# MARINE VESSEL AIR EMISSIONS IN THE LOWER FRASER VALLEY FOR THE YEAR 2000

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# Executive Summary

An emission inventory of air contaminant emissions from marine vessels has been prepared for the year 2000. This inventory has been carried out in two phases, and this report presents the emissions for a “Core Area” of study, quantifying emissions for the Greater Vancouver Regional District and Fraser Valley Regional District areas in southwestern B.C. Phase 2 of this study will address an “Expanded Area”, including coastal areas in B.C. and Washington State. The results of that study are reported under separate cover.

The source categories included in the 2000 marine vessel emission inventory are:

- Ocean-going vessels, including automobile carriers, bulk carriers, container ships, cargo ships, tankers and passenger ships, split into underway, manoeuvring and dockside emissions;
- Harbour vessels, including workboats, tugboats and charters;
- Ferries, consisting of B.C. Ferries and other public and commercial ferry operations;
- Fishing vessels; and
- Recreational vessels.

The pollutants which are included in this inventory are as follows:

- Criteria air contaminants
  - carbon monoxide (CO)
  - nitrogen oxides ($NO_x$), speciated
  - particulate matter (PM)
  - sulphur oxides ($SO_x$), speciated
  - volatile organic compounds (VOCs)
- Inhalable and fine particulate matter ($PM_{10}$ and $PM_{2.5}$ respectively)
- Greenhouse gases
  - carbon dioxide ($CO_2$)
  - methane ($CH_4$)
  - nitrous oxide ($N_2O$)
- Ammonia ($NH_3$)

Emissions were spatially resolved to a number of regions of interest, including the Greater Vancouver and Fraser Valley regional districts, and the Lower Fraser Valley[1], which contains the entire GVRD and the southwest portion of the FVRD. To facilitate the use of the emission inventory data in various air quality models, the emissions have been further resolved into a system of 1km by 1km grid squares, based on a Lambert conformal map projection.

The annual emission estimates have also been resolved by time, to allow reporting of emissions by month, day of the week, and hour of the day.

This 2000 emission inventory is an update to a similar emission inventory for the year 1993 (Levelton, 1995), prepared for Environment Canada, BC Environment and the GVRD. The 1993 inventory was for the Lower Fraser Valley, but included only the criteria air contaminants, and a coarser (5 km) spatial resolution, based on UTM coordinates.

The methodology for the 1993 inventory was reviewed and updated as appropriate, based on a review of the most current methods available for estimating emissions from marine vessels. In general, the emission estimates are developed using published emission factors, which relate the mass of emissions generated from a given source to some surrogate level of activity known as a "base quantity" (e.g. kilograms of NOx emitted per tonne of fuel burned). Base quantities such as fuel consumption, vessel counts or hours of operation were obtained from a variety of sources, such as vessel owners or operators, government agencies, commercial directories, and various shipping or boating associations. In some cases, information on vessel size, engine power, load, etc. were derived from available statistics or available models or correlations.

The results of the overall inventory are shown in Tables S-1 and S-2 for the Lower Fraser Valley for 2000.

- Ocean-going vessels are the predominant contributor to emissions of NOx, SOx, particulate matter and greenhouse gases, accounting for 58%, 95%, 82% and 58% of the total marine vessel emissions, respectively. Ocean-going vessels contribute 14% to the estimated marine totals for CO and VOC.
- Harbour vessels contribute 28% and 27% to NOx and GHG totals, and 10% or less to all other contaminant totals. Workboats and tugboats are the dominant category compared to charter vessels.
- Ferries contribute between 2% and 13% to each contaminant, including 13% of NOx, 12% of greenhouse gases, and 6% of CO. Of the total ferry operations, BC Ferries are the most significant contributor to emissions.
- Fishing vessels are not a significant contributor, estimated at less than 1% of the total for each contaminant.
- Recreational vessels are significant in terms of CO and VOC, but less than 10% for all other contaminants. The comparatively high emissions for CO and VOC reflect the use of a large number of more inefficient gasoline outboard engines.

[1] The Lower Fraser Valley has been defined in this study as a rectangular area bordered on the north by latitude 49$^{o}$ 30', on the south by the Canada-US border, on the east by longitude 121$^{o}$ 15' and on the west by longitude 123$^{o}$ 20', consistent with the definition used by the GVRD in their emission inventory reports.

Table S-3 provides a comparison of the 2000 marine vessel inventory to the previous study completed for the year 1993.

Ocean-going vessels have shown a significant increase in estimated emissions between 1993 and 2000, due in large part to a change in the emission estimation methodology. For 1993, each ocean-going vessel operating within the Lower Fraser Valley was assigned an estimated horsepower, using typical values based on the vessel type and weight. From the assigned horsepower, fuel consumption was estimated. For the current inventory, more recent correlations from the United States Environmental Protection Agency were used to estimate horsepower specific to each vessel, based on vessel type, weight, and in some cases, speed. The emission factors for 2000 were based on vessel-specific horsepower, in conjunction with time spent in different movement categories and the load associated with each category, rather than an estimated fuel consumption.

Emission estimates for harbour vessels (except for NOx), and ferries have not shown significant changes between 1993 and 2000.

Fishing vessel emission estimates have decreased significantly, through a combination of reduced activity since 1995, and revised methodologies used for this study.

The estimates for recreational vessels have increased, due in part to the inclusion of personal watercraft which were not inventoried in the previous study.

**Table S-1: Summary of Lower Fraser Valley Marine Vessel Emission Inventory for 2000 (CACs and Ammonia)**

| | emissions (tonnes/year) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | CO | VOC | NOx | | | SOx | | | PM ‡ | $NH_3$ |
| | | | total NOx* | NO | $NO_2$ | total SOx† | $SO_2$ | $SO_4^{=}$ | | |
| **Ocean Going Vessels** | | | | | | | | | | |
| Dockside | 418 | 179 | 7,189 | 4,501 | 287 | 3,795 | 3,744 | 76 | 560 | 1 |
| Manoeuvring | 85 | 5 | 640 | 400 | 26 | 48 | 47 | 1 | 32 | 8 |
| Underway | 163 | 51 | 2,756 | 1,725 | 110 | 1,043 | 1,029 | 21 | 153 | 36 |
| **Subtotal** | 666 | 235 | 10,584 | 6,627 | 423 | 4,886 | 4,821 | 98 | 745 | 44 |
| **Harbour Vessels** | | | | | | | | | | |
| workboats and tugboats | 409 | 128 | 4,911 | 3,075 | 196 | 140 | 138 | 3 | 51 | 3 |
| charters | 14 | 0 | 166 | 104 | 7 | 5 | 5 | 0 | 2 | 0 |
| **Subtotal** | 423 | 128 | 5,077 | 3,179 | 203 | 144 | 142 | 3 | 53 | 3 |
| **Ferries** | | | | | | | | | | |
| B.C. Ferries | | | | | | | | | | |
| Dockside | 33 | 2 | 430 | 269 | 17 | 5 | 5 | 0 | 3 | 0 |
| Manoeuvring | 62 | 8 | 171 | 107 | 7 | 6 | 6 | 0 | 1 | 0 |
| Underway | 119 | 38 | 1,371 | 859 | 55 | 87 | 87 | 0 | 19 | |
| Layup | 20 | 2 | 207 | 130 | 8 | 3 | 3 | 0 | 7 | 0 |
| Subtotal B.C. Ferries | 234 | 51 | 2,180 | 1,365 | 87 | 101 | 101 | 0 | 30 | 0 |
| SeaBus | 6 | 2 | 83 | 52 | 3 | 1 | 1 | < 0.02 | 1 | < 0.005 |
| Aquabus/Granville Island | 24 | 2 | 33 | 20 | 1 | 3 | 3 | < 0.02 | < 0.5 | < 0.005 |
| Albion Ferries | 4 | 1 | 43 | 27 | 2 | < 1 | 0 | < 0.02 | 1 | < 0.005 |
| Barnston Island | 1 | < 0.5 | < 7 | 4 | < 0.5 | 1 | 1 | < 0.02 | < 0.1 | < 0.0005 |
| **Subtotal Ferries** | 268 | 56 | 2,344 | 1,468 | 93 | 108 | 107 | 2 | 32 | 0 |
| **Fishing Vessels** | | | | | | | | | | |
| Gillnetters | 2 | 1 | 24 | 15 | 1 | 1 | 1 | < 0.02 | <0.3 | <0.02 |
| Seiners | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Trollers | 0 | 0 | < 6 | 4 | <0.3 | < 0.2 | <0.2 | <0.004 | <0.07 | <0.004 |
| **Subtotal** | 2 | 1 | 30 | 19 | 1 | 1 | 1 | 0 | <0.4 | <0.02 |
| **Recreational Vessels** | 3,448 | 1,232 | 161 | 101 | 6 | 4 | 4 | 0 | 76 | 0 |
| **Total** | 4,807 | 1,651 | 18,196 | 11,394 | 727 | 5,143 | 5,074 | 103 | 906 | 47 |

Notes: totals may not add up due to rounding
* NOx expressed as $NO_2$-equivalent
† SOx expressed as $SO_2$-equivalent
‡ PM from marine exhausts is assumed to be 100% $PM_{10}$ and 100% $PM_{2.5}$

**Table S-2: Summary of Lower Fraser Valley Marine Vessel Emission Inventory for 2000 (Greenhouse Gases)**

| | emissions (tonnes/year) | | | |
|---|---|---|---|---|
| | $CO_2$ | $CH_4$ | $N_2O$ | total, $CO_2$ equiv |
| **Ocean Going Vessels** | | | | |
| Dockside | 320,979 | 33 | 21 | 328,084 |
| Manoeuvring | 15,621 | 1 | 7 | 17,699 |
| Underway | 77,198 | 7 | 2 | 77,981 |
| **Subtotal** | 413,798 | 41 | 29 | 423,764 |
| **Harbour Vessels** | | | | |
| workboats and tugboats | 193,490 | 18 | 5 | 195,447 |
| charters | 6,535 | 1 | 0 | 6,601 |
| **Subtotal** | 200,025 | 18 | 5 | 202,048 |
| **Ferries** | | | | |
| B.C. Ferries | 76,685 | 4 | 28 | 85,494 |
| SeaBus | 2,694 | < 0.2 | 1 | 3,008 |
| Aquabus/Granville Island | 1,101 | < 0.2 | < 0.5 | 1,260 |
| Albion Ferries | 1,490 | < 0.1 | 1 | 1,663 |
| Barnston Island | 216 | < 0.02 | < 0.1 | 247 |
| **Subtotal** | 82,186 | 4 | 30 | 91,632 |
| **Fishing Vessels** | | | | |
| Gillnetter | 882 | <0.09 | <0.03 | 892 |
| Seiners | 0 | 0 | 0 | 0 |
| Trollers | 225 | <0.03 | <0.007 | 228 |
| **Subtotal** | 1,107 | <0.2 | <0.04 | 1,120 |
| **Recreational Vessels** | 21,343 | 25 | 1 | 22,228 |
| **Total** | 718,459 | 89 | 66 | 740,792 |

Notes: totals may not add up due to rounding

**Table S-3: Comparison of 1993 and 2000 Marine Vessel Emission Inventories**

| | emissions (tonnes/year) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | CO | | VOC | | NOx* | | SOx† | | PM ‡ | |
| | 1993 | 2000 | 1993 | 2000 | 1993 | 2000 | 1993 | 2000 | 1993 | 2000 |
| **Ocean Going Vessels** | | | | | | | | | | |
| Dockside | 156 | 418 | 269 | 179 | 963 | 7,189 | 888 | 3,795 | 57 | 560 |
| Manoeuvring | | 85 | | 5 | | 640 | | 48 | | 32 |
| Underway[2] | 109 | 163 | 30 | 51 | 1,018 | 2,756 | 478 | 1,043 | 56 | 153 |
| **Subtotal** | **265** | **666** | **299** | **235** | **1,981** | **10,584** | **1,366** | **4,886** | **113** | **745** |
| **Harbour Vessels** | | | | | | | | | | |
| workboats and tugboats | 516 | 409 | 84 | 128 | 1,099 | 4,911 | 145 | 140 | 54 | 51 |
| charters | 20 | 14 | 9 | 0 | 93 | 166 | 15 | 5 | 5 | 2 |
| **Subtotal** | **536** | **423** | **93** | **128** | **1,192** | **5,077** | **160** | **144** | **59** | **53** |
| **Ferries[3]** | | | | | | | | | | |
| B.C. Ferries | 180 | 234 | 61 | 51 | 1,327 | 2,180 | 144 | 101 | 53 | 30 |
| SeaBus | 8 | 6 | 3 | 2 | 55 | 83 | 6 | 1 | 2 | 1 |
| Aquabus/Granville Island | | 24 | | 2 | | 33 | | 3 | | < 0.5 |
| Albion Ferries | 6 | 4 | 2 | 1 | 41 | 43 | <0.5 | < 1 | <0.5 | 1 |
| Barnston Island | | 1 | | < 0.5 | | < 7 | | 1 | | < 0.1 |
| **Subtotal** | **231** | **268** | **78** | **56** | **1,688** | **2,344** | **178** | **108** | **66** | **32** |
| **Fishing Vessels[4]** | | | | | | | | | | |
| Gillnetters | 6 | 2 | 6 | 1 | 48 | 24 | 6 | 1 | 2 | <0.3 |
| Seiners | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Trollers | 1 | 0 | 1 | 0 | 7 | < 6 | 1 | < 0.2 | 0 | <0.07 |
| **Subtotal** | **7** | **2** | **7** | **1** | **55** | **30** | **7** | **1** | **2** | **<0.4** |
| **Recreational Vessels** | **1,401** | **3,448** | **436** | **1,232** | **43** | **161** | **6** | **4** | **<0.5** | **76** |
| **Total** | **2,440** | **4,807** | **913** | **1,651** | **4,959** | **18,196** | **1,717** | **5,143** | **240** | **906** |

Notes: [1] totals may not add up due to rounding
[2] for the 1993 study, underway emissions include both underway and manoeuvring estimates
[3] the 1993 study included B.C. Ferries, Albion, SeaBus, SeaLink, C.P. Ferries and Kingcome
[4] the 1993 study included an additional category, shell and groundfish (mixed vessels)

* NOx expressed as $NO_2$-equivalent
† SOx expressed as $SO_2$-equivalent
‡ PM from marine exhausts is assumed to be 100% $PM_{10}$ and 100% $PM_{2.5}$

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| | |
|---|---|
| CAC | criteria air contaminants (CO, VOC, NOx, SOx, total particulate matter) |
| CARB | Air Resources Board of California |
| $CH_4$ | methane |
| CO | carbon monoxide |
| $CO_2$ | carbon dioxide |
| DFO | Department of Fisheries and Oceans |
| DWT | dead weight tonnage |
| EPA | United States Environmental Protection Agency |
| FVRD | Fraser Valley Regional District |
| FVRD1 | Fraser Valley Regional District 1, portion within the Lower Fraser Valley |
| FVRD2 | Fraser Valley Regional District 2, portion outside the Lower Fraser Valley |
| GCCAB | Georgia Coast Cascade Air Basin |
| GHG | greenhouse gases |
| GVRD | Greater Vancouver Regional District |
| IPCC | Intergovernmental Panel on Climate Change |
| LFV | Lower Fraser Valley |
| $NH_3$ | ammonia |
| NOx | nitrogen oxides |
| $N_2O$ | nitrous oxide |
| PM | particulate matter |
| $PM_{10}$ | inhalable particulate matter, particles smaller than 10 microns in diameter |
| $PM_{2.5}$ | fine particulate matter, particles smaller than 2.5 microns in diameter |
| PWC | personal watercraft |
| SOx | sulphur oxides |
| UTM | Universal Transverse Mercator |
| VOC | volatile organic compounds |

# 1. INTRODUCTION

The Greater Vancouver Regional District (GVRD) Policy and Planning Department manages current air quality programs in the region including the development, implementation and enforcement of appropriate air quality management measures to improve regional air quality. To support these regulatory activities, the Policy and Planning Department maintains a comprehensive emissions inventory, which is updated every five years.

Amongst anthropogenic emission sources in the region, marine vessels have been identified as significant sources of Sulphur Oxides ($SO_X$) and Nitrogen Oxides ($NO_X$). The 1994 GVRD Air Quality Management Plan also identified this source sector as requiring further study with respect to its impact on regional air quality. The previous comprehensive emissions inventory for marine vessels, entitled "1993 Marine Vessel Air Emissions Inventory for the Lower Fraser Valley", was prepared in 1995. The GVRD, in partnership with Environment Canada, has contracted Levelton to update and expand this marine vessel inventory for the Georgia Coast Cascade Air Basin (GCCAB) and other coastal areas for the year 2000.

This report presents the emission estimates from marine vessel activities in the Canadian portion of the Lower Fraser Valley (LFV) for the year 2000 while emissions from these activities in other designated coastal areas for this project are provided in a separate report.

## 1.1 SCOPE OF WORK

The scope of work for this project includes the following tasks:

- Prepare/update emission estimates for each marine vessel category;
- Prepare/update emission estimates for pollutants of interest;
- Develop a 1km by 1km grid system for the study area based on the Lambert Conformal Projection;
- Prepare regional summaries of emissions (Lower Fraser Valley, Greater Vancouver Regional District, Fraser Valley Regional District);
- Prepare/update source spatial profiles for spatial allocation of emissions;
- Prepare/update source temporal profiles for temporal allocation of emissions.

## 1.2 STUDY AREA

A comprehensive marine vessel emissions inventory was prepared in two phases, covering a Core Area and an Expanded Area of study. The Core Area, as shown in Figure 1-1, encompasses the combined Greater Vancouver Regional District (GVRD) and Fraser Valley Regional District (FVRD). The Core Area includes the Lower Fraser Valley (LFV), indicated by the rectangular gridded area in Figure 1-1, which consists of the entire GVRD and the southwestern portion of the FVRD. For the purposes of reporting regional emissions in this report, the FVRD is differentiated into two areas, where FVRD1 is the portion within the LFV, and FVRD2 is the remainder of the FVRD, outside of the LFV.

The geographic scope of the second phase of this marine vessel emission inventory is an Expanded Area, which addresses emissions in and around Vancouver Island, the Queen Charlotte Islands and the B.C. coastline north to the US border, as well as Whatcom County, the

Puget Sound area, and coastal areas in the State of Washington. The inventory for the Expanded Area is reported under separate cover.

The majority of emissions within the Core Area occur within the Lower Fraser Valley study area, which has been defined by the GVRD in their emission inventory studies as being bounded by the U.S. border to the South, Lions Bay to the North, Bowen Island to the West, and Hope to the East. Previous Lower Fraser Valley inventories have used a system of 5km by 5 km grids to spatially allocate the emission estimates, based on the Universal Transverse Mercator (UTM) system. In UTM coordinates, the LFV border is 5,427,500 N to the south, 5,485,000 N to the north, 470,000 E to the west and 630,000 E to the east. For the current study, and for consistency with the grid used in the Cascadia Air Basin International Modelling Project, the inventory has been resolved to a 1km by 1km grid based on a Lambert Conic Conformal Projection. Using the Lambert Conformal map projection, the corresponding lower left and upper right corners of the LFV are –170.581km /+2.532km and –14.332km /+54.224km respectively, where the first coordinate is the easting and the second is the northing.

## 1.3 Emission Source Categories

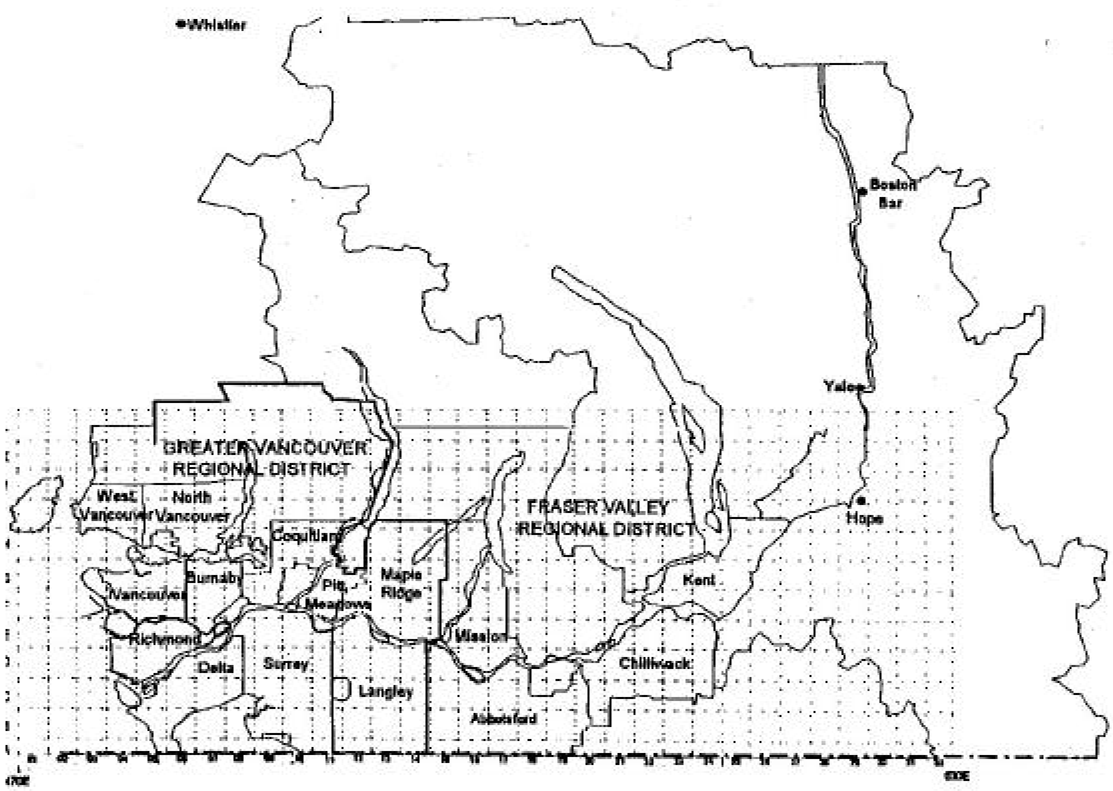
The marine vessel categories included in this inventory are:

- Ocean-going vessels
- Harbour vessels
- Ferries
- Fishing vessels
- Recreational vessels

The various vessel types within each category are described in more detail in Section 2 and Appendix B of this report.

Only exhaust emissions from vessel engines/power plants are considered in this inventory. This includes the main drives and auxiliary generators. Onboard ship incinerators are not considered a significant source and hence were not included in this inventory. Emissions related to product loading and unloading operations are outside of the scope of this project and hence these are not included.

**Figure 1.3-1: Lower Fraser Valley Study Area (Core Area)**




## 1.4 POLLUTANTS INVENTORIED

The pollutants of interest that are covered in this inventory are as follows:

- Criteria pollutants
  - CO,
  - $NO_X$ (speciated),
  - PM,
  - $SO_X$ (speciated) and
  - VOCs
- Inhalable and fine particulate - $PM_{10}$ & $PM_{2.5}$
- Greenhouse gases
  - $CO_2$
  - $CH_4$ and its $CO_2$ equivalent emissions
  - $N_2O$ and its $CO_2$ equivalent emissions
- Ammonia ($NH_3$)

# 2. DATA COLLECTION AND INVENTORY METHODOLOGIES

The general methodology used for estimating emissions from marine vessels is not complex. A fuel quantity is multiplied by a fuel specific emission factor to obtain the emission estimate for a given pollutant. The difficulty associated with the preparation of an inventory of marine vessel emissions is due to the challenge of estimating the fuel usage of many different types of vessels for which little direct data is available and activity levels and engine sizes are also poorly known. The level of detail for each marine vessel type in the inventory has been tailored according to its expected contribution to the overall inventory.

A detailed literature review was conducted at the outset of the project to determine current methodologies for estimating air emissions from marine vessels as well as the pollutant speciation profiles for species of interest. Relevant findings of the literature search were incorporated in the Year 2000 inventory and details are provided in the following sections.

## 2.1 OCEAN-GOING VESSELS

### 2.1.1 Characterization of Ocean Going Vessel Fleet

All international vessels travelling in the coastal waters of British Columbia must have a pilot on board in accordance with the Pilotage act to ensure that the environment, life, and property may be protected to the fullest extent possible. As such, the movement of every ocean-going vessel entering the study area is tracked by the Pacific Pilotage Authority. In addition, the Coast Guard tracks vessel movements and any vessels entering or leaving Canadian waters are also required to report to Canada Customs. Of these three sources, the Pacific Pilotage Authority maintains the most comprehensive database of vessel movement data. The Pacific Pilotage database of international vessel movements was provided to Levelton with data on individual vessel movements, some vessel specifications, a date and time, and both a to and from location. In total 15,681 entries were recorded in the Pacific Pilotage database for 2000. However, some 1,843 duplicate records were found (often due to double entries when more than one pilot is on board), and another 523 records were removed due to gross inconsistencies in start and end times (e.g. pilot times less than zero or greater than 60 hours). The resultant database contained 13,315 records.

