Emissions Estimation Technique Manual

for

Aggregated Emissions from Commercial Ships/Boats and Recreational Boats - Version 1.0

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Disclaimer

The Manual was prepared in conjunction with Australian States and Territories according to the National Environment Protection (National Pollutant Inventory) Measure.

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Erratum for the NPI Commercial Ships/Boats and Recreational Boats Aggregated Emissions Data Manual (Version 1.0 – 1 Nov 1999).

Page	Outline of alteration
	No changes to the Manual

**EMISSIONS ESTIMATION TECHNIQUE MANUAL:
AGGREGATED EMISSIONS FROM COMMERCIAL SHIPS/BOATS AND RECREATIONAL BOATS**

TABLE OF CONTENTS

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LIST OF TABLES AND FIGURES

1.0 Introduction

1.1 The NPI

The National Pollutant Inventory (NPI) was established under a National Environment Protection Measure (NEPM) made by the National Environment Protection Council (NEPC) under Commonwealth, State and Territory legislation on 27 February 1998. This Measure is to be implemented progressively through the laws and administrative arrangements of each of these participating jurisdictions (i.e. State and Territory Governments).

The NEPM and an associated Memorandum of Understanding for the NPI, which have been published as a single document by the NEPC, provide more details on the purpose and structure of the NPI, and the arrangements for implementation of the NEPM that have been agreed by the jurisdictions. Users of this Manual should read this publication if they are unfamiliar with the NEPM or the NPI.

1.2 Purpose and Scope of the Manual

The NPI will be developed as an internet database designed to provide information on the types and amounts of certain chemical substances being emitted to the air, land and water environments. If the NPI is to achieve its aim of communicating useful and reliable information to the community, industry and governments on pollutants present in our environment, the emissions estimation techniques (EETs) used to generate inputs to the NPI need to be consistent, and the process for developing these techniques needs to be transparent. This Manual has been developed, reviewed and finalised in this context.

The NEPM contains a list of substances for which emissions will be reported on an annual basis to the Commonwealth Government, which will then compile and publish the NPI. The aggregated emissions manuals, of which this is one, have been prepared to assist State and Territory Governments in preparing these submissions, and to facilitate consistent reporting between these jurisdictions.

State and Territory Governments will also be compiling and submitting emissions data based on annual inputs from reporting facilities. These facilities are primarily industrial enterprises which use (or handle, manufacture or process) more than specified amounts of certain polluting substances, burn more than specified amounts of fuel, or consume more than certain amounts of energy. These amounts or "thresholds" (which are clearly defined in the NEPM) govern whether an industrial facility is required to report and what substances it is required to report on, and industry handbooks are being developed to help industries to prepare the information for these reports.

The aggregated emissions manuals complement these handbooks, and are intended to enable Governments to estimate emissions from non-industrial activities (e.g. transportation, domestic and commercial activities) and emissions from industry which are not reported because the relevant thresholds are not exceeded or are exempt from reporting.

Annual submissions are also to be prepared and submitted in conformance with the NPI Data Model and Data Transfer Protocol. For emissions to the air environment, this Protocol only requires jurisdictions to submit data on emissions into the particular airsheds that are listed in the Protocol, and not to the rest of each jurisdictional area. For example, under the 1998 to 2000 Memorandum of Understanding, in Victoria, emissions data are only required for the Port Phillip and Latrobe Valley Regions. In addition, emissions data are required to be submitted on a gridded basis, with each jurisdiction determining a grid domain and grid cell size necessary to meet its obligations under Section 7 of the NEPM.

Therefore, in addition to recommending and providing details and examples of appropriate emissions estimation techniques (EETs) for the relevant NPI substances, this Manual provides guidance on the spatial allocation of emissions and the use of area-based surrogates for accurately distributing the activities or sources in question.

1.3 Application of the Manual

Each of the aggregated emissions manuals provides details of:

- the NPI substances that are expected to be emitted from the relevant aggregated source type;
- the origins or sources of the emissions, and the processes that may generate them;
- the impacts of any control equipment or procedures on those emissions;
- the broad approaches that may be employed in the estimation and spatial allocation of emissions;
- details of emission factors to be used in the estimation of emissions; and
- a series of illustrative sample calculations for each estimation technique.

Each of the manuals also contains a section on “Uncertainty Analysis”, which provides information and guidance to users on the reliability of the various estimation techniques, problems and issues associated with their development and application, and recommendations for their improvement. In preparing the aggregated emissions manuals it has been recognised that some jurisdictions already undertake detailed emissions inventories on a regular basis, based on relatively sophisticated methodologies. For these jurisdictions the manuals offer techniques which represent commonly available best practice for emissions estimation in Australia (i.e. techniques of high quality which can be employed by larger or more experienced jurisdictions with an acceptable expenditure of time and effort). The most recent developments in inventory methodology in Australia and overseas have been considered in selecting and documenting these techniques.

Where a more simplified methodology for emissions estimation of acceptable quality is available, it is recommended in the manual for the use of those jurisdictions which may, for the time being at least, lack the data, resources or expertise to employ a more sophisticated approach, or not see the need for highly reliable estimates in that particular part of the inventory.

2.0 Emissions Covered by the Manual

This manual covers emissions from commercial ships, commercial boats and recreational boats. Commercial ships include cargo ships, passenger ships, chemical tankers, colliers and naval ships. Commercial boats include fishing boats, tug boats, work boats, passenger and cargo boats, and other small commercial utility craft. Recreational boats are boats used for cruising, water skiing, sport fishing and other recreational activities. These include inboard/ outboard boats, jet-powered craft and sailboats when they use auxiliary power.

2.1 NPI Substances

Table 1 lists the NPI substances that are typically emitted from commercial ships, commercial boats and recreational boats.

Table 1: NPI Substances Emitted from Commercial Ships, Commercial Boats and Recreational Boats [a]

Acetaldehyde	n-Hexane
Antimony and compounds	Lead and compounds
Arsenic and compounds	Mercury and compounds
Benzene	Nickel and compounds
Beryllium and compounds	Oxides of nitrogen
1,3-Butadiene	Particulate matter $\leq$ 10 μm (PM10)
Cadmium and compounds	Polycyclic aromatic hydrocarbons
Carbon monoxide	Selenium and compounds
Cyclohexane	Styrene
Chromium (III) compounds	Sulphur dioxide
Chromium (VI) compounds	Toluene
Cobalt and compounds	Total volatile organic compounds (VOCs)
Copper and compounds	Xylenes
Ethylbenzene	Zinc and compounds
Formaldehyde	

[a] Paragraph 2 (e) of Schedule A to the NEPM requires that, for the purposes of emissions estimation, a substance listed in Tables 1 and 2 of that Schedule as " (a metal) and a compound" refers only to the amount of metal that may be emitted. The EETs described in this manual have been prepared accordingly. Thus, the emission factors for metals and their compounds relate only to the amount of the metal itself that may be emitted as a part of these compounds.

