MARINE VESSEL AIR EMISSIONS IN B.C. AND WASHINGTON STATE OUTSIDE THE GVRD AND FVRD FOR THE YEAR 2000

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ADDENDUM

Subsequent to the release of this report, "Marine Vessel Air Emissions in B.C. and Washington State Outside the GVRD and FVRD for the Year 2000" (July 2002), a followup study was conducted to forecast marine vessel emissions to the year 2025, and backcast emissions to 1985. These backcast/forecast studies[1] were based on emission inventories conducted for the year 2000, and covered two areas - the International Lower Fraser Valley area (GVRD, FVRD and Whatcom County), and coastal areas in B.C. and Washington State outside the International Lower Fraser Valley.

As a result of the backcast/forecast studies, some revisions were made to the emission totals for the Canadian and U.S. portions of the Expanded Area, documented in the attached report. The following data have been revised:

- Emissions from fishing vessels in the two areas in B.C., have been updated. This results in a change to the data previously shown for fishing vessels in B.C. in Tables S-1 and S-2. Revised versions of those tables are provided below.

- Regional emissions from recreational vessels in the B.C. and Washington Coast areas and Whatcom County have been reallocated, thus changing the spatial distribution of the emissions. This change reflects an improvement to the spatial allocation of recreational emissions in Washington State and the areas outside of the LFV in British Columbia. In the previous year 2000 emission inventory, the total emissions from recreational vessels outside of the BC LFV were allocated to either the entire BC or U.S. water areas, and re-summed to form regional totals. In the revised inventory, emissions are summed per region in Washington State and allocated over the water area in each region. While this results in a revision to the recreational vessel emissions reported for Whatcom County, Washington Coast and Puget Sound, the overall emissions total for recreational vessels shown in Tables S-3 and S-4 are unchanged.

- The subtotal for emissions from fishing vessels in the Washington Coast region have been revised. However, the emissions from each of the types of fishing vessels in this region have not changed, and the emission totals for areas in Washington State, shown in Tables S-3 and S-4 have not changed.

[1] **Backcast and Forecast of Year 2000 Lower Fraser Valley Marine Vessel Emissions**, prepared for GVRD and Environment Canada by Levelton Engineering Ltd., June 2003

Backcast and Forecast of Year 2000 Marine Vessel Emissions in B.C. and Washington State (Outside the International LFV), prepared for GVRD and Environment Canada by Levelton Engineering Ltd., January 2004

Table S-1: CAC and NH_3 Emissions for B.C. (outside GVRD and FVRD) 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	348	164	6,280	3,933	251	3,209	3,166	65	497	2
Manoeuvring	11	1	86	54	3	6	6	0	4	1
Reduced Speed Zone	122	38	2,060	1,290	82	780	769	16	114	27
Underway	757	236	12,778	8,001	511	4,838	4,773	97	709	166
Subtotal	**1,238**	**439**	**21,204**	**13,277**	**847**	**8,833**	**8,715**	**178**	**1,325**	**195**
Harbour Vessels										
workboats and tugboats	680	212	8,162	5,111	326	232	229	5	85	4
charters	30	9	361	226	14	10	10	0	4	0
Subtotal	**710**	**222**	**8,523**	**5,337**	**341**	**242**	**239**	**5**	**89**	**4**
Ferries										
B.C. Ferries										
Dockside	120	9	1,587	994	63	20	20	0	54	0
Layup	5	0	52	32	2	1	1	0	2	0
Manoeuvring	244	31	667	418	27	24	24	0	5	0
Underway	471	153	5,444	3,409	218	350	345	7	76	0
Coho Ferries	3	1	31	20	1	0	0	0	0	0
Victoria Clipper										
Dockside	1	0	15	9	1	0	0	0	1	0
Manoeuvring	4	0	10	7	0	0	0	0	0	0
Underway	2	1	28	18	1	2	2	0	0	0
Washington State Ferries										
Dockside	3	0	45	28	2	0	0	0	2	0
Manoeuvring	9	1	26	16	1	0	0	0	0	0
Underway	22	7	250	157	10	0	0	0	4	0
Subtotal	**884**	**204**	**8,156**	**5,107**	**326**	**398**	**392**	**8**	**144**	**1**
Fishing Vessels										
Gillnetters	17	5	188	118	8	6	6	0	2	0
Seiners	16	5	178	111	7	5	5	0	2	0
Trollers	8	3	96	60	4	3	3	0	1	0
Subtotal	**41**	**13**	**462**	**289**	**18**	**14**	**14**	**0**	**5**	**0**
Recreational Vessels	**1,272**	**455**	**60**	**37**	**2**	**1**	**1**	**0**	**28**	**0**
Total	**4,145**	**1,332**	**38,404**	**24,047**	**1,535**	**9,489**	**9,361**	**191**	**1,592**	**201**

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: GHG Emissions for B.C. (outside GVRD and FVRD) for 2000

	emissions (tonnes/year)			
	CO_2	**CH_4**	**N_2O**	**Total, CO_2.equiv**
Ocean Going Vessels				
Dockside	281,309	21.7	22.6	288,764
Manoeuvring	2,096	0.1	0.9	2,375
Reduced Speed Zone	57,699	5.3	1.5	58,284
Underway	357,969	33.1	9.2	361,521
Subtotal	**699,073**	**60.2**	**34.2**	**710,944**
Harbour Vessels				
workboats and tugboats	321,553	29.7	8.5	324,811
charters	14,204	1.3	0.4	14,348
Subtotal	**335,758**	**31.0**	**8.9**	**339,160**
Ferries				
B.C. Ferries				
Dockside	46,491	2.6	17.1	51,832
Layup	1,564	0.1	0.6	1,743
Manoeuvring	27,468	1.5	10.1	30,623
Underway	201,685	11.1	74.0	224,852
Coho Ferries	1,160	0.1	0.4	1,295
Victoria Clipper				
Dockside	429	0.0	0.2	479
Manoeuvring	428	0.0	0.2	478
Underway	1,038	0.1	0.4	1,158
Washington State Ferries				
Dockside	329	0.1	0.6	504
Manoeuvring	535	0.1	0.5	678
Underway	9,268	0.6	4.0	10,505
Subtotal	**290,395**	**16.2**	**107.8**	**324,146**
Fishing Vessels				
Gillnetter	6,900	0.6	0.2	6,978
Seiners	6,517	0.6	0.2	6,591
Trollers	3,504	0.3	0.1	3,543
Subtotal	**16,921**	**1.5**	**0.5**	**17,113**
Recreational Vessels	**7,877**	**9.3**	**0.4**	**8,204**
Total	**1,350,024**	**118**	**152**	**1,399,565**

Note: totals may not add up due to rounding

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 an "Expanded Area" of study, quantifying emissions for coastal areas in B.C. (outside of the Greater Vancouver Regional District and Fraser Valley Regional District), and Washington State. Phase 1 of this study addressed a "Core Area", covering the GVRD and FVRD areas in southwestern B.C. 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, Washington State 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 to nitric oxide (NO) and nitrogen dioxide (NO_2)
  - particulate matter (PM)
  - sulphur oxides (SO_x), speciated to sulphur dioxide (SO_2) and sulphate ($SO_4^{=}$)
  - 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 B.C.and Washington portions of the study area, and sub-regions such as Vancouver Island, B.C. coast, Whatcom County, Puget Sound and Washington Coast. 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 conic map projection. The spatial

allocation of data was facilitated by the use of a Geographical Information System, developed using ArcInfo.

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 and expansion of 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 only (GVRD and southwest portion of the FVRD), included only the criteria air contaminants, and was spatially resolved to a coarser grid (5 km), 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. For the Washington State portion of the expanded area, previous inventory studies were consulted. In some cases, emission estimates for Washington for 1996 or some other earlier year were adjusted to a year 2000 basis, while in other cases, the earlier inventory studies were used as a source of base quantity information.

Summary of Results for B.C. (outside the Core Area)

The results of the overall inventory are shown in Tables S-1, S-2 and Figure S-1 for the B.C. portion of the Expanded Area (outside the Core Area) for 2000.

- Ocean-going vessels are the predominant contributor to emissions of NOx, SOx, PM and greenhouse gases, accounting for 56%, 93%, 83% and 51% of the total marine vessel emissions, respectively. Ocean-going vessels contribute 30% and 33% to the estimated B.C. marine totals for CO and VOC.

- Harbour vessels contribute 22% and 24% of NOx and GHGs, and 17% of both CO and VOC. They contribute only 3% and 6% of the BC total for SOx and PM. Workboats and tugboats are the dominant category compared to charter vessels.

- Ferries contribute between 15% and 23% for CO, VOC, NOx and GHGs, but 9% or less for SOx and PM. Of the total ferry operations, BC Ferries are the most significant contributor to emissions.

- Fishing vessels are 1% or less for all contaminants.

- Recreational vessels are significant for CO and VOC (31% and 34%), but 0% to 2% 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.

Table S-1: CAC and NH_3 Emissions for B.C. (outside GVRD and FVRD) 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	348	164	6,280	3,933	251	3,209	3,166	65	497	2
Manoeuvring	11	1	86	54	3	6	6	0	4	1
Reduced Speed Zone	122	38	2,060	1,290	82	780	769	16	114	27
Underway	757	236	12,778	8,001	511	4,838	4,773	97	709	166
Subtotal	1,238	439	21,204	13,277	847	8,833	8,715	178	1,325	195
Harbour Vessels										
workboats and tugboats	680	212	8,162	5,111	326	232	229	5	85	4
charters	30	9	361	226	14	10	10	0	4	0
Subtotal	710	222	8,523	5,337	341	242	239	5	89	4
Ferries										
B.C. Ferries										
Dockside	120	9	1,587	994	63	20	20	0	54	0
Layup	5	0	52	32	2	1	1	0	2	0
Manoeuvring	244	31	667	418	27	24	24	0	5	0
Underway	471	153	5,444	3,409	218	350	345	7	76	0
Coho Ferries	3	1	31	20	1	0	0	0	0	0
Victoria Clipper										
Dockside	1	0	15	9	1	0	0	0	1	0
Manoeuvring	4	0	10	7	0	0	0	0	0	0
Underway	2	1	28	18	1	2	2	0	0	0
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Manoeuvring	9	1	26	16	1	0	0	0	0	0
Underway	22	7	250	157	10	0	0	0	4	0
Subtotal	884	204	8,156	5,107	326	398	392	8	144	1
Fishing Vessels										
Gillnetters	17	5	188	118	8	6	6	0	2	0
Seiners	16	5	178	111	7	5	5	0	2	0
Trollers	2	1	25	15	1	1	1	0	0	0
Subtotal	35	11	391	245	16	12	12	0	4	0
Recreational Vessels	1,272	455	60	37	2	1	1	0	28	0
Total	4,139	1,331	38,333	24,003	1,532	9,486	9,359	191	1,591	201

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: GHG Emissions for B.C. (outside GVRD and FVRD) for 2000

	emissions (tonnes/year)			
	CO_2	**CH_4**	**N_2O**	**Total, CO_2 equiv**
Ocean Going Vessels				
Dockside	281,309	21.7	22.6	288,764
Manoeuvring	2,096	0.1	0.9	2,375
Reduced Speed Zone	57,699	5.3	1.5	58,284
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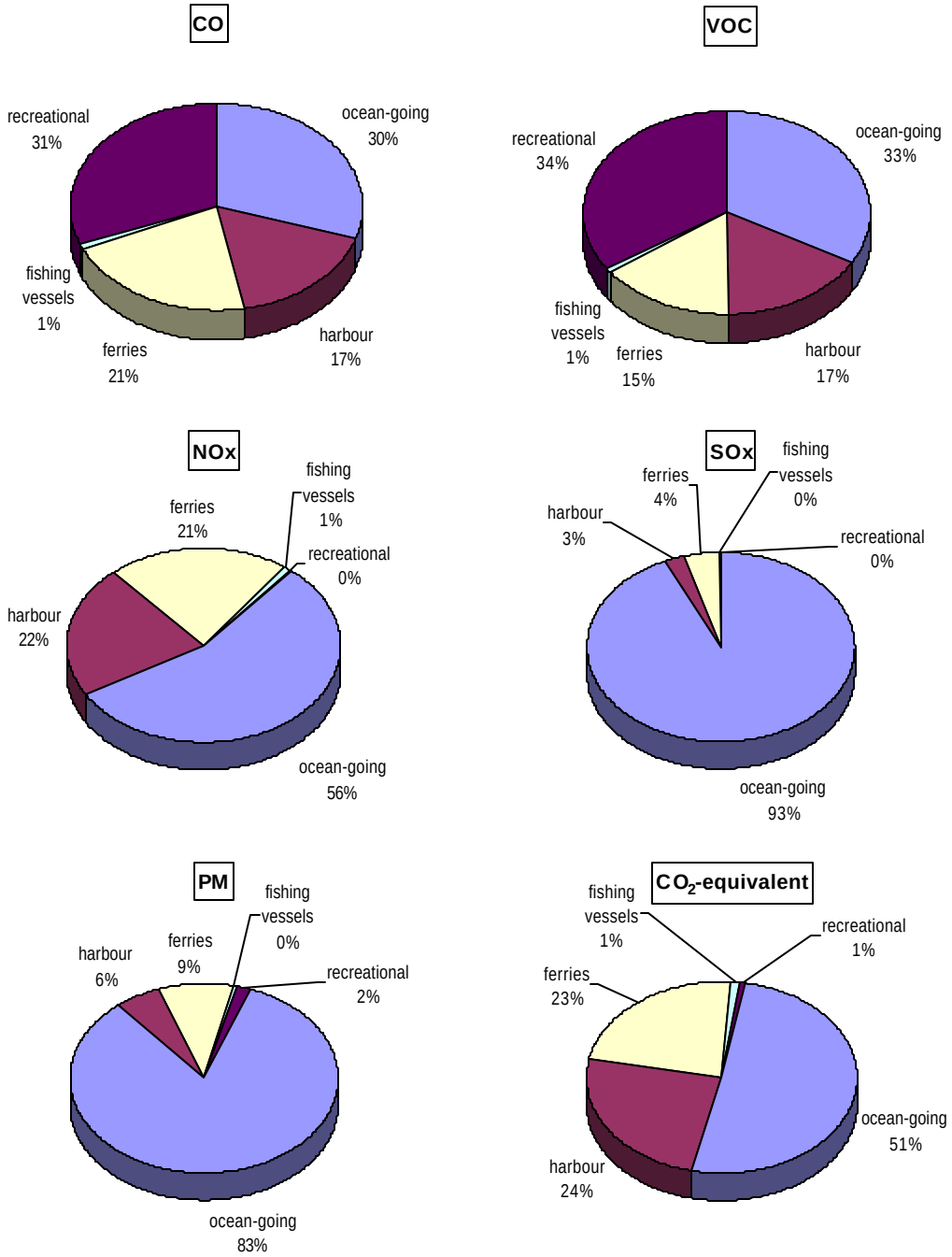
Subtotal	**699,073**	**60.2**	**34.2**	**710,944**
Harbour Vessels				
workboats and tugboats	321,553	29.7	8.5	324,811
charters	14,204	1.3	0.4	14,348
Subtotal	**335,758**	**31.0**	**8.9**	**339,160**
Ferries				
B.C. Ferries				
Dockside	46,491	2.6	17.1	51,832
Layup	1,564	0.1	0.6	1,743
Manoeuvring	27,468	1.5	10.1	30,623
Underway	201,685	11.1	74.0	224,852
Coho Ferries	1,160	0.1	0.4	1,295
Victoria Clipper				
Dockside	429	0.0	0.2	479
Manoeuvring	428	0.0	0.2	478
Underway	1,038	0.1	0.4	1,158
Washington State Ferries				
Dockside	329	0.1	0.6	504
Manoeuvring	535	0.1	0.5	678
Underway	9,268	0.6	4.0	10,505
Subtotal	**290,395**	**16.2**	**107.8**	**324,146**
Fishing Vessels				
Gillnetter	6,900	0.6	0.2	6,978
Seiners	6,517	0.6	0.2	6,591
Trollers	906	0.1	0.0	917
Subtotal	**14,324**	**1.3**	**0.4**	**14,486**
Recreational Vessels	**7,877**	**9.3**	**0.4**	**8,204**
Total	**1,347,427**	**118.0**	**151.7**	**1,396,939**

Note: totals may not add up due to rounding

Figure S-0-1: Contributions of Vessel Categories to Individual Co ntaminant Emission Totals (Canadian Portion of the Expanded Area)



Summary of Results for Washington State

The results of the overall inventory are shown in Tables S-3, S-4 and Figure S-2 for the Washington State portion of the Expanded Area for 2000.

- Ocean-going vessels are significant contributors to emissions of NOx, SOx, PM and greenhouse gases, accounting for 51%, 95%, 60% and 41% of the total marine vessel emissions, respectively. Ocean-going vessels represent only 4% of the Washington total for both CO and VOC.
- Harbour vessels contribute 28% to both NOx and GHGs, 6% of PM, 4% of SOx, and 3% for both CO and VOC. Workboats and tugboats are the dominant category compared to charter vessels.
- Ferries contribute 13% and 14% for GHGs and NOx, respectively, but 5% or less for all other contaminants (2%, 1%, 0% and 5% for CO, VOC, SOx and PM). Washington State Ferries are the largest source within this category.
- Fishing vessels are 3% of NOx and GHGs and 1% or less for all contaminants.
- Recreational vessels are significant for CO and VOC (91% and 92%), 28% for PM, and 15% of GHGs.

