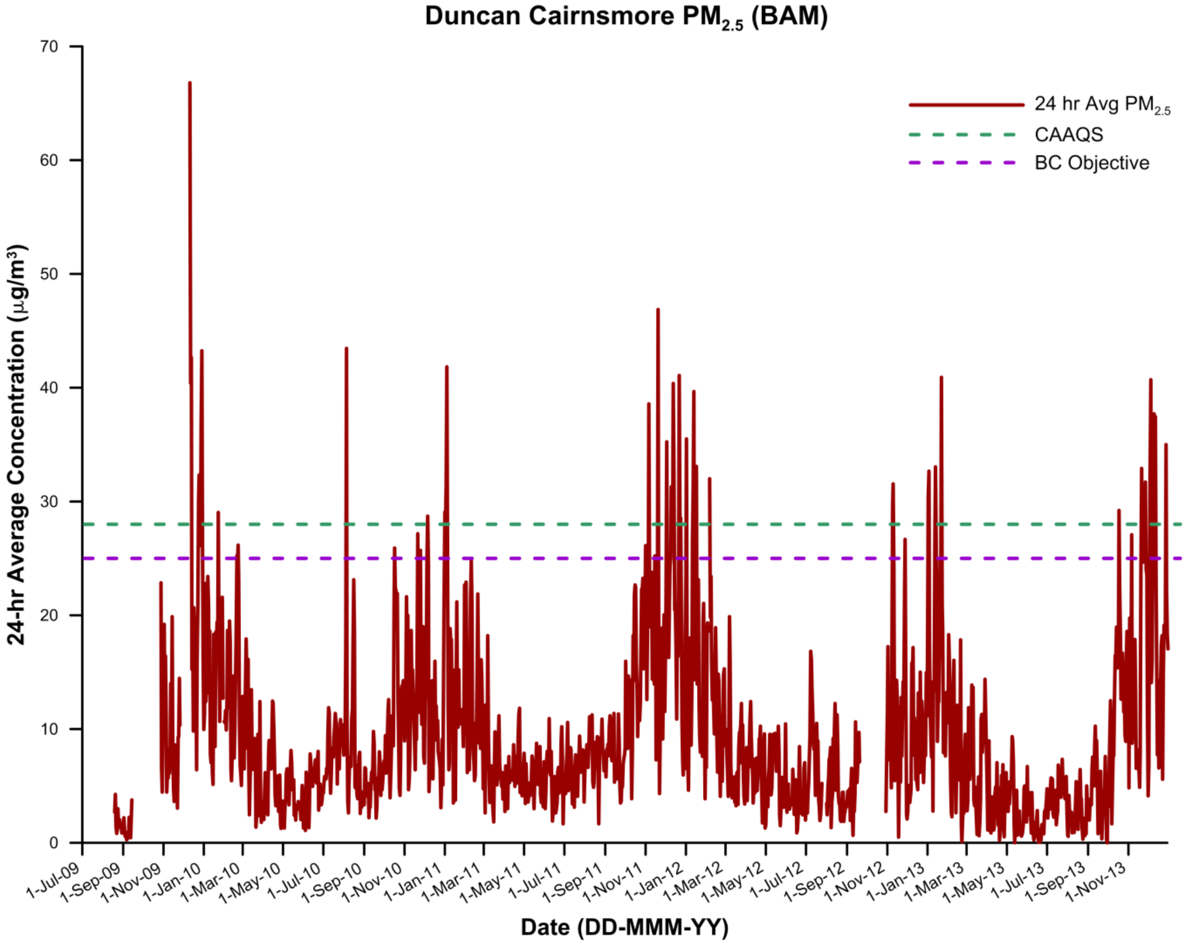


Figure 3-35 24 Hour Average $PM_{2.5}$ at Duncan Cairnsmore

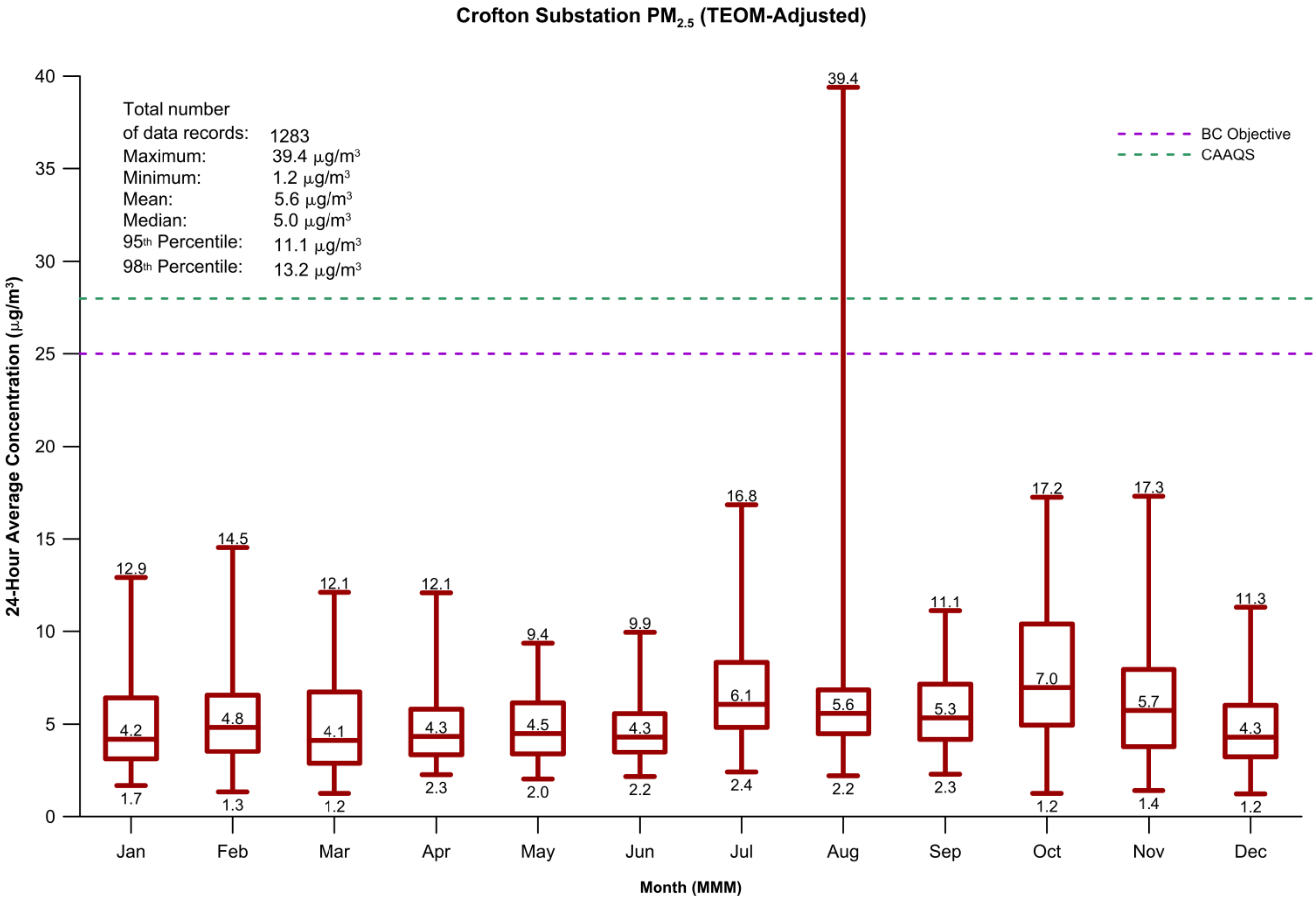


Figure 3-36 Monthly Variation of 24-Hour Average $PM_{2.5}$ Concentration at Crofton Substation Based on 2010–2013 Data

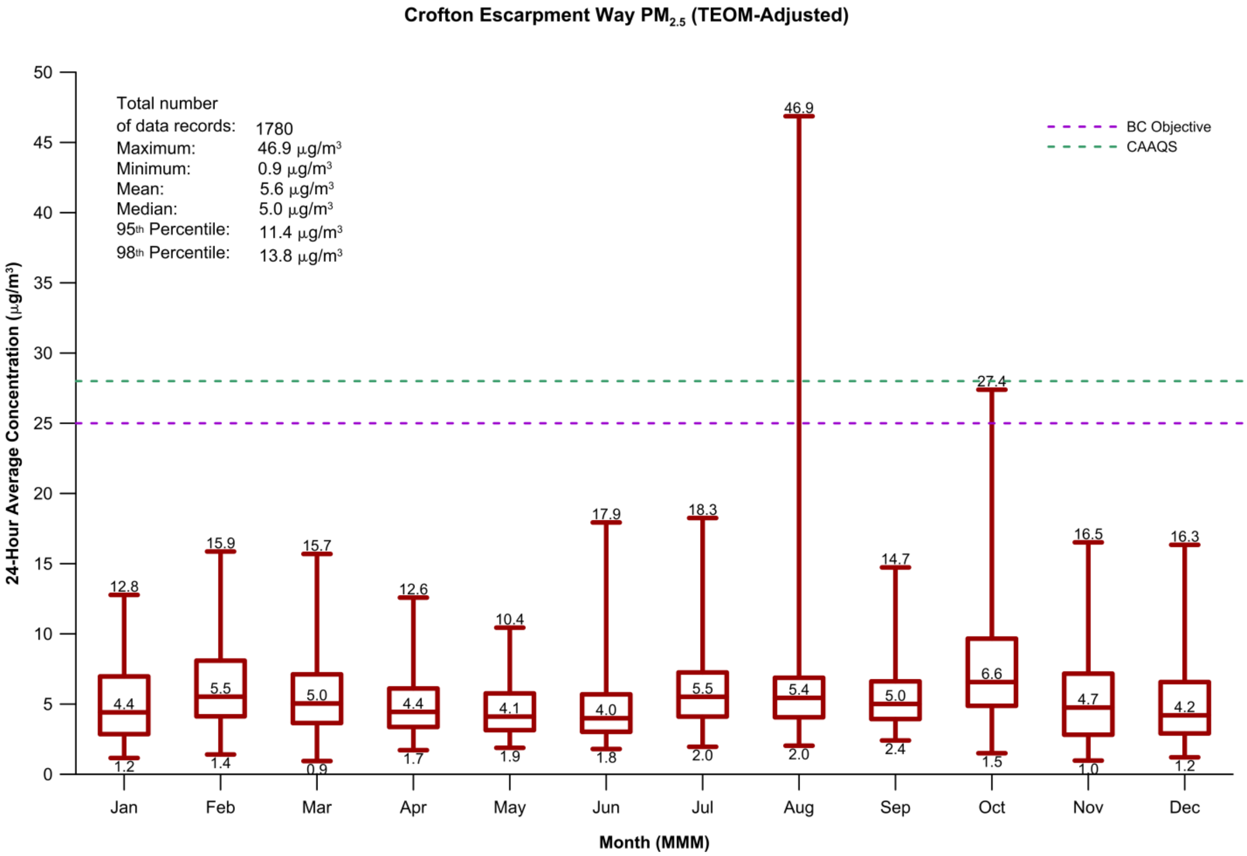


Figure 3-37 Monthly Variation of 24-Hour Average $PM_{2.5}$ Concentration at Crofton Escarpment Way Based on 2008–2013 Data

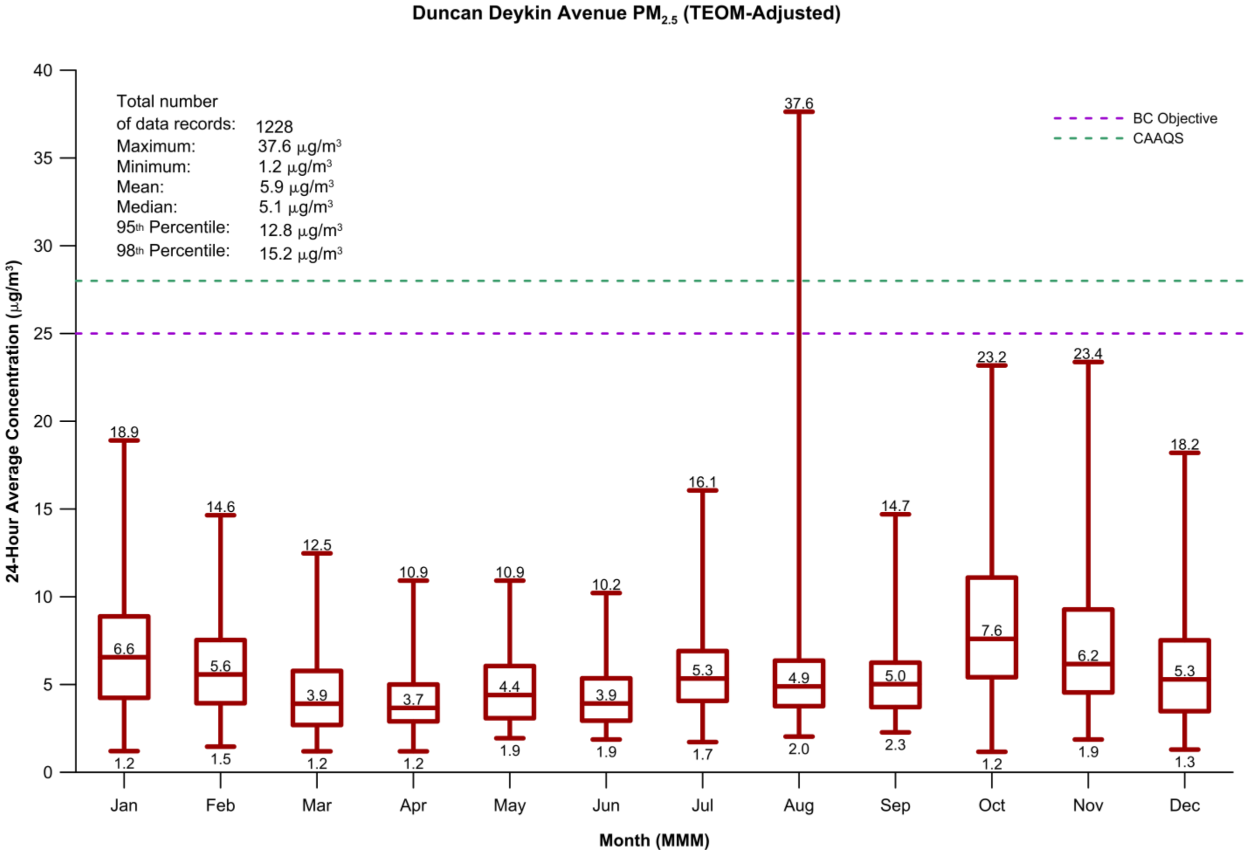


Figure 3-38 Monthly Variation of 24-Hour Average $PM_{2.5}$ Concentration at Duncan Deykin Avenue Based on 2010–2013 Data

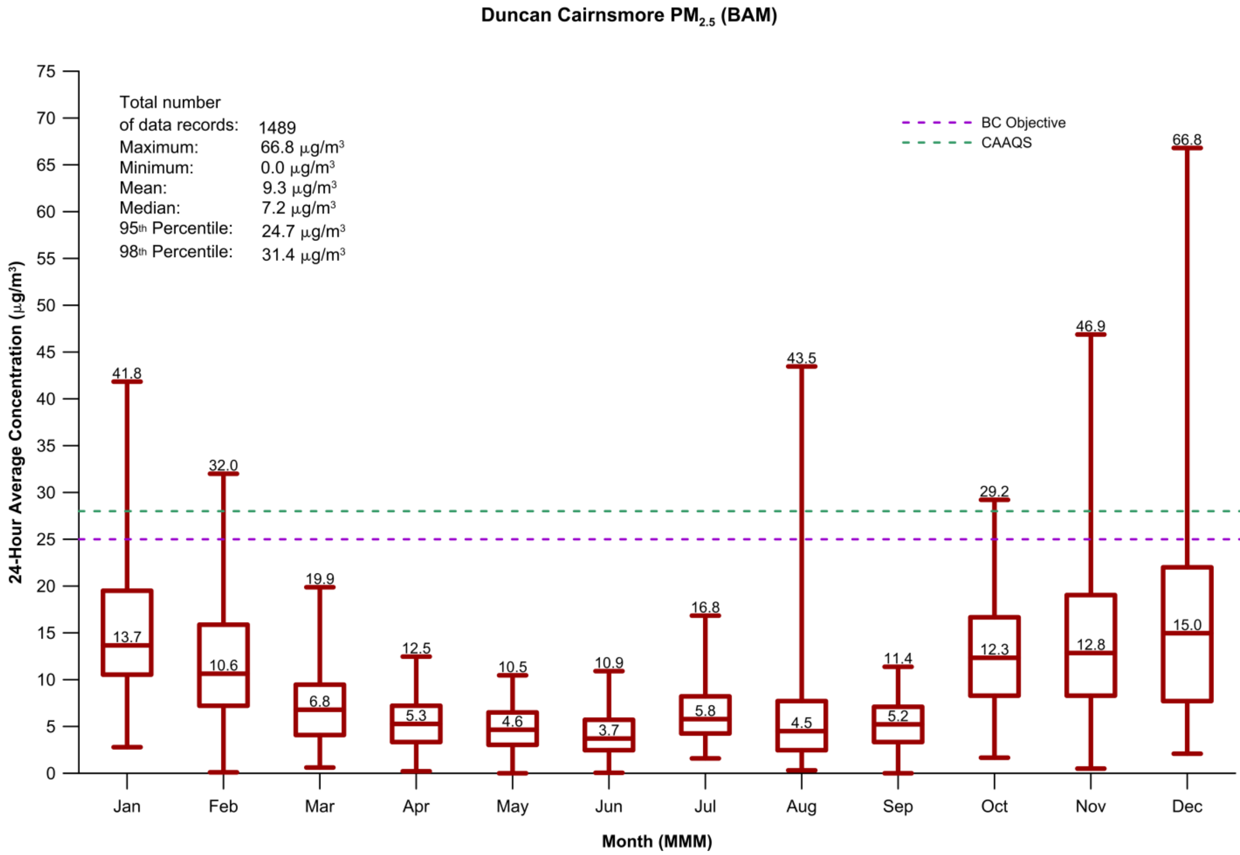


Figure 3-39 Monthly Variation of 24-Hour Average $PM_{2.5}$ Concentration at Duncan Cairnsmore Based on 2009–2013 Data

3.2.5.1 Diurnal Patterns

Diurnal trends in average hourly $PM_{2.5}$ concentration are shown in Figure 3-40 for all four stations. Similar to NO_2, the $PM_{2.5}$ diurnal cycle shows bimodal peaks in morning and evening. However, the peaks are a bit later for $PM_{2.5}$, especially in the evening. The daily maximum at Duncan Cairnsmore appears at 22:00, as compared to 19:00 for NO_2. This suggests that increased emissions from space heating is a stronger factor than motor vehicle traffic as diurnal a contributor to enhanced $PM_{2.5}$ concentrations.

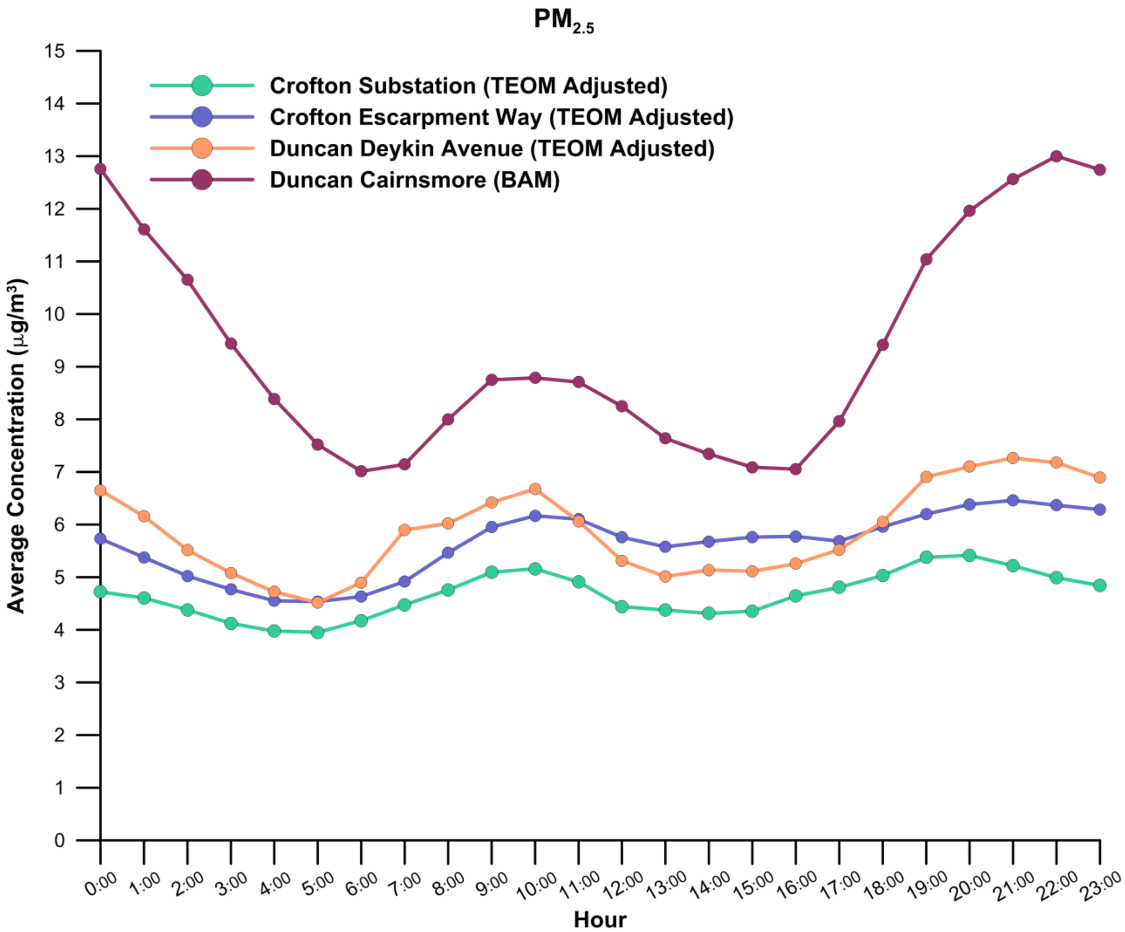


Figure 3-40 Diurnal Trends in $PM_{2.5}$ Concentration Based on all Available Hourly Data

To further investigate diurnal $PM_{2.5}$ cycles, the hourly data were separated by season for Duncan Cairnsmore, which is the station with the best-defined bimodal pattern. The resulting plots are shown in Figure 3-41. The morning and evening concentration peaks were most pronounced in winter, followed by fall and spring. In summer, rather than a bimodal pattern, there was just a minor midday peak in the $PM_{2.5}$ values. This supports the assumption that the bimodal peaks are due to emissions from space heating. The tendency for residents to stoke their woodstoves or otherwise turn up the heat in the morning and evening is reflected in the hourly data. The midday peak in summer may be due more to meteorology, e.g., convective mixing and creation of fugitive dust as a result of daily human activities.

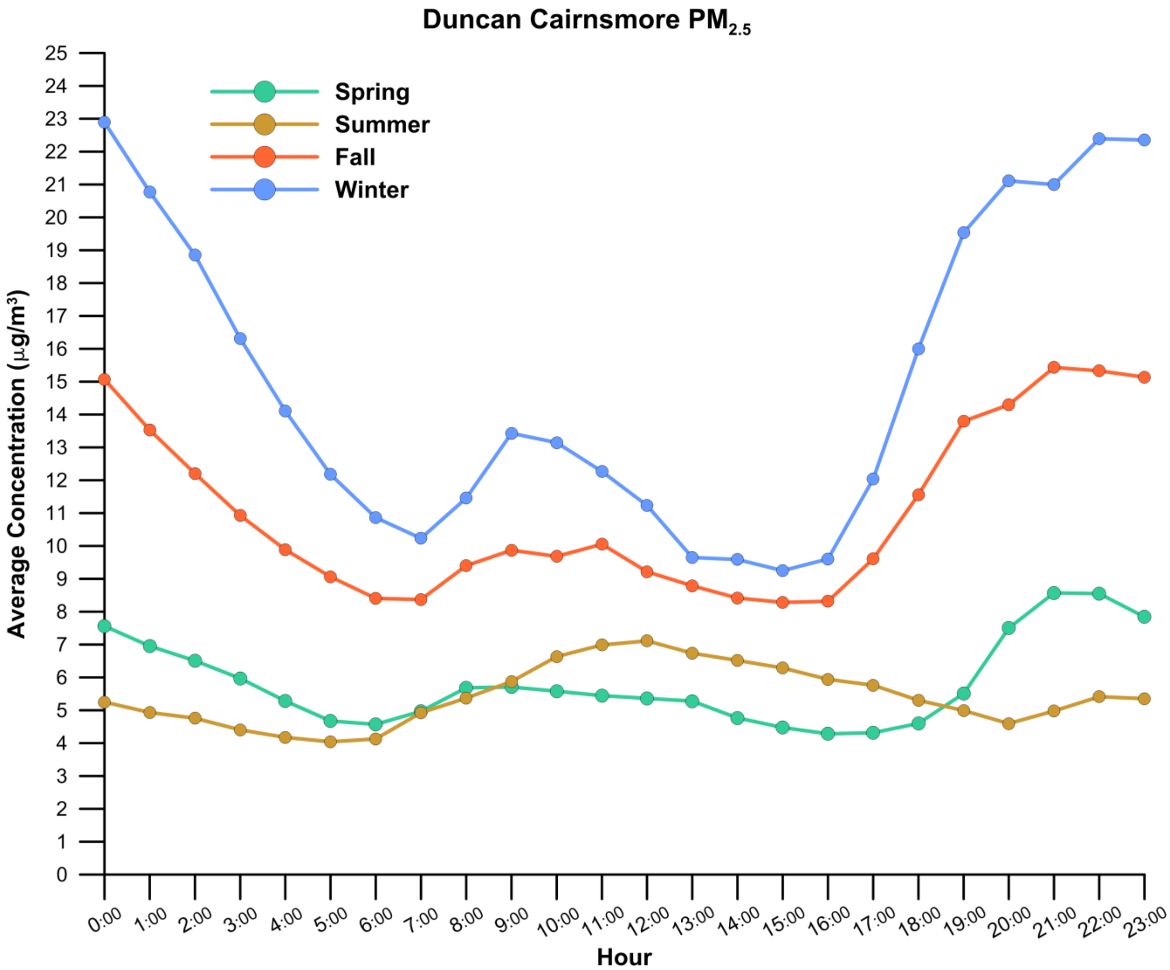


Figure 3-41 Diurnal Trends in $PM_{2.5}$ Concentration at Duncan Cairnsmore by Season

3.2.5.2 Hebdomadal Patterns

Mean concentrations for each day of the week are plotted in Figure 3-42 for the four stations with $PM_{2.5}$ data. There was little variation by day of week at any of the CVRD monitoring stations. Duncan Cairnsmore had slightly higher concentrations on the weekend than during the week, while the other three stations had their weekly peaks on Thursday.

The weekday vs. weekend concentrations at Duncan Cairnsmore are shown by month in Figure 3-43. Mean concentrations were higher on weekends during fall through spring, but not in the summer. This is probably because residential space heating and open burning emissions, which tend to be higher on weekends when more people are at home, are largely absent during the warm season. The seasonal cycle in $PM_{2.5}$ concentration in the Cowichan Valley is also readily apparent in Figure 3-43.

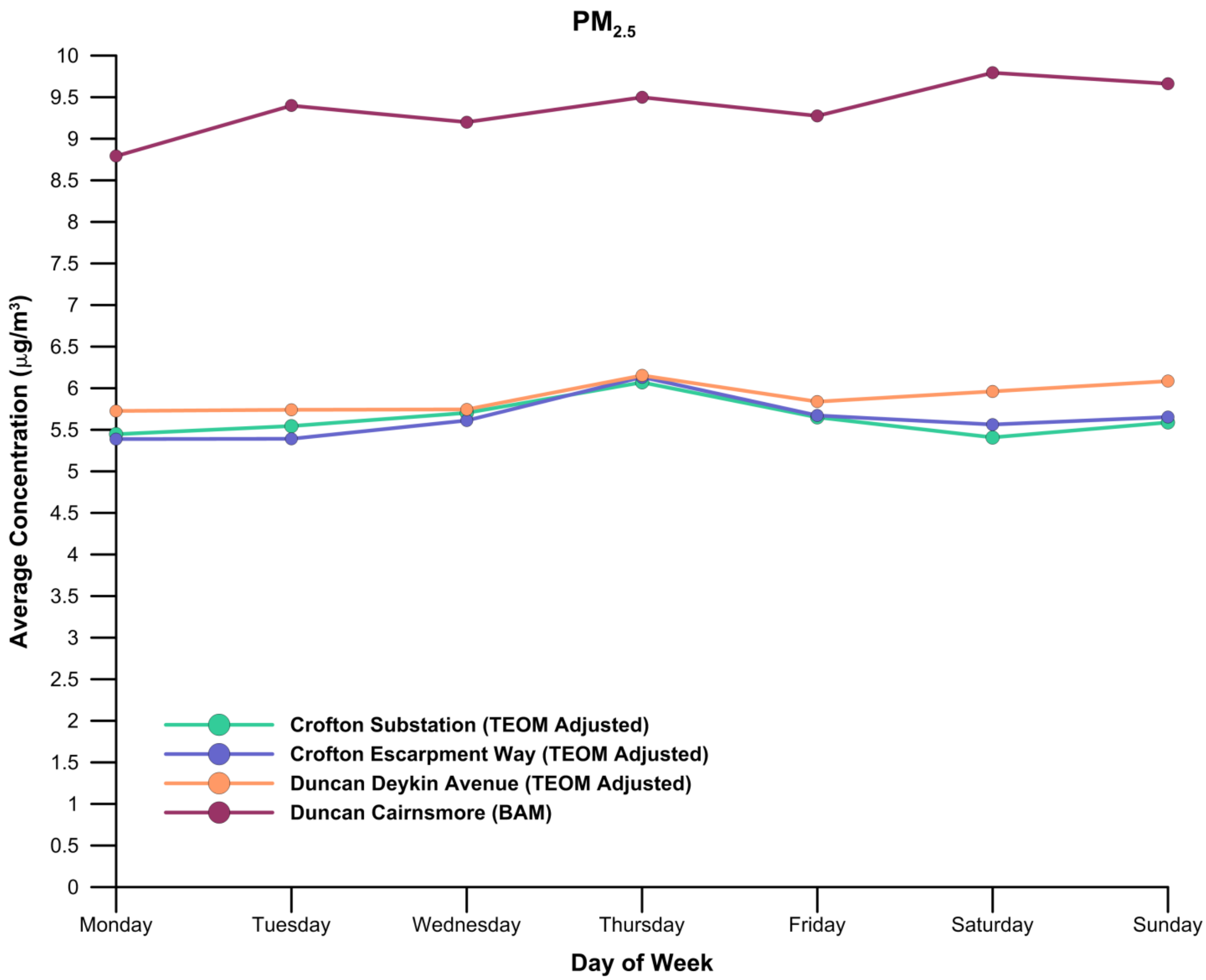


Figure 3-42 Average $PM_{2.5}$ Concentration by Day of Week at the Four CVRD Monitoring Stations

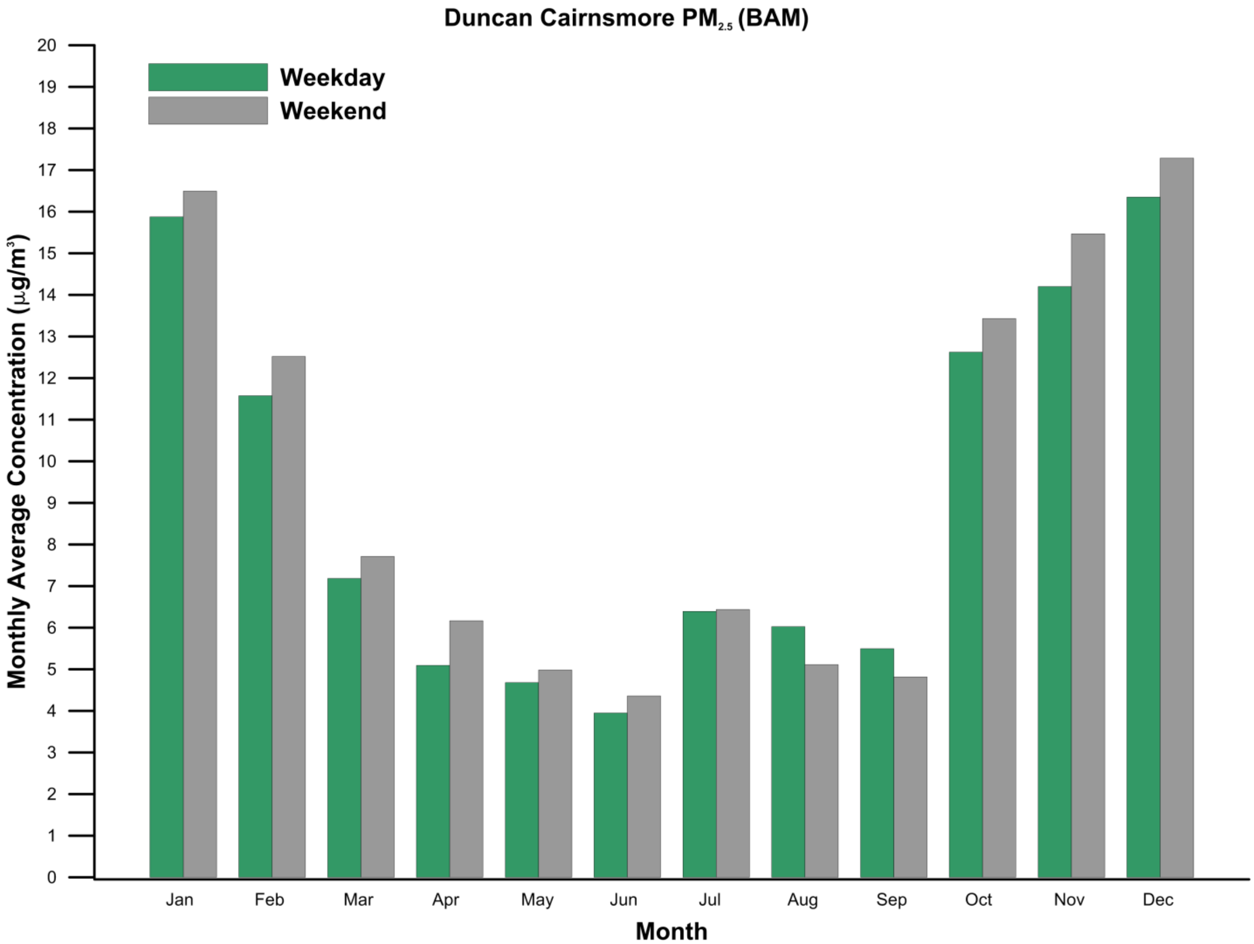


Figure 3-43 Monthly Average $PM_{2.5}$ Concentration for Weekdays and Weekends at Duncan Cairnsmore Based on 2009–2013 Data

3.2.5.3 Pollution Roses

Pollution roses for $PM_{2.5}$ at Crofton Substation and Duncan Cairnsmore are shown in Figure 3-44 and Figure 3-45, respectively. The $PM_{2.5}$ pollution rose for Crofton Substation is similar to that of SO_2, with highest concentrations during northeast winds and low concentrations during southwest flow. At Duncan Cairnsmore, hourly concentrations greater than 25 µg/m^3 occurred during all wind directions, but were more prevalent with winds from the northwest quadrant.