From the database, a “vessels” table, or listing of the ocean-going vessels “fleet” was extracted, finding 1,639 unique records signifying individual vessels. Of these vessels, 1,449 had values for dead weight tonnage (DWT) and 190 did not. To narrow this data gap, the “vessels” table from the Pilotage database was cross-queried with the existing vessel database provided by the Coast Guard. A comparison of the two databases showed some variation in vessel callsigns and names. Ultimately, a DWT value was assigned to 44 additional vessels, reducing the number of vessels which do not have DWT values to 146 out of 1,639. The remaining 146 vessels were assigned a DWT of less than 25,000 tonnes, and account for approximately 6% of all ocean-going trips.

### 2.1.2 Average Main Engine Horsepower

The emission factors for ocean-going vessels are expressed in kg per tonne of fuel, or in grams per kilowatt-hour of engine output. Lacking data on the fuel consumption per vessel, the horsepower for each vessel was estimated, using two relationships (Equation 2.1 and Equation 2.2) developed in a February 2000 analysis of commercial marine vessel emissions by the EPA (US EPA, 2000), which estimated horsepower as a function of either DWT alone, or in combination with speed, for eight different classes of ships. The relationships were derived from regressions developed for various classes of vessels with a range of sample sizes as listed in Tables 2-1 and 2-2.

Where only the DWT of the vessel is known, equation 2-1 was used:

**Equation 2-1: Engine Horsepower as a function of Vessel Deadweight**

$$Horsepower = DWT * DWTCoeff + Intercept$$

**Table 2-1: Results of Regressions between Horsepower and Deadweight Tonnage**

| Ship Types | Vessel Sample Size | Intercept | DWT Coeff | R-Square |
|---|---|---|---|---|
| All | 4,103 | 9070 | 0.1097 | 0.14 |
| Auto Carrier | 157 | 7602 | 0.4172 | 0.176 |
| Bulk Carrier | 1,644 | 6726 | 0.0985 | 0.55 |
| Container | 489 | -749.4 | 0.800 | 0.59 |
| General Cargo | 641 | 3046 | 0.288 | 0.56 |
| Passenger | 40 | -4877 | 6.81 | 0.72 |
| Reefer | 160 | 1364 | 1.007 | 0.58 |
| RoRo | 110 | 4358 | 0.5364 | 0.76 |
| Tanker | 861 | 6579 | 0.183 | 0.66 |

Source: EPA, 2000

Where the cruise speed and DWT of the vessel was provided in the available databases, equation 2-2 was used:

**Equation 2-2: Engine Horsepower as a function of Vessel Deadweight and Speed**

$$Horspower = DWTCoeff * (DWT)^{0.667} + SpeedCoeff * (Speed)^{3} + Intercept$$

**Table 2-2: Regression of Horsepower versus Deadweight and Cruise Speed**

| Ship Types | Vessel Sample Size | Intercept | DWT Coeff | Speed Coeff | R-Square |
|---|---|---|---|---|---|
| All | 4,103 | -4585 | 6.711 | 2.662 | 0.73 |
| Auto Carrier | 157 | 2956 | 14.41 | 0.381 | 0.25 |
| Bulk Carrier | 1,644 | 1586 | 5.901 | 0.791 | 0.61 |
| Container | 489 | -13924 | 20.06 | 2.342 | 0.73 |
| General Cargo | 641 | -1307 | 8.819 | 1.202 | 0.80 |
| Passenger | 40 | -25305 | 118.45 | 2.612 | 0.72 |
| Reefer | 160 | -2357 | 17.00 | 0.861 | 0.77 |
| RoRo | 110 | -3664 | 16.18 | 1.386 | 0.88 |
| Tanker | 861 | 156.6 | 6.271 | 1.291 | 0.78 |

Source: EPA, 2000

### 2.1.3 Underway and Manoeuvring Emissions

As ocean-going vessels enter the Vancouver harbour and near a port location, the fuel source is typically switched to a lighter marine diesel which allows for better speed adjustment control. This is referred to as "manoeuvring". "Underway" travel is outside the harbour, i.e. through the Strait of Georgia and in open ocean, and is characterized by the use of a heavier grade of fuel.

The estimation of emissions for both underway and manoeuvring requires information on the type of vessel, its characteristics, engine power and load factor(s), and travel time.

### 2.1.4 Travel Time

Using the Pacific Pilotage database, all of the "to" and "from" place codes and names were gathered and duplicates eliminated to give 214 place location entries. Again, the Coast Guard database was queried against the Pilotage database to provide the latitude and longitude of the port locations. These values were converted to UTM using the geotrans2 program in order to easily define the emissions spatially. Core Area travel essentially consists of three types of movements; from a Core Area port to a Core Area port; from a Core Area port to an Expanded Area port; and from an Expanded Area port to a Core Area port. Using the UTM location of each of the ports, the Core Area travel was separated from travel in the Expanded Area.

The travel time for each trip was calculated by the difference in the arrival and departure times for each movement record. For travel entirely within the Core Area, this was straight-forward, while travel times for movements between the Core and Expanded Areas was segregated into core and expanded area times.

Manoeuvring travel time was calculated by assuming all manoeuvring was done within the Vancouver Harbour (East of the Lion's gate bridge) or along the Fraser river (East from Sandheads). The time spent manoeuvring in these areas was calculated by using the east-west distance travelled divided by the assumed manoeuvring speed of 5 knots.

Calculation of the underway travel within the core area was a little more difficult. For travel strictly within the core area, the time spent underway was calculated as the overall trip time minus the manoeuvring time. However, for trips leaving or entering the core area the total time consists of manoeuvring, and underway time in both the core and expanded area. To calculate the underway time in the core area, trips which included both core and expanded area travel were further divided into western and southern travel. Whereas western travel is defined for trips travelling to ports west of Vancouver, namely on the eastern side of Vancouver island, southern travel is defined as any trip that required vessels to travel south out of the core area before reaching their final destination. Times for western travel were calculated as the distance between the western limit of the core area and one of the following: the Lion's gate bridge (exiting Vancouver harbour), Sandheads (exiting the Fraser river), or the actual port location (if neither of the previous two locations were valid) divided by the appropriate speed. For Southern travel, the core area time was calculated as the east-west distance described above plus the distance in the north:south direction from the southern limit of the core area, divided by the appropriate speed. Speeds were defined per ship type and dead weight class as listed below.

**Table 2-3 : Assumed Underway Speed by Ship Type**

| Shiptype | DWT Range | Assumed Underway speed |
|---|---|---|
| Bulk Carrier | <=50,000 DWT | 10 knots |
| Bulk Carrier | >50,000 DWT | 14 knots |
| Container ships | All | 18 knots |
| General Cargo<br>Passenger<br>Tanker<br>General Vessel | All | 14 knots |

### 2.1.5 Vessel Weight Categories

Typical profiles were developed for each of the vessel groups (bulk carrier, container, general cargo, passenger, tanker and general vessel/other) into the following dead weight sub-groups:

- 0 – 24,999 ton DWT
- 25,000 – 49,999 ton DWT
- 50,000 – 74,999 ton DWT
- 75,000 – 99,999 ton DWT
- >100,000 ton DWT

### 2.1.6 Load Factors

Load factors were expected to vary for underway and manoeuvring movements, and between vessel classes for underway movements. The estimated load factors used in this study are shown in Table 2-4.

**Table 2-4: Estimated Load Factors for Ocean-going Vessels**

| Travel Category | Vessel Categories | Load Factor (%) |
|---|---|---|
| Underway | Bulk Carriers > 50,000 DWT | 40 |
| Underway | Bulk Carriers <= 50,000 DWT | 80 |
| Underway | All Other Ships | 80 |
| Manoeuvring | All Ships | 20 |

### 2.1.7 Emission Factors

Using the total travel time and average engine power for each vessel class group and dead weight subgroup, the equation for calculating emissions is:

Emission (tonnes) = Average Engine Power (kW) x Total time (h) x Engine Load Factor (%) x Emission Factor (g/kWh) / 10^6 (g/tonne)

While in underway travel, vessels were assumed to be using heavy fuel oil which corresponds to the emission factors provided in Table 2-5. The emission factors used for manoeuvring of ocean-going vessels is listed in Table 2-6.

**Table 2-5: Emission Factors for Underway Ocean-going Vessels**

| Pollutants | Emission Factors | | Data Source |
|---|---|---|---|
| | Kg/tonne fuel | g/kWh (output) | |
| CO | 7.4 | 1.6 | Lloyd, 1995 |
| NOx | 93 | 18 | Lloyd, 1995 |
| SOx * | 20 x fuel S content (wt.%) 49 | 4.2 x fuel S content (wt.%) 10.3 | Lloyd, 1995 |
| VOC | 2.4 | 0.5 | Lloyd, 1995 |
| PM | 7.6 | 1.5 | Lloyd, 1995 |
| $CO_2$ | 3635 | 757 | Lloyd, 1995 |
| $CH_4$ | 0.4 | 0.07** | IPCC, 1997 |
| $N_2O$ | 0.09 | 0.02** | IPCC, 1997 |
| $NH_3$ | 0.1118 | 0.35** | Environment Canada, 2001 |

* Based on average S content of 2.45% (wt.) determined from analysis of fuel burned by slow speed vessels in the Port of Vancouver vessel testing program (Environment Canada, 1997)
** Conversion based on Lloyd

**Table 2-6: Emission Factors for Vessel Manoeuvring**

| Pollutants | Emission Factors | |
|---|---|---|
| | Kg/tonne fuel | g/kWh (output)** |
| CO | 17.2 | 3.7 |
| NOx | 87.4 | 18.6 |
| SOx * | 10 | 2.1 |
| VOC | 0.8 | 0.2 |
| PM | 6.4 | 1.4 |
| $CO_2$ | 3212 | 682 |
| $CH_4$ (IPCC, 1997) | 0.18 | 0.04 |
| $N_2O$ (IPCC, 1997) | 1.18 | 0.29 |
| $NH_3$ (Environment Canada, 2001) | 0.1118 | 0.35 |

Source: Environment Canada, 1997 unless indicated otherwise

* Based on Lloyd's correlation and average S content of 0.5% (wt.) determined from analysis of fuel burned by slow speed vessels in the Port of Vancouver vessel testing program (Environment Canada, 1997)

** Conversion based on Lloyd

### 2.1.8 Dockside Emissions

Dockside or hotelling refers to the time a vessel remains in port, typically using on-board generator sets to provide the ship's power needs.

The records of ship movements provided in the Pacific Pilotage database cover departures and arrivals at origin and final destination, i.e., total individual trip times. Data is not readily available to estimate time spent dockside. Thus rather than estimating dockside emissions from actual times, dockside emissions were based on average fuel usage in port, assumed for each vessel category. The fuel use data was collected by a survey of several vessels (summarized in Appendix C) of each of the major classes (container, bulk carrier, and cruise which represent 69% of all vessels, 15% of which are unclassified). The survey collected actual port arrival and departure times as well as fuel on board for an entire trip conducted by a particular ship. The equation used for dockside emission is:

Dockside Emissions = Number of Docksides x Average Fuel Use per Dockside (tonnes) x Dockside Emission Factor (kg/tonne)

The number of trips/records provided by the Pilotage data estimated the number of "docksides". For each trip within the Core Area, it was assumed that there was one dockside and for each trip from the Expanded Area into the Core Area, there was also one dockside. Thus docksides were counted at the time of arrival at a destination of a trip but not before departure, to avoid double-counting. The average fuel use per dockside for each of the investigated vessel classes is listed in Table 2-7 below. The emission factors used for dockside emissions from auxiliary engines are listed in Table 2-8.

**Table 2-7: Dockside Fuel Usage per Vessel for Ocean-going Vessel Classes**

| Vessel Class | Average Fuel use per dockside (tonnes) | |
|---|---|---|
| | Fuel Oil | Diesel |
| Bulk Carriers DWT: 0-24,999 | 2.9 | 0.6 |
| Bulk Carriers DWT: 25,000-49,999 | 10.7 | 1.3 |
| Bulk Carriers DWT: 50,000-74,999 | 12.7 | 1.4 |
| Bulk Carriers DWT: 75,000-100,000 | 15.1 | 1.0 |
| Bulk Carriers DWT: over 100,000 | 16.5 | 1.6 |
| Container Ships | 12.3 | 4.1 |
| Tankers | 0.9 | 0 |
| Passenger Vessels<br>General Cargo<br>General Vessels | 11.4 | 1.4 |

Source: Survey of vessel movement and fuel on board by F. McCague, Appendix B

**Table 2-8: Emission Factors for Auxiliary Engines**

| Pollutants | Emission Factors (kg/tonne fuel) | |
|---|---|---|
| | Diesel | Fuel Oil |
| CO | 4.7 | 4.7 |
| NOx | 53.4 | 53.4 |
| SOx * | 2.6 | 49 |
| VOC | 2.0 | 2.0 |
| PM | 6.3 | 6.3 |
| $CO_2$ | 3146 | 3681 |
| $CH_4$ (IPCC, 1997) | 0.18 | 0.4 |
| $N_2O$ (IPCC, 1997) | 1.18 | 0.09 |
| $NH_3$ (Environment Canada, 2001) | 0.006 | 0.006 |

Source: Environment Canada, 1997 unless indicated otherwise

* Based on Lloyd's correlation and average S content of 0.13% (wt.) in marine diesel fuel supplied by local marketing companies (S content ranges from 0.03 to 0.31%)

## 2.2 HARBOUR VESSELS

Harbour vessels include tugboats/towboats, work boats/crewboats and charter boats.

### 2.2.1 Workboats and Tugboats

The Annual Pacific Coast Tug and Workboat directory (Progress, 2001) for 2002 was used as a basis for determining the engine rating, area of operation, and total number of work boats and tugboats in operation. Area designations were determined based on whether the office address for each company was located within the Core or Expanded Area. The listings were then divided into 3 classes, each having its own assumed hours of operation and power load as listed in Table 2-9. Emission factors used for each pollutant are listed in Table 2-10.

In order to separate the overall emissions into Core or Expanded Area, workboats were assumed to travel in the area surrounding the company address. By segregating by address the total listing of 483 boats from the workboat directory is decreased to 262 boats with addresses in the core area. Of these 262 boats, 204 have addresses in either Richmond, Vancouver, North Vancouver or West Vancouver and are assumed to travel outside of the Core Area regularly.

One such company provided a list of their workboats per area of travel, which showed that 60% of their fleet travelled almost entirely within the Core Area. This 60% Core Area travel for assumption from one company was thus applied to all of the 204 boats operating from coastal/Vancouver locations providing 122 (204x60%) workboats assumed to work mainly in core area. The remaining 58 (262-204) boats with Core Area addresses further East in the Lower Fraser Valley were assumed to work 100% in the Core Area, mainly along the Fraser River or within the Burrard Inlet. Thus the total number of workboats (180) assumed to travel in the Core Area was the sum of boats working in the harbour and river (58) plus the percent of the coastal tugs which remain in the Core Area (122). Divided by the total number of workboats provides an estimate of 37% of workboats in the Core Area, which was conservatively rounded up to assume that 40% of the actual operation occurs within the Core Area.

Emissions for each class were calculated by the formula:

Work/Tug boat Emission = Average Power (kW) x Operation time (h/year) x Power Load (%) x Number of vessels x Emission Factor (g/kWh)

**Table 2-9: Vessel Classes and assumed factors for Harbour Workboats and Tugboats**

| Vessel Class | Number of Vessels | Average Power (hp) | Operation time (h/year) | Power Load |
|---|---|---|---|---|
| Barge | 33 | 2,171 | 2,500 | 30% |
| Small vessel<br>(Patrol, rescue, work boats, water taxis, etc.) | 145 | 300 | 2,000 | 30% |
| Tug | 319 | 978 | 4,000 | 60% |

**Table 2-10: Emission Factors for Harbour Vessels**

| Pollutants | Emission Factors | | Data Source |
|---|---|---|---|
| | Kg/tonne fuel | g/kWh (output) | |
| CO | 7.4 | 1.6 | Lloyd, 1995 |
| NOx | 60.6 | 12 | Lloyd, 1995 |
| SOx * | 20 x fuel S content (wt.%)<br>2.6 | 4.2 x fuel S content (wt.%)<br>0.55 | Lloyd, 1995 |
| VOC | 2.4 | 0.5 | Lloyd, 1995 |
| PM | 1.2 | 0.2 | Lloyd, 1995 |
| $CO_2$ | 3635 | 757 | Lloyd, 1995 |
| $CH_4$ | 0.4 | 0.05** | IPCC, 1997 |
| $N_2O$ | 0.09 | 0.02** | IPCC, 1997 |
| $NH_3$ | 0.06 | 0.01** | Environment Canada, 2001b |

* Based on average S content of 0.13% (wt.) in marine diesel fuel supplied by local marketing companies (S content ranges from 0.03 to 0.31%)

** Conversion based on Lloyd

### 2.2.2 Charter Vessels

Using a combination of the listings provided in the Chartering '99 directory (Drost, 2000) and the information provided by individual chartering companies, a database of charterboats was created as a sample of the overall total. The sample consisted of 193 boat listings with a range of supplied information, and 31 companies. The yellow pages, internet, and other resources were used to estimate a total of 394 charterboat companies within the province ranging from fishing boats and sail boats to large passenger charters. As with the work boats, the mailing address of each company was used to assume the location of the charter boat homeport, and only those inside the Core Area were used. As for total number of boats, it was assumed that all of the major charter companies, having 10-25 boats were sufficiently large enough to afford advertising such that they had already been accounted for. For the remaining companies it was assumed that 75% operate only 1 boat and 25% operate 3 boats. The total number of boats was estimated to be 187.

To calculate the emissions from the charter boat segment of marine vessels the following equation was used for each of 3 different size ranges:

Charter boat emissions = Number of vessels x Assumed Engine Power (kW) x Power Load (%) x Operation time (h/year) x Portion of time in Core Area (%) x Emission Factor (g/kWh)

The emission factors used were the same as those applied to the work boats as listed in Table 2-10. The sampling of charter boats provided the distribution of boats within the 3 different engine sizes listed in Table 2-11 and the following assumptions that were then applied to the entire fleet.

- 36% sail, 64% power (sailboats were not counted)
- operate 450 h/year
- 85% of time spent in Core Area (for those boats belonging to companies with addresses within the Core Area)
- 40% power load

**Table 2-11: Distribution of Charter Boats**

| Length | Engine Assumed | | Portion of Total fleet |
|---|---|---|---|
| Ft | hp | KW | |
| 0-49 | 300 | 221 | 79.3% |
| 50-100 | 950 | 699 | 15.3% |
| Over 100 | 1400 | 1030 | 5.3% |

## 2.3 FERRIES

Table 2-12 summarises the vessel population of all ferries in the Core Area.

**Table 2-12: Vessel Count for all Ferries within the LFV**

| Company | Number of Vessels Operating Within the Core Study Area | Service Type |
|---|---|---|
| B.C. Ferries | 24 | Vehicle/passenger |
| SeaBus | 2 | Passenger |
| Aquabus | 10 | Passenger |
| Granville Island Ferries | 9 | Passenger |
| Albion Ferry | 2 | Vehicle/passenger |
| Barnston Island Ferry | 1 | Vehicle/passenger |

### 2.3.1 Emission Factors and Base Quantities

Pollutant specific emission factors for underway-medium speed vessels, developed by Lloyd (1995) and others, are shown in Table 2-13. These factors were applied to the above fuel quantities to obtain ferry emission estimates for year 2000 for all ferries including B.C. Ferries for underway emissions only.

**Table 2-13: Emission Factors for all Ferries**

| | | NOx | CO | VOC | PM | |
|---|---|---|---|---|---|---|
| ***Emission Factor*** | ***Diesel [Kg/T]*** | 60.64 | 7.4 | 2.4 | 1.2 | |
| | ***Gasoline [g/HP-Hr]*** | 5.4 | 151 | 9.1 | 0.07 | |
| | | **$CO_2$** | **$N_2O$** | **$CH_4$** | **$NH_3$** | **$SO_x$** |
| ***Emission Factor*** | ***Diesel [Kg/T]*** | 3,170 | 1.16 | 0.17 | 0.006 | 20(%S*) |
| | ***Gasoline [g/L]*** | 2360 | 0.06 | 1.3 | 0.00267 [Kg/engine] | ** |

* Where sulphur content varies with Ferry Company

** $SO_2$ emissions are assumed to be 2x the S emissions (%wt) based on fuel consumption.

With the exception of BC Ferries, requests for available 2000 ferry fuel use and vessel statistics were made and compiled for all other ferry companies within the Core Area. These requests include fuel use for each vessel and the fuel sulphur content as well as vessel specific data shown below for each ferry company. Due to the very slight contribution of the "other" ferry companies to the total emissions within the LFV, a breakdown of the emissions by movement type was not completed. Therefore, although the power rating information was provided by most of the other ferry companies, it was not considered in the calculations. The emissions were calculated based on fuel consumption using underway emission factors only.

### 2.3.2 B.C Ferries

The entire fleet of B.C. Ferries accounts for up to 40 vessels in total. However, only 24 of these vessels travel within the Core Area on 6 of the 25 routes covered by B.C. Ferries. Moreover, some of these routes are not entirely within the Core Area requiring a calculation of the fraction of travel to allocate the proportion of emissions within the core study area. Three ferry terminals fall within the boundary, namely: Horseshoe Bay, Tsawwassen, and Bowen Island.

Table 2-14 shows the fractions used for each route within the LFV. The source of these fractions is the 1993 emission inventory for which B.C. Ferries provided the length of trip within the LFV and the total length of trip.

**Table 2-14: Fraction of B.C. Ferries Trip within the LFV by Route**

| Route # | Portion* of Service Emissions |
|---|---|
| 1 Tsawwassen/Swartz Bay | 7.2% |
| 2 Horseshoe Bay/Nanaimo | 26.1% |
| 3 Horseshoe Bay/Langdale | 71.4% |
| 8 Horseshoe Bay/Snug Cove | 100% |
| 9 Tsawwassen/Gulf Islands | 6.7% |
| 30 Nanaimo/Tsawwassen | 32.4% |

* portion = (Length of trip in LFV)/(Total length of trip)

B.C. Ferries undertook an independent emissions study of their fleet for the year 2000 that was provided to Levelton for the purpose of this study, along with fuel consumption data for the calculation of the emissions not considered in their study. However, the results provided were based on the fact that the entire volume of fuel on each route is consumed during underway travel. These conservative (for the most part) results therefore required adjustment to provide a more realistic representation of emissions from the B.C. Ferries fleet. Accordingly, a breakdown of the fuel consumed per route was assumed in terms of dockside, manoeuvring and underway movement using appropriate emission factors and/or fractions. This type of breakdown was not done for the greenhouse gases.

The load factors applied in calculating emissions from B.C. Ferries are shown in Table 2-15. These were required when no other information was available in terms of specific emission factors (for the different power ratings for idling, manoeuvring and underway).

**Table 2-15: Load Factors for B.C. Ferries**

| | |
|---|---|
| Dockside | 0.2 |
| Manoeuvering | 0.4 |
| Underway | 0.8 |

B.C. Ferries also included lay-up emissions separately. Lay-up emissions are those that occur whilst ships are being repaired (i.e. not in service). They occur mostly within the LFV at Deas Dock in Richmond. Of the six docks at which lay-up emissions are generated, 3 are within the core study area. Based on discussion with BC Ferries, it was assumed that 80% of total lay-up emissions from the entire B.C. Ferries fleet occurs within the LFV. Once again, B.C. Ferries assumed the lay-up emissions to occur entirely at the underway power level. An adjustment was required to calculate lay-up emissions at 90% dockside and 10% manoeuvring power levels based on discussion with B.C. Ferries. The calculations applied to both in service and lay-up emissions are explained below and the results are sub-sectioned into the three power levels shown in Table 3.1.

#### *2.3.2.1 Calculation of Dockside Emissions for B.C. Ferries*

Table 2-16 shows the dockside emission factors for B.C. Ferries developed by Environment Canada shown in the "B.C. Ferries Emissions Test Program" (1998) report.

**Table 2-16: Main Engine Dockside Emission Factors for B.C. Ferries**

| Pollutant | BCFC Factors* [Kg/T] |
|---|---|
| $NO_x$ | 72.1 |
| CO | 8.2 |
| $NH_3$ | 0.006 |
| PM | 3.7 |

* source "B.C. Ferries Emissions Test Program", Environment Canada, 1998

The calculation of dockside emissions differed from pollutant to pollutant. Depending on whether there was an available dockside emission factor (shown in Table 2-16 above), the following equation was used:

***Dockside emissions = Total fuel consumption x Emission factor x fraction of time***

***Where;***

***Total fuel consumption ® provided by B.C. Ferries (year 2000)***

***Emission Factor ® shown in Table 2-16***

***Fraction of time ® assumed for each route (see Table 2-17)***

A profile was assumed for each route in terms of fraction of time spent at each power (load) level. These are shown in table 2-17 below.

