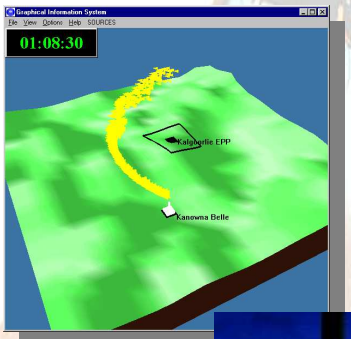
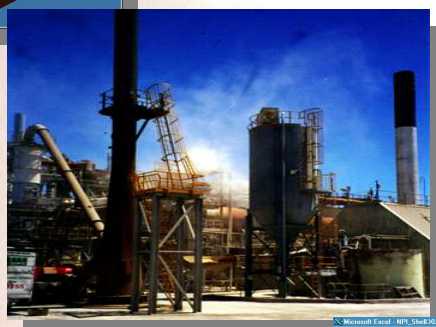
Department of Environmental Protection

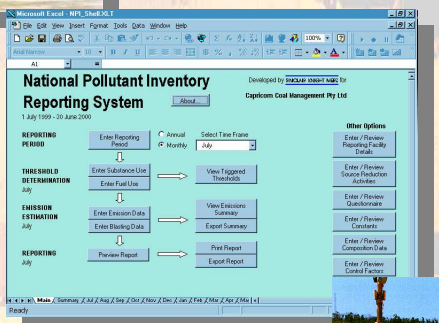
SINCLAIR KNIGHT MERZ

AGGREGATED EMISSIONS INVENTORY FOR THE PILBARA AIRSHED

1999/2000







Emissions Inventory Report

Revision 2 – June 2003

Executive Summary

Introduction

Sinclair Knight Merz has been commissioned by the WA Department of Environmental Protection (DEP) to prepare an Aggregated Emissions Inventory of National Pollutant Inventory (NPI) substances for the Pilbara Airshed for the NPI Database.

The NPI has been developed as a National Environmental Protection Measure (NEPM) by the National Environment Protection Council (NEPC). Aggregated emissions are emissions from sources that do not trigger the NPI reporting thresholds, but because of their number or distribution, may have a significant contribution to the total emissions in the Airshed. Aggregated emissions are defined in the Measure as estimates of the amount of a substance emitted to the environment annually from:

- Point source facilities which are not reporting facilities;
- Natural emissions, such as biogenic and windblown PM_{10} emissions; and
- Anthropogenic sources, other than facilities, which emit a significant amount of that substance to the environment.

The Pilbara Airshed has been identified as a priority for aggregated emissions reporting as part of the NPI in 1999/2000. The purpose of the air emissions inventory is the:

- Quantification of NPI pollutants being emitted in the Airshed;
- Identification of target sources for emissions reductions; and
- Provision of data on emissions to the wider community.

Methodology

The estimation of aggregate emissions was undertaken largely through use of the techniques detailed in the various Emission Estimation Technique (EET) Manuals developed for the National Pollutant Inventory. However, the techniques were altered where more accurate data or methods were available.

Base information was sourced through government and industry organisations, and surveys where appropriate. Where possible, emissions were estimated for each of the 90 substances included under Table 2 of the National Pollutant Inventory Guide (Environment Australia, 2002). The emissions were totalled for each type of aggregate emission source and also allocated spatially to identify key source areas of NPI pollutants.

Results Summary

Emissions of the six substances listed in the Ambient Air Quality NEPM (NEPC, 1998) (excluding ozone and including VOCs) are summarised below:

- Total emissions of CO are 1.64 million tonnes. These emissions of CO are dominated by that produced from wild fires which contribute 99.6% of all aggregate CO.

- Total PM_{10} emissions are 405,000 tonnes. Emissions of PM_{10} are dominated by "natural" sources with 48.1% from wild fires and 42.4% from windblown dust. These are followed by 9.1% from paved and unpaved roads and 0.3% from commercial ships and boats.
- Total NO_x emissions are 204,000 tonnes. These emissions are predominantly from "natural" sources with 60.8% and 30.6% from wild fires and biogenic emissions respectively. The next most significant emissions of NO_x are from commercial ships and boats, which contribute 5.2%.
- Total SO_2 emissions are 6,640 tonnes. These emissions are dominated by commercial shipping and boating, which contribute 94.1% of all aggregate SO_2. Railways are next highest, contributing 3.9%.
- Total lead emissions are 152 tonnes. These arise from dust emissions from paved and unpaved roads (82.1%), followed by windblown dust (8.7%) and wild fires (6.5%).
- Total VOC emissions are 217,000 tonnes with these predominantly arising from biogenic sources (95.3%) and wildfires (4.5%).

This indicates that natural emissions are the dominant source of CO, NO_x, PM_{10} and total VOC in the Pilbara Airshed, whilst anthropogenic emissions are the dominant sources of SO_2 and lead.

Considering only the anthropogenic sources, emissions of the five major air NEPM substances (excluding ozone and including total VOCs) for the Pilbara Airshed are summarised below:

- Emissions of CO are dominated by mobile sources, with motor vehicles contributing 40.3%, commercial shipping and boating 28.4%, recreational boating 10.4% and railways 10.2%.
- Emissions of PM_{10} are dominated by dust from paved and unpaved roads (96.6%), with commercial shipping and boating contributing 2.8%.
- Total NO_x emissions are dominated by mobile sources, with commercial shipping and boating contributing 60.2% and railways contributing 33.0%.
- SO_2 emissions are dominated by commercial shipping and boating, which contribute 94.1% of all aggregate SO_2. Railways are next highest, contributing 3.9%.
- Lead emissions are dominated by dust from paved and unpaved roads (96.7%), with railways contributing 2.7%.
- Total VOC emissions are mostly from mobile sources, including commercial shipping and boating (51.3%), motor vehicles (10.9%), railways (6.8%) and recreational boating (6.0%). However, domestic/commercial solvents/aerosols, solid fuel burning and architectural surface coatings also contribute 7.0%, 7.3% and 4.9% respectively.

Commercial and domestic transport is therefore the predominant anthropogenic source of aggregate emissions, through both mobile sources and dust emissions from roads.

Recommendations

The following recommendations are made:

- As wild fires are the dominant source for many substances, estimates of these emissions should be refined. This could be done using a system where fuel loading is classified by vegetation type across the study region and by considering the time since the last burn instead of the default constant factor. Such a technique may follow that used by Denlay *et al* (2000).

- As emissions from windblown sources are also predicted to be important, this estimate should be refined from the basic technique used here. It is considered that such estimates could most effectively be achieved by applying a model such as used by Shao *et al* (1996) for the whole Australian region (see Dudley and MacIntosh, 2000).

- Of the "man made" sources, emissions from ships are the major source in the study region. For these emissions it is recommended that:
  - The default EET emissions from auxiliary engines be modified to specify engine size and emissions as a function of ship size;
  - The main engine emission equations developed in the EET Manual are improved. It is recommended that the linear relationship between engine maximum power and gross tonnage be replaced with a non-linear fit as power requirements taper off for larger gross tonnage vessels. Secondly, as there are marked differences in the power/gross tonnage relationships for different types of ships (e.g. container ships compared to bulk carriers) it is recommended that a best practice technique be implemented that provides separate equations for the different types of ships. Such data on these relationships can be found in SKM (1999).
  - A new emission factor for vessels travelling in shipping channels is introduced to account for the potentially lower engine power setting and therefore emissions per unit time. For the shipping channels and ships in this study the emissions per unit time were 65% of the open sea emissions.

- For the study region, helicopters were estimated to be a large source of aircraft emissions. However, there is little information available regarding the emissions for various types of helicopters and more data is required to refine the estimates. The default LTO cycles for helicopters also appear too large based on discussions with helicopter pilots. Additionally it is recommended that default LTO cycles be developed for large metropolitan airports and smaller regional airports such as Karratha as taxiing times at small regional airports are thought to be much less than the defaults developed for busy city airports in the USA.

- Sulphur dioxide emission factors for aircraft appear inconsistent. This and lead emissions would be better estimated based on fuel consumption figures.

- Estimates of VOC emissions from the study region are considered preliminary. To refine these estimates, measurements of VOC emissions from the various vegetation categories are required. This is particularly the case for the very high temperatures in the Pilbara, where the use of equations with temperature dependency developed in temperate climates predict apparently excessive VOC emissions.

- Emissions from sub threshold facilities are uncertain. This is due to:
  - The uncertainty in the facilities that will be reporting for this reporting year, which is the first year that many facilities are expected to report.
  - Fuel usage figures for sub threshold categories were not available as fuel companies were reluctant to provide this; and
  - The expected large fuel usage for small generators given that a significant percentage of the population is not connected to a centralised power grid. Emissions from this source have been estimated and are anticipated to be larger than from the "traditional" sub threshold sources in the EET Manual of small industrial and commercial facilities.

- A review of the surface coating emission estimation suggests that some of the substances listed in Australian paints in the EET Manual are no longer used. For example there is no benzene in water based paints. The current EET Manual is based on data contained in USEPA (1992) for US paints. Therefore it is recommended that this EET Manual be updated with data from Australian paint manufacturers.

- As non-local recreational boat usage can be a significant proportion of recreational boat usage, this needs to be included in the EET Manual methodology. It is suggested that this be incorporated by using a non-local boat usage factor in the EET Manual to increase the boat usage derived from the residential survey of local users.

- For estimating NO_x from soils the methodology of Yienger and Levy (1995) is recommended. This methodology appears to be more scientifically valid than those used in previous Australian inventory studies as it incorporates the effects of soil wetting. For the Pilbara, estimated NO_x emissions were one half that estimated using the alternative methodology.

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1. Introduction

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The sources from which emissions were calculated for the Pilbara Airshed were:

- Mobile sources – including motor vehicles, trains, aircraft, commercial shipping/boating and recreational boating;
- Domestic/commercial sources – a number of domestic and commercial emission sources; and
- Biogenic and PM_{10} sources – including emissions from vegetation, soils and windblown PM_{10} emissions.

Emissions of substances were estimated for the 90 substances in Table 2 of the National Pollutant Inventory Guide (Environment Australia, 2002).

1.1 Study Area

The study area was defined by the following latitudes and longitudes:

- Lower left corner 113° E, 24° S; and
- Upper right corner 122.5°, 19° S

This region encompasses approximately 1,002 km by 558 km on a Lamberts Conforming Grid which corresponds to an area of 559,116 km^2, of which approximately 365,240 km^2 is land. For the study, substances were spatially allocated on a 2 km by 2 km grid for "man made" emissions, whilst natural emissions were allocated over a 10 km by 10 km grid. To ensure consistency with the grids the study area was defined on the Lamberts Conforming Grid as:

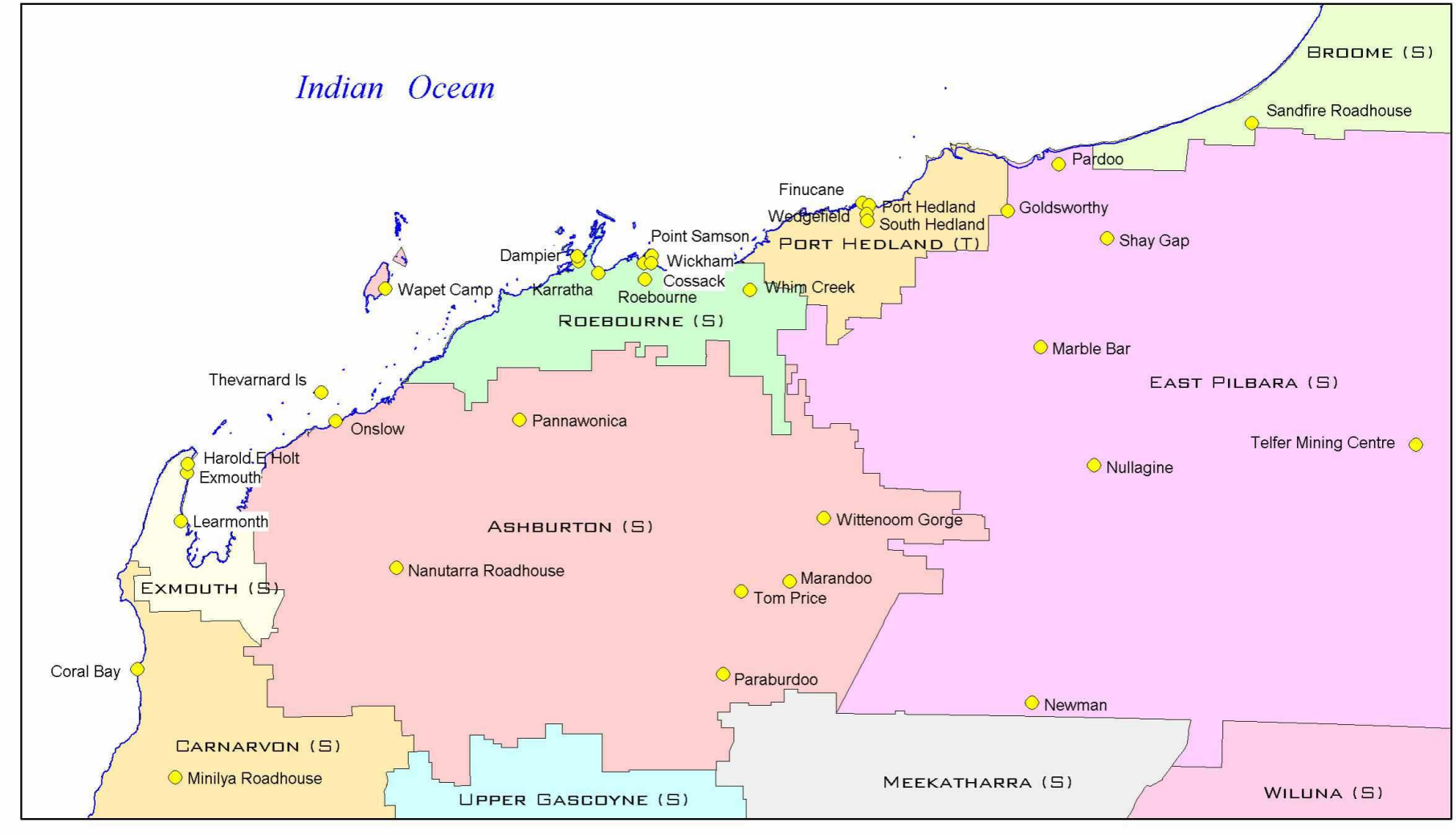
- Lower left – 9,578,000 mE 11,800,000 mN; and
- Upper right – 10,580,000 mE 12,360,000 mN.

That is an area of 1,000 km by 560 km in the east/west and north/south direction, with 500 by 280 cells for the 2 km by 2 km grid and 100 by 56 cells for the 10 km by 10 km grid.

The study area comprises all of the Shires of Ashburton, Exmouth and Roebourne and the Town of Port Hedland. The Shires of Carnarvon, Upper Gascoyne, Meekatharra, East Pilbara and Broome are partially contained within the study area (**Figure 1-1**).

The Pilbara region experienced a population decline during the 1980s. From 1981 to 1991 the population reduced marginally by 0.02 per cent per annum compared to growth of 2.33 per cent per annum for the state. The medium series projection for the region's population indicates an average decline of 0.21 per cent per annum from 1991 to 2001 (Pilbara Development Commission, 1996). In this study, population census data from 1996 was used for spatial allocation and, given previous trends, no significant increase in population was expected between 1996 and 1999/2000. The total population in the study area is 50,108. The total number of households in the study area is 18,913. Locations in the Pilbara area with populations greater than 50 people are detailed in **Table 1-1**.

■ **Figure 1-1 Shires and major towns in the Pilbara Study Area**



■ **Table 1-1 Population centres in the study area (1996 ABS census, 6 August)**

Shire/Town	Population	Percentage Population in Study Region
Shire of Ashburton		
Tom Price	3,919	7.8
Paraburdoo	2,020	4.0
Onslow	607	1.2
Pannawonica	769	1.5
Wakathuni[1]	120	0.24
Bindi Bindi[1]	200	0.40
Brockman[2]	100	0.20
Yandi[2]	80	0.16
Town of Port Hedland		
Port Hedland	12,601	25.1
Shire of Roebourne		
Dampier	1,405	2.8
Karratha	10,053	20.1
Roebourne	980	2.0
Wickham	1,636	3.3
Point Samson	228	0.46
East Pilbara Shire		
Newman	4,779	9.52
Marble Bar	335	0.67
Telfer[2]	493	0.98
Nullagine	164	0.33
Jigalong[1]	200	0.40
Coongan/Warralong[1]	120	0.24
Magurinya[1]	280	0.56
Goodabinya[1]	150	0.30
Irrungadji[1]	150	0.30
Yarri[2]	100	0.20
Mumbultjari[1]	50	0.10
Exmouth Shire		
Exmouth	3,079	6.1
Coral Bay	933	1.9
North Rankin A Gas Platform	85	0.17
Goodwyn Gas Platform	85	0.17
Cossack Pioneer	85	0.17
Barrow Island	100	0.20
Total (locations with populations more than 50)	45,806	91.4
Total Other (locations with populations less than 50)	4,302	8.6
Total Population	**50,108**	**100**

Notes:
1. Aboriginal Community – populations were estimated by the Aboriginal Affairs Department, Port Hedland.
2. Fly in-fly out Mining Camp.
3. It is noted that this breakdown is based on the Census on 6 August 1996, which will include the seasonal influx of tourists to the localities of Coral bay and Exmouth in particular.

This indicates that the majority (43508, 86.8%) of the population lives in towns greater than 50 people, 1,128 (2.25%) live in mining camps and 1,270 (2.53%) in Aboriginal communities. The remainder of the population, 4,202 (8.4%) live in small settlements (small mining camps e.g. Thevenard Island, Aboriginal out stations and homesteads).

For the study, the population and households were spatially allocated on the 2 km by 2 km grid using the locations of census districts. For large census districts covering a number of towns' populations and households were allocated based on the location of the aboriginal communities, mining camps with each homestead allocated a population of 20 people. The remainder of the population for each census districts

were then spread evenly based on the density of roads. Areas with no roads or tracks were assigned zero population.

The major economic activity in the Pilbara is mining (predominantly iron ore) and the production of oil and natural gas. Significant pastoral and fishing industries also exist. While there is some secondary processing in the region (i.e. the production of LNG and iron ore processing), there is little manufacturing industry throughout the Pilbara. The coastal areas of the Pilbara region support a number of industries including solar salt works and pearl farms, but the principal activity centres on the petroleum industry (Pilbara Development Commission, 1995).

The Pilbara is a semi-arid region characterised by high temperatures, low and variable rainfall and high evaporation. Rainfall and temperature extremes are common and tropical cyclones sometimes bring heavy rainfall between November and April.

2. Mobile Sources

2.1 Motor Vehicles

Emissions from motor vehicles arise from the by-products of the combustion process and from evaporation of the fuel itself. The combustion process results in a range of pollutants including VOCs, NO_x, CO, SO_2, lead, PM10, and trace metals. Evaporative emissions result in VOCs and small amounts of lead, and may occur through diurnal, running, hot soak and resting losses.

Evaporative emissions from refuelling at service stations and dust emissions from roads are covered under aggregated emissions from service stations and paved/ unpaved roads respectively.

The principal factors affecting vehicle emissions are:

- Vehicle type;
- Type and composition of the fuel used by a vehicle;
- Age of vehicle; and
- Type of roads on which a vehicle travels.

The approach used for the estimate of motor vehicle aggregate emissions closely follows the approach documented in the EET Manual for Aggregated Emissions from Motor Vehicles (Environment Australia, 2000a). Emissions estimates have been prepared for the 1999/2000 financial year for the following vehicle classes and fuel types:

- Petrol, diesel and LPG-fuelled passenger vehicles;
- Petrol, diesel and LPG-fuelled light commercial vehicles;
- Petrol, diesel and LPG-fuelled heavy duty vehicles; and
- Petrol-fuelled motorcycles.

Leaded, unleaded and lead replacement petrol are treated separately only in relation to data on fuel consumption and the lead and sulphur contents. These factors affect emissions of lead and SO_2. Lead replacement petrol was introduced in WA in 1 January 2000 and an allowance has been made in both in the allocation of travel estimates and in the parameters affecting emission rates.

LPG-fuelled vehicles are not treated separately but are grouped generically as LPG/LNG/dual fuelled vehicles. As recommended in the EET Manual, emission factors for LPG have been applied to all vehicles using this group of fuels.