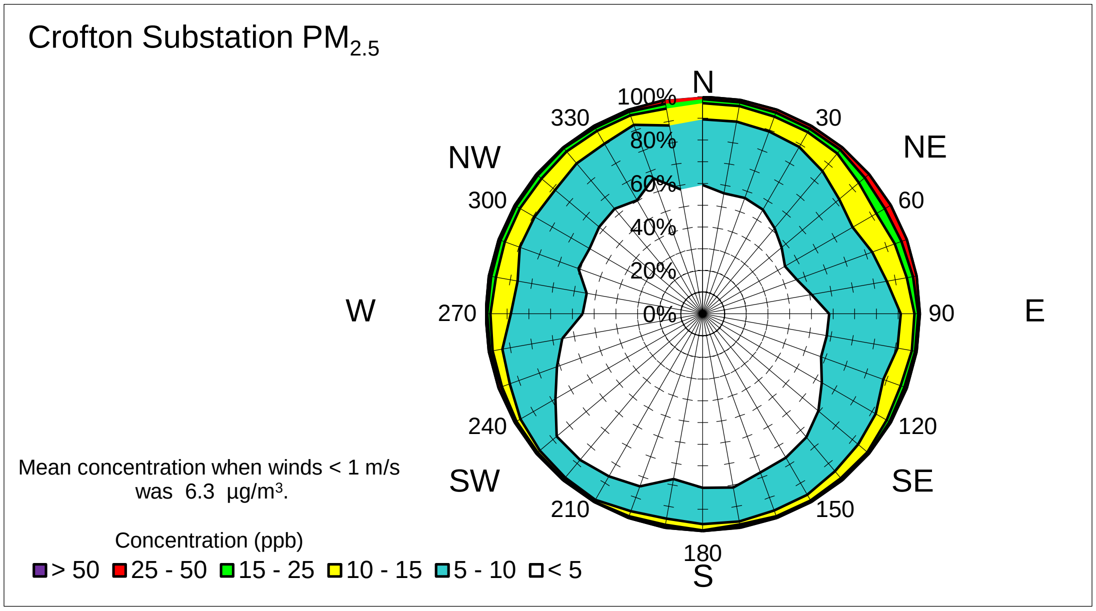


Figure 3-44 Pollution Rose for $PM_{2.5}$ at Crofton Substation Based on 2010–2013 Data

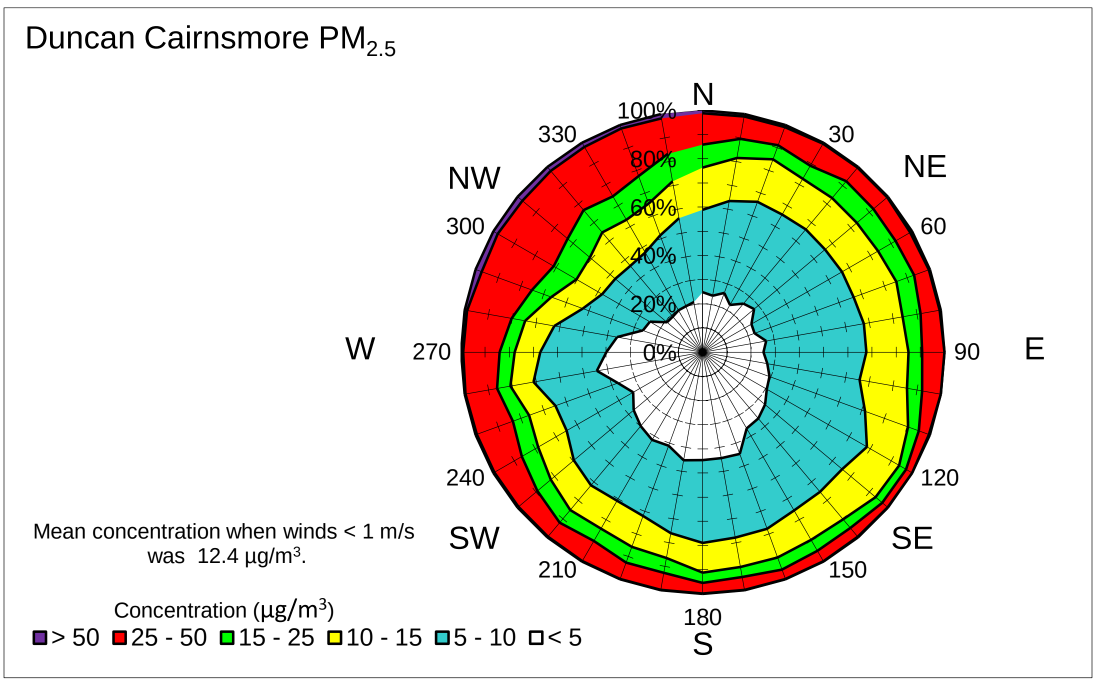


Figure 3-45 Pollution Rose for $PM_{2.5}$ at Duncan Cairnsmore Based on 2009–2013 Data

3.2.5.4 Episode Analysis

In this section, two periods of high $PM_{2.5}$ concentration—one from winter and one from summer—are examined in further detail.

At the Duncan Cairnsmore station, the month of December had the most exceedances of the BC AAQO of 25 µg/m³. A lengthy episode of high particulate concentrations occurred from December 24 to 30, 2009, when seven days in a row had 24-hour average $PM_{2.5}$ concentrations above 25 µg/m³. The highest daily mean concentration during the period was 43.4 µg/m³ on December 29th.

A review of meteorological observations from the Nanaimo Airport during this period revealed dry conditions with light winds and temperatures around freezing. Fog was reported on several of the days. These conditions are typical of a stagnant winter weather pattern caused by high pressure aloft. Data from the nearest upper air (weather balloon) observing site at Quillayute, Washington were obtained for the afternoon of December 26th (University of Wyoming 2014). The resulting temperature and dew point temperature profiles are shown in Figure 3-46. Starting just above the surface, there were several temperature inversions in the lower atmosphere. Such inversion layers are caused by strong high pressure aloft and result in very stable air in a shallow mixed layer near the surface. This is the type of meteorological situation that traps substances near the surface until the high pressure system is replaced by a more dynamic weather feature.

Hourly $PM_{2.5}$ concentrations at the Duncan Cairnsmore station from the December 2009 episode are shown in Figure 3-47. There were diurnal peaks each day, some of which exceeded 60 µg/m³. The diurnal peaks occurred in the late evening hours, suggesting that the highest concentrations were due to home heating emissions (mainly from woodstoves). However, during this period of stagnant air, there would have been a build-up of PM from various sources including indoor space heating, vehicle exhaust, and industrial emissions.

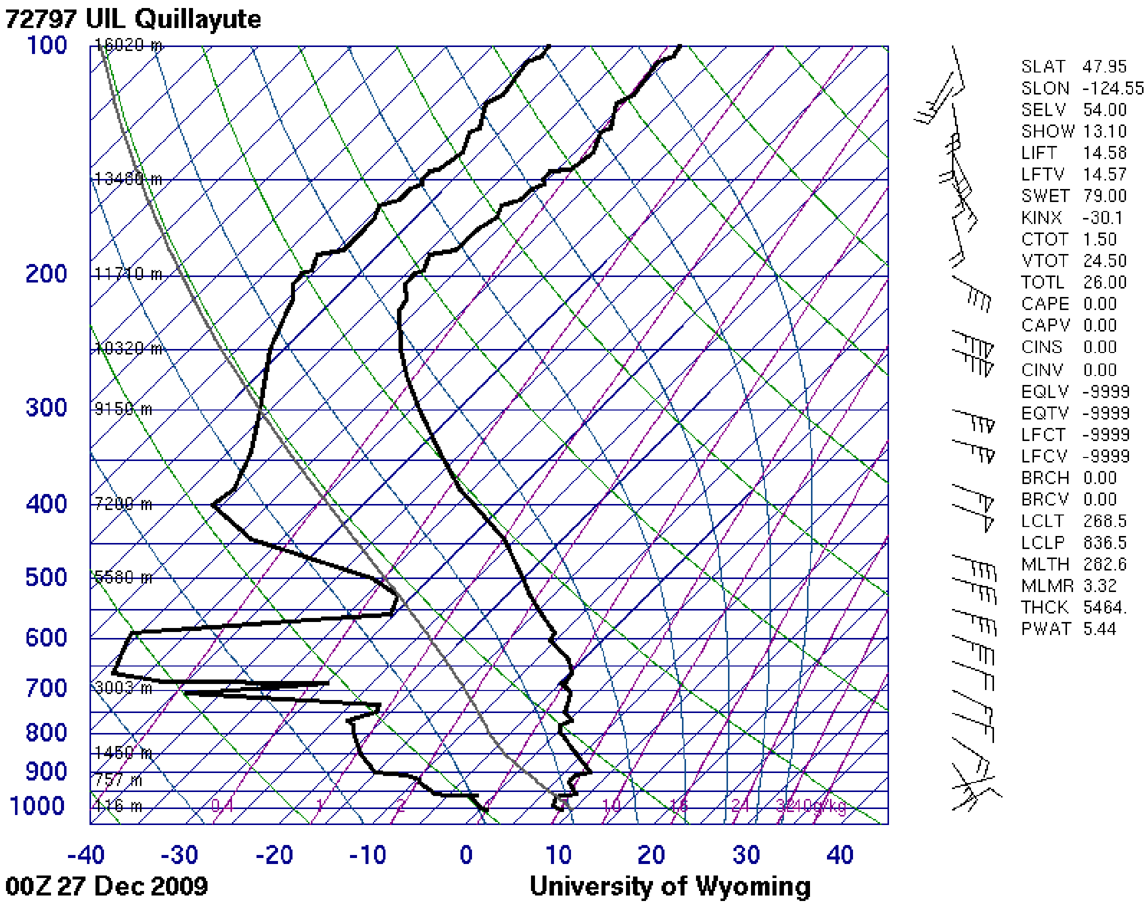


Figure 3-46 Temperature (Right) and Dew Point Temperature (Left) Profiles from Quillayute, WA at 16:00 LST on December 26, 2009

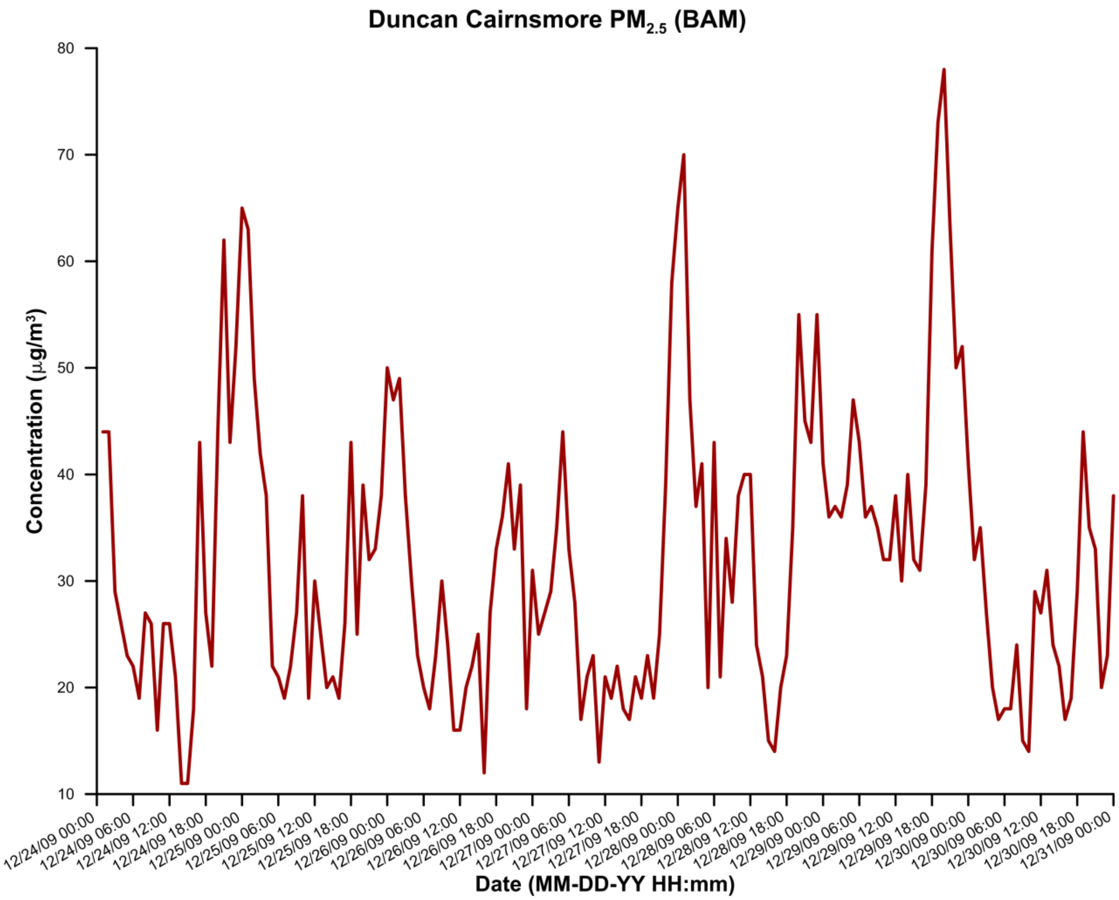


Figure 3-47 Time Series of Hourly $PM_{2.5}$ Concentration at Duncan Cairnsmore for December 24 to 30, 2009

A summertime pollution event that caused exceedances of the $PM_{2.5}$ objectives occurred on August 5, 2010. Figure 3-48 shows hourly concentration data from the four CVRD monitoring stations for August 4 to 6, 2010. This episode was short-lived, with the highest concentrations occurring on August 5th.

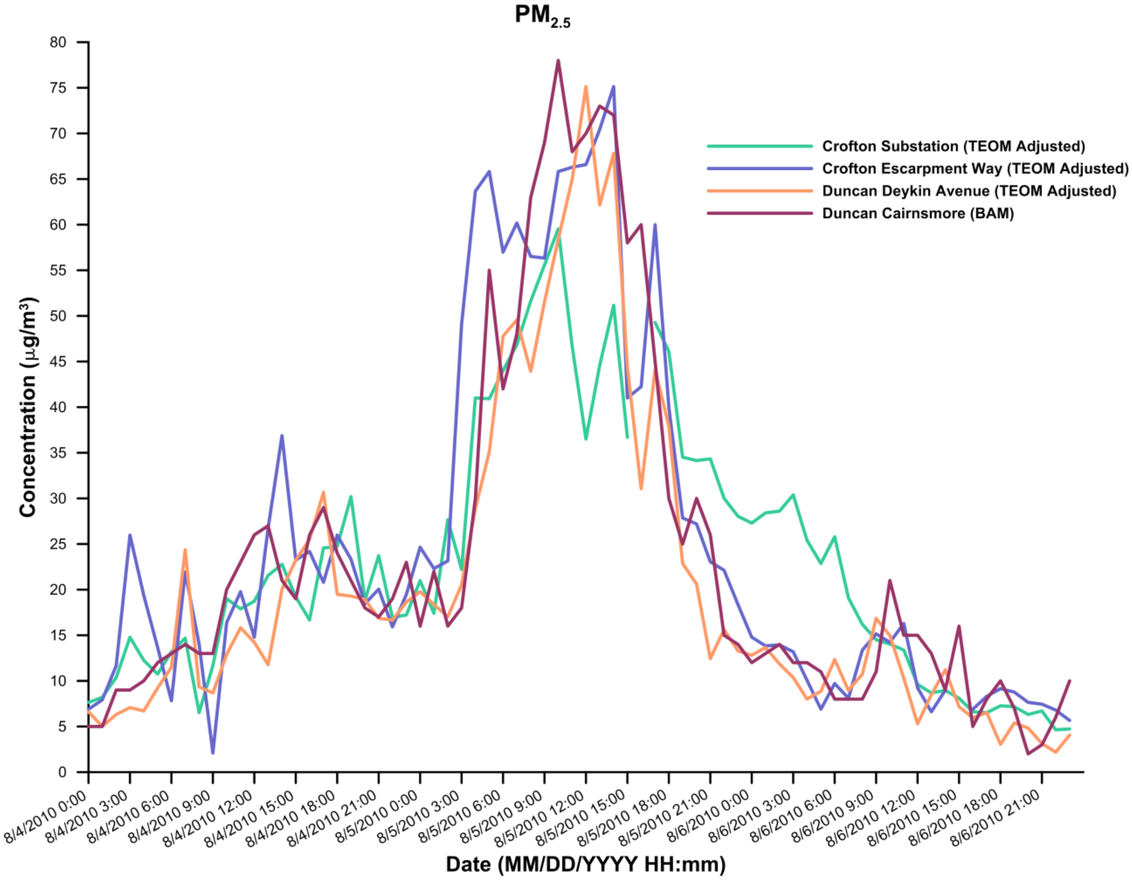


Figure 3-48 Time Series of Hourly $PM_{2.5}$ Concentration at the Four CVRD Monitoring Stations for August 4 to 6, 2010

Airport meteorological observations were reviewed to help determine the nature of this summertime PM episode. At Nanaimo, smoke was reported starting late on August 4th. Smoke was reported throughout the day on August 5th, with horizontal visibility reduced to less than 5 km in the afternoon hours. Smoke was observed at the Victoria Airport and haze was reported at Vancouver, indicating that this was a regional event. This regional event is responsible for the maxima shown in Figure 3-36 to Figure 3-39.

Atmospheric smoke is periodically observed in coastal BC during the summer wildfire season at times when offshore winds blow smoke from interior regions with active forest fires. To determine if this was the case on August 5, 2010, an atmospheric trajectory model was run to simulate where air arriving at Duncan had come from over the preceding three days. The HYSPLIT trajectory model (Draxler and Rolph 2014) uses historical meteorological model data to trace parcels of air over time. In order to account for the possibility of CACs entering the mixed layer from different altitudes, back-trajectories were run for ending heights of 2 m and 500 m above ground level.

The 72-hour back-trajectories ending at 12:00 LST (times on the HYSPLIT output are in Coordinated Universal Time, or UTC) are shown in Figure 3-49. The HYSPLIT simulation traced the air back to the central and northern interior of BC. A 2010 fire season summary confirms that late July and early August 2010 was a very active period for fire activity in the central interior and that most of the fires were started by lightning (BC Wildfire Management Branch 2014). This case provides an example of air quality objectives being exceeded by CACs of distant and natural origin.

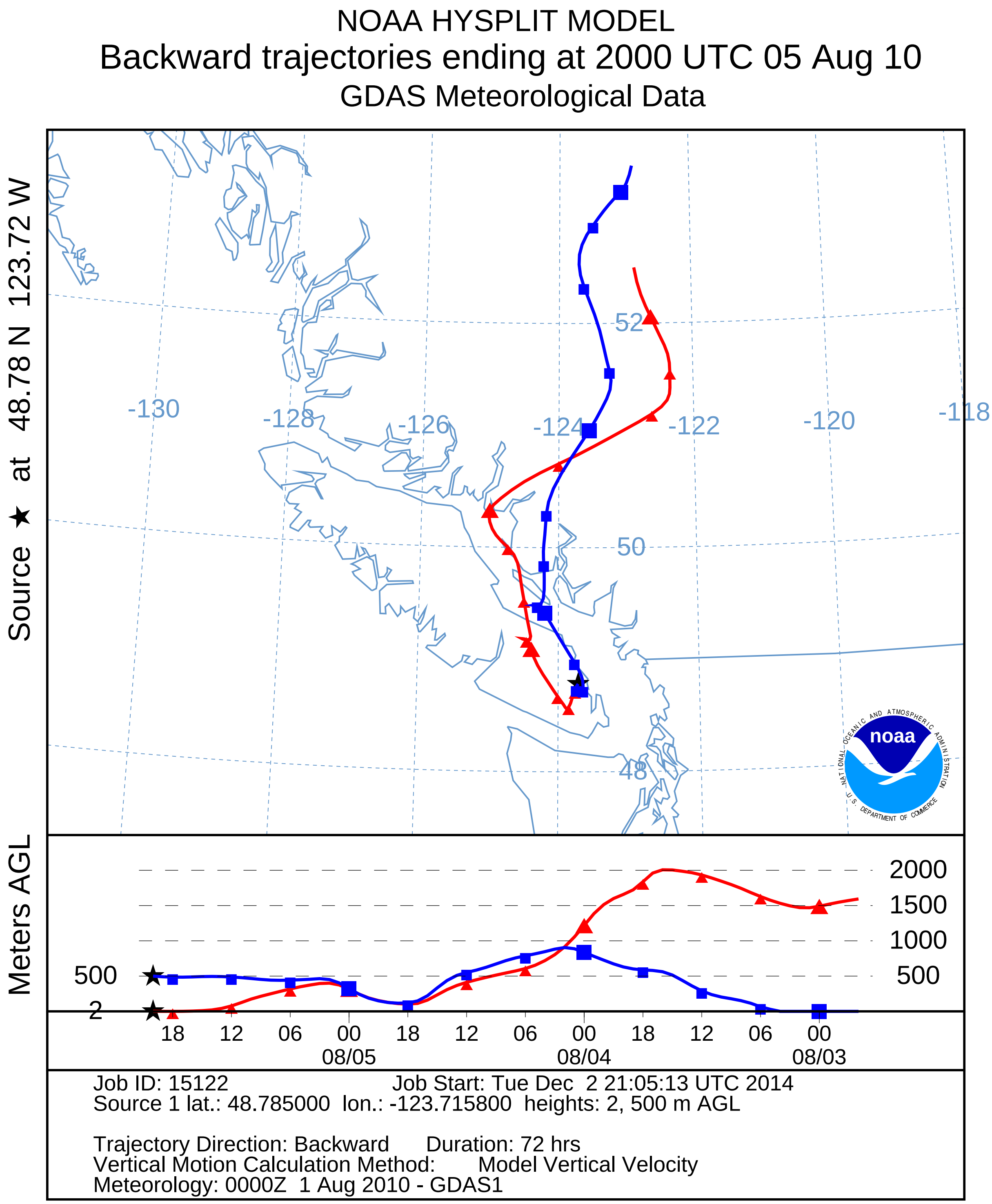


Figure 3-49 Modelled 72-Hour Back-Trajectory for Air Arriving at Duncan Cairnsmore at 12:00 LST on August 5, 2010

3.2.6 Total Reduced Sulphur

Ambient concentration data for TRS were available from the Crofton Substation, Crofton Escarpment Way, and Duncan Deykin Avenue monitoring stations. Measurement of TRS at Crofton Substation and Duncan Deykin Avenue began prior to 2003 and continued through 2013. At Crofton Escarpment Way, TRS measurements began in October 2008 and continued through 2013.

Total reduced sulphur includes a variety of compounds containing sulphur and hydrogen, occasionally carbon, but not oxygen. Examples include hydrogen sulphide (H_2S), methyl mercaptan (CH_4S), dimethyl disulfide (CH_3SSCH_3), and carbon disulfide (CS_2). TRS originates as a by-product of the Kraft pulp manufacturing process, the processing of sour natural gas and crude oil, and certain manufacturing processes (e.g., heavy water manufacture). Natural sources include anaerobic decomposition of organic matter and biological reactions in sea water resulting in TRS emissions from sea surfaces.

TRS is measured by first converting reduced sulphur compounds into SO_2 and then measuring the SO_2 concentration, which can be converted to TRS, expressed as if it were all in the H_2S form (Jacques Whitford 2004). The conversion of reduced sulphur compounds to SO_2 is done by oxidation in an oven heated to 900°C. The UV fluorescence instruments used to make the SO_2 measurements were TECO 43A (Crofton Escarpment Way and Duncan Deykin Avenue) and TECO 43C (Crofton Substation) models.

Annual average TRS concentrations showed considerable variability, ranging from 0.5 ppb to 1.7 ppb at Crofton Substation, from 0.3 ppb to 0.9 ppb at Crofton Escarpment Way, and from 0.1 ppb to 0.4 ppb at Duncan Deykin Avenue. The mean annual values decreased with distance from the Crofton Mill. Figure 3-50 shows the change in annual average TRS concentration from 2003 to 2013 at Crofton Substation. The figure shows that the lowest levels occurred in 2009 and then there is an increase in TRS concentrations from 2009 to 2013 which may be related to emissions from the Crofton Pulp and Paper Mill. The Crofton Mill curtailed production throughout 2008 and was fully shutdown from March 9, 2009 to September 30, 2009. Accordingly, TRS emissions reported by the Crofton Mill show that there was a decrease in 2009. The TRS emissions from the mill then increased again in 2010 and 2011as the mill gradually worked back up to full production and there were fewer facility shutdowns (Houle 2014). Time series graphs of all hourly TRS data are included in Appendix B.

Ambient air quality objectives for TRS are based on 1-hour and 24-hour averaging periods. Results for the 1-hour averaging period are shown in Figure 3-51, Figure 3-52, and Figure 3-53 for the Crofton Substation, Crofton Escarpment Way, and Duncan Deykin Avenue stations, respectively. The box and whisker plots show that mean and median TRS values were low at each station, but there were episodes of much higher concentrations that may have caused odour issues.

The summary table for TRS in Appendix B indicates that, for the years 2003–2013, the frequency of exceedance of the 1-hour BC Level A objective of 5 ppb at Crofton Substation ranged from 1.5% in 2009 to 8.9% in 2003. The frequency of exceedance of the objective dropped with distance from the Crofton Mill. At Crofton Escarpment Way, the highest frequency of exceedance of the 1-hour objective was 1.3% in 2013, and at Duncan Deykin Avenue the highest frequency of exceedance was 0.8% in 2003 and 2005.

Results for the 24-hour average data follow a similar pattern, but with higher frequencies of exceedance of the BC Level A objective of 2 ppb. At Crofton Substation, the frequency of exceedance of the 24-hour objective ranged from 4.0% in 2008 to 30.1% in 2013. At Crofton Escarpment Way, the frequency of exceedance ranged from 0% in 2008 to 6.6% in 2012. At Duncan Deykin Avenue, four of the eleven years had no exceedances of the 24-hour objective and the highest frequency of exceedance was 1.5% in 2003 and 2013.

Box and whisker plots for the 24-hour average TRS data are shown in Figure 3-54, Figure 3-55, and Figure 3-56 for the Crofton Substation, Crofton Escarpment Way, and Duncan Deykin Avenue stations, respectively. The plots also indicate the episodic nature of relatively high TRS concentrations, which are most likely caused by operational upsets at the Crofton Mill.

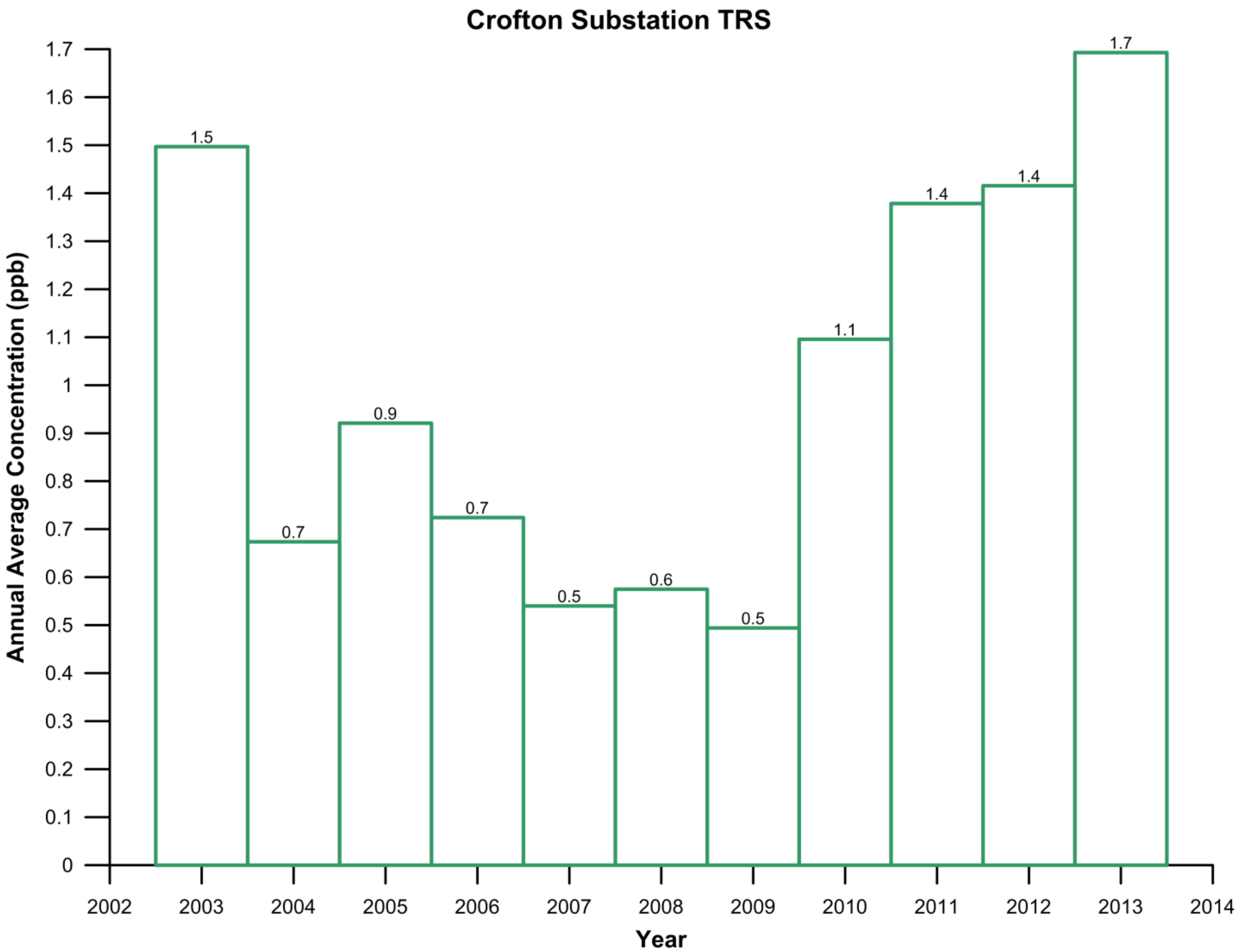


Figure 3-50 Annual Average TRS Concentration at Crofton Substation for 2003–2013 Data

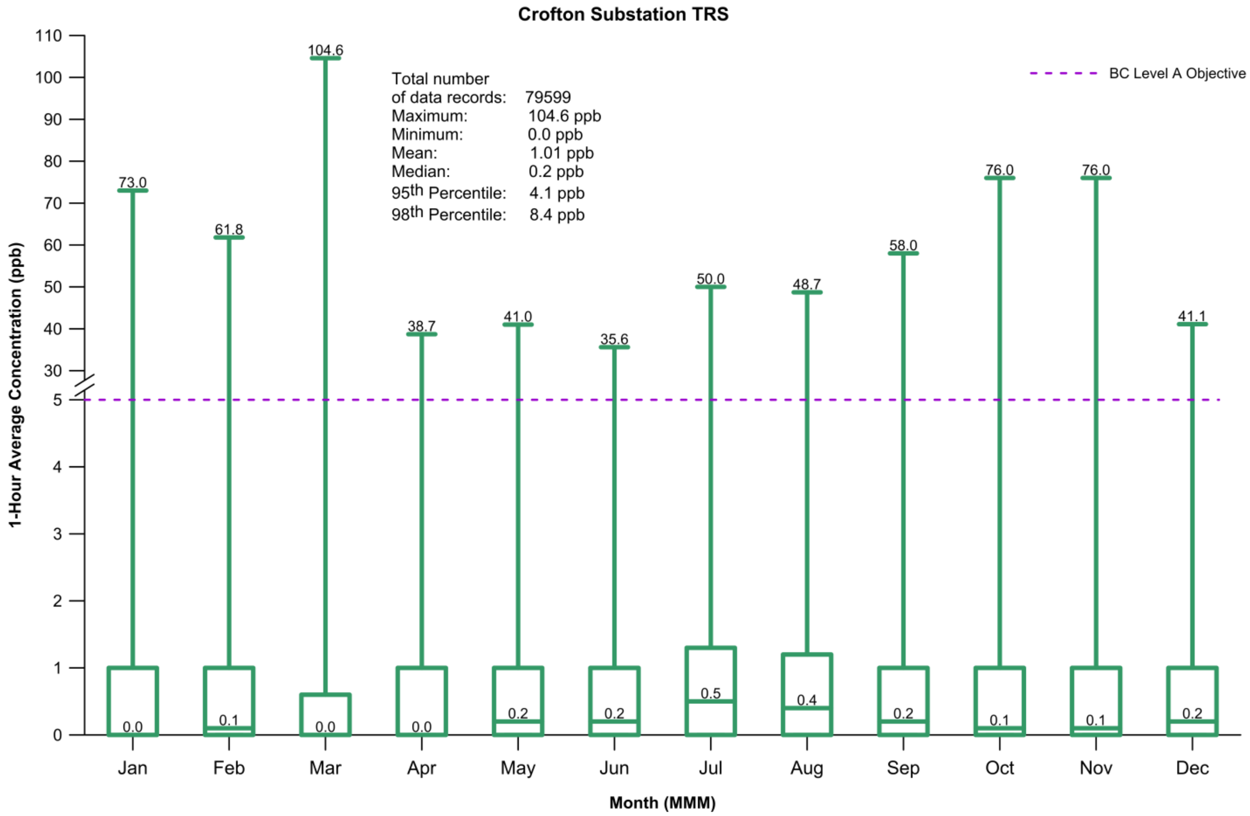


Figure 3-51 Monthly Variation of 1-Hour Average TRS Concentration at Crofton Substation Based on 2003–2013 Data

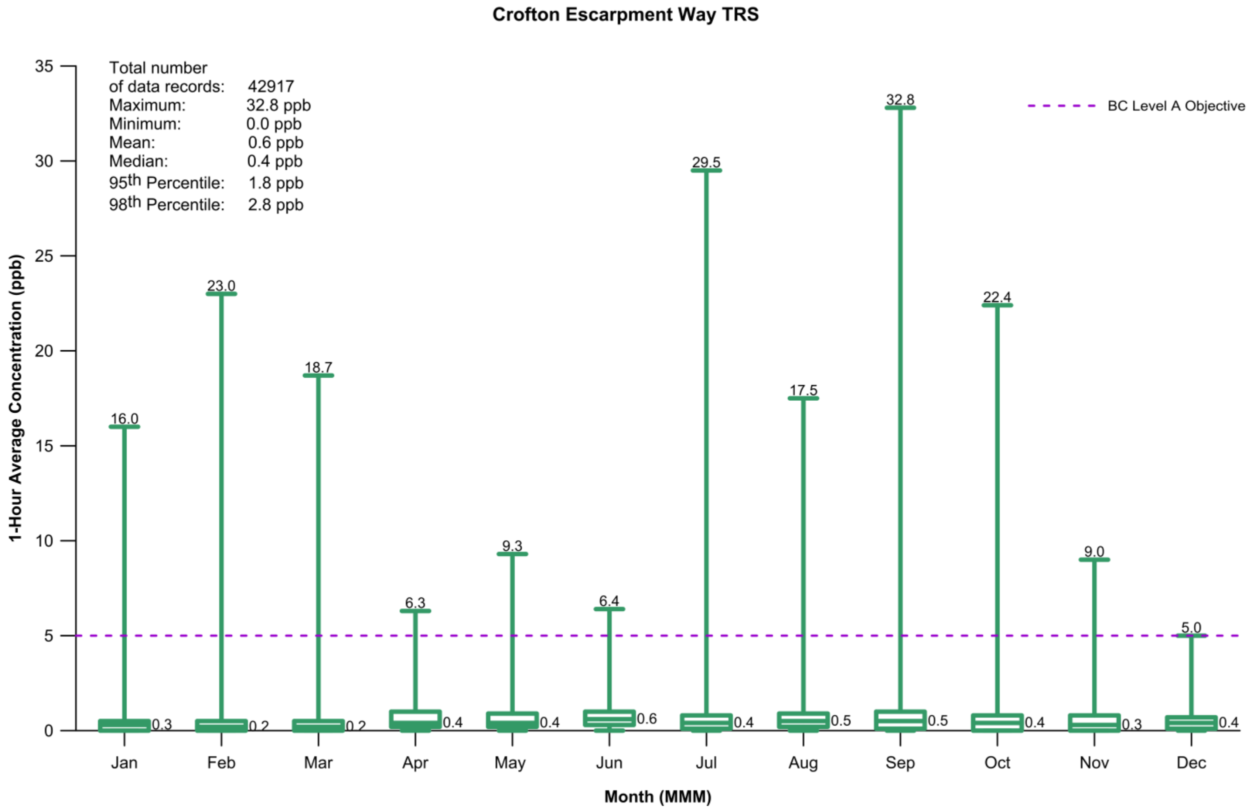


Figure 3-52 Monthly Variation of 1-Hour Average TRS Concentration at Crofton Escarpment Way Based on 2008–2013 Data