Table S-3: CAC and NH_3 Emissions for Washington State 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	193	117	4,043	2,532	162	1,729	1,706	35	326	4
Manoeuvring	48	3	362	227	14	27	27	1	18	5
Reduced Speed Zone	514	161	8,681	5,436	347	3,287	3,243	66	482	112
Underway	401	125	6,776	4,243	271	2,565	2,531	52	376	88
Subtotal	**1,156**	**406**	**19,862**	**12,437**	**794**	**7,608**	**7,506**	**153**	**1,202**	**209**
Harbour Vessels										
Workboats and tugboats	906	283	10,880	6,813	435	309	305	6	113	6
Charters	11	4	144	90	6	4	4	0	1	0
Subtotal	**916**	**287**	**11,023**	**6,903**	**441**	**313**	**309**	**6**	**115**	**6**
Ferries										
B.C. Ferries										
Dockside	0	0	0	0	0	0	0	0	0	0
Layup	0	0	0	0	0	0	0	0	0	0
Manoeuvring	3	0	7	5	0	0	0	0	0	0
Underway	4	1	46	29	2	3	3	0	1	0
Coho Ferries	3	1	38	24	2	0	0	0	1	0
Victoria Clipper										
Dockside	1	0	19	12	1	0	0	0	1	0
Manoeuvring	5	1	14	9	1	1	1	0	0	0
Underway	16	5	187	117	7	13	13	0	3	0
Washington State Ferries										
Dockside	48	3	631	395	25	0	0	0	26	0
Manoeuvring	166	21	455	285	18	0	0	0	4	0
Underway	348	113	4,025	2,520	161	2	2	0	56	0
Subtotal	**595**	**146**	**5,423**	**3,396**	**217**	**20**	**20**	**0**	**91**	**0**
Fishing Vessels										
Gillnetters	6	2	70	44	3	2	2	0	1	0
Seiners	12	4	136	85	5	4	4	0	2	0
Trollers	3	1	30	18	1	1	1	0	0	0
Trawlers	97	30	1,093	684	44	33	33	1	12	1
Subtotal	**118**	**37**	**1,329**	**832**	**53**	**40**	**40**	**1**	**15**	**1**
Recreational Vessels	**26,793**	**9,441**	**1,388**	**869**	**55**	**98**	**97**	**2**	**545**	**0**
Total	**29,578**	**10,316**	**39,026**	**24,437**	**1,560**	**8,081**	**7,972**	**163**	**1,967**	**216**

Notes: totals may not add up due to rounding

* NOx expressed as NO_2-equivalent

† SOx expressed as SO_2-equivalent

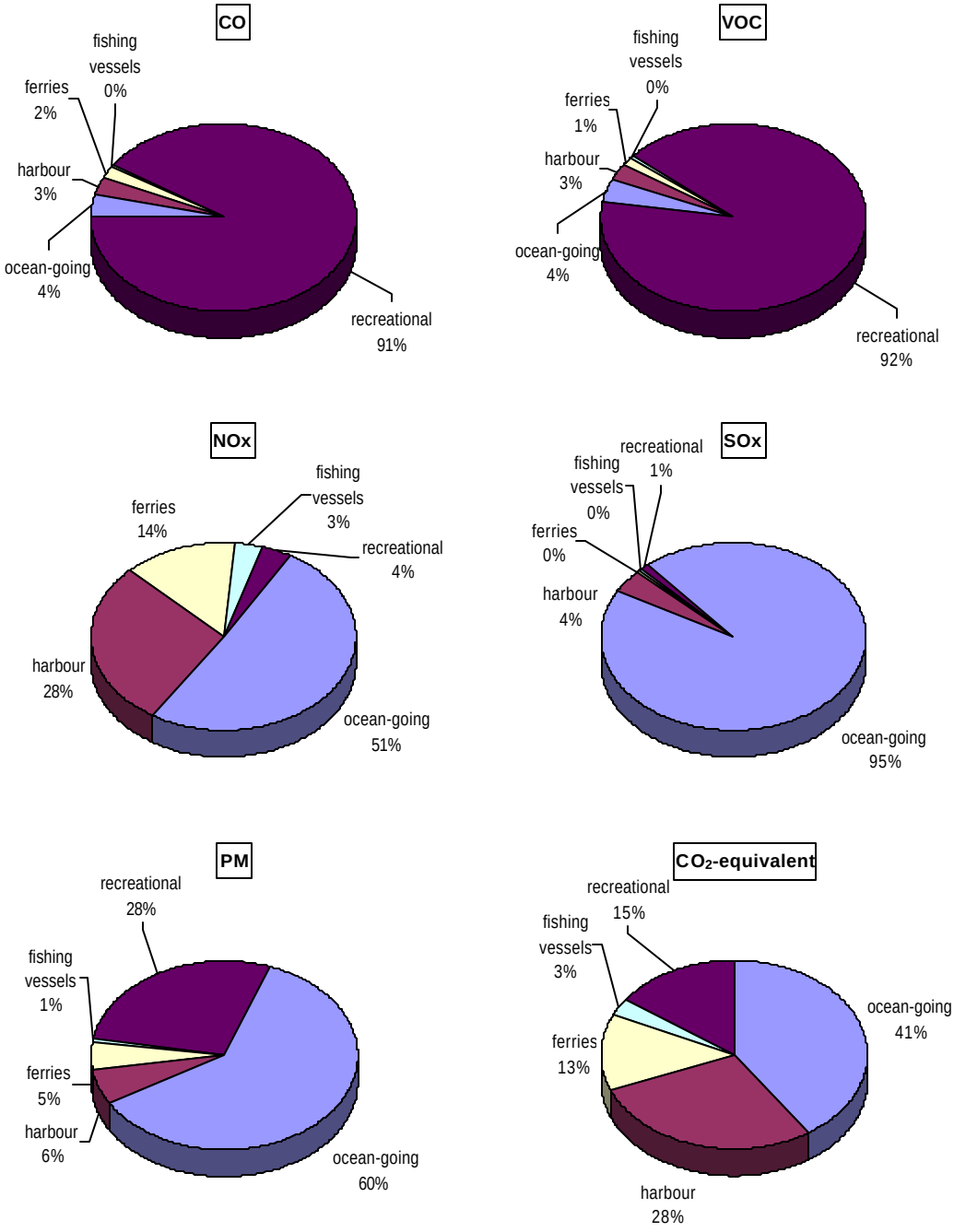
‡ PM from marine exhausts is assumed to be 100% PM_{10} and 100% $PM_{2.5}$

Table S-4: GHG Emissions for Washington State for 2000

	emissions (tonnes/year)			
	CO_2	CH_4	N_2O	total, CO_2-equiv
Ocean Going Vessels				
Dockside	177,105	2.0	24.4	184,704
Manoeuvring	8,836	0.5	3.8	10,011
Reduced Speed Zone	243,204	22.5	6.4	245,668
Underway	189,815	17.6	5.0	191,719
Subtotal	**618,960**	**42.6**	**39.5**	**632,103**
Harbour Vessels				
Workboats and tugboats	428,617	39.6	11.3	432,959
Charters	5,659	0.5	0.1	5,717
Subtotal	**434,276**	**40.2**	**11.5**	**438,676**
Ferries				
B.C. Ferries				
Dockside	0	0.0	0.0	0
Layup	0	0.0	0.0	0
Manoeuvring	298	0.0	0.1	332
Underway	1,715	0.1	0.6	1,912
Coho Ferries	1,402	0.1	0.5	1,565
Victoria Clipper				
Dockside	568	0.0	0.2	633
Manoeuvring	569	0.0	0.2	634
Underway	6,940	0.4	2.5	7,737
Washington State Ferries				
Dockside	4,621	1.2	7.9	7,089
Manoeuvring	9,363	1.2	8.0	11,865
Underway	149,109	9.5	63.6	169,025
Subtotal	**174,585**	**12.6**	**83.7**	**200,793**
Fishing Vessels				
Gillnetter	2,581	0.2	0.1	2,610
Seiners	4,992	0.5	0.2	5,049
Trollers	1,082	0.1	0.0	1,094
Trawlers	40,041	3.6	1.2	40,493
Subtotal	48,696	4.4	1.5	49,246
Recreational Vessels	223,410	254.6	14.3	233,187
Total	**1,499,926**	**354.3**	**150.5**	**1,554,005**

Note: totals may not add up due to rounding

Figure S-2: Contributions of Vessel Categories to Individual Contaminant Emission Totals (U.S. Portion of the Expanded Area)



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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
DOE	Washington State Department of Ecology
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
NO	nitric oxide
NO_2	nitrogen dioxide
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
SO_2	sulphur dioxide
$SO_4^=$	sulphate
UTM	Universal Transverse Mercator
VOC	volatile organic compounds

1. INTRODUCTION

Government agencies in both Canada and the United States use emission inventories as a tool for air quality management planning and policy development. Comprehensive emission inventories are typically prepared every five years in Canada. In B.C., inventories are a coordinated effort between Environment Canada, the B.C. Ministry of Water Land and Air Protection, and the Greater Vancouver Regional District (GVRD).

Amongst anthropogenic emission sources in B.C., 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 identified this source sector as requiring further study with respect to its impact on regional air quality. A previous comprehensive emissions inventory study 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 year 2000. This study is in support of overall year 2000 emission inventory efforts.

One of the goals of the 2000 inventory is to improve consistency of approach between the various jurisdictions, including airshed partners in neighbouring Washington State, and to harmonize inventory data with airshed modelling efforts. Accordingly, the overall 2000 marine inventory addresses a larger area than the Lower Fraser Valley, extending to all coastal areas in B.C. and Washington State.

This report presents the emission estimates from marine vessel activities in coastal areas in BC outside of the GVRD and Fraser Valley Regional District, and in Washington State for the year 2000. Emissions from marine vessel activities in a "Core Area" of study for this project (encompassing the GVRD and FVRD) are provided in a separate report (Levelton, 2002).

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 Conic Projection;
- Prepare regional summaries of emissions, as follows:
  - ***Canadian portion***
    - total BC outside of the GVRD and FVRD
    - Vancouver Island
    - coast of BC
  - ***U.S. portion***
    - total Washington State
    - Whatcom County
    - Puget Sound
    - coast of Washington
- 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" encompasses the combined Greater Vancouver Regional District (GVRD) and Fraser Valley Regional District (FVRD). The Core Area includes what is known as the Lower Fraser Valley (LFV) airshed which consists of the entire GVRD and the southwestern portion of the FVRD.

The geographic scope of the second phase of this marine vessel emission inventory, and the subject of this report, 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. For the purposes of this study, these areas have been defined as follows (refer to Figure 1-1 for BC portions, and Figure 1-2 for Washington State portions):

- *Vancouver Island* – the water area from mainland B.C. to the west coast of Vancouver Island, and the water area extending 25 km off the west coast of Vancouver Island. This area extends from the Canada –U.S. border to the south to Bull Harbour (Hope Island) to the north
- *B.C. coastline* – coastal areas north of Bull Harbour to the B.C.-Alaska border, and from the BC mainland to 25 km off the west coast of the Queen Charlotte Islands
- *B.C. total* (outside the GVRD and FVRD) – is the sum of the areas designated above as Vancouver Island and B.C. coastline, but excluding the areas of B.C. reported in the Core Area report
- *Whatcom County* – the portion of the Strait of Georgia / Strait of Juan de Fuca contained within the county boundaries for Whatcom County in Washington State
- *Puget Sound* – the Puget Sound water areas contained within Skagit, San Juan, Snohomish, King, Pierce, Kitsap, Island, Thurston and Mason counties in Washington State
- *Washington coastline* – the west coast of Washington State (excluding Whatcom County and Puget Sound as defined above), extending 25 km off the mainland and bounded by the Canada-US and Washington-Oregon borders to the north and south.
- *Washington total* – is the sum of the areas designated above as Whatcom County, Puget Sound and Washington coastline.

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 A 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.

1.4 POLLUTANTS INVENTORIED

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

- Criteria pollutants
  - Carbon monoxide (CO),
  - nitrogen oxides (NO_x), speciated to nitric oxide (NO) and nitrogen dioxide (NO_2),
  - particulate matter (PM),
  - sulphur oxides (SO_x), speciated to sulphur dioxide (SO_2) and sulphate ($SO_4^=$)
  - volatile organic compounds (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)

Figure 1-1: B.C. Study Area (Expanded Area)

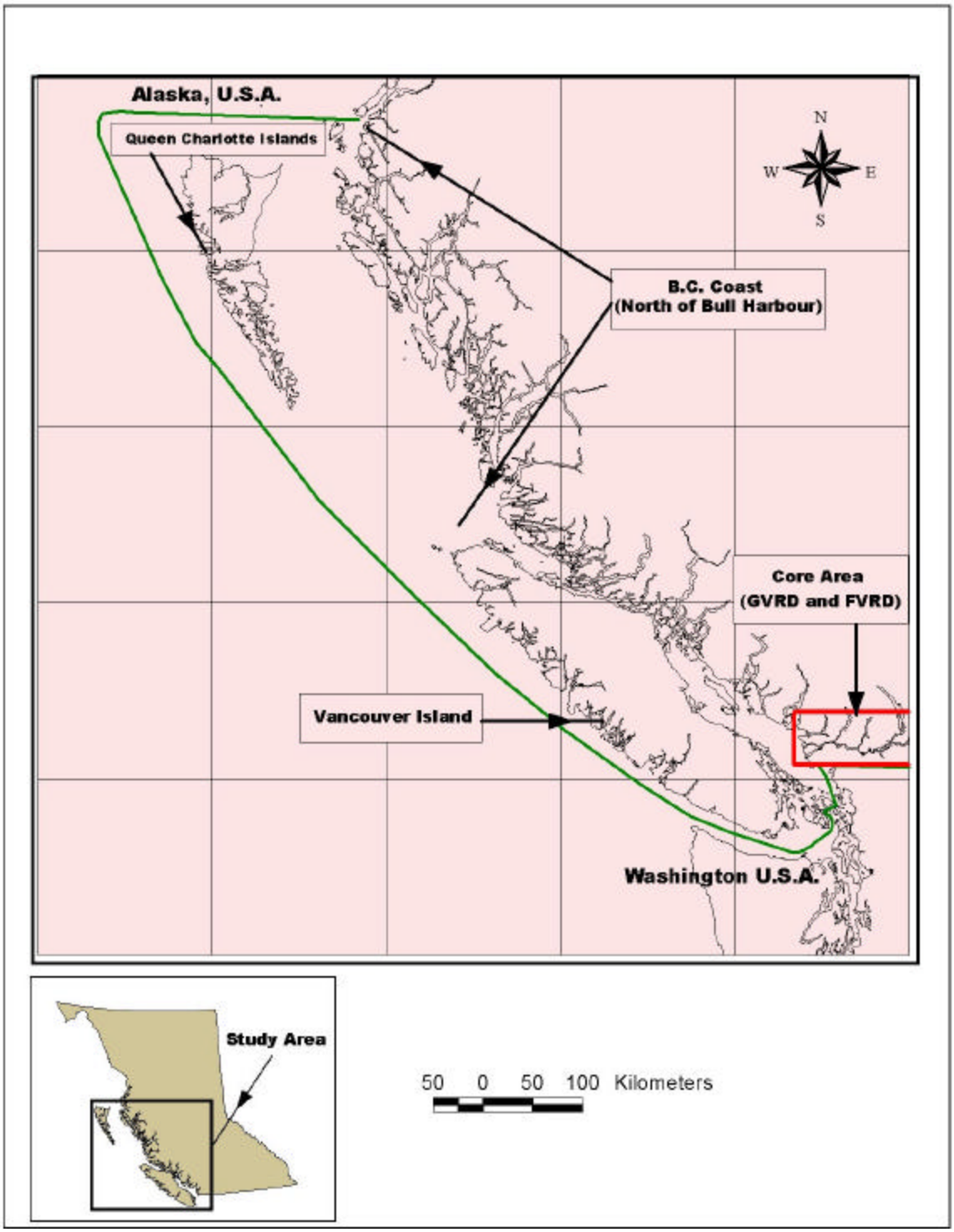


Figure 1-2: Washington Study Area (Expanded Area)

2. DATA COLLECTION AND INVENTORY METHODOLOGIES – CANADIAN PORTION

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 Table 2-1 and Table 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 Emissions

As ocean-going vessels enter a 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. Travel in the Canadian portion of the Expanded Area is typically to remote ports that may not require extensive manoeuvring. Thus the manoeuvring portion of travel in the Expanded Area is assumed to be negligible and is not calculated and all trip time remains as underway 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. Expanded Area travel essentially consists of three types of movements; from an Expanded Area port to an Expanded 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. Travel in the Expanded Area (Canadian portion) was assumed to be all underway. Thus the emissions from a manoeuvring portion of a trip from the Expanded Area into the Core Area are included in the Core Area analysis.

