# James Bay Air Quality Study: Phase II

# Report on the Results of CALPUFF Air Quality Dispersion Modelling 2007

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# 1.0 EXECUTIVE SUMMARY

The objective of the James Bay Air Quality Study (JBAQS) was to establish general levels of pollutants in outdoor air in the James Bay area of Victoria, BC, Canada. James Bay is a predominately residential neighbourhood in the City of Victoria, with a population of over 11,200 as of 2006. The main emission sources in the area include light and heavy-duty vehicle traffic, helicopters, float planes, and marine vessels such as cruise ships, the passenger/vehicle ferries MV Coho and Victoria Clipper, commercial fishing and whale watching boats, and recreational motorboats.

Prior to this study, no air quality measurements were available to indicate the spatial or temporal variation of various pollutants in the James Bay neighbourhood. This lack of information created significant uncertainty about air quality in the area in terms of actual levels of pollutants and the relative magnitude that different sources contribute to these levels. In order to begin understanding the specific air quality characteristics of the James Bay neighbourhood, a two-phase research study was developed.

Phase I of the JBAQS consisted of field monitoring in the study area during the summer of 2007 to establish existing levels of sulphur dioxide ($SO_2$), nitrogen dioxide ($NO_2$), fine particulates ($PM_{10}$ and $PM_{2.5}$), metals (nickel and vanadium), volatile organic compounds (VOCs), as well as vehicle traffic volume in selected locations. These monitored concentrations provide a baseline of measurements which can be used to indicate the current status of air quality in the region, and for comparative purposes in the future.

Phase II of the James Bay Air Quality Study, the focus of this report, examines predicted ambient concentrations of $SO_2$, $NO_2$, $PM_{10}$ and $PM_{2.5}$ predominately from the large marine sources (cruise ships and ferries) in the James Bay neighbourhood of Victoria through the use of a sophisticated air transport and dispersion model called the California Puff Model (CALPUFF). CALPUFF was configured for an analysis of a 20 $km^2$ study domain centered on the Ogden Point terminal for a study period spanning the 2007 cruise ship season, April 24 to November 3 inclusive.

Meteorological inputs were prepared for the CALPUFF model using the output fields of the Eta mesoscale model at 12 km horizontal resolution in combination with overland and over water surface observations from the Ogden Point breakwater meteorological station, the Environment Canada meteorological station at the Victoria International Airport, the BC Ministry of Environment station on Topaz Avenue, and the National Ocean and Atmospheric Administration's (NOAA) Hein Bank buoy. Terrain and land use data were used to characterize geophysical and thermodynamic properties for each 100 x 100 meter grid cell.

Cruise ships and ferry vessels (MV Coho and Victoria Clipper) were the main emissions sources included in the model, based on their specific scheduling during the modelling period. These sources were modelled as line sources to represent transit and manoeuvring to berth, and point sources while at berth. Detailed vessel and fuel characteristic information was obtained for ferries. Cruise ships were characterized based upon information from recent BC marine emissions inventories, a shoreside power feasibility study for San Francisco, and anecdotal remarks from ship engineers. Vehicle emissions were modelled for 16 line segments in the modelling domain, and used to investigate background concentrations from this source. Tour buses operating in the area were not included in the detailed model analysis, but total emissions from this source were estimated and compared to total traffic emissions. Helicopters and float planes were not included as emissions sources in the modelling exercise.

Predictions of pollutant concentrations were generated for the combination of cruise ship and ferry sources, as well as examined individually to determine the individual source contributions from the four main sources included in the model (ferry- transit & berth, cruise – transit & berth). Cruise ships at berth and in transit were the major contributors to maximum 1-hour, maximum 24-hour and average concentrations of all pollutants in the James Bay community, based on model outputs.

Predictions were combined with background concentrations established from the 98$^{th}$ percentile measured concentrations from the BC Ministry of Environment station on Topaz Avenue in order to compare with relevant CRD, BC, Canadian and World Health Organization (WHO) ambient air quality standards and objectives. The following is a summary of the modelling results for each of the pollutants modelled ($SO_2$, $NO_2$, $PM_{10}$, $PM_{2.5}$):

**Sulphur Dioxide ($SO_2$)**

- The maximum 1-hour $SO_2$ concentration in the James Bay community was predicted to be 164 µg/m$^3$ (151 µg/m$^3$ cruise ships/ferries; 13 µg/m$^3$ background). The highest maximum predicted 1-hour $SO_2$ concentration in the modelling domain was 270 µg/m$^3$ (257 µg/m$^3$ cruise ships/ferries; 13 µg/m$^3$ background) and occurred over the cruise ship berths at the Ogden Point terminal. Maximum 1-hour concentrations of $SO_2$ are well below the BC Level A and Canadian Maximum Desirable guideline of 450 µg/m$^3$ for maximum 1-hour concentrations of $SO_2$.

- The maximum 24-hour $SO_2$ concentration in the James Bay community was predicted to be 40 µg/m$^3$ (33 µg/m$^3$ cruise ships/ferries; 7 µg/m$^3$ background).

This is below the established CRD, BC Level A and Canadian Maximum Desirable guidelines of 125, 160 and 150 µg/m$^3$ respectively. The WHO maximum 24-hour guideline of 20 µg/m$^3$ may be exceeded in many areas of the James Bay community; however predicted concentrations above 20 µg/m$^3$ are experienced only infrequently (~3% of the time). Concentrations are below 20 µg/m$^3$ for approximately 97% of 24-hour periods in the modelling timeframe.

- The maximum average $SO_2$ concentration over the cruise ship season in the James Bay community was predicted to be 4 µg/m$^3$ (2 µg/m$^3$ cruise ships/ferries; 2 µg/m$^3$ background). This is well below established BC Level A and Canadian Maximum Desirable guidelines of 25 and 30 µg/m$^3$ for annual mean $SO_2$ concentrations. Field monitoring results from the *James Bay Air Quality Study: Phase I Report on the Results of Field Monitoring in 2007*[1] found that in general, average $SO_2$ concentrations in James Bay ranged from less than 1 µg/m$^3$ to 5.2 µg/m$^3$, based on two two-week sampling periods. These average measured $SO_2$ concentrations have good agreement with average concentrations predicted by the CALPUFF model.

**Nitrogen Dioxide ($NO_2$)**

- The maximum 1-hour $NO_2$ concentration in the James Bay community was predicted to be 136 µg/m$^3$ (85 µg/m$^3$ cruise ships/ferries; 51 µg/m$^3$ background). This is well below the established Canadian Maximum Acceptable guideline of 400 µg/m$^3$ for 1-hour concentrations of $NO_2$. Portions of Downtown Victoria and the Songhees region may experience higher maximum 1-hour concentrations than the James Bay community; in these areas predicted 1-hour maximum concentrations were 148 µg/m$^3$ (97 µg/m$^3$ cruise ships/ferries; 51 µg/m$^3$ background) and 204 µg/m$^3$ (153 µg/m$^3$ cruise ships/ferries; 51 µg/m$^3$ background) respectively. For Songhees, the predicted maximum 1-hour concentration exceeds the CRD and WHO guideline of 200 µg/m$^3$ for 1-hour $NO_2$ concentrations, although this only occurs for 1 out of 4656 hours in the modelling period. In other words, the CRD and WHO guidelines are exceeded less than 0.001% of the time in the Songhees region.

- The maximum 24-hour $NO_2$ concentration in the James Bay community was predicted to be 53 µg/m$^3$ (17 µg/m$^3$ cruise ships/ferries; 36 µg/m$^3$ background). This is well below the established Canadian Maximum Acceptable guideline of 200 µg/m$^3$.

[1] Available at: http://www.viha.ca/about_viha/news/publications/

- The maximum predicted average $NO_2$ concentration over the cruise ship season in the James Bay community was 22 µg/m$^3$ (1 µg/m$^3$ cruise ships/ferries; 21 µg/m$^3$ background). This value is well below established Canadian Maximum Desirable and WHO annual mean guidelines of 60 and 40 µg/m$^3$ respectively. Field monitoring results from the *James Bay Air Quality Study: Phase I Report on the Results of Field Monitoring in 2007*[2] found that in general, average $NO_2$ concentrations in James Bay ranged from 4.4 µg/m$^3$ to 23.7 µg/m$^3$ over a two-week period (see page 51 of Phase I report). These average measured $NO_2$ concentrations have good agreement with average concentrations predicted by the CALPUFF model.

**Particulate Matter ($PM_{10}$)**

- The maximum 1-hour $PM_{10}$ concentration in the James Bay community was predicted to be 39 µg/m$^3$ (20 µg/m$^3$ cruise ships/ferries; 19 µg/m$^3$ background). The maximum predicted 1-hour $PM_{10}$ concentration in the study area of 54 µg/m$^3$ (35 µg/m$^3$ cruise ships/ferries; 19 µg/m$^3$ background) occurred offshore of the Ogden Point terminal cruise ship berths. There are no established 1-hour ambient air quality objectives and standards for concentrations of $PM_{10}$.

- The maximum 24-hour $PM_{10}$ concentration in the James Bay community was predicted to be 18 µg/m$^3$ (4 µg/m$^3$ cruise ships/ferries; 14 µg/m$^3$ background). This value is well below the established CRD, BC Level B and WHO ambient air quality guidelines of 50 µg/m$^3$ for maximum 24-hour $PM_{10}$ concentrations.

- The maximum average $PM_{10}$ concentration over the cruise ship season in the James Bay community was predicted to be 6 µg/m$^3$ (0.3 µg/m$^3$ cruise ships/ferries; 5.7 µg/m$^3$ background). This value is well below the established WHO ambient guideline of 20 µg/m$^3$ for annual mean concentrations of $PM_{10}$.

**Particulate Matter ($PM_{2.5}$)**

- The maximum 1-hour $PM_{2.5}$ concentration in the James Bay community was predicted to be 32 µg/m$^3$ (16 µg/m$^3$ cruise ships/ferries; 16 µg/m$^3$ background). The maximum predicted 1-hour $PM_{2.5}$ concentration in the study area of 46 µg/m$^3$ (30 µg/m$^3$ cruise ships/ferries; 16 µg/m$^3$ background) occurred offshore of the Ogden Point terminal cruise ship berths. There are no established 1-hour ambient air quality objectives and standards for concentrations of $PM_{2.5}$.

[2] Available at: http://www.viha.ca/about_viha/news/publications/

- The maximum 24-hour $PM_{2.5}$ concentration in the James Bay community was predicted to be 16 µg/m$^3$ (4 µg/m$^3$ cruise ships/ferries; 12 µg/m$^3$ background). The maximum predicted 24-hour $PM_{2.5}$ concentration in the study area of 16 µg/m$^3$ (4 µg/m$^3$ cruise ships/ferries; 12 µg/m$^3$ background) occurred offshore of the Ogden Point terminal cruise ship berths. The maximum 24-hour concentrations are below the established CRD, Canada Wide Standard and WHO ambient air quality guidelines of 25, 30 and 25 µg/m$^3$ respectively.

- The maximum average $PM_{2.5}$ concentration over the cruise ship season predicted in the James Bay community was 5 µg/m$^3$ (0.2 µg/m$^3$ cruise ships/ferries; 4.8 µg/m$^3$ background). This value is below the WHO ambient air quality objective of 10 µg/m$^3$ for annual mean $PM_{2.5}$ concentrations. Field monitoring results from the *James Bay Air Quality Study: Phase I Report on the Results of Field Monitoring in 2007*[3] found that in general, average $PM_{2.5}$ concentrations in James Bay ranged from 1.3 µg/m$^3$ to 6.5 µg/m$^3$ (see page 80 of Phase I report). These average measured $PM_{2.5}$ concentrations have good agreement with average concentrations predicted by the CALPUFF model.

Atmospheric stability output from the CALMET model was examined to determine during which meteorological conditions the maximum 1-hour and maximum 24-hour concentrations of pollutants occurred. The greatest maximum predicted 1-hour concentrations were found to occur during stable, neutral/slightly stable, and neutral atmospheric stability conditions, particularly during the hours of 22:00 – 00:00 when 2-3 ships were in port, or departing. A maximum of 5 ships berthed at Ogden Point on only two days in 2007, with two during the day and three in the evening on May 11$^{th}$ and September 22$^{nd}$. The highest maximum predicted 24-hour concentrations for all pollutants ($SO_2$, $NO_2$, $PM_{10}$, and $PM_{2.5}$) occurred on these two days, when neutral atmospheric conditions were predominant, followed by slightly convective or slightly stable conditions.

At the community's request, an additional exploratory analysis of variability in concentrations with altitude was carried out to investigate differences in exposure to residents of apartment buildings. The locations of five apartment buildings were randomly selected and included in the model analysis. Based on this analysis, it was determined that predicted concentrations may vary from ground level to higher altitudes in apartment buildings. Buildings in closer proximity to, and downwind from, emissions sources may experience higher maximum predicted 1-hour concentrations with increasing height above ground. Maximum predicted 24-hour concentrations, however,

[3] Available http://www.viha.ca/about_viha/news/publications/

showed little difference between ground level and at heights above ground for all locations.

Comparison of predicted to measured concentrations at the BC Ministry of Environment Topaz Station was carried out as a quality assurance exercise. This analysis found that modelled 1-hour maximum concentrations at Topaz were lower than those actually measured for $SO_2$ (48 vs. 88 $\mu g/m^3$), $NO_2$ (60 vs. 77) and $PM_{2.5}$ (5 vs. 69 $\mu g/m^3$). The modelled maximum 24-hour concentrations were also significantly lower than measured concentrations at Topaz Station for all pollutants. This indicates that other sources may contribute to ambient concentrations of pollutants in the study area. There are many additional $PM_{2.5}$ sources operating in the area surrounding the Topaz station which may account for the higher measured values.

Based on the present model outputs, cruise ships were found to be the most influential source to air quality emissions of $SO_2$ and $NO_2$ in James Bay. The contributions of ferry emissions were found to be considerably less than cruise ship sources. No exceedences of BC or Canadian ambient air quality objectives were experienced in the James Bay community; however, the World Health Organization guideline of 20 $\mu g/m^3$ for 24-hour $SO_2$ may be exceeded infrequently (approximately 3% of the time) in James Bay, in a limited portion of Songhees, and in downtown Victoria.

Phase II of the James Bay Air Quality Study provides detailed information on short-term (1-hour) and longer term (24-hour and average) concentrations of select pollutants ($SO_2$, $NO_2$, $PM_{10}$ and $PM_{2.5}$) from specific sources (cruise ships and ferries). The James Bay community has expressed concern about additional emission sources and pollutants which were beyond the scope of this study (namely float planes, helicopters and diesel buses). There is particular concern about the impacts from volatile organic compounds (VOCs) which were not included in this analysis, and for which only limited field monitoring was conducted as part of the *Phase I Report on the Results of Field Monitoring in 2007*. These sources and pollutants are therefore recognized as a knowledge gap at this time and highlighted as an area in need of future air quality investigation.

Together, the two phases of the James Bay Air Quality Study provide a reasonable characterization of the typical short- and long-term levels of $SO_2$, NO, $NO_2$, $PM_{10}$ and $PM_{2.5}$ in the study area. It is recommended that these reports be provided to an appropriate expert for an assessment of potential health implications.

# 2.0 INTRODUCTION

## 2.1 PROJECT BACKGROUND

In 2006, researchers at the University of Victoria's Spatial Sciences Research Laboratory (SSRL) were approached by staff of the Population Health Surveillance Unit of the Vancouver Island Health Authority (VIHA) with a request to help initiate a study on air quality in the James Bay neighbourhood of Victoria. This was prompted in part by a request from the James Bay Neighbourhood Association (JBNA) to VIHA to investigate air quality and possible health risks in their area.

The James Bay Air Quality Study (JBAQS) was subsequently developed, as a two phase study designed to address the complexities of the emission sources in the vicinity. Phase I consisted of field monitoring in the study area during the 2007 summer season to establish existing levels of sulphur dioxide, nitrogen dioxide, fine particulates, metals, volatile organic compounds, as well as vehicle traffic volume in selected locations. More detailed information on Phase I can be found in the *James Bay Air Quality: Phase I Report on Results of Field Monitoring in 2007*.[4]

As Phase II of the James Bay Air Quality Study (JBAQS), SENES Consultants and researchers from the UVic SSRL were partners in conducting an air quality modelling analysis of ambient sulphur dioxide ($SO_2$), nitrogen dioxide ($NO_2$), and particulate matter ($PM_{2.5}$ and $PM_{10}$) concentrations in the multi-zoned neighbourhood of James Bay, Victoria, BC, Canada. Major emissions sources operating in the area include cruise vessels, passenger and vehicle ferries, diesel buses vehicle traffic, float planes, and helicopters. This document presents the findings of the JBAQS Phase II Air Quality Modelling portion of the study.

A sophisticated air transport and dispersion model called the California Puff Model (CALPUFF) was used to complete the ambient air quality modelling assessment. The CALPUFF model is recommended by the United States Environmental Protection Agency (EPA) for the prediction of long-range transport and deposition of pollutants. The EPA also indicates that CALPUFF may be used in complex meteorological situations where conditions change rapidly in space and time. CALPUFF uses a full 3-dimensional simulation of the atmosphere and determines the advection, dilution and deposition of released air contaminants by periodic "puff" releases from industrial sources such as stacks.

[4] Available at: http://www.viha.ca/about_viha/news/publications/

## 2.2 STUDY AREA

James Bay is a multi-zoned, but primarily residential, community at the southern tip of Vancouver Island, situated in the City of Victoria, approximately 2.5 km southwest of the downtown core (Figure 1). Significant emissions sources in this region include large marine vessels (passenger and vehicle ferries and cruise ships), diesel buses, vehicle traffic, float planes, helicopters, as well as home-heating during the cold-weather season. Some residents of the region have expressed concern regarding the impacts of emissions from these sources on local air quality. No regular program of air quality monitoring is conducted by local or provincial governments to assess the spatial or temporal variation of various emissions in the James Bay neighbourhood. More information about the different emission sources and associated air quality in the area is required to determine whether any potential health-related effects exist.

Marine transport significantly contributes to air pollution in coastal areas.[5,6] Diesel engines typically used as the main power supply of most large marine vessels[7] produce a range of emissions, including carbon monoxide (CO), carbon dioxide ($CO_2$), nitrous oxides ($NO_x$), sulphur oxides ($SO_x$), hydrocarbons (HC) and particulate matter (PM).[8] 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.[9] Substantial literature exist which report the impacts of diesel exhaust on human health, including deteriorated lung function[10], allergies and asthma[11], and increased risk of lung cancer.[12]

[5]Corbett et al. 2007. Mortality from ship emissions: a global assessment. *Environmental Science and Technology, 41(24),* 8512-8518.
[6] Lu et al. 2006. Identification and characterization of inland ship plumes over Vancouver, BC. *Atmospheric Environment, 40*, 2767-2782.
[7] Corbett and Fischbeck, 1997. Emissions from ships. *Science, 278,* 823-824.
[8] Eyring et al. 2005. Emissions from International Shipping: 1. the last 50 years. *Journal of Geophysical Research, 110* D1730. doi:10.1029/2004JD005619.
[9] Mauderly, J.R. 1992. Diesel Exhaust. In: Lippman, M., editor. Environmental toxicants: human exposures and their health effects. New York: Van Norstrand Reinhold; p.119-155.
[10] Rudell et al. 1996. Effect on symptoms and lung function in humans experimentally exposed to diesel exhaust. *Occupational Environmental Medicine, 53*(Suppl 38), 658-662.
[11] Pandya et al. 2002. Diesel exhaust and asthma: hypotheses and molecular mechanisms of action. *Environmental Health Perspectives, 110*(Suppl 1), 103-112.
[12] Bhatia et al. 1998. Diesel exhaust exposure and lung cancer. *Epidemiology, 9*, 84-91.

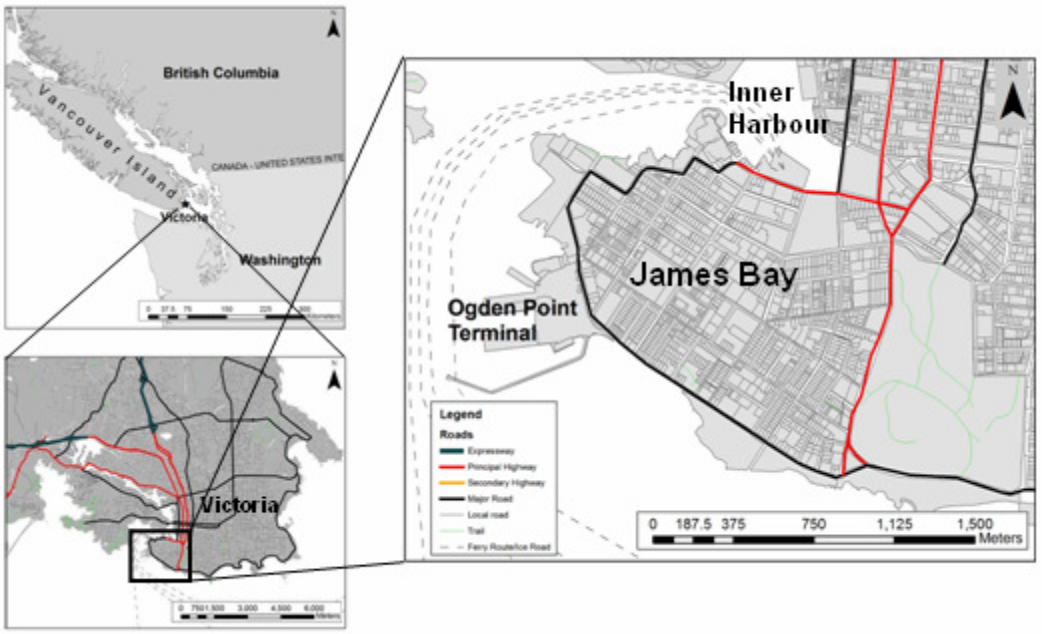



**Figure 1.** Location of James Bay, Victoria, BC, Canada.

Approximately one third of the population of James Bay is over 65 years of age.[13] The elderly represent one of the subpopulations recognized to be more susceptible to the effects of air pollution. Other at-risk subpopulations include those with cardio-respiratory disease, those with lower socioeconomic status, and children.[14] Considering the high percentage of elderly residents, as well as families with children living and attending school in the area, there is a significant percentage of the community of James Bay to which poor air quality may be of concern.

### 2.3 UNDERSTANDING DISPERSION MODELLING

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. [15]

[13] 2001 Canadian Census, as presented in the James Bay Neighbourhood Profile available on the City of Victoria website: http://www.victoria.ca/residents/profiles.shtml.
[14] Chen et al. 2008. Air quality risk assessment and management. *Journal of Toxicology and Environmental Health – Part A – Current Issues, 71*(1-2), 24-39.
[15] British Columbia Ministry of Environment. March 2008. Guidelines for Air Quality Dispersion Modelling in British Columbia. Available at: http://www.env.gov.bc.ca/air/airquality/.

Common reasons for the use of air quality models include[16]:

- 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);
- For evaluating existing air pollution levels from current sources.

While air quality modelling and monitoring can provide useful information, they should not be considered a *solution* to air quality problems. These two techniques are rather a relatively inexpensive way for providing information to guide the possible future implementation of more expensive emission reduction and control strategies.[13]

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. 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).

There are a variety of different 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 types of information trying to be obtained, is an important consideration for all modelling exercises. 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.

[16] Zannetti, P. 1946. Air Pollution Modelling: Theories, Computational Methods and Available Software. Van Nostrand Reinhold, New York.

The *Guidelines for Air Quality Dispersion Modelling in British Columbia*[17] is a comprehensive document developed by the BC Ministry of Environment to assist model practitioners in conducting modelling studies which are appropriate for the needs of the application, applied correctly and consistently using accepted scientific techniques, and used to reliably inform air quality management decisions. This document contains valuable information for air quality modelling applications, and can be referred to for further explanation or more detailed information on concepts discussed within this report. A smaller document, *A Primer on the Guidelines for Air Quality Dispersion Modelling in British Columbia*[18] provides a good overview of dispersion modelling in easy-to-understand layman's terms.

### 2.4 PROJECT GOALS

Phase II of the JBAQS uses the best currently available tools and approaches for assessing air quality impacts from emission sources such as large marine vessels. It balances the application of scientifically defensible approaches with the practical need to address outstanding questions being posed by the James Bay community about air quality in their neighbourhood. The general approach used is consistent with air quality assessment efforts for major projects in BC and North America[19] where the results are used by decision-makers regarding the air quality consequences of a project.

The main goals of the Phase II Air Quality Modelling portion of the JBAQS study include:

- To estimate concentrations of $SO_2$, $NO_2$, $PM_{10}$ and $PM_{2.5}$ in areas of the community where field monitoring during the JBAQS Phase I did not occur (horizontally and vertically) and for average time periods not captured (1-hour and 24-hour averages for $NO_2$ and $SO_2$);
- To establish estimates of emissions from various sources (cruise ships, ferries, vehicle traffic);
- To examine the contribution of pollutants attributable to different sources (cruise ships vs. ferries);
- To identify under which meteorological conditions the highest concentrations occurred;
- To compare estimated concentrations with regulatory and health air quality objectives and guidelines;

[17] British Columbia Ministry of Environment. March 2008. Guidelines for Air Quality Dispersion Modelling in British Columbia. Available at: http://www.env.gov.bc.ca/air/airquality/.
[18] Available: http://www.env.gov.bc.ca/air/airquality/pdfs/aq_disp_model_06_primer.pdf.
[19] For example, see Roberts Bank Container Expansion Project, Air Quality and Human Health Assessment (2005), prepared for the Deltaport Third Berth Project. Available from Port Metro Vancouver.

- To identify areas where there is large uncertainty, and where future refinements to the modelling approach can be applied;
- To provide information to the Vancouver Island Health Authority (VIHA) for an assessment of potential health implications;
- To develop recommendations for further research.

# 3.0 POLLUTANTS OF INTEREST

The four pollutants included in the modelling analysis are sulphur dioxide ($SO_2$), nitrogen dioxide ($NO_2$), and particulate matter ($PM_{10}$ and $PM_{2.5}$). This section describes each pollutant and their sources in the James Bay community.

## 3.1 SULPHUR DIOXIDE ($SO_2$)

Sulphur dioxide ($SO_2$) is a colourless gas and 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.[20] The amount of $SO_2$ produced depends on the sulphur content of the fuel used. Large coal-fired power plants and non-ferrous metal smelters can be large regional sources of $SO_2$.[21]

In the James Bay community, $SO_2$ is produced mainly by marine vessels, specifically cruise ships which use heavy fuel oil. The MV Coho and Victoria Clipper 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 $SO_2$ for the Victoria Inner Harbour.[22] 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.[23]

## 3.2 NITROGEN DIOXIDE ($NO_2$)

Nitrogen dioxide ($NO_2$) is a non-flammable red-orange gas and a strong oxidizing agent. It is produced by high-temperature combustion of fossil fuels and the conversion of NO.

[20] Environment Canada : http://www.ec.gc.ca/TOXICS/detail.cfm?par_substanceID=161&par_actn=s1.
[21] Brauer M. 2002. Chapter 2: Sources, Emissions, Concentrations, Exposures and Doses, in A Citizen's Guise to Air Pollution. Second Edition, Suzuki Foundation, Vancouver, BC.
[22] Tradewinds Scientific Ltd. (2000). Victoria Harbour Air Quality Impact Study, March 29, 2000. Prepared for Transport Canada Programs Branch, Vancouver, BC.
[23] SENES Consultants Ltd. (2006). Capital Regional District Air Contaminant Emissions Inventory for 2004. Prepared for the Capital Regional District, Victoria, BC.

$NO_2$ originates from both man-made and natural sources. In outdoor air, man-made sources include fossil fuel combustion for transportation, industry and electric power generation. Space heating may also contribute $NO_2$ to the atmosphere.[24] Natural sources include forest fires, lightning and soil microbes.[25]

The major sources of $NO_2$ in the study area are marine vessels, such as cruise ships, the MV Coho and Victoria Clipper, passenger and heavy duty vehicles, and commercial fishing boats. No significant industrial activities were identified as potential $NO_2$ 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 $NO_2$ concentrations in James Bay is unknown, and recognized as a knowledge gap at this time.

### 3.3 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.[26] $PM_{10}$ refers to airborne particles equal to or less than 10 micrometers (µm) in aerodynamic diameter and $PM_{2.5}$ refers to fine particulate matter equal to or less than 2.5 micrometers (µm) in aerodynamic diameter. For reference, a 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.[27] There are a number of sources of $PM_{10}$ in the James Bay neighbourhood, including emissions from cruise ships, ferries, passenger cars, and heavy duty vehicles. Space heating, from wood and fossil fuel burning, is a significant contributor to $PM_{10}$ emissions in James Bay during heating seasons.[28] Cement manufacturing at a site approximately two kilometers north of the study area also produces $PM_{10}$.[29]

Fossil fuel and wood combustion, along with industrial processes and activities release primary $PM_{2.5}$ into outdoor air. $PM_{2.5}$ can also be produced through chemical reactions in the air with sulphur dioxide ($SO_2$), nitric oxide (NO) and nitrogen dioxide ($NO_2$),

[24] SENES Consultants Ltd. (2006). Capital Regional District Air Contaminant Emissions Inventory for 2004. Prepared fro the Capital Regional District, Victoria, BC.
[25] Environment Canada : http://www.ec.gc.ca/TOXICS/EN/detail.cfm?par_substanceID=216&par_actn=s1
[26] Brauer, M. 2002. Chapter 2: Sources, Emissions, Concentrations, Exposures and Doses, in A Citizen's Guide to Air Pollution. Second Edition, Suzuki Foundation, Vancouver, BC.
[27] Chamber of Shipping. 2007. 2005-2006 BC Ocean-Going Vessel Emissions Inventory. Vancouver, BC.
[28] SENES Consultants Ltd. 2006. Capital Regional District Air Contaminant Emissions Inventory for 2005. Prepared for the Capital Regional District, Victoria, BC.
[29] National Pollutant Release Inventory : http://www.ec.gc.ca/pdb/npri/npri_online_data_e.cfm.

ammonia ($NH_3$), and volatile organic compounds (VOCs).[30] Other natural sources include dust storms, sea spray and forest fires. Sources of $PM_{2.5}$ in the James Bay community are similar to those listed for $PM_{10}$. Marine vessels, both large and small are estimated to produce the majority of $PM_{2.5}$, but emissions from passenger cars and heavy duty vehicles are also significant. Float planes and helicopters are estimated to be very small sources of $PM_{2.5}$.[31] During the heating season wood burning for residential heating is a significant source of $PM_{2.5}$.[32] Cement manufacturing at a site approximately two kilometers north of the study area produces $PM_{2.5}$.[33] $PM_{2.5}$ can be transported over very long distances, and sources outside of the study area may also contribute to local levels.

Smaller particles ($\leq$ 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.[34] 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.[35]

[30] Suzuki, N. 2003. Particulate matter in BC: a report on PM10 and PM2.5 mass concentrations up to 2000. BC Ministry of Water, Land and Air Protection and the Pacific and Yukon region of Environment Canada. Victoria, BC.
[31] Tradewinds Scientific Ltd. 2000. Victoria Harbour Air Quality Impact Study, March 29, 2000. Prepared for Transport Canada Programs Branch, Vancouver, BC.
[32] SENES Consultants Ltd. 2006. Capital Regional District Air Contaminant Emissions Inventory for 2005. Prepared for the Capital Regional District, Victoria, BC.
[33] National Pollutant Release Inventory : http://www.ec.gc.ca/pdb/npri/npri_online_data_e.cfm
[34] Suzuki, N. 2003. Particulate matter in BC: a report on PM10 and PM2.5 mass concentrations up to 2000. BC Ministry of Water, Land and Air Protection and the Pacific and Yukon region of Environment Canada. Victoria, BC.
[35] Ibid., pg 5.

# 4.0 DISPERSION MODELLING ANALYSIS

All meteorological and air simulations were performed using the California Puff (CALPUFF) modelling system. This model was initially developed by Sigma Research Corporation, and is now supported by TRC Solutions for the U.S. Environmental Protection Agency (EPA). The model is sanctioned by the EPA in their *Guideline on Air Quality Models* and by the BC Ministry of Environment in their *Dispersion Modelling Guidelines* as an appropriate model to use for situations involving complex air flow.

CALPUFF is a transport and dispersion model that advects "puffs" of emissions released from sources in the study domain. Three-dimensional fields of wind and temperature, along with information on atmospheric mixing heights, land surface characteristics (elevation and land use) and dispersion parameters are required. Sources of air contaminants can be represented with point, area, line, or volume designation.

CALPUFF was configured for an analysis of a 20 $km^2$ study domain centered on the Ogden Point Terminal, and subdivided into 100m by 100m grid cells. The modelled winds and estimated pollutant concentrations are averaged quantities relating to each grid cell. CALPUFF was also used to provide estimated pollutant concentrations at specific points of interest (discrete receptors). Table 1 provides a summary of the grid configuration.

**Table 1.** Grid configuration for CALPUFF modelling.

| Grid Element | Configuration |
|---|---|
| Size of Modelling Domain | 20 km by 20 km, centered on Ogden Point |
| Grid Horizontal Resolution | 100 m by 100 m |
| Grid Vertical Resolution | 12 levels (0 to 3300 m) |
| Input Terrain (elevation) | 30 m DEM |
| Input Vegetation (land use) | DMTI Spatial 2001 |

The following sections provide details on data development for the meteorological inputs and land surface characteristics, as well as source characterization and dispersion parameters. Information on validation of the inputs is also provided in each section.

### 4.1 METEOROLOGICAL INPUTS AND LAND SURFACE CHARACTERISTICS

CALMET, the meteorological processor included in CALPUFF, produces three-dimensional fields of wind, temperature, humidity and other parameters required for the dispersion model. Regional-level (mesoscale) meteorological fields produced by weather forecasting models can be used as input data for CALMET, and can be used in combination with measured data from surface stations via an internal blending process. For this study, meteorological fields from the Eta[36] forecasting model at 12 km horizontal resolution were used in combination with measured meteorological data from four surface stations. The meteorological inputs for CALMET are summarized in Table 2.

**Table 2.** Meteorological data used for input to 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 2 shows the locations of these stations, with the exception of the station at the Victoria Airport (located approximately 22 km north of Victoria). 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 4.1.1).

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. Terrain heights and land use classification are shown in Figure 3 and Figure 4, respectively.

[36] See http://www.emc.ncep.noaa.gov/ for further details. The Eta model has a long history of operational weather forecasting in North America, but has recently been replaced by a new generation model called WRF.

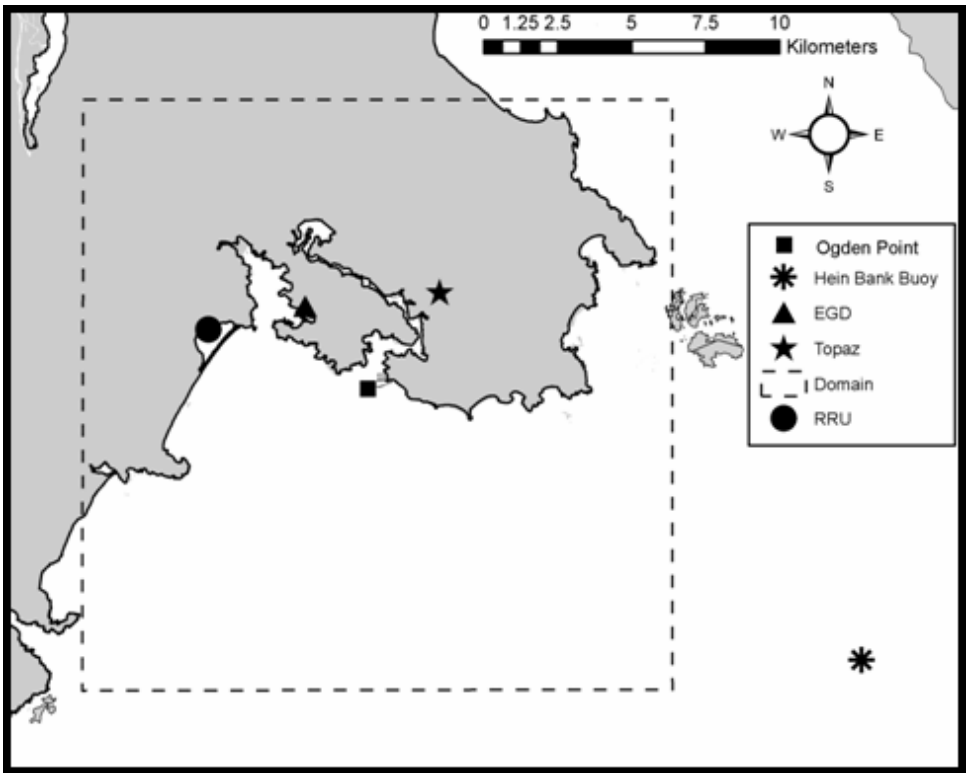



**Figure 2.** Surface meteorological stations used in the CALMET model (Ogden Point, Hein Bank Buoy and Topaz) and for model validation (EGD, RRU).

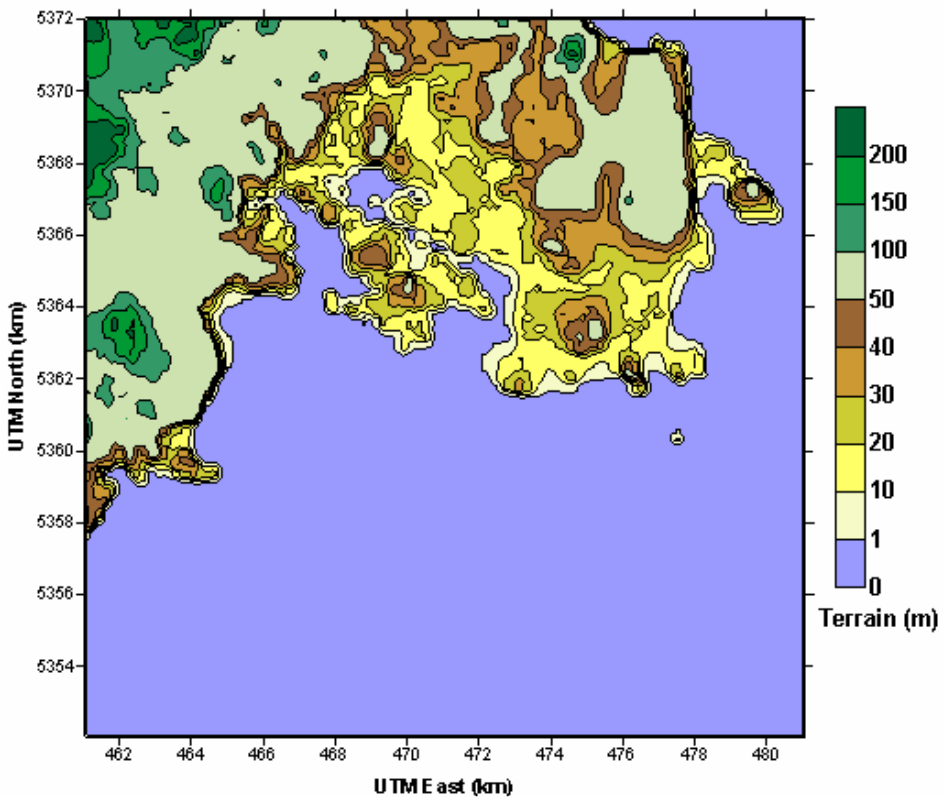



**Figure 3.** CALMET terrain heights (m).

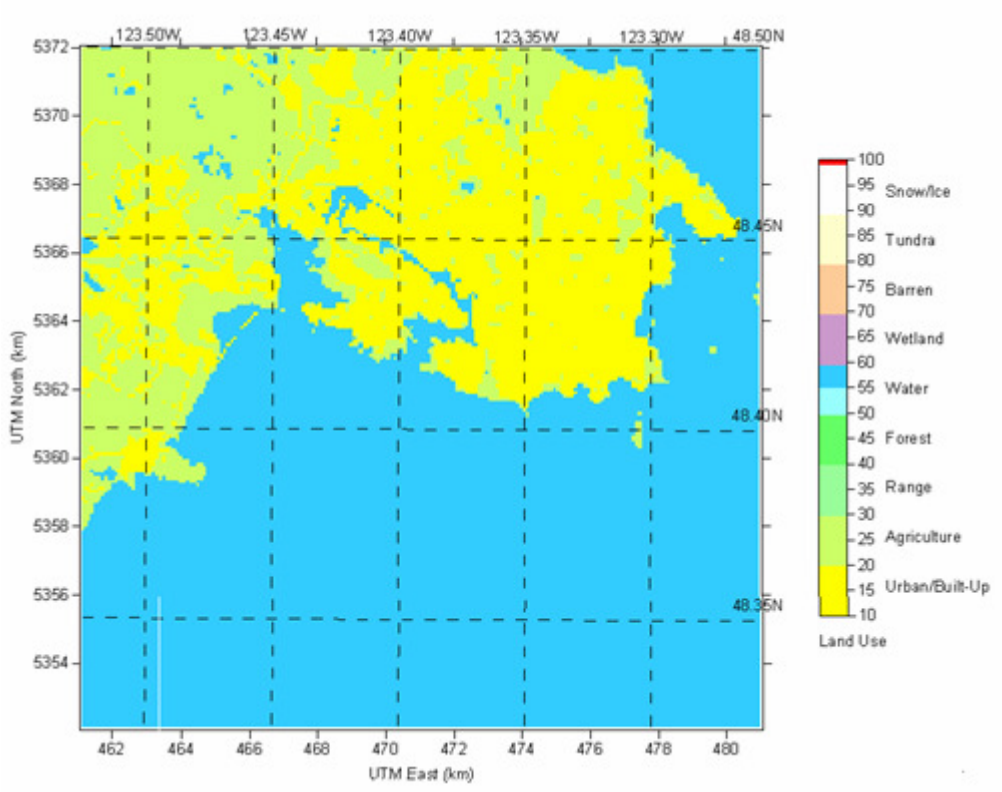



**Figure 4.** CALMET land use configuration.

Table 3 provides a summary of the CALMET configuration chosen for the meteorological simulation. Many of the options were set to their default state, consistent with the BC Dispersion Modelling Guidelines and EPA guidance.

**Table 3.** Significant CALMET 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. |

### 4.1.1 Meteorological Validation

Wind speed and direction data predicted by the CALMET model were compared to measurements at the Esquimalt Graving Dock (EGD) and Royal Roads University (RRU) to assess how well the model predicted winds at these locations in the modelling domain from which input data were not provided.

Figure 5 displays comparative wind roses for the EGD station and shows the model slightly underestimates the light offshore and stronger onshore winds in this area, but generally produces a realistic estimation of winds. Observed and modelled data from the RRU station are displayed in Figure 6, and show less agreement. This was expected, since the RRU winds are quite localized with a significant northerly flow.[37] 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 modelled and measured winds at RRU is not considered to be critical for this study.

[37] SENES Consultants. 2006. Air Quality in the Capital Regional District 2005. See http://www.crd.bc.ca.

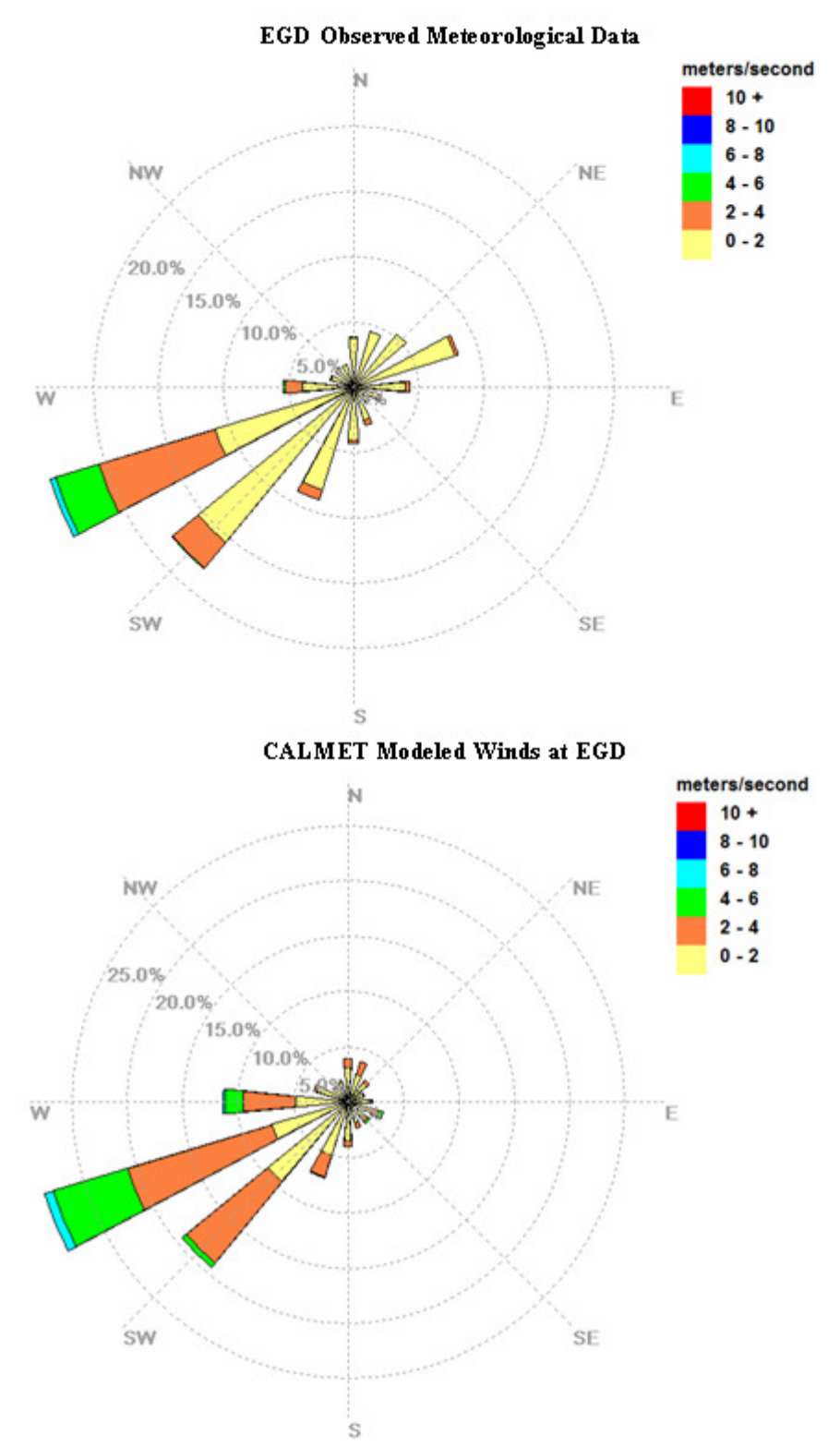



**Figure 5.** Comparison of observed and CALMET winds at the EGD site for the full modelling period April 24 – November 3, 2007.

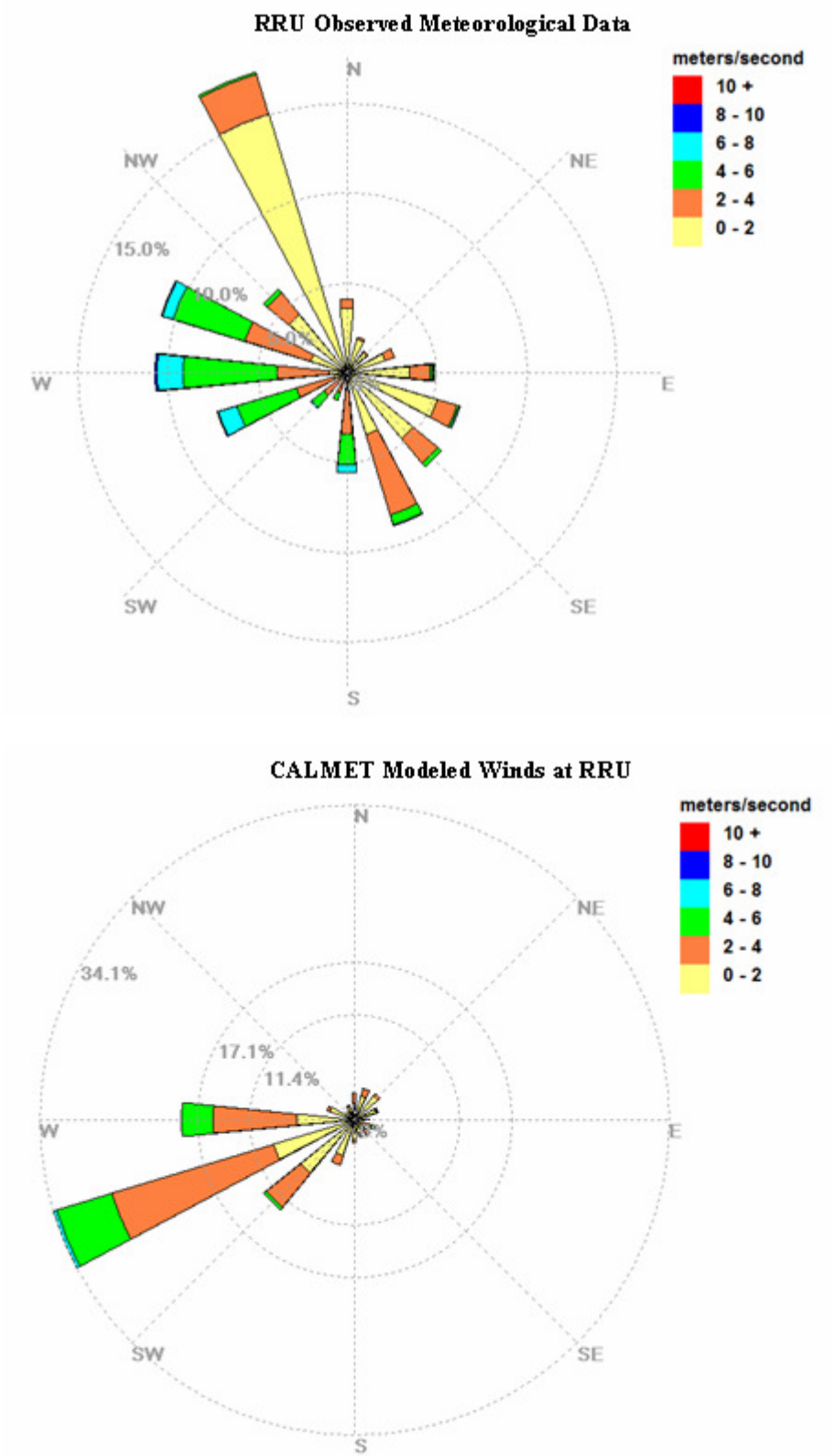



**Figure 6.** Comparison of observed and CALMET winds at the RRU site for the full modelling period April 24 – November 3, 2007.