2.2 Emission Sources and Related Processes

2.2.1 Commercial Ships

Commercial ships are driven primarily by large slow-speed and medium-speed diesel engines, and occasionally by steam turbines and gas turbines (the latter in high power-to-weight ratio vessels such as fast ferries and warships). The number of vessels equipped with steam or gas-turbine propulsion is small, however, since they are unable to compete with more efficient diesel engines in most applications. Because of their limited usage, steam and gas turbine powered ships are not considered in this manual.

Commercial ships may emit air pollutants under two major modes of operation: while underway, and at berth (under auxiliary power). Emissions underway come from a ship's engine exhaust and are influenced by a great variety of factors including engine size, the fuel used (residual oil or diesel oil), operating speed and load.

A ship continues its emissions at berth. Power must be made available for the ship's lighting, heating, pumps, refrigeration, ventilation and so on. Ships normally use diesel-powered generators to furnish auxiliary power. Emissions from these generators may also be a source of underway emissions if they are used away from port.

In addition to engine exhaust emissions, there are fugitive emissions from the loading and ballasting of petroleum tankers in port. During fuel loading and the taking on of ballast, vapour within tankers is vented to atmosphere.

Ballasting operations are a major source of evaporative emissions associated with the unloading of petroleum liquids at marine terminals. It is common practice to load several cargo tank compartments with seawater after the cargo has been unloaded. This water, termed "ballast", improves the stability of the empty tanker during the subsequent voyage. Ballasting emissions occur as vapour-laden air in the empty cargo tank is displaced to the atmosphere by ballast water being pumped into the tank. Emissions from ballast operations may occur at dock or at some distance out to sea. The reason for taking on ballast at sea is because of quarantine concerns over the transport of marine life rather than air pollution issues. Little ballast is taken on at dockside, as it is only necessary for trimming the ship when partial cargoes are unloaded.

The loading and unloading of certain cargoes (e.g. grain) may release particulate matter into the immediate area if conveyor belts are not enclosed. The operation of shipboard incinerators is another emission source for some large ships, with the nature of the substances emitted varying with the matter burnt. These two sources of emissions are relatively small in relation to fuel-related emissions, and are not considered further in this manual.

2.2.2 Commercial Boats and Recreational Boats

Emissions from commercial and recreational boats arise from boat engines while the boats are travelling. Engines are usually shut down while at berth.

While both inboard and outboard engines are used in commercial boats, most recreational boats use outboard engines. All outboard engines use petrol and most inboard engines use diesel as the fuel. Some outboards have underwater exhausts, however only emissions to air are considered in this manual.

2.3 Emission Controls

There are normally no particular controls on exhaust emissions from commercial ships, commercial boats and recreational boats.

Loading of petroleum liquids into marine tankers is usually carried out by a method called submerged loading. In submerged loading, the fill pipe opening is below the liquid surface (as opposed to splash loading in which the fill pipe opening is above the liquid surface). Liquid turbulence is controlled significantly during submerged loading, which results in much lower vapour generation.

3.0 Emissions Estimation Techniques

Emissions estimation techniques for commercial ships are discussed separately from those for commercial boats and recreational boats due to major differences in related activities, emission rates and spatial distributions.

3.1 Approaches Employed

3.1.1 Commercial Ships

<u>Exhaust Emissions</u>

The data required for estimating commercial ship exhaust emissions are:

- the location of ports in the relevant airshed;
- the number of ships visiting a port in a particular year in the following tonnage ranges: less than 1 000, 1 000 to 5 000, 5 000 to 10 000, 10 000 to 50 000, and over 50 000 tonnes;
- the average number of hours at berth;
- the average speed of ships in shipping channels; and
- the locations and lengths of shipping channels in the airshed.

The above information should be available from the relevant port authority, and waterway/channel authority. Some bookshops sell charts of shipping channels.

If data on the average number of hours at berth and the average speed of ships in shipping channels cannot be obtained, the default values listed in Table 2 can be used.

Table 2: Average Activity Data for Commercial Ships

Activity	Average Value
Time at berth	48 hr
Speed in channel	27 km hr^{-1} [a]
Deadweight tonnage of tankers	30 000 tonne [b]
Proportion of ballast emissions at berth	0.05 [c]

[a] P. Hinksman, Victorian Channel Authority (March 1997), pers. comm.
[b] D. Ross, Melbourne Port Corporation (March 1997), pers. comm.
[c] EPAV (1996a).

Emissions from commercial ships may be estimated by multiplying the number of hours spent at berth and in shipping channels by the relevant time-based emission factors (see Equations 1 and 2).

There are emission factors for main engines and auxiliary engines (Table 4) which vary for different tonnage ranges. When estimating emissions in channels, it is assumed that both main and auxiliary engines are operating.

Equation 1: Estimating exhaust emissions from commercial ships at berth

$$E_b = t_b * \sum_i (n_i * a_i)$$

where

E_b	=	Annual emissions at berth from commercial ships, kg yr^{-1}
t_b	=	Average time of ships at berth, hr
n_i	=	Number of commercial ships visiting the port each year in the tonnage range i, yr^{-1}
a_i	=	Emission factor for auxiliary engines for ships in the tonnage range i, kg hr^{-1}

Equation 2: Estimating exhaust emissions from commercial ships in a channel

$$E_c = \frac{d_c}{v_c} * \sum_i \{n_i * (m_i + a_i)\}$$

where

E_c	=	Annual emissions from commercial ships in a channel, kg yr^{-1}
d_c	=	Length of the channel in the airshed, km
v_c	=	Average speed of ships in the channel, km hr^{-1}
n_i	=	Number of commercial ships visiting the port each year in the tonnage range i, yr^{-1}
m_i	=	Emission factor for main engines for ships in the tonnage range i, kg hr^{-1}
a_i	=	Emission factor for auxiliary engines for ships in the tonnage range i, kg hr^{-1}

Emissions of some organic compounds may be estimated from speciation of total VOC emissions, and emissions of metals, PAHs and PM10 may be calculated from speciation of TSP emissions (see Equations 3 and 4).

For VOC species, the profile for diesel exhaust (see Table 9) should be used for commercial ships.

For particulate species, the profile for gas oil should be used for ships below 10 000 tonnes, and the profile for fuel oil should be used for ships equal to or greater than 10 000 tonnes (see Table 10).