The travel time for each trip was calculated by the difference in the arrival and departure times for each movement record. For travel entirely inside the Core Area or entirely within the Expanded Area

this was straight-forward, while travel times for movements between the Core and Expanded Areas was segregated into core and expanded area times.

Calculation of the underway travel within the Expanded Area for movements between two ports in the Expanded Area was simply calculated using the overall time difference of arrival and departure between the two ports. 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. Calculation of manoeuvring and underway times within the Core Area are described in more detail in the "Marine Vessel Air Emissions in the Lower Fraser Valley for the Year 2000" Report. The underway time in the Expanded Area was the difference of the overall time difference from the time spent in the Core Area.

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 between vessel classes for underway movements. The estimated load factors used in this study are shown in Table 2-3.

Table 2-3: 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

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 2-4.

Table 2-4: 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

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".

Based on the port locations, each movement record was deemed either as an international movement (to or from a US or other port outside of Canada) or a domestic movement (to and from Canadian ports). All travel to or from an Expanded Area port within Canada was assigned 1 dockside event. While trips between two Expanded Area ports, if both ports were Canadian (representing a domestic movement) were assigned 2 docksides. If one port was defined as an International location (typically in the United States), then only 1 dockside was assigned, assuming

any US docksides for the Expanded Area to be counted in the US portion of the study (see Section 3.1).

Table 2-5: 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 General Cargo General Vessels	11.4	1.4

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

Table 2-6: 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 2-7. Emission factors used for each pollutant are listed in Table 2-8.

In order to separate the overall emissions into Core or Expanded Area, workboats were assumed to travel in the area surrounding the company address. As detailed in the Core Area report, it was estimated that 60% of the operation of all tug and workboats listed in the compiled directory occurs within the Expanded 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 2-7: 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	9	2,280	2,500	30%
Small vessel (Patrol, rescue, work boats, water taxis, etc.)	173	300	2,000	30%
Tug	319	978	4,000	60%

Table 2-8: 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.%) 2.6	4.2 x fuel S content (wt.%) 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 within the Expanded Area limits were counted. 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 282.

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 Expanded Area (%) x Emission Factor (g/kWh)

The emission factors used were the same as those applied to the work boats as listed in Table Table 2-8. The sampling of charter boats provided the distribution of boats within the 3 different engine sizes listed in Table 2-9 and the following assumptions that were then applied to the entire fleet.

- 36% sail, 64% power (sailboats were not counted)
- operate 450 h/year
- 40% power load

In addition to the Expanded Area boats, Core Area boats (those boats belonging to companies with addresses within the Core Area) spend 15% of their time in the Expanded Area.

Table 2-9: Distribution of Charter Boats

Length	Engine Assumed		Portion of Total fleet
Ft	hp	KW	
0-49	300	221	79.4%
50-100	950	699	15.2%
Over 100	1400	1030	5.3%

2.3 FERRIES

Table 2-10 summarises the vessel population of all ferries that travel within the Expanded Area.

Table 2-10: Vessel Count for all Ferries within the Expanded Area

Company	Number of Vessels Operating Within the Expanded Study Area	Service Type
B.C. Ferries	39	Vehicle/passenger
Coho Ferry	1	Vehicle/passenger
Victoria Clipper	4	Passenger
Washington State Ferries	30	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 2-11. 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 2-11: Emission Factors for all Ferries

		NOx	CO	VOC	PM	
Emission Factor	***Diesel [Kg/T]***	57	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	0.007	6.2 (20x0.31% 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 20x the S emissions (%wt) based on fuel consumption.
*** Source: Environment Canada (April and September, 2001)

Requests for available 2000 ferry fuel use and vessel statistics were made to all Ferry companies within the Expanded area. The results were varied, from some companies providing detailed fuel usage per route or boat to other companies who provided no data in which case, vessel statistics were taken from online sources.

2.3.2 B.C Ferries

The entire fleet of B.C. Ferries accounts for up to 40 vessels in total with 39 of these vessels travelling within the Expanded Area on 24 of the 25 routes covered by B.C. Ferries. Forty-five terminals are included within the Expanded Area.

The estimation of emissions was based on the same methodology as used for the Core Area. This process was broken down into two parts:

- the balance of those routes partially located within the Core Area, and
- the calculation of the remaining routes which lie entirely within the Expanded Area.

Table 2-12 shows the balance (fraction of route in Expanded Area) of the routes that travel between the Core and Expanded Areas. 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 2-12: Fraction of B.C. Ferries Trip Outside the Core Area by Route

Route #	Portion* of Service Emissions
1 Tsawwassen/Swartz Bay	92.8%
2 Horseshoe Bay/Nanaimo	73.9%
3 Horseshoe Bay/Langdale	28.6%
9 Tsawwassen/Gulf Islands	93.3%
30 Nanaimo/Tsawwassen	67.3%

* portion = (Length of trip in expanded area)/(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. For those routes appearing in both the core and expanded areas, the dockside and manoeuvring emissions were divided in half.

The load factors applied in calculating emissions from B.C. Ferries are the same as those applied within the Core Area, as shown in Table 2-13. 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 2-13: Load Factors for B.C. Ferries

Dockside	0.2
Manoeuvring	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). Only 20% of these emissions occur within the Expanded Area at the Point Hope Dock in Victoria, which includes the Esquimalt Graving Dock.

As above, 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 2-14 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 2-14: 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 2-14 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 2-14

Fraction of time ® assumed for each route (see Table 2-15)

A profile was assumed for each route in terms of fraction of time spent at each power (load) level. These are shown in table 2-15 below.

Table 2-15: Fraction of Time Spent at each Power Level for B.C. Ferries Routes Travelling Between the Core and Expanded Areas

	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 2-16 below.

Table 2-16: 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 2-16)]*[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 manoeuvring power rating over underway (shown in Table 2-16 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 Washington State

Washington State Ferries operates the largest ferry fleet in Washington State. Washington State Ferries travel up and down the Puget Sound on pre-determined schedules for each route, including routes that enter into B.C. (to Sidney).

Washington State Ferries provided data directly to Levelton for the year 2000. The data provided was the fuel consumption per vessel per month with the fraction of time spent on each route for each vessel to aid in the spatial allocation of emissions. The sulphur content in the fuel was reported to be <0.05%, and this value was used for SOx estimation for all Washington State Ferries.

The methodology described in section 2.3.2 for B.C. Ferries was applied to the Washington State Ferries for the underway emissions and the extended calculation of manoeuvring and dockside emissions. It was assumed that the factors used for the B.C. Ferries are applicable to the Washington State Ferries.

2.3.4 Coho Ferry

The Coho Ferry service runs between Port Angeles (WA) and Victoria (B.C.) between one and four times per day depending on the time of year. The Coho Ferry operates only one vessel at a time, thus is a very small contributor to emissions, producing less than 1% of the total Ferry emissions. The same emission factors as those used for B.C. Ferries and Washington State Ferries were used but no breakdown by power level was applied due to its small contribution overall. The fuel supplied to this ferry company is approximately 50/50 from Canadian (Shell) and American suppliers. The %S used for the calculation of SO_2 was 0.03%.

The following table (Table 2-17) lists the data provided to Levelton directly from Coho Ferries:

Table 2-17: Specifications of the Coho Ferry

Specification	Value
Fuel Consumption	100 Gallons/hour
Fuel type	Marine diesel
Sulphur Content	0.03%
Hours of Operation	4 hours/trip (return)

2.3.5 Victoria Clipper

There are four ferries making up the fleet of the Victoria Clipper, which provides high-speed passenger ferry service between Seattle, Victoria, and the San Juan Islands. Although information was requested from Victoria Clipper directly, data was not provided, so the 2002 schedule and published ferry specifications were used to estimate the emissions for 2000. Along with vessel length and horsepower the underway average fuel consumption was found online. Initial calculation of the underway emissions were based on the overall travel times estimated from the sailing schedule and then the B.C. Ferries methodology for dividing the emissions into underway, manoeuvring and dockside emissions was applied with the same assumed emission and load factors.

2.4 FISHING VESSELS

To develop fishing vessel emission estimates, data was requested from the Department of Fisheries and Oceans (DFO) on the number of boat-days for the active fishing months in 2000 for all fisheries management areas in B.C., shown in Figure 2-1. Data was provided by DFO was incomplete, covering only the Northern coastal section of B.C. (extending to off the coast of the Queen Charlotte islands) as well as the previously reported emissions for the Core Area.

The available data was used to calculate the emissions from fishing vessels for the Northern portion of B.C. In addition, data for Northern B.C. and the Lower Fraser Valley (Area 29) were used to approximate fishing activity in areas where DFO did not provide data, as follows:

- for Vancouver Island and the southern coastline between Vancouver Island and the mainland (Areas 11-28), fishing activity data from the 1993 marine vessel emission inventory was forecast to the year 2000, based on the ratio of the increase in activity from 1993 to 2000 for Area 29. From this, an estimate of boat days for 2000 for Areas 11 to 28 was developed and used to estimate emissions.

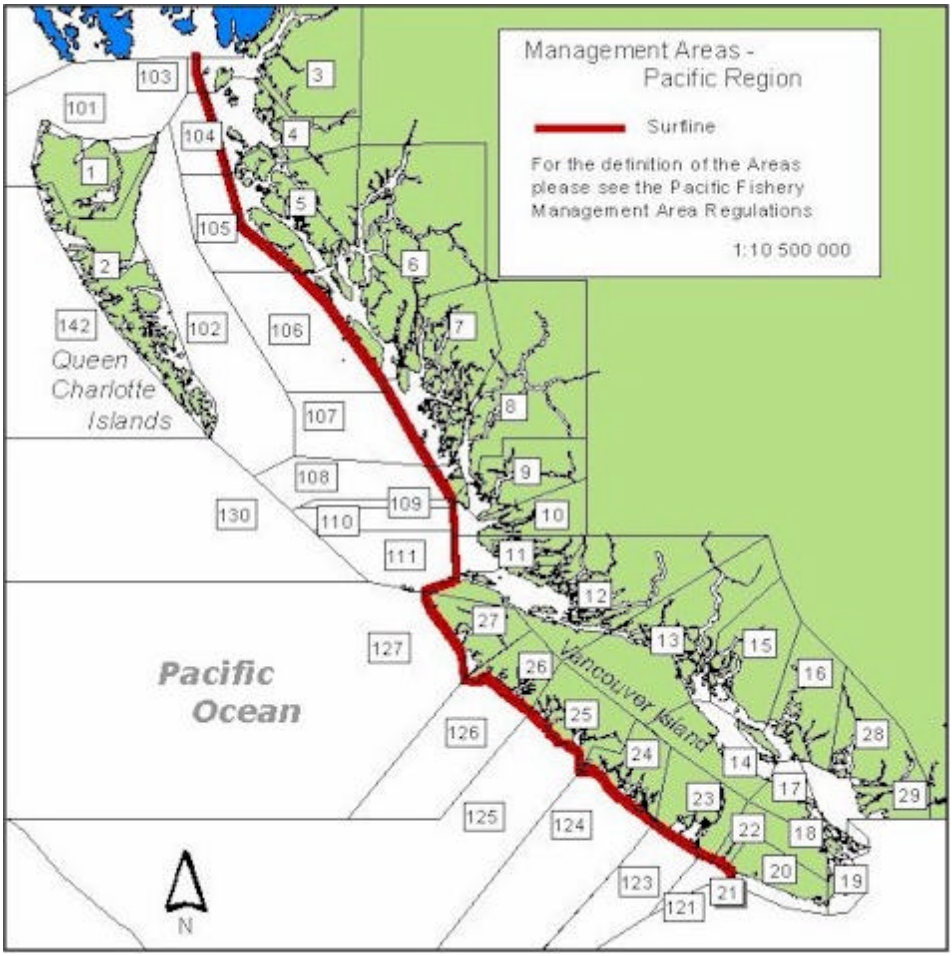
- No data was obtained for the remaining B.C. fishing areas 121-127, in either 2000 or 1993. The number of boat days reported for the western coast of the Queen Charlotte Islands was used as a surrogate for activity on the west coast of Vancouver Island, using a ratio of fishing activity per square kilometre of water area. This factor was multiplied by the water area within the study boundary off the coast of Vancouver island to estimate the number of boat-days for areas 121-127.

The final emission results were developed using the equation shown in section 2.4.3.

2.4.1 Canadian Vessel Population and Data Collection

Based on discussion with the DFO, the three main vessel types are Gillnetters, Trollers and Seiners. Moreover, it was assumed in this report that First Nations fishing uses very little vessel power, if any, in the expanded area based on discussion with the DFO. This being said, First Nation's emissions have not been calculated separately.

Figure 2-1: DFO Management Areas



source: DFO website, 2002 (www.pac.dfo-mpo.gc.ca/ops/fm/Areas/areamap.htm)

2.4.2 Emission Calculations (Canadian and American)

Based on discussions with the DFO, it was assumed that emissions from Gillnetters occur only during travel time (at 71% load) to and from fishing locations, and that while fishing, Gillnetters are at 0% power. Trollers and Seiners on the other hand, fish at 50% power. This was confirmed by the DFO to be one quarter of the total fishing time. In this case of Trollers and Seiners, the total hours of fishing (fishing time and travel between openings) provided by the DFO was accounted for. The estimates for the fishing activity under the Department of Fish and Wildlife were based on these

same power ratios and times. An average of 15 hours fishing was used for seiners and trollers as an initial estimate. 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 2-18 shows the emission factors applied to the equation.

Table 2-18: 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

For the Core Area study, year 2000 recreational vessel population was estimated based on a review of three data sources, including a recent report commissioned by the Transportation Table of the National Climate Change Process (ICF Kaiser, 1999), the 1993 LFV marine vessel emissions inventory (Levelton, 1995) and a 1996 Small Vessel Inventory (Consulting and Audit Canada, 1996). In terms of total powered vessel counts, the projected ICF Kaiser and 1993 inventory data for 2000 appears to be consistent. Vessel count estimates based on the 1996 Small Vessel Inventory do not distinguish between outboard, inboard and sterndrive categories, but were consistently low overall, when compared to the other two data sources. As a first approximation, averaged values were used to determine the recreational vessel population in LFV in 2000. For the purposes of the Expanded Area study, this LFV vessel estimate was projected to a provincial total based on human population. Vessel counts for Vancouver Island and the North Coast, given in Table 2-19, were obtained in a similar manner using population as the surrogate.

Table 2-19: Recreational Vessel Estimates for the Canadian Expanded Area for 2000

		2000 B.C. Vessel Population[1]	2000 Vancouver Island Vessel Population[2]	2000 North Coast Vessel Population[2]
Inboard	4 stroke	9,158	1,689	173
	Diesel	1,081	199	20
Outboard	2 stroke	127,378	23,494	2,405
	4 stroke	3,373	622	64
Sterndrive/inboard	2 stroke	367	68	7
	4 stroke	35,655	6,576	673
	Diesel	4,251	784	80
Personal Watercraft	2 stroke	46,040	8,492	869
Sailboat Auxiliary Inboard	4 stroke	2,320	428	44
	Diesel	5,900	1,088	111
Sailboat Auxiliary Outboard	2 stroke	2,147	396	41
	Diesel	4	1	0

[1] Projected from Canadian LFV vessel estimates

[2] Proration based on region to B.C. population ratio

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 given that a literature search has failed to identify any local data source.

Table 2-20 summarises the engine characteristics as well as the estimated fuel consumption for each type of recreational vessel in B.C. for 2000.

Table 2-20: 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 2-20 appear to be unreasonably high when compared to fuel consumption estimates from StatsCan for domestic marine transportation. Table 2-21 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 2-21: 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 2-20 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 2-21. Since local marketing sales data was not available, the above fuel use adjustments were made to arrive at estimates of recreational vessel fuel use in B.C. in 2000 and the subsequent fuel consumption per vessel in a given category. Regional fuel use was then derived from vessel population and estimated fuel consumption per vessel of a given type. The adjusted fuel consumption rates for B.C., Vancouver Island and the North Coast are shown in Table 2-22.

Table 2-22: Fuel Consumption Estimates for Recreational Vessels for Year 2000

	Engine Type	B.C. Recreational Vessel Fuel Use (m^3/y)	Vancouver Island Recreational Vessel Fuel Use (m^3/y)	North Coast Recreational Vessel Fuel Use (m^3/y)
Inboard	4 stroke	949	175	18
	Diesel	337	62	6
Outboard	2 stroke	8,850	1,632	167
	4 stroke	39	7	1
Sterndrive (inboard)	2 stroke	44	8	1
	4 stroke	2,900	535	55
	Diesel	1,172	216	22
Personal Watercraft	2 stroke	1,853	342	35
Sailboat auxiliary inboard	4 stroke	2	<0.5	<0.05
	Diesel	30	6	1
Sailboat auxiliary outboard	2 stroke	2	<0.5	<0.05
	Diesel	0.005	<0.01	<0.001
Total gasoline vessels		14,640	2,700	276
Total diesel vessels		1,539	284	29

2.5.3 Emission Factors

For recreational gasoline and diesel engines, published emission factors were available and these are summarised in Table 2-23 and Table 2-24 for common air contaminants and greenhouse gases, respectively. These emission factors were applied to the base quantities listed in Table 2-22 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 2-23: 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 2-24: 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 1µm 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 100 year GWPs of each gas, specifically 21 for methane and 310 for nitrous oxide. The GWPs used are from the Inter-Governmental Panel on Climate Change (IPCC) Second Assessment Report. Although a revised set of GWPs has been published in the IPCC Third Assessment Report (2001), according to the Kyoto Protocol, any revision to a GWP applies only "in respect of any commitment period adopted subsequent to that revision."