## 4.2 Source Characterization and Dispersion Parameters

The CALMET meteorological fields provide an hour-by-hour simulation of wind speed and direction at varying heights and are used within the CALPUFF dispersion model to simulate the movement of air contaminants released from a source, or sources. Sources must therefore be characterized in terms of amount of emissions hour-by-hour, as well as geographically. The following sections provide specific information for the sources included in this study: cruise ships and ferries, vehicles, tour buses, and a general 'other' category. Validation analyses for each source are provided in Section 4.3.

### 4.2.1 Cruise Ships

Cruise ships and ferries were characterized as point sources while at berth and as line sources while manoeuvring and transiting near berth, as shown in Figure 7.

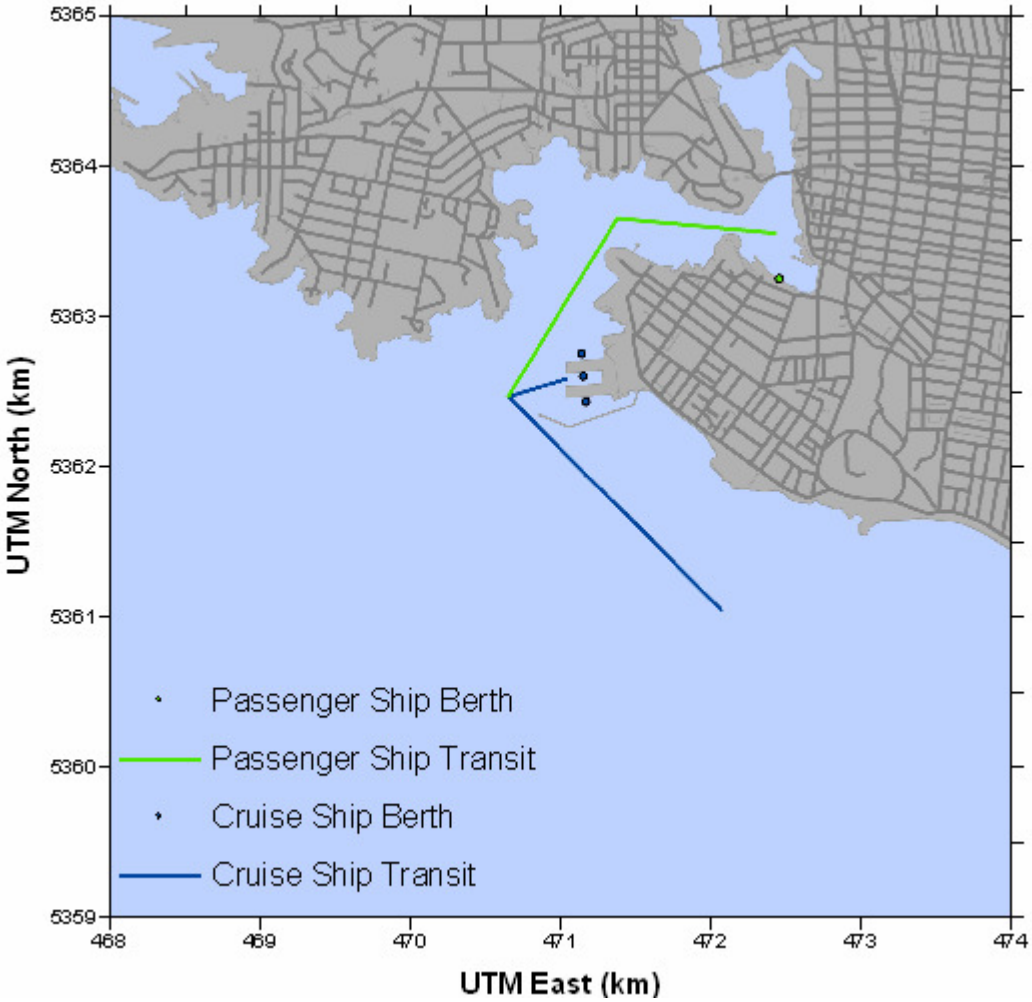



**Figure 7.** Locations of point and line sources used in the CALPUFF model to characterize cruise ships and ferries while at berth, underway and manoeuvring.

A detailed cruise ship schedule provided by the Greater Victoria Harbour Authority was used to characterize the hours during the 2007 cruise ship season when cruise ship activity was occurring in the study domain. To summarize the cruise activity during this time, there were 163 scheduled cruise ship visits to Ogden Point from April 24 to November 3. During this period, the majority of visits occurred on Thursdays, Fridays and Saturdays (18, 28 and 40% of total visits respectively), with the remaining 14% of visits occurring on days between Sunday and Wednesday. Table 4 displays frequency distributions of arrival and departure times of cruise ships over the season. The majority arrive either at 07:00 in the morning, or in the evening between 17:00 to 19:00. Most of the ships (74%) are scheduled to leave at 23:59. The full schedule is provided as reference in Appendix E.

**Table 4.** Frequency of cruise ship arrival and departure times at Ogden Point between April 24 and November 3, 2007.

| ARRIVALS | | DEPARTURES | |
|---|---|---|---|
| Time | % of Total (163 ships) | Time | % of Total (163 ships) |
| 0:700 | 16 | 13:00 | 1 |
| 07:30 | 1 | 14:00 | 7 |
| 08:00 | 9 | 16:00 | 2 |
| 10:00 | 1 | 17:00 | 8 |
| 12:00 | 2 | 18:00 | 2 |
| 14:00 | 1 | 19:00 | 2 |
| 17:00 | 12 | 22:00 | 3 |
| 18:00 | 47 | 23:59 | 74 |
| 19:00 | 12 | | |

Ship emission factors for 4-stroke marine diesel engines were used to characterize cruise ship emissions during at berth, manoeuvring and transit activity. Use of the 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 5 and are identical to those currently considered appropriate in recent Canadian marine emissions analyses.[38] In all cases, the cruise ships were assumed to be using intermediate fuel oil (IFO) with a sulphur content of 1.6%. Emission factors are also provided for marine diesel oil (MDO) for comparative purposes.

[38] 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 5 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.

**Table 5.** Energy-based emission factors for marine 4-stroke diesel engines.*

| | Emission Factor (g/kWh) | |
|---|---|---|
| **CAC** | **IFO** | **MDO** |
| $NO_x$ | 14.00 | 13.20 |
| $SO_x$ | 4.20 | 4.20 |
| $PM_{10}$ | 1.00 | 0.30 |
| $PM_{25}$ | 0.91 | 0.28 |

*$SO_x$ 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 be considered for cruise ships. The previous 2005/2006 BC Marine Emissions Inventory[39] (CoS Inventory) established an average boiler fuel consumption rate of 0.345 tonnes/hour for cruise ships at berth. This value was assumed for each cruise ship during all activities (in reality, boiler use during underway travel would be slightly higher on average). Boiler emission rates in kg/tonne fuel are provided in Table 6. The gas factors were taken from the 2005 BC Marine Emissions Inventory and the PM factors from the EPA 'AP-42' compilation of emission factors for boilers consuming no. 5 fuel oil.

**Table 6.** Boiler emission rates.*

| | Emission Rate |
|---|---|
| **CAC** | **kg/tonne** |
| $NO_x$ | 12.30 |
| $SO_x$ | 20.00 |
| $PM_{10}$ | 1.20 |
| $PM_{25}$ | 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 was reviewed.[40] This study provides an estimate of average (electric) power demand while dockside for three cruise vessels, as shown in Table 7. The 'Passenger' field was included in the table by the authors to indicate the potential relationship between electric load and number of passengers on ship. In effect, a greater number of passengers on board should require greater power developed by the engines.

[39] BC Chamber of Shipping, 2007. 2005-2006 BC Ocean-Going Vessel Emissions Inventory. See http://www.chamber-of-shipping.com.
[40] Environ International Corporation. 2006. Shoreside Power Feasibility Study for Cruise Ships Berthed at Port of San Francisco.

**Table 7.** Cruise ship characteristics from San Francisco Study (2006).

| Cruise Ship | Gross Tonnage | # Engines Used Dockside | Rated Power (kW) | Passenger | Fuel Used | Average Electric Load (kW) |
|---|---|---|---|---|---|---|
| Celebrity Mercury | ***77,713*** | 3 | 4,320 | 1,870 | IFO 380 | ***9,500*** |
| Dawn Princess | ***77,499*** | 1 | 11,650 | 1,950 | IFO 380 | ***6,800*** |
| Diamond Princess | ***116,000*** | 2 | 18,900 | 2,600 | IFO 380 | ***12,000*** |

Anecdotal remarks from ship engineers and the average engine power while at berth for cruise ships characterized in the CoS Inventory suggested the electric load values shown in Table 7 would be too high for ships berthing at Ogden Point. This issue was raised by the Victoria Harbour Authority and subsequently investigated by the authors. The following profile was developed to estimate the ship engine power level at dock for each cruise ship visit to Ogden Point:

**Average Power (kW) = (1 – monthvar) * [5,143 + (P – 1,250) * 2.857]**

Where:

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

**5,143** = engine power (kW) for a 1,250 passenger cruise ship

**P** = number of passengers for a particular vessel

It was assumed there would be a linear relationship 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 CoS 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). The difference between dockside engine load values for Ogden Point and those reported for San Francisco were assumed to be due to greater air conditioning requirements further south.

The 'monthvar' parameter was included in the expression above to account for the expected reduction in electrical power demand during cooler months. To serve as example, the Diamond Princess in this study 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.

The ship engine profile is simplistic due to a lack of available data at this time. For this reason, additional information was requested to assess how well the profile may represent the visiting ships. Figure 8 displays the linear emissions profile developed for Ogden Point (without accounting for month of year). A brief survey questionnaire was developed and made available to the Northwest Cruise Association. Two surveys were returned in short order from cruise ships that visited Ogden Point recently. The corresponding responses 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 the graph below. The survey point which lies above the profile line relates to a cruise ship stop at an undetermined time. .Use of the ship engine profile would under-estimate the value from the survey response in this case. The survey point falling below the line relates to a cruise ship stop in May (i.e., a cooler month). In this case, full use of the ship engine profile produces a good match to the survey response (taking into account the 'monthvar' parameter).

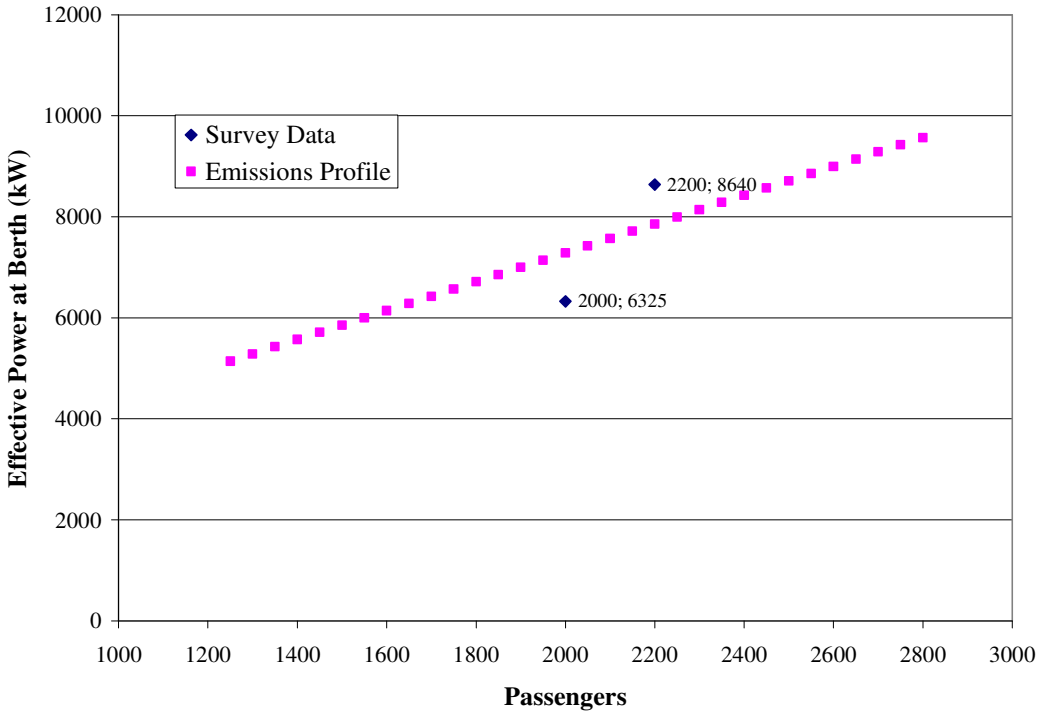



**Figure 8.** Emissions profile developed for cruise ships at Ogden Point

The CoS Inventory report contains additional characteristic information for cruise ships that can be used to estimate cruise ship engine activity during manoeuvring and slow speed movements. Power demand at berth for each ship was scaled by 1.25 and 2.0 to represent engine power required for manoeuvring and slow speed movements, respectively. Therefore, the Diamond Princess engine power would be characterized in the model as 11,250 kW for manoeuvring and 18,000 kW for slow speed travel, during July. The same monthly reduction ratios for cooler months would apply.

Cruise ship transit emissions were considered 'on' for a total time period of 0.17 hours and 0.18 hours for each ship visit, for manoeuvring and underway (slow speed) respectively. 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 the simulation as configured with CALPUFF, the short-term emissions had to be averaged out over a full hour each arrival or departure. This means that that the actual engine emission rates were lowered by the ratios indicated above, and applied over a full hour.

### 4.2.2 Ferries (M.V. Coho and Victoria Clipper)

The same model emission configuration for cruise ships (point source at berth and line source when manoeuvring and underway) was used for the ferries which dock at a terminal in the Victoria Inner Harbour, directly north of James Bay (Figure 7). Vessel and fuel characteristics for the Clipper and M.V. Coho ferries (Table 8) were provided by Clipper Navigation Inc. and Black Ball Transport Inc., respectively.

The same assumptions used for cruise ships were applied to the ferries, in terms of emission factors, transit speed and scheduling of periods with emissions 'on'. However, the ferries do not use their auxiliary engines during all periods at berth (shore power is used). This was accounted for in the emissions inputs.

**Table 8.** Ferry characteristics.

| Characteristic | Clipper | M.V. Coho |
|---|---|---|
| Fuel (Sulphur Content) | 500 ppm | 420 ppm |
| Engine Size | | |
| Main Engine | 4,000 kW | 3804 kW |
| Auxiliary Engine | 164 kW | 500 kW |
| Propulsion Load | | |
| Underway | 0.50 | 0.50 |
| Manoeuvre | 0.30 | 0.30 |
| Auxiliary Load | | |
| Berth | 0.40 | 0.25 |
| Underway/ Manoeuvre | 0.60 | 0.40 |

### 4.2.3 Vehicle Emissions

Vehicle emissions were not fully characterized in the modelling assessment since a great deal of effort would be required to determine realistic traffic counts on all nearby streets and computational time would be prohibitive. Estimates of average hourly vehicle counts were developed for selected road segments in the study area based on data from the CRD

Regional Transportation Model and traffic observed in the study area during the 2007 summer period.

Vehicle emission rates by vehicle class were previously determined in a comprehensive emissions inventory completed for the CRD in 2005/2006.[41] The emission rates were determined with the Mobile 6.2C model for that inventory, representative of the 2004 activity year. Since this study is representative of 2007, the vehicle emission rates from the CRD inventory study would likely be somewhat higher than reality (exception $SO_2$) due to lower engine emission rates for the newer vehicles. This approach was considered acceptable to determine the likely ambient concentration levels due to traffic in the community. In order to maintain manageable model run times, only major roadways were included (sixteen separate segments, shown in Figure 9) and traffic emissions were predicted at 25 selected community locations (discrete receptors, shown in Figure 10) rather than for every grid cell in the study domain.

The traffic vehicle modelling should be considered in the context of 'background' air quality. Further discussion of vehicle emissions and background concentrations is provided in Section 6.1.

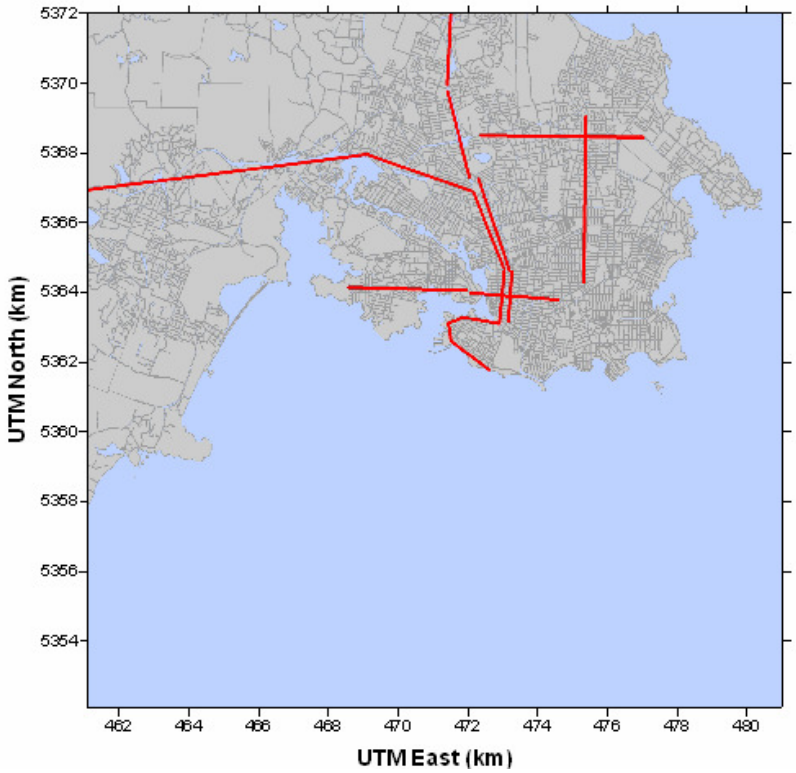



**Figure 9.** Locations of road segments used to characterize vehicle traffic in the CALPUFF model.

[41] SENES Consultants. 2006. Capital Regional District Air Emissions Inventory for 2004. See http://www.crd.bc.ca.

### 4.2.4 Tour Bus Emissions

Detailed information on bus counts, age of bus fleets and fuel types for the major tour bus companies servicing Ogden Point was not acquired in adequate time to be included for detailed modelling as line segments, such as was done for traffic in the previous section. Instead, an estimate of total emissions from buses was calculated based on distance traveled through the James Bay community (km) and emissions factors developed by Mobile 6.2C. More detailed information on total bus emissions is provided in the Emissions Validation Section 4.3.4.

### 4.2.5 Other Emission Sources

Float planes and helicopters were not included in the modelling exercise. Due to the nature of the CALPUFF model, and the behaviours of these two sources, it would have been very difficult to adequately model these two source groups. Emissions from helicopter and float planes are recognized as a knowledge gap at this time, and further research into their emissions and health impacts is recommended. However, these sources have much smaller engines compared to cruise and passenger ships, and use different fuel (with lower associated $SO_x$ and PM emission rates). For these reasons, it is unlikely that their direct representation in the model (if in fact this were possible) would significantly change the maximum predictions of $NO_2$, $SO_2$, $PM_{10}$ and $PM_{2.5}$ in James Bay. A discussion of these sources and their predicted emission levels can be found in the CRD emissions inventory report noted previously.

There are no other significant emissions sources to be considered in the James Bay area for the purposes of this modelling exercise. Residential heating would be a significant contributor to $NO_2$ emissions or particulate matter (PM) if wood appliances were used, but since this modelling exercise occurs generally throughout the non-heating season, contributions from this source were expected to be negligible during this period and therefore were not included.

## 4.3 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. The 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. Both of these approaches were used.

### 4.3.1 Cruise Ships

Estimated totals compiled directly from the CALPUFF hourly emissions input files were compared to annual total emissions calculated for the CoS Inventory.[42] For comparative purposes, modelled 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 (DRAFT).[43] This work includes a number of sub-inventories from the CoS Inventory for areas of interest in the province (one of which is Ogden Point).

Total modelled emissions while at berth were comparable to those calculated for the BC Inventory. Modelled 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. Modelled $SO_x$ 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 CoS Inventory.

[42] BC Chamber of Shipping, 2007. 2005-2006 BC Ocean-Going Vessel Emissions Inventory. See http://www.chamber-of-shipping.com.
[43] SENES Consultants, 2008. Marine Vessel Emissions Data Extraction for Select Areas in BC and the Georgia Basin. DRAFT April 3, 2008. Prepared for the British Columbia Ministry of Environment.

Total modelled emissions while manoeuvring and underway were comparably lower than the values from the CoS Inventory. This is likely due to several reasons:

- Ships transiting to/from Ogden Point were modelled as a 2 km line source, while total emissions from the CoS Inventory are for activity within a 2.5 km radius;
- Total underway emissions in the CoS inventory include additional (smaller) marine sources which operate within 2.5 km of Ogden Point, although the total presented is significantly dominated by passenger vessels.

**Table 9.** Comparison of total modelled cruise ship emissions to BC Inventory amounts.

| Activity | | Total Emissions (tonnes)* $SO_x$ | $NO_x$ | $PM_{10}$ | $PM_{2.5}$ |
|---|---|---|---|---|---|
| **Berth** | Modelled | 62.47 | 102.33 | 8.33 | 7.02 |
| | CoS Inventory | 59.77 | 81.32 | 6.47 | 5.82 |
| **Manoeuvring and Underway** | Modelled | 9.67 | 16.94 | 1.33 | 1.14 |
| | CoS Inventory** | 17.37 | 24.00 | 1.85 | 1.67 |

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

### 4.3.2 Ferries

The same procedure used to calculate total emissions for cruise ships was also applied to ferries. Modelled emission rates (g/sec) of vessels while in port and underway were converted to total emissions (tonnes) for the modelling period, as displayed in Table 10.

In this case, no comparison can be made to other sources of information to confirm validity of the emission rates (the CoS Inventory does not include these ferries). However, it can clearly be seen that total emissions from ferries are significantly lower than total emissions from cruise ships. This was 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 supports the emissions configuration of this source in the model.

**Table 10.** Total emissions modelled 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 |

### 4.3.3 Vehicle Traffic

Modelled emission rates (g/sec) of vehicle traffic along line segments were converted to total emissions (tonnes) for the modelling period. The emission rates based on a daily traffic profile of hour-by-hour counts for each line segment were first converted from emissions rates to hourly totals and then summed for the entire period. Total emissions from each line segment were summed to calculate the total emissions from all segments.

Total emissions modelled for the 16 traffic line sources (Figure 9) are included for reference to compare with other emissions sources. Total emissions from the 16 traffic line sources displayed in Table 11 show that traffic is a significant source of $NO_x$ in the study area, but not $SO_x$. Traffic should be considered a significant source of PM emissions, although these emissions would be widespread throughout the area.

**Table 11.** Total emissions modelled for vehicle traffic.

| CAC | Total Emissions (tonnes) |
|---|---|
| $SO_x$ | 0.79 |
| $NO_x$ | 228.41 |
| $PM_{10}$ | 2.71 |
| $PM_{2.5}$ | 1.30 |

### 4.3.4 Tour Bus Traffic

Detailed information on tour bus counts and fuel types was not acquired in time to model bus traffic as line segments similar to vehicular traffic. Data obtained from bus companies were therefore used to estimate the total emissions produced by buses traveling a route around the outer edges of the James Bay Community, as specified in the Cruise Tourism Community Initiative[44] according to three different fuel scenarios. Buses included in this estimate include those servicing Ogden Point only. Other tour bus companies operating in James Bay not affiliated with Ogden Point are not included.

[44] Greater Victoria Harbour Authority. 2007. Cruise Tourism Community Initiative. See: http://gvha.v3.ca/uploaded/ctci.pdf.

The maximum number of buses that might be expected in every hour of the day was used to calculate the total emissions of buses over the cruise season according to three fuel type scenarios: low sulphur (15 ppm) diesel, B20 and B100. Total emissions from each fuel type scenario are provided in Table 12. Combined with the maximum expected number of buses in an hour, this table provides a "worst-case" scenario of emissions according to different fuel types which might be used by tour bus companies in Victoria, due to lack of more detailed information on fuel type. In addition, total emissions from passenger vehicles in James Bay alone are also included in the table (based on the 4 traffic line segments located in James Bay). These total traffic emissions are calculated based upon a scenario of average traffic levels, unlike the maximum worst-case scenario for buses.

**Table 12.** Estimated total emissions for tour buses in the James Bay neighbourhood.

| | **Estimated Total Bus Emissions (Maximum)** | | | **Estimated Total Traffic Emissions** *Average*** *Traffic Levels* **(tonnes)** |
|---|---|---|---|---|
| | **Low Sulphur Diesel** | **B20** | **B100** | |
| **CAC** | **Total Emissions* (tonnes)** | **Total Emissions* (tonnes)** | **Total Emissions* (tonnes)** | |
| $SO_x$ | 0.002 | 0.001 | 0.000 | 0.022 |
| $NO_x$ | 2.360 | 2.408 | 2.596 | 6.353 |
| $PM_{10}$ | 0.111 | 0.101 | 0.021 | 0.075 |
| $PM_{2.5}$ | 0.101 | 0.060 | 0.070 | 0.036 |

***TOTAL emissions from Ogden Point buses over the cruise season based on distance travelled**
****TOTAL emissions from traffic in James Bay based on AVERAGE traffic levels of 4 line segments**

Total emissions from vehicles in James Bay are low compared to total emissions from all traffic line segments in the larger study area (Table 11). Total emissions from buses in James Bay are lower than for vehicle traffic, with the exception of $PM_{10}$ and $PM_{2.5}$ (Table 12). The emissions from buses, however, are based on maximum worst-case expected hourly counts, whereas traffic is calculated based on a daily average profile. Total emissions from buses would therefore be lower than those estimates supplied here, as the number of buses per hour for each day of the modelling period is an over-estimate and conservative in nature.

Due to the nature of the CALPUFF model, and the fact that the smallest time increment that can be simulated is 1-hour, the emissions produced from buses in James Bay are relatively insignificant. This does not indicate that tour buses have no impact on local air quality; large numbers of buses over short time periods may produce short-term effects which cannot be represented in the modelling exercise. Examining the short-term

impacts from bus emissions on air quality in James Bay is recognized as a knowledge gap at this time, and should be considered for future air quality investigations.

### 4.4 MODEL CONFIGURATION

As previously discussed, both point source and line source model representations were used. Table 13 and Table 14 show the point and line source characteristics used in the model, respectively.

**Table 13.** 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 14.** Line source characteristics.

| Source | 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 | 0.1 | 0 | 40 | 50 |
| Ferries Manoeuvring | 0.1 | 0 | 20 | 50 |
| Ferries Slow Transit | 0.1 | 0 | 20 | 50 |
| Vehicle Traffic | 0.1 | 30 | 2 | 0.1 |

The line source algorithm in CALPUFF was designed to represent long buildings with multiple stacks (for aluminum smelting operations). This source type has been used for moving exhaust sources such as vehicles, locomotives and ships in past CALPUFF modelling studies.[45] The 'building' dimensions are set very small to better represent a continuous emission stream rather than a number of individual stacks. It should be noted that moving ships have also been represented by use of area sources in other CALPUFF modelling efforts.

[45] This potential was first showcased in Radonjic, Z.R., Chambers D.B. and J. Kirkaldy, 2003. *Modelling Line Sources (Roads) Using CAL3QHCR, ISC3, AERMOD and CALPUFF*. Air and Waste Management Past Proceedings (awma.org/OnlineLibrary).

Additional CALPUFF model 'switch' options were chosen to be consistent with the BC Modelling 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 modelling study. The chemical transformation of NO to $NO_2$ was represented with an external method, as discussed in Appendix A.

# 5.0 UNCERTAINTY IN THE MODEL SIMULATIONS

Air quality models are tools for estimating ambient pollutant concentrations based on atmospheric processes approximated through the use of mathematical descriptions, and the accuracy of their results is often the subject of much debate.[46]

Naturally, describing complex atmospheric processes with mathematical equations involves simplifications and various assumptions, which can lead to inherent uncertainties in model predictions. The CALPUFF model used in this analysis is one of the core models recommended by the US Environmental Protection Agency. As such, this model has undergone significant evaluation. However, every model will vary in performance under different circumstances. The following statements have been developed by the US EPA and apply to their core models, as cited in the BC Modelling Guidelines[47]:

- 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 area. For example, error in *highest* estimated 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 result in large differences) or un-quantified inherent uncertainties. Such uncertainties (which can be on the order of 50% for the

[46] British Columbia Ministry of Environment. March 2008. Guidelines for Air Quality Dispersion Modelling in British Columbia. Available at: http://www.env.gov.bc.ca/air/airquality/.
[47] Ibid.

maximum concentrations) do not indicate an estimated concentration does not occur, only that the precise time and locations are in doubt.

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. The following assumptions made about specific emissions sources included in the model should be recognized and taken into consideration when examining 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 is believed that the average 1.6% sulphur (by mass) 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 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 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.

# 6.0 MODEL PREDICTIONS

This section presents the ambient concentration estimates of $SO_2$, $NO_2$, $PM_{10}$ and $PM_{2.5}$ generated by the CALPUFF model for the combination of cruise ship and ferry sources. For each pollutant, information is provided on the predicted maximum 1-hour, maximum 24-hour and period-average (4656-hour) concentrations. These results are first presented for each pollutant without the addition of background concentrations, in order to show the levels of pollutants expected incrementally from these sources over the region as a whole, as well as specifically in the James Bay community.

Model results are then compared to relevant air quality objectives and standards. Prior to such an analysis, predicted concentrations must first be added to existing background concentrations in the study area. The method used to establish background concentrations is described in Section 6.1, followed by the individual analyses of each pollutant in Sections 6.2 through 6.5. Section 6.6 provides a comparison of the four individual source contributions to total emissions (ferries – berth, ferries – transit, cruise – berth, and cruise – transit).

It should be noted that the figures of maximum 1-hour and maximum 24-hour concentrations represent levels that are expected to occur only *once* during the modelling period. The figures of maximum concentrations should not be considered a single "snap shot" in time of concentrations throughout the study area. These figures are comprised of the estimated 1-hour or 24-hour maximum concentrations experienced in each model cell at any time throughout the entire modelling period. Maximum concentrations experienced at one location are therefore not necessarily experienced on the same day or time as maximums at other locations.

## 6.1 BACKGROUND CONCENTRATIONS

When examining air quality in a study area, it is important to establish the concentration levels which already exist in that area – the "background" concentrations, or the result of the contribution from all sources except the source being modelled.[48] Establishing background allows the cumulative concentrations of existing and modelled concentrations to be examined. For example, there may be a relatively low modelled 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 ($100^{th}$ percentile) recorded at a station are used in screening-level analyses where the worst-case concentrations are modelled. For other

[48] British Columbia Ministry of Environment. March 2008. Guidelines for Air Quality Dispersion Modelling in British Columbia. Available at: http://www.env.gov.bc.ca/air/airquality/.

modelling purposes, such as determining compliance with ambient air quality objectives and guidelines, or for potential risk exposure estimates, a less conservative value such as the 99th or 98th value can be established.[49]

It is expected that vehicular traffic would be the greatest contributor to background air quality concentration for $NO_x$, CO, and $PM_{2.5}$ in the James Bay area. For this reason, a limited modelling assessment of vehicle emissions was conducted to complement the modelling of ship emissions. As described in Section 4.3.3, vehicle emissions along 16 significant sections of roadway in or near James Bay were estimated. These emission sources were modelled with CALPUFF such that ambient estimates were produced for every hour of the study duration at each of 25 discrete receptor locations as shown in Figure 10.

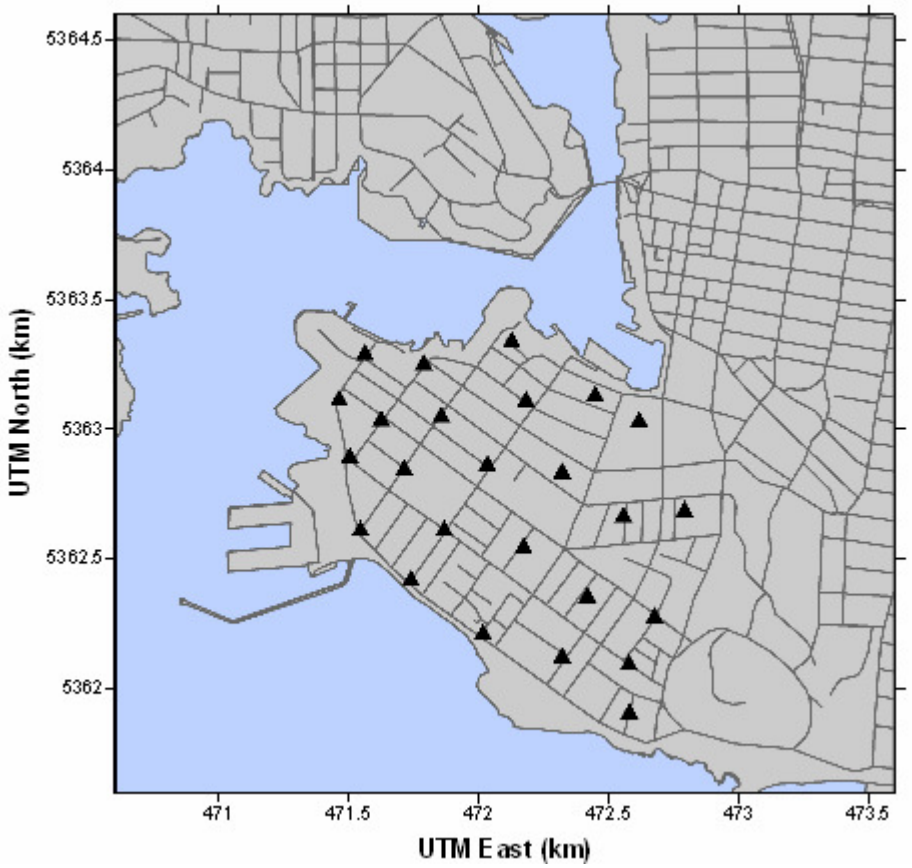



**Figure 10.** Discrete receptor locations (n=25) in the James Bay neighbourhood used to extract predicted ambient concentrations of modelled pollutants.

[49] British Columbia Ministry of Environment. March 2008. Guidelines for Air Quality Dispersion Modelling in British Columbia. Available at: http://www.env.gov.bc.ca/air/airquality/.

The average of the 98th percentile level from each receptor point was used to estimate background level concentrations of each pollutant that would be attributable to traffic emissions. The estimated ambient concentrations at a range of percentiles for 1-hour and 24-hour averaging periods are displayed in Table 15 and Table 16, respectively.

**Table 15.** Average predicted 1-hour concentrations ($\mu g/m^3$) from traffic segments based on receptor points (n=25) in the James Bay neighbourhood.

| Percentile | $SO_x$ | $NO_x$ | $PM_{2.5}$ | $PM_{10}$ |
|---|---|---|---|---|
| 100th | 0.17 | 48.33 | 0.27 | 0.27 |
| 99th | 0.07 | 20.12 | 0.11 | 0.11 |
| **98th** | **0.05** | **13.65** | **0.08** | **0.08** |
| 97th | 0.03 | 9.62 | 0.05 | 0.05 |
| 90th | 0.02 | 5.53 | 0.03 | 0.03 |
| 75th | 0.00 | 1.02 | 0.01 | 0.01 |

**Table 16.** Average predicted 24-hour concentrations ($\mu g/m^3$) from traffic segments based on receptor points (n=25) in the James Bay neighbourhood.

| Percentile | $SO_x$ | $NO_x$ | $PM_{2.5}$ | $PM_{10}$ |
|---|---|---|---|---|
| 100th | 0.03 | 8.90 | 0.05 | 0.11 |
| 99th | 0.03 | 7.25 | 0.04 | 0.09 |
| **98th** | **0.02** | **6.56** | **0.04** | **0.08** |
| 97th | 0.02 | 6.20 | 0.04 | 0.07 |
| 90th | 0.02 | 5.48 | 0.03 | 0.07 |
| 75th | 0.01 | 1.66 | 0.01 | 0.02 |

These values were then assessed against a more traditional estimate of general background concentrations (due to all emission sources) from station monitoring data.

The BC Ministry of Environment's fixed-site air quality monitoring station on Topaz Avenue (Figure 2), 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 only station in the study domain which measures 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.[50]

The 98th percentile at Topaz was selected to represent 1-hour and 24-hour background concentrations of $SO_2$, $NO_2$ and $PM_{2.5}$ (see Table 17 and Table 18). The 98th percentile was selected in order to minimize the influence of observed short-term peaks in $SO_2$ due

[50] James Bay Air Quality: Phase I Report on Results of Field Monitoring in 2007. Available at: http://www.viha.ca/about_viha/news/publications/

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 $PM_{2.5}$.[51]

**Table 17.** 1-hour frequency distribution and 98th percentile of measured concentrations ($\mu g/m^3$) at Topaz.

| Percentile | $SO_2$ | NO | $NO_2$ | $NO_x$ | $PM_{2.5}$ | Assumed $PM_{10}$* |
|---|---|---|---|---|---|---|
| 100th | 88.00 | 302.00 | 76.90 | 378.90 | 69.00 | 82.8 |
| 99th | 19.18 | 102.33 | 56.43 | 158.76 | 22.00 | 26.4 |
| **98th** | **13.00** | **77.93** | **50.30** | **128.23** | **16.42** | **19.7** |
| 97th | 11.00 | 66.55 | 47.20 | 113.75 | 14.00 | 16.8 |
| 90th | 5.00 | 27.80 | 36.50 | 64.30 | 9.00 | 10.8 |
| 75th | 3.00 | 11.68 | 27.90 | 39.58 | 6.00 | 7.2 |

**Table 18.** 24-hour frequency distribution and 98th percentile of measured concentrations ($\mu g/m^3$) at Topaz.

| Percentile | $SO_2$ | NO | $NO_2$ | $NO_x$ | $PM_{2.5}$ | Assumed $PM_{10}$* |
|---|---|---|---|---|---|---|
| 100th | 23.30 | 69.71 | 48.44 | 118.15 | 18.54 | 22.25 |
| 99th | 9.79 | 53.96 | 42.01 | 95.97 | 13.84 | 16.61 |
| **98th** | **7.12** | **47.32** | **36.07** | **83.39** | **11.64** | **13.97** |
| 97th | 5.72 | 38.51 | 33.35 | 71.86 | 10.92 | 13.10 |
| 90th | 3.91 | 26.75 | 29.70 | 56.45 | 8.19 | 9.83 |
| 75th | 2.61 | 15.01 | 24.60 | 39.61 | 5.96 | 7.15 |

***Assumed $PM_{10}$ = 1.2 * $PM_{2.5}$**

It is assumed that vehicle traffic is the main source of background NO and $NO_2$ in the study area, based on the implications of the CRD emissions inventory report.[52] However, the CALPUFF traffic modelling (Table 15 and Table 16) additionally implies that the Topaz station experiences higher concentrations due to vehicle activity than the receptors in James Bay. The study team chose the 98th percentile $NO_2$ concentration measured at Topaz to represent the general background level (that includes vehicle traffic). 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.

[51] James Bay Air Quality: Phase I Report on Results of Field Monitoring in 2007. Available at: http://www.viha.ca/about_viha/news/publications/

[52] SENES Consultants Ltd. (2006). Capital Regional District Air Contaminant Emissions Inventory for 2004. Prepared for the Capital Regional District, Victoria, BC.

Data from Topaz Station for the period of the modelling study (April 24 – November 3, 2007) were obtained from the BC Ministry of Environment, and used to calculate the 98$^{th}$ 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 19 displays the established 1-hour, 24-hour and period-average background concentrations of all air pollutants included in the study.

**Table 19.** 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 |

## 6.2 AMBIENT $SO_2$ CONCENTRATIONS

The CALPUFF model estimates concentrations of $SO_x$ (oxides of sulphur). All $SO_x$ emissions and resultant ambient $SO_x$ concentrations from the CALPUFF model were assumed to be $SO_2$ (in reality, 2 – 3% of the modelled $SO_x$ could be made up of other oxides of sulphur, such as $SO_3$ and $SO_4$).

### 6.2.1 Predicted Maximum 1-Hour $SO_2$ Concentrations

*6.2.1.1 Study Domain*

Figure 11 provides map of maximum predicted 1-hour concentrations of $SO_2$ throughout the modelling domain, based on modelled cruise and ferry emissions (no background). These maximum levels are expected to occur once during the modelling period (April 24 to November 3, 2007). The maximum modelled 1-hour $SO_2$ concentration experienced in the entire study domain was 257 $\mu g/m^3$. This maximum occurred over a berth at the Ogden Point terminal and not in the James Bay community (Figure 12).

*6.2.1.2 James Bay Community*

The maximum predicted 1-hour $SO_2$ ground-level concentration within the James Bay community from cruise and ferry sources was 151 $\mu g/m^3$. Figure 13 displays a closer view of the 1-hour maximum $SO_2$ isopleths for James Bay.

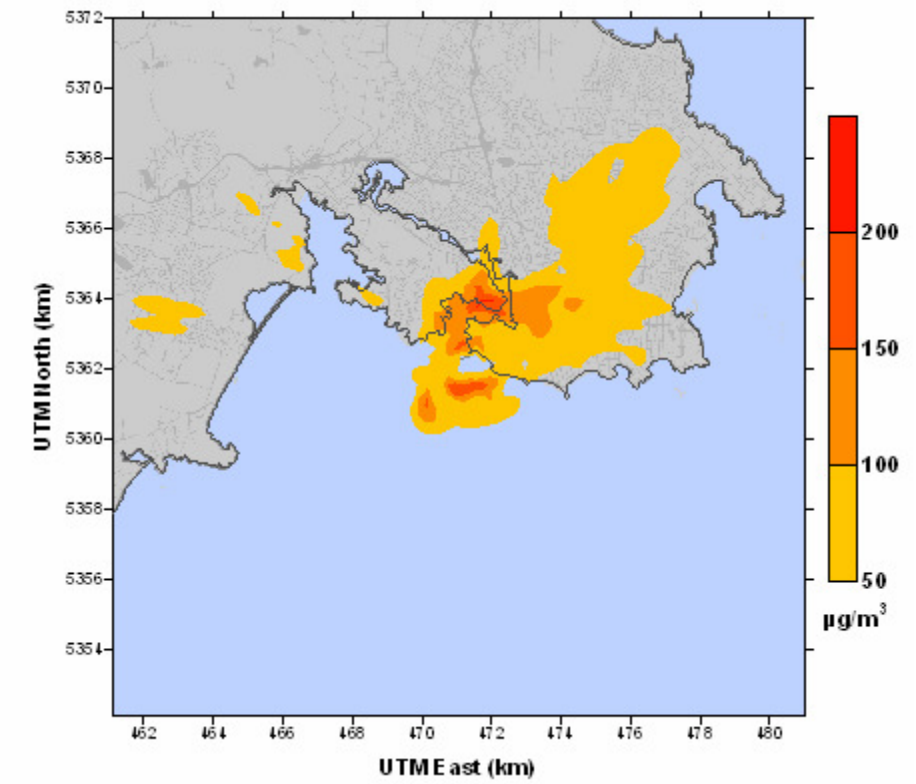



**Figure 11.** Maximum CALPUFF estimated 1-hour concentrations of $SO_2$ µg/m$^3$ due to cruise ship and ferry emissions (berth and transit) for entire study domain.

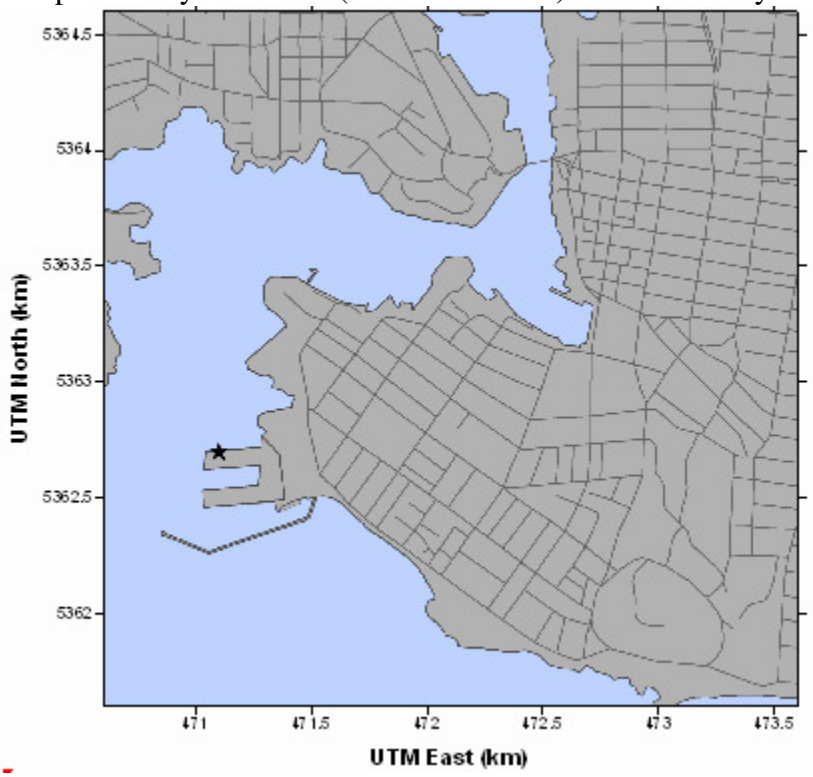



**Figure 12.** Location of CALPUFF maximum 1-hour and 24-hour $SO_2$ concentrations predicted in the entire study domain from cruise and ferry emissions sources.

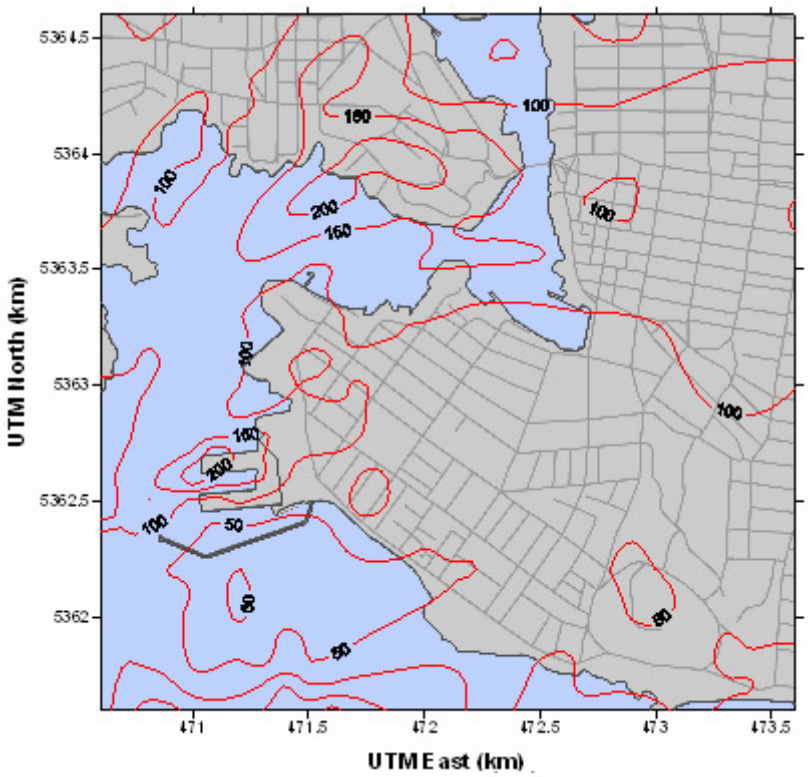



**Figure 13.** Maximum predicted CALPUFF 1-hour concentrations of $SO_2$ ($\mu g/m^3$) due to cruise ship and ferry emissions (berth and transit) in and around James Bay.