Equation 3: Estimating emissions of a VOC species

Emissions of a VOC species can be calculated by multiplying the total VOC emissions by the speciated weight fraction for that species

$$E_j = E_{voc} * w_i$$

where

E_j = Emissions of VOC species i, kg yr^{-1}
E_{voc} = VOC emissions, kg yr^{-1}
w_i = Weight fraction of VOC species i

Equation 4: Estimating emissions of a particulate species

Emissions of a particulate species can be calculated by multiplying TSP emissions by the speciated weight fraction for that species

$$E_j = E_{TSP} * w_i$$

where

E_j = Emissions of TSP species i, kg yr^{-1}
E_{TSP} = TSP emissions, kg yr^{-1}
w_i = Weight fraction of TSP species i

Loading and Ballasting Emissions

The following data are required for estimating loading and ballasting emissions:

- the volume of petrol or petroleum liquid loaded at port;
- the number of tankers for which the following types of activities take place - loading, unloading, and both;
- the average deadweight tonnage (DWT) of tankers; and
- the proportion of ballast emissions at berth.

The volume of petrol or petroleum liquid loaded at port should be available from oil companies, while the other information can be sought from the port authority. If the average DWT and proportion of ballast emissions at berth cannot be obtained, the default values listed in Table 2 can be used.

Most petroleum liquids consumed in Australia are petrol and diesel (ABARE 1999) and, since diesel is relatively non-volatile, only petrol needs to be considered in estimating loading emissions. The proportion of petrol loaded can be requested from oil companies or estimated from ABARE (1999), based on petroleum product consumption in a jurisdiction. Since nearly all of the fuel imported into Australia is crude oil, only crude oil is considered in estimating ballasting emissions.

Loading emissions may be estimated by multiplying the volume of petrol loaded with relevant emission factors (see Equation 5 and Table 5).

Ballasting emissions are estimated by multiplying the throughput of ballast with an emission factor. The amount of ballast used for a tanker can be estimated from the type of loading activity and DWT of the tanker, using the data in Table 3. Equation 6 shows how ballasting emissions are estimated. The emission factor is given in Table 5. Ballasting emissions that do not occur at berth are assumed to happen far offshore (e.g. 60 km) and are not usually assigned to an airshed.

Table 3: Ballast Throughput Factor for Different Types of Loading Activity

Loading Activity	Ballast Throughput per DWT [a] (L $tonne^{-1}$)
Loading	28.53
Unloading	3.211
Both	5.544

[a] EPAV (1996b).

Equation 5: Estimating loading emissions from ships

$$E_l = V * e_l$$

where

E_l = Annual loading emissions at berth, kg yr^{-1}
V = Annual volume of petrol loaded at port, 10^6 L yr^{-1}
e_l = Loading emission factor, mg L^{-1}

Equation 6: Estimating ballasting emissions from tankers

$$E_b = p * w * e_b * 10^{-6} * \sum_i (n_i * v_i)$$

where

E_b = Annual ballasting emissions at berth, kg yr^{-1}
p = Proportion of ballasting emissions at berth
w = Average DWT of tankers, tonne
e_b = Ballasting emission factor, mg L^{-1}
n_i = Number of loading activities of type i (loading, unloading or both) in the year, yr^{-1}
v_i = Ballast throughput factor for loading activity i, L $tonne^{-1}$

Equation 3 can also be used to speciate loading and ballasting emissions. The profiles for petrol and crude oil evaporative emissions in Table 9 should be used for speciating loading and ballasting emissions respectively.

It has been assumed that petrol is the representative fuel for loading activities, and crude oil for ballasting operations. More detailed emission factors can be used (USEPA 1995) if data on the type of petroleum liquid, compartment depth, tank condition and volatility of previous cargo are available.

3.1.2 Commercial Boats

Emissions from commercial boats depend on their fuel consumption. However, marine authorities do not usually keep records of fuel consumption for commercial boats (usually only their registration details). ABARE has figures for diesel consumption in domestic water transport, but not for petrol. The methodology adopted in this manual makes use of both sources of information to estimate fuel consumption by commercial boats.

The data required for estimating emissions from commercial boats are:

- annual registration of commercial boats by engine type (i.e. inboard and outboard) in an airshed;
- the annual fuel consumption in domestic water transport for a jurisdiction;
- the proportion of commercial boats used in the airshed; and
- the proportion of leaded and unleaded petrol used in the airshed (or jurisdiction); and
- the areas where commercial boats carry out their activities.

ABARE (1999) does not publish data separately for domestic and international water transport and the data has to be requested directly from ABARE. Since most commercial ships are international and most recreational boats use petrol, it is reasonable to assume that the reported consumption for automotive diesel oil (ADO) in domestic water transport is all consumed by inboard (assuming all diesel-powered) commercial boats.

Assuming inboard and outboard commercial boats have similar fuel consumption per boat, the fuel consumed by outboard (petrol-powered) commercial boats can be estimated by multiplying together the ratio of outboard and inboard registrations and the fuel consumption estimated above for inboard commercial boats. Since the consumption rates for petrol and diesel are different, the estimate can be improved if average consumption rates are available for petrol and diesel-fuelled commercial boats.

Fuel consumption can also be estimated from average fuel consumption rate and total hours of use for commercial boats. However, it is difficult to judge the number of commercial boats in use and the time they spend in an airshed without an extensive survey of all boating activities.

As ABARE data relates to jurisdictions, it is necessary to proportion the fuel consumption figures to an airshed. The proportion can only be roughly estimated with current techniques, for example by using the proportions of coastlines in the airshed and jurisdiction or some other professional judgment.

Marine authorities may be able to estimate the proportion of leaded and unleaded petrol used by commercial boats. If such information is not available, ABARE (1999) data for automotive gasoline can be used to proportion the leaded and unleaded petrol.

Emissions from commercial boats are estimated by applying fuel-based emission factors to the fuel consumption figures (see Equation 7 and Table 6). Figures provided by ABARE may be in megajoules, and thus may need to be converted to litres before applying Equation 7.

Equation 7: Estimating emissions from commercial boats

$$E = \sum_i C_i * e_i$$

where

E = Annual emissions from commercial boats in an airshed, kg yr^{-1}

C_i = Annual consumption for engine/fuel type i by commercial boats in an airshed, 10^3 L yr^{-1}

e_i = Emission factor for commercial boats with engine/fuel type i, g L^{-1}

and

engine/fuel types (i) may include inboard/diesel, outboard/leaded petrol or outboard/unleaded petrol

Equations 3 and 4 can be used to speciate VOC and particulate emissions from commercial boats respectively. The profiles for diesel and petrol exhaust emissions in Tables 9 and 10 should be used for speciating emissions from diesel and petrol-powered commercial boats respectively.

3.1.3 Recreational Boats

Fuel consumption data for recreational boats are usually not available from the marine authority or ABARE, and a domestic survey is necessary to obtain reliable activity data for recreational boats. Appendix A provides guidelines for the design and conduct of domestic surveys. A sample of a domestic questionnaire can be found in EPAV (1996c). Information that needs to be sought from the survey for recreational boats includes:

- the type of engine (inboard or outboard) and fuel (diesel, leaded petrol or unleaded petrol) used by a household;
- the amount of fuel consumed annually by the household for boating; and
- the typical locations of boating activities for the household, and the proportion of time spent in each location.