**Table 2-17: Fraction of Time Spent at each Power Level for all B.C. Ferries Routes Within the LFV**

| | Route 1 | Route 2 | Route 3 | Route 8 | Route 9 | Route 30 |
|---|---|---|---|---|---|---|
| Dockside | 0.2 | 0.2 | 0.1 | 0.2 | 0.2 | 0.2 |
| Maneuvering | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| Underway | 0.7 | 0.7 | 0.8 | 0.7 | 0.7 | 0.7 |

The emissions from the pollutants without available dockside emission factors had to be calculated based on the equation below:

***Dockside Emission =*** ***Underway Emissions (assumed at 100% underway) x dockside load factor/underway load factor x fraction of time at dockside power level***

This calculation is based on the assumption that there is a linear relationship between power rating and fuel consumption.

### *2.3.2.2 Calculation of Manoeuvring Emissions for B.C. Ferries*

The manoeuvring emissions for B.C. Ferries were calculated in one of two ways. Fractions were available relating manoeuvring emissions to underway emissions for medium speed engines from the "Marine Exhaust Emissions Research Program" (Lloyds Register, 1995). The fractions were only available for HC, CO and $NO_x$ since " From the emission profiles recorded, it was apparent that HC, CO and $NO_x$ emission concentrations were *principally* related to engine load and speed." (Lloyds Register, 1995). These factors are shown in table 2-18 below.

**Table 2-18: Manoeuvring/Underway Fractions for B.C. Ferries***

| | HC | CO | $NO_x$ |
|---|---|---|---|
| Ratio of Manoeuvring / Underway emissions | 1.5 | 3.8 | 0.9 |

* Source: Lloyds Register (1995) – Standardized for time and fuel consumption

Since these factors have been standardized for fuel consumption as well as for time, there was no need to incorporate the power rating in the calculation for the pollutants listed above. The calculation used was:

***Manoeuvring Emissions =*** ***[Fraction (table 2-18)]*[Emission assumed at 100% underway]*[fraction of time spent at Manoeuvring power level]***

The emissions for the pollutants not listed above were calculated based on the fraction of manoeuvering power rating over underway (shown in Table 2-18 above) as well as the portion of time spent at this power level. The base quantity used was the emissions based on 100% underway emissions (as provided by BC Ferries).

#### *2.3.2.3 Calculation of Underway Emissions for B.C. Ferries*

The underway emissions required a straightforward change to the original results that were based on the assumption that 100% of the fuel consumed was at the underway power level. The calculation was the portion of time spent at this power level (underway) multiplied by the original value directly.

### 2.3.3 SeaBus

The SeaBus is operated by the Greater Vancouver Transportation Authority (GVTA), and runs between Lonsdale Quay in North Vancouver and the Waterfront terminal at the foot of Granville Street in Vancouver. The data shown in Table 2-19 was provided by SeaBus.

**Table 2-19: SeaBus Fuel and Vessel Data**

| Specification | Value |
|---|---|
| Total Fuel Consumption for the year 2000 | 1,000,000 L of #2 diesel (0.05% S) |
| Number of Vessels | 2 |
| Primary engines | 1400 HP |
| Auxiliary engines | 360 HP |
| Approximate power level used during 15 minute trip | 80% for 7 minutes<br>50% for 5 minutes<br>10% for 3 minutes |
| Hours of Operation (per year) | 10,500 Hrs – 10,800Hrs (total) |
| Trip frequency* | 15 mins (Mon-Sat, 6am-7pm)<br>30 mins (Mon-Sat, 7pm-1am)<br>30 mins (Sun & Hol, 8am – 11:30pm)<br>15 mins (Sun & Hol, Jul-Sep, 10am – 6pm) |

* Used for temporal profile only

### 2.3.4 Aquabus/Granville Island Ferries

The Aquabus and Granville Island Ferry companies run between Granville Island, Hornby Street in downtown Vancouver, Yaletown, Stamps Landing and Science World. Both ferries run year round. Table 2-20 shows the specifications provided from each company.

**Table 2-20: Aquabus and Granville Island Fuel and Vessel Data**

| Aquabus Ferries | | Granville Island Ferries | |
|---|---|---|---|
| **Specification** | **Value** | **Specification** | **Value** |
| # of vessels | 9-Diesel<br>1-Gasoline | # of vessels | 8-Diesel<br>1-Electric* (n/a) |
| Fuel Consumption | 40,000L Diesel<br>2000L Gasoline | Fuel Consumption | 47,000L- Diesel |
| Sulfur Content | 0.5% in Diesel<br>0.015% in Gasoline | Sulphur Content | 0.5% |
| Hours of Operation | 30,000 Hrs (Total) | Hours of Operation | 44,300 Hrs (Total) |
| Approximate power level used | -50% power for 25% of time<br>-100% power for 75% of time | Approximate power level used | -30% of time at idle<br>-70% of time at 60% power |
| Power rating | Diesel (20HP-35HP)<br>Gasoline (9.9HP) | Power rating | 18HP-29HP |

* The emissions from the electric powered vessel are considered to be negligible in terms of exhaust emissions and are therefore not considered in this inventory.

### 2.3.5 Albion Ferry

The Albion Ferry is operated by Fraser River Marine Transportation, a subsidiary of the Greater Vancouver Transportation Authority. It runs approximately 21 hours per day across the Fraser River between Fort Langley and River Road in Maple Ridge. Table 2-21 shows the data on the vessels used.

**Table 2-21: Albion Ferry Fuel and Vessel Data**

| Specification | Value |
|---|---|
| # of vessels | 2 |
| Fuel Consumption | 553,176L of Diesel |
| Sulphur Content | 0.05% |
| Hours of Operation | Approx.10,000 Hrs |
| Approximate power level used | -Idle for 40% of time<br>-75% power 60% of time |
| Power rating | 2 engines at 325 HP |

### 2.3.6 Barnston Island Ferry

The Barnston Island Ferry operates under the Marine Branch of the Ministry of Transport running between Port Kells and Barnston Island upon demand. The data provided pertains to the vessel activity during the year 2000, as shown in Table 2-22.

**Table 2-22: Barnston Island Ferry Fuel and Vessel Data**

| Specification | Value |
|---|---|
| # of vessels | 1 |
| Fuel Consumption | 80,000L Diesel |
| Sulphur Content | 0.5% |
| Hours of Operation | 5,350 Hrs |
| Power rating | 380 HP |

## 2.4 FISHING VESSELS

Due to the difficulty in tracking fishing boat movements, activity levels and fuel consumption, and the small contribution of emissions from this category to the overall results, fishing vessel emissions in the LFV have been estimated based on "boat days", which represents how many boats were out for a given period of time. The methodology and assumptions used in the 1993 inventory have been reviewed. However, the fishing activity has changed so dramatically since 1993, in terms of vessel count and fishing time that the extrapolation of 1993 results to 2000 was considered unreliable. The final emission results were developed using the equation shown in section 2.4.2.

### 2.4.1 Vessel Population and Data Collection (Management Areas 28 and 29)

For the Core Area, only the activity in fishery management areas 28 and 29 was considered. Figure 2-2 and 2-3 below, show the location of both these areas within the area of study. The three main vessel types were tabulated: Gillnetters, Trollers and Seiners. The assumptions below are based on discussion with the DFO:

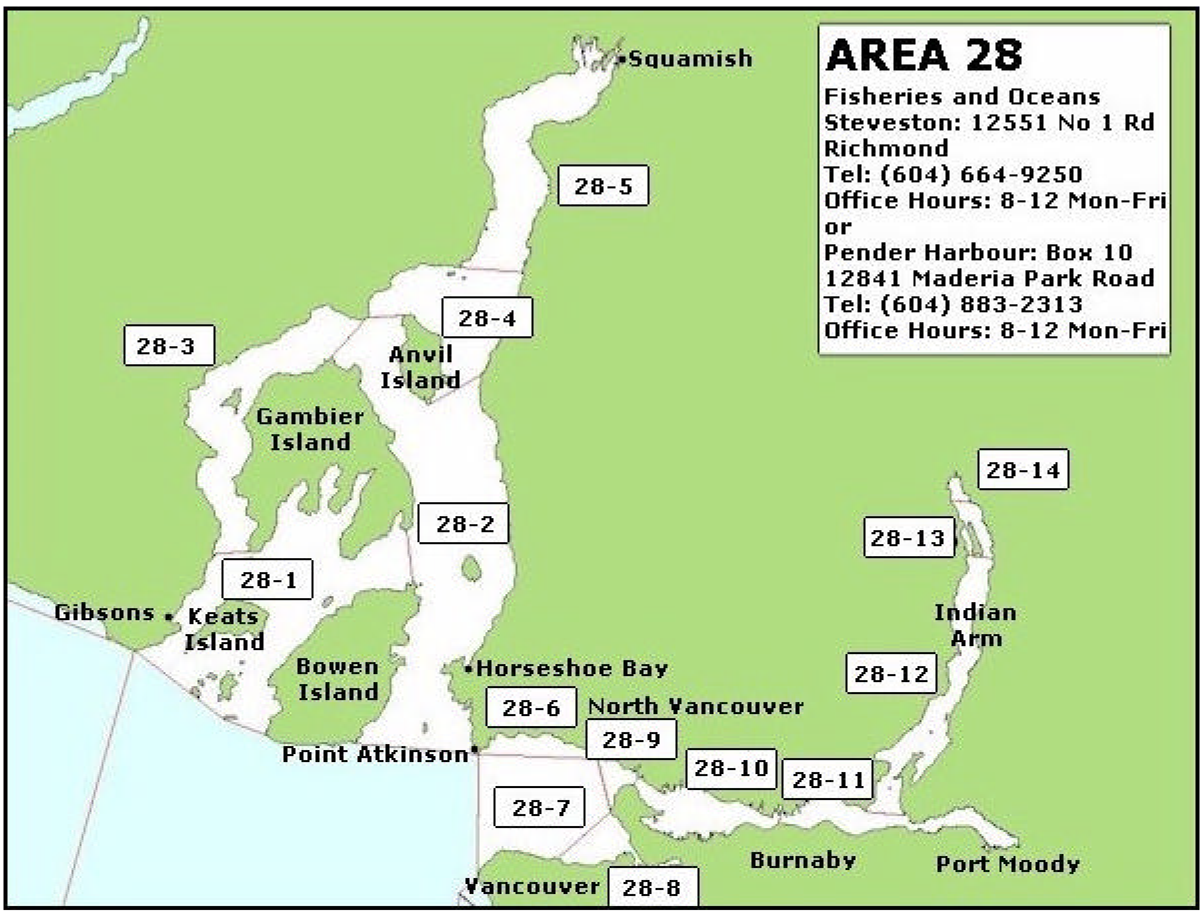
- Area 28 had no commercial fishing activity throughout the year 2000.
- It was assumed that very little First Nations fishing occurred in area 28 (from chartered commercial gearity). Discussion with the DFO and research on First Nations fishing activity* indicates that fishing occurs primarily on the river which falls into area 29. (No results were tabulated for area 28 First Nations in this study).
- Area 29 had commercial fishing using Gillnetters and Trollers only.
- First Nations chartered Gillnetters only in area 29.
- There was no use of Seiners for commercial fishing in the year 2000 in area 29.
- There was some First Nations Seiner fishing but the numbers are small and the hours of operation slight**. (Not considered in this study)

- Based on discussion with various employees of the DFO, the commercial fishing vessel fleet from 1995 on is approximately half of what it was in 1993
- Although commercial fishing has dropped tremendously throughout the years, there has been an increase in First Nations fishing activity in area 29.

* Source: Restructuring Canada's Pacific Fishery (Volume 3-Issue 1-June 2000).
** Source: Department of Fisheries and Oceans

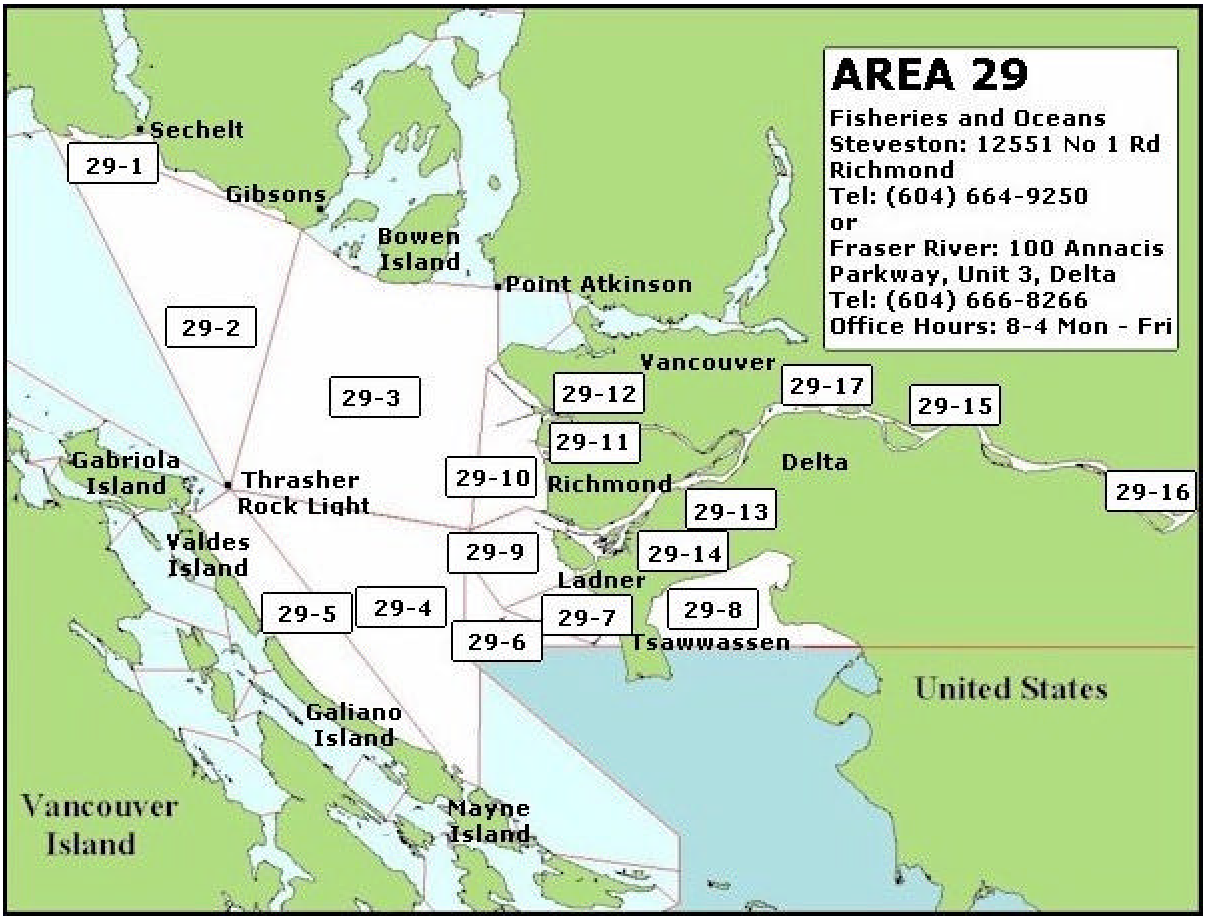
Although no fishing was accounted for in area 28 for the year 2000, a map is included in this report (Figure 2-2) for information purposes only as well as a map of area 29 shown in figure 2-3. Most of the First Nations fishing activity in this area falls along the Fraser river in sub-areas 29-13 to 29-17 inclusively with some commercial fishing activity as well. The remainder of the sub-areas within the area of study, 29-6 to 29-12 inclusively accounts mainly for commercial fishing. For interests sake, the small amount of First Nations chartered Seiner fishing not accounted for in this report, due to very small numbers, occurs within area 29-9. Most of the commercial fishing activity emissions occurs within sub-areas 29-10 and 29-9.

**Figure 2-2.4-1:DFO Management Area 28** (DFO Website*, 2002)




* URL: www.pac.dfo-mpo.gc.ca/ops/fm/Areas/areamap.htm

**Figure 2-2.4-2:DFO Management Area 29** (DFO Website*, 2002)




* URL: www.pac.dfo-mpo.gc.ca/ops/fm/Areas/areamap.htm

Table 2-23 below shows the data provided in part by the DFO for the year 2000.

**Table 2-23: Data on Fishing Vessels Provided by the DFO**

| Area of Management | Fishing Vessel Type | Engine Population 2000 | Percent of Fishing Activity Recorded | Hours of Use at specified load factor | Power (KW) | load factor |
|---|---|---|---|---|---|---|
| **29** | Gillnetter (Comm.) | **1861** | 82 % | 4 | 224 | 0.71 |
| | Gillnetter (F.N.) | **240** | 11% | 4 | 224 | 0.71 |
| | Seiner (F.N.) | **0** | 0% | 0 | 373 | 0.5 |
| | Troller (Comm.) | **182** | 7% | 15 | 250 | 0.5 |

*Note: No fishing activity recorded in Area 28.*

### 2.4.2 Emission Calculations

Following numerous discussions with the DFO, it was agreed that while fishing, Gillnetters are at 0% power while Trollers and Seiners fish at 50% power. With this in mind, the emissions from Gillnetters (largest portion of fishing activity) were calculated based on travel time to and from the fishing locations at 71% load. This was confirmed by the DFO to be ¼ of the total fishing time. The emissions from Trollers, were calculated based on the time spent fishing at 50% power. In this case, the total hours of fishing (fishing time and travel between openings) provided by the DFO was accounted for. The equation used for these calculations is shown below:

***Emissions (g) =*** ***Engine Population x Hours of Use per Vessel x Power x Load Factor x Emission Factor***

*Where:*

*Engine Population = number of vessels per management area (see Table 2-23)*

*Hours of Use Per Vessel [Hrs] = Hours used based on data provided by DFO (see Table 2-23)*

*Power [kW]= 224kW (Gillnetter); 373kW (Seiner); 250kW (Troller)*

*Load Factor = 71% (Gillnetters); 50% Trollers*

*Emission Factor [g/kWh] = see Table 2-24 below*

The overall emission results are shown in Table 3-1 in Section 3 of this report.

### 2.4.3 Emission Factors

The emission factors used were developed by Lloyds Register (1995) for medium speed vessels at steady state.

Table 2-24 shows the emission factors applied to the equation.

**Table 2-24: Emission Factors for Fishing Vessels**

| | $CO_2$ | $CH_4$** | $N_2O$** | $NH_3$** | VOC | NOx | CO | PM | SOx |
|---|---|---|---|---|---|---|---|---|---|
| Emission Factor (g/kWh) | 660 | 0.06 | 0.02 | 0.01 | 0.5 | 12 | 1.6 | 0.2 | 0.55 |

Source: Lloyds, 1995

** Conversion based on Lloyds

## 2.5 RECREATIONAL VESSELS

### 2.5.1 Vessel Population

Recreational vessel population for the year 2000 was estimated following the review of three separate data sources. The first data source comes from a recent report, which was commissioned by the Transportation Table of the National Climate Change Process. This report examined GHG emissions and mitigation measures for off-road vehicles and equipment including recreational marine engines (ICF Kaiser, 1999). The study provided estimates of 1997 national and provincial recreational vessel counts, which were based on data available from Statistics Canada as well as prorated vessel counts based on an EPA non-road engine and vehicle emission study (EPA, 1991). According to this ICF Kaiser report, B.C. accounted for 15.9% of the national vessel population in 1997 and the estimated growth rate in recreational vessel population is 1.84% annually. Based on these 2 assumptions, the estimated total B.C. recreational vessel population for 2000 was obtained, which was then prorated to the LFV study area based on LFV to B.C. population ratio for 2000. Estimated LFV vessel population based on this ICF Kaiser study is given in Table 2-25.

For validation, the above vessel counts were compared to estimates that were projected from the 1993 LFV marine vessel emissions inventory based on the same annual vessel growth rate of 1.84%. The 1993 estimates were used as another data source for comparison because these were based on actual survey data by the Marine Trades Association of B.C. The projected estimates for LFV for 2000 are also given in Table 2-25.

Another data source was a 1996 Small Vessel Inventory compiled by Consulting and Audit Canada (Consulting and Audit Canada, 1996). Vessel data was compiled based on a survey of about 80 households in each province. The 1996 B.C. data from this inventory was again projected to 2000 using the same growth rate as determined in the ICF Kaiser study. Vessel counts for the LFV, shown in Table 2-25, were subsequently prorated from the provincial estimates based on LFV to B.C. population ratio.

**Table 2-25: Comparison of Recreational Vessel Counts for the LFV for 2000**

| | 2000 LFV Vessel Population[1,2,3] | 2000 LFV Vessel Population[2] | 2000 LFV Vessel Population[2,3] | Estimated 2000 LFV Vessel Population[4] |
|---|---|---|---|---|
| Data Source | ICF Kaiser | 1993 Inventory | Small Vessel Inventory | |
| Outboard | 79,561 | 112,991 | 73,950 | 73,217 |
| Inboard | 11,050 | 2,511 | | 10,170 |
| Out/Inboard/Sterndrive | 24,109 | 12,554 | | 22,187 |
| Personal Watercraft (PWC) | 49,555 | 0 | 1,174 | 25,364 |
| Totals: | | | | |
| Powered vessels | 114,720 | 128,056 | 73,950 | 105,575 |
| PWC | 49,555 | 0 | 1,174 | 25,364 |
| All powered vessels | 164,275 | 128,056 | 75,124 | 130,939 |

[1] Projection based on B.C.'s share of 15.9% of national vessel population
[2] Annual vessel growth rate of 1.84% assumed
[3] Proration based on LFV to B.C. population ratio
[4] Totals represent averages while breakdown of vessel counts by category is according to ICF Kaiser study

As evident in the data presented in Table 2-25, recreational vessel counts for each vessel category can differ by an order of magnitude amongst the three data sources. In terms of total powered vessel counts, the projected ICF Kaiser and 1993 inventory data appears to be consistent. Personal watercrafts, such as Jet Skis and SeaDoos, were not included in the 1993 inventory. Vessel count estimates based on the 1996 Small Vessel Inventory do not distinguish outboard, inboard and sterndrive categories, but were consistently low overall, when compared to the other two data sources. The accuracy of this survey could be affected by the small survey sample size of 80 out of over 1.4 million households in B.C in 1996. Since none of the three data sources stands out as being more reliable or accurate than the others, averaged values, also shown in Table 2-25, were used for this inventory to approximate the recreational vessel population in LFV in 2000.

### 2.5.2 Fuel Consumption

Fuel consumption for a marine engine can be estimated based on its engine type, power rating, load factor, hours of use and the brake specific fuel consumption. The majority of available data for these parameters is based on findings of U.S. studies. Although these findings may not fully represent the local recreational vessel population, this data was adopted to the extent where appropriate, as the literature search for this project did not identify any local data source. Table 2-26 summarises the engine characteristics as well as the estimated fuel consumption for each type of recreational vessel in B.C. for 2000.

**Table 2-26: Engine Characteristics and Fuel Consumption**

| | Engine Type | Rated Power HP[1] | Load Factor[1] | Hours in use[1] | BSFC[2] gal/HP-h | B.C. 2000 Fuel Use m3/y |
|---|---|---|---|---|---|---|
| Inboard | 4 stroke | 164 | 0.38 | 93 | 0.100 | 20,095 |
| | Diesel | 244 | 0.35 | 88 | 0.038 | 1,171 |
| Outboard | 2 stroke | 170 | 0.32 | 48 | 0.149 | 187,391 |
| | 4 stroke | 36 | 0.32 | 48 | 0.116 | 817 |
| Sterndrive (inboard) | 2 stroke | 164 | 0.38 | 73 | 0.149 | 942 |
| | 4 stroke | 164 | 0.38 | 73 | 0.100 | 61,409 |
| | Diesel | 236 | 0.32 | 88 | 0.038 | 4,074 |
| Personal Watercraft | 2 stroke | 86 | 0.4 | 41 | 0.160 | 39,242 |
| Sailboat auxiliary inboard | 4 stroke | 10 | 0.35 | 10 | 0.138 | 43 |
| | Diesel | 27 | 0.32 | 10 | 0.054 | 104 |
| Sailboat auxiliary outboard | 2 stroke | 7 | 0.32 | 10 | 0.220 | 40 |
| | Diesel | 7 | 0.32 | 10 | 0.054 | 0.02 |
| Total gasoline ($m^3$/y) | | | | | | 309,979 |
| Total diesel ($m^3$/y) | | | | | | 5,349 |

[1] CARB, 1998
[2] Brake Specific Fuel Consumption, data per CARB, 1995

The fuel consumption estimates in Table 2-26 appear to be unreasonably high when compared to fuel consumption estimates from StatsCan for domestic marine transportation. Table 2-27 lists the fuel consumption figures from StatsCan for domestic marine fuels consumption in B.C. and the estimated quantities of gasoline and diesel used by recreational vessels.