2.1.1 Data Collection and Information Sources

Data collected for the estimation of emissions included:

- Traffic count data obtained from Main Roads Western Australia (Main Roads);
- Traffic count data obtained from Local Councils in the Pilbara;
- Vehicle registration information for the Pilbara;
- Motor vehicle usage information for WA from ABS;
- Fuel composition (Certificates of Quality) from distributors in the Pilbara; and
- Spatial road centrelines with road type information.

Traffic count data from Main Roads contained information on the composition of traffic based on the AustRoads Vehicle Classification System (January, 1994) of axle groupings. Within this classification system, vehicles such as light commercial vehicles, buses and non-freight commercial vehicles are not immediately identified by axle spacing. The proportions of buses and non-freight heavy vehicles (as opposed to empty freight vehicles) were assumed to be negligible. The proportion of light commercial vehicles (e.g. utes, vans, etc) was made using the defaults in the EET Manual.

Vehicle registration data was sourced from the WA Department of Transport (WADT). Queries performed by WADT were supplied to give cross tabulations of vehicle fuel type, age and type for vehicles in the Pilbara.

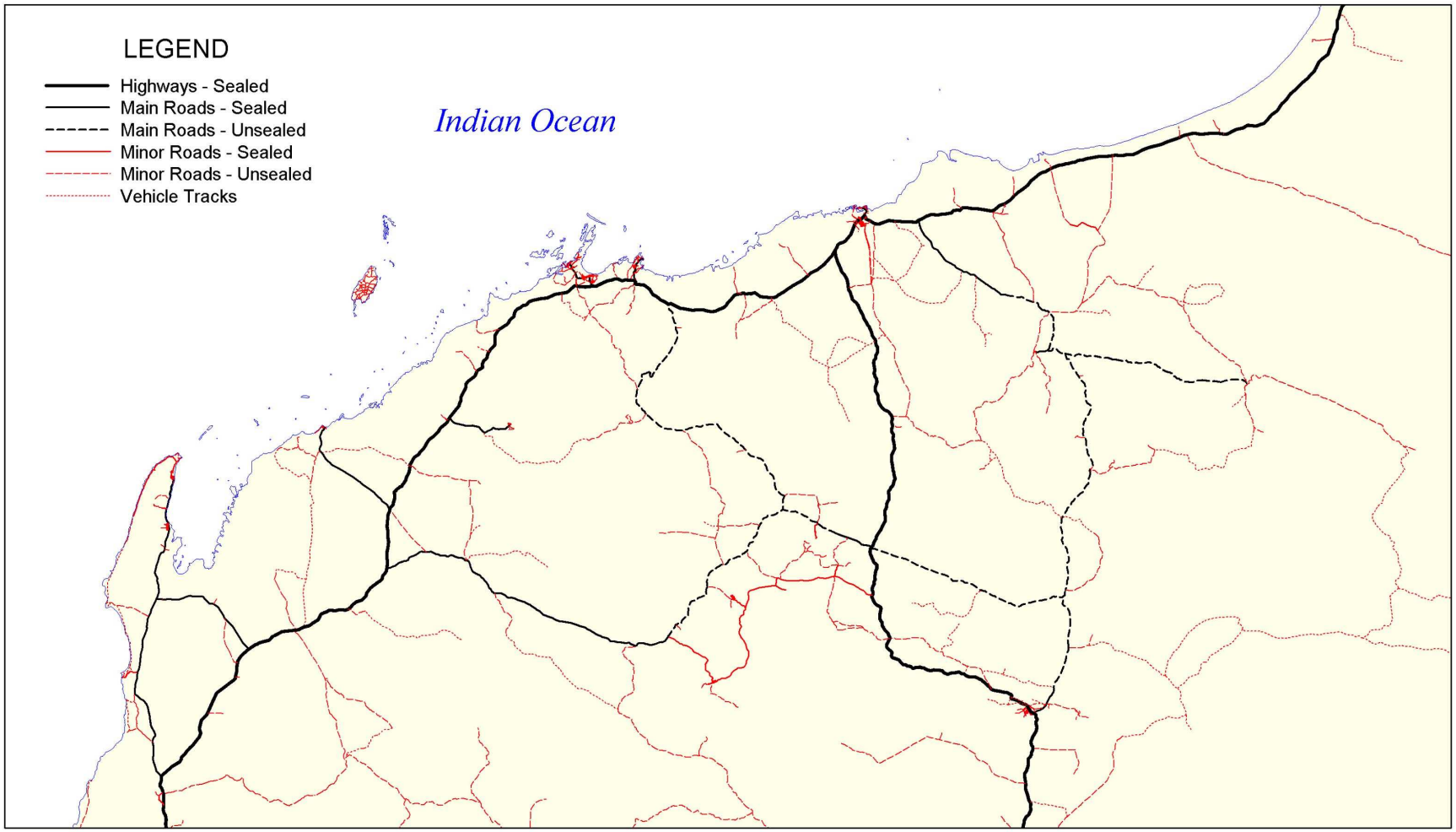
Motor vehicle usage data for WA was sourced from the Australian Bureau of Statistics publication *Survey of Motor Vehicle Use – 12 Months Ended July 1998.*

Fuel Certificates of Quality were sourced separately from Westside Petroleum (a major distributor in the Pilbara) for diesel and the Geelong Shell refinery for unleaded and leaded petrol. It should be noted that while sufficient information was obtained for diesel fuel (twelve records of shipments from Singapore or Geelong) throughout the analysis period, information for petrol was scarce and for LPG unobtainable. Where possible the information was used as a check of the national averages stated in the EET Manual.

Spatial road centrelines were compiled from a variety of sources, including digital information from Streetworks Release 2 and AUSLIG 1:2,500,000 data. The classification of roads was done using the latest available tourist road maps of the area from the RAC.

Figure 2-1 illustrates the road network for the Pilbara study area.

■ **Figure 2-1 Road network in Pilbara study area**



2.1.2 Emission Estimation

2.1.2.1 General Approach

The approach used for the estimation of motor vehicle aggregate emissions closely follows the approach documented in the EET Manual for Aggregated Emissions from Motor Vehicles (Environment Australia, 2000a). At the time this report was written, the manual was in a draft form with completion likely in the near future. The information and methodology in the manual appear to be both sound and logical based on SKM experience with studies of this nature. As such, the EET Manual approach has been adopted.

The methodology estimates vehicle kilometres travelled (VKT) and applies emission rates for the various substances. The broad steps followed for this study were:

- Traffic volume estimates for this study were located on road centreline segments;
- Traffic volumes were sub-divided by vehicle class and fuel type proportions;
- Road type details and location (i.e. length of road segments in each grid) were inherited from the spatial road centreline information;
- Grid based VKT estimates were calculated (i.e. volume x segment length in grid);
- Emission rates were developed for the representative vehicle class, fuel type, road type categories; and
- Emission rates were applied to the grid based VKT including speciation of VOCs and PM10 emissions.

The following equation (sourced from the EET Manual) shows how the motor vehicle emissions are calculated on a grid cell basis:

$$E_c = 365 * 0.001 * \sum_r \left\{ v_{r,c} * \sum_m \sum_f \sum_p \left(x_{r,m,f} * e_{r,m,f,p} \right) \right\} \qquad \textbf{Equation 2.1}$$

Where:

E_c	=	Annual emissions from motor vehicles in grid cell c, kg yr^{-1}
$v_{r,c}$	=	Average daily VKT for road type r in grid cell c, km day^{-1}
$x_{r,m,f}$	=	Relative VKT of vehicle type m and fuel type f on road type r
$e_{r,m,f,p}$	=	Emission factor for vehicle type m, fuel type f and emission process type p (exhaust, evaporative, or tyre and brake wear) on road type r, g km^{-1}
365	=	Conversion factor from day to year
0.001	=	Conversion factor from grams to kilograms

Detailed methodology information can be obtained from the EET Manual. The application of the EET Manual methodology for the Pilbara within this study is discussed below.

2.1.2.2 Treatment of Lead Replacement Petrol

Queries directed to the WA DEP regarding this relatively new fuel revealed that lead replacement petrol is essentially a premium unleaded fuel with an "anti valve seat recession" additive that reputedly breaks down to non-toxic compounds. As such, the following assumptions have been made regarding lead replacement petrol:

- No modification to emission rates will be made where the EET Manual methodology does not already split petrol into leaded and unleaded (i.e. for CO, NO_x and VOCs).
- Introduction of lead replacement petrol occurred on 1 January 2000 (or 6 months into the study 12 month time period) so leaded VKT will be evenly divided into "Leaded Petrol VKT" and "Lead Replacement Petrol VKT".
- In cases where the EET Manual methodology identifies different emissions for leaded and unleaded petrol, the emission rates for lead replacement petrol will be calculated as leaded petrol with a factor applied related to the respective fuel components for leaded and unleaded petrols (i.e. sulphur content for SO_2 and lead content for lead emissions).
  This assumes that the engines produce emissions at the same rate based on the average leaded engine characteristics but benefit from lower sulphur and lead contents.

The specific impacts on emission rates are discussed below where applicable.

2.1.2.3 Grid Based Vehicle Kilometres Travelled Estimates

A spatial data set of road segment centrelines (in MapInfo format) developed by SKM for this study was used as the basis for the location of traffic activity information. Segments were terminated at intersections to allow data (specifically counts) to differ either side of the intersections. The data set included road type categories of Highway, Main Road, Other and Tracks, designated as sealed or unsealed as appropriate.

Traffic counts obtained from Main Roads and local councils were entered into the MapInfo centreline data set for the appropriate road segments. The road type information was further categorised for the "Other – Sealed" roads into "Minor Street", "Street", and "Collector" in increasing road hierarchy function for urban areas. A flag was also added to indicate "Urban" and "Rural" environments.

Default traffic volumes were initially applied to road segments without count information based on the road type or hierarchy designations as given in **Table 2-1**. The defaults were developed following grouping traffic counts into hierarchy classification to develop representative averages.

A manual checking and adjustment of traffic volumes was then carried out to match counts between adjacent road segments. This overall process was used to allocate a traffic volume for all road segments in the study area such that traffic counts, manual inspection and defaults based on hierarchy group traffic count averages were used to refine estimates of traffic activity.

A "spatial overlay" process was applied to the road centreline segments to divide whole segments into lengths within individual grid cells. The estimates of VKT were then simply calculated as the product of length of the road segment in the grid and the traffic volume on the original whole road segment.

The EET Manual methodology recommends categorisation of road types into the three following categories:

- *Arterial*: Major roads with moderate average speed (30 km/hr) and moderate congestion levels (typically 20% idle time);
- *Freeway*: Major roads with high average speeds (in excess of 40 km/hr) and low congestion levels (less than 5% idle time); and
- *Residential*: Secondary roads with moderate average speed and negligible levels of congestion.

The roads in the Pilbara have been categorised into these road types based on the equivalence given in **Table 2-1**.

■ **Table 2-1 Road Types**

			Adopted EET Manual Road Type	
Road Hierarchy	**Road Surface**	**Default Initial Daily Volume**	**Rural Environment**	**Urban Environment**
Highway	Sealed	600 vpd	Freeway	Arterial
Main Road	Sealed	1000 vpd	Freeway	Arterial
Main Road	Unsealed	75 vpd	Freeway	N/A
Urban Collector	Sealed	2000 vpd	N/A	Residential
Urban Street	Sealed	200 vpd	N/A	Residential
Urban Minor Street	Sealed	100 vpd	N/A	Residential
Other Road	Sealed	25 vpd	Arterial	N/A
Other Road	Unsealed	10 vpd	Arterial	Residential
Track	Unsealed	5 vpd	Residential	Residential

Traffic volume proportions obtained from the Main Roads were not able to distinguish between cars and light commercial vehicles. However, the information obtained served to confirm that the defaults suggested by road type in the EET Manual were applicable to the Pilbara. Vehicle fuel proportions were calculated from a combination of registration cross-tabulations of vehicle class/fuel type/age and checks against the *ABS Survey of Motor Vehicle Use*.

The resulting proportions globally applied for traffic volume proportions and fuel type proportions are given in **Table 2-2**. Application of both these proportional factors in combination with the road type effectively produces the VKT estimates in categories to which the emission rates are applied.

■ **Table 2-2 Traffic Volume and Fuel Type Proportions**

	Vehicle Class			
	Motorcycle	**Passenger**	**Light Commercial**	**Heavy Duty**
Traffic Volume Proportions				
Arterial	1.10%	80.60%	13.10%	5.20%
Freeway	1.10%	80.60%	13.10%	5.20%
Residential	1.10%	89.75%	6.55%	2.60%
Fuel Type Proportions				
Leaded Petrol	13.08%	14.75%	13.08%	2.29%
Lead Replacement Petrol	13.08%	14.75%	13.08%	2.29%
Unleaded Petrol	43.87%	70.51%	43.87%	11.08%
Diesel	29.62%	0.00%	29.62%	84.34%
LPG/CNG	0.35%	0.00%	0.35%	0.00%

2.1.2.4 Emission Factors for CO, NO_x and VOCs

The EET Manual describes a detailed methodology for the derivation of CO, NO_x and VOCs emission rates for the various vehicle class, road type and fuel type categories. Application of this detailed approach was not possible for the Pilbara due to a general lack of detailed information specific to the area. The default values from the EET Manual have been used as shown in **Table 2-3**.

Petrol values have been applied to all leaded, unleaded and lead replacement petrol. Due to the lower volatility of diesel fuel, evaporative emissions are negligible.

■ **Table 2-3 Emission Rates for CO, NO_x and VOCs**

		Emission Rate (g/km) by Road Type		
Vehicle Class	**Fuel Type**	**Arterial**	**Freeway**	**Residential**
CO				
Passenger	Petrol	7.56	7.07	10.6
	Diesel	0.637	0.516	1.13
	LPG	6.59	5.33	11.7
Light commercial	Petrol	17.2	13.9	30.6
	Diesel	0.81	0.656	1.44
	LPG	19.1	15.4	34
Heavy duty	Petrol	53.7	43.4	95.6
	Diesel	4.42	3.58	7.87
	LPG	59.7	48.3	106
Motorcycle	Petrol	9.04	7.32	16.1
NOx				
Passenger	Petrol	0.844	1.24	1.04
	Diesel	0.785	1.33	1.02
	LPG	0.527	0.893	0.688
Light commercial	Petrol	1.32	2.24	1.73
	Diesel	1.03	1.75	1.35
	LPG	0.878	1.49	1.15
Heavy duty	Petrol	3.08	5.21	4.02
	Diesel	6.69	11.3	8.73
	LPG	2.04	3.46	2.66
Motorcycle	Petrol	0.428	0.724	0.558
VOCs (exhaust)				
Passenger	Petrol	0.579	0.559	0.766
	Diesel	0.331	0.31	0.513
	LPG	0.528	0.494	0.818
Light commercial	Petrol	1.64	1.53	2.53
	Diesel	0.554	0.517	0.857
	LPG	1.75	1.63	2.7
Heavy duty	Petrol	3.08	2.88	4.77
	Diesel	1.01	0.941	1.56
	LPG	3.29	3.07	5.09
Motorcycle	Petrol	1.23	1.15	1.9
VOCs (evaporative)				
Passenger	Petrol	0.535	0.241	0.535
	LPG	1.07	0.483	1.07
Light commercial	Petrol	0.586	0.275	0.586
	LPG	1.17	0.55	1.17
Heavy duty	Petrol	2.91	2.15	2.91
	LPG	5.81	4.29	5.81
Motorcycle	Petrol	0.803	0.803	0.803

2.1.2.5 Emission Factors for PM10, $S0_2$ and Lead

The default emission rates for particulate matter have also been adopted unchanged from the EET Manual (**Table 2-4**). Rates for buses have been ignored, as the proportion of buses in the Pilbara is small compared to other heavy vehicles (i.e.

trucks) and the identification of this proportionally small class of vehicles within the limited traffic count data was not possible. Tyre and brake wear emissions have been aggregated from the separate values in the EET Manual. The rates used are given in **Table 2-4**.

■ **Table 2-4 Emission Rates for PM10**

		Emission Rate (g/km) by Road Type		
Vehicle Type	**Fuel**	**Arterial**	**Freeway**	**Residential**
Exhaust				
Passenger	Petrol	0.00932	0.00513	0.00932
	Diesel	0.148	0.0813	0.148
	LPG	0.00329	0.00181	0.00329
Light commercial	Petrol	0.0118	0.00649	0.0118
	Diesel	0.222	0.122	0.222
	LPG	0.00493	0.00271	0.00493
Heavy duty	Petrol	0.12	0.066	0.12
	Diesel	0.584	0.321	0.584
	LPG	0.0278	0.0153	0.0278
Bus	Petrol	0.666	0.366	0.666
	Diesel	0.666	0.366	0.666
	LPG	0.0317	0.0174	0.0317
Motorcycle	Petrol	0.0124	0.00684	0.0124
Tyre Wear				
Passenger	All	0.00497	0.00497	0.00497
Light commercial	All	0.00497	0.00497	0.00497
Heavy duty	All	0.00746	0.00746	0.00746
Bus	All	0.00497	0.00497	0.00497
Motorcycle	All	0.00249	0.00249	0.00249
Brake Wear				
All vehicles	All	0.00808	0.00808	0.00808

Emission rates for SO_2 have been adopted from the default NPI emission rates, though scaled by the ratio of the local sulphur content of the fuel to national average sulphur contents. Sulphur contents for fuels for the Pilbara were obtained from Certificate of Quality (CoQ) records for the fuel delivered to the Pilbara in the 1999/2000 financial year were compared. For diesel the data indicates that sulphur levels are significantly higher than the national average, see **Table 2-5**.

■ **Table 2-5 Sulphur Contents of Fuels**

Fuel	Sulphur Content (EET Manual)	Sulphur Content (Pilbara)
Leaded Petrol	0.155 g/L	0.155 g/L
Lead Replacement Petrol	0.155 g/L (assuming leaded)	0.110 g/L
Unleaded Petrol	0.110 g/L	0.110 g/L
Diesel	1.270 g/L	2.236 g/L
LPG	0.00784 g/L	0.00784 g/L

For the petrols, similar comparisons of sulphur were not possible due to lack of a significantly representative sample of CoQ records. As such the national sulphur content value has been adopted. Similarly the sulphur content for lead replacement petrol has been adopted from the EET Manual value for unleaded petrol.

The emission rates have been factored using the ratio of the Pilbara sulphur content to the EET Manual national average sulphur content. As discussed earlier, the emission characteristics of unleaded vehicles have been used for lead replacement fuelled vehicles (i.e. the same vehicles with different fuel after 1 January 2000) with the rates factored by the ratio between the unleaded and leaded sulphur contents.

The resulting emission rates for SO_2 based on the factored defaults from the EET Manual are given in **Table 2-6**. The EET Manual gives separate values for rigid, articulated, non-freight trucks and buses. Both non-freight truck and bus volumes have been assumed to be negligible. A weighted value for heavy-duty vehicles has been calculated from the defaults assuming rigid trucks are 65% and articulated trucks are 35% of heavy-duty vehicles respectively.

- **Table 2-6 Emission Rates for SO_2**

		Emission Rate (g/km)		
Vehicle Type	**Fuel**	**Arterial**	**Freeway**	**Residential**
Passenger	Leaded petrol	0.0362	0.0254	0.0362
	Lead replacement petrol	0.02569	0.018026	0.0256903
	Unleaded petrol	0.0239	0.0168	0.0239
	Diesel	0.499603	0.348845	0.4996028
	LPG	0.00273	0.00191	0.00273
Light commercial	Leaded petrol	0.0421	0.0295	0.0421
	Lead replacement petrol	0.029877	0.020935	0.0298774
	Unleaded petrol	0.0272	0.0191	0.0272
	Diesel	0.529404	0.371634	0.5294036
	LPG	0.00262	0.00183	0.00262
Heavy duty	Leaded petrol	0.093725	0.06564	0.093725
	Lead replacement petrol	0.066515	0.046583	0.0665145
	Unleaded petrol	0.03042	0.021255	0.03042
	Diesel	1.578832	1.103684	1.5788324
	LPG	0.007708	0.005393	0.007708
Motorcycle	Leaded petrol	0.0176	0.0124	0.0176
	Lead replacement petrol	0.01249	0.0088	0.0124903
	Unleaded petrol	0.013	0.00907	0.013

Emission rates for lead have been modified in a similar fashion to that used for SO_2 although, as noted earlier, data from petrol CoQs was not sufficient to specifically modify leaded and unleaded emission rates. However, the EET Manual unleaded fuel lead content of 0.0014 g/L ratio to the leaded fuel lead content (0.13 g/L) was used to factor down the leaded fuel emission rates for use as the lead replacement petrol emission rates for lead.