The number of households in an airshed is also required for scaling up fuel consumption data from the survey. The number of households in the airshed would have been derived for estimating emissions from other sources, such as domestic solid fuel burning and lawn mowing, and may not be necessary to derive separately (see the AE Manuals for Domestic Solid Fuel Burning and Domestic Lawn Mowing).

Emissions from recreational boats may then be estimated using the results of the domestic survey (see Equation 8). The relevant emission factors are provided in Table 7.

Equation 8: Estimating emissions from recreational boats

$$E = N * \sum_i c_i * p_i * e_i$$

where

E	=	Annual emissions from recreational boats in an airshed, kg yr^{-1}
N	=	Number of households in the airshed
c_i	=	Average fuel consumption of recreational boats with engine/fuel type i, 10^3 L $household^{-1}$ yr^{-1}
p_i	=	Proportion of households which own boats with engine/fuel type i
e_i	=	Emission factor for boats with engine/fuel type i, g L^{-1}

and

engine/fuel types (i) may include inboard/diesel, inboard/leaded petrol, inboard/unleaded petrol, outboard/leaded petrol, or outboard/unleaded petrol

In Equation 8 the term c_i is averaged for only those households which own boats with engines, whereas p_i refers to the proportion in terms of all households in the airshed. Also, in deriving values for c_i and p_i, households which use their boats outside the airshed should be excluded.

The method for speciating recreational boat emissions is the same as for commercial boats (see Section 3.1.2).

3.1.4 Default Method

If the EETs in Sections 3.1.1, 3.1.2 and 3.1.3 cannot be employed because of lack of data, resources or expertise for the work, or any other reason, the following default method may be used.

The default method involves the use of ABARE data for fuel consumption in water transport. The following data are required:

- ADO, IDF and fuel oil consumption in domestic and international water transport for a jurisdiction in the relevant year.

ABARE (1999) does not publish data separately for domestic and international water transport and the data have to be requested directly from ABARE. Three types of fuel are reported by ABARE for water transport: automotive diesel oil (ADO), industrial diesel fuel (IDF) and fuel oil. It is assumed that all ADO for domestic water transport is consumed by commercial boats, and the other fuels are used by commercial ships. Since ABARE does not usually have figures for petrol consumption in water transport, recreational boating emissions are not estimated with this method.

As the ABARE data relate to a jurisdiction, it is necessary to proportion the fuel consumption figures to an airshed. For commercial ships this proportion is usually small as they spend most of their time in oceans. Some broad assumptions or professional judgements may be necessary to derive this proportion. For commercial boats the method described in Section 3.1.2 can be used to estimate the proportion.

Emissions are calculated by applying fuel-based emission factors to the fuel consumption figures (see Equations 9 and 10, and Table 8). Figures provided by ABARE may be in megajoules, and may need to be converted to litres before applying these equations.

Equation 9: Estimating emissions from commercial ships by the default method

$$E_s = \sum_i C_i * e_i$$

where

E_s = Annual emissions from commercial ships, kg yr^{-1}

C_i = Total annual consumption of fuel type i (ADO, IDF or fuel oil) by commercial ships in an airshed, 10^3 L yr^{-1}

e_i = Emission factor for commercial ships powered by fuel type i, g L^{-1}

i = ADO, IDF or fuel oil

Equation 10: Estimating emissions from commercial boats by the default method

$$E_b = C_b * e_b$$

where

E_b = Annual missions from commercial boats, kg yr^{-1}
C_b = Total annual consumption of ADO by commercial boats, 10^3 L yr^{-1}
e_b = Emission factor for commercial boats powered by ADO, g L^{-1}

Equations 3 and 4 can be used to speciate VOC and particulate emissions from commercial ships and boats. The VOC profile for diesel can be used for all three types of fuel (see Table 9), whereas the particulate profile for gas oil/ diesel can be used for ADO and IDF (Table 10).

3.2 Spatial Surrogates and Spatial Allocation

Emissions from ports (i.e. exhaust emissions at berth, and loading and ballasting at berth) should be assigned to those grid cells where the ports are situated, while emissions from channels should be evenly distributed to those grid cells which the channels occupy.

If the default method is used, some broad assumptions or professional judgements will be necessary to assign the emissions to ports and channels.

Emissions from commercial and recreational boats should be distributed to those grid cells where the activities are carried out. However, sometimes it is difficult to define the boundaries of these activities and the emissions may have to be evenly distributed to grid cells within, say, 5 km of the coast.

3.3 Emission and Speciation Factors

The emission factors and speciation factors used in this manual are presented below.

Total suspended particles (TSP) is not an NPI substance but is required for speciating emissions into metals, PAHs and PM10.

The emission factors for commercial ships of different tonnage ranges are derived from Lloyd's Register (1995) and a correlation between main engine power and gross tonnage basing on the Lloyd's Register Database (see Appendix B).

Table 4: Emission Factors for Commercial Ships of Different Tonnage Ranges

NPI Substance	Emission Factor (kg hr^{-1}) [a]				
	<1000	1000-5000	5000-10000	10000-50000	>50000
Main engines					
Carbon monoxide	0.481	1.63	3.03	13.5	28.5
Oxides of nitrogen	1.44	11.3	32.5	167	334
Sulphur dioxide	0.432	2.59	35.0	127	254
TSP	0.0374	0.224	0.561	16.8	33.7
Total VOCs	0.174	0.600	1.13	3.41	6.82
Auxiliary engines					
Carbon monoxide	1.19	1.19	1.19	1.19	1.19
Oxides of nitrogen	6.66	6.66	6.66	6.66	6.66
Sulphur dioxide	1.42	2.83	4.25	5.66	7.08
TSP	0.120	0.120	0.120	0.900	0.900
VOCs	0.436	0.436	0.436	0.436	0.436

[a] Derived from Lloyd's Register (1995).

Table 5: VOC Emission Factors for Loading and Ballasting

Process	Emission Factor [a] (mg L^{-1})
Loading	215
Ballasting	129

[a] USEPA (1995). Factors for typical situations are used. The factor for loading is based on that for petrol, and that for ballasting on crude oil.

Table 6: Emission Factors for Commercial Boats

NPI Substance	Emission Factor (g L^{-1})		
	Inboard Diesel [a]	Inboard Petrol [b,c]	Outboard Petrol [b]
Carbon monoxide	13	149	400
Lead and compounds		0.116 (0.00162) [d,e]	0.116 (0.00162) [d,e]
Oxides of nitrogen	32	15.7	0.79
Sulphur dioxide[f]	2.1	1.04 (0.304) [d]	1.04 (0.304) [d]
TSP	3.5	0.195 [g]	0.195 [g]
VOCs	6.0	9.49 [h]	120[h]

[a] CARB (1995).
[b] USEPA (1985).
[c] May not be used if all inboard commercial boats are assumed to be diesel powered.
[d] Values are for leaded and (in brackets) unleaded petrols.
[e] Based on emission of 77% (EPAV 1996c) of the lead content in leaded (0.15 g L^{-1}) and unleaded (2.10 mg L^{-1}) petrol in Australia (Challenger, B., AIP July 1998, pers. comm.). These figures should be adjusted if local lead contents are different.
[f] USEPA (1985). Factors are adjusted for Australian fuel sulphur content (diesel 0.15%, leaded petrol 0.058% and unleaded petrol 0.017%), Challenger, B., AIP July 1998, pers. comm.). These figures should be adjusted if local contents are different.
[g] Yumlu (1994).
[h] Converted from figures for hydrocarbons (HC), with VOC/HC = 0.971 (EPAV 1996c).