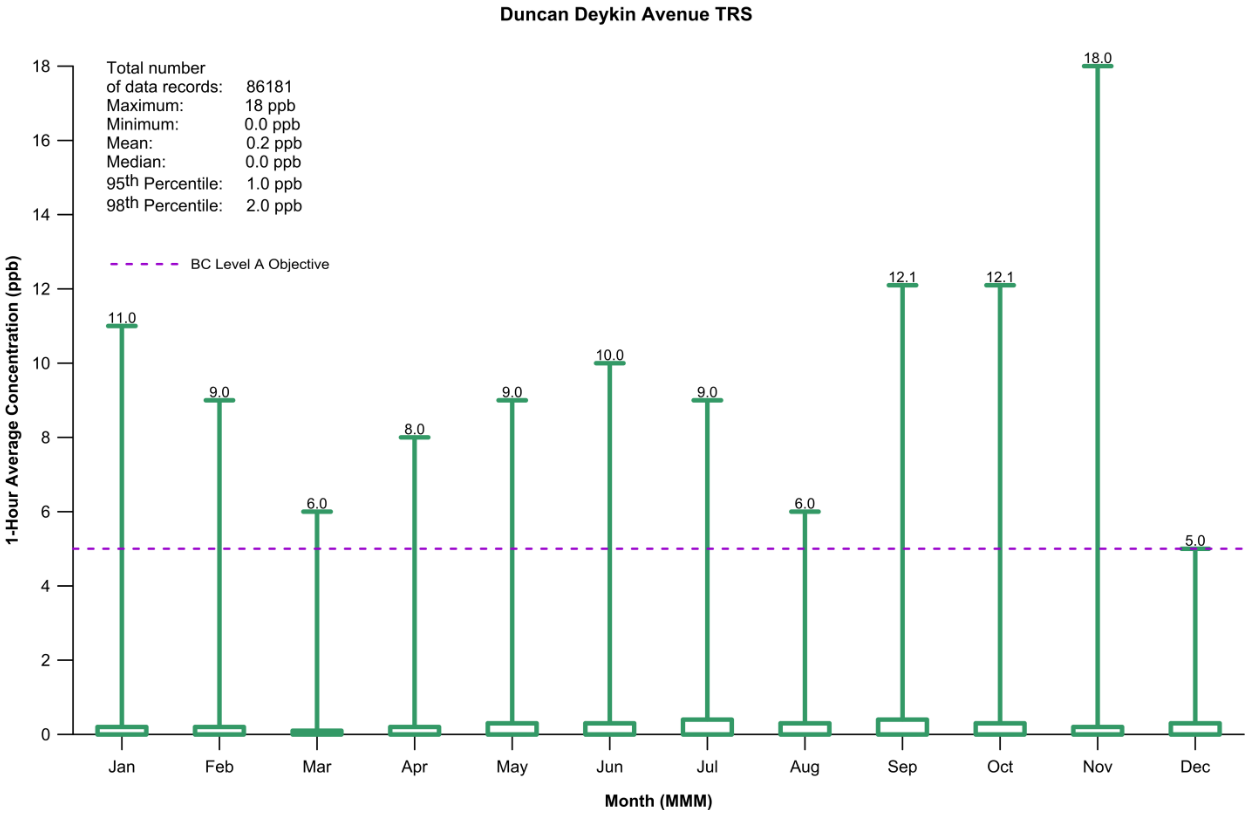


Figure 3-53 Monthly Variation of 1-Hour Average TRS Concentration at Duncan Deykin Avenue Based on 2003–2013 Data

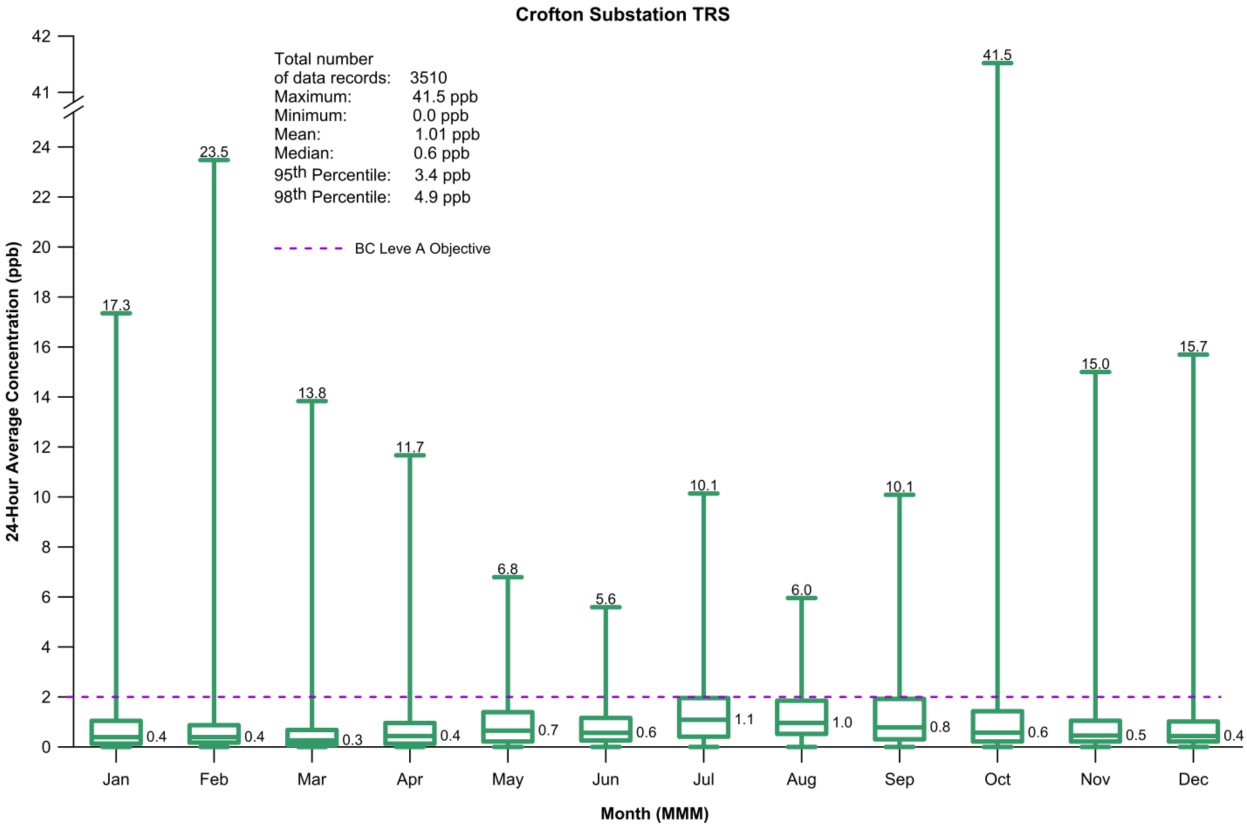


Figure 3-54 Monthly Variation of 24-Hour Average TRS Concentration at Crofton Substation Based on 2003–2013 Data

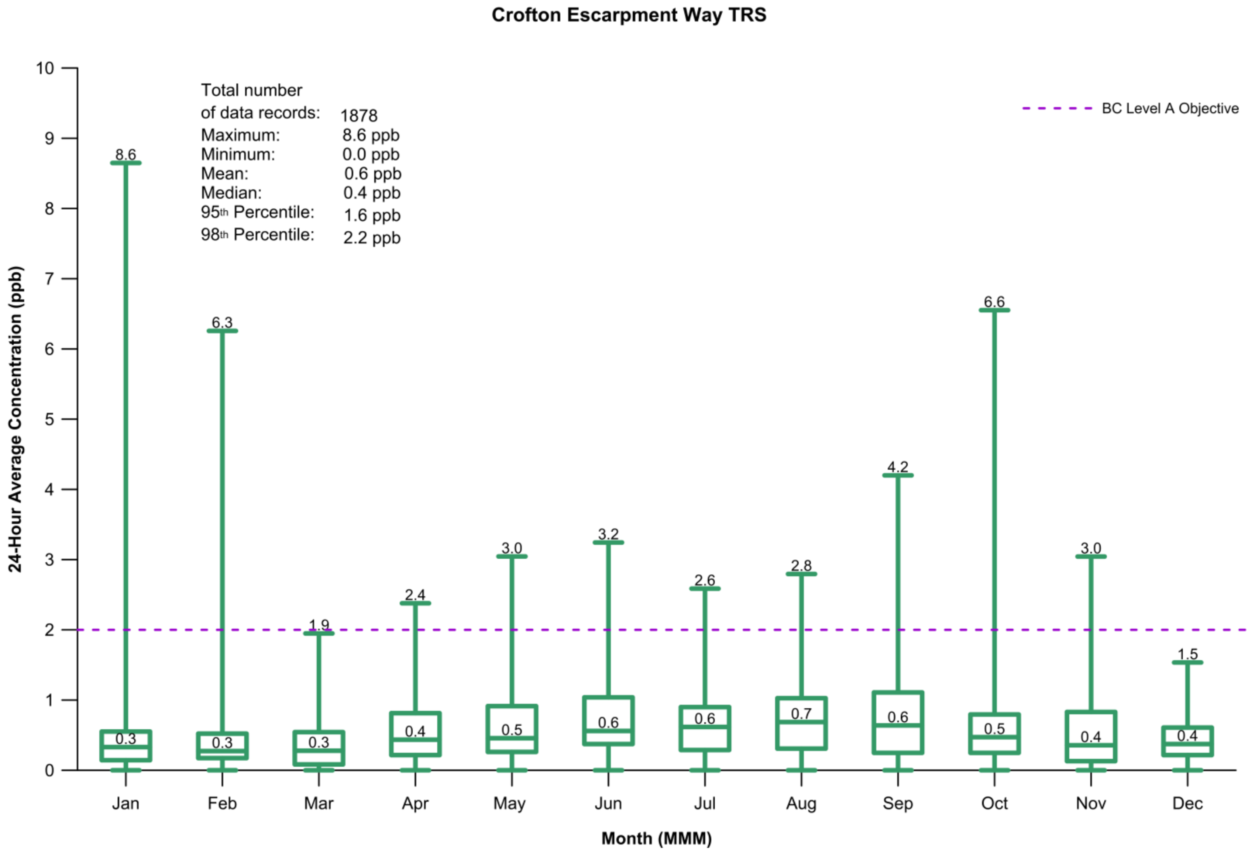


Figure 3-55 Monthly Variation of 24-Hour Average TRS Concentration at Crofton Escarpment Way Based on 2008–2013 Data

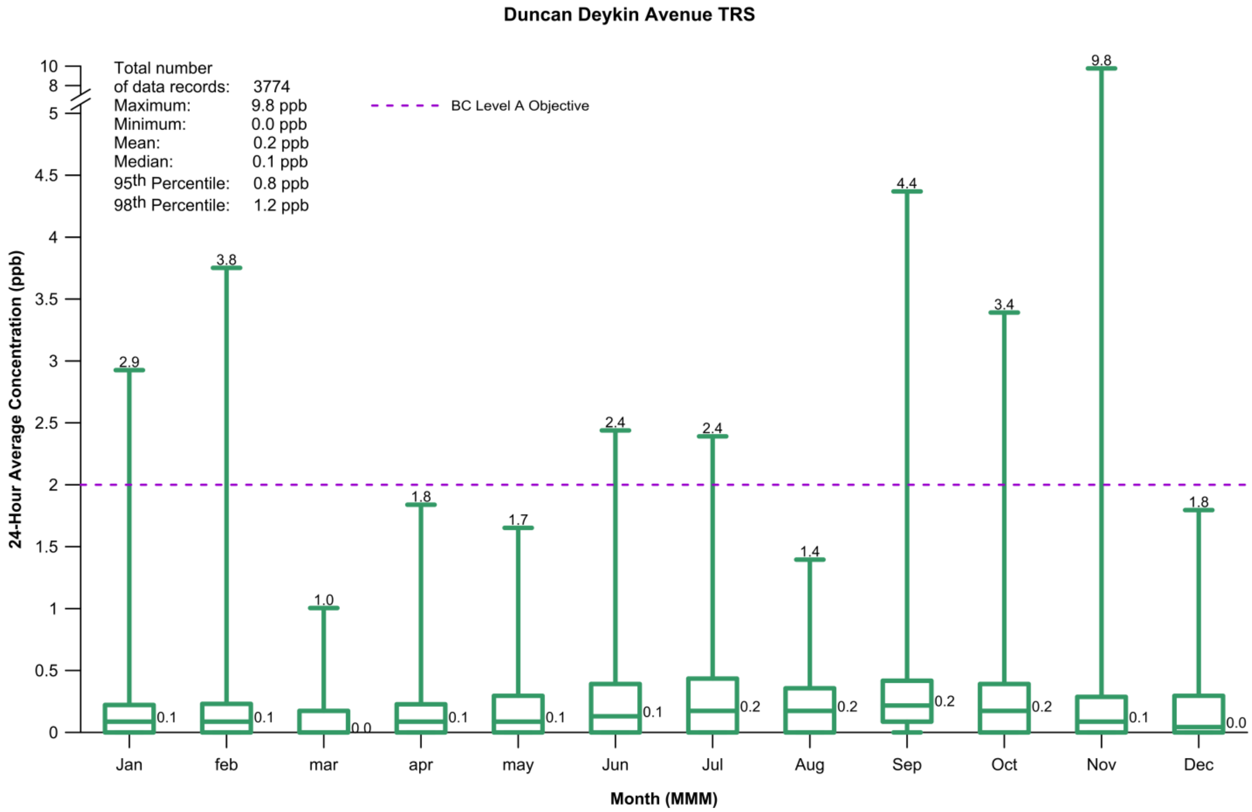


Figure 3-56 Monthly Variation of 24-Hour Average TRS Concentration at Duncan Deykin Avenue Based on 2003–2013 Data

3.2.6.1 Diurnal Patterns

Diurnal trends in average hourly concentration are shown in Figure 3-57 for the three stations with TRS data. The Crofton Substation site had a well-defined diurnal peak TRS concentration in late morning, similar to the pattern found for SO_2 (Figure 3-14). This is probably due primarily to shoreline fumigation events associated with the Crofton Mill. The Crofton Escarpment Way and Duncan Deykin Avenue stations had just minor late morning maxima in TRS concentration, suggesting that the fumigation effect for TRS was much less common just a few kilometres inland.

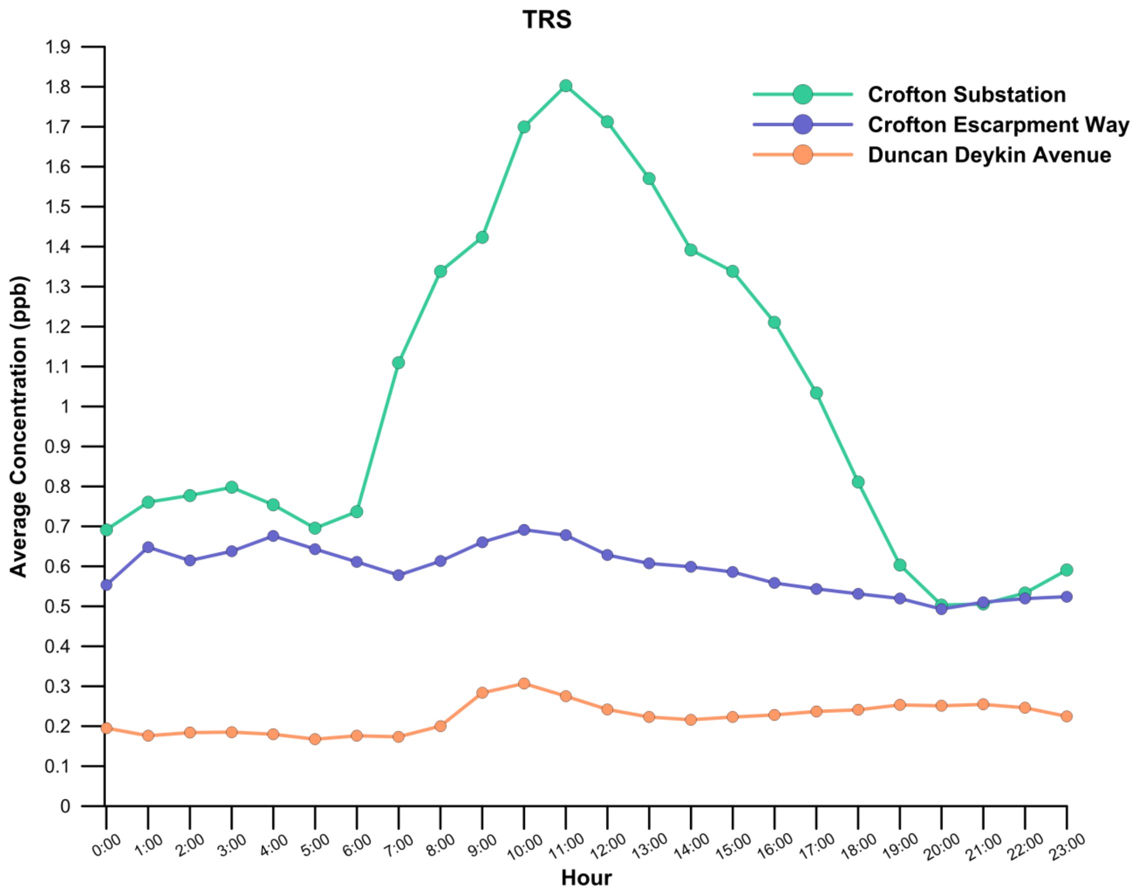


Figure 3-57 Diurnal Trends in TRS Concentration Based on all Available Hourly Data

3.2.6.2 Hebdomadal Patterns

Mean concentrations for each day of the week are plotted in Figure 3-58 for the three stations with TRS data. Similar to the results for SO_2, average TRS concentrations were essentially the same for each day of the week, reflecting fairly steady operations at the Crofton Mill. As with $PM_{2.5}$ (Figure 3-42), the highest daily average concentration at Crofton Substation occurred on Thursday.

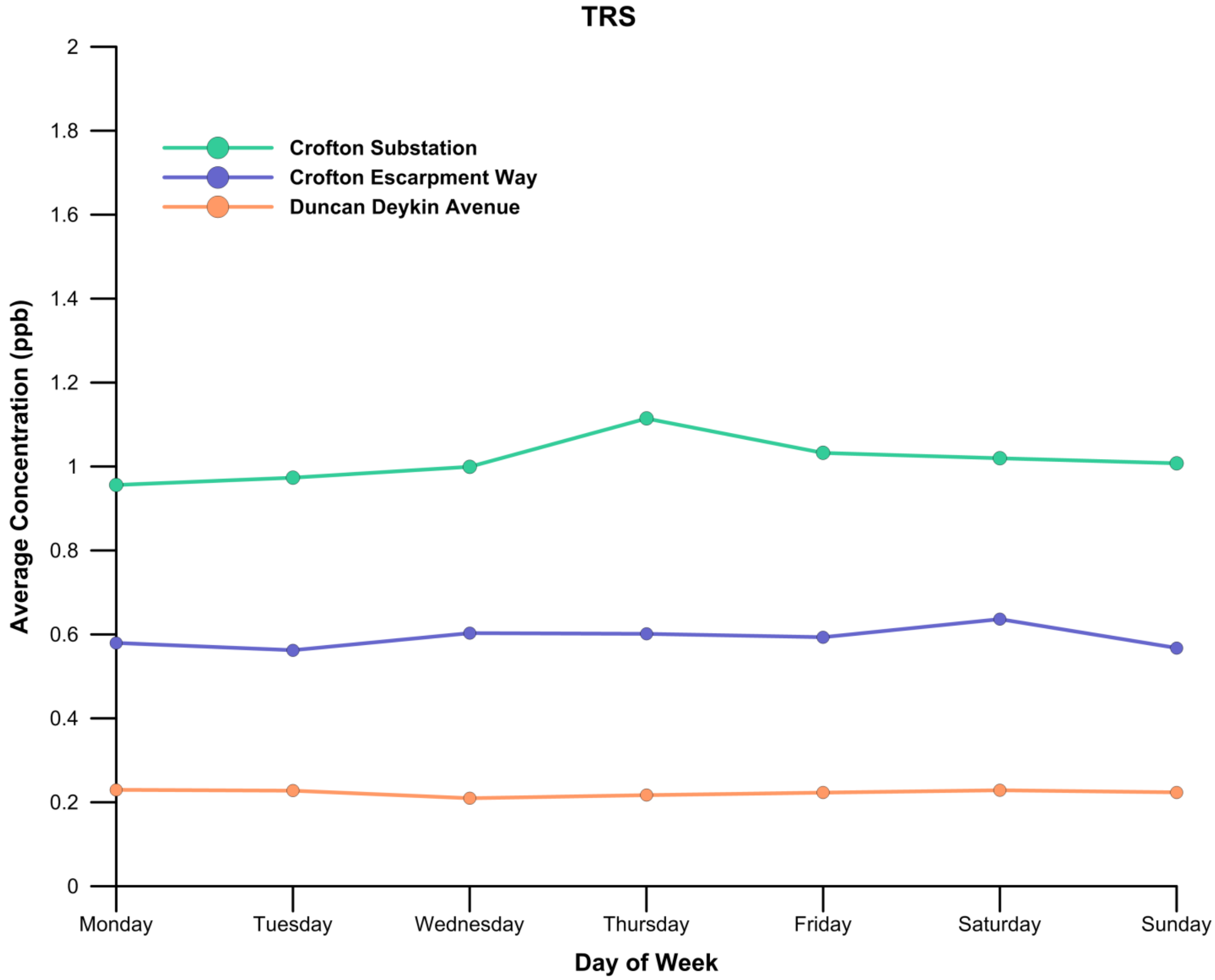


Figure 3-58 Average TRS Concentration by Day of Week at Crofton Substation, Crofton Escarpment Way, and Duncan Deykin Avenue

3.2.6.3 Pollution Roses

A pollution rose for TRS at Crofton Substation is shown in Figure 3-59. The TRS pattern rose for Crofton Substation is similar to that of SO_2, with highest concentrations during north through east winds and low concentrations during southerly flow due to the close proximity to the Croton Mill.

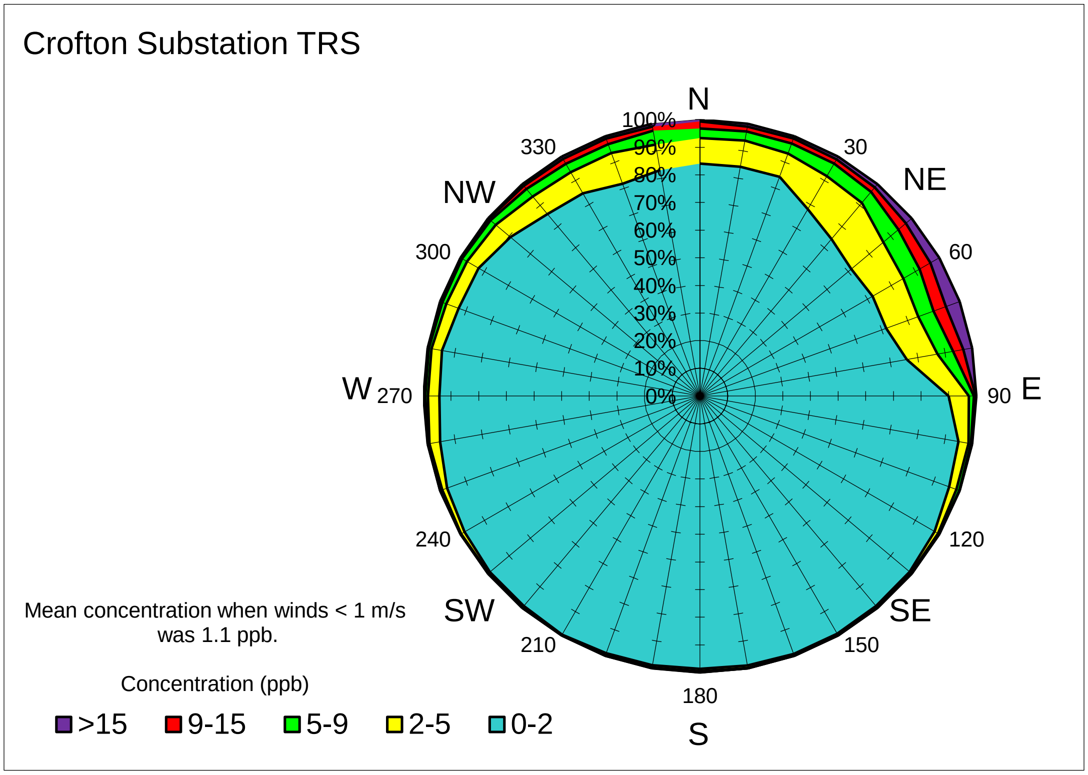


Figure 3-59 Pollution Rose for TRS at Crofton Substation Based on 2008–2013 Data

3.2.7 Ozone

The Duncan Cairnsmore monitoring site is the only station in the CVRD that measures ambient O_3 concentrations. Ozone measurements began in late July 2009 and continued through 2013.

Ozone is measured using a method based on UV photometry. Ultraviolet light is absorbed in proportion to the amount of ozone present in the sample chamber of the instrument. Ozone concentration can be calculated from the intensity of UV light measured along with the ambient pressure and temperature. The instrument model used at Duncan Cairnsmore is a Teledyne API 400E ozone analyzer.

Ground-level ozone is considered a secondary pollutant because it is produced through chemical reactions involving other, precursor substances. Oxides of nitrogen react with VOCs and sunlight to form O_3 (BC MOE 2013a). Ozone is also termed a downwind substance because these chemical reactions occur over a matter of hours, which means that areas downwind of precursor substance sources often experience the highest concentrations. The relatively long lifespan of O_3 in the atmosphere also means that it can—in certain atmospheric conditions—be carried long distances across regions, and even across continents and oceans, a phenomenon known as long-range transport.

Ozone concentrations in the Northern Hemisphere have been found to exhibit a springtime maximum at relatively rural and remote sites, while urban areas with local photochemical production of O_3 tend to have their annual maxima in summer when the most sunlight is available. Annual average background O_3 levels in the Northern Hemisphere typically range from 20 ppb to 45 ppb (Vingarzan 2004).

There are AAQO for O_3 for the 1-hour and 8-hour averaging periods. The annual average O_3 concentrations for the years 2010 to 2013 at the Duncan Cairnsmore station are shown in Figure 3-60. The year 2009 was not included because it did not meet the 75% data completeness requirement. Annual mean concentrations ranged from 16.2 ppb in 2013 to 20.2 ppb in 2012. The values are at the low end of the background O_3 range found by Vingarzan (2004).

Results for the 1-hour averaging period are shown in Figure 3-61. A springtime maximum is clearly evident, as the highest median concentration occurred in April. However, there are no exceedances of the 1-hour NAAQO of 82 ppb. The lowest O_3 concentrations were in December and January.

The 24-hour average box and whisker plot (Figure 3-62) shows a similar pattern. Monthly median values exceeded 15 ppb from March through September. The 8-hour O_3 CAAQS is not a straightforward metric based on the maximum value as is the case with most AAQO. It is based on the annual 4th highest daily 8-hour maximum, averaged over three consecutive years (BC MOE 2014b). The tabular summary for O_3 in Appendix B shows that this value was 48 ppb for the years 2010–2012, and 49 ppb for 2013, making the Duncan Cairnsmore station well within the CAAQS of 63 ppb.

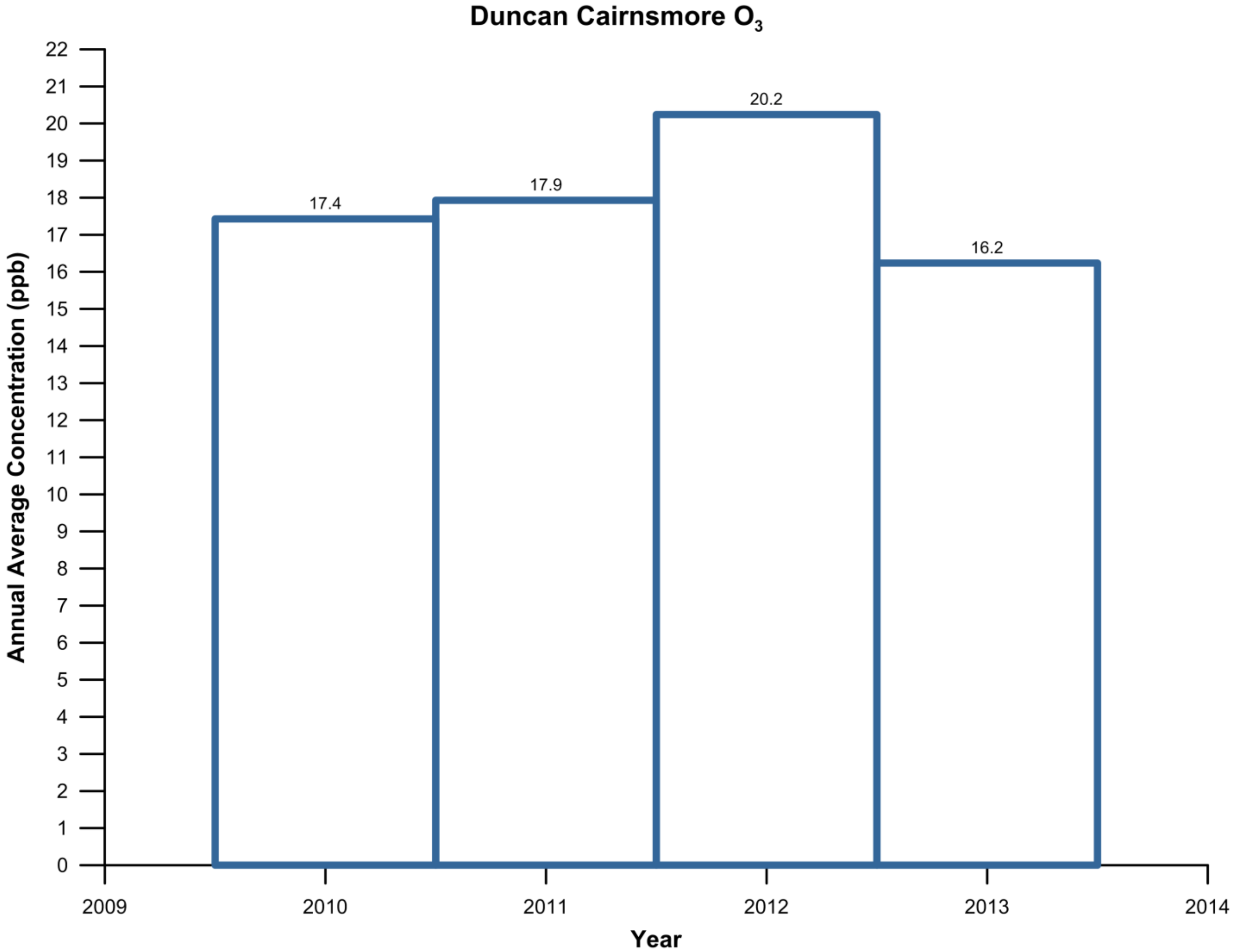


Figure 3-60 Annual Average O_3 Concentrations at Duncan Cairnsmore for 2010–2013

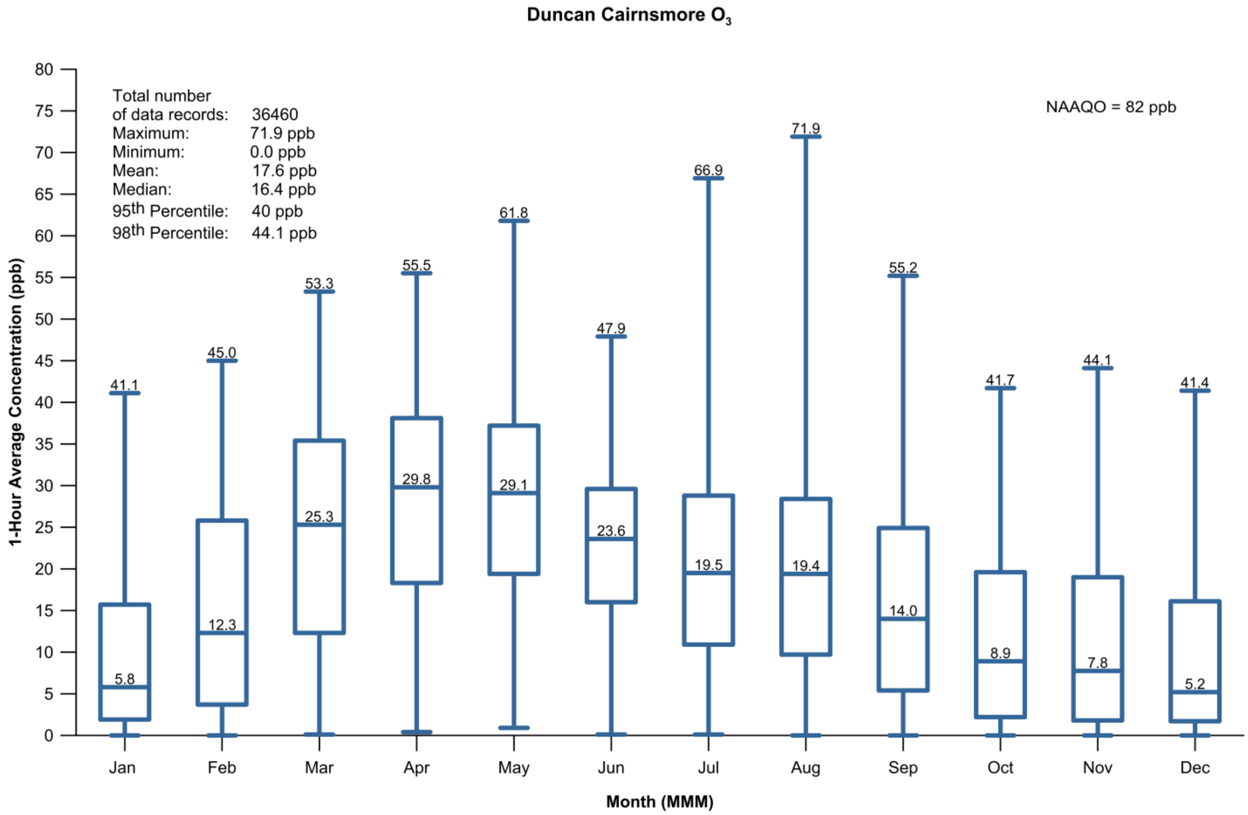


Figure 3-61 Monthly Variation of 1-Hour Average O_3 Concentration at Duncan Cairnsmore Based on 2009–2013 Data

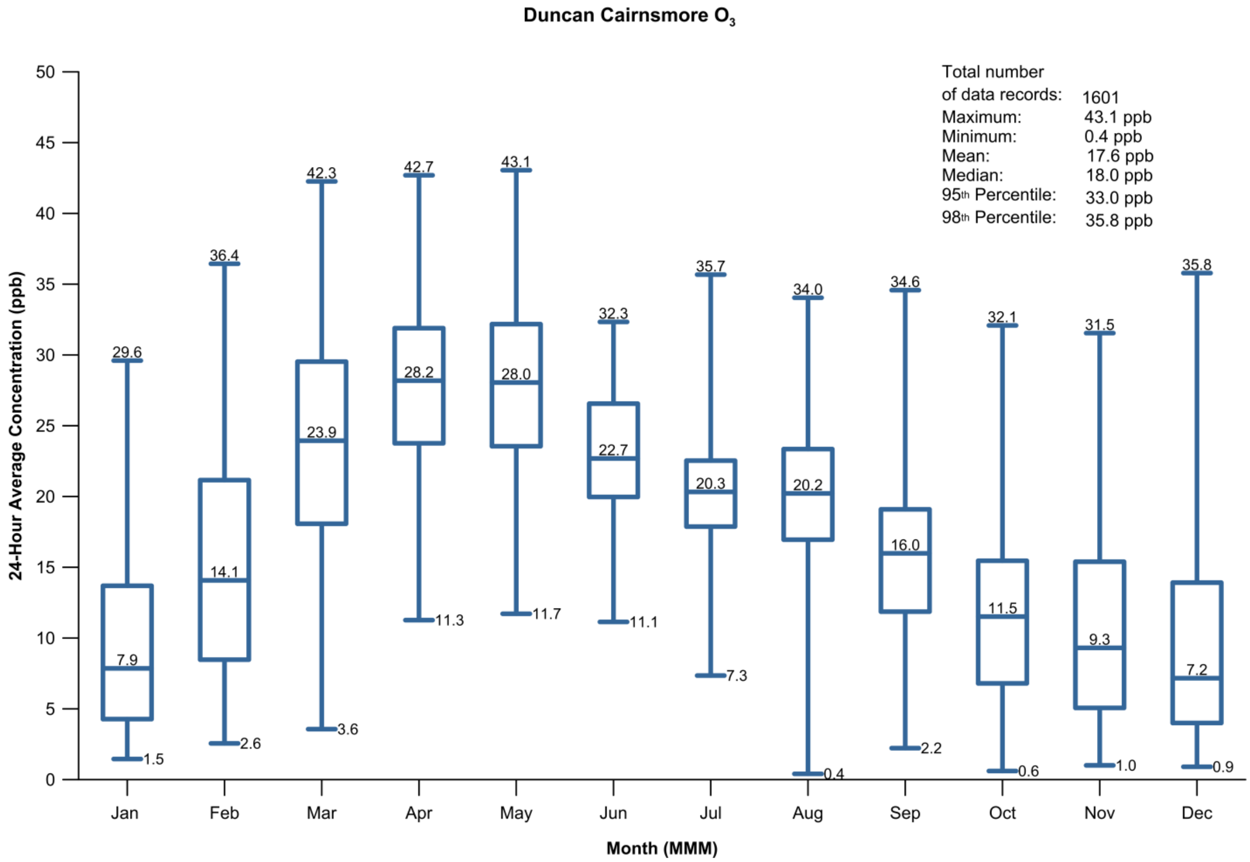


Figure 3-62 Monthly Variation of 24-Hour Average O_3 Concentration at Duncan Cairnsmore Based on 2009–2013 Data

3.2.7.1 Diurnal Patterns

Diurnal trends in average hourly O_3 concentration are shown in Figure 3-63 for the each season at Duncan Cairnsmore. Concentrations were highest in spring, followed by summer, fall, and winter. There was a well-defined diurnal peak in the afternoon hours for all seasons, indicating some local photochemical production of O_3. The nighttime decrease in O_3 may be due to chemical reactions with NO that scavenge O_3 to produce NO_2 (BC MOE 2013a). Also, O_3 that is produced during the day will tend to be transported downwind away from the precursor chemical sources by nighttime.