**Table 2-27: Provincial marine fuels consumed by Recreational Vessels**

| | B.C. Domestic Marine Transport Fuel Use[1] | | | 2000 B.C. Fuel Use for Recreational Vessels |
|---|---|---|---|---|
| **Data Source** | **StatsCan1993** | **StatsCan 1996** | **StatsCan 2000** | |
| Gasoline ($m^3$/y) | 19,600 | 15,500 | 17,550[2] | 14,640[3] |
| Diesel ($m^3$/y) | 331,600 | 339,700 | 252,300 | 1,539[4] |

[1] StatsCan Catalogue 57-003-XPB "Refined Petroleum Products", Table 12D
[2] 2000 value not available, entry is average of 1993 and 1996 values
[3] Based on estimate of marine gasoline sold to recreational vessels in the LFV in 1993 (83.6%)
[4] Based on estimate of marine diesel sold to recreational vessels in the LFV in 1993 (0.6%)

The fuel consumption estimates given in Table 2-26 will need to be reduced by 95% for gasoline and 71% for diesel, respectively, in order to be consistent with estimates based on Statistics Canada data shown in Table 2-27. Since local marketing sales data was not available at the time of this report, the above fuel use adjustments were made to arrive at estimates of recreational vessel fuel use in the LFV in 2000. The adjusted fuel consumption rates are shown in Table 2-28.

In the 1993 inventory, recreational vessel fuel use in the LFV was further reduced assuming that 65% of fuel purchased in the LFV was consumed in this area. Considering there is also fuel purchased outside the LFV that is being burned in this area, this 65% adjustment has not been applied to the data shown in Table 2-28.

**Table 2-28: Fuel Consumption Estimates for Recreational Vessels**

| | Engine Type | Adjusted 2000 B.C. Recreational Vessel Fuel Use ($m^3/y$) | Estimated 2000 LFV Fuel Consumption | | |
|---|---|---|---|---|---|
| | | | $m^3/y$[1] | kg/y[2] | kWh/y[3] |
| Inboard | 4 stroke | 949 | 523 | 386,497 | 1,030,319 |
| | Diesel | 337 | 186 | 158,007 | 960,388 |
| Outboard | 2 stroke | 8,850 | 4,876 | 3,604,096 | 6,456140 |
| | 4 stroke | 39 | 21 | 15,717 | 36,208 |
| Sterndrive (inboard) | 2 stroke | 44 | 25 | 18,110 | 32,441 |
| | 4 stroke | 2,900 | 1,598 | 1,181,079 | 3,148,508 |
| | Diesel | 1,172 | 646 | 549,403 | 3,340,284 |
| Personal Watercraft | 2 stroke | 1,853 | 1,021 | 754,747 | 1,280,414 |
| Sailboat auxiliary inboard | 4 stroke | 2 | 1 | 819 | 1,576 |
| | Diesel | 30 | 16 | 13,977 | 60,273 |
| Sailboat auxiliary outboard | 2 stroke | 2 | 1 | 771 | 933 |
| | Diesel | 0.005 | 0.003 | 2 | 10 |
| Total gasoline vessels | | 14,640 | 8,066 | 5,961,835 | 11,966,540 |
| Total diesel vessels | | 1,539 | 848 | 721,390 | 4,360,955 |

[1] Prorated based on population
[2] Based on gasoline density of 6.16 lb/gal (0.74 kg/l) and diesel density of 7.09 lb/gal (0.85 kg/l)
[3] Based on BSFC data shown in Table 2-26

### 2.5.3 Emission Factors

For recreational gasoline and diesel engines, published emission factors were available and these are summarised in Tables 2-29 and 2-30 for common air contaminants and greenhouse gases, respectively. These emission factors were applied to the base quantities listed in Table 2-28 to arrive at annual emission estimates. $SO_x$ emissions were based on the sulphur content of the fuel burned. Based on information from local marine vessel operators, the sulphur content of marine gasoline and diesel are about 0.015 wt.% and 0.13 wt.%, respectively. As a conservative estimate, all fuel sulphur has been assumed to be completely burned.

**Table 2-29: Recreational Vessel Emission Factors for Common Air Contaminants**

| | | HC[1] (g/kWh) | $NO_x$[1] (g/kWh) | CO[1] (g/kWh) | PM[1] (g/kWh) |
|---|---|---|---|---|---|
| Inboard | 4 stroke | 12 | 7.2 | 202 | 0.09 |
| | Diesel | 3.5 | 15 | 6.3 | 0.5 |
| Outboard | 2 stroke | 142 | 1.5 | 327 | 9.5 |
| | 4 stroke | 12 | 7.2 | 202 | 0.09 |
| Sterndrive (inboard) | 2 stroke | 142 | 1.5 | 327 | 9.5 |
| | 4 stroke | 12 | 7.2 | 202 | 0.09 |
| | Diesel | 3.5 | 15 | 6.3 | 0.5 |
| Personal Watercraft | 2 stroke | 193 | 1.1 | 353 | 9.2 |
| Sailboat Auxiliary Inboard | 4 stroke | 12 | 7.2 | 202 | 0.09 |
| | Diesel | 3.5 | 15 | 6.3 | 0.5 |
| Sailboat Auxiliary Outboard | 2 stroke | 142 | 1.5 | 327 | 9.5 |
| | Diesel | 3.5 | 15 | 6.3 | 0.5 |

[1] CARB, 1998

**Table 2-30: Recreational Vessel Emission Factors for GHGs and Ammonia**

| | | $CH_4$[1] (g/kg) | $N_2O$[1] (g/kg) | $CO_2$[1] (g/kg) | $NH_3$[2] (g/kg) |
|---|---|---|---|---|---|
| Inboard | 4 stroke | 1.7 | 0.08 | 3,200 | 0.00267 |
| | Diesel | 0.18 | 1.3 | 3,140 | 0.006[3] |
| Outboard | 2 stroke | 5.1 | 0.02 | 3,200 | 0.00267 |
| | 4 stroke | 1.7 | 0.08 | 3,200 | 0.00267 |
| Sterndrive (inboard) | 2 stroke | 5.1 | 0.02 | 3,200 | 0.00267 |
| | 4 stroke | 1.7 | 0.08 | 3,200 | 0.00267 |
| | Diesel | 0.18 | 1.3 | 3,140 | 0.006[3] |
| Personal Watercraft | 2 stroke | 5.1 | 0.02 | 3,200 | 0.00267 |
| Sailboat Auxiliary Inboard | 4 stroke | 1.7 | 0.08 | 3,200 | 0.00267 |
| | Diesel | 0.18 | 1.3 | 3,140 | 0.006[3] |
| Sailboat Auxiliary Outboard | 2 stroke | 5.1 | 0.02 | 3,200 | 0.00267 |
| | Diesel | 0.18 | 1.3 | 3,140 | 0.006[3] |

[1] IPCC, 1997
[2] Environment Canada, 2001b
[3] Factors are in kg/engine

## 2.6 POLLUTANT SPECIATION PROFILES

### 2.6.1 Nitrogen Oxides

Nitrogen oxides ($NO_X$) in marine engine exhaust consist of NO and $NO_2$. In its emissions testing program, Lloyd's Register of Shipping has examined the NO to $NO_X$ ratio under various engine load conditions for several marine fuel types (Lloyd's, 1995). NO accounts for about 94% of $NO_X$ emitted and the balance is made up of $NO_2$. This speciation profile was used in this inventory.

### 2.6.2 Sulphur Oxides

$SO_2$ accounts for about 98% of total sulphur oxides ($SO_X$) from fuel combustion (EPA, 1999). A small portion, about 1 to 3%, is $SO_3$. In the presence of moisture, such as in engine exhausts, the $SO_3$ will be completely converted to $H_2SO_4$. For this inventory, $SO_2$ has been assumed to account for 98% of $SO_X$, while the balance is made up of $SO_4^=$.

### 2.6.3 Particulates

The inhalable ($PM_{10}$) and fine ($PM_{2.5}$) fractions of the emitted particulate can lodge deep in the respiratory tract and result in adverse health impacts. According to a recent report by Lloyd's Register of Shipping (Lloyd's, 1995), the size of particulate found in marine vessel exhausts is very small, likely to be below 1um in diameter. The Air Resources Board of California has used the particulate profiles developed from land-based engines for marine diesel and gasoline engines. The $PM_{10}$ and $PM_{2.5}$ fractions, as adopted by CARB, both accounted for over 95% of the total particulate emitted. As a conservative first approximation, it has been assumed that the particulate emitted from marine engine exhausts is all below 2.5µm.

## 2.7 REPORTING OF EMISSION RESULTS

Emission factors in this Section 2 for NOx are expressed as the sum of NO and $NO_2$, based on the speciation profiles described above and are not expressed as $NO_2$-equivalent emissions. The emission results reported in Section 3 of this report also report NO and $NO_2$ at full molecular weight, however the NOx totals reported in Section 3 are corrected to $NO_2$-equivalent emissions.

Similarly, emission factors for SOx are expressed as the sum of $SO_2$ and $SO_4^=$ and are not expressed as $SO_2$-equivalents. The emission results in Section 3 report sulphur oxides species at full molecular weight but express total SOx as $SO_2$-equivalent emissions.

The greenhouse gas emission factors and results are reported as $CO_2$, $CH_4$ and $N_2O$, and summed to total GHG in $CO_2$-equivalent emissions based on the respective GWPs of each gas.

# 3. Emission Results

## 3.1 Overall Emissions for the Lower Fraser Valley

The emission results presented throughout this section are presented in 2 parts, criteria air contaminants (CACs) and greenhouse gas (GHGs) emissions. Criteria contaminants include CO and VOC, and $NO_x$, $SO_x$ and PM, reported as totals and with breakout of individual species. In all cases the PM emissions reported can be taken as equal to $PM_{10}$ and $PM_{2.5}$ emission values, i.e. 100% of the particulate matter is $PM_{2.5}$ or finer. Ammonia is reported with CACs. The greenhouse gas emission estimates presented in this section include $CO_2$, $CH_4$, and $N_2O$, as well as their $CO_2$ equivalent emissions. $CO_2$ equivalency is based on the 100 year global warming potential (GWP) multiplier of 21 times for $CH_4$ , and 310 times for $N_2O$ emissions. The criteria contaminants emission totals for marine vessels in the Lower Fraser Valley are shown in Table 3-1, and greenhouse gases in Table 3-2.

**Table 3-1: CAC and $NH_3$ Emissions for the Lower Fraser Valley for 2000**

| | emissions (tonnes/year) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | CO | VOC | NOx | | | SOx | | | PM ‡ | $NH_3$ |
| | | | total NOx* | NO | $NO_2$ | total SOx† | $SO_2$ | $SO_4^=$ | | |
| **Ocean Going Vessels** | | | | | | | | | | |
| Dockside | 418 | 179 | 7,189 | 4,501 | 287 | 3,795 | 3,744 | 76 | 560 | 1 |
| Manoeuvring | 85 | 5 | 640 | 400 | 26 | 48 | 47 | 1 | 32 | 8 |
| Underway | 163 | 51 | 2,756 | 1,725 | 110 | 1,043 | 1,029 | 21 | 153 | 36 |
| **Subtotal** | 666 | 235 | 10,584 | 6,627 | 423 | 4,886 | 4,821 | 98 | 745 | 44 |
| **Harbour Vessels** | | | | | | | | | | |
| workboats and tugboats | 409 | 128 | 4,911 | 3,075 | 196 | 140 | 138 | 3 | 51 | 3 |
| charters | 14 | 0 | 166 | 104 | 7 | 5 | 5 | 0 | 2 | 0 |
| **Subtotal** | 423 | 128 | 5,077 | 3,179 | 203 | 144 | 142 | 3 | 53 | 3 |
| **Ferries** | | | | | | | | | | |
| B.C. Ferries | | | | | | | | | | |
| Dockside | 33 | 2 | 430 | 269 | 17 | 5 | 5 | 0 | 3 | 0 |
| Manoeuvring | 62 | 8 | 171 | 107 | 7 | 6 | 6 | 0 | 1 | 0 |
| Underway | 119 | 38 | 1,371 | 859 | 55 | 87 | 87 | 0 | 19 | |
| Layup | 20 | 2 | 207 | 130 | 8 | 3 | 3 | 0 | 7 | 0 |
| Subtotal B.C. Ferries | 234 | 51 | 2,180 | 1,365 | 87 | 101 | 101 | 0 | 30 | 0 |
| SeaBus | 6 | 2 | 83 | 52 | 3 | 1 | 1 | < 0.02 | 1 | < 0.005 |
| Aquabus/Granville Island | 24 | 2 | 33 | 20 | 1 | 3 | 3 | < 0.02 | < 0.5 | < 0.005 |
| Albion Ferries | 4 | 1 | 43 | 27 | 2 | < 1 | 0 | < 0.02 | 1 | < 0.005 |
| Barnston Island | 1 | < 0.5 | < 7 | 4 | < 0.5 | 1 | 1 | < 0.02 | < 0.1 | < 0.0005 |
| **Subtotal Ferries** | 268 | 56 | 2,344 | 1,468 | 93 | 108 | 107 | 2 | 32 | 0 |
| **Fishing Vessels** | | | | | | | | | | |
| Gillnetters | 2 | 1 | 24 | 15 | 1 | 1 | 1 | < 0.02 | <0.3 | <0.02 |
| Seiners | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Trollers | 0 | 0 | < 6 | 4 | <0.3 | < 0.2 | <0.2 | <0.004 | <0.07 | <0.004 |
| **Subtotal** | 2 | 1 | 30 | 19 | 1 | 1 | 1 | 0 | <0.4 | <0.02 |
| **Recreational Vessels** | 3,448 | 1,232 | 161 | 101 | 6 | 4 | 4 | 0 | 76 | 0 |
| **Total** | 4,807 | 1,651 | 18,196 | 11,394 | 727 | 5,143 | 5,074 | 103 | 906 | 47 |

Notes: totals may not add up due to rounding
* NOx expressed as $NO_2$-equivalent
† SOx expressed as $SO_2$-equivalent
‡ PM from marine exhausts is assumed to be 100% $PM_{10}$ and 100% $PM_{2.5}$

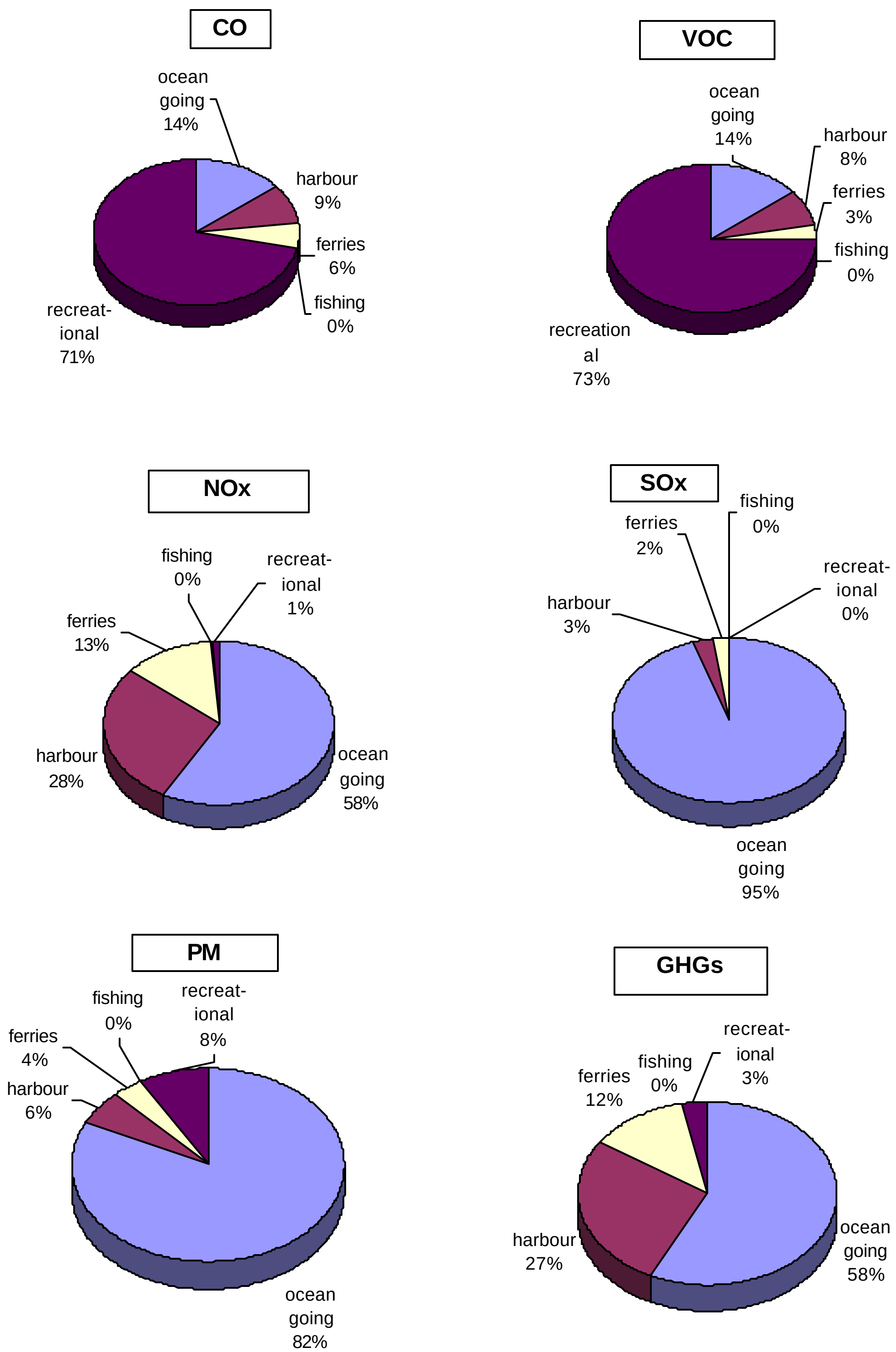
**Table 3-2: GHG Emissions for the Lower Fraser Valley for 2000**

| | emissions (tonnes/year) | | | |
|---|---|---|---|---|
| | **$CO_2$** | **$CH_4$** | **$N_2O$** | **total, $CO_2$-equiv** |
| **Ocean Going Vessels** | | | | |
| Dockside | 320,979 | 33 | 21 | 328,084 |
| Manoeuvring | 15,621 | 1 | 7 | 17,699 |
| Underway | 77,198 | 7 | 2 | 77,981 |
| **Subtotal** | 413,798 | 41 | 29 | 423,764 |
| **Harbour Vessels** | | | | |
| workboats and tugboats | 193,490 | 18 | 5 | 195,447 |
| charters | 6,535 | 1 | 0 | 6,601 |
| **Subtotal** | 200,025 | 18 | 5 | 202,048 |
| **Ferries** | | | | |
| B.C. Ferries | 76,685 | 4 | 28 | 85,494 |
| SeaBus | 2,694 | < 0.2 | 1 | 3,008 |
| Aquabus/Granville Island | 1,101 | < 0.2 | < 0.5 | 1,260 |
| Albion Ferries | 1,490 | < 0.1 | 1 | 1,663 |
| Barnston Island | 216 | < 0.02 | < 0.1 | 247 |
| **Subtotal** | 82,186 | 4 | 30 | 91,632 |
| **Fishing Vessels** | | | | |
| Gillnetter | 882 | <0.09 | <0.03 | 892 |
| Seiners | 0 | 0 | 0 | 0 |
| Trollers | 225 | <0.03 | <0.007 | 228 |
| **Subtotal** | 1,107 | <0.2 | <0.04 | 1,120 |
| **Recreational Vessels** | 21,343 | 25 | 1 | 22,228 |
| **Total** | 718,459 | 89 | 66 | 740,792 |

Note: totals may not add up due to rounding

Figure 3-1 presents the relative contributions of the main marine vessel categories to the individual contaminant totals. It can be seen that ocean-going vessels are the predominant contributor to emissions of NOx, SOx, particulate matter and greenhouse gases, accounting for 58%, 95%, 82% and 58% of the total marine vessel emissions, respectively. Harbour vessels contribute 28% and 27% to NOx and GHG totals, and 10% or less to all other contaminant totals. Ferries contribute between 2% and 13% to each contaminant, while fishing vessels are less than 1% in most cases. Recreational vessels are significant in terms of CO and VOC, but less than 10% for all other contaminants

**Figure 3.1-1: Contributions of Vessel Categories to Individual Contaminant Emission Totals**



## 3.2 OCEAN-GOING VESSELS

### 3.2.1 Underway, Manoeuvring and Dockside

The emission estimates for ocean-going vessels, for underway, manoeuvring and dockside, and broken down by ship type, are shown in Table 3-3 for criteria contaminants and ammonia, and Table 3-4 for greenhouse gases.

As noted earlier, ocean-going vessels are generally the most significant category in the marine vessel inventory for the Lower Fraser Valley, contributing over 50% for NOx and GHGs, and over 80% for particulate matter and SOx.

Additional details on emissions by dead weight class and fuel type are provided in the detailed emission listings in Appendix A.

**Table 3-3: CAC and $NH_3$ Emissions for Ocean-Going Vessels for the LFV for 2000**

| | emissions (tonnes/year) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | CO | VOC | NOx | | | SOx | | | PM ‡ | $NH_3$ |
| | | | total NOx* | NO | $NO_2$ | total SOx† | $SO_2$ | $SO_4^{=}$ | | |
| **Underway** | | | | | | | | | | |
| Bulk Carrier | 68.5 | 21.4 | 1156.1 | 723.9 | 46.2 | 437.7 | 431.9 | 8.8 | 64.2 | 14.97 |
| Container | 49.1 | 15.3 | 829.5 | 519.4 | 33.2 | 314.1 | 309.9 | 6.3 | 46.0 | 10.74 |
| General Cargo | 10.2 | 3.2 | 171.7 | 107.5 | 6.9 | 65.0 | 64.1 | 1.3 | 9.5 | 2.22 |
| Passenger | 1.0 | 0.3 | 16.1 | 10.1 | 0.6 | 6.1 | 6.0 | 0.1 | 0.9 | 0.21 |
| Tanker | 25.7 | 8.0 | 433.9 | 271.7 | 17.3 | 164.3 | 162.1 | 3.3 | 24.1 | 5.62 |
| Other Vessels | 8.8 | 2.7 | 148.3 | 92.9 | 5.9 | 56.2 | 55.4 | 1.1 | 8.2 | 1.92 |
| **Subtotal** | 163.2 | 51.0 | 2755.6 | 1725.5 | 110.1 | 1043.4 | 1029.4 | 21.0 | 153.0 | 35.7 |
| **Manoeuvring** | | | | | | | | | | |
| Bulk Carrier | 32.5 | 1.8 | 245.5 | 153.7 | 9.8 | 18.3 | 18.1 | 0.4 | 12.3 | 3.08 |
| Container | 30.4 | 1.6 | 229.7 | 143.9 | 9.2 | 17.2 | 16.9 | 0.3 | 11.5 | 2.88 |
| General Cargo | 13.3 | 0.7 | 100.4 | 62.9 | 4.0 | 7.5 | 7.4 | 0.2 | 5.0 | 1.26 |
| Passenger | 0.2 | 0.0 | 1.9 | 1.2 | 0.1 | 0.1 | 0.1 | 0.0 | 0.1 | 0.02 |
| Tanker | 4.9 | 0.3 | 36.9 | 23.1 | 1.5 | 2.8 | 2.7 | 0.1 | 1.8 | 0.46 |
| Other Vessels | 3.3 | 0.2 | 25.2 | 15.8 | 1.0 | 1.9 | 1.9 | 0.0 | 1.3 | 0.32 |
| **Subtotal** | 84.7 | 4.6 | 639.5 | 400.5 | 25.6 | 47.8 | 47.1 | 1.0 | 32.1 | 8.0 |
| **Dockside** | | | | | | | | | | |
| Bulk Carrier | 213.4 | 90.8 | 3640.5 | 2279.5 | 145.5 | 1986.2 | 1959.5 | 40.0 | 286.1 | 0.27 |
| Container | 73.8 | 31.4 | 1259.4 | 788.6 | 50.3 | 582.1 | 574.3 | 11.7 | 99.0 | 0.09 |
| General Cargo | 69.3 | 29.5 | 1182.2 | 740.3 | 47.3 | 649.8 | 641.1 | 13.1 | 92.9 | 0.09 |
| Passenger | 39.7 | 16.9 | 677.9 | 424.5 | 27.1 | 370.3 | 365.3 | 7.5 | 53.3 | 0.05 |
| Tanker | 19.5 | 8.3 | 332.5 | 208.2 | 13.3 | 181.6 | 179.2 | 3.7 | 26.1 | 0.02 |
| Other Vessels | 2.0 | 2.1 | 96.2 | 60.2 | 3.8 | 25.0 | 24.7 | 0.5 | 2.6 | 0.00 |
| **Subtotal** | 417.8 | 179.0 | 7188.7 | 4501.3 | 287.3 | 3795.0 | 3744.0 | 76.4 | 560.0 | 0.5 |
| **Total** | 665.7 | 234.6 | 10583.9 | 6627.3 | 423.0 | 4886.1 | 4820.5 | 98.4 | 745.0 | 44.2 |

Notes: totals may not add up due to rounding
* NOx expressed as $NO_2$-equivalent
† SOx expressed as $SO_2$-equivalent
‡ PM from marine exhausts is assumed to be 100% $PM_{10}$ and 100% $PM_{2.5}$

**Table 3-4: GHG Emissions for Ocean-Going Vessels for the LFV for 2000**

| | emissions (tonnes/year) | | | |
|---|---|---|---|---|
| | $CO_2$ | $CH_4$ | $N_2O$ | total, $CO_2$ equiv |
| **Underway** | | | | |
| Bulk Carrier | 32,388 | 3.0 | 0.9 | 32,716 |
| Container | 23,239 | 2.1 | 0.6 | 23,475 |
| General Cargo | 4,811 | 0.4 | 0.1 | 4,860 |
| Passenger | 450 | 0.0 | 0.0 | 455 |
| Tanker | 12,155 | 1.1 | 0.3 | 12,278 |
| Other Vessels | 4,155 | 0.4 | 0.1 | 4,198 |
| **Subtotal** | 77,198 | 7 | 2 | 77,981 |
| **Manoeuvring** | | | | |
| Bulk Carrier | 5,995 | 0.4 | 2.5 | 6,793 |
| Container | 5,611 | 0.3 | 2.4 | 6,358 |
| General Cargo | 2,452 | 0.1 | 1.0 | 2,778 |
| Passenger | 46 | 0.0 | 0.0 | 52 |
| Tanker | 901 | 0.1 | 0.4 | 1,021 |
| Other Vessels | 616 | 0.0 | 0.3 | 698 |
| **Subtotal** | 15,621 | 1 | 7 | 17,699 |
| **Dockside** | | | | |
| Bulk Carrier | 164,561 | 17.1 | 9.4 | 167,831 |
| Container | 55,712 | 5.4 | 5.7 | 57,602 |
| General Cargo | 53,496 | 5.6 | 2.9 | 54,523 |
| Passenger | 30,648 | 3.2 | 1.7 | 31,253 |
| Tanker | 15,035 | 1.6 | 0.9 | 15,332 |
| Other Vessels | 1,527 | 0.2 | 0.0 | 1,542 |
| **Subtotal** | 320,979 | 33 | 21 | 328,084 |
| **Total** | 413,798 | 41 | 29 | 423,764 |

Note: totals may not add up due to rounding

## 3.3 HARBOUR VESSELS

The emissions estimate for harbour vessels was divided into the two categories: work and tugboats; and charter vessels. Emissions of criteria air contaminants are shown in Table 3-1, and greenhouse gases in Table 3-2.