Table 7: Emission Factors for Recreational Boats

NPI Substance	Emission Factor ($g\ L^{-1}$) [a]		
	Inboard Diesel	**Inboard Petrol**	**Outboard Petrol**
Carbon monoxide	17	149	400
Lead and compounds		0.116 (0.00162) [b,c]	0.116 (0.00162) [b,c]
Oxides of nitrogen	41	15.7	0.79
Sulphur dioxide [d]	2.1	1.04 (0.304) [b]	1.04 (0.304) [b]
TSP	3.5 [e]	0.195 [f]	0.195 [f]
VOCs	22	9.49 [g]	120 [g]

[a] USEPA (1985).
[b] Values are for leaded and (in brackets) unleaded petrols.
[c] Based on emission of 77% (EPAV 1996c) of the lead content in leaded (0.15 $g\ L^{-1}$) and unleaded (2.10 $mg\ L^{-1}$) petrol in Australia (Challenger, B., AIP July 1998, pers. comm.). These figures should be adjusted if local lead contents are different.
[d] USEPA (1985). Factors are adjusted for Australian fuel sulphur content (diesel 0.15%, leaded petrol 0.058% and unleaded petrol 0.017%), Challenger, B., AIP July 1998, pers. comm.). These figures should be adjusted if local contents are different.
[e] CARB (1995).
[f] Yumlu (1994).
[g] Converted from figures for hydrocarbons (HC), with VOC/HC = 0.971 (EPAV 1996c).

Table 8: Emission Factors for Marine Vessels Used in the Default Method

NPI Substance	Emission Factor ($g\ L^{-1}$) [a]		
	ADO	**IDF**	**Fuel Oil**
Commercial ships			
Carbon monoxide	6.26	6.52	7.05
Oxides of nitrogen	48.2	50.2	82.9
Sulphur dioxide	8.46	8.81	51.4
TSP	1.02	1.06	7.14
VOCs	2.03	2.11	2.29
Commercial boats [b]			
Carbon monoxide	13		
Oxides of nitrogen	32		
Sulphur dioxide	2.1		
TSP	3.5		
VOCs	6.0		

[a] Lloyd's Register (1995), unless otherwise specified.
[b] Reproduced from Table 6.

Table 9: VOC Speciation for Exhaust and Evaporative Emissions from Marine Vessels

NPI Substance	Weight Fraction [a]			
	Diesel Exhaust	Petrol Exhaust	Petrol Evaporative [b]	Crude Oil Evaporative
Acetaldehyde	0.0327	0.0209		
Benzene	0.0191	0.0405	0.00950	0.0263
1,3-Butadiene	0.0158 [c]	0.00980 [c]		
Cyclohexane			0.000637	
Ethylbenzene	0.000661	0.00779	0.000791	
Formaldehyde	0.0968	0.0315		
n-Hexane	0.0155	0.00873	0.0173	0.0515
Lead and compounds			$6.32 * 10^{-5}$ ($6.84 * 10^{-7}$) [d]	
PAHs		0.00217 [e]		
Styrene		0.001 [e]	0.000132	
Toluene	0.0193	0.125	0.0108	0.0154
Xylenes	0.00992	0.0383	0.00433	

[a] Weight fractions from CARB (1991a), unless otherwise specified.
[b] NPI AE Manual for Service Stations.
[c] USEPA (1993).
[d] Values are for leaded and (in brackets) unleaded petrols.
[e] EPA (1996c).

Table 10: Particulate Speciation of Exhaust Emissions

NPI Substance	Weight Fraction		
	Fuel Oil [a]	Gas Oil/ Diesel [a]	Petrol [b]
Antimony and compounds	3.07×10^{-5}	6.39×10^{-5}	
Arsenic and compounds	8.64×10^{-5}	6.67×10^{-5}	
Beryllium and compounds	6.18×10^{-5}	2.44×10^{-4}	
Cadmium and compounds	2.19×10^{-6}	6.94×10^{-6}	
Chromium (III) compounds [c]	2.18×10^{-5}	1.86×10^{-5}	3.53×10^{-4}
Chromium (VI) compounds [c]	9.08×10^{-6}	7.74×10^{-6}	1.47×10^{-4}
Cobalt and compounds	5.61×10^{-5}	4.72×10^{-5}	0.0005
Copper and compounds	5.31×10^{-5}	6.92×10^{-4}	0.0005
Lead and compounds	1.86×10^{-5}	6.53×10^{-5}	
Manganese and compounds			0.0005
Mercury and compounds	2.00×10^{-6}	1.67×10^{-5}	
Nickel and compounds	0.00448	0.00549	0.0005
Particulate matter ≤ 10 µm [d]	1	1	0.74
Polycyclic aromatic hydrocarbons	8.19×10^{-6}	1.09×10^{-4}	
Selenium and compounds	3.77×10^{-5}	1.45×10^{-4}	
Zinc and compounds	9.87×10^{-5}	6.50×10^{-4}	0.0005

[a] Derived from Lloyd's Register (1995) as fractions of particulate emissions.
[b] CARB (1991b).
[c] Assuming the same fraction of chromium(VI) (29.3%) as that emitted from fuel oil combustion (USEPA 1998).
[d] Assuming the same fractions as those for diesel and petrol-powered heavy duty vehicles (EPAV 1996c).