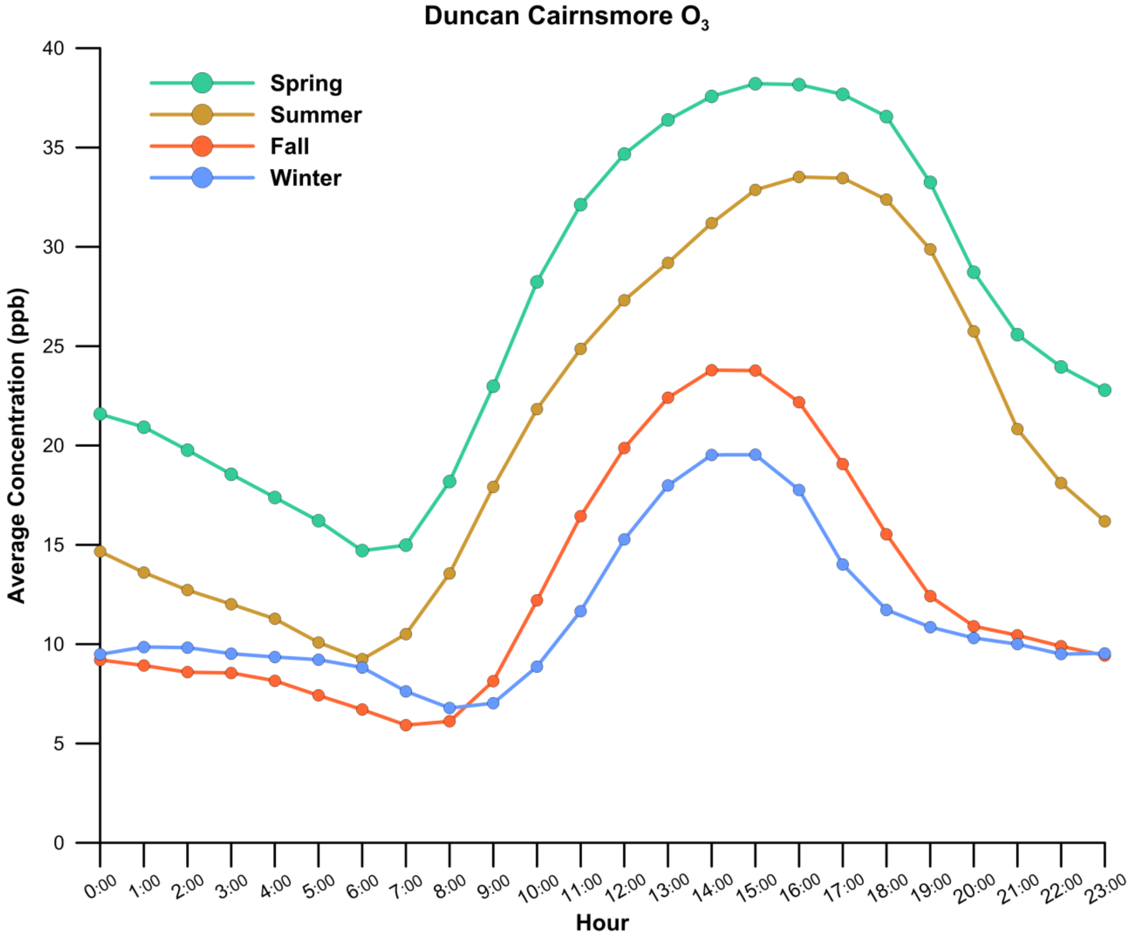


Figure 3-63 Diurnal Trends in O_3 Concentration at Duncan Cairnsmore by Season

Additional analysis of diurnal trends in O_3 concentration was done using a hierarchical cluster analysis developed by Bohm et al. (1995a, 1995b). This technique involves matching diurnal O_3 patterns to 17 characteristic profiles for the months of May to October (the ozone season). In this work, classifying ozone regimes involved a three step process:

I. Classifying each day in the 184 day May through October ozone season into one of 17 diurnal curves through use of a Visual Basic pattern matching algorithm
II. Categorizing each day into one of six defined categories
III. Classifying the day into one of eight regimes based on relative abundance of categories.

Each of the 17 diurnal curves has a letter and number designation, where the letters refers to the shape of the curve. Curves designated "A" have little diurnal fluctuation, whereas "E" curves exhibit large diurnal fluctuations. The number designation refers to the relative magnitude of the

24-h means (“1” being low and “6” being high). These 17 curves are consolidated into six categories designated as follows:

Remote (B1, B2, A3, A4) **Urban/small** (C1, C2, C3) **Urban/medium** (C4)
Inversion (B3, B4) **Urban/transport** (A5, A6, B5, C5, C6) **Urban/large** (D4, E5)

Classifying regimes is done by comparing the relative abundance or absence of diurnal curves falling in each of the six categories against the definitions for the eight regimes provided in Bohm, et al. (1995a, 1995b).

Four of the five available years (2010 to 2013) were analyzed with this technique. The 2009 data were not used because the May to October ozone season dataset was incomplete. The results are summarized in Figure 3-64. The analysis classifies the site as “Small-Urban”, which is consistent with the setting. It is dominated by the “remote” curves (57%), with frequent occurrences of the “urban/small” category of curves (38% of days). The “Inversion” curves were experienced occasionally (5%). None of the days fit the “transport” regime definition, suggesting that transport of O_3 from the Lower Fraser Valley (or most distant sources) is not an important factor. Note that the scheme does not classify a site as “Remote” unless 85–90% of the days fit that definition.

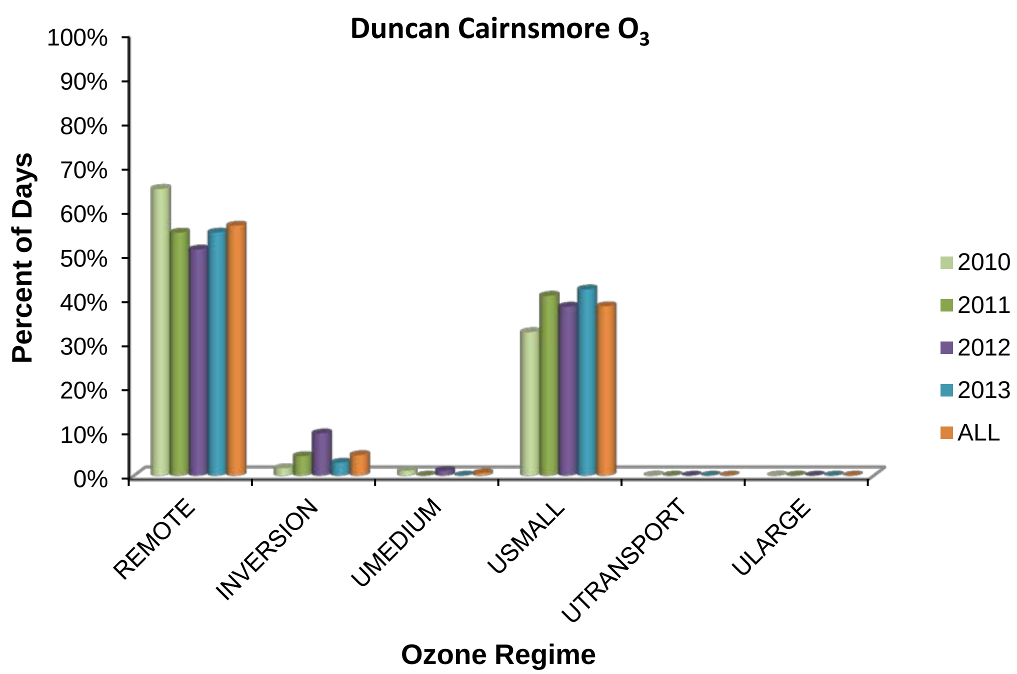


Figure 3-64 Ozone Regimes for Duncan Cairnsmore Based on a Hierarchical Cluster Analysis of 2010–2013 Data

3.2.7.2 Hebdomadal Patterns

Average weekday (Monday to Friday) and weekend (Saturday and Sunday) O_3 concentrations for each month are shown in Figure 3-65. Mean concentrations for each day of the week are shown in Figure 3-66. There was little variation in average concentration based on day of week, but there was a tendency for O_3 values to be slightly higher on weekends for eight of the twelve months. One possible explanation for this observation is that there is less nitric oxide (NO) available on the weekend for overnight scavenging of O_3 (see Figure 3-29).

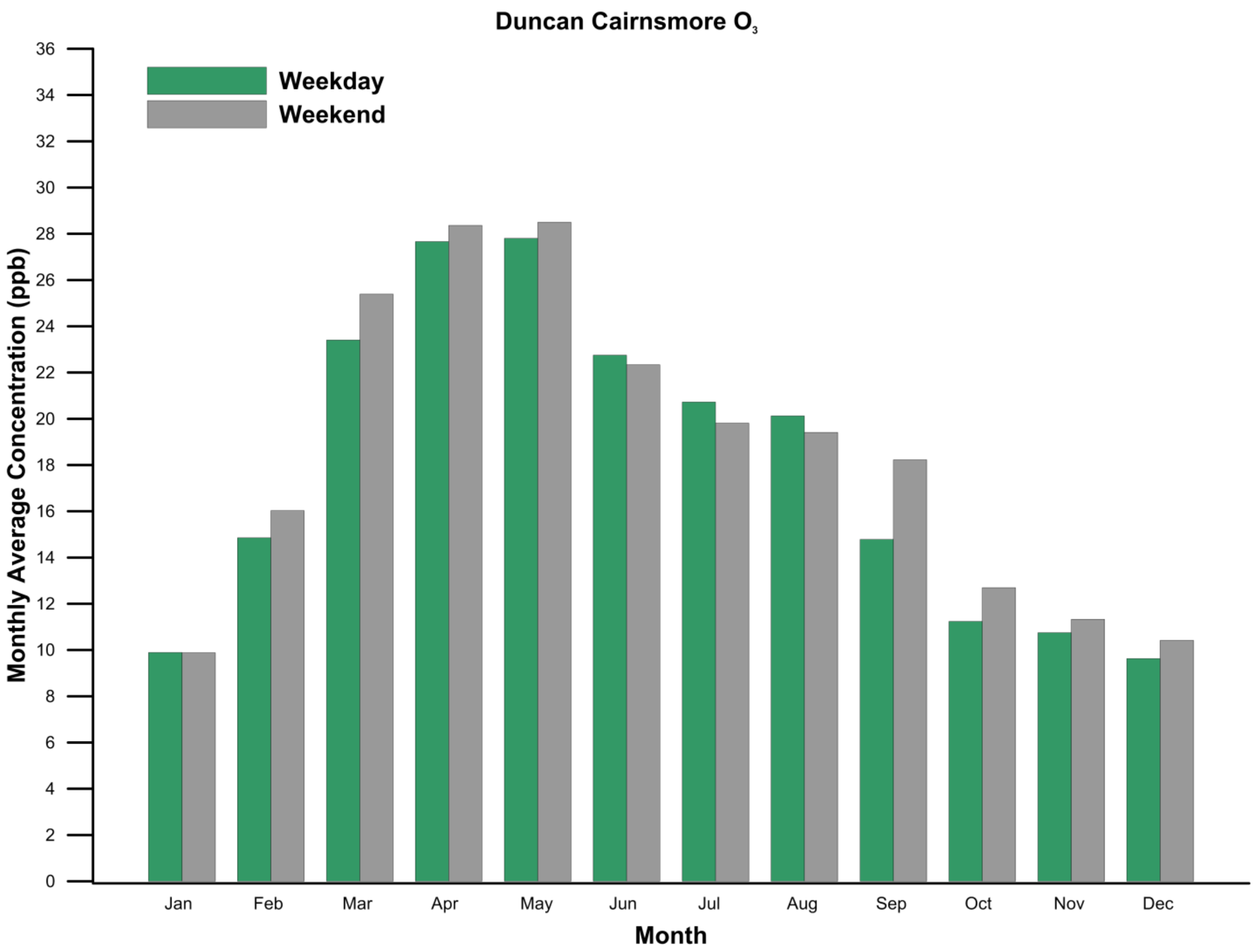


Figure 3-65 Monthly Average O_3 Concentration for Weekdays and Weekends at Duncan Cairnsmore Based on 2009–2013 Data

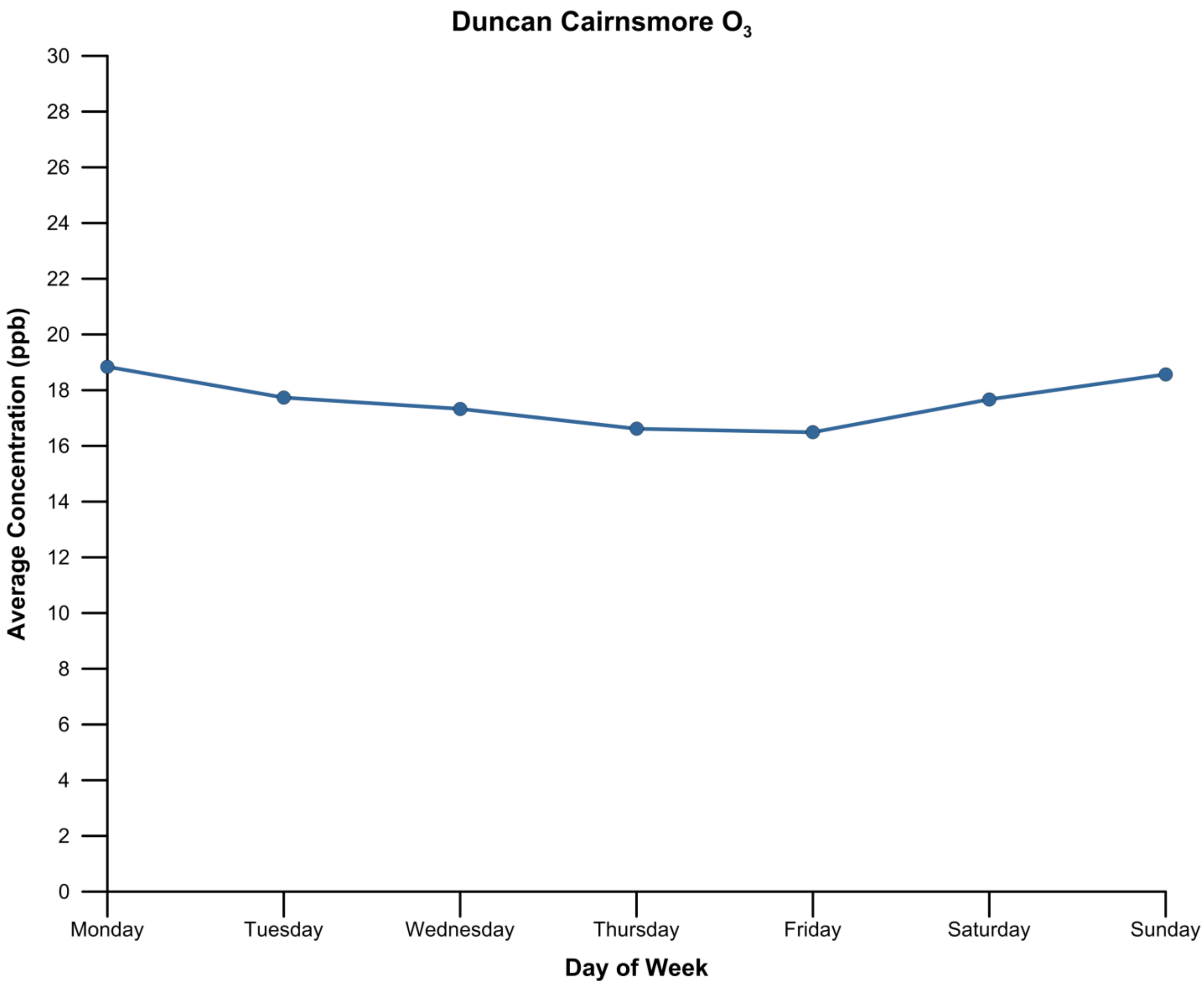


Figure 3-66 Average O_3 Concentration by Day of Week at Duncan Cairnsmore

3.2.7.3 Pollution Roses

A pollution rose for O_3 at Duncan Cairnsmore, is shown in Figure 3-67. There was a tendency for higher O_3 concentrations to occur with winds from the southeast. This correlates with the diurnal pattern found in both O_3 (Figure 3-63) and wind direction (Appendix A), particularly in the summer season. The diurnal peak in O_3 and the southeasterly sea breeze both occurred in the afternoon hours when solar radiation was most abundant. High concentrations during southeast winds may also be partially attributable to sources of precursor substances being plentiful southeast of the monitoring station. Since O_3 sources are not located in one specific location the pollution rose pattern for O_3 resembles the wind rose pattern.

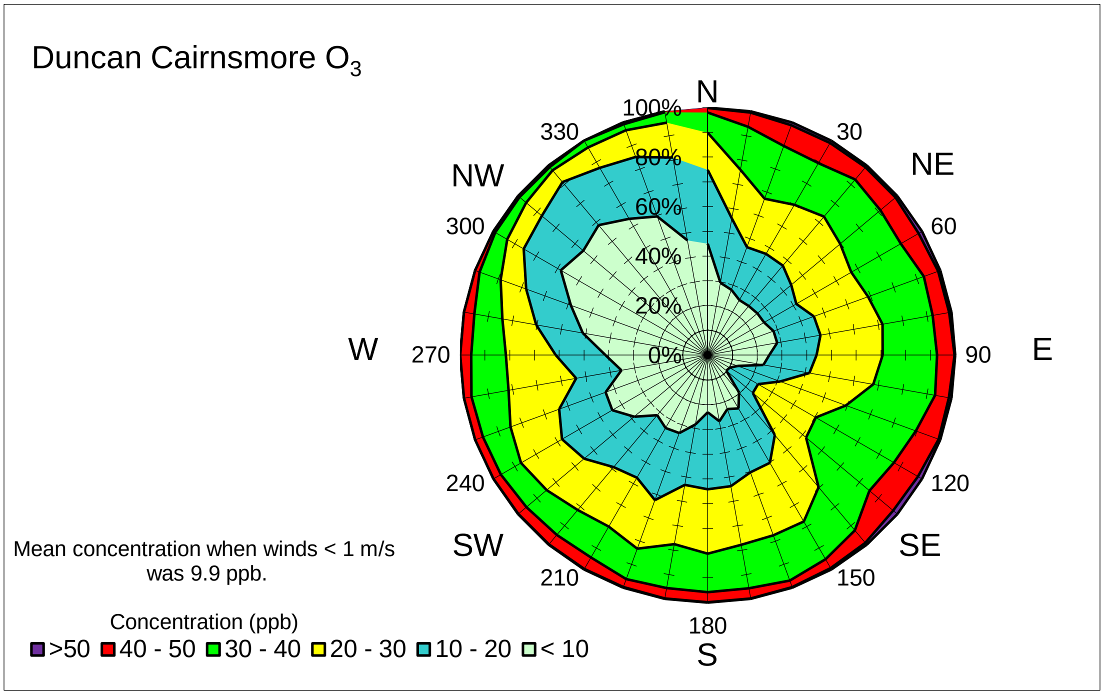


Figure 3-67 Pollution Rose for O_3 at Duncan Cairnsmore Based on 2009–2013 Data

3.2.7.4 Episode Analysis

The highest 1-hour average O_3 concentrations were observed during the month of August (see Figure 3-61). Additional datasets were examined for two episodes of elevated O_3 concentration in order to ascertain the conditions in which elevated levels of the 1-hour NAAQO occur in the Cowichan Valley.

The episode with the highest O_3 concentration during the study period occurred from August 15 to 17, 2010. A maximum O_3 concentration of 71.9 ppb was recorded at the Duncan Cairnsmore monitoring station at 17:00 LST on the 16th. Elevated levels of O_3 were observed in the afternoon hours of all three days. A time series of hourly observations from this period is shown in Figure 3-68. An hour of data was missing from each day (associated with instrument calibration), but the diurnal cycle in O_3 concentration is clearly evident, with peaks in the afternoon hours.

Another O_3 event occurred on August 17, 2012, when the 1-hour average concentration reached 69.1 ppb at 18:00 LST. This event was relatively short-lived in that the day before and day after did not have as elevated levels of O_3.

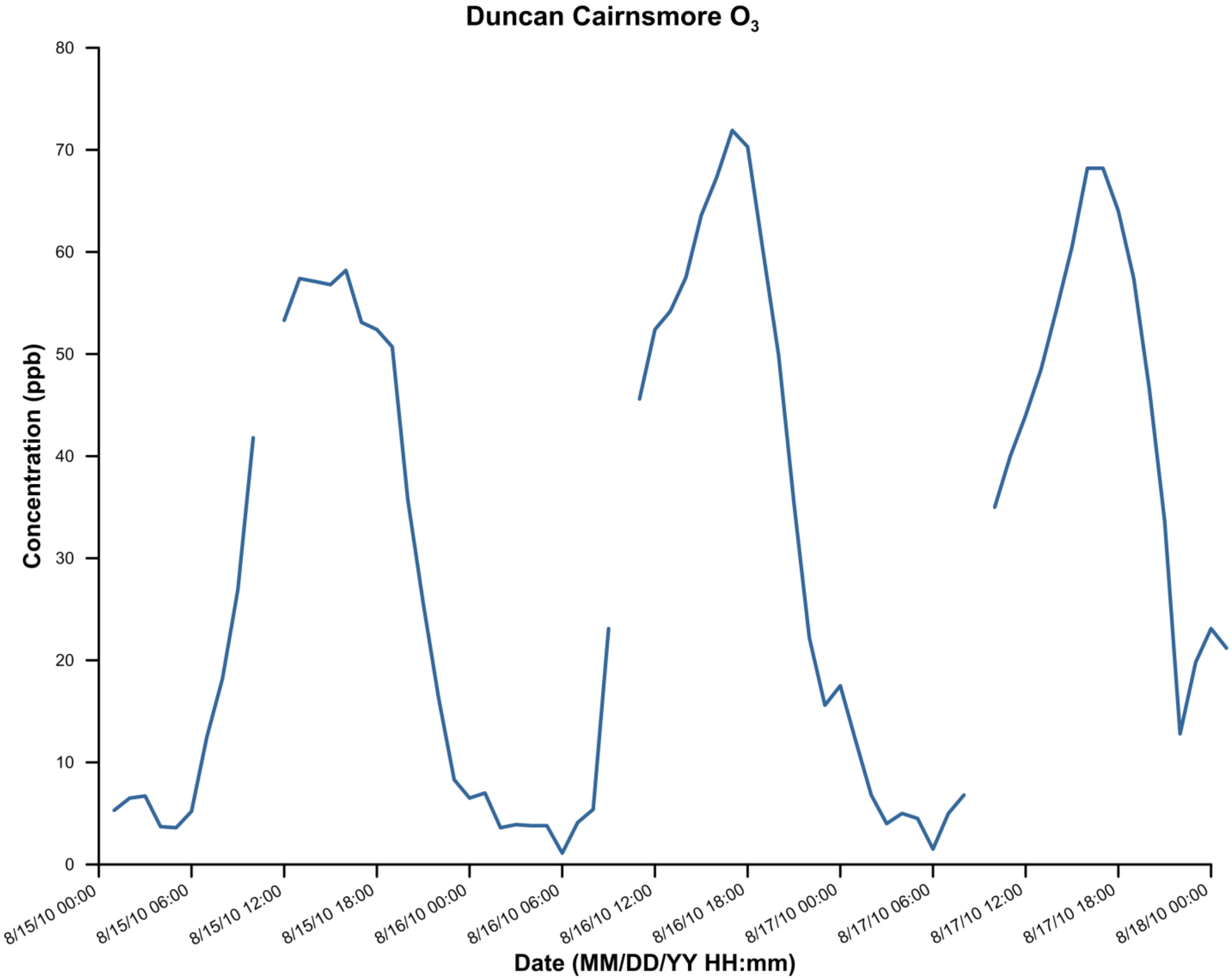


Figure 3-68 Time Series of Hourly O_3 Concentration at Duncan Cairnsmore from August 15–17, 2010

These elevated O_3 episodes both occurred several days into periods of hot, sunny weather. During the 2010 episode, temperatures reached rather extreme highs of 35°C at Duncan Cairnsmore and 34°C at Nanaimo Airport. On August 17, 2012, temperatures reached 32°C at Cairnsmore and 31°C at Nanaimo Airport. Thus, the meteorological conditions were ideal for photochemical production of O_3. The diurnal wind pattern of westerly flow at night and southeasterly winds in the afternoon was observed at the Cairnsmore station during these episodes.

4.0 CONCLUSIONS

Analysis of the SO_2 data sets showed that there are slightly higher concentrations measured at Crofton Substation than at Crofton Escarpment Way. There was little evidence of a seasonal trend with only slightly higher concentrations occurring in the late spring and summer. There were no exceedances of the most stringent BC AAQO for the 1-hour, 24-hour, or annual averaging periods. A diurnal pattern was found for SO_2 concentrations in which average values peaked in late morning and decreased through the night. This pattern was likely due to shoreline fumigation after the onset of onshore (easterly) wind flow. No hebdomadal pattern was apparent for SO_2. The pollution rose for Crofton Substation shows that enhanced SO_2 concentrations were associated mostly with winds from the north through east, from the direction of the Crofton Mill.

The Duncan Cairnsmore monitoring station had the highest NO_2 readings yet all measurements were below the national and provincial objectives. Annual NO_2 analysis at Duncan Cairnsmore showed there is a slight decrease in the annual average over the four year period, which may be due to the decreased emissions from motor vehicles. There was a clear seasonal pattern with lower concentrations in the summer and higher in the winter, likely due to seasonal changes in emissions as well as different meteorological conditions. The diurnal pattern for NO_2 showed two peaks, one in the morning and one in the evening, corresponding to times of peak motor vehicle traffic. A hebdomadal pattern was found for NO_2, with lower concentrations on weekends than during the week. Pollution roses for NO_2 did not show as strong of a dependence on wind direction as SO_2.

The Crofton Substation had the highest PM_{10} readings, with only one day in the period exceeding the BC AAQO. There were no other exceedances at either Crofton substation or Duncan Deykin Avenue. Between the two stations there were slightly different seasonal trends. At Crofton Substation there were slightly higher concentrations in the spring and summer whereas Duncan Deykin Avenue measured higher concentrations in October and February. Sources of PM_{10} are primarily from road dust while open burning and space heating do contribute.

The Duncan Cairnsmore monitoring station had the highest $PM_{2.5}$ readings, with exceedances of the BC AAQO for both the annual and 24-hour averaging periods. Exceedance of the 24-hour BC objective was more common at Duncan Cairnsmore, with one or more days exceeding the BC objective during six of the twelve months. In 2011 there were a total of 21 days above the BC AAQO. Duncan Cairnsmore was also the only station to show a clear seasonal trend in the 24-hour average $PM_{2.5}$ concentrations, with low values in summer and relatively high values in winter. There was also a bimodal peak in the diurnal pattern of $PM_{2.5}$, with maxima in the morning and evening. These patterns are likely attributable to the influence of emissions from space heating, especially woodstoves. Diurnal trend analysis of $PM_{2.5}$ suggests that increased emissions from space heating are a stronger factor to diurnal augmentations of $PM_{2.5}$ than motor vehicle traffic. Hebdomadal concentration patterns also show that weekend levels are higher possibly due to backyard open burning while people are at home. It was also found that exceedances of the 24-hour BC AAQO can occur in summer originating from forest fire smoke from distant origins.

Total reduced sulphur exhibited low average concentrations with short-term peaks that exceeded the most stringent BC AAQO for 1-hour and 24-hour averaging periods. These episodes of higher TRS concentration are mostly associated with emissions from the Pulp and Paper Mill in Crofton. Maximum annual TRS concentrations at locations close to Crofton Mill (Crofton Substation) are more than four times higher than at Duncan Deykin Avenue station.

Mean monthly O_3 concentrations at Duncan Cairnsmore exhibited a springtime peak, but the highest 1-hour average concentrations occurred in August. A well-defined diurnal cycle in O_3 concentration with a late afternoon maximum was observed for all seasons, indicating local photochemical production. Analysis of two high-concentration episodes found no evidence of O_3 transport from the Lower Fraser Valley. Although there is local ground level O_3 generation there were no instances of any exceedances of the O_3 objective for the 1-hour averaging period.

There are some seasonal and day-of-week (hebdomadal) variations in the concentrations, but most of the variability can be attributed to changes in the airshed meteorological conditions. Low concentrations prevail during dynamic meteorological situations, when fronts and low pressure systems bring wind and precipitation to the area, facilitating rapid dispersion of emitted substances. High concentrations occur when stable, stagnant air masses settle over the area for one or more days due to slow-moving high pressure systems. The topography of the Cowichan Valley contributes to the build-up of CACs by confining air emissions in the valley during stable, light wind periods.

In summary, the air quality data at the four monitoring stations in the CVRD found that high concentrations were observed only for certain CACs. There were no exceedances of national or provincial objectives for SO_2, NO_2, or O_3 during the study period, while exceedances of the most stringent objectives were sporadic for $PM_{2.5}$ and TRS. It was also determined that $PM_{2.5}$ concentrations were highest in the vicinity of the densely populated area of Duncan. At this location, air quality was generally below the applicable objectives during the spring and summer months but becomes degraded during the fall and winter months. With respect to the applicable objectives the overall air quality in the CVRD is relatively good in the summer, except for episodes of high TRS concentrations. Air quality often becomes degraded in the winter in the higher populated areas due to episodes of high $PM_{2.5}$ concentrations.

5.0 CLOSURE

Respectfully submitted,

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Meteorological Data

Appendix A METEOROLOGICAL DATA

Supplemental temperature and wind data are provided below for the three primary meteorological stations used in this study: Crofton Met, North Cowichan, and Duncan Cairnsmore.

A.1 TEMPERATURE

Monthly average temperature data for the stations included in Section 3.1.2 are provided for all years with available data during the 2003–2013 study period. Temperature data from the Crofton Met, North Cowichan, and Duncan Cairnsmore stations are provided in Table A-1, Table A-2, and Table A-3, respectively. Monthly mean temperatures from the Canadian Climate Normals Station at Duncan Kelvin Creek are included for comparison.

Table A-1 Monthly Mean Temperatures at Crofton Met for 2003–2013

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2003	7.2	5.8	7.9	9.3	12.6	17.7	19.5	19.0	16.6	12.3	5.8	5.6
2004	5.0	6.1	8.8	11.8	14.4	17.7	20.2	19.8	14.8	11.6	7.7	6.2
2005	4.9	5.5	8.9	10.9	14.6	15.5	18.7	19.3	15.1	11.6	6.4	6.0
2006	7.4	5.3	7.0	9.7	13.5	17.0	19.3	18.2	16.1	11.4	6.9	5.4
2007	4.3	6.1	7.8	9.3	13.0	15.1	19.3	18.0	14.7	10.5	6.8	4.8
2008	4.3	6.1	7.8	9.3	13.0	15.1	19.3	18.0	14.7	10.5	6.8	4.8
2009	3.3	4.6	5.5	9.3	12.9	17.5	20.4	18.3	16.2	11.2	8.4	3.3
2010	7.4	7.3	7.7	9.1	11.8	14.7	18.5	18.4	15.1	11.4	5.8	5.8
2011	5.0	3.9	6.9	7.2	10.5	15.1	17.1	18.3	17.0	10.3	6.2	5.1
2012	4.7	5.2	6.0	9.5	12.2	13.6	17.7	19.2	16.2	12.7	7.1	6.2
2013	4.7	7.4	8.9	11.0	15.5	16.6	20.1	19.0	15.9	9.8	6.7	3.6
Normal [A]	3.6	4.4	6.3	9.1	12.4	15.3	17.9	17.8	15.2	10.1	5.8	3.3

NOTE:
[A] Normal temperatures are 1981–2010 monthly means from the Duncan Kelvin Creek station (Environment Canada 2014a).

Table A-2 Monthly Mean Temperatures at North Cowichan for 2008–2013

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2008	1.9	3.9	4.1	5.9	11.8	13.5	16.5	16.5	13.3	7.8	6.4	0.0
2009	0.7	2.1	3.4	7.5	11.5	16.5	19.3	17.1	14.7	9.5	6.5	0.2
2010	3.3	4.3	4.9	7.8	10.4	14.5	18.4	18.0	14.4	9.7	4.1	3.6
2011	3.0	1.9	5.9	6.0	10.7	14.8	17.0	17.9	15.6	8.8	3.3	2.8
2012	2.4	4.1	4.7	8.9	11.9	13.9	18.2	18.9	15.1	9.8	6.2	3.7
2013	2.3	5.1	6.8	9.0	13.4	16.4	19.7	18.9	15.6	9.5	5.5	2.3
Normal [A]	3.6	4.4	6.3	9.1	12.4	15.3	17.9	17.8	15.2	10.1	5.8	3.3

NOTE:
[A] Normal temperatures are 1981–2010 monthly means from the Duncan Kelvin Creek station (Environment Canada 2014a).

Table A-3 Monthly Mean Temperatures at Duncan Cairnsmore for 2010–2013

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2010	6.4	6.8	7.2	8.8	12.0	15.3	19.0	18.7	14.9	10.6	4.5	3.8
2011	3.5	2.5	6.1	6.7	11.4	15.5	17.6	18.9	16.2	9.3	4.0	3.1
2012	3.6	4.7	5.2	9.4	12.5	14.2	18.6	19.5	15.7	10.2	6.8	3.7
2013	2.4	5.3	7.1	9.4	13.6	17.2	20.1	19.3	15.4	9.6	5.6	2.4
Normal [A]	3.6	4.4	6.3	9.1	12.4	15.3	17.9	17.8	15.2	10.1	5.8	3.3

NOTE:
[A] Normal temperatures are 1981–2010 monthly means from the Duncan Kelvin Creek station (Environment Canada 2014a).

A.2 WIND

Hourly wind datasets were partitioned into day and night periods based on sunrise and sunset times on the 15th day of each month. The following figures show seasonal wind roses for day and night periods at each of the three stations analyzed.