### 6.2.2 Predicted Maximum 24-Hour $SO_2$ Concentrations

*6.2.2.1 Study Domain*

Figure 14 provides a map of maximum predicted 24-hour concentrations of $SO_2$ throughout the modelling domain from cruise ship and ferry emissions (no background). These maximum levels are expected to occur once during the study period. The maximum modelled 24-hour $SO_2$ concentration in the entire study domain was 39 $\mu g/m^3$. This maximum occurred over the cruise ship berth at the Ogden Point terminal, as displayed in Figure 12.

*6.2.2.2 James Bay Community*

The maximum predicted 24-hour $SO_2$ concentration within the James Bay community from cruise and ferry sources was 33 $\mu g/m^3$. Figure 15 displays a closer view of the modelled 24-hour maximum $SO_2$ isopleths for James Bay.

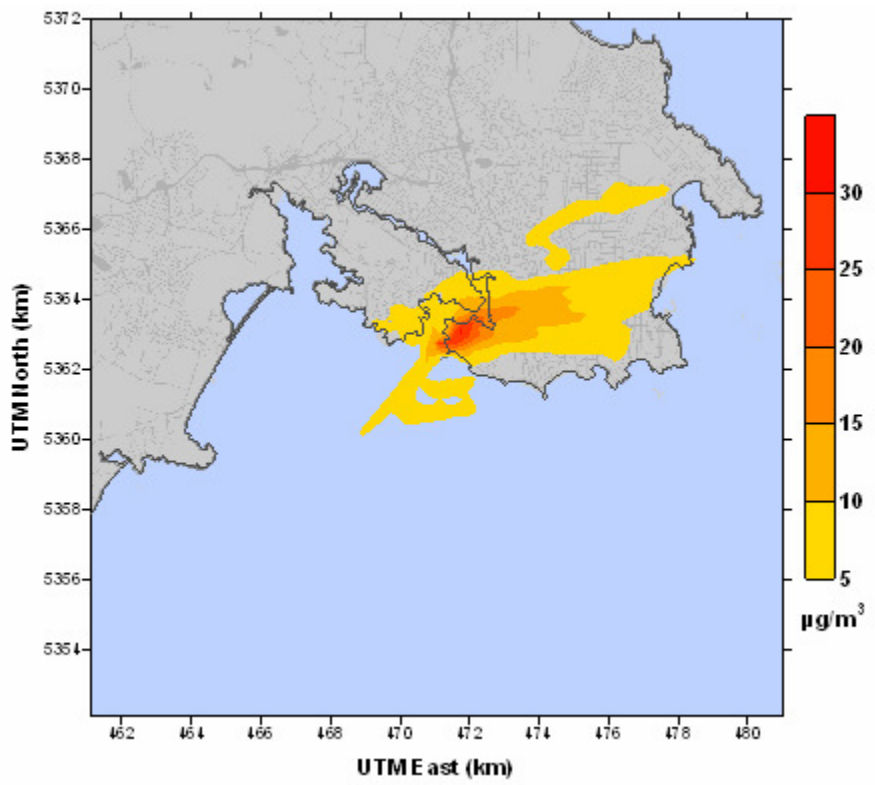



**Figure 14.** Predicted CALPUFF maximum 24-hour concentrations of $SO_2$ (µg/m$^3$) due to cruise ship and ferry emissions (berth and transit).

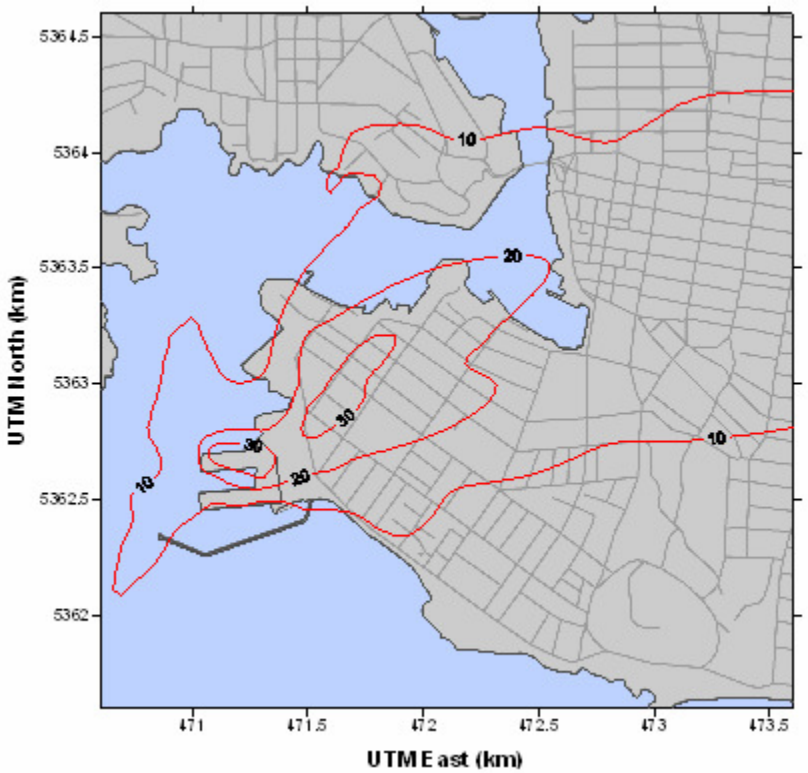



**Figure 15.** Predicted CALPUFF maximum 24-hour concentrations of $SO_2$ (µg/m$^3$) due to cruise ships and ferries (berth and transit) in and around James Bay.

### 6.2.3 Predicted Average $SO_2$ Concentrations During Cruise Season

The estimated average ambient $SO_2$ concentrations for the entire 4656-hour modelling period due to cruise and ferry sources range from approximately 0.00 - 1.79 µg/m$^3$ (no background). Isopleths of modelled average concentrations in the James Bay Community are provided in Figure 16.

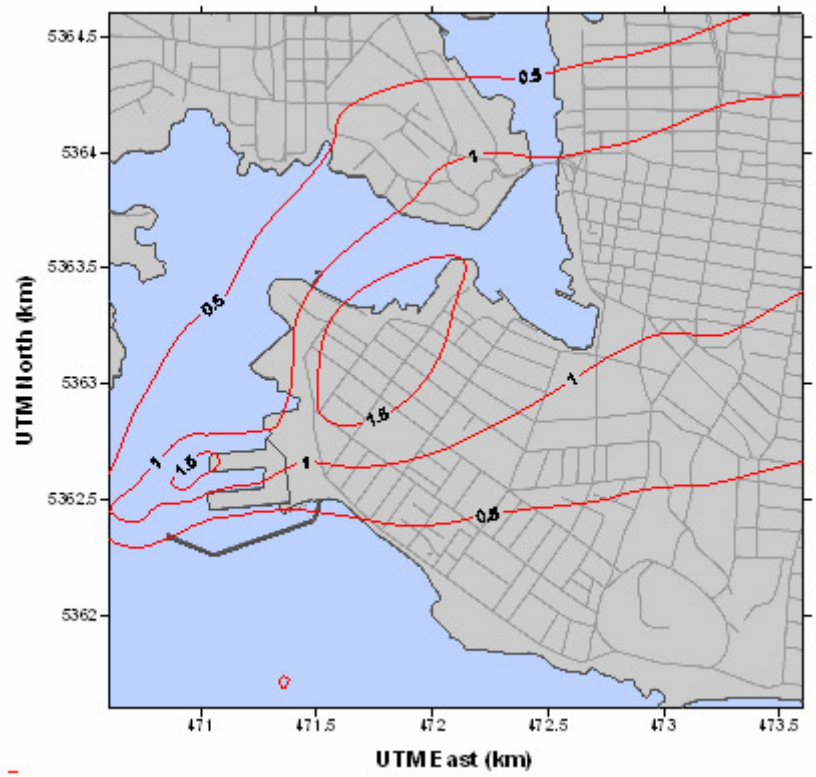



**Figure 16.** Predicted CALPUFF average 4656-hour concentrations of $SO_2$ (µg/m$^3$) due to cruise ship and ferry emissions (berth and transit) in and around James Bay.

### 6.2.4 $SO_2$ Ambient Air Quality Objectives

Table 20 presents Capital Regional District (CRD) Guidelines, British Columbia Air Quality Guidelines and Objectives, Government of Canada Air Quality Objectives, and World Health Organization (WHO) Air Quality Guidelines for ambient concentrations of $SO_2$. More detailed information about these guidelines can be referred to in Appendix B.

Background concentrations established from the Topaz monitoring site are 13 µg/m$^3$, 7 µg/m$^3$ and 1.83 µg/m$^3$ for 1-hour, 24-hour and the full cruise season averaging periods, respectively. Background $SO_2$ concentrations were added to the maximum modelled concentrations from cruise and ferry sources prior to the analysis presented below.

**Table 20.** Sulphur dioxide ($SO_2$) objectives and standards ($\mu g/m^3$).

| | | | BC | | | Canada | | | |
|---|---|---|---|---|---|---|---|---|---|
| **CAC** | **Averaging Period** | **CRD** | **Level A** | **Level B** | **Level C** | **Maximum Desirable** | **Maximum Acceptable** | **Maximum Tolerable** | **WHO** |
| **$SO_2$** | 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 | | |

*6.2.4.1 Maximum 1-Hour $SO_2$*

The maximum 1-hour concentration of $SO_2$ predicted in the James Bay community was 164 $\mu g/m^3$. Highest concentrations were at the location of the cruise ship berths, where the maximum predicted 1-hour level of $SO_2$ was 270 $\mu g/m^3$. Figure 17 displays a map of maximum predicted 1-hour $SO_2$ levels in the James Bay community (background included).

The 1-hour maximum $SO_2$ BC Level A and Canadian Maximum Desirable objectives of 450 $\mu g/m^3$ are not exceeded at any location within the modelling domain. There are no CRD or WHO guidelines which apply to 1-hour concentrations of $SO_2$.

Table 21 displays a frequency distribution of predicted 1-hour $SO_2$ concentrations from 25 receptor points (Figure 10) in the James Bay community. An explanation of how to understand the frequency distribution tables in this report is provided in Appendix C. The frequency distribution shows that concentrations close to background (13 $\mu g/m^3$) are experienced almost 90% of the time.

Figure 13 indicated that areas of higher predicted 1-hour $SO_2$ concentrations exist over the Inner Harbour, Songhees and downtown Victoria than in the James Bay community. Receptor points located at Songhees (n=6) and downtown Victoria (n=4) (Figure 18) were used to calculate additional frequency distributions of $SO_2$ for these areas (Table 23 and Table 24).

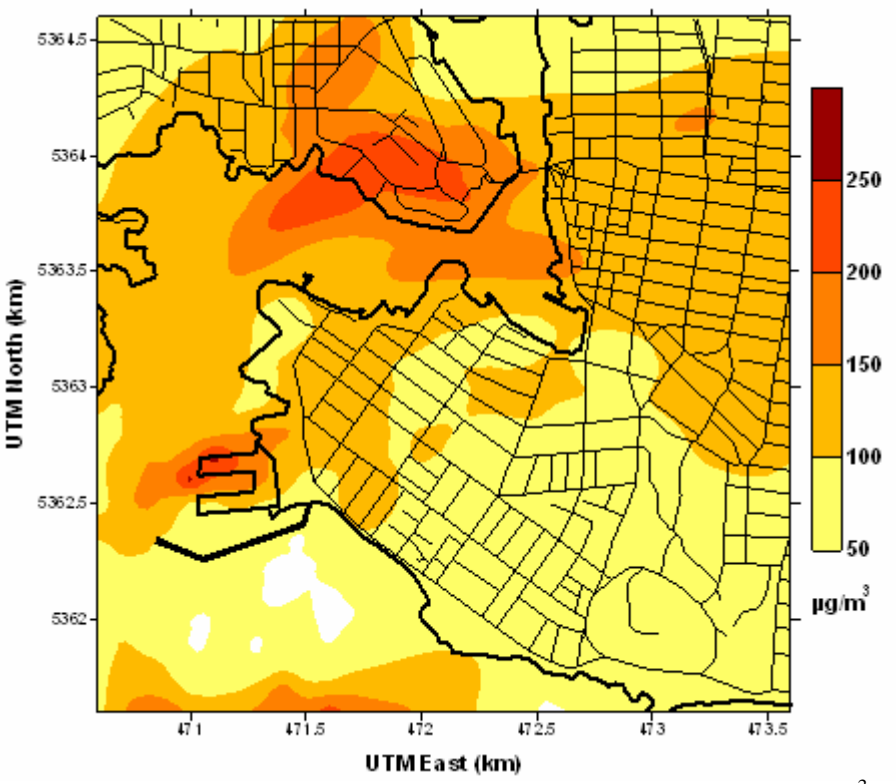



**Figure 17.** Maximum estimated 1-hour $SO_2$ concentrations (µg/m$^3$).

**Table 21.** Frequency distribution of predicted 1-hour $SO_2$ concentrations in James Bay.

| | $SO_2$ (µg/m$^3$) | | | |
|---|---|---|---|---|
| **Percentile** | **Min** | **Max** | **Average (n=25)** | **Std. Dev** |
| **100$^{th}$** | 79.59 | 162.75 | 111.25 | 20.35 |
| **99$^{th}$** | 21.93 | 64.81 | 39.96 | 14.23 |
| **98$^{th}$** | 17.88 | 50.69 | 29.20 | 9.72 |
| **97$^{th}$** | 16.21 | 38.03 | 23.91 | 6.77 |
| **95$^{th}$** | 14.58 | 24.65 | 17.86 | 3.04 |
| **90$^{th}$** | 13.03 | 14.44 | 13.51 | 0.46 |
| **80$^{th}$** | 13.00 | 13.02 | 13.01 | 0.00 |
| **75$^{th}$** | 13.00 | 13.01 | 13.00 | 0.00 |
| **50$^{th}$** | 13.00 | 13.00 | 13.00 | 0.00 |

These frequency distribution tables for predicted $SO_2$ concentrations highlight that the James Bay community experiences lower 1-hour maximum concentrations than surrounding populated areas, namely downtown Victoria and Songhees. Songhees is located north of the James Bay community, separated by the waters of the entrance to the Inner Harbour. This area experiences the highest predicted 1-hour $SO_2$ concentrations, reaching 247 µg/m$^3$.

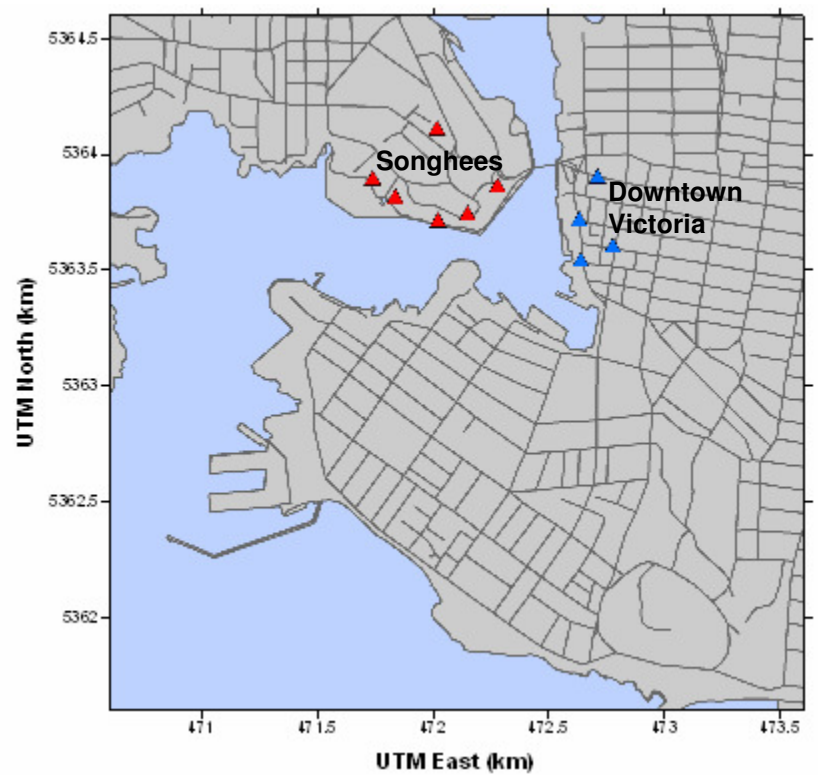



**Figure 18.** Discrete receptor locations in Songhees and Downtown Victoria used to calculate maximum 1-hour frequency distributions of $SO_2$ concentrations.

**Table 22.** Frequency distribution of predicted 1-hour $SO_2$ concentrations in Downtown Victoria.

| $SO_2$ (µg/m$^3$) | | | | |
|---|---|---|---|---|
| **Percentile** | **Min** | **Max** | **Average (n=4)** | **Std. Dev** |
| **100$^{th}$** | 142.69 | 164.69 | 152.56 | 10.86 |
| **99$^{th}$** | 44.98 | 52.11 | 48.82 | 2.93 |
| **98$^{th}$** | 29.37 | 35.29 | 32.87 | 2.51 |
| **97$^{th}$** | 23.86 | 27.46 | 26.21 | 1.62 |
| **95$^{th}$** | 18.18 | 20.19 | 19.50 | 0.91 |
| **90$^{th}$** | 14.18 | 14.48 | 14.38 | 0.14 |
| **80$^{th}$** | 13.02 | 13.02 | 13.02 | 0.00 |
| **75$^{th}$** | 13.01 | 13.01 | 13.01 | 0.00 |
| **50$^{th}$** | 13.00 | 13.00 | 13.00 | 0.00 |

**Table 23.** Frequency distribution of predicted 1-hour $SO_2$ concentrations in the Songhees area.

| $SO_2$ (µg/m$^3$) | | | | |
|---|---|---|---|---|
| **Percentile** | **Min** | **Max** | **Average (n=6)** | **Std. Dev** |
| **100$^{th}$** | 170.42 | 247.32 | 194.70 | 34.19 |
| **99$^{th}$** | 21.64 | 39.29 | 30.49 | 6.91 |
| **98$^{th}$** | 14.64 | 25.09 | 19.96 | 4.13 |
| **97$^{th}$** | 11.83 | 18.66 | 15.16 | 2.95 |
| **95$^{th}$** | 10.10 | 15.15 | 12.54 | 2.24 |
| **90$^{th}$** | 7.10 | 7.84 | 7.44 | 0.34 |
| **80$^{th}$** | 7.00 | 7.02 | 7.01 | 0.01 |
| **75$^{th}$** | 7.00 | 7.00 | 7.00 | 0.00 |
| **50$^{th}$** | 7.00 | 7.00 | 7.00 | 0.00 |

*6.2.4.2 Maximum 24-Hour $SO_2$*

The maximum predicted 24-hour concentration of $SO_2$ in the James Bay community was 40 µg/m$^3$. This maximum occurred in the same location as the 1-hour $SO_2$ maximum. Figure 19 displays a map of maximum predicted 24-hour 1-hour $SO_2$ levels in the James Bay community (background included).

This maximum is below the established CRD, BC Level A, and Canadian Maximum Desirable objectives of 125, 160 and 150 µg/m$^3$ respectively. A large portion of the James Bay community (area within the blue dashed line), including parts of Songhees and downtown Victoria, experience maximum predicted 24-hour concentrations above the WHO maximum 24-hour guideline of 20 µg/m$^3$.

Table 24 displays a frequency distribution of predicted 24-hour $SO_2$ concentrations from 25 receptor points in James Bay. An examination of the 24-hour time series of $SO_2$ concentrations at each receptor point shows that 24-hour concentrations above 20 µg/m$^3$ are experienced infrequently (approximately 3% of 24-hour periods). No consecutive 24-hour periods with average concentrations above 20 µg/m$^3$ occurred at any receptor site. At all locations, concentrations close to background (7 µg/m$^3$) are experienced 50 – 75 % of the time.

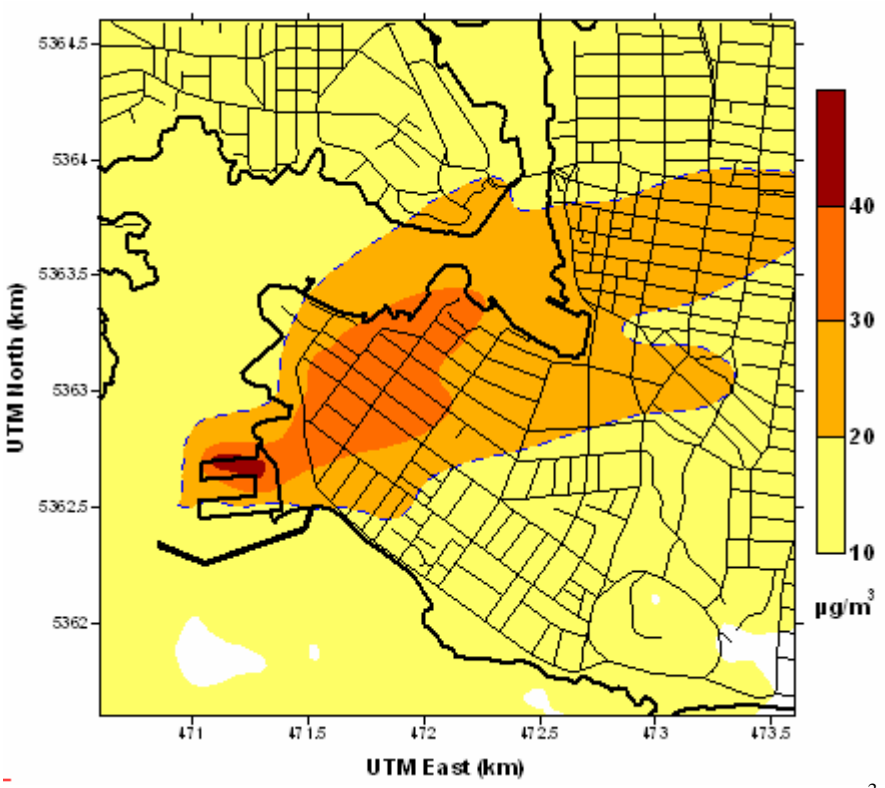



**Figure 19.** Maximum estimated 24-hour $SO_2$ concentrations (µg/m$^3$).

**Table 24.** Frequency distribution of predicted 24-hour $SO_2$ concentrations experienced at 25 receptor locations in the James Bay community.

| $SO_2$ (µg/m$^3$) | | | | |
|---|---|---|---|---|
| **Percentile** | **Min** | **Max** | **Average (n=25)** | **Std. Dev** |
| **100$^{th}$** | 12.11 | 41.00 | 24.87 | 9.85 |
| **99$^{th}$** | 10.50 | 30.15 | 17.95 | 5.53 |
| **98$^{th}$** | 10.07 | 23.13 | 15.50 | 4.05 |
| **97$^{th}$** | 9.21 | 20.31 | 13.72 | 3.43 |
| **95$^{th}$** | 8.41 | 15.61 | 11.80 | 2.55 |
| **90$^{th}$** | 7.98 | 13.31 | 10.06 | 1.77 |
| **80$^{th}$** | 7.64 | 10.40 | 8.54 | 0.86 |
| **75$^{th}$** | 7.54 | 9.17 | 8.06 | 0.53 |
| **50$^{th}$** | 7.01 | 7.04 | 7.02 | 0.01 |

*6.2.4.2 Average $SO_2$ Concentrations over the Cruise Season*

Average predicted $SO_2$ concentrations in the James Bay community range from 2 to 4 µg/m$^3$ when background is included. Figure 20 displays a map of average $SO_2$ concentrations in the James Bay community (background included). All average predicted $SO_2$ concentrations throughout the entire study domain are well below established BC and Canadian ambient air quality guidelines. There are no CRD or WHO guidelines for average $SO_2$ concentrations.

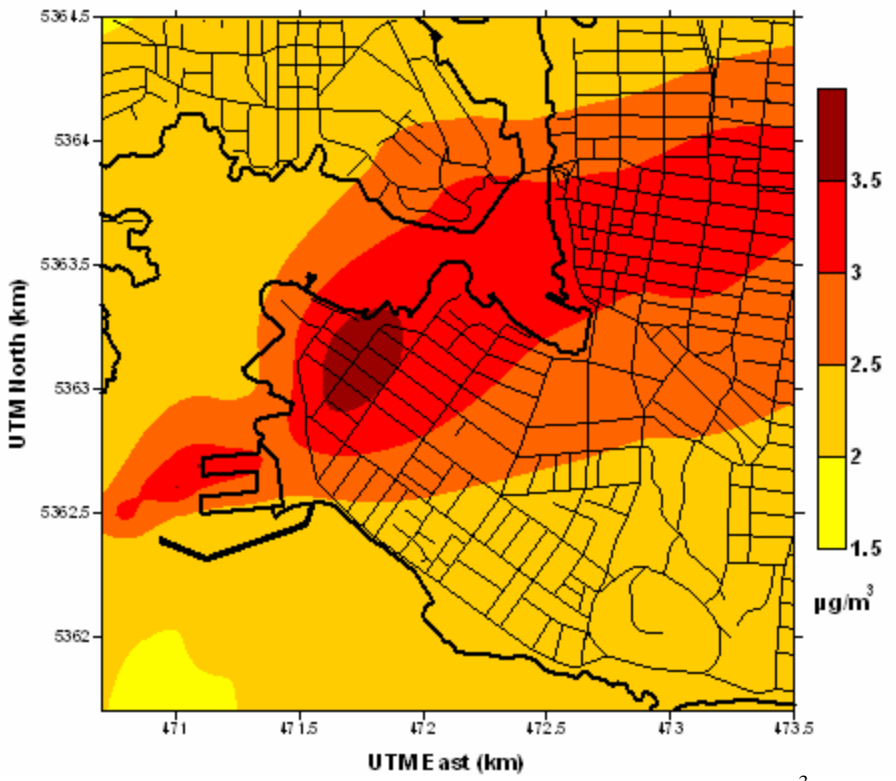



**Figure 20.** Average estimated $SO_2$ concentrations (µg/m$^3$).

### 6.2.5 Summary of $SO_2$ Findings

Table 25 presents a summary of the model findings for maximum 1-hour, maximum 24-hour and period-average $SO_2$ concentrations in the entire study domain and also the James Bay community. The table displays the 98$^{th}$ percentile background concentrations for $SO_2$ as established from the Topaz monitoring station, incremental emissions from the cruise ship and ferry sources, and the combination of these emissions in addition to background.

**Table 25.** Summary of predicted $SO_2$ concentrations (µg/m$^3$).

| Time Period | Background (BG) | Entire Study Domain | | James Bay Neighbourhood | |
|---|---|---|---|---|---|
| | | *Modelled Sources* | *Modelled Sources + BG* | *Modelled Sources* | *Modelled Sources + BG* |
| Max 1-hour | 13 | 257 | 270 | 151 | 164 |
| Max 24-hour | 7 | 39 | 46 | 33 | 40 |
| Max Period-average | 1.83 | 1.79 | 3.62 | 1.79 | 3.62 |

Field monitoring results from the *James Bay Air Quality Study: Phase I Report on the Results of Field Monitoring in 2007*[53] found that in general, average $SO_2$ concentrations in James Bay ranged from less than 1 µg/m$^3$ to 5.2 µg/m$^3$, based on two cumulative two-week sampling periods (see page 61 of Phase I report). These average measured $SO_2$ concentrations have good agreement with average concentrations predicted by the CALPUFF model. No short-term measurements of $SO_2$ were made in the James Bay neighbourhood, and a comparison cannot therefore be made for maximum 1-hour and maximum 24-hour concentrations.

Maximum predicted 1-hour, 24-hour and period-average $SO_2$ concentrations within the James Bay community are well below any relevant established CRD, BC or Canadian air quality objectives or standards. The WHO maximum 24-hour guideline of 20 µg/m$^3$ is exceeded in significant portions of the James Bay community; however, predicted concentrations above 20 µg/m$^3$ are experienced only infrequently (~3% of the time). Concentrations are below 20 µg/m$^3$ for approximately 97% of 24-hour periods in the modelling timeframe.

### 6.3 AMBIENT $NO_2$ CONCENTRATIONS

Much of the $NO_2$ in the atmosphere is generated from oxidation of NO. Although CALPUFF can be used to simulate $NO_2$ formation in the atmosphere, it is generally thought that the $NO_2$ formation approach used in the model results in $NO_2$ over-prediction. For this reason, $NO_2$ predictions are commonly estimated by use of external transformation methods. This practice is consistent with the BC Modelling Guidelines. Similar to other air studies involving CALPUFF, the model was used to simulate dispersion of total oxides of nitrogen ($NO_x$) which are comprised of both nitric oxide (NO) and nitrogen dioxide ($NO_2$). $NO_x$ emitted from diesel engines is made up primarily of NO (approximately 90 – 95%), with only 5 to 10% as $NO_2$. CALPUFF estimates of ambient $NO_x$ concentrations were then externally treated to account for the expected rate(s) of transformation of NO to $NO_2$.

A $NO_x/NO_2$ conversion method based on distance from source[54,55] was used to perform the conversion of modelled $NO_x$ to ambient $NO_2$ concentrations. Due to assumptions associated with the conversion ratios applied herein, there is a greater level of uncertainty related to $NO_2$ concentrations than to other pollutants modelled. In particular, greater

[53] Available at: http://www.viha.ca/about_viha/news/publications/

[54] Janssen et al. 1988. A classification of NO oxidation rates in power plant plumes based on atmospheric conditions. *Atmospheric Environment, 22*(1), 43-53.

[55] Oliveira and Simonsen. 2003. Utilization of a method to estimate $NO_2$ concentrations from a $NO_x$ simulation for thermal power plants. *Air & Waste Management Association Conference and Exhibition* (96th: 2003: San Diego, California).

uncertainty surrounds $NO_2$ estimates for shorter time periods (i.e. 1-hour and evening periods), as the conversion rates being applied were developed based on longer time-period averages. Further detail regarding how this method was applied is provided in Appendix A. In addition, Appendix A also examines maximum 1-hour and 24-hour $NO_2$ concentration levels calculated using the Ambient Ratio Method described in the BC Ministry of Environment *Guidelines for Air Quality Dispersion Modelling in British Columbia*.[56]

### 6.3.1 Predicted Maximum 1-Hour $NO_2$ Concentrations

*6.3.1.1 Study Domain*

Figure 21 provides a map of maximum predicted 1-hour concentrations of $NO_2$ throughout the modelling domain based on modelled cruise and ferry emissions (no background). These maximum levels are expected to occur once during the modelling period (April 24 to November 3, 2007). The maximum modelled 1-hour $NO_2$ concentration experienced in the entire study domain was 144 $\mu g/m^3$. This maximum occurred over the water off of the coast and not in the James Bay community (Figure 22).

*6.3.1.2 James Bay Community*

The maximum predicted 1-hour $NO_2$ ground-level concentration within the James Bay community due to cruise ship and ferry emissions was 85 $\mu g/m^3$. Figure 23 displays a closer view of the predicted 1-hour maximum isopleths for James Bay.

[56] British Columbia Ministry of Environment. March 2008. Guidelines for Air Quality Dispersion Modelling in British Columbia. Available at: http://www.env.gov.bc.ca/air/airquality/.

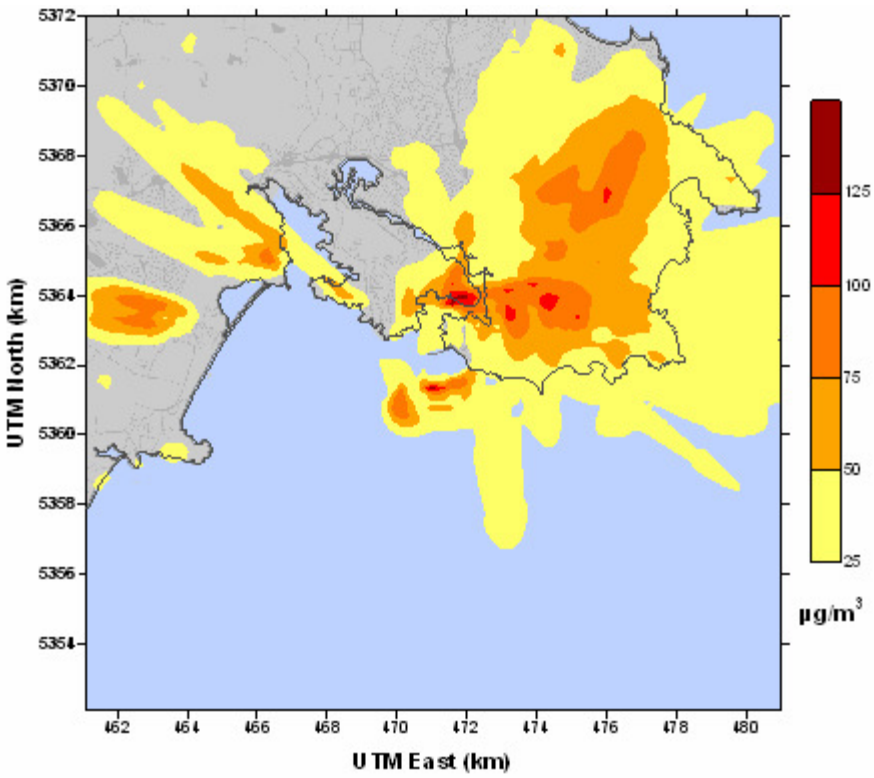



**Figure 21.** Maximum predicted 1-hour concentrations of $NO_2$ ($\mu g/m^3$) due to cruise ship and ferry emissions (berth and transit) for entire study domain.

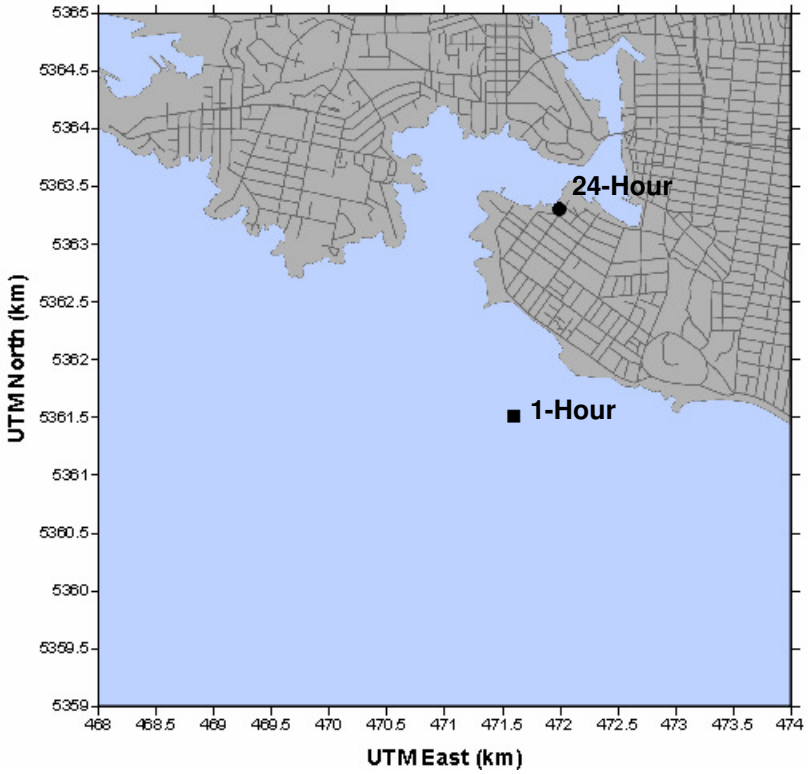



**Figure 22.** Location of maximum predicted 1-hour and 24-hour $NO_2$ concentrations in the entire study domain due to cruise and ferry emissions sources.

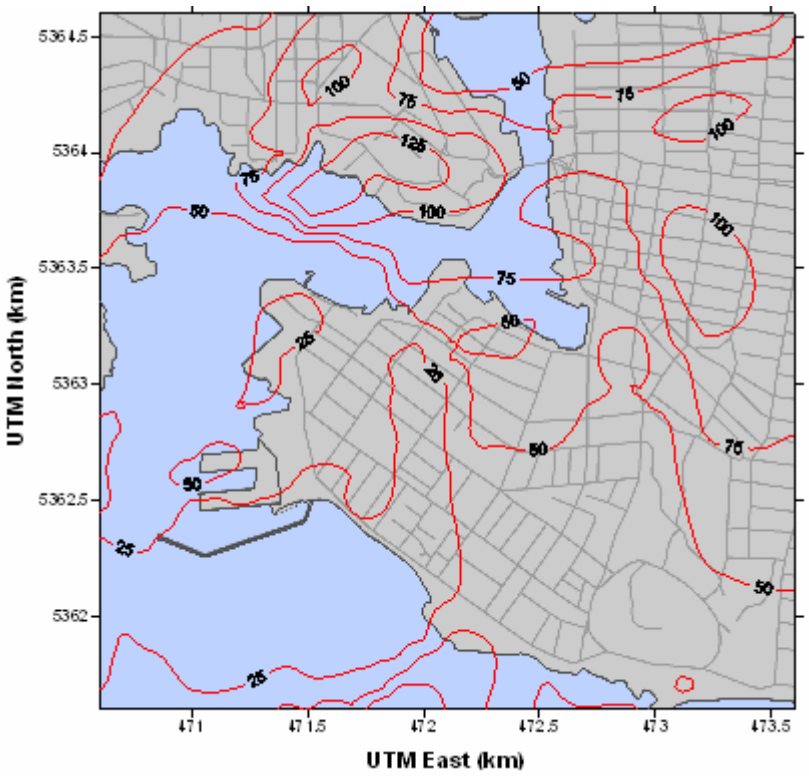



**Figure 23.** Maximum predicted 1-hour concentrations of $NO_2$ ($\mu g/m^3$) due to cruise ship and ferry emissions (berth and transit) in and around James Bay.

### 6.3.2 Predicted Maximum 24-Hour $NO_2$ Concentrations

*6.3.2.1 Study Domain*

Figure 24 provides a map of maximum predicted 24-hour concentrations of $NO_2$ throughout the modelling domain based on modelled cruise and ferry emissions (no background). These maximum levels are expected to occur once during the modelling period. The maximum predicted 24-hour $NO_2$ concentration experienced in the entire study domain was approximately 17 $\mu g/m^3$. Figure 22 displays the location of this maximum.

*6.3.2.2 James Bay Community*

The maximum predicted 24-hour $NO_2$ ground-level concentration within the James Bay community from cruise and ferry emission sources was 17 $\mu g/m^3$. Figure 25 displays a closer view of the modelled 24-hour maximum isopleths for James Bay.

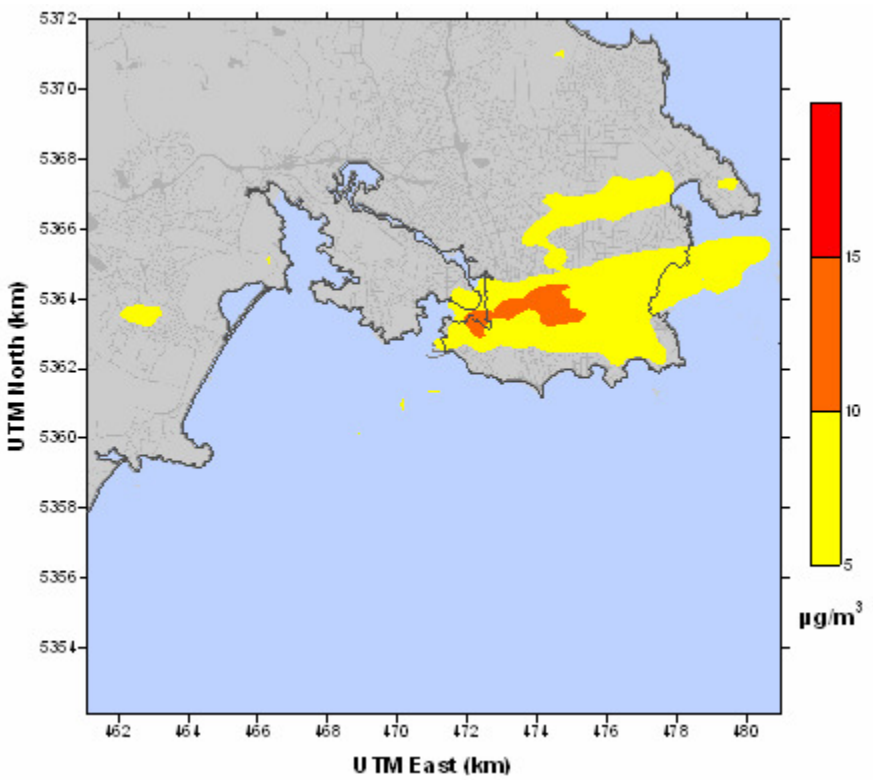



**Figure 24.** Maximum predicted 24-hour concentrations of $NO_2$ ($\mu g/m^3$) due to cruise ship and passenger vessel emissions (berth and transit).

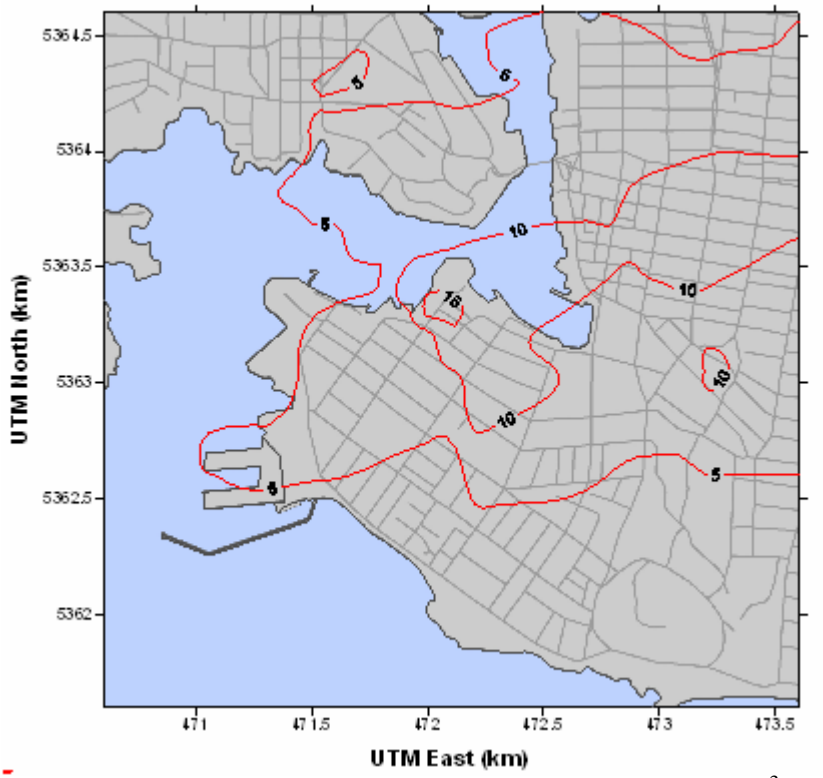



**Figure 25.** Maximum predicted 24-hour concentrations of $NO_2$ ($\mu g/m^3$) due to cruise ship and passenger vessel emissions (berth and transit) in James Bay.

### 6.3.3 Estimated Period-Average $NO_2$ Concentrations

The predicted average ambient $NO_2$ concentrations due to cruise and ferry sources, based on the entire 4656-hour assessment period range from approximately 0.00 to 1.20 µg/m$^3$ (no background). Isopleths of predicted average concentrations experienced in the James Bay Community are provided in Figure 26.

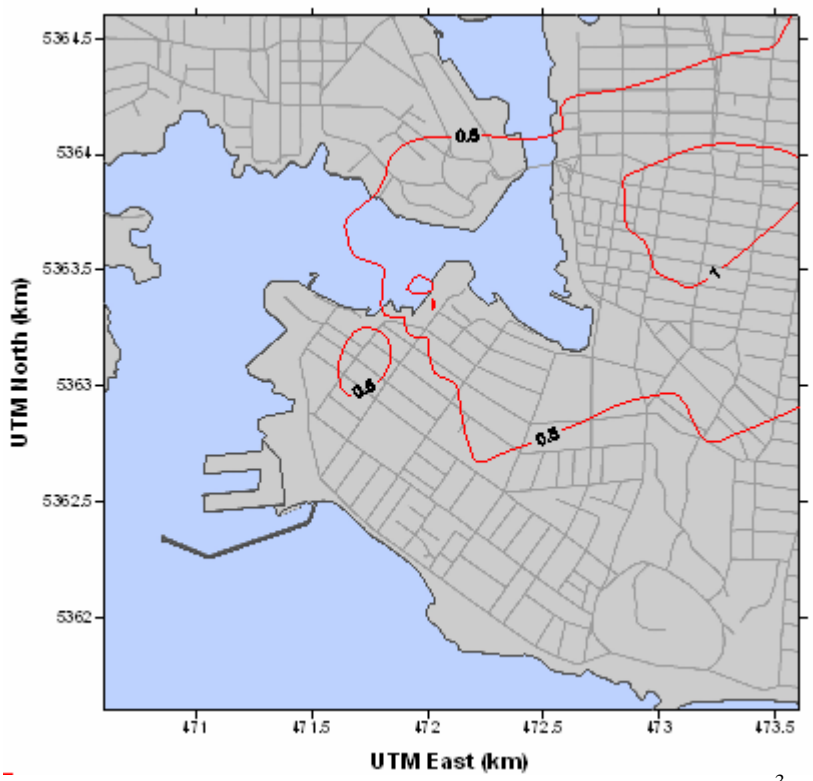



**Figure 26.** Estimated average 4656-hour concentrations of $NO_2$ (µg/m$^3$) due to cruise ship and ferry emissions (berth and transit).

### 6.3.4 $NO_2$ Ambient Air Quality Objectives

Table 26 presents Capital Regional District (CRD) Guidelines, British Columbia Air Quality Guidelines and Objectives, Government of Canada Air Quality Objectives, and World Health Organization (WHO) Air Quality Guidelines for ambient concentrations of $NO_2$.

Background concentrations established from the Topaz monitoring site are 51 µg/m$^3$, 36 µg/m$^3$ and 20.92 µg/m$^3$ for 1-hour, 24-hour and full cruise season averaging periods, respectively. The background $NO_2$ concentrations were combined with the model-derived ground level estimates from cruise and ferry sources prior to the analysis presented below.

**Table 26.** Nitrogen dioxide ($NO_2$) objectives and standards ($\mu g/m^3$).

| | | | BC | | | Canada | | | |
|---|---|---|---|---|---|---|---|---|---|
| **CAC** | **Averaging Period** | **CRD** | **Level A** | **Level B** | **Level C** | **Maximum Desirable** | **Maximum Acceptable** | **Maximum Tolerable** | **WHO** |
| **$NO_2$** | 1 hour | 200 | | | | | 400 | 1000 | 200 |
| | 24 hour | | | | | | 200 | 300 | |
| | Annual Mean | | | | | 60 | 100 | | 40 |

*6.3.4.1 Maximum 1-Hour $NO_2$*

The maximum predicted 1-hour $NO_2$ concentration in the James Bay community was 136 $\mu g/m^3$. The highest concentrations were predicted to occur at the location of the cruise ship berths, where the maximum modelled 1-hour level of $NO_2$ experienced was 195 $\mu g/m^3$. Figure 27 displays a map of maximum predicted 1-hour $NO_2$ levels in James Bay (background included).

The maximum value experienced in the James Bay community is well below the established Canadian Maximum Acceptable guideline of 400 $\mu g/m^3$ for maximum 1-hour concentrations of $NO_2$. Predicted concentrations in portions of Songhees, however, are approaching the CRD and WHO guideline of 200 $\mu g/m^3$. Songhees and Downtown Victoria experience higher predicted maximum 1-hour $NO_2$ concentrations than the James Bay community, with estimated 1-hour maximums of 204 $\mu g/m^3$ and 148 $\mu g/m^3$ respectively. The CRD and WHO guidelines for 1-hour $NO_2$ are exceeded over the Ogden Point terminal berths.

Table 27 displays frequency distributions of modelled 1-hour $NO_2$ concentrations based upon 25 discrete receptors in the James Bay community.