Similarly, a weighted value for heavy duty vehicles has been calculated from the EET Manual defaults assuming rigid trucks are 65% and articulated trucks are 35% of heavy duty vehicles respectively. The resulting emission rates for lead based on the factored defaults from the EET Manual are given in **Table 2-7**.

Neither diesel nor LPG fuelled vehicles emit lead compounds.

- **Table 2-7 Emission Rates for Lead**

		Emission Rate (g/km)		
Vehicle Type	**Fuel**	**Arterial**	**Freeway**	**Residential**
Passenger	Leaded petrol	0.0117	0.0082	0.0117
	Lead replacement petrol	0.000126	8.83077E-05	0.000126
	Unleaded petrol	0.000118	0.000082	0.000118
Light commercial	Leaded petrol	0.0136	0.0095	0.0136
	Lead replacement petrol	0.000146462	0.000102308	0.000146462
	Unleaded petrol	0.000134	0.000094	0.000134
Heavy duty	Leaded petrol	0.030275	0.02124	0.030275
	Lead replacement petrol	0.000326038	0.000228738	0.000326038
	Unleaded petrol	0.0001495	0.00010465	0.0001495
Motorcycles	Leaded petrol	0.00571	0.00399	0.00571
	Lead replacement petrol	6.14923E-05	4.29692E-05	6.14923E-05
	Unleaded petrol	0.0000636	0.0000445	0.0000636

2.1.2.6 Speciation Factors for VOCs and PM10

Further speciation of both VOCs and PM10 emissions has been carried out as per the recommended methodology in the EET Manual. The speciation factors have been adopted directly from the EET Manual and multiplied by the calculated grid emissions to give the further NPI substances listed in **Table 2-8** and **Table 2-9**.

- **Table 2-8 VOC Speciation of Motor Vehicle Emissions**

	Weight Fraction			
NPI Substance	**Petrol Exhaust**	**Petrol Evaporative**	**Diesel Exhaust**	**LPG Exhaust**
Acetaldehyde	0.00437		0.155	0.000615
Acetone	0.00286		0.0815	
Benzene	0.0087	0.017	0.0101	0.00000943
1,3-Butadiene	0.0155	0.0018	0.00115	0.0000552
Cyclohexane	0.0135	0.000713	0.000778	
Ethylbenzene	0.0106	0.0019		
Formaldehyde	0.0156		0.0826	0.00178
n-Hexane	0.00773	0.0147		
PAHs	0.00217		0.00667	
Styrene	0.0271	0.000308		
Toluene	0.0106	0.0224	0.0147	
Xylenes	0.0377	0.00992	0.0117	

- **Table 2-9 PM10 Speciation of Motor Vehicle Emissions**

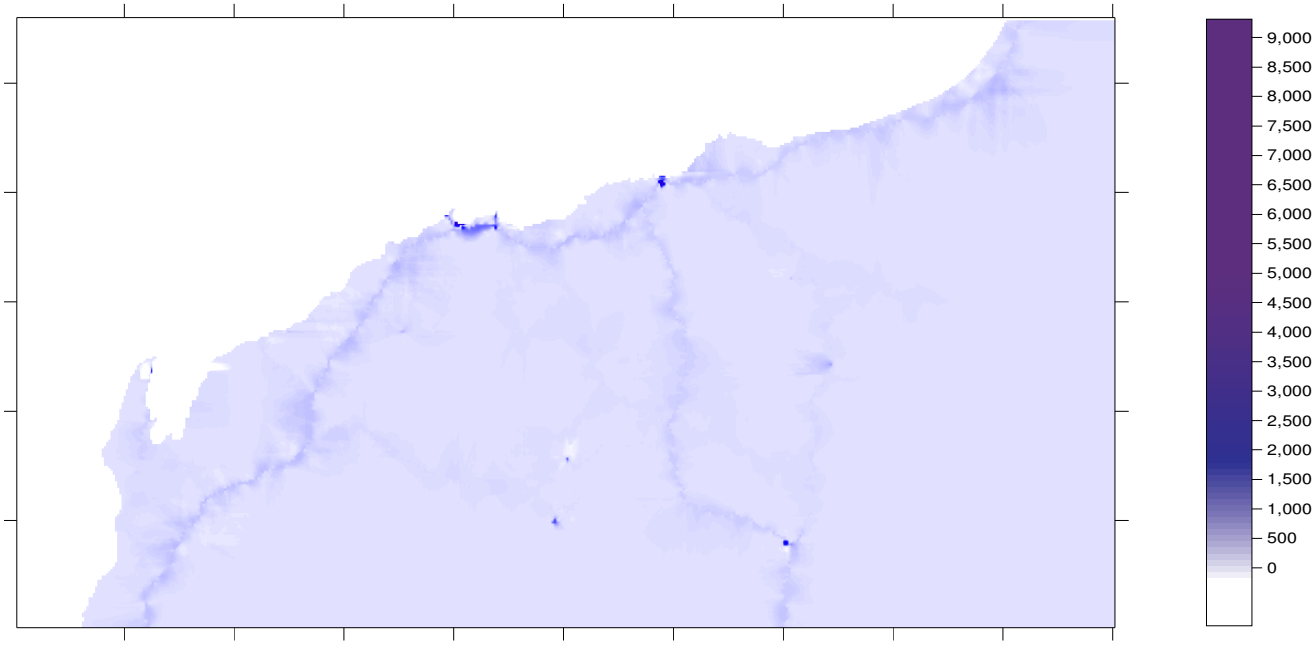
	Weight Fraction			
Substance	**Petrol Exhaust**	**Diesel Exhaust**	**LPG Exhaust**	**Tyre and Brake Wear**
Cadmium and compounds		0.0006		
Chromium (III) compounds	0.00007	0.00007	0.0055	
Chromium (VI) compounds	0.00003	0.00003	0.0055	
Cobalt and compounds		0.0001	0.02	
Copper and compounds	0.0003	0.0001	0.0005	
Lead and compounds		0.0001	0.0005	
Manganese and compounds	0.0002	0.0001	0.0005	
Nickel and compounds	0.0001		0.0055	
Zinc and compounds	0.0051	0.0007	0.0055	0.01

2.1.3 Spatial Allocation

The spatial allocation was performed based on the grid based vehicle kilometres travelled estimates discussed in **Section 2.1.2.3**.

Figure 2-2 below presents the distribution of VOC emissions across the Airshed. It indicates that the majority of the emissions arise from the major highways and towns within the study area.

■ **Figure 2-2 VOC Emissions from motor vehicles (kg per grid cell)**



2.1.4 Emissions

Emissions totals for the entire Pilbara from Motor Vehicles for the 1999/2000 financial year calculated using the above methodology is given in **Table 2-10**.

■ **Table 2-10 Aggregated Emissions from Motor Vehicles for the Pilbara**

NPI Substance Name	Total Pilbara Emissions (kg/year)
Acetaldehyde	10,900
Acetone	5,840
Benzene	4,460
1,3-Butadiene (vinyl ethylene)	3,790
Cadmium & compounds	11.8
Carbon monoxide	2,930,000
Chromium (III) compounds	1.55
Chromium (VI) compounds	0.674
Cobalt & compounds	2.03
Copper & compounds	2.62
Cyclohexane	3,200
Ethylbenzene	2,620
Formaldehyde (methyl aldehyde)	8,810
n-Hexane	3,350
Lead & compounds	546
Manganese & compounds	2.40
Nickel & compounds	0.238
Oxides of nitrogen	711,000
Particulate matter 10.0 um	27,500
Polycyclic aromatic hydrocarbons	918
Styrene (ethenylbenzene)	6,190
Sulphur dioxide	75,300
Toluene (methylbenzene)	5,770
Xylenes (individual or mixed isomers)	10,400
Zinc and compounds	81.8
Total volatile organic compounds	401,000

The NPI grid with the maximum largest vehicle emissions (VOCs = 67,105 kg/year) is the 2 km by 2 km grid located in central Karratha.

2.1.5 Comparison to Other Studies

Comparisons of emissions on a per capita basis with similar recent NPI studies of motor vehicle emissions in Darwin and Alice Springs are given in **Table 2-11**. Only NPI substances common to all three NPI study areas have been compared. However, generally the motor vehicle emissions estimates compare well with those from Darwin and Alice Springs.

■ **Table 2-11 Motor Vehicle Emission Rate Comparison**

	Emission Rates per Capita (kg/yr/person)		
NPI Substance Name	**Pilbara Region**	**Alice Springs**	**Darwin & Palmerston**
Acetaldehyde	0.22	0.021	0.024
Acetone	0.12	0.0004	0.001
Benzene	0.089	0.045	0.090
1,3-Butadiene (vinyl ethylene)	0.076	0.004	0.007
Carbon monoxide	58.50	54.80	101.00
Cyclohexane	0.064	0.009	0.019
Ethylbenzene	0.052	0.035	0.074
Formaldehyde (methyl aldehyde)	0.18	0.050	0.060
n-Hexane	0.067	0.035	0.076
Lead & compounds	0.011	0.035	0.069
Oxides of nitrogen	14.20	27.30	52.30
Particulate matter 10.0 um	0.55	0.54	0.65
Polycyclic aromatic hydrocarbons	0.018	0.0002	0.0005
Styrene (ethenylbenzene)	0.12	0.006	0.013
Sulphur dioxide	1.50	0.92	1.14
Toluene (methylbenzene)	0.12	0.12	0.26
Total volatile organic compounds	8.01	5.68	9.98
Xylenes (individual or mixed isomers)	0.21	0.10	0.23

Both these studies were undertaken by SKM, although a substantially different methodology was used as these studies predated the development EET Manual (May 2000). The Pilbara has similarities with the Darwin and Alice Springs environments and travel patterns, albeit both the Alice Springs and Darwin study areas had larger centralised population bases and were more constrained study areas (i.e. less inter-urban roads).

Comparison of the per capita rates for the various NPI substances shows that the EET Manual methodology estimates compare favourably with those produced with the methodology used in the Darwin and Alice Springs. The exception to this is for acetone with emissions per capita around 200 times those in the NT studies. This difference is due to the NT studies using emission factors for acetone from Parsons Australia (1998) that differ significantly than that in the EET Manual.

Of note is the lower emission rate per capita for lead in the Pilbara, undoubtedly affected considerably by the change to lead replacement petrol at the start of 2000.

2.2 Railways

All rail lines within the study area are operated by private mining companies, namely Robe River, Hamersley Iron and BHP.

Yard and shunting emissions are not reported as these emissions fall under reporting requirements for each mining company.

2.2.1 Data Collection and Information Sources

Electronic data sets of railways for the three operators in the Pilbara were gridded over a 2km by 2km grid. **Figure 2-3** illustrates railway tracks in the study area. These include all lines, except the small line to the new mine of Nimingarra near Yarrie as this had only a small amount of ore railed over the study period. The total length of track within the study area is 955 km.

Data on fuel consumption was obtained from each of the mining companies operating in the study area. The total estimated fuel consumption in the study area is 99.1ML.

2.2.2 Emission Estimation

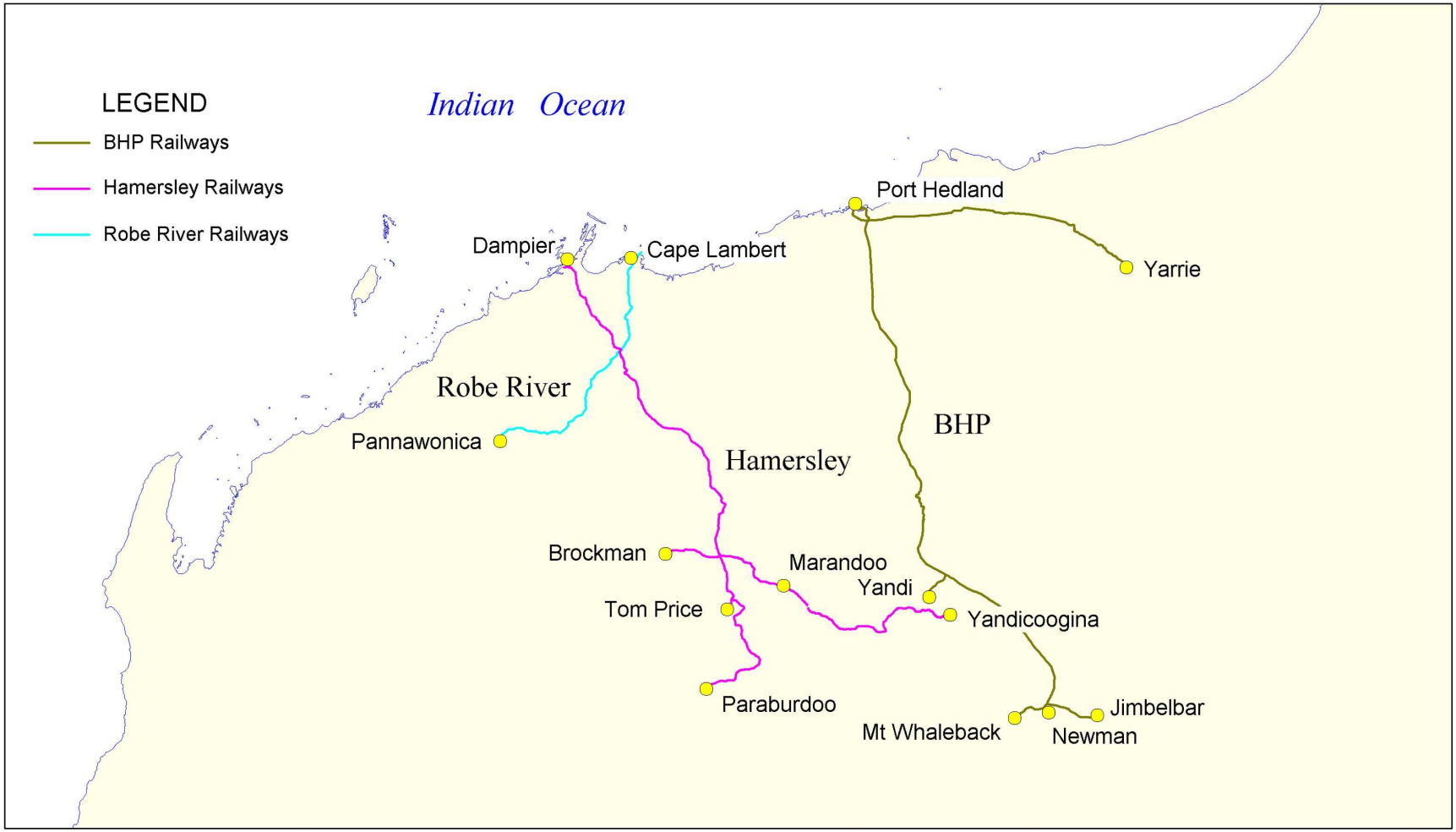
Emissions from trains were estimated using methods outlined in the EET Manual for Aggregated Emissions from Railways (Environment Australia, 1999l).

Emissions are calculated by multiplying the amount of fuel consumed by the appropriate emissions factors for NPI substances. Emissions factors for line haul locomotives and total emissions from railways are summarised in **Table 2-12**.

■ **Table 2-12 Emission factors for line haul locomotives**

Substance	Emission Factor (g/L)	Total Emissions (kg/yr)
Acetaldehyde	0.0755	7,480
Antimony and compounds	1.92×10^{-4}	19.0
Arsenic and compounds	4.17×10^{-6}	0.413
Benzene	0.0440	4,360
1,3-Butadiene	0.0401	3,970
Cadmium and compounds	9.31×10^{-5}	9.22
Carbon monoxide	7.50	743,000
Chromium (III) compounds	8.84×10^{-6}	0.876
Chromium (VI) compounds	3.67×10^{-6}	0.364
Cobalt and compounds	8.34×10^{-6}	0.826
Copper and compounds	4.17×10^{-5}	4.13
Ethylbenzene	3.20×10^{-5}	3.17
Formaldehyde	3.47×10^{-5}	3.44
Lead and compounds	0.0358	3,550
Manganese and compounds	2.08×10^{-5}	2.06
Oxides of Nitrogen	59.1	5,860,000
Particulate Matter (10.0 µm)	1.39	138,000
Polycyclic Aromatic Hydrocarbons	0.0188	1,860
Selenium and compounds	5.56×10^{-6}	0.551
Sulphur dioxide	2.59	257,000
Toluene	0.0445	4,410
Xylenes	0.00711	704
Zinc and compounds	5.56×10^{-4}	55.1
Total Volatile Organic Compounds	2.54	252,000

■ **Figure 2-3 Railway tracks in the Pilbara study area**



2.2.3 Spatial Allocation

Emissions from railways were spatially allocated in proportion to the length of track per grid cell. For the Hamersley operation, information was also obtained on the amount of ore railed between the major towns along the track. This allowed emissions to be spatially allocated more accurately for the Hamersley line running north-south between Dampier and Paraburdoo and east-west between Rosella Siding and Yandicoogina.

2.2.4 Comparison to Other Studies

Total fuel usage within the study area for trains is estimated at around 99.1 ML per year with estimates of emissions of NO_x at 5860 tonnes. For comparison, fuel usage in the Perth study area was 13.44 ML per year with emissions at 794 tonnes/year (SKM, 1999).

2.3 Aircraft

Emissions from aircraft were calculated using a methodology derived from the best practice technique in the EET Manual for Aggregated Emissions from Aircraft (Environment Australia, 2000a) with modification to account for the large number of airstrips (22) and landing points in the study area.

Emissions from aircraft were estimated using aircraft movements in the study region on a 2 km by 2 km grid up to a height of 1,000m as per the brief. Emissions only include those combustion products from the aircraft engines and do not include vehicles used at the airport, losses from fuel tanks and refuelling as these are captured under NPI emissions from these sites.

2.3.1 Emission Estimation:

The best practice methodology outlined in the EET Manual considers the landing/take-off (LTO) cycle and the time in the various cycles. Emission estimates are made by:

- Determining the type and number of engines each aircraft has;
- Determining emission rates for each pollutant for each 'flight' mode, i.e. approach, taxi/idle, take off and climb out for each engine type;
- Determining estimates of the time in mode for each aircraft type and airport;
- For each flight mode, pollutant and airport the aircraft is in, multiplying the modal emission rate by the time in that mode. This is then summed and multiplied by the number of engines to produce the emissions for that aircraft for that landing/take off cycle;
- The emissions per aircraft type are then obtained by multiplying by the number of landings/take-offs at each airport;
- This is then performed for each aircraft type; and
- Summing all the emissions.

The alternative default methodology uses emission factors for four aircraft fleet categories to simplify the emission estimates from the numerous aircraft types. Additionally the emissions are given for LTO cycles that simplify the four "flight" modes into one.

For the Pilbara region, the best practice methodology has been followed. That is, emissions have been calculated based upon individual modes within the LTO cycle and individual aircraft types, not the broad categories as in the default methodology. This approach was adopted, as the aircraft fleet at most of the airstrips was significantly different to the composite aircraft fleet used in the default methodology.

2.3.2 Data Collection and Information Sources

Data required for the estimates includes:

- Location of airports, runways, landing and approach flight paths, and associated ground movements;
- The number of landing/take off (LTO) cycles for each of the aircraft types operating at each airport;
- The prevalence of the different types of engines, and numbers of engines, used by each aircraft type; and
- Time spent in each operating mode (approach, taxi/idle, take off and climb out) for the airport.

Data on aircraft landings was available from only two of the airports (Karratha and Port Hedland) who provided a detailed breakdown of landings. For the other smaller airports and airfields no such detail breakdown exists. Therefore information on the number of landings/take offs were sourced from all aircraft operators who fly in and out of the region. These include:

- Qantas – Airlink;
- Ansett;
- Skywest;
- Bristow who operate helicopters to offshore areas for Woodside, Chevron on Barrow and Thevernard Islands;
- Flying doctor operating out of Port Hedland; and
- Private aircraft operators and private helicopter operators.

For airstrips such as Newman, Onslow, etc no data was obtainable on light aircraft use by pastoralists or other non-commercial users. However, given the small number of non-accounted light aircraft landings at Port Hedland and Karratha using the two methodologies of sourcing landings, this is thought to be small.