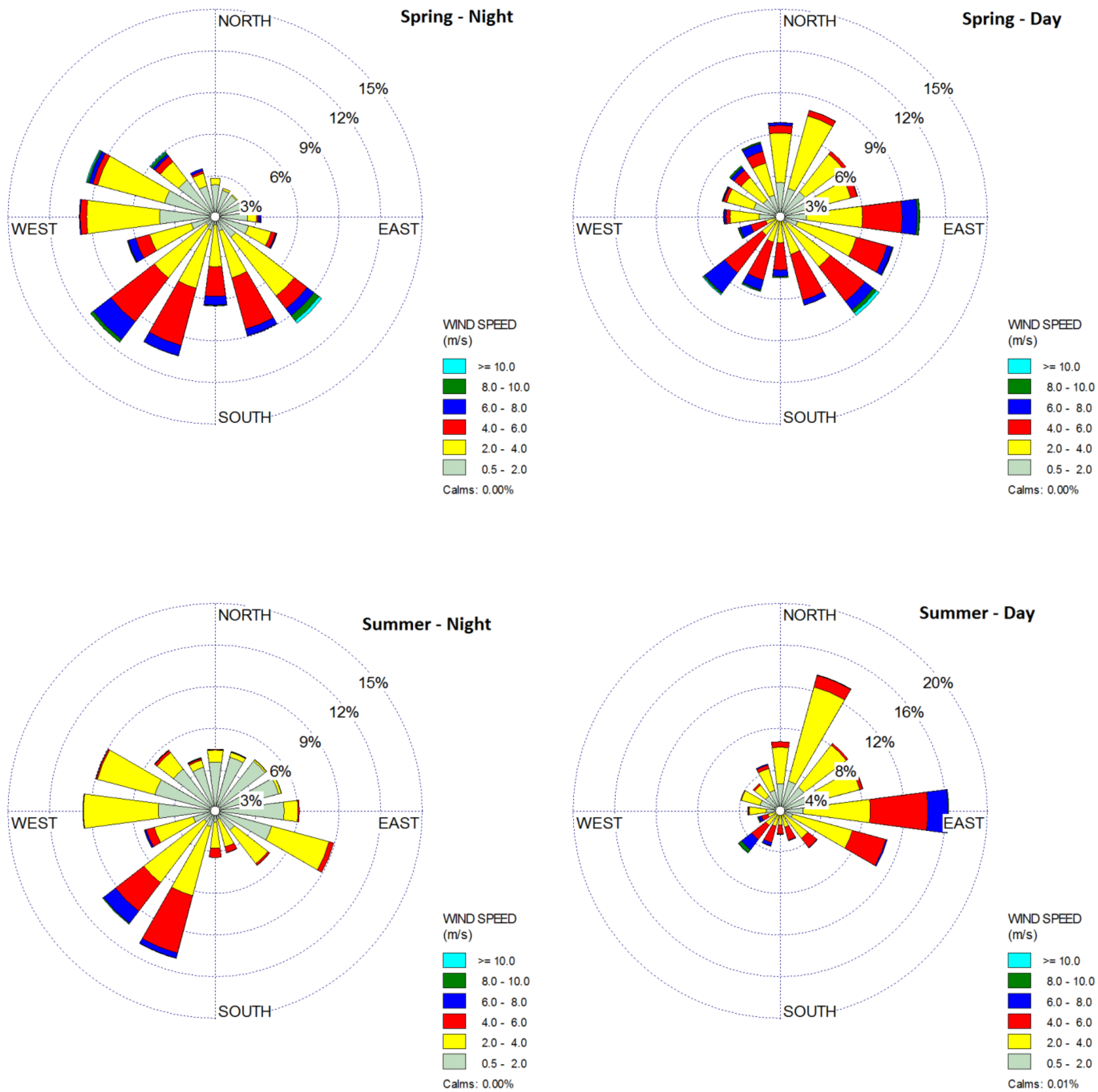

Figure A-1 Night and Day Wind Roses for Spring and Summer at the Crofton Met Station Based on 2008–2013 Hourly Data

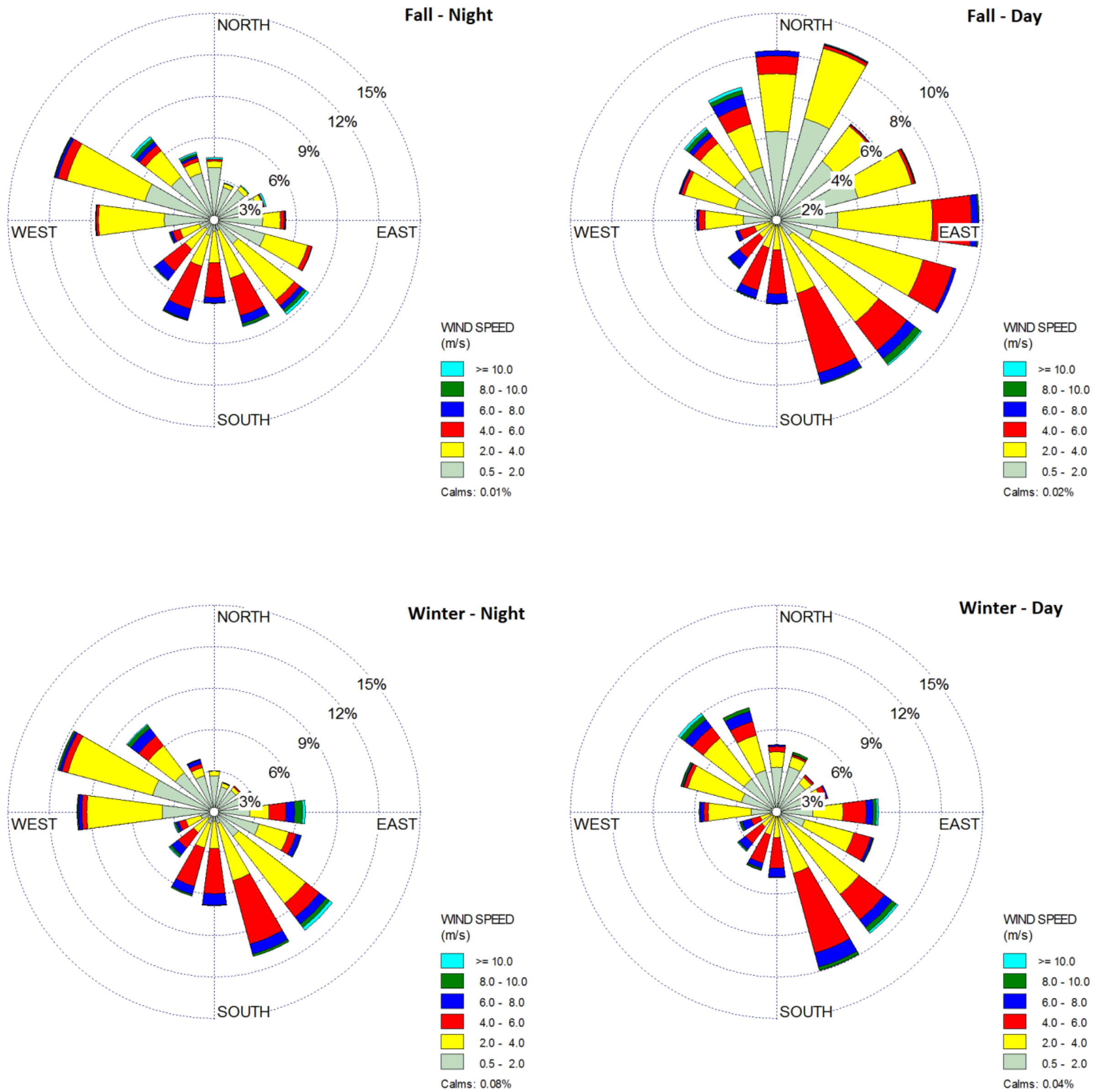

Figure A-2 Night and Day Wind Roses for Fall and Winter at the Crofton Met Station Based on 2008–2013 Hourly Data

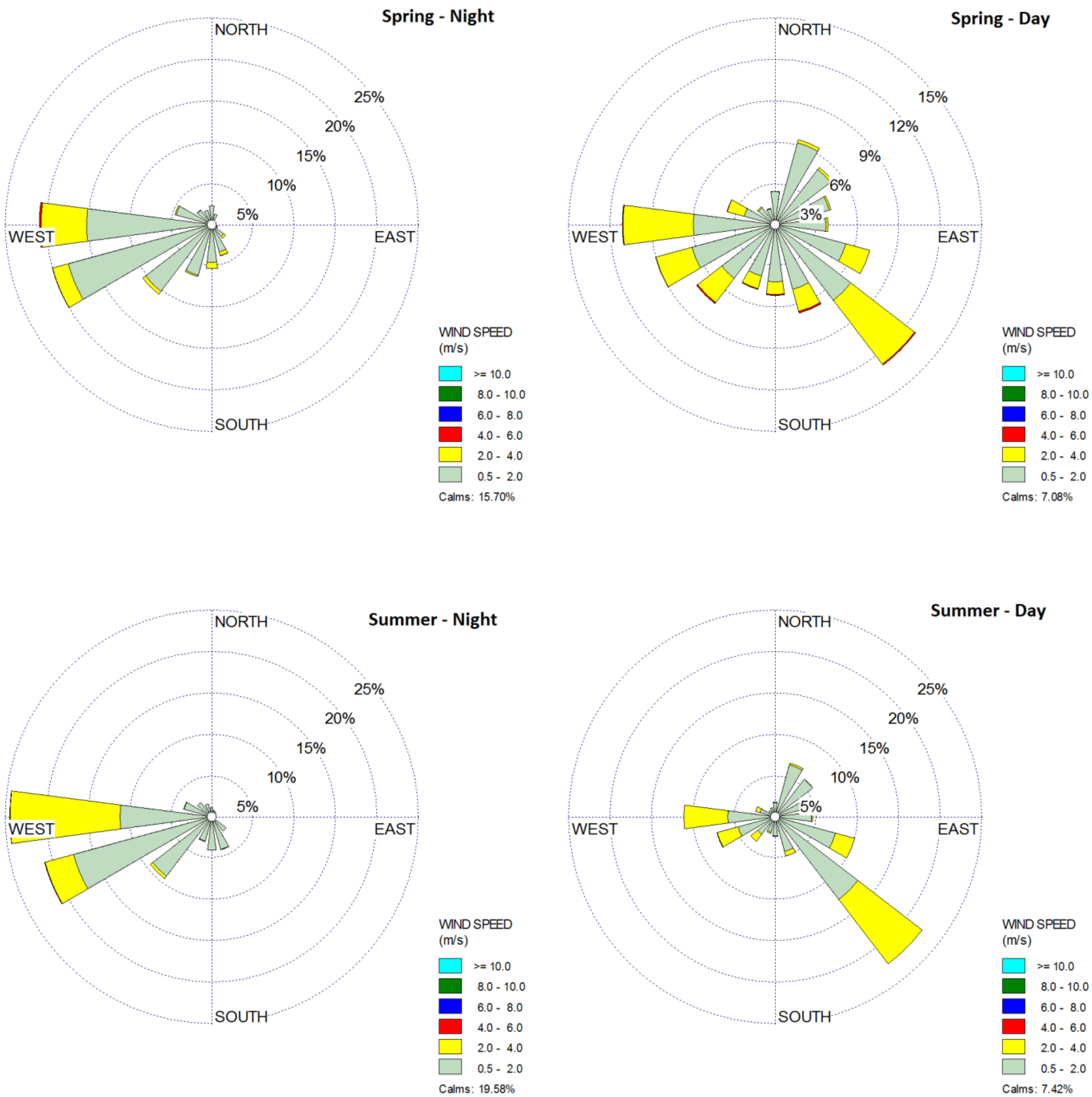

Figure A-3 Night and Day Wind Roses for Spring and Summer at the Duncan Cairnsmore Station Based on 2010–2013 Hourly Data

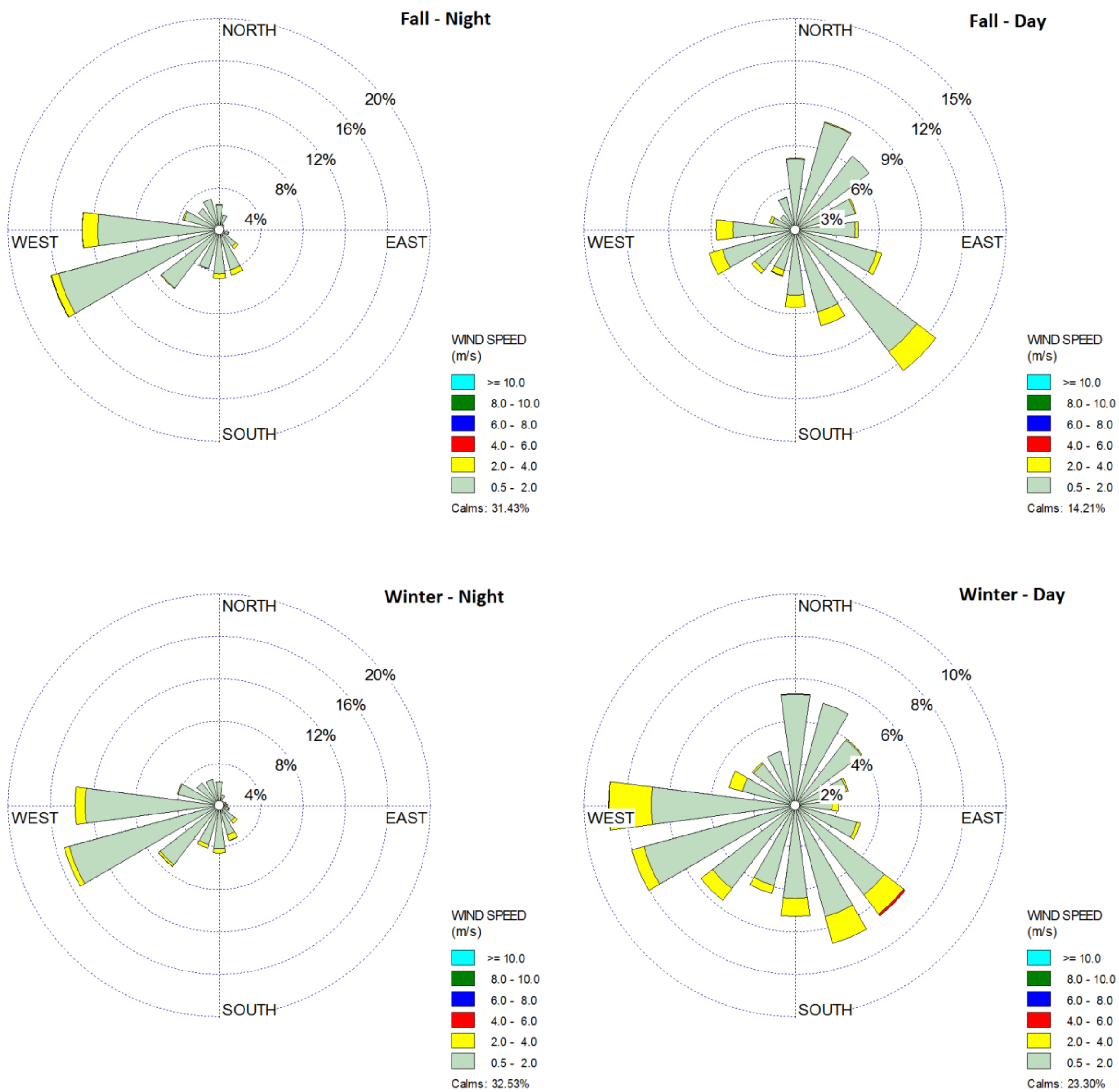

Figure A-4 Night and Day Wind Roses for Fall and Winter at the Duncan Cairnsmore Station Based on 2010–2013 Hourly Data

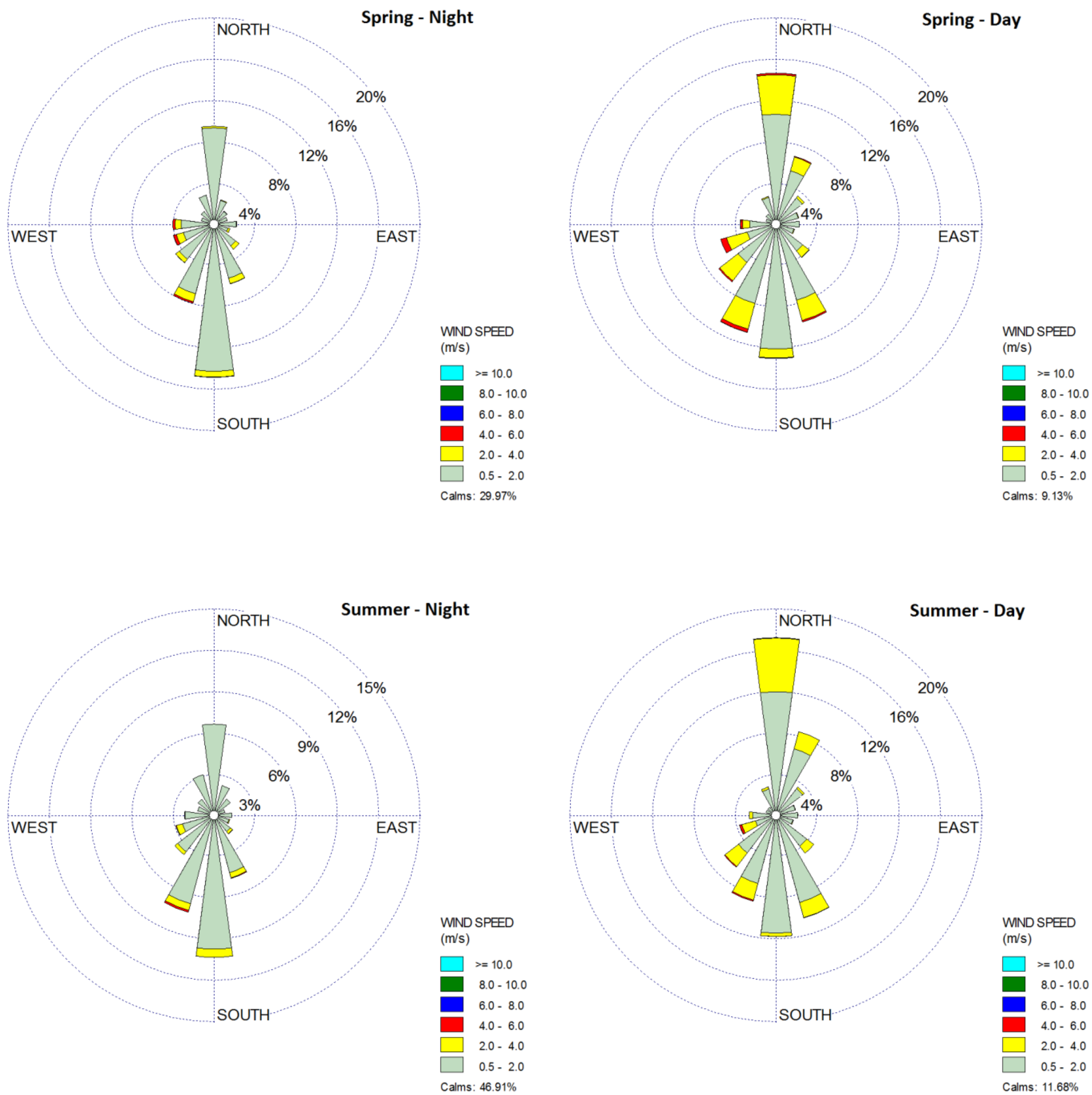

Figure A-5 Night and Day Wind Roses for Spring and Summer at the North Cowichan Station Based on 2008–2013 Hourly Data

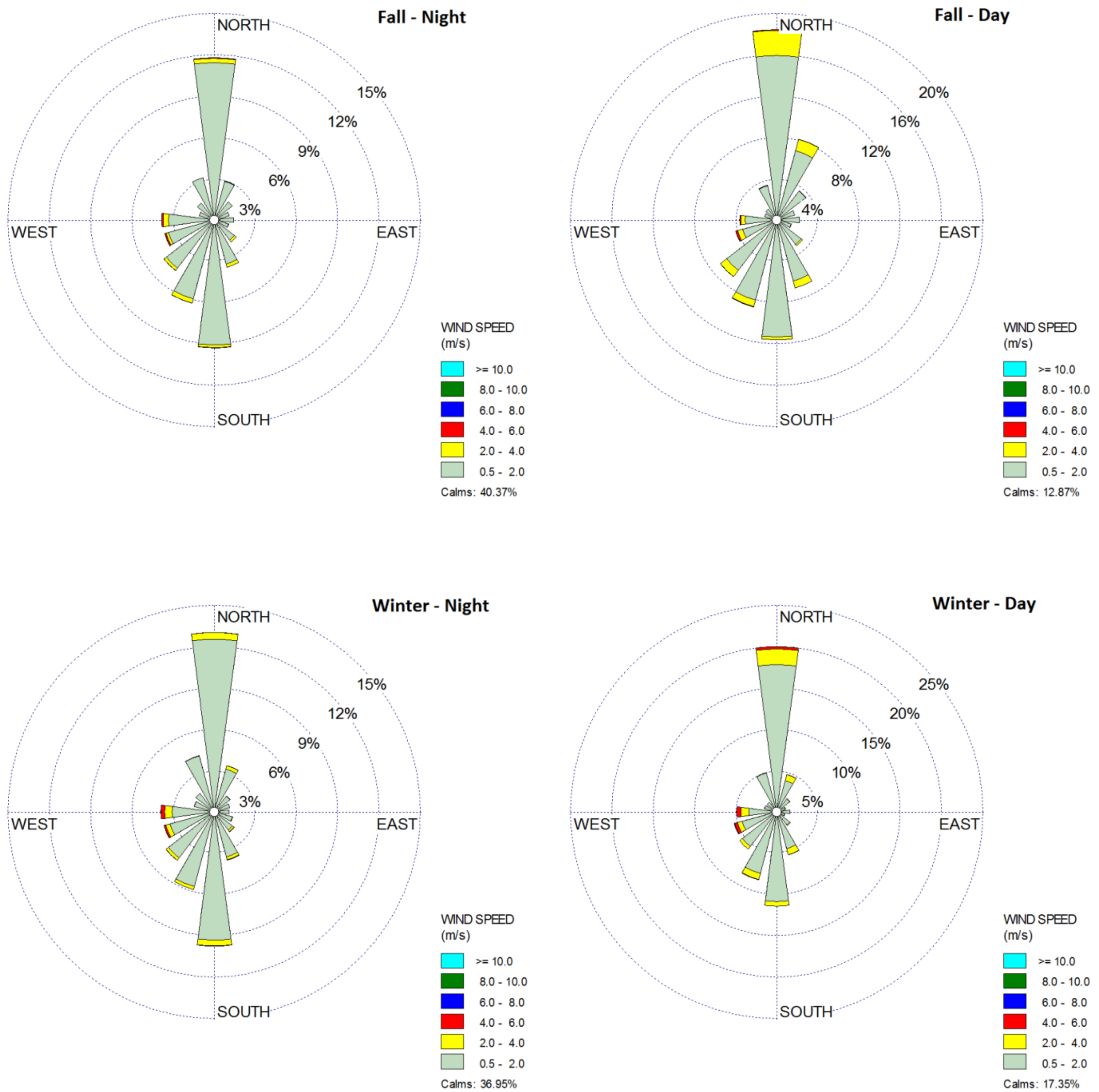

Figure A-6 Night and Day Wind Roses for Fall and Winter at the North Cowichan Station Based on 2008–2013 Hourly Data

Air Quality Data

Appendix B AIR QUALITY DATA

The air quality data included in this appendix supplement the quantitative and graphical information contained in the results section of the report (Section 3.2). Tabular data are provided in Sections B.1 and B.2, followed by graphics in Sections B.3 and B.4.

B.1 PERCENTILE AND EXCEEDANCE TABLES

The following tables provide annual means, 98th through 100th percentiles, and frequency of exceedance information for each CAC. The data were extracted from summaries compiled by BC MOE for air quality monitoring stations throughout the province (BC MOE 2013b). Years with incomplete datasets are included in these tables; the number of valid days and valid hours are shown for each year.

Table B-1 Percentile and Exceedance Data for Sulphur Dioxide

Station Name	Year	Valid Days	Valid Hours	Annual Mean (ppb)	Hourly Percentiles (ppb)			1-Hr Exceedances		Daily Percentiles (ppb)			24-Hr Exceedances	
					98	99	100	> 170 ppb	%	98	99	100	> 60 ppb	%
Crofton Substation	2005	287	6,641	1.0	7.0	10.0	39.0	0	0	4.5	5.5	7.3	0	0
	2006	355	8,200	1.2	8.0	12.0	55.0	0	0	4.0	5.8	14.7	0	0
	2007	360	8,305	0.8	6.0	8.0	66.0	0	0	2.9	3.4	6.6	0	0
	2008	366	8,411	0.9	6.0	9.0	74.0	0	0	2.8	4.4	11.2	0	0
	2009	365	8,397	0.6	3.0	4.0	46.0	0	0	2.0	3.0	4.0	0	0
	2010	338	7,810	1.4	6.5	8.2	46.8	0	0	3.6	4.1	4.8	0	0
	2011	365	8,386	1.3	6.3	8.5	37.8	0	0	3.1	3.7	9.8	0	0
	2012	363	8,385	1.6	5.5	7.3	24.2	0	0	3.4	4.0	5.5	0	0
	2013	322	7,609	1.2	5.5	8.6	40.7	0	0	3.2	3.4	10.1	0	0
Crofton Escarpment Way	2008	75	1,748	0.4	3.0	5.0	22.0	0	0	3.6	4.5	4.5	0	0
	2009	365	8,390	0.5	4.0	6.0	38.0	0	0	3.1	5.3	14.1	0	0
	2010	299	6,994	1.4	9.9	13.9	35.7	0	0	6.8	7.8	9.0	0	0
	2011	340	7,828	1.3	8.5	12.0	59.7	0	0	6.0	7.2	10.4	0	0
	2012	347	8,014	1.2	9.1	13.5	56.8	0	0	6.2	7.4	9.4	0	0
	2013	364	8,383	1.4	11.9	17.5	123.1	0	0	8.2	11.1	28.7	0	0

Table B-2 Percentile and Exceedance Data for Nitrogen Dioxide

Station Name	Year	Valid Days	Valid Hours	Annual Mean (ppb)	Hourly Percentiles (ppb)			1-Hr Exceedances		Daily Percentiles (ppb)			24-Hr Exceedances	
					98	99	100	> 213 ppb	%	98	99	100	> 106 ppb	%
Crofton Substation	2005	270	6,265	3.6	12.0	14.0	43.0	0	0	8.5	9.2	11.3	0	0
	2006	365	8,389	4.6	14.0	16.0	54.0	0	0	10.3	11.2	14.7	0	0
	2007	336	7,792	4.6	16.0	18.0	31.0	0	0	12.1	15.0	17.7	0	0
	2008	366	8,413	3.4	12.0	13.0	30.0	0	0	8.6	9.9	10.7	0	0
	2009	365	8,393	3.5	12.0	14.0	21.0	0	0	9.2	10.4	11.6	0	0
	2010	355	8,229	4.2	11.2	13.0	31.2	0	0	8.1	8.6	10.4	0	0
	2011	229	4,979	2.9	9.8	11.9	17.8	0	0	7.1	7.6	9.9	0	0
	2012	358	7,955	3.8	12.9	15.3	27.5	0	0	9.6	11.5	12.9	0	0
	2013	365	8,213	3.7	12.1	14.4	26.5	0	0	8.3	11.1	13.8	0	0
Crofton Escarpment Way	2008	83	1,918	3.4	13.0	16.0	26.0	0	0	10.4	12.7	12.7	0	0
	2009	361	7,657	2.8	9.0	11.0	20.0	0	0	7.4	8.3	10.8	0	0
	2010	322	6,851	3.8	10.5	12.0	31.0	0	0	7.7	8.8	10.1	0	0
	2011	205	4,497	3.3	9.6	11.5	20.9	0	0	7.0	8.4	9.2	0	0
	2012	363	8,030	3.5	10.1	12.3	20.5	0	0	8.3	9.4	13.0	0	0
	2013	364	8,173	3.7	12.1	14.3	25.2	0	0	9.9	11.5	15.2	0	0
Duncan Cairnsmore	2009	147	3,402	6.2	18.6	20.9	29.2	0	0	14.7	17.5	17.5	0	0
	2010	360	8,300	5.7	17.3	19.5	29.4	0	0	11.0	12.3	14.9	0	0
	2011	364	8,341	5.2	15.8	17.6	29.6	0	0	11.2	12.1	13.9	0	0
	2012	359	8,351	5.1	16.2	17.9	26.7	0	0	11.5	12.3	13.3	0	0
	2013	355	8,188	4.7	15.5	17.4	27.4	0	0	10.3	11.2	15.2	0	0

Table B-3 Percentile and Exceedance Data for PM_{10}

Station Name	Year	Valid Days	Valid Hours	Annual Mean (ppb)	Daily Percentiles (ppb)			24-Hr Exceedances	
					98	99	100	> 50 µg/m³	%
Crofton Substation	2005	326	7,848	11.7	24.3	25.8	31.5	0.0	0
	2006	365	8,727	10.9	24.8	27.9	66.5	1.0	0.3
	2007	360	8,637	10.3	22.7	27.3	44.7	0.0	0
	2008	362	8,684	10.3	23.7	24.9	26.3	0.0	0
	2009	365	8,731	10.6	25.6	27.3	33.5	0.0	0
	2010	112	2,741	9.7	21.7	25.7	30.2	0.0	0
Duncan Deykin Avenue	2003	361	8,587	10.7	23.6	27.6	32.6	0	0
	2004	339	8,299	11.4	21.8	22.3	31.3	0	0
	2005	283	6,864	11.5	21.3	22.1	27.3	0	0
	2006	346	8,276	10.5	21.7	24.1	24.9	0	0
	2007	291	7,411	9.6	22.9	25.1	29.8	0	0
	2008	363	8,578	9.6	19.9	22.0	24.8	0	0
	2009	336	8,154	9.7	19.0	22.0	24.6	0	0
	2010	106	2,561	9.2	16.6	16.7	25.5	0	0

Table B-4 Percentile and Exceedance Data for $PM_{2.5}$

Station Name	Year	Valid Days	Valid Hours	Annual Mean (ppb)	Daily Percentiles (ppb)			24-Hr Exceedances		Annual Exceedance
					98	99	100	> 25 µg/m³	%	> 8 µg/m³
Crofton Substation	2010	238	5,750	4.3	16.5	23.9	40.2	1	0.4	No
	2011	315	7,554	3.6	8.6	9.1	11.0	0	0.0	No
	2012	361	8,676	3.7	10.3	12.3	16.1	0	0.0	No
	2013	365	8,697	4.0	9.2	9.8	12.5	0	0.0	No
Crofton Escarpment Way	2008	76	1,822	4.5	10.7	10.7	10.7	0	0.0	No
	2009	333	8,018	3.9	10.0	10.9	16.3	0	0.0	No
	2010	323	7,823	3.7	12.8	18.4	47.6	1	0.3	No
	2011	316	7,602	3.4	7.8	8.5	11.7	0	0.0	No
	2012	345	8,264	3.8	10.4	11.6	17.9	0	0.0	No
	2013	355	8,473	4.2	11.8	12.1	20.3	0	0.0	No
Duncan Deykin Avenue	2010	211	5,024	4.3	14.8	20.7	37.8	1	0.5	No
	2011	331	7,918	3.8	10.7	11.0	13.3	0	0.0	No
	2012	365	8,694	3.9	11.0	13.7	17.0	0	0.0	No
	2013	323	7,678	4.1	11.6	12.9	14.3	0	0.0	No
Duncan Cairnsmore	2009	66	1,655	11.4	42.4	43.3	43.3	8	12.0	Yes
	2010	363	8,679	9.2	25.2	26.6	43.3	6	1.7	Yes
	2011	361	8,669	10.7	31.0	38.8	46.2	21	5.8	Yes
	2012	310	7,483	8.5	29.4	31.5	38.8	9	2.9	Yes
	2013	358	8,542	8.6	32.4	37.6	41.7	19	5.3	Yes

Table B-5 Percentile and Exceedance Data for Total Reduced Sulphur

Station Name	Year	Valid Days	Valid Hours	Annual Mean (ppb)	Hourly Percentiles (ppb)			1-Hr Exceedances		Daily Percentiles (ppb)			24-Hr Exceedances	
					98	99	100	> 5 ppb	%	98	99	100	> 2 ppb	%
Crofton Substation	2003	360	8,323	1.5	13.0	18.0	76.0	742	8.9	7.2	8.6	41.5	76	21.1
	2004	348	8,023	0.7	5.0	8.0	41.0	220	2.7	3.4	4.2	5.5	25	7.2
	2005	332	7,757	0.9	8.0	13.0	73.0	331	4.3	4.3	6.9	17.3	39	11.8
	2006	365	8,382	0.7	6.0	10.0	43.0	253	3.0	3.0	4.1	23.5	19	5.2
	2007	167	3,880	0.5	4.0	7.0	36.0	75	1.9	2.4	4.2	5.0	8	4.8
	2008	303	7,262	0.6	5.0	7.0	29.0	155	2.1	2.7	3.6	7.8	12	4.0
	2009	365	8,392	0.5	4.0	6.0	41.0	125	1.5	3.3	4.1	15.7	19	5.2
	2010	248	5,751	1.1	8.2	12.0	104.6	214	3.7	5.5	8.0	13.8	27	10.9
	2011	252	5,807	1.4	10.3	15.5	68.0	315	5.4	5.1	6.5	18.5	51	20.2
	2012	336	7,761	1.4	10.9	15.3	53.6	514	6.6	5.5	7.3	10.6	78	23.2
	2013	359	8,261	1.7	10.6	13.9	48.5	570	6.9	5.0	5.7	7.2	108	30.1
Crofton Escarpment Way	2008	82	1,907	0.2	2.0	3.0	9.0	7	0.4	1.7	1.7	1.7	0	0
	2009	365	8,393	0.3	2.0	3.0	23.0	58	0.7	2.0	3.6	5.2	7	1.9
	2010	347	8,032	0.5	2.0	2.7	17.5	17	0.2	1.5	1.7	2.5	2	0.6
	2011	340	7,832	0.5	2.2	3.0	12.0	20	0.3	1.5	1.8	2.6	1	0.3
	2012	364	8,376	0.9	3.6	4.5	32.8	63	0.8	2.7	3.1	6.8	24	6.6
	2013	364	8,379	0.9	3.6	6.0	22.4	108	1.3	3.3	4.7	7.9	19	5.2

Table B-5 Percentile and Exceedance Data for Total Reduced Sulphur

Station Name	Year	Valid Days	Valid Hours	Annual Mean (ppb)	Hourly Percentiles (ppb)			1-Hr Exceedances		Daily Percentiles (ppb)			24-Hr Exceedances	
					98	99	100	> 5 ppb	%	98	99	100	> 2 ppb	%
Duncan Deykin Avenue	2003	343	7,924	0.3	3.0	4.1	12.1	62	0.8	1.8	2.4	4.3	5	1.5
	2004	347	7,981	0.2	2.0	3.0	10.0	18	0.2	1.3	1.8	3.3	2	0.6
	2005	340	7,861	0.3	2.0	4.1	18.0	65	0.8	1.5	2.7	9.6	4	1.2
	2006	351	8,085	0.1	1.0	2.0	6.0	8	0.1	1.0	1.3	1.8	0	0
	2007	363	8,348	0.1	2.0	2.0	9.0	22	0.3	1.4	1.9	2.4	2	0.6
	2008	365	8,396	0.1	1.0	2.0	7.0	4	0.1	0.8	1.0	2.1	1	0.3
	2009	328	7,563	0.1	1.0	1.0	5.0	2	0.0	0.8	0.9	1.3	0	0
	2010	364	8,375	0.3	1.3	1.7	6.0	2	0.0	1.0	1.2	1.8	0	0
	2011	233	5,367	0.2	0.9	1.5	3.9	0	0	0.6	1.0	1.3	0	0
	2012	366	8,400	0.4	1.4	2.1	5.5	2	0.0	1.2	1.5	2.3	2	0.5
	2013	341	7,881	0.4	1.8	2.7	11.0	21	0.3	1.5	2.5	3.3	5	1.5

Table B-6 Percentile and Exceedance Data for Ozone

Station Name	Year	Valid Days	Valid Hours	Annual Mean	Hourly Percentiles (ppb)			1-Hr Exceedances		Daily Percentiles (ppb)			3-Year Average
					98	99	100	> 82 ppb	%	98	99	100	4th Highest 8-Hour Avg
Duncan Cairnsmore	2009	145	3,387	14.2	42	46	67	0	0	28.5	31.6	35.7	-
	2010	360	8,308	17.4	43	45	72	0	0	35.6	37.7	41.7	48
	2011	363	8,345	17.9	43	45	56	0	0	35.5	37.1	40.3	48
	2012	355	8,241	20.2	47	49	69	0	0	38.5	39.9	43.1	48
	2013	355	8,179	16.2	44	46	62	0	0	35.7	37.5	40.9	49

B.2 OXIDES OF NITROGEN AND NITRIC OXIDE DATA SUMMARIES

The following tables provide annual means and 98th through 100th percentile data for NO and NO_X. Exceedance statistics are not included because there are no applicable air quality objectives for these substances. Data were obtained from the BC MOE (2013c, 2014).