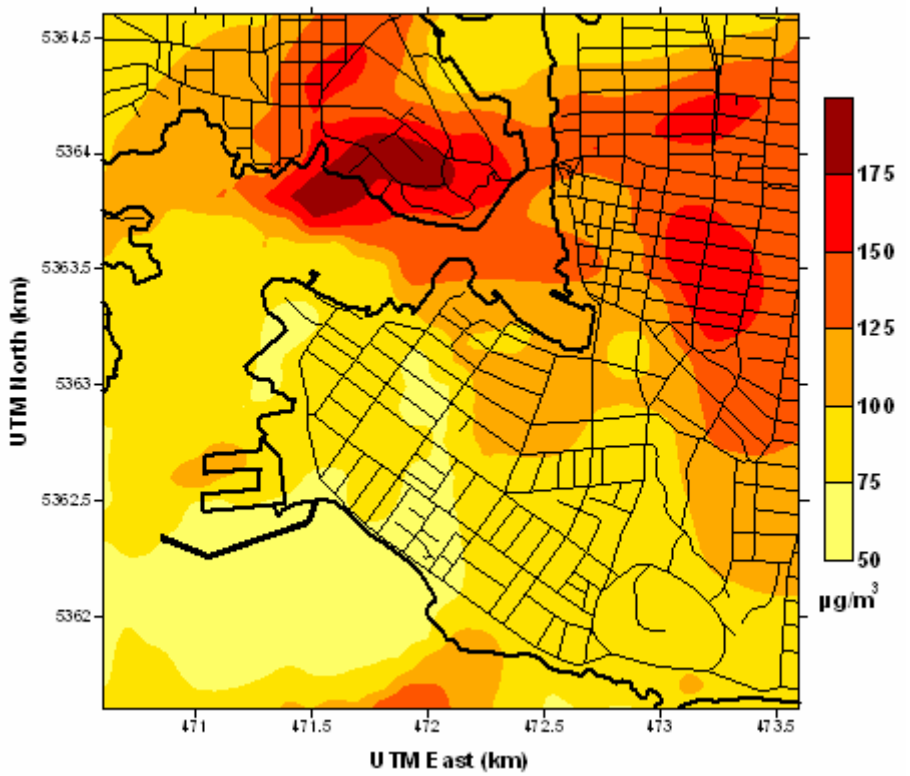



**Figure 27.** Maximum predicted 1-hour $NO_2$ concentrations (µg/m$^3$).

**Table 27.** Frequency distribution of estimated 1-hour $NO_2$ concentrations in the James Bay community based on 25 receptor locations*.

| | $NO_2$ (µg/m$^3$) | | | |
|---|---|---|---|---|
| **Percentile** | **Min** | **Max** | **Average (n=25)** | **Std. Dev** |
| **100$^{th}$** | 71.04 | 121.57 | 93.37 | 14.32 |
| **99$^{th}$** | 54.20 | 74.13 | 61.89 | 5.56 |
| **98$^{th}$** | 52.85 | 64.70 | 57.35 | 3.38 |
| **97$^{th}$** | 52.31 | 61.38 | 55.38 | 2.49 |
| **95$^{th}$** | 51.55 | 56.52 | 53.09 | 1.29 |
| **90$^{th}$** | 51.02 | 52.51 | 51.43 | 0.35 |
| **80$^{th}$** | 51.00 | 51.43 | 51.08 | 0.11 |
| **75$^{th}$** | 51.00 | 51.17 | 51.03 | 0.04 |
| **50$^{th}$** | 51.00 | 51.00 | 51.00 | 0.00 |

*Frequency distributions and 100$^{th}$ percentile maximum concentrations are calculated based on discrete receptor points within the community. Gridded receptors, which are established at regular intervals throughout the study domain, also provide estimates assumed to be representative of the surrounding grid cell (100x100 meters). It is possible that maximums calculated at receptor points may not exactly match the maximum concentrations based on the gridded receptors. In this case above, the maximum $NO_2$ concentration recorded at the discrete receptor locations is lower than the maximum $NO_2$ concentration calculated at a gridded receptor point in the community. The highest maximum from the gridded receptor is given above, but not reflected in the frequency distribution table.

Figure 27 displays areas of higher predicted 1-hour $NO_2$ concentrations over Songhees and downtown Victoria than in the James Bay neighbourhood. Receptor points located at Songhees (n=6) and downtown Victoria (n=4) (Figure 18) were used to calculate additional frequency distributions of $NO_2$ for these areas outside of the James Bay community, as displayed in Table 28 and Table 29. Although the CRD and WHO 1-hour guideline of 200 µg/m$^3$ is exceeded in Songhees (where the 100$^{th}$ percentile was 204 µg/m$^3$) this only occurs for 1 out of all 4656 hours in the modelling period; in other words, the 1-hour CRD and WHO guidelines are exceeded less than 0.001% of the time. The 99$^{th}$ percentile (70 µg/m$^3$) is well below the guidelines.

**Table 28.** Frequency distribution of estimated 1-hour $NO_2$ concentrations in Songhees.

| $NO_2$ (µg/m$^3$) | | | | |
|---|---|---|---|---|
| **Percentile** | **Min** | **Max** | **Average (n=6)** | **Std. Dev** |
| **100$^{th}$** | 149.07 | 204.23 | 167.59 | 24.38 |
| **99$^{th}$** | 59.73 | 70.10 | 65.10 | 3.99 |
| **98$^{th}$** | 55.87 | 61.43 | 58.81 | 2.35 |
| **97$^{th}$** | 54.11 | 58.26 | 56.09 | 1.78 |
| **95$^{th}$** | 52.37 | 54.71 | 53.48 | 1.00 |
| **90$^{th}$** | 51.25 | 51.83 | 51.56 | 0.24 |
| **80$^{th}$** | 51.02 | 51.12 | 51.06 | 0.04 |
| **75$^{th}$** | 51.01 | 51.03 | 51.02 | 0.01 |
| **50$^{th}$** | 51.00 | 51.00 | 51.00 | 0.00 |

**Table 29.** Frequency distribution of estimated 1-hour $NO_2$ concentrations in Downtown Victoria.

| $NO_2$ (µg/m$^3$) | | | | |
|---|---|---|---|---|
| **Percentile** | **Min** | **Max** | **Average (n=4)** | **Std. Dev** |
| **100$^{th}$** | 124.03 | 148.33 | 137.38 | 10.17 |
| **99$^{th}$** | 72.57 | 75.05 | 73.54 | 1.08 |
| **98$^{th}$** | 61.57 | 64.56 | 63.12 | 1.25 |
| **97$^{th}$** | 58.04 | 60.19 | 59.34 | 0.95 |
| **95$^{th}$** | 54.45 | 55.65 | 55.09 | 0.49 |
| **90$^{th}$** | 51.89 | 52.05 | 51.97 | 0.07 |
| **80$^{th}$** | 51.12 | 51.13 | 51.13 | 0.01 |
| **75$^{th}$** | 51.04 | 51.06 | 51.05 | 0.01 |
| **50$^{th}$** | 51.00 | 51.00 | 51.00 | 0.00 |

*6.3.4.2 Maximum 24-Hour $NO_2$*

The maximum predicted 24-hour concentration of $NO_2$ in the James Bay community was 53 µg/m$^3$. Figure 28 displays a map of maximum predicted 24-hour $NO_2$ concentrations in James Bay (background included).

All predicted 24-hour $NO_2$ concentrations are below the Canadian air quality guidelines and objectives. There are no maximum 24-hour $NO_2$ guidelines established for the CRD, BC or WHO. Table 30 displays a frequency distribution of modelled 24-hour $NO_2$ concentrations from 25 receptor points in the James Bay community.

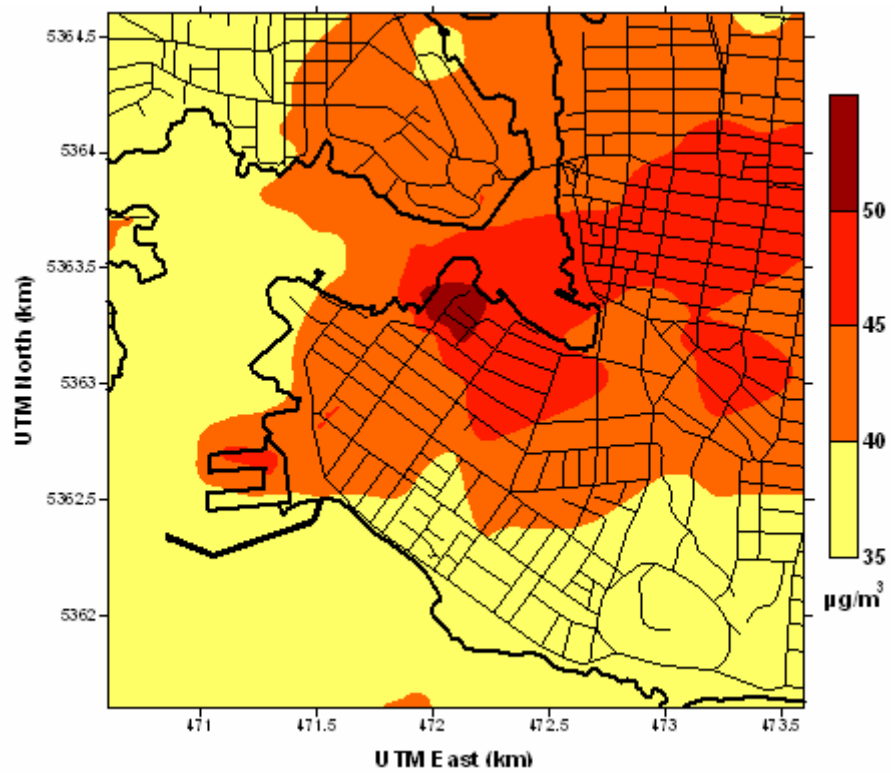



**Figure 28.** Maximum predicted 24-hour $NO_2$ concentrations (µg/m$^3$).

**Table 30.** Frequency distribution of predicted 24-hour $NO_2$ concentrations in the James Bay community.

| $NO_2$ (µg/m$^3$) | | | | |
|---|---|---|---|---|
| **Percentile** | **Min** | **Max** | **Average (n=25)** | **Std. Dev** |
| **100$^{th}$** | 37.77 | 52.45 | 42.94 | 3.62 |
| **99$^{th}$** | 36.20 | 37.20 | 36.50 | 0.25 |
| **98$^{th}$** | 36.04 | 36.11 | 36.07 | 0.02 |
| **97$^{th}$** | 36.01 | 36.03 | 36.02 | 0.00 |
| **95$^{th}$** | 36.00 | 36.00 | 36.00 | 0.00 |
| **90$^{th}$** | 36.00 | 36.00 | 36.00 | 0.00 |
| **80$^{th}$** | 36.00 | 36.00 | 36.00 | 0.00 |
| **75$^{th}$** | 36.00 | 36.00 | 36.00 | 0.00 |
| **50$^{th}$** | 36.00 | 36.00 | 36.00 | 0.00 |

The frequency distribution table for 24-hour $NO_2$ concentrations shows that in general, background concentrations of 36 µg/m$^3$ are experienced on approximately 80% of days during the modelling period.

*6.3.4.3 Average $NO_2$ Concentrations over the Cruise Season*

Average predicted $NO_2$ concentrations in the James Bay community range from 21-22 µg/m$^3$ when background is included. Figure 29 displays a map of average $NO_2$ concentrations in the James Bay community (background included).

All average $NO_2$ concentrations throughout the entire study domain are well below the established Canadian and WHO ambient air quality guidelines for average $NO_2$ concentrations. There are no established CRD or BC guidelines for average $NO_2$.

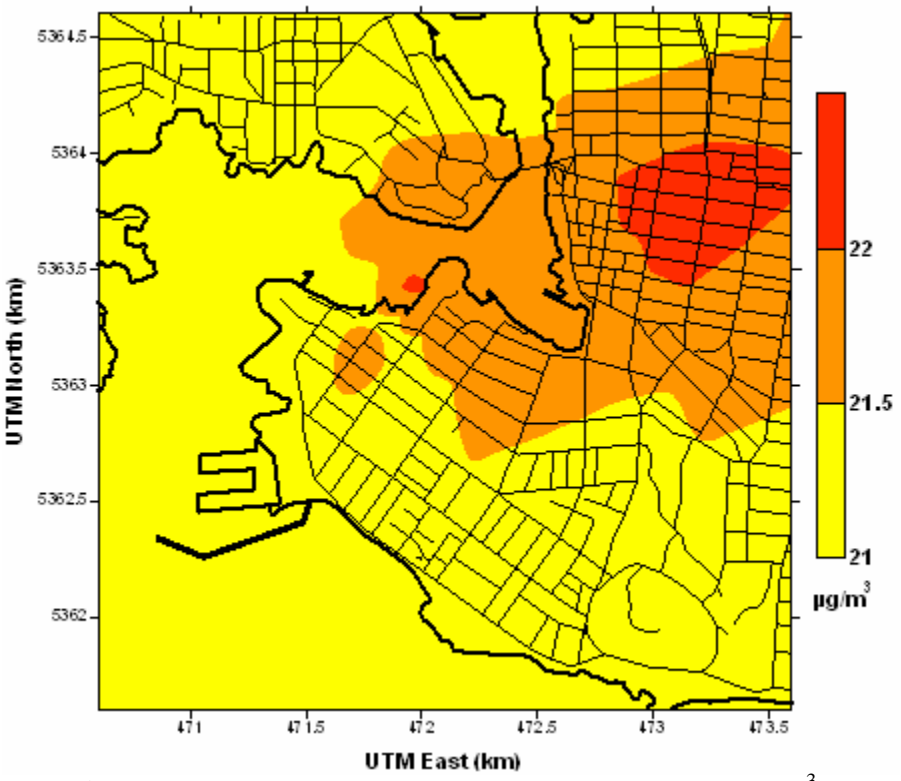



**Figure 29.** Average estimated $NO_2$ concentrations (µg/m$^3$).

### 6.3.5 Summary of $NO_2$ Findings

Table 31 presents a summary of the estimated maximum 1-hour, maximum 24-hour and average $NO_2$ concentrations in the entire study domain and also the James Bay community. The table displays the 98$^{th}$ percentile background concentrations for $NO_2$ as established from the Topaz monitoring station, incremental emissions from the cruise ship and ferry sources, and the combination of these emissions in addition to background.

**Table 31.** Summary of estimated $NO_2$ concentrations ($\mu g/m^3$).

| Time Period | Background (BG) | Entire Study Domain | | James Bay Neighbourhood | |
|---|---|---|---|---|---|
| | | *Modelled Sources* | *Modelled Sources + BG* | *Modelled Sources* | *Modelled Sources + BG* |
| Max 1-hour | 51 | 144 | 195 | 85 | 136 |
| Max 24-hour | 36 | 17 | 53 | 17 | 53 |
| Average (max) | 21 | 1 | 22 | 1 | 22 |

Field monitoring results from the *James Bay Air Quality Study: Phase I Report on the Results of Field Monitoring in 2007*[57] found that in general, average multi-day $NO_2$ concentrations in James Bay ranged from 4.4 $\mu g/m^3$ to 23.7 $\mu g/m^3$ (see page 51 of Phase I report). These average measured $NO_2$ concentrations have good agreement with average concentrations predicted by the CALPUFF model. No short-term measurements of $NO_2$ were made in the James Bay neighbourhood, and a comparison cannot therefore be made for maximum 1-hour and maximum 24-hour concentrations.

Maximum modelled 1-hour, maximum 24-hour and average $NO_2$ concentrations within the James Bay community are well below any relevant established CRD, BC, Canadian or WHO air quality objectives or standards.

## 6.4 AMBIENT $PM_{10}$ CONCENTRATIONS

### 6.4.1 Predicted Maximum 1-Hour $PM_{10}$ Concentrations

*6.4.1.1 Study Domain*

Figure 30 provides a map of maximum predicted 1-hour concentrations of $PM_{10}$ throughout the modelling domain based on modelled cruise and ferry emissions (no background). These maximum levels are expected to occur once during the modelling period (April 24 to November 3, 2007). The maximum modelled 1-hour $PM_{10}$ concentration experienced in the entire study domain was 35 $\mu g/m^3$. This maximum occurred over the water off of the Ogden Point terminal and not in the James Bay community (Figure 31).

*6.4.1.2 James Bay Community*

The maximum predicted 1-hour $PM_{10}$ concentration within the James Bay community from cruise and ferry emissions was 20 $\mu g/m^3$. Figure 32 displays a closer view of the predicted 1-hour maximum isopleths for James Bay.

[57] Available at: http://www.viha.ca/about_viha/news/publications/

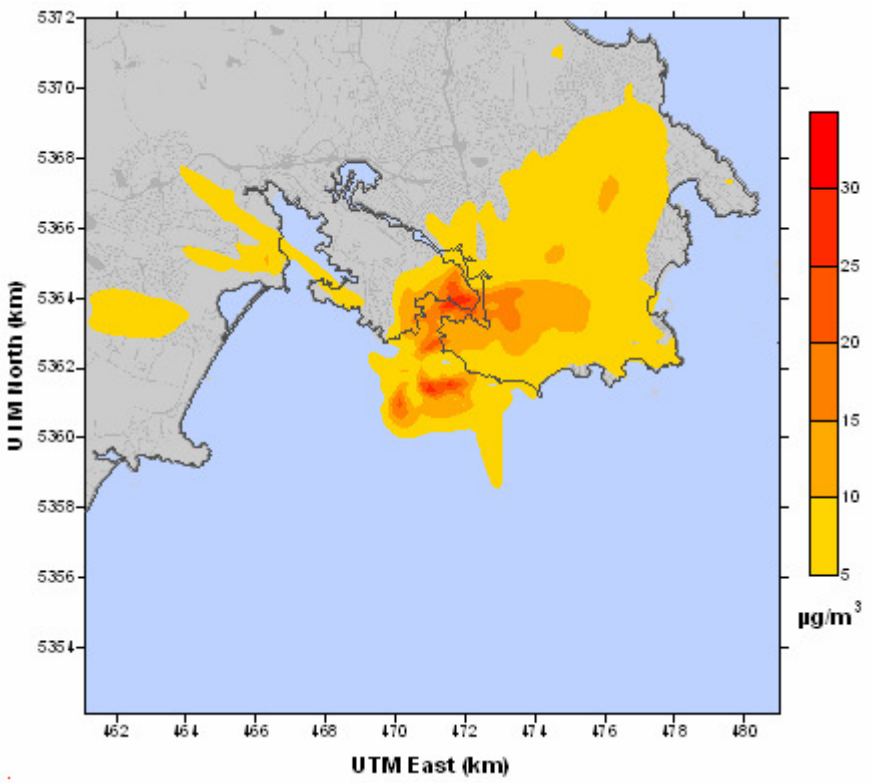



**Figure 30.** Maximum CALPUFF estimated 1-hour concentrations of $PM_{10}$ ($\mu g/m^3$) due to cruise ship and ferry emissions (berth and transit) for the entire study domain.

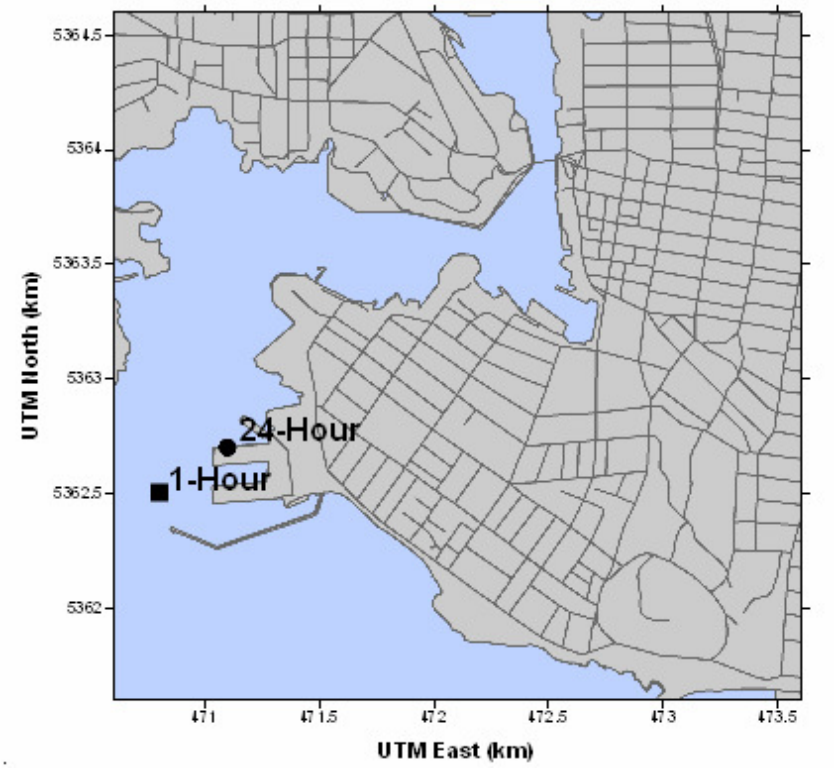



**Figure 31.** Location of CALPUFF maximum modelled 1-hour and 24-hour $PM_{10}$ concentrations in the entire study domain from cruise and ferry emissions sources.

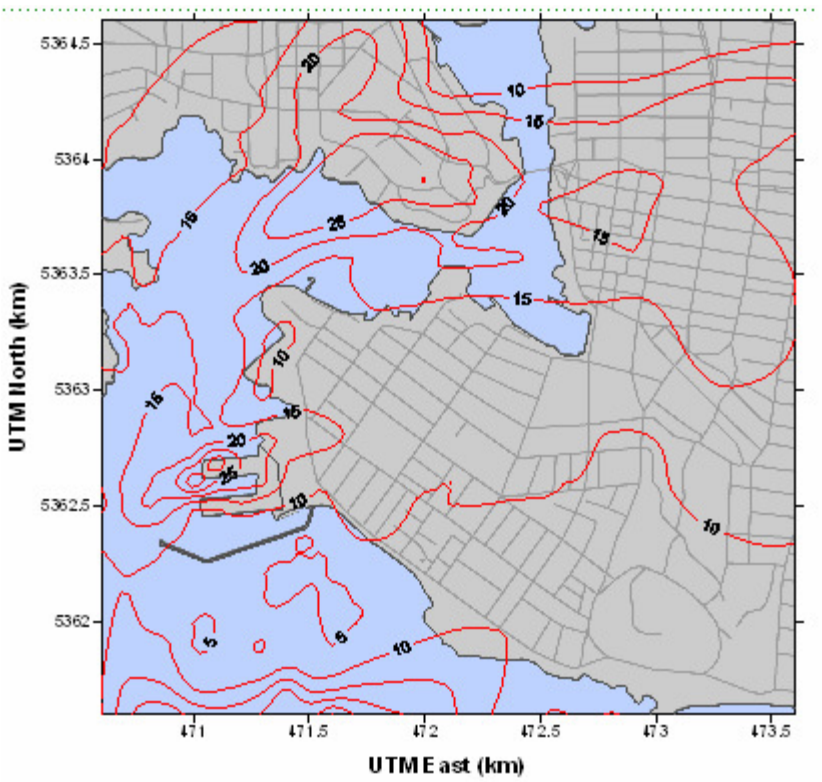



**Figure 32.** Maximum estimated CALPUFF 1-hour concentrations of $PM_{10}$ ($\mu g/m^3$) due to cruise ship and ferry emissions (berth and transit) in and around James Bay.

### 6.4.2 Predicted Maximum 24-Hour $PM_{10}$ Concentrations

*6.4.2.1 Study Domain*

Figure 33 provides a map of maximum predicted 24-hour concentrations of $PM_{10}$ throughout the modelling domain based on modelled cruise and ferry emissions (no background). These maximum levels are expected to occur once during the modelling period. The maximum modelled 24-hour concentration experienced in the entire study domain was 5 $\mu g/m^3$. Figure 31 displays the location of this maximum in the modelling domain.

*6.4.2.2 James Bay Community*

The maximum modelled 24-hour $PM_{10}$ concentration within the James Bay community from cruise ship and ferry sources was 4 $\mu g/m^3$. Figure 34 displays a closer view of the predicted 1-hour maximum isopleths for James Bay.

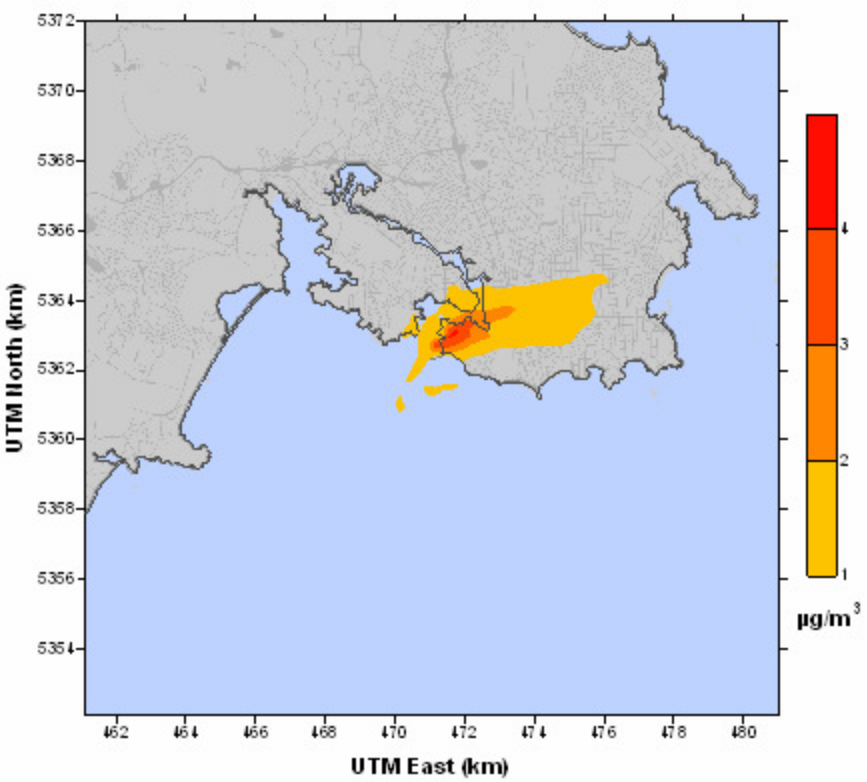



**Figure 33.** Predicted CALPUFF 24-hour concentrations of $PM_{10}$ ($\mu g/m^3$) due to cruise ship and ferry emissions (berth and transit).

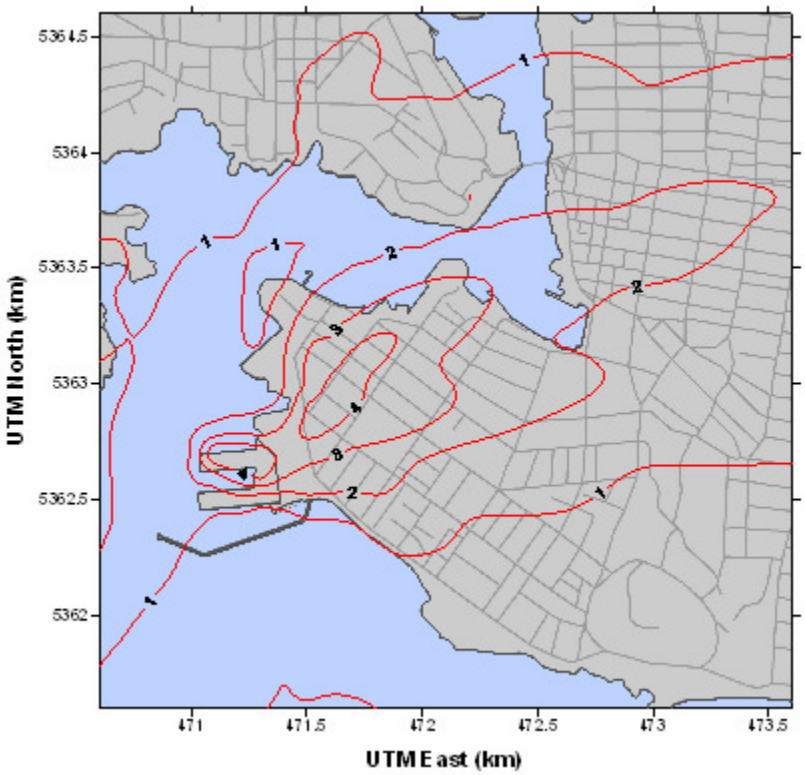



**Figure 34.** CALPUFF maximum predicted 24-hour concentrations of $PM_{10}$ ($\mu g/m^3$) due to cruise ship and ferry emissions (berth and transit) in and around James Bay.

### 6.4.3 Predicted Average $PM_{10}$ Concentrations over the Cruise Season

The predicted average ambient $PM_{10}$ concentrations from cruise and ferry sources (no background) range from approximately 0.00 -0.25 µg/m$^3$, based on the entire 4656-hour modelling period. Isopleths of average concentrations are displayed in Figure 35.

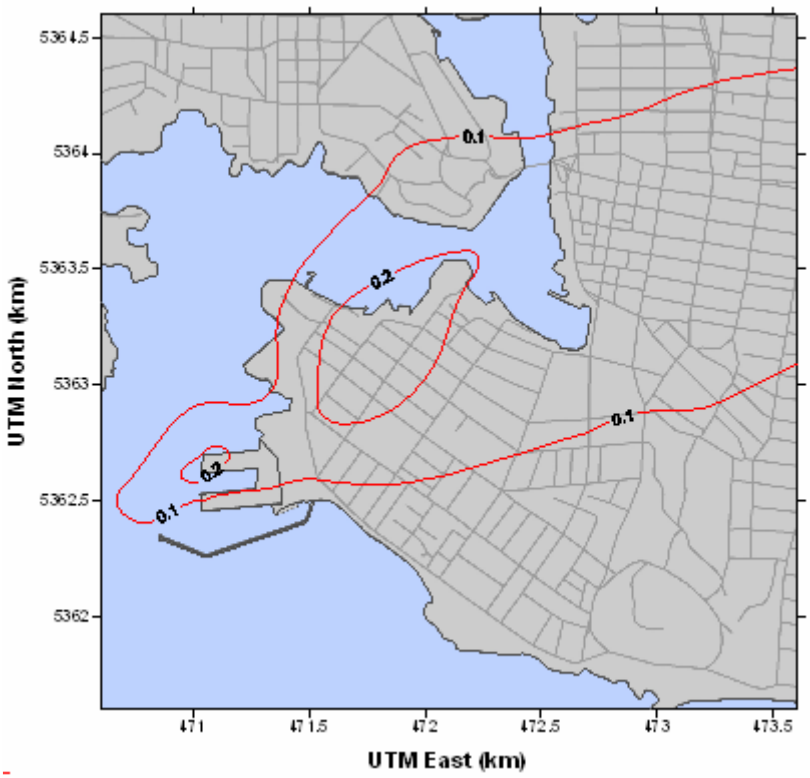



**Figure 35.** CALPUFF predicted average 4656-hour estimated concentrations of $PM_{10}$ (µg/m$^3$) due to cruise ship and ferry emissions (berth and transit).

### 6.4.4 $PM_{10}$ Ambient Air Quality Objectives

Table 32 presents Capital Regional District (CRD) Guidelines, British Columbia Air Quality Guidelines and Objectives, Government of Canada Air Quality Objectives, and World Health Organization (WHO) Air Quality Guidelines for ambient concentrations of $PM_{10}$.

**Table 32.** Particulate matter ($PM_{10}$) objectives and standards (µg/m$^3$).

| | | | BC | | | Canada | | | |
|---|---|---|---|---|---|---|---|---|---|
| **CAC** | **Averaging Period** | **CRD** | **Level A** | **Level B** | **Level C** | **Maximum Desirable** | **Maximum Acceptable** | **Maximum Tolerable** | **WHO** |
| **$PM_{10}$** | 24 hour | 50 | | 50 | | | | | 50 |
| | Annual Mean | | | | | | | | 20 |

Background concentrations established from the Topaz monitoring site are 19 µg/m$^3$, 14 µg/m$^3$ and 5.76 µg/m$^3$ for 1-hour, 24-hour and full cruise season averaging periods. The background $PM_{10}$ concentrations were combined with the model-derived ground level estimates from cruise and ferry sources prior to the analysis presented below.

*6.4.4.1 Maximum 1-Hour $PM_{10}$*

The maximum predicted 1-hour concentration of $PM_{10}$ in the James Bay community was 39 µg/m$^3$. Highest concentrations were experienced at the location of the cruise ship berths, where the maximum modelled 1-hour level of $PM_{10}$ experienced was 54 µg/m$^3$. Figure 36 displays a map of maximum predicted 1-hour $PM_{10}$ levels experienced in James Bay community (background included).

There are no established 1-hour CRD, BC, Canadian or WHO air quality guidelines for concentrations of $PM_{10}$.

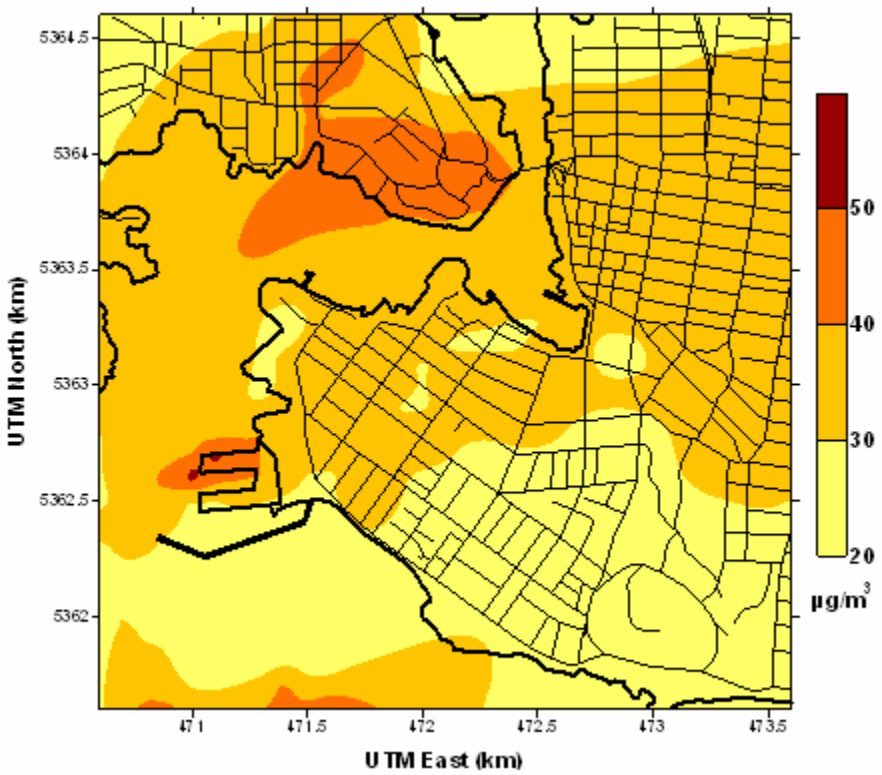



**Figure 36.** Maximum predicted 1-hour $PM_{10}$ concentrations (µg/m$^3$).

Table 33 displays a frequency distribution of 1-hour $PM_{10}$ concentrations from 25 receptor points in the James Bay community. The frequency distribution shows that background 1-hour $PM_{10}$ concentration of 19 $\mu g/m^3$ are experienced at all receptor point locations for 90% of 1-hour periods.

**Table 33.** Frequency distribution of 1-hour $PM_{10}$ concentrations in the James Bay community.

| $PM_{10}$ ($\mu g/m^3$) | | | | |
|---|---|---|---|---|
| **Percentile** | **Min** | **Max** | **Average (n=25)** | **Std. Dev** |
| **100th** | 28.12 | 39.64 | 32.37 | 2.77 |
| **99th** | 20.21 | 25.96 | 22.64 | 1.89 |
| **98th** | 19.66 | 23.98 | 21.17 | 1.29 |
| **97th** | 19.44 | 22.30 | 20.47 | 0.90 |
| **95th** | 19.21 | 20.58 | 19.66 | 0.41 |
| **90th** | 19.02 | 19.20 | 19.08 | 0.06 |
| **80th** | 19.00 | 19.01 | 19.01 | 0.00 |
| **75th** | 19.00 | 19.01 | 19.00 | 0.00 |
| **50th** | 19.00 | 19.00 | 19.00 | 0.00 |

Figure 32 showed that higher 1-hour $PM_{10}$ concentrations are predicted over the Victoria Harbour, Songhees and downtown Victoria than in the James Bay community. Receptor points located at Songhees (n=6) and downtown Victoria (n=4) (Figure 18) were used to calculate additional frequency distributions of $PM_{10}$ for these areas outside of the James Bay community (Table 34 and Table 35).

**Table 34.** Frequency distribution of 1-hour $PM_{10}$ concentrations in the Songhees area.

| $PM_{10}$ ($\mu g/m^3$) | | | | |
|---|---|---|---|---|
| **Percentile** | **Min** | **Max** | **Average (n=6)** | **Std. Dev** |
| **100th** | 40.95 | 52.13 | 44.59 | 4.95 |
| **99th** | 20.95 | 23.25 | 22.14 | 0.90 |
| **98th** | 20.06 | 21.41 | 20.75 | 0.56 |
| **97th** | 19.67 | 20.59 | 20.12 | 0.40 |
| **95th** | 19.42 | 20.11 | 19.77 | 0.30 |
| **90th** | 19.04 | 19.15 | 19.10 | 0.04 |
| **80th** | 19.00 | 19.02 | 19.01 | 0.01 |
| **75th** | 19.00 | 19.00 | 19.00 | 0.00 |
| **50th** | 19.00 | 19.00 | 19.00 | 0.00 |

**Table 35.** Frequency distribution of 1-gour $PM_{10}$ concentrations in Downtown Victoria.

| | $PM_{10}$ ($\mu g/m^3$) | | | |
|---|---|---|---|---|
| **Percentile** | **Min** | **Max** | **Average (n=4)** | **Std. Dev** |
| **100th** | 35.94 | 38.82 | 37.35 | 1.31 |
| **99th** | 23.31 | 24.28 | 23.85 | 0.40 |
| **98th** | 21.21 | 21.94 | 21.66 | 0.32 |
| **97th** | 20.47 | 20.96 | 20.79 | 0.22 |
| **95th** | 19.71 | 19.97 | 19.88 | 0.12 |
| **90th** | 19.17 | 19.22 | 19.20 | 0.02 |
| **80th** | 19.02 | 19.02 | 19.02 | 0.00 |
| **75th** | 19.01 | 19.01 | 19.01 | 0.00 |
| **50th** | 19.00 | 19.00 | 19.00 | 0.00 |

*6.4.4.2 Maximum 24-Hour $PM_{10}$*

The maximum predicted 24-hour concentration of $PM_{10}$ in the James Bay community was 18 $\mu g/m^3$. A slightly higher predicted maximum 24-hour $PM_{10}$ concentration of 19 $\mu g/m^3$ was experienced at the location of the cruise ship berths. Figure 37 displays a map of maximum predicted 24-hour $PM_{10}$ levels in James Bay community (background included).

All maximum 24-hour $PM_{10}$ concentrations were well below the established CRD, BC Level B, and WHO guidelines of 50 $\mu g/m^3$. There are no established Canadian guidelines for maximum 24-hour $PM_{10}$ concentrations.

Table 36 displays a frequency distribution of predicted 24-hour concentrations from 25 receptor points in the James Bay community. For all sites, maximum 100th percentile 24-hour concentrations are within 3 $\mu g/m^3$ of background $PM_{10}$ concentrations.

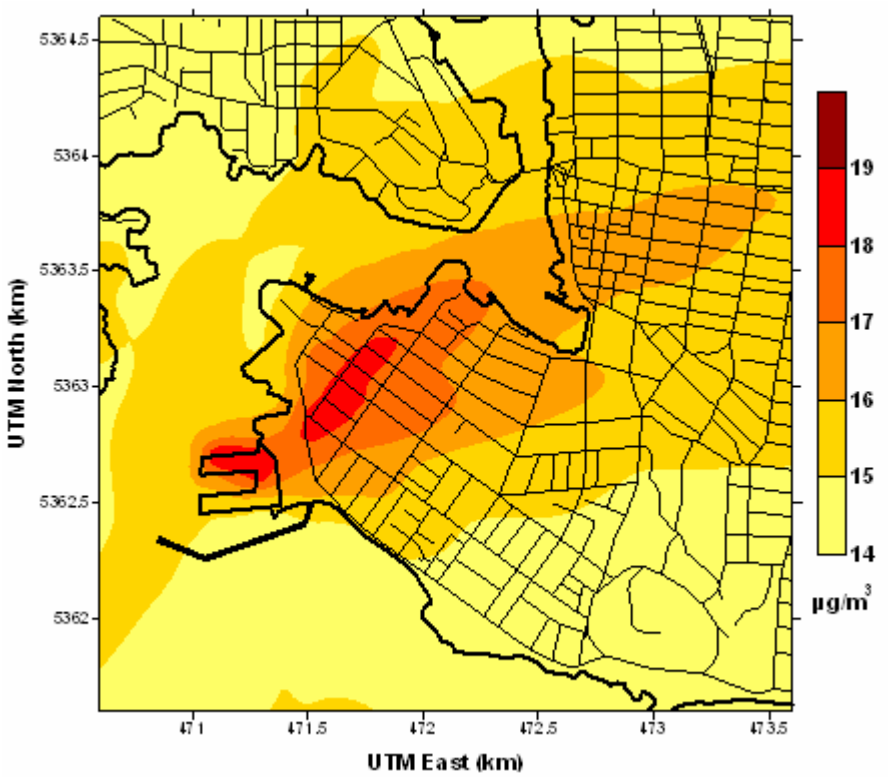



**Figure 37.** Maximum estimated 24-hour $PM_{10}$ concentrations ($\mu g/m^3$).

**Table 36.** Frequency distribution of 24-hour $PM_{10}$ concentrations in the James Bay community.

| | $PM_{10}$ ($\mu g/m^3$) | | | |
|---|---|---|---|---|
| **Percentile** | **Min** | **Max** | **Average (n=25)** | **Std. Dev** |
| **100th** | 14.70 | 18.56 | 16.40 | 1.31 |
| **99th** | 14.48 | 17.08 | 15.47 | 0.74 |
| **98th** | 14.42 | 16.12 | 15.14 | 0.54 |
| **97th** | 14.31 | 15.81 | 14.91 | 0.46 |
| **95th** | 14.19 | 15.17 | 14.65 | 0.34 |
| **90th** | 14.14 | 14.85 | 14.41 | 0.24 |
| **80th** | 14.09 | 14.46 | 14.21 | 0.11 |
| **75th** | 14.08 | 14.29 | 14.15 | 0.07 |
| **50th** | 14.00 | 14.01 | 14.01 | 0.00 |

*6.4.4.3 Average $PM_{10}$ Concentrations over the Cruise Season*

Average predicted $PM_{10}$ concentrations in James Bay range from 5.7 to 5.9 $\mu g/m^3$ when background is included. Figure 38 displays a map of average $PM_{10}$ concentrations in the James Bay community (background included).

There are no established CRD, Canadian or BC ambient air quality guidelines for annual average $PM_{10}$ concentrations. All average $PM_{10}$ concentrations throughout the entire

study domain are well below the WHO annual ambient air quality guideline for $PM_{10}$ of 20 µg/m$^3$.

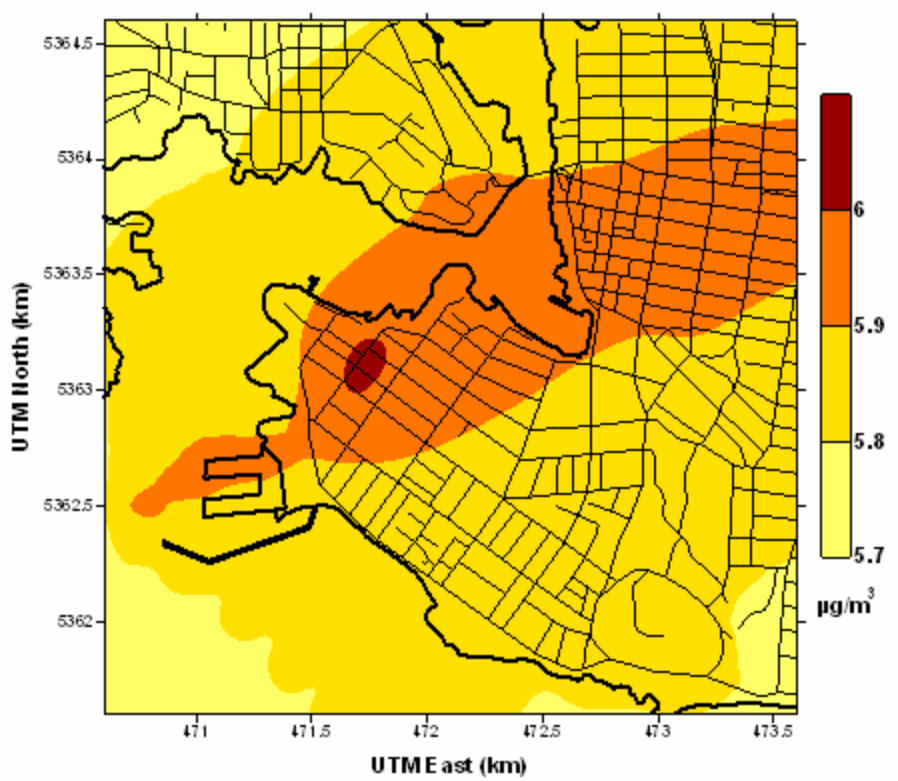



**Figure 38.** Period-average estimated $PM_{10}$ concentrations.

### 6.4.5 Summary of $PM_{10}$ Findings

Table 37 presents a summary of the model findings for maximum 1-hour, maximum 24-hour and period-average $PM_{10}$ concentrations in the entire study domain and also the James Bay community. The table displays the 98$^{th}$ percentile background concentrations for $PM_{10}$ as established from the Topaz monitoring station, incremental emissions from the cruise ship and ferry sources, and the combination of these emissions with background.

**Table 37.** Summary of modelled $PM_{10}$ concentrations ($\mu g/m^3$).

| Time Period | Background (BG) | Entire Study Domain | | James Bay Neighbourhood | |
|---|---|---|---|---|---|
| | | *Modelled Sources* | *Modelled Sources + BG* | *Modelled Sources* | *Modelled Sources + BG* |
| Max 1-hour | 19 | 35 | 54 | 20 | 39 |
| Max 24-hour | 14 | 5 | 19 | 4 | 18 |
| Average (max) | 5.7 | 0.2 | 5.9 | 0.2 | 5.9 |

Concentrations of $PM_{10}$ were not measured as part of the field monitoring campaign in the *James Bay Air Quality Study: Phase I Report on the Results of Field Monitoring in 2007*[58]; however, particulate matter <2.5 µm in diameter ($PM_{2.5}$) was measured and a summary analysis is provided in Section 6.5.5.

Maximum modelled 1-hour, maximum 24-hour and average $PM_{10}$ concentrations within the James Bay community are well below any relevant established CRD, BC, Canadian or WHO air quality objectives or standards.

## 6.5 AMBIENT $PM_{2.5}$ CONCENTRATIONS

### 6.5.1 Predicted Maximum 1-Hour $PM_{2.5}$ Concentrations

*6.5.1.1 Study Area*

Figure 39 provides a map of maximum predicted 1-hour concentrations of $PM_{2.5}$ throughout the modelling domain, based on modelled cruise and ferry emissions (no background). These maximum levels are expected to occur once during the study period (April 24 to November 3, 2007). The maximum modelled 1-hour concentration of $PM_{2.5}$ experienced in the entire study domain was 30 $\mu g/m^3$. The location of this maximum is displayed in Figure 40.

*6.5.1.2 James Bay Community*

The maximum predicted 1-hour $PM_{2.5}$ concentration within the James Bay community from cruise and ferry sources was 16 $\mu g/m^3$. Figure 41 displays a closer view of the modelled 1-hour maximum isopleths for James Bay.

[58] Available at: http://www.viha.ca/about_viha/news/publications/

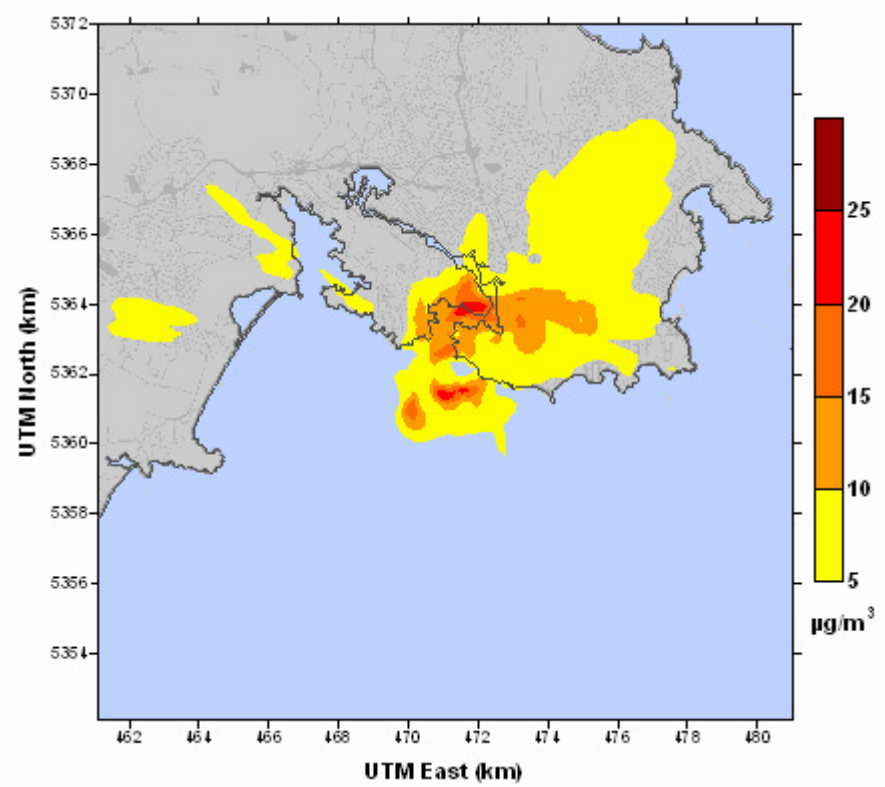



**Figure 39.** Maximum CALPUFF estimated 1-hour concentrations of $PM_{2.5}$ ($\mu g/m^3$) due to cruise ship and ferry emissions (berth and transit) for entire study domain.