Compared to the total marine vessel inventory, harbour vessels are a significant contributor to emissions of NOx and GHGs (approximately 30% of the total in both cases), and between 3 and 10% for the other criteria contaminants. In general, workboats and tugboats are the predominant emission source within the harbour vessel category.

## 3.4 FERRIES

The emission results for all ferries are shown in Tables 3-1 and 3-2.

Noteworthy changes between the 1993 and 2000 emission results include the addition of two fast ferries to the B.C. Ferries fleet, travelling between Tsawwassen and Swartz Bay, and the percent of sulphur in the fuel. Moreover, the methodology applied in 1993 does not include any breakdown of emissions by load factor for different movement categories, which was developed for this report. The emission estimates provided by BC Ferries for this study were based on all fuel for ferries being consumed for "underway" travel. The application of load profiles for underway, manoeuvring and dockside has resulted in an increase in CO emissions compared to BC Ferries' estimates, while all other pollutants decreased between 5% and 25%.

Keeping in mind the differences in methodologies, Table 3-5 provides a comparison of emissions within the LFV between 1993 and the year 2000.

**Table 3-5: 1993 Emission Results and % Change with Year 2000 Results**

| | NOx | CO | VOC | $SO_x$ | PM** |
|---|---|---|---|---|---|
| **1993 Emissions** | 1327 | 180 | 61 | 144 | 53 |
| **% Change for year 2000** | + 9.4% increase | + 30% increase | - 16% decrease | - 28% decrease | - 51% decrease |

### 3.4.1 Other Ferries

Emission estimates for the SeaBus, Albion Ferry and Barnston Island Ferry are shown in Tables 3-1 and 3-2. Since both the Aquabus and Granville Island Ferry companies share the same routes and make a comparatively small contribution to the emission inventory, the results for the Aquabus and Granville Island Ferries have been summed as shown in Tables 3-1 and 3-2.

## 3.5 FISHING VESSELS

Although the methodology, fleet characteristics and fishing activity vary between the 1993 and 2000 study, a comparison between the two results is provided in table 3-6 below. The results shown are consistent with the trend observed by the DFO, namely that approximately 50% of the commercial fleet has been cut since 1993, the hours of operation have been reduced and very little commercial activity was recorded in area 28 in the year 2000. While there may have been some First Nations activity in area 28, data was not available from DFO to quantify emissions. However, additional research on First Nations fishing activity indicates that very little First Nations fishing occurs in this area as most of their fishing occurs on the river. Although there has been an increase in First Nations fishing activity in area 29 (relative to the 1993 inventory), the increase does not offset the decrease in commercial fishing in the LFV. To provide a representative comparison, only the results from area 29 were compared.

**Table 3-6: Comparison Between 1993 and 2000 Fishing Results**

| DFO Management Area | Gear Type | Emissions 1993/2000 (Tonnes) | | | | |
|---|---|---|---|---|---|---|
| | | CO | NOx | PM | SOx | VOC |
| 29 | Gillnetter | 6/2 | 48/16 | 2/0.3 | 6/0.7 | 6/0.7 |
| | Seiner | 0/0 | 0/0 | 0/0 | 0/0 | 0/0 |
| | Troller | 1/0.6 | 7/4 | 0/0 | 1/0.2 | 1/0.2 |
| TOTAL Emissions in area 29 (T) | | 7/3 | 55/20 | 2/0.3 | 7/1 | 7/1 |
| Overall % Decrease in Area 29 from 1993 Results | | 63% | 64% | 85% | 86% | 86% |

Tables 3-1 and 3-2 summarise the emission results for fishing vessels in the Core Area for each type of vessel (i.e. Gillnetters, Seiners and Trollers). The emissions shown are the sum of commercial fishing with assumed First Nations fishing activity.

## 3.6 RECREATIONAL VESSELS

Emissions from recreational vessel activities in the Lower Fraser Valley study area are summarised in Table 3-7 and 3-8.

**Table 3-7: CAC and $NH_3$ Emissions from Recreational Vessels in the LFV for 2000**

| | emissions (tonnes/year) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | CO | VOC | NOx | | | SOx | | | PM ‡ | $NH_3$ |
| | | | total NOx* | NO | $NO_2$ | total SOx † | $SO_2$ | $SO_4^{=}$ | | |
| **Inboard** | | | | | | | | | | |
| 4 stroke | 209 | 13 | 12 | 7 | <1 | 1 | <1 | <0.01 | <1 | <0.01 |
| diesel | 6 | 3 | 22 | 14 | 1 | 1 | <1 | <0.01 | <1 | <0.01 |
| **Subtotal** | 215 | 16 | 33 | 21 | 1 | 1 | <1 | <0.01 | <1 | <0.01 |
| **Outboard** | | | | | | | | | | |
| 2 stroke | 2,112 | 917 | 15 | 9 | 1 | 1 | 1 | <0.1 | 61 | <0.1 |
| 4 stroke | 7 | <0.5 | 2 | <1 | <0.1 | 0 | <0.01 | <0.001 | <0.01 | <0.0001 |
| **Subtotal** | 2,119 | 917 | 15 | 9 | 1 | 1 | 1 | <0.1 | 61 | <0.1 |
| **Sterndrive** | | | | | | | | | | |
| 2 stroke | 11 | 5 | 0 | <0.1 | <0.01 | 0 | <0.01 | <0.001 | <1 | <0.0001 |
| 4 stroke | 637 | 38 | 33 | 21 | 1 | 1 | <1 | <0.01 | <1 | <0.01 |
| diesel | 21 | 12 | 77 | 48 | 3 | 1 | 1 | <0.1 | 2 | <0.1 |
| **Subtotal** | 669 | 55 | 110 | 69 | 4 | 1 | 1 | <0.1 | 2 | <0.1 |
| **PWC** | 444 | 243 | 3 | 1 | <1 | 1 | <1 | <0.01 | 12 | <0.01 |
| **Sailboat Auxiliary Inboard** | | | | | | | | | | |
| 4 stroke | <1 | <0.1 | 0 | <0.1 | <0.01 | 0 | <0.001 | <0.00001 | <0.001 | <0.00001 |
| diesel | <1 | <1 | 3 | 1 | <1 | 0 | <0.1 | <0.0001 | <0.1 | <0.1 |
| **Subtotal** | <1 | <1 | 3 | 1 | <1 | 0 | <0.1 | <0.0001 | <0.1 | <0.1 |
| **Sailboat Auxiliary Outboard** | | | | | | | | | | |
| 2 stroke | <1 | <1 | < 0.2 | <0.01 | <0.001 | 0 | <0.001 | <0.00001 | <0.1 | <0.00001 |
| diesel | <0.001 | <0.0001 | <0.002 | <0.001 | <0.0001 | 0 | <0.00001 | <0.000001 | <0.00001 | <0.0001 |
| **Subtotal** | <1 | <1 | <0.2 | <0.01 | <0.001 | 0 | <0.001 | <0.00001 | <0.1 | <0.0001 |
| **Total, 2000** | 3,448 | 1,232 | 161 | 101 | 6 | 4 | 4 | <0.1 | 76 | <0.1 |
| **Total, 1993** | 1,401 | 436 | 43 | n.a. | n.a. | 6 | n.a. | n.a. | 0 | n.a |

Notes: totals may not add up due to rounding
n.a. = not available
* NOx expressed as $NO_2$-equivalent
† SOx expressed as $SO_2$-equivalent
‡ PM from marine exhausts is assumed to be 100% $PM_{10}$ and 100% $PM_{2.5}$

**Table 3-8: GHG Emissions for Recreational Vessels for the Lower Fraser Valley for 2000**

| | emissions (tonnes/year) | | | |
|---|---|---|---|---|
| | $CO_2$ | $CH_4$ | $N_2O$ | total, $CO_2$ equiv |
| **Inboard** | | | | |
| 4 stroke | 1,237 | 1 | <0.1 | 1,260 |
| diesel | 496 | <0.1 | <1 | 560 |
| **Subtotal** | 1,733 | 1 | <1 | 1,820 |
| **Outboard** | | | | |
| 2 stroke | 11,533 | 18 | <0.1 | 11,941 |
| 4 stroke | 50 | <0.1 | <0.01 | 51 |
| **Subtotal** | 11,583 | 18 | <0.1 | 11,992 |
| **Sterndrive** | | | | |
| 2 stroke | 58 | <1 | <0.001 | 60 |
| 4 stroke | 3,779 | 2 | <0.1 | 3,851 |
| diesel | 1,725 | <1 | <1 | 1,949 |
| **Subtotal** | 5,562 | 2 | <1 | 5,860 |
| **PWC** | 2,415 | 4 | <0.1 | 2,501 |
| **Sailboat Auxiliary Inboard** | | | | |
| 4 stroke | 3 | <0.01 | <0.001 | 3 |
| diesel | 44 | <0.01 | <0.1 | 50 |
| **Subtotal** | 47 | <0.01 | <0.1 | 53 |
| **Sailboat Auxiliary Outboard** | | | | |
| 2 stroke | 2 | <0.01 | <0.0001 | 3 |
| diesel | <0.1 | <0.000001 | <0.00001 | <0.1 |
| **Subtotal** | 2 | <0.01 | <0.0001 | 3 |
| **Total, 2000** | 21,343 | 25 | 1 | 22,228 |

Note: totals may not add up due to rounding

# 4. SPATIAL ALLOCATION OF EMISSIONS

## 4.1 REGIONAL EMISSIONS

The regional breakdown was developed from a file containing the emissions per grid cell for all marine vessels. Each one of these grid cells has a corresponding regional district code based on the boundaries of each of the regions of interest shown below. Using Access, a query was used to sum up all values of emissions for the grid cells within each region.

Tables 4-1 through 4-6 show emissions of criteria contaminants, ammonia and greenhouse gases by regional district. FVRD is broken down into FVRD1 and FVRD2 to allow a distinction between what is inside and outside of the Lower Fraser Valley area.

**Table 4-1: CAC and $NH_3$ Emissions for the GVRD for 2000**

| | emissions (tonnes/year) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | CO | VOC | NOx | | | SOx | | | PM ‡ | $NH_3$ |
| | | | total NOx* | NO | $NO_2$ | total SOx † | $SO_2$ | $SO_4^=$ | | |
| **Ocean-going vessels** | | | | | | | | | | |
| Dockside | 418 | 179 | 7,189 | 4,501 | 287 | 3,795 | 3,744 | 76 | 560 | 1 |
| Manoeuvring | 85 | 5 | 640 | 400 | 26 | 48 | 47 | 1 | 32 | 8 |
| Underway | 163 | 51 | 2,756 | 1,725 | 110 | 1,043 | 1,029 | 21 | 153 | 36 |
| Subtotal | 666 | 235 | 10,584 | 6,627 | 423 | 4,886 | 4,821 | 98 | 745 | 44 |
| **Harbour vessels** | | | | | | | | | | |
| Workboats and Tugboats | 401 | 125 | 4,812 | 3,013 | 192 | 137 | 135 | 3 | 50 | 3 |
| Charters | 11 | 0 | 134 | 84 | 5 | 4 | 4 | 0 | 1 | 0 |
| Subtotal | 412 | 125 | 4,947 | 3,097 | 198 | 141 | 139 | 3 | 51 | 3 |
| **Ferries** | | | | | | | | | | |
| BC Ferries | | | | | | | | | | |
| Dockside | 33 | 2 | 430 | 269 | 17 | 5 | 5 | | 3 | 0 |
| Manoeuvring | 62 | 8 | 171 | 107 | 7 | 6 | 6 | | 1 | 0 |
| Underway | 119 | 38 | 1,371 | 859 | 55 | 87 | 87 | | 19 | 0 |
| Layup | 20 | 2 | 207 | 130 | 8 | 3 | 3 | | 7 | 0 |
| Subtotal B.C. Ferries | 234 | 51 | 2,180 | 1,365 | 87 | 103 | 101 | 2 | 30 | 0 |
| SeaBus | 6 | 2 | 83 | 52 | 3 | 1 | 1 | 0 | 1 | 0 |
| Aquabus/Granville Island | 24 | 2 | 33 | 20 | 1 | 3 | 3 | 0 | 0 | 0 |
| Albion Ferry | 4 | 1 | 43 | 27 | 2 | 0 | 0 | 0 | 1 | 0 |
| Barnston Island Ferry | 1 | 0 | 6 | 4 | 0 | 1 | 1 | 0 | 0 | 0 |
| Subtotal | 268 | 56 | 2,344 | 1,468 | 94 | 108 | 107 | 2 | 32 | 0 |
| **Fishing Vessels** | 3 | 1 | 29 | 18 | 1 | 1 | 1 | 0 | 0 | 0 |
| **Recreational Vessels** | 3,098 | 1,107 | 145 | 91 | 6 | 3 | 3 | 0 | 68 | 0 |
| **Total** | 4,447 | 1,524 | 18,049 | 11,302 | 721 | 5,139 | 5,070 | 103 | 897 | 47 |

Notes: totals may not add up due to rounding
* NOx expressed as $NO_2$-equivalent
† SOx expressed as $SO_2$-equivalent
‡ PM from marine exhausts is assumed to be 100% $PM_{10}$ and 100% $PM_{2.5}$

**Table 4-2: GHG Emissions for the GVRD for 2000**

| | emissions (tonnes/year) | | | |
|---|---|---|---|---|
| | $CO_2$ | $CH_4$ | $N_2O$ | total, $CO_2$ equiv |
| **Ocean-going vessels** | | | | |
| Dockside | 320,979 | 33 | 21 | 328,084 |
| Manoeuvring | 15,621 | 1 | 7 | 17,699 |
| Underway | 77,198 | 7 | 2 | 77,981 |
| Subtotal | 413,798 | 41 | 29 | 423,764 |
| **Harbour vessels** | | | | |
| Workboats and Tugboats | 189,582 | 17 | 5 | 191,500 |
| Charters | 5,298 | 0 | 0 | 5,352 |
| Subtotal | 194,880 | 18 | 5 | 196,851 |
| **Ferries** | | | | |
| BC Ferries | 76,685 | 4 | 28 | 85,494 |
| SeaBus | 2,694 | 0 | 1 | 3,007 |
| Aquabus/Granville Island | 1,101 | 0 | 0 | 1,228 |
| Albion Ferry | 1,490 | 0 | 1 | 1,662 |
| Barnston Island Ferry | 216 | 0 | 0 | 241 |
| Subtotal | 82,186 | 5 | 30 | 91,632 |
| **Fishing Vessels** | 1,065 | 0 | 0 | 1,077 |
| **Recreational Vessels** | 19,179 | 23 | 1 | 19,974 |
| **Total** | 711,108 | 86 | 66 | 733,299 |

Note: totals may not add up due to rounding

**Table 4-3: CAC and $NH_3$ Emissions for the FVRD1 for 2000**

| | emissions (tonnes/year) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | CO | VOC | NOx | | | SOx | | | PM ‡ | $NH_3$ |
| | | | total NOx* | NO | $NO_2$ | total SOx† | $SO_2$ | $SO_4^=$ | | |
| **Ocean-going vessels** | | | | | | | | | | |
| Dockside | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Manoeuvring | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Underway | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Subtotal | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Harbour vessels** | | | | | | | | | | |
| Workboats and Tugboats | 8 | 3 | 99 | 62 | 4 | 3 | 3 | 0 | 1 | 0 |
| Charters | 3 | 0 | 31 | 20 | 1 | 1 | 1 | 0 | 0 | 0 |
| Subtotal | 11 | 3 | 131 | 82 | 5 | 4 | 4 | 0 | 1 | 0 |
| **Ferries** | | | | | | | | | | |
| BC Ferries | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| SeaBus | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Aquabus/Granville Island | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Albion Ferry | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Barnston Island Ferry | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Subtotal | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Fishing Vessels** | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Recreational Vessels** | 350 | 125 | 16 | 10 | 1 | 0 | 0 | 0 | 8 | 0 |
| **Total** | 361 | 128 | 148 | 93 | 6 | 4 | 4 | 0 | 9 | 0 |

Notes: totals may not add up due to rounding
* NOx expressed as $NO_2$-equivalent
† SOx expressed as $SO_2$-equivalent
‡ PM from marine exhausts is assumed to be 100% $PM_{10}$ and 100% $PM_{2.5}$

**Table 4-4: GHG Emissions for the FVRD1 for 2000**

| | emissions (tonnes/year) | | | |
|---|---|---|---|---|
| | $CO_2$ | $CH_4$ | $N_2O$ | total, $CO_2$ equiv |
| **Ocean-going vessels** | | | | |
| Dockside | 0 | 0 | 0 | 0 |
| Manoeuvring | 0 | 0 | 0 | 0 |
| Underway | 0 | 0 | 0 | 0 |
| Subtotal | 0 | 0 | 0 | 0 |
| **Harbour vessels** | | | | |
| Workboats and Tugboats | 3,908 | 0.4 | 0.1 | 3,947 |
| Charters | 1,237 | 0.1 | 0 | 1,250 |
| Subtotal | 5,145 | 0.5 | 0.1 | 5,197 |
| **Ferries** | | | | |
| BC Ferries | 0 | 0 | 0 | 0 |
| SeaBus | 0 | 0 | 0 | 0 |
| Aquabus/Granville Island | 0 | 0 | 0 | 0 |
| Albion Ferry | 0 | 0 | 0 | 0 |
| Barnston Island Ferry | 0 | 0 | 0 | 0 |
| Subtotal | | | | |
| **Fishing Vessels** | 42 | 0 | 0 | 43 |
| **Recreational Vessels** | 2,164 | 2.6 | 0.1 | 2,254 |
| **Total** | 7,351 | 3.0 | 0.3 | 7,493 |

Note: totals may not add up due to rounding

**Table 4-5: CAC and $NH_3$ Emissions for the FVRD2 for 2000**

| | emissions (tonnes/year) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | CO | VOC | NOx | | | SOx | | | PM ‡ | $NH_3$ |
| | | | total NOx* | NO | $NO_2$ | total SOx † | $SO_2$ | $SO_4^{=}$ | | |
| **Ocean-going vessels** | | | | | | | | | | |
| Dockside | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Manoeuvring | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Underway | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Subtotal | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Harbour vessels** | | | | | | | | | | |
| Workboats and Tugboats | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Charters | 1 | 0 | 15 | 9 | 1 | 0 | 0 | 0 | 0 | 0 |
| Subtotal | 1 | 0 | 15 | 9 | 1 | 0 | 0 | 0 | 0 | 0 |
| **Ferries** | | | | | | | | | | |
| BC Ferries | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| SeaBus | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Aquabus/Granville Island | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Albion Ferry | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Barnston Island Ferry | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Subtotal | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Fishing Vessels** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Recreational Vessels** | 24 | 8 | 2 | 1 | 0 | 0 | 0 | 0 | 1 | 0 |
| **Total** | 25 | 8 | 17 | 10 | 1 | 1 | 1 | 0 | 1 | 0 |

Notes: totals may not add up due to rounding
* NOx expressed as $NO_2$-equivalent
† SOx expressed as $SO_2$-equivalent
‡ PM from marine exhausts is assumed to be 100% $PM_{10}$ and 100% $PM_{2.5}$

**Table 4-6: GHG Emissions for the FVRD2 for 2000**

| | emissions (tonnes/year) | | | |
|---|---|---|---|---|
| | $CO_2$ | $CH_4$ | $N_2O$ | total, $CO_2$ equiv |
| **Ocean-going vessels** | | | | |
| Dockside | 0 | 0 | 0 | 0 |
| Manoeuvring | 0 | 0 | 0 | 0 |
| Underway | 0 | 0 | 0 | 0 |
| Subtotal | 0 | 0 | 0 | 0 |
| **Harbour vessels** | | | | 0 |
| Workboats and Tugboats | 0 | 0 | 0 | 0 |
| Charters | 594 | 0.1 | 0 | 600 |
| Subtotal | 594 | 0.1 | 0 | 600 |
| **Ferries** | | | | 0 |
| BC Ferries | 0 | 0 | 0 | 0 |
| SeaBus | 0 | 0 | 0 | 0 |
| Aquabus/Granville Island | 0 | 0 | 0 | 0 |
| Albion Ferry | 0 | 0 | 0 | 0 |
| Barnston Island Ferry | 0 | 0 | 0 | 0 |
| Subtotal | 0 | 0 | 0 | 0 |
| **Fishing Vessels** | 0 | 0 | 0 | 0 |
| **Recreational Vessels** | 147 | 0 | 0 | 147 |
| **Total** | 741 | 0.1 | 0 | 747 |

Note: totals may not add up due to rounding

## 4.2 DOMESTIC AND INTERNATIONAL GREENHOUSE GAS EMISSIONS

Table 4-7 shows the split of total greenhouse gas emissions for the Lower Fraser Valley (GVRD and FVRD1) area into "domestic" and "international" emissions. Emissions in the FVRD2 portion of the Core Area are all domestic. Domestic and international GHGs were assigned by vessel type as follows:

- Ocean-going vessels – movements into and out of BC are accounted for within the Pacific Pilotage Authority database, and underway emissions are split into domestic and international based on arrival and departure points.
- Harbour vessels – emissions from vessels travelling exclusively within one country are allocated to that country, while vessels which move back and forth across the Canada-U.S. border are considered international
- Ferries – all routes for the Core Area travel in BC only and are considered domestic
- Fishing – it was assumed that all BC registered boats are Canadian (i.e., domestic) emissions
- Recreational – similar to fishing, emissions were allocated as domestic

**Table 4-7: Domestic and International GHG Emissions for the Lower Fraser Valley, 2000**

| | emissions (tonnes/year) | | | |
|---|---|---|---|---|
| | **$CO_2$** | **$CH_4$** | **$N_2O$** | **total, $CO_2$ equiv** |
| **Domestic** | | | | |
| Ocean-Going Vessels | 291,536 | 29.4 | 20.2 | 298,409 |
| Harbour Vessels | 193,614 | 17.9 | 5.1 | 195,573 |
| Ferries | 82,186 | 4.2 | 30.2 | 91,632 |
| Fishing Vessels | 1,107 | <0.2 | <0.04 | 1,120 |
| Recreational Vessels | 21,343 | 25.1 | 1.2 | 22,228 |
| **Subtotal** | 589,787 | 77 | 57 | 608,962 |
| **International** | | | | |
| Ocean-Going Vessels | 122,262 | 11.6 | 9.2 | 125,355 |
| Harbour Vessels | 6,411 | 0.6 | 0.2 | 6,476 |
| Ferries | 0 | 0.0 | 0.0 | 0 |
| Fishing Vessels | 0 | 0.0 | 0.0 | 0 |
| Recreational Vessels | 0 | 0.0 | 0.0 | 0 |
| **Subtotal** | 128,673 | 12 | 9 | 131,831 |
| **Total** | 718,459 | 89 | 66 | 740,792 |

Note: totals may not add up due to rounding

## 4.3 GRIDDED EMISSIONS

Marine vessel emissions have been spatially allocated to a system of 1km by 1km grid squares, based on the Lambert conformal projection. The spatial resolution data is provided in electronic form, and paper reporting of emissions to this level of resolution is not meaningful here. However, some discussion of methodology follows.