3.4 Sample Calculations

Example 1: Estimating exhaust VOC emissions from commercial ships

Assuming the following data for a port in an airshed in a given year:

Gross Tonnage	Number of Visits
< 1000	10
1000 - 5000	230
5000 - 10000	733
10000 - 50000	1710
> 50000	51
Average hours	35.5
Average speed in channel	26.9 km hr^{-1}
Distance travelled in channel	237 km

Emissions of VOC can be estimated from Equation 1 (with emission factors from Table 4) as

$$E_b = t_b * \sum_i (n_i * a_i)$$
$$= 35.5 * (10 + 230 + 733 + 1710 + 51) * 0.436$$
$$= 4.23 * 10^4 \text{ kg yr}^{-1}$$

Emissions of VOC in the channel are estimated from Equation 2 as

$$E_c = \frac{d_c}{v_c} * \sum_i \{n_i * (m_i + a_i)\}$$
$$= (237 / 26.9) * \{10 * (0.174 + 0.436) + 230 * (0.600 + 0.436) +$$
$$733 * (1.13 + 0.436) + 1710 * (3.41 + 0.436) + 51 * (6.82 + 0.436)\}$$
$$= 7.35 * 10^4 \text{ kg yr}^{-1}$$

Example 2: Estimating loading emission from ships

The following data are assumed for a port in a given year:

Volume of petroleum liquid loaded at port is 2200 $*10^6$ L
Petrol consumption in jurisdiction is 4.58 $*10^9$ L
Petroleum liquid consumption in jurisdiction is 11.42 $*10^9$ L

Loading emissions are estimated from Equation 5 (with emission factors from Table 5) as

$$E_l = V * e_l$$
$$= (4.58 * 10^9) / (11.42 * 10^9) * 2200 * 215$$
$$= 1.9 * 10^5 \text{ kg yr}^{-1}$$

Example 3: Estimating ballasting emissions from tankers

The following data are assumed:

Loading Activity	Number of Tanker Visits
Loading	51
Unloading	105
Both	77

Average DWT and fraction of ballasting emissions at berth are taken from Table 2

Ballasting emissions are estimated from Equation 6 (with throughput factors from Table 3 and emission factors from Table 5) as

$$E_b = p * w * e_b * 10^{-6} * \sum_i (n_i * v_i)$$

$= 0.05 * 30\,000 * 129 * 10^{-6} * (51 * 28.53 + 105 * 3.211 + 77 * 5.544)$

$= 4.29 * 10^2$ kg yr^{-1}

Example 4: Estimating VOC emissions from commercial boats

The following data are assumed for an airshed in a given year:

Engine Type	Fuel Type	Registration
Inboard	Diesel	840 000
Outboard	Petrol	492 000

ADO consumption in domestic water transport is 0.52 PJ

Energy content of ADO is 38.6 MJ L^{-1}

Half of the jurisdiction's coastline is within the airshed

Applying a coastline factor of 0.5 and proportioning outboard and inboard fuel consumption according to registration data (as described in Section 3.1.2), the emissions of VOCs in the airshed are estimated from Equation 7 (with emission factors from Table 6) as

$$E = \sum_i C_i * e_i$$

$= 0.5 * [0.52 * 10^6 / 38.6 * \{6.0 + (492\,000 / 840\,000) * 120\}]$

$= 5.1 * 10^5$ kg yr^{-1}

Example 5: Estimating VOC emissions from recreational boats

It is assumed that the following data are obtained from a domestic survey for commercial boats in an airshed:

Engine Type	Fuel Type	Fuel consumption (10^3 L household^{-1} yr^{-1})	Fraction of Households (%)
Inboard	Diesel	0.498	0.51
	Leaded	0.607	0.43
	Unleaded	0.233	0.14
Outboard	Leaded	0.099	2.16
	Unleaded	0.483	2.48

The number of households in the airshed is 1 590 000

Emissions of VOCs in the airshed may then be estimated from Equation 8 (with emission factors from Table 7) as

$$E = N * \sum_i c_i * p_i * e_i$$

$$= 1.590 * 10^6 * (0.498 * 0.0051 * 22 + 0.607 * 0.0043 * 9.49 + 0.233 * 0.0014 * 9.49 + 0.099 * 0.0216 * 120 + 0.483 * 0.0248 * 120)$$

$$= 2.83 * 10^6 \text{ kg yr}^{-1}$$

Example 6: Estimating VOC emissions from commercial ships and boats using the default method

It is assumed that the following data are obtained from ABARE for water transport for a jurisdiction in a given year:

Sector	Fuel	Consumption (PJ)	Energy Content (MJ L^{-1})
Domestic	ADO	0.52	38.6
	IDF	0.04	39.6
	Fuel oil	3.08	40.8
International	ADO	1.40	38.6
	IDF	0.14	39.6
	Fuel oil	9.27	40.8

Commercial ships and commercial boats spend 10% and 50% of their time in the airshed respectively

Emissions of VOCs from commercial ships in the airshed are estimated from Equation 9 (with emission factors from Table 8) as

$$E_s = \sum_i C_i * e_i$$

$= 0.1 * \{1.40 / 38.6 * 2.03 + (0.04 + 0.14) / 39.6 * 2.11 + (3.08 + 9.27) / 40.8 * 2.29\} * 10^6$

$= 7.76 * 10^4$ kg yr^{-1}

Emissions of VOCs from commercial boats in the airshed are estimated from

Equation 10 (with the emission factor from Table 8) as

$$E_b = C_b * e_b$$
$$= 0.5 * 0.52 * 10^6 / 38.6 * 6.0$$
$$= 4.04 * 10^4 \text{ kg yr}^{-1}$$

Example 7: Estimating xylene emissions from commercial ships at berth of a port

Based on the result from Example 1, emissions of xylenes from commercial ships at berth of a port are estimated by speciation of VOC emissions according to Equation 3 (with the speciation factors in Table 9) as

$$E_j = E_{voc} * w_i$$
$$= 42\,300 * 0.00992$$
$$= 4.2 * 10^2 \text{ kg yr}^{-1}$$

4.0 Uncertainty Analysis

In the following discussion the reliability of data and other estimates is classified into 3 levels of confidence: high (uncertainty of 20% or less), medium (uncertainty of between 20% and 80%) and low (uncertainty of greater than 80%).

4.1 Data Reliability

Port and marine authorities usually keep good records of shipping activities and their data are of high reliability.

ABARE data for water transport is of medium reliability. However, broad assumptions often have to be made in scaling down energy consumption figures to airshed level, and the resultant data are hence of low reliability.

Results from domestic surveys are usually of high reliability. However, the proportion of households which have boats is often low, and there may not be enough responses from the survey to derive accurate activity data. The results of domestic surveys for recreational boats are therefore of medium reliability.

4.2 Reliability of Emission Factors

Emission factors for commercial ships are derived from factors published by Lloyd's Register. A total of sixty engines on fifty vessels were tested by Lloyd's Register, and the emission factors reported by Lloyd's Register are considered to be of high reliability. Emission factors for loading and ballasting are based on typical ship conditions in the US and the reliability of the emission factors is considered to be medium.

Emission factors for commercial boats and recreational boats are mostly based on those published by USEPA (1985). These factors are quite old and based on historical test results, and their reliability is only medium.

Particulate speciation factors used for fuel oil and gas oil powered ships are derived from Lloyd's Register and their reliability is considered to be medium. Other speciation factors used for marine vessels are often based on those derived for road vehicles and other sources and, as such, their reliability for marine vessels is low.

4.3 Problems and Issues Encountered

Accurate fuel consumption figures are usually not available for estimating emissions from commercial boats. A survey of commercial boating activities would be hard to conduct as there are so many types of commercial boats (e.g. patrol boats, barges, fishing vessels, tourist boats, ski boats) and a large number of associations, organisations or individuals to target.