In addition to the above sources, the following other sources of aircraft emissions have been excluded:

- Emissions from the use of Learmonth airstrip by the Royal Australian airforce were not included. The RAAF would only comment that around two trips to Learmonth per year were made using Machi and PC9 trainer jets and a helicopter. The number of take offs and landings however was not known and as such no estimates were made.
- Mustering operations or geophysical survey work after they leave the major airstrips. Both these operations typically occur below 100 to 200 m height, but are spread right across the study region and not at an airport/airfield.
- Landing and takeoff from oil and gas platforms and ships. Only emissions from airports and airstrips were considered as advised by the DEP.

The number of resolved flights is summarised in **Appendix A**. This indicates around 21,000 landing/take offs occur in the Pilbara area per annum. For comparison Perth airport has around 110,000 landing/take offs per year (SKM, 1999).

The data in **Appendix A** also indicates a very high percentage of helicopter landing/take offs comprising 38% of movements the study area and 51% at the busiest airport, Karratha. These take offs are also by large helicopters (Sikorsky S76, 12 passengers, 2 pilots and Super Puma, 18 passengers, 2 pilots) compared to 3.2% of take offs from helicopters at Perth airport from smaller helicopters.

2.3.3 Emission Factors and Emission Estimates

Emission factors for the LTO cycles were derived from the EET Manual for all engine types detailed and are presented in **Appendix A**. Additional engine information for aircraft not given in the EET Manual were derived from:

- Scaling emissions from other similar aircraft by the engine power; and
- Pratt and Whittney (1999) for PW125 etc.

Time spent in each operating mode was derived from the standard defaults in the EET Manual. For take off, climbout and approach for aircraft these are considered appropriate as they are not considered to vary widely by location of the airport and the size. However for taxi/idle time it is considered that some are questionable. For example, the turboprop idle time of 26 minutes is derived from the USEPA figures for a busy airport, where the commercial jets were specified with a taxi/idle time of 26 minutes. This figure was revised to 18 minutes in the Manual based on data for Melbourne. SKM (1999) found that for Perth the figure was 14 minutes. As such, for the Pilbara airports with commercial jets, the same time used in the Perth study was assumed. Likewise, for the commercial turboprop aircraft, a time of 14 minutes was used. For piston aircraft the default time of 16 minutes was used in lieu of no data.

For helicopter LTO cycles, discussion with a pilot of the large helicopters operating out of Karratha indicated that the total LTO time was around 25 minutes. Additionally these aircraft only climb out to around 500 m before flying out offshore and do not rise above 1000 m as assumed in the default methodology. Based on this information the taxi times for helicopters was reduced to a total of 14 minutes. This time is much shorter than the default 35 minutes in the manual but is more in line with the 7 and 15 minutes given for civil and military helicopters (USEPA, 1985). For approach and climbout no changes were made due to the default times to produce emissions from the LTO cycle only, which was the original intent of the why the 1,000m (3,000 ft) limit as adopted by the USEPA (1985).

The results for all aircraft emissions estimated in the Pilbara region are summarised in **Table 2-13**.

■ **Table 2-13 Summary of aircraft emissions from landing, taxiing and takeoff in the Pilbara**

NPI Substance	Total Emissions (kg/year)
Carbon Monoxide (CO)	147,400
Hydrocarbons (HC)	45,100
Nitrogen Oxides (NO_x)	32,500
Sulphur Dioxide (SO_2)	7,580
Total Suspended. Particulates (TSP)	0
Total Volatile Organic Carbon (VOC)	49,200
Acetaldehyde	2,290
Acetone	1,210
Benzene	955
1,3-Butadiene	886
Ethylbenzene	84.7
Formaldehyde	7,390
Polycyclic aromatics	522
Phenol	118
Styrene	192
Toluene	256
Xylenes	236
Metals	Not Determined

Note: TSP and PM10 emissions are specified as zero as there were no emission factors for the aircraft given in the EET Manual. Therefore metal emissions in the particulate matter have also not been estimated.

2.3.4 Spatial Allocation

Estimates of emissions for each airfield spatially allocated to grid cells around the airfield according to typical flight paths and out to a distance of 10 km.

The best practice methodology detailed in the EET Manual involves allocating emissions to grid cells based upon the estimated length of the different flight modes (for each aircraft type) within the grid cells. This methodology was not adopted due to the large number of airstrips in the Pilbara region, which would make the best practice methodology impracticably long to undertake.

2.3.5 Comparison to Other Studies

Comparison of the above emissions to those from Perth airport (SKM, 1999) indicate that the NO_x and SO_2 and VOC emissions are around 8.4, 103 and 49% of the emissions from Perth airport (384, 43.6 and 112 tpa respectively). Between aircraft types it is seen that emissions are greatest from helicopters, accounting for 18% of CO emissions, 50% of VOC emissions, 51% of NO_x emissions and 37% of SO_2 emissions.

2.4 Commercial Shipping and Boating

2.4.1 Introduction

Commercial shipping and boating activities in the study area occurs from the ports listed in **Table 2-14**.

■ **Table 2-14 Summary of Ports in the Pilbara Study area**

Port	Major Exports	Major Imports	Commercial Fishing (Reg Boats)	Service Vessels
Port Hedland	Public Port exporting Iron Ore, Salt, Manganese and Cattle	Petrol/Diesel	5	Minor
Point Samson	None	None	17	None
Cape Lambert	Private Port for Robe River Iron Ore	None	0	None
Dampier	Public Port with separate facilities at: Woodside for LNG/LPG and Condensate Hamersley Iron – Iron Ore Mistaken Island – Salt King Bay and Dampier Public Wharf for service vessels	Petrol/Diesel	4	Large number of vessels servicing the oil and gas industry
Onslow	None	None	13	Small amount servicing oil and gas industry
Exmouth	None	None	28 mainly trawlers	Minor with small tourist charter

Note: Commercial fishing from Fisheries WA (2000) with an additional 5 boats registered at Coral Bay.

Additionally there are a number of offshore facilities within the study region that export oil. These are:

- Barrow Island (Chevron);
- Thevenard Island (Chevron);
- Cossack Pioneer Floating Production Storage Offloading facility (FPSO) (Woodside);
- Griffin Venture FPSO (BHP Petroleum);
- Airlie Island (Apache Energy);
- Varanus Island (Apache Energy);
- Stag Floating SO (Apache Energy); and
- Wandoo Concrete gravity structure (Mobil).

Therefore there is a reasonable level of activity from very large vessels (+50,000 tonnes gross weight) in the study area, and a high number of commercial boats servicing the oil and gas industry with a smaller commercial fishing industry.

2.4.2 Data Collection and Information Sources

Within the EET Manual emissions are estimated based on a classification of commercial "ships" and "boats". Ships are defined as cargo ships, passenger ships, chemical tankers, colliers and naval ships. Commercial boats are defined as fishing boats, tug boats, work boats and passenger and cargo boats and other small commercial utility craft. This distinction between boats and ships for cargo vessels is a little unclear with typical terminology being to use the term vessels instead of the classification of ships and boats.

Ship emissions are estimated based on emission rates per hour, therefore data is required regarding berthing and anchorage times, as well as the length of designated shipping channels and average speed in the channels. Boat emissions are based on fuel consumption.

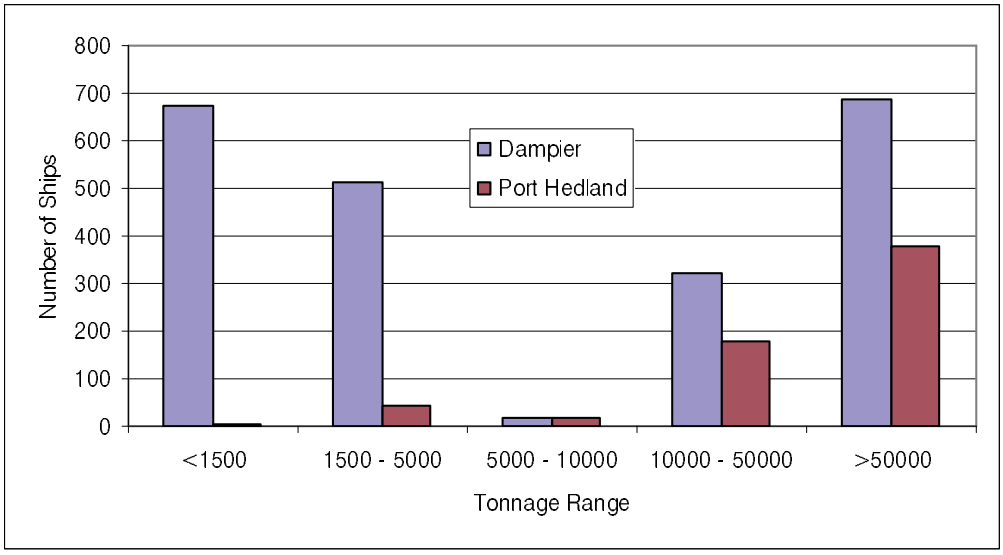
2.4.2.1 Shipping

The two major public ports in the Airshed are located at Port Hedland and Dampier. The locations of the two Ports are shown in **Figure 2-6**. Port Hedland Port Authority and Dampier Port Authority both provided information from July 1999 to June 2000 on the:

- Number of ships berthing;
- Tonnage of ships berthing;
- Cargo imported and exported;
- Average speed in shipping channels (9 knots and 7 knots respectively compared to the EET Manual default of 15 knots); and
- Anchorage times which are an average of 2.5 days at Port Hedland. Discussion with Dampier personnel indicates that this was also a reasonable number for Dampier ships.

The data from these sources is presented in **Figure 2-4** and **Figure 2-5**.

■ **Figure 2-4 Tonnage distribution of commercial ships**



■ **Figure 2-5 Cargo type distribution of commercial ships**

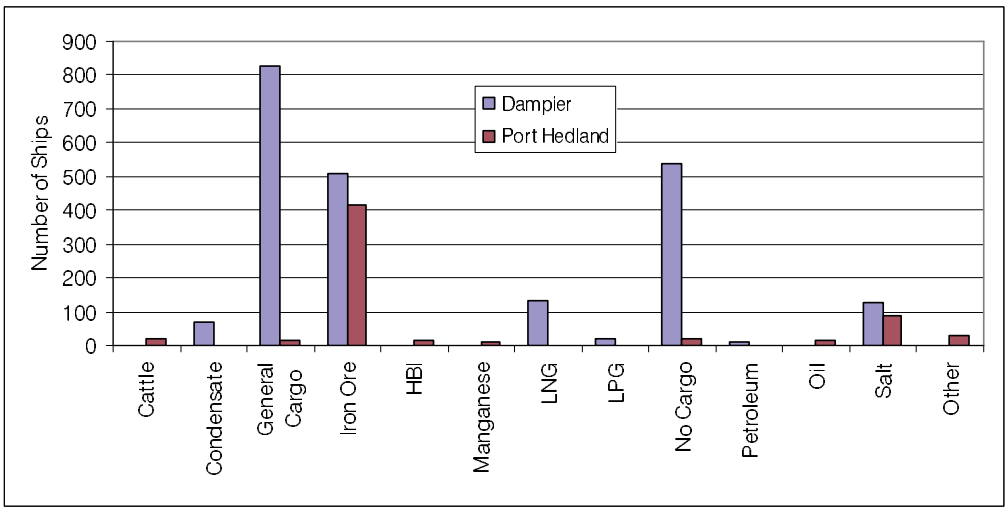


Figure 2-4 and **Figure 2-5** indicates a significant difference between these two ports with a large number of small vessels berthing at Dampier. These small vessels (typically in the range 25 to 2,000 gross tonnes) service the oil and gas industry and travel between Dampier and the Islands and offshore facilities. These vessels dock at either the King Bay or Dampier Public wharf, whilst the large ships berth at the various companies wharves. As these vessels refuel at these wharves, their emissions can be estimated either by the ship methodology or by the boating methodology. In this study the emissions in the port regions have been estimated by the ship methodology as this provides the most accurate means to allocate their contribution in the port, whilst their overall contribution to emissions in the study area have been estimated by their fuel consumption using the boating methodology. For estimates using the ship methodology some adjustments have been made to the standard EET Manual methodology (see **Section 2.4.3.2**).

For the offshore facilities, information on the number of ships, their sizes and berthing times were sourced from the various companies in **Table 2-14**. This data is summarised in **Appendix B**. For these facilities with the low frequency of vessels visiting (generally under 20 vessels per year), no anchorage or waiting time is required. Also for the majority of these facilities, there are no shipping channels with the ship being able to come directly to the off take point and berth.

Cape Lambert berthing data was obtained from Robe River Iron Ore. The average berthing time for the iron ore ships was 49 hours, with anchorage time of 13.5 hours. Additionally, data is collected at Cape Lambert on fuel consumption used by the ships whilst berth.

Time spent by the vessels in the shipping channels were estimated from the channel length and average vessel speed in the channel. For the ports in the study region shipping channel lengths varied from 0 km at the offshore production ships, to 19 – 30 km at Dampier, 29 km at Cape Lambert and 41 km at Port Hedland. Speeds for Ports other than Dampier and Port Hedland were estimated at 7 knots for Cape Lambert and 10 knots at the offshore facilities. Travel time from the end of the shipping channel to outside the study region was estimated from this distance and an average speed of 15 knots, as estimated from a pilot at Dampier.

2.4.2.2 Boating

Emissions from commercial boats depend on their fuel consumption. Information on commercial boating activity and fuel consumption by commercial boats was collected from a number of sources as outlined below:

- Information on locations of fuel bowsers and fuel suppliers obtained from the Department of Transport, boat clubs and Marina operators; and
- Fuel consumption from marine refuelling facilities obtained directly from the fuel suppliers.

The annual fuel usage amounts are presented in **Appendix B** and summarised in **Table 2-15**. This indicates the majority of fuel is used by boats servicing the oil and gas industry, with lesser amounts used by commercial fishing vessels and tugs. Recreational vessels are estimated to use a minor amount compared to the commercial vessels.

■ **Table 2-15 Fuel use from commercial and recreational boats**

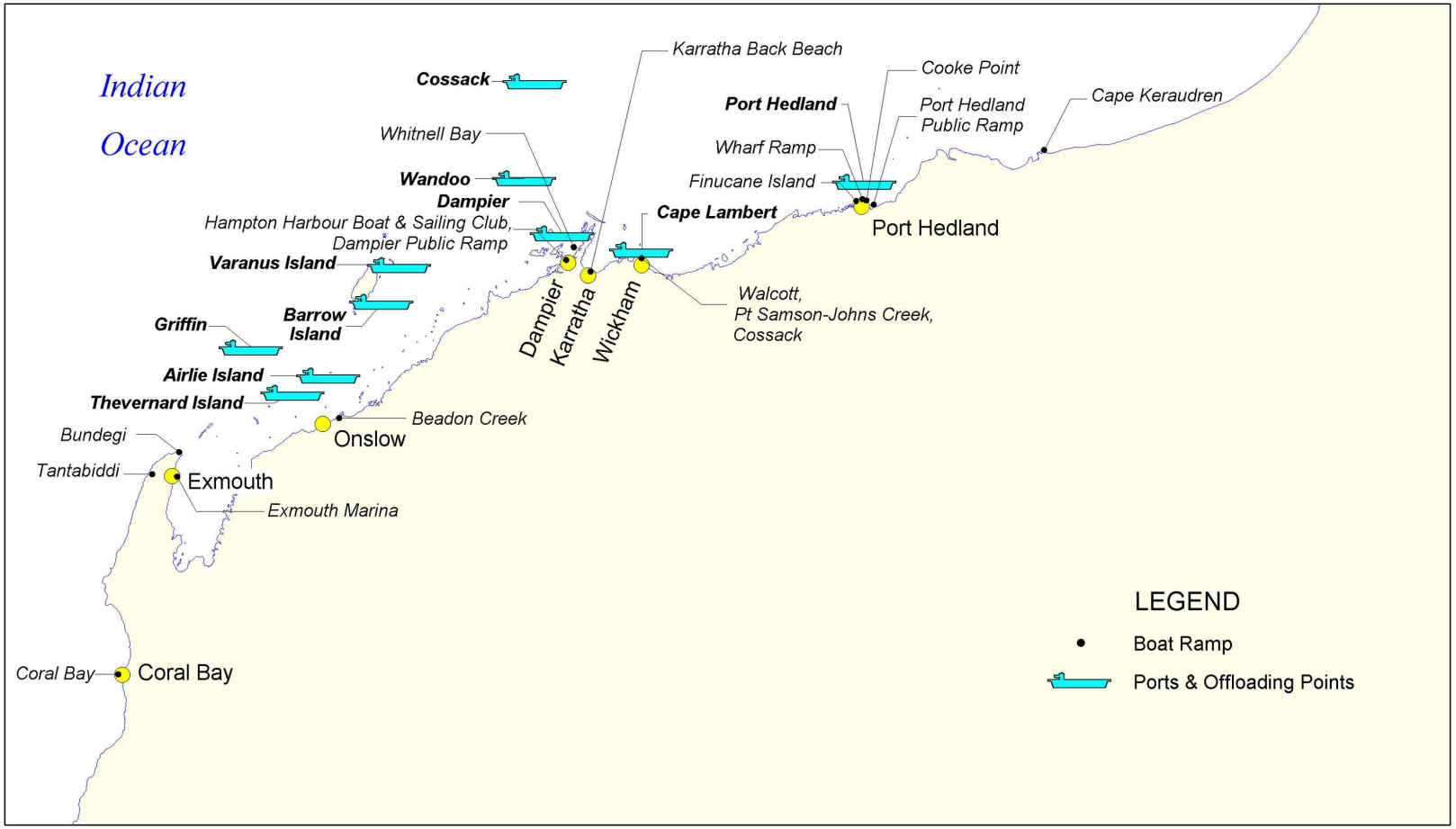
Vessel	Diesel (ML/yr)	Leaded (ML/yr)	Unleaded (ML/yr)
Commercial- Boating	62.6	-	-
Commercial - Fishing	9.1	-	-
Tugs	4.6		
Recreational – Moored	0.535	-	-
Recreational – Trailerable	0.597	0.782	1.37

Notes
1. Commercial and moored recreational boat fuel consumption was derived from fuel sales at marine bowsers
2. Recreational trailerable fuel consumption is derived from survey of usage at Port Hedland extrapolated to study area by households in the study area and proportion of outside boats (see **Section 2.5**).
3. Tug emissions excludes that from Chevron at Barrow Island as this has been reported by Chevron under their facility emissions.

2.4.3 Emission Estimation

Emissions from commercial shipping were calculated based on the prescribed methodology in the EET Manual for Aggregated Emissions from Commercial Ships/ Boats and Recreational Boats (Environment Australia, 1999a).

■ **Figure 2-6 Location of Port Authorities and boat ramps in the study area**



2.4.3.1 Ship - Exhaust Emissions

Emission factors for commercial ships for the different tonnage ranges is presented in **Table 2-16**.

■ **Table 2-16 Emission factors for commercial ships**

Substance	Emission Factor (kg/hr)						
	<400	400 – 1,000	1,000 – 1,500	1,500 – 5,000	5,000 – 10,000	10,000 – 50,000	> 50,000
Main Engines							
Carbon monoxide	0.481	0.481	1.63	1.63	3.03	13.5	28.5
Oxides of nitrogen	1.44	1.44	11.3	11.3	32.5	167	334
Sulphur Dioxide	0.432	0.432	2.59	2.59	35.0	127	254
TSP	0.0374	0.0374	0.224	0.224	0.561	16.8	33.7
VOCs	0.174	0.174	0.6	0.6	1.13	3.41	6.82
Auxiliary Engines							
Carbon monoxide	0	0.2975	0.2975	0.595	1.19	1.19	1.19
Oxides of nitrogen	0	1.665	1.665	3.33	6.66	6.66	6.66
Sulphur dioxide	0	1.0625	1.0625	2.125	4.25	5.66	7.08
TSP	0	0.06	0.06	0.12	0.12	0.9	0.9
VOCs	0	0.109	0.109	0.218	0.436	0.436	0.436

This methodology of grouping the emissions based on broad tonnage classes was checked against emissions based on the engine size from Lloyds (1995). This is presented in **Appendix B** and shows for the main engines:

- For CO, NO_x and PM10, good agreement, though with the EET Manual methodology slightly over predicting emissions. For VOC and SO_2 the EET Manual methodology however significantly over predicts emissions by up to a factor 2. This over-prediction is due primarily to the gross tonnage/power relationship assumed in the EET Manual to derive engine sizes from the more readily obtainable vessel gross tonnage. The EET Manual relationship was derived from a limited number of vessels of gross tonnage up to 50,000 tonnes where a linear line of best fit was fitted. For larger vessels there is a tapering off in engine size with vessel size such that a linear fit will over-predict the engine size for the typical larger vessels used in this study area. Secondly, this over-prediction is due to the mix of vessels used in study area. These vessels comprise bulk carriers and tankers which are lower powered for a given vessel size than higher powered vessels such as container ships. For example, SKM (1999) in the Perth study found that container vessels had main engine sizes around 2.5 times the engine size of bulk carriers for a similar gross tonnage ship. Therefore the EET Manual methodology over-predicts emissions from larger vessels, particularly bulk carriers and oil tankers.