### 4.3.1 Ocean-going Vessels

Emissions from ocean-going vessels are divided into three vessel states, dockside, manoeuvring and underway. An analysis of the Pilotage database, the percentages of ocean-going vessels travelling to each port region determined the following distribution of emissions. Dockside emissions were divided into 4 main areas with the following percentage of emissions assigned:

* Vancouver Harbour 56.2%
* Fraser River 29.2%
* English Bay/Burrard Inlet 11.5 %
* Roberts Bank 3.1%

Manoeuvring emissions were divided into the Vancouver Harbour (47.8%) and the Fraser River (52.2%). Underway emissions were distributed over the shipping lanes in either the western (34.9%) or southern (65.1%) direction.

### 4.3.2 Harbour Vessels

Emissions from harbour vessels are divided into the two subgroups; work boats and tug boats; and charter boats. Examination of typical movement profiles from Washington Marine Group tugs which accounts for 20% of the one tugs within the core area led to the following distribution of total emissions from workboats and tug boats:

* Western Travel 25%
* Southern Travel 7%
* Roberts Bank 20%
* Vancouver Harbour and English Bay 20%
* Fraser River 18%
  * (Sandheads to Tilbury Island 10%)
  * (Sandheads to New Westminster 4%)
  * (Sandheads to Mission 4%)
* Howe Sound 10%

The distribution of emissions from charterboats was defined based in part by discussion with charter boat companies in the region and from intuitive knowledge of the area. For these emissions, six key chartering areas were defined and the emissions distributed equally (16.7% each). The chartering area consists of: the Vancouver harbour and English Bay; Howe Sound, Indian Arm, Robert's Bank, the Fraser to Mission, and Harrison Lake.

### 4.3.3 Ferries

The spatial distribution of emissions for ferries was calculated by plotting each ferry route within the grid system. The calculation of the portion of grid cell coverage for BC Ferries was based upon the length of each line (route) within a particular grid cell divided by the total length of the line within each section of power rating (dockside, manoeuvring and dockside). For example, manoeuvring emissions occur within anywhere from two to four cells, depending on the route. Therefore, the total length used is the sum of the line that falls within these cells. Each cell is then proportioned based on the length of the line within the cell. Dockside emissions are applied to one cell for all but one route that is entirely within the core area meaning that there are two dockside grid cells (departure and arrival locations). The underway emissions were distributed amongst the remaining grid cells in the same fashion as the manoeuvring emissions described above.

Lay-up emissions were gridded based on water coverage based on the locations of the docks within the LFV:

- Deas Dock (Richmond)
- Vancouver Shipyard
- New Westminster Quay

Of the total lay-up emissions occurring within the LFV, it was further assumed that 80% occurs at Deas Dock, based on discussion with BC Ferries. The remainder was distributed accordingly amongst the remaining locations.

An even distribution was applied for all other ferries based on water portions of each grid cell.

### 4.3.4 Fishing Vessels

Following discussion with the DFO with respect to the whereabouts of fishing vessels throughout the core area, it was confirmed that the *spatial* profile used in the 1993 emission inventory still applies to the year 2000 with respect to area 29. The distribution was slightly refined to account for the increased fishing by First Nations along the Fraser River up to Mission. The base spatial distribution of the 1993 study that was used here was based on a 5km x 5km grid that was translated into the current 1km x 1km grid. Details on the concentration of emissions within the study area are given in section 2.4.1 along with maps of the DFO management areas.

### 4.3.5 Recreational Vessels

Since recreational vessels do not follow defined routes, emissions allocated to each water area were distributed evenly.

# 5. TEMPORAL ALLOCATION OF EMISSIONS

## 5.1 OCEAN-GOING VESSELS

The hourly, daily and monthly distribution of port calls by shiptype from the Pacific Pilotage database of ocean-going vessel movements was used as a basis for the temporal distribution.

## 5.2 HARBOUR VESSELS

Emissions from harbour vessels are currently divided into the two subgroups: work boats and tug boats; and charter boats. As the operation of work and tugboats does not vary greatly between time of day or season, all emissions will be evenly divided over the entire year. Charterboat however, do follow a more seasonal operation profile as provided by a sampling of charterboat companies. Emissions from charterboats are more heavily divided among the high season operation occurring during the summer months and for a small range of days in December. The hourly distribution of emissions from both of these sub-classes of vessels remained the same as per the 1993 inventory.

## 5.3 FERRIES

Most ferries included in this study follow predetermined schedules. Those that do not follow year-round schedules have provided seasonal patterns from which a temporal breakdown could be developed. In some cases, the same temporal breakdown as the 1993 emission inventory was used, as those with schedules have remained essentially the same. Since BC Ferries provided fuel consumption for each month, it was possible to develop an exact monthly profile from which the daily and hourly profiles were developed on an incremental basis.

## 5.4 FISHING VESSELS

A temporal breakdown has been provided by the DFO per day of the week for the year 2000 in terms of vessel count. The temporal profiles used in 1993 were therefore updated to better represent the activity throughout the year 2000.

## 5.5 RECREATIONAL VESSELS

Temporal profiles from the 1993 inventory were adopted for this project as significant changes are not expected in recreational boating activities.

## 5.6 RESULTS OF TEMPORAL ALLOCATION

Table 5-1 shows the monthly distribution of emissions for all sources. Figure 5-1 illustrates a number of monthly distribution profiles for individual vessel categories.

Temporal allocation of emissions to days of the week and hours of the day are not presented here, but temporal profiles to allow disaggregation to this level are supplied with the electronic files that accompany this report.

**Table 5-1: Monthly Distribution of Lower Fraser Valley Marine Vessel Emissions for 2000**

| | emissions (tonnes) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | CO | VOC | NOx | | | SOx | | | PM ‡ | $NH_3$ |
| | | | total NOx* | NO | $NO_2$ | total SOx† | $SO_2$ | $SO_4^{=}$ | | |
| January | 208 | 69 | 1,529 | 958 | 61 | 439 | 433 | 9 | 73 | 4 |
| February | 201 | 67 | 1,383 | 866 | 55 | 376 | 371 | 8 | 63 | 3 |
| March | 207 | 68 | 1,455 | 911 | 58 | 400 | 394 | 8 | 67 | 3 |
| April | 205 | 68 | 1,436 | 899 | 57 | 403 | 398 | 8 | 67 | 3 |
| May | 215 | 71 | 1,587 | 994 | 63 | 462 | 456 | 9 | 76 | 5 |
| June | 982 | 345 | 1,637 | 1,025 | 65 | 470 | 464 | 9 | 94 | 5 |
| July | 986 | 346 | 1,696 | 1,062 | 68 | 488 | 481 | 10 | 97 | 5 |
| August | 986 | 346 | 1,683 | 1,054 | 67 | 476 | 470 | 10 | 96 | 5 |
| September | 214 | 71 | 1,567 | 981 | 63 | 453 | 447 | 9 | 75 | 5 |
| October | 206 | 68 | 1,442 | 903 | 58 | 403 | 398 | 8 | 68 | 4 |
| November | 200 | 67 | 1,387 | 868 | 55 | 391 | 386 | 8 | 66 | 3 |
| December | 198 | 66 | 1,396 | 874 | 56 | 383 | 378 | 8 | 65 | 3 |
| **Total** | **4,807** | **1,651** | **18,197** | **11,394** | **727** | **5,143** | **5,074** | **104** | **906** | **47** |

Notes: totals may not add up due to rounding
* NOx expressed as $NO_2$-equivalent
† SOx expressed as $SO_2$-equivalent
‡ PM from marine exhausts is assumed to be 100% $PM_{10}$ and 100% $PM_{2.5}$

**Figure 5.6-1: Monthly Emission Distribution for Selected Vessel Types**

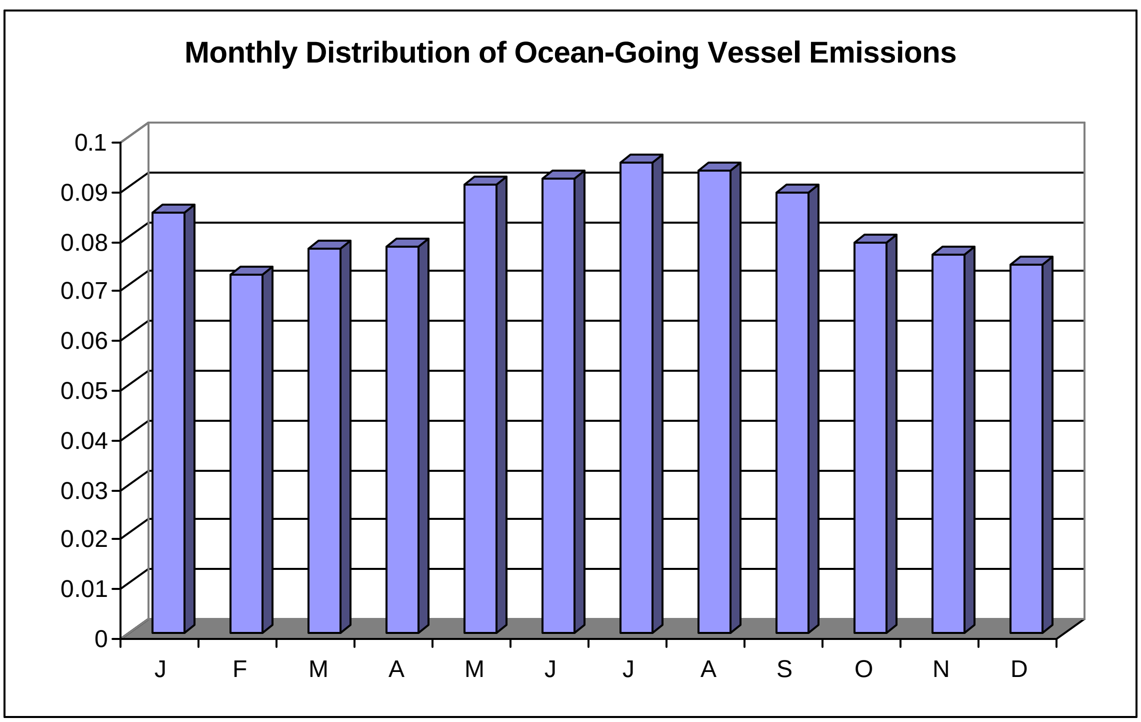
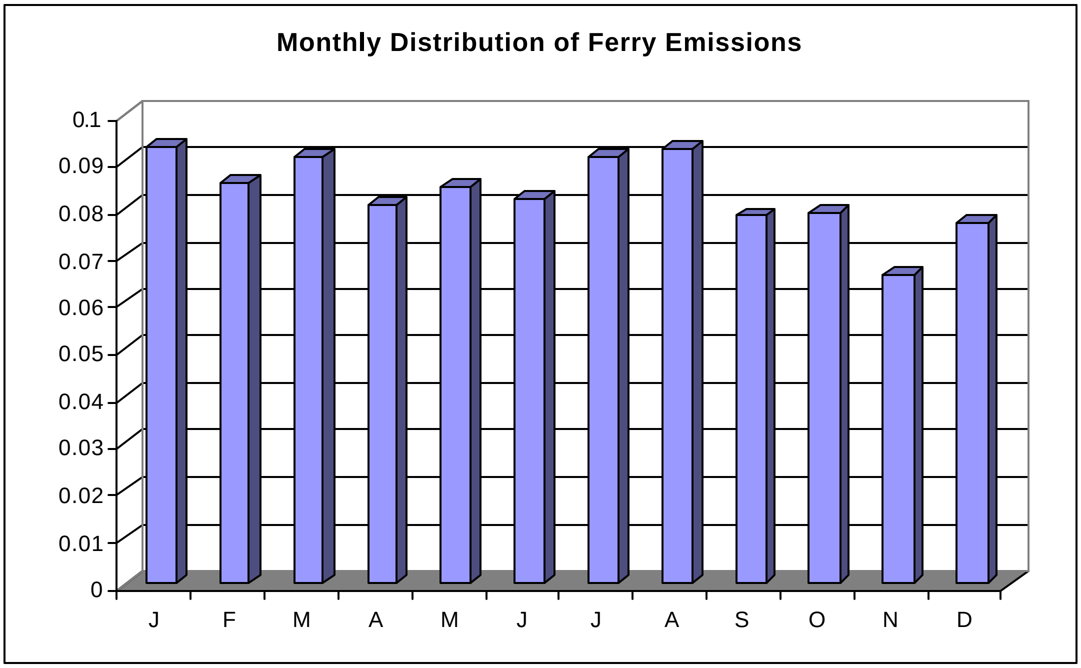
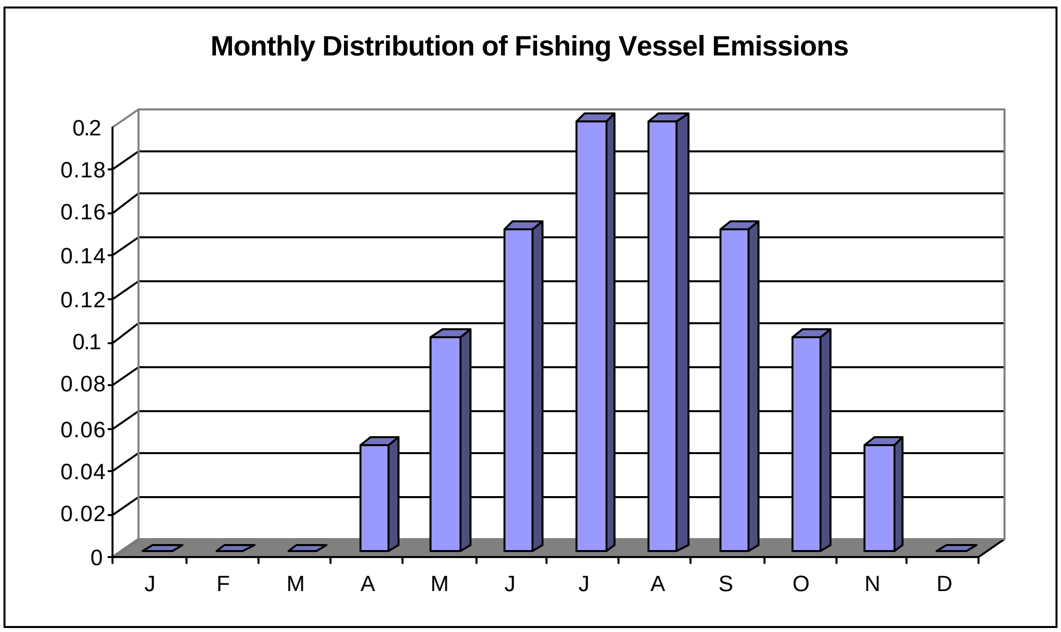


**Figure 5-1 (continued): Monthly Emission Distribution for Selected Vessel Types**



# 6. CONCLUSIONS AND RECOMMENDATIONS

Table 6-1 provides a comparison of emission estimates between this study and the previous marine vessel inventory for 1993 (Levelton, 1995). Changes in methodology and the resulting changes in emission estimates, are discussed below by vessel type.

**Table 6-1: Comparison of 1993 and 2000 Emission Inventory Results**

| | emissions (tonnes/year) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **CO** | | **VOC** | | **NOx*** | | **SOx†** | | **PM ‡** | |
| | **1993** | **2000** | **1993** | **2000** | **1993** | **2000** | **1993** | **2000** | **1993** | **2000** |
| **Ocean Going Vessels** | | | | | | | | | | |
| Dockside | 156 | 418 | 269 | 179 | 963 | 7,189 | 888 | 3,795 | 57 | 560 |
| Manoeuvring | | 85 | | 5 | | 640 | | 48 | | 32 |
| Underway[2] | 109 | 163 | 30 | 51 | 1,018 | 2,756 | 478 | 1,043 | 56 | 153 |
| **Subtotal** | **265** | **666** | **299** | **235** | **1,981** | **10,584** | **1,366** | **4,886** | **113** | **745** |
| **Harbour Vessels** | | | | | | | | | | |
| workboats and tugboats | 516 | 409 | 84 | 128 | 1,099 | 4,911 | 145 | 140 | 54 | 51 |
| charters | 20 | 14 | 9 | 0 | 93 | 166 | 15 | 5 | 5 | 2 |
| **Subtotal** | **536** | **423** | **93** | **128** | **1,192** | **5,077** | **160** | **144** | **59** | **53** |
| **Ferries[3]** | | | | | | | | | | |
| B.C. Ferries | 180 | 234 | 61 | 51 | 1,327 | 2,180 | 144 | 101 | 53 | 30 |
| SeaBus | 8 | 6 | 3 | 2 | 55 | 83 | 6 | 1 | 2 | 1 |
| Aquabus/Granville Island | | 24 | | 2 | | 33 | | 3 | | < 0.5 |
| Albion Ferries | 6 | 4 | 2 | 1 | 41 | 43 | <0.5 | < 1 | <0.5 | 1 |
| Barnston Island | | 1 | | < 0.5 | | < 7 | | 1 | | < 0.1 |
| **Subtotal** | **231** | **268** | **78** | **56** | **1,688** | **2,344** | **178** | **108** | **66** | **32** |
| **Fishing Vessels[4]** | | | | | | | | | | |
| Gillnetters | 6 | 2 | 6 | 1 | 48 | 24 | 6 | 1 | 2 | <0.3 |
| Seiners | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Trollers | 1 | 0 | 1 | 0 | 7 | < 6 | 1 | < 0.2 | 0 | <0.07 |
| **Subtotal** | **7** | **2** | **7** | **1** | **55** | **30** | **7** | **1** | **2** | **<0.4** |
| **Recreational Vessels** | **1,401** | **3,448** | **436** | **1,232** | **43** | **161** | **6** | **4** | **<0.5** | **76** |
| **Total** | **2,440** | **4,807** | **913** | **1,651** | **4,959** | **18,196** | **1,717** | **5,143** | **240** | **906** |

Notes: totals may not add up due to rounding
* NOx expressed as $NO_2$-equivalent
† SOx expressed as $SO_2$-equivalent
‡ PM from marine exhausts is assumed to be 100% $PM_{10}$ and 100% $PM_{2.5}$

[1] totals may not add up due to rounding

[2] for the 1993 study, underway emissions include both underway and manoeuvring estimates

[3] the 1993 study included B.C. Ferries, Albion, SeaBus, SeaLink, C.P. Ferries and Kingcome

[4] the 1993 study included an additional category, shell and groundfish (mixed vessels)

## 6.1 OCEAN-GOING VESSELS

As for the 1993 inventory, data on ocean-going vessel movements was obtained from the Pacific Pilotage Authority. In 1993, each ship in the Pacific Pilotage database was assigned a horsepower, using typical values by vessel type and DWT, compiled by Booz-Allen & Hamilton. The assumed horsepower was then used to estimate fuel consumption (at full power) as a function of vessel weight. Finally, emission factors expressed in kilograms of contaminant per tonne of fuel used were applied to the maximum fuel consumption, with adjustment for the fraction of power used while underway or manoeuvring.

For the current study, more recent correlations (U.S. EPA, 2000) estimating horsepower as a function of either DWT alone, or in combination with speed, were used. This is expected to give a more reliable estimate of horsepower rating, since eight different ship types are distinguished, compared to only three in the previous work. In addition, the EPA correlations use the DWT of the ship directly, rather than the more generic DWT ranges used previously. The horsepower estimates are then used with emission factors from the Lloyd's Register "Marine Exhaust Emissions Research Programme" (Lloyd, 1995) which are expressed in units of grams of contaminant per kilowatt-hour of output. Different emission factors were applied for underway and manoeuvring, in conjunction with time spent in each movement category, and load factors by vessel category and weight. This approach is more vessel-specific than the 1993 method, which required the estimation of maximum fuel consumption, again by generic weight class and for a limited number of ship types.

For both the 1993 and 2000 inventories, typical auxiliary generator fuel consumption rates were obtained from a survey of ship agents and used with emission factors expressed in kilograms of contaminant per tonne of fuel burned. One trend which was observed is an increase between 1993 and 2000 in the use of fuel oil while dockside, compared to diesel. The split was approximately 55:45 in 1993, and 88:12 in 2000.

***Recommendations***

- Although difficult to obtain, better data is needed on the quality of fuel purchased outside the study area, and the use of that fuel within the study area. In particular, international vessels may arrive with fuel purchased in other parts of the world, which may be subject to different fuel quality standards.

- Survey ocean-going ships to determine actual underway speed profiles, power levels, fuel use and fuel type when travelling in the study area. This would complement assumptions made in this study based on descriptive accounts obtained from marine industry contacts.

- The survey of dockside fuel use by ocean-going vessels conducted for this study provided excellent data and future surveys could be conducted in a similar manner.

## 6.2 HARBOUR VESSELS

The Westcoast Mariner Workboat Directory and Charterboat Directory were used for the 1993 marine vessel inventory to generate listings of companies operating tugboats, workboats and charter vessels. The boat counts for 1993 were 209, 128, and 126, respectively. The 2000 study used the Annual Pacific Coast Tug and Workboat Directory (262 boats within the Core Area) and the Chartering '99 Directory (187 boats). The total number of boats is similar, 463 for 1993 and 449 for the current study.

The 1993 emission factors were broken down into full, cruise and slow power levels, for different horsepower ranges. Cooperation from tugboat companies was excellent for the 1993 study, allowing the surveying and collection of fuel use data for 81% of the tugboats in the study area. Similarly fuel consumption data was obtained for workboats. For the 2000 study, however, fuel consumption data was not so readily available and emission estimates are based on vessel counts, average boat power and load, and time of operation.

***Recommendations***

- Good fuel consumption data was obtained for the 1993 inventory, due to the assistance of the Council of Marine Carriers who circulated a memo to their members. The same level of co-operation would be helpful for future studies.
- The use of directory information necessitates various assumptions about the fraction of time spent in the Core Area by harbour vessels. Better information on where harbour vessels operate, and for what duration, could be obtained through company surveys.

## 6.3 FERRIES

The 1993 study recommended that BC Ferries fuel use data be broken down into dockside and underway fuel use. The 2000 methodology and estimates for BC Ferries represent an improvement over 1993, since emissions have been estimated for dockside (idling), manoeuvring (at reduced load), and underway. In addition, emissions for "layup" operations (fuel consumption while ships are out of service and being repaired) have been included, calculated in terms of dockside and maneuvering emissions for the year 2000.

Emissions for SeaBus and the Albion Ferry have not changed significantly between the 1993 and 2000 studies. The Aquabus, Granville Island and Barnston Island ferries were added for 2000, while SeaLink Express, C.P. Ferries and Kingcome Navigation are no longer providing ferry services.

***Recommendations***

- BC Ferries provided total fuel consumption data, by ferry and by route, along with their own estimates of emissions. These estimates were improved for this study to adjust for fuel consumption at different load categories for idling, manoeuvring and underway. Better data could be requested from BC Ferries with respect to fuel consumption in each load category
- Better information on the use of auxiliary generators on the BC Ferries fleet, and the associated fuel consumption, could be requested.

## 6.4 FISHING VESSELS

Fishing vessel activity is not tracked by vessel, nor is there any available fuel consumption data. As for the 1993 study, the difficulty in estimating activity levels was significant since the fishing fleet is very mobile and variable in activity level.