In deriving emissions from recreational boats, households which use their boats outside the airshed are excluded. However, there are also households outside the airshed which use their boats within it. Since such households are not included in the domestic survey, emissions will be under estimated.

Techniques for assigning ABARE data to an airshed are often fairly rough, and considerable errors may be introduced. Assigning ABARE data spatially within an airshed introduces further errors as shipping activities in different ports may differ quite considerably.

4.4 Recommendations for Further Work

Boat registration numbers are usually readily available for an airshed. If annual average fuel consumption figures for different types of commercial boats and recreational boats are developed for all jurisdictions (by a nation-wide survey), it would be relatively easy to estimate total fuel consumption by multiplying registrations by annual average consumption. This would improve the accuracy of emissions estimation considerably, especially for commercial boats, as broad assumptions currently have to be made when estimating emissions from these sources.

There is also a need to develop new emission factors for commercial boats and recreational boats, as the USEPA emission factors are quite old and there are no emission factors specifically for commercial boats.

VOC speciation factors and petrol particulate speciation factors need development, as these are usually based on motor vehicles or other sources.

5.0 Glossary of Terms and Abbreviations

ABARE	Australian Bureau of Agricultural and Resource Economics
ADO	Automotive diesel oil
AE	Aggregated emissions
AIP	Australian Institute of Petroleum
CARB	California Air Resources Board
DWT	Deadweight tonnage (the weight in tonnes of cargo, stores, fuel, passengers and crew carried by a ship when it is loaded to the maximum summer loadline)
EET	Emissions estimation technique
EPAV	Environment Protection Authority of Victoria
HC	Hydrocarbons
IDF	Industrial diesel fuel
NEPC	National Environment Protection Council
NEPM	National Environment Protection Measure
NPI	National Pollutant Inventory
PM10	Particulate matter less than or equal to 10 µm
PAH	Polycyclic aromatic hydrocarbons
TSP	Total suspended particulates
US	United States
USEPA	United States Environmental Protection Agency
VOC	Volatile organic compound

6.0 References

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7.0 Appendices

APPENDIX A: GUIDELINES FOR CONDUCT OF DOMESTIC SURVEYS

APPENDIX B: DERIVATION OF EMISSION FACTORS FOR COMMERCIAL SHIPS

APPENDIX A
GUIDELINES FOR CONDUCT OF DOMESTIC SURVEYS

1 Background

Manuals for estimating aggregated emissions are required to assist State and Territory Governments in preparing annual inputs to the Commonwealth for the National Pollutant Inventory (NPI). The aggregated emissions manuals complement the industry handbooks, and are intended to enable Governments to estimate emissions from non-industrial activities (e.g. transportation, domestic and commercial activities) and emissions from industry which are not reported because the relevant NEPM thresholds are not exceeded.

For emissions from domestic sources the estimation techniques are generally based on estimates of overall household activity levels, such as the combustion of fuel, consumption of materials, and usage of equipment and appliances. Information on some of these activities can be derived to an acceptable accuracy with a survey questionnaire distributed to a representative number of households in a particular airshed.

For other activities accurate data may be available from other sources (e.g. usage of surface coatings and aerosols) and so a survey will not be required. Also, although the usual estimation technique may be relatively crude (e.g. for domestic and commercial solvents the estimate is based on a US EPA per capita emission factor), it is unlikely that a survey would be particularly useful because of the large number of products involved.

In summary, a survey should be used where sufficiently accurate data are not available from other sources, where a survey is appropriate and practicable, and where it offers the prospect of better data than other approaches.

2 Development of Survey Technique

Surveys of this type have been successfully undertaken as part of NPI Trials in Dandenong, Launceston, Newcastle and Port Pirie in 1995 and 1996, and for the Port Phillip Region emissions inventory in 1997. These surveys in turn evolved from earlier exercises undertaken for the Brisbane, Sydney and Auckland regions in the early 1990s.

For the NPI trials project, assistance was obtained from ABS in refining previous surveys and sampling processes, and a market firm was engaged for the PPR survey to further refine survey techniques. Best practice in survey design and execution is now considered to provide highly reliable data for emission estimation purposes.

These techniques are now sufficiently trialled that pilot surveys are not considered necessary, although minor adaptations for each survey region are usually required.

3 The Survey Process

A typical domestic survey can be completed within about three months. The process can be summarised as follows:

- The jurisdiction engages a market research or similar firm to assist with survey design and execution.
- The jurisdiction and firm jointly design the questionnaire.
- The firm designs a sampling plan.
- The firm prints the questionnaire and, with input from the jurisdiction, prepares covering letters and envelopes using the latter's letterhead, and reply-paid envelopes addressed to the jurisdiction.
- The population is sampled by the firm with a mail-out questionnaire.
- The jurisdiction receives the completed returns and provides an initial technical check.
- The returns are passed to the firm for data entry.
- The firm sends a second mail-out to increase return rate.
- Again, the second round of returns is checked by the jurisdiction, and the additional data is entered by the firm.
- The full data set analysed by the jurisdiction and/or firm.
- The jurisdiction uses the survey data to generate emissions data.

One of the key tasks of the assisting firm is to design the sample, ensuring that the sample size leads to an overall return which keeps sampling error to an acceptable level, and that the sample obtained is genuinely representative of the population within the Region.

It is possible to divide the survey region into sub-regions to improve the spatial accuracy of the data obtained. However, unless there are good reasons for believing that there are distinct differences in activity levels between these sub-regions, this approach is not recommended as it effectively amounts to treating each sub-region as a discrete area for survey, each requiring a similar level of sampling. This would obviously result in a significant increase in survey costs. Also, given the uncertainties in the survey process and emissions estimation, the resulting improvements in spatial accuracy may be difficult to justify.

4 Design of Questionnaire

The survey questions should be developed by the jurisdiction, and discussed and refined with the firm. Questionnaires and covering letters used in other jurisdictions (as described above) provide a useful starting point, as they are the product of a series of lessons learnt over the last decade about domestic activity surveys.

It is recommended that the temptation to ask for data that is unlikely to be used should be resisted, including information on attitudes and opinions, as the shorter and simpler the questionnaire, the better the response rate is likely to be.

It should also be recognised that if relevant aggregated data is already available (e.g. data on overall domestic gas consumption may be available from gas retailers), there is little point in asking households for this information, as its accuracy would almost certainly be reduced.

5 Use of Mail Surveys

The nature of the data required for emissions inventories lends itself very well to a mail survey, as potential respondents may need to spend a little time in developing accurate responses (e.g. by discussing questions with other household members, checking equipment details, etc). Allowing surveys to be completed over a few days is therefore likely to produce more accurate responses.

While telephone or door-to-door survey methods produce quicker results, it is difficult to achieve response rates comparable with mail surveys without repeated call-backs to households, and hence comparatively high costs. Also, mail surveys are considered to be more suited to the gathering of factual information, whereas phone or door-to-door methods are usually better for gathering information on opinions and attitudes.