For the auxiliary engine the data shows:

- For vessels greater than 5,000 tonnes there is a slight increase in total auxiliary power with vessel size, with the total auxiliary power increasing to around 2,000 kW for the large iron ore vessels.
- For vessels less than 5,000 tonnes the auxiliary engine size decreases more rapidly and was generally below 400 kW for vessels less than 1000 tonnes.
- There is not much variation in the total auxiliary power between iron ore, petroleum and oil tankers. However the LPG and LNG tankers have larger total installed auxiliary engine capacity than other vessels, with some vessels having 8,000 kW of auxiliary power. For the LNG and LPG tankers, these engines are associated with the refrigeration systems on these vessels.

Therefore from the above, with the large number of small vessels at Dampier the default auxiliary engine size was modified. From discussions with vessel operators the following was used:

- Vessels of less than 300 gross tonnes were assumed to not have or operate auxiliary engines whilst at berth.
- Vessels in the range 400 to 1,500 gross tonnes were taken to have 150 kW of power (taken from discussions that indicate that the auxiliary engines were in the order of 200 to 300 kW with these run when at berth at around 50% load).
- For vessel between 1,500 and 5,000 gross tonnes a value of 300 kW was used.
- From discussion with the operators berthing times for vessels less than 1,500 tonnes were taken as 18 hours and in the range 1,500 to 5,000 tonnes as 32 hours.
- For the larger vessels, the default power usage of 600 kW was adopted. This was used though there it is indicated, especially for the LNG/LPG tankers that they have a larger auxiliary power use. From discussions (Dampier Port Authority, Copeman, L., personal communication, 2000), auxiliary power requirements are typically less when at berth and will be higher when at sea.

Further, given the slow speeds used in the shipping channels, relative to their open sea speeds, the emissions whilst travelling in the shipping channels were reduced. From Lloyds (1995) emissions from slow speed main engines are essentially linearly related to the power. For the shipping channels, discussion with an ex captain (Dampier Port Authority, Copeman, L., personal communication, 2000) indicated that the ships would use around 50-60% of their engine rating in the channels, whilst 80-90% on the open sea. Therefore the power and therefore emissions per hour during travel through the shipping channels was taken as 55/85 (65%) of the stated NPI emissions. (The NPI emissions are based on an assumed 85% engine load).

Estimates of emissions using the above were made at each of the ports and offshore facilities at berth, anchorage (if applicable), in the shipping channel (if applicable) and for travel to and from the Port. For the Port of Dampier, because the wharves are spread over a distance of 15 km, each separated by several kilometres, the individual wharves were considered as individual berthing points. These are the Hamersley Iron wharves at Parker Point and East Intercourse Island, Dampier Salt Mistaken Island wharf, Woodside Wharf LNG/LPG facilities, Woodside's King Bay facilities for service vessels and the Dampier Public Wharf.

2.4.3.2 Ship - Loading and Ballasting Emissions

Loading of liquids in the study region occurs for only crude oil and condensate from the Woodside facilities. According to the EET Manual emissions from loading need only be considered for loading petroleum products with higher vapour pressures. Therefore emissions from loading have been discounted as negligible in this study.

Ballasting occurs after unloading of petroleum liquids at marine terminals when seawater (the ballast) is loaded into several compartments to improve the stability of the ship. Ballasting emissions occur as the ballast displaces the vapour laden air to the atmosphere. Within the study area petrol and distilate cargo is unloaded at Dampier and Port Hedland (226,000 and 242,000 tpa respectively). To estimate emissions from ballasting the following has been assumed:

- EET Manual default values of unloading of ballast water intake of 3.211 L/DWT with 0.05 of this loaded at berth;

- An average dead-weight tonnage from the Port Hedland data was used for both ports; and
- 11 and 15 ships that unloaded fuel at Dampier and Port Hedland respectively.

Using these calculations, total VOC emissions from all ships for the period were around 25 kg at Port Hedland. As this compared to emissions of 11,000 kg from the auxiliary engines during berthing these emissions were neglected. Further, discussions with BP (BP Refinery, King, A., personal communication, 2000,) indicates that vessels have separate compartments for ballast water, such that no VOCs are displaced during ballasting operations.

2.4.3.3 Boat – Exhaust Emissions

Emission factors used for estimating emissions from commercial boats are summarised in **Table 2-17**.

■ **Table 2-17 Emission factors for Commercial Boating**

Substance	Emission Factor (g/L)		
	Inboard Diesel	Inboard Petrol	Outboard Petrol
Carbon monoxide	13	149	400
Lead and compounds	-	0.116 (0.00162)(1)	0.116 (0.00162)(1)
Oxides of nitrogen	32	15.7	0.79
Sulphur dioxide	2.1	1.04 (0.304)(1)	1.04 (0.304)(1)
TSP	3.5	0.195	0.195
VOCs	6.0	9.49	120

Notes:
1. Values for leaded and (in brackets) unleaded petrol.

2.4.4 Spatial Allocation

Emissions from the shipping operations were estimated (see **Appendix B**) for each port and for each of the categories:

- At berth;
- In the shipping channel if this exists;
- At anchorage; and
- For travel from outside the shipping channel to outside the study region.

Each port's emissions at berth and at anchorage were allocated according to their respective locations. Shipping channel emissions and travel outside the shipping channel were distributed evenly along the Ports shipping channel and an assumed path outside the channel to the edge of the study region

Commercial boat emissions were determined by the total fuel usage. Spatial allocation for the boats using the King Bay facilities was determined by estimating the emissions at berth and in the shipping channel using the ship methodology and allocating to this area. The remainder of the emissions were allocated between the major destimations (North Rankin area and out to Barrow and Thevenard Islands). Commercial fishing was allocated by survey of fishing boat days in the Pilbara area supplied by Fisheries WA (Sumner, 2000).

2.4.5 Emission Estimates

Emissions from commercial ships and boats are presented in **Appendix B** and are summarised in **Table 2-18.** This indicates that emissions from commercial shipping predominate for emissions such as NO_x and SO_2, whilst that from commercial boats

predominate for VOC. Emissions from commercial shipping are shown to be relatively small.

■ **Table 2-18 Commercial Shipping and Commercial Boating Emissions**

Substance	Commercial Ships (kg/yr)	Commercial Boats (kg/yr)	Commercial Fishing (kg/yr)	Total (kg/yr)
Carbon Monoxide (CO)	766,402	1,141,988	154,186	2,062,577
Nitrogen Oxides (NO_x)	7,567,977	2,754,207	371,860	10,694,044
Sulphur Dioxide (SO_2)	6,087,547	141,069	19,047	6,247,663
Total Susp. Part. (TSP)	804,769	235,115	31,744	1,071,628
Volatile Organics (VOC)	215,003	1,477,867	199,535	1,892,405
benzene	4,107	28,227	3,811	36,145
1,3-Butadiene	3,397	23,350	3,153	29,900
Toluene	4,150	28,523	3,851	36,523
Xylenes	2,133	14,660	1,979	18,773
Arsenic & Compounds	69.5	15.7	2.12	87.3
Cadmium & Compounds	1.76	1.63	0.22	3.61
Chromium (VI) compounds	7.31	1.82	0.25	9.37
Cobalt & compounds	45.1	11.1	1.50	57.7
Lead & compounds	13.5	15.4	2.07	30.9
Mercury & compounds	1.61	3.93	0.53	6.07
PM < 10um	804,769	235,115	31,744	1,071,628
PAHs	6.59	25.6	3.46	35.7

Note: Commercial boating includes service vessels to the oil and gas industry and tugs.

2.4.6 Comparison with Other Studies

Emissions from this study and from the Perth Airshed and Port Phillip Region study are presented in **Table 2-19**. This indicates fair agreement between the studies with nitrogen oxides, sulphur dioxide and carbon monoxide being the major pollutants in each study. Comparison between the largest individual port emitter in the Pilbara (Dampier) indicates that the emissions are around 60% and 33% of the Perth and Port Phillip region emissions respectively for most substances. The PM10 and VOC emissions from Perth are relatively smaller than expected in comparison to the other two studies.

■ **Table 2-19 Emissions from Ships and Commercial Boats for Selected Studies**

Substance	Pilbara (kg/yr)	Dampier (kg/yr)	Perth (kg/yr)	Port Phillip Region (kg/yr)
Carbon Monoxide	2,050	189	296	1,730
Nitrogen Oxides	10,700	1,450	2,593	4,540
Sulphur Dioxides	6,250	1,083	1,607	3,225
PM10	1,070	146	83	421
VOC	1,880	100	86	900

Notes: Perth data from SKM (1999) and Port Phillip Bay from EPAV (1998)

2.5 Recreational Boating

2.5.1 Data Collection and Information Sources

Fuel consumption information was used to calculate emissions from recreational boats. The domestic survey conducted in Port Hedland and Marble Bar (see **Section 3.2**) included questions on:

- Boat ownership;
- The type of engine (inboard or outboard, horsepower, 2 or 4 stroke or diesel);
- Boat use; and
- Amount of fuel used.

The Department of Transport also provided recreational boat registrations by postcode and size of boat for the Pilbara area. Additionally, Fisheries WA had information on use of boat ramps in the Pilbara area between December 1999 and July 2000. Since Exmouth and Coral Bay, at the southern end of the study area, are popular fishing destinations for people residing in Perth and other places outside of the study area, information on postcode of origin for people using boat ramps was collated from over 2000 surveys collected by Fisheries WA. The location of boat ramps in the study area is shown in **Figure 2-6**.

2.5.2 Emission Estimation

Emissions from recreational boating were estimated using the EET Manual for Aggregated Emissions from Commercial Ships/ Boats and Recreational Boats (Environment Australia, 1999a) with an additional factor introduced to account for non-local boats.

$$E = F * N * \sum c_i * p_i * e_i \qquad \textbf{Equation 2.2}$$

Where

E is the annual emissions from recreational boats in the Airshed (kg/yr);
N is the number of households in the Airshed;
c_i is the average fuel consumption of recreational boats with engine type i, 10^3 L /household/year;
p_i is the number of households which own boats with engine/fuel type i;
e_i is the emission factor for boats with engine/fuel type i g/L; and
F factor to account for non-local boat usage = (total boats/local boats).

Emission factors used for recreational boating are summarised in **Table 2-20**.

■ **Table 2-20 Emission factors for recreational boats**

Substance	Emission Factor (g/L)		
	Inboard Diesel	Inboard Petrol	Outboard Petrol
Carbon monoxide	17	149	400
Lead and compounds		0.116 (0.00162)[1]	0.116 (0.00162)[1]
Oxides of nitrogen	41	15.7	0.79
Sulphur dioxide	2.1	1.04 (0.304)[1]	1.04 (0.304)[1]
TSP	3.5	0.195	0.195
VOCs	22	9.49	120

Notes:
1. Values for leaded and (in brackets) unleaded petrol

Data for the average fuel consumption for engine and fuel type were obtained from a domestic survey from the Port Hedland and Marble Bar as summarised in **Table 2-21**.

■ **Table 2-21 Fuel consumption for recreational boats**

Engine/Fuel	Percentage of Vessels (%)	Average Fuel Consumption (L/year)
Inboard Diesel	9.5	905
Inboard Petrol	7.1	905
Outboard Petrol –Leaded	23.8	294
Outboard Petrol – Unleaded	59.6	294
Total or Average	100.0	378

Notes:
1. 66% of inboard petrol engines use leaded fuel.
2. Inboard diesel and petrol fuel consumption was determined as an average of the two due to the low number of vessels involved. Likewise an average of outboard unleaded and leaded fuel consumption was determined.
3. Outboard engines comprised 14% 4 strokes and 86% 2 strokes.

The number of households with various engine/fuel types was estimated using the total registered recreational boats in the study region (4,516), (DOT, Innes, C., personal communication, 2000) multiplied by the vessel breakdowns reported in **Table 2-21**.

Equation 2.2 was modified to include an additional factor (F) to account for non-local boat usage in the study region. This was defined as total boat usage/local usage. These factors were determined from the Fisheries WA surveys at the various boat ramps and is summarised in **Table 2-22**.

■ **Table 2-22 Local and non-local boat ramp usage in the Pilbara**

Boat Ramp	Percent Local (%)	Non Local Factor (Total/Local Boats)	Boat ramp usage as a percentage of all boat ramps (%)
Cossack	96.0	1.04	1.0
Dampier Public Ramp	98.0	1.02	18.2
HHBSC	97.2	1.03	7.3
Johns Creek	100.0	1.00	0.5
Karratha Back Beach	99.4	1.01	12.9
Point Samson	94.6	1.06	1.5
Walcott	100.0	1.00	0.4
Whitnell Bay	100.0	1.00	1.4
Beadon Creek	100.0	1.00	0.6
Cape Keraudren	82.4	1.21	0.7
Coral Bay	17.9	5.60	19.4
Bundegi	26.6	3.77	7.3
Marina	53.3	1.88	3.8
Tantabiddi	20.4	4.91	11.1
Port Hedland Public Ramp	97.4	1.03	6.4
Finucane Island	91.5	1.09	1.9
Port Hedland Wharf Ramp	100.0	1.00	0.1
Onslow	59.7	1.68	5.3
Average	**64.7**	**1.55**	**100.0 (Total)**

This indicates a substantial variation across the study region, with usage from boat ramps from Exmouth south being dominated by non-local boats, with much fewer non-local boats from Exmouth north. For **Equation 2.2** the overall factor of 1.55 was used to multiply the study area fuel usage (or emissions). This assumption is valid if the fuel usage per trip (therefore boat size) is the same as for local and non-local boat trips.

Using the percentage boat distribution and average fuel consumption figures from the Port Hedland survey, the number of registered recreational boats in the study area, and the factor of non-local boats, total fuel consumption for recreational boats in the study area was derived as presented in **Table 2-21**.

2.5.3 Spatial Allocation

Boat ownership by household varies markedly across the study region as presented in **Table 2-23**.

■ **Table 2-23 Household boat ownership**

Town	Household Boat Ownership (%)
Karratha	43.6
Dampier	29.3
Port Hedland	14.0
Newman	4.8
Tom Price	4.0
Exmouth	26.3
Study Area	**23.9**

The coastal town of Dampier recording the highest with 43.6% boat ownership and lowest at inland towns of Newman and Tom Price with under 5% ownership. To account for variations in usage, emissions from recreational boats from the entire study area were allocated by the boat ramp usage as presented in **Table 2-22**. At each boat ramp these were then approximately distributed in the area by the trip destinations as indicated by the Fisheries boat survey records.

2.5.4 Emission Estimates

Annual emissions from recreational boats are presented in **Table 2-24**.

■ **Table 2-24 Recreational boat emissions for the Pilbara Study Area**

Substance	Emissions (kg/year)
Carbon Monoxide	758,848
Lead and Compounds	93
Oxides of nitrogen	32,878
Sulphur Dioxide	2,486
VOCs	222,025
Arsenic and Compounds	0.140
Cadmium and Compounds	0.015
Chromium (VI) compounds	0.078
Cobalt and compounds	0.309
Mercury and compounds	0.035
PM10	2,403
Benzene	8,711
1,3-Butadiene	2,255
PAHs	453
Toluene	26,363
Xylenes	8,130

2.5.5 Comparison to Other Studies

Emissions from the Perth Airshed for recreational boats were estimated at 210 tpa, 363 tpa and 16.3 tpa for NO_x, VOC and PM10 respectively. These compare to the Pilbara study region of 33 tpa, 222 tpa and 2.4 tpa respectively. On a per capita basis emissions of the three substances are 0.165, 0.286 and 0.013 kg/person/year and for the Pilbara study region 0.66, 4.43 and 0.048 kg/person/year. As such emissions from the Pilbara region are 4, 15.5 and 3.7 times per capita than for the Perth region. The approximate four times increase in NO_x and PM10 is due to the relative high usage of boats for recreational purposes in the Pilbara (23.9% households with boats compared to 8% Perth, SKM, 1999) and also to the high percentage of boat usage from people outside the study region. For comparison EPAV, 1996 found boats usage of 12.8%, 5.4% and 14.1% for Port Pirie, Newcastle and Launceston. The 15.5 times higher emissions per capita in VOC emissions is due both to higher boat usage and much larger proportion of outboard usage in the Pilbara.

3. Domestic and Commercial Sources

3.1 Introduction

The purpose of this phase of the project is to estimate area based emissions from domestic and commercial sources that are too small to trigger the NPI reporting thresholds.

3.2 Domestic Surveys

To account for the wide range in population centres in the Pilbara study region (see **Section 1.1**) three different categories were used to distinguish between population centres with likely different lifestyles and consumption patterns. These categories were:

- Typical urban centres, such as Karratha and Port Hedland. These account for 86.8% of the study area population.
- Aboriginal communities, such as Jigalong, where many of the goods are provided through a central "store". These communities account for 2.53% of the population; and
- Mining camps, such as Telfer, where the "residents" are flown in and out on a shift basis. As such these camps provide all services to the "residents" with typically little movement outside the camp and little time for activities other than work. These camps account for 2.25% of the population.

Additionally a fourth category of residences with less than 50 people could also be defined, such as would occur for homesteads, small mining camps (Thevenard Island) and small Aboriginal communities. This category accounts for 8.4% of the study area population.

Three surveys were conducted to determine usage of fuels for the following activities:

- Heating;
- Cooking;
- Barbecue activities;
- Garden/landscaping equipment;
- Marine engines; and
- LPG gas fuelled recreational equipment e.g. caravans.

The first survey, for "typical" urban centres, was conducted by telephone by Patterson Market Research. This was undertaken on the weekend of the 8 - 9 July 2000 and included survey of two hundred and seven residents from Port Hedland, and 20 from the inland town of Marble Bar. These towns were considered to be representative of a typical large urban centre and a smaller inland centre, primarily to ascertain differences that might occur in usage of garden equipment, heating fuel and marine craft. Sample size for both was chosen to reduce sample error to around 7%, which is thought acceptable for the purposes of this study.

Sampling for both towns was conducted by means of a random dial process of an electronic database of the 'white pages' telephone listings for those regions. Households that could not be contacted on the first attempt were called a minimum of two further occasions over the course of the interviewing schedule. A number of validation interviews were also completed as a quality check on responses.

A survey of a typical fly in – fly out mining camp was conducted of Hamersley Iron by telephone. An attempt was made to survey the Telfer camp, however, the operation was closed down recently and only limited information was available. Likewise a survey of fuel usage at the Jigalong Aboriginal community was conducted by telephone and mail out to the administrators, and information was provided on solid and gaseous fuel use, and use of garden and landscaping equipment.

The results of the findings have been used to estimate emissions from a number of domestic sources. Detailed survey results and a summary of the findings are presented in **Appendix C**.

3.3 Domestic/Commercial Solvent and Aerosol Use

This category refers to products containing solvents that are used in a wide variety of domestic and commercial applications including:

- Personal care products;
- Household cleaning products;
- Motor vehicle aftermarket products;
- Adhesive and sealant products;
- Pesticide and herbicide products;
- Coatings and related products; and
- Miscellaneous products.

Volatile organic compounds (VOCs) are emitted from these products during use. The recommended techniques for estimating emissions from domestic and commercial solvent and aerosol use rely on per capita usage for the various products. These factors have been derived from comprehensive research undertaken in the United States and it is assumed that the use of these products in Australia is comparable to that is the USA.

3.3.1 Data Collection and Information Sources

Population data only was required for estimating emissions from this source.

