Investigating Air Quality Impacts of Cruise Ship and Ferry Emissions in James Bay, Victoria, BC, Canada

by

Karla Marjorie Lina Poplawski
BSc, University of Victoria, 2006

A Thesis Submitted in Partial Fulfillment
of the Requirements for the Degree of

MASTER OF SCIENCE

in the Department of Geography

Supervisory Committee

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The purpose of this thesis is to investigate air quality in the James Bay neighbourhood of Victoria, BC, Canada, and determine the effects of emissions from cruise ships and ferries on local air quality. A combination of field monitoring and air quality modeling conducted during the 2007 cruise ship season in Victoria is used to achieve this objective. Pollutants examined include nitrogen dioxide (NO_2), sulphur dioxide (SO_2) and particulate matter ($PM_{2.5}$ and PM_{10}). Field monitoring provides long-term average concentration levels throughout the area, while the California Puff Model (CALPUFF) is used to predict concentrations from ferry and cruise ship sources at shorter time periods (1-hour and 24-hour). The two methodologies used for this research quantify air quality in James Bay and establish a baseline of concentration levels which can be referred to during any future air quality studies in the area. Results show possible, yet infrequent, exceedences of Capital Regional District and World Health Organization 1-hour NO_2 and 24-hour SO_2 air quality guidelines in the study domain. The potential implications of these exceedences on health of residents will be assessed by the Vancouver Island Health Authority.

Table of Contents

List of Tables

List of Figures

Acknowledgements

First and foremost, I would like to thank my supervisor, Dr. Peter Keller, for allowing me the opportunity to carry out this research, and for providing ongoing support and encouragement throughout the process. I would also like to express my extreme gratitude to Dr. Eleanor Setton, who I have had the pleasure to work with over the past three years in the Spatial Sciences Research Laboratory. Eleanor is truly inspirational- I could not have asked for a better teacher or role model. She has provided me with so many opportunities to learn and work on interesting projects in the field of air quality and health, for which I am extremely grateful. Eleanor also deserves recognition for her efforts in the establishment of, and ongoing involvement in the James Bay Air Quality Study. Members of my supervisory committee, Dr. Andrew Kmetic and Dr. Maycira Costa must also be thanked for their involvement in my research, by reading drafts and providing constructive questions and comments.

This research would not have been possible without the many people who were involved in various aspects of the James Bay Air Quality Study (JBAQS). In particular, Bryan McEwen from SENES Consultants Ltd. deserves special recognition for providing immeasurable assistance in teaching me how to use the CALPUFF model. I would also like to thank those who were part of the JBAQS advisory committee – Steve Sakiyama, Chris Robins, Michael Pennock, Mike Kory, Warren McCormick, Marg Gardner, Doug Craig and Tim Van Alstine. This project is truly a collaborative research study, and would not have been possible without the contribution of everyone who has been involved along the way.

Special thanks to my colleagues and staff in the Geography department at the University of Victoria. The undertaking of a masters degree is simply not possible without the support of friends and those important people who work behind the scenes to make things go so smoothly and successfully – Darlene Li, Kathie Merriam, Diane Braithwaite, Marta Ausio-Esteve, Ole Heggen and Rick Sykes, thank you so much!

Last, but definitely not least, I extend thanks to my friends and family. In particular, thank you to my best friends, Ariane Lunardi and Joshua Bartley, for helping me with the field monitoring, rain or shine. The biggest thank you of all, however, goes to my parents, Christine and Gunther Poplawski.

List of Acronyms

CARF	Clean Air Research Fund
CO	Carbon Monoxide
CO_2	Carbon Dioxide
COSBC	BC Chamber of Shipping
CRD	Capital Regional District
DFO	Distillate Fuel Oil
EGD	Esquimalt Graving Dock
GVHA	Greater Victoria Harbour Authority
HC	Hydrocarbons
HFO	Heavy Fuel Oil
JBAQS	James Bay Air Quality Study
JBNA	James Bay Neighbourhood Association
MARPOL	International Convention for the Prevention of Pollution from Ships
MGO	Marine Gas Oil
MOE	BC Ministry of Environment
NAPS	National Air Pollution Surveillance
NO	Nitric Oxide
NO_2	Nitrogen Dioxide
NO_X	Nitrogen Oxides
PM	Particulate Matter
$PM_{2.5}$	Particulate Matter less than 2.5 µm in Aerodynamic Diameter
PM_{10}	Particulate Matter less than 10 µm in Aerodynamic Diameter
RRU	Royal Roads University
SECA	Sulphur Emission Control Area
SENES	SENES Consulting Ltd., Vancouver, BC
SO_2	Sulphur Dioxide
SO_X	Sulphur Oxides
SSRL	Spatial Sciences Research Lab
Tg	Million Metric Tonnes
UVic	University of Victoria
VIHA	Vancouver Island Health Authority
VOCs	Volatile Organic Compounds

Disclaimer

This thesis presents air quality data obtained by field monitoring and the use of an air quality computer simulation model during the 2007 cruise ship season. Field monitoring provides actual measurements of pollutants observed in the James Bay community and may include emissions from all contributing sources in the region. The air quality modeling simulation estimates community level concentrations of pollutants emitted from cruise ship and ferry sources only. The contribution from other emission sources in the area is represented by an estimated general background concentration, as large marine vessels operating in James Bay was the focus of this thesis, and adequate information to characterize other sources could not be obtained.

Air quality modeling simulations were performed based on the best available information at the time of analysis in order to characterize terrain, meteorology and emission sources. Data assumptions and limitations are cited throughout the thesis and should be taken into consideration when interpreting results. Data accuracy where cited from other studies are reported at the same level of significance as in the source. A best effort has been made to report data derived first hand at their appropriate level of significance in order not to mislead on precision. The thesis does not provide sensitivity or error analysis of model parameterization or concentration estimates, and therefore no error margin associated with estimated concentrations is provided. Limited quality assurance and quality control exercises are performed when possible, by comparing estimated meteorological and emissions data to actual measurements observed in the study domain.

The analyses presented herein represent the first stage of ongoing air quality study in James Bay, and provide a baseline of observed concentrations and an initial modeling platform for estimating emissions from particular sources of community interest. Ongoing or future study should include sensitivity analysis of model parameterization and characterization of emission sources. Future availability of more specific data about individual cruise ship vessels, or data to characterize other sources not included in the analysis, may also be used to improve future model simulation exercises.

Chapter 1

Background Information

The impacts of air pollution on human health have been extensively researched and well-documented in the literature (e.g. Kaiser, 2005; Kappos et al., 2004; Brunekreef and Holgate, 2002; Hoek et al., 2002; Burnett et al., 1998). The combustion of fossil fuels produces pollutants such as fine particulates ($PM_{2.5}$), sulphur oxides (SO_x), volatile organic compounds (VOCs), nitrogen oxides (NO_x), and carbon monoxide (CO). Exposure to these contaminants has been linked to a wide range of health impacts, including increased hospital admissions (Corbett et al., 2007), development of asthma and respiratory infections (de Jongste et al., 2004), as well as increased cancer and cardiopulmonary mortalities (Abbey et al., 1999).

Power production, industrial operations, home heating, and motor vehicle exhaust are major anthropogenic sources of land-based air pollution. Maritime regions, however, are also subject to additional emissions from ships. Historically, marine emission sources have not received the same level of attention as the land-based sector in regards to emission reduction strategies (Cooper, 2003). While improved marine emissions inventories are now recognizing the important contribution of ships to local and global emissions (Corbett et al., 1997; Eyring et al., 2005), few studies have yet to examine the contribution of marine emissions to community level air concentrations.

This thesis investigates air quality impacts of emissions from cruise ships on local air quality in the James Bay community of Victoria, BC, Canada. Air quality in the study area was assessed for the 2007 cruise ships season (April 24 to November 3, inclusive) using a combination of field monitoring and air quality modeling techniques. A variety of field monitoring equipment was used to establish general long-term levels of pollutants in James Bay, with a sampling campaign designed to explore whether contributions from

cruise ships could be observed in measured levels. Air quality modeling was used to assess predicted shorter-term (1-hour and 24-hour) concentration levels in the region from cruise ships at the Ogden Point terminal, and also from passenger and vehicle ferries in the Victoria Inner Harbour.

The majority of this research was conducted as part of the larger James Bay Air Quality Study (JBAQS). Two comprehensive reports[1] produced for the JBAQS directly correspond to information provided in this thesis on the field monitoring and air quality modeling analyses. Although the JBAQS investigated a wider range of emissions sources of concern to members of the James Bay community, this thesis focuses specifically on cruise ship and ferry (M.V. Coho and Victoria Clipper) sources. The JBAQS Phase I and Phase II reports can be referred to for additional information on other sources and emissions, which are not included in this thesis.

This chapter provides background information about the JBAQS, the James Bay community, and characteristics of the cruise activity occurring there (Sections 1.1 to 1.3). This is followed by a literature review of marine emissions, the main pollutants which will be focused on in this thesis, available methods of estimating exposure to air pollution, and current air quality standards and guidelines (Sections 1.4 to 1.7). The chapter finishes by examining data from an air quality monitoring station in the Capital Regional District (CRD), located just outside of James Bay, to assess whether cruise ship emissions can be detected in measured concentrations in the region, and if an air quality study is warranted (Section 1.8). The final section of this chapter (Section 1.9) establishes the main goals and research questions this thesis will attempt to answer.

Chapter 2 of this thesis provides a summary of the multi-stakeholder process which was essential for the successful completion of this research. Chapters 3 and 4 correspond to the field monitoring program and air quality modeling analysis, respectively. Finally, Chapter 5 provides final thoughts and conclusions based on the two research techniques, and summarized answers to the main research questions posed in Section 1.9. Recommendations and areas of future research are also identified.

[1] JBAQS Phase I and Phase II reports available from the Vancouver Island Health Authority (http://www.viha.ca/about_viha/news/publications/)

1.1 James Bay Air Quality Study (JBAQS)

In 2006, the Vancouver Island Health Authority's (VIHA) Population Health Surveillance Unit approached researchers at the University of Victoria's Spatial Sciences Research Lab (SSRL) with a request to help initiate a study on the air quality in the James Bay neighbourhood of Victoria, BC. This was prompted in part by a request from the James Bay Neighbourhood Association (JBNA) to VIHA to investigate air quality and potential health risks in their residential area. Representatives from the SSRL and VIHA attended a community meeting of the JBNA in May 2007, where residents expressed an interest in understanding both short-term (several hours) and long-term (weeks to months) impacts on air quality in their neighbourhood, with specific sources of concern being car and bus traffic, marine vessels, float planes and helicopters. These sources typically emit nitrogen oxides (NO_x), sulphur dioxide (SO_2), particulate matter (PM), and volatile organic compounds (VOCs).

The "James Bay Air Quality Study" (JBAQS) was subsequently developed, designed as a two-phase research study with the objective of establishing general levels of pollutants in outdoor air in the James Bay neighbourhood. The JBAQS was conducted by a team of researchers and specialists, including the University of Victoria SSRL, SENES Consultants Limited, Vancouver Island University Applied Environmental Research Laboratories, as well as project advisors from the Greater Victoria Harbour Authority (GVHA), the BC Ministry of Environment (MOE), VIHA, and the CRD Environmental Services. Funding for the project was provided by Health Canada (Border Air Quality Study), the MOE, the Clean Air Research Fund (CARF), the GVHA, the Mathematics of Information Technology and Complex Systems (MITACS) internship program and the National Sciences and Engineering Research Council (NSERC).

The JBAQS provided a unique opportunity for a wide range of stakeholder groups with differing interests to engage in an ongoing collaborative research process to produce outcomes which all parties involved could agree were unbiased and scientifically sound. Researchers from the UVic SSRL effectively adopted a mediator role between stakeholder groups with particularly conflicting interests (i.e. community members and the port authority), to ensure that all sides felt their needs and interests were being taken into consideration equally with those of other parties involved. The final deliverables of

the JBAQS are the Phase I Monitoring and Phase II Modeling reports, which have been provided to VIHA for an assessment of potential health implications. VIHA has since contracted third party assessment of the monitoring and modeling reports by researchers from the BC Centre for Disease Control. It is anticipated that a final report on health implications will be available in the fall of 2009.

1.2 James Bay, Victoria, BC, Canada

James Bay is a multi-zoned, but primarily residential neighbourhood at the southern tip of Vancouver Island, situated in the City of Victoria, southwest of the downtown core (Figure 1). The Strait of Juan de Fuca forms the southern and western edges of the James Bay neighbourhood, with the Victoria Harbour bordering the north and Beacon Hill Park the east. Surrounded by water on 3 sides, the economy in this region is largely dependent on marine transport, as well as tourism. Attractions in the general area include the BC Parliament Buildings, Fisherman's Wharf, the Victoria Harbour, the Empress Hotel, Beacon Hill Park, and the Royal BC Museum.

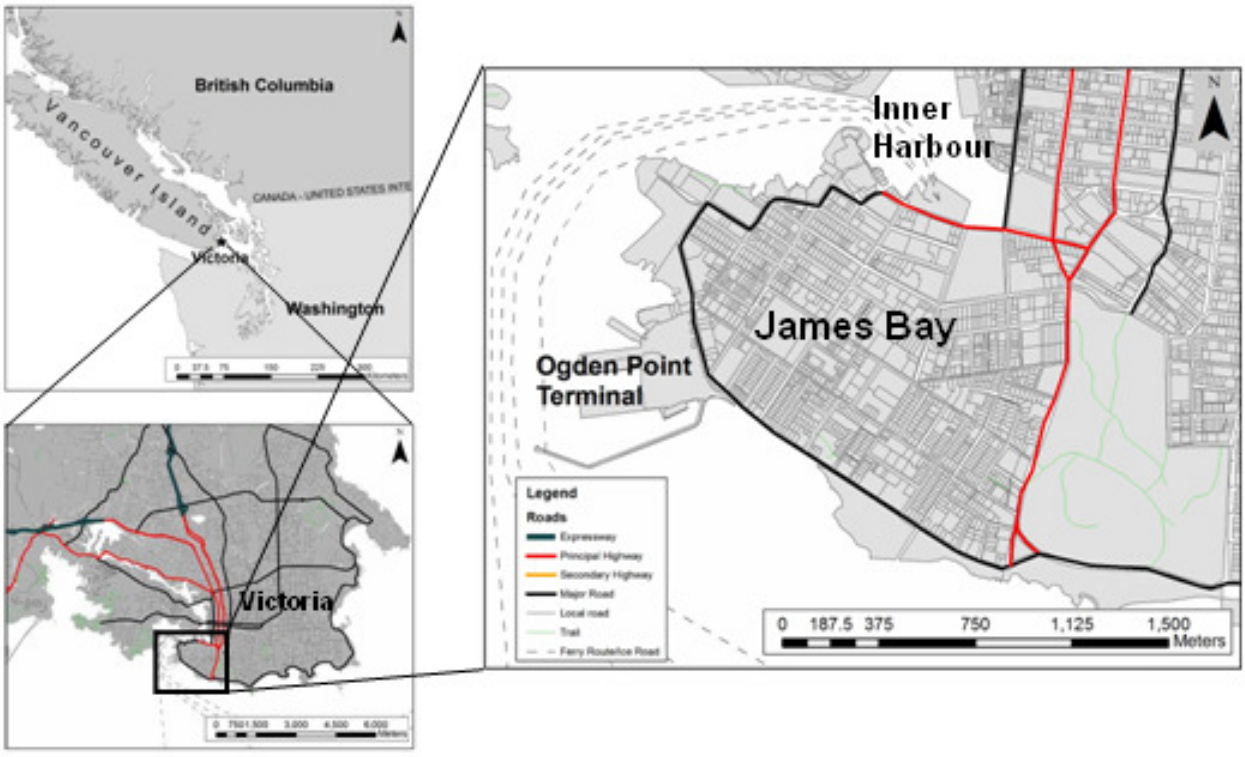


Figure 1. Location of James Bay, Victoria, BC, Canada

In 2001, the population of James Bay was 11,135 (City of Victoria, 2001). Of this total, approximately one-third of residents are over 65 years of age. Family sizes are small, with almost 80 percent comprised of two people. Over 80 percent of residents live in apartment buildings, which is the dominant form of residence (77 percent of dwellings). By comparison, in Victoria apartments comprise only 64 percent of dwellings. Over 36 percent of James Bay residents walk to work, and another 14 percent cycle or take the bus, potentially due to the near proximity to downtown Victoria. In Victoria, only 25 percent of employed people walk to work, while just over 21 percent cycle or bus (City of Victoria, 2001).

The main sources of land-based emissions in James Bay include light and heavy duty vehicular traffic (including both local and tourist traffic), transit and tour buses, and home heating. Many different types of marine vessels operate in the waters surrounding James Bay, including cruise ships, harbour ferries, private vessels, whale-watching and charter vessels, fishing boats, commercial passenger ferries (M.V. Coho and Victoria Clipper), and government vessels (Coast Guard, Fisheries and RCMP). Two additional emission sources include float planes and helicopters, given James Bay's proximity to the Victoria floating airport and the helijet airport.

Residents of the James Bay region have expressed concern regarding the impacts of emissions from these sources on local air quality, particularly from cruise ships and associated diesel bus traffic, which transport passengers to and from tourist destinations in the area. Anecdotal evidence provided by residents describes visible pollution plumes within the community, strong lingering odours, and layers of grime on buildings. However, no air quality measurements are available to indicate the spatial or temporal variation of various pollutants in the James Bay neighbourhood. This lack of information creates uncertainty about air quality in the area in terms of actual levels of pollutants, and the relative contributions of different sources to these levels.

1.3 Ogden Point Cruise Ship Terminal

Constructed between 1914 and 1917, Ogden Point has historically operated as a lumber facility, fish port and packaging plant. These activities have seized, and it currently operates as a cruise ship port-of-call, managed by the not-for-profit GVHA. The facility

encompasses a total of 34.5 hectares and includes 4 deep-sea berths – one 1000 ft in length and the other three 800 ft in length (Greater Victoria Harbour Authority [GVHA], 2007).

Cruise season typically begins in late April, extending until mid-October (although the main bulk of cruise activity ends in mid-September). Most port visits are from ships either destined to, or returning from Alaska. Table 1 summarizes cruise ship and passenger activity for the years 2005 to 2008. The majority of cruise ship visits in all years are from Princess Cruise Lines and Holland America Line. In the past four years there has been a 40% increase in the number of cruise ships and passengers visiting Ogden Point, and cruise traffic is generally expected to increase in the future as Victoria builds its reputation as a notable port-of-call.

Cruise ships generate substantial revenue for the Victoria region. It is estimated, based on the 2007 cruise ship season, that the average spending per cruise ship visit in Victoria was $56.85 per passenger, and $56.04 per crew member (GVHA, 2009). Based on these figures, the total estimated amount of spending in Victoria in 2008 was $29 million, with a total indirect economic impact of $148.2 million (GVHA, 2009). The upcoming 2009 year is expected to exceed this value, as a record number 215 ships are scheduled to make port.

Table 1. Victoria (Ogden Point) cruise ship and passenger summary 2005 – 2008

Year	Cruise Season	Total Ships	Passengers		Length – Range (ft)	Main Cruise Lines (% of total visits)
			Avg #/Ship	Season Total		
2005	Apr 23 – Oct 14	148	1950	288,806	670 - 971	Princess Cruise Lines (37%) Holland America (30%) Norwegian Cruise Line (15%) Celebrity Cruise Line (9%)
2006	Apr 29 – Oct 14	182	1830	333,433	547 - 971	Holland America (36%) Princess Cruise Lines (30%) Royal Caribbean Int'l (14%) Norwegian Cruise Line (12%)
2007	Apr 24 – Nov 3	163	1990	324,290	720 - 971	Holland America (39%) Princess Cruise Lines (36%) Norwegian Cruise Line (13%) Celebrity Cruise Line (10%)
2008	Apr 3 – Oct 14	211	1878	396,292	720 - 971	Holland America (35%) Princess Cruise Lines (30%) Celebrity Cruise Line (18%) Norwegian Cruise Line (11%)

Although Ogden Point has four deep sea berths, only three can be used simultaneously (Figure 2). This limits the number of cruise ships idling at berth at any one time to three. The maximum number of recorded cruise ship visits per day is five, but the majority of days experience only 1 to 3 visits (Table 2). On rare days when 5 cruise ships are scheduled in port, two will usually arrive in the morning, and depart prior to three additional arrivals in the afternoon, or evening.

Source: Google Earth (http://earth.google.com/)

Source: CVS Cruise Victoria
(http://www.cvscruisevictoria.com/ShipCalendar.htm)

Figure 2. Aerial views of the Ogden Point terminal berths

Table 2. Frequency of days with 1, 2, 3, 4 or 5 ships visiting Ogden Point (2005-2008)

Year	Days With Cruise Ships	Frequency of Days with # of Ships in Port (%)				
		1	2	3	4	5
2005	78	45	27	23	4	1
2006	89	33	38	21	7	1
2007	88	49	23	25	1	2
2008	105	38	30	26	4	2

During the cruise ship season, visits of ships are not evenly distributed during the week. The majority of cruise ship visits generally occur on three days: Thursday, Friday and Saturday (Table 3). In 2005, most cruise ship visits were concentrated on Friday and Saturdays, but increasing numbers of ship visits in following years (2006-2008) have since expanded this period of activity to include Thursdays as well.

Table 3. Daily distribution (%) of cruise ship visits to Ogden Point from 2005-2008

Year	Mon	Tues	Wed	Thurs	Fri	Sat	Sun
2005	7	5	5	4	32	41	6
2006	3	3	3	24	26	38	3
2007	5	2	5	18	28	39	3
2008	3	4	9	25	22	34	3

On those days when cruise ships visit Ogden Point, there are specific periods during the day when the majority of activity occurs. During the past 4 cruise ship seasons in Victoria, the majority of cruise ships arrived at Ogden Point between 17:00 and 20:00 (majority at 18:00), or between 06:00 and 08:00 in the morning (Figure 3). Although there is some variability in arrival times from year to year, departure times display a distinct pattern in all years. The vast majority of cruise ships depart from Ogden Point at 23:59 (Figure 4). In order to prevent paying an additional day of port fees, cruise liners avoid staying at Ogden Point past 23:59, and time their schedules to continue traveling through the night. During the 2007 cruise ship season, the average length of time spent in port by cruise ships was 7 hours (range 3 – 16 hours).

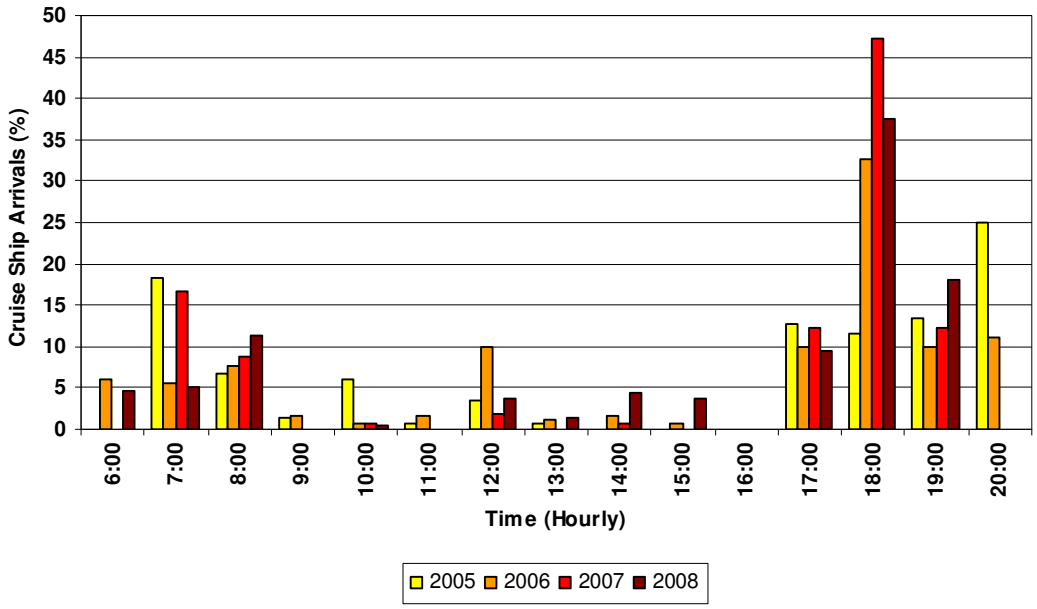


Figure 3. Hourly distribution of cruise ship arrivals at Ogden Point from 2005-2008

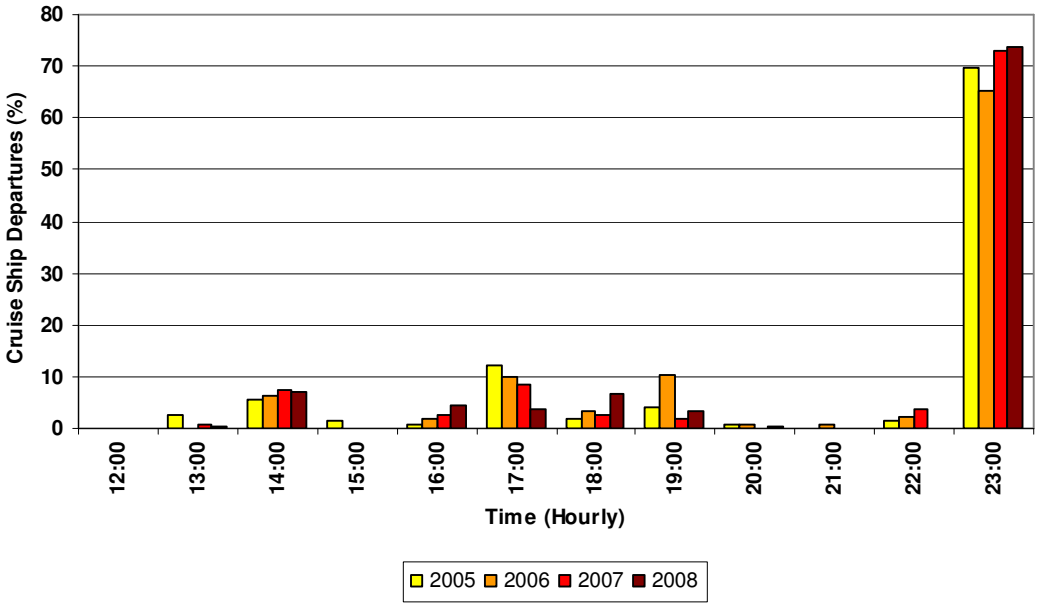


Figure 4. Hourly distribution of cruise ship departures at Ogden Point from 2005-2008

1.4 Marine Emissions

Marine transport substantially contributes to air pollution in coastal areas (Corbett et al., 2007; Lu et al., 2006). Diesel engines typically used as the main power supply of most large marine vessels (Corbett and Fischbeck, 1997) produce a range of emissions, including carbon monoxide (CO), carbon dioxide (CO_2), nitrogen oxides (NO_x), sulphur oxides (SO_x), hydrocarbons (HC) and particulate matter (PM) (Eyring et al., 2005). Diesel exhaust has been estimated to be comprised of 450 different compounds, with approximately 40 listed as toxic air contaminants associated with negative environmental and health impacts (Mauderly, 1992).

Per ton of fuel consumed, ship engines are one of the highest polluting combustion sources worldwide (Corbett and Fischbeck, 1997). Annually, ocean going ships emit an estimated 1.2 - 1.6 million metric tones (Tg) of PM_{10} (particulate matter with diameter 10 micrometers or less), 4.7 – 6.5 Tg of SO_x, and 5.0 – 6.9 Tg of NO_x into the atmosphere (Corbett et al., 2007). Globally, these totals constitute only a fraction of total emissions (Vutukuru and Dabdub, 2008). Marine vessels are estimated to emit 14% of NO and 5% of SO_x from all fossil fuel sources (Corbett et al., 2007); however, the contribution of the marine sector to global emissions is projected to substantially increase

over time (Bailey and Solomon, 2004). This is in part due to an increase in international commerce (Vutukuru and Dabdub, 2008; Lin and Lin, 2006), but also from emission reductions in the land-based sector.

While land-based sources have been subject to considerable regulation and emission reduction strategies, the same level of effort has not been expended to reduce emissions from marine vessels (Bailey and Solomon, 2004; Cooper, 2003). For instance, in the European Union emissions from land-based sources have decreased over time, while contributions from the marine sector have increased and are predicted to surpass those emissions from land-based sources (Figure 5). In Los Angeles, emissions from ocean-going ships, harbour tugs and commercial vessels are double the amount of emissions from power plants (Mitchell, 2001). Considering that approximately 70 – 80% of ship emissions occur within 400 km of land (Corbett et al., 1999), ship emissions can be the dominant source of emissions in coastal regions with heavy marine traffic.

Figure 5. Contribution of land-based and international shipping to emissions in Europe
(Source: International Council on Clean Transportation [ICCT], 2007)

In the past, international shipping has not been viewed as a major contributor to air pollution (Corbett et al., 1999). This can be attributed to inaccurate or incomplete emissions inventories, or a greater focus on domestic ships and regional air district boundaries, and less concern with emissions from ships operating in open waters farther from shore that are perceived to have more widely distributed emissions (Corbett et al., 1999). Improving global inventories of emissions from ocean shipping has been an important focus of researchers over recent years (Eyring et al., 2005; Corbett et al., 1999). Newer inventories show that emissions from this source have been considerably underestimated in the past (Corbett and Koehler, 2003). Emissions from international shipping are therefore receiving an increasing amount of attention by local, national and international regulatory agencies. Greater knowledge about this source can assist policy makers to develop the most appropriate and effective reduction strategies (Eyring et al., 2005).

The International Maritime Organization (IMO) is a regulatory agency of the United Nations responsible for the maritime sector, with a global mandate of safer shipping and cleaner oceans. More then 150 countries belong to the IMO, making it the most powerful international ocean shipping organization (Lin and Lin, 2006). Annex VI of the MARPOL 73/79/97 International Convention for the Prevention of Pollution from Ships protocol produced by the IMO regulates air emissions from shipping activities. Annex VI was ratified in 2004 and came into effect on May 19, 2005 (International Petroleum Industry Environmental Conservation Association [IPIECA], 2007). Annex VI contains specific regulations relating to NO_x, SO_x and VOC emissions, as well as requirements for ship-board incinerators and restricted use of ozone-depleting substances like CFCs and halon (Lin and Lin, 2006).

Regulations 13 and 14 of MARPOL Annex VI relate to NO_x and SO_x emissions, respectively. Regulation 14 establishes a global cap on the sulphur content of fuel (4.5 % m/m), or the use of alternative emissions limiting systems, and also establishes SO_x Emissions Control Areas (SECAs) (1.5 % m/m limit). The Baltic Sea and the North Sea/English Channel are two regions to-date which have been declared as SECAs. The United States and Canadian governments are currently working on an application to the IMO to potentially establish all of North America as a SECA. Based on the active

participation and support of operators, ports, and governments, it is expected that a designation may be reached within 5 years time (IPIECA, 2007).

The BC Chamber of Shipping (COSBC) conducted an emissions inventory of ocean-going (deep sea) vessels operating in BC waters which made port calls from April 1, 2005 to March 31, 2006. This inventory is based on high-resolution ship tracking data from the Canadian Coast Guard and comprehensive surveys of vessel characteristics and behaviours. The area of study for the 2005-2006 BC Ocean-Going Vessel Emissions Inventory includes all inland and territorial waters along the BC coast, the US and Canadian portions of the Strait of Juan de Fuca, and oceanic waters extending 50 nautical miles offshore (BC Chamber of Shipping [COSBC], 2007). Examining the fleet mix, based on number and percent of voyages or vessels (Figure 6), demonstrates the variety of vessel types operating in BC waters. Bulk vessels are the largest category, by number of voyages (34%) and by number of vessels (55%). Container ships and general cargo vessels also represent a large portion of vessels (26% and 14% of voyages, respectively). Cruise ships represent only 2% of the actual vessels which operate within BC waters, but account for 12% of total voyages.

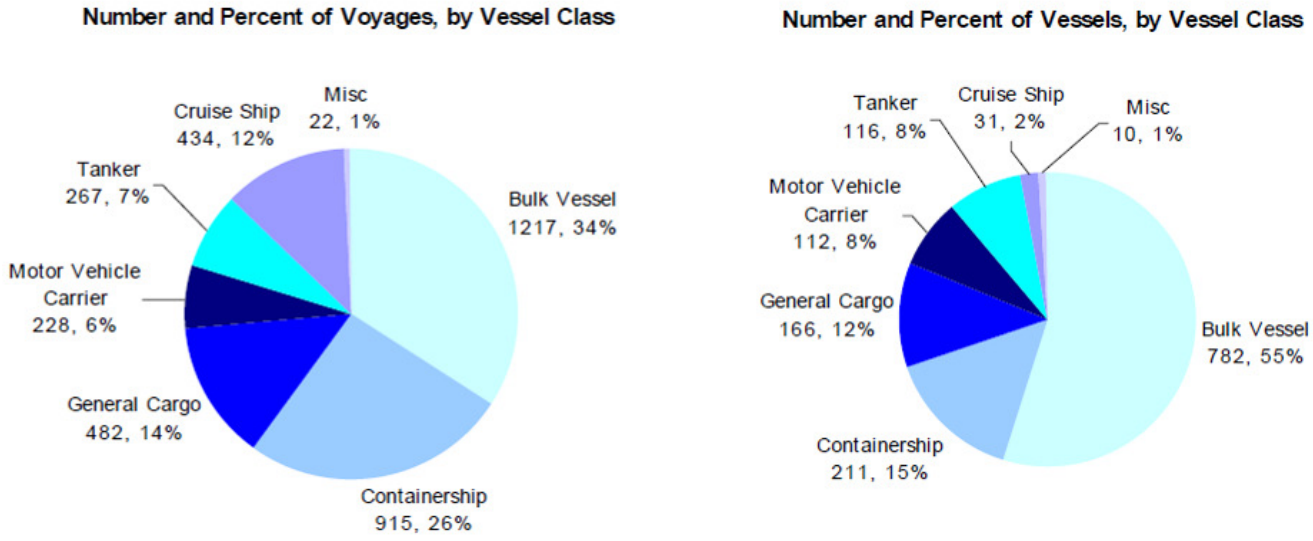


Figure 6. BC ocean-going fleet characteristics (April 1, 2005 to March 31, 2006)
Source: 2005-2006 BC Ocean-Going Vessel Emissions Inventory (COSBC, 2007)

Table 4 displays the total volume of fuel consumed by each type of vessel class during all modes of activity (underway, manoeuvring, berthed and anchored) as calculated by the COSBC emissions inventory. Manoeuvring refers to the activities of vessels as they approach or leave a dock, such as turning, slowing down or accelerating. The engine use associated with these activities is more energy-consuming than sailing at a constant speed over the same distance (Saxe and Larsen, 2004).

HFO, DFO and MGO specify different specific types of fuel: heavy fuel oil (also known as "bunker fuel"), distillate fuel oil, and marine gas oil. HFO (IFO 380 or 180) contains 1.5 – 5.0% sulphur (15,000 – 50,000 ppm) and cost approximately US $185 per ton in 2006 (COSBC, 2006). The main engines of most marine vessels worldwide are fueled by these more economical heavy fuel oils. They contain high levels of sulphur and metallic compounds (Lin and Lin, 2006), and can produce notable amounts of pollutants such as NO_x, HC, SO_X and CO_2. DFO and MGO are lighter distillate fuels that are not as commonly used since they are more expensive. Lighter fuels allow better vessel control and speed adjustment while manoeuvring. MGO is the most expensive and highest quality fuel typically used in marine vessels today, contains 0.5% sulphur (5,000 ppm) on average, and cost approximately US $310-320 per ton in 2006 (COSBC, 2006), nearly twice the cost of bunker fuel. For comparison, the average sulphur content of fuels (petrol and diesel) used in domestic vehicles in North America can range from approximately 30 ppm to 500 ppm (Environment Canada [EC], 2000).

Table 4. Inventory total volume (metric tonnes) of fuel used by vessel class during all modes of activity (April 1, 2005 to March 31, 2006)

	All Modes		
Vessel Class	**HFO**	**DFO**	**MGO**
Bulk Vessel	81,892	1,722	2,059
Containership	103,767	2,020	1,762
Cruise Ship	87,292	0	43,816
General Cargo	42,403	944	3,671
Misc	2,208	0	1,794
Motor Vehicle Carrier	10,479	174	427
Tanker	15,053	287	792

Source: 2005-2006 BC Ocean-Going Vessel Emissions Inventory (COSBC, 2007, pg. 50)

Results of the COSBC Inventory found that 95-100% of vessels (depending on class) reported to use HFO in their main engines, except for cruise ships (only 85% reported using HFO). Although cruise ships use approximately one-third of total fuel consumed by all vessel classes, they also use a larger portion of higher quality MGO.

British Columbia currently has two different types of fuel regulations, depending on whether the fuel is produced, imported, or sold in Canada, or whether it is just used within Canadian waters (applicable to international shipping and fuels purchased elsewhere). Environment Canada regulates fuels produced, imported, or sold in Canada, while Transport Canada regulates those used in Canadian waters (COSBC, 2006). The national average sulphur content of HFO sold in Canada in 2001 was 1.7% (17,280 ppm), and while the HFO used in Canada is unregulated, the US EPA estimates that the worldwide average is approximately 2.7% (27,000 ppm) (COSBC, 2006). At the end of 2007, marine gas oil manufactured in Canada was limited to 0.005% (500 ppm) sulphur, which is expected to be further reduced to 0.0015% (15 ppm) by 2012 (COSBC, 2006). As with HFO, there are no regulations regarding the sulphur content of MGO used within Canada (COSBC, 2006).

The two main types of engines normally onboard large marine vessels include: 1) main engines for propulsion, navigation and manoeuvring, and; 2) auxiliary engines for generating electrical power. Main engines account for the largest amount of emissions, particularly while vessels are at sea. At port, however, the contribution from auxiliary engines can also be important, particularly where shoreside power is not available (Cooper, 2003). Shoreside electrical hook-ups eliminate emissions from auxiliary engines, which are also mainly powered by HFO. In December 2005, the California Air Resources Board (CARB) adopted the rule that ships must switch the fuel being used in auxiliary engines from HFO to lighter, lower sulphur fuels when within 24 miles of any California Port (Christen, 2006). This rule is part of a plan to reduce diesel particulate matter, NO_x and SO_x between the years 2007 and 2020. Controls placed on auxiliary engines are expected to reduce emissions by 75% for PM, 80% for SO_x and 6% for NO_x (Christen, 2006). Only 13% of vessels surveyed as part of the 2005/2006 BC Marine Emissions Inventory reported switching the fuels in their main engines while in BC

waters, as improved engine technologies are allowing better control and maneuverability while using HFO (COSBC, 2007).

The COSBC Inventory recognizes cruise ships as having a unique type of engine category. Cruise ships do not distinguish between main and auxiliary engines because they use electric drives operated by multiple generators, either gas turbines or diesel, for both propulsion and onboard electrical requirements (COSBC, 2007). Gas turbines are gaining popularity in cruise liners worldwide because in addition to lowering NO_x emissions, they are smaller and lighter, and produce less noise and vibration (Saxe and Larsen, 2004). Cruise ships do, however, maintain a third engine type called a boiler, which is responsible for heating hot water and providing general onboard heat. Boiler engines are typically onboard most vessel classes, but are of more importance to those vessels carrying large amounts of passengers. Cruise ships may contain up to 3 boiler engines. Boilers are often not included in inventories because they produce lower emissions than other engine types, and they are more difficult to characterize. To provide more accurate estimates of emissions from all vessel categories, the 2005/2006 BC Marine Emissions Inventory (COSBC, 2007) includes boiler engines.

The Fraser River Port, Robert's Bank, Victoria, and the Vancouver Harbour are four areas which produce the greatest amounts of marine emissions in British Columbia (Table 5), according to the COSBC 2005-2006 Inventory. Total emissions from the Vancouver Harbour, however, exceed that at any other location. This is to be expected, as Vancouver is the central hub of shipping activity in BC, serving a variety of ship traffic including large cargo ships, cruise ships, and ferry boats (Lu et al., 2006).

Annually, the Port of Vancouver trades $43 billion in goods with more than 90 trading economies, and ranks as the #1 port in total foreign exports in North America, and #3 in total cargo volume on the West Coast (Vancouver Port Authority [VPA], 2007). The Port of Vancouver includes 25 major marine terminals, for bulk (17), container (3), cruise (2) and breakbulk or general cargo (3) vessels (VPA, 2007), and services 3 major railways (Canadian National, Canadian Pacific Railway and Burlington Northern). The level of cruise ship traffic exceeds that of Victoria; in 2007, there were 275 sailings from Vancouver (VPA, 2007), compared to the 163 in Victoria.

Table 5. Total emissions by geographic area (tonnes per year) in British Columbia

Geographic Area	NO_x	SO_x	CO_2	HC	PM_{10}	$PM_{2.5}$	CO	CH_4	N_2O	NH_{26}	PM_{alt}
Crofton	82	56	5420	2	5	4	8	0	0	0	5
Campbell River	48	33	3088	1	3	2	5	0	0	0	3
Fraser River Port	294	297	21043	8	21	18	32	2	0	0	21
Kitimat	80	75	5678	2	5	5	9	0	0	0	5
Nanaimo	61	51	4124	2	4	4	6	0	0	0	4
Port Mellon	26	25	1713	1	2	2	3	0	0	0	2
Prince Rupert	121	119	8724	4	9	8	13	1	0	0	9
Robert's Bank	342	391	25349	10	23	20	38	2	0	0	25
Squamish	65	58	4258	2	5	4	6	0	0	0	5
Victoria	352	295	24068	11	26	23	34	2	1	0	24
Vancouver Harbour	1752	1674	130398	50	123	108	191	10	3	0	120

Source: 2005-2006 BC Ocean-Going Vessel Emissions Inventory (COSBC, 2007, pg. 55)

Large marine ports operating worldwide, such as the Port of Vancouver, are major sources of air pollution, due to the large amount of marine vessels operating on dirtier fuels like HFO, but also from all the additional emissions of the land-based pollution sources associated with ports, such as large diesel trucks, cargo-handling equipment like cranes and forklifts, and locomotives (Bailey and Solomon, 2004). The Victoria Harbour, unlike Vancouver, receives minimal traffic from bulk, cargo, container or tanker vessels.

Table 6 is an extraction of emissions data from the 2005/2006 BC Emissions Inventory by the Chamber of Shipping for a 2.5 km area surrounding the Ogden Point terminal. Note that the Misc* category in Table 6 refers to two cable laying ships which berth at Ogden Point throughout the year. The emissions from these ships are erroneously high since the inventory did not take into account that these vessels hook up to shoreside power (SENES, 2008), and rather calculated their emissions based on idling auxiliary engines for periods at berth. Since ferries were not included in the emissions inventory, the "Passenger" field refers to cruise ships at the Ogden Point terminal. Cruise ships stand out as the dominant source of marine emissions in Victoria.

Table 6. Total emissions (tonnes per year) based on a 2.5 km radius around the Ogden Point Terminal

Vessel Class	NO_x	SO_x	CO_2	HC	PM_{10}	$PM_{2.5}$	CO	CH_4	N_2O	NH_3
Bulk	.43	.3	18	.02	.04	.03	.04	.0	.0	.0
Cargo	.05	.03	2	.0	.0	.0	.01	.0	.0	.0
Container	.53	.44	21	.04	.05	.05	.05	.0	.0	.0
Misc.*	60.59	61.02	4035	1.71	6.12	5.51	6.08	.36	.08	.01
Passenger	103.84	76.03	7536	3.55	8.19	7.37	9.47	.56	.23	.15
Tanker	.04	.05	2	.0	.01	.0	.0	.0	.0	.0
Vehicle	.04	.02	2	.0	.0	.0	.0	.0	.0	.0
Total	165.53	137.88	11615	5.33	14.41	12.97	15.66	.92	.31	.16

* Cable Ships (2) docked at Ogden Point. These emissions may be false.
(Source: SENES Consultants Limited, 2008)

If shoreside power were available for cruise ships at the Ogden Point terminal, the majority of emissions while at berth would be eliminated. Although "cold-ironing" (the official term for shoreside power for ships) has been used by the US Navy for decades, very few ports worldwide have electrical hook-ups available for cruise ships (Siuru, 2008). Juneau, Alaska and Seattle, Washington are the only two ports in the world currently having cold-ironing available for cruise ships (Siuru, 2008). Cold-ironing can be considered an expensive investment, both for establishing the required infrastructure at the dockside, and for either building new vessels or retrofitting older vessels with the newer technology. In Juneau, establishing the shoreside equipment cost $2.5 million, and $500,000 per ship (4 ships converted), for a total of $4.5 million (Princess Cruises [PC], 2008). The cost of operating a ship on the new electrical system is actually more expensive ($4-5000/day) than using diesel fuel ($3500/day) (American Association of Port Authorities [AAPA], 2007). In 2005, Princess Cruises initiated the second program in Seattle (AAPA, 2007) and invested $1.8 million to building two new vessels with cold-ironing capability (Port of Seattle, 2005). The Port of Vancouver will be the third port with shoreside power for cruise ships, beginning in the 2009 cruise ship season with its new installation at Canada Place (Nagel, 2008). Princess Cruises and Holland America will make use of Vancouver power hook-ups.

Cold-ironing is one of several methods available for reducing emissions at marine ports (Bailey and Solomon, 2004). Other possible methods include using cleaner or

lower sulphur fuels, adopting cleaner engine technologies and retrofitting older vessels to also use upgraded cleaner technologies (Bailey and Solomon, 2004), using after-combustion treatment methods, or improving operational efficiency (AAPA, 2007).

Reducing impacts to the environment and human health are influential reasons for limiting emissions sources not only on land, but also increasingly from the overlooked marine sector. Substantial amounts of literature report the impacts of diesel exhaust on human health, including deteriorated lung function (Rudell et al., 1996), allergies and asthma (Pandya et al., 2002), and increased risk of lung cancer (Bhatia et al., 1998). In coastal regions, marine emissions are responsible for an increasing share of public health impacts of exposure to air pollution from ships (ICCT, 2007). On a global scale, shipping-related particulate matter emissions are estimated to be responsible for 60,000 cardiopulmonary and lung cancer deaths annually (Corbett et al., 2007). Further investigation is needed to assess air quality and health impacts in local coastal communities.

1.5 Pollutants of Interest

This thesis will focus on the following pollutants: sulphur dioxide (SO_2), nitrogen oxides (NO_x) – which includes nitric acid (NO) and nitrogen dioxide (NO_2), and particulate matter ($PM_{2.5}$ and PM_{10}). Large marine vessels are argued to be major producers of these pollutants in the James Bay study area. There are, however, other sources operating in James Bay which produce them, and their emissions will also contribute to ambient concentrations in the study area. This section provides an overview of each pollutant, sources which produce it, and potential associated health impacts.

1.5.1 Sulphur Dioxide (SO_2)

SO_2 is a colourless gas that occurs in outdoor air primarily due to the combustion of sulphur-containing fuels, including coal, oil and vehicle fuels, and from industrial processes such as ore smelting and natural gas processing (EC, 2001). The amount of SO_2 produced depends on the sulphur content of the fuel used (Corbett and Fischbeck, 1997). Large coal-fired power plants and non-ferrous metal smelters can be large

regional sources of SO_2. Natural SO_2 sources include volcanoes, hot springs, and terrestrial and aquatic organic decomposition.

In the James Bay community, SO_2 is produced mainly by marine vessels, specifically cruise ships which use heavy fuel oil. The M.V. Coho and Victoria Clipper ferries are also producers, but to a lesser extent since they use fuels with lower sulphur content than cruise ships. Commercial fishing boats may also produce SO_2, although these vessels use light fuel oil or lower sulphur diesel fuel. All other sources together, including recreational motorboats, whale-watching boats, float planes, helicopters, passenger and heavy duty vehicles are estimated to be responsible for 15 percent or less of the total emissions of SO_2 (Tradewinds Scientific Ltd. [TSL], 2000). No major industrial sources of SO_2 were identified in the region, and releases from space heating and natural sources are expected to be negligible (SENES, 2006).

Water vapour in the air can react with SO_2 to produce acidic aerosols that when inhaled can irritate the lungs of healthy people or cause severe respiratory symptoms in asthmatics (Nicolai, 1999). Lung function in asthmatics decreased by 25-30% in controlled exposure to SO_2 at concentration levels of found near pollution sources such as ports (Gong et al., 1996).