3. DATA COLLECTION AND INVENTORY METHODOLOGIES – U.S. PORTION

In general, the estimation of marine vessel emissions for the U.S. portion of the Expanded Area was based on two methods:

1. Contacting agencies in Washington State to obtain base quantities which could be used with the same methodologies developed for the Canadian portion of the study area; or
2. Working from existing emission inventory studies for Washington State, including:
    a) 1991 Booz-Allen Hamilton study for US EPA
    b) Analysis of Commercial Marine Vessels Emissions and Fuel Consumption Data (US EPA, 2000)
    c) Review of the Washington State Visibility Protection State Implementation Plan (Washington State Department of Ecology, 1999)
    d) Development of 1996 On-Road and Off-Road Mobile Source Emission Inventory for the Western Regional Air Partnership (Environ et al, 2001)
    e) Commercial Marine Vessel Inventory Review and Preparation for the Northwest U.S. (Corbett, 2001)
    f) Commercial Marine Activity for Deep Sea Ports in the United States (EPA, 1999)

The methodology used for this study is described by marine vessel category below. Where the data from previous inventory studies listed above were used, adjustments were required since the emission estimation methodologies and the year for which the inventory was prepared varied.

3.1 OCEAN-GOING VESSELS

A 1999 US EPA report on Commercial Marine Activity for Deep Sea Ports in the United States provided the most comprehensive data set of all sources investigated. The number of port calls to the Puget Sound are listed per shiptype and deadweight for 1996, thus providing a base data set similar to that used for the Core Area of British Columbia already investigated. The data summarized in the EPA report was provided by the Marine Exchange of Puget Sound (MEPA) and included the number of port calls, average power, and average time per call in each of four operational modes. These modes were: cruise, reduced speed zone, manoeuvring, and hotelling (referred to as dockside in the core report). Cruise speed was defined as the average continuous speed of the vessel in open water from 25 miles out from Cape Flattery, the entrance point of the Strait of San Juan de Fuca. The reduced speed zone is the time the vessel is at a speed less than full cruise and greater than the 4 knot average assumed for the manoeuvring portion. It was assumed that a typical vessel reduces speed to 3-5 knots for approximately 4 miles to pick up a pilot from Port Angeles, then depending on the weather conditions and cargo port the vessel will regain speeds of between 4 to 13 knots. As mentioned, the manoeuvring speed of 4 knots is assumed from 2 nautical miles from the dock until the vessel is secured. Hotelling, or dockside time are calculated as the time when the vessel is at anchorage or at a berth minus any manoeuvring times.

The method of calculating emissions, similar to that outlined in section 2.1.7 is based on the number of port calls and average power for each of the shiptypes and deadweight categories as described in section 2.1.5. Where:

Emissions (tonnes) = Number of port calls x Average Power (kW) x Average time per call (hr/call)

x Emission factor (g/kWh)) / 10^6 (g/tonne) x Engine Load factor (%)

The average time per call varied in each of the four modes. The emission and load factors used for cruise are the same as outlined in the Canadian portion of the Expanded Area, Tables 2-3 and 2-4. The emission and load factors for the manoeuvring portion of each trip are the same as were used in the associated Marine Vessel Air Emissions in the Lower Fraser Valley for 2000 (Core Area) Report. The emission factors are listed in Table 3-1 and the engine load factor for all ships was assumed to be 20%.

Table 3-1: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

The third mode of operation (reduced speed zone) was defined as travel when the vessel is travelling at less than full cruise speed and greater than the 4 knot average used for maneuvering. As such the emission factors for cruise operation (Table 2.3) were used in conjunction with a 50% load rather than an 80% engine load factor.

In the B.C. portion of the report, dockside emissions were based on average fuel consumption per dockside calculated from a survey of typical fuel consumption by various vessels in Vancouver. This was due to the unavailability of time-in-port (dockside) data from the Pacific Pilotage base data. As previously mentioned, the EPA report provided average estimates of hotelling (dockside) times for the Puget Sound port calls allowing a method similar to that for cruising and maneuvering to be used. The emissions were calculated using the same equation as above with the emission factors for diesel listed and for fuel oil in Table 3-2 with an engine load factor of 10%. The average hotelling

time was split into hoteling diesel time and hotelling fuel oil time based on the results per shiptype provided by the BC survey.

After calculation of the emissions for Ocean-going vessels in the Puget Sound for 1996, each individual total was "grown" to a 2000 estimate using the assumption that all ocean-going vessel traffic decreased by 3% from 1996. The percentage change in traffic was calculated by the ratio of the sum of inbound and outbound vessels in 2000 to 1996 from the US Army Corps of Engineers Waterborne Commerce Statistics Centre. The data used was only for self-propelled tankers, passenger, and cargo vessels for the ports deemed to be within the defined Puget Sound/Washington coast area. These ports included: Grays Harbor, Port Angeles, Olympia, Tacoma, Seattle, Everett, Bellingham, Anacortes, and Snohomish. Although this data was more current, it was less detailed, and thus was used only for establishing a yearly ratio of traffic for this region, rather than a base data set.

Table 3-2: Emission Factors for Auxiliary Engines

Pollutants	Emission Factors (g/kWh)	
	Diesel	Fuel Oil
CO	1.0	1.0
NOx	11.4	11.4
SOx *	0.5	10.3
VOC	0.5	0.5
PM	1.4	1.4
CO_2	668	782
CH_4 (IPCC, 1997)	0.001	0.003
N_2O (IPCC, 1997)	0.29	0.02
NH_3 (Environment Canada, 2001)	0.019	0.019

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%)

3.2 HARBOUR VESSELS

Similar to the Canadian portion of the study, the harbour vessel category can be split into tug and workboats; and charter boats. Detailed listings of tug and workboats for Washington State are not available (as was the case for B.C.), thus the emissions calculation method for these vessels required more estimation toward the overall vessel count. The EPA report on Commercial Marine Activity for Deep Sea Ports in the United States gave a listing of tugs in the Puget Sound for 1996. Additional research lead to patrol/rescue boat counts for the US Coast Guard and assumptions for estimation of police and fireboats in the Puget Sound area. The total numbers of confirmed boats are listed by type in Table 3-3. In addition, it was estimated that between county and state fire and police marine units, there is an additional 36 boats with an average of 300 hp and 25 smaller vessels of 100hp or less. These estimated boat counts were the result of investigating the specifications for the boating equipment used for several county marine units and applying the overall average situation to all counties and cities reporting an active coastal marine patrol unit.

Table 3-3 Tug and Workboat Confirmed Boats for Puget Sound/Washington Coast for 1996

Boat Category	Patrol/Rescue	Tug	Workboat	Other	Grand Total
Average Horsepower	1647	2883	524	6250	2771
Number of Boats	12	176	9	4	201

Calculations of emissions from tug and workboats followed the same assumptions, engine load factors, operating hours and emission factors as outlined in section 2.2. As the boat counts given in Table 3-3 reflect 1996 totals, the overall emissions were decreased to 65% of those calculated to reflect the change in the number of tow and tugboat trips from 1996 to 2000 as listed by the US Army Corps of Engineers for the Puget Sound and Washington Coast Area (ports listed in the ocean-going vessels section).

Emissions from charter boats in Washington state were calculated using the same methodology as for emissions from charter boats in the expanded area. The number of charter boat operators was taken from the compilation of listings of motorboat, diving, and fishing charter companies in Washington State (Charternet.com, 2001).

3.3 FERRIES

3.3.1 B.C. Ferries

Detailed information on the data collection and inventory methodology for B.C. Ferries was provided in Section 2.3.2 of this report.

3.3.2 Washington State

Washington State Ferries operates the largest ferry fleet in Washington State. Twenty-five ferries cross the Puget Sound and its inland waterways, “carrying over 23 million passengers to 20 different ports of call” (source:www.wsdot.wa.gov/ferries/your_wsf/our_fleet/). Washington State Ferries travel up and down the Puget Sound on pre-determined schedules for each route, including routes that enter into B.C. (to Sidney).

Washington State Ferries provided data directly to Levelton for the year 2000. The data provided was the fuel consumption per vessel per month with the fraction of time spent on each route for each vessel to aid in the spatial allocation of emissions. The sulphur content in the fuel was reported to be <0.05%, and this value was used for SOx estimation for all Washington State Ferries.

The methodology described in section 2.3.2 for B.C. Ferries was applied to the Washington State Ferries for the underway emissions and the extended calculation of manoeuvring and dockside emissions. It was assumed that the factors used for the B.C. Ferries are applicable to the Washington State Ferries.

3.3.3 Coho Ferry

The Coho Ferry service runs between Port Angeles (WA) and Victoria (B.C.) between one and four times per day depending on the time of year. The Coho Ferry operates only one vessel at a time, thus is a very small contributor to emissions, producing less than 1% of the total Ferry emissions.

The same emission factors as those used for B.C. Ferries and Washington State Ferries were used but no breakdown by power level was applied due to its small contribution overall. The fuel supplied to this ferry company is approximately 50/50 from Canadian (Shell) and American suppliers. The %S used for the calculation of SO_2 was 0.03%.

The following table (Table 3-4) lists the data provided to Levelton directly from Coho Ferries:

Table 3-4: Specifications of the Coho Ferry

Specification	Value
Fuel Consumption	100 Gallons/hour
Fuel type	Marine diesel
Sulphur Content	0.03%
Hours of Operation	4 hours/trip (return)

3.3.4 Victoria Clipper

There are four ferries making up the fleet of the Victoria Clipper, which provides high-speed passenger ferry service between Seattle, Victoria, and the San Juan Islands. Although information was requested from Victoria Clipper directly, data was not provided, so the 2002 schedule and published ferry specifications were used to estimate the emissions for 2000. Along with vessel length and horsepower the underway average fuel consumption was found online. Initial calculation of the underway emissions were based on the overall travel times estimated from the sailing schedule and then the B.C. Ferries methodology for dividing the emissions into underway, manoeuvring and dockside emissions was applied with the same assumed emission and load factors.

3.4 FISHING VESSELS

The same methodology applied in the Core Area study was applied to the expanded area fishing vessel emission estimates.

As explained in Section 2.4, data on Canadian fishing vessels was incomplete for certain fishing areas, necessitating the use of various assumptions. The American data set is complete in terms of boat counts, however, since the dominating boat types in the U.S differ from those in Canada, specifications on those vessels (power, load factor, time spent at power level) were assumed using the Marine Power Selection Guide as a basis.

3.4.1 American Vessel Population and Data Collection

The Department of Fish and Wildlife in Washington State has provided Levelton with “ticket numbers” which are analagous to boat days used to calculate the Canadian fishing vessel emissions. Indications are that, unlike the Canadian portion of the study area, gillnetters, seiners and trollers are not the primary contributors of emissions from fishing vessels in Washington State. It appears that the larger contributors are the groundfish vessels such as trawlers. Little information is available about the use of powered vessels by First Nations, as their fishing management is not as closely tagged as commercial fishing activity.

3.5 RECREATIONAL VESSELS

3.5.1 Vessel Population

In the State of Washington, all motorboats and sailboats 16 feet and over are titled and registered with the Department of Licensing (DOL), which differs from requirements in Canada. Registration statistics for 2000 were obtained from DOL for each of the counties located in the U.S. portion of the Expanded Area. Boat counts are shown in Table 3-5 for the Washington coast, Whatcom County and Puget Sound.

Table 3-5: Vessel Population in the U.S. Portion of the Expanded Area for 2000

		2000 Registered Boats	
Region	County	Counts	% State Total
Coast	Clallam	4,653	1.8
	Clark	13,309	5.1
	Cowlitz	5,415	2.1
	Grays Harbor	3,808	1.5
	Jefferson	2,843	1.1
	Pacific	1,328	0.5
	Wahkiakum	469	0.2
U.S. LFV	Whatcom	8,491	3.3
Puget Sound	Island	5,380	2.1
	King	60,867	23.5
	Kitsap	12,080	4.7
	Mason	4,796	1.9
	Pierce	28,559	11.0
	San Juan	2,806	1.1
	Skagit	8,438	3.3
	Snohomish	26,842	10.4
	Thurston	10,115	3.9
	County Subtotal	200,199	77.3
	State Total	258,923	100.0

Since engine characteristics were needed for emissions estimation, engine type distribution for each county was based on a general profile developed for the EPA Non-road Model for Washington State for 1998. The profile was applied to the vessel population of each county to determine the vessel count for each engine type.

3.5.2 Fuel Consumption

Annual fuel consumption of a marine engine is dependent on factors such as its hours of use, horsepower rating, and load factor. This data was extracted from input files compiled by Washington State for use in the EPA Non-road Model. These parameters are summarized in Table 3-6 and were used to estimate annual fuel use for a marine engine in a given engine category.

Table 3-6: Parameters for Fuel Consumption Estimates

Pleasure Crafts	Activity (hr/boat/y)	Load Factor (%)	BSFC (lb/HP-h)
Outboard	35	21	1.3
Personal Water Craft	77	21	1.3
Sterndrive/Inboard	48	21	0.7
Diesel Sterndrive/Inboard	200	35	0.4
Diesel Outboard	150	29	0.4

3.5.3 Emission Factors

The emission factors used to estimate marine vessel emissions from the Canadian portion of the Expanded Area were also used for this U.S. study area. Factors have been summarized in Table 2-23 and Table 2-24. Gasoline and diesel fuel sulphur contents of 0.03 wt.% and 0.34 wt.%, as provided by the Washington Department of Ecology, were used to estimate SOx emissions for this portion of the Expanded Area.

3.6 POLLUTANT SPECIATION PROFILES

3.6.1 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.

3.6.2 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 $SO_4^=$.

3.6.3 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 1µm 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.

3.7 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 100 year GWPs of each gas, specifically 21 for methane and 310 for nitrous oxide. The GWPs used are from the Inter-Governmental Panel on Climate Change (IPCC) Second Assessment Report. Although a revised set of GWPs has been published in the IPCC Third Assessment Report (2001), according to the Kyoto Protocol, any revision to a GWP applies only "in respect of any commitment period adopted subsequent to that revision."

4. EMISSION RESULTS – CANADIAN PORTION

4.1 OVERALL EMISSIONS FOR THE CANADIAN PORTION OF THE EXPANDED AREA

The emission results in 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 Canadian portion are shown in Table 4-1, and greenhouse gases in Table 4-2.