3.3.2 Emission Estimation

Emissions were calculated using the technique described in the EET Manual for Aggregated Emissions from Domestic/Commercial Solvent and Aerosol Use (Environment Australia, 1999c). The total population of the Airshed is 50,108. Emissions were calculated using the following equation:

$$E_i = TEF_i \times P \qquad \textbf{Equation 3.1}$$

Where

E_i = total Airshed emissions of VOC species i (kg/yr);
TEF_i = total emission factor for VOC species i (kg/yr/person); and
P = population of the Airshed.

It was assumed that no control strategies were used to reduce emissions of total and speciated VOCs from this source. Emission factors and total emissions for the relevant compounds are summarised in **Table 3-1**. The emission factors have been adjusted to account for biodegradation of VOCs and therefore relate entirely to atmospheric emissions.

■ **Table 3-1 Emission factors and total emissions from domestic/commercial solvent and aerosol use**

Substance	Emission Factor (kg/yr/person)	Total Emissions (kg/yr)
Acrylic acid	1.79×10^{-9}	8.97×10^{-5}
Benzene	2.14×10^{-6}	1.07×10^{-1}
Chloroform	4.49×10^{-4}	2.25×10^{1}
1,2-Dichloroethane	2.12×10^{-6}	1.06×10^{-1}
Dichloromethane	1.65×10^{-2}	8.27×10^{2}
Ethylbenzene	9.42×10^{-4}	4.72×10^{1}
Ethylene oxide	6.85×10^{-3}	3.43×10^{2}
Formaldehyde	5.75×10^{-4}	2.88×10^{1}
Ethylene glycol	4.14×10^{-2}	2.07×10^{3}
Fluoride compounds	6.44×10^{-6}	3.23×10^{-1}
n-Hexane	3.91×10^{-2}	1.96×10^{3}
Hydrochloric acid	7.94×10^{-7}	3.98×10^{-2}
Methanol	3.19×10^{-1}	1.60×10^{4}
Methyl ethyl ketone	2.29×10^{-2}	1.15×10^{3}
Methyl isobutyl ketone	3.44×10^{-3}	1.72×10^{2}
Tetrachloroethylene	1.28×10^{-2}	6.41×10^{2}
Toluene	1.94×10^{-1}	9.72×10^{3}
Trichloroethylene	2.20×10^{-4}	1.10×10^{1}
Xylenes	9.21×10^{-2}	4.61×10^{3}
Total VOCs	5.15	2.58×10^{5}

3.3.3 Spatial Allocation

Emissions from domestic/commercial solvent and aerosol use were spatially allocated proportionally to the population distribution on a 2 km by 2 km grid.

3.3.4 Comparison to Other Studies

Comparison to the South East Queensland (SEQ) study (QDEH, 1999) indicated good agreement with emissions on a per capita basis. Differences were found in substances such as Benzene and VOC that were due to the SEQ study apparently using different emission per capita values.

3.4 Industrial Solvents (Sub-Threshold)

This category estimates emissions from the industrial use of solvents exclusively for solvent degreasing and surface cleaning. Metalworking industries are the major users of solvent degreasing processes. The types of equipment used for solvent degreasing are categorised as vapour degreasing, cold degreasing and conveyorised degreasing.

3.4.1 Data Collection and Information Sources

The EET Manual for Aggregated Emissions from Use of Industrial Solvents (Sub-threshold) (Environment Australia, 1999n) requires the acquisition of accurate sales data of trichloroethylene on a national and jurisdiction level from Stelco Chemicals. Sales are assumed to be equal to consumption which is then scaled to Airshed level by use of either employee numbers or population figures.

Stelco Chemicals provided information on distributors in WA and also noted that, compared to New South Wales and Victoria, very little trichloroethylene was distributed in WA (Stelco Chemicals, Bradley, A., personal communication, 2000,). Stelco Chemicals was not able to supply State sales figures for trichloroethylene and although national sales figures were available, scaling national sales figures to population for the Pilbara was considered not necessarily indicative of use. Three distributors of trichloroethylene in the Perth area (APS, Spectrum Distributors,

Consolidated Chemicals) were contacted and provided information on state sales figures. However, all three distributors indicated that, to their knowledge, there were no current customers in the Pilbara area. One distributor suggested that trichloroethylene may be too volatile for use in the Pilbara and that alternative products may be used. The distributors also noted that non-chlorinated solvents are more commonly in use now as well as other newer technologies for degreasing.

3.4.2 Emissions Estimation

The default method outlined in the EET Manual is an emission factor based on the total population in the study region. This method was used for the Kalgoorlie Mining Trial Aggregated Emissions Inventory. However, based on the information above, we believe that this will result in a gross overestimation of emissions. Therefore for the Pilbara study area, emissions of all compounds from industrial solvents (sub-threshold) is assumed to be zero. NPI substances that are emitted from this source include trichloroethylene and volatile organic compounds.

3.4.3 Spatial Allocation

No spatial allocation was required as emissions were assumed to equal zero.

3.5 Cutback Bitumen

Bituminous materials used in road construction and maintenance emit volatile organic compounds (VOCs). Cutback bitumen primer and primer binder are commonly used in spray sealing operations. The bitumen is 'cut back' by blending with solvents (the 'cutter') to enable the bitumen to be used for spray sealing. Cutback bitumen is the major source of VOCs resulting from the evaporation of the cutter oil used to reduce the viscosity of the bitumen. The largest source of emissions is from the road surface. Methods of road surfacing and associated VOC emissions vary significantly between regions due primarily to variations in temperature.

3.5.1 Data Collection and Information Sources

The majority of road maintenance and construction activities in the Pilbara region are carried out by:

- Boral Asphalt;
- Pioneer Road Services; and
- CSR Emoleum.

Approximate usage of bitumen, cutter oil (kerosene) and flux oil (diesel) for the past year was obtained from each company. The use of flux oil was assumed to be negligible as it is primarily used in colder areas such as the south west of WA (Pioneer Road Services, Hall, J., personal communication, 2000). In the Pilbara, the pavement temperatures are high enough to use just cutter oil.

3.5.2 Emission Estimation

Aggregated emissions from cutback bitumen were estimated using prescribed methods outlined in the EET Manual for Aggregated Emissions from Cutback Bitumen (Environment Australia, 1999b). Emission estimates were made using volumes of cutter oil consumed as this was the best practice methodology outline in the EET Manual. A total volume of cutter oil used in the Pilbara over the past year is summarised in **Table 3-2**.

■ **Table 3-2 Cutter oil consumption**

Activity	Cutter Oil Volume (L/yr)
Resealing	15,000
Construction	50,000

Material safety data sheets (MSDSs) for cutter oil indicate a specific gravity of between 0.808 and 0.825. Default properties of fraction evaporated (65%) and density (0.813) were used.

Total VOC emissions from cutback bitumen was calculated using:

$$E_{VOC,cutter} = T_c\ (d_c * 10^{-2})\rho_c \qquad \textbf{Equation 3.2}$$

Where:

$E_{VOC,cutter}$ = total VOC emissions from use of cutter oils (kg/yr)
T_c = Total cutter oil consumption in the Airshed (L/yr)
d_c = Fraction of cutter oil evaporated = 65%
ρ_c = Density of cutter oil = 0.813 kg/L

Table 3-3 summarises total VOC emissions and emissions of VOC speciated compounds.

■ **Table 3-3 Total emissions and speciation of VOC compounds from cutback bitumen operations**

Compound	Weight (%)	Total Emissions (kg/yr)
Total VOCs	100.0	50,200
Benzene	0.00575	2.9
Biphenyl	0.017	8.5
Cumene	4.05	2030
Cyclohexane	0.00025	0.1
Ethylbenzene	0.278	140
n-Hexane	0.00025	0.1
PAHs	0.32	161
Styrene	0.0008	0.4
Toluene	0.171	85.8
Xylenes	1.42	713

3.5.3 Spatial Allocation

Gridded VKT data for paved roads was used for the spatial allocation of emissions on a 2 km by 2 km grid. This assumes that roads with more traffic require proportionally more maintenance.

3.5.4 Comparison to Other Studies

The Kalgoorlie NPI trial estimated emissions from cutback emissions for two substances; VOC and xylenes. These were estimated at 9,990 and 1,900 kg/year respectively or on a per capita basis as 0.32 and 0.061 kg/person/year. The Pilbara study area emissions are estimated at 50,200 and 713 kg respectively or on a per capita basis of 1.0 and 0.014 kg/person/year. The larger value per capita for VOC for the Pilbara is due to the larger road network there. The discrepancy in xylene emissions is due to the different VOC speciation used in the studies, with Coffey Geosciences (1999) using a speciation based on a reference that suggested that xylene was 19% of the VOC emissions as opposed to 1.42% in the EET Manual.

3.6 Service Stations

Evaporative fuel losses from service stations and fuel distribution activities are due to the following:

- Transfer of fuel from delivery tankers to underground storage tanks at service stations;
- Refuelling of motor vehicles; and
- Breathing of the underground fuel storage tanks with changes in temperature and pressure.

There are generally two methods of fuel transfer from delivery tankers to underground tanks: splash filling involving lowering the outlet pipe above the liquid surface, and submerged filling, where the outlet pipe is lowered below the fuel level.

3.6.1 Data Collection and Information Sources

A commercial survey was carried out of service stations in the study area to estimate the amount of fuel sold, broken down into different fuel types and fuel handling practices.

The total number of service stations in the study area is 33. Commercial surveys were issued to 15 service stations and a response was received from 5 (including one who included wholesale figures). Average annual fuel sales (L) of the different fuel types are summarised in **Table 3-4**.

Monthly fuel sales information for automotive fuels in WA was obtained from the Department of Industry, Science and Resources, Petroleum Industry Branch (DISR, 2000) and a per capita fuel consumption figure was calculated for the Pilbara area. These figures for petrol and diesel are contained in **Table 3-4**. The per capita automotive fuel consumption figures for petrol derived from the service station survey are 50% lower than those derived from the State sales figures, while diesel consumption per capita is apparently higher in the Pilbara than the average for the State. Diesel sales from service stations in the Pilbara accounted for 32.3% of the volume of fuel sold, while in the Perth Airshed study the figure was 17.5%. In the Kalgoorlie study diesel sales amounted to 39% of the volume of fuel sold. The higher proportion of diesel sales in these rural areas may be due to the higher prevalence of diesel 4-wheel drive utilities, trucks and road trains than occurs in city areas. The lower value of petrol sales may indicate that the 4 retail outlets were not representative of the Pilbara. However, given the expected higher diesel usage the survey values have been used in the evaporative emission estimates.

■ **Table 3-4 Average annual retail fuel sales in the Pilbara Airshed and in WA**

	Unleaded Petrol	Leaded Petrol	Diesel	LPG
Average Fuel Sales per Facility (L)	703,000	118,000	391,000	790
Estimated Total Fuel Sales in Study Area (L) (1)	23,200,000	3,900,000	1,290,000	26,100
% of Sales in Pilbara	57.9	9.8	32.3	0.1
Average fuel consumption per capita in Pilbara	531		253	0.016
Average per capita fuel consumption in WA (2)	787		179	56
% of Sales in WA (2)	75.0		17.5	5.5

Notes
1. Pilbara values derived from an average of 4 retail outlets multiplied by the number of outlets in the Pilbara.
2. Per capita fuel consumption in WA from 1999 retail sales of 1470, 104.5 and 335 ML of gasoline, LPG and diesel (DISR, 2000) and a population for 1999 of 1.866 million people.

Submerged filling of underground tanks is employed in the study area. Filling of vehicle tanks in the study region is uncontrolled and fuel vapour is displaced directly to the atmosphere. Spillage of fuel during tank filling occurs as a result of nozzle drip, spit-back of petrol and tank overflow.

3.6.2 Emission Estimation

Emissions were calculated using the prescribed method outlined in the EET Manual for Aggregated Emissions from Service Stations (Environment Australia, 1999m). Emission factors for volatile organic compounds are summarised in **Table 3-5**.

■ **Table 3-5 Emission factors for emission sources at service stations**

Emission Source	Emission Rate (mg/L of throughput)
PETROL	
Underground tank filling	
Submerged filling	880
Splash filling	1380
Submerged filling & vapour balance	40
Underground tank breathing/emptying	120
Vehicle refuelling	
Displacement losses (uncontrolled)	1320
Displacement losses (controlled)	132
Spillage	80
DIESEL (includes filling underground tanks, vehicle refuelling losses and tank breathing)	176
LPG	0.04

Details of the composition of petrol and the lead content of petrol and petrol vapour is summarised in **Table 3-6** and **Table 3-7** as detailed in the EET Manual.

■ **Table 3-6 Composition of petrol**

Species	Petrol Liquid (% weight)	Petrol Vapour (% weight)
Benzene	2.9	0.95
Cyclohexane	0.2	0.0637
Ethylbenzene	2	0.0791
n-Hexane	3.5	1.73
Styrene	0.1	0.00282
Toluene	10.4	1.08
Xylenes	12.2	0.433

■ **Table 3-7 Lead content of petrol and petrol vapour**

Species	Leaded Petrol	Unleaded Petrol
Lead content of petrol (% weight)	0.0176	1.9 x 10-4
Estimated lead concentration in petrol vapour (% weight)	6.32 x 10-5	6.84 x 10-7

The introduction of lead free fuel in WA in January 2000 was accounted for by estimating emissions for the 6 months of lead free super with the unleaded petrol lead emission factor.

Emissions as per the EET Manual were calculated based on submerged filling and uncontrolled displacement losses during vehicle refuelling. Total VOC emissions for the Airshed was calculated to be 6.73×10^{4} kg/yr with 6.50×10^{4} kg/yr contributed from petrol, 2.27×10^{3} kg/yr from diesel and 1.04×10^{-3} kg/yr from spillage. A summary of the calculated emissions is presented in **Table 3-8**.

■ **Table 3-8 Total emissions from service stations**

Species	Total Emissions (kg/yr)
Total VOCs	67,300
Benzene	660
Cyclohexane	44.4
Ethylbenzene	93.1
n-Hexane	1,160
Styrene	3.94
Toluene	904
Xylenes	537
Lead	0.0346

Note: Vapour emissions from diesel vapour are only provided for VOC as no VOC speciation data was available.

3.6.3 Spatial Allocation

Emissions from service stations were spatially allocated according to the number and location of service stations in each grid cell. Emissions were gridded using a 2 km by 2km grid.

3.6.4 Comparison to Other Studies

Emissions from service stations were estimated in the Kalgoorlie NPI trial at 11,900 kg of VOC or 3.8 kg/person per annum. This is higher than that estimated for the Pilbara of 67,300 kg or 1.34 kg/person and is a result of the higher petrol usage estimated in the Kalgoorlie region (1,520 L/person for Kalgoorlie, compared to 531 L/person for the Pilbara and 787 L/person for WA).

3.7 Architectural Surface Coatings

Architectural surface coatings are applied to surfaces to enhance the aesthetic value of structures and to protect surfaces from corrosion, decay, water damage, abrasion and ultra-violet light damage. The three main components of surface coatings are resins, pigments and solvents. The predominant emissions come from VOCs contained in the coatings, and in the solvents used for cleaning up and thinning. Architectural surface coatings are generally classified as solvent-based or water-based.

3.7.1 Data Collection and Information Sources

Accurate sales and distribution data of architectural surface coatings are not available for the Pilbara region such that the best practice EET Manual could not be used. As such the default method based on factors for household usage multiplied by the number of households was used. Household data for the Pilbara was obtained from the 1996 census as detailed in **Section 1.1**.

3.7.2 Emission Estimation

Architectural surface coating emissions were calculated using the default method outlined in the EET Manual for Aggregated Emissions from Architectural Surface Coatings (Environment Australia, 2003). This method is based on emission factors per dwelling as developed in the South East Queensland Trial (QDEH, 1999). The total number of dwellings in the study area is 18,913.

Table 3-9 summarises the emission factors and total emissions for compounds emitted by architectural surface coatings.

■ **Table 3-9 Emission Factors and Total Emissions from Architectural Surface Coatings**

Substance	Emission Factor[1] (kg/dwelling/yr)	Total Emissions (kg/yr)
Solvent-Based Coatings		
Acetone	0.258	4,880
Cyclohexane	1.670	31,585
2-Ethoxyethanol acetate	0.105	1,986
Ethanol	0.048	913
Ethylene glycol	0.048	913
n-Hexane	1.670	31,585
Isomers of xylene	0.209	3,953
Methanol	0.314	5,939
Methyl ethyl ketone	0.451	8,530
Methyl isobutyl ketone	0.048	913
Toluene	0.419	7,925
Water-Based Coatings		
Benzene	0.005	86
Dichloromethane	0.083	1,575
Ethylene glycol	0.008	143
Total VOCs	**9.560**	**180,808**

Notes:
1) Source EET Manual for Aggregated Emissions from Architectural Surface Coatings (Environment Australia, 2003)

3.7.3 Spatial Allocation

Emissions from architectural surface coatings were spatially allocated according to the distribution of dwellings in the study area.

3.7.4 Comparison to Other Studies

A comparison of the emissions of VOC and benzene with that from other Airsheds is given in **Table 3-10**.

On a per capita basis, the values are similar for all studies as expected using default values, with the differences believed to be due to different year's sales data.

■ **Table 3-10 Comparison of VOC and Benzene Emissions from Architectural Surface Coatings with Other WA Airsheds**

Study	VOCs Emissions (kg/yr)	Benzene Emissions (kg/yr)	VOCs (kg/capita/yr)	Benzene (kg/capita/yr)
Pilbara	181,000	90	3.61	0.0018
Perth[1]	4,450,000	1,913.4	3.40	0.0015
Kalgoorlie[2]	193,000	46.4	6.21	0.0015

Notes:
1) Source DEP (2000).
2) Source Coffey Geosciences (1999).

3.8 Domestic Gaseous Fuel Burning

Domestic gaseous fuel burning is undertaken for cooking, heating and hot water heating. Emissions are dependent on the amount and type of fuel burnt.

3.8.1 Data Collection and Information Sources

Emissions from domestic gaseous fuel burning were calculated using the prescribed methods in the EET Manual for Aggregated Emissions from Domestic Gaseous Fuel Burning (Environment Australia, 1999d) and results of the various surveys.

The results of the domestic survey of "typical towns" indicated that 52% of Pilbara residents use LPG gas in and around their home. Of the 52% of respondents who used LPG, the following proportions of respondents used LPG in these appliances (some respondents indicated use in more than one appliance):

- 81% - stove top/oven;
- 31% - outdoor barbecue;
- 4% - flued heater (with vent outside);
- 1% - unflued heater; and
- 28% - other applications.

The average size of the gas cylinder was 49.5 kg and cylinders were filled on average 3.1 times per year.

LPG gas was also reported to be used by caravan owners. Five percent of residents reported that they own or live in a caravan. Almost all the caravan owners (92%) indicated that the caravan uses LPG fuel, and the gas bottle was filled an average of 2.6 times per year. The average weight of a caravan gas cylinder was 8kg. Based on these figures and a density of 0.52 kg/L (LPGA, 1998) an average fuel usage for towns of 153 L/household or 58.2 L/person was derived (**Table 3-11**).

Results from the survey of the mining communities indicated that negligible LPG is used apart from occasionally for an outside barbecue. Usage at Aboriginal communities was found to be around 169 L/household or 31.3 L/person (**Table 3-11**). This is similar in usage per household, but less per person than used in town.

For estimating emissions throughout the study area an estimate of 55 L/person has been used. This is based on the town usage, but slightly reduced to reflect the zero use in mining camps, lower use in Aboriginal communities and with the usage for the other 11.6% of the population not known.

The average consumption of 55 L/person/year (30.3 kg/person/year) in the Pilbara contrasts with the estimated annual average consumption per person of LPG in

Kalgoorlie of 119 kg/year. The Kalgoorlie figure was also derived from a domestic survey of residents but also includes the use of LPG by light industry and commercial users which has not been included in our calculations. The Perth Airshed study did not calculate emissions from LPG since Perth has domestic natural gas reticulation. There is no domestic natural gas reticulation in the Pilbara area.