1.5.2 Nitrogen Oxides (NO_x): Nitric Oxide (NO) and Nitrogen Dioxide (NO_2)

NO_x is used to refer to the oxides of nitrogen: NO and NO_2. These oxides are produced during high temperature combustion of fossil fuels. At high temperatures, endothermic reactions between nitrogen and oxygen take place (which does not occur at ambient air temperatures), allowing NO_x to form. High temperature combustion occurs for transportation, industry, electrical power generation and space heating. Natural sources of NO_x include forest fires, lightning, and soil microbes.

A study conducted in 2000 estimated that the major sources of NO_x in the study area are from marine vessels, such as the M.V. Coho and Victoria Clipper, passenger and heavy duty vehicles, and commercial fishing boats (TSL, 2000). Cruise ships were not included in this study's estimates, which focused solely on sources in the Victoria Inner Harbour. Cruise ships, however, represent a major, if not arguably the largest source of NO_x in James Bay, followed by motor vehicles. No notable industrial activities were

identified as potential NO_x sources in the study area, or in the general region. Natural sources and space heating are expected to be relatively low during the period of study. The contribution of float planes and helicopters to NO_x concentrations in James Bay is unknown, and recognized as a knowledge gap at this time.

Exposure to NO_x can cause inflammation and asthmatic reactions (Davies et al., 1997), as well as stronger reactions to common allergens like pollen when exposed simultaneously to NO_x (Davies et al., 1998). When ambient concentrations of NO_2 are elevated, children who suffer from asthma have a greater probability to cough and wheeze, and suffer from decreased pulmonary function (Chauhan et al., 2003; Nicolai, 1999).

1.5.3 Primary Particulate Matter (PM_{10} and $PM_{2.5}$)

Particulate matter refers to airborne particles, which can be solid or liquid, and of varying chemical and physical composition (Brauer, 2002). PM_{10} refers to airborne particles equal to or less than 10 micrometers (µm) in aerodynamic diameter and $PM_{2.5}$ to fine particulate matter equal to or less than 2.5 µm in aerodynamic diameter. For reference, an average human hair is about 50 µm wide.

Coarser particles (PM_{10}) are produced by mechanical processes such as construction, industrial processes and erosion. Another anthropogenic source of PM_{10} is road dust. Natural sources of PM_{10} include sea spray, windblown dust and pollen (Brauer, 2002). Fine particulate matter ($PM_{2.5}$) is released into the air by fossil fuel and wood combustion, along with industrial processes and activities. $PM_{2.5}$ can also be produced through chemical reactions in the air with SO_2, NO, NO_2, ammonia (NH_3), and volatile organic compounds (VOCs) (Suzuki, 2003). Natural sources of $PM_{2.5}$ include dust storms, sea spray and forest fires.

There are a number of sources of PM_{10} and $PM_{2.5}$ in the James Bay neighbourhood besides sea spray, including emissions from cruise ships, ferries, passenger cars and heavy-duty vehicles. Space heating, from wood and fossil fuel burning, is a contributor of particulate matter during heating seasons (SENES, 2006). Cement manufacturing at a site approximately two kilometers north of the study area is

an additional regional source. Float planes and helicopters are estimated to be very small sources of particulate matter (TSL, 2000).

Smaller particles (2.5 μm) can remain suspended in the air for many days or weeks until finally settling on surfaces or being removed by precipitation. Very fine particles (≤ 0.1 μm) are typically formed through gas-to-gas particle conversion and quickly form larger particles by joining together, or condensing on nuclei (Suzuki, 2003). Larger particles, such as PM_{10} do not remain suspended as long in the atmosphere, settling out in hours or days due to gravitational forces.

Many studies have linked particulate matter to increased hospital admissions, asthma, heart attacks, chronic obstructive lung disease, bronchitis, pneumonia and heart disease (Corbett et al., 2007; Dockery et al., 1989; Peters et al., 2001). In particular, $PM_{2.5}$ is estimated to attribute to 0.8 million deaths per year worldwide, as well as to 1.2% of global premature mortalities (Cohen et al., 2005). Particulate matter pollution has also been found to have a strong association with lung cancer (Pope et al., 2002).

1.5.4 Summary of Emission Sources

Of the many land, air, and marine-based emissions sources in the James Bay study area, large marine vessels (M.V. Coho, Victoria Clipper and cruise ships) are argued to be the largest producers of the main pollutants of interest (SO_2, NO, NO_2, PM_{10} and $PM_{2.5}$). The M.V. Coho and Victoria Clipper ferries dock in the Victoria Inner Harbour, while the much larger cruise vessels dock at the Ogden Point terminal, located in the southwest corner of James Bay.

The M.V. Coho and Victoria Clipper maintain close to the same schedule seven days per week, which is also typical of other sources, such as float planes and helicopters. Automobile traffic, which may display some variation according to weekdays and weekends, is generally also expected to stay relatively constant. Cruise ships, however, are the only emissions source which displays any large variation in operational schedule that may be detectable in concentration levels examined over long periods of time.

Cruise ships, and the large amount of associated bus and taxi traffic that transport cruise passengers to and from tourist destinations in the area, are considered to be one of the most problematic pollution sources by members of the James Bay community. The

Vancouver Island Public Interest Research Group (VIPIRG) has published an independent report highlighting many of the concerns regarding possible air, ocean, community, and economic impacts of the cruise industry in Victoria (Wallace and Gorecki, 2003); however, due to the lack of air quality measurements in the area, whether cruise ships are substantially affecting air quality and health in James Bay remains speculation.

1.6 Estimating Air Pollution Exposure

The community of James Bay is interested in knowing if cruise ship emissions are causing any health impacts to people living in the area. Prior to an evaluation of potential health implications, an estimate of typical exposure levels from this air pollution source needs to be produced. This section examines what is meant by exposure, and how it has traditionally been assessed for epidemiological studies in urban areas. The appropriate method for estimating community level concentrations from cruise ship emissions in James Bay is then discussed.

The term "exposure" in relation to air pollution refers to the amount of pollutants an individual comes into contact with, which is a function of time and concentration level (Brauer, 2002). Estimates of exposure are used in epidemiological studies to examine the association between the relative concentrations of pollutants that populations or individuals have been subjected to, and associated health impacts. This can include health effects of both short-term (acute), and longer-term (chronic) exposures to air pollution.

There are a variety of different methods which are currently used to characterize exposure to air pollution for health studies. Most epidemiological studies rely on ambient concentration measurements from central site monitors (Sheppard et al., 2005) that are usually part of a regulatory monitoring network. These networks, established either for compliance- or population-oriented monitoring interests, are generally of poor density and distribution (Briggs et al., 1997), with monitors placed in areas that reflect higher population exposures (Smith et al., 2006). In the past, health assessments of long-term exposure to air pollution typically consisted of between-city comparisons relying on city average concentration levels measured from these regulatory monitoring networks. Data

from such networks may not be adequate for estimating individual exposure for epidemiological studies assessing health impacts *within* cities (Hochadel et al., 2006; Levy et al., 2003), as estimates assuming exposure is homogenous over large areas (Hoek et al., 2001) overlook small-scale variations that exist, which may result in misclassification of exposure (Briggs et al., 1997).

Epidemiological studies using regulatory monitoring networks have had to rely on surrogate variables (i.e. traffic density, or distance to road) to account for intra-urban variability in pollutant concentration levels (Brauer et al., 2003; Huang and Batterman, 2000). Surrogate variables, however, are often not validated as exposure measures (Brauer et al., 2003) and their true relationship to exposure may be unclear (Cyrys et al., 2005). Developing better methods to assess intra-urban variability in air pollution has been highlighted as an area in need of future research (Jerrett et al., 2005).

Personal monitoring is one method which can perhaps provide the most detailed and accurate information of exposure at the individual level. In personal monitoring studies, individuals from a population of interest wear real-time continuous air quality monitors which record concentrations of pollutants throughout their specific daily activities. Personal monitoring goes beyond merely using outdoor ambient concentration levels as a proxy for exposure, by calculating exact exposure amounts. These studies, however, can often be difficult to implement, are time consuming and more expensive than other alternative methods.

Exposure modeling has become an attractive alternative to personal monitoring studies, since it can provide more detailed estimates of intra-urban variability of pollutants than measurements from one or two regulatory air quality monitors. Recent years have seen increasing interest in assessing intra-urban variability in pollutant concentrations, particularly related to traffic emissions (Kanaroglou et al., 2005; Smith et al., 2006). Exhaust from motor vehicles is a major source or air pollution in urban environments (Reungoat et al., 2003), and has been shown to have high spatial variability within small distances from emissions sources (Hewitt, 1991; Zhu et al., 2002). While many studies have demonstrated the acute effects of traffic-related pollution on health (Cyrys et al., 2005), there is greater uncertainty regarding chronic effects due to a lack of individual or small-scale exposure estimates at the intra-urban level (Briggs et al., 2000).

A review of available methods for modeling intraurban exposure (Jerrett et al., 2005) identified six main classes of models: (1) proximity modeling; (2) statistical interpolation; (3) land use regression; (4) dispersion models, and; two classes of hybrid models which either (5) combine personal or household measurements with a previous method, or (6) a combination of two previous methods with regional monitoring. The choice of which model to use for a particular application usually depends upon a research project's budget, available time, hardware and data requirements, as well as the acceptable accuracy level of results.

Proximity models are the most simplistic method available. This method makes assumptions about the relationship between pollution and health based on the distance to emissions sources (Jerrett et al., 2005). For example, in regards to traffic-related pollution, this technique would assume that subjects closer to major roadways would receive higher exposure estimates. In general, this technique possesses limitations, yet is still recognized as a useful technique for exploratory analyses.

Interpolation models measure pollutant concentrations at a set of monitoring locations throughout the study area, and use this information to generate pollution concentration estimates at non-monitored locations through numerical interpolation. Common interpolation methods include kriging, inverse distance weighted, and spline. Although a useful technique, spatial interpolation may result in prediction errors due to the high spatial variability of pollutant concentrations (Hoek et al., 2001), particularly when sparsely distributed regulatory monitoring networks are used. Research-oriented monitoring programmes have developed as a feasible alternative, or supplement, to regulatory air quality monitoring networks. The development of less-expensive and more portable monitoring equipment, such as passive diffusion samplers, has allowed researchers to design their own intra-urban networks to assess spatial variability at finer scale resolutions and provide more detailed information for epidemiological studies (Smith et al., 2006).

Many studies also use land use and demographic data in geographic information systems (GIS) to complement monitored data (Jerrett et al., 2005). One popular method now in use for estimating traffic-related emissions is a regression based approach called land use regression (LUR). Land use regression models have emerged as a desirable

choice over other types of exposure models because they incorporate a wider range of factors which may influence exposure than interpolation, and they are more economical and simpler to compute than dispersion models (Brauer et al., 2003). LUR uses series of exposure indicators in combination with actual measurements of air pollution and a GIS to predict pollution concentrations (Hoek et al., 2002). Indicator variables of exposure are generally classified as traffic or land use variables, or population characteristics. LUR uses ordinary least squares regression to analyze which variables act as the strongest predictors, and then concentrations of air pollution at specific sites can be estimated based on the characteristics of land use and traffic in the surrounding area (Kanaroglou, 2005).

Air quality dispersion models are more complicated and data-intensive models to use for estimating exposure. These models generally rely on Gaussian plume equations and require extensive input data about emissions, land use, topography and meteorology. Although estimates from dispersion models can be of greater spatial and temporal resolution, they have heavy data, operability and validation requirements associated with their use (Jerrett et al., 2005). Air quality dispersion models use science-based equations to mathematically describe the behaviour of emitted gases/particles in the air. They are useful tools for decision makers by providing a way of evaluating different emission control policy scenarios which would be expensive, difficult or destructive to do in the real world (BC Ministry of Environment [MOE], 2008).

Air quality dispersion models, in their most basic sense, use location-specific conditions such as topography, atmospheric conditions (winds, precipitation, mixing height, stability, etc.), and the location and characteristics of emission sources (height, type of pollutants, exit temperature, exit dimensions, etc.) to estimate the concentrations of contaminants in a defined study area (Figure 7). Local topography and how it affects the meteorology of a region will largely determine how and where pollutants are carried within it. In addition, the position of the emission sources is another large factor (for instance, whether down- or up-wind of a community, or above or below the height of inversions leading to stagnant atmospheric conditions).

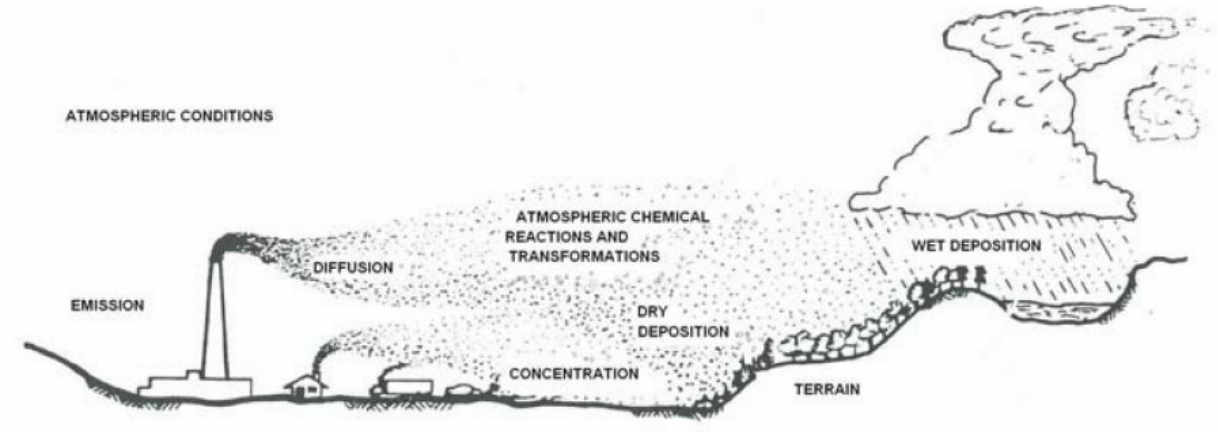


Figure 7. Visual schematic of an atmospheric dispersion model
(Source: MOE, 2006)

Common reasons for the use of air quality models include: to establish emission control legislation (i.e., to determine the maximum allowable emission rate which will meet air quality standards); to evaluate proposed emission control techniques and strategies (i.e., evaluate the impacts of future control); to select locations of future sources of pollutants, in order to minimize environmental or health impacts; for planning the control of air pollution episodes (devising intervention strategies), and; for evaluating existing air pollution levels from current sources. While air quality models can provide useful information, they should not be considered a *solution* to air quality problems. Rather, they are an inexpensive technique for providing information to guide the possible future implementation of more expensive emission reduction and control strategies.

There are a variety of different air quality models available and some are more suitable to specific scenarios than others. Identifying the correct model to use based on the scenario at hand and the type of information trying to be obtained is an important consideration for all modeling exercises. In general, the following factors will reflect the choice of air quality dispersion model for a particular application: 1) the complexity of the environment; 2) the dimensions of the model; 3) the nature of the particle source; 4) the computing power and time that is required, and; 4) the desired time scale of the calculated concentrations (Holmes and Morawska, 2006). Substantial effort is also required for obtaining input data for dispersion models. Data which is of poor quality will produce poor model results ("garbage in, garbage out!"). Therefore, considerable

time and effort is spent acquiring and preparing input data for dispersion models, as well as in quality assurance and assessment checks of their output to ensure they are performing properly.

Estimating Exposure in James Bay

The use of an extensive personal monitoring study to conduct an initial investigation of typical pollution levels in James Bay is not warranted, based on existing assessments of general levels of air quality in the Capital Regional District (CRD) (SENES, 2006), and a lack of validated information indicating poor levels of air quality in James Bay. Limited regulatory air quality monitors in the area (see Section 1.8), and the coastal location of James Bay, where meteorology can be more complex due to land- and sea-breezes, also deters the use of modeling techniques such as proximity modeling or interpolation. Proximity modeling would be too simplistic, assuming that those living within a certain distance of the cruise ship terminal have higher exposure when little information is actually known about the path of pollutants from ship stacks throughout the region. Interpolation based off of regulatory monitors would also be insufficient, as the regulatory network in the CRD is too sparse to adequately characterize emissions from this source in James Bay. LUR, although a useful method for estimating variations of urban and traffic emissions, would likely not operate effectively in James Bay for cruise ships sources. This type of model would essentially operate as a proximity model with distance to source (cruise ship berths) as the main predictor variable, since land use, population density or traffic density would not effectively predict cruise emissions.

The air quality dispersion modeling technique is the only model type which will allow time varying schedules of sources, changing meteorology, and a range of temporal resolutions to be explored. Air quality dispersion models have been used in several studies to model the effects of ship or port emissions on local air quality, in locations such as southern California (Vutukuru and Dabdub, 2008), Göteborg, Sweden (Isakson et al., 2001), Denmark (Saxe and Larsen, 2004) and Vancouver, BC (Port Metro, 2005). Larger aerosol models have also been used to estimate global emissions and mortalities from oceangoing ships (Corbett et al., 2007).

Ultimately, the best way to characterize concentration levels in James Bay would be from a dense grid of real-time monitors situated throughout the neighbourhood capable of measuring very short-term (i.e. minutes or hours) levels of pollutants over long periods of time (i.e. several years). Such an array of monitors, if properly distributed, could be used to interpolate high resolution maps of the area for a range of temporal resolutions, and several years' worth of data would establish trends over time. A proposal for such a network, however, would likely not be seriously considered by air quality managers. The first reason is that the cost of such a network would be prohibitive. Second, air quality in the Victoria region as a whole is considered to be very good, and a network such as this would be considered unnecessary. Air quality modeling is a more cost-feasible approach, and can provide results similar to those which could be acquired from such a network. Field monitoring campaigns that are more affordable and smaller in scale can still assist air quality modeling exercises by providing verification of model results.

1.7 Air Quality Guidelines, Standards and Objectives

Air quality guidelines, standards or objectives are terms used to describe levels of ambient (outdoor) air pollution which countries or regulatory agencies have adopted to be protective of public health (Bates et al., 2002). Generally, countries establish air quality guidelines and standards taking not only health impacts into consideration, but also technological feasibility and economic, social and political factors in a cost-benefit analysis (World Health Organization [WHO], 2006). Targets set by countries in the way of guidelines are important for risk management and policy development. Monitoring from regulatory networks or from air quality assessment studies which represent population exposures can be compared to established guidelines or standards as a method of assessing potential health impacts. For some pollutants, such as particulate matter, it is recognized that there is no threshold level, or very low threshold levels, below which no adverse health effects occur.

There are 4 sets of air quality guidelines and standards which are applicable to the James Bay study area: (1) CRD air quality guidelines; (2) BC Air Quality Guidelines; (3)

Canada National Ambient Air Quality Objectives (NAAQOs), and; (4) WHO Air Quality Guidelines. Concentration levels set by these guidelines are compared in Table 7.

The CRD guidelines were developed in 2004, for the purpose of assessing annual air quality monitoring data and reporting to the Environmental Committee Board (CRD, 2007). The CRD notes that these guidelines should not be considered regulatory standards like the BC or Canada NAAQOs.

Canadian NAAQOs were originally established in the late 1970s, but have been reviewed in 1996 or 1998 (Canadian Council of Ministers of the Environment [CCME], 1999). They are divided into three groups, or levels – "desirable", "acceptable" and "tolerable". The desirable level sets a long-term air quality goal, provides a baseline for anti-degradation policy for unpolluted areas of Canada and for the development of pollution control and reduction technologies (Health Canada, 2006). The acceptable level provides adequate protection for personal comfort and well-being, and environmental effects on soil, water, vegetation, animals and visibility. Finally, the tolerable level is the level beyond which appropriate action is required without delay to protect the health of the general population.

BC air quality guidelines and objectives are established for three levels (A, B and C), for which no definition exists, but are generally inferred to correspond to the National desirable, acceptable and tolerable levels.

The final guidelines are those established most recently in 2005 by the World Health Organization. The WHO air quality guidelines were designed for worldwide use, to offer guidance in reducing the health impacts of air pollution based on expert evaluation of current scientific evidence. These guidelines are intended to inform policy-makers and to provide appropriate targets for a broad range of policy options for air quality management in different parts of the world. Levels set by the WHO are more stringent than guidelines set by most countries in the world, yet are set as goals for countries to strive towards improving air quality and health of citizens. The WHO also provides interim targets for countries with high concentration levels to progressively reduce ambient levels.

Table 7. Comparison of CRD, BC, Canada and WHO ambient air quality objectives and standards for pollutants of interest (SO_2, NO_2, PM_{10} and $PM_{2.5}$)

CAC	Averaging Period	CRD	BC			Canada			WHO
			Level A	Level B	Level C	Maximum Desirable	Maximum Acceptable	Maximum Tolerable	
SO_2	10-minute								500
	1 hour		450	900	900-1300	450	900		
	3 hour		375	665					
	24 hour	125	160	260	360	150	300	800	20
	Annual Mean		25	50	80	30	60		
NO_2	1 hour	200					400	1000	200
	24 hour						200	300	
	Annual Mean					60	100		40
PM_{10}	24 hour	50		50					50
	Annual Mean								20
$PM_{2.5}$	24 hour	25					30		25
	Annual Mean								10

1.8 James Bay – is an air quality study warranted?

This section examines available meteorological and emissions data from the 2006 year for evidence of a cruise ship signal, in order to determine if cruise ship emissions are having short- or long-term influences on pollutant levels measured in the region, and if further investigation is warranted. The CRD regulatory air quality monitoring network is used in combination with meteorological variables (wind speed and wind direction) collected at the Ogden Point breakwater station for this investigation.

1.8.1 Dominant Wind Speed and Wind Direction

Wind speed and wind direction data recorded at the Ogden Point breakwater meteorological station from May to October 2006 (Figure 8) reveal that the majority of winds during typical cruise ship season months of the year blow on-shore from the west-

south-west (especially the stronger ones >5 m/s). This pattern highlights the potential for emissions from cruise ships berthed at the Ogden Point terminal to be transported over the northwest portion of the James Bay community towards downtown Victoria.

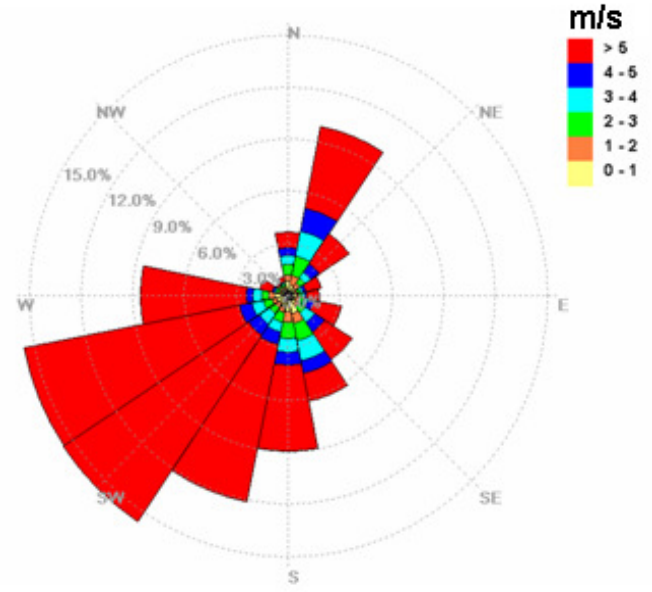


Figure 8. Wind rose of wind speed (m/s) and wind direction measured at Ogden Point from May to October, 2006

1.8.2 CRD Regulatory Air Quality Monitoring Network

The CRD operates a network of air quality monitoring stations throughout the Victoria area in partnership with the BC Ministry of Environment. The main purposes of this network are to characterize air quality in the region, to provide information on air quality to the public, to conduct long-term trend analysis, to fulfill federal reporting requirements, and to compare ambient concentrations to air quality objectives (SENES, 2006). Monitoring locations are chosen to be representative of large geographic areas, or specific areas of interest where higher concentrations are suspected.

In 2006, five monitoring stations in the region were operational measuring some, or all, of the pollutants of interest for this study (Figure 9). The Topaz Station, which is in closest proximity to the James Bay neighbourhood, is part of the National Air Pollution Surveillance (NAPS) Network. Established in 1969, NAPS is a country-wide network of more than 152 air pollution monitoring stations with the purpose of assessing air quality in Canadian urban centers (EC, 2001). Criteria air contaminants measured at

most stations include SO_2, CO, NO_2, ozone (O_3) and total suspended particulates (TSP). Table 8 provides a list of the air quality monitoring locations in the CRD, and the pollutants measured at each site during the 2006 season.

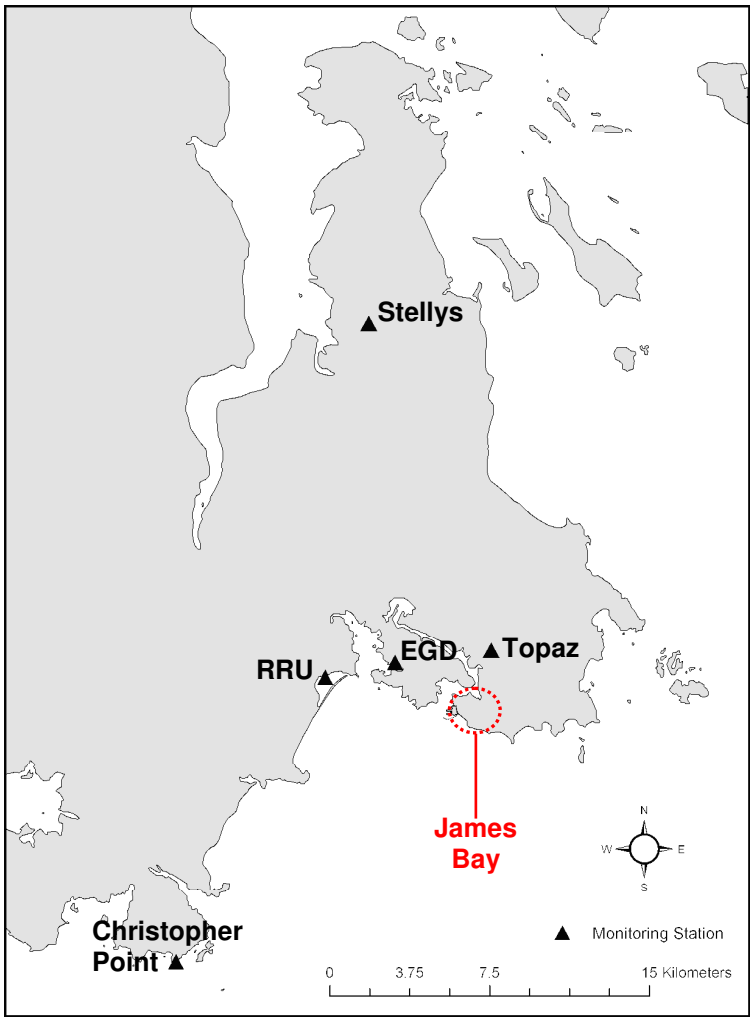


Figure 9. Regulatory monitoring network in the CRD

Table 8. Pollutants measured at regulatory monitoring stations in the CRD

Station	Criteria Air Contaminants Measured in 2006
Topaz Avenue	CO, NO, NO_2, O_3, $PM_{2.5}$, SO_2
Royal Roads University	NO, NO_2, O_3, $PM_{2.5}$
Esquimalt Graving Dock	PM_{10}
Christopher Point	CO, NO, NO_2, O_3, $PM_{2.5}$, SO_2
Saanich Stellys Crossroad	NO, NO_2, O_3, $PM_{2.5}$

The Topaz Station is the most comprehensive monitoring site in the region, and has the longest record of continuous data capture. As the previous wind rose in Figure 8 displayed, Topaz is downwind from the Ogden Point terminal, so it is possible emissions from ship stacks may be detectable at this location. Meteorological data measured at the Topaz Station during evening hours when the mail bulk of cruise ship activity occurs are from the southwest, which supports the possibility of pollutants emitted from cruise ships reaching the Topaz Station (Figure 10).

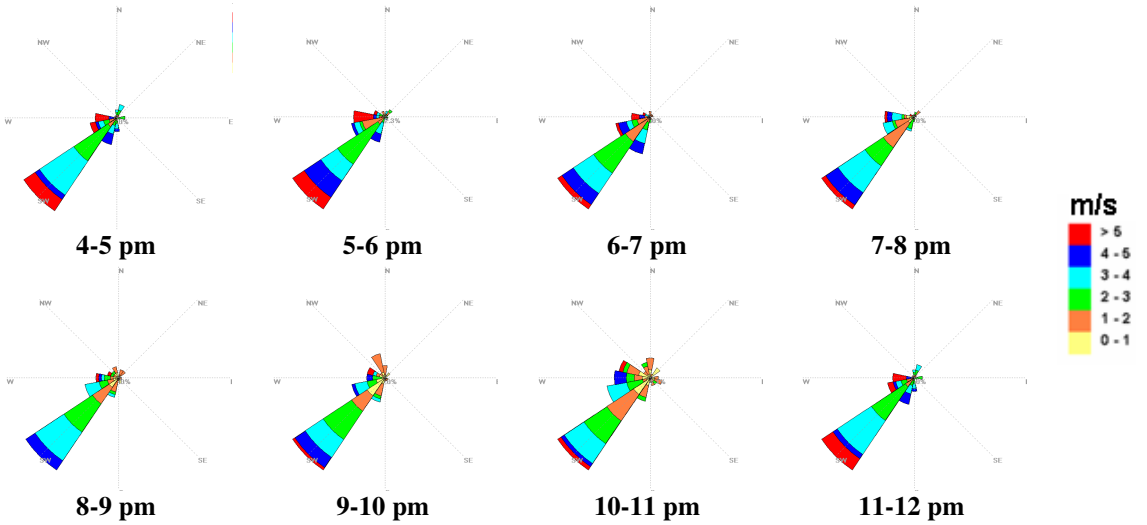


Figure 10. Evening wind activity measured at Topaz Station on cruise ship days in 2006

The Esquimalt Graving Dock (EGD) and Royal Roads University (RRU) are the second and third closest monitoring stations to the James Bay community, after Topaz. The EGD provides only very limited air quality measurements; it uses an instrument that records PM_{10} on a one-in-six day cycle. RRU provides measurements of some of the pollutants of interest, but notably not SO_2 which is of great interest due to the marine sector being the dominant source of this emissions type. These two sites, as well as Stellys and Christopher Point are farther from the Ogden Point terminal, and due to the dominant wind direction measured in the area, it is not as likely that cruise emissions are detectable at these sites.

Hourly average concentrations of the main pollutants of interest for this study were obtained from the MOE for the Topaz Station for the full 2006 year. Examining concentration levels of the pollutants of interest that are measured at the Topaz Station

during the cruise ship season (while taking known periods of cruise ship activity into account), compared to measured concentrations during the off-season may provide insight into expected concentration levels, as well as the relative concentration levels between different time periods.

The following sections examine 2006 time series data at Topaz for NO, NO_2, $PM_{2.5}$ and SO_2. The following three scenarios are represented as separate lines on each graph: 1) average concentration during the cruise season (May to October) on days when ships were in port ("cruise ships"); 2) average concentration on days during the cruise season when no ships were in port ("no cruise ships"), and; 3) average concentration on all other remaining days of the year ("off season"). These graphs show the diurnal patterns of concentrations which occur during all three time periods, as well as differences which occur between time periods where cruise ships are present and absent.

1.8.3 Nitric Oxide and Nitrogen Dioxide

Nitric Oxide

NO is highly reactive and rapidly converted through oxidation to NO_2. This relationship is a function of time and temperature. Average hourly concentrations of NO range between 4 and 48 $\mu g/m^3$ for all three time periods (Figure 11). Morning weekday traffic causes NO levels to peak between 8 am and 9 am. Decreases in traffic after the morning rush hour, in conjunction with increased solar heating and atmospheric mixing, contribute to lower levels throughout the day. A slight increase again in the late evening is likely in part associated with residential heating (SENES, 2006).

Morning peak levels in NO are highest on days without cruise ships between May and October, inclusive. The majority of these days tend to be weekdays (Sunday to Wednesday) with high morning traffic. Off-season levels are generally lower due to cooler temperatures. NO levels appear to be unaffected by the presence or absence of cruise ships.

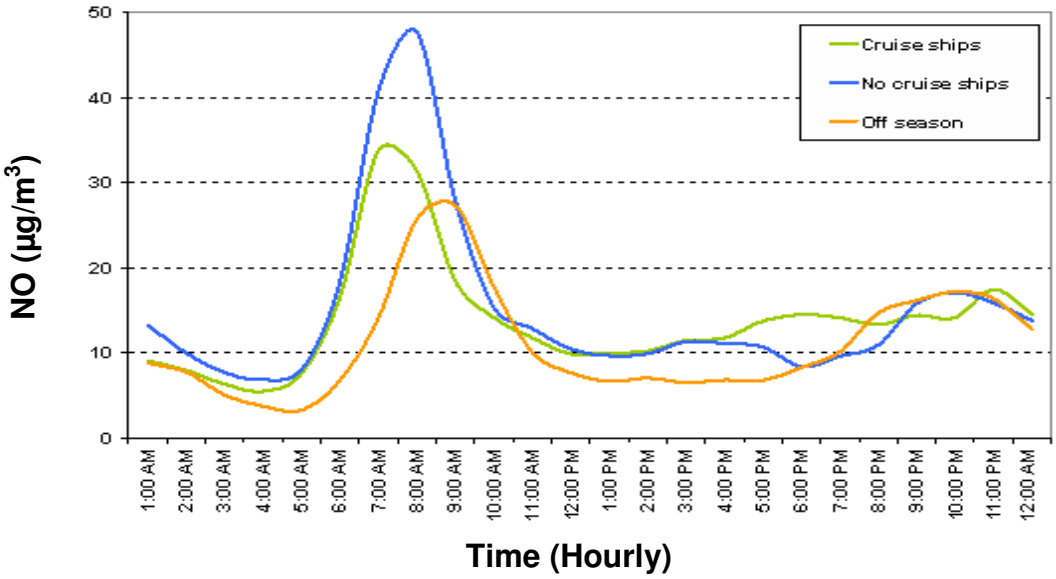


Figure 11. Average diurnal pattern of NO at Topaz Station in 2006, on days during the cruise ship season with and without cruise ships, and during the off season

Statistics on individual hourly NO concentrations are presented in Table 9. The mean concentration of all cruise ship day hours (14 µg/m^3) is lower than days during the cruise ship season with no cruise ships (15 µg/m^3), and the highest hourly maximum concentrations occur on non-cruise ship days and during the off season, rather than on days with cruise ships in port (353 µg/m^3 and 326 µg/m^3 vs. 203 µg/m^3 respectively). The non-cruise and off season hours also display greater variation (larger standard deviations) and have higher NO concentration levels at the 98th and 99th percentiles, indicating more frequent higher magnitude peaks.

Table 9. Hourly NO concentrations (µg/m^3) measured at Topaz in 2006

Percentile Values (µg/m^3)						Max	Min	Mean	Std. Dev.	Missing Values
5	25	50	75	98	99	µg/m^3	µg/m^3	µg/m^3	µg/m^3	(% total hours)
					Cruise					
1	3	8	16	74	102	203	0	14	19	2
					No-Cruise					
1	3	6	14	98	141	353	0	15	27	4
					Off Season					
0	1	4	9	107	139	326	0	12	26	4

Nitrogen Dioxide

NO_2 levels also peak between 8 am and 9 am, but then again between 9 pm and 10 pm (Figure 12). Average hourly levels range from between 14 and almost 40 µg/m^3. NO_2 is higher between 5 pm and 11 pm on days with cruise ships present. There is a high frequency of arrivals and departures during this time period, suggesting that NO_2 related to cruise ships emissions may be reaching this monitoring site.

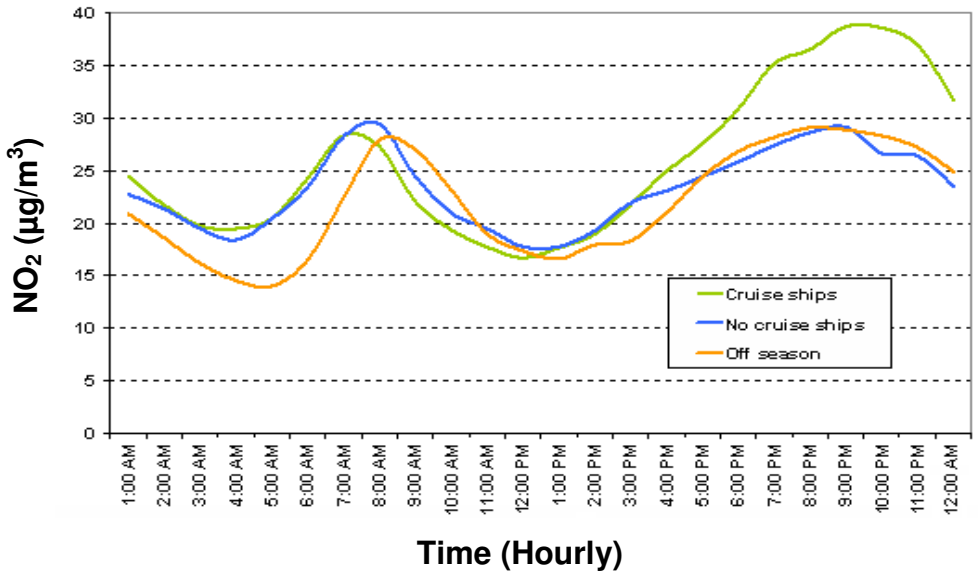


Figure 12. Average diurnal pattern of NO_2 at Topaz Station in 2006, on days during the cruise ship season with and without cruise ships, and during the off season

The highest hourly NO_2 level measured at the Topaz Station on days when cruise ships were present was 98 µg/m^3 and occurred on May 4th, 2006 between 9 pm and 10 pm when one cruise ship was present; however, on this day winds measured at the Topaz Station were predominantly from the north and northeast, so it is unlikely that this maximum is due to cruise ship emissions. The second highest hourly level recorded was 94 µg/m^3 on September 2nd, 2006, when three cruise ships were in port. Winds at Topaz Station during this period were coming from the direction of the cruise ship terminal, suggesting that this short-term peak may be associated with cruise ship emissions. Comparing all hourly emissions from each time period (Table 10) also suggests the presence of cruise ship emissions. Cruise ship days display higher maximum and mean concentration levels than other periods. Concentrations are also higher on cruise days from the 25th to 99th percentiles.

Table 10. Hourly NO_2 concentrations ($\mu g/m^3$) measured at Topaz in 2006

Percentile Values ($\mu g/m^3$)						Max	Min	Mean	Std. Dev.	Missing Values
5	25	50	75	98	99	$\mu g/m^3$	$\mu g/m^3$	$\mu g/m^3$	$\mu g/m^3$	(% total hours)
Cruise										
6	13	23	34	71	78	98	2	26	17	4
No-Cruise										
6	12	19	31	60	63	90	2	23	14	6
Off Season										
4	12	19.1	31	57	61	78	0	22	15	4

1.8.4 Particulate Matter ($PM_{2.5}$)

Averaged hourly levels of $PM_{2.5}$ at Topaz station range from approximately 3 to 9 $\mu g/m^3$ (Figure 13). Levels peak in the morning due to increased vehicle traffic and then peak again at about 10 pm. These later peaks are most likely associated with increased $PM_{2.5}$ from residential heating, particularly wood-burning fireplaces. The morning peak at Topaz station is highest on non-cruise days, which tend to be weekdays and therefore have more morning traffic. The evening peak is highest on off-season days, which occur between November and April when most residential heating is required. There is no evidence that $PM_{2.5}$ associated specifically with cruise ship emissions is reaching the Topaz station.

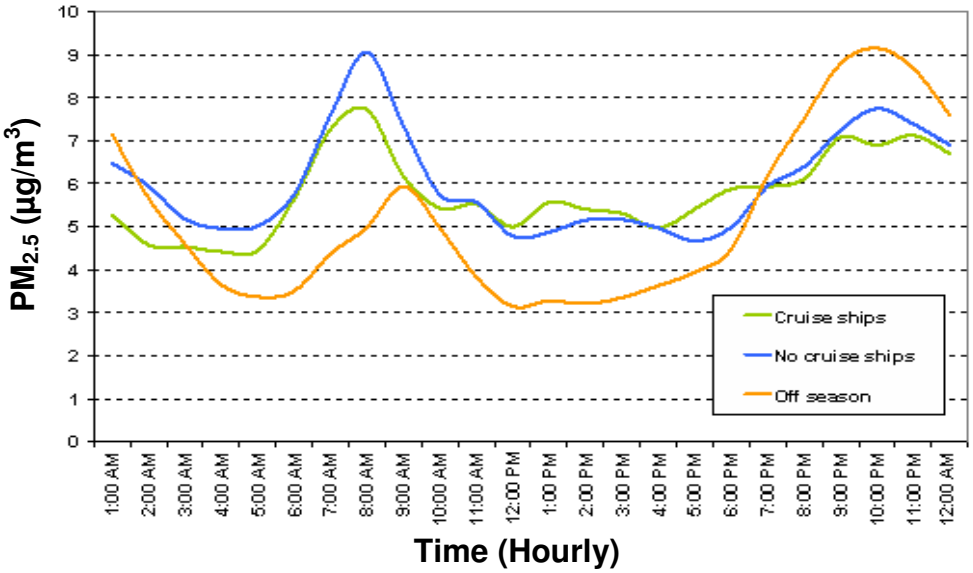


Figure 13. Average diurnal pattern of $PM_{2.5}$ at Topaz Station in 2006, on days during the cruise ship season with and without cruise ships, and during the off season

Statistics based on individual hourly observations (Table 11) show that mean concentration levels are equal for cruise and non-cruise periods (6 µg/m^3), and greater than the mean during the off season (5 µg/m^3). The maximum concentration level recorded in the off season (74 µg/m^3) is more than double that of the cruise and non-cruise periods (32 and 35 µg/m^3). The off season also has higher concentration levels at the 98th and 99th percentiles, and a higher standard deviation. These results also support the conclusion that $PM_{2.5}$ emissions from cruise ships are not evident at measurements from the Topaz monitoring site.

Table 11. Hourly $PM_{2.5}$ (µg/m^3) concentrations measured at Topaz in 2006

Percentile Values (µg/m^3)						Max	Min	Mean	Std. Dev.	Missing Values
5	25	50	75	98	99	µg/m^3	µg/m^3	µg/m^3	µg/m^3	(% total hours)
Cruise										
0	3	5	8	16	19	32	0	6	4	8
No-Cruise										
0	2	5	8	19	23	35	0	6	5	2
Off Season										
0	2	4	7	25	31	74	0	5	6	1

1.8.4 Sulphur Dioxide (SO_2)

The daily pattern of SO_2 on days without cruise ships and on off season days is very similar (Figure 14). Concentrations are generally around 2 µg/m^3, although there is a small increase to between 3 and 4 µg/m^3 associated with morning commuter traffic. The daily pattern on days with cruise ships present shows a marked peak, with levels beginning to rise around 4 pm, peaking at 11 µg/m^3 around 8 pm, and then declining to less than 4 µg/m^3 by midnight. This suggests that SO_2 associated with cruise ship arrivals is reaching the Topaz station.

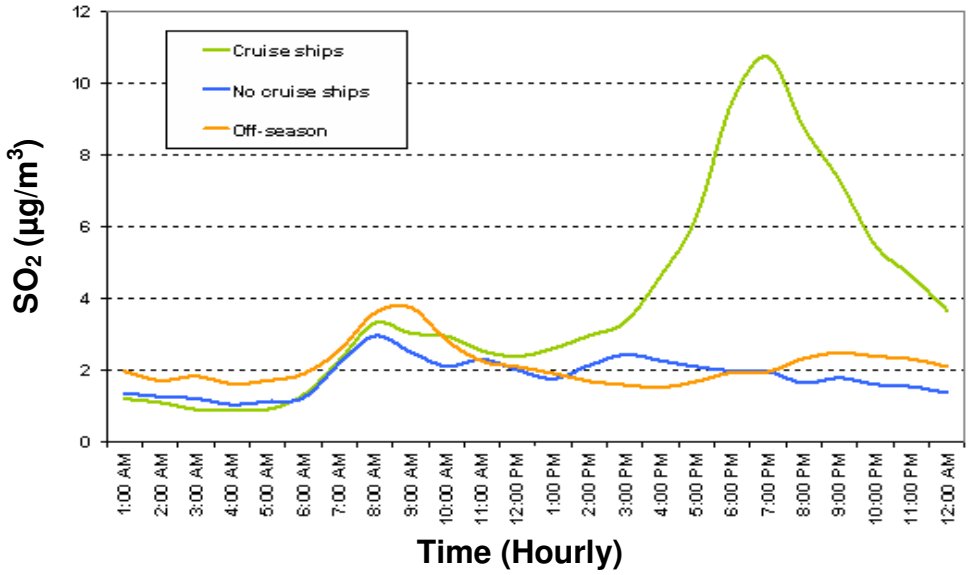


Figure 14. Average diurnal pattern of SO_2 at Topaz Station in 2006, on days during the cruise ship season with and without cruise ships, and during the off season

The highest hourly level of SO_2 measured at Topaz Station in 2006 was 77 µg/m^3 and occurred twice, on June 24th at 8 pm when three cruise ships were present, and on July 21st at 8 pm when 2 cruise ships were present. In both cases, winds measured at Topaz Station were coming from the direction of the cruise ship terminal. This suggests there may be short term (i.e., hourly) fluctuations in SO_2 associated with cruise ship emissions that are important to investigate. Hourly statistics (Table 12) also confirm this finding. Mean concentrations on hours during cruise ship days (4 µg/m^3) are higher than the other two time periods (2 µg/m^3 no-cruise; 2 µg/m^3 off season), there is a much greater variation in concentration levels as shown by the large difference in standard deviation, and maximum concentrations are higher at the 98th to the 100th percentiles. SO_2 concentrations during the cruise season have a larger range, and there are more frequent high magnitude peaks than on no-cruise days or during the off season.

Table 12. Hourly SO_2 concentrations ($\mu g/m^3$) measured at Topaz in 2006

Percentile Values ($\mu g/m^3$)						Max	Min	Mean	Std. Dev.	Missing Values
5	25	50	75	98	99	$\mu g/m^3$	$\mu g/m^3$	$\mu g/m^3$	$\mu g/m^3$	(% total hours)
Cruise										
0	0	0	3	30	43	77	0	4	8	13
No-Cruise										
0	0	0	3	13	17	48	0	2	4	14
Off Season										
0	0	3	3	11	11	19	0	2	3	4

1.8.5 Conclusions of Topaz Emissions Analysis

Based on the air quality data from the Topaz station during the 2006 cruise season, field monitoring and modeling may be warranted. Evidence suggests there may be short-term (hourly) fluctuations in both NO_2 and SO_2 in the region that are potentially attributable to cruise emissions. Although NO and $PM_{2.5}$ do not display the same trends, it is possible that concentrations of all pollutants may be different nearer to the source. Further exploration of air quality in James Bay by field monitoring and dispersion modeling will help to answer questions about the spatial and temporal variation of pollutants throughout the community, as well as if any air quality standards or objectives are being approached or exceeded. In addition, if the dispersion model specifies a larger study domain than just the James Bay area, the extent of cruise ship emissions throughout a larger area of the CRD can also be assessed.

1.9 Main Goals and Research Questions

The main goal of the JBAQS and this research thesis is to fill a noted knowledge gap about air quality in James Bay, Victoria, BC. Prior to this study, little information about the state of air quality in this region left many residents asking for answers about how emissions sources, such as cruise ships and ferries, affect local air quality, and in turn whether health implications should be a consideration. Additionally, air quality managers and emission source operators did not have adequate information regarding the impacts that cruise emissions have in the Victoria region, and whether current or future management plans are adequate. The general lack of information made communication

and decision making between all parties difficult, with much discussion based on speculation and general assumptions.

Phase I and Phase II of the JBAQS, and this thesis, attempt to answer the first question outlined above. A combination of air quality monitoring and modeling are used to establish existing concentration levels of various pollutants in the James Bay neighbourhood, and surrounding regions of Victoria. This information can then be provided to the Vancouver Island Health Authority for an expert opinion on potential health implications. The information can also be used by additional stakeholders, such as local and regional agencies responsible for air quality management, and the local port authority, to assess current source contributions and discuss future impacts and management scenarios. The JBAQS is a unique research project, with many stakeholders working together to achieve a common goal: finding unbiased and scientifically-based answers to questions about air quality in James Bay.