Table 4-1: CAC and NH_3 Emissions for B.C. (outside GVRD and FVRD) for 2000

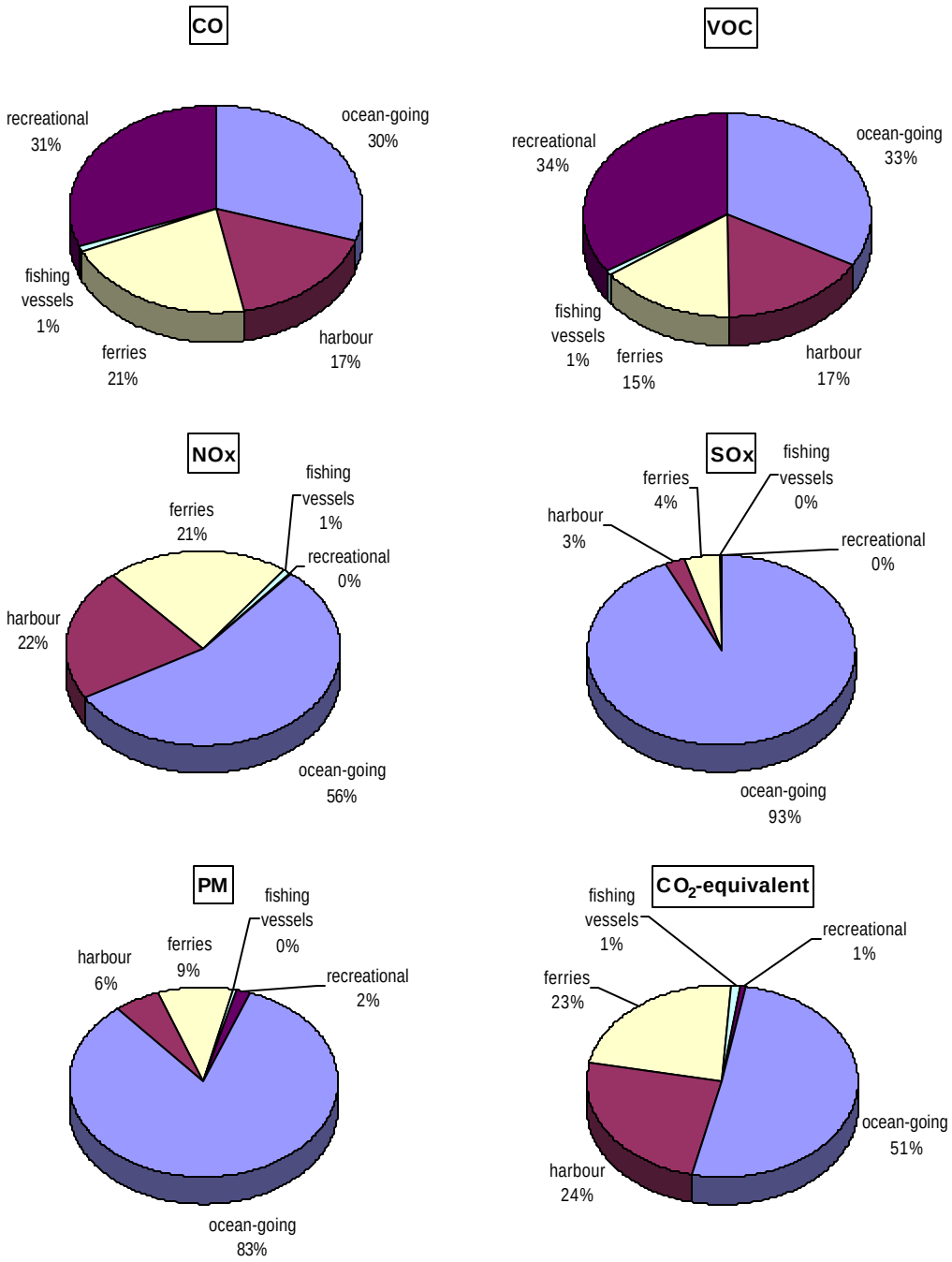
	emissions (tonnes/year)									
	CO	VOC	NOx			SOx			PM ‡	NH_3
			total NOx*	NO	NO_2	total SOx †	SO_2	$SO_4^=$		
Ocean Going Vessels										
Dockside	348	164	6,280	3,933	251	3,209	3,166	65	497	2
Manoeuvring	11	1	86	54	3	6	6	0	4	1
Reduced Speed Zone	122	38	2,060	1,290	82	780	769	16	114	27
Underway	757	236	12,778	8,001	511	4,838	4,773	97	709	166
Subtotal	1,238	439	21,204	13,277	847	8,833	8,715	178	1,325	195
Harbour Vessels										
workboats and tugboats	680	212	8,162	5,111	326	232	229	5	85	4
charters	30	9	361	226	14	10	10	0	4	0
Subtotal	710	222	8,523	5,337	341	242	239	5	89	4
Ferries										
B.C. Ferries										
Dockside	120	9	1,587	994	63	20	20	0	54	0
Layup	5	0	52	32	2	1	1	0	2	0
Manoeuvring	244	31	667	418	27	24	24	0	5	0
Underway	471	153	5,444	3,409	218	350	345	7	76	0
Coho Ferries	3	1	31	20	1	0	0	0	0	0
Victoria Clipper										
Dockside	1	0	15	9	1	0	0	0	1	0
Manoeuvring	4	0	10	7	0	0	0	0	0	0
Underway	2	1	28	18	1	2	2	0	0	0
Washington State Ferries										
Dockside	3	0	45	28	2	0	0	0	2	0
Manoeuvring	9	1	26	16	1	0	0	0	0	0
Underway	22	7	250	157	10	0	0	0	4	0
Subtotal	884	204	8,156	5,107	326	398	392	8	144	1
Fishing Vessels										
Gillnetters	17	5	188	118	8	6	6	0	2	0
Seiners	16	5	178	111	7	5	5	0	2	0
Trollers	2	1	25	15	1	1	1	0	0	0
Subtotal	35	11	391	245	16	12	12	0	4	0
Recreational Vessels	1,272	455	60	37	2	1	1	0	28	0
Total	4,139	1,331	38,333	24,003	1,532	9,486	9,359	191	1,591	201

Table 4-2: GHG Emissions for B.C. (outside GVRD and FVRD) for 2000

	emissions (tonnes/year)			
	CO_2	**CH_4**	**N_2O**	**total, CO_2equiv**
Ocean Going Vessels				
Dockside	281,309	21.7	22.6	288,764
Manoeuvring	2,096	0.1	0.9	2,375
Reduced Speed Zone	57,699	5.3	1.5	58,284
Underway	357,969	33.1	9.2	361,521
Subtotal	**699,073**	**60.2**	**34.2**	**710,944**
Harbour Vessels				
workboats and tugboats	321,553	29.7	8.5	324,811
charters	14,204	1.3	0.4	14,348
Subtotal	**335,758**	**31.0**	**8.9**	**339,160**
Ferries				
B.C. Ferries				
Dockside	46,491	2.6	17.1	51,832
Layup	1,564	0.1	0.6	1,743
Manoeuvring	27,468	1.5	10.1	30,623
Underway	201,685	11.1	74.0	224,852
Coho Ferries	1,160	0.1	0.4	1,295
Victoria Clipper				
Dockside	429	0.0	0.2	479
Manoeuvring	428	0.0	0.2	478
Underway	1,038	0.1	0.4	1,158
Washington State Ferries				
Dockside	329	0.1	0.6	504
Manoeuvring	535	0.1	0.5	678
Underway	9,268	0.6	4.0	10,505
Subtotal	**290,395**	**16.2**	**107.8**	**324,146**
Fishing Vessels				
Gillnetter	6,900	0.6	0.2	6,978
Seiners	6,517	0.6	0.2	6,591
Trollers	906	0.1	0.0	917
Subtotal	**14,324**	**1.3**	**0.4**	**14,486**
Recreational Vessels	**7,877**	**9.3**	**0.4**	**8,204**
Total	**1,347,427**	**118.0**	**151.7**	**1,396,939**

Figure 4-1 presents the relative contributions of the main marine vessel categories to the individual contaminant totals for BC. Ocean-going vessels are the predominant contributor to emissions of NOx, SOx, PM and greenhouse gases, accounting for 56%, 93%, 83% and 51% of the total marine vessel emissions, respectively. Harbour vessels contribute 22% and 24% of NOx and GHGs, and 17% of CO and VOC. Ferries contribute between 15% and 23% for CO, VOC, NOx and GHGs, but 9% or less for SOx and PM. Fishing vessels are 1% or less for all contaminants. Recreational vessels are significant for CO and VOC (31% and 34%), but 0% to 2% for all other contaminants.

Figure 4-1: Contributions of Vessel Categories to Individual Contaminant Emission Totals (Canadian Portion of the Expanded Area)



4.2 OCEAN-GOING VESSELS

4.2.1 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 4-3 for criteria contaminants and ammonia, and Table 4-5 for greenhouse gases.

Table 4-3: CAC and NH_3 Emissions for Ocean-Going Vessels for BC (outside the GVRD and FVRD) 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	165.1	51.6	2,788.8	1,746.2	111.5	1,055.9	1,041.8	21.3	154.8	36.1
Container	48.8	15.3	824.5	516.3	33.0	312.2	308.0	6.3	45.8	10.7
General Cargo	55.6	17.4	938.7	587.8	37.5	355.4	350.7	7.2	52.1	12.2
Other Vessels	3.9	1.2	65.6	41.1	2.6	24.8	24.5	0.5	3.6	0.8
Passenger	449.5	140.5	7,592.0	4,753.9	303.4	2,874.6	2,836.0	57.9	421.4	98.3
Tanker	33.7	10.5	568.4	355.9	22.7	215.2	212.3	4.3	31.6	7.4
Subtotal	**756.6**	**236.4**	**12,777.9**	**8,001.1**	**510.7**	**4,838.2**	**4,773.2**	**97.4**	**709.3**	**165.5**
Reduced Speed Zone										
Bulk Carrier	15.4	4.8	259.6	162.6	10.4	98.3	97.0	2.0	14.4	3.4
Container	70.7	22.1	1,194.3	747.9	47.7	452.2	446.2	9.1	66.3	15.5
General Cargo	5.7	1.8	96.2	60.2	3.8	36.4	35.9	0.7	5.3	1.2
Other Vessels	12.4	3.9	209.8	131.3	8.4	79.4	78.4	1.6	11.6	2.7
Passenger	0.6	0.2	10.4	6.5	0.4	3.9	3.9	0.1	0.6	0.1
Tanker	17.1	5.4	289.3	181.2	11.6	109.6	108.1	2.2	16.1	3.7
Subtotal	**122.0**	**38.1**	**2,059.6**	**1,289.7**	**82.3**	**779.8**	**769.4**	**15.7**	**114.3**	**26.7**
Manoeuvring										
Bulk Carrier	1.5	0.1	11.3	7.1	0.5	0.8	0.8	0.0	0.6	0.1
Container	3.7	0.2	27.7	17.4	1.1	2.1	2.0	0.0	1.4	0.3
General Cargo	0.5	0.0	3.5	2.2	0.1	0.3	0.3	0.0	0.2	0.0
Other Vessels	0.9	0.0	7.0	4.4	0.3	0.5	0.5	0.0	0.3	0.1
Passenger	0.0	0.0	0.3	0.2	0.0	0.0	0.0	0.0	0.0	0.0
Tanker	4.8	0.3	36.1	22.6	1.4	2.7	2.7	0.1	1.8	0.5
Subtotal	**11.4**	**0.6**	**85.8**	**53.7**	**3.4**	**6.4**	**6.3**	**0.1**	**4.3**	**1.1**
Dockside										
Bulk Carrier	194.3	85.8	3,359.4	2,103.6	134.3	1,803.1	1,778.9	36.3	265.0	0.7
Container	27.3	18.4	626.7	392.4	25.0	215.8	212.9	4.3	50.6	0.7
General Cargo	37.1	16.8	653.1	409.0	26.1	347.0	342.3	7.0	51.6	0.2
Other Vessels	37.2	17.4	661.5	414.2	26.4	345.1	340.5	6.9	52.4	0.3
Passenger	36.8	15.8	629.8	394.4	25.2	343.0	338.4	6.9	49.5	0.1
Tanker	15.0	10.2	349.8	219.0	14.0	154.6	152.6	3.1	28.2	0.4
Subtotal	**347.8**	**164.2**	**6,280.4**	**3,932.6**	**251.0**	**3,208.7**	**3,165.6**	**64.6**	**497.3**	**2.2**
Total	**1,237.7**	**439.4**	**21,203.8**	**13,277.1**	**847.5**	**8,833.1**	**8,714.5**	**177.8**	**1,325.3**	**195.5**

Table 4-4: GHG Emissions for Ocean-Going Vessels for BC (outside the GVRD and FVRD) for 2000

	emissions (tonnes/year)			
	CO_2	CH_4	N_2O	total, CO_2-eq
Underway				
Bulk Carrier	78,126	7.2	2.1	78,918
Container	23,097	2.1	0.6	23,331
General Cargo	26,298	2.4	0.7	26,564
Other Vessels	1,837	0.2	0.0	1,855
Passenger	212,688	19.7	5.4	214,768
Tanker	15,923	1.5	0.4	16,085
Subtotal	**357,969**	**33.1**	**9.2**	**361,521**
Reduced Speed Zone				
Bulk Carrier	7,273	0.7	0.2	7,347
Container	33,459	3.1	0.9	33,798
General Cargo	2,694	0.2	0.1	2,721
Other Vessels	5,876	0.5	0.2	5,936
Passenger	291	0.0	0.0	294
Tanker	8,105	0.7	0.2	8,188
Subtotal	**57,699**	**5.3**	**1.5**	**58,284**
Manoeuvring				
Bulk Carrier	276	0.0	0.1	313
Container	678	0.0	0.3	768
General Cargo	85	0.0	0.0	96
Other Vessels	170	0.0	0.1	193
Passenger	7	0.0	0.0	7
Tanker	881	0.1	0.4	998
Subtotal	**2,096**	**0.1**	**0.9**	**2,375**
Dockside				
Bulk Carrier	151,500	13.7	9.6	154,756
Container	26,838	0.1	5.2	28,462
General Cargo	29,411	2.6	2.0	30,077
Other Vessels	29,714	2.2	2.2	30,437
Passenger	28,463	2.9	1.6	29,035
Tanker	15,381	0.1	2.0	15,997
Subtotal	**281,309**	**21.7**	**22.6**	**288,764**
Total	**699,073**	**60.2**	**34.2**	**710,944**

4.3 ALL OTHER VESSEL TYPES

Emission estimates for all other vessel types in the Canadian portion of the expanded study area are summarized in Tables 4-1 and 4-2.

Notes (for Tables in Section 4): 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% $PM_{2.5}$

5. EMISSION RESULTS – U.S. PORTION

5.1 OVERALL EMISSIONS FOR THE U.S. PORTION OF THE EXPANDED AREA

The emission results in 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 U.S. portion are shown in Table 5-1, and greenhouse gases in Table 5-2.

Table 5-1: CAC and NH_3 Emissions for Washington State for 2000

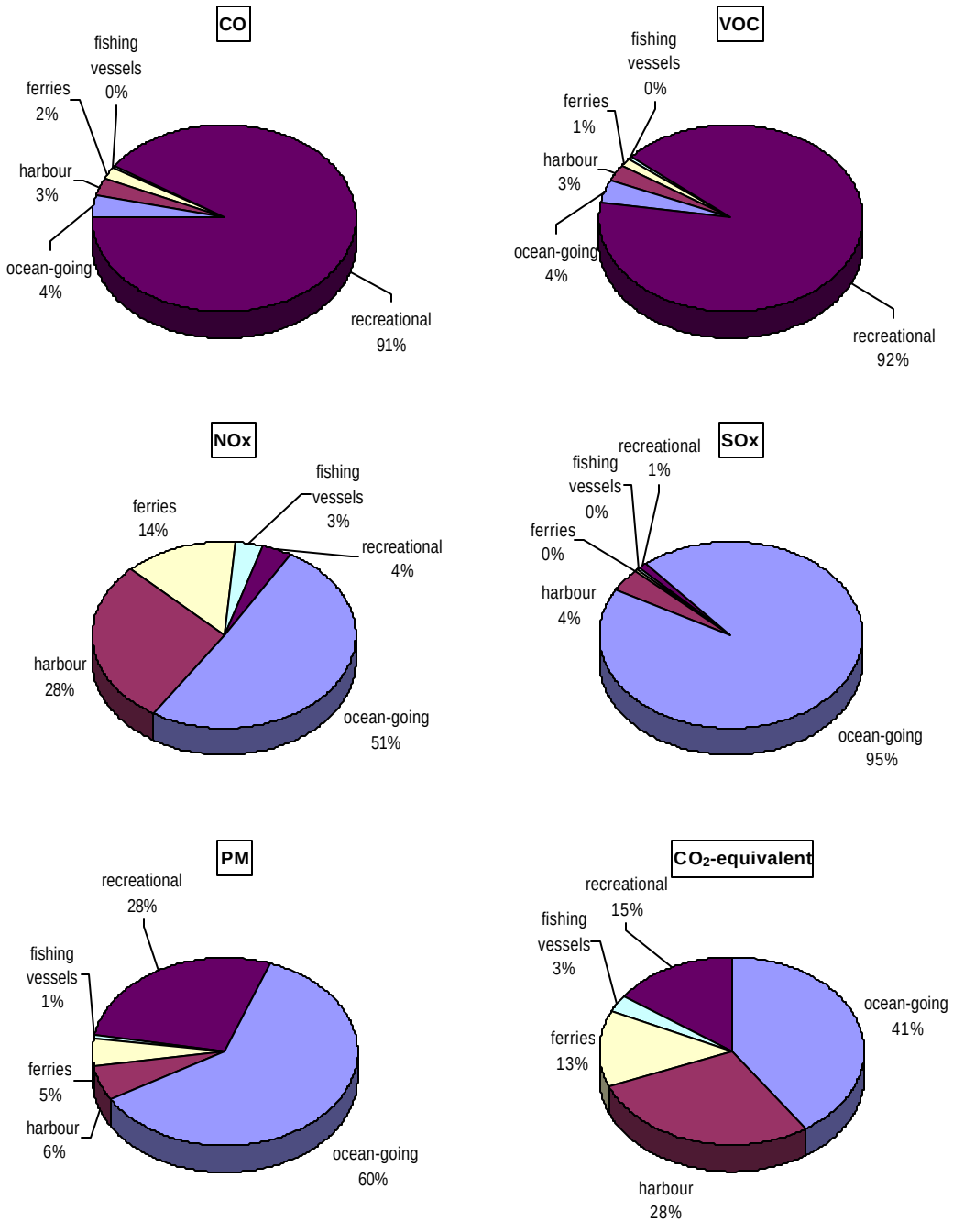
	emissions (tonnes/year)									
	CO	VOC	NOx			SOx			PM ‡	NH_3
			total NOx*	NO	NO_2	total SOx †	SO_2	$SO_4^=$		
Ocean Going Vessels										
Dockside	193	117	4,043	2,532	162	1,729	1,706	35	326	4
Manoeuvring	48	3	362	227	14	27	27	1	18	5
Reduced Speed Zone	514	161	8,681	5,436	347	3,287	3,243	66	482	112
Underway	401	125	6,776	4,243	271	2,565	2,531	52	376	88
Subtotal	**1,156**	**406**	**19,862**	**12,437**	**794**	**7,608**	**7,506**	**153**	**1,202**	**209**
Harbour Vessels										
Workboats and tugboats	906	283	10,880	6,813	435	309	305	6	113	6
Charters	11	4	144	90	6	4	4	0	1	0
Subtotal	**916**	**287**	**11,023**	**6,903**	**441**	**313**	**309**	**6**	**115**	**6**
Ferries										
B.C. Ferries										
Dockside	0	0	0	0	0	0	0	0	0	0
Layup	0	0	0	0	0	0	0	0	0	0
Manoeuvring	3	0	7	5	0	0	0	0	0	0
Underway	4	1	46	29	2	3	3	0	1	0
Coho Ferries	3	1	38	24	2	0	0	0	1	0
Victoria Clipper										
Dockside	1	0	19	12	1	0	0	0	1	0
Manoeuvring	5	1	14	9	1	1	1	0	0	0
Underway	16	5	187	117	7	13	13	0	3	0
Washington State Ferries										
Dockside	48	3	631	395	25	0	0	0	26	0
Manoeuvring	166	21	455	285	18	0	0	0	4	0
Underway	348	113	4,025	2,520	161	2	2	0	56	0
Subtotal	**595**	**146**	**5,423**	**3,396**	**217**	**20**	**20**	**0**	**91**	**0**
Fishing Vessels										
Gillnetters	6	2	70	44	3	2	2	0	1	0
Seiners	12	4	136	85	5	4	4	0	2	0
Trollers	3	1	30	18	1	1	1	0	0	0
Trawlers	97	30	1,093	684	44	33	33	1	12	1
Subtotal	**118**	**37**	**1,329**	**832**	**53**	**40**	**40**	**1**	**15**	**1**
Recreational Vessels	**26,793**	**9,441**	**1,388**	**869**	**55**	**98**	**97**	**2**	**545**	**0**
Total	**29,578**	**10,316**	**39,026**	**24,437**	**1,560**	**8,081**	**7,972**	**163**	**1,967**	**216**