■ **Table 3-11 Annual domestic fuel usage in the Pilbara**

Fuel Type	Units	Town	Mining Camp	Aboriginal Community	Study Area
Diesel for electricity	L/person	0	0[1]	1,500	Not used over entire area
	L/household	0	0[1]	8,100	
LPG	L/person	58.2	0	31.2	~ 55 (see text)
	L/household	153	0	169	~145
Wood	kg/person	8.4	0[1]	1,480	47
	kg/household	22	0	8,000	124
Coal	kg/person	1.7	0	0	1.6
	kg/household	4.4	0	0	4.2

1. Typically the main generators at mining camp are situated at the mine and are reported under the emissions for the mine, e.g. Telfer.
2. The fuel consumption for electricity generation at Aboriginal communities was based on a consumption of 250 tonnes of diesel (300kL) for the generator at the Jigalong community. This is not far short of the NPI reporting threshold of 400 tonnes. Sites such as this, small mining camps and homesteads are not connected to the limited electricity grid in the area.

3.8.2 Emission Estimation

Emission factors used in determining aggregated emissions and total emissions for each compound are summarised in **Table 3-12**.

■ **Table 3-12 Emission factors and emissions from domestic gaseous fuel burning**

Substance	Emission Factor (kg $\times 10^{-3}$/L)[(a)]	Total Emissions (kg/yr)
Arsenic and compounds	0	0
Benzene	0.00266	7.33
Beryllium and compounds	0	0
Cadmium and compounds	0	0
Chromium (III) compounds	0.000187	0.515
Chromium (VI) compounds	0.0000775	0.214
Carbon monoxide	0.228	628
Cobalt and compounds	0.00096	2.65
Copper and compounds	0.000024	0.0661
Cyclohexane	0.000713	1.96
Formaldehyde	0.00628	17.3
n-Hexane	0.000738	2.03
Lead and compounds	0.000024	0.0661
Manganese and compounds	0.000024	0.0661
Mercury and compounds	0	0
Nickel and compounds	0.000264	0.728
Oxides of Nitrogen	1.68	4,630
PM10	0.048	132
PAHs	0	0
Selenium and compounds	0.000264	0.728
Sulphur Dioxide	9.45E-09	0.000026
Toluene	0.00134	3.69
Total VOCs	0.036	99.2
Zinc and compounds	0.000264	0.728

Notes:
1. Emission factor for LPG

3.8.3 Spatial Allocation

Emissions were spatially allocated in the study region according to population.

3.8.4 Comparison to Other Studies

Estimated emissions of the NPI criteria pollutants per head of population for Perth are presented in **Table 3-13.** These show results that are generally within a factor of 3. The differences are primarily the result of the different emission factors for LPG as compared to LNG (which is used in Perth and not the Pilbara) with there being a wide variation quoted in the EET Manual.

- **Table 3-13 Per capita emissions (from domestic fuel combustion**

Substance	Emissions – Perth (kg/person/yr)	Emissions – Pilbara (kg/person/yr)
Carbon Monoxide	0.088	0.013
Lead	0.0	0.0
Oxides of Nitrogen	0.21	0.092
PM10	0.025	0.0026
Sulphur Dioxide	0.002	0.0026
Volatile Organic Compounds	0.016	0.002

3.9 Domestic Solid Fuel Burning

Wood is the main solid fuel in use in Australia. Coal and briquettes are also used in smaller amounts. Emissions from solid fuel burning are dependent on the type of wood burnt, the type of heater used and operating practices.

3.9.1 Data Collection and Information Sources

Emissions from domestic solid fuel burning were calculated using the prescribed methods in the EET Manual for Aggregated Emissions from Domestic Solid Fuel Burning (Environment Australia, 1999f) and results of the domestic survey.

The results of the domestic town survey indicated that only 1.76% of households use wood and only 0.44% use coal for cooking, heating or hot water (see **Table 3-11**). This contrasts with both the Kalgoorlie and Perth studies where wood was the primary source of fuel used in 60% and 21% of households respectively. Neither the Perth nor the Kalgoorlie study estimated emissions from use of coal so no comparative figures are available.

For those households who indicated that they used solid fuel in the Pilbara study area, the average usage of was 1.25 t/household/yr for wood and 1.0 t/household/yr for coal. These figures compare with 2.6 t/household/yr in the Kalgoorlie study and 2 t/household/yr in the Perth study for households using wood.

With regard to types of “appliances”, 2.64% of households indicated that they have some form of open fire. Of these 0.88% were indoor, whilst 1.76% had outdoor fires (barbecues) which were used for day to day cooking. Of these solid fuel users 2.2% used firewood and 0.44% used coal. Of the firewood users, 80% used hardwood at a rate of 1.25 t/household/yr and 20% used softwood at approximately 1.0 t/household/yr.

For mining campsites, no wood use was reported. For Aboriginal communities wood use was reported for 100% of the households with an average of 8 t/household/yr or 1.48 t/person/yr.

Assuming wood use for the all "households" apart from aboriginal communities and mining campsites (i.e. 96% of the population) is at the "town" rate of 0.0084 t/person/yr a total of 402 tonnes/yr of wood use is derived. For the aboriginal communities (1,320 people at 1.48 t/person/yr) a wood usage of 1,950 tonnes/yr is obtained. Therefore the total study area wood use is 2,350 tonnes/yr or 0.047 t/person/yr or 0.124 t/household/yr.

For the total usage of coal in the study area, the Aboriginal communities and mining camps were taken to have zero usage. Therefore the study area estimate was based on 96% of population using an average of 1.7 kg/person which gives an annual usage of 80 tonnes/year in the study area.

3.9.2 Emission Estimation

Emission factors and total emissions for each compound are summarised in **Table 3-14**.

■ **Table 3-14 Emission factors and emissions from solid fuel burning**

Substance	EF Wood (Open Fireplace) (g/kg)	EF Coal (Open Fireplace) (g/kg)	Total Emissions (kg/yr)
Acetaldehyde	8.87	2.85×10^{-4}	20,900
Acetone	6.56		15,400
Antimony and compounds	1.13×10^{-4}		0.266
Arsenic and compounds	7.52×10^{-5}	9.5×10^{-5}	0.185
Benzene		6.5×10^{-4}	0.0522
Beryllium and compounds		1.55×10^{-4}	0.0125
1,3-Butadiene	0.36		847
Cadmium and compounds	9.4×10^{-5}	3.55×10^{-5}	0.224
Chromium (III) compounds		9.05 x 10-5	0.00727
Chromium (VI) compounds		3.95 x 10-5	0.00317
Carbon disulphide		6.5 x 10-5	0.00522
Carbon monoxide	126.3	138	308,000
Cobalt and compounds	1.88×10^{-5}		0.0442
Cyanide compounds		1.25×10^{-3}	0.1
Dichloromethane		2.65×10^{-4}	0.0213
Ethylbenzene		4.7×10^{-5}	0.00378
Di-(2-ethylexyl) phthalate (DEHP)		3.65×10^{-5}	0.00293
Fluoride compounds		0.075	6.03
Formaldehyde	9.55	1.2×10^{-4}	22,500
n-Hexane		3.35×10^{-5}	0.00269
Hydrochloric acid		0.6	48.2
Lead and compounds	3.01×10^{-4}	4.45×10^{-3}	1.07
Manganese and compounds	5.45×10^{-4}	1.8×10^{-3}	1.43
Mercury and compounds		6.5×10^{-5}	0.00522
Methyl ethyl ketone		1.95×10^{-4}	0.0157
Nickel and compounds		1.3×10^{-4}	0.0104
Oxides of nitrogen	1.3	1.5	3,180
PAHs	8.01 x 10-4	1.12×10^{-3}	1.97
Phenol		8.0×10^{-6}	0.000643
PM10	17.3	1.15	40,800
Selenium and compounds	1.88×10^{-5}	6.5×10^{-4}	0.0965
Sulphur dioxide	0.2	3.9	784
Styrene	0.175	1.25×10^{-5}	412
Tetrachloroethylene		2.15×10^{-5}	0.00173
Toluene	1.17	1.2×10^{-4}	2,750
Total VOCs	114.5	5	270,000
Xylenes	0.71	1.85×10^{-5}	1,670
Zinc and compounds	0.0139		32.7

Note: From the survey 100% of fireplaces were given as open fireplaces

3.9.3 Spatial Allocation

Emissions from solid fuel combustion were spatially allocated by population. This will under estimate emissions at aboriginal communities.

3.9.4 Comparison to Other Studies

Emissions per capita are presented in **Table 3-15**

- **Table 3-15 Emissions per capita for various study regions of domestic solid fuel burning**

Substance	Perth (kg/year/person)	Kalgoorlie (kg/year/person)	Pilbara (kg/year/person)
Carbon Monoxide	16.5	59	6.1
Lead	0.0	0.0	0.00002
Oxides of Nitrogen	0.19	0.72	0.063
PM10	1.8	4.4	0.81
Sulphur Dioxide	0.032	0.064	0.016
VOC	6.7	13.7	5.4

These indicate emissions are in the range of 1 to 3 times lower than the Perth area and 3 to 10 times lower for the Kalgoorlie region. These differences in emissions are due to:

- The various wood usage (as coal use is negligible) of 0.047, 0.16 and 0.51 t/person/yr for the Pilbara, Perth and Kalgoorlie study regions; and
- The relatively higher emissions from some substances from open fires that are used exclusively in the Pilbara than that from the controlled space heaters primarily used in Perth and Kalgoorlie

3.10 Domestic Lawn Mowing

Atmospheric emissions from residential lawn mowing activities are generated from the use of 2-stroke and 4-stroke engine mowers. Generally, 4-stroke mowers have lower emissions of VOCs, CO and PM10 but higher NO_x emissions. The fuel type will also affect emissions, particularly for the compounds lead and SO_2.

3.10.1 Data Collection and Information Sources

Results of the domestic survey were used to estimate emissions from domestic lawn mowing for town sites. The phone survey addressed the following:

- Percentage of survey population using lawn mowers and other gardening equipment such as whipper snippers, chain saws and garden blowers;
- Type of lawn mower – i.e. 2-stroke or 4-stroke engine mower;
- Type of fuel used – i.e. unleaded or leaded fuel;
- Frequency of use (number of times per year); and
- Average duration of use (hours).

A total of 62% of respondents reported that they have one form or other of a garden power tool fuelled by either 2 or 4-stroke fuel. The range of power tools held was:

- 52% have a lawn mower;
- 35% a whipper snipper or brush cutter;
- 10% a chain saw;
- 4% a garden blower;
- 2% referred to some other form of powered garden appliance; and
- 38% reported that they have no petrol powered garden tools.

Note that the above figures add to greater than 100% due to ownership of multiple categories of power garden tools. A further 24% of respondents indicated that they have their lawn mowed for them, which means that effectively 76% of respondents have lawn mowing activity on their properties. The results of the domestic survey are summarised below in **Table 3-16.**

These figures are lower than from those obtained from the Perth and Kalgoorlie studies where 92.5% and 90% of respondents respectively owned or used a lawn mower (DEP, 2000, Coffey Geosciences, 1999). This is likely due to the climate of the region, where "lawns" are more difficult to maintain, as well as lifestyle differences.

- **Table 3-16 Results of domestic lawn mowing survey**

Appliance	House-hold Usage (%)	Motor			Fuel			Frequency (/yr)	Duration (hrs)	Annual hours of use/house-hold
		4-Stroke (%)	2-Stroke (%)	Other	Unleaded (%)	Leaded (%)	Other (%)			
Lawn mower	52%	58%	40%	2% elec	68%	30%	2% uns	28.2	0.56	15.8
Whipper snipper	35%	6%	86%	5% elec 3% uns	69%	20%	11% uns	27.6	0.56	15.46
Chain saw	10.1%	9%	78%	13% uns or elec	52%	30%	18% oth	8.4	1.53	12.85
Garden blower	4%	0	33%	66% uns or elec	33%	11%	56% elec	46.2	0.94	43.43

Notes: elec = electric, uns = unsure, oth = other

The annual hours of lawn mower usage estimate compares with estimates of 13 hours in the Kalgoorlie study and 14.2 hours (in the summer) in the Perth study. Neither the Perth nor the Kalgoorlie study collected data or estimated emissions for other garden appliances.

Table 3-17 below summarises the engine/fuel type combinations for each of the above garden instruments.

- **Table 3-17 Percentage of Households with different engine/fuel type combinations**

	4-Stroke Leaded	4-Stroke Unleaded	2-Stroke Leaded	2-Stroke Unleaded	Electric
Lawn mower	6.7%	13.4%	8.5%	22.4%	0.9%
Whipper snipper	6.7%	23.2%	0.4%	1.3%	3.6%
Chain saw	3.1%	4.4%	0.0%	0.9%	1.8%
Garden blower	0.4%	1.3%	0.0%	0.0%	2.2%

Note: Engine and fuel types that were unsure have been spread between engine and fuel types based on percentage of the known engine types and fuel use.

Default figures for mower fleet composition were 60% for 2-stroke and 40% for 4-stroke mowers. However, the results of the domestic survey were contradictory to this, and indicated that the composition for the study area was 40% for 2-stroke and 58% for 4-stroke mowers. This breakdown in the Pilbara also compares with that found in Perth where 2 and 4 stroke mowers made up 44.6% and 50.4% respectively (the remainder being comprised of electric and push mowers).

Mining camp data indicated that lawn mowing activities were low. The Aboriginal community data from Jigalong indicated usage on a household basis was 10.4, 14.7 and 2.8 hours per year for lawn mowers, whipper snippers and chainsaws. For lawn mowers and whipper snippers these annual hours of usage are similar to that in

Towns, though this activity level is also thought to include activity for general maintenance around community facilities such as the school. As such, somewhat lower domestic usage than for town sites would result. For estimating an annual usage across the study area, given the uncertainty in usage for the small settlements, the values from the domestic survey have been applied across the study area.

3.10.2 Emission Estimation

Emissions were calculated using the prescribed method in the EET Manual for Aggregated Emissions from Domestic Lawn Mowing (Environment Australia, 1999e).

$$E_{ifj} = T_{if} \times F_{ifj} \times 10^{-3}$$ **Equation 3.3**

Where:

E_{ifj} = annual emissions of substance j from mower type i using fuel f (kg/yr)
T_{if} = annual hours of usage for mower type i using fuel type f (hr/yr)
F_{ifj} = emission factor for substance j in mower type I using fuel type f (g/hr)

Where

$$T_{if} = (P_{if}/100) \times H_{if} \times N_a$$ **Equation 3.4**

And

P_{if} is the percentage of surveyed households using mower type i and with fuel type f
H_{if} is the annual hours of mowing per household using mower type i and fuel type f
N_a is the number of households in the Airshed.

To account for contract mowing of private residences, the emissions for lawn mowing, whipper snipping and blowing were then increased by 1.46. That is the ratio of total mowing (76%) conducted to that undertaken by the householder (52%).

Emission factors for domestic lawn mowers based on engine and fuel type are summarised in **Table 3-18**.

■ **Table 3-18 Emission factors and emissions from domestic lawn mowing**

Substance	Emission Factor (g/hr)			
	2-stroke Engine		4-stroke Engine	
	Leaded	Unleaded	Leaded	Unleaded
Benzene	17	17	2.3	2.3
1,3-Butadiene	2.16	2.16	0.292	0.292
Carbon monoxide	731	731	489	489
Chromium (III) compounds	0.00332	0.00332	0.000219	0.000219
Chromium (VI) compounds	0.00138	0.00138	0.000091	0.000091
Cobalt and compounds	0.0047	0.0047	0.00031	0.00031
Copper and compounds	0.0047	0.0047	0.00031	0.00031
Cyclohexane	0.517	0.517	0.07	0.07
Ethylbenzene	3.96	3.96	0.534	0.534
Formaldehyde	2.8	2.8	0.68	0.68
n-Hexane	0.548	0.548	0.74	0.74
Lead and compounds	0.11	0.002	0.066	0.001
Manganese and compounds	0.0047	0.0047	0.00031	0.00031
Nickel and compounds	0.0047	0.0047	0.00031	0.00031
Oxides of nitrogen	1.45	1.45	4.85	4.85
PM10	7.8	7.8	0.515	0.515
PAHs	0.895	0.895	0.121	0.121
Styrene	0.304	0.304	0.041	0.041
Sulphur dioxide	1.02	0.3	0.701	0.206
Toluene	28.6	28.6	3.87	3.87
Total VOCs	304	304	41.1	41.1
Xylenes	21	21	2.83	2.83
Zinc and compounds	0.0047	0.0047	0.00031	0.00031

The EET Manual does not provide emission estimation techniques for the calculation of emissions from other fossil fuel powered garden instruments such as whipper snippers and chains saws. Likewise the emission factors in the combustion engine manual relate to engines of larger size and were thought not appropriate for these smaller engines. Emission factors for these instruments were determined by scaling the emissions from the above sources by their engine power. The standard engine sizes used were 3.4 hp (2.55 kW) (USEPA, 1985) for the lawn mowers; whipper snippers 0.75 kW; chainsaws 1.75 kW and blowers 1.25 kW (from standard engine sizes in current catalogues). This procedure is adequate as long as there is not too large a variation in engine size, as it is known that emissions of VOC and CO especially increase with decreasing engine size (see European Environmental Agency, 1996). Note an alternative would be to use the equations in European Environmental Agency (EEA) (1996) that relate emissions to engine power and assume a 40% load in the engine as per the derivation of the original USEPA equations. This was not done as the CO and VOC emissions listed in the EET Manual and that in EEA (1996) were substantially different, such that a mix of inconsistent factors would result.

Total emissions calculated for lawn mowers and the other garden instruments are summarised in **Table 3-19**.

■ **Table 3-19 Total emissions from domestic lawn mowing**

Compound	Lawn Mowing (kg/yr)	Miscellaneous Garden Equipment (kg/yr)	Total Emissions (kg/yr)	Emissions per Capita (mg/capita/yr)
Benzene	1,800	777	2,580	51.5
1,3-Butadiene	229	98.8	328	6.54
Carbon monoxide	130,000	34,600	165,000	3,290
Chromium (III) compounds	0.321	0.151	0.472	0.00943
Chromium (VI) compounds	0.134	0.0628	0.196	0.00392
Cobalt and compounds	0.455	0.214	0.669	0.0133
Copper and compounds	0.455	0.214	0.669	0.0133
Cyclohexane	54.9	23.6	78.5	1.57
Ethylbenzene	420	181	601	12
Formaldehyde	338	129	467	9.31
n-Hexane	148	27.1	175	3.49
Lead and compounds	5.88	1.49	7.37	0.147
Manganese and compounds	0.455	0.214	0.669	0.0133
Nickel and compounds	0.455	0.214	0.669	0.0133
Oxides of nitrogen	781	80.3	861	17.2
PM10	755	355	1110	22.1
PAHs	94.9	40.9	136	2.71
Styrene	32.2	13.9	46.1	0.921
Sulphur dioxide	93.6	23.5	117	2.34
Toluene	3,030	1,310	4,340	86.7
Total VOCs	32,200	13,900	46,100	921
Xylenes	2,230	960	3,190	63.6
Zinc and compounds	0.455	0.214	0.669	0.0133

This shows that lawn mowing typically accounts for between 59 and 87% of emissions from residential garden maintenance with other equipment contributing between 13 and 41%. The major contributors to the other equipment are whipper snippers and chainsaws.

3.10.3 Spatial Allocation

Emissions were spatially allocated in the Airshed in proportion to the distribution of households.

3.10.4 Comparison to Other Studies

In terms of per capita emissions the total emissions of pollutants such as NO_x, VOC and PM10 (18, 1050 and 25.4 mg/capita/yr) are similar to that from other cities in Australia from lawn mowing (9.6 - 17.9, 668 – 1240, 22.5- 41.7 mg/capita/yr) (EPAV, 1996). This occurs as the average time spent lawn mowing in the Pilbara is 15.8 hours compared to estimates of 13 hours in the Kalgoorlie study and 14.2 hours (in the summer) in the Perth study, though the percentage of households that had their lawns mowed was lower, 76%, compared to 92.5% and 90% for households in Perth and Kalgoorlie (DEP, 2000; Coffey Geosciences, 1999).

3.11 Lawn Mowing – Public Open Spaces

Public open space lawn mowing includes mowing activities carried out by local councils, schools and golf courses.

3.11.1 Data Collection and Information Sources

Councils

Information was collected on mowing activity from the major councils in the study area. Information was not able to be obtained from the Town of Port Hedland and Shire of Carnarvon. Mowing activity details obtained from other councils were scaled

to reflect the likely activity of these councils. Total mowing activity for councils is summarised in **Table 3-20**.