Table B-7 Percentile Data for Nitric Oxide

Station Name	Year	Valid Days	Valid Hours	Annual Mean (ppb)	Hourly Percentiles (ppb)			Daily Percentiles (ppb)		
					98	99	100	98	99	100
Crofton Substation	2005	270	6,266	1.2	8.0	12.0	39.0	3.8	5.4	9.0
	2006	365	8,391	1.2	7.0	9.0	34.0	3.8	4.5	8.6
	2007	338	7,811	1.5	9.0	13.0	53.0	5.7	6.1	10.7
	2008	366	8,414	1.0	6.0	8.0	34.0	3.2	4.2	9.1
	2009	365	8,392	1.2	5.0	7.0	35.0	3.0	3.3	5.3
	2010	355	8,200	2.4	8.7	12.0	47.5	6.1	6.7	9.1
	2011	231	5,321	2.0	8.3	10.5	36.2	4.8	5.0	9.0
	2012	361	8,331	1.2	6.3	8.9	37.3	3.6	5.1	7.6
	2013	365	8,385	1.4	8.0	11.1	48.9	5.1	6.3	8.0
Crofton Escarpment Way	2008	83	1,918	0.7	3.0	5.0	27.0	2.7	7.0	7.0
	2009	365	8,395	0.5	2.0	3.0	14.0	1.3	1.6	4.3
	2010	322	7,485	1.1	3.6	4.4	18.1	2.6	2.9	3.4
	2011	205	4,765	0.9	3.3	4.2	26.7	2.0	2.4	2.6
	2012	364	8,385	0.7	2.3	2.9	15.5	1.3	1.5	5.7
	2013	365	8,388	0.9	4.2	6.3	30.0	3.3	5.9	8.9
Duncan Cairnsmore	2009	147	3,402	5.8	36.1	47.2	78.9	22.8	25.5	26.2
	2010	360	8,300	4.2	31.3	40.8	124.8	18.4	22.4	28.3
	2011	364	8,341	4.1	32.8	44.1	127.7	22.3	27.2	29.6
	2012	359	8,351	3.2	23.7	34.8	96.9	15.5	21.9	36.0
	2013	355	8,193	4.1	30.2	43.4	121.3	24.1	28.7	37.0

Table B-8 Percentile Data for Oxides of Nitrogen

Station Name	Year	Valid Days	Valid Hours	Annual Mean (ppb)	Hourly Percentiles (ppb)			Daily Percentiles (ppb)		
					98	99	100	98	99	100
Duncan Cairnsmore	2009	142	3,340	11.0	48.5	53.1	102.0	30.5	33.6	41.0
	2010	356	8,237	9.8	42.8	53.0	140.1	27.0	32.3	38.7
	2011	361	8,283	9.3	44.6	54.3	150.8	29.7	34.7	41.8
	2012	329	7,899	7.8	35.2	47.2	114.3	24.4	27.8	41.2
	2013	355	8,190	8.9	40.5	52.9	139.1	32.1	36.1	44.4

B.3 HOURLY DATA TIME SERIES

Time Series graphs for SO_2, NO_2, NO, NO_X, PM_{10}, $PM_{2.5}$ (TEOM Adjusted, TEOM Unadjusted, and BAM), TRS, and O_3 are presented below. The graphs are based on all available hourly data for each station during the 2003–2013 study period. Negative NO_X values were discarded.

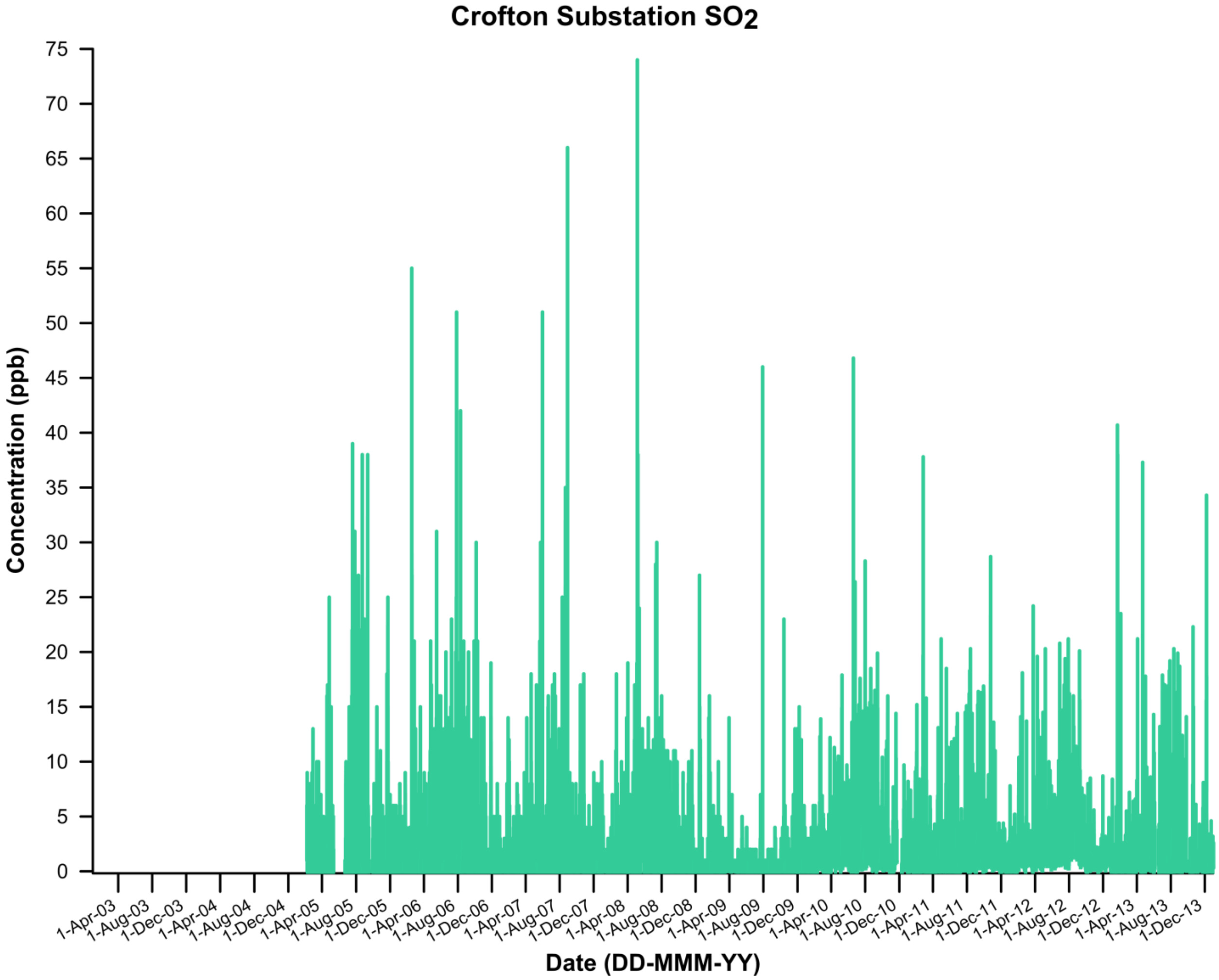

Figure B-1 Time Series of SO_2 Concentration at Crofton Substation Based on 2005–2013 Hourly Data

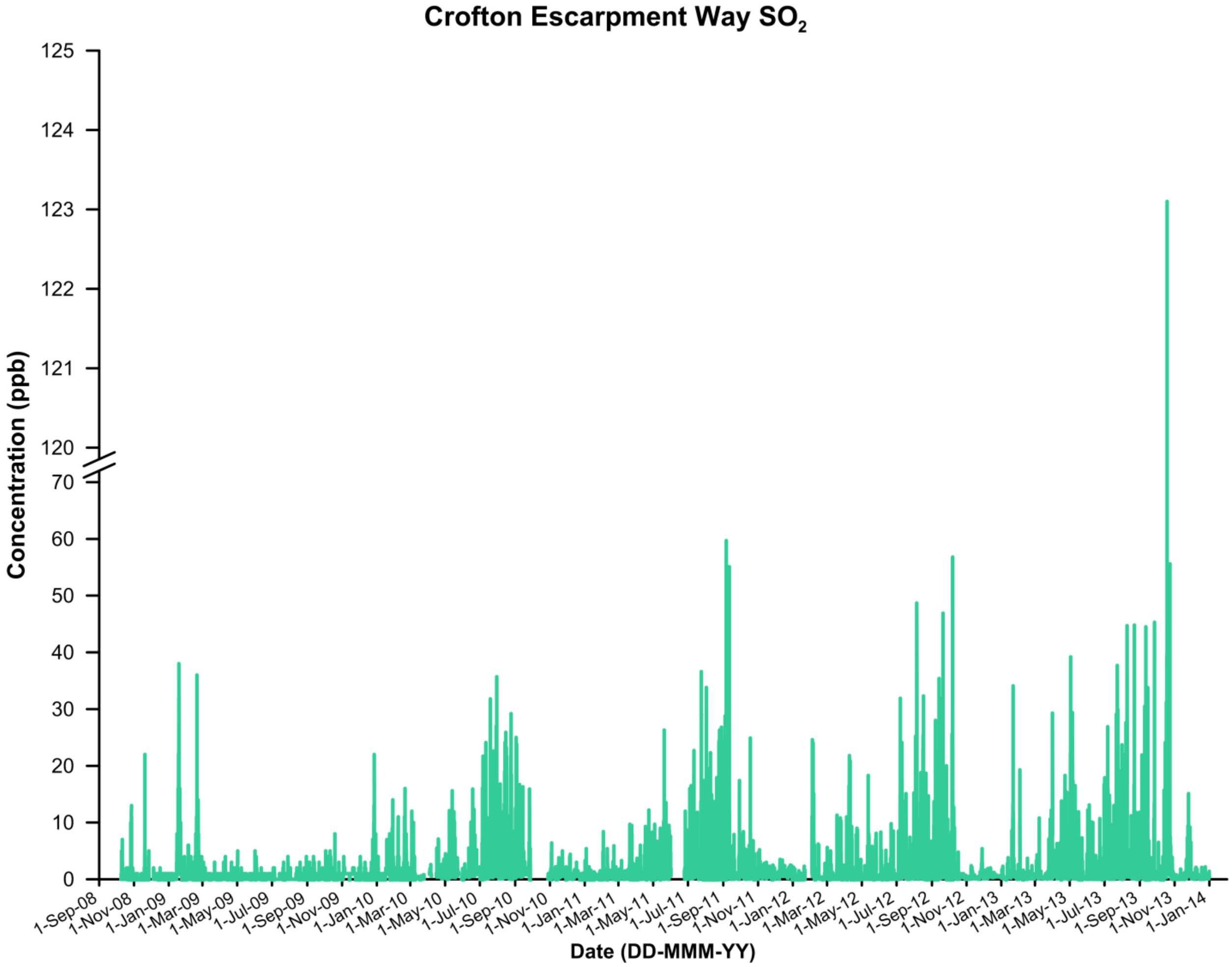

Figure B-2 Time Series of SO_2 Concentration at Crofton Escarpment Way Based on 2008–2013 Hourly Data

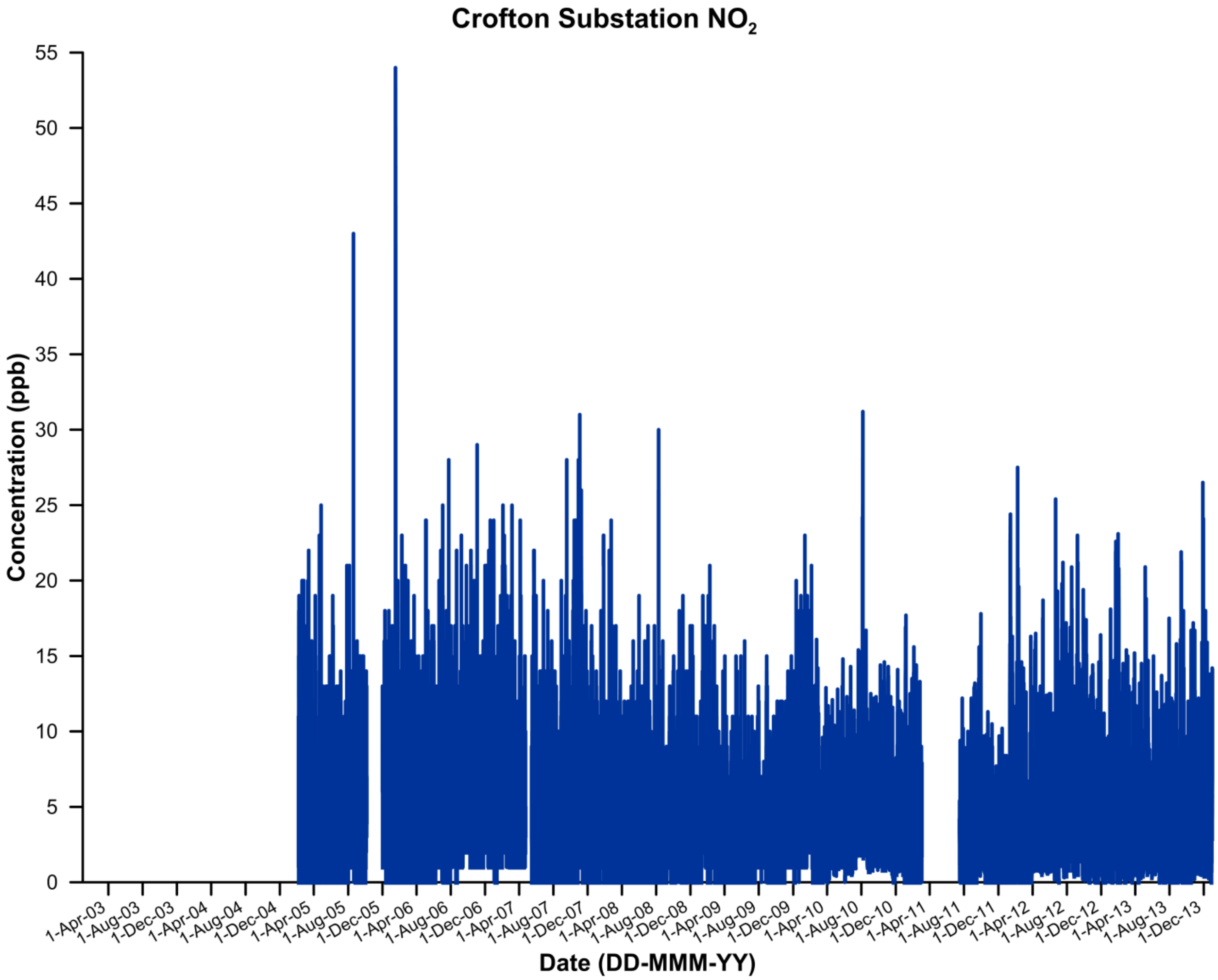

Figure B-3 Time Series of NO_2 Concentration at Crofton Substation Based on 2005–2013 Hourly Data

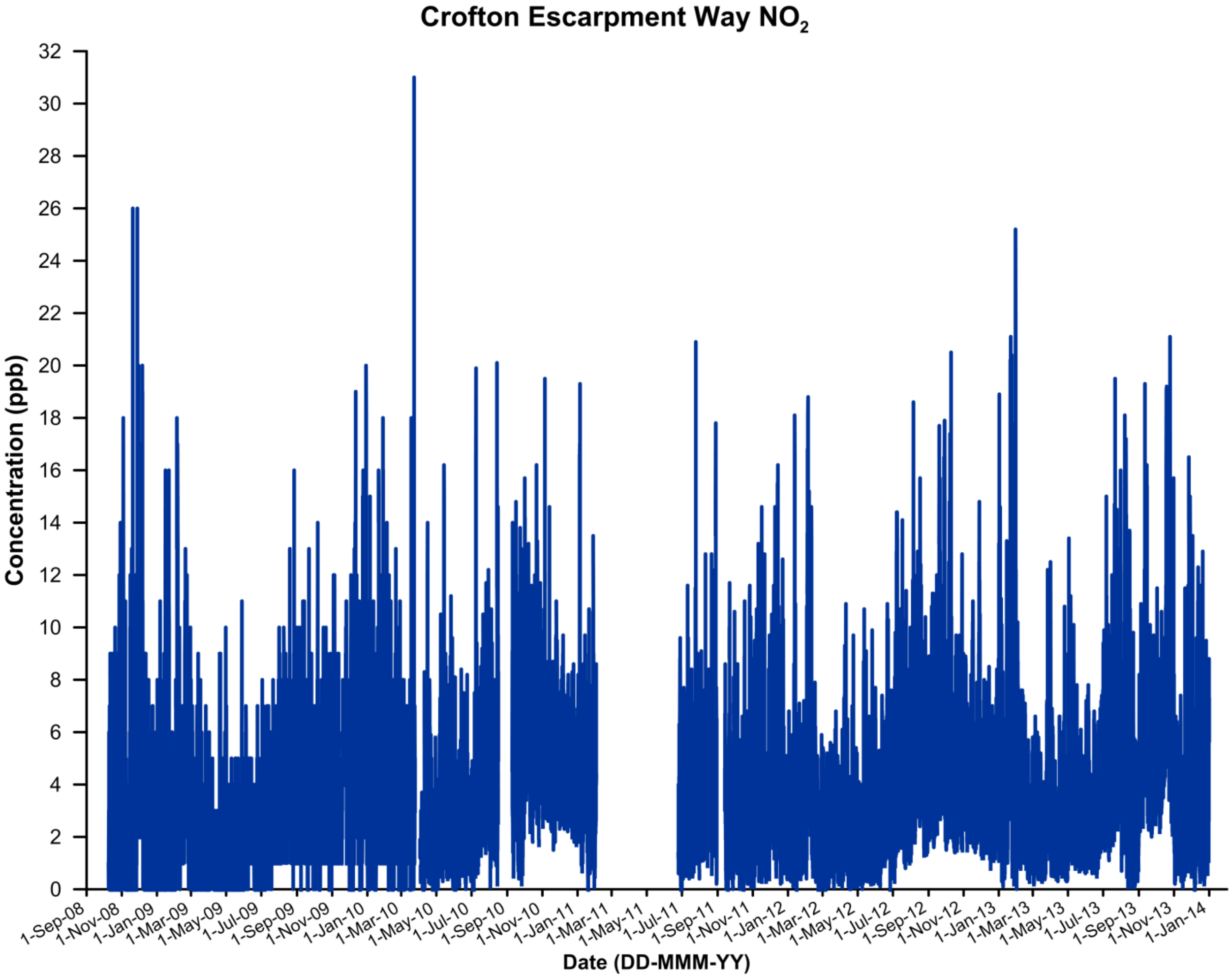

Figure B-4 Time Series of NO_2 Concentration at Crofton Escarpment Way Based on 2008–2013 Hourly Data

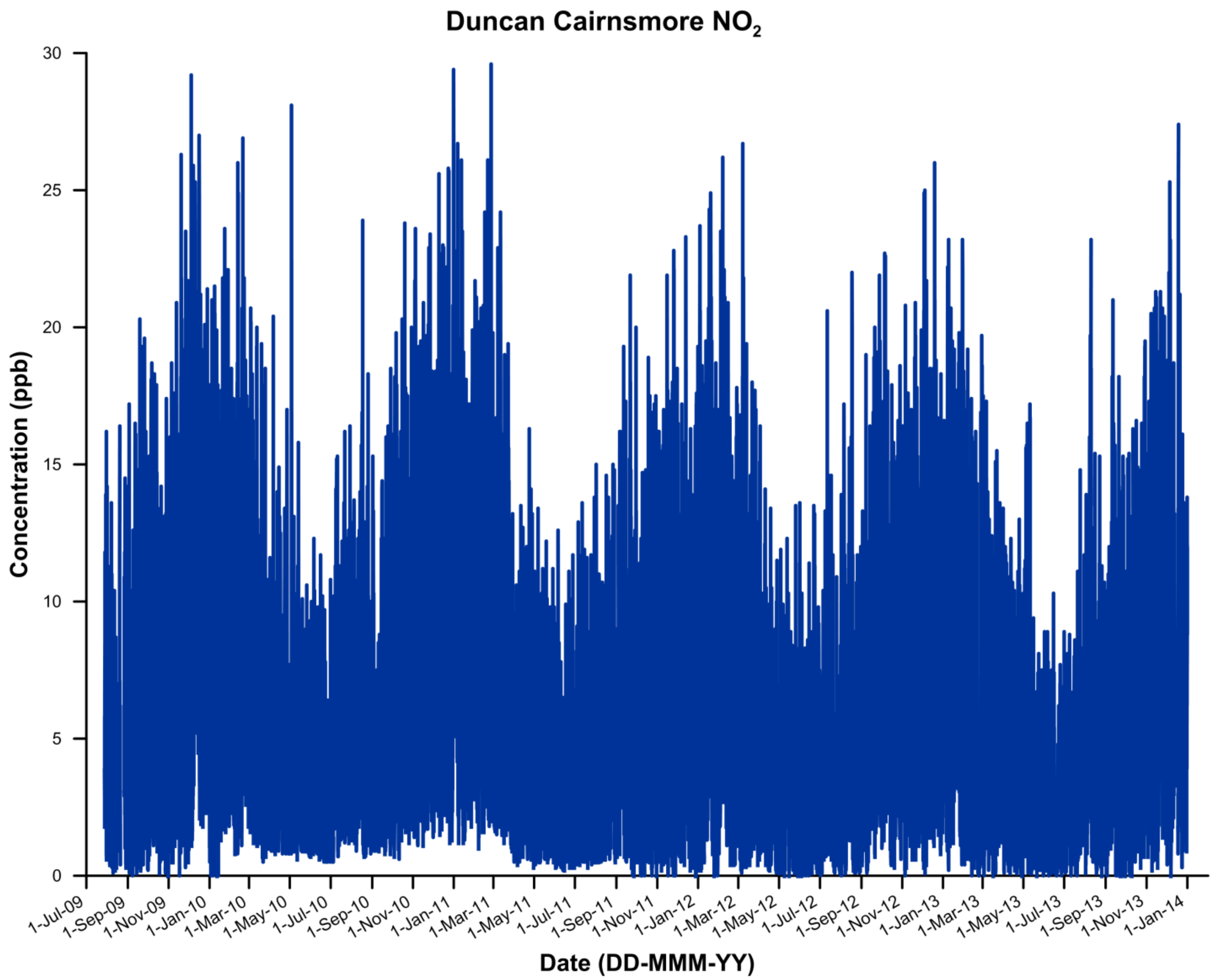

Figure B-5 Time Series of NO_2 Concentration at Duncan Cairnsmore Based on 2009–2013 Hourly Data

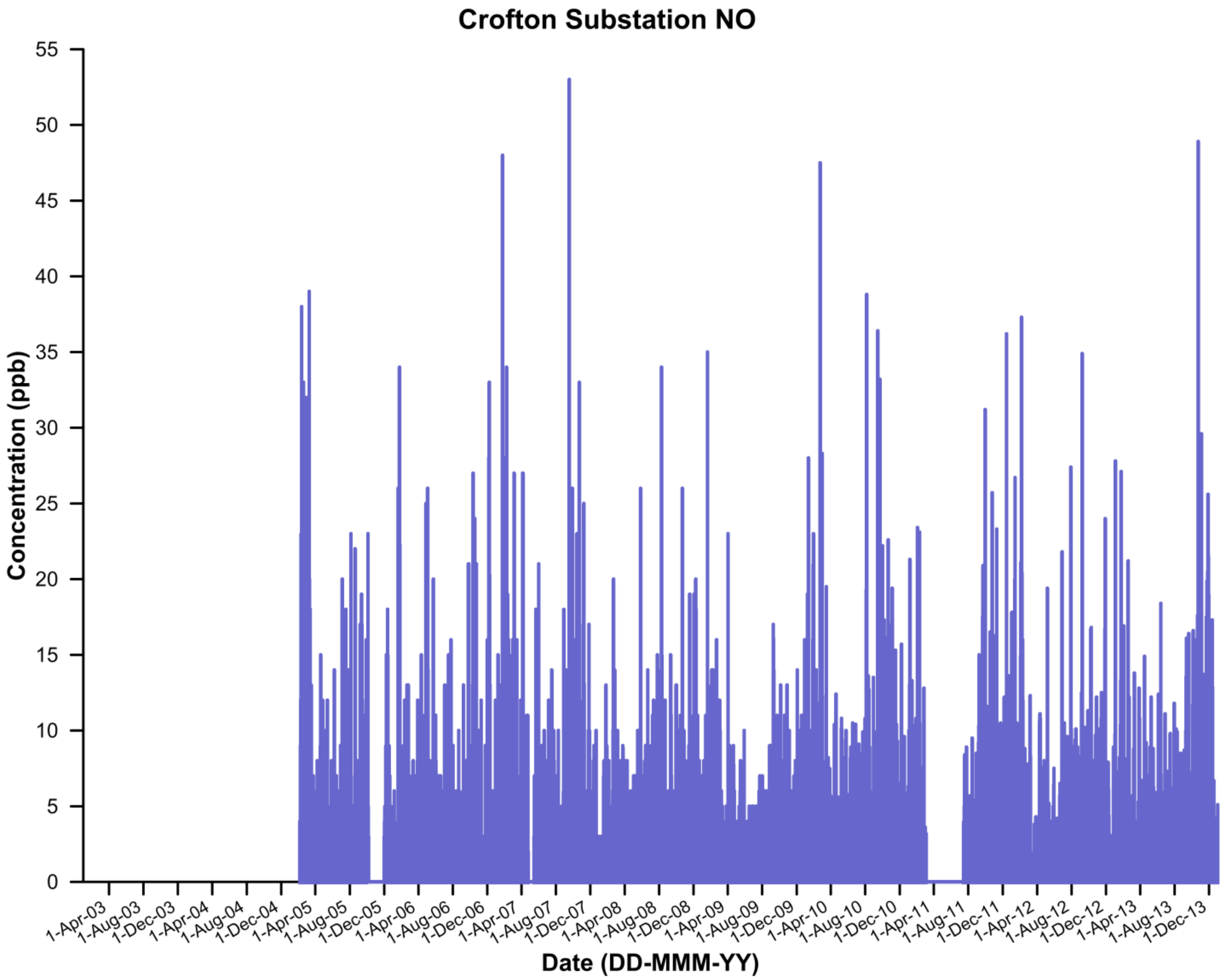

Figure B-6 Time Series of NO Concentration at Crofton Substation Based on 2005–2013 Hourly Data

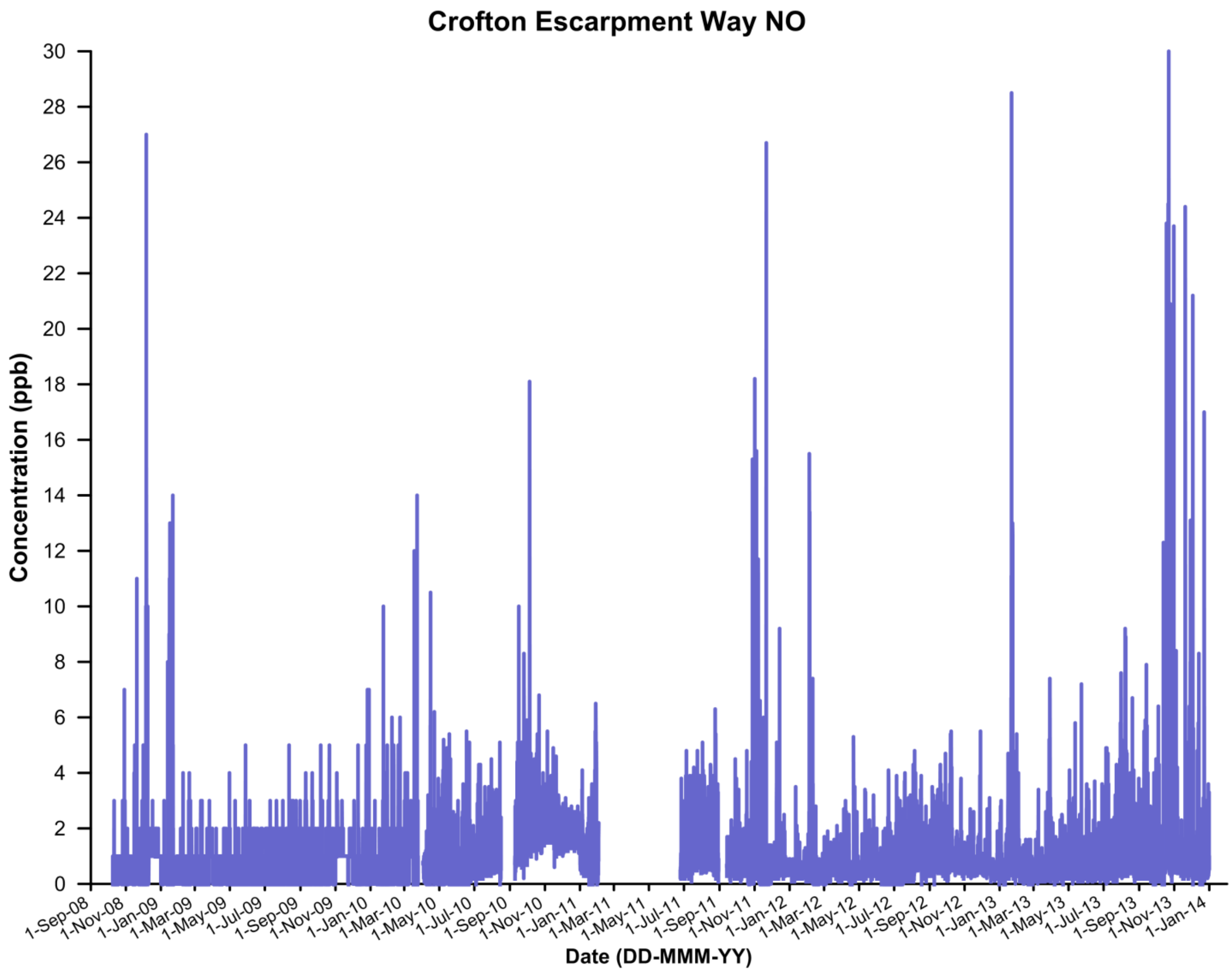

Figure B-7 Time Series of NO Concentration at Crofton Escarpment Way Based on 2008–2013 Hourly Data

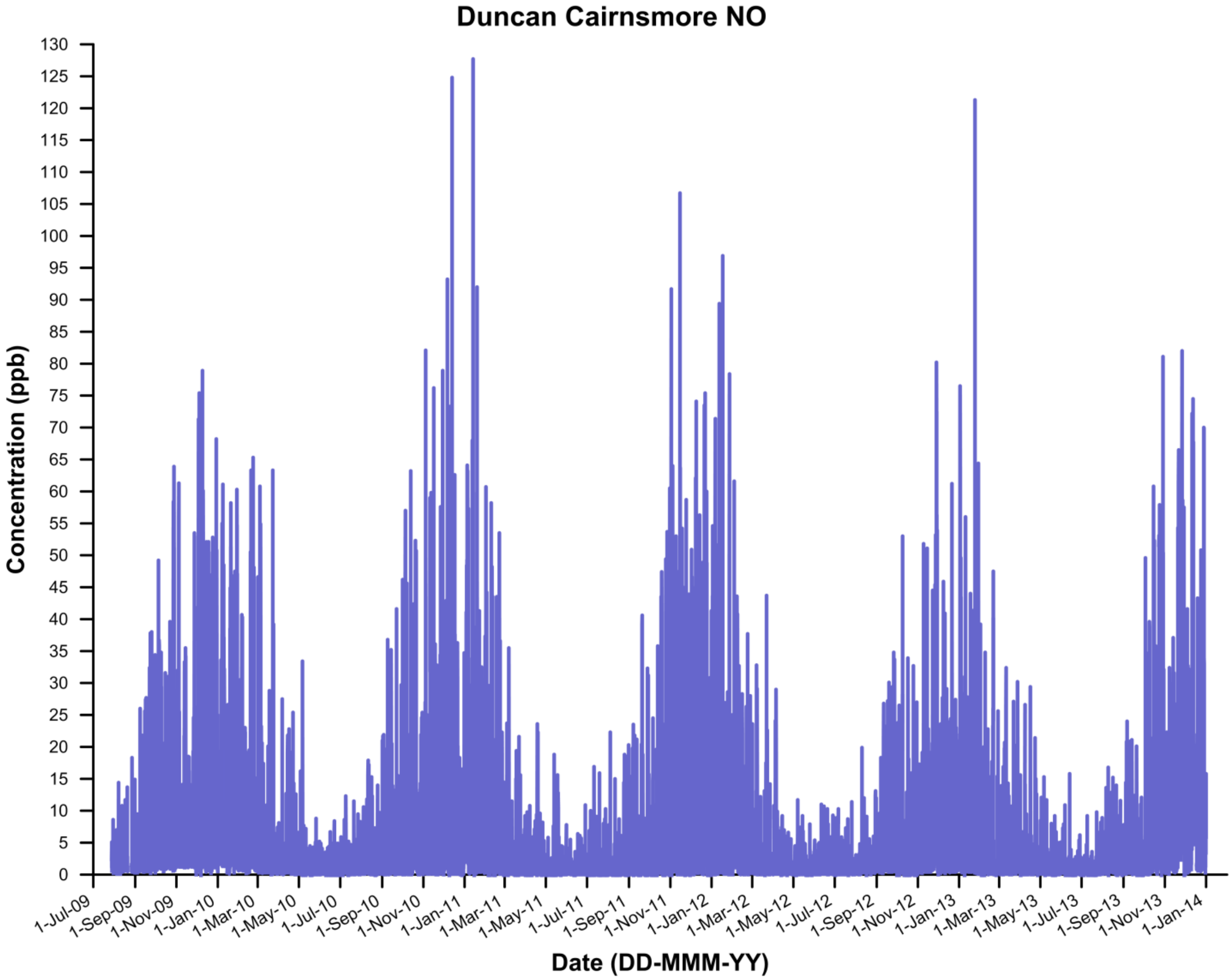

Figure B-8 Time Series of NO Concentration at Duncan Cairnsmore Based on 2009–2013 Hourly Data

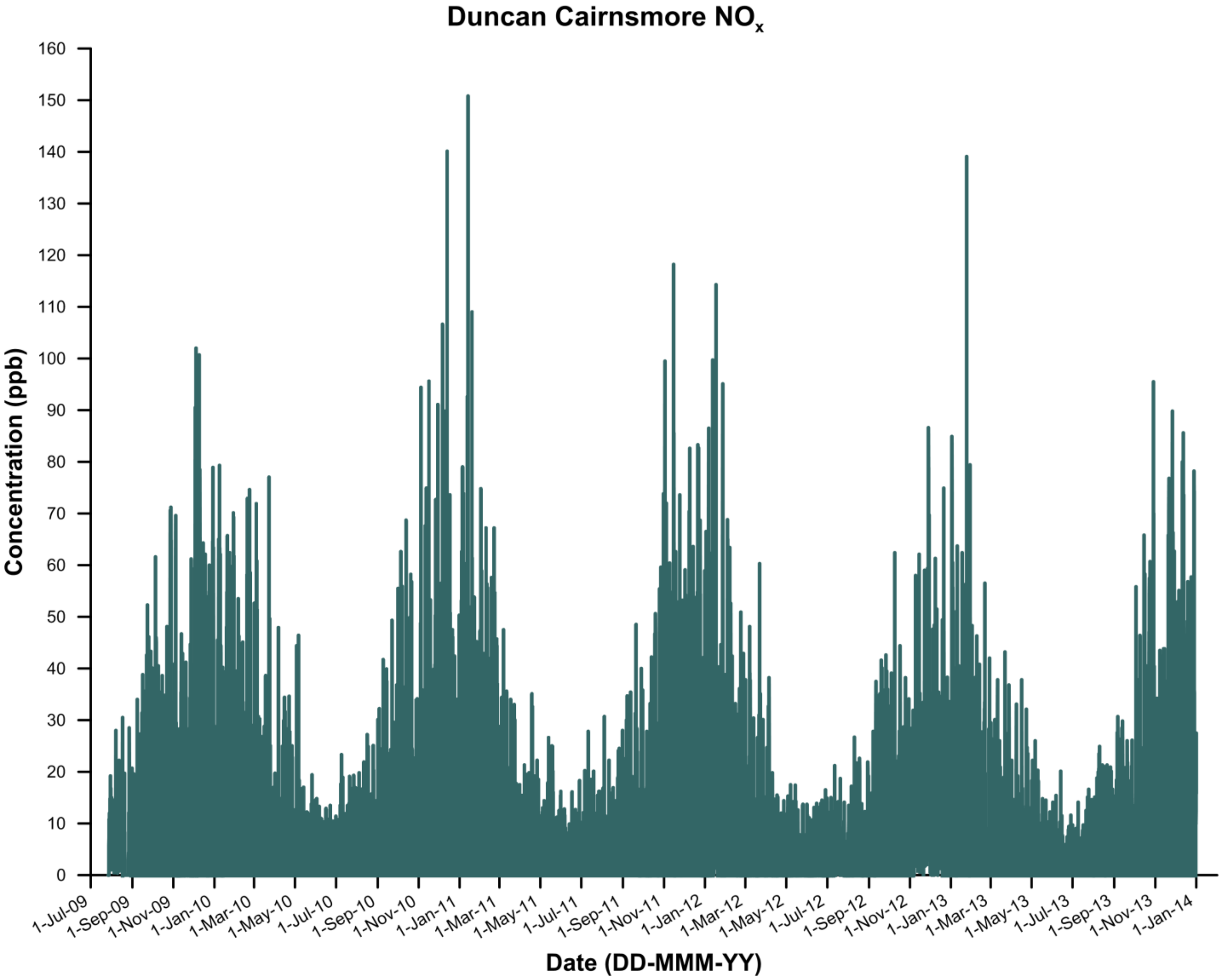

Figure B-9 Time Series of NO_x Concentration at Duncan Cairnsmore Based on 2009–2013 Hourly Data