Table 5-2: GHG Emissions for Washington State for 2000

	emissions (tonnes/year)			
	CO_2	**CH_4**	**N_2O**	**total, CO_2-equiv**
Ocean Going Vessels				
Dockside	177,105	2.0	24.4	184,704
Manoeuvring	8,836	0.5	3.8	10,011
Reduced Speed Zone	243,204	22.5	6.4	245,668
Underway	189,815	17.6	5.0	191,719
Subtotal	**618,960**	**42.6**	**39.5**	**632,103**
Harbour Vessels				
Workboats and tugboats	428,617	39.6	11.3	432,959
Charters	5,659	0.5	0.1	5,717
Subtotal	**434,276**	**40.2**	**11.5**	**438,676**
Ferries				
B.C. Ferries				
Dockside	0	0.0	0.0	0
Layup	0	0.0	0.0	0
Manoeuvring	298	0.0	0.1	332
Underway	1,715	0.1	0.6	1,912
Coho Ferries	1,402	0.1	0.5	1,565
Victoria Clipper				
Dockside	568	0.0	0.2	633
Manoeuvring	569	0.0	0.2	634
Underway	6,940	0.4	2.5	7,737
Washington State Ferries				
Dockside	4,621	1.2	7.9	7,089
Manoeuvring	9,363	1.2	8.0	11,865
Underway	149,109	9.5	63.6	169,025
Subtotal	**174,585**	**12.6**	**83.7**	**200,793**
Fishing Vessels				
Gillnetter	2,581	0.2	0.1	2,610
Seiners	4,992	0.5	0.2	5,049
Trollers	1,082	0.1	0.0	1,094
Trawlers	40,041	3.6	1.2	40,493
Subtotal	48,696	4.4	1.5	49,246
Recreational Vessels	223,410	254.6	14.3	233,187
Total	**1,499,926**	**354.3**	**150.5**	**1,554,005**

Figure 5-1 presents the relative contributions of the main marine vessel categories to the individual contaminant totals for Washington State. Ocean-going vessels are significant contributors to emissions of NOx, SOx, PM and greenhouse gases, accounting for 51%, 95%, 60% and 41% of the total marine vessel emissions, respectively. Harbour vessels contribute 28% to both NOx and GHGs, 6% of PM and 4% or less for CO, VOC and SOx. Ferries contribute 13% and 14% for GHGs and NOx, but 5% or less for all other contaminants. Fishing vessels are 3% of NOx and GHGs and 1% or less for all contaminants. Recreational vessels are significant for CO and VOC (91% and 92%), 28% for PM, and 15% of GHGs.

Figure 5-1: Contributions of Vessel Categories to Individual Contaminant Emission Totals (U.S. Portion of the Expanded Area)



5.2 OCEAN-GOING VESSELS

5.2.1 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 5-3 for criteria contaminants and ammonia, and Table 5-4 for greenhouse gases.

Table 5-3: CAC and NH_3 Emissions for Ocean-Going Vessels for Washington State 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	34.3	10.7	580.0	363.2	23.2	219.6	216.6	4.4	32.2	7.5
Container	193.8	60.6	3,273.6	2,049.8	130.8	1,239.5	1,222.9	25.0	181.7	42.4
General Cargo	12.1	3.8	205.2	128.5	8.2	77.7	76.6	1.6	11.4	2.7
Other Vessels	14.9	4.7	251.8	157.6	10.1	95.3	94.0	1.9	14.0	3.3
Passenger	116.6	36.4	1,968.5	1,232.6	78.7	745.3	735.3	15.0	109.3	25.5
Tanker	29.4	9.2	496.6	310.9	19.8	188.0	185.5	3.8	27.6	6.4
Subtotal	**401.2**	**125.4**	**6,775.6**	**4,242.6**	**270.8**	**2,565.5**	**2,531.0**	**51.7**	**376.1**	**87.8**
Reduced Speed Zone										
Bulk Carrier	64.8	20.2	1,094.3	685.2	43.7	414.4	408.8	8.3	60.7	14.2
Container	298.1	93.2	5,034.2	3,152.2	201.2	1,906.1	1,880.5	38.4	279.5	65.2
General Cargo	24.0	7.5	405.3	253.8	16.2	153.5	151.4	3.1	22.5	5.2
Other Vessels	52.4	16.4	884.1	553.6	35.3	334.8	330.3	6.7	49.1	11.5
Passenger	2.6	0.8	43.8	27.4	1.8	16.6	16.4	0.3	2.4	0.6
Tanker	72.2	22.6	1,219.5	763.6	48.7	461.8	455.6	9.3	67.7	15.8
Subtotal	**514.0**	**160.6**	**8,681.3**	**5,435.9**	**347.0**	**3,287.1**	**3,242.9**	**66.2**	**481.9**	**112.4**
Manoeuvring										
Bulk Carrier	6.3	0.3	47.6	29.8	1.9	3.6	3.5	0.1	2.4	0.6
Container	15.5	0.8	117.0	73.2	4.7	8.7	8.6	0.2	5.9	1.5
General Cargo	1.9	0.1	14.6	9.1	0.6	1.1	1.1	0.0	0.7	0.2
Other Vessels	3.9	0.2	29.4	18.4	1.2	2.2	2.2	0.0	1.5	0.4
Passenger	0.1	0.0	1.1	0.7	0.0	0.1	0.1	0.0	0.1	0.0
Tanker	20.2	1.1	152.1	95.2	6.1	11.4	11.2	0.2	7.6	1.9
Subtotal	**47.9**	**2.6**	**361.8**	**226.5**	**14.5**	**27.0**	**26.7**	**0.5**	**18.1**	**4.5**
Dockside										
Bulk Carrier	58.4	31.5	1,092.5	684.1	43.7	534.2	527.1	10.8	88.0	1.1
Container	58.8	39.6	1,352.2	846.7	54.0	465.1	458.8	9.4	109.2	1.5
General Cargo	17.5	9.6	342.8	214.6	13.7	162.4	160.2	3.3	27.5	0.3
Other Vessels	26.8	14.7	513.5	321.6	20.5	245.5	242.2	4.9	41.3	0.5
Passenger	1.5	0.8	29.7	18.6	1.2	14.0	13.8	0.3	2.4	0.0
Tanker	29.8	20.9	712.6	446.2	28.5	307.7	303.5	6.2	57.6	0.8
Subtotal	**192.8**	**117.1**	**4,043.4**	**2,531.8**	**161.6**	**1,728.9**	**1,705.6**	**34.8**	**325.9**	**4.1**
Total	**1,155.9**	**405.7**	**19,862.0**	**12,436.9**	**793.8**	**7,608.4**	**7,506.3**	**153.2**	**1,202.1**	**208.9**

Table 5-4: GHG Emissions for Ocean-Going Vessels for Washington State for 2000

	emissions (tonnes/year)			
	CO_2	CH_4	N_2O	total, CO_2-eq
Underway				
Bulk Carrier	16,247	1.5	0.4	16,412
Container	91,709	8.5	2.4	92,638
General Cargo	5,748	0.5	0.2	5,806
Other Vessels	7,053	0.7	0.2	7,124
Passenger	55,147	5.1	1.4	55,686
Tanker	13,912	1.3	0.4	14,053
Subtotal	**189,815**	**17.6**	**5.0**	**191,719**
Reduced Speed Zone				
Bulk Carrier	30,657	2.8	0.8	30,968
Container	141,032	13.0	3.7	142,460
General Cargo	11,354	1.0	0.3	11,469
Other Vessels	24,769	2.3	0.7	25,020
Passenger	1,228	0.1	0.0	1,241
Tanker	34,165	3.2	0.9	34,511
Subtotal	**243,204**	**22.5**	**6.4**	**245,668**
Manoeuvring				
Bulk Carrier	1,163	0.1	0.5	1,318
Container	2,857	0.2	1.2	3,237
General Cargo	357	0.0	0.2	404
Other Vessels	717	0.0	0.3	812
Passenger	28	0.0	0.0	31
Tanker	3,714	0.2	1.6	4,208
Subtotal	**8,836**	**0.5**	**3.8**	**10,011**
Dockside				
Bulk Carrier	48,641	0.7	4.7	50,120
Container	57,900	0.2	11.3	61,407
General Cargo	15,202	0.5	1.6	15,713
Other Vessels	22,798	0.4	2.4	23,543
Passenger	1,318	0.1	0.1	1,363
Tanker	31,246	0.1	4.2	32,557
Subtotal	**177,105**	**2.0**	**24.4**	**184,704**
Total	**618,960**	**42.6**	**39.5**	**632,103**

5.3 ALL OTHER VESSEL TYPES

Emission estimates for all other vessel types in the U.S. portion of the expanded study area are summarized in Tables 5-1 and 5-2.

Notes (for Tables in Section 5): 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% $PM_{2.5}$

6. SPATIAL ALLOCATION OF EMISSIONS

Emission totals for the B.C. and Washington State portions of the expanded study area were presented in Sections 4 and 5. This section discusses the allocation of BC and Washington emissions into sub-regions of interest, such as specified coastal areas, domestic and international emissions (for greenhouse gases), and to a 1 km by 1 km grid system.

6.1 REGIONAL EMISSIONS

The regions of interest for this study include Vancouver Island and the B.C. coastline (north of Bull Harbour), for B.C., and Whatcom County, Puget Sound, and the Washington coastline for the State of Washington. Section 1.2 provides details on how these spatial areas were defined for the purposes of this study. Wherever possible, the data needed for estimating emissions was obtained as aggregate totals for these regions. For example, vessel counts for harbour and recreational vessels were obtained by area, and Canadian fishing vessel data was obtained for specific fisheries management areas. Much of the Washington State inventory data was available by county, which allowed the assignment of specific county data to one of Whatcom County, Puget Sound, or the Washington coastline. In other cases, where specific data on vessel movements and docking (e.g. ocean-going vessels and ferries) was available, spatial allocation was facilitated using the GIS system described in Section 6.3.

Tables 6-1 through 6-10 show emissions of criteria air contaminants, ammonia and greenhouse gases allocated to the regions of interest for this study.

Table 6-1: CAC and NH_3 Emissions for Vancouver Island 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	256	125	4,713	2,951	188	2,353	2,321	47	374	2
Manoeuvring	11	1	86	54	3	6	6	0	4	1
Reduced Speed Zone	122	38	2,060	1,290	82	780	769	16	114	27
Underway	420	131	7,096	4,443	284	2,687	2,651	54	394	92
Subtotal	809	295	13,954	8,738	558	5,826	5,747	117	887	122
Harbour Vessels										
workboats and tugboats	480	150	5,769	3,612	231	164	162	3	60	3
charters	7	2	87	55	3	2	2	0	1	0
Subtotal	488	152	5,856	3,667	234	166	164	3	61	3
Ferries										
B.C. Ferries										
Dockside	101	7	1,334	835	53	17	17	0	46	0
Layup	5	0	52	32	2	1	1	0	2	0
Manoeuvring	190	24	520	326	21	19	18	0	4	0
Underway	140	45	1,614	1,010	64	104	102	2	23	0
Coho Ferries	3	1	31	20	1	0	0	0	0	0
Victoria Clipper										
Dockside	1	0	15	9	1	0	0	0	1	0
Manoeuvring	4	0	10	7	0	0	0	0	0	0
Underway	2	1	28	18	1	2	2	0	0	0
Washington State Ferries										
Dockside	3	0	45	28	2	0	0	0	2	0
Manoeuvring	9	1	26	16	1	0	0	0	0	0
Underway	22	7	250	157	10	0	0	0	4	0
Subtotal	480	88	3,925	2,457	157	143	141	3	81	0
Fishing Vessels										
Gillnetters	4	1	46	29	2	1	1	0	1	0
Seiners	6	2	71	45	3	2	2	0	1	0
Trollers	0	0	0	0	0	0	0	0	0	0
Subtotal	10	3	118	74	5	4	4	0	1	0
Recreational Vessels	308	110	14	9	1	0	0	0	7	0
Total	2,095	649	23,867	14,944	954	6,139	6,057	124	1,037	125

Table 6-2: GHG Emissions for Vancouver Island for 2000

	emissions (tonnes/year)			
	CO_2	**CH_4**	**N_2O**	**total, CO_2.equiv**
Ocean Going Vessels				
Dockside	210,449	14.3	18.6	216,503
Manoeuvring	2,096	0.1	0.9	2,375
Reduced Speed Zone	57,699	5.3	1.5	58,284
Underway	198,780	18.4	5.1	200,758
Subtotal	**469,025**	**38.1**	**26.1**	**477,920**
Harbour Vessels				
workboats and tugboats	227,259	21.0	6.0	229,562
charters	3,436	0.3	0.1	3,471
Subtotal	**230,695**	**21.3**	**6.1**	**233,033**
Ferries				
B.C. Ferries				
Dockside	39,060	2.1	14.3	43,546
Layup	1,564	0.1	0.6	1,743
Manoeuvring	21,405	1.2	7.9	23,864
Underway	59,777	3.3	21.9	66,644
Coho Ferries	1,160	0.1	0.4	1,295
Victoria Clipper				
Dockside	429	0.0	0.2	479
Manoeuvring	428	0.0	0.2	478
Underway	1,038	0.1	0.4	1,158
Washington State Ferries				
Dockside	329	0.1	0.6	504
Manoeuvring	535	0.1	0.5	678
Underway	9,268	0.6	4.0	10,505
Subtotal	**134,993**	**7.6**	**50.8**	**150,893**
Fishing Vessels				
Gillnetter	1,697	0.2	0.1	1,716
Seiners	2,614	0.2	0.1	2,644
Trollers	0	0.0	0.0	0
Subtotal	**4,311**	**0.4**	**0.1**	**4,360**
Recreational Vessels	**1,905**	**2.2**	**0.1**	**1,985**
Total	**840,930**	**69.7**	**83.2**	**868,190**

Table 6-3: CAC and NH_3 Emissions for the B.C. Coast (North of Bull Harbour) 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	92	39	1,567	981	63	856	844	17	123	0
Underway	336	105	5,682	3,558	227	2,152	2,123	43	315	74
Subtotal	**428**	**144**	**7,250**	**4,540**	**290**	**3,008**	**2,967**	**61**	**439**	**74**
Harbour Vessels										
workboats and tugboats	199	62	2,394	1,499	96	68	67	1	25	1
charters	23	7	273	171	11	8	8	0	3	0
Subtotal	**222**	**69**	**2,667**	**1,670**	**107**	**76**	**75**	**2**	**28**	**1**
Ferries										
B.C. Ferries										
Dockside	19	1	254	159	10	3	3	0	9	0
Manoeuvring	54	7	147	92	6	5	5	0	1	0
Underway	331	107	3,831	2,399	153	246	243	5	54	0
Layup	0	0	0	0	0	0	0	0	0	0
Subtotal	**404**	**116**	**4,232**	**2,650**	**169**	**255**	**251**	**5**	**64**	**0**
Fishing Vessels										
Gillnetters	13	4	142	89	6	4	4	0	2	0
Seiners	9	3	107	67	4	3	3	0	1	0
Trollers	2	1	25	15	1	1	1	0	0	0
Subtotal	**24**	**8**	**273**	**171**	**11**	**8**	**8**	**0**	**3**	**0**
Recreational Vessels	**965**	**345**	**45**	**28**	**2**	**1**	**1**	**0**	**21**	**0**
Total	**2,044**	**682**	**14,467**	**9,058**	**578**	**3,347**	**3,302**	**67**	**554**	**76**