***Recommendations***

- With improved tracking of fishing vessels in terms of location, fuel consumption and time spent in transit and idling, a more accurate inventory would result.
- Tracking travel of fishing vessels and time spent at various fishing locations would facilitate better spatial allocation of emissions.

## 6.5 RECREATIONAL VESSELS

The estimated emissions from recreational vessels show a significant increase between 1993 and 2000. Compared to 1993, the 2000 marine vessel inventory includes a better breakdown of recreational vessels by engine type (2 and 4 stroke) and fuel type. For 2000, personal watercraft were included, and for the most part, these are gasoline-fired engines with comparatively high VOC emissions.

***Recommendations***

- Fuel consumption estimates for recreational vessels was estimated from a variety of sources, including a calculation from statistics on engine type, power rating, load factor, hours of use and brake specific fuel consumption, and data from Statistics Canada. A wide range was found. Better fuel consumption estimates could be obtained from fuel suppliers in the study area.

# 7. REFERENCES

CARB (Air Resources Board of California), 1998, "Public Meeting to Consider Approval of California's Pleasure Craft Emissions Inventory", Staff Report in Mailout MSC 98-34, December.

CARB (Air Resources Board of California), 1995, "Development of an Improved Inventory of Emissions from Pleasure Craft in California", Report by Systems Applications International (SAI), June.

Consulting and Audit Canada, 1996, "Small Vessel Inventory in Canada", Report prepared in conjunction with Goss Gilroy Inc. for The Small Vessel Partnership Project of the Canadian Coast Guard, October.

Department of Fisheries and Oceans (DFO), “Restructuring Canada’s Pacific Fishery”, Volume 3-Issue 1, June 2000.
URL: http://www. comm.pac.dfompo.gc.ca/english/restruct/PDFs/june00_eng.pdf

Department of Fisheries and Oceans (DFO)
URL: http://www.pac.dfo-mpo.gc.ca

Drost, J., 2000, “Chartering ’99”, Pacific Yachting: Power and Sail in British Columbia, January.

Environment Canada, 1994, "Estimates of Emissions from Pleasure Craft in Canada", Report EPA 5/AP/5, March.

Environment Canada, 1997, “Port of Vancouver Marine Vessel Emissions Test Project”, Interim report ERMD#97-04.

Environment Canada, 2001a, "Canada's Greenhouse Gas Inventory 1990-1999, Emission and Removal Estimation Practices and Methods", April.

Environment Canada, 2001b, "1995 National Emissions Inventory for Atmospheric Ammonia - Guidebook", Final Draft, September.

EPA, 1991, "Nonroad Engine and Vehicle Emission Study - Report", November.

EPA, 1999, “Final Regulatory Impact Analysis: Control of Emissions from Marine Diesel Engines”, Report EPA420-R-99-026, November.

EPA, 1999b, “Exhaust Emission Factors for Nonroad Engine Modeling – Spark Ignition”, Report EPA420-R-99-009.

ICF Kaiser Consulting Group, 1999, “Off-road vehicle and equipment: GHG Emissions and Mitigation Measures”, Prepared for the National Climate Change Process: Technology Issues Table by ICF Kaiser Consulting Group, August.

IPCC, 1997, "IPCC Guidelines for National Greenhouse Gas Inventories - Volume 3 Reference Manual".

Levelton, 1995, "1993 Marine Vessel Air Emissions Inventory for the Lower Fraser Valley", Prepared for Environment Canada, B.C. Ministry of Environment, Land and Parks and the Greater Vancouver Regional District.

Lloyd's Register of Shipping, 1995, "Marine Exhaust Emissions Research Programme".

Progress Publishing Co. Ltd., 2001, "Annual Pacific Coast Tug and Workboat directory 2002", Harbour and Shipping, volume 84, number 12, December.

US EPA, and Energy and Environmental Analysis, Inc. (EEA), "Analysis of Commercial Marine Vessels Emissions and Fuel Consumption Data", EPA420-R-00-002, February 2000

# APPENDIX A: DETAILED EMISSION LISTINGS

**Table A-0-1: Ocean-going Vessels Underway Emissions-Criteria Contaminants and $NH_3$**

| | | Emission (tonnes/year) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Ship Type** | **DWT Class** | **CO** | **NOx** | **NO** | **$NO_2$** | **PM** | **SOx** | **$SO_2$** | **$SO_4$** | **VOC** | **$NH_3$** |
| Bulk Carrier | 0: 24999 | 6.7 | 75.7 | 71.1 | 4.5 | 6.3 | 43.3 | 42.4 | 0.9 | 2.1 | 1.5 |
| | 25000: 49999 | 26.6 | 299.0 | 281.1 | 17.9 | 24.9 | 171.1 | 167.7 | 3.4 | 8.3 | 5.8 |
| | 50000: 74999 | 18.2 | 204.7 | 192.4 | 12.3 | 17.1 | 117.1 | 114.8 | 2.3 | 5.7 | 4.0 |
| | 75000: 99999 | 2.8 | 31.4 | 29.5 | 1.9 | 2.6 | 18.0 | 17.6 | 0.4 | 0.9 | 0.6 |
| | 100000: | 14.2 | 159.3 | 149.8 | 9.6 | 13.3 | 91.2 | 89.3 | 1.8 | 4.4 | 3.1 |
| Bulk Carrier Total | | 68.5 | 770.1 | 723.9 | 46.2 | 64.2 | 440.7 | 431.9 | 8.8 | 21.4 | 15.0 |
| Container | 0: 24999 | 3.9 | 43.8 | 41.2 | 2.6 | 3.6 | 25.1 | 24.6 | 0.5 | 1.2 | 0.9 |
| | 25000: 49999 | 32.7 | 367.9 | 345.9 | 22.1 | 30.7 | 210.5 | 206.3 | 4.2 | 10.2 | 7.2 |
| | 50000: 74999 | 12.4 | 139.9 | 131.6 | 8.4 | 11.7 | 80.1 | 78.5 | 1.6 | 3.9 | 2.7 |
| | 75000: 99999 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | 100000: | 0.1 | 0.9 | 0.9 | 0.1 | 0.1 | 0.5 | 0.5 | 0.0 | 0.0 | 0.0 |
| Container Total | | 49.1 | 552.6 | 519.4 | 33.2 | 46.0 | 316.2 | 309.9 | 6.3 | 15.3 | 10.7 |
| General Cargo | 0: 24999 | 5.5 | 62.2 | 58.4 | 3.7 | 5.2 | 35.6 | 34.9 | 0.7 | 1.7 | 1.2 |
| | 25000: 49999 | 4.0 | 44.6 | 41.9 | 2.7 | 3.7 | 25.5 | 25.0 | 0.5 | 1.2 | 0.9 |
| | 50000: 74999 | 0.7 | 7.6 | 7.2 | 0.5 | 0.6 | 4.4 | 4.3 | 0.1 | 0.2 | 0.1 |
| | 75000: 99999 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | 100000: | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| General Cargo Total | | 10.2 | 114.4 | 107.5 | 6.9 | 9.5 | 65.5 | 64.1 | 1.3 | 3.2 | 2.2 |
| Passenger | 0: 24999 | 25.7 | 289.0 | 271.7 | 17.3 | 24.1 | 165.4 | 162.1 | 3.3 | 8.0 | 5.6 |
| | 25000: 49999 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | 50000: 74999 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | 75000: 99999 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | 100000: | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Passenger Total | | 25.7 | 289.0 | 271.7 | 17.3 | 24.1 | 165.4 | 162.1 | 3.3 | 8.0 | 5.6 |
| Tanker | 0: 24999 | 4.4 | 49.2 | 46.2 | 3.0 | 4.1 | 28.2 | 27.6 | 0.6 | 1.4 | 1.0 |
| | 25000: 49999 | 4.3 | 48.5 | 45.6 | 2.9 | 4.0 | 27.7 | 27.2 | 0.6 | 1.3 | 0.9 |
| | 50000: 74999 | 0.1 | 1.1 | 1.1 | 0.1 | 0.1 | 0.6 | 0.6 | 0.0 | 0.0 | 0.0 |
| | 75000: 99999 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | 100000: | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Tanker Total | | 8.8 | 98.8 | 92.9 | 5.9 | 8.2 | 56.5 | 55.4 | 1.1 | 2.7 | 1.9 |
| Other Vessels | 0: 25000 | 0.9 | 10.2 | 9.6 | 0.6 | 0.8 | 5.8 | 5.7 | 0.1 | 0.3 | 0.2 |
| | 25000: 50000 | 0.0 | 0.5 | 0.5 | 0.0 | 0.0 | 0.3 | 0.3 | 0.0 | 0.0 | 0.0 |
| | 50000: 75000 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | 75000: 100000 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | 100000: | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Other Vessels Total | | 1.0 | 10.7 | 10.1 | 0.6 | 0.9 | 6.1 | 6.0 | 0.1 | 0.3 | 0.2 |
| Grand Total | | 163.2 | 1835.6 | 1725.5 | 110.1 | 153.0 | 1050.4 | 1029.4 | 21.0 | 51.0 | 35.7 |

*Note:* NOx and SOx emissions are reported here as the sum of NO and $NO_2$, and $SO_2$ and $SO_4^{=}$ respectively, without correction to $NO_2$- and $SO_2$-equivalents

**Table A-0-2: Ocean-going Vessels Underway Emissions-Greenhouse Gases**

| | | Emission (tonnes/year) | | | |
|---|---|---|---|---|---|
| **Ship Type** | **DWT Class** | **$CH_4$** | **$N_2O$** | **$CO_2$** | **$CO_2$ -equivalents** |
| Bulk Carrier | 0: 24999 | 0.3 | 0.1 | 3,183 | 3,215 |
| | 25000: 49999 | 1.2 | 0.3 | 12,575 | 12,702 |
| | 50000: 74999 | 0.8 | 0.2 | 8,610 | 8,697 |
| | 75000: 99999 | 0.1 | 0.0 | 1,320 | 1,333 |
| | 100000: | 0.6 | 0.2 | 6,701 | 6,768 |
| Bulk Carrier Total | | 3.0 | 0.9 | 32,388 | 32,716 |
| Container | 0: 24999 | 0.2 | 0.0 | 1,841 | 1,860 |
| | 25000: 49999 | 1.4 | 0.4 | 15,474 | 15,631 |
| | 50000: 74999 | 0.5 | 0.2 | 5,886 | 5,945 |
| | 75000: 99999 | 0.0 | 0.0 | 0 | 0 |
| | 100000: | 0.0 | 0.0 | 38 | 39 |
| Container Total | | 2.1 | 0.6 | 23,239 | 23,475 |
| General Cargo | 0: 24999 | 0.2 | 0.1 | 2,615 | 2,641 |
| | 25000: 49999 | 0.2 | 0.0 | 1,875 | 1,894 |
| | 50000: 74999 | 0.0 | 0.0 | 321 | 325 |
| | 75000: 99999 | 0.0 | 0.0 | 0 | 0 |
| | 100000: | 0.0 | 0.0 | 0 | 0 |
| General Cargo Total | | 0.4 | 0.1 | 4,811 | 4,860 |
| Passenger | 0: 24999 | 1.1 | 0.3 | 12,155 | 12,278 |
| | 25000: 49999 | 0.0 | 0.0 | 0 | 0 |
| | 50000: 74999 | 0.0 | 0.0 | 0 | 0 |
| | 75000: 99999 | 0.0 | 0.0 | 0 | 0 |
| | 100000: | 0.0 | 0.0 | 0 | 0 |
| Passenger Total | | 1.1 | 0.3 | 12,155 | 12,278 |
| Tanker | 0: 24999 | 0.2 | 0.1 | 2,069 | 2,090 |
| | 25000: 49999 | 0.2 | 0.1 | 2,039 | 2,060 |
| | 50000: 74999 | 0.0 | 0.0 | 48 | 48 |
| | 75000: 99999 | 0.0 | 0.0 | 0 | 0 |
| | 100000: | 0.0 | 0.0 | 0 | 0 |
| Tanker Total | | 0.4 | 0.1 | 4,155 | 4,198 |
| Other Vessels | 0: 25000 | 428.3 | 428.3 | 428 | 142,209 |
| | 25000: 50000 | 0.0 | 0.0 | 22 | 22 |
| | 50000: 75000 | 0.0 | 0.0 | 0 | 0 |
| | 75000: 100000 | 0.0 | 0.0 | 0 | 0 |
| | 100000: | 0.0 | 0.0 | 0 | 0 |
| Other Vessels Total | | 0.0 | 0.0 | 450 | 455 |
| Grand Total | | 7.1 | 2.0 | 77,198 | 77,981 |

**Table A-0-3: Ocean-going Vessels Manoeuvring Emissions- CAC and $NH_3$**

| | | Emission (tonnes/year) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Ship Type** | **DWT Class** | **CO** | **NOx** | **NO** | **$NO_2$** | **PM** | **SOx** | **$SO_2$** | **$SO_4$** | **VOC** | **$NH_3$** |
| Bulk Carrier | 0: 24999 | 4.9 | 24.6 | 23.1 | 1.5 | 1.9 | 2.8 | 2.7 | 0.1 | 0.3 | 0.5 |
| | 25000: 49999 | 20.3 | 101.9 | 95.8 | 6.1 | 7.7 | 11.5 | 11.3 | 0.2 | 1.1 | 1.9 |
| | 50000: 74999 | 5.8 | 29.4 | 27.6 | 1.8 | 2.2 | 3.3 | 3.3 | 0.1 | 0.3 | 0.6 |
| | 75000: 99999 | 0.5 | 2.5 | 2.4 | 0.2 | 0.2 | 0.3 | 0.3 | 0.0 | 0.0 | 0.0 |
| | 100000: | 1.0 | 5.1 | 4.8 | 0.3 | 0.4 | 0.6 | 0.6 | 0.0 | 0.1 | 0.1 |
| Bulk Carrier Total | | 32.5 | 163.5 | 153.7 | 9.8 | 12.3 | 18.5 | 18.1 | 0.4 | 1.8 | 3.1 |
| Container | 0: 24999 | 4.2 | 21.0 | 19.8 | 1.3 | 1.6 | 2.4 | 2.3 | 0.0 | 0.2 | 0.4 |
| | 25000: 49999 | 16.8 | 84.3 | 79.3 | 5.1 | 6.3 | 9.5 | 9.3 | 0.2 | 0.9 | 1.6 |
| | 50000: 74999 | 9.3 | 46.7 | 43.9 | 2.8 | 3.5 | 5.3 | 5.2 | 0.1 | 0.5 | 0.9 |
| | 75000: 99999 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | 100000: | 0.2 | 1.0 | 0.9 | 0.1 | 0.1 | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 |
| Container Total | | 30.4 | 153.0 | 143.9 | 9.2 | 11.5 | 17.3 | 16.9 | 0.3 | 1.6 | 2.9 |
| General Cargo | 0: 24999 | 10.0 | 50.2 | 47.2 | 3.0 | 3.8 | 5.7 | 5.6 | 0.1 | 0.5 | 0.9 |
| | 25000: 49999 | 2.4 | 12.2 | 11.4 | 0.7 | 0.9 | 1.4 | 1.3 | 0.0 | 0.1 | 0.2 |
| | 50000: 74999 | 0.9 | 4.5 | 4.3 | 0.3 | 0.3 | 0.5 | 0.5 | 0.0 | 0.0 | 0.1 |
| | 75000: 99999 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | 100000: | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| General Cargo Total | | 13.3 | 66.9 | 62.9 | 4.0 | 5.0 | 7.6 | 7.4 | 0.2 | 0.7 | 1.3 |
| Passenger | 0: 24999 | 4.9 | 24.6 | 23.1 | 1.5 | 1.8 | 0.1 | 0.1 | 0.0 | 0.3 | 0.5 |
| | 25000: 49999 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | 50000: 74999 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | 75000: 99999 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | 100000: | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Passenger Total | | 4.9 | 24.6 | 23.1 | 1.5 | 1.8 | 0.1 | 0.1 | 0.0 | 0.3 | 0.5 |
| Tanker | 0: 24999 | 1.8 | 9.1 | 8.6 | 0.5 | 0.7 | 2.8 | 2.7 | 0.1 | 0.1 | 0.2 |
| | 25000: 49999 | 1.5 | 7.5 | 7.0 | 0.4 | 0.6 | 0.0 | 0.0 | 0.0 | 0.1 | 0.1 |
| | 50000: 74999 | 0.0 | 0.2 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | 75000: 99999 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | 100000: | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Tanker Total | | 3.3 | 16.8 | 15.8 | 1.0 | 1.3 | 2.8 | 2.7 | 0.1 | 0.2 | 0.3 |
| Other Vessels | 0: 25000 | 0.2 | 1.2 | 1.1 | 0.1 | 0.1 | 1.0 | 1.0 | 0.0 | 0.0 | 0.0 |
| | 25000: 50000 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.8 | 0.8 | 0.0 | 0.0 | 0.0 |
| | 50000: 75000 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | 75000: 100000 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | 100000: | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Other Vessels Total | | 0.2 | 1.2 | 1.2 | 0.1 | 0.1 | 1.9 | 1.9 | 0.0 | 0.0 | 0.0 |
| Grand Total | | 84.7 | 426.0 | 400.5 | 25.6 | 32.1 | 48.1 | 47.1 | 1.0 | 4.6 | 8.0 |

*Note:* NOx and SOx emissions are reported here as the sum of NO and $NO_2$, and $SO_2$ and $SO_4^{=}$ respectively, without correction to $NO_2$- and $SO_2$-equivalents

**Table A-0-4: Ocean-going Vessels Manoeuvring Emissions-Greenhouse Gases**

| | | Emission (tonnes/year) | | | |
|---|---|---|---|---|---|
| **Ship Type** | **DWT Class** | **$CH_4$** | **$N_2O$** | **$CO_2$** | **$CO_2$ – equivalents** |
| Bulk Carrier | 0: 24999 | 0.1 | 0.4 | 902 | 1,022 |
| | 25000: 49999 | 0.2 | 1.6 | 3,735 | 4,232 |
| | 50000: 74999 | 0.1 | 0.5 | 1,077 | 1,221 |
| | 75000: 99999 | 0.0 | 0.0 | 93 | 105 |
| | 100000: | 0.0 | 0.1 | 188 | 213 |
| Bulk Carrier Total | | 0.4 | 2.5 | 5,995 | 6,793 |
| Container | 0: 24999 | 0.0 | 0.3 | 771 | 873 |
| | 25000: 49999 | 0.2 | 1.3 | 3,092 | 3,503 |
| | 50000: 74999 | 0.1 | 0.7 | 1,713 | 1,941 |
| | 75000: 99999 | 0.0 | 0.0 | 0 | 0 |
| | 100000: | 0.0 | 0.0 | 36 | 40 |
| Container Total | | 0.3 | 2.4 | 5,611 | 6,358 |
| General Cargo | 0: 24999 | 0.1 | 0.8 | 1,840 | 2,085 |
| | 25000: 49999 | 0.0 | 0.2 | 446 | 505 |
| | 50000: 74999 | 0.0 | 0.1 | 166 | 188 |
| | 75000: 99999 | 0.0 | 0.0 | 0 | 0 |
| | 100000: | 0.0 | 0.0 | 0 | 0 |
| General Cargo Total | | 0.1 | 1.0 | 2,452 | 2,778 |
| Passenger | 0: 24999 | 0.1 | 0.4 | 901 | 1,021 |
| | 25000: 49999 | 0.0 | 0.0 | 0 | 0 |
| | 50000: 74999 | 0.0 | 0.0 | 0 | 0 |
| | 75000: 99999 | 0.0 | 0.0 | 0 | 0 |
| | 100000: | 0.0 | 0.0 | 0 | 0 |
| Passenger Total | | 0.1 | 0.4 | 901 | 1,021 |
| Tanker | 0: 24999 | 0.0 | 0.1 | 334 | 378 |
| | 25000: 49999 | 0.0 | 0.1 | 275 | 311 |
| | 50000: 74999 | 0.0 | 0.0 | 7 | 8 |
| | 75000: 99999 | 0.0 | 0.0 | 0 | 0 |
| | 100000: | 0.0 | 0.0 | 0 | 0 |
| Tanker Total | | 0.0 | 0.3 | 616 | 698 |
| Other Vessels | 0: 25000 | 44.8 | 44.8 | 45 | 14,873 |
| | 25000: 50000 | 0.0 | 0.0 | 1 | 1 |
| | 50000: 75000 | 0.0 | 0.0 | 0 | 0 |
| | 75000: 100000 | 0.0 | 0.0 | 0 | 0 |
| | 100000: | 0.0 | 0.0 | 0 | 0 |
| Other Vessels Total | | 0.0 | 0.0 | 46 | 52 |
| Grand Total | | 0.9 | 6.6 | 15,621 | 17,699 |

**Table A-0-5: Ocean-going Vessels Dockside Emissions- CAC and $NH_3$**

| | | Emission (tonnes/year) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Ship Type** | **DWT Class** | **CO** | **NOx** | **NO** | **$NO_2$** | **PM** | **SOx** | **$SO_2$** | **$SO_4$** | **VOC** | **$NH_3$** |
| Bulk Carrier | 0: 24999 | 37.9 | 430.4 | 404.6 | 25.8 | 50.8 | 354.9 | 347.8 | 7.1 | 16.1 | 0.0 |
| | 25000: 49999 | 123.7 | 1405.1 | 1320.8 | 84.3 | 165.8 | 1158.6 | 1135.4 | 23.2 | 52.6 | 0.2 |
| | 50000: 74999 | 35.8 | 406.8 | 382.3 | 24.4 | 48.0 | 335.4 | 328.7 | 6.7 | 15.2 | 0.0 |
| | 75000: 99999 | 4.3 | 48.6 | 45.7 | 2.9 | 5.7 | 40.1 | 39.3 | 0.8 | 1.8 | 0.0 |
| | 100000: | 11.8 | 134.2 | 126.1 | 8.0 | 15.8 | 110.6 | 108.4 | 2.2 | 5.0 | 0.0 |
| Bulk Carrier Total | | 213.4 | 2425.0 | 2279.5 | 145.5 | 286.1 | 1999.5 | 1959.5 | 40.0 | 90.8 | 0.3 |
| Container | 0: 24999 | 14.2 | 160.8 | 151.2 | 9.6 | 19.0 | 112.3 | 110.1 | 2.2 | 6.0 | 0.0 |
| | 25000: 49999 | 44.9 | 510.3 | 479.7 | 30.6 | 60.2 | 356.5 | 349.3 | 7.1 | 19.1 | 0.1 |
| | 50000: 74999 | 14.7 | 166.8 | 156.8 | 10.0 | 19.7 | 116.5 | 114.2 | 2.3 | 6.2 | 0.0 |
| | 75000: 99999 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | 100000: | 0.1 | 1.0 | 0.9 | 0.1 | 0.1 | 0.7 | 0.7 | 0.0 | 0.0 | 0.0 |
| Container Total | | 73.8 | 839.0 | 788.6 | 50.3 | 99.0 | 586.0 | 574.3 | 11.7 | 31.4 | 0.1 |
| General Cargo | 0: 24999 | 51.8 | 588.0 | 552.7 | 35.3 | 69.4 | 488.4 | 478.6 | 9.8 | 22.0 | 0.1 |
| | 25000: 49999 | 14.4 | 164.0 | 154.1 | 9.8 | 19.3 | 136.2 | 133.5 | 2.7 | 6.1 | 0.0 |
| | 50000: 74999 | 3.1 | 35.6 | 33.4 | 2.1 | 4.2 | 29.5 | 29.0 | 0.6 | 1.3 | 0.0 |
| | 75000: 99999 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | 100000: | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| General Cargo Total | | 69.3 | 787.5 | 740.3 | 47.3 | 92.9 | 654.1 | 641.1 | 13.1 | 29.5 | 0.1 |
| Passenger | 0: 24999 | 19.5 | 221.5 | 208.2 | 13.3 | 26.1 | 182.9 | 179.2 | 3.7 | 8.3 | 0.0 |
| | 25000: 49999 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | 50000: 74999 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | 75000: 99999 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | 100000: | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Passenger Total | | 19.5 | 221.5 | 208.2 | 13.3 | 26.1 | 182.9 | 179.2 | 3.7 | 8.3 | 0.0 |
| Tanker | 0: 24999 | 1.2 | 37.5 | 35.3 | 2.3 | 1.5 | 14.8 | 14.5 | 0.3 | 1.2 | 0.0 |
| | 25000: 49999 | 0.8 | 25.9 | 24.4 | 1.6 | 1.1 | 10.2 | 10.0 | 0.2 | 0.8 | 0.0 |
| | 50000: 74999 | 0.0 | 0.6 | 0.6 | 0.0 | 0.0 | 0.2 | 0.2 | 0.0 | 0.0 | 0.0 |
| | 75000: 99999 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | 100000: | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Tanker Total | | 2.0 | 64.1 | 60.2 | 3.8 | 2.6 | 25.2 | 24.7 | 0.5 | 2.1 | 0.0 |
| Other Vessels | 0: 25000 | 30.1 | 342.5 | 321.9 | 20.5 | 40.4 | 282.7 | 277.1 | 5.7 | 12.8 | 0.0 |
| | 25000: 50000 | 6.3 | 71.3 | 67.0 | 4.3 | 8.4 | 58.8 | 57.7 | 1.2 | 2.7 | 0.0 |
| | 50000: 75000 | 2.5 | 28.7 | 27.0 | 1.7 | 3.4 | 23.7 | 23.2 | 0.5 | 1.1 | 0.0 |
| | 75000: 100000 | 0.3 | 3.3 | 3.1 | 0.2 | 0.4 | 2.8 | 2.7 | 0.1 | 0.1 | 0.0 |
| | 100000: | 0.5 | 5.7 | 5.4 | 0.3 | 0.7 | 4.7 | 4.6 | 0.1 | 0.2 | 0.0 |
| Other Vessels Total | | 39.7 | 451.6 | 424.5 | 27.1 | 53.3 | 372.8 | 365.3 | 7.5 | 16.9 | 0.1 |
| Grand Total | | 417.8 | 4788.7 | 4501.3 | 287.3 | 560.0 | 3820.4 | 3744.0 | 76.4 | 179.0 | 0.5 |