The two main methodologies used within this research include long-term air quality monitoring throughout the James Bay community, complimented by an air quality dispersion simulation capable of examining shorter time periods (1-hour and 24-hour). This combination provides actual measurements taken within the study area, which can be used as a baseline for future research, and also for comparison with modeled results. The air quality dispersion model provides information which field monitoring is not capable of providing, such as high spatial and temporal estimates of pollutant concentrations throughout the study area.

This thesis investigates and attempts to answer the following questions:

(1) What were the maximum 1-hour, maximum 24-hour and full-season average concentration levels of NO_2, SO_2, PM_{10} and $PM_{2.5}$ in James Bay during the 2007 cruise ship season?
(2) Do maximum emissions exceed established air quality standards and objectives? If so, with what frequency?
(3) Which pollution sources (cruise ships or ferries) are the main contributors to emissions?
(4) During what meteorological conditions do these maximum concentrations occur?

Although this thesis does not attempt to answer health-related questions posed by James Bay community members, it does compare estimated emissions to current ambient air quality objectives and standards as a point of reference. The four main air quality objectives used for comparison include the CRD Air Quality Guidelines, British Columbia Air Quality Guidelines and Objectives, Canadian National Ambient Air Quality Objectives, and WHO Air Quality Guidelines.

Chapter 2

Overview of the Research Process

The James Bay Air Quality Study (JBAQS) is a collaborative research project with a diverse stakeholder group. The study process was initiated in 2006 as a partnership between researchers at the University of Victoria's Spatial Sciences Lab (SSRL) and the Vancouver Island Health Authority's (VIHA) Population Health Surveillance Unit. Members of the James Bay community had approached VIHA with a request to investigate air quality in their neighbourhood, and determine if emissions from sources such as cruise ships, diesel buses, float planes or helijets were impacting people's health. Staff from VIHA, already having an established working relationship with researchers at the UVic SSRL from past collaborations on air quality research studies, proposed a partnership effort to apply for an initial seed grant from the Centre for Urban Health Initiatives (CUHI) for a pilot project.

The preparation of this grant application, although unsuccessful for procuring funding in the end, was an invaluable process for establishing the main research problem, initiating connections with other stakeholder and partnerships groups, and identifying potential research methods. The SSRL inquired among its contacts with government agencies like the CRD Environmental Services and BC Ministry of Environment, air quality consultants responsible for yearly assessments of air quality in the CRD (SENES Consultants Limited), and fellow air quality researchers in academia about potential research methods, costs, and additional sources of funding. Contact and agreed collaboration was also achieved between the SSRL and the GVHA.

The James Bay Neighbourhood Association (JBNA) is a grassroots, community led group which was established in 1993. The JBNA involves itself in many areas that have effect on the neighbourhood and residents of James Bay, such as air quality, noise

issues and transportation. It also participates in City of Victoria initiatives, like the design of harbour or pedestrian walkways, parks reviews, and also with the review of re-zoning and land-use proposals. The JBNA holds monthly meetings that are open to participation of all community members, and are also an outlet where residents may voice concerns about issues relating to the community. During the initial period of developing grant applications (late 2006 to early 2007), little or no contact occurred between researchers at UVic and the JBNA. The JBNA is a very active community group, and already had established relationships and expressed their concerns to other stakeholder groups, such as VIHA and the GVHA, with whom UVic was directly in contact and working with.

The CUHI seed grant for a pilot project was a source of funding to initiate the study, with the hopes of securing larger federal funding at a later date. This application focused on collaborative research, air pollution modeling to establish a zone of impact in the community, and analyzing health data for rates of respiratory illness. A potential source of subsequent funding at this time was the Canadian Institutes of Health Research (CIHR). The focus of the original project was very much on health related impacts of emissions in James Bay, as per the community's concerns. During discussions with SENES Consultants regarding air quality modeling, an additional source of funding suggested was the BC Clean Air Research Fund (CARF). This fund was established in 1995, and its purpose is to fund research projects on air quality issues in the province with a particular focus on transportation and fuels. The fund is jointly managed by the Canadian Petroleum Products Institute, Greater Vancouver Regional District, and the BC Ministry of Environment. Unlike the seed grant application, which was largely focused on health impacts of air pollution and developing a spatial database of respiratory illness, the CARF fund required a different perspective of the proposed project. The main purpose of the project in this proposal then shifted to characterizing marine emissions in the CRD, with a specific focus on the downtown area surrounding the Ogden Point Terminal, and less of a direct focus on health.

An application to the CARF was developed, outlined as a three phase project. The first phase would include "screening"-level (worst-case scenario) modeling to establish the spatial extent of cruise related emissions. The second phase consisted of

field monitoring throughout the area during the cruise ship season, guided in part by the screening-level dispersion model results. Finally, the third phase would consist of a comprehensive dispersion model including a more enhanced emissions inventory of cruise ships and ferries, as well as potential other local emissions sources such as motor vehicle traffic. The CARF only provides funding upon final deliverables, so the product to be submitted to receive the CARF funds was established as a report presenting the results of the screening-level model and the field monitoring, and collecting all the data necessary to perform an advanced dispersion model. The process of developing the application to CARF required input and collaboration with other groups. A working group was developed by UVic, consisting of SENES Consultants Limited to perform the modeling, the GVHA, the BC Ministry of Environment, VIHA, CRD Environmental Services and Vancouver Island University Applied Environmental Research Laboratories. The products from this project (modeling estimates and measured data) would be useful to air quality managers by establishing the relative contribution of different sources of emissions in the area and identifying the spatial extent of the marine emissions influence on populated areas. The data would also be provided to the VIHA Population Health Surveillance Unit for evaluating and informing health risk reduction policy, in accordance with their goals from early on to address health-related issues in James Bay.

The failure of the CIHR seed grant, in combination with a re-focusing of the project for the application to CARF and its success at securing funds, inadvertently transferred direct control of the research project from joint VIHA-UVic management to a university-directed study with VIHA as a main project advisor. The outcomes of the research remained as deliverables to VIHA for use in health-related studies, and they therefore remained actively engaged in the process. Other project funders which became involved during the CARF procedure included the BC Ministry of Environment and the GVHA. The CARF presented an interesting challenge for the JBAQS, mainly because the JBNA was not included among the working group at this initial stage of the process to secure funds, which led to some misunderstanding and conflict later on.

The first interaction between UVic and the James Bay community occurred in May 2007, when researchers attended the monthly JBNA community meeting. At this

meeting, researchers from UVic presented an overview of what was planned for the study in terms of a field monitoring campaign and a detailed air quality dispersion model and the types of data that would be produced. Staff from VIHA also attended the presentation and provided answers to community's questions about the use of the air quality data for examining health outcomes. This first meeting between UVic and the JBNA, where researchers approached the community with a proposal to examine a problem which they had identified as important in their neighbourhood, and which allowed them to express any and all concerns relating to air quality, established the beginnings of an open and trusting relationship between the community and the university.

Although the main research design had already been developed during the funding applications, this meeting provided a valuable opportunity for UVic to hear from community members first-hand, and also identify any other air quality issues which may have been overlooked that could also be included in the study. Community members had many suggestions for UVic researchers, many of which were beyond the capabilities or scope of the research project, yet it was a chance for community members to feel that their concerns were being heard, and considered important as input into the research. In the past, requests for research and studies into air quality made to local government or the GVHA by the JBNA had been turned down, and frustration was evident. Community members were incredibly grateful that researchers from UVic had volunteered to take on the research study. This meeting was the official launch of JBAQS. After this initial meeting, an official "Advisory Group" was developed, to be involved through regular updates, meetings and report reviews of the field monitoring and dispersion modeling stages of the research study. Representatives of the JBNA were appointed to sit on the advisory committee.

The JBNA, and their initial request for a research study, established them as a key stakeholder at the initial stages of the research process. Even though not actively involved in the CARF working group, JBNA interests in an air quality investigation and health impacts was the primary topic being addressed. Unlike other research studies, where cooperation from communities must be acquired, this study was fortune to have early and on-going collaboration with members of the James Bay community.

Establishing UVic researchers as an individual identity, operating separately and independently from VIHA, and other stakeholders or funders, was beneficial to this research study. The representative from VIHA who originally sought seed funding and developed the idea for the research project based on the JBNA's request left the JBAQS research group early on due to medical reasons. Two additional representatives subsequently filled in the position. UVic remained the key leader in the research process, so although members from VIHA may have changed over time, the process was never disrupted or forced to change course, as UVic researchers were the main directors to keep it focused and on track.

Of the main stakeholders in the project, the two with most opposing interests were the JBNA and the GVHA. The GVHA, responsible for managing the port facilities of the Inner Harbour and Ogden Point, has an invested interest in maintaining ongoing operations of marine vessels, such a cruise ships and ferries. Cruise ships provide important economic revenue to the Victoria region. Community members who question the environmental integrity of the industry, or claim that it is negatively affecting health in the region, without research or scientific data to back their claims can be viewed as threatening to the GVHA and their management objectives and practices. Alternately, when the community's requests for research into air quality impacts appear to be ignored, they may assume that the GVHA has a greater interest in the bottom line than the environment or people's health. In reality, the situation is far more complicated, and neither side is 'out to get one another'. Yet, care had to be taken with these two particular groups, to ensure that UVic was seen as an impartial party, and that final results would not be influenced by either group, but be based on sound, unbiased scientific research. In fact, this scenario is ideally what both parties desired, in order that they could have equal trust in the study outcomes.

Field monitoring in the James Bay neighbourhood took place between May and August, 2007. Residents which had volunteered their yards to house air quality monitoring equipment at the May JBNA meeting were contacted to set up nephelometer and partisol equipment. Not all volunteered locations were suitable for siting the equipment however, and by mid-summer there were a lack of sites to place the equipment. Researchers began to distribute flyers in desirable parts of the

neighbourhood. The JBNA was also contacted and asked to send a message through their email distribution network that UVic was looking for additional sites and volunteers. Two members of the JBNA immediately volunteered to distribute flyers throughout the neighbourhood. The response from the community was tremendous. In fact, certain residents were upset when their yards were not selected as sites, as they believed their particular locations were especially important and worth contributing to the study, even though only a limited number of locations could be included in the field monitoring.

Field monitoring was conducted simultaneously as the deliverable report for CARF, on the screening-level model and field results, was being written by UVic and reviewed by the original working group, not including the James Bay representatives. Although UVic would have liked to include JBNA in the meeting, so that the process was entirely open and transparent to all members of the project, it was felt by other members that the details of the CARF report were preliminary in nature, and that if involved at this time the James Bay representatives might disclose information to the public. UVic researchers learned that when dealing with groups with such diverse interests, it is important to attempt to contain as much information as possible from becoming public prior to the release of "official" final results. The JBNA and the GVHA both accused each other on separate occasions of divulging information which was gained during advisory group meetings, yet not ready for public consumption. While the James Bay representatives were not included at this point in time, it was understood that they would be included in all future discussions and meetings pertaining to the Phase I Field Monitoring and Phase II Air Quality Modeling portions of the project.

The overlap of the final CARF report and the draft field monitoring report, and public comments made alluding to the CARF report and its findings, caused James Bay representatives to question whether the field monitoring report had already been distributed. If so, an explanation as to the reason James Bay representatives had not received a copy was demanded, as they viewed themselves as partners in the process. In a way, the JBNA believed they had some ownership over the study, as it was their requests which had initiated the entire process. The nature of the application to the CARF fund had to be explained, and JBNA had to be reassured that the Phase I draft

monitoring report had not been released, and that their involvement was to the same degree as the other parties involved.

In order to avoid conflict and misinterpretation of results, it was decided that primary press releases and the JBAQS Phase I and Phase II reports should be distributed by VIHA. Other parties wishing to make public statements on findings should wait until the information was first released by VIHA before providing their own public announcements or comments. Once reports were finalized, researchers from UVic were requested to provide presentations for the JBNA and GVHA, as well as for other air quality management groups. The JBNA was always the first group to receive presentations on the field monitoring and air quality modeling, as UVic believed that this group was the initiator of the project and deserved the first dissemination of data findings.

The process for each of the Phase I and Phase II reports consisted of the following steps: initial meetings to discuss logistics and goals, execution of the field monitoring or modeling by UVic and other parties and development of a draft report for distribution to the Advisory Group, a meeting to discuss the contents of the draft report followed by written comments from all parties, the development of a final report and either an additional meeting or following rounds of written comments. Each stakeholder had equal opportunity to provide verbal or written comments, to make suggestions about additional things they thought should be included or removed, and to ask questions about things they did not understand. In the end, all parties should have felt that they were actively engaged and had equal and ample opportunity to contribute to the study. Meetings were coordinated and directed by UVic researchers, and by the end of the process it appeared that good relationships had formed between members of the group and that they were able to effectively work together. This is not to say that disagreements did not arise between stakeholders, but UVic was able to effectively resolve any conflicts that may have arisen. Stakeholders expressed their satisfaction with the research process, the conduct of the UVic SSRL researchers and VIHA, and the final results.

An additional challenge faced during the research process was obtaining detailed information about diesel buses that transport cruise passengers, and about the individual cruise ships which visit Ogden Point in order to configure them in the dispersion model.

The GVHA requested that UVic work through their agency to obtain information on buses, since the GVHA already works with these bus agencies and could more easily facilitate interaction between them and UVic. Unfortunately, this did not occur. Instead, letters of intent and requests for data drafted by UVic were never passed on to bus agencies, and no data were obtained via this route. In the end, UVic contacted individual bus companies directly and requested data, which were willingly provided by the bus companies. This information was obtained so late in the research process that buses were not able to be included in advanced dispersion modeling as originally intended. Similarly, the BC Chamber of Shipping and Northwest Cruise Association were contacted with data requests. Although conference calls were held, and researchers provided detailed information to these groups about the study and the CALPUFF model and its reputable use in air quality applications, these agencies never delivered any information. In the end, researchers and SENES Consulting had to rely on previous research studies and make reasonable assumptions to generally characterize ships in the model. It seemed that due the potential contentious nature of results, should they not be desirable for the cruise industry, these agencies would prefer to remain on the sidelines rather than support the research study. Such a position would make it easier to criticize final results, should they be controversial.

Phase I and Phase II of the JBAQS were primarily carried out and guided by UVic. At the end of this process, however, both reports were provided to the VIHA so that health inquiries expressed by the JBNA could be addressed. In order to address the question of what these results mean for the health of residents in James Bay, VIHA hired an independent consultant, who is a researcher from the BC Center for Disease Control (BCCDC). This person has substantial experience in community air quality studies in other areas of Canada, and is a distanced third party from the project. Their position and expertise will provide a professional and unbiased assessment, and which can also put air quality levels in James Bay in context with air quality in other areas of Canada. This health consultant was present at the presentation of the Phase II Modeling results to the JBNA in December 2008. UVic researchers first presented a summary of the main findings from the advanced dispersion model, and this was followed by a detailed presentation from the BCCDC researcher. James Bay community members expressed

their interest in the latter presentation, as it outlined how air quality objectives and guidelines are derived, how measured and modeled concentrations in James Bay compare to other areas of Canada, and what this means for health of residents of James Bay based on local hospitalization rate data. The presentation was only meant to be a be a first look at the Phase I and Phase II results, with a more comprehensive report (being referred to as JBAQS Phase III) to be completed by the fall of 2009.

The JBAQS Phase I and Phase II reports generally focused on cruise ship and ferry sources, and were not able to specifically measure or model other emission sources or pollutants which were of interest to the James Bay community. These include float planes and diesel buses, and emissions of volatile organic compounds (VOCs). Limitations to funding and research methods prevented all of the community's requests to be investigated. These knowledge gaps were carefully cited within the reports as areas in need of future research. The JBNA was aware of the limitations of the research project from the onset, namely what information it would be able to provide and what it would not, yet were willing to accept this project as a good starting point. Community members were grateful that their requests were finally being addressed. The JBAQS provides information which did not exist previously, and which can answer some of the questions they had about emissions from cruise ships and ferries, and what general levels of pollutants are like on the long-term over the summer season. The JBNA recognizes this as a basis for developing additional and ongoing investigations into the air quality in their region.

Chapter 3

Air Quality Monitoring

3.1 Introduction

In this chapter, a variety of field monitoring techniques establish the general concentration levels of nitric oxide (NO), nitrogen dioxide (NO_2), sulphur dioxide (SO_2), and particulate matter ($PM_{2.5}$) in James Bay during the 2007 cruise ship season. This field monitoring was conducted as part of Phase I of the James Bay Air Quality Study (JBAQS). The monitoring program used was designed to take advantage of readily available and relatively inexpensive monitoring equipment, which limited where sampling occurred and over what time periods. In the absence of equipment capable of continuously monitoring hourly or daily levels over long periods of time i.e., several months, which would have been useful for establishing trends over time, the focus of this study was to identify the general range of pollutant levels in the James Bay area. Therefore, most sites were sampled in only one of several sampling periods between May and September 2007.

In addition to establishing general pollutant levels, field monitoring was also designed to explore whether the contribution of cruise ship emissions could be observed in the measured levels. While there are a variety of emissions sources in the James Bay region, most maintain relatively constant schedules over time, with the exception of cruise ships and their associated bus traffic. This provided an opportunity to sample on days with and without cruise ships present at the Ogden Point terminal. Data from the BC Ministry of Environment's regulatory monitoring station on Topaz Avenue for 2007 are also examined to determine whether a cruise ship signal is detectable at this nearby site.

Detailed information on the different monitoring methods used for each pollutant is provided in the next section. A "spot" monitoring approach was adopted for the field research, meaning that continuous monitoring of pollutants at specific sites over the duration of the cruise ship season was not conducted due to considerations of cost, time and other logistics. Instead, equipment used were capable of providing only average levels over the duration of the sampling periods, which in the case of days with ships in port included many hours when cruise ships were not actually present. This means that the chances of measuring a difference due to cruise ship presence are diminished. For these reasons, it is important to consider the pollutant levels measured on days with and without cruise ships as averages over the entire sampling period, not an indication of levels for any shorter time periods.

In addition, comparing results from different time periods is complicated by the fact that some influential factors may not be consistent i.e., wind speed, wind direction and precipitation. Wind rose and precipitation data are provided with sampling results to aid in the assessment of possible effects of differing conditions. However, while comparisons are made between days with cruise ships present/absent, these should not be considered definitive proof of differences.

3.2 Methods

Three different field monitoring methods were used to investigate ambient levels of pollutants in James Bay. These included: 1) examining available data on all pollutants from the nearest regulatory monitoring station for the full 2007 year; 2) passive diffusion sampling of NO, NO_2 and SO_2 in three different sampling periods at 23 different sites throughout the James Bay neighbourhood, and; 3) measurement of particulate mass (total amount) and composition (nickel, vanadium and absorbance – markers for marine fuel or diesel exhaust) at 6 to 9 different sites during three monitoring periods. The JBAQS Phase I Report can be referred to for further details on all field monitoring results and analysis, particularly for pollutants not the focus of this thesis research, such as volatile organic compounds (VOCs).

3.2.1 Regulatory Monitoring Network Data

Hourly air quality measurements of NO, NO_2, $PM_{2.5}$ and SO_2 were obtained from the Topaz Avenue continuous air quality monitoring station (Figure 15) for the full 2007 year (January 1 to December 31). Data were then divided into three categories for analysis:

(1) Off Season: January 1 - April 23, 2007 and November 4 – December 31, 2007

(2) Cruise Season (non-cruise): days during the cruise ship season (April 24 – November 3, 2007) with no ships scheduled in port

(3) Cruise Season (cruise): days during the cruise ship season (April 24 – November 3, 2007) with ships scheduled in port

In each category, the average for every hour was calculated based on daily measurements for that hour, and then graphed to show the average daily pattern for each group. Statistics on all individual hourly observations are also provided.

Figure 15. Location of Topaz Station in relation to the Ogden Point terminal and meteorological station

3.2.2 Passive Diffusion Samplers

Concentrations of NO, NO_2, and SO_2 were measured using Ogawa passive diffusion samplers (Ogawa and Co., USA) in three sampling periods during the 2007 cruise ship season. Passive samplers work by trapping the pollutant of interest on filters coated with triethanolamine as a trapping agent, and are then extracted into water so that nitrite and sulphate can be analyzed by ion chromatography. The samplers are double-ended with two filters to simultaneously monitor for both NO/NO_2 and SO_2. Samplers are usually mounted just out of reach on hydro poles or light standards, and are protected from rain and wind velocity by a protective shelter. More detailed information about Ogawa sampler design and performance can be found elsewhere (Yamada et al., 1999; Mukerjee et al., 2005; Sather et al., 2007).

Sampling was performed in three separate periods (Period A, B and C). The first round of monitoring (Sample Period A) took place from May 22 to June 6, 2007. Five sampling sites were selected to represent major (2 sites), medium (2 sites) and minor (1 site) roads. At each location, three samplers were placed at varying distances away from the roadway (0 – 80 meters) in order to establish if a gradient of concentrations away from roads could be detected. The second sampling period (Period B) took place at 11 sites from June 15 to July 28, and the third sampling period (Period C) at 9 sites from August 17 to September 23. During sampling periods B and C, two sets of samplers were deployed at each sample site. Each individual set was separately exposed for a non-consecutive 14-day period; one set of samplers was exposed only on days when cruise ships were scheduled to visit the Ogden Point terminal, and the other set only on days when cruise ships were absent, for a total of 336 ± 3 hours per sampler. Between exposures, each sample was kept sealed in an airtight plastic bag stored in an opaque airtight screw-top plastic container at room temperature (20ºC) in the UVic Spatial Sciences Laboratory. Samples were not stored in a refrigerator to avoid condensation on the filters.

All samplers were attached to hydro poles at a height of 2.5 meters, with the exception of three samplers in the first round of gradient monitoring (one sampler was attached to a fence and two others to the side of a housing complex). Field blanks and duplicate samplers were used in all three sampling periods for quality control purposes.

Field blanks were used to determine how transport and handling may have affected sampler concentrations and duplicates were deployed to assess the precision of the Ogawa sampling technique. All samplers were processed at the School of Occupational and Environmental Health laboratory at the University of British Columbia, using standard procedures.

3.2.3 Nephelometers and Partisol Monitors

$PM_{2.5}$ was measured in three sampling periods: Period D in June/July, Period E in July/August, and Period F in August/September. A combination of monitoring instruments (Nephelometer and/or Partisol) were used to examine the total amount of $PM_{2.5}$ (mass) in Period D and E, as well as differences in the amount of contained metals and absorbance (composition) in Period D, E, and F (Figure 16).

$PM_{2.5}$ Mass

Light scattering was measured at 6 locations in the study area from late June to early August, 2007. Monitoring locations were chosen from yards volunteered by local residents, which fulfilled the requirements of having an electrical outlet, and a fence or hedge to shield visibility of equipment from roads (for security reasons). Sites were also preferentially chosen to be in the downwind direction of the terminal. At each location, a Radiance Research M903 Nephelometer was used to measure and log 5-minute average light scattering from particles in the air over a 6-day period. Sampling periods were selected to coincide with three days having cruise vessels present at the Ogden Point Terminal, and three days where they were absent.

The nephelometer equipment measures light scatter from particles in the air. There is no filtering of air prior to measuring the light scatter, so particles of all sizes are present in the sample. The nephelometer does, however, measure $PM_{2.5}$ well because of the wavelength of the light source in the instrument. Equipment was calibrated according to the manufacturer's instructions prior to use in the field. In addition, nephelometers were operated side-by-side for 24 hours in the UVic Spatial Sciences Laboratory after field use, and were found to have a high correlation between the levels measured by each instrument (R^2 between .986 and .991).

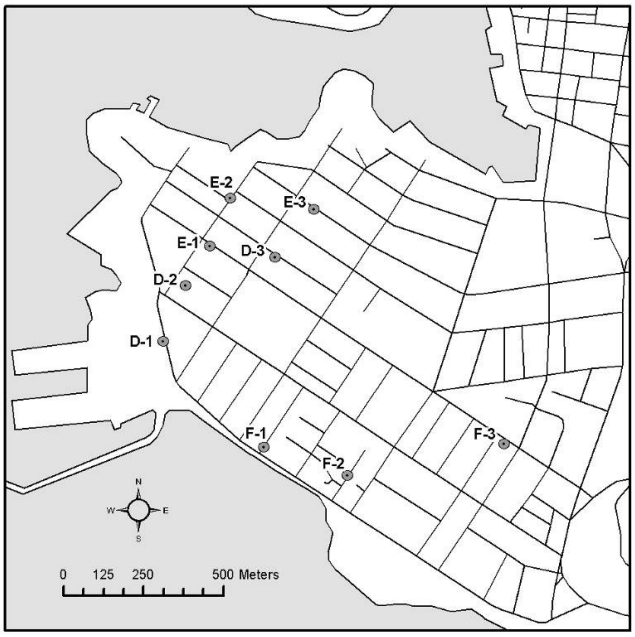


Figure 16. Particulate matter mass and composition sampling sites
(note: sites F-1, F-2 and F-3 composition only)

The light scattering coefficient was converted to $PM_{2.5}$ ($\mu g/m^3$) using the following equation, as per Allen et al. (2003):

$$PM_{2.5}\ (\mu g/m^3) = ((100{,}000 * \text{light scatter value}) - 0.01) / 0.28$$

Although this formula is based on only one season's worth of measurements, it has been found to show good agreement (Pearson's R = 0.8 or 80% agreement) with the $PM_{2.5}$ levels measured at the CRD Topaz and Royal Roads University stations using tapered element oscillating microbalance (TEOM) equipment. The level of agreement will vary based on time, geographical location and $PM_{2.5}$ source type. Therefore, when considering $PM_{2.5}$ levels provided in this thesis, it should be noted they may be up to ± 20% different than that which would have been obtained by TEOM equipment.

Traffic counting strips were installed on roadways as close to each sampling location as possible, and data were collected for the same 6-day sampling periods as $PM_{2.5}$. The traffic counting strips provide 15-minute average counts of westbound and eastbound traffic, classified according to 13 different vehicle classes and 12 different speed classes. Traffic data were compared to $PM_{2.5}$ concentrations to determine the

influence traffic emissions may have on recorded levels, and to help distinguish a cruise ship signal from traffic on local roads.

$PM_{2.5}$ Composition

Particulate matter is the product of a number of sources and therefore includes a variety of materials. $PM_{2.5}$ can include organic and inorganic carbon compounds, sulphates, nitrates, ammonium and various trace metals (Suzuki, 2003). Analysis of $PM_{2.5}$ composition can indicate which sources are contributing to measured levels. For example, elemental carbon (indicated by measuring optical absorbance) has been found to be associated with diesel exhaust (Henderson and Brauer, 2005), while vanadium and nickel can be associated with the combustion of heavy residual fuel oil typically used in large ocean-going vessels (Hopke et al., 2006).

$PM_{2.5}$ composition was measured at 9 locations in the study area. In sample Period D and E, Model 2000-H Partisol samplers were co-located with nephelometers and used to collect $PM_{2.5}$ on pre-weighed GELMAN Teflo 0.38 mm filters, provided by CANTEST. The Partisol samplers use an air pump to draw air in through a cyclonic head which settles out larger particulates prior to the sample filter. Equipment was calibrated for air flow volume according to manufacturer's instructions at the beginning of the field season by staff at the BC Ministry of Environment. During sampling Period F, Partisol samplers were deployed without the co-located nephelometers, according to the methods just described.

At each of the nine sample sites, one filter was used continuously over two or three days when no ships were at dock, and a second filter was used for two or three days when cruise ships were at dock. In addition, a single filter was exposed to the air in the study area for each monitoring period, to serve as a field blank for quality assurance purposes. Filters were sent for analysis to the School of Occupational and Environmental Health laboratory at the University of British Columbia, where reflectance of $PM_{2.5}$ measured by a M43D Smokestain Reflectometer was converted to absorbance. Absorbance is related to the concentration of elemental carbon in the $PM_{2.5}$, which has been shown to be present in $PM_{2.5}$ resulting from incomplete diesel combustion and heavy duty vehicles.

Following absorbance analysis, filters were shipped to the CANTEST laboratory in Vancouver, BC where they were weighed for total mass, and analyzed for a full range of metals using procedures based on WCB Method 1051, acid digestion of filter followed by analysis using inductively coupled plasma-mass spectroscopy (ICP/MS). This method can detect metals present in quantities as low as 0.005 to 0.75 micrograms (.000000005 to .00000075 grams). Total metals on each filter were measured and divided by the total volume of air pumped through the filter to produce an average level per cubic meter of air.

3.2.4 Field Monitoring Summary

Table 13 provides a summary of all field monitoring activity, including equipment used, duration of sampling, dates, and total number of sites sampled. The influence of cruise ship emissions and related traffic on levels of NO, NO_2, SO_2 as well as $PM_{2.5}$ composition (absorbance, vanadium and nickel) was explored by taking measurements on days with cruise ships in port and on days without cruise ships in port.

Table 13. Summary of field sampling equipment and duration

Pollutant	Equipment	Duration	Dates	Total Sites	Notes
NO NO_2 $PM_{2.5}$ SO_2	Topaz Station	Short-term (hourly)	Jan - Dec	1	2.5 km from Ogden Point
NO NO_2 SO_2	Ogawa passive samplers	Long-term – 14 consecutive days	May - June	5	5 transects (3 samplers/site)
		Long-term – 14 non-consecutive days over 2 months	June – July Aug - Sept	11 9	Paired samplers: one set cruise days; one set no-cruise
$PM_{2.5}$ (mass)	Radiance Research M903 Nephelometers (light scatter)	Short-term – 5 minute averages for 6 consecutive days	June July	3 3	3 days with cruise and 3 days no-cruise
$PM_{2.5}$ (composition)	Partisol samplers (filters)	Medium-term – 2 or 3 consecutive days	June July August	3 3 3	2 filters/site: one for cruise days, one for no-cruise days
Traffic	Pneumatic tube counters	Short-term – 15 minute averages for 6 consecutive days	June July	3 3	3 days with cruise and 3 days no-cruise

3.3 Results

3.3.1 CRD Regulatory Network – Topaz Station

Although Topaz monitoring station is not located in the James Bay community, an examination of data from the 2006 year indicated that hourly NO_2 and SO_2 concentrations at this site may have been influenced by emissions from cruise ships. The dominant wind direction measured at Ogden Point meteorological station in 2006 was from the south-west quadrant, or from the cruise ship terminal towards Topaz Station. Peaks in hourly concentration levels were evident during certain hours when cruise ships were in port. Wind speed and wind direction in 2007 follows a similar pattern as in 2006 (Figure 17) and it is therefore possible that emissions from ships during the 2007 cruise ship season may also be detectable at the downwind Topaz Station, as in the previous year. This section presents an analysis of continuously monitored air quality data from the Topaz Station for the 2007 year, to investigate if similar trends exist.

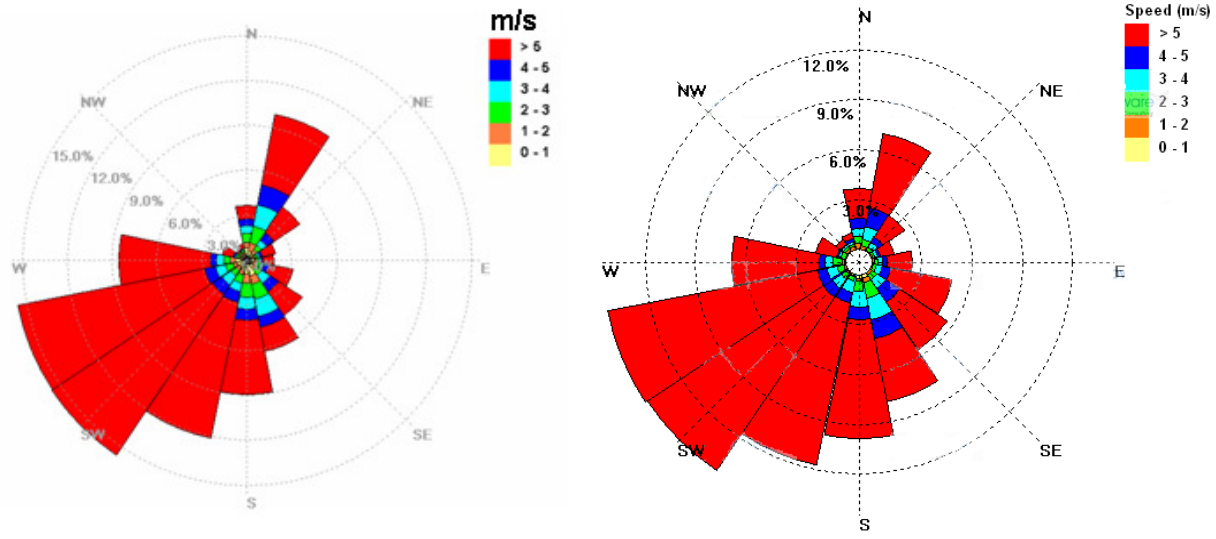


Figure 17. Comparison of wind speed and direction from 2006 (left) to 2007 (right) measured at Ogden Point meteorological station (May to October)

Nitric Oxide

Average hourly NO concentrations range from 3 to 32 µg/m^3 (Figure 18). Concentration levels show a similar pattern during all three time periods. There is a morning peak in concentration levels associated with traffic, which decreases throughout the day due to

decreased traffic, increased solar heating and atmospheric mixing. This is the same pattern that was seen in the 2006 data, along with the slight increases in late evening associated with residential heating in part (SENES, 2006), particularly in the off season. The graph displays no evident trend associated with cruise ships.

Summary statistics of individual hourly NO levels (Table 14) also do not show any indication of higher NO concentrations on days during the cruise ship season when ships were in port; in fact, highest maximum NO concentration levels occurred on no-cruise days (302 µg/m^3), as well as during the off season (296 µg/m^3). The off season also had greater variability in concentration levels, and higher concentrations at the 98th and 99th percentiles. While cruise and no-cruise days may have had an event which created a high peak in levels during one hour, the off season had multiple occasions where concentrations reached over 100 µg/m^3.

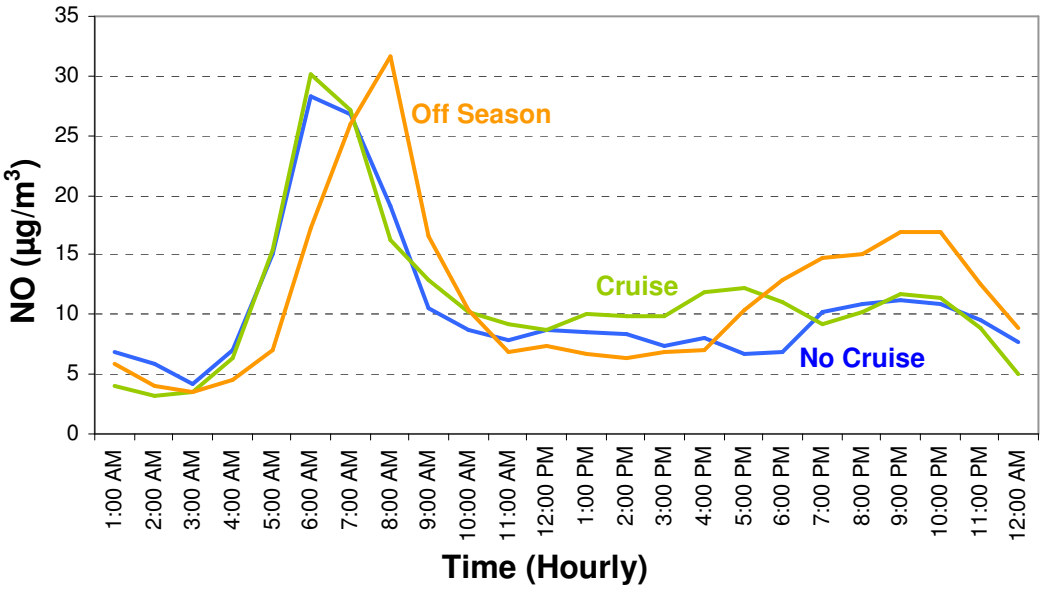


Figure 18. Average diurnal pattern of NO at Topaz Station in 2007, on days during the cruise ship season with and without cruise ships, and during the off season

Table 14. Hourly NO (µg/m^3) concentrations measured at Topaz in 2007

Percentile Values (µg/m^3)						Max	Min	Mean	Std. Dev.	Missing Values
5	25	50	75	98	99	µg/m^3	µg/m^3	µg/m^3	µg/m^3	(% total hours)
					Cruise					
0	2	5	12	70	88	217	0	11	18	7
					No-Cruise					
0	2	4	20	76	101	302	0	11	21	5
					Off Season					
1	2	4	9	105	146	296	0	12	26	7

Nitrogen Dioxide

Average hourly NO_2 concentrations range from 13 to 32 µg/m^3. Concentration levels show a peak between 6 am and 8 am from morning traffic, as well as an evening peak of equal magnitude (Figure 19). As with NO, the evening peak is greater in the off season (colder weather months), which is likely associated with evening home heating. The evening peak of average NO_2 concentrations, however, is approximately 1 to 3 µg/m^3 higher on cruise than no-cruise days. While the 2006 data showed evening hours to be up to 10 µg/m^3 higher on cruise ship days than on either no-cruise or off season, this same phenomenon is not evident in the 2007 data.

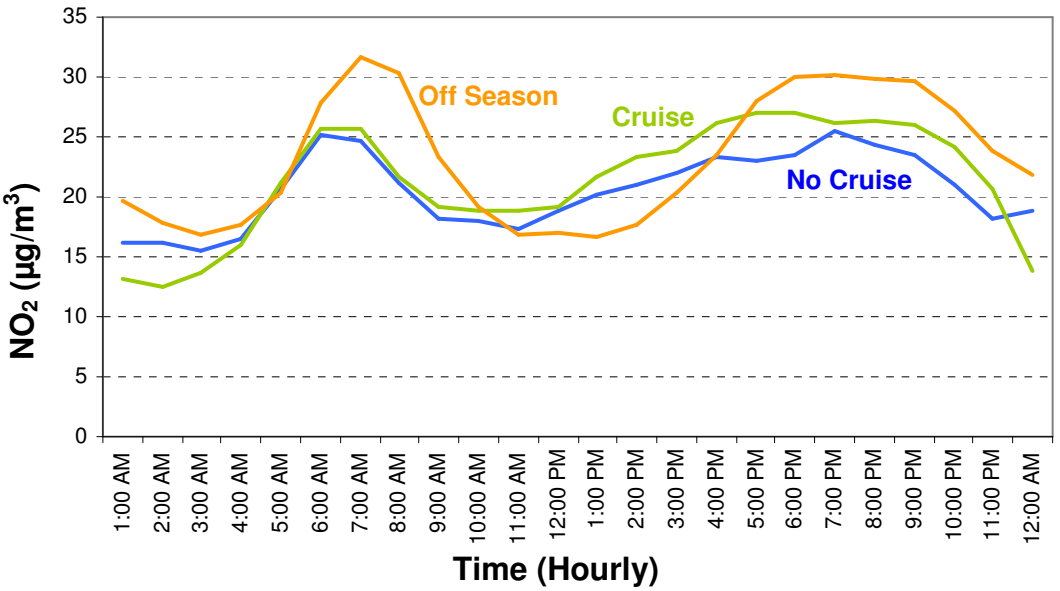


Figure 19. Average diurnal pattern of NO_2 at Topaz Station in 2007, on days during the cruise ship season with and without cruise ships, and during the off season

A summary of all hourly NO_2 observations (Table 15) confirms that that the maximum NO_2 concentrations occur during the off season (79 µg/m^3) and not during cruise (77 µg/m^3) or no-cruise (73 µg/m^3) periods. The off season also experiences1 to 2 µg/m^3 higher mean concentration levels, and a greater variation in levels. In general, however, NO_2 patterns and levels are similar for all three time periods, and there is not a distinct signal of cruise ship-related emissions detectable in the measured data.

Table 15. Hourly NO_2 concentrations (µg/m^3) measured at Topaz in 2007

Percentile Values (µg/m^3)						Max	Min	Mean	Std. Dev.	Missing Values
5	25	50	75	98	99	µg/m^3	µg/m^3	µg/m^3	µg/m^3	(% total hours)
Cruise										
6	13	20	28	50	57	77	0	21	12	7
No-Cruise										
6	11	18	27	51	55	73	1	20	12	5
Off Season										
7	13	20	32	58	62	79	1	23	15	7

Particulate Matter ($PM_{2.5}$)

Average hourly levels of $PM_{2.5}$ range from approximately 3 to 9 µg/m^3. Concentrations peak in the morning between 6 am and 8 am, and again in the evening at approximately 9 pm (Figure 20). The smaller morning peak is associated with morning traffic, while the evening peak with home heating. The evening peak is especially evident during the off season (3-4 µg/m^3 higher than summer season months), when colder temperatures increase the need for home heating, a major source of particulate matter.

Cruise and no-cruise display a similar trend; however, an evening peak in $PM_{2.5}$ levels is not present for cruise days. Concentrations on days with cruise ships are about 1 to 2 µg/m^3 lower between 7 pm to 5 am. Midday concentrations, from approximately 10 am to 4 pm, are roughly 2 µg/m^3 lower during the off season than the other two periods. This may be explained by additional $PM_{2.5}$ sources during the summer season that contribute to concentration levels during the day. Such sources may possibly include increased summer bus and tourist traffic, or greater numbers of boats operating around the area, which may contribute to greater regional $PM_{2.5}$ concentrations. Statistics on

hourly observations for the three time periods (Table 16) confirm that there is not an evident signal from cruise ships at the Topaz Station.

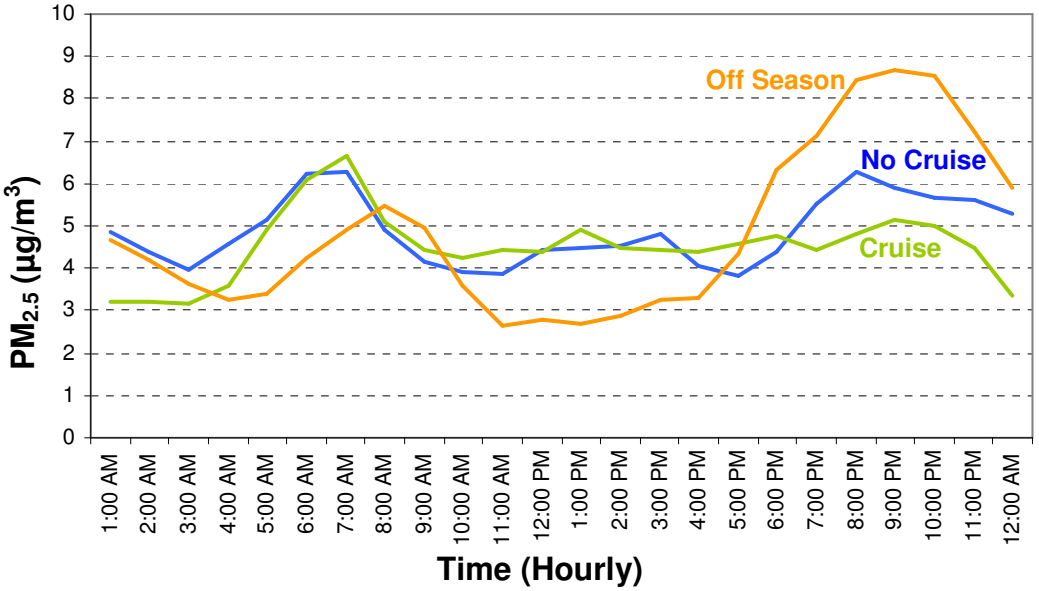


Figure 20. Average diurnal pattern of $PM_{2.5}$ at Topaz Station in 2007, on days during the cruise ship season with and without cruise ships, and during the off season

Table 16. Hourly $PM_{2.5}$ concentrations ($\mu g/m^3$) measured at Topaz in 2007

Percentile Values ($\mu g/m^3$)						Max	Min	Mean	Std. Dev.	Missing Values
5	25	50	75	98	99	$\mu g/m^3$	$\mu g/m^3$	$\mu g/m^3$	$\mu g/m^3$	(% total hours)
Cruise										
0	2	4	6	13	15	35	0	5	3	2
No-Cruise										
0	2	4	6	19	25	69	0	5	5	2
Off Season										
0	1	3	6	23	29	55	0	5	6	1

Sulphur Dioxide (SO_2)

Average hourly concentrations ranged from 0 to 7 $\mu g/m^3$ (Figure 21.). As with the other pollutants examined, there is a morning peak in concentrations between 6 am to 9 am associated with morning traffic. The off season displays a gradual increase in concentrations over the evening, to a secondary peak at approximately 9 pm. No-cruise

days do not display any evident peak in evening concentrations. Cruise ship days, however, display elevated concentration levels in the afternoon and evening, with a major peak in average concentration levels at approximately 5 pm (6 to 7 µg/m^3), and levels decreasing and peaking again at 5 µg/m^3 at 10 pm.

Hourly concentration levels of SO_2 are higher at the 98th and 99th percentiles during on cruise days, and concentrations also show greater variation than observations from no-cruise days or the off season (Table 17). A signal from cruise ships appears to be present in SO_2 observations from Topaz; peak hourly concentrations are over 60 µg/m^3 higher on days when ships are in port, compared to days when they are not or during the off season, and average hourly concentration levels are highest during the evening hours when cruise ships show the most activity. A similar pattern was also observed in the 2006 data from the Topaz Station.

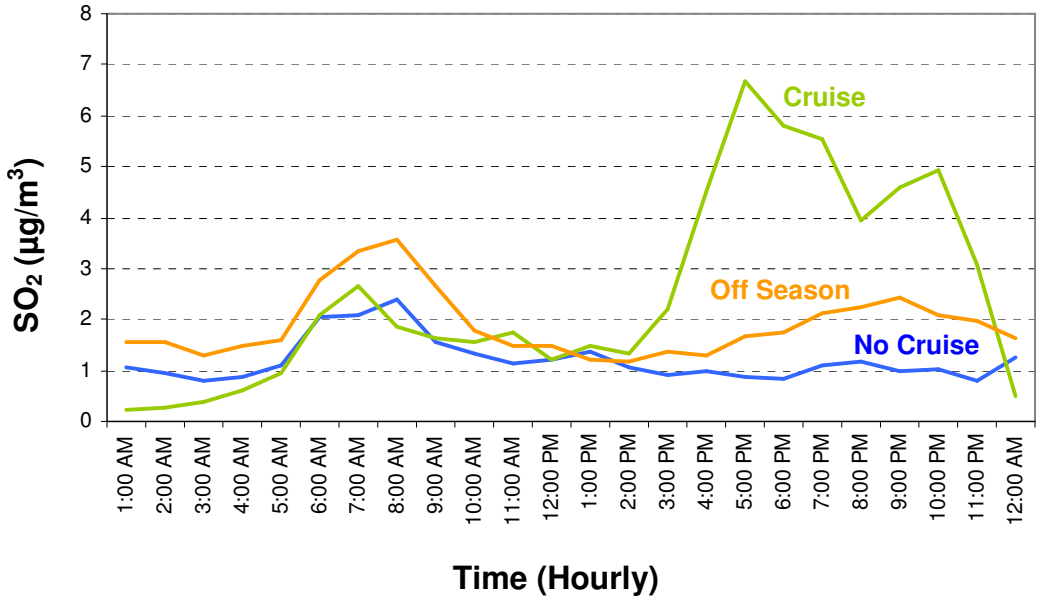


Figure 21. Average diurnal pattern of SO_2 at Topaz Station in 2007, on days during the cruise ship season with and without cruise ships, and during the off season

Table 17. Hourly SO_2 concentrations ($\mu g/m^3$) measured at Topaz in 2007

Percentile Values ($\mu g/m^3$)						Max	Min	Mean	Std. Dev.	Missing Values
5	25	50	75	98	99	$\mu g/m^3$	$\mu g/m^3$	$\mu g/m^3$	$\mu g/m^3$	(% total hours)
Cruise										
0	0	0	3	21	36	88	0	3	67	20
No-Cruise										
0	0	0	3	5	8	16	0	1	2	21
Off Season										
0	0	0	3	8	11	24	0	2	2	4

The highest hourly SO_2 concentration measured at Topaz in 2006 was 88 $\mu g/m^3$. This occurred on June 2nd at 7 pm, when three ships were present. The second highest concentration was 77 $\mu g/m^3$ and occurred on August 17th at 10 pm when two ships were present. Winds were blowing onshore during both periods, from a southerly direction overall. It is therefore likely these peaks are associated with cruise ship emissions.