Table 6-4: GHG Emissions for the B.C. Coast (North of Bull Harbour) for 2000

	emissions (tonnes/year)			
	CO_2	CH_4	N_2O	total, CO_2.equiv
Ocean Going Vessels				
Dockside	70,859	7.4	4.0	72,261
Underway	159,189	14.7	4.1	160,763
Subtotal	230,048	22.1	8.1	233,024
Harbour Vessels				
workboats and tugboats	94,294	8.7	2.5	95,250
charters	10,768	1.0	0.3	10,877
Subtotal	105,063	9.7	2.8	106,127
Ferries				
B.C. Ferries				
Dockside	7,432	0.4	2.7	8,285
Manoeuvring	6,063	0.3	2.2	6,759
Underway	141,908	7.8	52.1	158,208
Subtotal	155,402	8.6	57.0	173,253
Fishing Vessels				
Gillnetter	5,203	0.5	0.2	5,262
Seiners	3,903	0.4	0.1	3,947
Trollers	906	0.1	0.0	917
Subtotal	10,013	0.9	0.3	10,126
Recreational Vessels	5,971	7.0	0.3	6,219
Total	506,497	48.3	68.5	528,749

Table 6-5: CAC and NH_3 Emissions for Whatcom County 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	31	17	615	385	25	279	275	6	49	1
Manoeuvring	7	0	53	33	2	4	4	0	3	1
Reduced Speed Zone	75	24	1,275	798	51	483	476	10	71	17
Underway	36	11	616	386	25	233	230	5	34	8
Subtotal	**150**	**53**	**2,559**	**1,603**	**102**	**999**	**985**	**20**	**157**	**26**
Harbour Vessels										
workboats and tugboats	34	11	405	254	16	12	11	0	4	0
charters	1	0	8	5	0	0	0	0	0	0
Subtotal	**34**	**11**	**413**	**259**	**17**	**12**	**12**	**0**	**4**	**0**
Ferries										
B.C. Ferries										
Dockside	0	0	0	0	0	0	0	0	0	0
Layup	0	0	0	0	0	0	0	0	0	0
Manoeuvring	3	0	7	5	0	0	0	0	0	0
Underway	4	1	46	29	2	3	3	0	1	0
Subtotal	**7**	**2**	**54**	**34**	**2**	**3**	**3**	**0**	**1**	**0**
Fishing Vessels										
Gillnetters	3	1	38	24	2	1	1	0	0	0
Seiners	1	0	12	7	0	0	0	0	0	0
Trollers	0	0	0	0	0	0	0	0	0	0
Trawlers	49	15	553	346	22	17	17	0	6	0
Subtotal	**54**	**17**	**603**	**377**	**24**	**18**	**18**	**0**	**7**	**0**
Recreational Vessels	**1,525**	**537**	**79**	**49**	**3**	**6**	**6**	**0**	**31**	**0**
Total	**1,769**	**619**	**3,708**	**2,322**	**148**	**1,038**	**1,024**	**21**	**200**	**26**

Table 6-6: GHG Emissions for Whatcom County for 2000

	emissions (tonnes/year)			
	CO_2	**CH_4**	**N_2O**	**total, CO_2.equiv**
Ocean Going Vessels				
Dockside	27,121	0.9	3.3	28,147
Manoeuvring	1,298	0.1	0.6	1,470
Reduced Speed Zone	35,718	3.3	0.9	36,080
Underway	17,265	1.6	0.4	17,437
Subtotal	**81,402**	**5.8**	**5.2**	**83,135**
Harbour Vessels				
workboats and tugboats	15,957	1.5	0.4	16,119
charters	320	0.0	0.0	323
Subtotal	**16,277**	**1.5**	**0.4**	**16,442**
Ferries				
B.C. Ferries				
Dockside	0	0.0	0.0	0
Layup	0	0.0	0.0	0
Manoeuvring	298	0.0	0.1	332
Underway	1,715	0.1	0.6	1,912
Subtotal	**2,012**	**0.1**	**0.7**	**2,244**
Fishing Vessels				
Gillnetter	1,394	0.1	0.0	1,410
Seiners	438	0.0	0.0	443
Trollers	0	0.0	0.0	0
Trawlers	20,253	1.8	0.6	20,482
Subtotal	**22,085**	**2.0**	**0.7**	**22,334**
Recreational Vessels	**12,717**	**14.5**	**0.8**	**13,274**
Total	**134,493**	**23.9**	**7.8**	**137,428**

Table 6-7: CAC and NH_3 Emissions for Puget Sound 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	162	100	3,428	2,147	137	1,450	1,431	29	277	4
Manoeuvring	41	2	309	193	12	23	23	0	15	4
Reduced Speed Zone	439	137	7,406	4,638	296	2,804	2,767	56	411	96
Underway	297	93	5,016	3,141	200	1,899	1,874	38	278	65
Subtotal	**938**	**332**	**16,159**	**10,119**	**646**	**6,177**	**6,094**	**124**	**982**	**168**
Harbour Vessels										
workboats and tugboats	658	206	7,898	4,945	316	225	222	5	82	4
charters	4	1	50	31	2	1	1	0	1	0
Subtotal	**661**	**207**	**7,948**	**4,977**	**318**	**226**	**223**	**5**	**83**	**4**
Ferries										
Coho Ferries	3	1	38	24	2	0	0	0	1	0
Victoria Clipper										
Dockside	1	0	19	12	1	0	0	0	1	0
Manoeuvring	5	1	14	9	1	1	1	0	0	0
Underway	16	5	187	117	7	13	13	0	3	0
Washington State Ferries										
Dockside	48	3	631	395	25	0	0	0	26	0
Manoeuvring	166	21	455	285	18	0	0	0	4	0
Underway	348	113	4,025	2,520	161	2	2	0	56	0
Subtotal	**588**	**145**	**5,369**	**3,362**	**215**	**17**	**17**	**0**	**90**	**0**
Fishing Vessels										
Gillnetters	3	1	32	20	1	1	1	0	0	0
Seiners	10	3	116	72	5	4	3	0	1	0
Trollers	0	0	3	2	0	0	0	0	0	0
Trawlers	16	5	179	112	7	5	5	0	2	0
Subtotal	**29**	**9**	**330**	**207**	**13**	**10**	**10**	**0**	**4**	**0**
Recreational Vessels	**9,370**	**3,302**	**486**	**304**	**19**	**34**	**34**	**1**	**191**	**0**
Total	**11,587**	**3,994**	**30,292**	**18,968**	**1,211**	**6,464**	**6,378**	**130**	**1,348**	**173**

Table 6-8: GHG Emissions for Puget Sound for 2000

	emissions (tonnes/year)			
	CO_2	**CH_4**	**N_2O**	**total, CO_2.equiv**
Ocean Going Vessels				
Dockside	149,984	1.1	21.1	156,557
Manoeuvring	7,538	0.4	3.2	8,541
Reduced Speed Zone	207,485	19.2	5.5	209,588
Underway	140,525	13.0	3.7	141,937
Subtotal	**505,532**	**33.8**	**33.5**	**516,623**
Harbour Vessels				
workboats and tugboats	311,148	28.8	8.2	314,300
charters	1,964	0.2	0.1	1,984
Subtotal	**313,112**	**29.0**	**8.3**	**316,284**
Ferries				
Coho Ferries	1,402	0.1	0.5	1,565
Victoria Clipper				
Dockside	568	0.0	0.2	633
Manoeuvring	569	0.0	0.2	634
Underway	6,940	0.4	2.5	7,737
Washington State Ferries				
Dockside	4,621	1.2	7.9	7,089
Manoeuvring	9,363	1.2	8.0	11,865
Underway	149,109	9.5	63.6	169,025
Subtotal	**172,572**	**12.4**	**83.0**	**198,549**
Fishing Vessels				
Gillnetter	1,180	0.1	0.0	1,193
Seiners	4,233	0.4	0.1	4,281
Trollers	127	0.0	0.0	129
Trawlers	6,554	0.6	0.2	6,628
Subtotal	**12,095**	**1.1**	**0.4**	**12,232**
Recreational Vessels	**78,133**	**89.0**	**5.0**	**81,553**
Total	**1,081,445**	**165.3**	**130.1**	**1,125,241**

Table 6-9: CAC and NH_3 Emissions for the Washington Coast 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										
Underway	68	21	1,143	716	46	433	427	9	63	15
Subtotal	**68**	**21**	**1,143**	**716**	**46**	**433**	**427**	**9**	**63**	**15**
Harbour Vessels										
workboats and tugboats	215	67	2,577	1,613	103	73	72	1	27	1
charters	6	2	86	54	3	2	2	0	1	0
Subtotal	**221**	**69**	**2,662**	**1,667**	**106**	**76**	**75**	**2**	**28**	**1**
Fishing Vessels										
Gillnetters	0	0	0	0	0	0	0	0	0	0
Seiners	1	0	9	5	0	0	0	0	0	0
Trollers	2	1	26	16	1	1	1	0	0	0
Trawlers	32	10	361	226	14	11	11	0	4	0
Subtotal	**52**	**16**	**588**	**368**	**23**	**18**	**18**	**0**	**7**	**0**
Recreational Vessels	**15,897**	**5,602**	**824**	**516**	**33**	**58**	**57**	**1**	**323**	**0**
Total	**16,238**	**5,708**	**5,217**	**3,267**	**209**	**585**	**577**	**12**	**421**	**17**

Table 6-10: GHG Emissions for the Washington Coast for 2000

	emissions (tonnes/year)			
	CO_2	CH_4	N_2O	total, CO_2-equiv
Ocean Going Vessels				
Underway	32,026	3.0	0.8	32,345
Subtotal	**32,026**	**3.0**	**0.8**	**32,345**
Harbour Vessels				
workboats and tugboats	101,512	9.4	2.7	102,540
charters	3,376	0.3	0.1	3,410
Subtotal	**104,887**	**9.7**	**2.8**	**105,950**
Fishing Vessels				
Gillnetter	7	0	0	7
Seiners	321	0	0	325
Trollers	954	0.1	0	965
Trawlers	13,234	1.2	0.4	13,383
Subtotal	**14,516**	**1.3**	**0.4**	**14,680**
Recreational Vessels	**132,559**	**151.0**	**8.5**	**138,361**
Total	**283,988**	**165.0**	**12.5**	**291,336**

6.2 DOMESTIC AND INTERNATIONAL GREENHOUSE GAS EMISSIONS

Table 6-11 shows the split of total greenhouse gas emissions for the Expanded Area into "domestic" and "international" emissions. 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. For Washington State ports, movements staying within Washington State, although domestic to the U.S., are deemed international for the purposes of this study, i.e., Canadian domestic GHG emissions are quantified, not US domestic
- 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 – routes travelling in BC only are considered domestic, routes travelling in Washington only are international, and emissions for routes travelling back and forth between BC and Washington are split into domestic (Canadian) and international segments
- Fishing – it was assumed that all Washington registered boats are US (and therefore international) emissions and all BC registered boats are Canadian (i.e., domestic) emissions
- Recreational – similar to fishing, emissions were allocated as domestic or international based on the country of origin.

Table 6-11: Domestic and International GHG Emissions for the Expanded Area, 2000

	emissions (tonnes/year)			
	CO_2	**CH_4**	**N_2O**	**total, CO_2.equiv**
Domestic				
Ocean-Going Vessels	509,992	49.3	19.2	516,994
Harbour Vessels	294,667	27.2	7.8	297,653
Ferries	279,220	15.4	102.4	311,294
Fishing Vessels	14,324	1.3	0.4	14,486
Recreational Vessels	7,877	9.3	0.4	8,204
Subtotal	**1,106,080**	**102.5**	**130.3**	**1,148,630**
International				
Ocean-Going Vessels	808,041	53.4	54.5	826,052
Harbour Vessels	475,363	44.0	12.6	480,180
Ferries	185,760	13.4	89.0	213,645
Fishing Vessels	48,696	4.4	1.5	49,246
Recreational Vessels	223,410	254.6	14.3	233,187
Subtotal	**1,741,269**	**369.7**	**171.9**	**1,802,310**
Total	**2,847,349**	**472.3**	**302.2**	**2,950,941**

6.3 GRIDDED EMISSIONS

Due to the fine resolution of the 1 kilometre gridding required for this study, as well as the wide geographic scope of the expanded study area, the spatial allocation of emissions has been facilitated by the use of a G.I.S (Geographic Information System) program developed using ArcInfo. Base maps encompassing the study area were obtained and a grid system overlain with a 1km by 1km grid system corresponding to the coordinates in the Lambert conic projection. The system allows the estimation of water coverage for the entire area of study based, and the location of shipping lanes, ferry routes, ports, fisheries management areas, ferry terminals, etc. To allow for variation in ship movements from standard routes each route was approximated using a series of 1 km by 1 km grid squares, rather than a linear route of a fixed width.

Figure 6-1 shows an example of the plotting of routes within the GIS system, for ferries.

6.3.1 Ocean-going Vessels

Emissions from ocean-going vessels are divided into dockside and underway emissions for B.C., and cruise, reduced speed, manoeuvring and hotelling for Washington. Using the GIS system, major ports in the study area and typical routes for each vessel type were plotted.

For the B.C. portion, dockside emissions were divided between all ports equally where a port was represented by a 1 km by 1 km grid square.

For the U.S. portion of the study area, the same apportioning method was followed for underway and dockside emissions while manoeuvring and reduced speed emissions were spread over grid cells within 5 kilometers of a port.

6.3.2 Harbour Vessels

In both the expanded area in B.C. and in Washington state, emissions for workboats were spread over high traffic areas using the ocean-going vessel routes as a basis. Emissions from charter boats in each of the two major areas were divided between all grid cells which contained water, according to the percentage of water in a particular grid cell.

6.3.3 Ferries

The spatial distribution of emissions for ferries was developed by plotting each ferry route within the grid system, which was used to allocate underway emissions. Dockside emissions were allocated to ferry terminals (which were plotted as a 1 km grid square), while manoeuvring emissions were distributed to grid cells within 5 kilometres of a terminal.

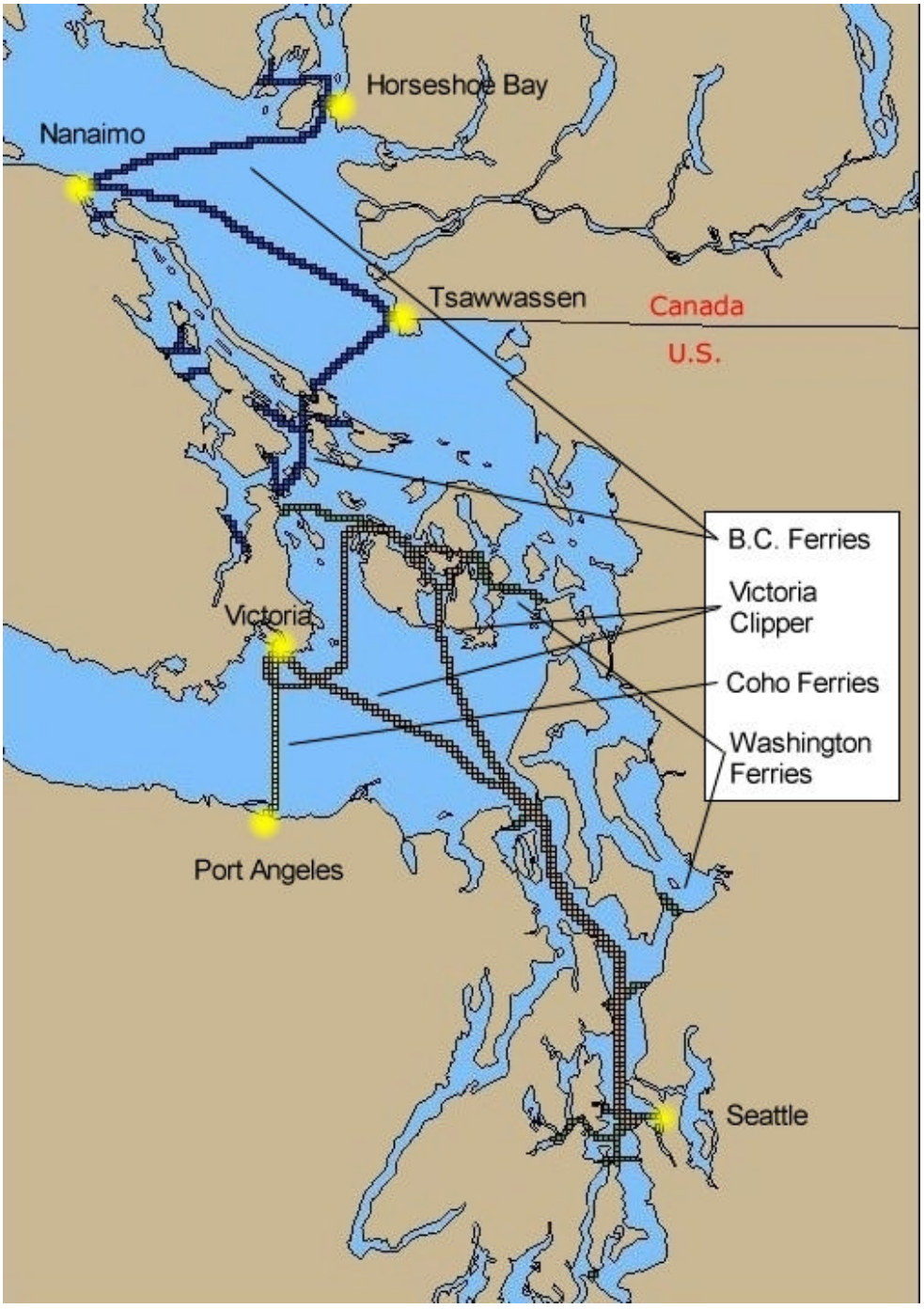
6.3.4 Fishing Vessels

As the major fishing areas both in B.C. and Washington state are clearly defined by management areas, the emissions calculated for a particular area were spread evenly for these defined areas. In some cases, where the base data was provided for a particular management area (such as area 1) the emissions allocation may be more accurate than in other cases where several management areas were aggregated due to the lack of area-specific data on the number of boat-days (e.g. areas 121-127).