*Note:* NOx and SOx emissions are reported here as the sum of NO and $NO_2$, and $SO_2$ and $SO_4^{=}$ respectively, without correction to $NO_2$- and $SO_2$-equivalents

**Table A-0-6: Ocean-going Vessels Dockside Emissions-Greenhouse Gases**

| | | Emission (tonnes/year) | | | |
|---|---|---|---|---|---|
| **Ship Type** | **DWT Class** | **$CH_4$** | **$N_2O$** | **$CO_2$** | **$CO_2$ – equivalents** |
| Bulk Carrier | 0: 24999 | 3.0 | 1.7 | 29206.7 | 29,787 |
| | 25000: 49999 | 9.9 | 5.4 | 95352.2 | 97,247 |
| | 50000: 74999 | 2.9 | 1.6 | 27601.9 | 28,150 |
| | 75000: 99999 | 0.3 | 0.2 | 3297.1 | 3,363 |
| | 100000: | 0.9 | 0.5 | 9103.4 | 9,284 |
| Bulk Carrier Total | | 17.1 | 9.4 | 164561.3 | 167,831 |
| Container | 0: 24999 | 1.0 | 1.1 | 10679.4 | 11,042 |
| | 25000: 49999 | 3.3 | 3.5 | 33889.9 | 35,040 |
| | 50000: 74999 | 1.1 | 1.1 | 11076.2 | 11,452 |
| | 75000: 99999 | 0.0 | 0.0 | 0.0 | 0 |
| | 100000: | 0.0 | 0.0 | 66.1 | 68 |
| Container Total | | 5.4 | 5.7 | 55711.6 | 57,602 |
| General Cargo | 0: 24999 | 4.2 | 2.2 | 39942.7 | 40,710 |
| | 25000: 49999 | 1.2 | 0.6 | 11137.2 | 11,351 |
| | 50000: 74999 | 0.3 | 0.1 | 2416.2 | 2,463 |
| | 75000: 99999 | 0.0 | 0.0 | 0.0 | 0 |
| | 100000: | 0.0 | 0.0 | 0.0 | 0 |
| General Cargo Total | | 5.6 | 2.9 | 53496.1 | 54,523 |
| Passenger | 0: 24999 | 2.4 | 1.3 | 23245.4 | 23,705 |
| | 25000: 49999 | 0.5 | 0.3 | 4837.4 | 4,933 |
| | 50000: 74999 | 0.2 | 0.1 | 1947.9 | 1,986 |
| | 75000: 99999 | 0.0 | 0.0 | 227.3 | 232 |
| | 100000: | 0.0 | 0.0 | 389.6 | 397 |
| Passenger Total | | 3.2 | 1.7 | 30647.6 | 31,253 |
| Tanker | 0: 24999 | 1.6 | 0.9 | 15034.7 | 15,332 |
| | 25000: 49999 | 0.0 | 0.0 | 0.0 | 0 |
| | 50000: 74999 | 0.0 | 0.0 | 0.0 | 0 |
| | 75000: 99999 | 0.0 | 0.0 | 0.0 | 0 |
| | 100000: | 0.0 | 0.0 | 0.0 | 0 |
| Tanker Total | | 1.6 | 0.9 | 15034.7 | 15,332 |
| Other Vessels | 0: 25000 | 0.1 | 0.0 | 895.1 | 904 |
| | 25000: 50000 | 0.1 | 0.0 | 618.0 | 624 |
| | 50000: 75000 | 0.0 | 0.0 | 14.2 | 14 |
| | 75000: 100000 | 0.0 | 0.0 | 0.0 | 0 |
| | 100000: | 0.0 | 0.0 | 0.0 | 0 |
| Other Vessels Total | | 0.2 | 0.0 | 1527.3 | 1,542 |
| Grand Total | | 33.0 | 20.7 | 320978.5 | 328,084 |

**Table A-0-7: Ocean-going Vessels – Summary of Greenhouse Gas Emissions**

| | | Emission (tonnes/year) | | | |
|---|---|---|---|---|---|
| **Emission Source** | **Fuel** | **$CH_4$** | **$N_2O$** | **$CO_2$** | **$CO_2$ Equivalents** |
| Dockside | Fuel Oil | 2.1 | 13.7 | 36,618 | 40,919 |
| | Marine Diesel | 30.9 | 7.0 | 284,361 | 287,165 |
| Dockside Total | | 33.0 | 20.7 | 320,979 | 328,084 |
| Manoeuvring | Marine Diesel | 0.9 | 6.6 | 15,621 | 17,699 |
| Underway | Fuel Oil | 7.1 | 2.0 | 77,198 | 77,981 |
| Grand Total | | 41.1 | 29.4 | 413,798 | 423,764 |

**Table A-0-8: Ocean-going Vessels – Summary of CAC and $NH_3$ Emissions**

| | | Emission (tonnes/year) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Type of Emission** | **Fuel** | **CO** | **NOx** | **NO** | **$NO_2$** | **PM** | **SOx** | **$SO_2$** | **$SO_4$** | **VOC** | **$NH_3$** |
| Dockside | Fuel Oil | 55 | 663 | 624 | 40 | 73 | 35 | 34 | 1 | 24 | 0.07 |
| | Marine Diesel | 363 | 4,125 | 3,878 | 248 | 487 | 3,785 | 3,710 | 76 | 155 | 0.46 |
| Dockside Total | | 418 | 4,789 | 4,501 | 287 | 560 | 3,820 | 3,744 | 76 | 179 | 0.53 |
| Manoeuvring | Marine Diesel | 85 | 426 | 400 | 26 | 32 | 48 | 47 | 1 | 5 | 8 |
| Underway | Fuel Oil | 163 | 1,836 | 1,725 | 110 | 153 | 1,050 | 1,029 | 21 | 51 | 36 |
| Grand Total | | 666 | 7,050 | 6,627 | 423 | 745 | 4,919 | 4,821 | 98 | 235 | 44 |

*Note:* NOx and SOx emissions are reported here as the sum of NO and $NO_2$, and $SO_2$ and $SO_4^{=}$ respectively, without correction to $NO_2$- and $SO_2$-equivalents

# APPENDIX B: DISCUSSION OF MARINE VESSEL TYPES IN STUDY AREA

**BY MR. FRED MCCAGUE OF CARGOMASTER SERVICES INC.**

# VESSEL CATEGORIES

## A. OCEAN-GOING VESSELS

Ocean-going vessel traffic in British Columbia is centered on the ports of Vancouver (more than 3,000 ship calls per year), Fraser Port (more than 400 shipcalls), and Prince Rupert (about 700 calls). Few ships call the province without making a port call at least one of these ports.

In Vancouver, the number of ship calls has remained almost constant for more than 30 years, while the ships size has grown and tonnage loaded has tripled over the same period.

The largest ships calling B.C. load more than 160,000 tonnes of coal.

Vancouver handles more than 70 million tonnes of international and domestic cargo each year. It is Canada's largest port and the largest dry cargo port on the West Coast of the Americas. The Port of Vancouver is second to Vancouver International Airport in job creation.

Fraser Port handles domestic and international freight of almost 25 million tonnes per year, a greater tonnage than handled at the Port of Montreal. North Fraser Port handles another 17 million tonnes, all domestic cargo.

- **Cruise ships** – large passenger vessels, which can carry up to 2,600 passengers per voyage, make over 300 port calls at the Port of Vancouver each year. Most use medium-speed diesel-electric propulsion. In 2000, there were two steam-powered ships operating. In 2001, there were one steam-powered ship and two new gas turbine powered vessels. Almost all (more than 98 percent) of the fuel consumed is purchased in North America with most purchased in Vancouver. The ships are in port for 10 or 11 hours. During the summer, they will sail on the Inside Passage to Alaska remaining in B.C. waters for about 24 hours each way. The ships use lighter IFO 180 fuel. The operators continue to upgrade their ships, in 2001 they introducing two new ships fitted cleaner-burning diesels and two with gas turbines to reduce visible exhaust and other emissions.

- **Bulk Carriers** – The majority of ships calling Vancouver, Fraser Port and Prince Rupert are bulk carriers loading coal, grain, sulphur, potash and other bulk cargoes or discharging salt, phosphates or concentrates. Bulk carriers will also call Texada Island, Kitimat, and beginning in 2001, Sechelt. There are overflow anchorages in the Gulf Islands that will be used for ships awaiting cargo in Vancouver. The ships range in size, with cargo capacities from 20,000 to more than 160,000 tonnes. Most call British Columbia only occasionally. The ships feature slow-speed diesel engines and medium speed diesel generators. The ships normally use IFO 380 fuel oil for their main engines and generators, switching to marine diesel fuel for manoeuvring. Some ships, especially older vessels, use diesel fuel for their generators. Bulk carriers arrive with fuel purchased elsewhere, either in a port between Japan and Singapore or on a previous voyage.

- **General Cargo and Forest Products Carriers** – There are very few traditional "general cargo" ships in service, most having been displaced by container ships. The dominate ship-type in this category is the open-hatched bulk carrier, a ship with two large gantry cranes on board, which, in British Columbia load woodpulp, paper, lumber plus other cargo including bulk cargo and containers. This type of ship will call Vancouver and Fraser Port, usually more than one berth, plus one or more other ports including pulpmill docks at Nanaimo, Crofton, Squamish, Campbell River (Duncan Bay), Kitimat, etc. There are other specialised lumber carriers and roll-on roll-off ships in similar services. The ships are generally in regular services between B.C. and the U.S. West Coast and Asia or Europe. The ships are powered by large slow-speed diesels. They normally have larger generators to provide power for their cranes and other machinery. Fuel would be purchased either in North America or Asia.

- **Container Ships** – Container ships are large purpose-built vessels designed to carry standardised containers full of manufactured products around the world. The ships operate on fixed schedules at high speeds of between 19 and 26 knots. They call at four terminals in the Port of Vancouver and Fraser Port, usually remaining in port less than 24 hours. They will also call one or more U.S. ports, usually in Puget Sound. They have large slow-speed diesel main engines with 30,000 to 70,000 hp. The ships also feature large generators to provide power for refrigerated containers. In 2000, the ships generally purchased fuel either in Asia, Puget Sound or California.

- **Tankers** – Three types of tankers call British Columbia. Chemical tankers to load methanol and similar products at Vancouver, Kitimat and Prince Rupert, small tankers for imports and exports of refined products including gasoline and jet fuel, and about once per month, a larger tanker at Vancouver for crude oil. They are powered by slow-speed diesels. Chemical tanker fuel is either the U.S. or Asia. Oil tankers fuel mainly from the U.S.

- **Car ships** – Car ships call at two terminals in Fraser Port, often as part of a voyage that will include one or more U.S. West Coast ports. The main feature is a large ramp where new automobiles and trucks are driven of the ship. The ships are powered by slow speed diesels. They are usually in port for just 8 to 24 hours.

- **Government vessels** – There are occasional visits to Vancouver and other B.C. ports by ocean-going training and research vessels owned by various foreign governments. The visits are rare and do not form a significant source of marine emissions in the GVRD.

- **Military and Rescue Vessels** – The Canadian Coast Guard has bases in Vancouver at Kitsilano and a hovercraft base at Vancouver International Airport to provide search and rescue services in Georgia Strait. The Coast Guard also has buoy tenders, lifeboats and patrol vessels based in Victoria, Prince Rupert and other locations along the coast. The Canadian Navy has a major base at Esquimalt. Canadian naval vessels occasionally call Vancouver, New Westminster and other B.C. ports. The RCMP operates four patrol vessels and some small craft in B.C. Ships of the U.S. Navy and other navies will call Victoria, Vancouver and Nanoose Bay.

- **Large Foreign Fishing Vessels** – Large trawlers will call Vancouver and Victoria on a regular basis for supplies, repairs, drydockings and layovers. They are smaller ships and will fish in the North Pacific, some under licence within Canada's Exclusive Economic Zone, but outside the Coastal Area for emissions inventory. The fuel used is purchased either in Vancouver or Puget Sound.

## B. HARBOUR AND COASTAL VESSELS

The protected waters of the Inside Passage has allowed creation of a unique transportation industry in British Columbia.

The efficient system of tugs and barges augmented by ferries that moves an immense tonnage. Fraser Port, Port North Fraser and the Port of Vancouver combine for more than 44 million metric tons of domestic cargo per year, almost all towed and passing almost unnoticed through the heart of the metropolitan area.

This three-port tonnage figure rivals the total of 46 million metric tons of domestic and international cargo passing annually through the Welland Canal/St. Lawrence Seaway system.

Many tows are under 100 miles. Routes between the Fraser River and Howe Sound, Sechelt and Vancouver Island predominate at least in frequency.

The industry uses comparatively lightly powered tugs. Just four tugs have more horsepower than the Canadian Pacific Railway's new 4,300 hp locomotives. A few more are over 3,000 hp. Most coastal tugs are just over or just under 2,000 hp, small tugs by U.S. or international standards.

The slow economy and decline of the coastal forest industry has also resulted in a fairly old fleet, with in 2000, more than 80 percent of the tugs and barges over 29 years old.

In 2000, the West Coast fleet included 376 coastal tugs over 10 gross tons, 310 small tugs (5 to 10 gt) and 42 ship-berthing tugs. There were also 617 barges over 100 gross tons. The Fraser River Port Authority notes one woodchip barge takes 65 trucks off the road.

- **Harbour and River Tugs** - There are number of tugs dedicated to working on the Fraser River and Burrard Inlet shifting barges and log booms. These are generally smaller, lightly powered tugboats.
- **Shipberthing tugs** – specially designed comparatively high-powered tugs are used to assist ships into and out of dock and escort them in some areas. There are approximately 20 ship-assist tugs in the Lower Mainland.
- **Coastal Tugs** – Smaller tugs with 1,500 to 2,000 hp used to haul logs and barges on Georgia Strait and other sheltered waters.
- **Ocean going tugs** – These are larger tugs usually about 3,000 hp or more used to tow log barges and other large barges in the open waters of the Pacific Ocean. This type of tug provides service to the west coast of Vancouver Island and the Queen Charlotte Islands as well as along the U.S. West Coast and Alaska. The largest are the *Seaspan Commodore*, *Seaspan Regent* and *Rivtow Capt. Bob* with more than 5,000 hp.

## C. FERRIES

B.C. Ferries operates a fleet of more than 40 ferries along the British Columbia coast. The company's largest vessels operate between the Lower Mainland and Vancouver Island and the Sechelt Peninsula. Seaspan Coastal Intermodal operates trailer ferries from its Tilbury Terminal in Delta and Vancouver Island. Translink has two car ferries across the Fraser River and two passenger ferries across Burrard Inlet.

There are no transborder services from Greater Vancouver. In the Coastal Area, transborder car ferries operate between Port Angeles and Victoria, Anacortes and Sidney as well as Prince Rupert and Alaska. Victoria Clipper operates passenger-only ferries between Victoria and Seattle and there are also some smaller operators.

A twice-weekly ferry sails in U.S. domestic service from Bellingham to Alaska along the B.C. Inside Passage.

**D. FISHING VESSELS** – Thousands of small fishing vessels are licensed to fish along the entire B.C. coast. Reduced catches have restricted their time at sea.

**E. RECREATIONAL VESSELS** – inboard and outboard power boat and jet-skis are active throughout the region.

**F. U.S. DOMESTIC SERVICE** – There is a significant movement of U.S. ships, tugs, ferries and fishing vessels between Washington State and Alaska most of it using the Inside Passage and passing through the Core Area.

# APPENDIX C: DATA FROM SURVEY OF SHIP AGENTS

## BY MR. FRED MCCAGUE OF CARGOMASTER SERVICES INC.

# Table C-1: Ocean-Going Vessels - Survey of Ship Agents - Ship Data and In-Harbour Fuel Use

| Type | DWT | HP | Generators 1 kW | 2 kW | 3 kW | 4 kW | Total kW | Cargo | Berths | Time in Port hours | Total Fuel Use Fuel Oil t | Diesel t | Manoevring Fuel Use t | Fuel Use Dockside t | Fuel Used Per Day t/d | Averaged Data Fuel/Day t/d | Gen.Power kW |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CAR CARRIERS | 18,777 | 15,900 | 627 | 627 | 627 | 627 | 2,508 | Automobiles | Fraser Wharves or Annacis | 20.0 | 3.4 | 0.8 | 0.0 | 4.2 | 5.0 | 4.5 | 1516 |
| | 18,293 | 9,900 | 560 | 560 | 560 | | 1,680 | Automobiles | Fraser Wharves or Annacis | 19.0 | 1.0 | 0.8 | 0.0 | 1.8 | 2.3 | | |
| | 13,224 | 12,410 | 680 | 680 | 680 | | 2,040 | Automobiles | Fraser Wharves or Annacis | 6.0 | 1.5 | 0.0 | 0.0 | 1.5 | 6.0 | | |
| | 14,101 | n/a | n/a | | | | 0 | Automobiles | Fraser Wharves or Annacis | 18.5 | 3.8 | 0.1 | 0.0 | 3.9 | 5.1 | | |
| | 16,045 | 15,360 | n/a | | | | 0 | Automobiles | Fraser Wharves or Annacis | 8.0 | 1.2 | 0.1 | 0.0 | 1.3 | 3.9 | | |
| BULK CARRIERS 20 - 75,000 DWT | 38,891 | 8,000 | n/a | | | | 0 | Woodchips | Fibreco | 120.4 | 10.7 | 1.3 | 0.0 | | | 3.0 | 0 |
| | 22,020 | 7,200 | n/a | | | | 0 | Logs | Fraser Surrey | 99.7 | 6.4 | 1.5 | 0.0 | 7.9 | 1.9 | | |
| | 22,020 | 7,200 | n/a | | | | 0 | Logs | Prince Rupert | 25.8 | 3.4 | 1.0 | 0.0 | 4.4 | 4.1 | | |
| | | | n/a | | | | 0 | | | | 0.0 | 0.0 | 0.0 | 0.0 | | | |
| | | | n/a | | | | 0 | | | | 0.0 | 0.0 | 0.0 | 0.0 | | | |
| | | | n/a | | | | 0 | | | | 0.0 | 0.0 | 0.0 | 0.0 | | | |
| | | | n/a | | | | 0 | | | | 0.0 | 0.0 | 0.0 | 0.0 | | | |
| BULK CARRIERS 75,000+ DWT | 168,208 | 26,740 | n/a | | | | 0 | Coal | Anchorage + Westshore Term | 81.4 | 18.3 | 0.9 | 0.0 | 19.2 | | 4.1 | 0 |
| | 166,279 | 20,940 | n/a | | | | 0 | Coal | Anchorage + Westshore Term | 130.7 | 19.6 | 0.3 | 0.0 | 19.9 | 3.7 | | |
| | 166,279 | 20,940 | n/a | | | | 0 | Coal | Pr Rupert anchorage + Ridley | 191.4 | 26.0 | 1.0 | 0.0 | 27.0 | 3.4 | | |
| | 148,832 | 22,920 | n/a | | | | 0 | Coal | Prince Rupert - Ridley | 31.2 | 2.1 | 4.3 | 0.0 | 6.4 | 4.9 | | |
| | 91,439 | n/a | n/a | | | | 0 | Coal | Westshore Terminal | 84.0 | 15.1 | 1.0 | 0.0 | 16.1 | 4.6 | | |
| TANKERS | 24,090 | 5,800 | 362 | 362 | 362 | | 1,086 | Chemicals | Lynnterm | 6.8 | 0.5 | 0.1 | 0.0 | 0.6 | 2.1 | 1.4 | 271.5 |
| | 15,389 | 6,160 | n/a | | | | 0 | Chemicals | Lynnterm | 20.0 | 4.1 | 0.0 | 0.0 | 4.1 | 4.9 | | |
| | | | n/a | | | | 0 | | | 124.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | | |
| | | | n/a | | | | 0 | | | 96.7 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | | |
| | | | n/a | | | | 0 | | | 105.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | | |
| FOREST PRODUCT CARRIERS | 47,069 | 12,170 | 750 | 750 | 750 | | 2,250 | Forest Products | Vancouver - 2 berths | 136.6 | 25.4 | 0.2 | 0.0 | 25.6 | 4.5 | 4.5 | 1800 |
| | 46,076 | 10,344 | 750 | 750 | 750 | | 2,250 | Forest Products | Lynnterm | 124.8 | 14.6 | 3.7 | 0.0 | 18.3 | 3.5 | | |
| | 47,029 | 10,344 | 750 | 750 | 750 | | 2,250 | Forest Products | Nanaimo, Vanc, Fraser, Vanc | 204.5 | 45.0 | 1.4 | 0.0 | 46.4 | 5.4 | | |
| | 47,032 | 13,510 | n/a | 0 | 0 | | 0 | Forest Products | Vancouver - 2 berths | 184.6 | 29.8 | 2.2 | 0.0 | 32.0 | 4.2 | | |
| | 47,032 | 13,510 | 750 | 750 | 750 | | 2,250 | Forest Products | Squam, Van, Fraser, Crofton | 168.0 | 32.5 | 1.2 | 0.0 | 33.7 | 4.8 | | |
| CONTAINER SHIPS | 43,547 | 31,480 | 1200 | 1200 | 1000 | | 3,400 | Containers | DELTAPORT | 36.5 | 3.5 | 6.5 | 0.0 | 10.0 | 6.6 | 7.5 | 2720 |
| | 43,547 | 31,480 | 1200 | 1200 | 1000 | | 3,400 | Containers | DELTAPORT | 21.8 | 0.0 | 7.3 | 0.0 | 7.3 | 8.0 | | |
| | 43,547 | 31,480 | 1200 | 1200 | 1000 | | 3,400 | Containers | DELTAPORT | 24.5 | 0.0 | 7.6 | | | | | |
| | 43,547 | 31,480 | 1200 | 1200 | 1000 | | 3,400 | Containers | DELTAPORT | 26.3 | 8.2 | 0.5 | 0.0 | 8.7 | 7.9 | | |
| | | | n/a | | | | 0 | Containers | DELTAPORT | | 0.0 | 0.0 | 0.0 | 0.0 | | | |
| CRUISE SHIPS | | | 2 x 2400, 2 x 2000, 2 x 900 = | | | | 10,600 | Passengers | CANADA PLACE | 11.0 | | | 0.0 | 0.0 | 0.0 | 0.0 | 6653 |
| | | | 600 | 600 | 0 | 0 | 1,200 | Passengers | CANADA PLACE | 11.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | | |
| | | | | | | | 12,000 | Passengers | CANADA PLACE | 11.0 | | | 0.0 | 0.0 | 0.0 | | |
| | | | 1350 | 1350 | 1350 | 1350 | 5,400 | Passengers | CANADA PLACE | 11.0 | | | 0.0 | 0.0 | 0.0 | | |
| | | | 7 x 552, 1 x 200 = | | | | 4,064 | Passengers | CANADA PLACE | 11.0 | | | 0.0 | 0.0 | 0.0 | | |

NOTES:

Vessel name, age, and arrival/departure dates are not listed to protect confidentiality.
Manoevring fuel use was subtracted from total fuel use to obtain dockside fuel use.
Manoevring fuel use was estimated using transit time between berth and fuel consumption rates for in-transit operation.
Where only one berth was listed above, manoevring fuel use set to 0.
Overall sulphur content to use:

| | | | | |
|---|---|---|---|---|
| Fuel Oil %S = | 3.00% | 55% | Weighted %S = | 1.79% |
| Diesel Oil %S = | 0.31% | 45% | | |