3.3.2 Passive Sampling: NO, NO_2, SO_2

Table 18 summarizes the range in average NO, NO_2 and SO_2 concentrations per hour of sampler exposure which were measured during all three passive sampling periods. The Ogawa samplers used measure total nitrogen oxides (NO_x) and NO_2, and NO levels are then calculated by subtracting the measured NO_2 level from the measured NO_x level. The samplers are capable of measuring NO_x, NO_2 and SO_2 concentrations as low as 1 $\mu g/m^3$ when exposed for 168 hours or more. Samplers were exposed for 336 hours for this study. The passive samplers used are not suitable for measuring short-term fluctuations in pollutants under normal outdoor conditions, such as might occur over several hours. Measured concentrations are therefore considered to indicate long-term averages. Due to logistics, the samplers used to monitor days with cruise ships present were exposed for many hours in which no cruise ships were present (approximately 70% of total exposure time). This would reduce the overall impact of short-term high levels of cruise ship related emissions on measured levels.

Table 18. Range of measured NO, NO_2 and SO_2 concentrations during all sampling periods

Pollutant	Range (µg/m^3)	Accuracy Estimation
NO	3 – 52	+/- 10-15%
NO_2	4 – 24	+/- 10-15%
SO_2	1 – 5	+/- 50%

Concentrations measured by field blanks deployed within each sampling period were subtracted from the results at each sample site in that round (i.e. the values displayed in all tables and maps are blank adjusted). Based on duplicate samples made as part of the field monitoring, the precision of NO, NO_2 and SO_2 results were estimated to be +/- 10%, 10% and 50%, respectively. The large range for SO_2 is attributed to the generally low levels of SO_2 measured, often at or near the detection limit of the Ogawa samplers. See Appendix A for further technical information about Ogawa samplers, including field blanks and duplicate samplers.

Sample Period A

This sampling period explored concentrations at and away from roadways at five locations in the James Bay neighbourhood. Distinctive gradients of higher concentrations at curbside to lower concentrations away from roads were not observed for all pollutants at all sampling locations. Concentrations during this sample period ranged from 9 – 52 µg/m^3 for NO, 4 – 18 µg/m^3 for NO_2, and 0 – 2 µg/m^3 for SO_2. Samplers were exposed for 336 consecutive hours, which included hours of both cruise (13%) and non-cruise (87%) activity. The average temperature during this time period was 15°C, with a total of 1.02 mm precipitation. Strongest winds experienced were predominately from the south-west quadrant, and lighter winds from all directions with the exception of the north-west (Figure 22).

Samplers A-01 to A-03, which experienced the highest concentration levels of NO and NO_2, were also at the only location that displayed an actual gradient from higher to lower concentrations with greater distance away from the road (Figure 23). It is also the only site where samplers away from roads were not placed along perpendicular side-roads to the road of interest, but rather onto residential property. The fact that samplers at

other sites were placed along less busy side roads to the main road of interest may have confounded the results by having additional side road traffic emissions contribute to the samples. Samplers A-01 to A-03 are along a street with high volumes of car and bus traffic. The high concentration level recorded here is not likely associated with cruise ship-related traffic however, as this location is not along the designated route for buses serving the cruise ships.

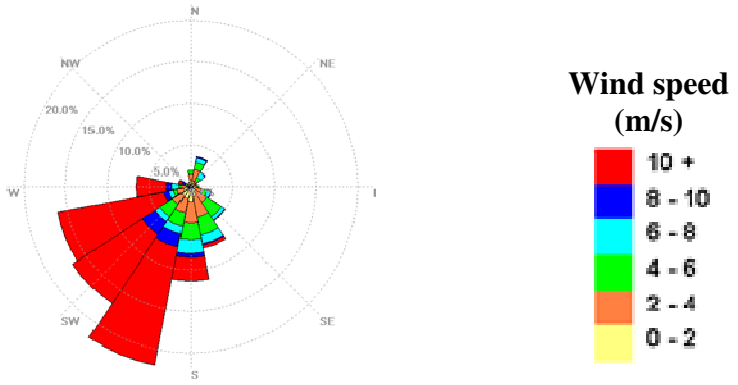
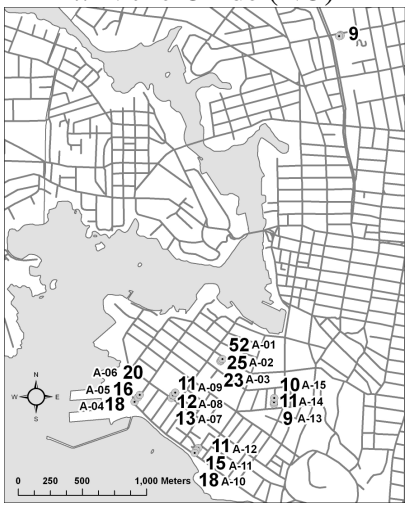


Figure 22. Wind rose for Sample Period A (NO, NO_2 and SO_2)

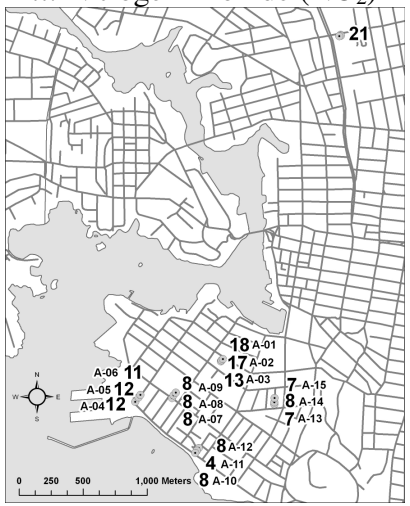
Figure 23. Sample Period A measuring concentration gradient away from roads (14-day consecutive exposure)

i. Nitric Oxide (NO)



Site	14-day average hourly NO (µg/m^3)	
	Actual	± 15%
A-01	52	44 – 60
A-02	25	21 – 29
A-03	23	20 – 26
A-04	18	15 – 21
A-05	16	14 – 18
A-06	20	17 – 23
A-07	13	11 – 15
A-08	12	10 – 14
A-09	11	9 – 13
A-10	18	15 – 21
A-11	15	13 – 17
A-12	11	9 – 13
A-13	9	8 – 10
A-14	11	9 – 13
A-15	10	8 – 12
Reference – Topaz Station**	9	

ii. Nitrogen Dioxide (NO_2)



Site	14-day average hourly NO_2 (µg/m^3)	
	Actual	± 15%
A-01	18	15 – 21
A-02	17	14 – 20
A-03	13	11 – 15
A-04	12	10 – 14
A-05	12	10 – 14
A-06	11	9 – 13
A-07	8	7 – 9
A-08	8	7 – 9
A-09	8	7 – 9
A-10	8	7 – 9
A-11	4	3 – 5
A-12	8	7 – 9
A-13	7	6 – 8
A-14	8	7 – 9
A-15	7	6 – 8
Reference – Topaz Station**	21	

iii. Sulphur Dioxide (SO_2)

Site	14-day average hourly SO_2 (µg/m^3)	
	Actual	± 50%
A-01	2	1 - 3
A-02	1	0 – 2
A-03	2	1 – 3
A-04	0	--
A-05	2	1 - 3
A-06	2	1 – 3
A-07	1	0 – 2
A-08	1	0 – 2
A-09	2	1 – 3
A-10	1	0 – 2
A-11	1	0 – 2
A-12	0	--
A-13	1	0 – 2
A-14	1	0 – 2
A-15	1	0 – 2
Reference – Topaz Station**	5	

Sample Period B

During this sampling period, wind speed and wind direction were similar for both cruise and non-cruise sampling sets (Figure 24). Samplers were exposed for 336 non-consecutive hours. The non-cruise sample set comprised of 95% hours with no cruise ships, and the cruise sample set 71% no-cruise ship hours. Concentrations of NO and NO_2 were found to be higher at 8 of 11 sample sites on cruise ship days (Figure 25). The average temperature during this time period was 15.7°C, with a total of 10.15 mm rain during non-cruise day sampling, and 15.49 mm rain during cruise-day sampling.

Results of the second sampling period are displayed in Figure 24 and Table 19. During this sampling period, concentrations on non-cruise ship days ranged from 3 – 13 $\mu g/m^3$ for NO, 7 – 13 $\mu g/m^3$ for NO_2, and 0 – 18 $\mu g/m^3$ for SO_2. Alternatively, concentrations on cruise ship days ranged from 5 – 31 $\mu g/m^3$ for NO, 5 – 17 $\mu g/m^3$ for NO_2, and 0 – 23 $\mu g/m^3$ for SO_2.

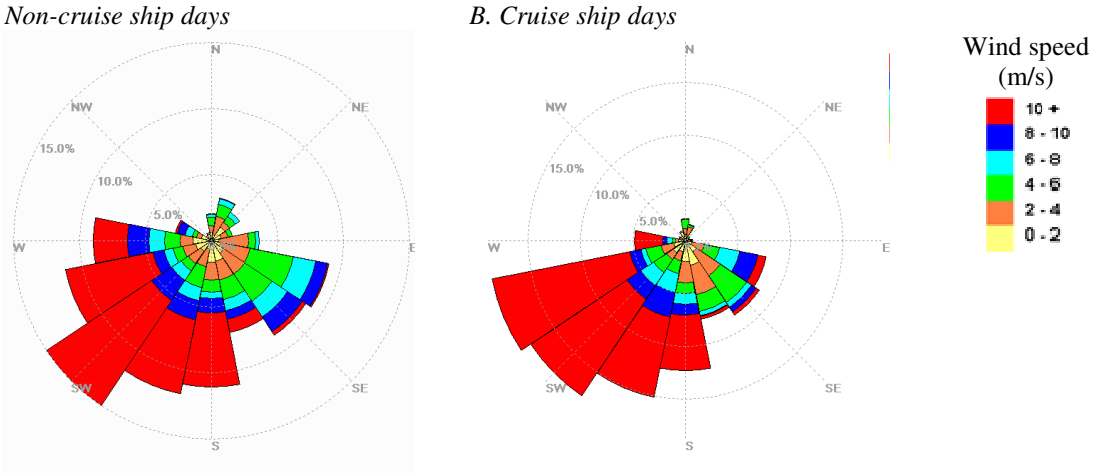


Figure 24. Wind roses for Sample Period B (NO, NO_2 and SO_2)

Figure 25. Sample Period B: June 15 to July 28, 2007 (non-consecutive exposure)

Days with no cruise ships ***Days with cruise ships***

i. Nitric Oxide (NO)

ii. Nitrogen Dioxide (NO_2)

iii. Sulphur Dioxide (SO_2)

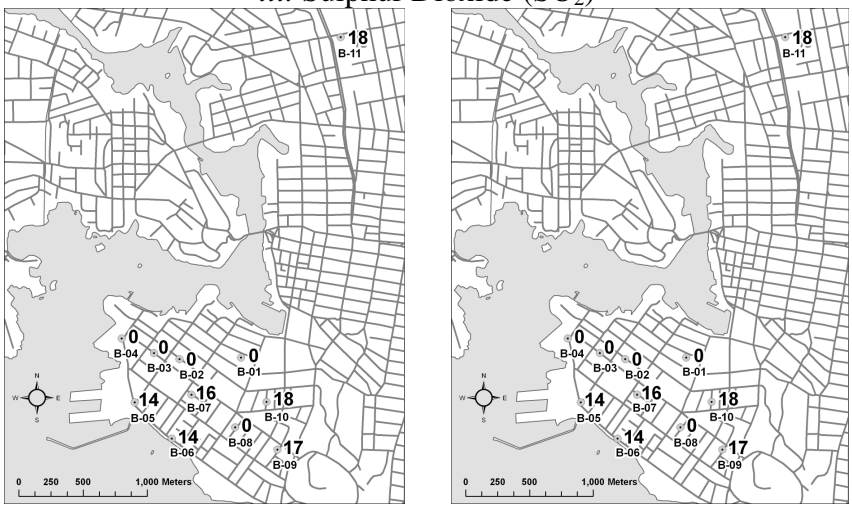


Table 19. Sample Period B: 14-day average hourly concentrations ($\mu g/m^3$)

i. Nitric Oxide (NO)

Site	Days with no cruise ships		Days with cruise ships	
	Actual	+/- 10 %	Actual	+/- 10 %
B-01	8	7 – 9	9	8 – 10
B-02	9	8 – 10	8	7 – 9
B-03	10	9 – 11	15	14 – 17
B-04	8	7 – 9	16	14 – 18
B-05	13	12 – 14	31	28 – 34
B-06	7	6 – 7	15	14 – 17
B-07	3	3	13	12 – 14
B-08	9	8– 10	12	11 – 13
B-09	3	3	5	5 – 6
B-10	3	3	11	10 – 12
B-11	7	6 - 8	8	7 – 9
Reference – Topaz Station**				
	9		7	

ii. Nitrogen Dioxide (NO_2)

Site	Days with no cruise ships		Days with cruise ships	
	Actual	+/- 10 %	Actual	+/- 10 %
B-01	8	7 – 9	12	11 – 13
B-02	10	9 – 11	14	13 – 15
B-03	8	7 – 9	13	12 – 14
B-04	9	8 – 10	12	11 – 13
B-05	11	10 – 12	17	15 – 19
B-06	9	8 – 10	12	11 – 13
B-07	8	7 – 9	12	11 – 13
B-08	7	6 – 8	5	5 – 6
B-09	10	9 – 11	12	11 – 13
B-10	8	7 – 9	10	9 – 11
B-11	13	12 – 14	12	11 – 13
Reference – Topaz Station**				
	20		20	

iii. Sulphur Dioxide (SO_2)

Site	Days with no cruise ships		Days with cruise ships	
	Actual	+/- 50 %	Actual	+/- 50 %
B-01	0	--	17	9 – 26
B-02	0	--	23	12 – 35
B-03	0	--	13	7 – 20
B-04	0	--	1	1 – 2
B-05	14	7 – 21	4	2 – 6
B-06	14	7 – 21	19	10 – 29
B-07	16	8 – 24	1	1 – 2
B-08	0	--	17	89 – 26
B-09	17	9 – 26	0	--
B-10	18	9 – 27	0	--
B-11	18	9 – 27	18	9 – 27
Reference – Topaz Station**				
	1		2	

Sample Period C

Wind speed and direction experienced on cruise and non-cruise days were not as similar as in Sample Period B; the wind rose for the days with cruise ships shows a higher percentage of winds of >10 m/s (approximately 30% from south and west directions) compared to the wind rose for days without cruise ships (approximately 15% coming from south and west directions) (Figure 26). Wind speeds during this sampling period were also lower than the previous. The average temperature during sample Period C was 16.1°C, with 6.35 mm of precipitation on non-cruise days and 9.92 mm on cruise days. Results of the third sampling period are displayed in Figure 27 and Table 20.

Concentrations on non-cruise ship days ranged from 15 – 36 µg/m^3 for NO, 16 – 23 µg/m^3 for NO_2, and 1 µg/m^3 at all sites for SO_2. On cruise days, concentrations ranged from 11 – 45 µg/m^3 for NO, 14 – 24 µg/m^3 for NO_2, and 1 – 5 µg/m^3 for SO_2. Maximum concentrations of NO_2 and NO in this sample period were 6 to 14 µg/m^3 higher respectively than in Sample Period B, but were similar at each site regardless of the presence or absence of cruise ships. Samplers were also exposed for 336 non-consecutive hours, with the non-cruise sample set comprised of 95% hours with no cruise ships and the cruise sample set with 69%.

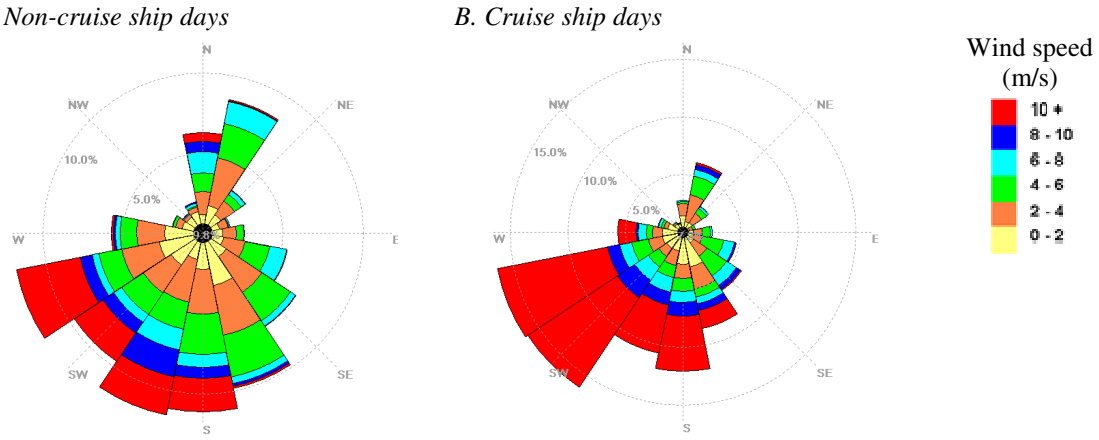
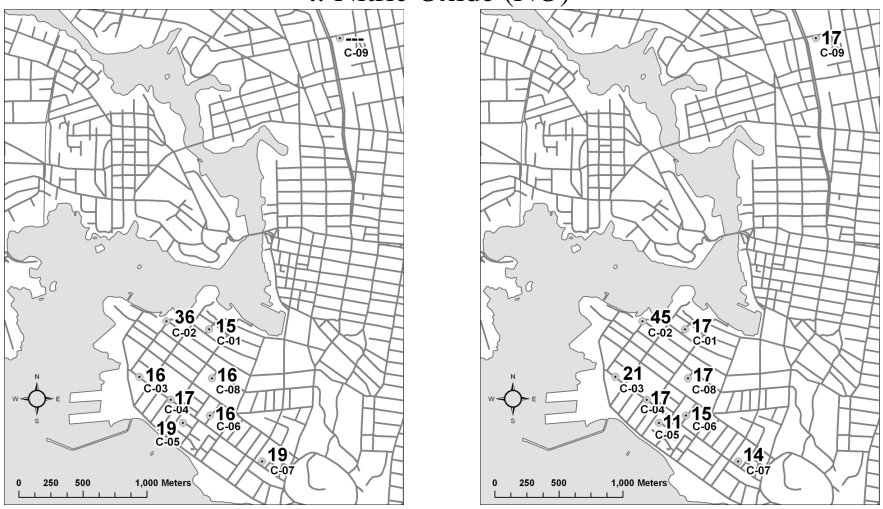


Figure 26. Wind roses for Sample Period C (NO, NO_2 and SO_2)

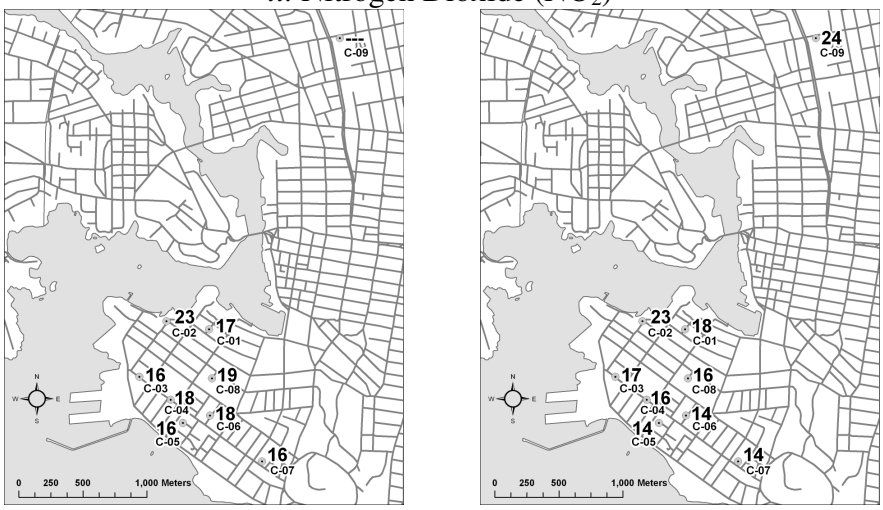
Figure 27. Sample Period C: August 17 to September 23, 2007 (non-consecutive exposure)

Days with no cruise ships ***Days with cruise ships***

i. Nitric Oxide (NO)



ii. Nitrogen Dioxide (NO_2)



iii. Sulphur Dioxide (SO_2)

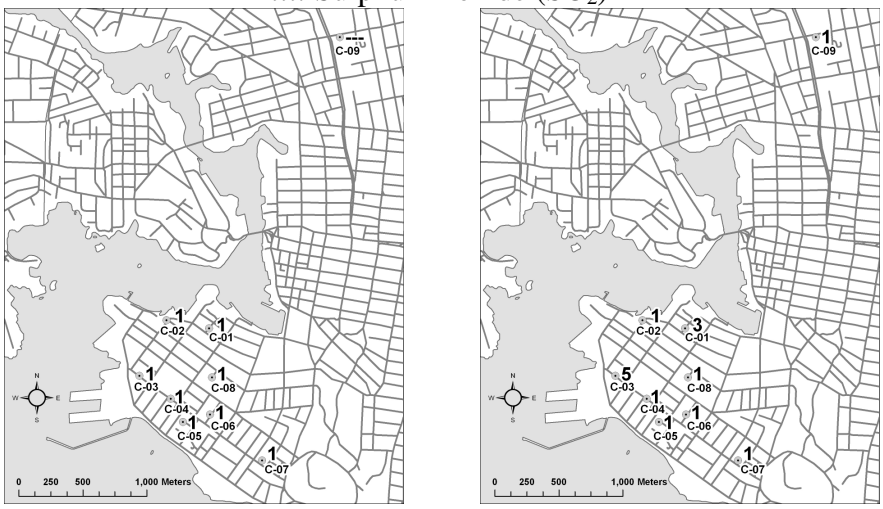


Table 20. Sample Period C: 14-day average hourly concentrations ($\mu g/m^3$)

i. Nitric Oxide (NO)

Site	Days with no cruise ships		Days with cruise ships	
	Actual	+/- 10 %	Actual	+/- 10 %
C-01	15	14 – 17	17	15 – 19
C-02	36	32 – 40	45	41 – 50
C-03	16	14 – 18	21	19 – 23
C-04	17	15 – 19	17	15 – 19
C-05	19	17 – 21	11	10 – 12
C-06	16	14 – 18	15	14 – 17
C-07	19	17 – 21	14	13 – 15
C-08	16	14 – 18	17	15 – 19
C-09	--		17	15 – 19
Reference – Topaz Station**	not available		not available	

ii. Nitrogen Dioxide (NO_2)

Site	Days with no cruise ships		Days with cruise ships	
	Actual	+/- 10 %	Actual	+/- 10 %
C-01	17	15 – 19	18	16 – 20
C-02	23	21 – 25	23	21 – 25
C-03	16	14 – 18	17	15 – 19
C-04	18	16 – 20	16	14 – 18
C-05	16	14 – 18	14	13 – 15
C-06	18	16 – 20	14	13 – 15
C-07	16	14 – 18	14	13 – 15
C-08	19	17 – 21	16	14 – 18
C-09	--		24	22 – 26
Reference – Topaz Station**	not available		not available	

iii. Sulphur Dioxide (SO_2)

Site	Days with no cruise ships		Days with cruise ships	
	Actual	+/- 50 %	Actual	+/- 50 %
C-01	1	1 - 2	3	2 – 5
C-02	1	1 – 2	1	1 – 2
C-03	1	1 – 2	5	3 – 8
C-04	1	1 – 2	1	1 – 2
C-05	1	1 – 2	1	1 – 2
C-06	1	1 – 2	1	1 – 2
C-07	1	1 – 2	1	1 – 2
C-08	1	1 – 2	2	1 – 3
C-09	--		1	1 – 2
Reference – Topaz Station**	not available		not available	

3.3.3 Particulate Matter: Mass and Composition

$PM_{2.5}$ Mass

Table 21 and Table 22 provide summaries of 24-hour $PM_{2.5}$ concentrations measured at sample sites D-1 to D-3, and E-1 to E-3. These tables also include measured concentrations from the Ministry of Environment continuous monitoring locations at Royal Roads University or Topaz Avenue for the same time period, if available. 24-hour concentrations in James Bay ranged from 1 - 7 µg/m^3, with highest concentration levels measured on days when cruise ships were present in the study area. In the June/July sampling period, the highest average 24-hour concentration of 4 µg/m^3 was observed at sites D-1, D-2 and D-3 on June 28 – 29 and June 30 – July 1. In the July/August sampling period, the three highest average 24-hour concentration levels measured on August 4 – 5 were 7, 5 and 5 µg/m^3 at sites E-2, E-1, and E-3 respectively. Further information on nephelometer sampling dates and duration are provided in Appendix B.

Table 21. 24-hour average $PM_{2.5}$ levels measured with nephelometer at sites D-1, D-2 and D-3 from June 25th to July 4th

Date	$PM_{2.5}$ (µg/m^3)					Notes
	Site D-1	Site D-2	Site D-3	Topaz	RRU	
June 25th – 26th	--	2	2	2	1	Non-cruise ship day
June 26th – 27th	--	2	2	5	5	Non-cruise ship day
June 27th – 28th	--	2	2	3	4	Non-cruise ship day
June 28th – 29th	3	4	4	5	5	Cruise ship day
June 29th – 30th	2	2	2	3	2	Cruise ship day
June 30th – July 1st	4		4	4	5	Cruise ship day
July 1st – 2nd	2	--	--	3	3	Non-cruise ship day
July 2nd – 3rd	2	--	--	4	3	Non-cruise ship day
July 3rd – 4th	2	--	--	4	3	Non-cruise ship day

Table 22. 24-hour average $PM_{2.5}$ levels measured with nephelometer at sites E-1, E-2 and E-3 from July 30th to August 5th

Date	$PM_{2.5}$ ($\mu g/m^3$)					Notes
	Site E-1	Site E-2	Site E-3	Topaz	RRU	
July 30th – 31st	3	3	3	5		Non-cruise ship day
July 31st – Aug. 1st	3	4	4	6	no data	Non-cruise ship day
August 1st – 2nd	3	3	3	7		Non-cruise ship day
August 2nd – 3rd	1	1	2	3		Cruise ship day
August 3rd – 4th	3	3	3	4	no data	Cruise ship day
August 4th – 5th	5	7	5	7		Cruise ship day

Figure 28 and Figure 29 display shorter-term $PM_{2.5}$ concentration levels (15-minute averages smoothed to approximate a moving 1-hour average) and traffic counts. Traffic volumes on roads adjacent to sampling sites did not appear to affect the short-term $PM_{2.5}$ levels at all locations. Although traffic volumes vary among sample sites, the pattern and levels of $PM_{2.5}$ remained similar. This suggests traffic emissions very near the monitors had less influence than area wide sources, in general. For example, $PM_{2.5}$ from traffic on a busy road may influence $PM_{2.5}$ on nearby, less busy roads. Short-term $PM_{2.5}$ (moving 1-hour average) ranged from near 0 to 14 $\mu g/m^3$.

Very short term $PM_{2.5}$ levels (5-minute averages) strongly showed events associated with cruise ship activity (see Figure 30 and Figure 31). In the first example, a peak in $PM_{2.5}$ levels at all three sampling sites is associated with the departure of three cruise ships from the Ogden Point terminal, and levels remained elevated for some time after departure. The maximum 5-minute averaged reached was 15 $\mu g/m^3$. In the second example, peaks in 5-minute average concentration levels are observed at all three sampling sites on both cruise ship arrivals and on departures. The arrival peaks are lower, reaching approximately 10 $\mu g/m^3$ at one site, while the departure peaks are higher, reaching approximately 17 $\mu g/m^3$ at one site.

Figure 28. Smoothed 15-minute average $PM_{2.5}$ and traffic volume on June 28th – July 4th at site D-1, and June 25th – July 1st at sites D-2 and D-3

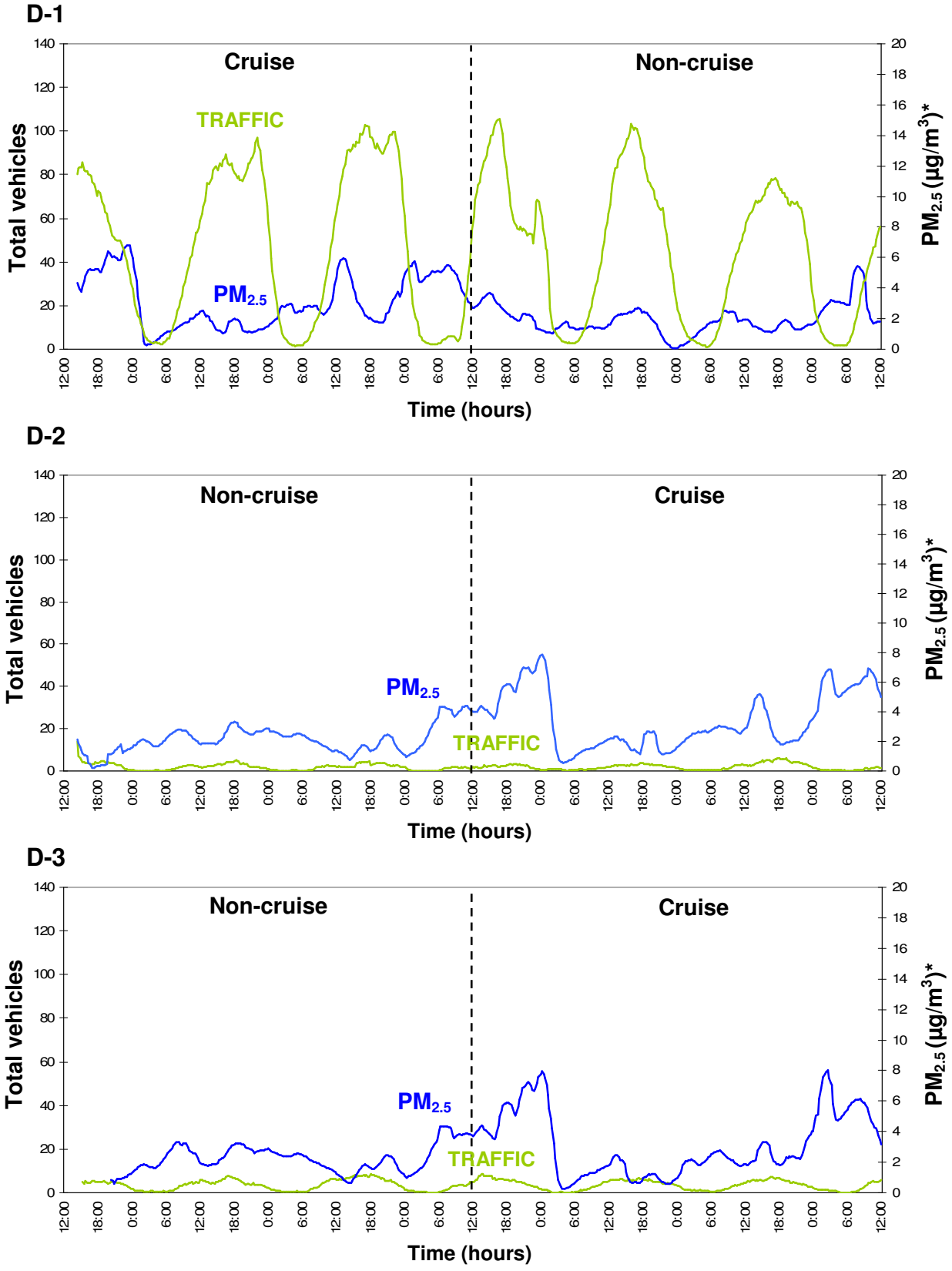


Figure 29. Smoothed 15-minute average $PM_{2.5}$ and traffic volume on July 30th – August 5th at sites E-1, E-2 and E-3

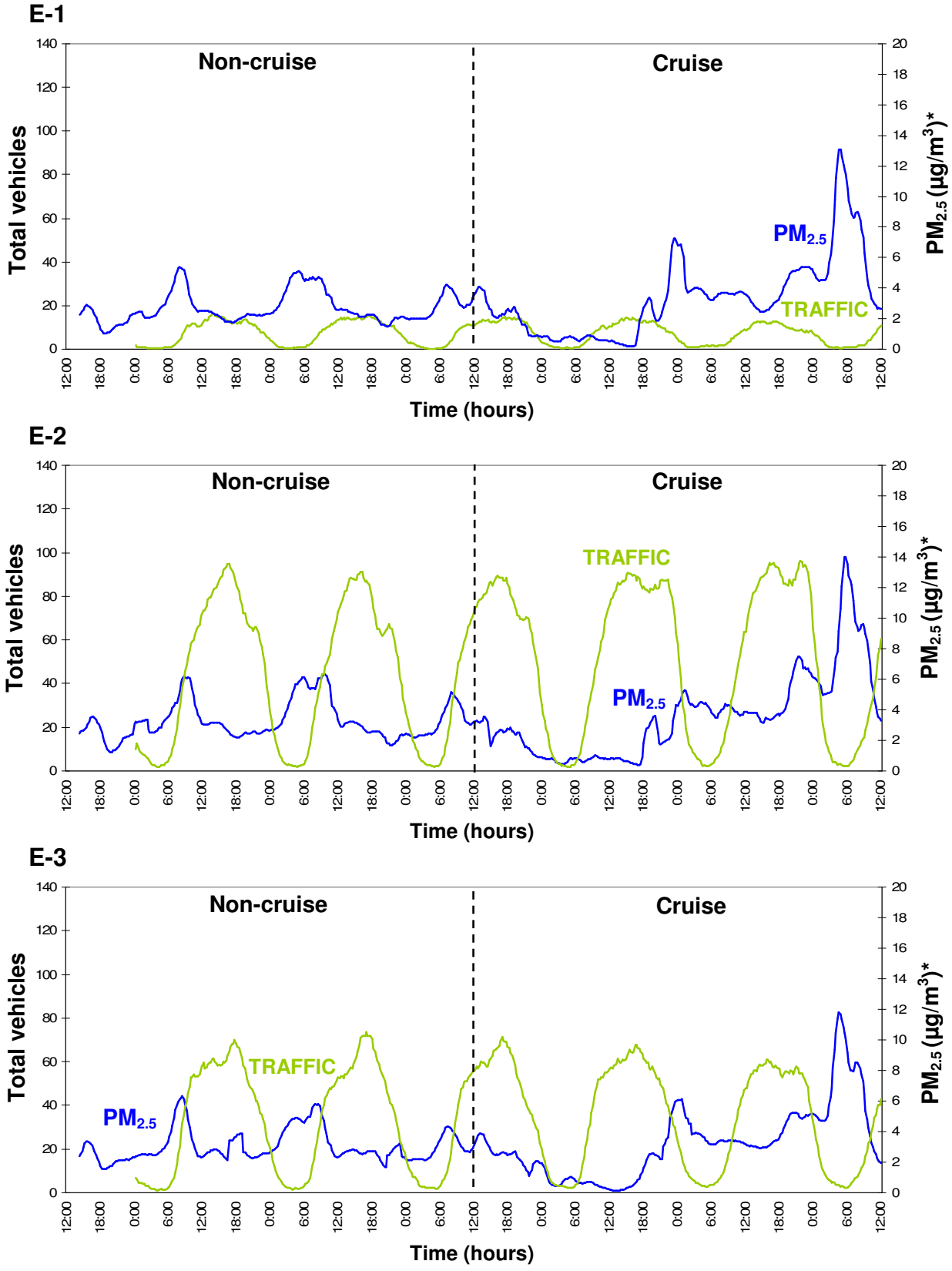


Figure 30. $PM_{2.5}$ event associated with cruise ship departures on June 30th to July 1st, 2007 at Sites D-1, D-2 and D-3

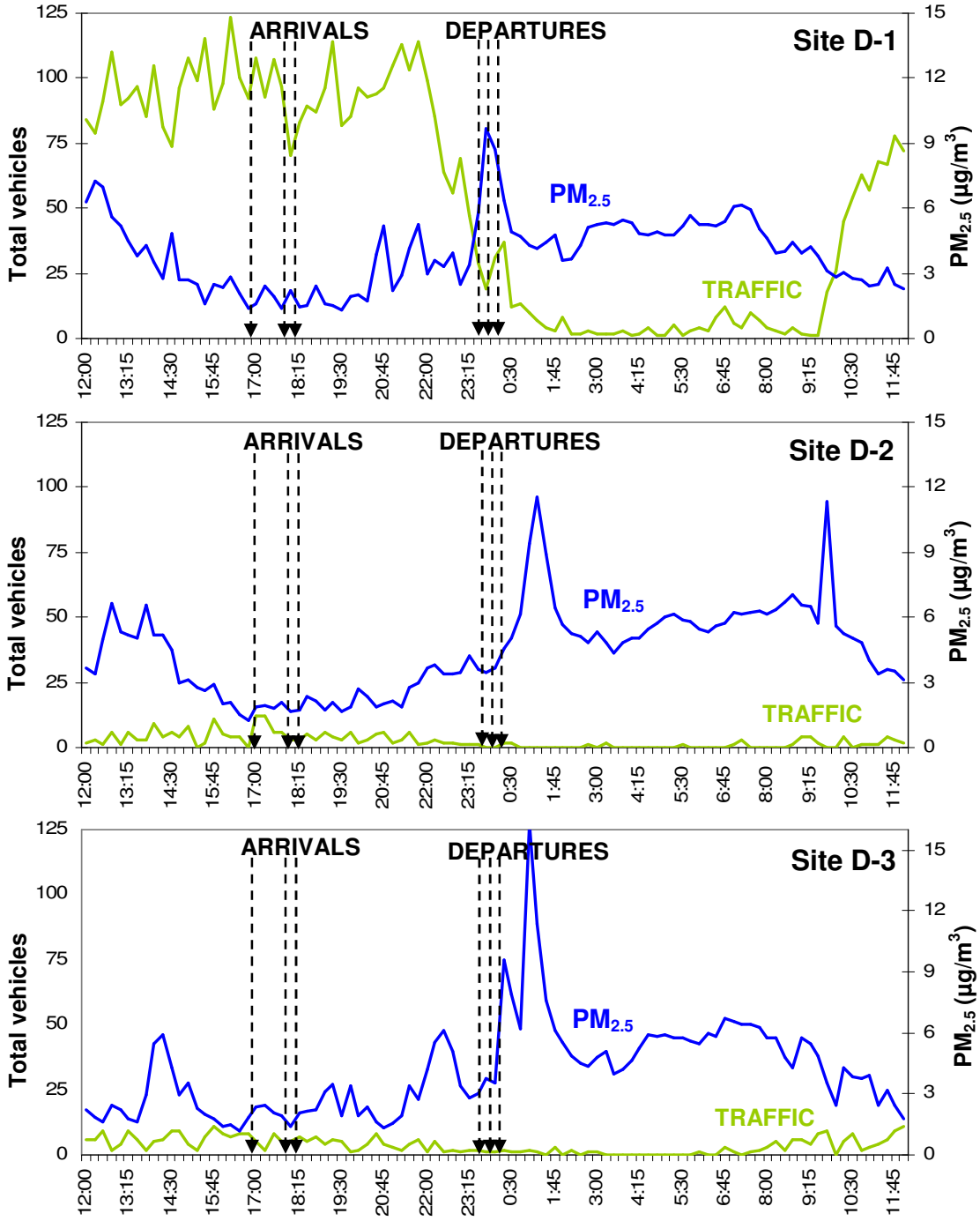
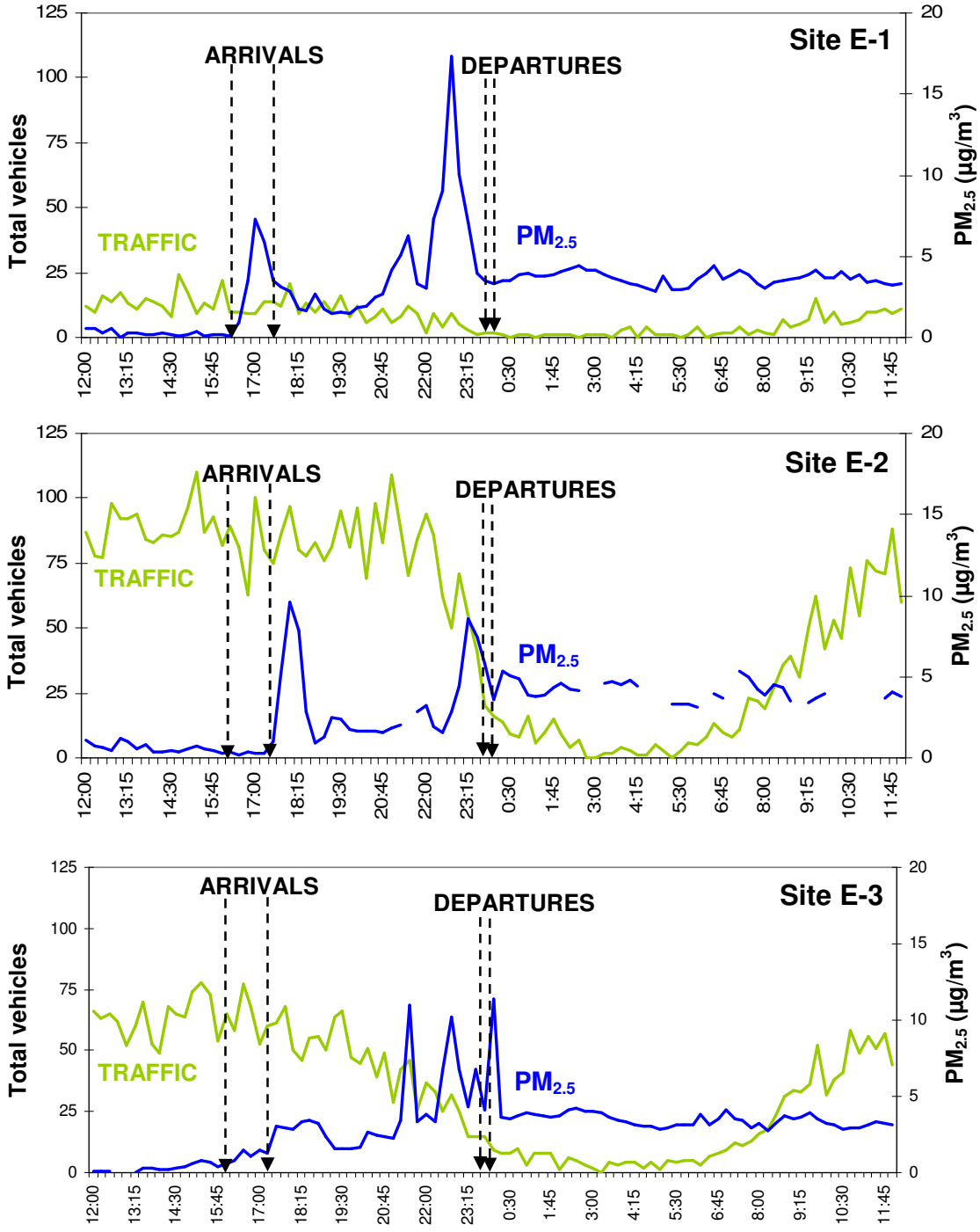


Figure 31. $PM_{2.5}$ event associated with cruise ship departures on August 3rd and 4th at Sites E-1, E-2 and E-3



$PM_{2.5}$ Composition (Metals and Absorbance)

Sampling periods for $PM_{2.5}$ composition are provided in Table 23 and can be cross-referenced to Figure 16 for locations within the study area. Nickel (Ni) and Vanadium (V) were detected on all sample filters (Table 24). At all 9 sites, V was always higher on days with cruise ships in port. Ni was higher on days with ships in port in comparison to days without, with the exception of sites F-1 to F-3.

Previous studies examining the relationship between vanadium and nickel report high V/Ni ratios (>1-1.5) to be indicative of ship emissions and the use of bunker fuel (Krudysz et al., 2008). Ratios of V/Ni observed in this study range from 1.9 to 2.7 on cruise ship days and 1.4 to 2.7 on no-cruise days. These high ratios indicate that emissions from large ocean-going vessels contributed to $PM_{2.5}$ levels measured in the study area, during periods when cruise ships are both present and absent.

Table 23. $PM_{2.5}$ composition sampling dates

Sampling dates	Days with cruise ships	Days without cruise ships
D-1	July 1st – July 4th	June 28th – July 1st
D-2	June 25th – 28th	June 28th – July 1st
D-3	June 25th – 28th	June 28th – July 1st
E-1	July 30th – Aug 2nd	Aug 2nd – Aug 5th
E-2	July 30th – Aug 2nd	Aug 2nd – Aug 5th
E-3	July 30th – Aug 2nd	Aug 2nd – Aug 5th
F-1	September 18th – Sept 20th	Sept 21st – Sept 23rd
F-2	September 18th – Sept 20th	Sept 21st – Sept 23rd
F-3	September 18th – Sept 20th	Sept 21st – Sept 23rd

The filters used for metal analysis and absorbance were exposed for two- or three-day periods, which for samplers on cruise days would include substantial amounts of time when no cruise ships were present. This would tend to diminish the chances of seeing differences between filters used on days with cruise ships present and those used on days with no cruise ships in port. A difference in levels between cruise and non-cruise samples is most obviously seen in the July/August sampling period. During this period,

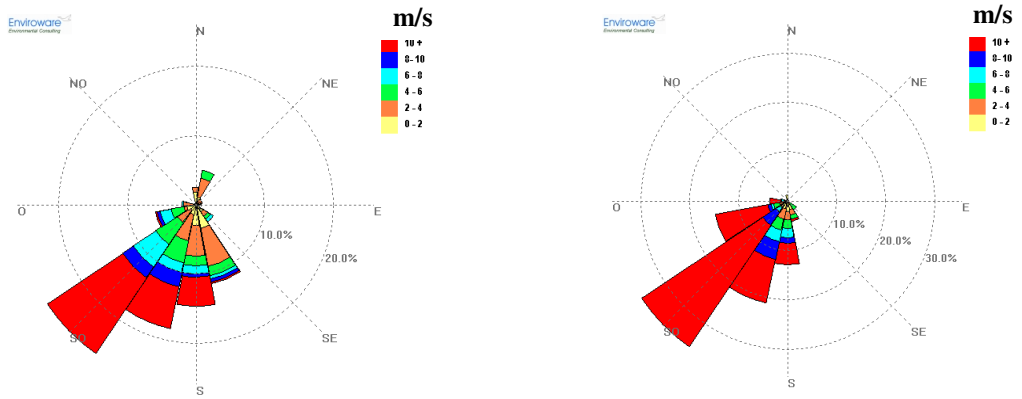
wind speed and direction (Figure 32) were similar during both periods, with sampling sites immediately downwind of the Ogden Point terminal, which provided good conditions for detecting the influence of cruise ship emissions.