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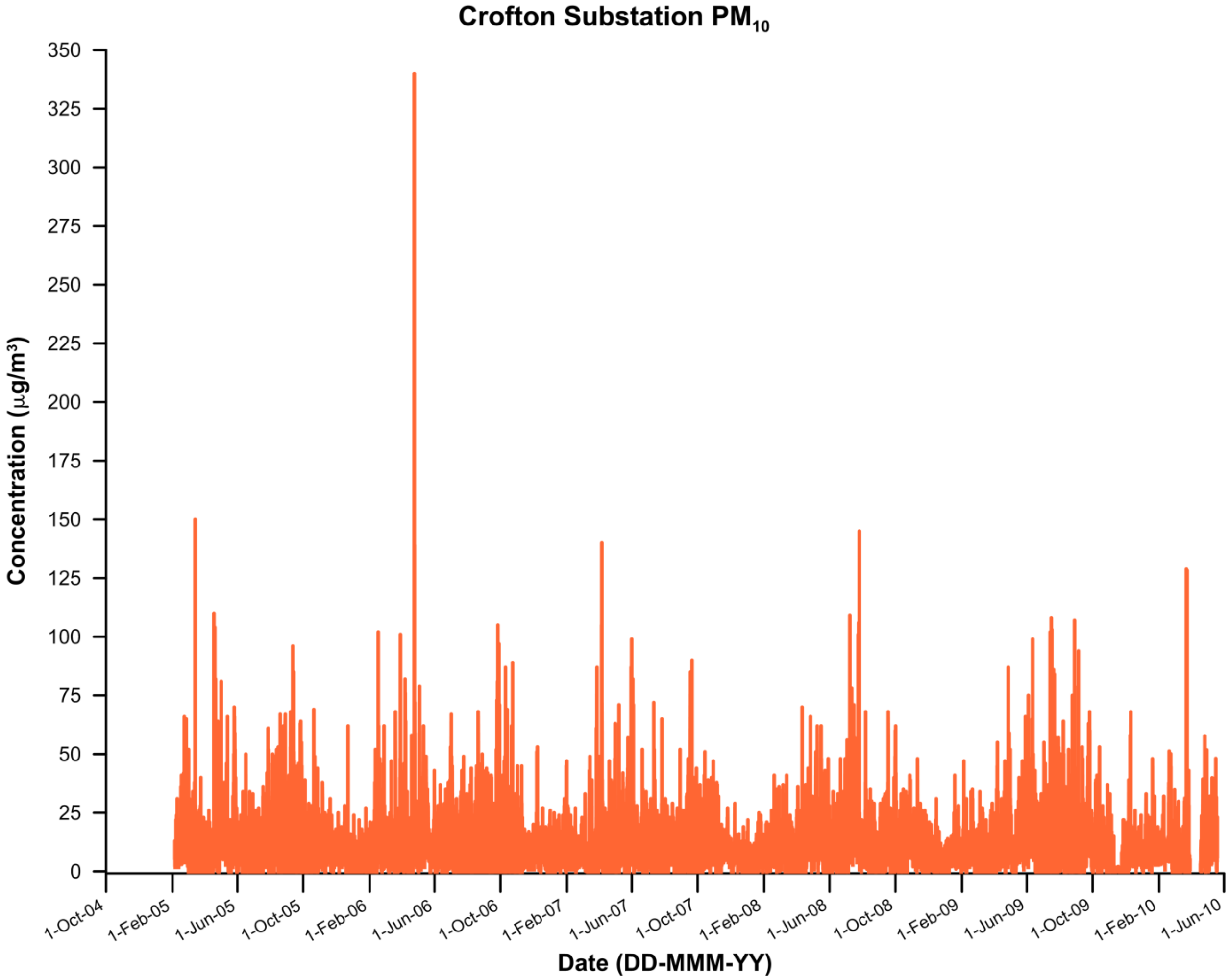

Figure B-10 Time Series of PM_{10} Concentration at Crofton Substation Based on 2005–2010 Hourly Data

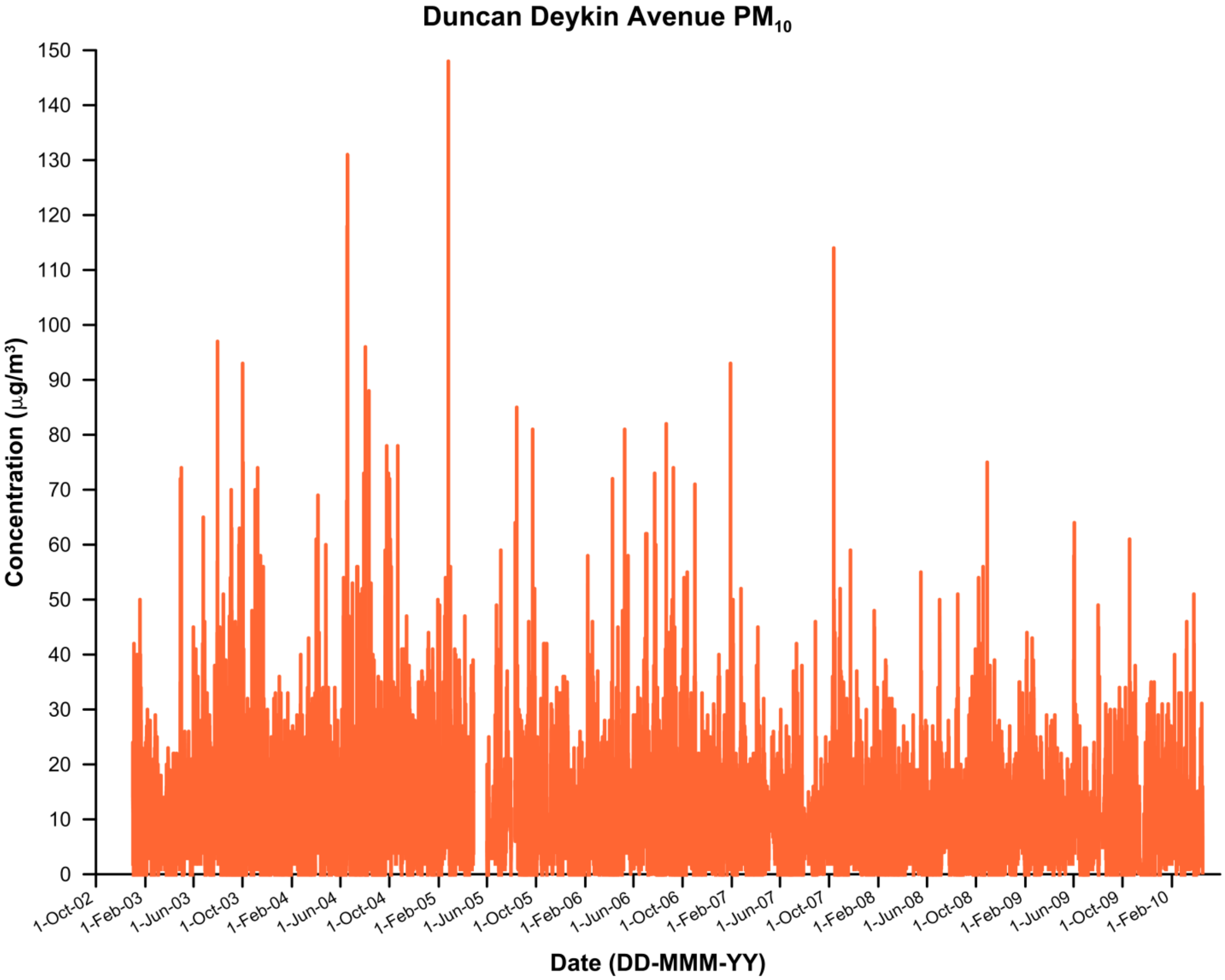

Figure B-11 Time Series of PM_{10} Concentration at Duncan Deykin Avenue Based on 2003–2010 Hourly Data

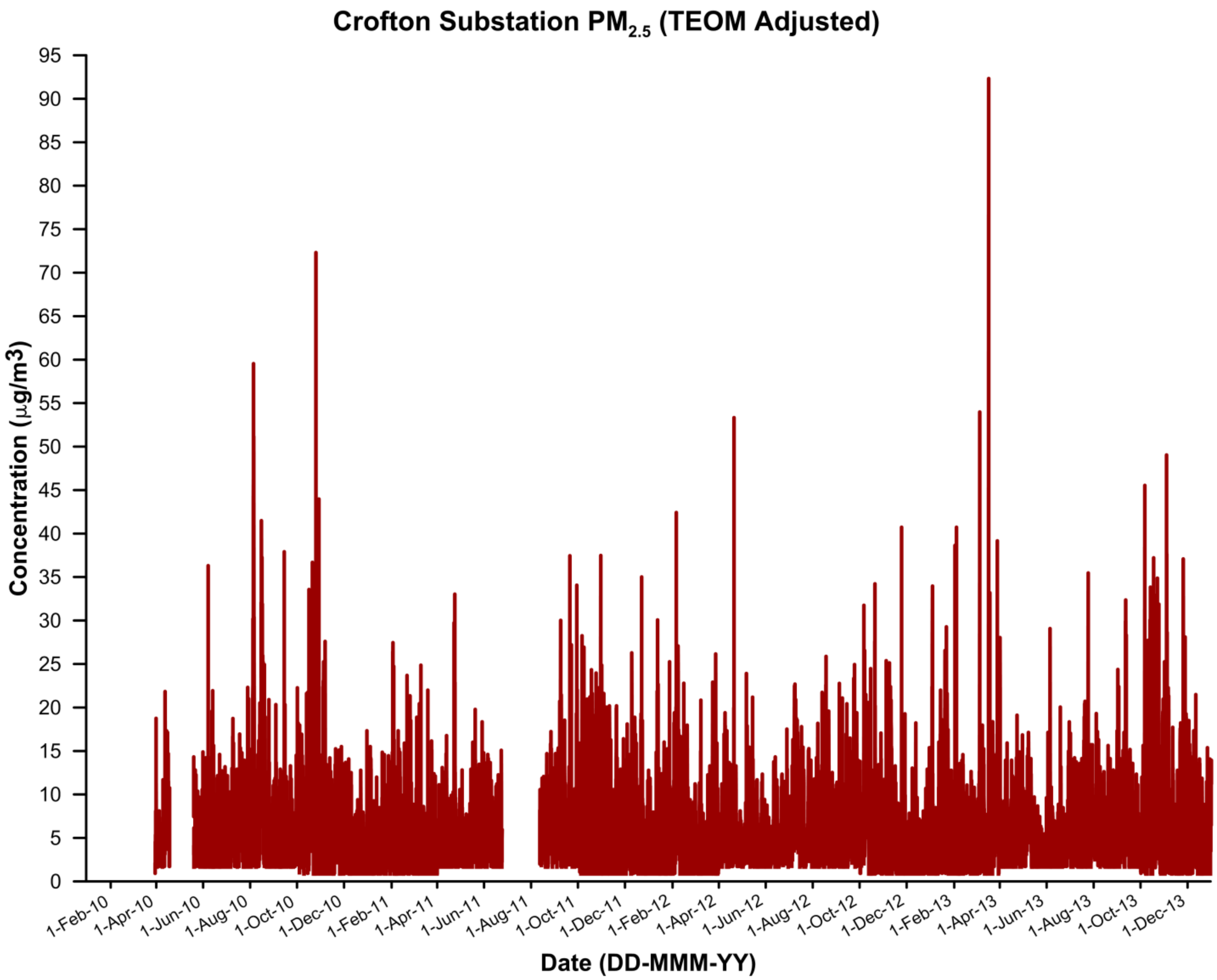

Figure B-12 Time Series of TEOM Adjusted $PM_{2.5}$ Concentration at Crofton Substation Based on 2010–2013 Hourly Data

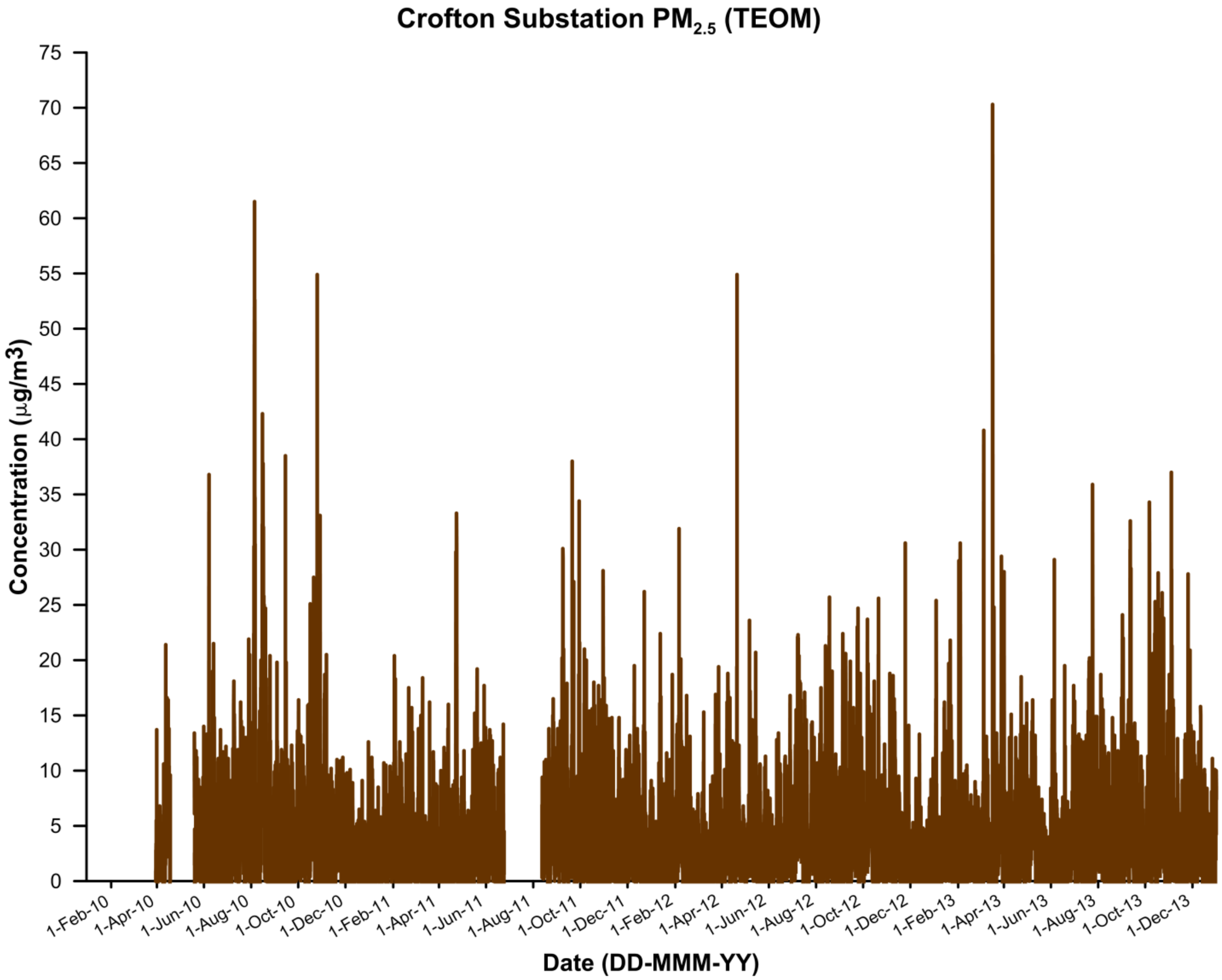

Figure B-13 Time Series of TEOM Unadjusted $PM_{2.5}$ Concentration at Crofton Substation Based on 2010–2013 Hourly Data

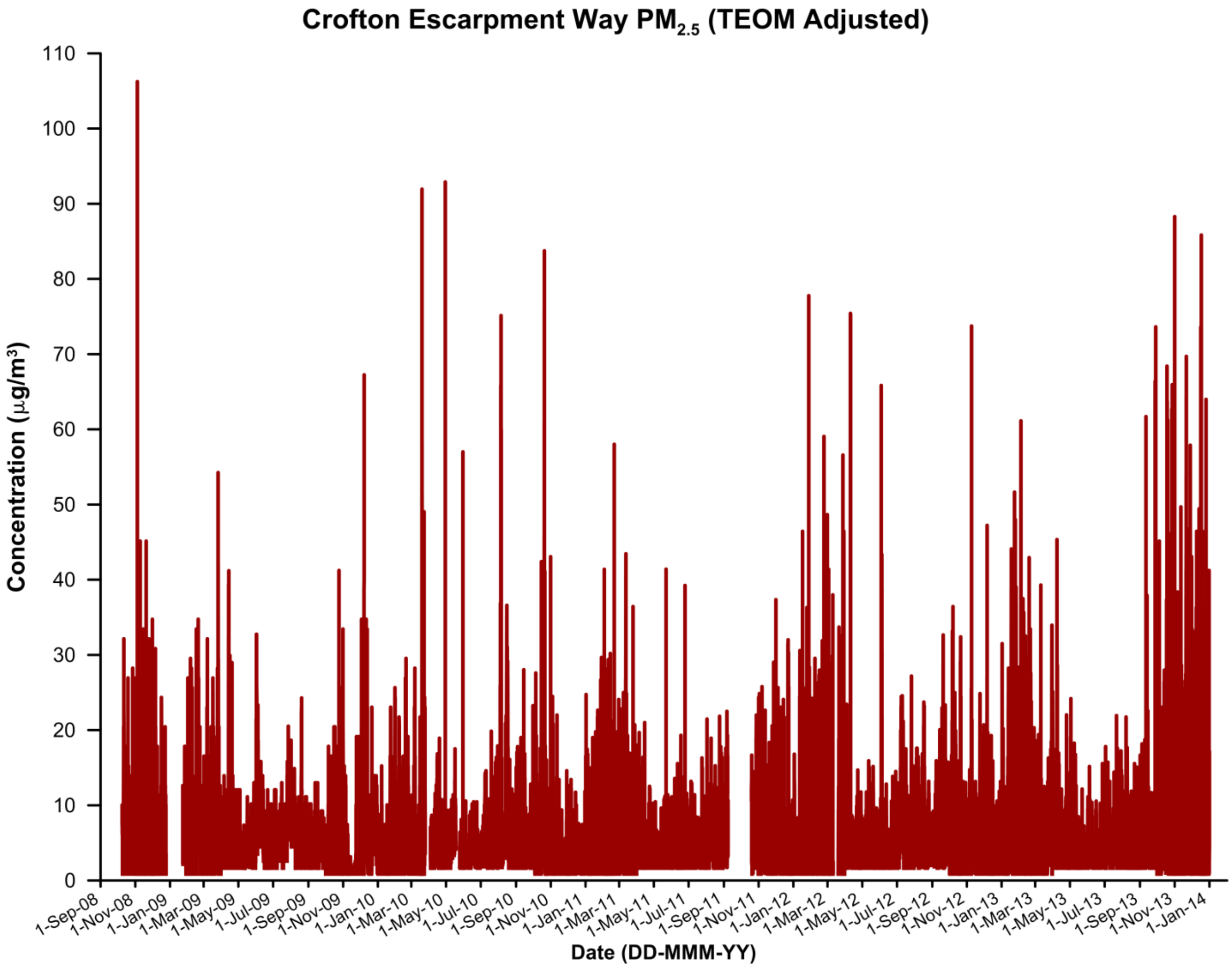

Figure B-14 Time Series of TEOM Adjusted $PM_{2.5}$ Concentration at Crofton Escarpment Way Based on 2008–2013 Hourly Data

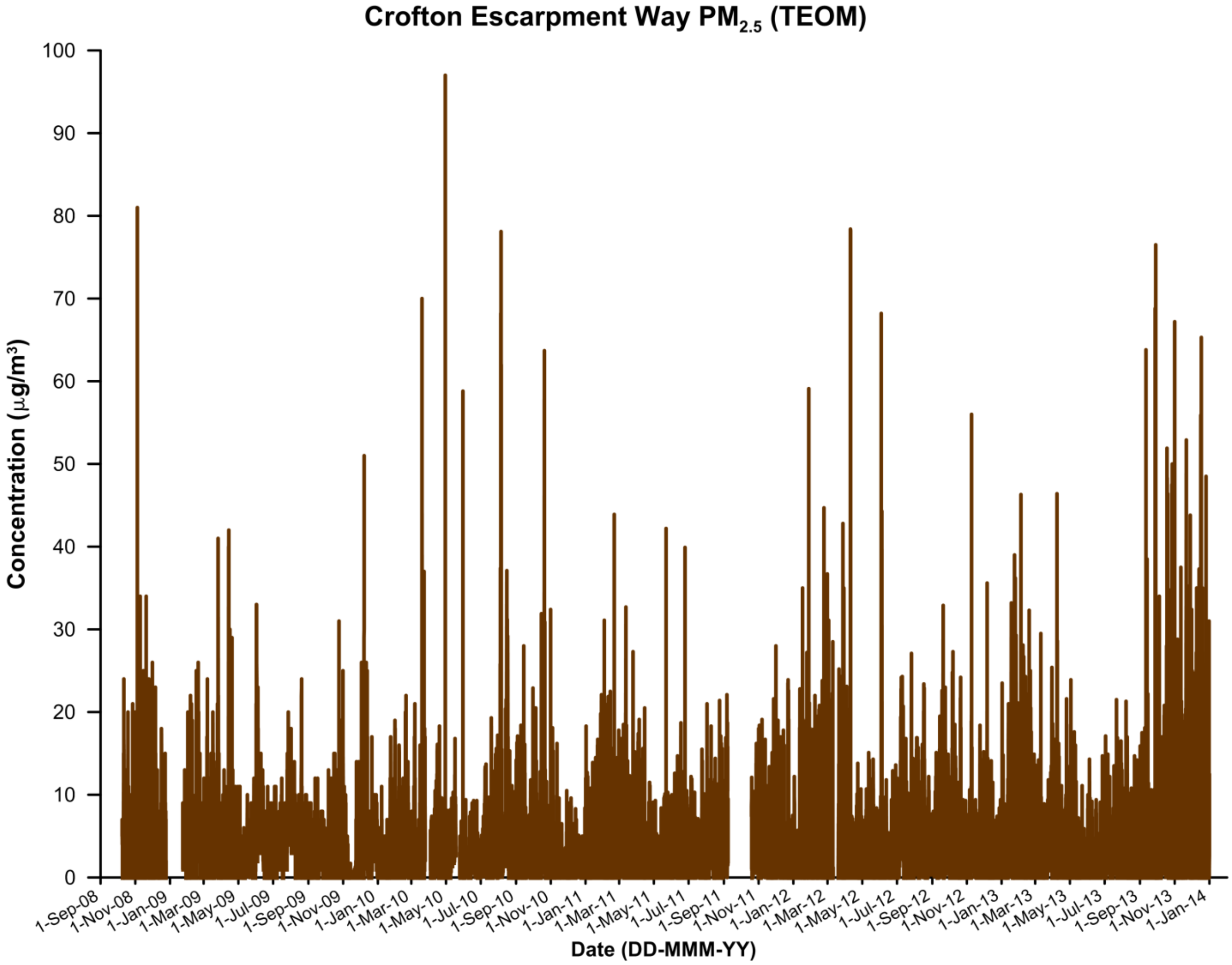

Figure B-15 Time Series of TEOM Unadjusted $PM_{2.5}$ Concentration at Crofton Escarpment Way Station Based on 2008–2013 Hourly Data

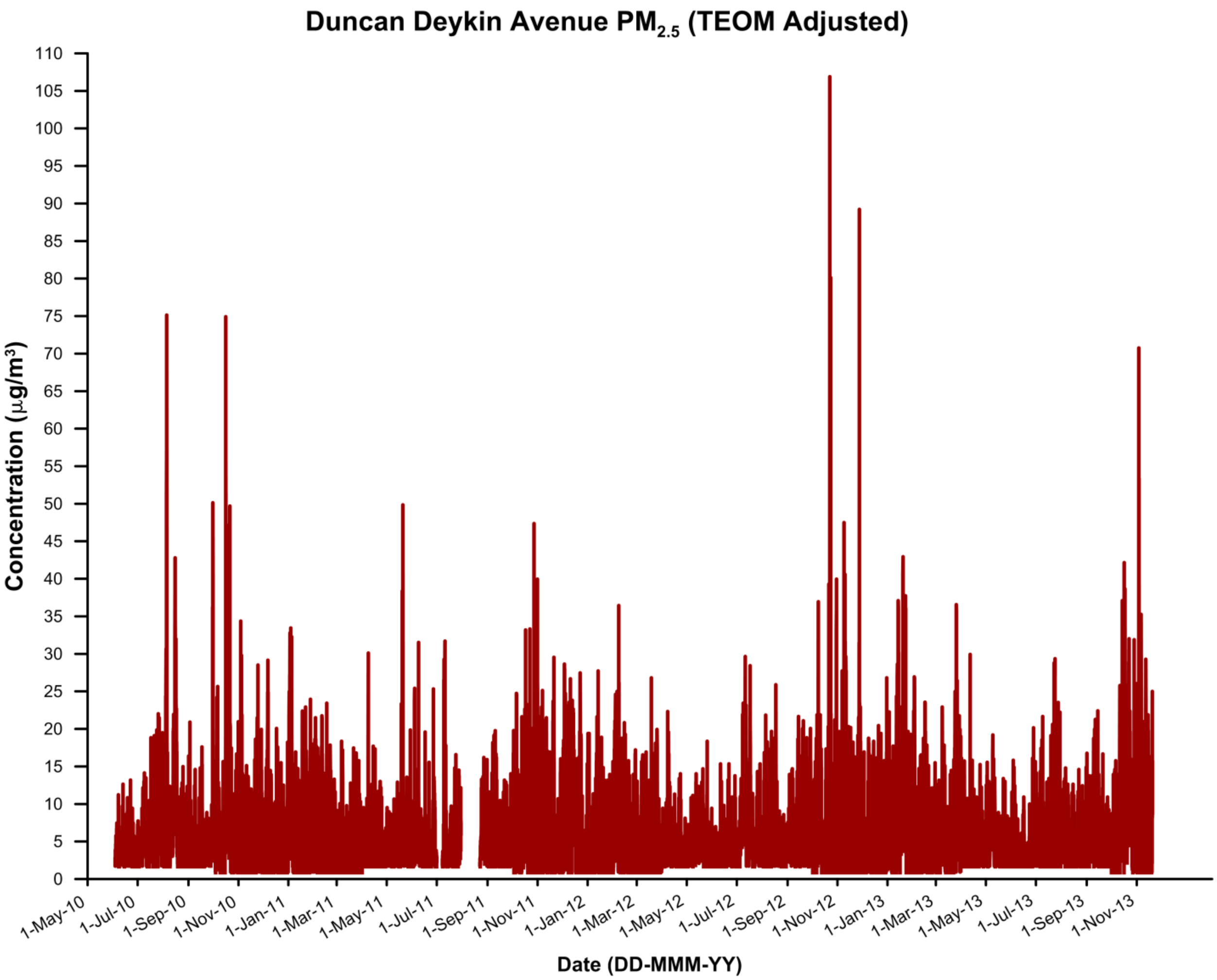

Figure B-16 Time Series of TEOM Adjusted $PM_{2.5}$ Concentration at Duncan Deykin Avenue Based on 2010–2013 Hourly Data

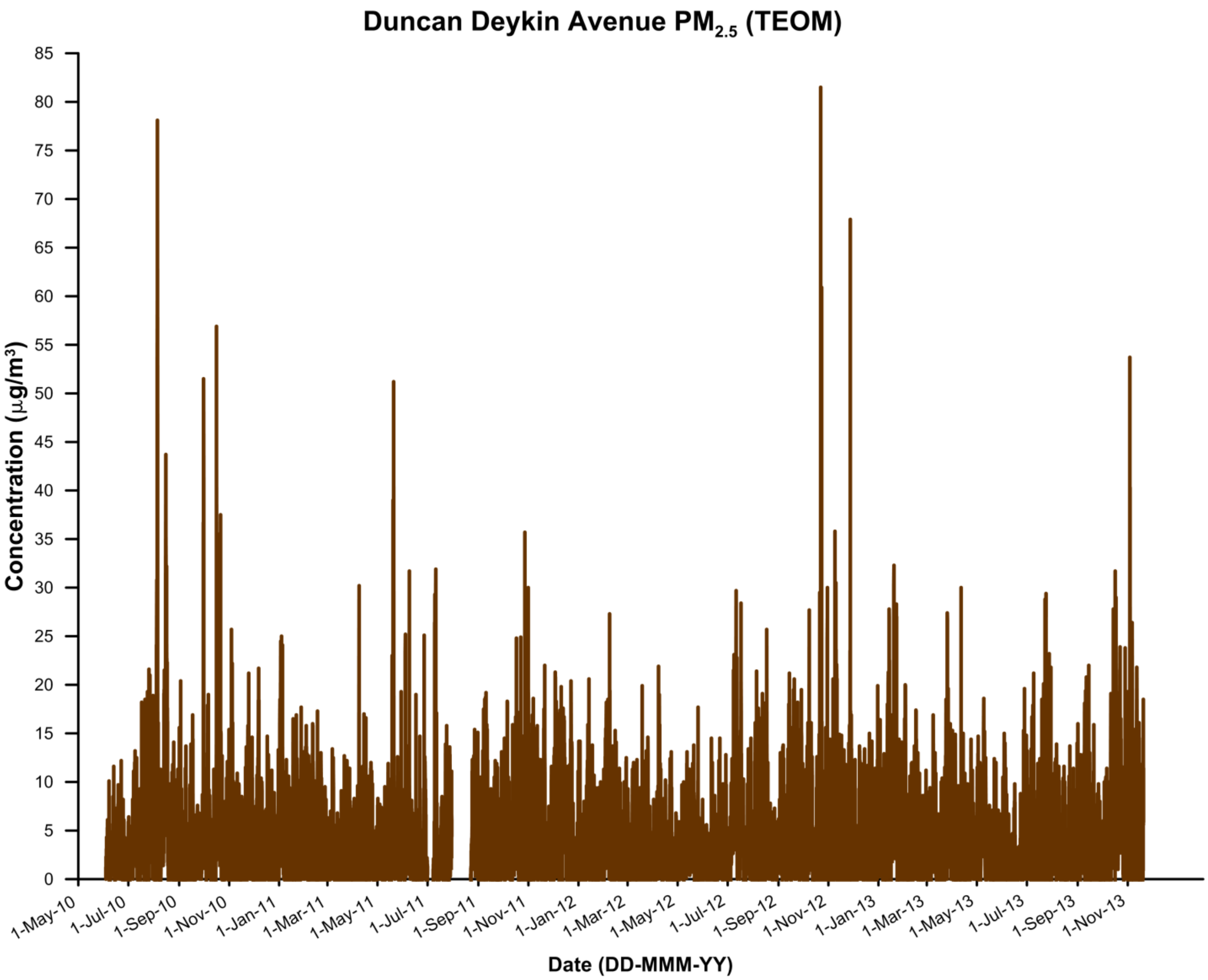

Figure B-17 Time Series of TEOM Unadjusted $PM_{2.5}$ Concentration at Duncan Deykin Avenue Based on 2010–2013 Hourly Data

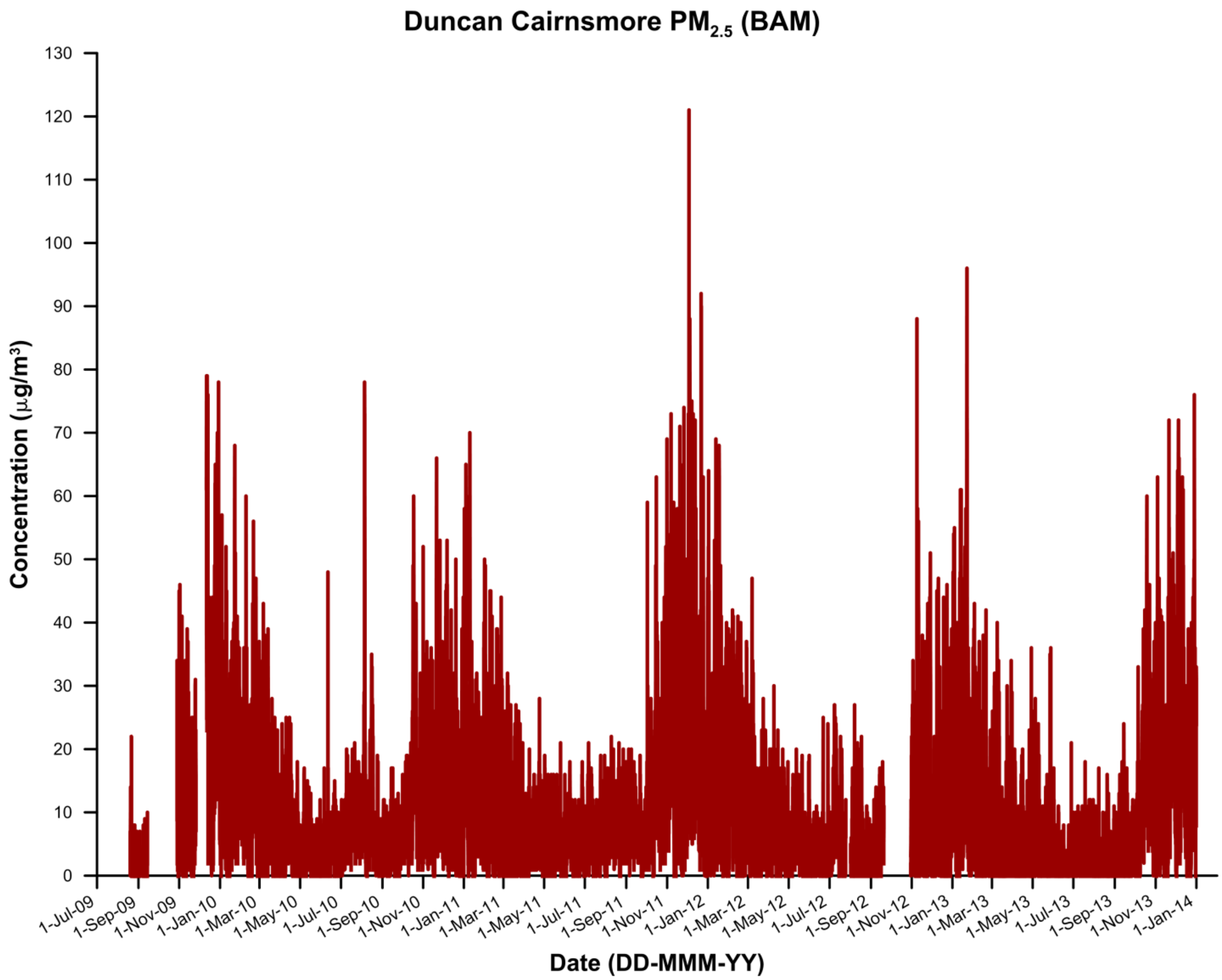

Figure B-18 Time Series of BAM $PM_{2.5}$ Concentration at Duncan Cairnsmore Based on 2010–2013 Hourly Data