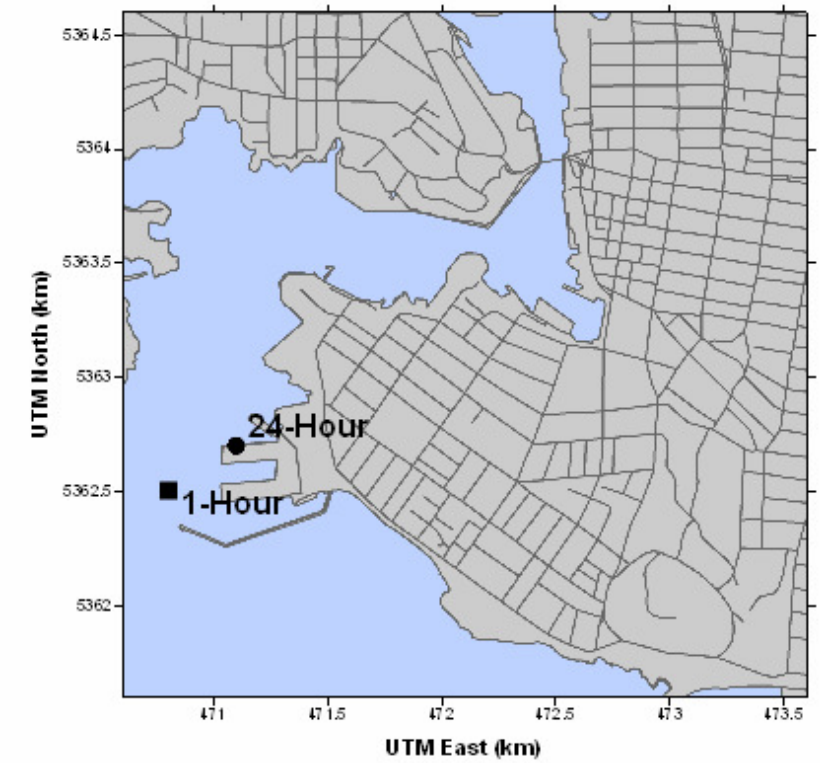



**Figure 40.** Location of CALPUFF predicted maximum 1-hour and 24-hour $PM_{2.5}$ concentrations in the entire study domain from cruise and ferry emissions sources.

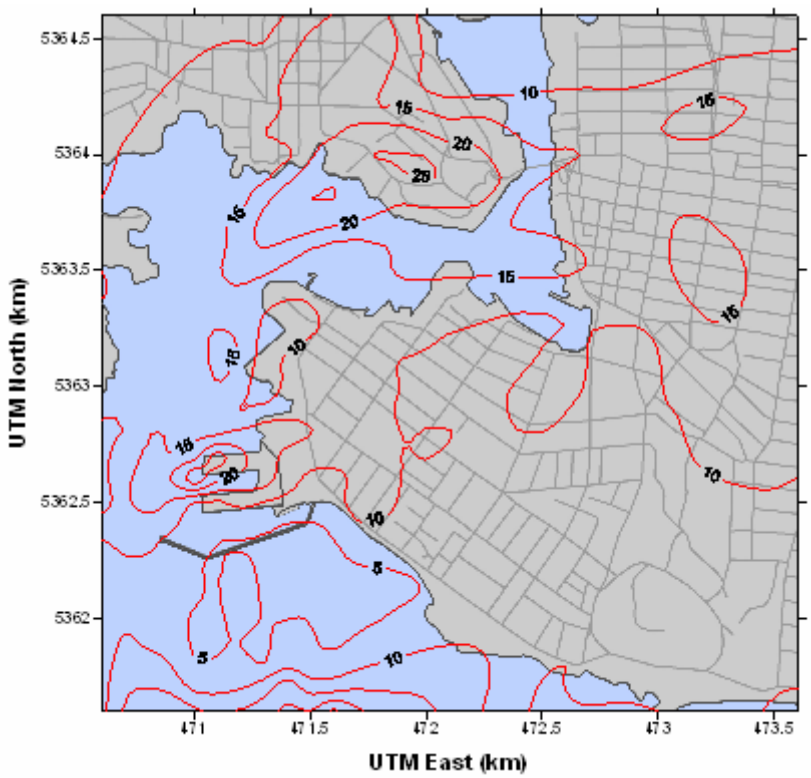



**Figure 41.** CALPUFF maximum estimated 1-hour concentrations of $PM_{2.5}$ ($\mu g/m^3$) due to cruise ship and ferry emissions (berth and transit) in James Bay.

### 6.5.2 Predicted Maximum 24-Hour $PM_{2.5}$ Concentrations

*6.5.2.1 Study Area*

Figure 42 provides a map of maximum predicted 24-hour concentrations of $PM_{2.5}$ throughout the modelling domain based on modelled cruise and ferry emissions (no background). These maximum levels are expected to occur once during the modelling period. The maximum modelled 24-hour concentration of $PM_{2.5}$ experienced in the entire study domain was 4 $\mu g/m^3$. Figure 40 displays the location of this maximum.

*6.5.2.2 James Bay Community*

The maximum modelled 24-hour $PM_{2.5}$ concentration within the James Bay community from cruise and ferry sources was 4 $\mu g/m^3$. Figure 43 displays a closer view of the 24-hour maximum isopleths for James Bay.

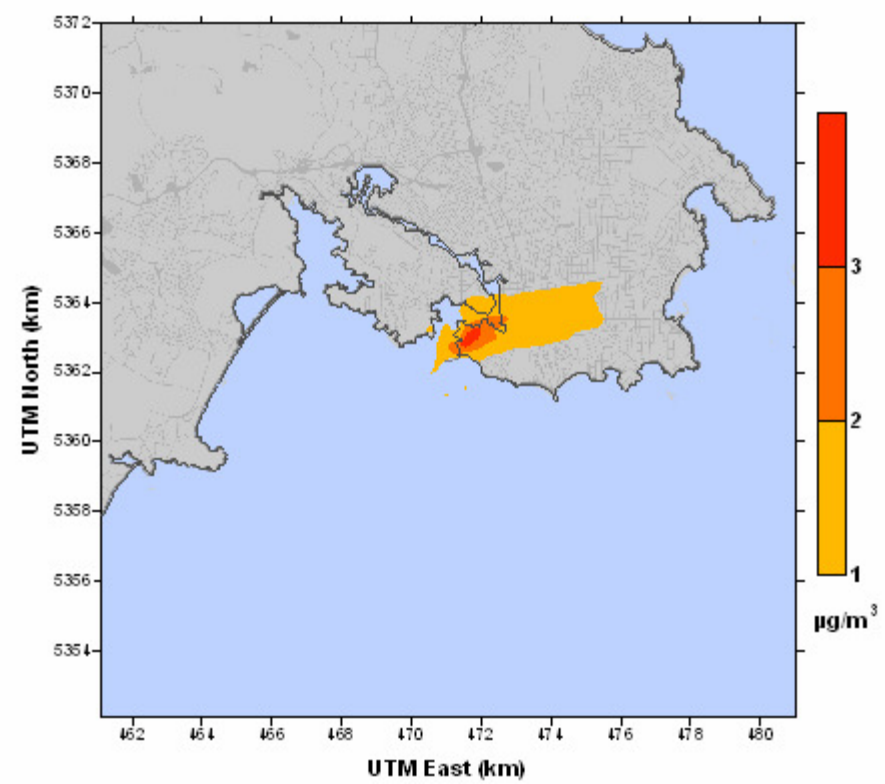



**Figure 42.** CALPUFF maximum estimated 24-hour concentrations of $PM_{2.5}$ ($\mu g/m^3$) due to cruise ship and ferry emissions (berth and transit).

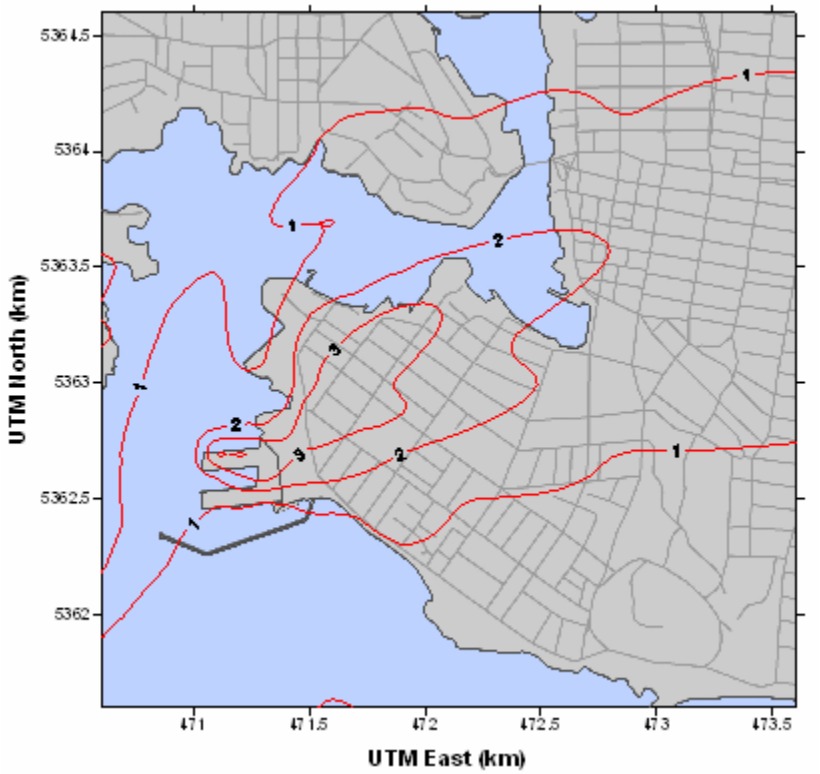



**Figure 43.** Maximum estimated 24-hour concentrations of $PM_{2.5}$ ($\mu g/m^3$) due to cruise ship and ferry emissions (berth and transit) in James Bay.

### 6.5.3 Predicted Average $PM_{2.5}$ Concentrations over the Cruise Season

The average predicted ambient $PM_{2.5}$ concentrations, based on the entire 4656-hour modelling period from cruise and ferry sources (no background) range from 0.0 – 0.2 µg/m$^3$. Isopleths of average concentrations in the James Bay community are displayed in Figure 44.

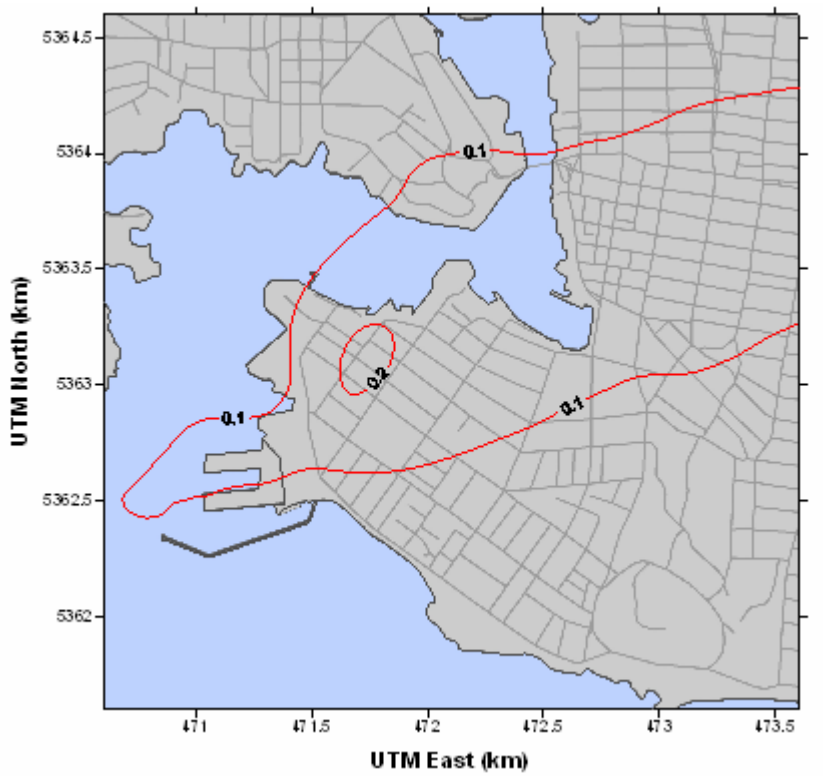



**Figure 44.** CALPUFF average predicted 4656-hour concentrations of $PM_{2.5}$ (µg/m$^3$) due to cruise ship and ferry emissions (berth and transit).

### 6.5.4 $PM_{2.5}$ Ambient Air Quality Objectives

Table 38 presents Capital Regional District (CRD) Guidelines, British Columbia Air Quality Guidelines and Objectives, Canada Wide Standards, and World Health Organization (WHO) Air Quality Guidelines for ambient concentrations of $PM_{2.5}$.

Background concentrations established from the Topaz monitoring site are 16 µg/m$^3$, 12 µg/m$^3$ and 4.80 µg/m$^3$ for 1-hour, 24-hour and the full cruise season averaging periods, respectively. Background $PM_{2.5}$ concentrations were added to the maximum modelled concentrations from cruise and ferry sources prior to the analysis presented below.

**Table 38.** Particulate matter ($PM_{2.5}$) objectives and standards ($\mu g/m^3$).

| | | | BC | | | Canada | | | |
|---|---|---|---|---|---|---|---|---|---|
| **CAC** | **Averaging Period** | **CRD** | **Level A** | **Level B** | **Level C** | **Maximum Desirable** | **Maximum Acceptable** | **Maximum Tolerable** | **WHO** |
| **$PM_{25}$** | 24 hour | 25 | | | | | 30* | | 25 |
| | Annual Mean | | | | | | | | 10 |

***There is no "Canadian Maximum Acceptable" objective for $PM_{2.5}$. The Canada Wide Standard (CWS) for $PM_{2.5}$ is 30 $\mu g/m^3$ based on the 98th percentile ambient measured annually, averaged over three consecutive years. The modelling period does not contain enough information to calculate the CWS metric, and therefore measured concentrations are compared with the numeric value of the CWS (30 $\mu g/m^3$).**

*6.5.4.1 Maximum 1-Hour $PM_{2.5}$*

The maximum predicted 1-hour $PM_{2.5}$ concentration experienced in the James Bay community was 32 $\mu g/m^3$. Highest modelled concentrations were experienced over the cruise ship berths at the Ogden Point terminal, where maximum predicted 1-hour $PM_{2.5}$ concentrations reached 46 $\mu g/m^3$. Figure 45 displays a map of maximum predicted 1-hour $PM_{2.5}$ concentrations in the James Bay community (background included).

There are currently no established 1-hour CRD, BC, Canadian or WHO guidelines for maximum 1-hour $PM_{2.5}$ concentrations.

Table 39 displays a frequency distribution of estimated 1-hour $PM_{2.5}$ concentrations from 25 discrete receptor locations in the James Bay community (Figure 10).

Higher predicted concentrations exist in the Songhees region than in the James Bay community. An additional frequency distribution of predicted 1-hour $PM_{2.5}$ concentrations experienced in the Songhees area is provided in Table 40.

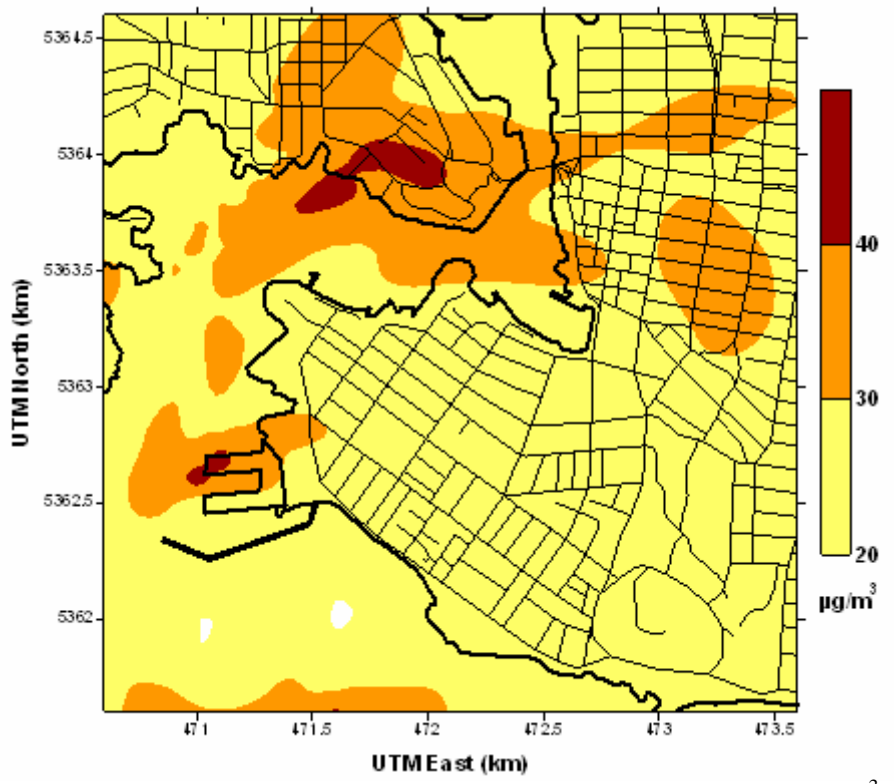



**Figure 45.** Maximum estimated 1-hour $PM_{2.5}$ concentrations (µg/m$^3$).

**Table 39.** Frequency distribution of 1-hour $PM_{2.5}$ concentrations in the James Bay community.

| | $PM_{2.5}$ (µg/m$^3$) | | | |
|---|---|---|---|---|
| **Percentile** | **Min** | **Max** | **Average (n=25)** | **Std. Dev** |
| **100$^{th}$** | 23.81 | 33.82 | 27.44 | 2.38 |
| **99$^{th}$** | 17.03 | 21.89 | 19.09 | 1.60 |
| **98$^{th}$** | 16.56 | 20.17 | 17.83 | 1.07 |
| **97$^{th}$** | 16.38 | 18.76 | 17.24 | 0.75 |
| **95$^{th}$** | 16.18 | 17.34 | 16.56 | 0.34 |
| **90$^{th}$** | 16.02 | 16.17 | 16.07 | 0.05 |
| **80$^{th}$** | 16.00 | 16.01 | 16.01 | 0.00 |
| **75$^{th}$** | 16.00 | 16.01 | 16.00 | 0.00 |
| **50$^{th}$** | 16.00 | 16.00 | 16.00 | 0.00 |

**Table 40.** Frequency distribution of 1-hour $PM_{2.5}$ concentrations in the Songhees area.

| $PM_{2.5}$ ($\mu g/m^3$) | | | | |
|---|---|---|---|---|
| **Percentile** | **Min** | **Max** | **Average (n=6)** | **Std. Dev** |
| **100th** | 34.55 | 44.59 | 37.88 | 4.44 |
| **99th** | 17.64 | 19.59 | 18.66 | 0.76 |
| **98th** | 16.90 | 17.99 | 17.47 | 0.46 |
| **97th** | 16.58 | 17.35 | 16.95 | 0.33 |
| **95th** | 16.36 | 16.94 | 16.65 | 0.26 |
| **90th** | 16.04 | 16.13 | 16.09 | 0.04 |
| **80th** | 16.00 | 16.02 | 16.01 | 0.01 |
| **75th** | 16.00 | 16.00 | 16.00 | 0.00 |
| **50th** | 16.00 | 16.00 | 16.00 | 0.00 |

*6.5.4.2 Maximum 24-Hour $PM_{2.5}$*

The maximum predicted 24-hour $PM_{2.5}$ concentration experienced in the entire study domain (which occurred over the cruise ship berths at Ogden Point) was 16 $\mu g/m^3$. Figure 46 displays a map of maximum predicted 24-hour $PM_{2.5}$ concentrations in the James Bay community (background included).

All predicted $PM_{2.5}$ concentrations are well below the CRD guideline of 25 $\mu g/m^3$, the Canada Wide Standard of 30 $\mu g/m^3$ and the WHO guideline of 25 $\mu g/m^3$.

Table 41 displays a frequency distribution of 24-hour $PM_{2.5}$ concentrations from 25 discrete receptor locations in the James Bay community. The frequency distribution shows that all $100^{th}$ percentile maximum 24-hour concentrations are within approximately 4 $\mu g/m^3$ of background.

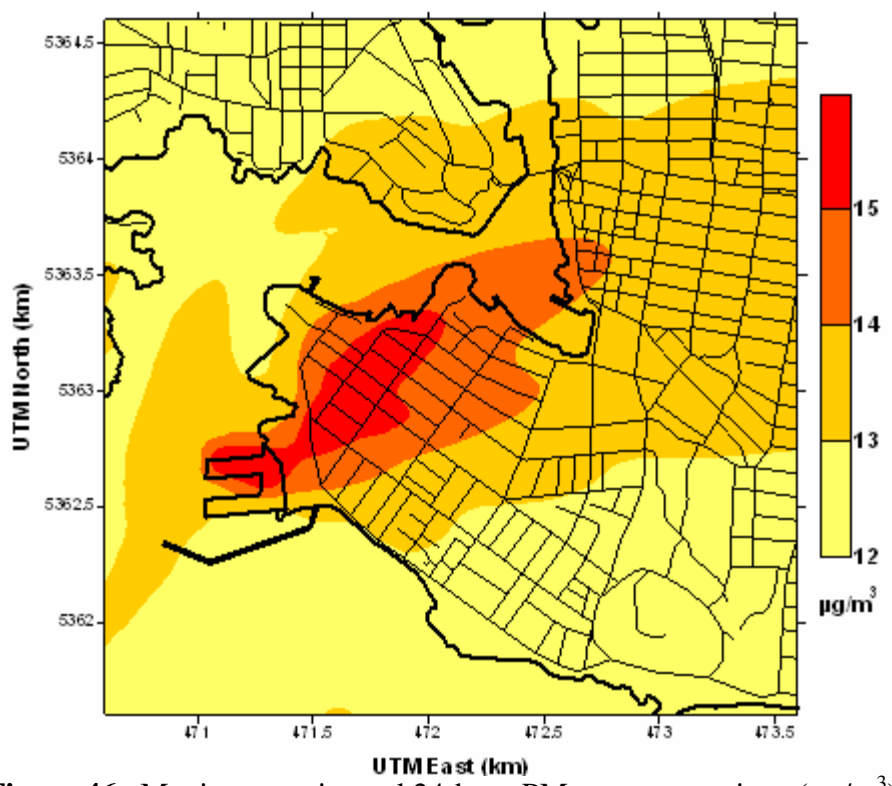



**Figure 46.** Maximum estimated 24-hour $PM_{2.5}$ concentrations (µg/m$^3$).

**Table 41.** Frequency distribution of 24-hour $PM_{2.5}$ concentrations in the James Bay community.

| $PM_{2.5}$ (µg/m$^3$) | | | | |
|---|---|---|---|---|
| **Percentile** | **Min** | **Max** | **Average (n=25)** | **Std. Dev** |
| **100$^{th}$** | 12.60 | 15.87 | 14.03 | 1.11 |
| **99$^{th}$** | 12.41 | 14.59 | 13.25 | 0.62 |
| **98$^{th}$** | 12.36 | 13.78 | 12.97 | 0.45 |
| **97$^{th}$** | 12.26 | 13.55 | 12.77 | 0.39 |
| **95$^{th}$** | 12.17 | 13.00 | 12.55 | 0.29 |
| **90$^{th}$** | 12.12 | 12.72 | 12.35 | 0.20 |
| **80$^{th}$** | 12.08 | 12.38 | 12.18 | 0.10 |
| **75$^{th}$** | 12.06 | 12.25 | 12.12 | 0.06 |
| **50$^{th}$** | 12.00 | 12.01 | 12.01 | 0.00 |

*6.5.4.3 Average $PM_{2.5}$ Concentrations over the Cruise Season*

The period-average $PM_{2.5}$ concentrations in the James Bay community range from 4.8 to 5.0 µg/m$^3$. Figure 47 displays a map of average $PM_{2.5}$ concentrations in the James Bay community (background included).

There are no established CRD, BC or Canadian ambient air quality guidelines for average $PM_{2.5}$ concentrations. All predicted average $PM_{10}$ concentrations throughout the entire

study domain are well below the WHO ambient air quality guideline for annual $PM_{2.5}$ of 10 µg/m$^3$.

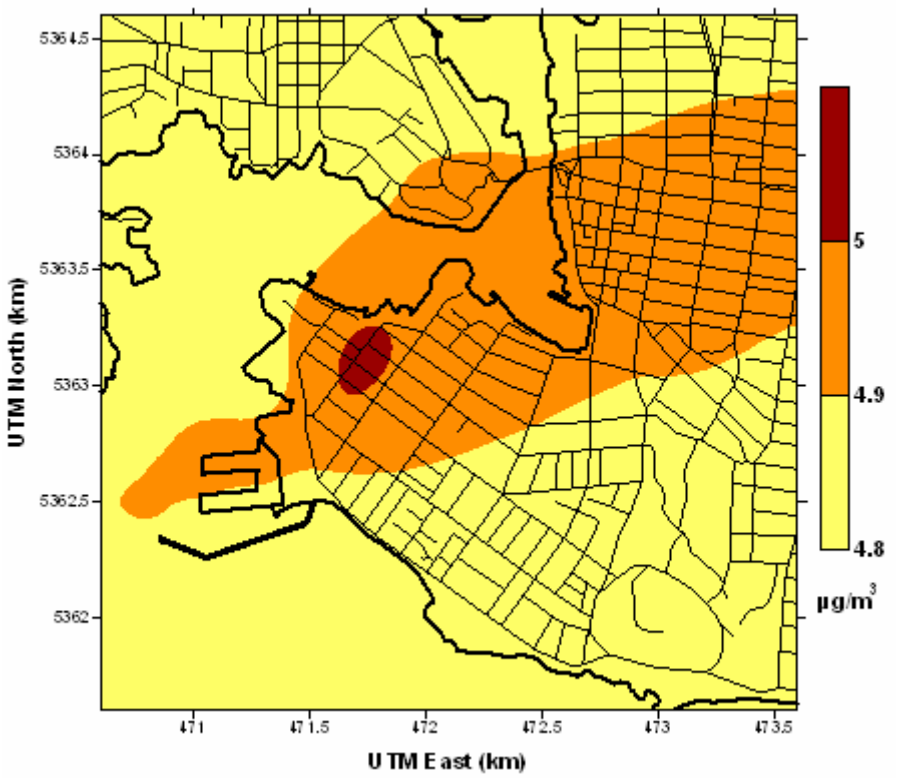



**Figure 47.** Predicted average $PM_{2.5}$ concentrations over the cruise season.

### 6.5.5 Summary of $PM_{2.5}$ Findings

Table 42 presents a summary of the model findings for maximum 1-hour, maximum 24-hour and average $PM_{2.5}$ concentrations in the entire study domain and also the James Bay community. The table displays the 98$^{th}$ percentile background concentrations for $PM_{2.5}$ as established from the Topaz monitoring station, incremental emissions from the cruise ship and ferry sources, and the combination of these emissions in addition to background.

**Table 42.** Summary of modelled $PM_{2.5}$ concentrations (µg/m$^3$).

| Time Period | Background (BG) | Entire Study Domain | | James Bay Neighbourhood | |
|---|---|---|---|---|---|
| | | *Modelled Sources* | *Modelled Sources + BG* | *Modelled Sources* | *Modelled Sources + BG* |
| Max 1-hour | 16 | 30 | 46 | 16 | 32 |
| Max 24-hour | 12 | 4 | 16 | 4 | 16 |
| Average (max) | 4.8 | 0.2 | 5.0 | 0.2 | 5.0 |

Field monitoring results from the *James Bay Air Quality Study: Phase I Report on the Results of Field Monitoring in 2007*[59] found that in general, average $PM_{2.5}$ concentrations in James Bay ranged from 1.3 µg/m$^3$ to 6.5 µg/m$^3$ (see page 80 of Phase I report). These average measured $PM_{2.5}$ concentrations have good agreement with average concentrations predicted by the CALPUFF model.

Shorter-term concentrations of $PM_{2.5}$ (15-minute averages) were measured in James Bay for a limited sample of sites (6 locations) over six consecutive days at each site (3 sites measured in June/July and 3 measured in July/August). Moving 1-hour averages of measured concentrations ranged from near 0 µg/m$^3$ to 14 µg/m$^3$. This maximum measured 1-hour concentration (14 µg/m$^3$) is lower than the model-derived 1-hour maximum $PM_{2.5}$ concentration (34 µg/m$^3$); however, the monitoring campaign was both spatially and temporally limited. Had a greater number of sites been measured over a longer time period, a similar maximum to that predicted by the model may have been experienced.

Maximum modelled 1-hour, maximum 24-hour and average $PM_{2.5}$ concentrations within the James Bay community are well below any relevant established CRD, BC, Canadian or WHO air quality objectives or standards.

[59] Available at: http://www.viha.ca/about_viha/news/publications/

### 6.6 SOURCE CONTRIBUTIONS

The CALPUFF modelling approach used for this study allows each of the four source types to be assessed individually to determine which may have the greatest contribution to the maximum predicted ambient concentrations (Table 43). The four source types simulated were: (1) ferries – berth; (2) ferries – transit; (3) cruise ships – berth; and (4) cruise ships – transit. The maximum predicted ambient concentrations due to each emissions source in isolation are provided.

**Table 43.** Source contributions to ground level maximum 1-hour, maximum 24-hour and average concentrations in the James Bay Community (no background included).

**$SO_2$ ($\mu g/m^3$)**

| 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 |

**$NO_2$ ($\mu g/m^3$)**

| 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 |

**$PM_{10}$ ($\mu g/m^3$)**

| 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 |

**$PM_{2.5}$ ($\mu g/m^3$)**

| 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 |

As displayed in the table above, ferries at berth and in transit minimally contribute to the total maximum predicted 1-hour, 24-hour and average concentrations determined by the model. Cruise ships represent the major contributors to the maximum predicted ambient concentrations, moreso while at berth than in transit. Individual source contribution maps for each pollutant and time period (1-hour, 24-hour and average) are provided in Appendix D.

## 6.7 METEOROLOGICAL CONDITIONS DURING PERIODS OF MAXIMUM PREDICTED CONCENTRATIONS

This section presents an analysis of the main meteorological conditions (atmospheric stability) during modelled periods which experience the greatest predicted 1-hour and 24-hour concentrations. The stability of the atmosphere is defined as its tendency to resist or enhance vertical motion in the boundary layer. The Pasquill-Gifford (P-G) atmospheric stability class typing scheme that can be extracted from the CALPUFF (CALMET) model is useful to summarize the atmospheric conditions during the study period and to examine what conditions may lead to relative maximums. Table 44 provides a key to the Pasquill (P-G) stability categories.

**Table 44.** Classification of P-G stability with atmospheric conditions.

| **Surface** | **Daytime Insolation** | | | **Nighttime Cloud Cover** | |
|---|---|---|---|---|---|
| **Wind Speed (m/s)** | Strong | Moderate | Slight | Thin Overcast or 4/8 Cloudiness | 3/8 Cloudiness |
| <2 | A | A-B | B | - | - |
| 2-3 | A-B | B | C | E | F |
| 3-5 | B | B-C | C | D | E |
| 5-6 | C | C-D | D | D | D |
| >6 | C | D | D | D | D |

**A** – highly convective **B** – moderately convective **C** – slightly convective **D** – neutral **E** – slightly stable **F** – stable

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.

The frequency distribution of atmospheric conditions in the James Bay neighbourhood during the modelling period (April 24 to November 3) is provided in Table 45. These frequencies are further divided based upon time of day in Table 46.

As displayed in the tables, neutral atmospheric conditions are most dominant over the entire modelling period. Neutral conditions occur most commonly late at night and in the early morning. The majority of cruise ships (74%) are scheduled to leave Ogden Point at 23:59, which is dominated by neutral, slightly stable and stable atmospheric conditions when there is limited vertical dispersion of pollutants.

**Table 45.** Distribution of atmospheric conditions (P-G class) in James Bay from April 24 to November 3, 2007.

| Distribution | Atmospheric Stability Class |
|---|---|
| 4% | Highly Convective |
| 13% | Moderately Convective |
| 16% | Slightly Convective |
| 44% | Natural |
| 8% | Slightly Stable |
| 14% | Stable |

**Table 46.** Daily distribution of Pasquill-Gifford atmospheric stability classifications in James Bay, April 24 – November 3, 2007
(% of each stability class during the four hour period).

| Time Period | Highly Convective | Moderately Convective | Slightly Convective | Neutral | Slightly Stable | Stable |
|---|---|---|---|---|---|---|
| **22:00 – 01:00** | 0 | 0 | 0 | 51 | 19 | 30 |
| **02:00 – 05:00** | 0 | 0 | 6 | 55 | 13 | 26 |
| **06:00 – 09:00** | 5 | 18 | 30 | 44 | 1 | 2 |
| **10:00 – 13:00** | 20 | 32 | 23 | 25 | 0 | 0 |
| **14:00 – 17:00** | 2 | 29 | 29 | 37 | 1 | 2 |
| **18:00 – 21:00** | 0 | 0 | 10 | 49 | 14 | 26 |

### 6.7.1 Maximum 1-hour Concentrations

Table 47 presents the top five 1-hour periods in the modelling domain which experienced the highest concentrations of all pollutants, based on the 25 receptor points in James Bay.

**Table 47.** CALPUFF atmospheric stability conditions during 1-hour periods with maximum predicted concentrations of pollutants.

| 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 – background concentrations are NOT included in table.**

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 in the afternoon when 2 ships were present at the Ogden Point berth, approximately 2 hours before the scheduled time of departure.

### 6.7.2 Maximum 24-hour Concentrations

Table 48 presents the top five 24-hour periods in the modelling domain which experienced the highest concentrations of all 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 11$^{th}$ and September 22$^{nd}$, 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.

**Table 48.** CALPUFF atmospheric stability conditions during 24-hour periods with maximum predicted concentrations of pollutants.

| | Max 24-HR* (µg/m$^3$) | | | | | |
|---|---|---|---|---|---|---|
| **Date** | **$SO_2$** | **$NO_x$** | **$PM_{10}$** | **$PM_{2.5}$** | **Atmospheric Stability** | **Cruise Ship Activity** |
| May 11 | 34 | 57 | 5 | 4 | 54% Neutral<br>25% Slightly Convective<br>21% Moderately Convective | 5 ships |
| Sept. 22 | 33 | 54 | 4 | 3 | 58% Neutral<br>25% Slightly Stable<br>9% Stable<br>8% Slightly Convective | 5 ships |
| May 17 | 29 | 48 | 4 | 3 | 67 % Neutral<br>20% Slightly Convective<br>13% Moderately Convective | 2 ships |
| Sept. 24 | 23 | 38 | 3 | 3 | 63% Neutral<br>17% Stable<br>8% Slightly Convective<br>8% Moderately Convective<br>4% Highly Convective | 2 ships |
| July 6 | 21 | 37 | 3 | 2 | 58% Neutral<br>21% Slightly Convective<br>13% Moderately Convective<br>8% Slightly Stable | 2 ships |

***Maximum 24-hour concentrations are from incremental cruise/ferry sources only – background concentrations are NOT included in table.**

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.

### 6.8 HOURLY CONCENTRATIONS DURING MAXIMUM 24-HOUR PERIODS

An additional request by members of the James Bay community was to examine the pattern of hourly concentration levels which occur on those specific days identified as experiencing the highest 24-hour concentration levels (Table 48). This section presents hourly time series graphs for the 5 highest 24-hour periods: May 11, September 22, May 17, September 24 and July 6. Sulphur dioxide ($SO_2$) was selected as an example for the time series graphs, in part because these specific five days represent those 3% of 24-hour periods which experience concentration levels above the WHO guideline of 20 $\mu g/m^3$ for $SO_2$. Although the actual concentration levels ($\mu g/m^3$) will vary for the other pollutants of interest, it is expected that their hourly concentration levels would display similar patterns in the rise and fall of concentration levels over time corresponding to source activity.

For each graph presented below, hourly concentrations of $SO_2$ are plotted for three locations: 1) the receptor point in James Bay experiencing the highest 24-hour concentration level; 2) the receptor location in Songhees experiencing the highest 24-hour concentration level, and; 3) 30 meters above ground level at Apartment #5 (see Section 8.0 Apartment Building Analysis Figure 54). Estimated concentration levels are from cruise ship and ferry sources only, without the addition of background concentrations.

It should be noted that although the 24-hour concentration levels experienced are in excess of the WHO 24-hour guideline, all 1-hour periods experienced throughout all five days are more than three times below the BC Level A and Canada Maximum Desirable Guidelines and Objectives of 450$\mu g/m^3$ for 1-hour $SO_2$.

Please refer to Section 6.7 for the corresponding meteorological conditions and number of ships present for each of the following graphs. Specific ship arrival and departure times can also be obtained from the cruise ship schedule provided in Appendix E.

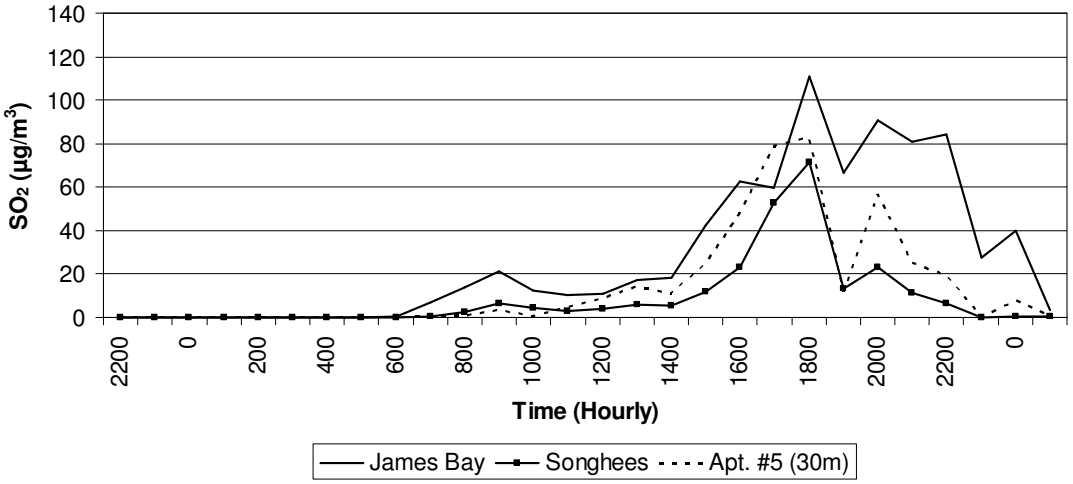



**Figure 48.** Estimated hourly $SO_2$ concentrations on May 11, 2007.

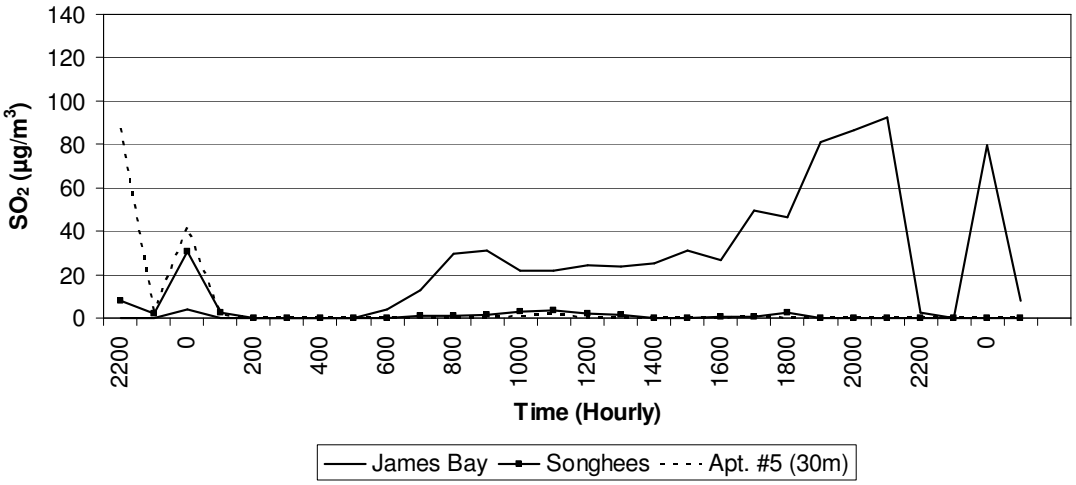



**Figure 49.** Estimated hourly $SO_2$ concentrations on September 22, 2007.

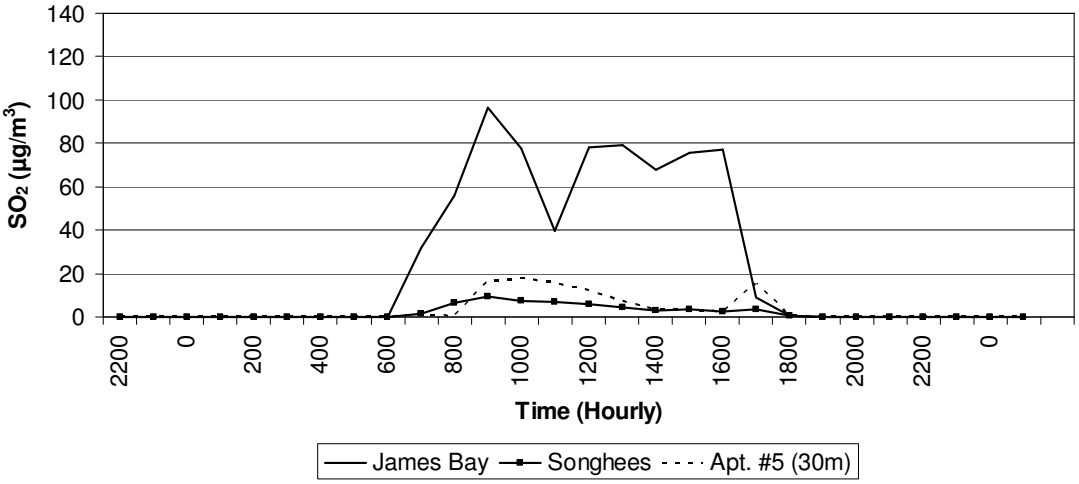



**Figure 50.** Estimated hourly $SO_2$ concentrations on May 17, 2007

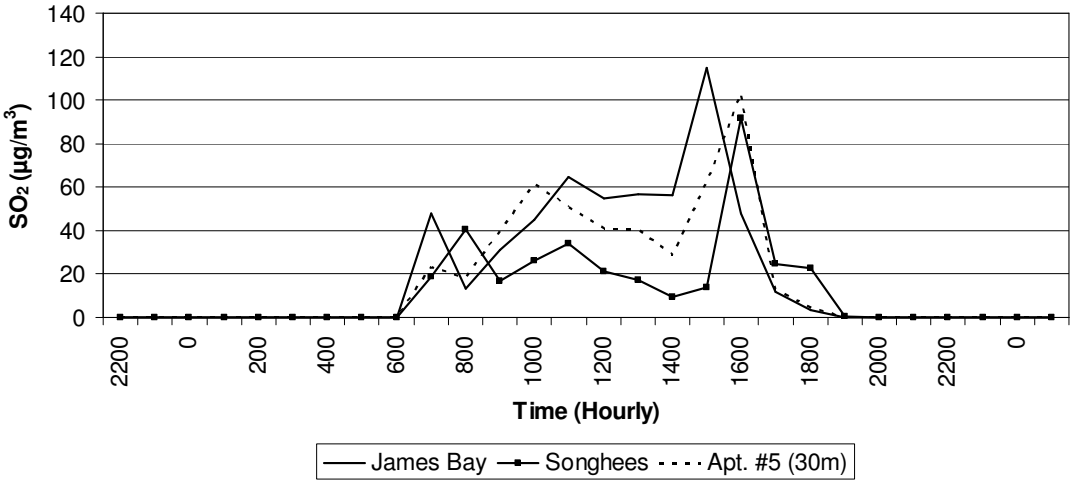



**Figure 51.** Estimated hourly $SO_2$ concentrations on September 24, 2007

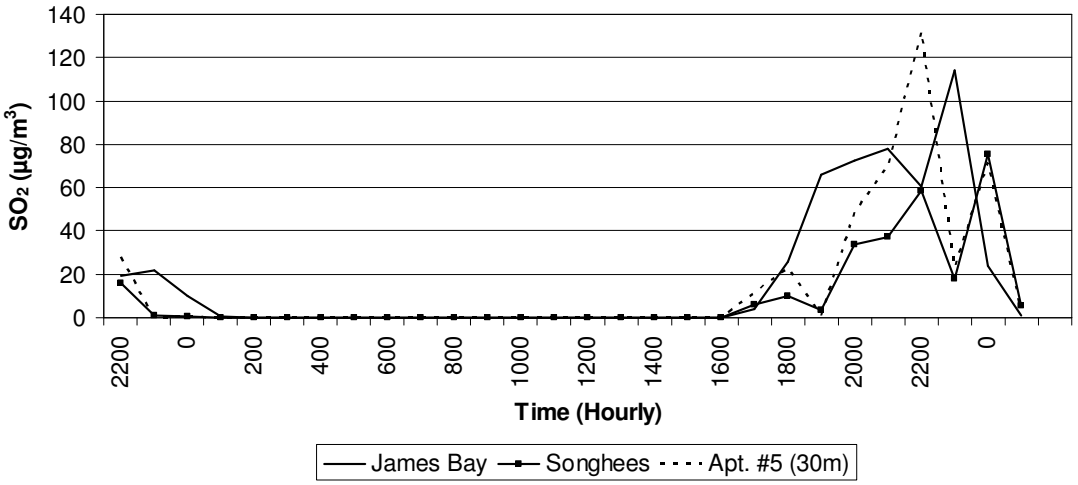



**Figure 52.** Estimated hourly $SO_2$ concentrations on July 6, 2007

# 7.0 COMPARATIVE ANALYSIS AT TOPAZ STATION

A quality assurance test commonly performed to assess predicted model concentrations is a comparison of model outputs to actual measurements from a fixed-site monitoring station in the study area. The Ministry of Environment Topaz station was selected as a specific point to include in the model analysis as a point for comparison. In this section the frequency distributions of estimated concentrations from the CALPUFF model (cruise ships and ferries without background) are compared to the distributions of recorded concentrations from the monitoring site at Topaz for the modelling period.

## 7.1 DISTRIBUTION OF 1-HOUR CONCENTRATIONS

1-hour frequency distributions of modelled and measured pollutants are provided in Table 49 and Table 50 respectively. It should be noted that there are missing data in the Topaz records during the 2007 cruise season. The data record is 94.3% complete for NO and $NO_2$, 98.4% complete for $PM_{2.5}$, and 79.3% complete for $SO_2$. In some cases, the 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.

**Table 49.** Frequency distribution of modelled 1-hour concentrations at Topaz.

| Percentile | $SO_2$ (µg/m$^3$) | $NO_2$ (µg/m$^3$) | $PM_{10}$ (µg/m$^3$) | $PM_{25}$ (µg/m$^3$) |
|---|---|---|---|---|
| **100$^{th}$** | 47.99 | 59.54 | 6.41 | 5.49 |
| **99$^{th}$** | 4.05 | 5.57 | 0.57 | 0.49 |
| **98$^{th}$** | 4.05 | 2.83 | 0.57 | 0.49 |
| **97$^{th}$** | 1.23 | 1.82 | 0.17 | 0.15 |
| **95$^{th}$** | 0.55 | 0.88 | 0.08 | 0.07 |
| **90$^{th}$** | 0.03 | 0.26 | 0.01 | 0.01 |
| **80$^{th}$** | 0.00 | 0.03 | 0.00 | 0.00 |
| **75$^{th}$** | 0.00 | 0.01 | 0.00 | 0.00 |
| **50$^{th}$** | 0.00 | 0.00 | 0.00 | 0.00 |

**Table 50.** Frequency distribution of measured 1-hour concentrations at Topaz.

| Percentile | $SO_2$ (µg/m$^3$) | $NO_2$ (µg/m$^3$) | $PM_{10}$ (µg/m$^3$) | $PM_{25}$ (µg/m$^3$) |
|---|---|---|---|---|
| **100$^{th}$** | 88.00 | 76.90 | n/a | 69.00 |
| **99$^{th}$** | 19.18 | 56.43 | n/a | 22.00 |
| **98$^{th}$** | 13.00 | 50.30 | n/a | 16.42 |
| **97$^{th}$** | 11.00 | 47.20 | n/a | 14.00 |
| **95$^{th}$** | 8.00 | 43.20 | n/a | 12.00 |
| **90$^{th}$** | 5.00 | 36.50 | n/a | 9.00 |
| **80$^{th}$** | 3.00 | 29.80 | n/a | 7.00 |
| **75$^{th}$** | 3.00 | 27.90 | n/a | 6.00 |
| **50$^{th}$** | 0.00 | 19.30 | n/a | 4.00 |

Modelled 1-hour maximum concentrations at Topaz were lower than those actually measured for $SO_2$ (48 vs. 88 µg/m$^3$) and $NO_2$ (60 vs. 77 µg/m$^3$). Modelled 1-hour maximum predictions of $PM_{2.5}$ for Topaz station were lower than those measured (5 vs. 69 µg/m$^3$), but there are many additional $PM_{2.5}$ sources active in the area surrounding the Topaz station which account for this higher value. Due to the fact that marine sources clearly dominate $SO_2$ emissions in the region, the reasonable agreement between modelled and measured 1-hour $SO_2$ concentrations supports the ship emission estimates and modelling approach used in this study. However, the much higher percentile $SO_2$ concentrations (99th, 98th etc) from the monitoring indicate that other emission sources not characterized in this study likely have significance to short term ambient concentrations near Topaz also.