Table 24. $PM_{2.5}$ composition (partisol filters) sampling results

Site	Days with cruise ships					Days without cruise ships				
	V µg/m^3	Ni µg/m^3	V/Ni Ratio	Abs. coeff.	Mass µg/m^3	V µg/m^3	Ni µg/m^3	V/Ni Ratio	Abs. coeff.	Mass µg/m^3
D-1	0.01	0.005	2.1	4	5	0.004	0.002	2.2	4	4
D-2	0.01	0.004	2.2	4	5	0.004	0.002	2.3	4	4
D-3	0.01	0.005	2.7	4	6	0.005	0.003	2.0	4	5

Site	Days with cruise ships					Days without cruise ships				
	V µg/m^3	Ni µg/m^3	V/Ni Ratio	Abs. coeff.	Mass µg/m^3	V µg/m^3	Ni µg/m^3	V/Ni Ratio	Abs. coeff.	Mass µg/m^3
E-1	0.02	0.009	2.6	4	5	0.006	0.002	2.5	4	5
E-2	0.02	0.009	2.5	4	5	0.006	0.002	2.5	4	5
E-3	0.04	0.02	2.3	4	7	0.006	0.002	2.7	4	6

Site	Days with cruise ships					Days without cruise ships				
	V µg/m^3	Ni µg/m^3	V/Ni Ratio	Abs. coeff.	Mass µg/m^3	V µg/m^3	Ni µg/m^3	V/Ni Ratio	Abs. coeff.	Mass µg/m^3
F-1	0.005	0.002	2.2	6	6	0.004	0.002	1.4	6	6
F-2	0.005	0.002	1.9	6	6	0.003	0.002	1.9	7	5
F-3	0.005	0.002	2.7	6	5	0.004	0.002	2.1	6	5

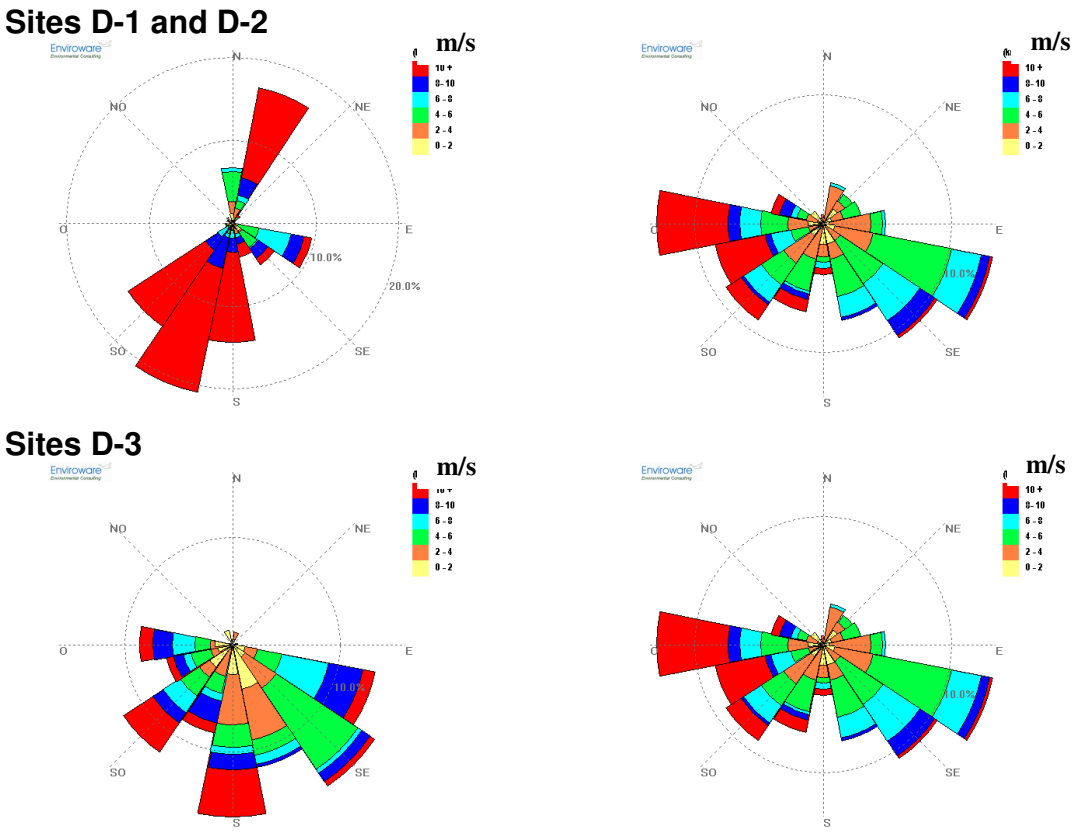


A. Non-cruise ship days *B. Cruise ship days*

Figure 32. Wind roses for July/August sampling period at sites E-1, E-2 and E-3

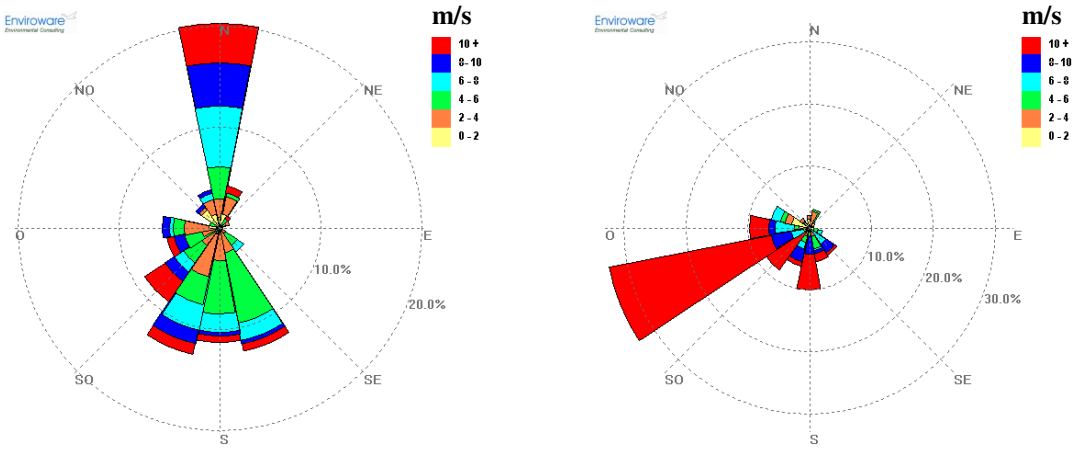
Conditions in the other two sampling periods (June/July and August/September) were not as favorable for capturing cruise ship-related emissions, with wind speeds being lighter and wind direction not coming predominately from the Ogden Point terminal with respect to the sampling sites. Figure 33 displays wind speed and wind direction data for the June/July sampling period, and Figure 34 for August/September.

Absorbance levels of $PM_{2.5}$ suggested diesel emissions were similar during cruise ship and no-cruise ship periods and slightly higher at one location (F-2) on days with no cruise ships (weekdays) in one sampling period. This suggests that weekday traffic, which might include more frequent buses, may be an important source of diesel emissions in the study area. Sources other than cruise ships and their related traffic may potentially have equal or greater influence on $PM_{2.5}$ composition depending on meteorological conditions.



A. Non-cruise ship days *B. Cruise ship days*

Figure 33. Wind roses for June/July sampling period at sites D-1, D-2 and D-3



A. Non-cruise ship days *B. Cruise ship days*

Figure 34. Wind roses for August/September sampling period at sites F-1, F-2 and F-3

See Appendix C for further information on partisol sampling and metals analysis, including limit of detection and field blank analysis.

3.3.4 Summary of Results

A main goal of the field monitoring conducted in the James Bay study area during the 2007 season was to collect baseline data of average concentration levels throughout the neighbourhood. This was accomplished at a variety of monitoring locations. Although attempts were made to distinguish concentrations between cruise and no-cruise ship days, variable meteorological conditions and sampling logistics lowered chances of successfully capturing a difference. Data from Topaz Station were also examined as another method for examining relative concentrations between periods with cruise ships present or absent, but also between this location and the James Bay community.

Average concentration levels at Topaz and James Bay are compared in Table 25, including minimum and maximum concentrations for reference. In general, average concentration levels appear to be consistent between the two areas (the average at Topaz falls within the range of averages measured in James Bay). Data from the Topaz Station show that average concentration levels of NO and $PM_{2.5}$ are similar between cruise, no-cruise and the off season, but this is not observed for SO_2 or NO_2. Average concentrations of NO_2 and SO_2 are 1 to 2 $\mu g/m^3$ higher during the off season and cruise season, respectively. Averages for James Bay are provided as a range from the results of

Sample Period B and C, and correspond well to those measured at Topaz. Note that SO_2 measurements from James Bay appear to be higher on average, yet there are questions regarding the accuracy of the measurements (± 50%).

There was an indication that concentrations of NO and NO_2 were higher on days with cruise ships in port during one sampling period, while during the other period wind directions were not as favourable and differences were not seen. Notably, cruise ships were present only for approximately 30% of the total exposure time for the samplers used on days with cruise ships, so differences would be minimized. The highest average levels of NO and NO_2 were found on high traffic streets. While there are no short-term or long-term air quality guidelines or standards for ambient NO, measured levels of NO_2 were found to be roughly 25 to 30 percent of the current ambient air quality standard (annual hourly maximum desirable is 60 $\mu g/m^3$; the maximum acceptable is 100 $\mu g/m^3$).

The 24-hour average levels of $PM_{2.5}$ are below the Canada Wide Standard for $PM_{2.5}$ (maximum 24-hour average of 7 $\mu g/m^3$ vs. 30 $\mu g/m^3$ standard), and there is no indication that 24-hour average levels are consistently higher on days with cruise ships present in the study area. The influence of cruise ship-related activity, however, could be seen in 5-minute average $PM_{2.5}$ levels. Levels and ratios of vanadium and nickel present in the $PM_{2.5}$ mass samples indicate that ship-related emissions contribute to levels in the area. Levels of absorbance in one week-day sampling period indicated that diesel emissions were higher on days with no cruise ships, highlighting that diesel buses may be an important source of diesel emissions in the region.

Table 25. Summary of concentrations ($\mu g/m^3$) of NO, NO_2, SO_2 and $PM_{2.5}$ (mass) measured at the Topaz Station and in the James Bay Community

		Topaz Station					James Bay
Nitric Oxide (NO)							
		Min	Max	Avg			Avg
Regulatory	Cruise	0	217	11	Ogawa	Cruise	5 to 45
	No-Cruise	0	302	11		No-Cruise	3 to 36
	Off Season	0	296	11			
Nitrogen Dioxide (NO_2)							
		Min	Max	Avg			Avg
Regulatory	Cruise	0	77	21	Ogawa	Cruise	5 to 24
	No-Cruise	1	73	20		No-Cruise	7 to 23
	Off Season	1	79	23			
Sulphur Dioxide (SO_2)							
		Min	Max	Avg			Avg
Regulatory	Cruise	0	88	3	Ogawa	Cruise	0 to 23
	No-Cruise	0	16	1		No-Cruise	0 to 18
	Off Season	0	24	2			
Particulate Matter ($PM_{2.5}$)							
		Min	Max	Avg			Avg
Regulatory	Cruise	0	35	5	Nephelometer	Cruise	1 to 7
	No-Cruise	0	69	5		No-Cruise	2 to 4
	Off Season	0	55	5			

3.4 Discussion

The field monitoring campaign for this study was designed to use equipment not able to continuously monitor pollutants over the entire cruise ship season. The monitoring equipment chosen, therefore, limited the examination of temporal variations of pollutants in James Bay. Although $PM_{2.5}$ mass was measured with a nephelometer capable of recording relatively short-term concentrations (5-minute averages), all other pollutants were limited to 2-3 day ($PM_{2.5}$ composition) or two-week (NO, NO_2 and SO_2) exposures. These longer time periods were confounded by the fact that they were not measured over continuous 14-day periods, but rather an accumulation of 14-days over a two-month

period. Differing meteorological conditions between sampling periods makes comparison of concentration levels difficult and therefore measured values must be considered as averages over longer periods of time.

Continuously monitoring pollutants over the entire cruise ship season would have provided very high resolution temporal data. The drawback of such an approach, however, is that the cost of such a system, even to monitor at just one location, would have exceeded the cost of the entire field monitoring campaign and air quality modeling analysis deployed in this research thesis. With little information on potential hotspots in the area, critical decisions would have to have been made about the location to place the continuous monitor, or whether the monitor should change location in the study area over time. Operating more than one continuous air quality monitor in James Bay would increase the spatial resolution, yet a lack of evidence to indicate that the air quality level is of concern in this area is a deterrent for an investment in such equipment (measurements from nearby continuous monitoring stations in the CRD, such as Topaz, may have shown an influence from cruise emissions, but do not indicate that air quality is at a level in excess of current ambient air quality objectives or standards).

The spot monitoring approach chosen for this study attempted to provide a balance between adequate spatial and temporal resolutions, by monitoring at as many different locations as possible throughout the study area, and examining long-term concentration levels over periods when cruise ships were at berth, and when they were not. Phase II of the JBAQS study, which examines more highly resolved concentration estimates (both spatially and temporally) of all pollutants from cruise ship and ferry emissions (see Chapter 4) can be used to compliment field monitoring data and provide a more complete analysis than opting for the use of continuous air quality monitors in the region. The results of the field monitoring and air quality modeling, however, may indicate regions where further investigation using such monitors may be worthwhile.

Continuously monitored data from the Topaz Station were examined in addition to the field monitoring data from directly within the study area. In general, mean levels measured at the Topaz Station corresponded well to the long-term concentrations measured in James Bay. Therefore, it may be acceptable to use data from the Topaz Station to characterize average air quality in James Bay over the long term. On a

regional basis, sources such as vehicle and marine traffic may impact James Bay, and the Topaz station only 2 kilometers away, to an equal degree. Short-term concentrations (hourly) measured at Topaz were not comparable to any measurements made in James Bay. Unlike long-term average concentrations, a greater variation in shorter-term concentration levels may exist between James Bay and the Topaz Station, depending on the activities of local emissions sources. This research showed that although local differences in traffic levels did not largely impact short-term $PM_{2.5}$ concentrations at nephelometer monitors, elevated concentrations occurred during times of cruise ship activity. This indicates that source type influences the local short-term behaviours of pollutants.

While hourly data from the Topaz Station in 2006 indicated a possible cruise ship signal associated with both NO_2 and SO_2 measurements, this same pattern was not entirely evident in the 2007 data. On days with cruise ships in port in 2006, average levels of NO_2 were almost 10 $\mu g/m^3$ higher than on days during the cruise season with no ships in port, or days during the off season (see Figure 12). In 2007, NO_2 concentrations during the evening hours are very similar for cruise and non-cruise days, and both are lower than during the off season. Measured concentrations of SO_2 do show similar trends in 2006 and 2007; the evening concentrations of SO_2 in both years show a divergence between non cruise and off season concentrations and elevated cruise day concentrations. The shape of the distribution between years varies, with 2006 concentrations of SO_2 in the afternoon/evening showing a greater unimodal peak, and 2007 concentrations for the same time period being slightly lower with a bimodal distribution. Cruise ships are one of the only large SO_2 emissions sources operating in the region, and it is likely their presence explains the elevated concentration levels evident in both the 2006 and 2007 data.

Measurements of SO_2 made at the Topaz station on June 2, 2007 can be used as an example to illustrate how cruise ship emissions may impact short-term concentration levels in the region. On this particular day, one cruise ship arrived at 17:00 and two others at 18:00, and all departed at 23:59. This day experienced the maximum measured 1-hour SO_2 concentration at the Topaz Station (88 $\mu g/m^3$), yet other hours on this day also ranked as top concentrations measured at Topaz. The hours 15:00 – 23:00 rank as 9

out of 15 hours with highest 1-hour SO_2 concentrations measured at Topaz (Figure 35). Wind direction from this period indicate that these emissions are likely from cruise ships at the Ogden Point terminal.

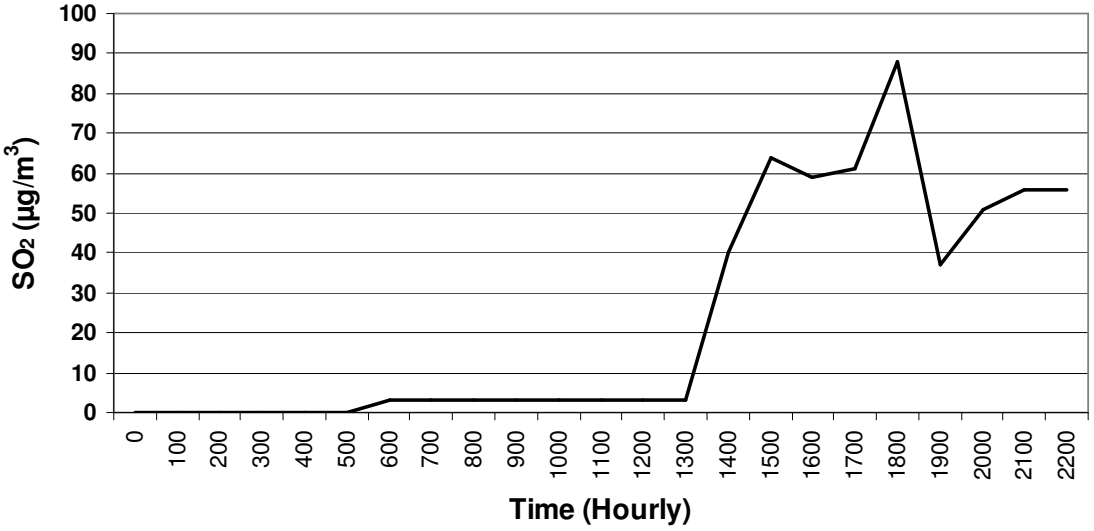


Figure 35. Hourly SO_2 concentrations measured at the Topaz Station on June 2, 2007

Mean concentration levels at the Topaz Station during 2007 are generally lower for all pollutants and time periods (cruise, no-cruise and off season) than levels in 2006. Annual variations in background concentration levels can be expected to exist in a region, based on larger regional events and meteorological conditions. Yet, the 2006 cruise ship season did receive 12% greater visits (19 more vessels) than the following 2007 year, and wind speed and direction were very similar. This difference in concentrations is greatest on days with cruise ships, followed by days during the cruise ship season without ships, and then by the off season. Additional analyses, including an examination of air quality and cruise schedules from 2005 and 2008 could be conducted to further investigate this relationship.

Data from the Topaz Station can also be used to supplement the analysis of metals in ambient air. Analyses for the presence of metals in $PM_{2.5}$ have been conducted by the BC Ministry of Environment using filters at the Topaz Station. At the Topaz Station, PM filters are deployed for 24-hours on one day out of every seven, and these filters were subsequently analyzed for metals present in the $PM_{2.5}$ fraction. In total, 47 filter samples

were collected in 2006. Of these, 11 (23 percent) were taken on days when cruise ships were in port, 16 (34 percent) on days without ships in port between May and October, and the remaining 20 (43 percent) were taken on off season days in the winter or early spring. Measurements of vanadium and nickel for this study are compared to those measured at the Topaz Station in 2006 in Table 26.

Table 26. Comparison of Vanadium and Nickel levels in James Bay and at Topaz Station

	Level in micrograms per cubic metre (µg/m^3) of air					
	Days with Cruise ships		**Days with no cruise ships**		**Off season**	
	Avg.	Max.	Avg.	Max.	Avg.	Max.
Vanadium						
Sites 1 – 9*	0.014	0.037	0.005	0.006	--	--
Topaz**	0.011	0.021	0.007	0.015	0.002	0.006
Nickel						
Sites 1 – 9*	0.006	0.016	0.002	0.003	--	--
Topaz**	0.008	0.018	0.009	0.011	0.005	0.009

* Averages based on 9 three-day samples in 2007

** Averages based on 11 one-day samples (cruise ships present), 16 one-day samples (no cruise ships present), or 20 one-day samples (off-season) in 2006

Levels of vanadium measured in James Bay for this study are consistent with measurements made at the Topaz Station. While average V concentrations measured in James Bay on cruise ship days are higher than those measured at Topaz, the opposite is true for days with no cruise ships. Nickel concentrations are also higher in James Bay on cruise days than non cruise days, but not at Topaz. Topaz Station is situated in a high traffic location which receives a lot of bus traffic, and higher nickel concentration levels on no-cruise days might indicate that an alternative source, like diesel buses, have an equal or larger influence at this location.

An additional analysis of $PM_{2.5}$ along the Pacific Coast has been conducted by researchers under contract to the California Air Resources Board (Hopke et al., 2006). In their research, V and Ni were found to be associated with residual fuel oil combustion at four sites in the vicinity of the study area (Figure 36). One site is located in Olympic National Park, and the other three in the Seattle area.

At the Olympic National Park site, average V was 0.001 µg/m^3, and average Ni was 0.0004 µg/m^3, based on 293 filter samples taken between August 2001 and May 2004. These levels can reasonably be considered to be representative of a clean, rural area. Still, it was noted that the signal for residual fuel oil combustion showed "a strong summer-high seasonal variation and weekend-high variation…suggesting the sources of the oil combustion are likely residual oil burning ships and ferries that show increased activities on the weekend in the summer" (Hopke et al. 2006). In Seattle, average levels of V ranging from 0.004 to 0.007 µg/m^3, and average levels of Ni ranging from 0.002 to 0.004 µg/m^3 were reported at three sites. No seasonal variation was observed at these sites, and the likely sources of the emissions were identified as cargo ships, tugs, commercial harbour craft, ferries, cargo-handling machines and trains associated with the Port of Seattle (Hopke et al., 2006). These three sites are located between 2 and 6 km away from the waterfront. Table 27 provides a comparison of these levels with the results from the field monitoring and levels measured at Topaz station in 2006.

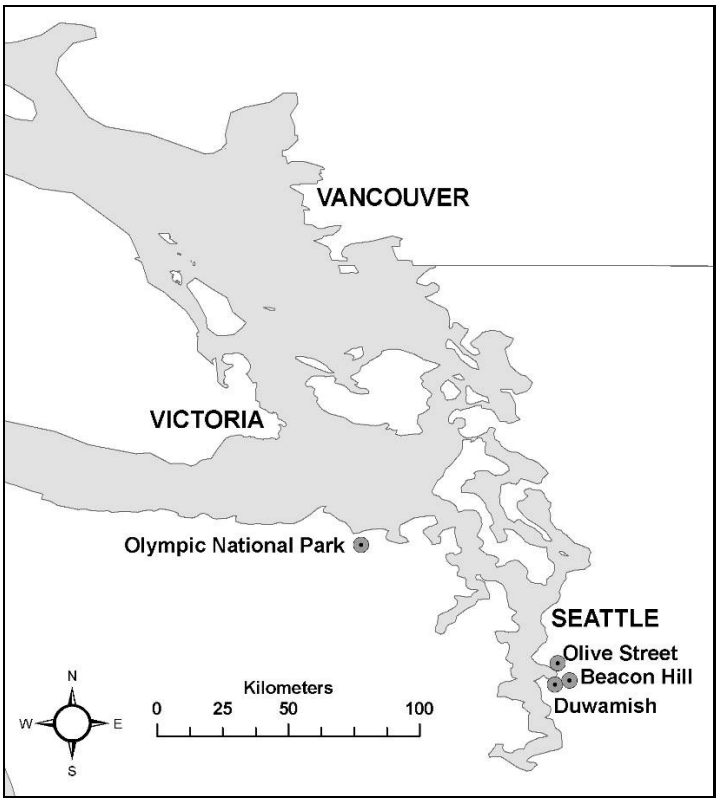


Figure 36. Locations of monitoring sites included in the Pacific Coast Study (Hopke et al., 2006)

Table 27. Comparison of vanadium and nickel levels in the study area and at sites located in Washington State

Location	Vanadium (µg/m^3)		Nickel (µg/m^3)	
	average	maximum	average	Maximum
All sites in James Bay (18 3-day samples, 2007)	0.009	0.037	0.004	0.016
Topaz (47 one-day samples, 2006)	0.006	0.021	0.006	0.018
Olympic National Park (293 one-day samples, 2001-2004)	0.001	0.006	0.0004	0.002
Olive St, Seattle WA (128 one-day samples, 2000-2005)	0.005	0.027	0.002	0.009
Beacon Hill, Seattle WA (546 one-day samples, 2000-2005)	0.004	0.047	0.002	0.032
Duwamish, Seattle WA (154 one-day samples, 2000-2005)	0.007	0.039	0.004	0.036

Levels of V and Ni measured in James Bay for this study in 2007 were consistent with levels measured at the Topaz Station in 2006 and with more distant sites in the Georgia Basin – Puget Sound area measured in 2001 to 2005. Overall, these results indicate that cruise ship emissions do contribute to $PM_{2.5}$ in the study area above background levels.

3.5 Conclusion

In this study, the influence of cruise ship emissions and related traffic on levels of NO, NO_2, SO_2 and $PM_{2.5}$ in James Bay was explored by taking measurements on days with cruise ships in port, and on days without cruise ships in port. In all cases except for $PM_{2.5}$ mass, the equipment used was capable only of providing average levels over the duration of the sampling period, which in the case of days with cruise ships in port, included many hours when cruise ships were not actually present. This means that the chances of measuring a difference due to cruise ship presence are diminished. For NO, NO_2 and SO_2, it was not feasible to exchange samplers to capture only the hours with cruise ships in port. For example, assuming cruise ships are in port three days per week for approximately six hours per day, the samplers would have to be exchanged on 56 days to

accumulate a total of 14 days exposure. For these reasons, it is important to consider the pollutant levels measured on days with cruise ships and days without cruise ships as averages over the entire sampling period, not as an indication of average levels for any shorter time periods.

Prior to the field monitoring conducted for this research, and the larger James Bay Air Quality Study, there were no actual air quality measurements of pollutant levels in James Bay. Emission sources frequenting the region emit visible pollution plumes, which viewed by community members must have some impact upon local air quality; however, a lack of measured data generated uncertainty about the issue. Although the field monitoring results presented here are limited to long-term average concentration levels, they do provide some answers to questions raised by members of the James Bay community. These results quantify long-term average concentration levels in the community, which establish the level of current air quality and can be used as a baseline for future studies. They also highlight that a cruise ship signal can be detected above background concentration levels, which may be worth further investigation, especially over shorter time periods.

Chapter 4

Air Quality Modeling

4.1 Introduction

This chapter presents results of an air quality modeling simulation to predict ambient concentration levels of nitrogen dioxide (NO_2), sulphur dioxide (SO_2), and particulate matter (PM_{10} and $PM_{2.5}$) in the James Bay community, and surrounding region, from large marine emissions sources (cruise ships and ferries). This study examines the period spanning the 2007 cruise ship season in Victoria, from April 24 to November 3 inclusive. The modeling work was conducted as part of Phase II of the James Bay Air Quality study (JBAQS). Model set-up, configuration and computation were performed primarily by Bryan McEwen from SENES Consultants Limited. Data acquisition, processing, extraction and analysis were conducted as part of this thesis research.

All air quality modeling simulations were performed using the California Puff (CALPUFF) model. This model was selected because of its ability to model both near-term and long-range transport of pollutants, as well as for modeling in complex terrain, such as the water-land interface in the James Bay study area. Unlike other models, CALPUFF accounts for land-sea circulation patterns and differences in winds and mixing heights over water versus land. This model is approved by both the US Environmental Protection Agency and the BC Ministry of Environment for use in complex terrain. The modeling system is described in detail in the next section, followed by a summary of the specific model configuration used for this research study.

Quality assurance evaluations of meteorological and emissions data inputs are described prior to analysis of final results. Model results are reported for the maximum 1-hour, maximum 24-hour, and average concentration levels of pollutants in James Bay,

and the larger modeling domain. Results are presented as a summary table in order to compare to current air quality standards and guidelines. Detailed results, consisting of maps and frequency distributions, are then provided for pollutants which were found to approach or exceed current air quality guidelines. Although this chapter focuses detailed results only for select pollutants, more detailed results for all pollutants can be found in the JBAQS Phase II Air Quality Modeling Report.

4.2 Methodology

4.2.1 CALPUFF Modeling System

The CALPUFF model (Earth Tech, Concord, MA) is a multi-layer, multi-species, non-steady state Lagrangian Gaussian puff dispersion model which can simulate the effects of temporally and spatially variable meteorological conditions on pollutant transport emitted from point, line, area or volume sources (Scire et al., 2000). The CALPUFF model is available free of charge and can be downloaded from the Atmospheric Studies Group website[2]. It is one of the core modeling systems recommended by the United States Environmental Protection Agency for the long-range transport of air pollution.

The model is comprised of three main components: (1) CALMET, a diagnostic meteorological model for developing hourly wind and temperature fields; (2) CALPUFF, a Gaussian puff-based transport model; and (3) CALPOST, a post-processor for the CALPUFF outputs. It also includes various other pre- and post- processors. Figure 37 displays a schematic representation of the CALPUFF model, demonstrating the organizational structure of the different components and processors.

CALMET, the first main component of the model, requires the greatest number of separate input datasets to describe the geophysical and meteorological environments of the study area (see Table 28 for specifics about data inputs and outputs of the three CALPUFF components). The geophysical and meteorological processing packages allow data from various sources to be converted into the appropriate standard formats accepted by the CALMET meteorological model (Oshan et al., 2006). Using the input datasets,

[2] http://www/src/com/calpuff/calpuff_eula.htm

CALMET produces hourly fields of three-dimensional winds and various meteorological variables (Elbir, 2003).

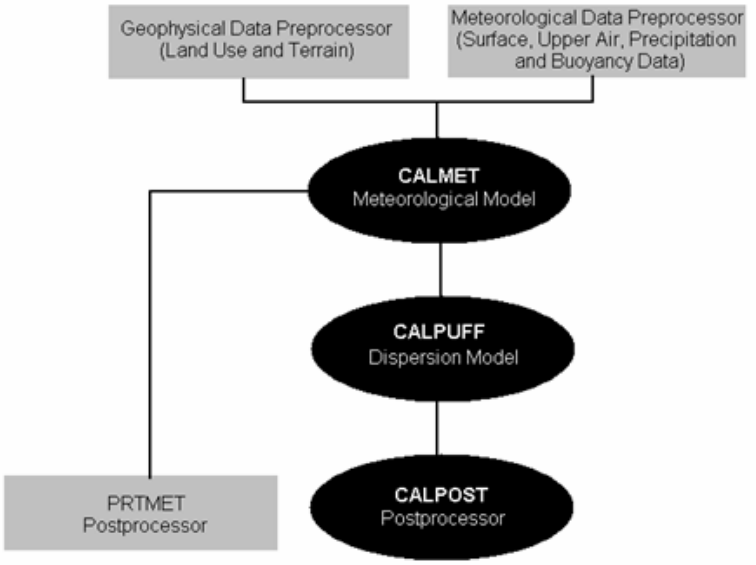


Figure 37. CALPUFF model: schematic representation of main components and additional processors (Adapted from Oshan et al., 2006)

Table 28. Required input and output of the three components of the CALPUFF system

Component	Input Requirements	Output
1. CALMET	*Geophysical* Terrain elevations Land cover Leaf area index Surface roughness length Albedo Bowen Ratio Soil heat flux & anthropogenic heat flux *Meteorological* Hourly surface observations (wind speed & direction, cloud cover, ceiling cloud height, surface pressure, relative humidity) Upper air observations (wind speed & direction, temperature and pressure) Hourly precipitation	Hourly wind and temperature fields
2. CALPUFF	Emissions Inventory Information (Ex. Stack height, exit velocity, exit temperature, geographic coordinates, elevation, emission rates) CALMET Output	ASCII textfile
3. CALPOST	CALPUFF Output	Rank or exceedance tables (and associated plots)

The CALMET output is then combined with emissions inventory information for input into the second component, CALPUFF. CALPUFF uses algorithms for near-source effects (building downwash, transitional plume rise, partial plume penetration and sub-grid scale terrain interactions) in addition to longer-range effects (pollutant removal through wet scavenging/dry deposition, chemical transformation, vertical wind shear, over-water transport, and coastal interaction effects) (Oshan et al., 2006). The following equations are used to calculate the concentration of a pollutant at any given location downwind, and at user-specified locations called "receptors" (Pfender et al., 2006):

$$C = \frac{Q}{2\pi\sigma_y\sigma_z} g \exp\left(-\frac{d_a^2}{2\sigma_x^2}\right)\exp\left(-\frac{d_c^2}{2\sigma_y^2}\right) \quad (1)$$

$$g = \frac{2}{(2\pi)^{1/2}\sigma_z}\sum_{n=-\infty}^{\infty}\exp\left[-(H_e + 2nh)^2/(2\sigma_z^2)\right] \quad (2)$$

Where C = ground level pollution concentration (g/m^3), Q = pollutant mass in the puff (g), σ_x = standard deviation (m) of the Gaussian distribution in along-wind direction, σ_y = standard deviation (m) of the Gaussian distribution in cross-wind direction, σ_z = standard deviation (m) of the Gaussian distribution in vertical direction, d_a = distance (m) from puff center to receptor in along-wind direction, d_c = distance (m) from the puff center to the receptor in cross-wind direction, g = vertical term (m^{-1}) of Gaussian equation, H = effective height (m) above ground of puff center; h = mixed layer height (m), and n= extent of vertical plume spread inclusive of multiple reflections off the mixing lid and the ground. The CALPUFF model simulates continuous puffs released from a source into the ambient wind flow, and adjusts the path each puff takes according to changes in wind flow over time (Scire et al., 2000). Ground level concentrations are directly proportional to the emission rate, and inversely proportional to the magnitude of horizontal spreading, with a decrease in concentration with distance from the plume centerline. The vertical spread of the plume parallel to the Z-axis is influenced by the exponential terms which account for the effect of eddy reflection at ground level. Small eddies that encounter the ground are reflected upward without a loss of mass (Turner and Schulze, 2007).

Gaussian models assume that continuously released pollutants are transported directly opposite to the wind direction, and that the time-averaged spread of pollutants has normal distributions of pollutant concentrations horizontally and vertically in the plume (Figure 38) (Turner and Schulze, 2007). Vertical and horizontal spreading depend upon the characteristics of the atmosphere, and are assumed to increase with time and distance from a source. Factors such as surface roughness, atmospheric stability and source characteristics will also influence the spreading of the plume.

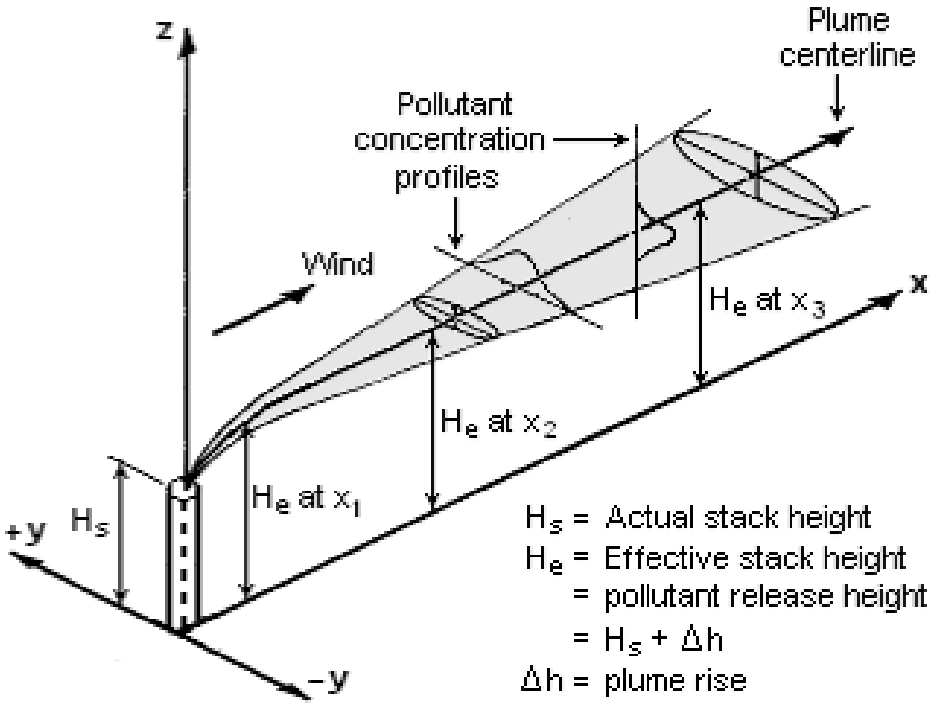


Figure 38. Simplified representation of Gaussian plume dispersion
(Source: http://www.ourairspace.org/environmental.html)

The CALPUFF model also contains dispersion and deposition algorithms which apply to shorter modeling distances (Pfender et al., 2006). For very near-field applications, the use of "slug" mode is recommended, which stretches the Gaussian "puffs" emitted from the source in the along-wind direction (Pfender et al., 2006). For each hour of the modeling domain, CALPUFF tracks: the mass emitted, the amount deposited, amounts remaining in the surface and mixed layer, or above the mixed layer, and the amount advected out of the modeling domain (Pfender et al., 2006).

The combination of the two components, CALMET and CALPUFF, allows complex terrain (such as valleys, ravines, steep slopes etc.) to be addressed in a physically-realistic manner (Taynaç and Berçin, 2007). This system offers advantages over straight-line, steady-state Gaussian models, including: its ability to treat dispersion in calm conditions (Elbir, 2003); allowing more than a single wind vector throughout the study area (Godfrey and Clarkson, 1998); being able to address line, point, area and volume sources; having the option to model from 1 hour to 1 year averaging periods, and; being capable of addressing small to large study domains (Jackson et al., 2006). In addition, the CALMET and CALPUFF pair is able to model rough or complex terrain, inert pollutants, and also those subjected to linear removal and chemical conversion mechanisms (Jackson et al., 2006).

CALPOST, the third component of the dispersion modeling system, requires output from the CALPUFF model. This postprocessor allows users to average and report concentrations of wet/dry deposition flux results based on the hourly data contained in the CALPUFF output file (Oshan et al., 2006). Specific averaging times can be selected based on the interest of the researcher (e.g. 1 hr, 3 hr, 24 hr, or full modeling period) and results can be reported as rank or exceedance tables, with associated plots (Oshan et al., 2006).

Due to the computationally intensive nature of the CALPUFF model, all CALMET and CALPUFF model simulations were performed on a LINUX system at SENES Consulting Limited in Vancouver. This allowed computational time to be reduced to 3-4 days per run, from up to 2 weeks run time on a desktop computer at UVic. The computational complexity and underlying run times combined with other logistical requirements placed limitations on the number of model runs which could be performed, and prevented additional model sensitivity analyses to be included. Sensitivity and error analysis should be a focus of future research, as cited in the disclaimer at the beginning of the thesis.

4.2.2 Model Configuration

The CALPUFF model was configured for an analysis of a 20 km^2 study domain (Figure 39) centered on the Ogden Point cruise ship terminal, subdivided into 100 x 100 m grid cells. Modeled winds and estimated concentrations of sulphur dioxide (SO_2), nitrogen dioxide (NO_2) and particulate matter ($PM_{2.5}$ and PM_{10}) are averaged quantities relating to each grid cell. CALPUFF was also used to provide estimated pollutant concentrations at specific points of interest (discrete receptors). Vertically, the modeling domain is resolved into 12 layers up to 3000 m height. Terrain and land use data from DMTI Spatial (Markham, Ontario) were used to characterize terrain heights at the horizontal scale of 100 m, and to characterize surface friction and thermodynamic properties for each grid cell. Other important model parameters are provided in Table **29**.

Table 29. Important CALMET configuration options

CALMET Element	Configuration
Grid Projection	UTM Zone 10N
Grid Definition (horizontal)	200 x 200 grid cells, 100 m spacing
Grid Definition (vertical)	12 layers, boundaries at 0, 20, 40, 60, 80, 100, 150, 200, 500, 1000, 1500, 2200, 3000 m
Wind Field Model	On, with model defaults used for all switches
Sfc and Upper Air Meteorology	NOOBS=1
Initial Guess Wind Fields	IPROG=14: Use Eta winds
Wind Interpolation	RMAX1,2 = 5, 10km
Relative Weighting of Wind Data	R1 = 2 km, R2 not applicable
Terrain influence on winds	TERRAD=5 km, although terrain is relatively flat.

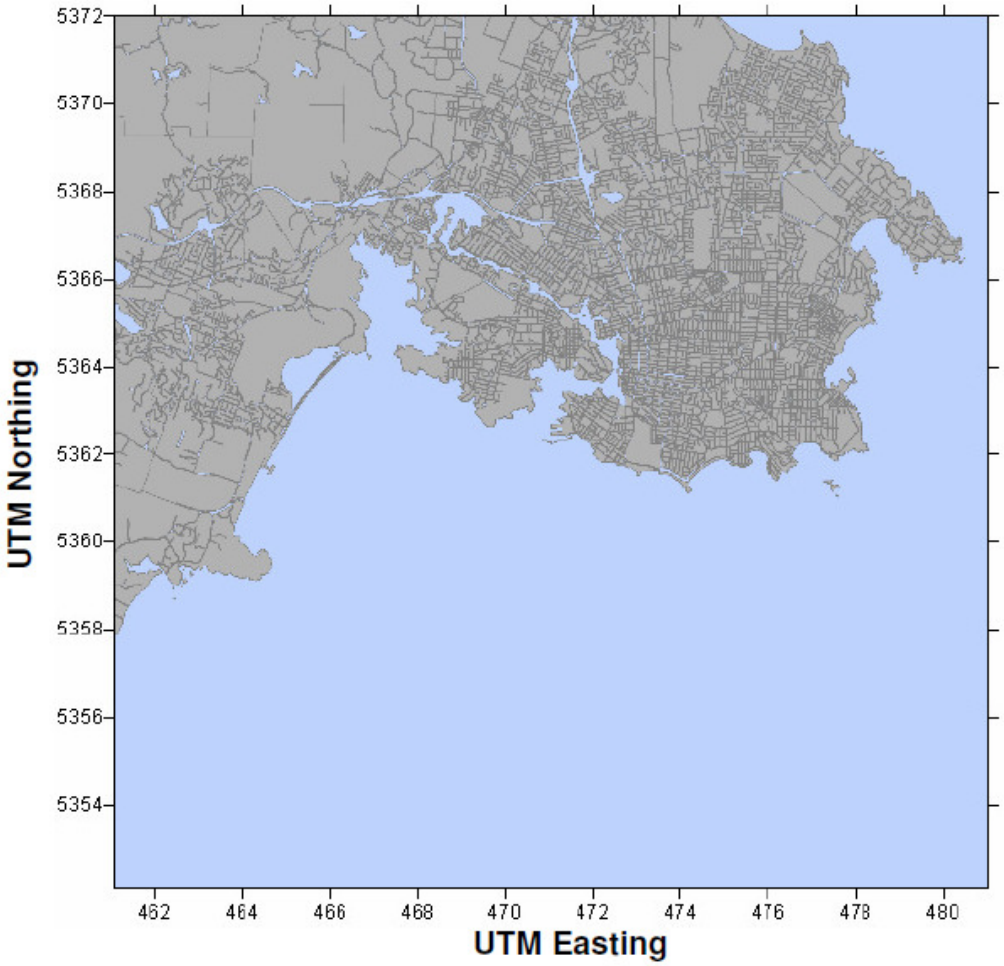


Figure 39. 20 km^2 modeling domain centered on the Ogden Point Terminal

CALMET, the meteorological processor included in CALPUFF, produces three dimensional fields of wind, temperature, humidity and other parameters required by the dispersion model. Regional-level (mesoscale) meteorological fields produced by weather forecasting models can be used as input data for CALMET, and can be combined with measured data from surface stations via an internal blending process. For this study, meteorological fields from the Eta forecasting model at 12 km resolution were used in combination with data from four surface stations. The meteorological inputs for CALMET are summarized in Table 30, and locations of sites displayed in Figure 40.

Table 30. Meteorological data used for input into the CALMET model

Data Source	Meteorological Data
Eta model fields, North America 12 km simulation. Extraction from tile situated over Victoria, B.C.	Wind speed, wind direction, temperature, pressure, humidity
Ogden Point Breakwater Meteorological Station	Wind speed, wind direction, temperature
Victoria International Airport (Environment Canada meteorological station)	Wind speed, wind direction, temperature, pressure, humidity, ceiling, cloud cover
Topaz Station (BC Ministry of Environment air quality monitoring station)	Wind speed, wind direction, temperature
Hein Bank Buoy Station 46088 (National Ocean and Atmospheric Administration)	Wind speed, wind direction, air temperature, water temperature

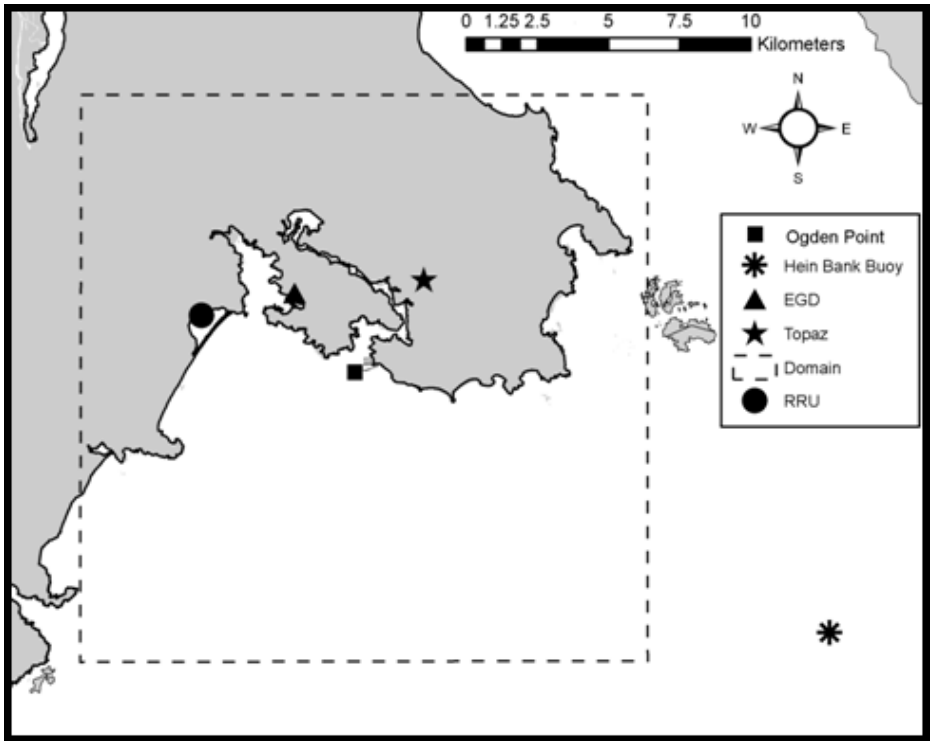


Figure 40. Surface meteorological stations used in the CALMET model (Ogden Point, Hein Bank Buoy and Topaz) and for model validation (EGD, RRU)

The Victoria airport is located approximately 22 km north of Victoria, and is not displayed in Figure 40. Data from the Royal Roads University (RRU) and Esquimalt Graving Dock (EGD) stations were not included in CALMET, but were used to critically assess the CALMET winds (see Section 4.2.6.1).

4.2.3 Cruise Ship Emissions

Cruise ships were characterized as point sources while at berth and as line sources while manoeuvring and transiting near berth. A detailed cruise ship schedule provided by the GVHA was used to characterize the hours during the 2007 cruise ship season when cruise ship activity was occurring in the study domain.

Ship emission factors for 4-stroke marine diesel engines were used to characterize cruise ship emissions during at berth, manoeuvring and transit activity. The use of emission factors requires an estimate of the average power (kW) developed by ship engines in each mode of activity. The engine emission factors used for this study are shown in Table 31 and are identical to those currently considered appropriate in recent Canadian marine emissions analyses[3]. In all cases, cruise ships were assumed to be using intermediate fuel oil (IFO) with a sulphur content of 1.6%. For discussion on fuel see Section 1.4.

Table 31. Energy-based emission factors for marine 4-stroke diesel engines*

Common Air Contaminant	Emission Factor (g/kWh)
NO_x	14.00
SO_x	4.20
PM_{10}	1.00
$PM_{2.5}$	0.91

*SO_x factor is multiplied by sulphur content of fuel in %
PM factors for marine fuel assume sulphur level of 1.6%

In addition to engine emissions, boiler emissions must also be considered for cruise ships. The 2005/2006 BC Marine Emissions Inventory (COSBC, 2007) established an average boiler rate of 0.345 tonnes/hour for cruise ships. This value was assumed for each cruise ship during all modes of activity. Boiler emission rates in kg/tonne fuel are provided in Table 32. The gas factors were taken from the 2005/2006

[3] The Canadian "Marine Tool" is a ship database emissions model that has been developed from a partnership between Transport Canada and Environment Canada. The current version of the Tool is V2.5. The emission factors in Table 31 are consistent with the Marine Tool. A description of the Marine Tool can be found at http://www.tc.gc.ca/tdc/projects/marine/g/5612.htm.

Marine Emissions Inventory (COSBC, 2007) and the PM factors from the EPA 'AP-42' compilation of emission factors for boilers consuming no. 5 fuel oil.

Table 32. Boiler emission rates*

Common Air Contaminant	Emission Rate (kg/tonne)
NO_x	12.30
SO_x	20.00
PM_{10}	1.20
$PM_{2.5}$	0.60

*SO_x emission rate is multiplied by sulphur level of fuel in % (assumed to be 1.6%)

To determine ship-specific cruise ship emission rates, a shoreside power feasibility study for San Francisco (Environ, 2006) was reviewed. The San Francisco study provides an estimate of average (electric) power demand while dockside for three vessels (Table 33). A 'passenger' field has been included in the table to indicate the potential relationship between electric load and the number of passengers on board; in effect, a greater number of passengers should require greater power developed by the engines.