6 Use of Stationery of Jurisdiction

The use of Government stationery (preferable signed by a Government official) is considered to be a significant factor in obtaining good response rates.

7 Response Rates

For mail surveys of this type response rates are generally 50 to 55%, with the initial mail-out generating around 30% of returns and the follow-up a further 20%.

With these types of response rates, a sample size of 600 (i.e. about 300 returns) results in a sampling error of only about 5.6% at 95% probability. Increasing the sample size to 1000 only reduces the error to 4.4%.

Questionnaires could be numbered, allowing identification of households which have submitted returns and elimination of them from the second mail-out. However, this reduces confidentiality and may discourage reporting of activities which may not be strictly legal or acceptable (e.g. waste incineration). It is therefore considered preferable for the second mail-out to include the full initial sample. The initial covering letter should therefore make it clear that this process is being followed to ensure confidentiality, and apologise in advance to people who return their questionnaires quickly.

8 Checking of Returns

Returns should be forwarded in the first instance to the jurisdiction, as there are benefits in an initial technical check of returns prior to data entry. This increases data quality, and allows obviously conflicting, inaccurate or incomplete responses to be removed. This can be done progressively as returns are received, thereby not delaying the overall process.

APPENDIX B
DERIVATION OF EMISSION FACTORS FOR COMMERCIAL SHIPS

Lloyd's Register has reported emission factors for ships in the format as shown in Table 11.

Table 11: Emission Factors for Commercial Ships

	Main Engines (kg hr^{-1})		**Auxiliary Engines (kg hr^{-1})**
	Medium Speed	**Slow Speed**	
NO_x	$4.25 * 10^3 * P^{1.15} * N$	$17.50 * 10^3 * P * N$	$4.25 * 10^3 * A^{1.15}$
CO	$15.32 * 10^3 * P^{0.68} * N$	$0.68 * 10^3 * P^{1.08} * N$	$15.32 * 10^3 * A^{0.68}$
HC	$4.86 * 10^3 * P^{0.69} * N$	$0.28 * 10^3 * P * N$	$4.86 * 10^3 * A^{0.69}$
SO_2[a]	$2.31 * 10^3 * P * N$		
SO_2[b]	$12.47 * 10^3 * P * N$	$11.34 * 10^3 * P * N$	
SO_2			$2.36 * 10^3 * A * C$
Where P = engine power (kW) * engine load (85% MCR) N = number of engines A = auxiliary power (kW) C = 1, 2, 3, 4 and 5 where vessel gross tonnage is <1000; 1000 – 5000; 5000 -10000; 10000 - 50000, and >50000 respectively			

[a] for engines <2000 kW
[b] for engines ≥2000 kW

In order to express emission factors in terms of tonnage, it is necessary to relate engine power with tonnage. A data set containing main engine power and gross tonnage of ships was obtained from the Lloyd's Register Database. From this data set an equation can be established which relates engine power to tonnage (see Figure 1).

The following assumptions were used to derive the emission factors in Table 4:

- ships smaller than 10 000 tonnes have medium-speed engines and use gas oil with a sulphur content of 0.5%, and larger ships have slow-speed engines and use fuel oil with a sulphur content of 2.7%;
- there is only one main engine in a ship;
- the average weights for the tonnage ranges <1000; 1000 – 5000; 5000 - 10000; 10000 - 50000 and >50000 are 500, 3000, 7500, 30000 and 60000 respectively; and
- the auxiliary power of all ships is 600 kW.

The emission factors were then derived for each of the five tonnage ranges.

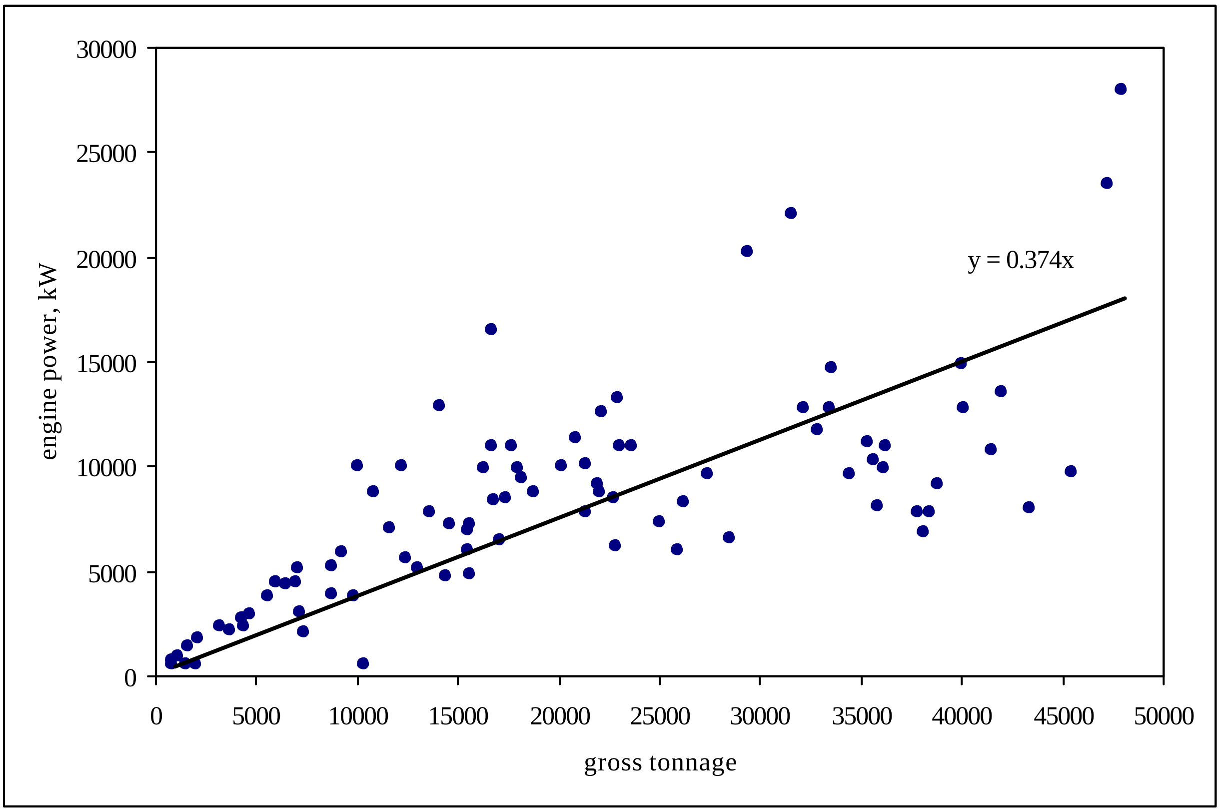

Figure 1: Correlation between Main Engine Power and Gross Tonnage