### 7.2 DISTRIBUTION OF 24-HOUR CONCENTRATIONS

24-hour frequency distributions of modelled and measured pollutants are provided in Table 51 and Table 52, respectively. The average 24-hour concentrations measured at the Topaz station are sequential averages of daily 1-hour concentrations. As noted in the previous section, occasional missing data entries are present in the Topaz dataset. Daily averages were still calculated regardless of missing entries. Large portions of missing data, such as in the case of $SO_2$ were treated as no data, and not as values of 0.

**Table 51.** Frequency distribution of modelled 24-hour concentrations at Topaz.

| Percentile | $SO_2$ (µg/m$^3$) | $NO_2$ (µg/m$^3$) | $PM_{10}$ (µg/m$^3$) | $PM_{25}$ (µg/m$^3$) |
|---|---|---|---|---|
| **100th** | 4.28 | 5.18 | 0.57 | 0.49 |
| **99th** | 2.88 | 3.67 | 0.39 | 0.34 |
| **98th** | 2.88 | 2.46 | 0.39 | 0.34 |
| **97th** | 1.66 | 2.07 | 0.23 | 0.19 |
| **95th** | 1.11 | 1.46 | 0.15 | 0.13 |
| **90th** | 0.49 | 0.64 | 0.07 | 0.06 |
| **80th** | 0.20 | 0.32 | 0.03 | 0.02 |
| **75th** | 0.14 | 0.25 | 0.02 | 0.02 |
| **50th** | 0.00 | 0.24 | 0.00 | 0.00 |

**Table 52.** Frequency distribution of measured 24-hour concentrations at Topaz

| Percentile | $SO_2$ (µg/m$^3$) | $NO_2$ (µg/m$^3$) | $PM_{10}$ (µg/m$^3$) | $PM_{25}$ (µg/m$^3$) |
|---|---|---|---|---|
| **100th** | 23.30 | 48.44 | n/a | 18.54 |
| **99th** | 9.79 | 42.01 | n/a | 13.84 |
| **98th** | 7.12 | 36.07 | n/a | 11.64 |
| **97th** | 5.72 | 33.35 | n/a | 10.92 |
| **95th** | 4.86 | 32.31 | n/a | 9.68 |
| **90th** | 3.91 | 29.70 | n/a | 8.19 |
| **80th** | 2.94 | 25.85 | n/a | 6.29 |
| **75th** | 2.61 | 24.60 | n/a | 5.96 |
| **50th** | 1.23 | 20.60 | n/a | 4.29 |

Modelled maximum 24-hour concentrations were significantly lower than measured concentrations at Topaz station for all pollutants. This indicates that other sources contribute to ambient concentrations over a longer time period.

### 7.3 Influence of Emissions from Passing ships on $SO_2$ Concentrations at Topaz

During a conference with the Greater Victoria Harbour Authority (GVHA), the Northwest Cruise Association and the BC Chamber of Shipping (CoS), it was suggested that marine traffic and related emissions from a greater distance from James Bay may significantly influence the local air quality. The CoS provided access to the 2005/2006 marine inventory so that emissions could be extracted along the main shipping lane nearest James Bay. This lane is approximately 2.5 km off of the coast of Victoria.

As shown in Figure 53, a database extraction was performed with the intent of capturing all marine activity along a 5 km length of this lane near James Bay. 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 this investigation. 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 CoS inventory amounts for this section of the near shipping lane are 4.5, 6.8, 0.6 and 0.5 g/s 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.

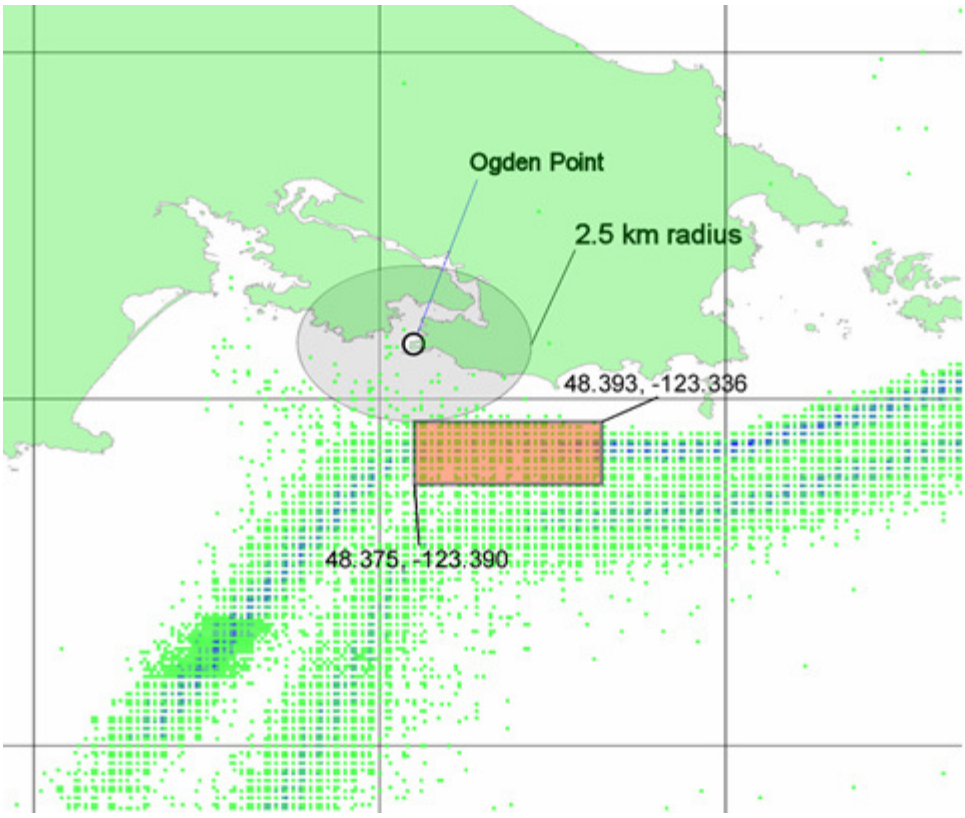



**Figure 53.** Database extraction of 5 km length of shipping lane off the coast of Victoria.

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 53.

**Table 53.** 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. 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 Topaz station).

# 8.0 APARTMENT BUILDING ANALYSIS

Over 77 percent of residences in James Bay are apartment buildings (50 percent are five storeys or less, 27 percent are more than five storeys).[60] James Bay community members expressed concern about the possibility of varying pollutant concentrations with altitude which may be affecting residents living at distances above ground level in apartment buildings.

To investigate this question, the locations of 5 randomly selected apartment buildings in the community (Figure 54) were chosen to calculate frequency distributions of pollutant concentrations at ground level and varying levels in height.

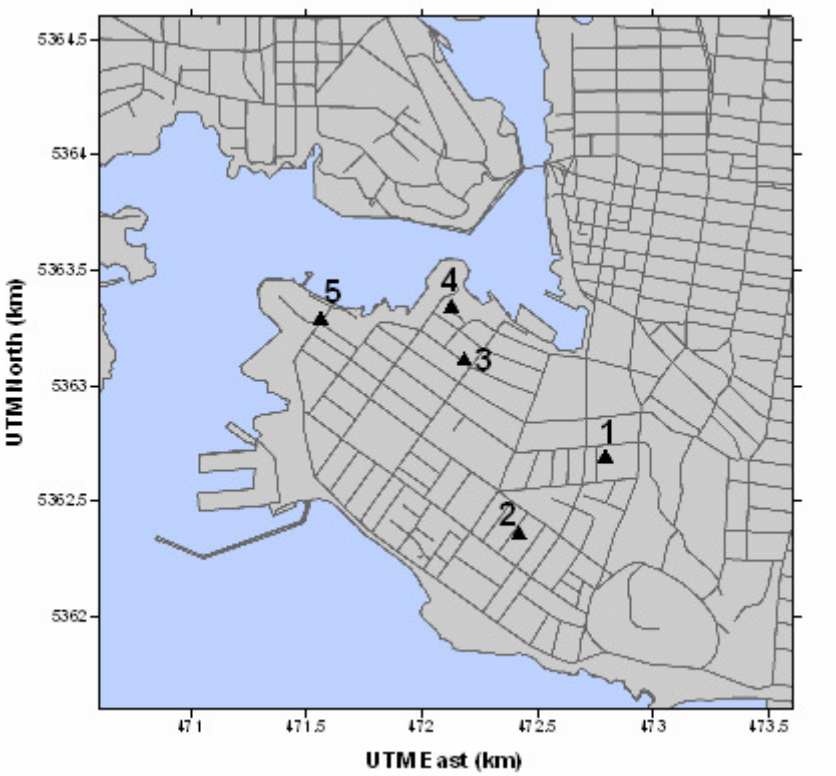



**Figure 54.** Location of apartment buildings used in analysis of pollutant concentrations with altitude.

Apartment 1 and 2, which are located farther from cruise and ferry emissions sources generally experienced decreasing maximum 1-hour concentrations of all pollutants with height above ground. Apartments 3, 4 and 5 have the opposite relationship and the maximum 1-hour concentrations increase with altitude. These three apartments are closer to the cruise ship and ferry terminals, and therefore may experience more direct exposure

[60] James Bay Neighbourhood Profile available on the City of Victoria website: http://www.victoria.ca/residents/profiles.shtml

to a plume rather than a mass of relatively well-mixed air. Apartments farther away likely benefit from greater atmospheric mixing and stratification of pollutants such that ground level concentrations are higher than those at elevated positions. The Apartment 5 location experienced the most extreme differences in concentrations with elevation above ground. The frequency distribution for this site is displayed in Table 58.

Of the four pollutants, $SO_2$ and $NO_x$ experience the greatest differences in maximum concentrations with altitude (up to a 60 $\mu g/m^3$ difference in 1 hour $SO_2$ between ground and 30 m). There is not as large a difference in maximum 24-hour concentrations with altitude. In general, for all apartment sites there is less then a 5 $\mu g/m^3$ difference between ground and upper levels.

This analysis showed that a difference in pollutant concentrations can exist with altitude at apartment building sites in the James Bay community. The analysis did not include background concentrations, as background is established for locations at ground level and may not adequately characterize concentrations at higher altitudes.

**Table 54.** Apartment #1 1-Hour and 24-Hour Frequency Distribution of $SO_2$, $NO_X$, $PM_{10}$ and $PM_{2.5}$.

| | $SO_x$ 1- Hour | | | | | $SO_x$ 24-Hour | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Percentile** | **1.5 m** | **15 m** | **30 m** | **60 m** | **Percentile** | **1.5 m** | **15 m** | **30 m** | **60 m** |
| **100th** | 81.14 | 86.22 | 97.94 | 109.76 | **100th** | 9.54 | 9.57 | 9.69 | 10.14 |
| **99th** | 15.04 | 15.23 | 15.97 | 16.04 | **99th** | 6.98 | 6.95 | 6.86 | 7.14 |
| **98th** | 8.34 | 8.35 | 8.36 | 8.80 | **98th** | 5.71 | 5.74 | 5.81 | 6.18 |
| **97th** | 5.03 | 5.21 | 5.24 | 6.04 | **97th** | 4.76 | 4.82 | 5.22 | 5.79 |
| **95th** | 2.42 | 2.44 | 2.51 | 2.89 | **95th** | 3.85 | 4.04 | 4.26 | 4.18 |
| **90th** | 0.29 | 0.31 | 0.35 | 0.58 | **90th** | 1.79 | 1.83 | 1.97 | 2.02 |
| **80th** | 0.01 | 0.01 | 0.01 | 0.01 | **80th** | 0.83 | 0.84 | 0.86 | 1.07 |
| **75th** | 0.00 | 0.00 | 0.00 | 0.00 | **75th** | 0.60 | 0.60 | 0.62 | 0.63 |
| **50th** | 0.00 | 0.00 | 0.00 | 0.00 | **50th** | 0.01 | 0.01 | 0.02 | 0.03 |

| | $NO_x$ 1- Hour | | | | | $NO_x$ 24-Hour | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Percentile** | **1.5 m** | **15 m** | **30 m** | **60 m** | **Percentile** | **1.5 m** | **15 m** | **30 m** | **60 m** |
| **100th** | 140.64 | 149.41 | 169.61 | 189.18 | **100th** | 16.11 | 16.16 | 16.31 | 16.95 |
| **99th** | 25.37 | 25.60 | 26.79 | 28.63 | **99th** | 11.81 | 11.77 | 11.61 | 12.20 |
| **98th** | 13.78 | 14.23 | 14.43 | 15.05 | **98th** | 9.60 | 9.65 | 9.77 | 10.52 |
| **97th** | 8.78 | 8.93 | 8.89 | 10.02 | **97th** | 8.00 | 8.14 | 8.75 | 9.76 |
| **95th** | 4.21 | 4.26 | 4.40 | 5.17 | **95th** | 6.92 | 7.25 | 7.40 | 7.13 |
| **90th** | 0.88 | 0.89 | 1.01 | 1.31 | **90th** | 3.08 | 3.16 | 3.37 | 3.58 |
| **80th** | 0.26 | 0.27 | 0.29 | 0.32 | **80th** | 1.46 | 1.47 | 1.60 | 1.92 |
| **75th** | 0.01 | 0.01 | 0.02 | 0.02 | **75th** | 1.12 | 1.11 | 1.16 | 1.16 |
| **50th** | 0.00 | 0.00 | 0.00 | 0.00 | **50th** | 0.16 | 0.16 | 0.16 | 0.18 |

| | $PM_{10}$ 1- Hour | | | | | $PM_{10}$ 24-Hour | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Percentile** | **1.5 m** | **15 m** | **30 m** | **60 m** | **Percentile** | **1.5 m** | **15 m** | **30 m** | **60 m** |
| **100th** | 11.10 | 11.80 | 13.40 | 14.98 | **100th** | 1.29 | 1.29 | 1.30 | 1.36 |
| **99th** | 2.06 | 2.07 | 2.14 | 2.17 | **99th** | 0.94 | 0.94 | 0.93 | 0.97 |
| **98th** | 1.11 | 1.13 | 1.13 | 1.20 | **98th** | 0.77 | 0.77 | 0.78 | 0.84 |
| **97th** | 0.69 | 0.72 | 0.70 | 0.81 | **97th** | 0.64 | 0.65 | 0.69 | 0.78 |
| **95th** | 0.33 | 0.34 | 0.34 | 0.39 | **95th** | 0.53 | 0.56 | 0.58 | 0.57 |
| **90th** | 0.05 | 0.05 | 0.05 | 0.08 | **90th** | 0.24 | 0.25 | 0.27 | 0.28 |
| **80th** | 0.01 | 0.01 | 0.01 | 0.01 | **80th** | 0.11 | 0.11 | 0.12 | 0.15 |
| **75th** | 0.00 | 0.00 | 0.00 | 0.00 | **75th** | 0.08 | 0.08 | 0.09 | 0.09 |
| **50th** | 0.00 | 0.00 | 0.00 | 0.00 | **50th** | 0.00 | 0.01 | 0.01 | 0.01 |

| | $PM_{2.5}$ 1- Hour | | | | | $PM_{2.5}$ 24-Hour | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Percentile** | **1.5 m** | **15 m** | **30 m** | **60 m** | **Percentile** | **1.5 m** | **15 m** | **30 m** | **60 m** |
| **100th** | 9.51 | 10.10 | 11.47 | 12.81 | **100th** | 1.09 | 1.10 | 1.11 | 1.15 |
| **99th** | 1.72 | 1.76 | 1.80 | 1.86 | **99th** | 0.80 | 0.80 | 0.78 | 0.83 |
| **98th** | 0.94 | 0.96 | 0.97 | 1.02 | **98th** | 0.65 | 0.66 | 0.66 | 0.71 |
| **97th** | 0.58 | 0.60 | 0.59 | 0.69 | **97th** | 0.54 | 0.55 | 0.59 | 0.66 |
| **95th** | 0.28 | 0.28 | 0.29 | 0.33 | **95th** | 0.46 | 0.48 | 0.50 | 0.48 |
| **90th** | 0.04 | 0.04 | 0.05 | 0.07 | **90th** | 0.21 | 0.21 | 0.23 | 0.24 |
| **80th** | 0.01 | 0.01 | 0.01 | 0.01 | **80th** | 0.10 | 0.10 | 0.10 | 0.13 |
| **75th** | 0.00 | 0.00 | 0.00 | 0.00 | **75th** | 0.07 | 0.07 | 0.07 | 0.07 |
| **50th** | 0.00 | 0.00 | 0.00 | 0.00 | **50th** | 0.00 | 0.00 | 0.01 | 0.01 |

**Table 55.** Apartment #2 1-Hour and 24-Hour Frequency Distribution of $SO_2$, $NO_X$, $PM_{10}$ and $PM_{2.5}$.

| | $SO_x$ 1- Hour | | | | $SO_x$ 24-Hour | | |
|---|---|---|---|---|---|---|---|
| **Percentile** | **1.5 m** | **20 m** | **40 m** | **Percentile** | **1.5 m** | **20 m** | **40 m** |
| **100th** | 79.98 | 93.06 | 109.96 | **100th** | 6.70 | 6.63 | 7.12 |
| **99th** | 10.57 | 10.67 | 10.69 | **99th** | 5.15 | 5.69 | 6.43 |
| **98th** | 5.60 | 5.91 | 6.25 | **98th** | 3.93 | 4.36 | 5.25 |
| **97th** | 3.80 | 3.88 | 3.99 | **97th** | 2.39 | 2.50 | 2.74 |
| **95th** | 1.98 | 2.02 | 2.02 | **95th** | 1.58 | 1.58 | 1.59 |
| **90th** | 0.13 | 0.13 | 0.16 | **90th** | 1.10 | 1.13 | 1.28 |
| **80th** | 0.01 | 0.01 | 0.01 | **80th** | 0.78 | 0.85 | 0.84 |
| **75th** | 0.00 | 0.00 | 0.00 | **75th** | 0.60 | 0.61 | 0.59 |
| **50th** | 0.00 | 0.00 | 0.00 | **50th** | 0.01 | 0.01 | 0.04 |

| | $NO_x$ 1- Hour | | | | $NO_x$ 24-Hour | | |
|---|---|---|---|---|---|---|---|
| **Percentile** | **1.5 m** | **20 m** | **40 m** | **Percentile** | **1.5 m** | **20 m** | **40 m** |
| **100th** | 141.26 | 164.36 | 194.22 | **100th** | 11.49 | 11.36 | 12.60 |
| **99th** | 18.31 | 18.07 | 19.43 | **99th** | 8.96 | 10.23 | 11.05 |
| **98th** | 10.13 | 10.53 | 11.12 | **98th** | 6.85 | 7.54 | 8.95 |
| **97th** | 6.79 | 7.08 | 7.22 | **97th** | 4.10 | 4.28 | 6.33 |
| **95th** | 3.71 | 3.75 | 3.83 | **95th** | 2.63 | 2.64 | 3.49 |
| **90th** | 0.92 | 0.95 | 1.06 | **90th** | 2.01 | 2.11 | 2.32 |
| **80th** | 0.23 | 0.25 | 0.29 | **80th** | 1.44 | 1.54 | 1.61 |
| **75th** | 0.00 | 0.01 | 0.01 | **75th** | 1.17 | 1.18 | 1.25 |
| **50th** | 0.00 | 0.00 | 0.00 | **50th** | 0.19 | 0.20 | 0.25 |

| | $PM_{10}$ 1- Hour | | | | $PM_{10}$ 24-Hour | | |
|---|---|---|---|---|---|---|---|
| **Percentile** | **1.5 m** | **20 m** | **40 m** | **Percentile** | **1.5 m** | **20 m** | **40 m** |
| **100th** | 11.03 | 12.83 | 15.16 | **100th** | 0.91 | 0.90 | 0.98 |
| **99th** | 1.43 | 1.43 | 1.48 | **99th** | 0.70 | 0.79 | 0.87 |
| **98th** | 0.78 | 0.81 | 0.87 | **98th** | 0.54 | 0.60 | 0.71 |
| **97th** | 0.52 | 0.53 | 0.57 | **97th** | 0.33 | 0.34 | 0.38 |
| **95th** | 0.28 | 0.28 | 0.28 | **95th** | 0.21 | 0.21 | 0.22 |
| **90th** | 0.03 | 0.03 | 0.04 | **90th** | 0.15 | 0.16 | 0.18 |
| **80th** | 0.01 | 0.01 | 0.01 | **80th** | 0.11 | 0.12 | 0.12 |
| **75th** | 0.00 | 0.00 | 0.00 | **75th** | 0.09 | 0.09 | 0.09 |
| **50th** | 0.00 | 0.00 | 0.00 | **50th** | 0.01 | 0.01 | 0.01 |

| | $PM_{2.5}$ 1- Hour | | | | $PM_{2.5}$ 24-Hour | | |
|---|---|---|---|---|---|---|---|
| **Percentile** | **1.5 m** | **20 m** | **40 m** | **Percentile** | **1.5 m** | **20 m** | **40 m** |
| **100th** | 9.51 | 11.07 | 13.08 | **100th** | 0.78 | 0.77 | 0.85 |
| **99th** | 1.22 | 1.22 | 1.27 | **99th** | 0.59 | 0.68 | 0.74 |
| **98th** | 0.67 | 0.68 | 0.75 | **98th** | 0.46 | 0.51 | 0.60 |
| **97th** | 0.45 | 0.46 | 0.49 | **97th** | 0.27 | 0.29 | 0.32 |
| **95th** | 0.23 | 0.24 | 0.24 | **95th** | 0.18 | 0.18 | 0.19 |
| **90th** | 0.03 | 0.03 | 0.03 | **90th** | 0.13 | 0.14 | 0.15 |
| **80th** | 0.01 | 0.01 | 0.01 | **80th** | 0.09 | 0.10 | 0.10 |
| **75th** | 0.00 | 0.00 | 0.00 | **75th** | 0.07 | 0.07 | 0.08 |
| **50th** | 0.00 | 0.00 | 0.00 | **50th** | 0.00 | 0.01 | 0.01 |

**Table 56.** Apartment #3 1-Hour and 24-Hour Frequency Distribution of $SO_2$, $NO_X$, $PM_{10}$ and $PM_{2.5}$.

| | $SO_x$ 1- Hour | | | | $SO_x$ 24-Hour | | |
|---|---|---|---|---|---|---|---|
| **Percentile** | **1.5 m** | **15 m** | **30 m** | **Percentile** | **1.5 m** | **15 m** | **30 m** |
| **100th** | 101.35 | 106.36 | 120.21 | **100th** | 21.26 | 21.62 | 22.60 |
| **99th** | 33.62 | 33.70 | 35.87 | **99th** | 13.13 | 13.09 | 13.34 |
| **98th** | 21.19 | 21.80 | 22.90 | **98th** | 11.49 | 11.73 | 12.33 |
| **97th** | 15.19 | 15.57 | 15.78 | **97th** | 9.20 | 9.32 | 9.65 |
| **95th** | 7.32 | 7.68 | 8.02 | **95th** | 6.40 | 6.44 | 6.80 |
| **90th** | 1.22 | 1.26 | 1.29 | **90th** | 4.22 | 4.31 | 4.50 |
| **80th** | 0.01 | 0.01 | 0.01 | **80th** | 1.99 | 1.98 | 1.96 |
| **75th** | 0.00 | 0.00 | 0.00 | **75th** | 1.48 | 1.48 | 1.60 |
| **50th** | 0.00 | 0.00 | 0.00 | **50th** | 0.02 | 0.02 | 0.03 |

| | $NO_x$ 1- Hour | | | | $NO_x$ 24-Hour | | |
|---|---|---|---|---|---|---|---|
| **Percentile** | **1.5 m** | **15 m** | **30 m** | **Percentile** | **1.5 m** | **15 m** | **30 m** |
| **100th** | 165.94 | 174.10 | 196.66 | **100th** | 35.08 | 35.67 | 37.27 |
| **99th** | 57.73 | 57.35 | 59.95 | **99th** | 21.89 | 22.10 | 22.64 |
| **98th** | 35.55 | 35.85 | 37.62 | **98th** | 19.32 | 19.68 | 20.50 |
| **97th** | 24.85 | 25.36 | 26.47 | **97th** | 15.46 | 15.64 | 16.18 |
| **95th** | 12.64 | 13.01 | 12.96 | **95th** | 10.98 | 10.95 | 11.50 |
| **90th** | 2.25 | 2.31 | 2.59 | **90th** | 7.25 | 7.38 | 7.73 |
| **80th** | 0.46 | 0.47 | 0.50 | **80th** | 3.46 | 3.44 | 3.40 |
| **75th** | 0.03 | 0.04 | 0.04 | **75th** | 2.56 | 2.57 | 2.74 |
| **50th** | 0.00 | 0.00 | 0.00 | **50th** | 0.27 | 0.28 | 0.31 |

| | $PM_{10}$ 1- Hour | | | | $PM_{10}$ 24-Hour | | |
|---|---|---|---|---|---|---|---|
| **Percentile** | **1.5 m** | **15 m** | **30 m** | **Percentile** | **1.5 m** | **15 m** | **30 m** |
| **100th** | 13.50 | 14.17 | 16.01 | **100th** | 2.84 | 2.89 | 3.02 |
| **99th** | 4.54 | 4.56 | 4.88 | **99th** | 1.75 | 1.76 | 1.80 |
| **98th** | 2.84 | 2.88 | 3.05 | **98th** | 1.55 | 1.58 | 1.66 |
| **97th** | 2.05 | 2.07 | 2.12 | **97th** | 1.24 | 1.25 | 1.30 |
| **95th** | 1.00 | 1.05 | 1.06 | **95th** | 0.87 | 0.87 | 0.92 |
| **90th** | 0.16 | 0.17 | 0.18 | **90th** | 0.57 | 0.58 | 0.61 |
| **80th** | 0.01 | 0.01 | 0.01 | **80th** | 0.27 | 0.27 | 0.27 |
| **75th** | 0.00 | 0.00 | 0.00 | **75th** | 0.20 | 0.20 | 0.22 |
| **50th** | 0.00 | 0.00 | 0.00 | **50th** | 0.01 | 0.01 | 0.01 |

| | $PM_{2.5}$ 1- Hour | | | | $PM_{2.5}$ 24-Hour | | |
|---|---|---|---|---|---|---|---|
| **Percentile** | **1.5 m** | **15 m** | **30 m** | **Percentile** | **1.5 m** | **15 m** | **30 m** |
| **100th** | 11.41 | 11.97 | 13.52 | **100th** | 2.40 | 2.44 | 2.55 |
| **99th** | 3.89 | 3.86 | 4.11 | **99th** | 1.48 | 1.50 | 1.53 |
| **98th** | 2.40 | 2.45 | 2.58 | **98th** | 1.31 | 1.34 | 1.40 |
| **97th** | 1.71 | 1.73 | 1.79 | **97th** | 1.05 | 1.06 | 1.10 |
| **95th** | 0.85 | 0.88 | 0.89 | **95th** | 0.74 | 0.74 | 0.78 |
| **90th** | 0.14 | 0.15 | 0.15 | **90th** | 0.49 | 0.49 | 0.52 |
| **80th** | 0.01 | 0.01 | 0.01 | **80th** | 0.23 | 0.23 | 0.23 |
| **75th** | 0.00 | 0.00 | 0.00 | **75th** | 0.17 | 0.17 | 0.18 |
| **50th** | 0.00 | 0.00 | 0.00 | **50th** | 0.01 | 0.01 | 0.01 |

**Table 57.** Apartment #4 1-Hour and 24-Hour Frequency Distribution of $SO_2$, $NO_X$, $PM_{10}$ and $PM_{2.5}$.

| | $SO_x$ 1- Hour | | | | $SO_x$ 24-Hour | | |
|---|---|---|---|---|---|---|---|
| **Percentile** | **1.5 m** | **15 m** | **30 m** | **Percentile** | **1.5 m** | **15 m** | **30 m** |
| **100th** | 113.98 | 115.24 | 118.57 | **100th** | 27.64 | 28.25 | 29.91 |
| **99th** | 38.33 | 40.12 | 42.54 | **99th** | 12.00 | 12.20 | 12.74 |
| **98th** | 22.43 | 22.95 | 25.03 | **98th** | 9.97 | 10.03 | 10.35 |
| **97th** | 17.14 | 17.36 | 18.62 | **97th** | 8.94 | 9.22 | 9.47 |
| **95th** | 9.25 | 9.52 | 10.12 | **95th** | 7.61 | 7.88 | 8.48 |
| **90th** | 1.39 | 1.44 | 1.64 | **90th** | 5.16 | 5.27 | 5.53 |
| **80th** | 0.01 | 0.02 | 0.02 | **80th** | 2.82 | 2.91 | 3.14 |
| **75th** | 0.00 | 0.00 | 0.00 | **75th** | 1.86 | 1.86 | 2.04 |
| **50th** | 0.00 | 0.00 | 0.00 | **50th** | 0.01 | 0.01 | 0.01 |

| | $NO_x$ 1- Hour | | | | $NO_x$ 24-Hour | | |
|---|---|---|---|---|---|---|---|
| **Percentile** | **1.5 m** | **15 m** | **30 m** | **Percentile** | **1.5 m** | **15 m** | **30 m** |
| **100th** | 195.49 | 197.63 | 203.28 | **100th** | 45.62 | 46.61 | 49.30 |
| **99th** | 64.07 | 66.67 | 71.91 | **99th** | 20.38 | 20.71 | 21.60 |
| **98th** | 37.95 | 38.85 | 42.18 | **98th** | 16.90 | 16.97 | 17.54 |
| **97th** | 28.91 | 29.73 | 32.02 | **97th** | 15.21 | 15.67 | 16.22 |
| **95th** | 15.55 | 15.74 | 17.10 | **95th** | 12.64 | 13.01 | 14.06 |
| **90th** | 2.92 | 3.04 | 3.48 | **90th** | 8.59 | 8.68 | 9.21 |
| **80th** | 0.57 | 0.58 | 0.61 | **80th** | 4.68 | 4.80 | 5.35 |
| **75th** | 0.04 | 0.05 | 0.06 | **75th** | 3.28 | 3.26 | 3.42 |
| **50th** | 0.00 | 0.00 | 0.00 | **50th** | 0.34 | 0.37 | 0.49 |

| | $PM_{10}$ 1- Hour | | | | $PM_{10}$ 24-Hour | | |
|---|---|---|---|---|---|---|---|
| **Percentile** | **1.5 m** | **15 m** | **30 m** | **Percentile** | **1.5 m** | **15 m** | **30 m** |
| **100th** | 15.49 | 15.66 | 16.11 | **100th** | 3.69 | 3.77 | 3.99 |
| **99th** | 5.15 | 5.36 | 5.75 | **99th** | 1.62 | 1.65 | 1.72 |
| **98th** | 3.03 | 3.07 | 3.42 | **98th** | 1.35 | 1.36 | 1.40 |
| **97th** | 2.31 | 2.36 | 2.52 | **97th** | 1.21 | 1.25 | 1.29 |
| **95th** | 1.23 | 1.27 | 1.36 | **95th** | 1.02 | 1.05 | 1.12 |
| **90th** | 0.19 | 0.20 | 0.24 | **90th** | 0.69 | 0.70 | 0.74 |
| **80th** | 0.01 | 0.02 | 0.02 | **80th** | 0.38 | 0.39 | 0.42 |
| **75th** | 0.00 | 0.00 | 0.00 | **75th** | 0.25 | 0.25 | 0.27 |
| **50th** | 0.00 | 0.00 | 0.00 | **50th** | 0.01 | 0.01 | 0.01 |

| | $PM_{2.5}$ 1- Hour | | | | $PM_{2.5}$ 24-Hour | | |
|---|---|---|---|---|---|---|---|
| **Percentile** | **1.5 m** | **15 m** | **30 m** | **Percentile** | **1.5 m** | **15 m** | **30 m** |
| **100th** | 13.25 | 13.40 | 13.78 | **100th** | 3.13 | 3.19 | 3.38 |
| **99th** | 4.35 | 4.51 | 4.88 | **99th** | 1.38 | 1.40 | 1.46 |
| **98th** | 2.58 | 2.63 | 2.89 | **98th** | 1.15 | 1.15 | 1.19 |
| **97th** | 1.96 | 2.01 | 2.14 | **97th** | 1.03 | 1.06 | 1.10 |
| **95th** | 1.04 | 1.07 | 1.14 | **95th** | 0.86 | 0.89 | 0.95 |
| **90th** | 0.17 | 0.17 | 0.20 | **90th** | 0.58 | 0.59 | 0.63 |
| **80th** | 0.01 | 0.01 | 0.01 | **80th** | 0.32 | 0.33 | 0.36 |
| **75th** | 0.00 | 0.00 | 0.00 | **75th** | 0.21 | 0.21 | 0.23 |
| **50th** | 0.00 | 0.00 | 0.00 | **50th** | 0.01 | 0.01 | 0.01 |

**Table 58.** Apartment #5 1-Hour and 24-Hour Frequency Distribution of $SO_2$, $NO_X$, $PM_{10}$ and $PM_{2.5}$.

| | $SO_2$ 1- Hour | | | | $SO_2$ 24-Hour | | |
|---|---|---|---|---|---|---|---|
| **Percentile** | **1.5 m** | **15 m** | **30 m** | **Percentile** | **1.5 m** | **15 m** | **30 m** |
| **100th** | 112.10 | 127.31 | 171.82 | **100th** | 19.77 | 19.89 | 21.00 |
| **99th** | 42.36 | 44.49 | 53.59 | **99th** | 13.21 | 15.05 | 20.29 |
| **98th** | 26.08 | 26.91 | 31.47 | **98th** | 11.43 | 12.09 | 16.28 |
| **97th** | 17.32 | 18.51 | 20.78 | **97th** | 10.15 | 11.32 | 14.45 |
| **95th** | 6.74 | 7.41 | 8.35 | **95th** | 7.41 | 7.55 | 10.82 |
| **90th** | 0.57 | 0.64 | 0.77 | **90th** | 5.12 | 5.87 | 7.07 |
| **80th** | 0.01 | 0.01 | 0.02 | **80th** | 2.08 | 2.28 | 2.97 |
| **75th** | 0.00 | 0.00 | 0.00 | **75th** | 1.61 | 1.78 | 1.93 |
| **50th** | 0.00 | 0.00 | 0.00 | **50th** | 0.01 | 0.01 | 0.02 |

| | $NO_x$ 1- Hour | | | | $NO_x$ 24-Hour | | |
|---|---|---|---|---|---|---|---|
| **Percentile** | **1.5 m** | **15 m** | **30 m** | **Percentile** | **1.5 m** | **15 m** | **30 m** |
| **100th** | 186.59 | 211.75 | 285.41 | **100th** | 33.26 | 33.47 | 35.89 |
| **99th** | 70.54 | 74.92 | 88.48 | **99th** | 23.03 | 25.72 | 34.18 |
| **98th** | 42.48 | 44.74 | 51.74 | **98th** | 19.61 | 20.41 | 27.35 |
| **97th** | 28.87 | 30.92 | 34.54 | **97th** | 16.85 | 18.56 | 24.23 |
| **95th** | 12.15 | 13.04 | 15.29 | **95th** | 12.00 | 12.81 | 18.61 |
| **90th** | 2.65 | 2.91 | 3.26 | **90th** | 8.75 | 10.01 | 11.56 |
| **80th** | 0.42 | 0.45 | 0.53 | **80th** | 3.82 | 4.09 | 5.28 |
| **75th** | 0.01 | 0.02 | 0.02 | **75th** | 2.94 | 3.13 | 3.59 |
| **50th** | 0.00 | 0.00 | 0.00 | **50th** | 0.40 | 0.47 | 0.55 |

| | $PM_{10}$ 1- Hour | | | | $PM_{10}$ 24-Hour | | |
|---|---|---|---|---|---|---|---|
| **Percentile** | **1.5 m** | **15 m** | **30 m** | **Percentile** | **1.5 m** | **15 m** | **30 m** |
| **100th** | 15.07 | 17.11 | 23.07 | **100th** | 2.66 | 2.68 | 2.83 |
| **99th** | 5.73 | 6.05 | 7.18 | **99th** | 1.81 | 2.05 | 2.74 |
| **98th** | 3.44 | 3.59 | 4.21 | **98th** | 1.55 | 1.63 | 2.19 |
| **97th** | 2.35 | 2.48 | 2.79 | **97th** | 1.34 | 1.50 | 1.95 |
| **95th** | 0.92 | 1.00 | 1.14 | **95th** | 0.98 | 1.01 | 1.47 |
| **90th** | 0.10 | 0.11 | 0.14 | **90th** | 0.69 | 0.80 | 0.94 |
| **80th** | 0.01 | 0.01 | 0.02 | **80th** | 0.29 | 0.31 | 0.40 |
| **75th** | 0.00 | 0.00 | 0.00 | **75th** | 0.22 | 0.24 | 0.27 |
| **50th** | 0.00 | 0.00 | 0.00 | **50th** | 0.01 | 0.01 | 0.02 |

| | $PM_{2.5}$ 1- Hour | | | | $PM_{2.5}$ 24-Hour | | |
|---|---|---|---|---|---|---|---|
| **Percentile** | **1.5 m** | **15 m** | **30 m** | **Percentile** | **1.5 m** | **15 m** | **30 m** |
| **100th** | 12.74 | 14.46 | 19.49 | **100th** | 2.27 | 2.28 | 2.42 |
| **99th** | 4.83 | 5.12 | 6.07 | **99th** | 1.55 | 1.74 | 2.33 |
| **98th** | 2.86 | 3.05 | 3.51 | **98th** | 1.33 | 1.38 | 1.86 |
| **97th** | 1.96 | 2.11 | 2.32 | **97th** | 1.12 | 1.26 | 1.66 |
| **95th** | 0.78 | 0.86 | 0.98 | **95th** | 0.82 | 0.86 | 1.25 |
| **90th** | 0.09 | 0.10 | 0.12 | **90th** | 0.59 | 0.68 | 0.79 |
| **80th** | 0.01 | 0.01 | 0.01 | **80th** | 0.25 | 0.26 | 0.34 |
| **75th** | 0.00 | 0.00 | 0.00 | **75th** | 0.19 | 0.20 | 0.23 |
| **50th** | 0.00 | 0.00 | 0.00 | **50th** | 0.01 | 0.01 | 0.01 |

# 9.0 RECOMMENDATIONS

This report provides the results of the second phase of the James Bay Air Quality Study. The following recommendations are based on the overall project (Phase I and II) results, and on consultation with project advisors:

1. Typical levels of VOCs were not established by the field monitoring, and were not explored in the dispersion modelling analysis due to the difficulties of accurately modelling the complex behaviour of these pollutants in the atmosphere. An existing study of VOCs in the Victoria Inner Harbour was conducted in 2001[61] that monitored levels at 4 sites, but only one was in the current study area. Since turbo-prop aircraft movements have more than doubled in the last 10 years, the levels measured in 2001 are likely not representative of the current situation. Data on VOCs remains a significant gap at this time and should be the subject of additional study.

2. Ambient ground-level concentrations of pollutants from diesel bus traffic were not explored in the detailed dispersion modelling analysis, due to the unavailability of data at the time of model configuration, as well as a lack of adequate detail about fuel characteristics. Large numbers of buses are known to pass through the community at times just prior to arrival of ships, as well as before departure to drop off passengers. The shortest time period capable of being analyzed in the CALPUFF model (as configured) was 1-hour and this may not adequately capture the short-term influences of a large number of diesel buses passing through over a relatively short period of time. Air quality impacts of emissions from buses in James Bay also remains a gap at this time, and should be the subject of additional study, perhaps with a traffic model capable of examining shorter time periods (i.e., minutes).

3. Helicopters and float planes are two other emissions sources in the James Bay community which were not focused on in either Phase I or Phase II of this study. Concern regarding float planes in particular has been expressed anecdotally by certain members of the James Bay and Songhees communities as having negative impacts on air quality. The number of take off and landings from float planes has significantly increased over recent years. Quantifying the level and spatial distribution of emissions from float planes, as well as helicopters, should be the subject of additional study.

[61] Tradewind Scientific Ltd (2001). Volatile Organic Compound Monitoring Program at Victoria Harbour Airport. Prepared for Transport Canada Programs Branch, Vancouver, BC.

4. Comparison of modelled to measured concentrations at the Topaz Station revealed that additional emission sources likely influence maximum 1-hour and maximum 24-hour concentrations in the study region. An exploratory analysis of emissions from passing ships in the Juan de Fuca Strait show that nearby marine traffic likely influence longer term ambient concentrations in James Bay. A modelling analysis could be conducted to estimate the impact of emissions from passing ships in the off-shore shipping lane on air quality within James Bay, as well as the overall region as a whole.

5. Additional study of source type characteristics and simulation properties in the CALPUFF model should be investigated. In particular, the representation of a moving ship in the model has not been thoroughly studied and the source representation chosen for this study (line source) is reasonable based on the limited amount of model testing to date. Particular attention should be paid to this issue should an investigation be conducted for the offshore commercial marine traffic in the Strait of Juan de Fuca.

6. Together, the two phases of this study provide a reasonable characterization of the typical short- and long-term levels of $SO_2$, $NO_2$, $PM_{10}$ and $PM_{2.5}$ in the study area. Phase I and Phase II, however, do not constitute a health risk assessment. It is recommended that these reports be provided to an appropriate expert for the purpose of conducting an assessment of potential health implications, including a review of all relevant provincial, national and international health-based air quality standards.

# APPENDIX A - CONVERSION OF $NO_X$ TO $NO_2$

There are several different approaches which can be used to convert estimated concentrations of nitrogen oxides ($NO_x$) to nitrogen dioxide ($NO_2$). The associated chemical conversion processes in the atmosphere are complex and difficult to represent accurately in a dispersion model (especially for near-source areas). For this reason, empirical adjustments are commonly made to the modelled $NO_x$ concentrations to achieve representation of $NO_2$ concentrations.

## METHOD 1: 100% CONVERSION

The first and simplest method is to assume 100% conversion and report all $NO_x$ concentrations as $NO_2$. This method is highly conservative and not very realistic. However, if maximum $NO_2$ concentrations from this method are below ambient air quality guidelines then no further efforts to use a more realistic conversion process for establishing $NO_2$ are necessary (from a regulatory perspective).

*Maximum 1-Hour $NO_x$*

The maximum predicted 1-hour $NO_x$ concentration in the entire study domain was 451 $\mu g/m^3$. This maximum did not occur in the James Bay community, but offshore over the cruise ship berths at the Ogden Point terminal. Figure 55 provides a map of maximum predicted 1-hour concentrations of $NO_x$ throughout the modelling domain.

The maximum predicted 1-hour $NO_x$ concentration in James Bay was 236 $\mu g/m^3$. A closer view of the maximum 1-hour $NO_x$ isopleths for the James Bay community is displayed in Figure 56.

If 100% conversion of $NO_x$ to $NO_2$ is assumed, then the maximum 1-hour $NO_2$ concentration in the James Bay community is below the Canadian maximum acceptable guideline of 400 $\mu g/m^3$, but exceeds the CRD and WHO guidelines of 200 $\mu g/m^3$. There is no BC objective or guideline for maximum 1-hour $NO_2$.

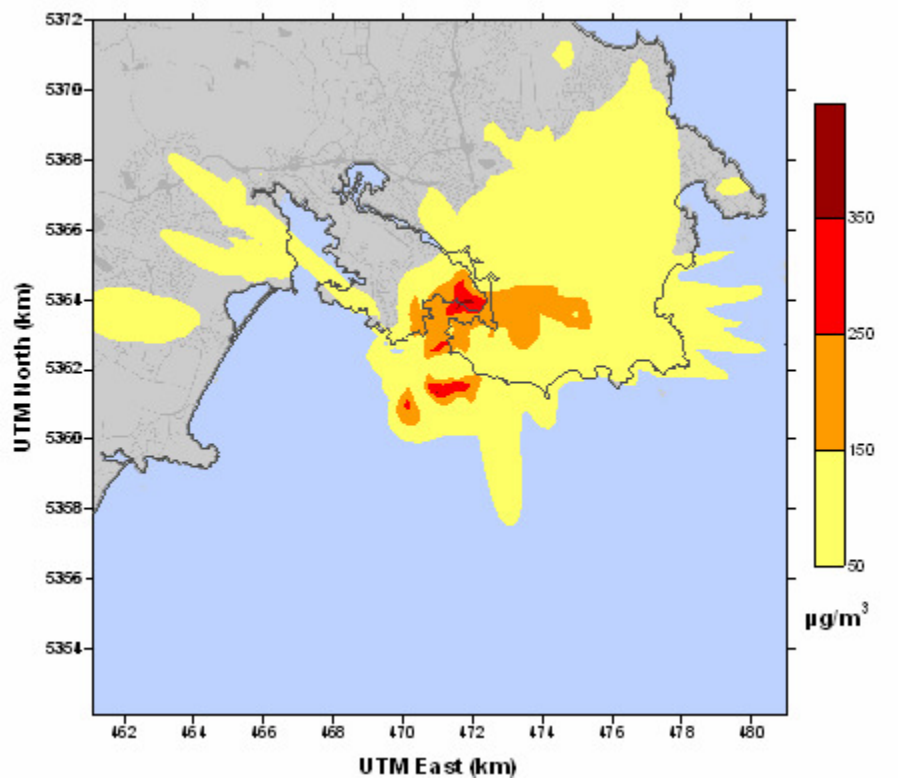



**Figure 55.** CALPUFF maximum estimated 1-hour concentrations of $NO_x$ ($\mu g/m^3$) due to cruise ship and ferry emissions (berth and transit).

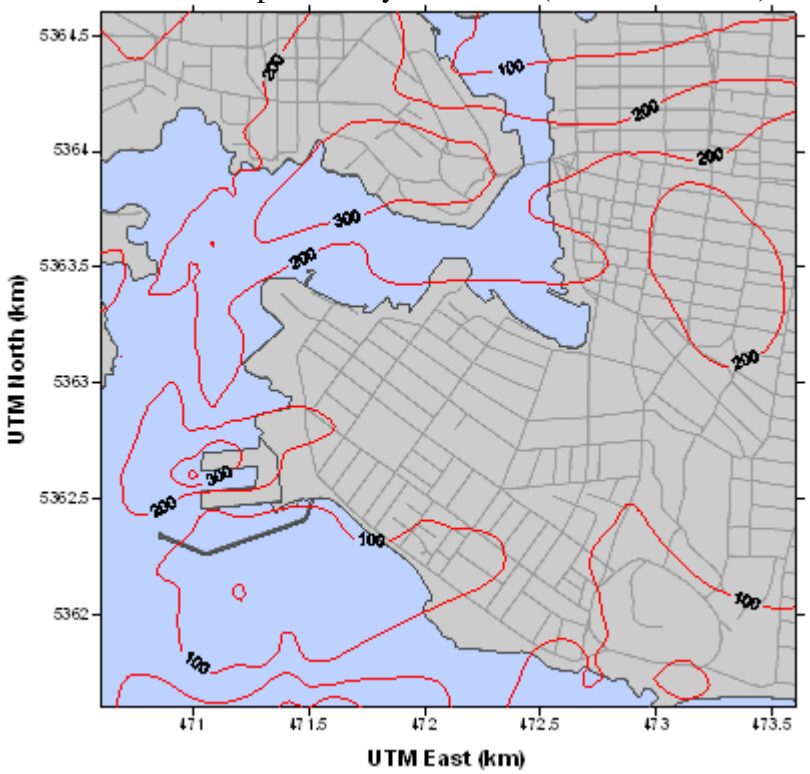



**Figure 56.** CALPUFF maximum estimated 1-hour concentrations of $NO_x$ ($\mu g/m^3$) due to cruise ship and ferry emissions (berth and transit).

*Maximum 24-Hour $NO_x$*

The maximum predicted 24-hour $NO_x$ concentration in the entire study domain was 63 µg/m$^3$. This maximum did not occur in the James Bay community, but offshore over the cruise ship berths at the Ogden Point terminal. Figure 55 provides isopleths of maximum predicted 24-hour average concentrations of $NO_x$ throughout the modelling domain.

The maximum predicted 24-hour $NO_x$ concentration in James Bay was 55 µg/m$^3$. A closer view of the maximum 24-hour NOx isopleths for the James Bay community is displayed in.

If 100% conversion of $NO_x$ to $NO_2$ is assumed, then the maximum 24-hour $NO_2$ concentration in the James Bay community is below the Canadian maximum acceptable guideline of 200 µg/m$^3$. There are no relevant CRD, BC or WHO objectives or guidelines for maximum 24-hour $NO_2$.