Table 33. Cruise ship characteristics from San Francisco Study (Environ, 2006)

Cruise Ship	Gross Tonnage	# Engines Used Dockside	Rated Power (kW)	Passenger	Fuel Used	Average Electric Load (kW)
Celebrity Mercury	77713	3	4320	1870	IFO 380	9500
Dawn Princess	77499	1	11650	1950	IFO 380	6800
Diamond Princess	116000	2	18900	2600	IFO 380	12000

Electric loads used in the San Francisco study are likely too high for ships berthing at Ogden Point, as mentioned anecdotally by ship engineers, and based on the average engine power while at berth for cruise ships as characterized in the 2005/2006

BC Marine Emissions Inventory (COSBC, 2007). In order to characterize electric load for cruise ships at Ogden Point, an emissions profile was developed by SENES Consulting (Figure 41). A linear relationship was assumed between number of passengers and effective power demand while at berth. The basic linear relationship was assigned based on the average power demand at berth indicated in the COSBC Inventory and information related to one particular cruise ship that frequents Ogden Point (information supplied by the GVHA from discussions with ship engineer). Use of this relationship implies lower engine power levels for the ships at Ogden Point than what the San Francisco study suggests (taking into account the different size of vessels).

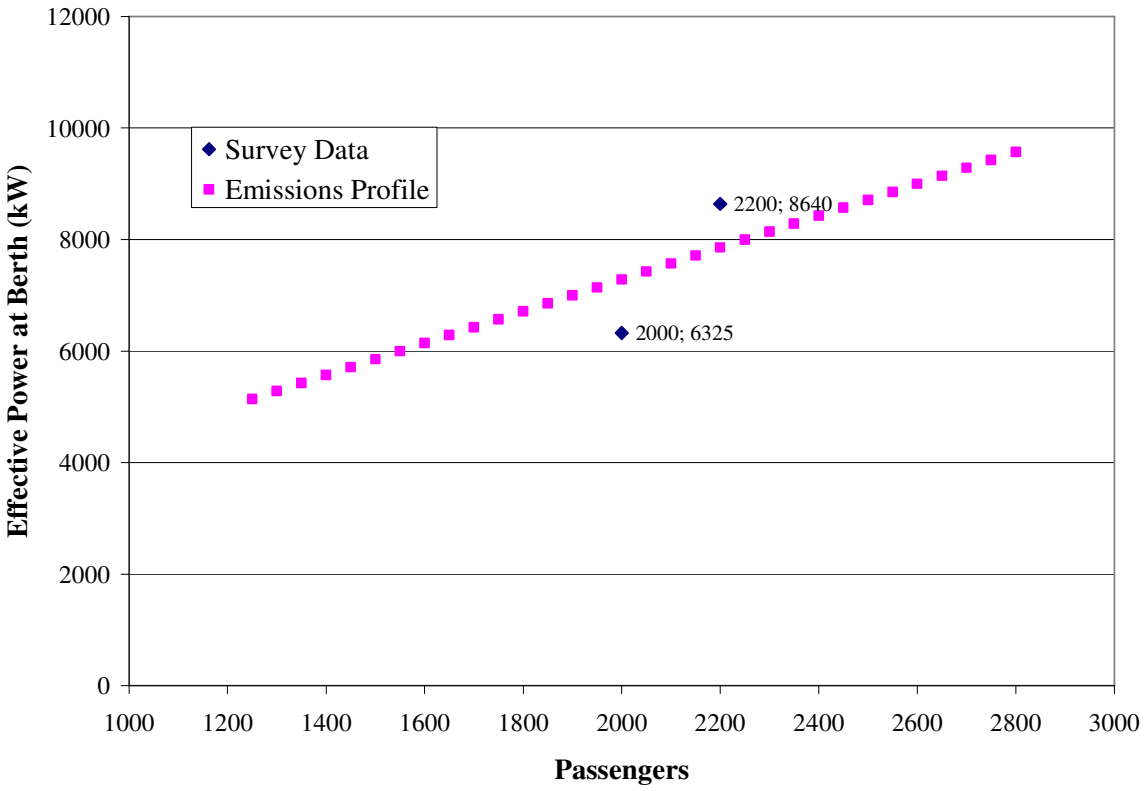


Figure 41. Emissions profile developed for cruise ships by SENES Consultants, Ltd.

The linear profile was then adapted to incorporate electrical variability of cruise ships at Ogden Point based on different air conditioning requirements on a monthly basis:

$$AveragePower(kw) = (1 - month\,\mathrm{var}) * [5143 + (P - 1250) * 2.857] \quad (3)$$

Where:

Monthvar = 0.3 (April, October)
0.2 (May, September)
0.1 (June, August)
0.0 (July)

5143 = engine power (kW) for a 1250 passenger cruise ship

P = number of passengers for a particular vessel

The 'Monthvar' parameter was included in the expression above to account for the expected reduction in dockside engine load during cooler months. To serve as example, the Diamond Princess would be expected to use an average of 9,000 kW while berthing at Ogden Point in July, and 6,300 kW while berthing in April or October. This ship engine profile is simplistic, due to a lack of available information on specific ship characteristics and behaviours.

The linear emissions profile in Figure 41 displays the linear emissions profile developed for Ogden Point without accounting for month of the year. Two ship surveys provided by the Northwest Cruise Association allowed the emissions profile to be assessed, based on actual ship engine and fuel usage for two cruise vessels while at stopped at Ogden Point. The results of this assessment are indicated on Figure 41. The survey point which lies above the line relates to a cruise ship stop at an undetermined time. Use of the ship engine profile would underestimate the value from the survey response in this case. The survey point falling below the line relates to a cruise ship call in May (i.e. a cooler month), and in this case full use of the ship engine profile produces a good match to the survey response (taking the 'monthvar' parameter into account).

Additional characteristic information for cruise ship engine activity during manoeuvring and slow speed movement was obtained from the COSBC Marine Emissions Inventory. Power demand at berth for each vessel was scaled by 1.25 and 2.0 to represent engine power required for manoeuvring and slow speed movements, respectively (JBAQS, 2009). For each ship visit cruise ship transit emissions were considered 'on' for a total time period of 0.17 hours for manoeuvring and 0.18 hours for underway (slow speed) (JBAQS, 2009). Transit emissions were set with the model to

coincide with berth times (immediately before arrival and immediately following departure). However, due to the limitations of dispersion simulation with CALPUFF, the short-term emissions had to be averaged out over a full hour for each arrival or departure. Therefore, the engine emissions rates were lowered by the ratios indicated above, and applied over a full hour (JBAQS, 2009).

4.2.4 Ferry Emissions (M.V. Coho & Victoria Clipper)

The same model emissions configuration for cruise ships (point source at berth and line source when manoeuvring and underway) was used for the ferries. Figure 42 displays the point and line source locations for cruise ships and ferries within the domain. The M.V. Coho and Victoria Clipper vessels dock at a terminal in the Victoria Inner Harbour, directly north of James Bay.

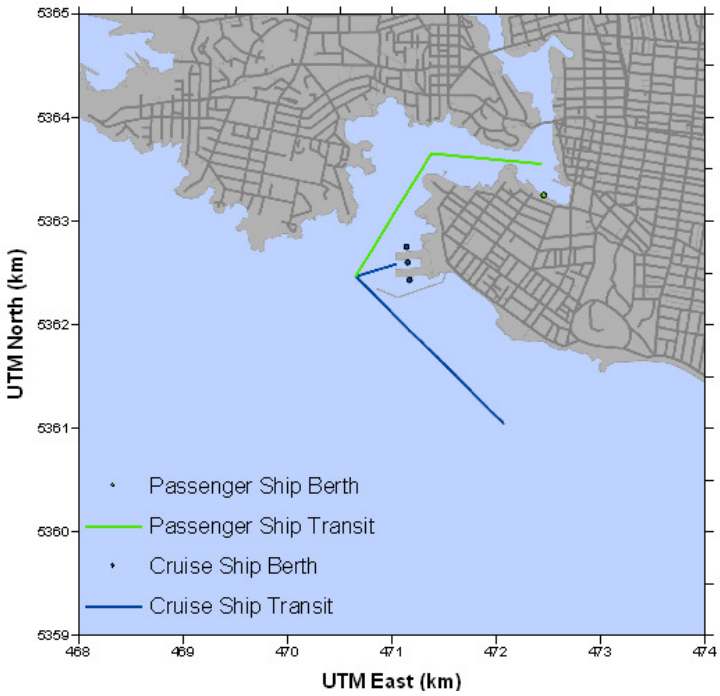


Figure 42. Locations of point and line sources used in the CALPUFF model to characterize cruise ships and ferries while at berth, underway, and manoeuvring

Vessel and fuel characteristics for the M.V. Coho and Victoria Clipper ferries (Table 34) were provided by Black Ball Transport Inc. and Clipper Navigation Inc., respectively. The same assumptions used for cruise ships were applied to the ferries, in terms of emissions factors, transit speed and scheduling periods with emissions 'on'.

However, the ferries do not use their auxiliary engines during all periods at berth, as shore power is used. This was accounted for in the emissions inputs.

Table 34. Ferry vessel characteristics

Characteristic	M.V. Coho	Victoria Clipper
Fuel (Sulphur Content)	420 ppm	500 ppm
Engine Size		
Main Engine	3804 kW	4000 kW
Auxiliary Engine	500 kW	164 kW
Propulsion Load		
Underway	0.50	0.50
Manoeuvre	0.30	0.30
Auxiliary Load		
Berth	0.25	0.25
Underway/Manoeuvre	0.40	0.60

4.2.5 Line and Point Source Configuration

Both point and line source model representations were used to characterize cruise ships and ferries in the model simulation. Table 35 and Table 36 provide point and line source characteristics used in the model, respectively.

Table 35. Point source characteristics

Source	Temperature (°K)	Stack Height (m)	Stack Diameter (m)	Plume Exit Velocity (m/s)	Plume Momentum
Cruise Ships at Berth	573.2	50	1.0	22	'on'
Ferries at Berth	573.2	25	1.0	22	'on'

Table 36. Line source characteristics

Source	Length (km)	All 'Building' Dimensions (m)	Base Height (m)	Release Height (m)	Buoyancy Parameter (m^4/s^3)
Cruise Ships Manoeuvring		0.1	0	40	50
Cruise Ships Slow Transit	2	0.1	0	40	50
Ferries Manoeuvring		0.1	0	20	50
Ferries Slow Transit	2	0.1	0	20	50

The line source algorithm used in CALPUFF was designed to represent long buildings with multiple stacks (for aluminum smelting operations). This source type has been used for moving exhaust such as vehicles, locomotives and ships in past CALPUFF modeling studies (Radonjic et al., 2003). The 'building' dimensions are set very small to better represent a continuous emission stream rather than a number of individual stacks.

Additional CALPUFF model 'switch' options were chosen to be consistent with the BC Modeling Guidelines (which in most cases means use of the model defaults). An exception was made for MCHEM (turned off, since chemical transformation was not represented in the model) and MWET/MDRY (turned off, since no wet or dry removal of pollutants was represented). In both cases, these choices were made largely due to the fact that near-source concentrations were of interest in the modeling study, since wet and dry deposition generally have a greater impact at longer distances. In addition, turning off wet and/or dry deposition provides more conservative estimates of ambient pollutant concentrations. The chemical transformation of NO to NO_2 was represented with an external method, as discussed in greater detail in the Phase II Modeling report.

4.2.6 Meteorological and Emissions Data Validation

4.2.6.1 Meteorological Validation

Wind speed and direction data predicted by the CALMET model were compared to measurements from the Esquimalt Graving Dock (EGD) and Royal Roads University (RRU) to assess how well the model predicted winds at locations in the modeling domain from which input data were not provided (Figure 43 and Figure 44, respectively). Comparative wind roses of measured to modeled winds at the EGD show that the model slightly underestimates the light offshore and stronger onshore winds, but generally produces a realistic estimation of winds at this point in the study area. Observed and modeled data from the RRU station show less agreement. This was expected, since the RRU winds are quite localized with a northerly flow (SENES, 2006). Given the distance of the RRU station from James Bay and the downtown area, and the predominant wind direction measured at Ogden Point and Topaz stations, the lack of agreement between the modeled and measured winds at RRU was not considered to be critical for this study.

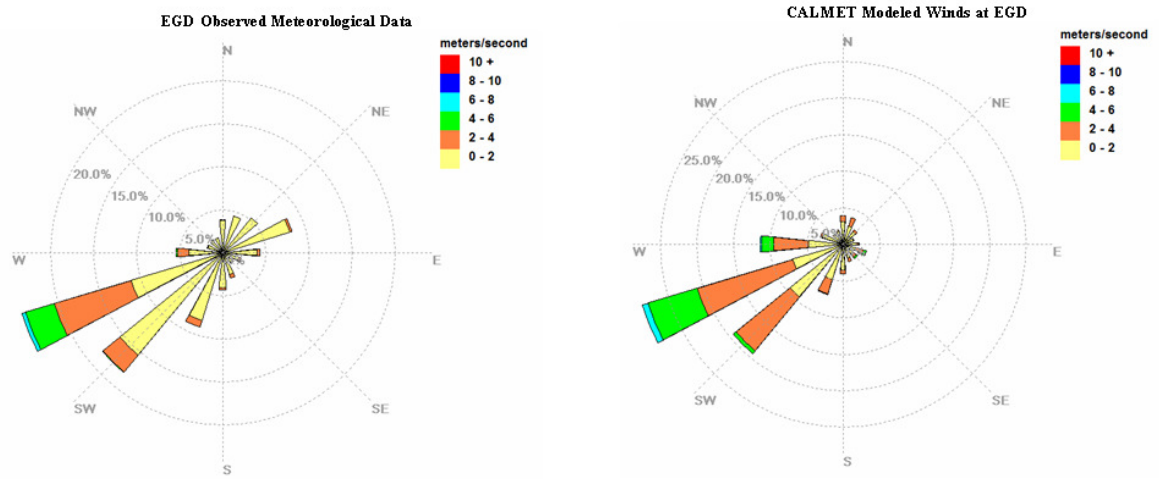


Figure 43. Comparison of observed and CALMET winds at the EGD for the full modeling period April 24 – November 3, 2007

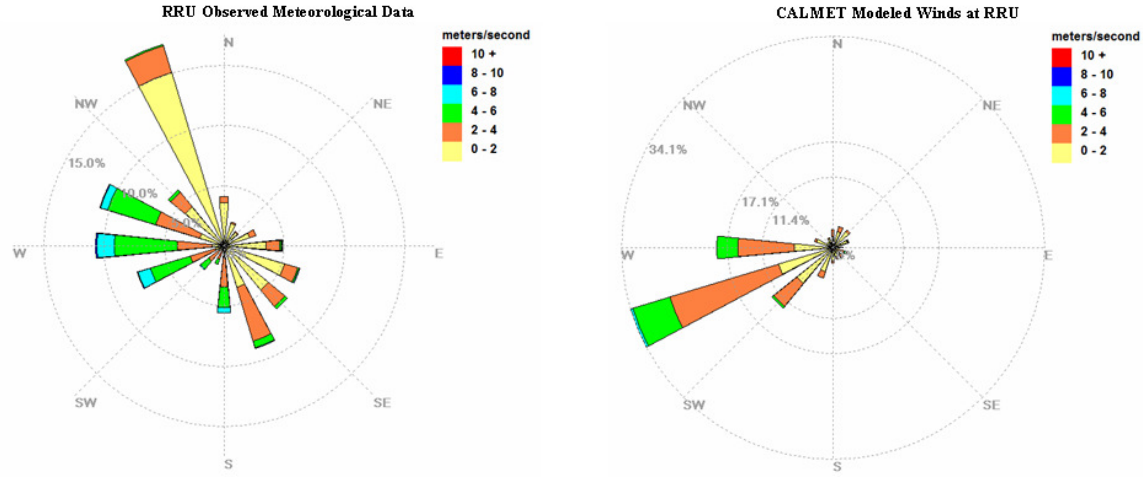


Figure 44. Comparison of observed and CALMET winds at the RRU site for the full modeling period April 24 – November 3, 2007

4.2.6.2 Emissions Validation

Emission rates were set in the CALPUFF model by using specific vessel emission characteristics (in particular, engine use) and vessel scheduling. This necessitates use of variable emissions input files that establish specific emission rates for the sources for each hour of the study period. This approach increases the representativeness of the model simulation for both maximum ambient concentrations and frequency of concentrations above a threshold of interest. However, the approach also increases the potential for error in the estimated emission rates.

An important quality assurance check of the emission rates is to calculate the total amount of emissions for each pollutant produced by each source during the study period. These values can then be compared to one another in order to determine whether the relative contributions are as expected. In addition, total emissions can also be compared with estimates from existing air emissions inventories, if available. The following sections compare total cruise ship and ferry emissions to values calculated for the BC Chamber of Shipping marine emissions inventory.

Cruise Ship Emissions

Estimated totals compiled directly from the CALPUFF hourly emissions input files were compared to annual total emissions calculated for the COSBC Inventory (Table 37). For comparative purposes, modeled emission rates (g/sec) of cruise ships while in port and underway were converted to hourly totals and then summed for the entire period (April 24 to November 3, 2007). Emissions inventory estimates specific to the Ogden Point berth and within a 2.5 km radius in 2005-2006 were obtained from the Marine Vessel Emissions Data Extraction for Select Areas in BC and the Georgia Basin report (SENES, 2008). This work includes a number of sub-inventories from the COSBC Inventory for areas of interest in the province (one of which is Ogden Point).

Total modeled emissions while at berth were comparable to those calculated for the BC Inventory. Modeled emissions were slightly higher, yet within 25% of inventory calculations for each pollutant. This was not unexpected, since changes occur to the number (and type) of cruise ship visits each year. Modeled SO_x emissions were only slightly higher, due to the 2007 assumed average sulphur content of fuel at Ogden Point (1.6%) being lower than the average in the COSBC Inventory.

Total modeled emissions while manoeuvring and underway were comparably lower than the values from the COSBC Inventory. This is likely due to the fact that ships transiting to/from Ogden Point were modeled as a 2 km line source, while total emissions from the inventory are for activity with a 2.5 km radius, as well as because total underway emissions in the inventory include additional smaller marine sources which operate within 2.5 km of Ogden Point (although the total presented is largely dominated by passenger vessels).

Table 37. Comparison of total modeled cruise ship emissions to BC Inventory amounts

Activity		Total Emissions (tonnes)*			
		SO_x	NO_x	PM_{10}	$PM_{2.5}$
Berth	Modeled	62.47	102.33	8.33	7.02
	COSBC Inventory	59.77	81.32	6.47	5.82
	Absolute Difference	**2.70**	**21.01**	**1.86**	**1.20**
	Relative % Difference	**4**	**23**	**25**	**19**
Manoeuvring and Underway	Modeled	9.67	16.94	1.33	1.14
	COSBC Inventory**	17.37	24.00	1.85	1.67
	Absolute Difference	**7.7**	**7.06**	**0.52**	**0.53**
	Relative % Difference	**57**	**34**	**33**	**38**

*Total emissions are expressed for the duration of the modeling period
**Total underway and manoeuvring within 2.5 km radius of Ogden Point

Ferries (M.V. Coho and Victoria Clipper)

The same procedure used to calculate total emissions for cruise ships was also applied to ferries. Modeled emission rates (g/sec) of vessels while in port and underway were converted to total emissions (tonnes) for the modeling period, as displayed in Table 38.

Table 38. Total emissions modeled for ferries

Activity	Total Emissions (tonnes)*			
	SO_x	NO_x	PM_{10}	$PM_{2.5}$
Berth	0.02	1.06	0.02	0.02
Underway	0.32	16.22	0.37	0.34

*Total emissions are expressed for the duration of the modeling period

In the case of ferries, no comparison can be made to other sources of information to confirm validity of the emission rates (the COSBC Inventory does not include these ferries). However, it can be observed that total emissions from ferries are lower than

total emissions from cruise ships. This was as expected, as ferries use fuel with much lower sulphur content and require little power while docked. The comparison of relative concentrations between cruise and ferry sources generally supports the emissions configuration of this source in the model.

4.2.7 Discrete Receptors

Specific locations of interest within the James Bay neighbourhood (n=25), and also at Topaz Station, were included in the modeling analysis as "discrete receptor" points at which to predict ambient concentrations of pollutants. Gridded receptors are the standard output of the CALPUFF model, and are averaged quantities relating to each 100 x 100 m grid cell. While gridded receptors can be used to calculate the maximum 1-hour, maximum 24-hour, and average concentrations in each cell of the modeling domain, discrete receptors can be used to generate time series data and examine frequency distributions of concentration levels. Figure 45 displays the location of discrete receptor points in James Bay community.

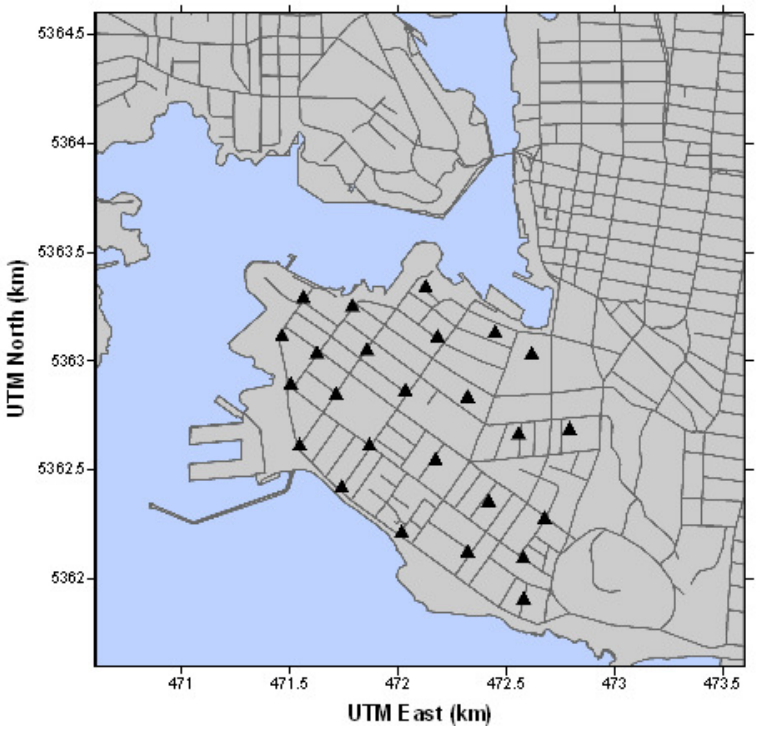


Figure 45. Discrete receptor locations (n=25) in the James Bay neighbourhood

Additional discrete receptor points were also established in the Songhees region and downtown Victoria, as displayed in Figure 46:

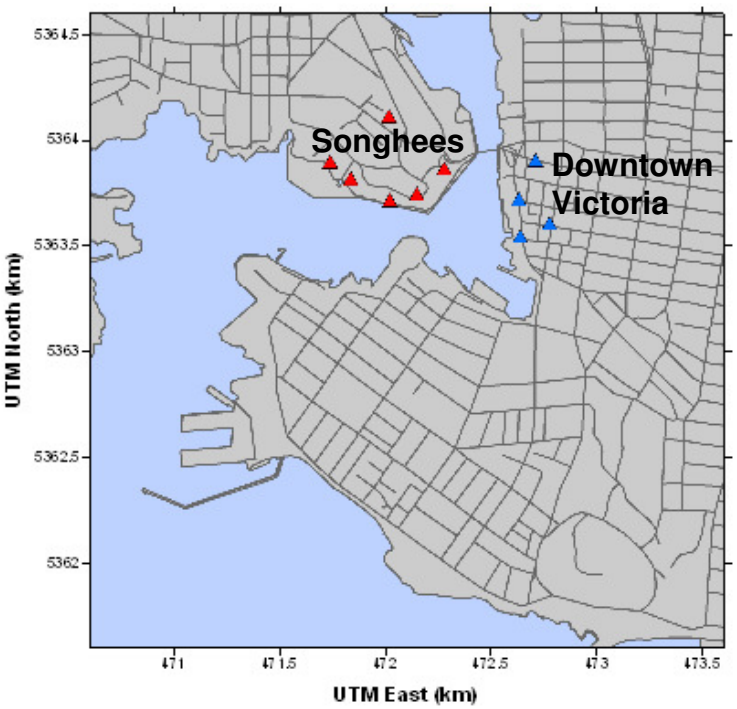


Figure 46. Discrete receptor locations is Songhees (*n*=6) and Downtown Victoria (*n*=4)

4.2.8 Background Concentration Levels

When modeling air quality from a specific source in a study area, it is important to establish the concentration levels which already exist in that area – the "background" concentration, or the result of the contribution from all sources except those being modeled (MOE, 2008). Establishing background allows the cumulative concentrations of existing and modeled concentrations to be examined. For example, there may be a relatively low modeled concentration which would not be of concern with respect to air quality guidelines, but in conjunction with background levels might be enough to exceed the guidelines.

Typically, the maximum concentrations (100th percentile) recorded at a station are used in screening-level analyses where the worst-case concentrations are modeled. For other modeling purposes, such as determining compliance with ambient air quality objectives and guidelines, or for potential risk exposure estimates, a more conservative value such as the 99th or 98th percentile value can be established (MOE, 2008).

The BC Ministry of Environment's fixed-site air quality monitoring station on Topaz Avenue, approximately 3.5 km northeast of the Ogden Point terminal, was selected to establish background concentration levels (due to all additional sources) for the study domain. This is the closest station in the study domain, as well as the only station in the domain which measures continuous concentrations of SO_2, NO, NO_2 and $PM_{2.5}$. This station, however, is highly influenced by traffic emissions, and there is also some evidence that SO_2 from cruise ships reaches this location. The 98th percentile at Topaz was selected to represent 1-hour, 24-hour and average background concentrations of SO_2, NO_2 and $PM_{2.5}$. The 98th percentile was selected in order to minimize the influence of observed short-term peaks in SO_2 due to ship or other activity. Previous analysis of the Topaz data showed little or no influence of cruise ship activity levels of NO, NO_2 or $PM_{2.5}$ (See Section 3.3.1).

Vehicle traffic was assumed to be the main source of background NO and NO_2 in the study area, based on the implications of the CRD emissions inventory report (SENES, 2006). However, it is likely that the Topaz station experiences higher concentrations due to vehicle activity than the receptor in James Bay (based on traffic count data and CRD traffic model). The 98th percentile NO_2 concentration measured at Topaz was used to represent the general background level, which is a conservative estimate for the James Bay community. Similarly, the $PM_{2.5}$ level at Topaz was assumed to be generally representative of background in the James Bay area. Measured PM_{10} concentrations are not available at Topaz and it was assumed that background PM_{10} would be slightly higher than $PM_{2.5}$ due to additional sources such as road dust. The background $PM_{2.5}$ level measured at Topaz was therefore increased by 20% to represent background PM_{10} concentrations.

Data from Topaz Station for the period of the modeling study (April 24 – November 3, 2007) were obtained from the BC Ministry of Environment, and used to calculate the 98th percentile of SO_2, NO_2 and $PM_{2.5}$ for use as background. The background $PM_{2.5}$ level was increased by 20% and used to represent background PM_{10} concentrations. Table 39 displays the established 1-hour, 24-hour and period-average background concentrations of all air pollutants included in the study.

Table 39. Background SO_2, NO_2, PM_{10} and $PM_{2.5}$ concentrations ($\mu g/m^3$) established from the Topaz monitoring data (98^{th} percentile)

Contaminant	1-Hour 98^{th} Percentile	24-Hour 98^{th} Percentile	Period Average
SO_2	13	7	1.83
NO_2	51	36	20.92
PM_{10}	19	14	5.76
PM_{25}	16	12	4.80

4.3 Results

4.3.1 Uncertainty Related to Model Results

Uncertainties associated with input data (such as meteorological and geophysical data) and assumptions made about emissions sources can affect the output results of the model. This research made several assumptions about specific emissions sources included in the model and these should be recognized and taken into consideration when examining the model results:

- **Cruise Ship Fuel Quality -** It was not possible to obtain information on the specific fuel quality (sulphur content) used by each individual cruise ship visiting James Bay during the study period. It was believed that the average 1.6% (by mass) sulphur in fuel assumed for all cruise ships is a reasonable representation of reality for the model simulations, but it is likely that the actual fuel sulphur levels for individual ships varies between 1.0 and 2.0%.

- **Manoeuvring and Underway Emissions** - Representation of manoeuvring and underway emissions in the model has greater uncertainty compared to stationary (berthing) emissions, since the emitted plume is immediately affected by the wind due to the ship's motion, which limits buoyancy and increases the initial lateral dispersion. In addition, each vessel leaves the study area relatively quickly. Since the model (as configured) requires hourly averaged emission rates, the

underway emissions had to be estimated over a realistic period (e.g. 10 minutes) and then reduced to be representative of the full hour.

- **Manoeuvring Time Periods and Related Activities -** The model simulations assumed a short period (10 minutes) of manoeuvring for each cruise ship that arrived or departed Ogden Point during the study period. This is likely reasonable for departure, since the cruise ships are able to leave quickly, without the support of tugboats. However, tugboats are sometimes used for arrival periods, which could cause the manoeuvring periods to be longer than that represented in the model, and could also indicate additional emissions due to tugboats which should be considered for the manoeuvring line source.

- **Plume Downwash –** Due to the structure of a cruise ship, it should be expected that plume downwash is experienced during sufficiently high wind speeds. This effect is usually referred to as 'building downwash' since it commonly results from an industrial stack sitting atop a building. The CALPUFF model can simulate building downwash if the 'building' dimensions are entered. Cruise ship dimensions were not used to simulate this effect for two reasons: the dimensions are variable (depending on ship and its alignment relative to the direction of the wind) and downwash effects occur near the source. Ambient concentrations in the James Bay community (and not necessarily within the Ogden Point terminal grounds) were the focus of this study. Stack tip downwash was simulated in the model, since ship dimensions are not required to estimate this effect.

Emission sources were characterized for the CALPUFF model based upon the best information available at the time of configuration. Limitations acknowledged above may be resolved with future research and analysis as new or more detailed information becomes available. The current results presented herein, obtained from the model taking these limitations into account, still provide valuable information towards an assessment of air quality in James Bay based upon these emission sources.

4.3.2 Maximum Model Predictions

Table 40 provides a summary of estimated maximum 1-hour, 24-hour and average concentration levels for each pollutant (SO_2, NO_2, PM_{10} and $PM_{2.5}$). Results are presented for the larger study domain as a whole, as well as for the specific James Bay area of interest. Concentration levels are given both without background (BG) ('Modeled Sources') and for the combination of background and incremental sources ('Modeled sources + BG'). Maximum concentration values from this table can be compared to established air quality guidelines and standards to determine whether any exceedences are occurring within the James Bay community, or at other locations in the study domain.

Although the goal of Phase I and Phase II of the JBAQS were not to assess health outcomes, predicted concentration levels were compared to existing air quality guidelines and standards as a reference. There are pollutants, such as particulate matter, for which no threshold level exists for health impacts. There are no 1-hour guidelines for exposure to $PM_{2.5}$ or PM_{10}, and therefore it is important that an expert on the health effects of air pollution assess the potential implications that levels predicted by this research may have on residents in James Bay.

Predicted maximum 24-hour SO_2 in the entire domain (46 $\mu g/m^3$) and in James Bay (41 $\mu g/m^3$) exceed the WHO guideline of 20 $\mu g/m^3$ for 24-hour SO_2 concentrations. Also, predicted maximum 1-hour NO_2 in the domain (204 $\mu g/m^3$) just exceeds the CRD and WHO guidelines of 200 $\mu g/m^3$ for 1-hour NO_2. More detailed model output is now examined for 24-hour SO_2 and 1-hour NO_2 to determine both spatial and temporal variations in maximum estimated concentrations. These two pollutants and reference time periods were selected on the basis that they exceeded established guidelines or standards. This level of detailed information has also been produced for all pollutants of interest for 1-hour, 24-hour and average time periods. For further information, please refer to the JBAQS Phase II report.

Table 40. Predicted maximum concentration levels (µg/m^3) in James Bay and in the larger study domain

Time Period	Background (BG)	Entire Study Domain		James Bay Neighbourhood	
		Modeled Sources	*Modeled Sources + BG*	*Modeled Sources*	*Modeled Sources + BG*
SO_2					
1-hour	13	257	270	151	164
24-hour	7	39	46	33	40
Average	1.8	1.8	3.6	1.8	3.6
NO_2					
1-hour	51	153	204	85	136
24-hour	36	17	53	17	53
Average	21	1	22	1	22
PM_{10}					
1-hour	19	35	54	20	39
24-hour	14	5	19	4	18
Average	5.7	0.2	5.9	0.2	5.9
$PM_{2.5}$					
1-hour	16	30	46	16	32
24-hour	12	4	16	4	16
Average	4.8	0.2	5.0	0.2	5.0

Note that figures of maximum concentrations in the following sections represent levels that are expected to occur only *once* during the modeling period i.e., 100th percentile value for every point on the map, and should not be considered as single "snapshots" in time. Maximum concentrations at one location do not necessarily occur simultaneously with maximums at other locations.

4.3.3 Maximum 24-hour SO_2

The maximum 24-hour SO_2 concentration predicted in the entire study domain was 46 µg/m^3 and occurred over the Ogden Point terminal berth (Figure 47). The maximum concentration estimated to occur within the James Bay community was 40 µg/m^3. A large portion of the James Bay community, parts of Songhees and Downtown Victoria, are estimated to have maximum 24-hour SO_2 concentrations above the WHO guideline of 20 µg/m^3 (see region within the dashed line in Figure 47).

The extent of the area with 24-hour concentration levels above 20 µg/m^3 is limited to the region previously shown in Figure 47, over northwestern James Bay, the southern tip of Songhees, the Inner Harbour and Downtown Victoria. The background concentration level of SO_2 was established as 7 µg/m^3, and therefore the extent of concentrations between 10-20 µg/m^3 throughout the study domain (Figure 48), shows that emissions from modeled sources are experienced up to 5 km away from their origins. Concentrations are detected at longer distances to the east and north-east, likely due to the dominant onshore winds experienced on average over the season.

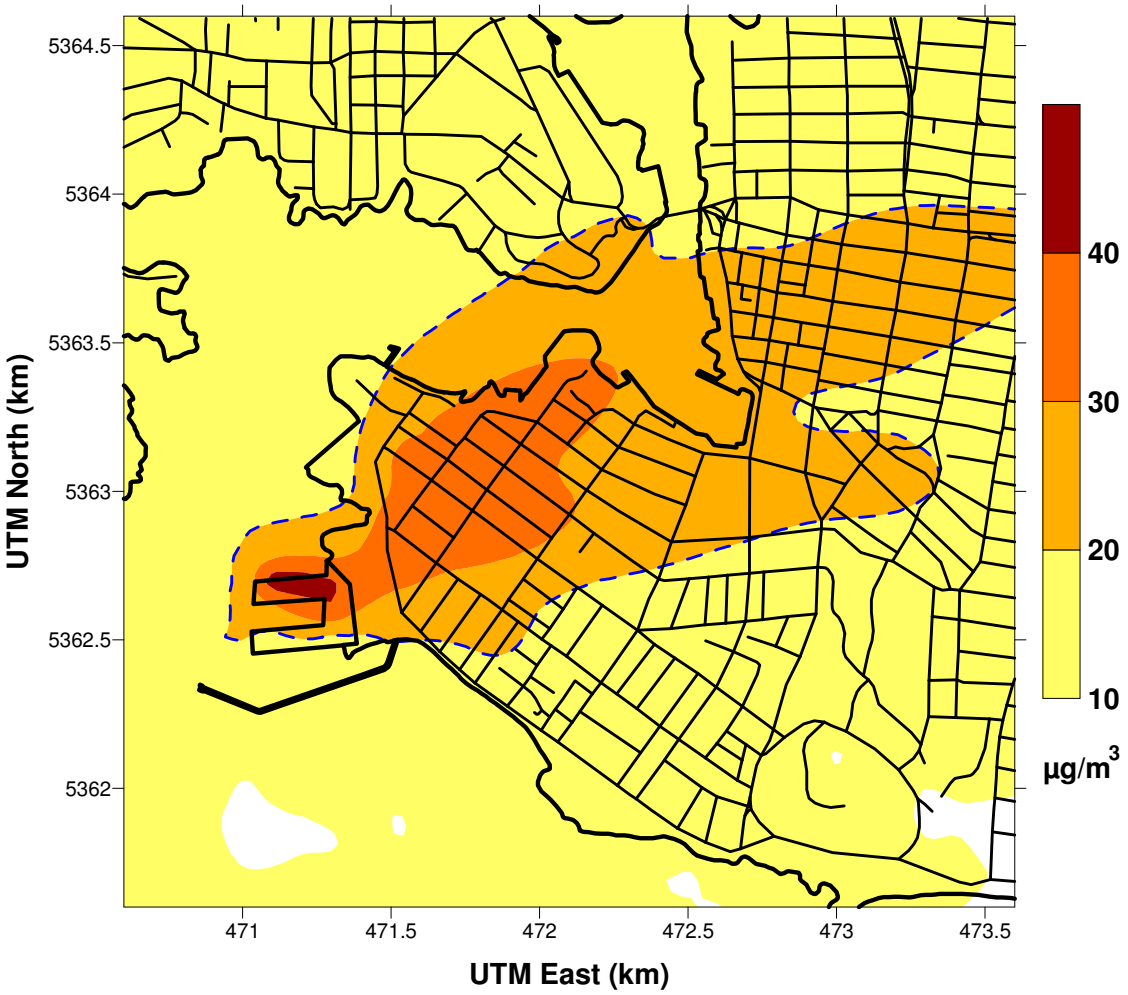


Figure 47. Maximum estimated 24-hour SO_2 concentrations (µg/m^3)

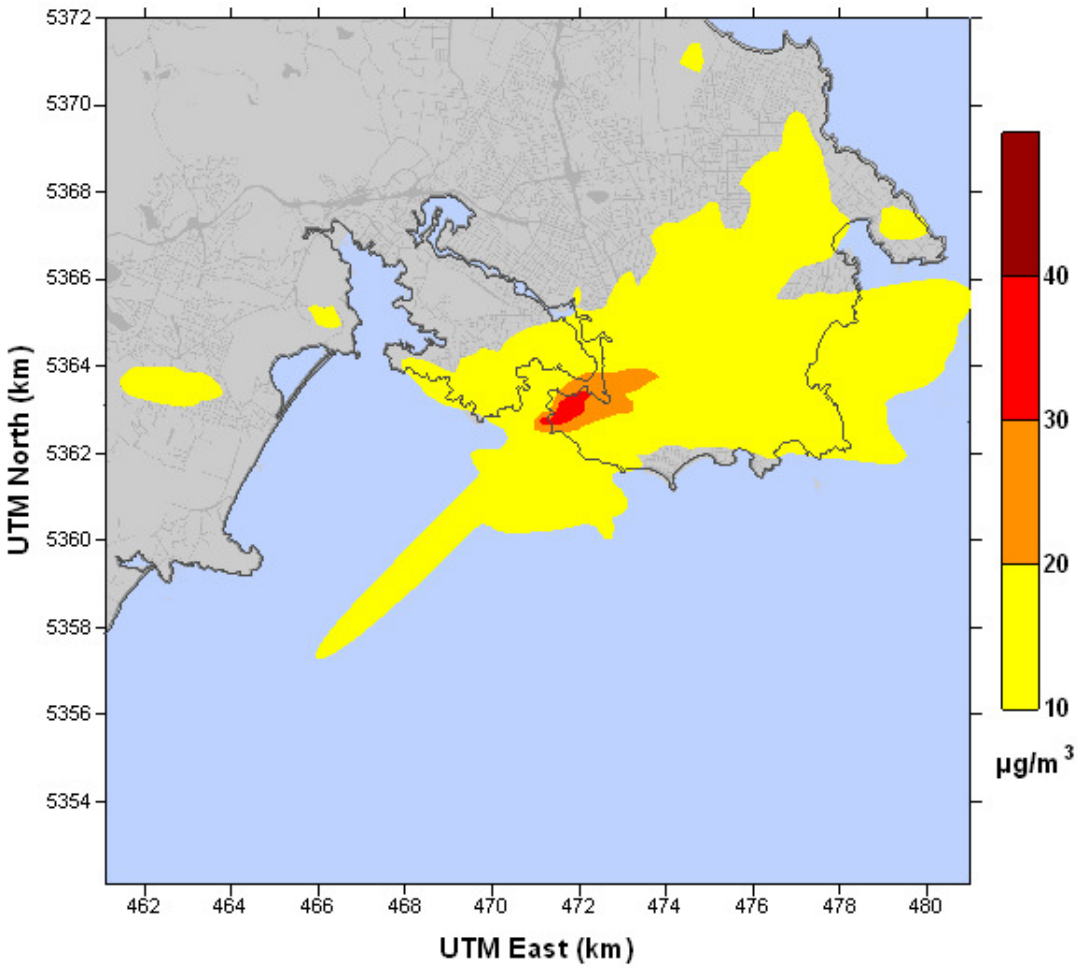


Figure 48. Estimated 24-hour SO_2 concentrations in the study domain

Time-series data calculated from the 25 receptor points in the James Bay community indicates that concentrations above 20 µg/m^3 occur for approximately 3% of 24-hour periods in the modeling time period (Table 41), which equates to approximately 5 days out of 194 modeled. The maximum 24-hour SO_2 concentration in James Bay was estimated to occur on May 11th, which is one of two days out of the season with the maximum number of ships in port over a 24-hour period (5 ships). The other day with 5 ships in port was September 22nd, and this day experienced the second highest 24-hour SO_2 concentrations in James Bay (40 µg/m^3).

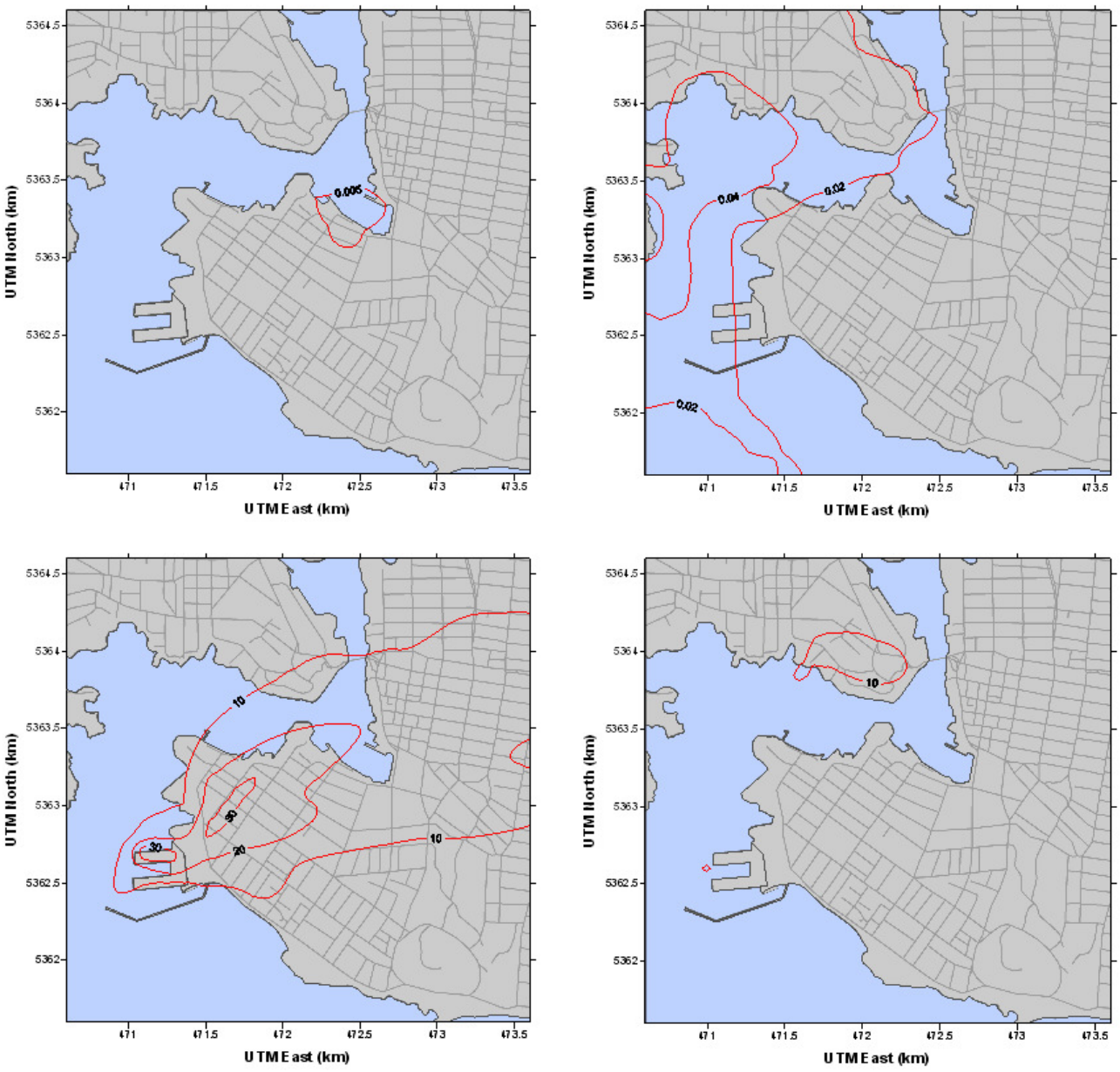
Table 41. Frequency distribution of estimated 24-hour SO_2 ($\mu g/m^3$) in James Bay

Percentile	Min	Max	Average (n=25)	Std. Dev
100th	12	41	25	10
99th	11	30	18	6
98th	10	23	16	4
97th	9	20	14	3
95th	8	16	12	3
90th	8	13	10	2
80th	8	10	9	1
75th	8	9	8	1
50th	7	7	7	0

The CALPUFF modeling approach used for this study allows each of the four source types modeled to be assessed individually to determine which may have the greatest contribution to maximum predicted values. The four source types simulated were: (1) ferries – berth; (2) ferries – transit; (3) cruise ships – berth, and; (4) cruise ships –transit. Individual maps for these sources (Figure 49), without the addition of background concentrations, show that cruise ships at berth are the dominant contributor to maximum 24-hour SO_2 concentrations. The maximum concentrations in James Bay from ferries at berth (0.01 $\mu g/m^3$) and in transit (0.04 $\mu g/m^3$) are lower than the maximums from cruise ships at berth (31 $\mu g/m^3$) and in transit (6 $\mu g/m^3$).

A. Ferries – berth

B. Ferries – transit



C. Cruise – berth

D. Cruise - transit

Figure 49. Individual source contributions ($\mu g/m^3$) to maximum 24-hour SO_2

4.3.4 Maximum 1-hour NO_2

The maximum 1-hour NO_2 concentration predicted in the study domain was 204 µg/m^3 and occurred in the Songhees region (Figure 50). This value just exceeds the CRD and WHO guidelines of a maximum of 200 µg/m^3 for a 1-hour period. Maximum estimated 1-hour NO_2 concentrations are lower in James Bay than the surrounding areas of Songhees and Downtown Victoria. Emissions of NO_x emitted from cruise sources is converted to NO_2 in the atmosphere, which explains why concentrations in a radius around the stack are lower than those a farther distance away.