6.3.5 Recreational Vessels

Since recreational vessels do not follow defined routes, emissions were distributed evenly to water areas within the study boundaries.

Figure 6-1: Ferry Routes Plotted in 1 km by 1km Grid System



7. TEMPORAL ALLOCATION OF EMISSIONS

7.1 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. The data for Washington state's ocean-going vessels only included the number of portcalls, but no information regarding time of each trip. As a result the hourly, daily, and monthly profiles for Canadian ocean-going vessels were assumed to be similar and thus applied to the U.S. counterparts.

7.2 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 were evenly distributed over the entire year. Charterboats 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.

7.3 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 for BC Ferries, from which the daily and hourly profiles were developed on an incremental basis using sailing schedules.

7.4 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.

7.5 RECREATIONAL VESSELS

Temporal profiles used in the Core Area were adopted for the Canadian portion of the Expanded Area. Monthly and daily temporal profiles for recreational vessels in Washington State were available and were applied to the U.S. portion of the Expanded Area. The same hourly profile has been adopted for the both the Canadian and U.S. portion of the Expanded Area.

7.6 RESULTS OF TEMPORAL ALLOCATION

Figures 7-1 through 7-3 illustrate 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.

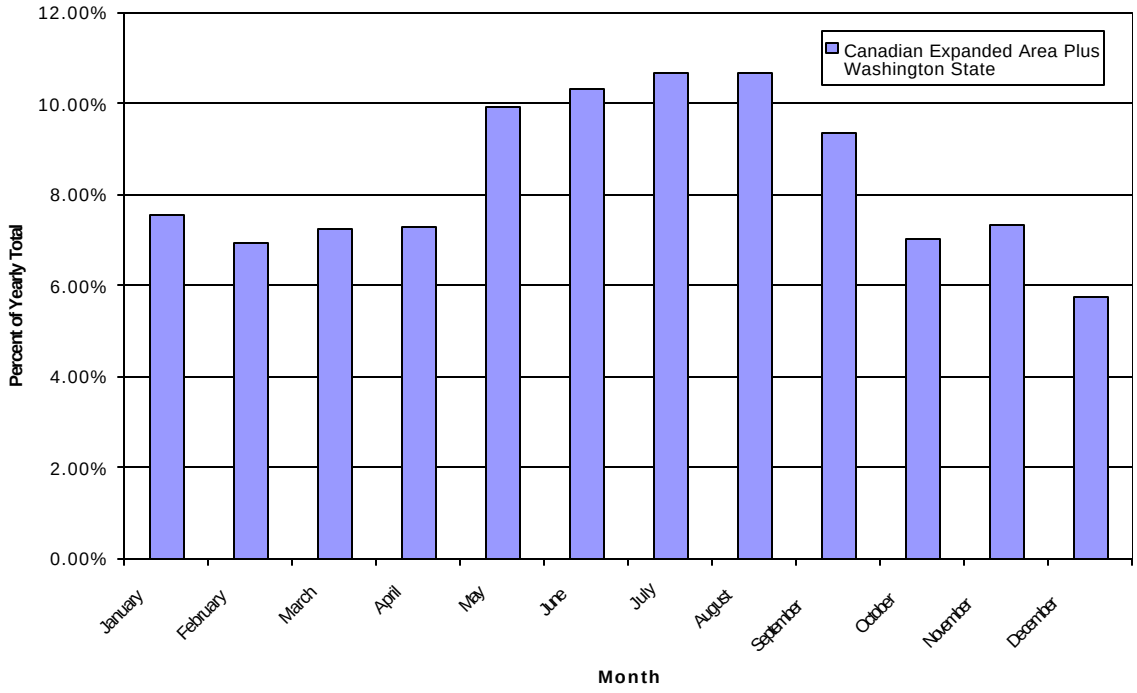


Figure 7-1: Monthly Emission Distribution for Ocean-going Vessels

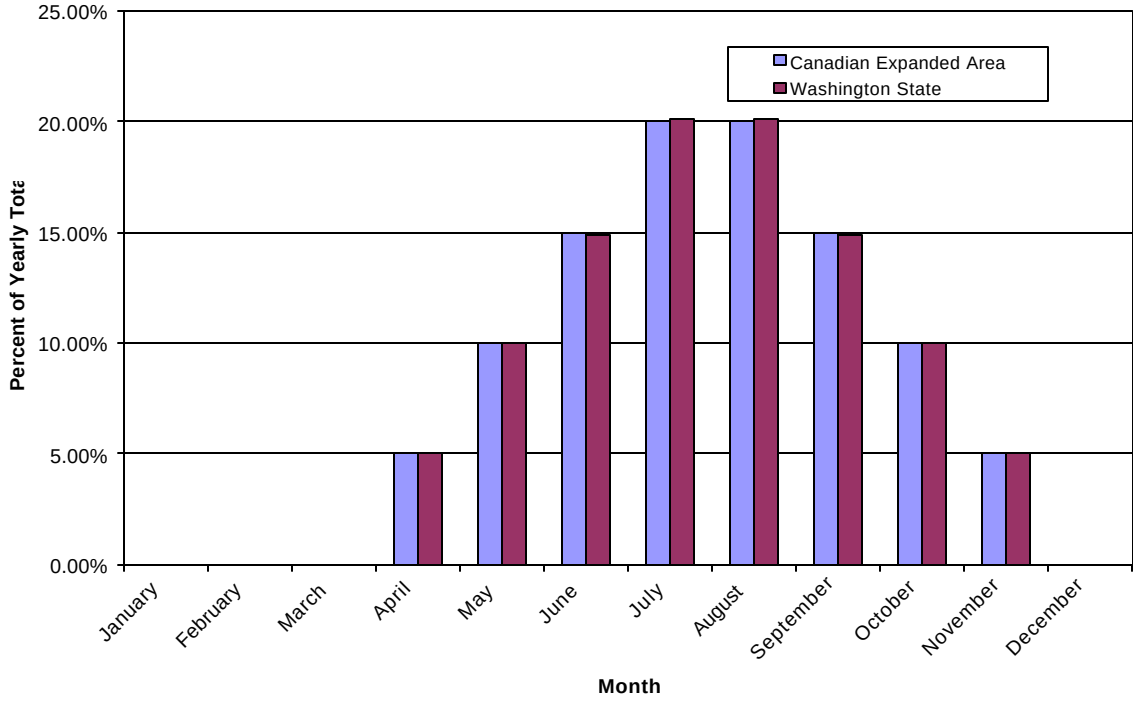


Figure 7-2: Monthly Emission Distribution for Fishing Vessels

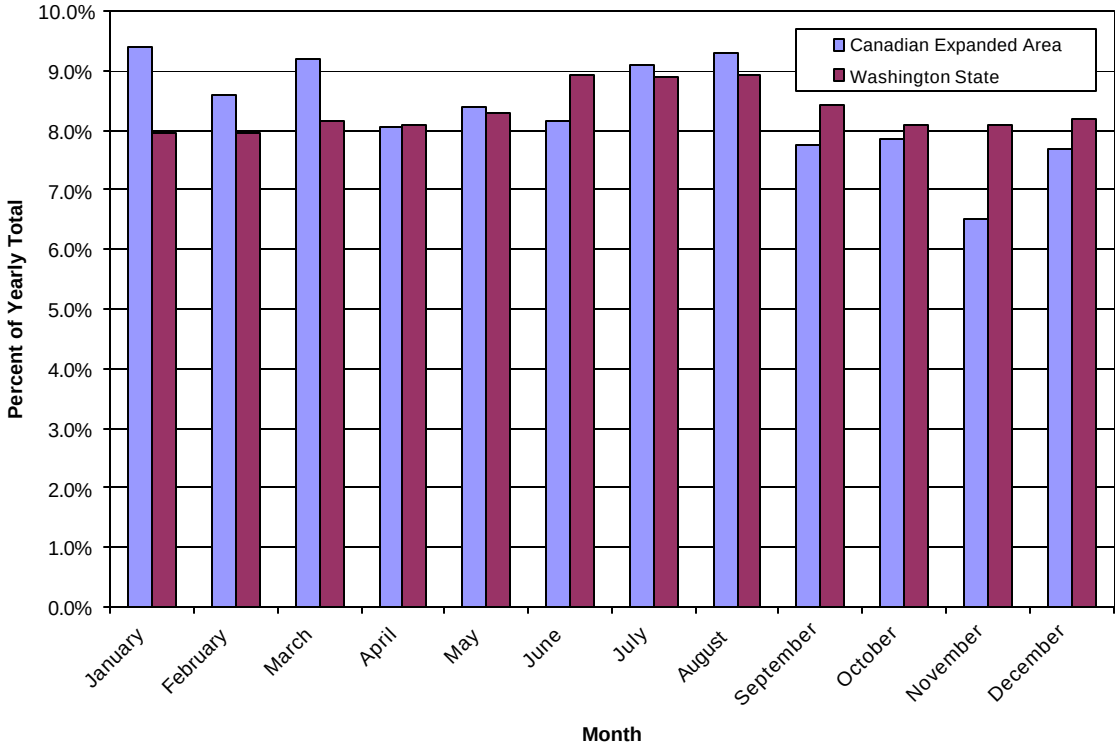


Figure 7-3: Monthly Emission Distribution for Ferries

8. CONCLUSIONS AND RECOMMENDATIONS

A previous marine vessel emission inventory study has been completed for the "Core Area" for 1993 (Levelton, 1995), which provides a basis for comparison of the 1993 and 2000 results for the Lower Fraser Valley. In terms of the Expanded Area, marine vessel emissions have been quantified for B.C. outside of the Lower Fraser Valley (B.C. Ministry of Environment, Lands and Parks, 1999), and in the series of studies prepared by or for the Washington State Department of Ecology, listed in Section 3 of this report.

The provincial 1995 inventory followed similar methodologies to those used for the 1993 LFV report, with emission estimates based on fuel consumption data obtained from various operating agencies, or data contained in industry directories. A comparison of the 1995 and 2000 emission estimates is shown in Table 8-1 below, with comments on the differences in methodology and results discussed by vessel type below.

As discussed in Section 3, a range of different data sources and methodologies were used for the previous Washington State inventories, and in general, the coverage of vessel types has been inconsistent. A meaningful comparison cannot be made between the previous estimates and the ones presented in this report.

Table 8-1: Comparison of 1995 and 2000 Marine Vessel Inventory for B.C. (outside LFV)

	emissions (tonnes/year)[1]									
	CO		**VOC**		**NOx**		**SOx**		**PM**	
	1995	**2000**	**1995**	**2000**	**1995**	**2000**	**1995**	**2000**	**1995**	**2000**
ocean-going vessels										
underway[2]	3,541	890	1,148	275	41,630	14,923	19,379	5,624	2,201	828
dockside	642	348	1,115	164	3,975	6,280	495	3,209	237	497
subtotal	4,183	1,238	2,263	439	45,604	21,204	19,875	8,833	2,438	1,325
harbour vessels										
workboats and tugboats	952	680	244	212	3,616	8,162	396	232	180	85
charter	22	30	15	9	118	361	13	10	6	4
subtotal	973	710	259	222	3,733	8,523	410	242	186	89
ferries	674	884	245	204	5,191	8,156	703	398	218	144
fishing vessels	41	35	45	11	339	391	32	12	15	4
recreational vessels	3,298	1,272	1,073	455	54	60	7.2	1.3	1.4	28
Total	9,169	4,139	3,885	1,331	54,921	38,333	21,027	9,486	2,859	1,591

Notes: [1] Totals may not add up due to rounding

[2] For the 2000 data shown, underway emissions include both underway and manoeuvring; for 1995, manoeuvring emissions were not quantified

8.1 OCEAN-GOING VESSELS

Canadian Portion

For the 1995 inventory prepared by MWLAP, emission estimates were based primarily on fuel consumption estimates for commercial vessels, by average fuel consumption by vessel class and average distance travelled.

For the current study, data on ocean-going vessel movements was obtained from the Pacific Pilotage Authority. More recent correlations (U.S. EPA, 2000) estimating horsepower as a function of either DWT alone, or in combination with speed, were used. This provides an estimate of horsepower rating, and for eight different ship types, compared to only three in the previous work. In addition, the EPA correlations use the DWT of the ship directly, rather than the three generic vessel classes 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 1995 method, which required the estimation of fuel consumption, again by generic weight class and for a limited number of ship types.

For the 1995 inventory, dockside fuel consumption was estimated based on an assumed fuel consumption rate and the number of days spent at dockside. For this study, 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.

US Portion

Emissions from US ocean-going vessels were calculated using the number of port calls and vessel speeds for various vessel types and dead weight categories from the EPA's Commercial Marine Activity for deep Sea Ports report for 1996. Data for the year 2000 was extrapolated from data collected by US Army Corps of Engineers (US ACE) in 1996 and 2000. The accuracy of this is dependent on the assumption that growth/decline in activity and emissions is equivalent across all types and sizes of vessels, which may not necessarily be valid. Further as the total port calls for all vessels is compared and ratioed with the total port calls to all locations, it is plausible that major decreases or increases in vessel movements could occur at some port locations misleading the spatial distribution of emissions. Obviously it would be better to have more current and/or more detailed data.

Further the data reported by the EPA shows only the number of port calls per type and dead weight class of vessel, without providing any information on the date or time of the vessel movement. In the absence of temporal data from the EPA report, the temporal profiles used for Canadian ocean-going vessels has been assumed to provide a reasonable approximation here.

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, although limited, provided excellent data and future surveys could be conducted in a similar manner.

8.2 HARBOUR VESSELS

The Westcoast Mariner Workboat Directory and Charterboat Directory were used for the 1993 LFV marine vessel inventory to generate listings of companies operating tugboats, workboats and charter vessels. The 2000 study used the Annual Pacific Coast Tug and Workboat Directory for the Canadian portion. For the US portion, a report to congress on private sector tugboats, with additions for patrol and fire boats as found for units within the study counties, was used.

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, despite several contacts with the Council of Marine Carriers, and two major tug operators, data on fuel consumption was not available. Thus 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 LFV inventory, due to the assistance of the Council of Marine Carriers who circulated a memo to their members. This type of 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 different spatial regions by harbour vessels. Better information on where harbour vessels operate, and for what duration, could be obtained through company surveys.

8.3 FERRIES

The 1995 study for B.C. used data on fuel consumption by route, provided by BC Ferries. However, that fuel consumption was not broken down into dockside and underway fuel use. The 2000 methodology and estimates for BC Ferries represent an improvement over 1995, 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 manoeuvring emissions for the year 2000. The same assumptions regarding dockside, underway, and manoeuvring have been applied to Washington State ferries.

Data for temporal resolution has been based in part on current ferry schedules, with the assumption that the 2000 schedules were similar to present day operation.

Recommendations

- BC Ferries provided total fuel consumption data, by ferry and by route, along with their own estimates of emissions. Washington State Ferries provided fuel consumption data. 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 and Washington State Ferries which would allow a better estimate of the quantity or duration of fuel consumption in each load category, as well as the specific operating characteristics.

- Better information on the use of auxiliary generators on the ferries fleets, and the associated fuel consumption, could be requested.

8.4 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.

Significant data gaps exist for certain Canadian fisheries management areas in the Expanded Area. A lack of information from DFO for certain areas required the use of several assumptions about the fishing fleet, regarding the variation in fishing from year to year for different management areas based on the type of vessel (seiner, troller, gillnetter); and that fishing activity in the coastal area of Vancouver Island is similar to the coast of the Queen Charlotte Islands.

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.

8.5 RECREATIONAL VESSELS

Compared to previous Canadian inventories, 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 statistical agencies. A wide range was found. Better fuel consumption estimates could be obtained from fuel suppliers in the study area. This may be complicated by the fact that recreational vessels may purchase fuel at motor vehicle service stations or marine stations, however data from marine sales would help to validate some of the assumptions made.

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APPENDIX A: 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.