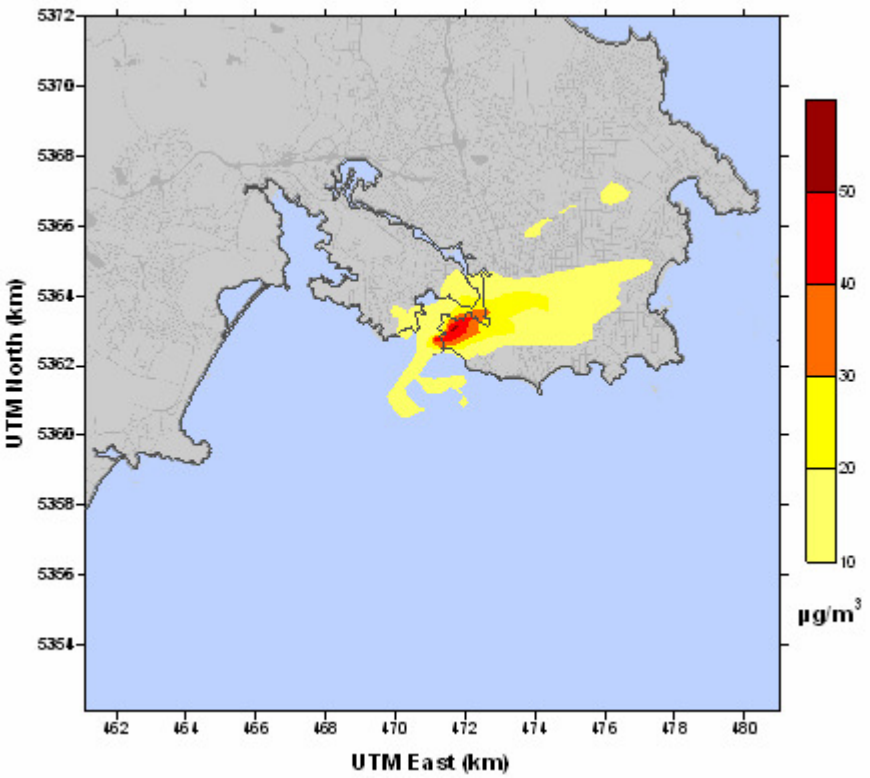



**Figure 57.** CALPUFF maximum estimated 24-hour concentrations of $NO_x$ (µg/m$^3$) due to cruise ship and ferry emissions (berth and transit).

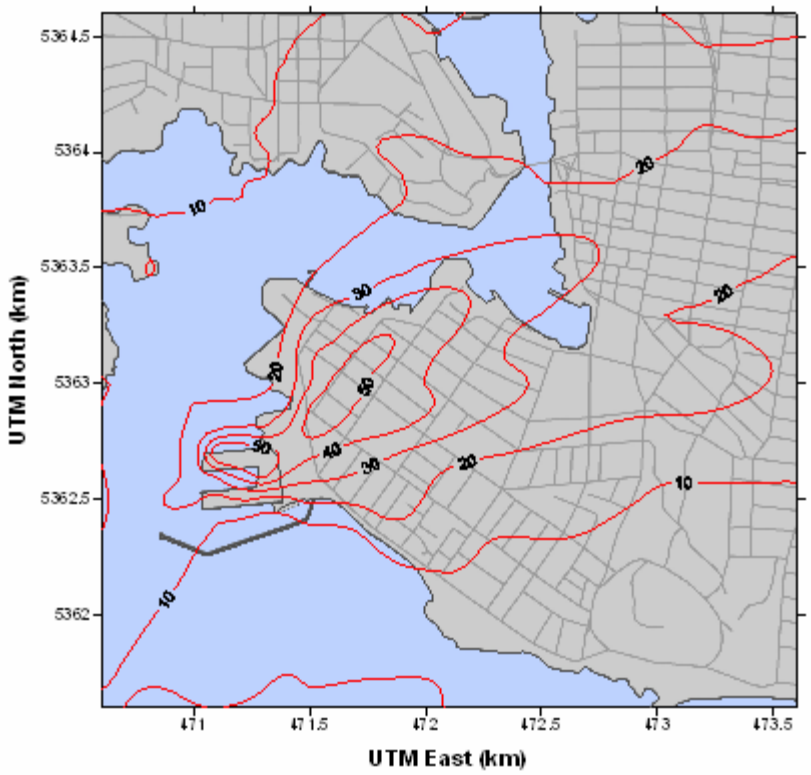



**Figure 58.** CALPUFF maximum estimated 24-hour concentrations of $NO_x$ ($\mu g/m^3$) due to cruise ship and ferry emissions (berth and transit).

*Period-average $NO_x$*

The average predicted ambient $NO_x$ concentrations, based on the entire 4656-hour modelling period, range from approximately 0 -3 $\mu g/m^3$. Isopleths of predicted average $NO_x$ concentrations are displayed in Figure 59.

If 100% conversion of $NO_x$ to $NO_2$ is assumed, then the predicted average $NO_2$ concentrations in the James Bay community are well below the Canadian maximum desirable objective of 60 $\mu g/m^3$, as well as the WHO guideline of 40 $\mu g/m^3$. There are no relevant CRD or BC guidelines or objectives for average concentrations of $NO_2$.

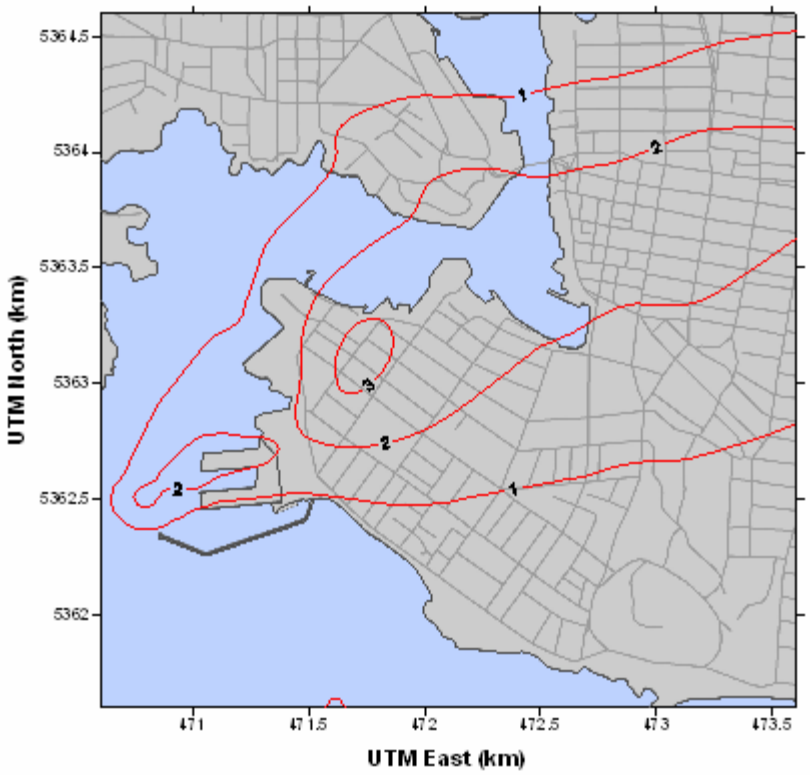



**Figure 59.** CALPUFF estimated average $NO_x$ concentrations.

### METHOD 2: AMBIENT RATIO (AR METHOD)

A second approach is to use the Ambient Ratio (AR) Method[62]. This method requires at least one year of representative ambient hourly NO and $NO_2$ monitoring data, which in the case of this study could be obtained from the BC Ministry of Environment monitoring site on Topaz Ave. A conversion ratio is developed by fitting an exponential function to the upper envelope of the scatter of plotted observed data. Although this approach is supported by the Ministry, a different approach was adopted for the James Bay study (see next section on Method 3). The AR method was explored in addition to the main approach adopted, as described below.

Exponential equations developed for converting predicted maximum1-hour and 24-hour $NO_x$ to $NO_2$ were determined by plotting the $NO_2/NO_x$ against $NO_x$ observations and fitting a line to the upper envelope of the scatter. This was performed separately for 1-hour (Figure 60) and 24-hour rolling averages (Figure 61) to obtain the following formulas:

[62] British Columbia Ministry of Environment. March 2008. Guidelines for Air Quality Dispersion Modelling in British Columbia. Available at: http://www.env.gov.bc.ca/air/airquality/.

**1-Hour $NO_2/NO_X = 63*NO_x^{-0.96}$**

**24-Hour $NO_2/NO_X = 10*NO_x^{-0.68}$**

Based on these equations, the maximum 1-hour and 24-hour $NO_2$ concentrations in the James Bay community were 81 µg/m$^3$ and 50 µg/m$^3$ respectively. These values are well below any CRD, BC, Canadian or WHO objectives or standards for either maximum 1-hour or maximum 24-hour concentrations of $NO_2$.

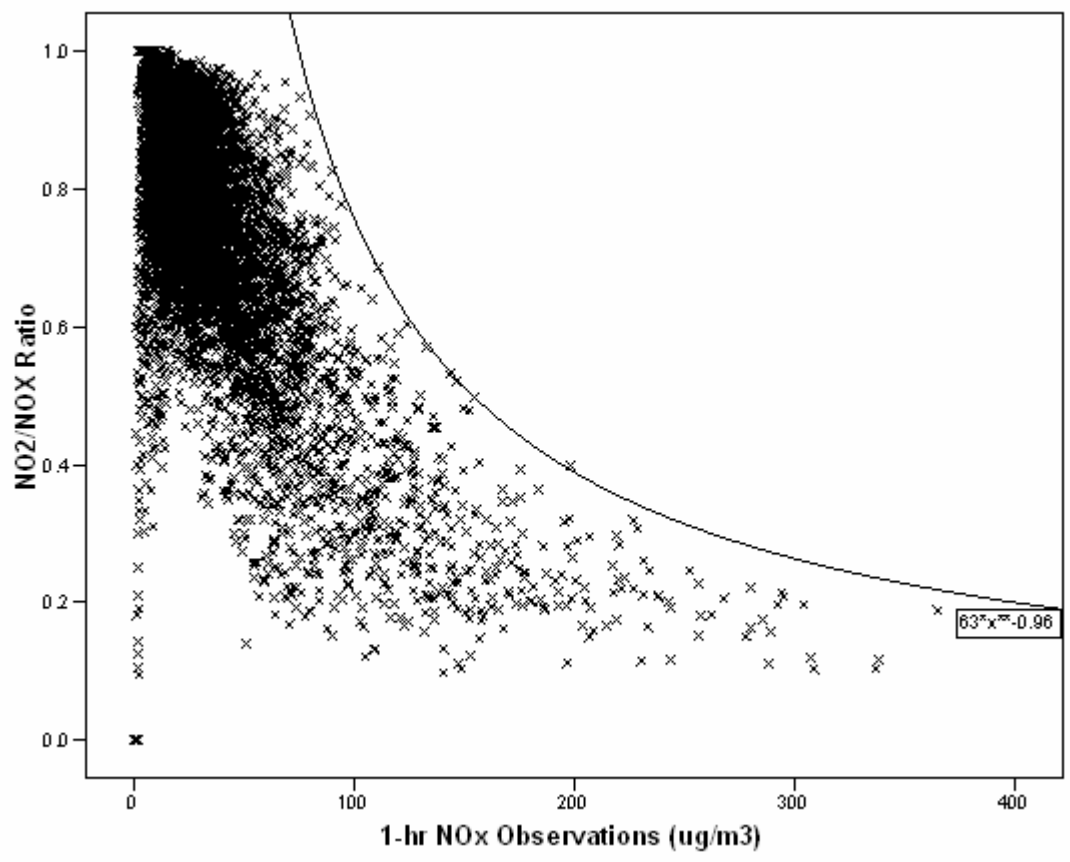



**Figure 60.** Dependence of $NO_2/NO_x$ ratio to 1-hour average $NO_x$ concentration.

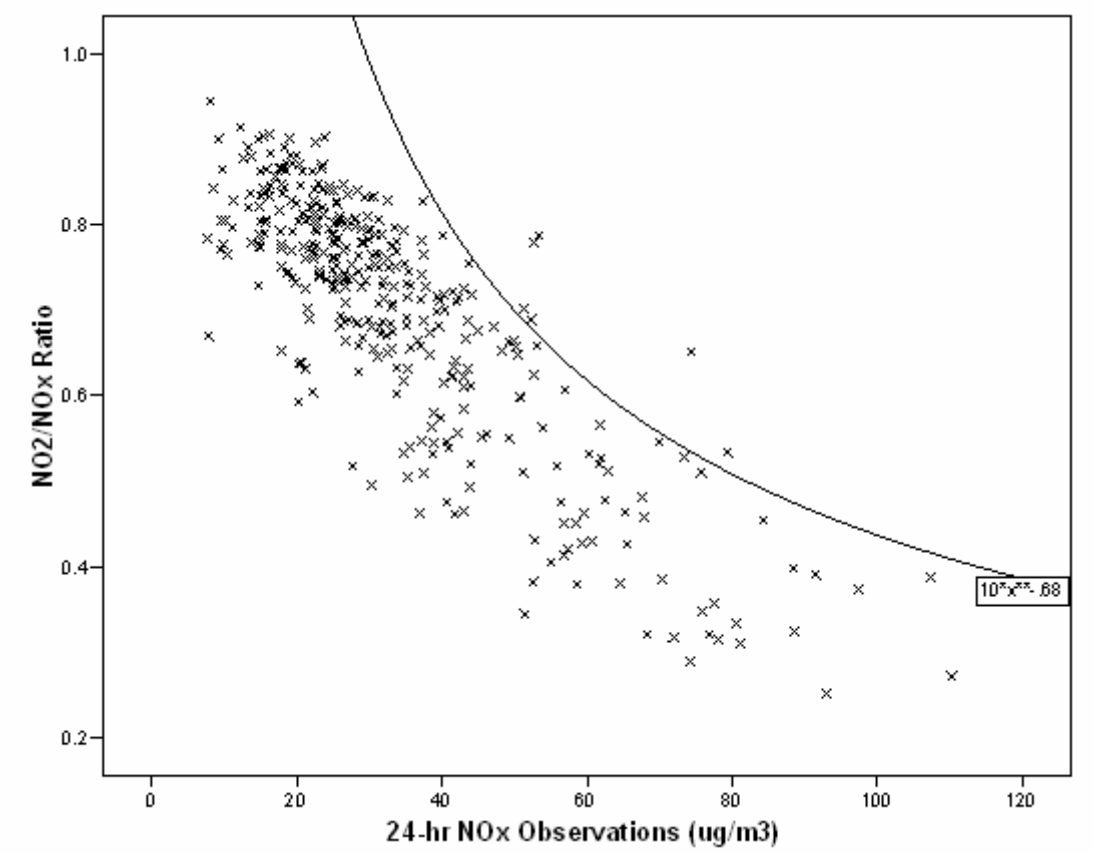



**Figure 61.** Dependence of $NO_2/NO_x$ ratio to 24-hour average $NO_x$ concentration.

### METHOD 3: DISTANCE FROM SOURCE (JANSSEN 1998)

Concentrations of nitrogen oxides ($NO_x$) estimated by the CALPUFF model were converted to nitrogen dioxide ($NO_2$) using a method based on distance from source.[63,64] In the atmosphere, concentrations of nitric oxide (NO) which are emitted from emissions sources (90-95% of emissions are comprised of NO, and only 5-10% $NO_2$) react with atmospheric ozone to form $NO_2$. This conversion occurs over time and with distance from the source. The approach adopted in this study attempts to provide a more realistic estimate of $NO_2$ concentrations than the other two methods described above by taking this distance factor into account.

The Janssen (1998) method developed $NO_x/NO_2$ ratios based on the study of measured stack plumes of Dutch power plants between 1975-1985. As part of this study, over 60

[63] Janssen et al. 1988. A classification of NO oxidation rates in power plant plumes based on atmospheric conditions. *Atmospheric Environment, 22*(1), 43-53.
[64] De Oliveira and Simonsen. 2003. Utilization of a method to estimate $NO_2$ concentrations from a $NO_x$ simulation for thermal power plants. *Air & Waste Management Association Conference and Exhibition* (96th : 2003: San Diego, California).

air flights measuring concentrations at distances from the source were carried out under widely varying atmospheric conditions. $NO_x$ to $NO_2$ correction factors were developed as a function of the distance to the source, according to the diurnal variability of meteorological parameters.

In the present study, the majority of emissions are produced by cruise ships at berth, and therefore distance from this source was used as a determining factor when choosing conversion rates. In order to perform the conversion analysis, a geographic information system (GIS) was used to create buffers around the cruise ship berth point locations. Figure 62 displays the varying buffer distances around this location. Estimated $NO_x$ concentrations from the combined emissions sources were then converted to $NO_2$ based upon which buffer distance from the source and the corresponding conversion rates displayed in Table 59.

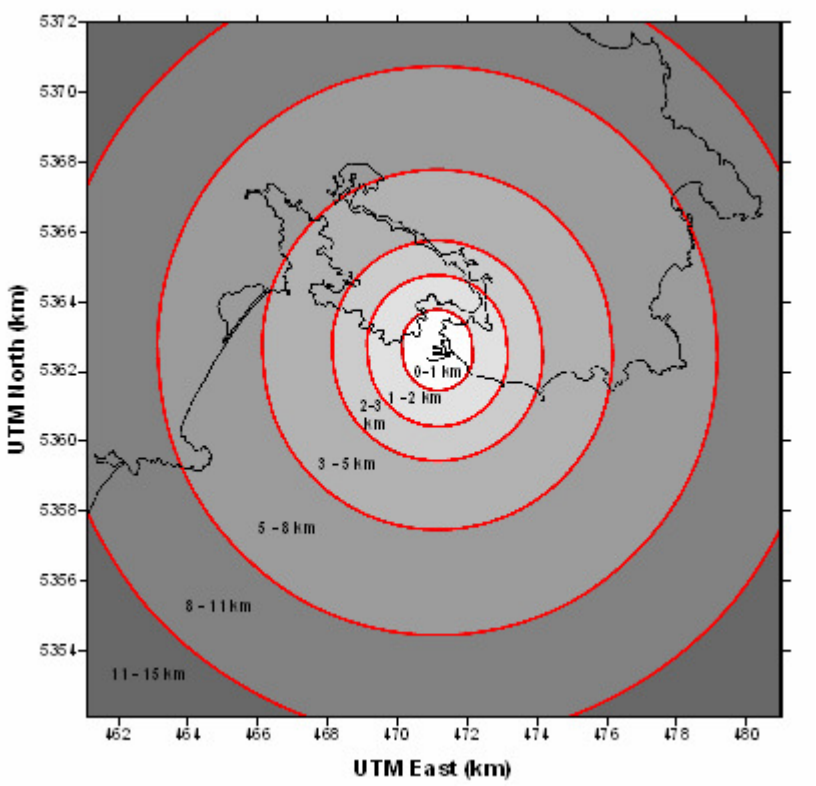



**Figure 62.** Varying buffer distances around cruise ship point sources.

**Table 59.** $NO_x/NO_2$ conversion rate based on distance from source.

| Distance from source (km) | Conversion Rate |
|---|---|
| 0-1 | .074 |
| 1-2 | 0.29 |
| 2-3 | 0.4 |
| 3-5 | 0.56 |
| 5-8 | 0.7 |
| 8-11 | 0.78 |
| 11-15 | 0.84 |
| >15 | 1 |

The conversion rates were applied to $NO_x$ concentrations by assuming 10% of $NO_x$ is emitted directly as $NO_2$, and adjusting the remainder based on the appropriate conversion rate with distance from source according to the following formula:

$$\mathbf{NO_2 = (0.10 * [NOx]) + (conv\_rate * 0.90 * [NOx])}$$

$NO_x$ values are expressed as $NO_2$ equivalent and therefore no mass adjustment is necessary in the equation.

# APPENDIX B – INFORMATION ON AIR QUALITY OBJECTIVES

## Canadian National Ambient Air Quality Objectives

The following information in regards to the Canadian National Ambient Air Quality Objectives (NAAQOs) is provided by Health Canada[65]:

NAAQOs prescribe targets for air quality, measured at the relevant receptor (persons, plants, animals, material). These targets may incorporate some element of cost-benefit-risk, reflecting a philosophy of environmental health protection and long-term risk reduction while recognizing technological and economical limits. Consequently, the resulting objectives may be set above a level at which no effects are observed. The objectives are established to provide background information, a uniform scale for assessing the quality of air in all parts of Canada, and guidance to governments for making risk management decisions, such as planning control strategies and setting local standards.

Three ranges of air quality are prescribed – "desirable," "acceptable," and "tolerable." The numerical values for the highest levels of contaminant in each range are based on the following qualitative definitions:

- The **maximum desirable level** is the long-term goal for air quality and provides a basis for an anti-degradation policy for unpolluted parts of the country and for the continuing development of pollution control technology.
- The **maximum acceptable level** is intended to provide adequate protection against effects on soil, water, vegetation, materials, animals, visibility, and personal comfort and well-being.
- The **maximum tolerable level** denotes time-based concentrations of air contaminants beyond which, owing to a diminishing margin of safety, appropriate action is requires without delay to protect the health of the general population.

## British Columbia Air Quality Guidelines and Objectives

The BC Level A, Level B and Level C objectives and guidelines correspond to the three Canadian National levels described above. No definitions of Level A, B and C exist, however, they can be inferred by the general correspondence to the National maximum desirable, acceptable and tolerable levels.

[65] http://www.hc-sc.gc.ca/ewh-semt/pubs/air/naaqo-onqaa/carbon-monoxyde-carbone/index_e.html

**World Health Organization (WHO) Air Quality Guidelines[66]**

Air quality objectives established by WHO are designed 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.

The WHO state in their report that their air quality guidelines are intended for worldwide use but have been developed to support actions to achieve air quality that protects public health in different contexts (pg.7). Air quality standards, on the other hand, are set by each country to protect the public health of their citizens and as such are an important component of national risk management and environmental policies. National standards will vary according to the approach adopted for balancing health risks, technological feasibility, economic considerations and various other political and social factors, which in turn will depend on, among other things, the level of development and national capability in air quality management.

**Capital Regional District (CRD) Air Quality Guidelines[67]**

CRD Air quality guidelines were developed in 2004 for the purposes of assessing annual monitoring data and reporting to the Environment Committee Board. They should not be considered regulatory standards, such as the National Ambient Air Quality Objectives or British Columbia Air Quality Guidelines and Objectives.

[66] World Health Organization (WHO). Air quality guidelines – global update 2005. Available: http://www.who.int/phe/health_topics/outdoorair_aqg/en/index.html

[67] http://www.crd.bc.ca/reports/environmentcommittee_/2007_/11november_/28nov07item06/28Nov07Item06.pdf.

# APPENDIX C - UNDERSTANDING FREQUENCY DISTRIBUTIONS

Frequency distributions in this report are presented in the form of percentiles. A percentile is the value of a variable below which a certain percent of the observations fall. For instance, the concentration value corresponding to the maximum 100$^{th}$ percentile would be the maximum concentration recorded, below which all remaining concentrations fall. In the example table provided below, the maximum 1-hour $SO_2$ concentration recorded out of the full 4656-hour modelling period was 162.75 µg/m$^3$. Observed concentrations for all other 1-hour periods will be less than this value.

To further illustrate, the 99$^{th}$ percentile (64.81 µg/m$^3$) is the concentration value below which 99% of all other 1-hour periods fall, the 95$^{th}$ percentile (24.65 µg/m$^3$) is the concentration below which 95% of all other 1-hour periods fall, etc. In the example provided here, the table displays that background concentrations (13 µg/m$^3$) are generally experienced in 80% of the 1-hour periods (i.e. concentrations above background are detected approximately 20% of the 1-hour periods).

**Frequency distribution of predicted 1-hour $SO_2$ concentrations in James Bay.**

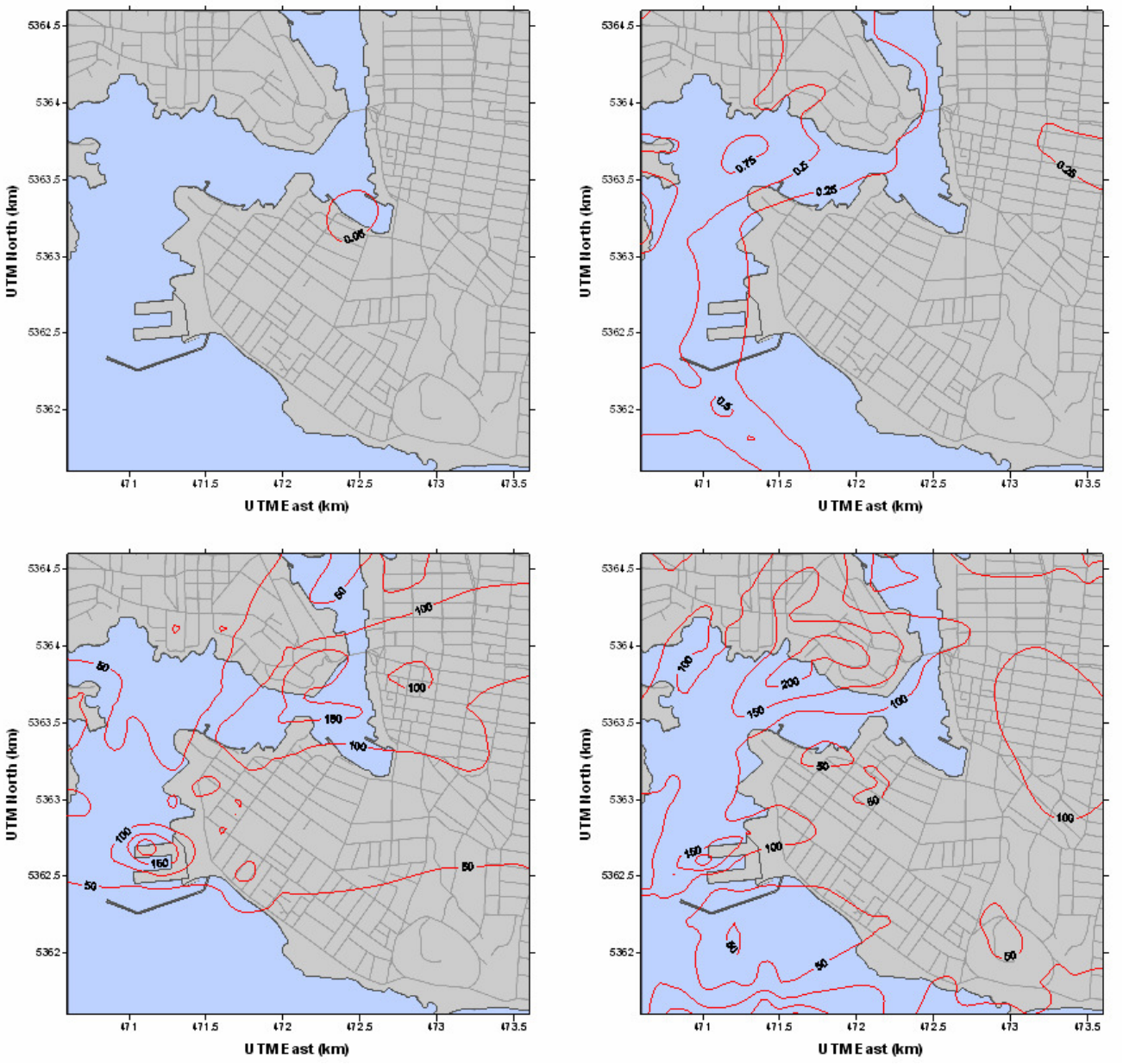
| | $SO_2$ (µg/m$^3$) | | | |
|---|---|---|---|---|
| **Percentile** | **Min** | **Max** | **Average (n=25)** | **Std. Dev** |
| **100$^{th}$** | 79.59 | 162.75 | 111.25 | 20.35 |
| **99$^{th}$** | 21.93 | 64.81 | 39.96 | 14.23 |
| **98$^{th}$** | 17.88 | 50.69 | 29.20 | 9.72 |
| **97$^{th}$** | 16.21 | 38.03 | 23.91 | 6.77 |
| **95$^{th}$** | 14.58 | 24.65 | 17.86 | 3.04 |
| **90$^{th}$** | 13.03 | 14.44 | 13.51 | 0.46 |
| **80$^{th}$** | 13.00 | 13.02 | 13.01 | 0.00 |
| **75$^{th}$** | 13.00 | 13.01 | 13.00 | 0.00 |
| **50$^{th}$** | 13.00 | 13.00 | 13.00 | 0.00 |

# APPENDIX D – SOURCE CONTRIBUTION MAPS

This section provides individual maps for each source included in the model. The four source types simulated were: (1) ferries – berth; (2) ferries –transit; (3) cruise ships – berth; and (4) cruise ships – transit. These maps allow the individual contribution from each source type to be compared to the overall concentration levels estimated in previous results throughout the report. Note that the following maps do not include the addition of background concentrations – they rather allow the relative contributions from each source to be compared for each pollutant ($SO_2$, $NO_2$, $PM_{10}$, and $PM_{2.5}$) and time period (1-hour, 24-hour and average) to be assessed.

A. Ferry – berth

B. Ferry – transit



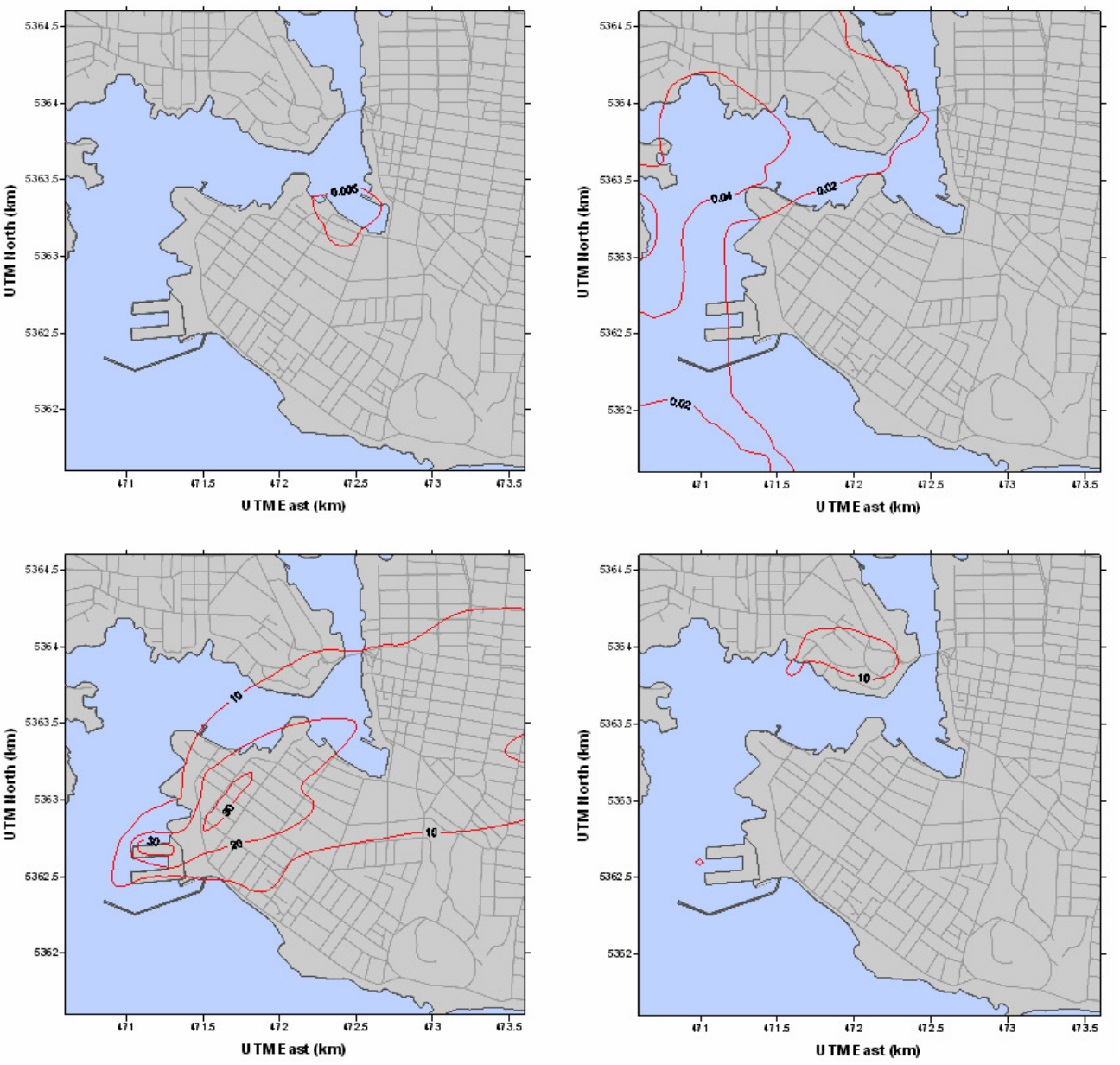

C. Cruise – berth

D. Cruise - transit

**Figure 63.** Source contributions to estimated maximum 1-hour $SO_2$ concentrations.

A. Ferry – berth

B. Ferry – transit



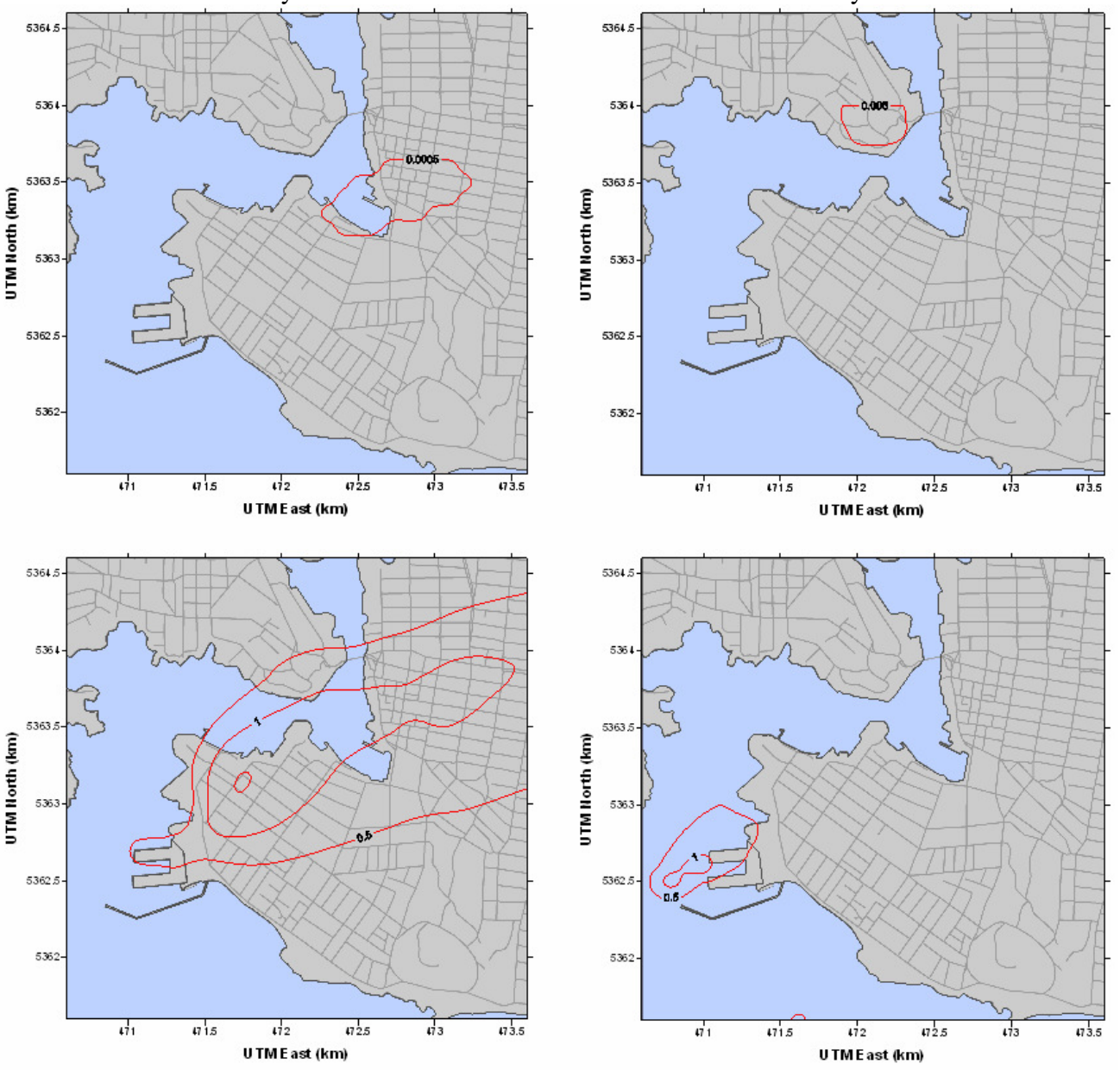

C. Cruise – berth

D. Cruise - transit

**Figure 64.** Source contributions to estimated maximum 24-hour $SO_2$ concentrations.

A. Ferry – berth

B. Ferry – transit




C. Cruise – berth

D. Cruise - transit

**Figure 65.** Source contributions to estimated average $SO_2$ concentrations.

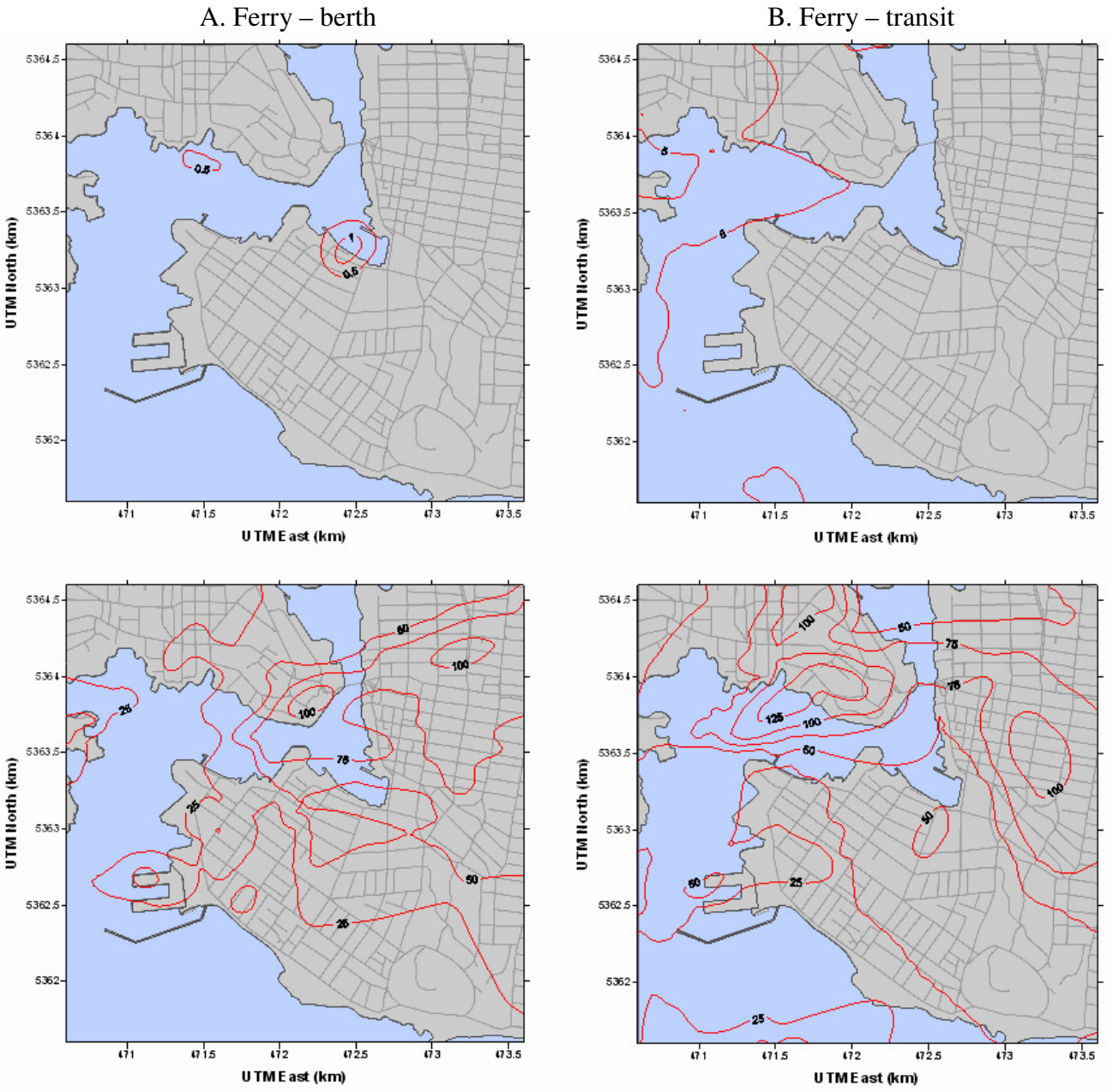



**Figure 66.** Source contributions to estimated maximum 1-hour $NO_2$ concentrations.

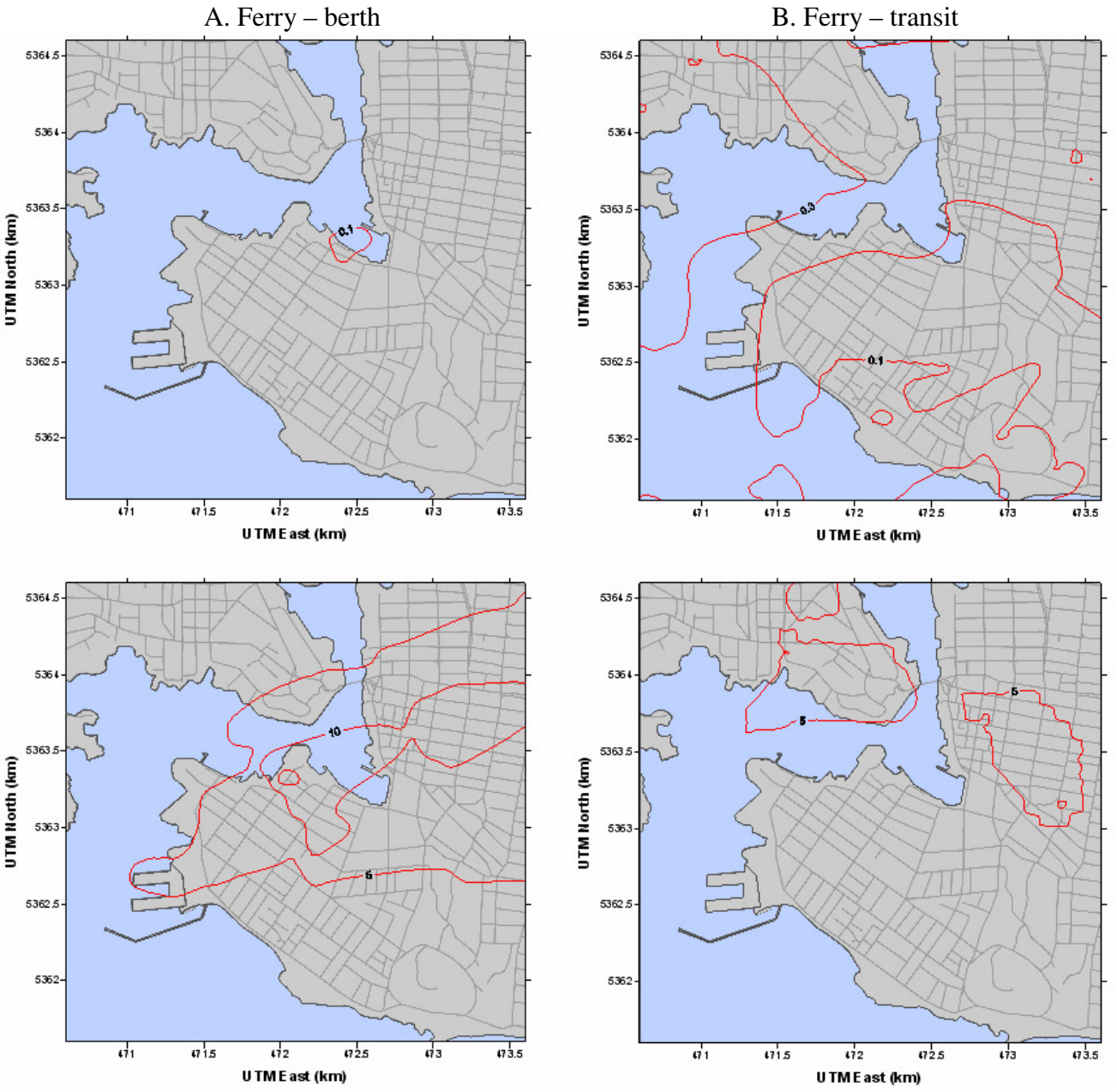
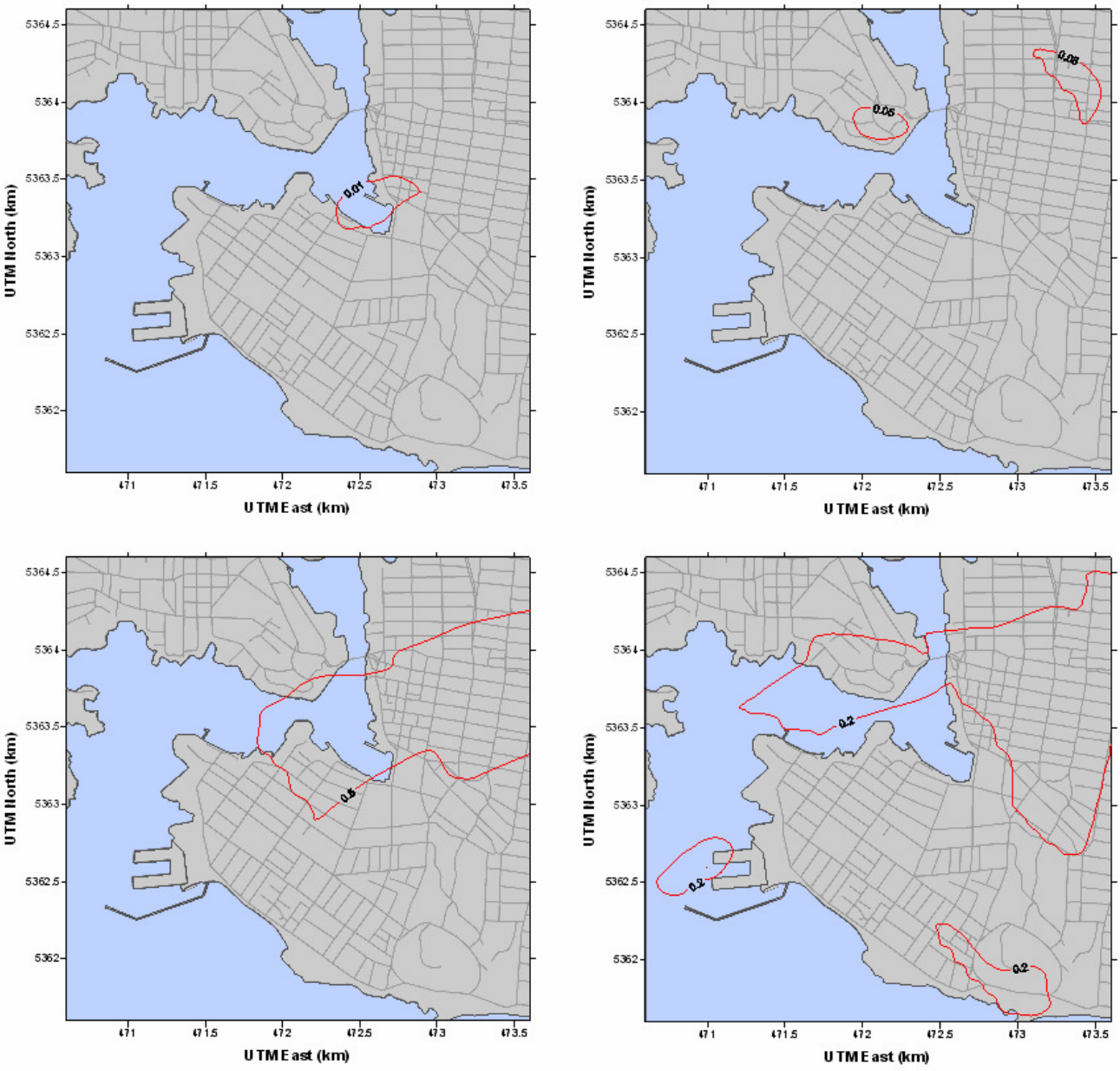