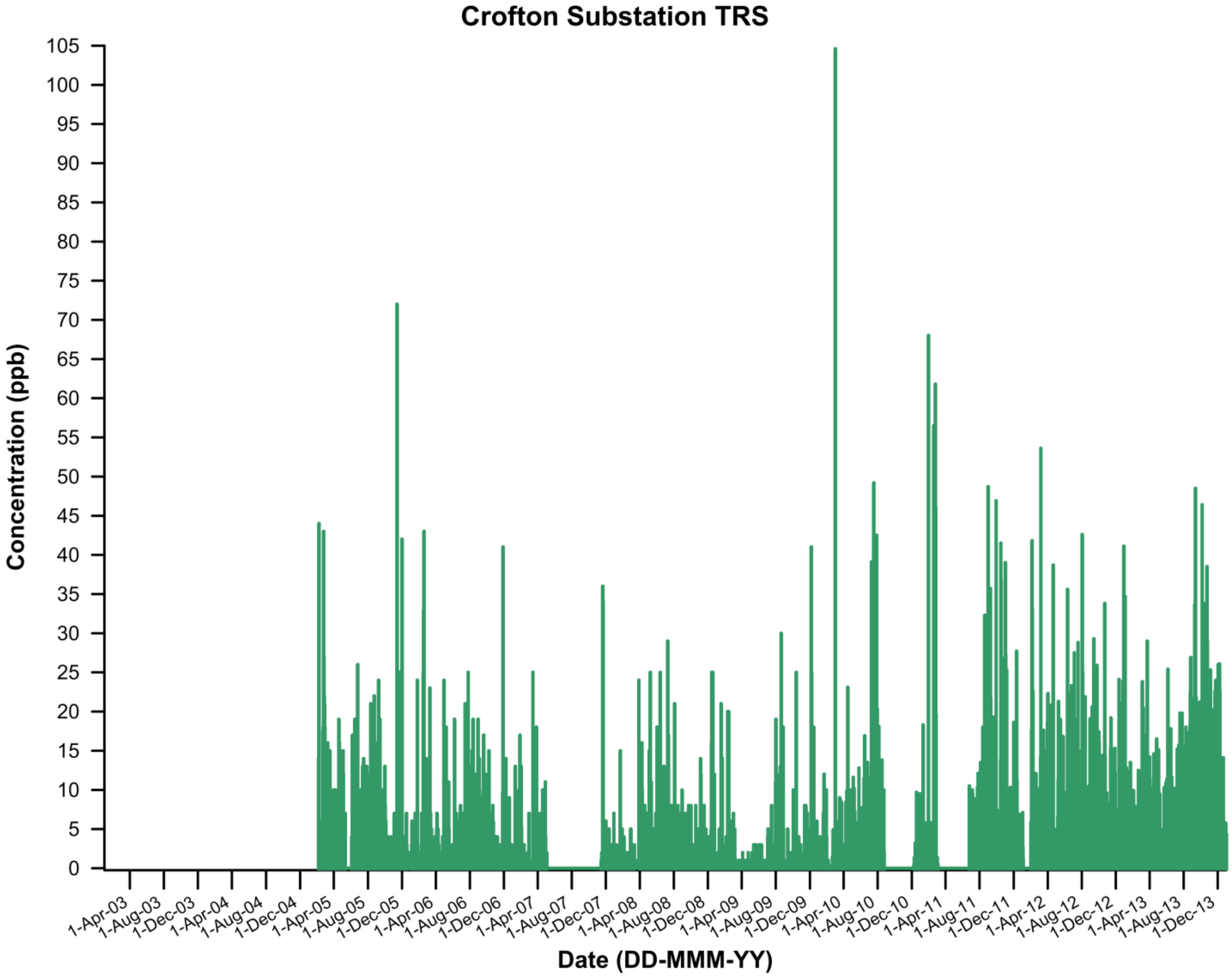

Figure B-19 Time Series of TRS Concentration at Crofton Substation Based on 2005–2013 Hourly Data

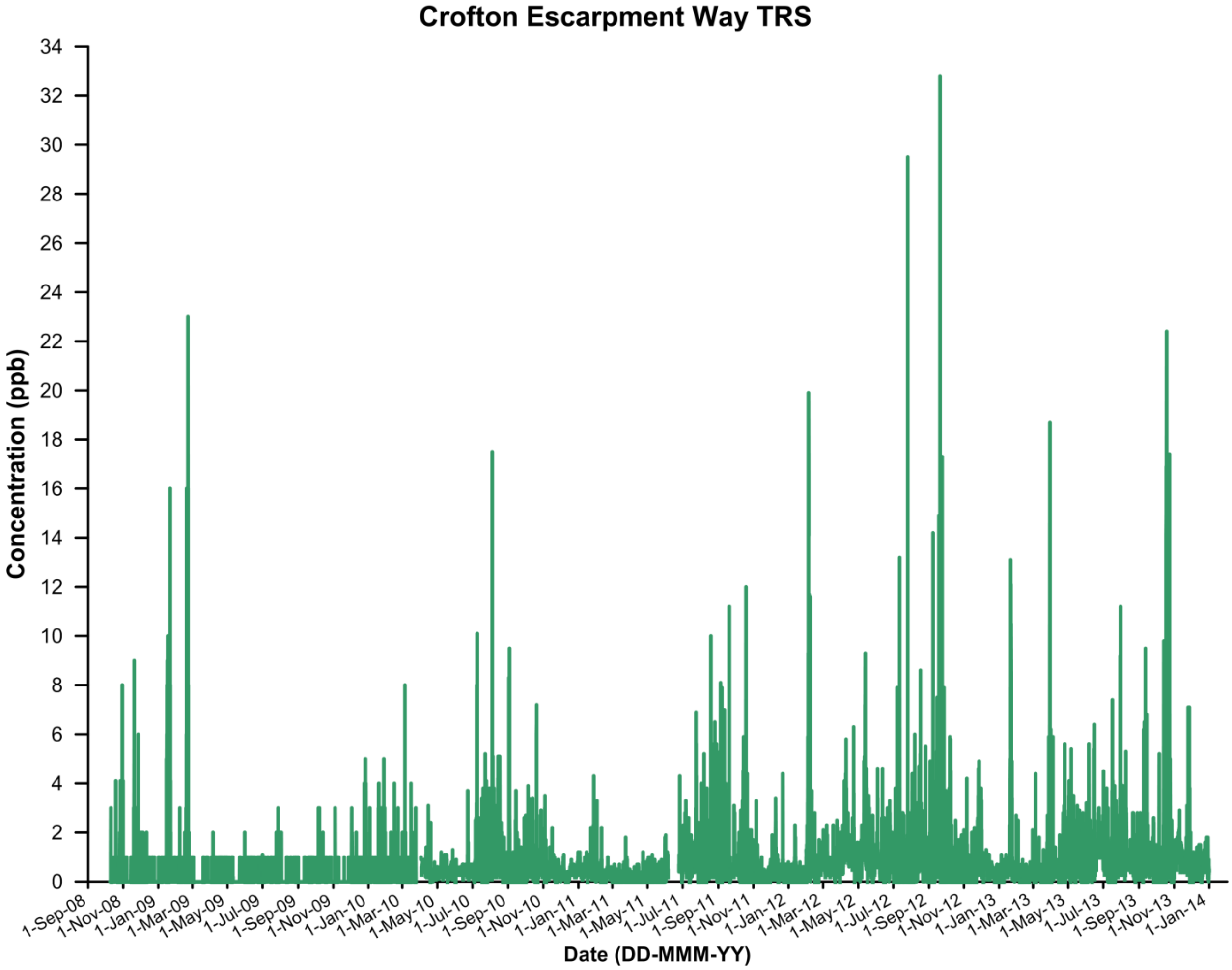

Figure B-20 Time Series of TRS Concentration at Crofton Escarpment Way Based on 2008–2013 Hourly Data

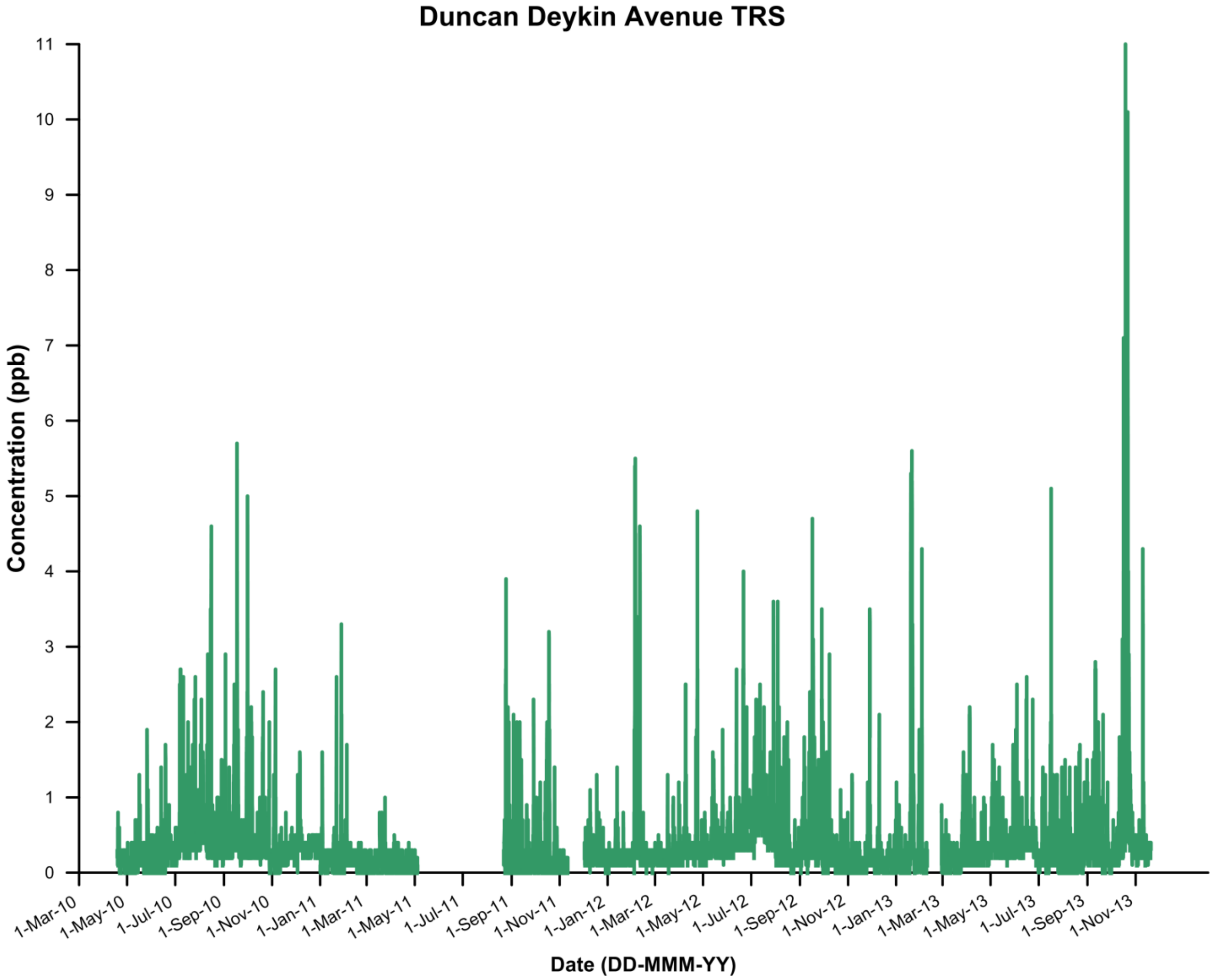

Figure B-21 Time Series of TRS Concentration at Duncan Deykin Avenue Based on 2010–2013 Hourly Data

Stantec

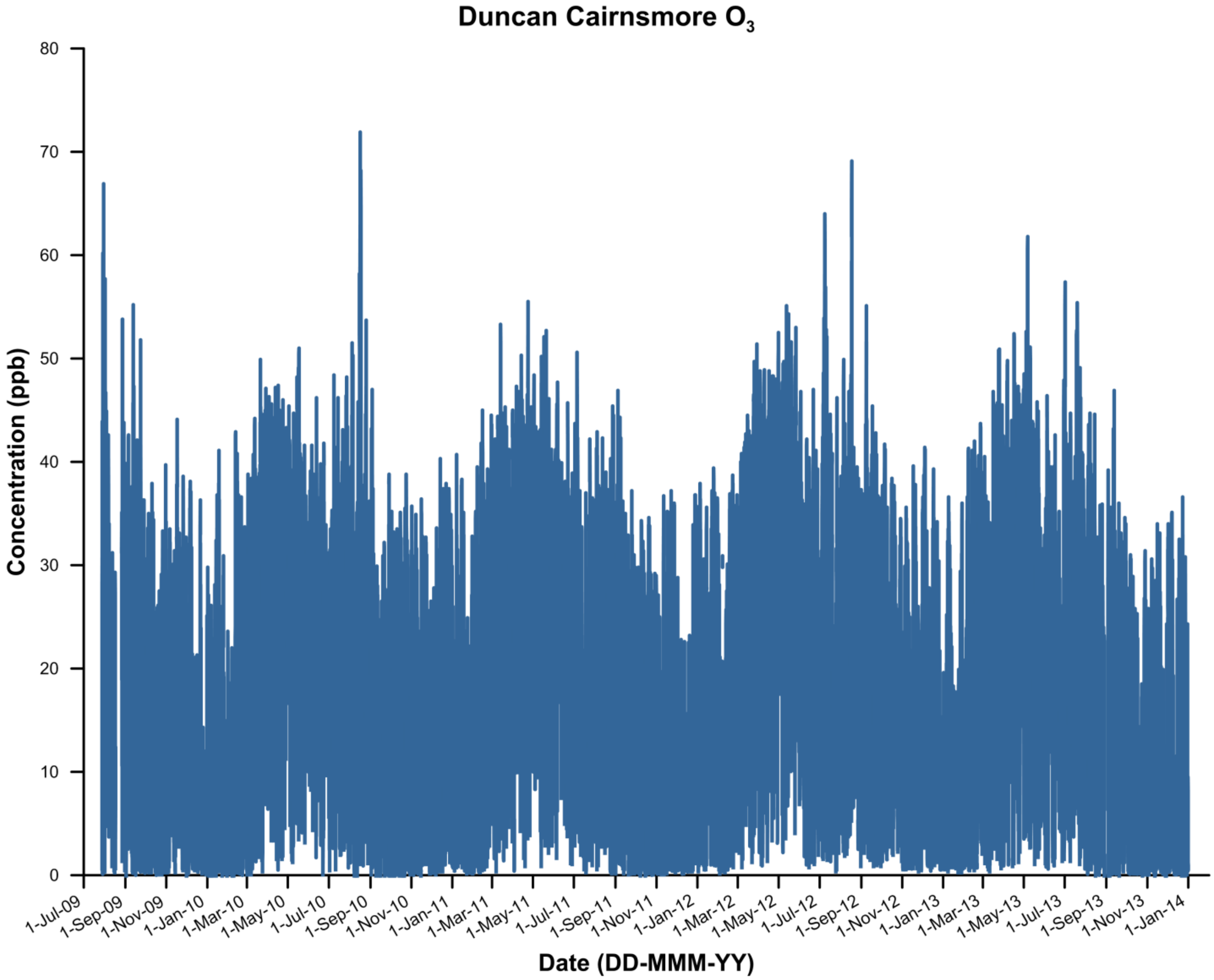

Figure B-22 Time Series of O_3 Concentration at Duncan Cairnsmore Based on 2009–2013 Hourly Data

B.4 UNADJUSTED $PM_{2.5}$ DATA FROM TEOM INSTRUMENTS

As discussed in Section 3.2.5, $PM_{2.5}$ data obtained from TEOM instruments at the Crofton Substation, Crofton Escarpment Way, and Duncan Deykin Avenue monitoring stations were adjusted based on the Environment Canada technique (Environment Canada 2014c) to make results more comparable to data from BAM instruments. This section contains the unadjusted TEOM $PM_{2.5}$ results in graphics analogous to those found in Section 3.2.5. Annual averages, 24-hour box and whisker plots, diurnal trends, and hebdomadal trends for unadjusted TEOM $PM_{2.5}$ data are presented below.

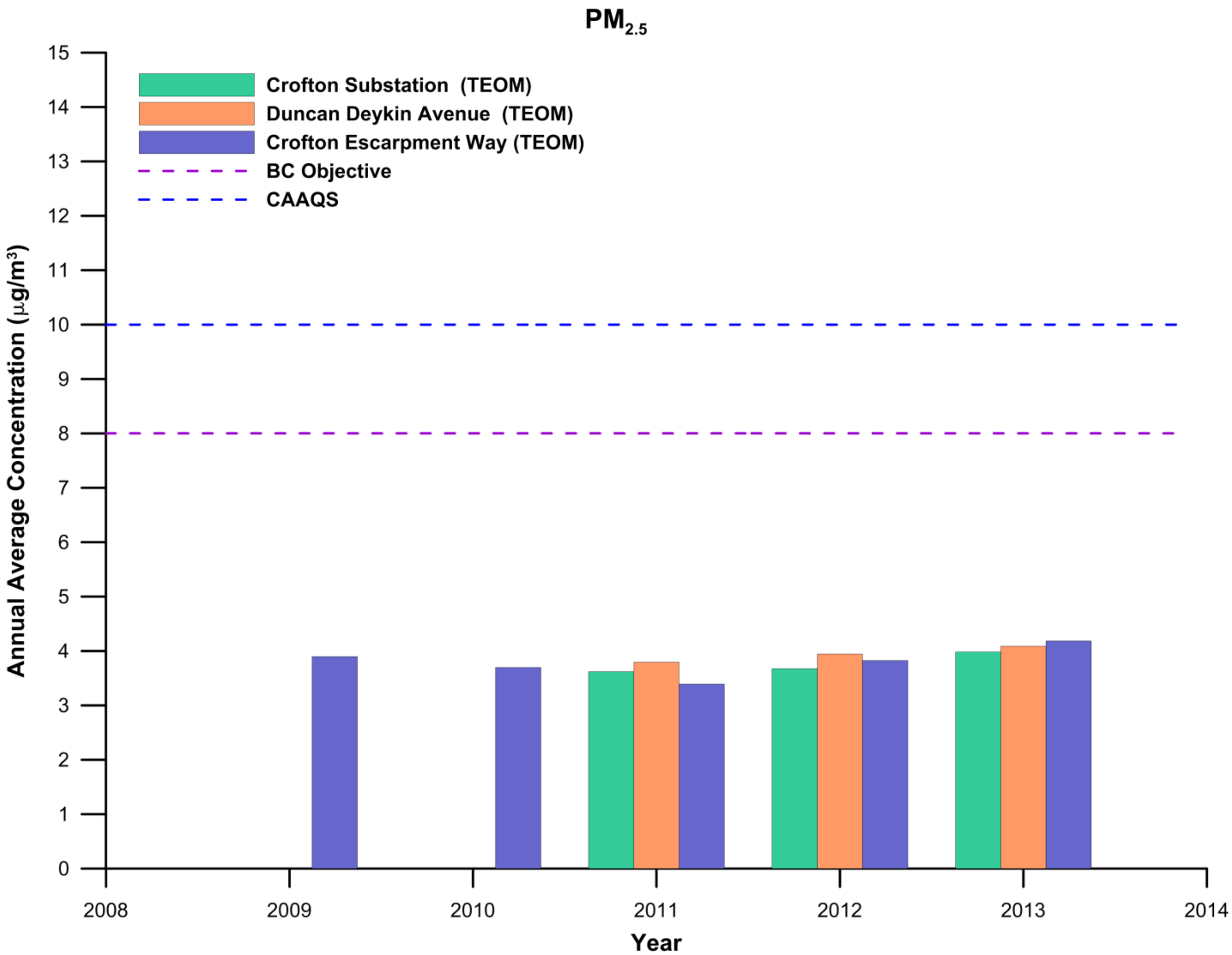

Figure B-23 Annual Average Unadjusted TEOM $PM_{2.5}$ Concentrations in the CVRD

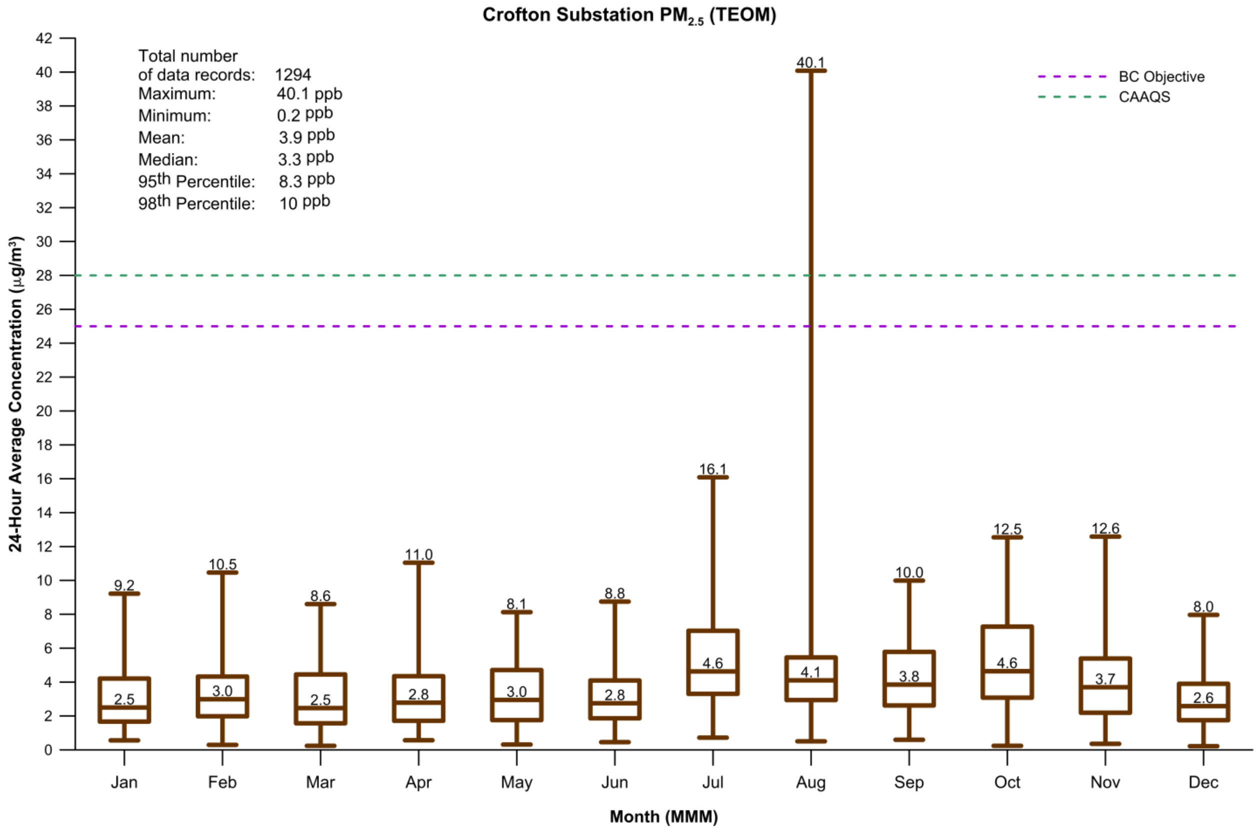

Figure B-24 Monthly Variation of 24-Hour Average Unadjusted TEOM $PM_{2.5}$ Concentration at Crofton Substation Based on 2010–2013 Data

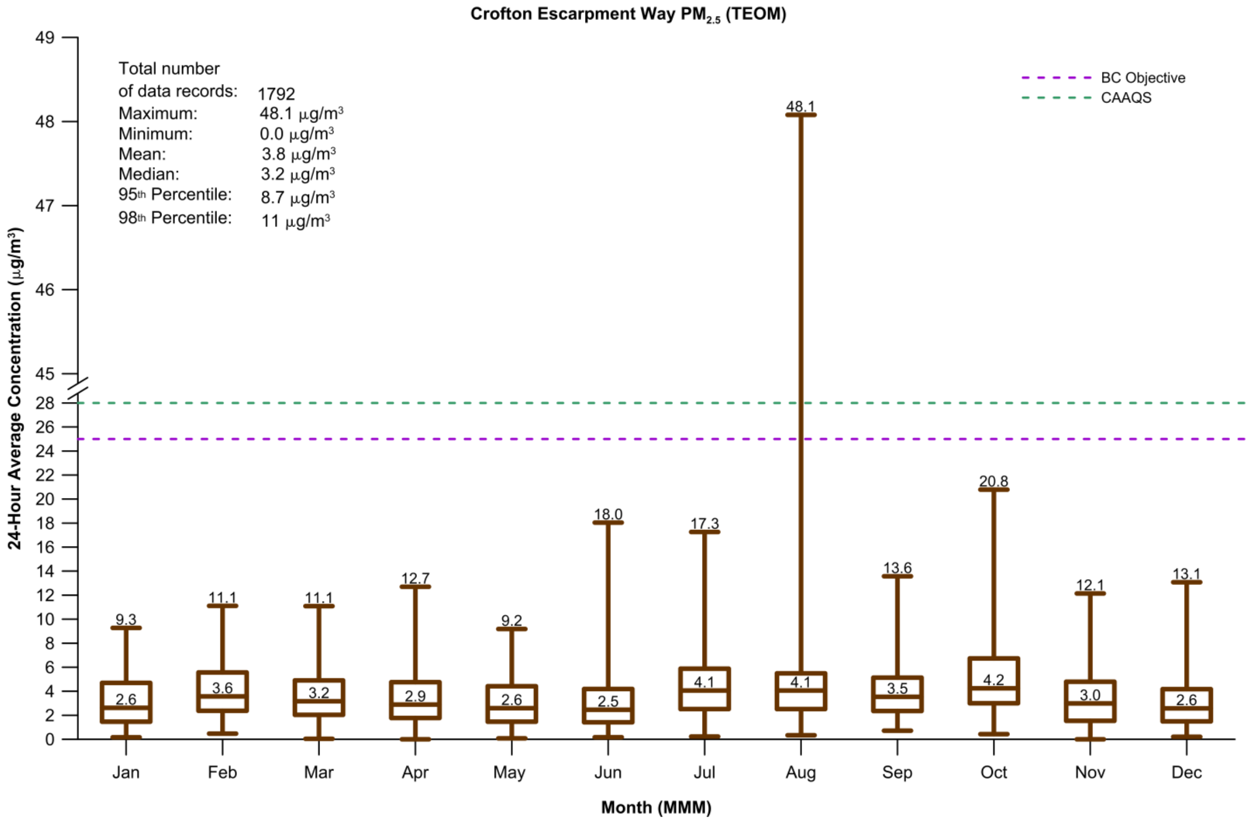

Figure B-25 Monthly Variation of 24-Hour Average Unadjusted TEOM $PM_{2.5}$ Concentration at Crofton Escarpment Way Based on 2008–2013 Data

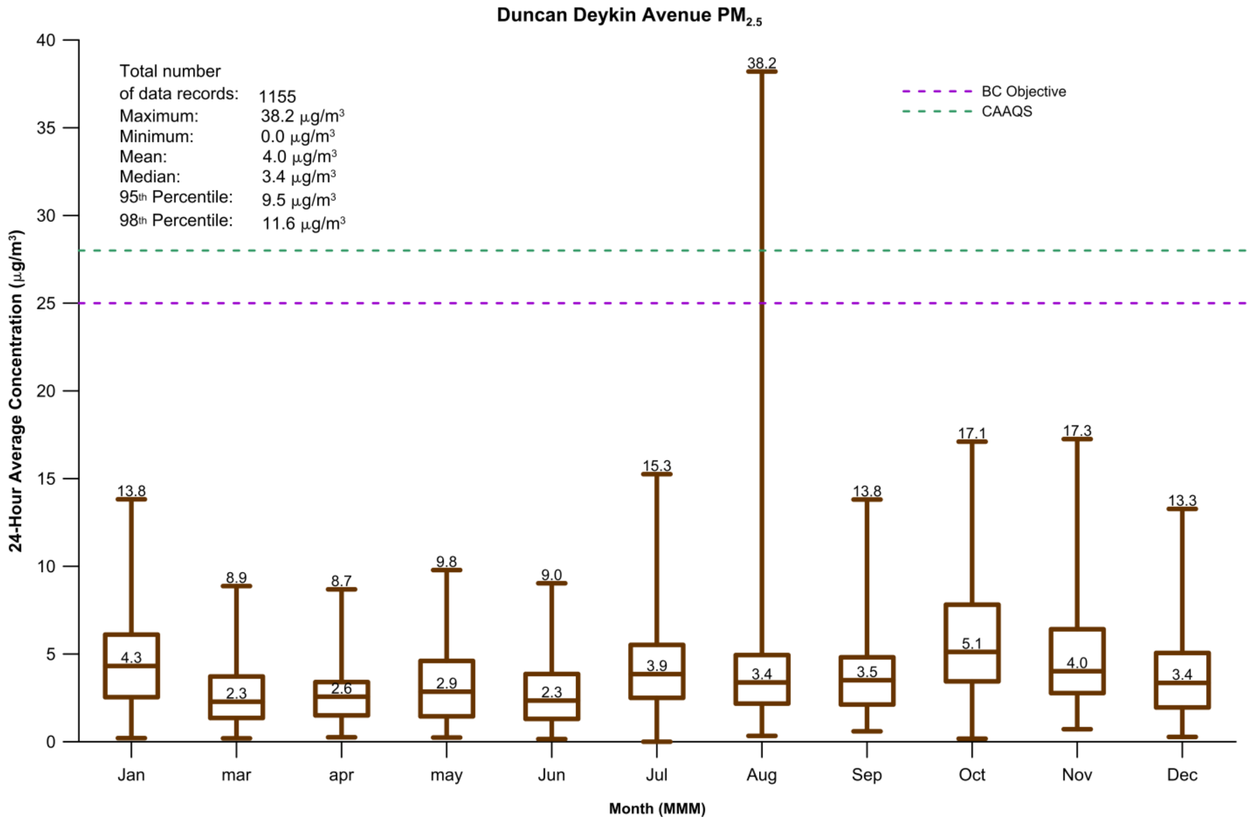

Figure B-26 Monthly Variation of 24-Hour Average Unadjusted TEOM $PM_{2.5}$ Concentration at Duncan Deykin Avenue Based on 2010–2013 Data

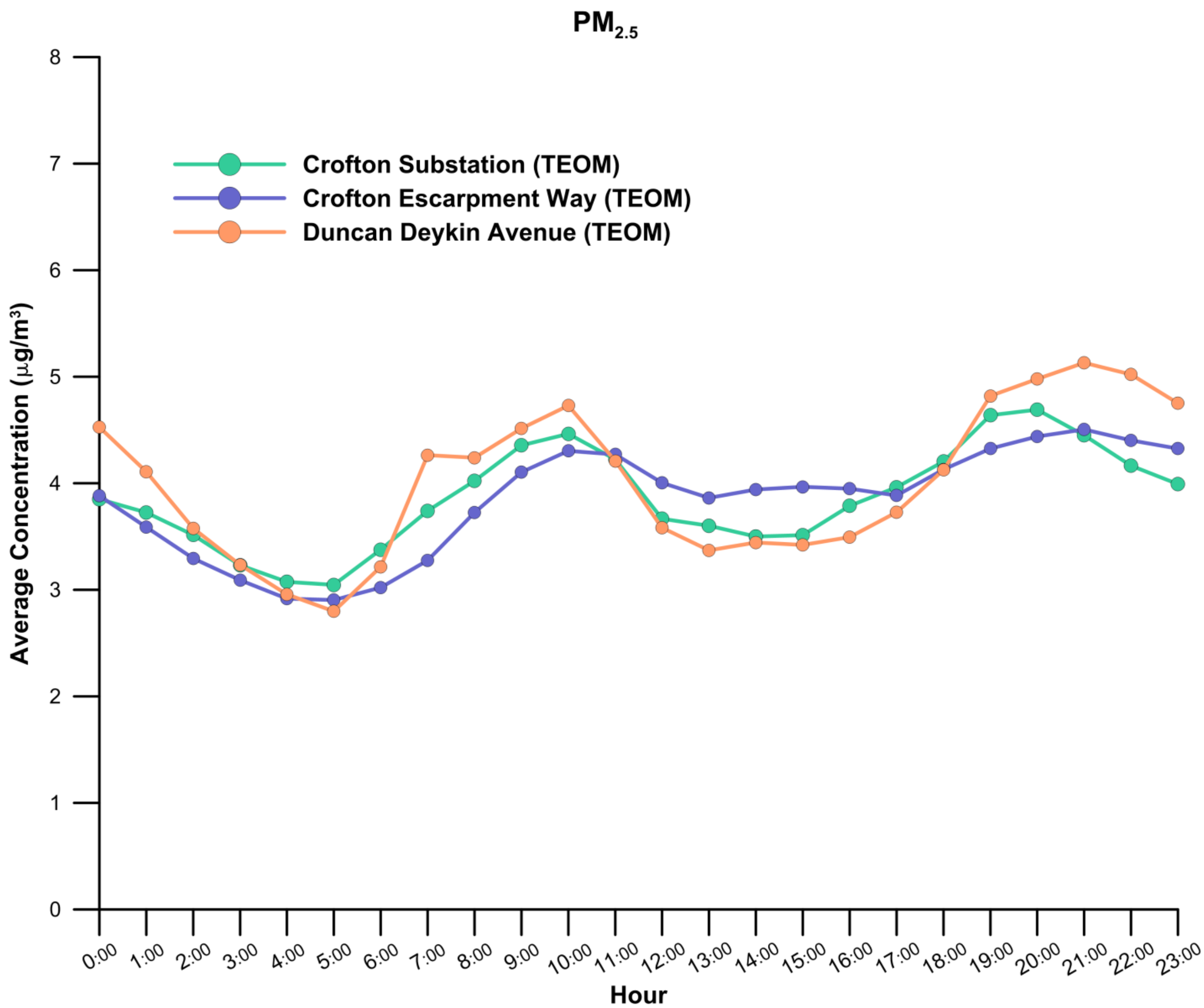

Figure B-27 Diurnal Trends in Unadjusted TEOM $PM_{2.5}$ Concentration Based on all Available Hourly Data

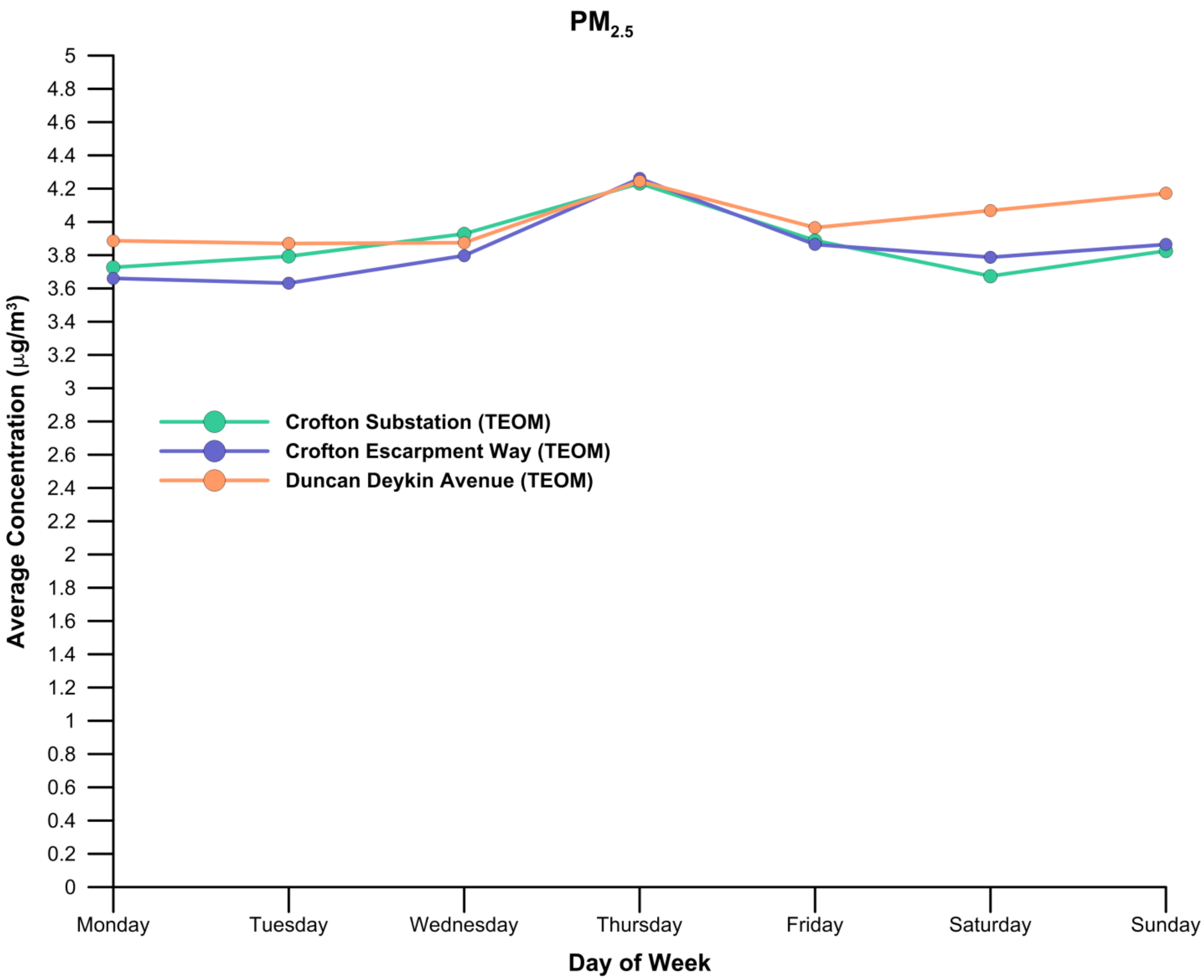

Figure B-28 Average Unadjusted TEOM $PM_{2.5}$ Concentration by Day of the Week at Crofton Substation, Crofton Escarpment Way, and Duncan Deykin Avenue