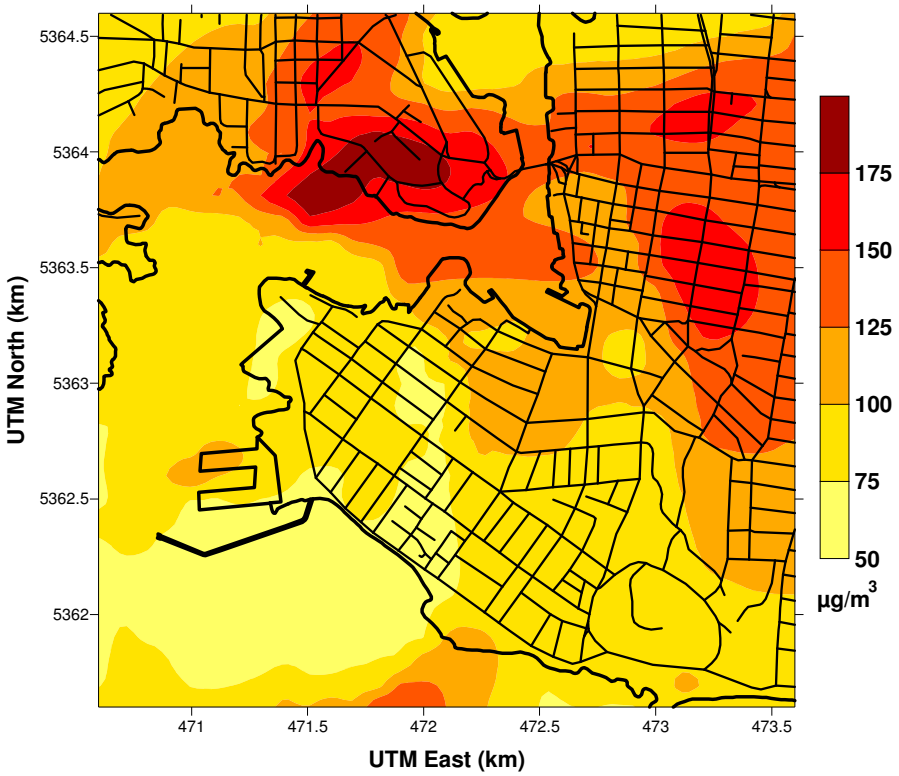


Figure 50. Maximum predicted 1-hour NO_2 concentrations (µg/m^3)

Time series data from discrete receptors in Songhees can be used to determine the frequency of concentrations above 200 µg/m^3 (Figure 44). The maximum recorded value in Songhees is limited to the 100th percentile concentration measured at one receptor site. Concentration levels at the 99th percentile are notably lower (70 µg/m^3); in fact, closer examination of the data reveals that concentrations above 200 µg/m^3 occur in only one out of 4656 hours in the modeling period, or less than 0.001% of the time. The 1-hour

period when this maximum predicted NO_2 concentration occurred was on July 1 from 0:00 to 01:00, following two cruise ship departures at 23:59 on June 30.

Table 42. Frequency distribution of estimated 1-hour NO_2 ($\mu g/m^3$) concentrations in Songhees

Percentile	Min	Max	Average (n=6)	Std. Dev
100th	149	204	168	24
99th	60	70	65	4
98th	56	61	59	2
97th	54	58	56	2
95th	52	55	53	1
90th	51	52	52	0
80th	51	51	51	0
75th	51	51	51	0
50th	51	51	51	0

Frequency distributions calculated for James Bay (Table 43) and Downtown Victoria (Table 44) also show similar values at the 99th percentile (74 $\mu g/m^3$ and 75 $\mu g/m^3$ respectively). Unlike Songhees, the 100th percentile concentrations in these locations do not exceed the CRD or WHO guidelines. For all three locations, 1-hour NO_2 concentration levels are equal to the background (51 $\mu g/m^3$) for 80% of 1-hour periods.

Table 43. Frequency distribution of estimated 1-hour NO_2 ($\mu g/m^3$) concentrations in James Bay

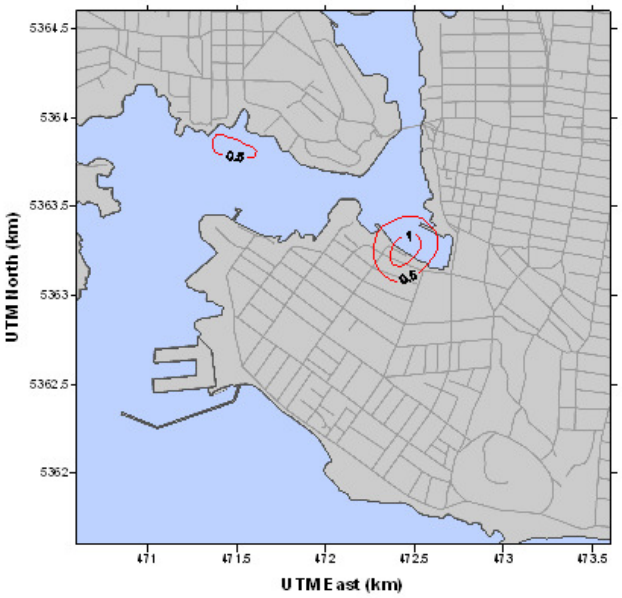
Percentile	Min	Max	Average (n=25)	Std. Dev
100th	71	122	93	14
99th	54	74	62	6
98th	53	65	57	3
97th	52	61	55	2
95th	51	57	53	1
90th	51	53	51	0
80th	51	51	51	0
75th	51	51	51	0
50th	51	51	51	0

Table 44. Frequency distribution of estimated 1-hour NO_2 ($\mu g/m^3$) concentrations in Downtown Victoria

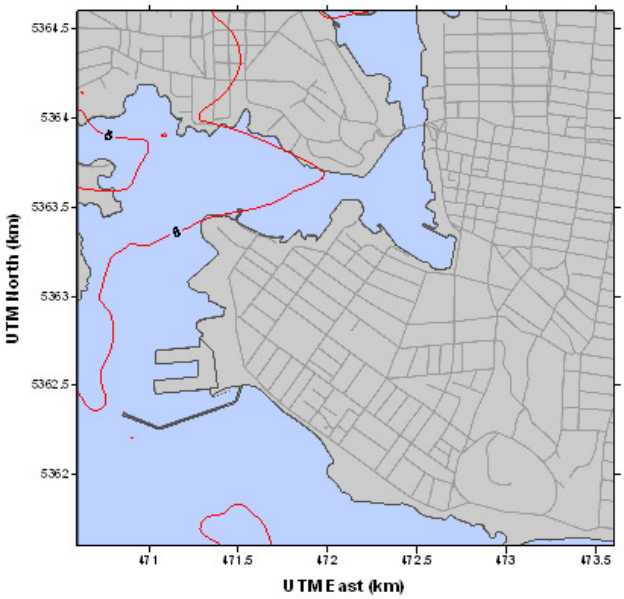
Percentile	Min	Max	Average (n=4)	Std. Dev
100th	124	148	137	10
99th	73	75	74	1
98th	62	65	63	1
97th	58	60	59	1
95th	54	56	55	0
90th	52	52	51	0
80th	51	51	51	0
75th	51	51	51	0
50th	51	51	51	0

Figure 51 displays individual figures of maximum 1-hour NO_2 concentrations from each of the four source types (in effect, combining these four maps and adding background would create the image in Figure 50). Ferries at berth and in transit minimally contribute to the maximum predicted 1-hour concentrations in James Bay (1 $\mu g/m^3$ and 5 $\mu g/m^3$, respectively), compared to cruise ships at berth and in transit have greater contribute greater predicted 1-hour concentrations in the study area (85 $\mu g/m^3$ and 57 $\mu g/m^3$, respectively).

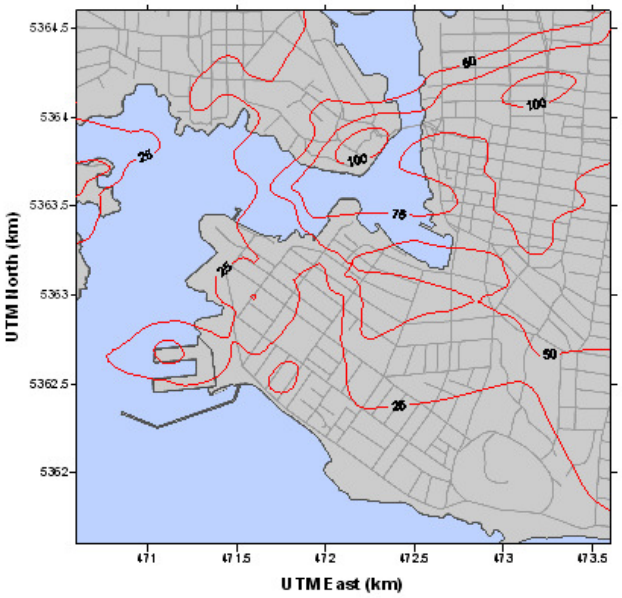
1. Ferries – berth



2. Ferries – Transit



3. Cruise - berth



4. Cruise – transit

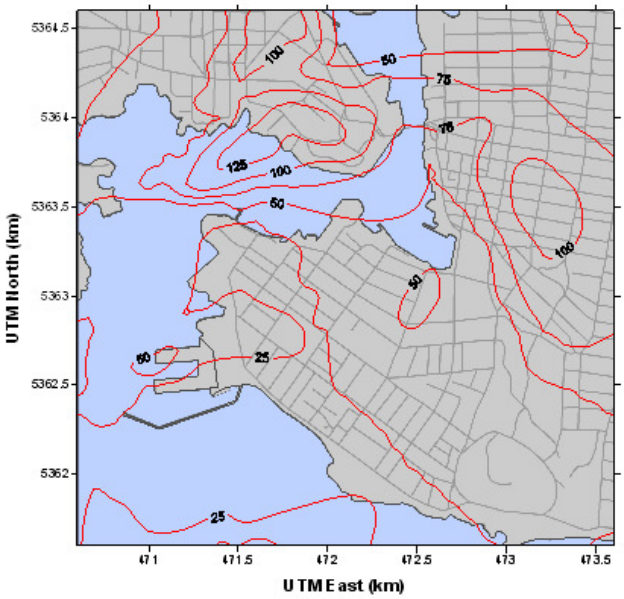


Figure 51. Individual source contributions (µg/m^3) to maximum 1-hour NO_2 concentrations

4.3.5 Meteorological Conditions during Periods of Maximum Concentrations

The stability of the atmosphere is defined as its tendency to resist or enhance vertical motion in the boundary layer. Convective, or unstable, conditions occur during the daytime. Vertical dispersion of pollutants is greatest under these types of conditions. Neutral conditions typically occur during day-night transition periods, overcast conditions or with strong winds. During neutral conditions, parcels of air tend to remain at constant levels once the forces causing movement have been removed. Stable conditions are generally experienced over land during clear nights with weak winds or when a ground-based temperature inversion is present. Vertical dispersion of pollutants is least effective during periods of stable atmospheric conditions.

Table 45 presents the five 1-hour periods in the modeling scenario which experienced the highest 1-hour concentrations of all pollutants, based on the 25 receptor point in James Bay. The greatest maximum predicted 1-hour concentrations occurred during stable, neutral/slightly stable, and neutral atmospheric stability conditions. Four of these maximums occurred at night between 22:00 – 0:00 when 2-3 ships were in port or departing. The other highest predicted 1-hour maximum concentration occurred approximately 2 hours before the scheduled time of departure in the afternoon during neutral atmospheric conditions when 2 ships were present at the Ogden Point berth.

Table 45. CALPUFF atmospheric stability conditions during 1-hour periods with maximum predicted concentrations of pollutants in James Bay

Date/Time		Max 1-HR* (µg/m^3) SO_2	NO_x**	PM_{10}	$PM_{2.5}$	Atmospheric Stability	Cruise Ship Activity
July 1	0:00	150	264	21	18	Stable	2 departures at 23:59 June 30
July 28	23:00	146	200	16	14	Neutral/Slightly Stable	2 departures at 23:59
Sept. 24	15:00	118	192	15	13	Neutral	2 ships in port
July 6	23:00	114	195	15	13	Neutral/Slightly Stable	2 departures at 23:59
June 2	22:00	112	187	15	13	Neutral/Slightly Stable	3 ships in port

***Maximum 1-hour concentrations are from incremental cruise/ferry sources ONLY (no background)**
****NO_x reported instead of NO_2. See JBAQS Phase II Report for further explanation.**

Table 46 presents the top five 24-hour periods in the modeling domain which experienced the highest concentrations of SO_2 (as well as all other pollutants), based on the 25 receptor points in James Bay. Only two days during the entire 2007 cruise ship season had a total of 5 ships berth at Ogden Point. These two days, May 11th and September 22nd, are the two days with the highest maximum predicted 24-hour concentrations. The three other days with maximum 24-hour concentrations occurred when only 2 ships were in berth.

Neutral atmospheric conditions were the most common on all days, followed by slightly stable and moderately convective for the majority of the 5 days in the table above. It is interesting to note that May 19th, a day with 4 cruise ships, did not rank among the maximum predicted 24-hour concentrations. On this day, the frequency distribution of stability conditions was 38% neutral, 25% moderately convective, 17% slightly stable, 13% slightly convective and 8% stable. A greater percentage of more convective atmospheric conditions on this day explain the lower concentrations than on other days with less cruise ships in port which have less-dispersive atmospheric conditions.

Table 46. CALPUFF atmospheric stability conditions during 24-hour periods with maximum predicted concentrations of SO_2

Date	SO_2 ($\mu g/m^3$)	Atmospheric Stability	Cruise Ship Activity	
May 11	41	54% Neutral 25% Slightly Convective 21% Moderately Convective	5 ships	Arrive – 7:00, 8:00 (2); 18:00, 19:00 Depart – 17:00, 18:00, 23:59 (3)
Sept. 22	40	58% Neutral 25% Slightly Stable 9% Stable 8% Slightly Convective	5 ships	Arrive – 7:00, 8:00, 17:00, 18:00 (2) Depart – 16:00, 17:00. 23:59 (3)
May 17	36	67 % Neutral 20% Slightly Convective 13% Moderately Convective	2 ships	Arrive – 7:30, 8:00 Depart – 17:00 (2)
Sept. 24	30	63% Neutral 17% Stable 8% Slightly Convective 8% Moderately Convective 4% Highly Convective\	2 ships	Arrive – 8:00 (2) Depart – 17:00 (2)
July 6	28	58% Neutral 21% Slightly Convective 13% Moderately Convective 8% Slightly Stable	2 ships	Arrive – 18:00, 19:00 Depart – 23:59 (2)

4.3.6 Model Performance Evaluation

Atmospheric dispersion models, such as CALPUFF, can be useful tools for air quality analyses where field monitoring is not available, or too expensive, to provide adequate information on the temporal and spatial variation of pollutants throughout a study domain. Results from air quality dispersion models, however, need to be assessed before they can be used with confidence (Borrego et al., 2008). Uncertainties in model output may exist due to errors in input data or model mathematics, or due to inherent uncertainty from to the random nature of turbulence in the atmosphere (Borrego et al., 2008) and this may introduce error into the results. There is no such thing as a "perfect" model (Borrego et al., 2008), and the margin of error associated with dispersion models is often larger than other engineering calculations (Turner and Schulze, 2007).

The United States Environmental Protection Agency (US EPA) has developed several statements which apply to the performance of their core air quality dispersion models, such as CALPUFF. These statements are provided below, as cited in the BC Air Quality Modeling Guidelines (MOE, 2008):

- Models are more reliable for estimating longer time-averaged concentrations than for estimating short-term concentrations at specific locations.

- The models are reasonably reliable in estimating the magnitude of *highest* concentrations occurring sometime, somewhere in the study area. For example, error in *highest* concentrations of ±10 to 40% are found to be typical (assuming appropriate inputs).

- Estimates of concentrations that occur at a specific time and site are poorly correlated with actual observed concentrations (paired in space and time) and are much less reliable.

- The above poor correlations between paired concentrations at fixed stations may be due to reducible uncertainties (i.e., error in plume location due to input wind direction error can resulting large differences) or un-qualified inherent uncertainties. Such uncertainties (which can be on the order of 50% for the maximum concentrations) do not indicate an estimated concentration does not occur, only that the precise time and locations are in doubt.

These statements are important to keep in mind, while also taking into account the quality and assumptions associated with the input data to the model. Sections 4.2.6.1 and 4.2.6.2

examined uncertainties related to input meteorological and emissions data, and acknowledged assumptions of the particular model configuration, respectively.

Often, the application or purpose of the modeling exercise will govern the required of accuracy of the model results, and the level of quality assurance and quality control (QA/QC) evaluation to be performed (Chang and Hanna, 2004). For many regulatory purposes, where compliance with air quality guidelines is of concern, models are required to estimate the highest or second highest concentrations over a certain time period (i.e. 1-hour, 24-hour or annual average) which occur somewhere in the domain (Turner and Schulze, 2007; Chang and Hanna, 2004). Other applications, such as toxic gas releases, may require more stringent temporal and spatial estimates of concentrations.

The most commonly used method to assess dispersion model output has historically been to compare predicted concentrations to actual measurements from fixed-site monitoring stations located in the study domain. For some studies, this is the only form of model evaluation, while others perform detailed sensitivity analyses and/or calculate an array of statistical quality indicators. There are currently no standard QA/QC procedures for evaluating dispersion model results (Borrego et al., 2008), and a large range in the quality and depth of assessments is present in the literature.

As cited in the disclaimer at the beginning of this thesis, this study does not perform sensitivity or detailed error analyses. In the case of this study, the Ministry of Environment's Topaz Station is the only suitable continuous fixed-site monitoring location in the study domain to use for model evaluation purposes, and QA/QC is limited to this one location. This station was selected as a discrete receptor point to be included in the model analysis; therefore, estimates of maximum 1-hour, 24-hour and average concentrations, including frequency distributions, predicted at this specific location can be compared to the actual concentrations which were measured. There are, however, missing data in the Topaz records during the 2007 cruise season. The data record is 94.3% complete for NO_2, 98.4% complete for $PM_{2.5}$, and 79.3% complete for SO_2. In some cases, missing records are attributable to monitor recalibration (missing 1 or two hours), but occasionally a larger period of time was absent (i.e. a few days). In the case of SO_2, records for the entire month of May are absent for reasons unknown to the author.

Table 47 and Table 48 compare the maximum 1-hour and 24-hour modeled concentrations, with and without the addition of a background estimate, to available data measured at the Topaz Station. The sources included in the model estimates include both the cruise ships and the ferries. The method for determining background is described in Section 4.2.8.

Comparing maximum concentrations without the addition of background assumes that peak concentrations at the Topaz site are attributable to only cruise ship and ferry sources. This assumption may be applicable for 1-hour SO_2, since marine sources are the only major source in the region. However, for other pollutants such as $PM_{2.5}$ of NO_2, which are largely produced by vehicular traffic, it is more appropriate to compare peak concentrations taking background into account. Also, for longer time periods SO_2 sources such as diesel buses may also contribute and should not be overlooked.

Table 47. Comparison of modeled to measured 1-hour concentrations at Topaz Station

Percentile	SO_2 (µg/m^3)		FAC	NO_2 (µg/m^3)		FAC	PM_{25} (µg/m^3)		FAC
	Model	Meas	(P/O)	Model	Meas	(P/O)	Model	Meas	P/O
No Background	48	88	0.5	60	77	0.8	5	69	0.1
With Background	61		0.7	111		1.4	21		0.3

Table 48. Comparison of modeled to measured 24-hour concentrations at Topaz Station

Percentile	SO_2 (µg/m^3)		FAC	NO_2 (µg/m^3)		FAC	PM_{25} (µg/m^3)		FAC
	Model	Meas	(P/O)	Model	Meas	(P/O)	Model	Meas	P/O
No Background	4	23	0.2	5	48	0.1	1	19	0.1
With Background	11		0.5	41		0.9	12		0.6

The CALPUFF model underestimated maximum 1-hour and 24-hour concentrations for all pollutants when the addition of background was not taken into consideration. When background is considered, the model then overestimates maximum 1-hour NO_2. Unlike SO_2 and $PM_{2.5}$ estimates, there is greater uncertainty associated with NO_2 concentrations, as NO_x must be converted to NO_2 using an external conversion method which relies on several assumptions (See JBAQS Phase II Report).

The FAC statistic reported in the tables above is the ratio of predicted to observed concentrations, calculated by dividing the predicted by the observed. The agreement of modeled to measured concentrations of air quality models is often compared by assessing if the agreement is within a factor of 2, or FAC 0.5 – 2.0, depending on whether the model under or over-predicts concentrations, respectively. This can be calculated for individual predicted/observed pairs, or for the percentage of the entire dataset. In the case of maximum 1-hour concentrations, the model is predicting within a factor of 2 for SO_2 and NO_2 with and without the addition of background, but not for $PM_{2.5}$ in either case. For maximum 24-hour concentrations, when background is taken into consideration, the model predicts within a factor of 2 for all pollutants. In all cases, with the exception of 1-hour NO_2, the model is under predicting.

It is possible that the current model configuration is not adequately characterizing cruise ship and ferry sources. It is also likely that other emission sources are contributing to maximum concentrations measured at the Topaz Station. In the case of NO_2 and $PM_{2.5}$, vehicular traffic is a major source, particularly since Topaz is located along a busy roadway. For SO_2, large diesel buses may be an important contributing factor at the Topaz Station. Other sources, such as large marine vessels in offshore shipping lanes may also be contributing to SO_2 emissions in the Victoria region.

4.4 Discussion

The use of CALPUFF to model cruise ship and ferry sources in James Bay and the surrounding region allowed shorter (1-hour and 24-hour) and longer (season average) time periods to be examined, over a more finely resolved study domain than that captured by regulatory monitoring stations (20 km^2 study domain with 200 x 200 model grid cells as opposed to CRD network with 3-4 stations for the same area).

The CALPUFF model uses meteorological inputs from the study area to estimate hourly three dimensional winds in every grid cell, and uses these to estimate the dispersion of pollutants throughout the domain. Another benefit of the modeling analysis is that contributions from individual sources can also be examined, as was the case for the four source types in this study (ferries – berth and transit; cruise ships – berth and transit). Field monitoring merely captures information on emissions at a given site, regardless of

the source, and requires speculative analysis of wind data to determine where the emissions came from (unless there is a specific detectable marker in the emissions which can specify the exact source). Modeling allows determination of concentrations in all areas specific to any source included in the model.

When compared to measured concentrations at the Topaz Station, the model was found to under-predict peak concentrations of all pollutants (SO_2, NO_2, and $PM_{2.5}$). There are several reasons which may explain the under-prediction of modeled concentrations at the Topaz Site. First, small variations in predicted wind speed and directions may have a large influence on whether the peak concentration is detected at a specific receptor point downwind, or whether it is missed entirely yet does occur at another nearby location. Comparative wind rose analysis at the EGD station showed that while the overall pattern of winds appeared reasonable, there were slight differences that did exist. Secondly, assumptions made when configuring cruise ship and ferry sources in the model may have affected the results. Assumptions about fuel quality or manoeuvring time and emission rates may explain some of the discrepancies. Comparing total modeled emissions at berth and for manoeuvring/underway from this study to that of the 2005/2006 BC Chamber of Emissions Inventory showed better agreement with emissions while at port, than for the transiting counterpart for which greater assumptions were required. A third reason may also be that there are additional SO_2 sources which are being detected at the Topaz Station. One possible source might be diesel tour buses which travel along Blanshard Street past the Topaz site. Another suggested source is passing ship traffic in the nearest shipping lane approximately 2.5 km off the coast of Victoria in the Strait of Juan de Fuca.

To explore the possibility of offshore ship emissions influencing concentration levels measured at Topaz, a database extraction was performed by SENES Consultants Limited from the BC Chamber of Shipping 2005/2006 Marine Emissions Inventory for a 5 km long section of the nearest ship traffic lane (Figure 52). Although a longer section of this lane has the potential to influence air quality in James Bay, a full accounting of these emissions was beyond the scope of the JBAQS, or this thesis research. The extraction results show that approximately 3200 ships used this traffic lane in the year, with the

maximum month of activity (within the cruise season) being September, with 298 ship transits. The average ship characteristics for these 298 vessels are as follows:

- Main engine size and fuel sulphur: 20,616 kW, 2.6%;
- Effective auxiliary power underway and fuel sulphur: 821 kW, 2.1%;
- Boiler fuel consumption underway and fuel sulphur: 0.16 tonnes/hr, 2.4%

On a monthly average emissions (September) basis, the COSBC inventory emission rates (g/s) for this section of the near shipping lane are 4.5, 6.8, 0.6 and 0.5 for SO_x, NO_x, PM_{10} and $PM_{2.5}$, respectively. The highest 1-hour emissions were estimated to be 41.8, 54.6, 5.4 and 5.0 g/s respectively. These emissions are associated with the passing of three large ships (2 container vessels and 1 bulk carrier) during the same hour. A comparison of the estimated emissions from the 5 km length of shipping lane to the emissions from the sources represented in the dispersion model is provided in Table 49.

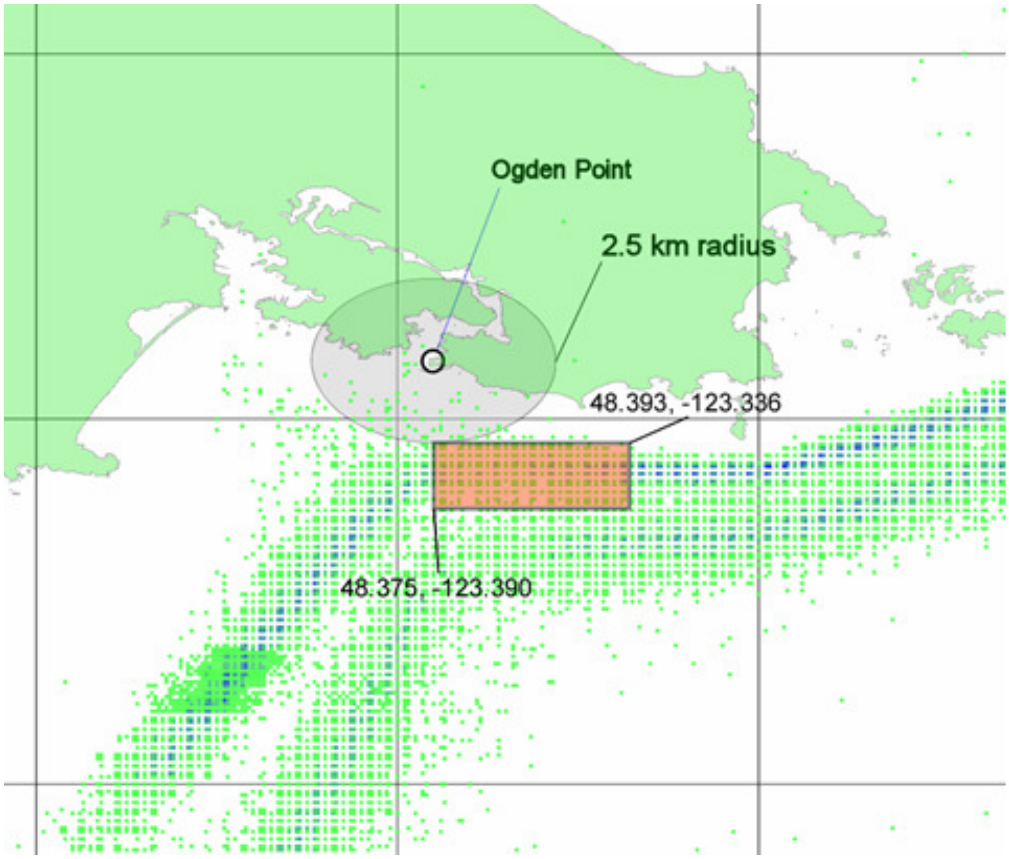


Figure 52. Database extraction of 5 km length of shipping lane off the coast of Victoria

Table 49. Comparison of estimated emission rates (maximum and average hourly) from cruise ships in study area and passing ships in offshore shipping lane

Activity		Hourly Emissions (g/s) SO_x	NO_x	PM_{10}	$PM_{2.5}$
Maximum Hourly Emissions					
Cruise Ships (at and near Ogden Point)	Berth (point source)	52.7	89.3	7.1	6.1
	Manoeuvre/Transit (line source)	23.9	42.8	3.3	2.9
5km Shipping Lane	Transit*	41.8	54.6	5.4	5.0
Average Hourly Emissions					
Cruise Ships (at and near Ogden Point)	Berth (point source)	3.7	6.1	0.5	0.4
	Manoeuvre/Transit (line source)	0.49	0.86	0.07	0.06
5km Shipping Lane	Transit**	4.5	6.8	0.6	0.5

*Maximum estimated hourly emissions in September, due to three ships passing through the shipping lane in one hour.
** Average hourly emission rates during September.

The maximum estimated hourly emission rates from the 5 km stretch of shipping lane nearest James Bay are lower than the maximum modelled emission rates due to cruise ship activity at and around the Ogden Point terminal. In addition, the shipping lane is situated at a greater distance from James Bay. For these reasons, the shipping lane does not have a similar potential for causing relatively high 1-hour ambient concentrations of air contaminants in the community. However, these offshore emissions likely do influence longer term (background) ambient concentrations in James Bay, and at the Topaz Station.

Cruise ships at berth were found to be most influential emissions source of the 4 source types modeled. The M.V. Coho and Victoria Clipper ferries use fuel with much lower sulphur contents than cruise ships that port at the Ogden Point terminal, and they do not idle their engines while they are stationary at berth because they have available shoreside power hookups. These are two major reasons which explain why this source was not seen as a major contributor to maximum emissions, unlike the cruise ships which use higher sulphur content fuel and continuously run their boiler engines while in port.

Cruise ships may sit at the Ogden Point terminal for up to 16 hours, and while transit times are relatively short in comparison to this (10 minutes of activity on average, spread out over the 1-hour model time step), the higher engine emissions activity of main propulsion engines for manoeuvring can contribute comparable maximum 24-hour concentrations.

4.5 Conclusion

The objective of this study was to estimate ambient concentration levels of SO_2, NO_2 and particulate matter (PM_{10} and $PM_{2.5}$) in the James Bay neighbourhood and surrounding region of Victoria, from large marine emissions sources such as cruise ships at the Ogden Point terminal and the M.V. Coho and Victoria Clipper ferries in the Inner Harbour. To accomplish this, the California Puff (CALPUFF) air quality model was used to perform meteorological and emissions simulations from these sources for the 2007 cruise ship season, and provide estimates of maximum 1-hour, 24-hour and average concentration levels throughout a 20 km^2 study domain centered on the Ogden Point terminal.

Challenges encountered in the modeling exercise included how to best configure a moving source such as a ship, as well as manoeuvring times and variable emission rates of cruise ships while at berth. Considering the necessary assumptions which had to be made about modeled sources, quality assurance assessments performed on meteorological and emissions outputs indicated that the model did provide reasonable results comparable to other modeling studies. There was also some indication that an additional SO_2 source, such as offshore shipping lanes, may also contribute to longer term concentration levels in the region.

Meteorological conditions were found to have an important influence on emissions estimates. Highest maximum 1-hour concentration levels tended to occur during more stable or neutral time periods with 2 to 3 ships in port, rather than during more convective daytime periods with the same numbers of ships present. Maximum 24-hour periods were found to be most influenced by having a large number of ships in port (the highest 24-hour concentrations occurred on those 2 days that had a maximum of 5 ships), followed by days which were dominated by neutral rather than convective atmospheric conditions.

Estimates of maximum 1-hour, 24-hour and average concentrations predicted by the model were compared to current ambient air quality standards and guidelines established locally by the CRD, provincially, nationally and internationally by the World Health Organization. Maximum 1-hour NO_2 and 24-hour SO_2 were the only cases where guidelines were met or exceeded. In the case of 1-hour NO_2, concentrations in Songhees (204 $\mu g/m^3$) just reached the CRD and WHO guideline of 200 $\mu g/m^3$; however, this was found to be a very rare occurrence (less than 0.001% of the time). For 24-hour SO_2, the WHO guideline of 20 $\mu g/m^3$ is exceeded infrequently (on approximately 3% of 24-hour periods) in a large area of James Bay and Downtown Victoria. The WHO guideline is quite stringent when compared to the equivalent CRD, BC and Canadian guidelines (125, 160 and 150 $\mu g/m^3$, respectively). The origins of each regulatory guideline and its overall relationship to the protection of human health must be reviewed by the Vancouver Island Health Authority prior to a statement about potential health implications associated with estimated emissions from this modeling study.

Chapter 5

Final Discussion and Conclusions

A combination of field monitoring and air quality modeling was used in this research to characterize air quality in the James Bay neighbourhood of Victoria, BC. Field monitoring provided long-term average concentration levels throughout the study area; this method provides "real" measurements which actually occurred in James Bay, from all emissions sources operating in the area. Alternatively, air quality modeling was used to predict concentration levels throughout the area at shorter time periods (1-hour and 24-hour) than that examined by field monitoring. The model focused on cruise ship and ferry emissions, with an estimate of background concentrations from all other sources based on measurements from a nearby regulatory monitoring site. These two methodologies compliment each other well- a relatively inexpensive monitoring campaign provides not only baseline data quantifying the existing level of air quality, but also measurements which can be compared to the dispersion model for verification, and the model is able to examine concentrations at spatial and temporal resolutions prohibited by the monitoring methodology.

Results from field monitoring, however, only represent long-term average concentrations throughout the study area. Comparisons made to modeled results can therefore only be compared to the predicted average concentrations, which the model is capable of estimating in addition to shorter-term 1-hour and 24-hour values. Average concentration levels measured by field monitoring correspond well to estimated levels predicted by the CALPUFF model (Table 50). Field samplers used in this study provide an average value of concentration levels at the specific site which they were located at, and the range of these from all sample sites are compared to the maximum average

concentration modeled within the James Bay community. Levels of PM_{10} were not measured as part of the field monitoring campaign and cannot be compared to the average modeled concentrations.

Table 50. Comparison of average concentrations ($\mu g/m^3$) measured to the maximum average modeled in James Bay

	Average Measured (range)	**Maximum Average Modeled**
SO_2	1 – 5	4
NO_2	4 – 24	22
PM_{10}	-	6
$PM_{2.5}$	1 – 7	5

This comparison of measured to modeled concentrations in James Bay displays better agreement than the model evaluation exercise comparing 1-hour and 24-hour measured to modeled levels at the Topaz Station. As previously discussed, there are several reasons which may explain the poor agreement at the Topaz site, such as small differences in predicted wind speed and direction than what occurred in reality, the specific configuration of the emission sources in the model (uncertainties about sulphur content of fuel, line source configuration, etc.), or sources unaccounted for in the model, such as offshore shipping in the Strait of Juan de Fuca or diesel buses operating in the area. Based on statements made by the USEPA about the performance of air quality models, and the level of agreement found between measured and modeled concentrations in this study, it can be assumed that the CALPUFF model used in this research is providing a reasonable performance, particularly based upon model configuration and required assumptions.

Long-term concentrations taken throughout the James Bay community correspond well to modeled concentrations for the same area. Comparing the modeled average at Topaz over the modeling period compared to the average measured (no background included) underestimates concentrations (Table 51) like the comparison for 1-hour and 24-hour.

Table 51. Comparison of average measured to modeled concentrations ($\mu g/m^3$) at Topaz

	Measured	Modeled
SO_2	2	0.20
NO_2	21	0.28
PM_{10}	-	0.03
$PM_{2.5}$	4	0.02

It was expected that maximum concentrations of NO_2 and $PM_{2.5}$ would be underestimated by the model when comparing to Topaz, as there are so many additional sources of these emissions impacting concentrations at this site. The evaluation comparison made in Chapter 4 was conducted with and without background due to an interest in comparing the agreement between the peak SO_2 concentrations predicted by the model. The estimated contribution of non-marine sources to SO_2 in the region was considered to be quite low, based on the CRD emissions inventory (SENES, 2006) for SO_2 sources in the area (no industrial sources, 97% of SO_x estimated to be from marine vessels), and therefore the spikes in concentrations would be due to marine emissions. If an additional regional source was affecting background concentrations of SO_2 at the Topaz site, then it is possible that accounting for this background would improve the agreement between the measured and modeled maximums at the Topaz site

Further analyses experimenting with different model configurations could be conducted to determine how parameters such as sulphur content of fuel, manoeuvring time, or source type (line as opposed to a series of points to represent moving ships) affect the community level concentrations, and if they improve the agreement with the Topaz site. A modeling effort to estimate concentrations in Victoria from offshore shipping could also be conducted, to determine what influence emissions from these sources have on the nearby James Bay community, and other areas of Victoria.

Emissions inventories, such as that conducted by the BC Chamber of Shipping, are important because they provide estimated total emissions from marine sources in coastal areas. This type of estimate, while a proxy for the level of air quality (particularly when compared to totals emitted in other areas), does not indicate how pollutant concentrations are dispersed throughout coastal areas or how local air quality is affected. As noted by Corbett (2004), the relationship between ship emissions and local air quality

is not well-quantified. This study represents an attempt to fill the knowledge gap identified by Corbett, by estimating how emissions from vessel stacks are carried throughout a coastal region by local meteorological conditions. As more modeling efforts are conducted to estimate emission from ship sources, a better methodology for modeling this particular source (i.e. the challenge of representing a moving ship, variable emissions while at dock) can be developed. This study presents one way of characterizing ships as lines while in transit and as points while at berth; other model configurations may be developed in the future. This study contributes to the field of air quality modeling and marine emissions by developing one characterization method.

This thesis successfully answered the following research questions that were established to characterize air quality in James Bay, and to investigate the impact of large marine vessels on community air quality levels:

(1) What were the maximum 1-hour, maximum 24-hour and full-season average concentration levels of NO_2, SO_2, PM_{10} and $PM_{2.5}$ in James Bay during the 2007 cruise ship season?

The CALPUFF air quality model was able to predict the maximum 1-hour, 24-hour and average concentration levels experienced in the James Bay community, and at other areas within the 20 km^2 study domain centered on Ogden Point. Field monitoring, while limited to average long-term concentrations contributed to the research by providing actual observed concentration levels measured in the region, which were found to correspond with model predictions. The concentration levels for these 4 pollutants and time periods are presented in the format of a table, and as maps with corresponding frequency plots. Although this thesis focused detailed results only on 24-hour SO_2 and 1-hour NO_2, the Phase II Air Quality Modeling report provides complete information on all pollutants and time periods. The two JBAQS reports, (field monitoring and modeling) quantify air quality in James Bay, and establish a baseline of concentration levels which can be referred to during any future ongoing studies into air quality in the area.

(2) Do maximum emissions exceed established air quality standards and objectives? And, if so, with what frequency?

Monitoring and modeled results were compared to 4 air quality standards and guidelines: 1) local CRD management guidelines, 2) Provincial BC air quality guidelines, 3) Canadian National Ambient Air Quality Objectives, and 4) World Health Organization Air Quality Guidelines. This research found that infrequent exceedences of certain air quality guidelines occurred in the study domain. The WHO 24-hour SO_2 guideline of 20 $\mu g/m^3$ for a 24-hour period was exceeded in 3% of 24-hour periods, and the CRD and WHO guideline of 200 $\mu g/m^3$ for 1-hour NO_2 less than 0.001% of the time. The potential implications of these exceedences on the health of residents of the area will be assessed by the consultant appointed by VIHA, as well as include a review of the current air quality standards and guidelines. In addition, estimated concentrations of all pollutants should be examined, to determine if concentration levels for pollutants without established guidelines have potential implications.

(3) Which pollution sources (cruise ships or ferries) are the main contributors to emissions?

The dispersion modeling analysis allowed each source in the model (cruise – berth & transit, ferries – berth & transit) to be analyzed separately. While Chapter 3 presented maps of emissions from each source type only for those pollutants and time periods found to exceed air quality guidelines (24-hour SO_2 and 1-hour NO_2), Table 52 compares the maximum estimated concentration to occur in James Bay from each source type for each time period.

Cruise ships at berth are the main contributors to maximum concentrations in James Bay. Ferries contribute minimal amounts in comparison to their cruise ship counterparts, which is largely explained by the lower sulphur fuel they use, and because they have shoreside power available at dockside. The transit activities of ferries contributes higher concentrations than while at berth, as transiting requires greater engine use which accounts for higher emissions than the minimal use of auxiliary engines at port.

Cruise ships at berth, on the other hand, contribute higher emissions than their transit activities. Cruise ships spend a large amount of time idling at berth, explaining why the difference between berth and transit emissions is more pronounced when examining longer periods of time (24-hour or average) than the 1-hour emissions, where cruise transit can have almost an equal impact on maximum concentrations experienced in the community.

Table 52. Source contributions to ground level maximum 1-hour, maximum 24-hour and average concentrations in the James Bay Community (no background included)

SO_2 (µg/m^3)

Source	1-hour	24-Hour	Period-Average
Ferries – berth	0.11	0.01	0.001
Ferries – transit	0.50	0.04	0.004
Cruise – berth	150.71	31.19	1.510
Cruise - transit	128.90	6.38	0.420

NO_2 (µg/m^3)

Source	1-hour	24-Hour	Period-Average
Ferries – berth	1.27	0.14	0.012
Ferries – transit	4.56	0.35	0.035
Cruise – berth	85.13	16.11	0.790
Cruise - transit	56.61	3.24	0.123

PM_{10} (µg/m^3)

Source	1-hour	24-Hour	Period-Average
Ferries – berth	0.17	0.02	0.002
Ferries – transit	0.61	0.05	0.005
Cruise – berth	19.71	4.18	0.200
Cruise - transit	17.77	0.88	0.060

$PM_{2.5}$ (µg/m^3)

Source	1-hour	24-Hour	Period-Average
Ferries – berth	0.16	0.02	0.002
Ferries – transit	0.57	0.04	0.004
Cruise – berth	16.38	3.54	0.170
Cruise - transit	15.34	0.76	0.050

(4) During what meteorological conditions do these maximum concentrations occur?

Meteorological conditions were examined for the five 24-hour and 1-hour periods experiencing highest predicted concentration levels in James Bay. The highest 24-hour concentrations were found to occur on days which had a maximum number of 5 cruise ships in port, independent of meteorological conditions. Following these two days, meteorology then appeared to influence the 24-hour concentration levels, as the remaining three top 24-hour periods only had 2 ships in port. Other days with greater numbers of ships in port, such as the example provided of May 19th with 4 ships, experienced more convective atmospheric conditions than the days with 2 ships which were dominated by neutral conditions. Four of the five maximum 1-hour concentration periods occurred between 22:00 and 0:00 during stable, slightly stable or neutral atmospheric conditions, when 2 or 3 ships were either in port just prior to, or when departing. During these conditions there is very little vertical dispersion of pollutants throughout the atmosphere to mix pollutants.

The GVHA is currently planning a $4.5 million expansion of its mooring facility at Ogden Point to accommodate a new, larger "Freedom" class of cruise ships that is part of the Royal Caribbean line. The passenger capacity of these new cruise ships are double those which currently port at Ogden Point. The GVHA is planning to extend the existing pier by 70 meters in order to accommodate the 160,000 tonne vessels, which are so large they cannot fit under the Lion's Gate Bridge or currently travel through the Panama Canal (Weatherbe, 2009). Cruise traffic is not likely to decrease in coming years, but likely to remain at current levels and potentially begin to attract new vessels such as the Freedom class. The 2009 cruise ship season has 215 scheduled cruise visits and displays similar patterns in weekly arrivals (majority on Thursdays, Fridays, and Saturdays), as well as times of arrivals and departures (most leaving at 23:59). A noticeable difference in the 2009 cruise schedule compared to previous years is no days with 5 scheduled cruise ship visits, but rather more a greater number of days with 4 or 3 ships (3% and 9% increase, respectively, from 2008 levels).

The amount of money which the GVHA plans to invest in expanding the Ogden Point pier and upgrading the facility are comparable to that which has been invested in Juneau, Alaska, and Seattle, Washington, for installing shoreside power. The two main cruise liners visiting Victoria are Princess Cruises and Holland America Line, which both have cold-ironing capabilities. Although this research did not focus on evaluating the feasibility of shoreside power in Victoria, it is one option which should be taken into consideration if current air quality is considered to pose potential health risks to local residents, or if future increases in ship numbers and scheduling begin to have negative impacts on air quality in the area.

With the installation of shoreside power, emissions from cruise ships while at dock would be reduced- the total emissions are not eliminated completely, as approximately half-an-hour of idling at berth would still occur upon arrival and departure while hooking up and unplugging from the power. The main emissions from this source would instead be dominated by transit emissions. In the case of 24-hour SO_2, this might effectively eliminate the predicted exceedences of the WHO (see Figure 49 D). It would likely also reduce the 1-hour NO_2 emissions to a level below the CRD and WHO guideline (Figure 51 D). Further modeling analysis, with configuration for a shoreside power scenario would be required to determine this with certainty, yet it appears that this is an option which could be adopted in Victoria to reduce emissions from ships should current or future levels be deemed unacceptable.

The main purpose of this research was to quantify the level of air quality in James Bay, and investigate the contributions of emissions from large marine sources, like cruise ships and ferries, to community level concentrations. Field monitoring, although limited to longer-term average concentrations, was also designed to investigate if a cruise ship signal could be detected in measured levels. Differences in meteorological conditions between sampling periods presented a challenge in conclusively determining that concentrations of NO_2, SO_2 or $PM_{2.5}$ were on average higher on days with cruise ships in port, although there was some evidence this did occur during one period when conditions were favourable. Levels of vanadium (metal associated with heavy marine diesel fuel) were also found to be higher on cruise ship days in the study area, and surrounding regions of the airshed, indicating that the presence of these sources is detectable. In

addition, hourly measurements from the Topaz Station displayed elevation concentrations of NO_2 and SO_2 on days with cruise ships in 2006, and SO_2 in 2007.

Detailed air quality modeling of cruise ship and ferry sources provided more detailed information about the maximum 1-hour, 24-hour and average concentration levels expected to occur in the James Bay community, and also which of these sources were the main contributors. Cruise ships were found to be a greater source than ferries burning cleaner fuel and plugging into shoreside power at port. Predicted emissions from the modeling analysis were found to infrequently exceed certain air quality guidelines and standards. Whether this has implications for the health of residents in the region will be determined by an air quality and health expert appointed by the Vancouver Island Health Authority as part of Phase III of the JBAQS.

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Appendix A

Ogawa Passive Diffusion Samplers: Technical Details

Ogawa passive samplers[4] were used to measure long-term average levels of NO, NO_2 and SO_2 in the study area. These samplers are 'passive', meaning that they simply absorb pollutants from the surrounding air, and therefore require relatively long exposure times, on the order of 14 days. Table 53 displays the lowest detectable range of NO_2, NO_x and SO_2 for the Ogawa samplers based on 24-hour and 168 hour exposures; in this research samplers were exposed for 336 hours and therefore the 168 hour levels are applicable. While Ogawa results were reported in parts per billion (ppb) from the laboratory analysis, these values have been converted into average micrograms per cubic meter ($\mu g/m^3$) per hour of sampling, assuming a temperature of 20 degrees Celsius and 1 atmospheric pressure.

Table 53. Lowest detectable range of Ogawa Samplers

Pollutant	**24 hr ($\mu g/m^3$)**	**168 hr ($\mu g/m^3$)**
NO_2	4.4	0.6
NO_x	4.4	0.6
SO_2	10.0	1.0

Field blanks and duplicate samplers were used in all sampling periods for quality control purposes. Field blanks were used to determine how transport and handling may have affected sampler concentrations. Table 54 displays the levels detected on the field blank from each sampling round. Within each sampling period, field blank values were

[4] http://www.ogawausa.com/passive.html

subtracted from the results at each sample site (i.e. the values displayed in all tables in this thesis are blank adjusted).

Table 54. Field blank concentrations ($\mu g/m^3$)

Sampling Period	#	NO_2	NO	NO_x	SO_2
May (5 blanks) *Period A*	1	0.8	0.6	1.3	0.0
	2	0.8	0.4	1.1	1.3
	3	0.6	1.7	2.3	0.8
	4	0.6	0.8	1.3	1.1
	5	0.8	0.6	1.3	1.1
June/July (1 blank) *Period B*	1	1.5	1.9	3.4	2.1
August/September (1 blank) *Period C*	1	1.9	4.6	6.5	0.5

Duplicate samplers were deployed to assess the precision of the Ogawa sampling technique. One set of duplicate samplers was deployed for the June/July sampling round, and two for the August/September round. The relative percent difference between each set of duplicates (one set for the June/July period, and two for August/September) are presented in Table 55 and Table 56.

Table 55. Relative percent difference between Ogawa Samplers (*Period A*)

	Duplicate Values ($\mu g/m^3$) (Relative Percent Difference)*		
Sample Number	NO_2**	NO	SO_2***
1	8.7 and 9.2 (6%)	13.0 and 13.6 (5%)	0.5 and 0.0 (200%)
2	5.4 and 6.4 (17%)	10.0 and 11.4 (13%)	0.8 and 0.0 (200%)
3	2.5 and 4.1 (49%)	8.5 and 10.0 (16%)	0.0 and 0.0 (0 %)
4	4.3 and 4.4 (2%)	6.2 and 7.0 (12%)	0.0 and 1.6 (200%)
5	3.0 and 4.1 (5%)	5.4 and 5.7 (5%)	0.2 and 0.0 (200%)

*Relative Percent Difference: the absolute difference between the two results for a duplicate pair, divided by the average result, and multiplied by 100 to express as a percentage

**NO_2 values were reported ± 15% although one sampler read anomalously higher than the others

*** SO_2 values appear to be below or at the limit of detection, so relative percent difference is less meaningful. SO_2 levels in May are reported as +/- 50%, in keeping with June/July and August/September samples.