**Figure 67.** Source contributions to estimated maximum 24-hour $NO_2$ concentrations.

A. Ferry – berth

B. Ferry – transit



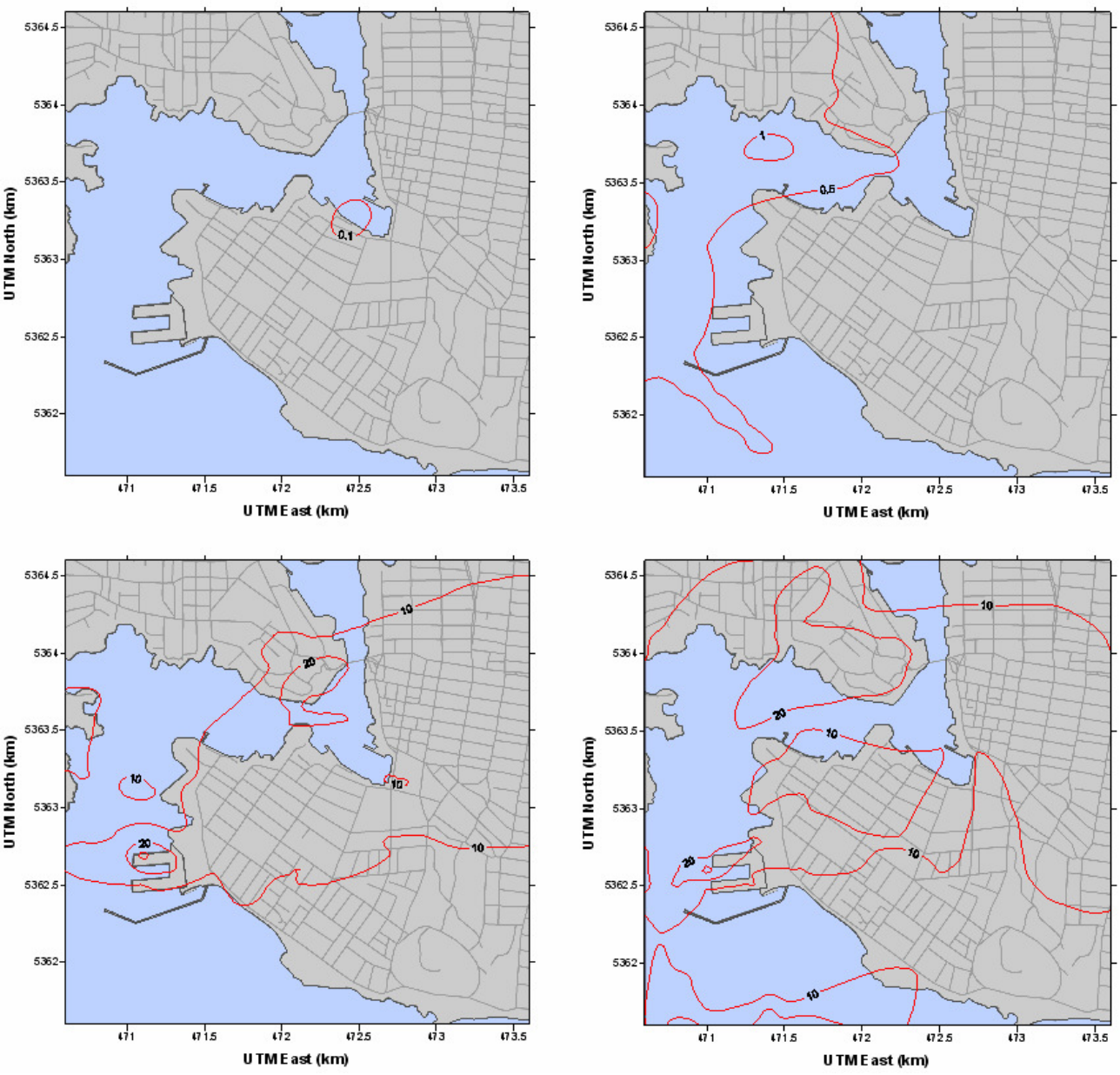

C. Cruise – berth

D. Cruise - transit

**Figure 68.** Source contributions to estimated average $NO_2$ concentrations.

A. Ferry – berth

B. Ferry – transit




C. Cruise – berth

D. Cruise - transit

**Figure 69.** Source contributions to estimated maximum 1-hour $PM_{10}$ concentrations.

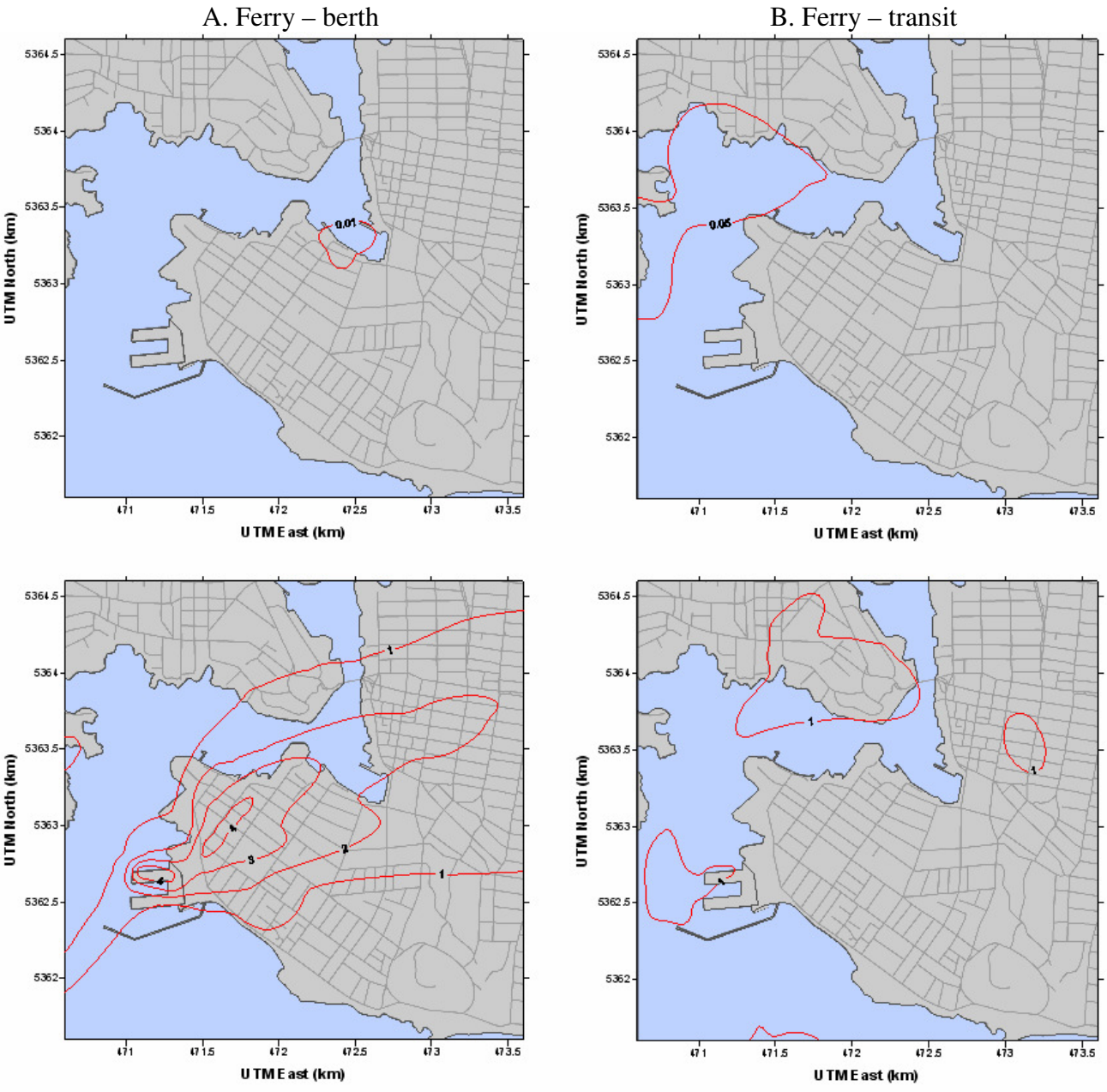



**Figure 70.** Source contributions to estimated maximum 24-hour $PM_{10}$ concentrations.

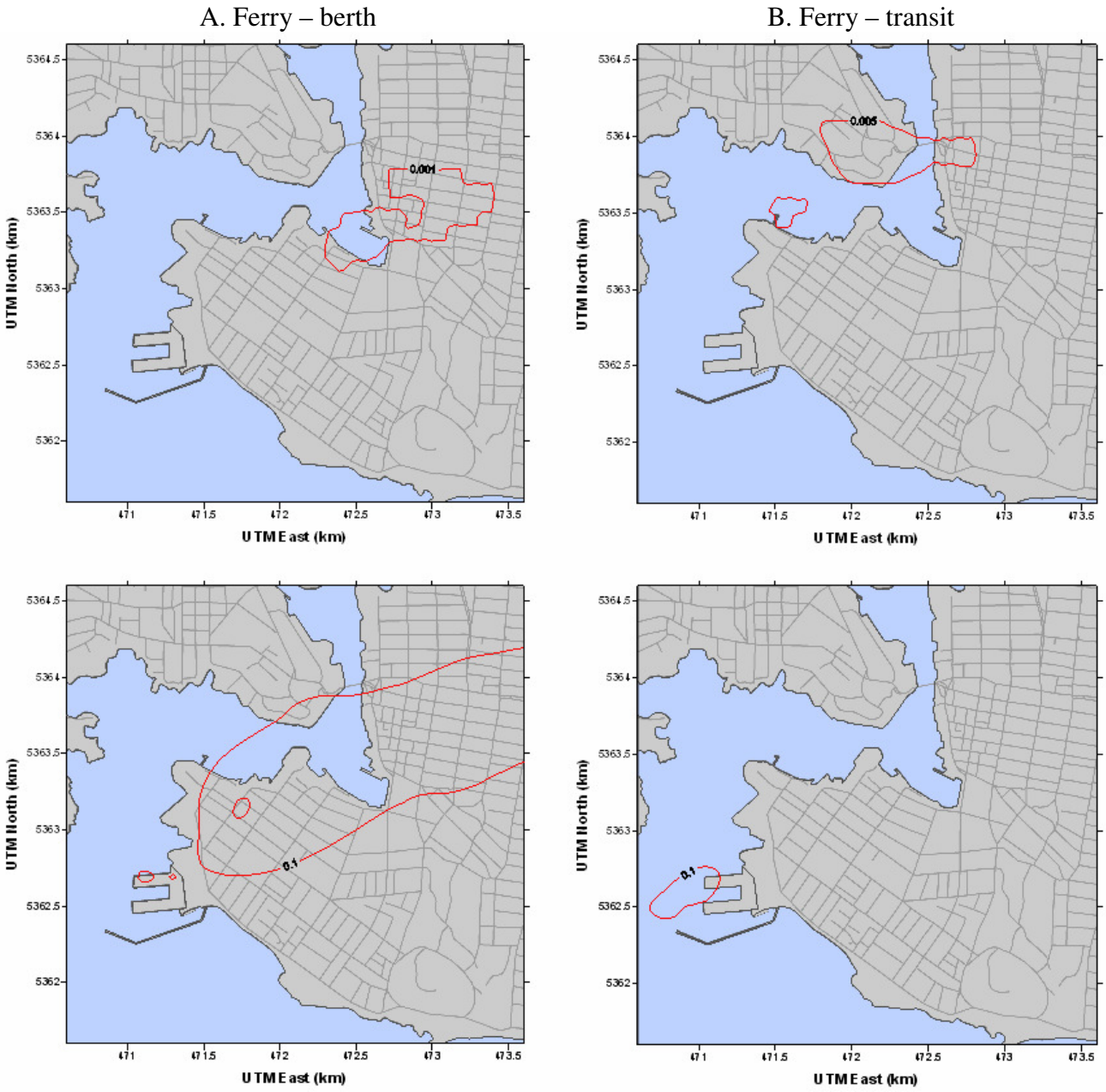



**Figure 71.** Source contributions to estimated average $PM_{10}$ concentrations.

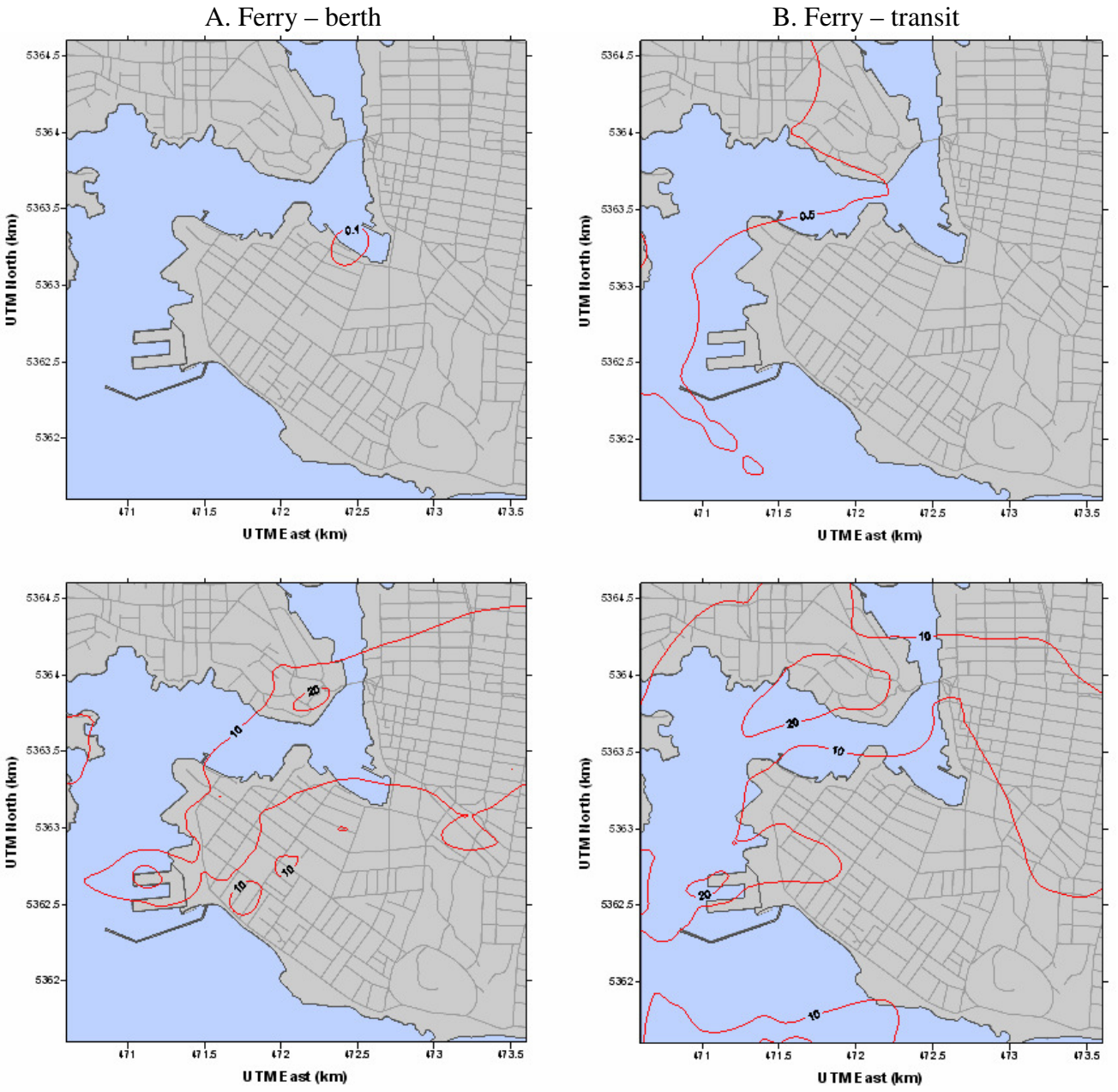



**Figure 72.** Source contributions to estimated maximum 1-hour $PM_{2.5}$ concentrations.

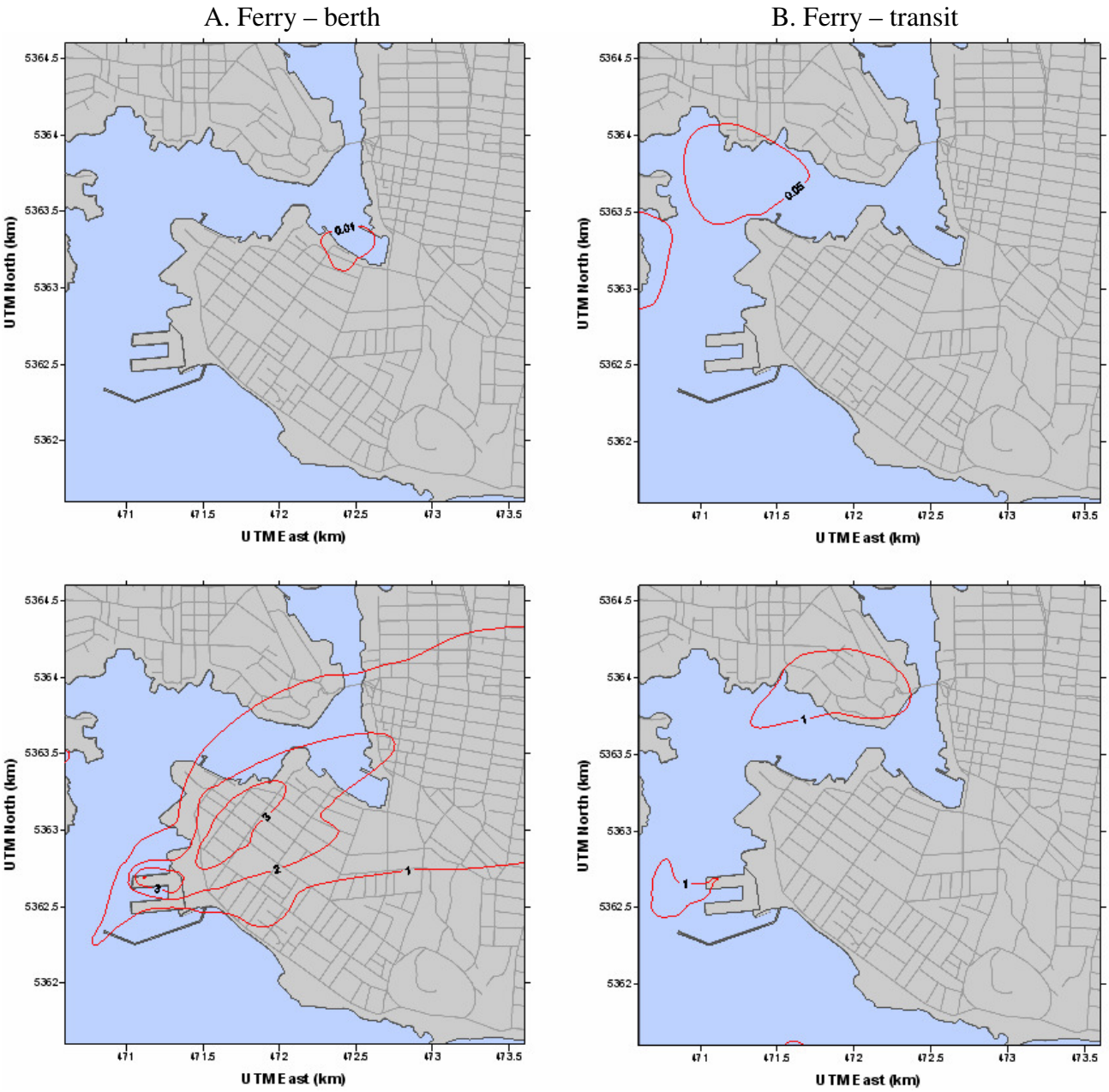



**Figure 73.** Source contributions to estimated maximum 24-hour $PM_{2.5}$ concentrations.

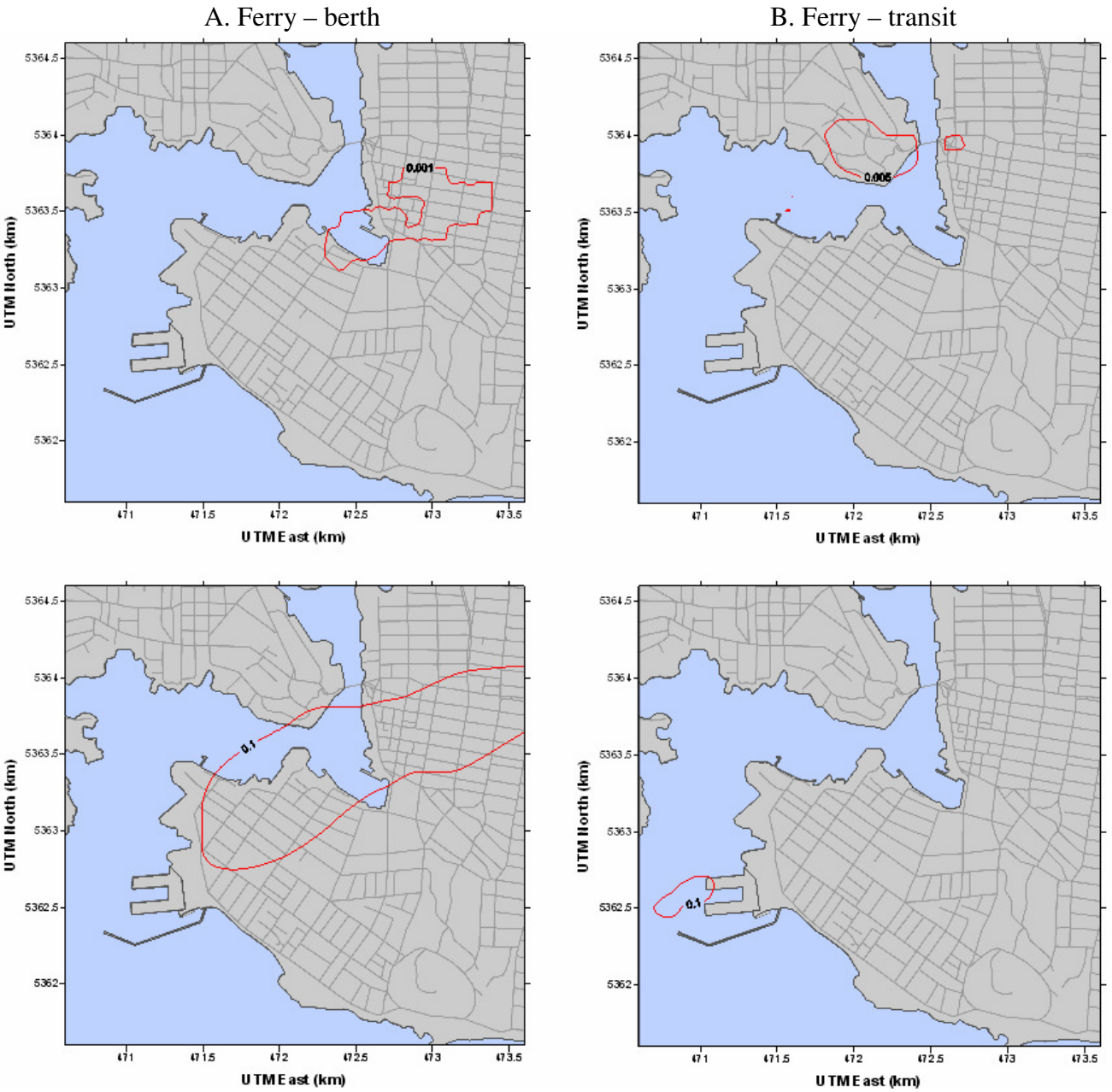



**Figure 74.** Source contributions to estimated average $PM_{2.5}$ concentrations.

# APPENDIX E – CRUISE SHIP SCHEDULE 2007

| | DATE | VESSEL | FROM | ETA | ETD | TO | # PASS | CRUISE LINE | LGTH |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 24-Apr Tue | OOSTERDAM | San Diego | 14:00 | 17:00 | Drydock | 1,840 | Holland America Line | 951 ' |
| 2 | 25-Apr Wed | MERCURY | Vancouver | 7:00 | 14:00 | San Francisco | 1,870 | Celebrity Cruise Line | 866 ' |
| 3 | 3-May Thu | MERCURY | Seattle | 7:00 | 17:00 | Vancouver | 1,870 | Celebrity Cruise Line | 866 ' |
| 4 | 3-May Thu | OOSTERDAM | Vancouver | 8:00 | 17:00 | Astoria | 1,840 | Holland America Line | 951 ' |
| 5 | 3-May Thu | VISION OF THE SEAS | San Francisco | 10:00 | 18:00 | Vancouver | 2,000 | Royal Caribbean Int'l | 915 ' |
| 6 | 9-May Wed | INFINITY | San Francisco | 8:00 | 17:00 | Nanaimo | 2,000 | Celebrity Cruise Line | 965 ' |
| 7 | 10-May Thu | NORWEGIAN PEARL | San Francisco | 7:00 | 16:00 | Vancouver | 2,200 | Norwegian Cruise Line | 971 ' |
| 8 | 11-May Fri | SERENADE OF THE SEAS | Nanaimo | 7:00 | 18:00 | Vancouver | 2,500 | Royal Caribbean Int'l | 962 ' |
| 9 | 11-May Fri | DIAMOND PRINCESS | Astoria | 8:00 | 17:00 | Vancouver | 2,600 | Princess Cruise Lines | 951 ' |
| 10 | 11-May Fri | ZUIDERDAM | San Diego | 8:00 | 23:59 | Vancouver | 1,840 | Holland America Line | 951 ' |
| 11 | 11-May Fri | OOSTERDAM | Ketchikan | 18:00 | 23:59 | Seattle | 1,840 | Holland America Line | 951 ' |
| 12 | 11-May Fri | GOLDEN PRINCESS | Ketchikan | 19:00 | 23:59 | Seattle | 2,600 | Princess Cruise Lines | 951 ' |
| 13 | 12-May Sat | SUN PRINCESS | Skagway | 17:00 | 23:59 | Seattle | 1,950 | Princess Cruise Lines | 856 ' |
| 14 | 17-May Thu | RADIANCE OF THE SEAS | Astoria | 7:30 | 17:00 | Vancouver | 2,500 | Royal Caribbean Int'l | 962 ' |
| 15 | 17-May Thu | SUMMIT | Seattle | 8:00 | 17:00 | Ketchikan | 2,000 | Celebrity Cruise Line | 965 ' |
| 16 | 18-May Fri | SAPPHIRE PRINCESS | Los Angeles | 8:00 | 17:00 | Vancouver | 2,600 | Princess Cruise Lines | 951 ' |
| 17 | 18-May Fri | OOSTERDAM | Ketchikan | 18:00 | 23:59 | Seattle | 1,840 | Holland America Line | 951 ' |
| 18 | 18-May Fri | GOLDEN PRINCESS | Ketchikan | 19:00 | 23:59 | Seattle | 2,600 | Princess Cruise Lines | 951 ' |
| 19 | 19-May Sat | DAWN PRINCESS | Ketchikan | 7:00 | 14:00 | San Francisco | 1,950 | Princess Cruise Lines | 856 ' |
| 20 | 19-May Sat | SUN PRINCESS | Skagway | 17:00 | 23:59 | Seattle | 1,950 | Princess Cruise Lines | 856 ' |
| 21 | 19-May Sat | NOORDAM | Ketchikan | 18:00 | 23:59 | Seattle | 1,918 | Holland America Line | 935 ' |
| 22 | 19-May Sat | NORWEGIAN PEARL | Ketchikan | 18:00 | 23:59 | Seattle | 2,200 | Norwegian Cruise Line | 971 ' |

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|---|---|---|---|---|---|---|---|
| 23 | 24-May Thu | AMSTERDAM | Ketchikan | 18:00 | 23:59 Seattle | 1,380 Holland America Line | 780 ' |
| 24 | 25-May Fri | OOSTERDAM | Ketchikan | 18:00 | 23:59 Seattle | 1,840 Holland America Line | 951 ' |
| 25 | 25-May Fri | GOLDEN PRINCESS | Ketchikan | 19:00 | 23:59 Seattle | 2,600 Princess Cruise Lines | 951 ' |
| 26 | 26-May Sat | SUN PRINCESS | Skagway | 17:00 | 23:59 Seattle | 1,950 Princess Cruise Lines | 856 ' |
| 27 | 26-May Sat | NORWEGIAN PEARL | Ketchikan | 18:00 | 23:59 Seattle | 2,200 Norwegian Cruise Line | 971 ' |
| 28 | 26-May Sat | NOORDAM | Ketchikan | 18:00 | 23:59 Seattle | 1,918 Holland America Line | 935 ' |
| 29 | 29-May Tue | DAWN PRINCESS | Skagway | 7:00 | 14:00 San Francisco | 1,950 Princess Cruise Lines | 856 ' |
| 30 | 31-May Thu | AMSTERDAM | Ketchikan | 18:00 | 23:59 Seattle | 1,380 Holland America Line | 780 ' |
| 31 | 1-Jun Fri | OOSTERDAM | Ketchikan | 18:00 | 23:59 Seattle | 1,840 Holland America Line | 951 ' |
| 32 | 1-Jun Fri | GOLDEN PRINCESS | Ketchikan | 19:00 | 23:59 Seattle | 2,600 Princess Cruise Lines | 951 ' |
| 33 | 2-Jun Sat | SUN PRINCESS | Skagway | 17:00 | 23:59 Seattle | 1,950 Princess Cruise Lines | 856 ' |
| 34 | 2-Jun Sat | NOORDAM | Ketchikan | 18:00 | 23:59 Seattle | 1,918 Holland America Line | 935 ' |
| 35 | 2-Jun Sat | NORWEGIAN PEARL | Ketchikan | 18:00 | 23:59 Seattle | 2,200 Norwegian Cruise Line | 971 ' |
| 36 | 7-Jun Thu | AMSTERDAM | Ketchikan | 18:00 | 23:59 Seattle | 1,380 Holland America Line | 780 ' |
| 37 | 8-Jun Fri | DAWN PRINCESS | Juneau | 7:00 | 14:00 San Francisco | 1,950 Princess Cruise Lines | 856 ' |
| 38 | 8-Jun Fri | OOSTERDAM | Ketchikan | 18:00 | 23:59 Seattle | 1,840 Holland America Line | 951 ' |
| 39 | 8-Jun Fri | GOLDEN PRINCESS | Ketchikan | 19:00 | 23:59 Seattle | 2,600 Princess Cruise Lines | 951 ' |
| 40 | 9-Jun Sat | SUN PRINCESS | Skagway | 17:00 | 23:59 Seattle | 1,950 Princess Cruise Lines | 856 ' |
| 41 | 9-Jun Sat | NOORDAM | Ketchikan | 18:00 | 23:59 Seattle | 1,918 Holland America Line | 935 ' |
| 42 | 9-Jun Sat | NORWEGIAN PEARL | Ketchikan | 18:00 | 23:59 Seattle | 2,200 Norwegian Cruise Line | 971 ' |
| 43 | 14-Jun Thu | AMSTERDAM | Ketchikan | 18:00 | 23:59 Seattle | 1,380 Holland America Line | 780 ' |
| 44 | 15-Jun Fri | OOSTERDAM | Ketchikan | 18:00 | 23:59 Seattle | 1,840 Holland America Line | 951 ' |
| 45 | 15-Jun Fri | GOLDEN PRINCESS | Ketchikan | 19:00 | 23:59 Seattle | 2,600 Princess Cruise Lines | 951 ' |
| 46 | 16-Jun Sat | SUN PRINCESS | Skagway | 17:00 | 23:59 Seattle | 1,950 Princess Cruise Lines | 856 ' |
| 47 | 16-Jun Sat | NOORDAM | Ketchikan | 18:00 | 23:59 Seattle | 1,918 Holland America Line | 935 ' |
| 48 | 16-Jun Sat | NORWEGIAN PEARL | Ketchikan | 18:00 | 23:59 Seattle | 2,200 Norwegian Cruise Line | 971 ' |
| 49 | 18-Jun Mon | DAWN PRINCESS | Skagway | 7:00 | 14:00 San Francisco | 1,950 Princess Cruise Lines | 856 ' |

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|---|---|---|---|---|---|---|---|
| 50 | 21-Jun Thu | AMSTERDAM | Ketchikan | 18:00 | 23:59 Seattle | 1,380 Holland America Line | 780 ' |
| 51 | 22-Jun Fri | OOSTERDAM | Ketchikan | 18:00 | 23:59 Seattle | 1,840 Holland America Line | 951 ' |
| 52 | 22-Jun Fri | GOLDEN PRINCESS | Ketchikan | 19:00 | 23:59 Seattle | 2,600 Princess Cruise Lines | 951 ' |
| 53 | 23-Jun Sat | SUN PRINCESS | Skagway | 17:00 | 23:59 Seattle | 1,950 Princess Cruise Lines | 856 ' |
| 54 | 23-Jun Sat | NOORDAM | Ketchikan | 18:00 | 23:59 Seattle | 1,918 Holland America Line | 935 ' |
| 55 | 23-Jun Sat | NORWEGIAN PEARL | Ketchikan | 18:00 | 23:59 Seattle | 2,200 Norwegian Cruise Line | 971 ' |
| 56 | 28-Jun Thu | DAWN PRINCESS | Skagway | 7:00 | 14:00 San Francisco | 1,950 Princess Cruise Lines | 856 ' |
| 57 | 28-Jun Thu | AMSTERDAM | Ketchikan | 18:00 | 23:59 Seattle | 1,380 Holland America Line | 780 ' |
| 58 | 29-Jun Fri | OOSTERDAM | Ketchikan | 18:00 | 23:59 Seattle | 1,840 Holland America Line | 951 ' |
| 59 | 29-Jun Fri | GOLDEN PRINCESS | Ketchikan | 19:00 | 23:59 Seattle | 2,600 Princess Cruise Lines | 951 ' |
| 60 | 30-Jun Sat | SUN PRINCESS | Skagway | 17:00 | 23:59 Seattle | 1,950 Princess Cruise Lines | 856 ' |
| 61 | 30-Jun Sat | NORWEGIAN PEARL | Ketchikan | 18:00 | 23:59 Seattle | 2,200 Norwegian Cruise Line | 971 ' |
| 62 | 30-Jun Sat | NOORDAM | Ketchikan | 18:00 | 23:59 Seattle | 1,918 Holland America Line | 935 ' |
| 63 | 2-Jul Mon | DAWN PRINCESS | San Francisco | 12:00 | 19:00 Sitka | 1,950 Princess Cruise Lines | 856 ' |
| 64 | 5-Jul Thu | AMSTERDAM | Ketchikan | 18:00 | 23:59 Seattle | 1,380 Holland America Line | 780 ' |
| 65 | 6-Jul Fri | OOSTERDAM | Ketchikan | 18:00 | 23:59 Seattle | 1,840 Holland America Line | 951 ' |
| 66 | 6-Jul Fri | GOLDEN PRINCESS | Ketchikan | 19:00 | 23:59 Seattle | 2,600 Princess Cruise Lines | 951 ' |
| 67 | 7-Jul Sat | SUN PRINCESS | Skagway | 17:00 | 23:59 Seattle | 1,950 Princess Cruise Lines | 856 ' |
| 68 | 7-Jul Sat | NORWEGIAN PEARL | Ketchikan | 18:00 | 23:59 Seattle | 2,200 Norwegian Cruise Line | 971 ' |
| 69 | 7-Jul Sat | NOORDAM | Ketchikan | 18:00 | 23:59 Seattle | 1,918 Holland America Line | 935 ' |
| 70 | 12-Jul Thu | AMSTERDAM | Ketchikan | 18:00 | 23:59 Seattle | 1,380 Holland America Line | 780 ' |
| 71 | 13-Jul Fri | OOSTERDAM | Ketchikan | 18:00 | 23:59 Seattle | 1,840 Holland America Line | 951 ' |
| 72 | 13-Jul Fri | GOLDEN PRINCESS | Ketchikan | 19:00 | 23:59 Seattle | 2,600 Princess Cruise Lines | 951 ' |
| 73 | 14-Jul Sat | SUN PRINCESS | Skagway | 17:00 | 23:59 Seattle | 1,950 Princess Cruise Lines | 856 ' |
| 74 | 14-Jul Sat | NOORDAM | Ketchikan | 18:00 | 23:59 Seattle | 1,918 Holland America Line | 935 ' |
| 75 | 14-Jul Sat | NORWEGIAN PEARL | Ketchikan | 18:00 | 23:59 Seattle | 2,200 Norwegian Cruise Line | 971 ' |
| 76 | 18-Jul Wed | DAWN PRINCESS | Skagway | 7:00 | 14:00 San Francisco | 1,950 Princess Cruise Lines | 856 ' |
| 77 | 19-Jul Thu | AMSTERDAM | Ketchikan | 18:00 | 23:59 Seattle | 1,380 Holland America Line | 780 ' |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 78 | 20-Jul Fri | OOSTERDAM | Ketchikan | 18:00 | 23:59 Seattle | 1,840 Holland America Line | 951 ' |
| 79 | 20-Jul Fri | GOLDEN PRINCESS | Ketchikan | 19:00 | 23:59 Seattle | 2,600 Princess Cruise Lines | 951 ' |
| 80 | 21-Jul Sat | SUN PRINCESS | Skagway | 17:00 | 23:59 Seattle | 1,950 Princess Cruise Lines | 856 ' |
| 81 | 21-Jul Sat | NOORDAM | Ketchikan | 18:00 | 23:59 Seattle | 1,918 Holland America Line | 935 ' |
| 82 | 21-Jul Sat | NORWEGIAN PEARL | Ketchikan | 18:00 | 23:59 Seattle | 2,200 Norwegian Cruise Line | 971 ' |
| 83 | 22-Jul Sun | DAWN PRINCESS | San Francisco | 12:00 | 19:00 Juneau | 1,950 Princess Cruise Lines | 856 ' |
| 84 | 26-Jul Thu | AMSTERDAM | Ketchikan | 18:00 | 23:59 Seattle | 1,380 Holland America Line | 780 ' |
| 85 | 27-Jul Fri | OOSTERDAM | Ketchikan | 18:00 | 23:59 Seattle | 1,840 Holland America Line | 951 ' |
| 86 | 27-Jul Fri | GOLDEN PRINCESS | Ketchikan | 19:00 | 23:59 Seattle | 2,600 Princess Cruise Lines | 951 ' |
| 87 | 28-Jul Sat | SUN PRINCESS | Skagway | 17:00 | 23:59 Seattle | 1,950 Princess Cruise Lines | 856 ' |
| 88 | 28-Jul Sat | NOORDAM | Ketchikan | 18:00 | 23:59 Seattle | 1,918 Holland America Line | 935 ' |
| 89 | 28-Jul Sat | NORWEGIAN PEARL | Ketchikan | 18:00 | 23:59 Seattle | 2,200 Norwegian Cruise Line | 971 ' |
| 90 | 2-Aug Thu | AMSTERDAM | Ketchikan | 18:00 | 23:59 Seattle | 1,380 Holland America Line | 780 ' |
| 91 | 3-Aug Fri | OOSTERDAM | Ketchikan | 18:00 | 23:59 Seattle | 1,840 Holland America Line | 951 ' |
| 92 | 3-Aug Fri | GOLDEN PRINCESS | Ketchikan | 19:00 | 23:59 Seattle | 2,600 Princess Cruise Lines | 951 ' |
| 93 | 4-Aug Sat | SUN PRINCESS | Skagway | 17:00 | 23:59 Seattle | 1,950 Princess Cruise Lines | 856 ' |
| 94 | 4-Aug Sat | NOORDAM | Ketchikan | 18:00 | 23:59 Seattle | 1,918 Holland America Line | 935 ' |
| 95 | 4-Aug Sat | NORWEGIAN PEARL | Ketchikan | 18:00 | 23:59 Seattle | 2,200 Norwegian Cruise Line | 971 ' |
| 96 | 7-Aug Tue | DAWN PRINCESS | Skagway | 7:00 | 14:00 San Francisco | 1,950 Princess Cruise Lines | 856 ' |
| 97 | 9-Aug Thu | AMSTERDAM | Ketchikan | 18:00 | 23:59 Seattle | 1,380 Holland America Line | 780 ' |
| 98 | 10-Aug Fri | OOSTERDAM | Ketchikan | 18:00 | 23:59 Seattle | 1,840 Holland America Line | 951 ' |
| 99 | 10-Aug Fri | GOLDEN PRINCESS | Ketchikan | 19:00 | 23:59 Seattle | 2,600 Princess Cruise Lines | 951 ' |
| 100 | 11-Aug Sat | SUN PRINCESS | Skagway | 17:00 | 23:59 Seattle | 1,950 Princess Cruise Lines | 856 ' |
| 101 | 11-Aug Sat | NORWEGIAN PEARL | Ketchikan | 18:00 | 23:59 Seattle | 2,200 Norwegian Cruise Line | 971 ' |
| 102 | 11-Aug Sat | NOORDAM | Ketchikan | 18:00 | 23:59 Seattle | 1,918 Holland America Line | 935 ' |
| 103 | 16-Aug Thu | AMSTERDAM | Ketchikan | 18:00 | 23:59 Seattle | 1,380 Holland America Line | 780 ' |
| 104 | 17-Aug Fri | DAWN PRINCESS | Juneau | 7:00 | 14:00 San Francisco | 1,950 Princess Cruise Lines | 856 ' |
| 105 | 17-Aug Fri | OOSTERDAM | Ketchikan | 18:00 | 23:59 Seattle | 1,840 Holland America Line | 951 ' |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 106 | 17-Aug Fri | GOLDEN PRINCESS | Ketchikan | 19:00 | 23:59 Seattle | 2,600 Princess Cruise Lines | 951 ' |
| 107 | 18-Aug Sat | SUN PRINCESS | Skagway | 17:00 | 23:59 Seattle | 1,950 Princess Cruise Lines | 856 ' |
| 108 | 18-Aug Sat | NORWEGIAN PEARL | Ketchikan | 18:00 | 23:59 Seattle | 2,200 Norwegian Cruise Line | 971 ' |
| 109 | 18-Aug Sat | NOORDAM | Ketchikan | 18:00 | 23:59 Seattle | 1,918 Holland America Line | 935 ' |
| 110 | 23-Aug Thu | AMSTERDAM | Ketchikan | 18:00 | 23:59 Seattle | 1,380 Holland America Line | 780 ' |
| 111 | 24-Aug Fri | OOSTERDAM | Ketchikan | 18:00 | 23:59 Seattle | 1,840 Holland America Line | 951 ' |
| 112 | 24-Aug Fri | GOLDEN PRINCESS | Ketchikan | 19:00 | 23:59 Seattle | 2,600 Princess Cruise Lines | 951 ' |
| 113 | 25-Aug Sat | SUN PRINCESS | Skagway | 17:00 | 23:59 Seattle | 1,950 Princess Cruise Lines | 856 ' |
| 114 | 25-Aug Sat | NORWEGIAN PEARL | Ketchikan | 18:00 | 23:59 Seattle | 2,200 Norwegian Cruise Line | 971 ' |
| 115 | 25-Aug Sat | NOORDAM | Ketchikan | 18:00 | 23:59 Seattle | 1,918 Holland America Line | 935 ' |
| 116 | 27-Aug Mon | DAWN PRINCESS | Skagway | 7:00 | 14:00 San Francisco | 1,950 Princess Cruise Lines | 856 ' |
| 117 | 30-Aug Thu | AMSTERDAM | Ketchikan | 18:00 | 23:59 Seattle | 1,380 Holland America Line | 780 ' |
| 118 | 31-Aug Fri | OOSTERDAM | Ketchikan | 18:00 | 23:59 Seattle | 1,840 Holland America Line | 951 ' |
| 119 | 31-Aug Fri | GOLDEN PRINCESS | Ketchikan | 19:00 | 23:59 Seattle | 2,600 Princess Cruise Lines | 951 ' |
| 120 | 1-Sep Sat | SUN PRINCESS | Skagway | 17:00 | 23:59 Seattle | 1,950 Princess Cruise Lines | 856 ' |
| 121 | 1-Sep Sat | NOORDAM | Ketchikan | 18:00 | 23:59 Seattle | 1,918 Holland America Line | 935 ' |
| 122 | 1-Sep Sat | NORWEGIAN PEARL | Ketchikan | 18:00 | 23:59 Seattle | 2,200 Norwegian Cruise Line | 971 ' |
| 123 | 6-Sep Thu | DAWN PRINCESS | Skagway | 7:00 | 14:00 San Francisco | 1,950 Princess Cruise Lines | 856 ' |
| 124 | 6-Sep Thu | AMSTERDAM | Ketchikan | 18:00 | 23:59 Seattle | 1,380 Holland America Line | 780 ' |
| 125 | 7-Sep Fri | OOSTERDAM | Ketchikan | 18:00 | 23:59 Seattle | 1,840 Holland America Line | 951 ' |
| 126 | 7-Sep Fri | GOLDEN PRINCESS | Ketchikan | 19:00 | 23:59 Seattle | 2,600 Princess Cruise Lines | 951 ' |
| 127 | 8-Sep Sat | SUN PRINCESS | Skagway | 17:00 | 23:59 Seattle | 1,950 Princess Cruise Lines | 856 ' |
| 128 | 8-Sep Sat | NORWEGIAN PEARL | Ketchikan | 18:00 | 23:59 Seattle | 2,200 Norwegian Cruise Line | 971 ' |
| 129 | 8-Sep Sat | NOORDAM | Ketchikan | 18:00 | 23:59 Seattle | 1,918 Holland America Line | 935 ' |
| 130 | 10-Sep Mon | DAWN PRINCESS | San Francisco | 12:00 | 19:00 Sitka | 1,950 Princess Cruise Lines | 856 ' |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 131 | 13-Sep Thu | AMSTERDAM | Ketchikan | 18:00 | 23:59 Seattle | 1,380 Holland America Line | 780 ' |
| 132 | 14-Sep Fri | OOSTERDAM | Ketchikan | 18:00 | 23:59 Seattle | 1,840 Holland America Line | 951 ' |
| 133 | 14-Sep Fri | GOLDEN PRINCESS | Ketchikan | 19:00 | 23:59 Seattle | 2,600 Princess Cruise Lines | 951 ' |
| 134 | 15-Sep Sat | SUN PRINCESS | Skagway | 17:00 | 23:59 Seattle | 1,950 Princess Cruise Lines | 856 ' |
| 135 | 15-Sep Sat | NOORDAM | Ketchikan | 18:00 | 23:59 Seattle | 1,918 Holland America Line | 935 ' |
| 136 | 15-Sep Sat | NORWEGIAN PEARL | Ketchikan | 18:00 | 23:59 Seattle | 2,200 Norwegian Cruise Line | 971 ' |
| 137 | 16-Sep Sun | DIAMOND PRINCESS | Vancouver | 8:00 | 17:00 Los Angeles | 2,600 Princess Cruise Lines | 951 ' |
| 138 | 17-Sep Mon | NORWEGIAN SUN | Vancouver | 8:00 | 16:00 Kahului HI | 1,900 Norwegian Cruise Line | 853 ' |
| 139 | 20-Sep Thu | AMSTERDAM | Ketchikan | 18:00 | 23:59 Seattle | 1,380 Holland America Line | 780 ' |
| 140 | 21-Sep Fri | OOSTERDAM | Ketchikan | 18:00 | 23:59 Seattle | 1,840 Holland America Line | 951 ' |
| 141 | 21-Sep Fri | GOLDEN PRINCESS | Ketchikan | 19:00 | 23:59 Seattle | 2,600 Princess Cruise Lines | 951 ' |
| 142 | 22-Sep Sat | MERCURY | Seattle | 7:00 | 17:00 Nanaimo | 1,870 Celebrity Cruise Line | 866 ' |
| 143 | 22-Sep Sat | SUMMIT | Sitka (I.P.) | 8:00 | 16:00 Seattle | 2,000 Celebrity Cruise Line | 965 ' |
| 144 | 22-Sep Sat | SUN PRINCESS | Skagway | 17:00 | 23:59 Seattle | 1,950 Princess Cruise Lines | 856 ' |
| 145 | 22-Sep Sat | NOORDAM | Ketchikan | 18:00 | 23:59 Seattle | 1,918 Holland America Line | 935 ' |
| 146 | 24-Sep Sat | NORWEGIAN PEARL | Ketchikan | 18:00 | 23:59 Seattle | 2,200 Norwegian Cruise Line | 971 ' |
| 147 | 24-Sep Mon | GOLDEN PRINCESS | Vancouver | 8:00 | 17:00 San Francisco | 2,600 Princess Cruise Lines | 951 ' |
| 148 | 26-Sep Mon | NORWEGIAN STAR | Vancouver | 8:00 | 17:00 Seattle | 2,200 Norwegian Cruise Line | 971 ' |
| 149 | 27-Sep Wed | MERCURY | Nanaimo | 7:00 | 22:00 Seattle | 1,870 Celebrity Cruise Line | 866 ' |
| 150 | 27-Sep Thu | DAWN PRINCESS | Ketchikan | 7:00 | 14:00 San Francisco | 1,950 Princess Cruise Lines | 856 ' |
| 151 | 27-Sep Thu | INFINITY | Nanaimo | 7:00 | 16:00 San Francisco | 2,000 Celebrity Cruise Line | 965 ' |
| 152 | 27-Sep Thu | ZAANDAM | Vancouver | 8:00 | 17:00 Astoria | 1,440 Holland America Line | 777 ' |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 153 | 29-Sep Sat | NOORDAM | Ketchikan | 18:00 | 23:59 Seattle | 1,918 Holland America Line | 935 ' |
| 154 | 30-Sep Sun | OOSTERDAM | Vancouver | 8:00 | 23:59 Seattle | 1,840 Holland America Line | 951 ' |
| 155 | 3-Oct Wed | MERCURY | Nanaimo | 7:00 | 22:00 Seattle | 1,870 Celebrity Cruise Line | 866 ' |
| 156 | 6-Oct Sat | MERCURY | Seattle | 7:00 | 18:00 Nanaimo | 1,870 Celebrity Cruise Line | 866 ' |
| 157 | 8-Oct Mon | RYNDAM | Vancouver | 7:00 | 13:00 San Diego | 1,250 Holland America Line | 720 ' |
| 158 | 10-Oct Wed | MERCURY | Nanaimo | 7:00 | 22:00 Seattle | 1,870 Celebrity Cruise Line | 866 ' |
| 159 | 17-Oct Wed | MERCURY | Nanaimo | 7:00 | 22:00 Seattle | 1,870 Celebrity Cruise Line | 866 ' |
| 160 | 20-Oct Sat | MERCURY | Seattle | 7:00 | 18:00 Nanaimo | 1,870 Celebrity Cruise Line | 866 ' |
| 161 | 24-Oct Wed | MERCURY | Nanaimo | 7:00 | 22:00 Seattle | 1,870 Celebrity Cruise Line | 866 ' |
| 162 | 31-Oct Wed | MERCURY | Nanaimo | 7:00 | 22:00 Seattle | 1,870 Celebrity Cruise Line | 866 ' |
| 163 | 3-Nov Sat | MERCURY | Seattle | 8:00 | 17:00 Seattle | 1,870 Celebrity Cruise Line | 866 ' |