Table 56. Relative percent difference between duplicate Ogawa Samplers for *Period B* and *Period C*

Sampling Period	Duplicate Values (µg/m^3) (Relative Percent Difference)* NO_2	NO	NO_x	SO_2
June/July (1 duplicate)	6.7 and 6.4 (5%)	6.9 and 7.1 (3%)	13.6 and 13.5 (1%)	2.9 and 2.4 (19%)
August/September (1 duplicate)	13.4 and 14.9 (11%)	15.5 and 14.3 (8%)	29.0 and 29.2 (1%)	0.5 and 0.8 (46%)

*Relative Percent Difference: the absolute difference between the two results for a duplicate pair, divided by the average result, and multiplied by 100 to express as a percentage
NO_2 values were reported ± 10%, NO values were reported ± 10%, SO_2 values were reported ± 50%

The June/July sample set was found to be more precise, with relative percent differences ranging from 1 percent for NO_x to 19 percent for SO_2. The August/ September sample set had relative percent differences ranging from 1 percent for NO_x to 46 percent for SO_2. There was a large difference in precision for SO_2 between the two sampling periods, and many of the samples from the second round measured levels at or near the detection limit. Details of the exact dates and times samplers were exposed are provided in Table 57, Table 58 and Table 59.

Table 57. $NO_2/NO_x/NO$ and SO_2 sampling times and dates for May (*Period A)*

Site	Street	Distance from curb (m)	OPEN – May 22	CLOSE – June 6
A-01	Superior	0.0	11:26	10:10
A-02		14.7	11:20	10:04
A-03		25.1	11:12	10:01
A-04	Montreal/Dallas	18.0	11:49	10:18
A-05		54.3	11:57	10:23
A-06		76.4	12:09	10:28
A-07	Niagara	0.0	12:51	10:54
A-08		24.7	13:00	10:58
A-09		51.9	1:14	11:02
A-10	Lewis/Dallas	9.4	12:36	10:44
A-11		31.0	12:29	10:41
A-12		55.8	12:22	10:37
A-13	Heather/Toronto	30.0	1:32	11:15
A-14		46.9	1:26	11:10
A-15		79.6	1:39	11:19

Table 58. $NO_2/NO_x/NO$ and SO_2 Sampling times and dates for June/July (*Period B*)

PERIOD A	NON-CRUISE			CRUISE		
SITE	Open	Close	Total Minutes	Open	Close	Total Minutes
B-01	6/17/07 1:15 PM	6/21/07 1:18 PM	5763	6/15/07 1:17 PM	6/17/07 1:12 PM	2875
	6/24/07 1:21 PM	6/26/07 1:20 PM	2879	6/22/07 1:03 PM	6/24/07 1:20 PM	2897
	7/1/07 12:55 PM	7/3/07 1:15 PM	2900	6/28/07 1:15 PM	7/1/07 12:54 PM	4299
	7/8/07 1:01 PM	7/10/07 12:03 PM	2822	7/6/07 1:07 PM	7/8/07 1:00 PM	2873
	7/15/07 1:08 PM	7/17/07 1:09 PM	2881	7/13/07 1:39 PM	7/15/07 1:07 PM	2848
	7/22/07 1:11 PM	7/24/07 1:10 PM	2879	7/20/07 1:05 PM	7/22/07 1:10 PM	2885
				7/27/07 1:34 PM	7/28/07 1:55 PM	1460
		total minutes exposed	**20124**		total minutes exposed	**20137**
B-02	6/17/07 1:24 PM	6/21/07 1:26 PM	5762	6/15/07 1:32 PM	6/17/07 1:23 PM	2871
	6/24/07 1:29 PM	6/26/07 1:26 PM	2877	6/22/07 1:08 PM	6/24/07 1:28 PM	2900
	7/1/07 1:01 PM	7/3/07 1:20 PM	2894	6/28/07 1:21 PM	7/1/07 1:01 PM	4300
	7/8/07 1:07 PM	7/10/07 12:08 PM	2821	7/6/07 1:12 PM	7/8/07 1:06 PM	2874
	7/15/07 1:13 PM	7/17/07 1:15 PM	2882	7/13/07 1:43 PM	7/15/07 1:13 PM	2850
	7/22/07 1:18 PM	7/24/07 1:16 PM	2878	7/20/07 1:13 PM	7/22/07 1:17 PM	2884
				7/27/07 1:39 PM	7/28/07 2:02 PM	1463
		total minutes exposed	**20114**		total minutes exposed	**20142**
B-03	6/17/07 1:33 PM	6/21/07 1:31 PM	5758	6/15/07 1:51 PM	6/17/07 1:31 PM	2860
	6/24/07 1:35 PM	6/26/07 1:31 PM	2876	6/22/07 1:13 PM	6/24/07 1:34 PM	2901
	7/1/07 1:07 PM	7/3/07 1:25 PM	2898	6/28/07 1:26 PM	7/1/07 1:06 PM	4300
	7/8/07 1:12 PM	7/10/07 12:12 PM	2820	7/6/07 1:17 PM	7/8/07 1:12 PM	2875
	7/15/07 1:19 PM	7/17/07 1:20 PM	2881	7/13/07 1:47 PM	7/15/07 1:18 PM	2851
	7/22/07 1:26 PM	7/24/07 1:21 PM	2875	7/20/07 1:18 PM	7/22/07 1:24 PM	2886
				7/27/07 1:44 PM	7/28/07 2:08 PM	1464
		total minutes exposed	**20108**		total minutes exposed	**20137**

PERIOD A	NON-CRUISE			CRUISE		
SITE	Open	Close	Total Minutes	Open	Close	Total Minutes
B-04	6/17/07 1:39 PM	6/21/07 1:37 PM	5758	6/15/07 2:01 PM	6/17/07 1:38 PM	2857
	6/24/07 1:40 PM	6/26/07 1:36 PM	2877	6/22/07 1:20 PM	6/24/07 1:39 PM	2899
	7/1/07 1:12 PM	7/3/07 1:30 PM	2898	6/28/07 1:30 PM	7/1/06 1:11 PM	4301
	7/8/07 1:18 PM	7/10/07 12:18 PM	2820	7/6/07 1:22 PM	7/8/07 1:17 PM	2875
	7/15/07 1:23 PM	7/17/07 1:25 PM	2882	7/13/07 1:51 PM	7/15/07 1:22 PM	2851
	7/22/07 1:32 PM	7/24/07 1:27 PM	2875	7/20/07 1:22 PM	7/22/07 1:31 PM	2889
				7/27/07 1:48 PM	7/28/07 2:14 PM	1466
		total minutes exposed	**20110**		total minutes exposed	**20138**
B-05	6/17/07 1:46 PM	6/21/07 1:41 PM	5755	6/15/07 2:10 PM	6/17/07 1:44 PM	2854
	6/24/07 1:45 PM	6/26/07 1:41 PM	2876	6/22/07 1:24 PM	6/24/07 1:45 PM	2901
	7/1/07 1:18 PM	7/3/07 1:34 PM	2896	6/28/07 1:35 PM	7/1/07 1:17 PM	4302
	7/8/07 1:25 PM	7/10/07 12:22 PM	2817	7/6/07 1:26 PM	7/8/07 1:24 PM	2878
	7/15/07 1:28 PM	7/17/07 1:29 PM	2881	7/13/07 1:53 PM	7/15/07 1:27 PM	2854
	7/22/07 1:39 PM	7/24/07 1:32 PM	2873	7/20/07 1:26 PM	7/22/07 1:38 PM	2892
				7/27/07 1:53 PM	7/28/07 2:20 PM	1467
		total minutes exposed	**20098**		total minutes exposed	**20148**
B-06	6/17/07 1:53 PM	6/21/07 1:46 PM	5753	6/15/07 2:19 PM	6/17/07 1:51 PM	2852
	6/24/07 1:51 PM	6/26/07 1:35 PM	2874	6/22/07 1:29 PM	6/24/07 1:51 PM	2902
	7/1/07 1:22 PM	7/3/07 1:37 PM	2895	6/28/07 1:40 PM	7/1/07 1:22 PM	4302
	7/8/07 1:30 PM	7/10/07 12:26 PM	2816	7/6/07 1:30 PM	7/8/07 1:29 PM	2878
	7/15/07 1:33 PM	7/17/07 1:33 PM	2880	7/13/07 1:58 PM	7/15/07 1:31 PM	2853
	7/22/07 1:44 PM	7/24/07 1:38 PM	2874	7/20/07 1:31 PM	7/22/07 1:43 PM	2892
				7/27/07 1:57 PM	7/28/07 2:26 PM	1469
		total minutes exposed	**20092**		total minutes exposed	**20148**

PERIOD A	NON-CRUISE			CRUISE		
SITE	**Open**	**Close**	**Total Minutes**	**Open**	**Close**	**Total Minutes**
B-07	6/17/07 2:02 PM	6/21/07 1:52 PM	5750	6/15/07 2:34 PM	6/17/07 1:59 PM	2845
	6/24/07 1:58 PM	6/26/07 1:50 PM	2872	6/22/07 1:34 PM	6/24/07 1:57 PM	2903
	7/1/07 1:29 PM	7/3/07 1:42 PM	2893	6/28/07 1:46 PM	7/1/07 1:27 PM	4301
	7/9/07 1:36 PM	7/10/07 12:31 PM	2815	7/6/07 1:35 PM	7/9/07 1:35 PM	2880
	7/15/07 1:39 PM	7/17/07 1:39 PM	2880	7/13/07 2:02 PM	7/15/07 1:37 PM	2853
	7/22/07 1:54 PM	7/24/07 1:44 PM	2870	7/20/07 1:37 PM	7/22/07 1:53 PM	2896
				7/27/07 2:02 PM	7/28/07 2:34 PM	1472
		total minutes exposed	**20080**		total minutes exposed	**20150**
B-07 DUPLICATE				6/15/07 2:36 PM	6/17/07 2:01 PM	2844
				6/22/07 1:34 PM	6/24/07 1:57 PM	2903
				6/29/07 1:46 PM	7/1/07 1:27 PM	4301
				7/6/07 1:35 PM	7/8/07 1:35 PM	2880
				7/13/07 2:03 PM	7/15/07 1:38 PM	2855
				7/20/07 1:38 PM	7/22/07 1:53 PM	2895
				7/27/07 2:02 PM	7/28/07 2:36 PM	1474
					total minutes exposed	**20152**
B08	6/17/07 2:10 PM	6/21/07 1:58 PM	5748	6/15/07 2:46 PM	6/17/07 2:09 PM	2843
	6/24/07 2:04 PM	6/26/07 1:55 PM	2871	6/22/07 1:40 PM	6/24/07 2:04 PM	2904
	7/1/07 1:35 PM	7/3/07 1:46 PM	2891	6/28/07 1:52 PM	7/1/07 1:34 PM	4302
	7/8/07 1:42 PM	7/10/07 12:36 PM	2814	7/6/07 1:41 PM	7/8/07 1:42 PM	2879
	7/15/07 1:44 PM	7/17/07 1:44 PM	2880	7/13/07 2:10 PM	7/15/07 1:44 PM	2854
	7/22/07 2:01 PM	7/24/07 1:50 PM	2869	7/20/07 1:43 PM	7/22/07 2:00 PM	2897
				7/27/07 2:07 PM	7/28/07 2:24 PM	1457
		total minutes exposed	**20073**		total minutes exposed	**20136**

PERIOD A	NON-CRUISE			CRUISE		
SITE	**Open**	**Close**	**Total Minutes**	**Open**	**Close**	**Total Minutes**
B-09	6/17/07 2:17 PM	6/21/07 2:02 PM	5745	6/15/07 2:58 PM	6/17/07 2:15 PM	2837
	6/24/07 2:10 PM	6/26/07 2:00 PM	2870	6/22/07 1:46 PM	6/24/07 2:09 PM	2903
	7/1/07 1:40 PM	7/3/07 1:51 PM	2891	6/28/07 1:59 PM	7/1/01 1:39 PM	4300
	7/8/07 1:49 PM	7/10/07 12:40 PM	2811	7/6/07 1:46 PM	7/8/07 1:48 PM	2882
	7/15/07 1:50 PM	7/17/07 1:50 PM	2880	7/13/07 2:16 PM	7/15/07 1:49 PM	2853
	7/22/07 2:07 PM	7/24/07 1:57 PM	2870	7/20/07 1:48 PM	7/22/07 2:05 PM	2897
				7/27/07 2:11 PM	7/28/07 2:49 PM	1478
		total minutes exposed	**20067**		total minutes exposed	**20150**
B-10	6/17/07 2:24 PM	6/21/07 2:09 PM	5745	6/15/07 3:09 PM	6/17/07 2:22 PM	2833
	6/24/07 2:16 PM	6/26/07 2:04 PM	2868	6/22/07 1:49 PM	6/24/07 2:15 PM	2906
	7/1/07 1:45 PM	7/3/07 1:55 PM	2890	6/29/07 2:04 PM	7/1/07 1:44 PM	4300
	7/8/07 1:54 PM	7/10/07 12:45 PM	2811	7/6/07 1:50 PM	7/8/07 1:53 PM	2883
	7/15/07 1:55 PM	7/17/07 1:55 PM	2880	7/13/07 2:20 PM	7/15/07 1:54 PM	2854
	7/22/07 2:12 PM	7/24/07 2:03 PM	2871	7/20/07 1:53 PM	7/2//07 2:12 PM	2899
				7/27/07 2:16 PM	7/28/07 2:56 PM	1480
		total minutes exposed	**20065**		total minutes exposed	**20155**
B-11	6/17/07 2:40 PM	6/21/07 2:21 PM	5741	6/15/07 3:29 PM	6/17/07 2:38 PM	2829
	6/24/07 2:29 PM	6/26/07 2:19 PM	2870	6/22/07 2:10 PM	6/24/07 2:28 PM	2898
	7/1/07 2:00 PM	7/3/07 2:09 PM	2889	6/28/07 2:23 PM	7/1/07 1:59 PM	4296
	7/8/07 2:07 PM	7/10/07 12:57 PM	2810	7/6/07 2:04 PM	7/8/07 2:06 PM	2882
	7/15/07 2:07 PM	7/17/07 2:09 PM	2882	7/13/07 2:32 PM	7/15/07 2:06 PM	2854
	7/22/07 2:25 PM	7/24/07 2:17 PM	2872	7/20/07 2:06 PM	7/22/07 2:24 PM	2898
				7/27/07 2:28 PM	7/28/07 3:11 PM	1483
		total minutes exposed	**20064**		total minutes exposed	**20140**

Table 59. $NO_2/NO_x/NO$ and SO_2 Sampling times and dates for August/September (*Period C*)

PERIOD C	NON-CRUISE			CRUISE		
SITE	**Open**	**Close**	**Total**	**Open**	**Close**	**Total**
C-01	8/19/07 1:17 PM	8/22/07 1:06 PM	4312	8/17/07 12:18 PM	8/19/07 1:16 PM	2938
	8/26/07 1:18 PM	8/29/07 1:27 PM	4329	8/24/07 1:19 PM	8/26/07 1:17 PM	2882
	9/2/07 11:01 AM	9/5/07 12:05 PM	4384	8/31/07 1:15 PM	9/2/07 11:00 AM	2745
	9/9/07 12:54 PM	9/12/07 11:55 PM	4261	9/6/07 11:43 AM	9/9/07 12:53 PM	4390
	9/16/07 1:04 PM	9/16/07 2:27 PM	83	9/14/07 12:38 PM	9/16/07 1:03 PM	2905
	9/18/07 1:42 PM	9/20/07 12:09 PM	2787	9/20/07 12:09 PM	9/23/07 11:52 PM	4303
		total minutes exposed	**20156**		total minutes exposed	**20163**
C-02	8/19/07 1:22 PM	8/22/07 1:14 PM	4312	8/17/07 12:28 PM	8/19/07 1:21 PM	2933
	8/26/07 1:25 PM	8/29/07 1:32 PM	4327	8/24/07 1:24 PM	8/26/07 1:24 PM	2880
	9/2/07 11:07 AM	9/5/07 12:11 PM	4384	8/31/07 1:20 PM	9/2/07 11:07 AM	2747
	9/9/07 1:03 PM	9/12/07 11:59 PM	4256	9/6/07 11:47 AM	9/9/07 1:03 PM	4396
	9/16/07 1:10 PM	9/16/07 2:31 PM	81	9/14/07 12:43 PM	9/16/07 1:09 PM	2906
	9/18/07 1:46 PM	9/20/07 12:14 PM	2788	9/20/07 12:15 PM	9/23/07 12:00 PM	4305
		total minutes exposed	**20148**		total minutes exposed	**20167**
C-03	8/19/07 1:32 PM	8/22/07 1:22 PM	4310	8/17/07 12:50 PM	8/19/07 1:31 PM	2921
	8/26/07 1:35 PM	8/29/07 1:37 PM	4322	8/24/07 1:32 PM	8/26/07 1:34 PM	2882
	9/2/07 11:15 AM	9/5/07 12:16 PM	4381	8/31/07 1:26 PM	9/2/07 11:14 AM	2748
	9/9/07 1:10 PM	9/12/07 12:04 PM	4254	9/6/07 11:53 AM	9/9/07 1:10 PM	4397
	9/16/07 1:18 PM	9/16/07 2:36 PM	78	9/14/07 12:47 PM	9/16/07 1:17 PM	2910
	9/18/07 1:52 PM	9/20/07 12:22 PM	2790	9/20/07 12:22 PM	9/23/07 12:07 PM	4305
		total minutes exposed	**20135**		total minutes exposed	**20163**

PERIOD C	NON-CRUISE			CRUISE		
ID	**Open**	**Close**	**Total**	**Open**	**Close**	**Total**
C-04	8/19/07 1:39 PM	8/22/07 1:26 PM	4307	8/17/07 12:59 PM	8/19/07 1:37 PM	2918
	8/26/07 1:39 PM	8/29/07 1:41 PM	4322	8/24/07 1:36 PM	8/26/07 1:39 PM	2883
	9/2/07 11:20 AM	9/5/07 12:19 PM	4379	8/31/07 1:31 PM	9/2/07 11:19 AM	2748
	9/9/07 1:15 PM	9/12/07 12:08 PM	4253	9/6/07 11:56 AM	9/9/07 1:14 PM	4398
	9/16/07 1:23 PM	9/16/07 2:39 PM	76	9/14/07 12:50 PM	9/16/07 1:22 PM	2912
	9/18/07 1:56 PM	9/20/07 12:27 PM	2791	9/20/07 12:27 PM	9/23/07 12:13 PM	4306
		total minutes exposed	**20128**		total minutes exposed	**20165**
C-05	8/19/07 1:44 PM	8/22/07 1:29 PM	4305	8/17/07 1:09 PM	8/19/07 1:44 PM	2915
	8/26/07 1:44 PM	8/29/07 1:44 PM	4320	8/24/07 1:40 PM	8/26/07 1:43 PM	2883
	9/2/07 11:25 AM	9/5/07 12:22 PM	4377	8/31/07 1:36 PM	9/2/07 11:25 AM	2749
	9/9/07 1:21 PM	9/12/07 12:11 PM	4250	9/6/07 12:00 PM	9/9/07 1:20 PM	4400
	9/16/07 1:29 PM	9/16/07 2:42 PM	73	9/14/07 12:52 PM	9/16/07 1:29 PM	2917
	9/18/07 1:59 PM	9/20/07 12:32 PM	2793	9/20/07 12:32 PM	9/23/07 12:17 PM	4305
		total minutes exposed	**20118**		total minutes exposed	**20169**
C-06	8/19/07 1:50 PM	8/22/07 1:33 PM	4299	8/17/07 1:27 PM	8/19/07 1:49 PM	2902
and	8/26/07 1:50 PM	8/29/07 1:49 PM	4319	8/24/07 1:43 PM	8/26/07 1:49 PM	2886
duplicate	9/2/07 11:32 AM	9/5/07 12:25 PM	4373	8/31/07 1:47 PM	9/2/07 11:31 AM	2744
	9/9/07 1:27 PM	9/12/07 12:15 PM	4248	9/6/07 12:03 PM	9/9/07 1:26 PM	4403
	8/16/07 1:36 PM	9/16/07 2:47 PM	71	9/14/07 12:57 PM	9/16/07 1:35 PM	2918
	9/18/07 2:05 PM	9/20/07 12:38 PM	2793	9/20/07 12:40 PM	9/23/07 12:23 PM	4303
		total minutes exposed	**20103**		total minutes exposed	**20156**

PERIOD C	NON-CRUISE			CRUISE		
ID	**Open**	**Close**	**Total**	**Open**	**Close**	**Total**
C-07	8/19/07 1:56 PM	8/22/07 1:39 PM	4303	8/17/07 1:38 PM	8/19/07 1:55 PM	2897
	8/26/07 1:57 PM	8/29/07 1:52 PM	4315	8/24/07 1:48 PM	8/26/07 1:56 PM	2888
	9/2/07 11:37 AM	9/5/07 12:29 PM	4372	8/31/07 1:41 PM	9/2/07 11:37 AM	2756
	9/9/07 1:33 PM	9/12/07 12:19 PM	4246	9/6/07 12:07 PM	9/9/07 1:32 PM	4405
	9/16/07 1:45 PM	9/16/07 2:52 PM	67	9/14/07 1:01 PM	9/16/07 1:44 PM	2923
	9/18/07 2:09 PM	9/20/07 12:45 PM	2796	9/20/07 12:46 PM	9/23/07 12:28 PM	4302
		total minutes exposed	**20099**		total minutes exposed	**20171**
C-08	8/19/07 2:02 PM	8/22/07 1:44 PM	4302	8/17/07 1:50 PM	8/19/07 2:01 PM	2891
	8/26/07 2:04 PM	8/29/07 1:57 PM	4313	8/24/07 1:53 PM	8/26/07 2:04 PM	2891
	9/2/07 11:45 AM	9/5/07 12:35 PM	4370	8/31/07 1:54 PM	9/2/07 11:45 AM	2751
	9/9/07 1:42 PM	9/12/07 12:25 PM	4243	9/6/07 12:13 PM	9/9/07 1:41 PM	4408
	9/16/07 1:55 PM	9/16/07 2:57 PM	62	9/14/07 1:07 PM	9/16/07 1:54 PM	2927
	9/18/07 2:18 PM	9/20/07 12:53 PM	2795	9/20/07 12:53 PM	9/23/07 1:10 PM	4337
		total minutes exposed	**20085**		total minutes exposed	**20205**
C-09	vandalized			8/17/07 2:20 PM	8/19/07 2:28 PM	2887
				8/24/07 2:06 PM	8/26/07 2:18 PM	2892
				8/31/07 2:08 PM	9/2/08 11:58 AM	2750
				9/6/07 12:31 PM	9/9/07 1:55 PM	4404
				9/14/07 1:19 PM	9/16/07 2:11 PM	2932
				9/20/07 1:12 PM	9/23/07 1:25 PM	4333
					total minutes exposed	**20198**

Appendix B

Nephelometer Monitoring Dates and Durations

Table 60. Nephelometer and traffic counters sampling dates and durations

Site #	Location	Date/Time In	Date/Time Out	Cruise or Non-Cruise
D-01	Dallas	12:02 June 28 12:29 July 1	12:26 July 1 12:17 July 4	Cruise Non-Cruise
D-02	Ladysmith	13:36 June 25 12:52 June 28	12:48 June 28 12:05 July 1	Non-Cruise Cruise
D-03	Ontario	13:58 June 25 13:06 June 28	13:00 June 28 12:21 July 1	Non-Cruise Cruise
E-01	Simcoe	12:35 July 30 12:38 August 2	12:35 August 2 12:35 August 5	Non-Cruise Cruise
E-02	St. Lawrence	12:22 July 30 12:15 August 2	12:09 August 2 12:20 August 5	Non-Cruise Cruise
E-03	Superior	12:06 July 30 12:01 August 2	11:57 August 2 12:01 August 5	Non-Cruise Cruise

Appendix C

Partisol Sampling and Metals Analysis

Table 61. Dates and durations for partisol filter samples

Site #	Location	Date/Time In	Date/Time Out	Cruise or Non-Cruise
D-1	Dallas	12:02 June 28 12:29 July 1	12:26 July 1 12:17 July 4	Cruise Non-Cruise
D-2	Ladysmith	13:36 June 25 12:52 June 28	12:48 June 28 12:05 July 1	Non-Cruise Cruise
D-3	Ontario	13:58 June 25 13:06 June 28	13:00 June 28 12:21 July 1	Non-Cruise Cruise
E-1	Simcoe	12:35 July 30 12:38 August 2	12:35 August 2 12:35 August 5	Non-Cruise Cruise
E-2	St. Lawrence	12:22 July 30 12:15 August 2	12:09 August 2 12:20 August 5	Non-Cruise Cruise
E-3	Superior	12:06 July 30 12:01 August 2	11:57 August 2 12:01 August 5	Non-Cruise Cruise
F-1	San Jose	13:15 September 18 13:09 September 21	11:51 September 20 12:53 September 23	Non-Cruise Cruise
F-2	Lewis	13:29 September 18 13:14 September 21	11:57 September 20 12:42 September 23	Non-Cruise Cruise
F-3	South Turner	13:07 September 18 13:02 September 21	11:43 September 20 12:31 September 23	Non-Cruise Cruise

Table 62. Metals analysis – detection limits, field and lab blanks for June 28th – July 4th – Total Mass

Metal	Detection Limit (ug)	Blanks		Site D-1		Site D-2		Site D-3	
		Field	Lab	Cruise	No cruise	Cruise	No cruise	Cruise	No cruise
Aluminum	0.025	0.75	0.39	1.57	2.52	1.82	2.26	1.76	2.24
Antimony Sb	0.005	<0.01	<0.01	0.021	0.015	0.018	0.017	0.026	0.016
Arsenic As	0.005	<0.01	<0.01	0.036	0.013	0.033	0.019	0.039	0.021
Barium Ba	0.005	<0.01	<0.01	0.18	0.095	0.15	0.079	0.25	0.17
Beryllium Be	0.005	<0.01	<0.01	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
Boron B	0.25	2.7	0.8	0.9	2.1	1.4	3.3	1	3.3
Cadmium Cd	0.001	0.002	<0.002	0.005	0.005	0.005	0.004	0.006	0.002
Calcium Ca	0.25	7.1	7.3	7.9	12.4	5.4	176	8.6	16.3
Chromium Cr	0.005	0.13	0.11	0.13	0.17	0.12	0.16	0.16	0.15
Cobalt Co	0.005	<0.01	<0.01	0.006	< 0.005	0.005	< 0.005	0.006	< 0.005
Copper Cu	0.005	0.01	0.02	0.12	0.082	0.12	0.097	0.16	0.11
Iron Fe	0.25	<0.5	<0.5	1.8	2.3	1.4	2.7	2.9	3.8
Lead Pb	0.005	0.02	0.02	0.11	0.095	0.1	0.1	0.13	0.072
Magnesium Mg	0.25	<0.5	<0.5	2	2.3	2	4.7	2.5	3.3
Manganese Mn	0.005	<0.01	<0.01	0.048	0.073	0.041	0.094	0.065	0.066
Molybdenum Mo	0.0025	<0.01	<0.01	0.014	0.009	0.013	0.01	0.019	0.014
Nickel Ni	0.005	<0.01	<0.01	0.33	0.13	0.31	0.13	0.33	0.19
Phosphorus P	0.75	0.6	0.4	< 0.75	0.8	< 0.75	1.1	0.8	0.9
Potassium K	0.5	0.8	0.7	5.7	2.9	4.4	2.5	4.7	3.6
Selenium Se	0.005	<0.3	<0.3	0.011	0.009	0.012	0.012	0.014	0.014
Silver Ag	0.00125	<0.001	<0.001	< 0.00125	< 0.00125	0.002	< 0.00125	0.002	< 0.00125
Sodium Na	0.25	3.7	2	13.3	15.6	14.9	19.8	17.5	26.7
Strontium Sr	0.005	<0.01	<0.01	0.055	0.029	0.049	0.093	0.062	0.036
Tellurium Te	0.005	<0.3	<0.3	< 0.005	< 0.005	0.005	< 0.005	0.005	< 0.005
Thallium Tl	0.0005	<0.3	<0.3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
Tin Sn	0.005	0.12	0.09	0.1	0.14	0.099	0.065	0.12	0.14
Titanium Ti	0.005	0.01	<0.01	0.07	0.089	0.056	0.08	0.11	0.12
Vanadium V	0.005	<0.01	<0.01	0.7	0.28	0.68	0.3	0.77	0.37
Zinc Zn	0.025	0.55	0.61	0.63	0.88	0.45	10.6	0.68	1.05
Zirconium Zr	0.05	<0.1	<0.1	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05

Table 63. Metals analysis – detection limits, field and lab blanks for July 30th – August 5th – total mass

Metal	Detection Limit (ug)	Blanks		Site E-1		Site E-2		Site E-3	
		Field	Lab	Cruise	No cruise	Cruise	No cruise	Cruise	No cruise
Aluminum	0.025	0.97	0.41	1.36	3.29	1.34	2.88	3.01	2.48
Antimony Sb	0.005	<	<	0.013	0.017	0.005	0.009	0.007	0.011
Arsenic As	0.005	0.016	0.009	<	0.012	<	0.017	<	0.014
Barium Ba	0.005	0.034	<	0.18	0.17	0.13	0.094	0.18	0.096
Beryllium Be	0.005	<	<	<	<	<	<	<	<
Boron B	0.25	1.4	0.3	1.0	5.2	<	1.0	0.8	5.8
Cadmium Cd	0.001	0.001	<	0.001	0.001	0.001	0.001	0.002	0.002
Calcium Ca	0.25	3.1	1.7	3.9	8.3	4.5	5.2	9.7	4.6
Chromium Cr	0.005	0.14	0.13	0.13	0.11	0.12	0.12	0.13	0.19
Cobalt Co	0.005	<	<	0.014	<	0.014	<	0.024	<
Copper Cu	0.005	0.022	0.012	0.070	0.10	0.042	0.057	0.055	0.065
Iron Fe	0.25	0.8	0.6	2.6	3.3	1.9	2.3	2.8	3.1
Lead Pb	0.005	0.017	0.009	0.029	0.072	0.045	0.095	0.063	0.060
Magnesium Mg	0.25	0.3	0.3	2.1	3.3	2.2	3.2	3.4	4.4
Manganese Mn	0.005	0.011	0.007	0.037	0.072	0.035	.060	0.048	0.074
Molybdenum Mo	0.0025	0.004	0.004	0.018	0.015	0.019	0.011	0.022	0.014
Nickel Ni	0.005	0.025	<	0.69	0.17	0.69	0.17	1.21	0.17
Phosphorus P	0.75	1.0	1.0	1.3	1.1	1.4	<	1.0	1.2
Potassium K	0.5	1.0	0.7	1.8	3.3	5.0	2.8	2.5	2.9
Selenium Se	0.005	<	<	0.005	0.003	0.005	0.007	0.007	0.009
Silver Ag	0.00125	0.003	<	<	0.004	<	<	<	<
Sodium Na	0.25	3.0	1.3	15.7	29.3	19.1	23.6	22.0	39.1
Strontium Sr	0.005	0.011	<	0.030	0.046	0.030	0.030	0.067	0.031
Tellurium Te	0.005	<	<	<	<	<	<	<	<
Thallium Tl	0.0005	<	<	<	<	<	<	<	<
Tin Sn	0.005	0.064	0.091	0.054	0.027	0.040	0.021	0.028	0.062
Titanium Ti	0.005	0.035	0.026	0.10	0.13	0.076	0.095	0.12	0.13
Vanadium V	0.005	<	<	0.80	0.42	1.75	0.43	2.72	0.46
Zinc Zn	0.025	0.17	0.13	0.19	0.31	0.21	0.23	0.72	0.22
Zirconium Zr	0.05	<	<	<	<	<	<	<	0.05

Table 64. Metals analysis – setection limits, field and lab blanks for September 18th – 23rd (*Period F*)– total mass

	Detection	Blanks		Site F-1		Site F-2		Site F_3	
Metal	Limit (ug)	Field	Lab	Cruise	No cruise	Cruise	No cruise	Cruise	No cruise
Aluminum	0.025	0.82	0.37	1.08	6.69	0.91	2.06	0.61	1.43
Antimony Sb	0.005	< 0.005	0.012	0.007	0.009	< 0.005	0.008	0.006	0.01
Arsenic As	0.005	< 0.005	0.019	0.019	0.011	0.023	0.007	0.049	0.014
Barium Ba	0.005	0.007	< 0.005	0.041	0.065	0.033	0.051	0.034	0.062
Beryllium Be	0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
Boron B	0.25	2.6	0.9	0.8	0.8	1.2	4.1	0.4	1
Cadmium Cd	0.001	0.001	0.001	0.001	0.002	0.002	0.003	0.001	0.002
Calcium Ca	0.25	4.9	4.9	6.7	11.4	12.4	7.7	10.5	8.5
Chromium Cr	0.005	0.095	0.11	0.1	0.13	0.11	0.11	0.14	0.13
Cobalt Co	0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
Copper Cu	0.005	0.019	0.042	0.043	0.089	0.044	0.059	0.034	0.09
Iron Fe	0.25	0.4	0.3	0.9	2.7	0.7	1.5	0.8	1.8
Lead Pb	0.005	0.01	0.06	0.056	0.1	0.063	0.068	0.056	0.099
Magnesium Mg	0.25	0.3	0.4	4	2.4	5.4	2.3	4.3	2.3
Manganese Mn	0.005	0.009	0.009	0.018	0.069	0.017	0.043	0.021	0.056
Molybdenum Mo	0.0025	< 0.0025	< 0.0025	0.005	0.012	0.005	0.012	0.005	0.014
Nickel Ni	0.005	0.19	0.005	0.12	0.12	0.12	0.082	0.1	0.081
Phosphorus P	0.75	< 0.75	< 0.75	< 0.75	1	1.8	0.8	0.8	0.9
Potassium K	0.5	< 0.5	0.5	2.4	2.9	3.2	2.9	2.5	2.5
Selenium Se	0.005	< 0.005	< 0.005	0.007	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
Silver Ag	0.00125	< 0.00125	< 0.00125	< 0.00125	< 0.00125	0.002	< 0.00125	< 0.00125	< 0.00125
Sodium Na	0.25	5.1	2	31.2	15.6	44.4	21.3	31.9	14.1
Strontium Sr	0.005	< 0.005	< 0.005	0.025	0.022	0.037	0.017	0.028	0.02
Tellurium Te	0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
Thallium Tl	0.0005	0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
Tin Sn	0.005	0.1	0.061	0.023	0.074	0.29	0.07	0.02	0.069
Titanium Ti	0.005	0.011	0.019	0.021	0.073	0.026	0.05	0.023	0.068
Vanadium V	0.005	< 0.005	< 0.005	0.26	0.17	0.22	0.16	0.26	0.17

Zinc Zn	0.025	0.13	0.14	0.24	0.5	0.15	0.39	0.16	0.38
Zirconium Zr	0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05

Table 65. Metals analysis: June 28th to July 4th – mass by volume

	Amount (micrograms/cubic metre) (< indicates no detectable levels)					
Metal	**Site D-01 Cruise**	**Site D-1 No Cruise**	**Site D-2 Cruise**	**Site D-2 No Cruise**	**Site D-3 Cruise**	**Site D-3 No Cruise**
Aluminum	0.01833255	0.04444865	0.01804495	0.03895735	0.04056987	0.03340157
Antimony Sb	0.00017524	0.00022967	0.00006733	0.00012174	0.00009435	0.00014815
Arsenic As	<	0.00016212	<	0.00022996	<	0.00018856
Barium Ba	0.00242637	0.00229674	0.00175063	0.00127152	0.00242610	0.00129296
Beryllium Be	<	<	<	<	<	<
Boron B	0.01347981	0.07025318	<	0.01352686	0.01078269	0.07811658
Cadmium Cd	0.00001348	0.00001351	0.00001347	0.00001353	0.00002696	0.00002694
Calcium Ca	0.05257127	0.11213489	0.06059872	0.07033966	0.13074010	0.06195453
Chromium Cr	0.00175238	0.00148612	0.00161597	0.00162322	0.00175219	0.00255899
Cobalt Co	0.00018872	<	0.00018853	<	0.00032348	<
Copper Cu	0.00094359	0.00135102	0.00056559	0.00077103	0.00074131	0.00088891
Iron Fe	0.03504752	0.04458375	0.02558612	0.03111177	0.03773941	0.04175197
Lead Pb	0.00039091	0.00097274	0.00060599	0.00128505	0.00084914	0.00080810
Magnesium Mg	0.02830761	0.04458375	0.02962604	0.04328594	0.04582643	0.05926086
Manganese Mn	0.00049875	0.00097274	0.00047132	0.00081161	0.00064696	0.00099666
Molybdenum Mo	0.00024264	0.00020265	0.00025586	0.00014880	0.00029652	0.00018856
Nickel Ni	0.00930107	0.00229674	0.00929180	0.00229957	0.01630882	0.00228962
Phosphorus P	0.01752376	0.01486125	0.01885293	<	0.01347836	0.01616205
Potassium K	0.02426367	0.04458375	0.06733191	0.03787520	0.03369590	0.03905829
Selenium Se	0.00006740	0.00010808	0.00006733	0.00009469	0.00009435	0.00012122
Silver Ag	<	0.00005404	<	<	<	<
Sodium Na	0.21163308	0.39584966	0.13601045	0.31923384	0.29652393	0.52661351
Strontium Sr	0.00040439	0.00062147	0.00040399	0.00040581	0.00090305	0.00041752
Tellurium Te	<	<	<	<	<	<
Thallium Tl	<	<	<	<	<	<
Tin Sn	0.00072791	0.00036478	0.00053866	0.00028406	0.00037739	0.00083504
Titanium Ti	0.00134798	0.00175633	0.00102344	0.00128505	0.00161740	0.00175089
Vanadium V	0.02426367	0.00567430	0.02356617	0.00581655	0.03666114	0.00619545
Zinc Zn	0.00256116	0.00418817	0.00282794	0.00311118	0.00970442	0.00296304
Zirconium Zr	<	<	<	<	<	0.00006731

Table 66. Metals analysis – July 30th – August 5th – mass by volume

Metal	Amount (micrograms/cubic metre) (< indicates no detectable levels)					
	Site E-01 Cruise	Site E-1 No Cruise	Site E-2 Cruise	Site E-2 No Cruise	Site E-3 Cruise	Site E-3 No Cruise
Aluminum	0.02199095	0.03540569	0.02550484	0.03167839	0.02426080	0.03072197
Antimony Sb	0.00029415	0.00021075	0.00025225	0.00023829	0.00035840	0.00021944
Arsenic As	0.00050425	0.00018265	0.00046245	0.00026632	0.00053760	0.00028802
Barium Ba	0.00252126	0.00133474	0.00210205	0.00110734	0.00344614	0.00233158
Beryllium Be	<	<	<	<	<	<
Boron B	0.01260628	0.02950474	0.01961911	0.04625606	0.01378455	0.04526004
Cadmium Cd	0.00007003	0.00007025	0.00007007	0.00005607	0.00008271	0.00002743
Calcium Ca	0.11065511	0.17421848	0.07567371	2.46698999	0.11854711	0.22355716
Chromium Cr	0.00182091	0.00238848	0.00168164	0.00224272	0.00220553	0.00205727
Cobalt Co	0.00008404	<	0.00007007	<	0.00008271	<
Copper Cu	0.00168084	0.00115209	0.00168164	0.00135965	0.00220553	0.00150867
Iron Fe	0.02521256	0.03231472	0.01961911	0.03784587	0.03997519	0.05211762
Lead Pb	0.00154077	0.00133474	0.00140136	0.00140170	0.00179199	0.00098749
Magnesium Mg	0.02801395	0.03231472	0.02802730	0.06587985	0.03446137	0.04526004
Manganese Mn	0.00067233	0.00102564	0.00057456	0.00131760	0.00089600	0.00090520
Molybdenum Mo	0.00019610	0.00012645	0.00018218	0.00014017	0.00026191	0.00019201
Nickel Ni	0.00462230	0.00182648	0.00434423	0.00182221	0.00454890	0.00260588
Phosphorus P	<	0.01123990	<	0.01541869	0.01102764	0.01234365
Potassium K	0.07983976	0.04074464	0.06166006	0.03504247	0.06478737	0.04937459
Selenium Se	0.00015408	0.00012645	0.00016816	0.00016820	0.00019298	0.00019201
Silver Ag	<	<	0.00002803	<	0.00002757	<
Sodium Na	0.18629277	0.21917808	0.20880337	0.27753637	0.24122958	0.36619487
Strontium Sr	0.00077038	0.00040745	0.00068667	0.00130358	0.00085464	0.00049375
Tellurium Te	<	<	<	<	<	<
Thallium Tl	<	<	<	<	<	<
Tin Sn	0.00140070	0.00196698	0.00138735	0.00091110	0.00165415	0.00192012
Titanium Ti	0.00098049	0.00125044	0.00078476	0.00112136	0.00151630	0.00164582
Vanadium V	0.00980488	0.00393397	0.00952928	0.00420510	0.01061410	0.00507461
Zinc Zn	0.00882439	0.01236389	0.00630614	0.14858008	0.00937349	0.01440092
Zirconium Zr	<	<	<	<	<	<

Table 67. Metals analysis – September 18th – 23rd – mass by volume

Metal	Amount (micrograms/cubic metre) (< indicates no detectable levels) Site F-1 Cruise	Site F-1 No Cruise	Site F-2 Cruise	Site F-2 No Cruise	Site F-3 Cruise	Site F-3 No Cruise
Aluminum	0.02179265	0.13846058	0.01848955	0.04276787	0.01238679	0.02958886
Antimony Sb	0.00014125	0.00018627	0.00005080	0.00016609	<	0.00020692
Arsenic As	0.00038339	0.00022766	0.00046732	0.00014533	0.00099500	0.00028968
Barium Ba	0.00082731	0.00134528	0.00067050	0.00105882	0.00069041	0.00128287
Beryllium Be	<	<	<	<	<	<
Boron B	0.01614270	0.01655732	0.02438182	0.08512052	0.00812249	0.02069151
Cadmium Cd	0.00002018	0.00004139	0.00004064	0.00006228	0.00002031	0.00004138
Calcium Ca	0.13519512	0.23594180	0.25194547	0.15986049	0.21321529	0.17587784
Chromium Cr	0.00201784	0.00269056	0.00223500	0.00228372	0.00284287	0.00268990
Cobalt Co	<	<	<	<	<	<
Copper Cu	0.00086767	0.00184200	0.00089400	0.00122491	0.00069041	0.00186224
Iron Fe	0.01816054	0.05588095	0.01422273	0.03114165	0.01624497	0.03724472
Lead Pb	0.00112999	0.00206966	0.00128005	0.00141175	0.00113715	0.00204846
Magnesium Mg	0.08071351	0.04967196	0.10971819	0.04775053	0.08731674	0.04759047
Manganese Mn	0.00036321	0.00142807	0.00034541	0.00089273	0.00042643	0.00115872
Molybdenum Mo	0.00010089	0.00024836	0.00010159	0.00024913	0.00010153	0.00028968
Nickel Ni	0.00242141	0.00248360	0.00243818	0.00170241	0.00203062	0.00167601
Phosphorus P	<	0.02069665	0.03657273	0.01660888	0.01624497	0.01862236
Potassium K	0.04842810	0.06002028	0.06501818	0.06020720	0.05076554	0.05172878
Selenium Se	0.00014125	<	<	<	<	<
Silver Ag	<	<	0.00004064	<	<	<
Sodium Na	0.62956536	0.32286773	0.90212731	0.44221147	0.64776835	0.29175029
Strontium Sr	0.00050446	0.00045533	0.00075177	0.00035294	0.00056857	0.00041383
Tellurium Te	<	<	<	<	<	<
Thallium Tl	<	<	<	<	<	<
Tin Sn	0.00046410	0.00153155	0.00589227	0.00145328	0.00040612	0.00142771
Titanium Ti	0.00042375	0.00151086	0.00052827	0.00103806	0.00046704	0.00140702
Vanadium V	0.00524638	0.00351843	0.00447000	0.00332178	0.00527962	0.00351756
Zinc Zn	0.00484281	0.01034832	0.00304773	0.00809683	0.00324899	0.00786277
Zirconium Zr	<	<	<	<	<	<

Table 68. Vanadium and nickel levels in $PM_{2.5}$ at Topaz Station – 2006

Dichotomous Sampler Concentrations (µg/m3) at VICTORIA - 923 TOPAZ NAPS No. 100304					
Date	**Category**	**Vanadium**	**Detection Limit.**	**Nickel**	**Detection Limit**
23-Jan-06	off season	0.0020	0.0027	0.0049	0.0043
29-Jan-06	off season	--	0.0027	0.0070	0.0045
04-Feb-06	off season	0.0005	0.0029	0.0033	0.0048
10-Feb-06	off season	0.0007	0.0030	0.0054	0.0049
22-Feb-06	off season	0.0044	0.0027	0.0079	0.0047
28-Feb-06	off season	0.0013	0.0035	0.0016	0.0052
06-Mar-06	off season	--	0.0032	0.0067	0.0046
12-Mar-06	off season	--	0.0025	0.0076	0.0045
18-Mar-06	off season	0.0003	0.0029	0.0074	0.0047
24-Mar-06	off season	0.0015	0.0028	**0.0087**	0.0046
11-May-06	cruise ship present	0.0007	0.0031	0.0069	0.0045
17-May-06	no cruise ships	0.0065	0.0037	0.0093	0.0049
23-May-06	no cruise ships	0.0050	0.0034	0.0088	0.0048
29-May-06	no cruise ships	0.0025	0.0031	0.0084	0.0047
04-Jun-06	no cruise ships	0.0027	0.0033	**0.0111**	0.0048
10-Jun-06	cruise ship present	0.0143	0.0039	**0.0176**	0.0051
16-Jun-06	cruise ship present	0.0077	0.0024	0.0055	0.0041
22-Jun-06	cruise ship present	0.0021	0.0031	0.0060	0.0042
28-Jun-06	no cruise ships	0.0119	0.0116	--	0.0026
04-Jul-06	no cruise ships	**0.0144**	0.0117	--	0.0026
10-Jul-06	no cruise ships	0.0148	0.0116	--	0.0026
16-Jul-06	no cruise ships	0.0000	0.0124	--	0.0026
22-Jul-06	cruise ship present	**0.0209**	0.0119	0.0061	0.0026
28-Jul-06	cruise ship present	0.0184	0.0115	--	0.0025
03-Aug-06	cruise ship present	--	0.0123	--	0.0026
21-Aug-06	no cruise ships	--	0.0125	--	0.0026
27-Aug-06	no cruise ships	--	0.0126	--	0.0026
02-Sep-06	cruise ship present	--	0.0126	--	0.0026
08-Sep-06	cruise ship present	--	0.0128	--	0.0027
14-Sep-06	cruise ship present	--	0.0125	--	0.0026
20-Sep-06	no cruise ships	--	0.0126	--	0.0026
26-Sep-06	no cruise ships	--	0.0122	--	0.0026
02-Oct-06	no cruise ships	--	0.0122	--	0.0025
08-Oct-06	no cruise ships	--	0.0123	--	0.0026
14-Oct-06	cruise ship present	--	0.0123	--	0.0026
20-Oct-06	no cruise ships	--	0.0121	--	0.0025
26-Oct-06	no cruise ships	--	0.0125	--	0.0026

01-Nov-06	off season	--	0.0125	--	0.0025
07-Nov-06	off season	--	0.0126	--	0.0026
13-Nov-06	off season	--	0.0124	--	0.0026
25-Nov-06	off season	0.0032	0.0024	0.0007	0.0045
01-Dec-06	off season	0.0046	0.0027	0.0012	0.0045
07-Dec-06	off season	0.0010	0.0023	0.0042	0.0041
13-Dec-06	off season	0.0018	0.0029	0.0060	0.0047
19-Dec-06	off season	0.0030	0.0029	0.0055	0.0048
25-Dec-06	off season	**0.0062**	0.0027	0.0043	0.0044
31-Dec-06	off season	0.0014	0.0026	--	0.0042
Average cruise		0.0107		0.0084	
Average no cruise		0.0072		0.0094	
Average off season		0.0023		0.0051	
Average All samples		0.0055		0.0065	

Bold denotes maximum level in category, data provided by BC Ministry of Environment