■ **Table 3-20 Council mowing activity in Pilbara study area (hrs per year)**

Petrol Ride on Mower	Diesel Ride on Mower	Push Mower	Whipper Snipper	Blower	Diesel Tractor
4,940	13,250	1,610	6,080	4,210	5,480

Golf Courses
From discussions with recreation authorities in the Pilbara, there are a total of 7 golf courses in the Pilbara Airshed:

- Newman Golf Course;
- Karratha Golf Course;
- Tom Price Mountain View Golf Course;
- Port Hedland Golf Course;
- Onslow Golf Course;
- Exmouth Golf Course; and
- Roebourne Golf Course.

Details of mowing frequency and duration was obtained from Newman, Karratha and Onslow golf courses, and extrapolated to the remainder. Lawn mowing was conducted on average 438 hrs/year per golf course. This represents a total of 3,066 hrs in the study area (7 golf courses). From the respondents, the method of mowing ranged from a diesel tractor to an old model slasher.

Schools
Information on the number of schools and students in the study area was obtained from the Education Department WA (EDWA, 2000). There are a total of 35 schools in the study area with 9,787 students enrolled. Details on mowing practices was obtained from 10 schools and extrapolated to the remainder. This included a combination of private/government and primary/secondary schools. Of the respondents, mowing was typically completed using a ride on mower (4-stroke) powered by unleaded fuel. On average, mowing of school grounds was conducted for 264 hrs per year (ranging between 52 and 702 hrs/year). Mowing activity estimates for the remainder of schools in the study area was scaled according to the number of students. On average, the number of hours of mowing was 0.71 per student, which corresponds to 6,948 hrs of mowing in the study area.

3.11.2 Emission Estimation

Emissions from lawn mowing of public open spaces were estimated using emission factors as used in the Perth Emissions Inventory. These factors are summarised in **Table 3-21** below.

■ **Table 3-21 Emission factors for commercial mowing activities**

Source	Emission Factor (g/hr)					
	NO_x	VOC	CO	SO_2	TSP	Lead
Tractor (diesel 70hp)	452	6.55	161	28.8	61.8	0.00
Ride on mower (diesel 17hp)	110	1.59	39.1	6.99	15.0	0.00
Ride on mower (petrol 17hp)	21.7	173	1,910	0.90	3.10	0.092

Note: PM10 factor is 90% of TSP factor

Total emissions from the mowing of golf courses, schools and councils are summarised in **Table 3-22**.

■ **Table 3-22 Total emissions from lawn mowing of public open spaces**

Compound	Council Mowing (kg/yr)	Golf Courses (kg/yr)	Schools (kg/yr)	Total Emissions (kg/yr)
Benzene	68.9	0.11	79.2	148
1,3-Butadiene	8.75	0.0139	10.1	18.8
Carbon monoxide	16,000	143	16,800	33,000
Chromium (III) compounds	0.00656	1.04E-05	0.00754	0.0141
Chromium (VI) compounds	0.00273	4.34E-06	0.00313	0.00586
Cobalt and compounds	0.00928	1.48E-05	0.0107	0.02
Copper and compounds	0.00928	1.48E-05	0.0107	0.02
Cyclohexane	2.1	0.00334	2.41	4.51
Ethylbenzene	16	0.0254	18.4	34.4
Formaldehyde	20.4	0.0324	23.4	43.8
n-Hexane	22.2	0.0353	25.5	47.7
Lead and compounds	0.03	4.76E-05	0.0344	0.0644
Manganese and compounds	0.00928	1.48E-05	0.0107	0.02
Nickel and compounds	0.00928	1.48E-05	0.0107	0.02
Oxides of Nitrogen	4,080	337	167	4,580
PM10	553	46	17.7	617
PAHs	3.62	0.00577	4.17	7.8
Styrene	1.23	0.00195	1.41	2.64
Sulphur Dioxide	256	21.4	7.09	285
Toluene	116	0.184	133	249
Total VOCs	1,290	6.84	1,420	2,710
Xylenes	84.8	0.135	97.5	182
Zinc and compounds	0.00928	1.48E-05	0.0107	0.02

3.11.3 Spatial Allocation

Emissions from lawn mowing of public open spaces were spatially allocated proportionally to the number of households in the study area.

3.11.4 Comparison to Other Studies

Emissions from the Perth Airshed and this Pilbara study on a per capita basis are presented in **Table 3-23.**

■ **Table 3-23 Emissions from lawn mowing of public open spaces**

Substance	Perth (kg/person/year)	Pilbara (kg/person/year)
Carbon Monoxide	0.24	0.66
Lead	0.00001	0.0000013
Oxides of Nitrogen	0.073	0.091
PM10	0.008	0.0012
VOC	0.027	0.054

This indicates that emissions per person in the Pilbara for carbon monoxide, oxides of nitrogen and VOCs are in the range 1.25 to 2 times higher than in Perth. This higher value may be the result of efficiencies achieved by councils and shires in Perth with much larger populations and relatively small area over which to maintain public open spaces. The lower values of PM10 and lead are due to the very low usage of unleaded and 2-stroke mowers for the open space mowing in the Pilbara.

3.12 Motor Vehicle Refinishing

Emissions from motor vehicle refinishing includes emissions from spray painters, smash repairers and panel beaters. Motor vehicle refinishing consists of applying primer, a topcoat and hardener to motor vehicle surfaces to protect the surface from corrosion, abrasion, decay and damage from sunlight and water. VOCs are emitted during the application of coatings, the drying phase and from cleaning equipment such as spray guns.

3.12.1 Data Collection and Information Sources

A commercial survey form was issued to the 5 motor vehicle refinishers in the Port Hedland region, from which a response was received from only 1. The total number of motor vehicle refinishers in the study area is 14. The survey addressed the number of employees in the company and the total volume of paints and solvents used, including primers, basecoats, topcoats, hardeners and thinners. A summary of the survey response is presented in **Table 3-24**. Each motor vehicle refinishing facility that did not return a survey was contacted and each facility provided employee numbers over the phone. Usage for the remainder of the facilities was scaled in proportion to employee numbers. From the five motor vehicle refinishers surveyed, the average number of employees per facility was 3. Therefore a total estimate for the study region is 42.

■ **Table 3-24 Product usage from motor vehicle refinishers**

	Usage per Facility (Survey) (L/yr)	Usage in Study Area (Survey) (L/yr)	Usage (Survey) (L/person/yr)
Paint (solvent based)	160	2240	0.0447
Enamel	0	0	0.0
Thinner	520	7280	0.145
Primer	48	672	0.0134
Lacquer	0	0	0.0
Adhesive	0	0	0.0

3.12.2 Emission Estimation

Emissions were calculated using all three techniques outlined in the EET Manual for Aggregated Emissions from Motor Vehicle Refinishing (Environment Australia, 1999i). The best practice method uses the consumption of automotive surface coatings by product type in the Airshed that is determined by surveys. Emissions of VOC are then estimated for each surface coating type by the following equation:

$$E = C_i \times EF_i \qquad \textbf{Equation 3.5}$$

Where:

E = total VOC emissions in the Airshed (kg/yr)

C_i = total consumption of coating type i in the Airshed (L/yr)

EF_i = VOC content for coating type i (kg/L), as presented in **Table 3-25**.

■ **Table 3-25 VOC content by surface coating type (EF_i)**

Substance	VOC Content (kg/L)
Paint (solvent based)	0.672
Enamel	0.420
Lacquer	0.732
Primer	0.792
Thinner	0.883
Adhesive	0.528

The VOC is then speciated using the speciation profile prescribed in the EET Manual as summarised in **Table 3-26**.

■ **Table 3-26 Emission factors of NPI compounds**

	Emission Factor (kg/L)					
	Paint	Enamel	Thinner	Primer	Lacquer	Adhesive
Acetone	8.53×10^{-3}	2.34×10^{-2}				7.50×10^{-2}
Cyclohexane	3.49×10^{-3}	9.53×10^{-3}				
Ethyl acetate	1.37×10^{-2}	3.76×10^{-2}				7.02×10^{-2}
Ethylbenzene	3.63×10^{-3}	9.91×10^{-3}				
Methyl ethyl ketone	3.63×10^{-3}	9.91×10^{-3}	2.21×10^{-2}			2.80×10^{-2}
Methyl isobutyl ketone	2.42×10^{-3}	6.59×10^{-3}				2.27×10^{-2}
Toluene	2.54×10^{-1}	6.68×10^{-2}	2.21×10^{-1}	3.51×10^{-1}	3.26×10^{-1}	1.07×10^{-1}
Xylenes	5.49×10^{-2}	9.70×10^{-2}	1.77×10^{-1}	2.12×10^{-2}	3.06×10^{-2}	

Total emissions estimated using the best practice methodology of the above compounds are summarised in **Table 3-27**.

As the best practice methodology estimates are based on only one respondent, the default techniques have also been used to provide estimates. In order of preference these methodologies are to use the number of employees in the study region and appropriate employee emission factors and least preferably by using the population of the study region and appropriate population emission factor. Estimates derived using these two default methodologies are presented in **Table 3-27**.

■ **Table 3-27 Total emissions from motor vehicle refinishing**

Substance	Total emissions (kg/year)		
	Best Practice Mass Balance	Default Methodology Based on No. Employees	Default Methodology Based on Population
Acetone	19.1	-	-
Cyclohexane	7.8	-	-
Ethyl acetate	30.7	-	-
Ethylbenzene	8.1	-	-
Methyl ethyl ketone	168.8	1,107	7,155
Methyl isobutyl ketone	5.4	195	1,263
Toluene	2,413	2,148	13,890
Xylenes	1,423	1,888	12,206
Total VOC	8,466	6,510	42,091

The results indicate considerable variation, with the emissions based on the one survey respondent (mass balance) and the number of employees showing reasonable agreement, with the emissions based on the population being much greater. As the results derived from one respondent is seen as statistically questionable, emissions for the study region have been based on the next preferred methodology of using the number of employees.

3.12.3 Spatial Allocation

Emissions from motor vehicle refinishing were spatially allocated in proportion to the number of premises in each grid cell, on a 2 km by 2 km grid.

3.12.4 Comparison with Other Studies

Emissions per capita from motor vehicle refinishing are presented in **Table 3-28.**

- **Table 3-28 Emissions per capita from motor vehicle refinishing for various studies**

Substance	Emissions (g/person/year)		
	Perth	Kalgoorlie	Pilbara
Methyl ethyl ketone	84		22
Methyl isobutyl ketone	12.7		4
Total VOCs	877	415	130
Toluene	237	21.6	43
Xylenes	231	10.8	38

These indicate fair agreement between the Pilbara and the Kalgoorlie estimates on a per capita basis, whilst being much less than estimated for the Perth region. The Perth estimates have been based on the Population methodology, which would appear to over-predict emissions.

3.13 Dry Cleaning

Two general types of cleaning fluids are used in the dry cleaning industry; petroleum solvents and synthetic solvents. The principal solvent used is tetrachloroethylene, while only a small amount of petroleum solvents are generally used, such as white spirit. The solvent itself is the primary emission from dry cleaning operations and is given off by washer, drier, solvent still, cooker, still residue and filtercake storage areas, as well as by leaky pipes, flanges and pumps.

3.13.1 Data Collection and Information Sources

There is only one dry cleaning facility in the Pilbara study area, located in Karratha. A response was received to the commercial survey issued to the facility. The questionnaire addressed the total number of employees and the total volume of dry cleaning solvents, including perchloroethylene (Perc) and white spirit. Note that perchloroethylene is an equivalent name to tetrachloroethylene. The survey indicated that 600 L of Perc and no white spirit had been consumed during the 1999/2000 financial year. Phone calls to other laundries in the study area indicated that dry cleaning was generally sent to Perth from the Pilbara. Consumption in the Pilbara compares with 880 kg of Perc estimated to be used in the Kalgoorlie study.

3.13.2 Emission Estimation

Emissions were calculated using the prescribed methods in the EET Manual for Aggregated Emissions from Dry Cleaning (Environment Australia, 1999g). The best practice method is a mass balance approach which assumes that all solvent used is eventually emitted. A material safety data sheet for tetrachloroethylene gave a density of 1.623 tonne/m^3 for the compound. Therefore, the total emissions of tetrachloroethylene in the Airshed from dry cleaning operations is 974 kg.

The estimate of 974 kg per year for the study area does not correlate well with either of the default emissions factors given in the EET Manual. The per capita estimate in the EET Manual would give an emission estimate of 30,064 kg/yr while the employee based default figure would give an estimate of 100.6 kg/yr. The per capita figure obviously grossly overestimates emissions while the employee based figure significantly underestimates emissions. The Perth Airshed study assumed that 90% of perchloroethylene imported into WA was consumed in the Perth Airshed. Based on the findings of this study it is likely that this may be an underestimation.

3.13.3 Spatial Allocation

Emissions from dry cleaning were spatially allocated according to the location of the facility on a 2 km by 2 km grid.

3.13.4 Comparison to Other Studies

The Perth Airshed study also reported that only a relatively small number of dry cleaning premises used white spirit in their operation. Therefore the zero emissions from this substance in the Pilbara area is most likely accurate.

3.14 Bread Manufacturing

There were ten premises identified in the Pilbara study area that baked bread. This ranged from small pastry shops to large chain grocery shops with a bakery section. No commercial bakeries were identified in the study region. A commercial survey form was issued to the bakeries identified and followed up by telephone. From this survey two provided information on the amount of bread baked. Of the others, particularly the large chain stores with bakeries, no data was obtained due to concerns of commercial confidentiality. Therefore, with the large uncertainty in usage in the study region an alternative methodology to the EET Manual that is based on surveyed bread making was adopted. This method used a per capita consumption of bread that took into account the amount of imported bread.

For bread consumption, a per capita consumption figure of 45 kg/year was obtained from BRI (1999). This is similar to the figure derived for the Kalgoorlie region of 41.5 kg/year (Coffey Geosciences, 1999). Based on conversations with retailers in the area, only 10% of the bread consumed is assumed baked in the Pilbara with the majority brought in from Perth or even from Broome. Using these estimates and the Industry EET Manual for Bread Manufacturing (Environment Australia, 1999o) (**Table 3-29**) emissions were calculated as presented in **Table 3-29**.

■ **Table 3-29 Emission factors and total emissions from bread manufacturing**

Substance	Emission Factor (kg/tonne of bread)	Total Emissions (kg/yr)
Ethanol	2.7500	620
Total VOCs	2.7522	621

3.14.1 Spatial Allocation

Emissions from bread manufacturing were spatially allocated in proportion to the number of bakeries per grid cell on a 2 km by 2km grid.

3.14.2 Comparison to Other Studies

Due to the unique Pilbara study area, where bread is imported from other regions, no meaningful comparisons could be made for other Airsheds for this source. The estimates were checked against emissions from the Kalgoorlie study (Coffey Geosciences, 1999) where the emission per capita for this study was found to be around a factor of 6 lower, as expected based on the assumption of the amount of imported bread.

3.15 Paved and Unpaved Roads

Paved and unpaved roads have been found to be a major source of atmospheric particulate matter. Emissions from paved roads occur due to the suspension or re-suspension of loose material on the road surface. Deposition processes then result in a constant supply of loose material accumulating on the road surface. On unpaved roads, vehicular movement crushes surface material into fine particles. These fine particles are removed by traffic and re-entrained to the atmosphere leaving a higher percentage of coarse material on the road surface.

3.15.1 Data Collection and Information Sources

Data was obtained from VKT estimates for paved and unpaved roads as detailed in **Section 2.1.2.3** and default values used in the EET Manual for Aggregated Emissions from Paved and Unpaved Roads (Environment Australia, 1999j).

3.15.2 Emission Estimation

Emissions were calculated using the prescribed methods in the EET Manual.

Paved Roads
Emissions from paved roads are calculated using the following set of equations.

$$E_{ip} = EF_{ip} \times VKT_p \qquad EF_{ip} = k_{ip}\left(\frac{sL}{2}\right)^{0.65}\left(\frac{AW}{3}\right)^{1.5} \qquad \textbf{Equation 3.6}$$

Where:

E_{ip} = total Airshed emissions from paved roads of particle size category i (kg/yr)
EF_{ip} = emission factor for particle size category i and paved roads (kg/km)
VKT_p = Vehicle Kilometres Travelled on paved roads in Airshed (km/yr)
k_{ip} = empirical factor for particle size category i and paved roads (kg/km) [PM10 = 0.0046 and TSP = 0.024]
sL = road surface silt loading (g/m^2)
AW = average weight of vehicles (tonnes)

The default road surface silt loading of 0.4 g/m^2 for low average daily traffic roads was adopted. An average vehicle weight of 3.1 tonnes for the Pilbara study area was also used to calculate emission factors for PM10 and TSP as per the default value in the EET Manual. A weighted value for unloaded licensed vehicles of 1.49 tonnes is given for Pilbara vehicles (DOT, Innes, C., personal communication, 2000). However, this does not take into account the amount of loading, (including fuel), and the relative usage of different vehicle types. For the Kalgoorlie NPI trial (Coffey Geosciences, 1999) a value of 2.2 tonnes as the default USEPA fleet value was used. The resultant emission factors for this study are 1.70 g/km for PM10 and 8.86 g/km for TSP.

VKT on paved roads in the Pilbara study area is estimated to be approximately 380 million km per year. Annual emissions of PM10 from paved roads in the Pilbara study area are therefore estimated to be 645 tonnes (**Table 3-30**). A number of other NPI substances are also emitted in trace amounts. Emissions of these compounds are calculated using a weight fraction of TSP emissions. A summary of the weight fraction of these compounds and total annual emissions is summarised below in **Table 3-30.**

■ **Table 3-30 Total emissions from paved roads**

Substance	Weight Fraction (1) (from EET Manual)	Total Emissions (kg/yr)
PM10		645,000
TSP		3,370,000
Antimony and compounds	0.000013	43.8
Arsenic and compounds	0.000015	50.5
Cadmium and compounds	0.000019	64
Cobalt and compounds	0.000116	391
Copper and compounds	0.000161	542
Lead and compounds	0.000951	3,200
Manganese and compounds	0.000795	2,680
Mercury and compounds	0.000016	53.9
Nickel and compounds	0.000068	229
Selenium and compounds	0.000002	6.74
Zinc and compounds	0.000936	3,150

Notes:
1. Weight fraction is proportion of total TSP emissions

Unpaved Roads

Emissions from unpaved roads are calculated using the following set of equations from the EET Manual:

$$E_{iu} = EF_{iu} \times VKT_u$$

$$EF_{iu} = \frac{k_{iu}\left(\frac{s}{12}\right)^{A}\left(\frac{AW}{3}\right)^{B}}{\left(\frac{M}{0.2}\right)^{C}} \qquad \textbf{Equation 3.7}$$

Where:

Eiu = total Airshed emissions of particle size category i from unpaved roads (kg/yr)
EF_{iu} = emission factor for particle size i and unpaved roads (kg/km)
VKT_u = VKT on unpaved roads in Airshed (km/yr)
k_{iu} = empirical factor for particle size i and unpaved roads (kg/km)
s = surface material silt content
AW = average weight of vehicles (tonnes)
M = surface material moisture content (%)
A,B,C = empirical constants

A default silt content of 11.0% (as provided for roads made out of local material, compacted, bladed and crowned from the EET Manual) and the default moisture content of 0.2% was used. An average vehicle weight of 3.1 tonnes for the Pilbara was used. Other empirical constants used to calculate emission factors for PM10 and TSP are summarised in **Table 3-31** (from the EET Manual).

■ **Table 3-31 Empirical constants for unpaved road emissions**

k_{iu} (kg/km)	PM10	TSP
	0.733	2.82
A	0.8	0.8
B	0.4	0.5
C	0.3	0.4

The above parameters result in an emission factor of 693 g/km for PM10 and 2,670 g/km for TSP. These factors are around 300 to 400 times greater than that for paved roads. Factors used in the Kalgoorlie trial were 486 g/km for PM10. This lower value in the Kalgoorlie trial was the result that Coffey Geosciences (1999) used a lower silt value of 10% and a correction to account for rain days (when zero dust is assumed to be emitted).

VKT on unpaved roads in the Pilbara is estimated to be approximately 52.6 million km per year. Annual emissions of PM10 from unpaved roads in the Pilbara is therefore estimated to be 36,400 tonnes. Emissions of other compounds emitted were calculated as a weight fraction of TSP emissions according to the EET Manual. The weight fractions (from the EET Manual) and total emissions of these compounds are summarised in **Table 3-32**.

■ **Table 3-32 Total emissions from unpaved roads**

Substance	Weight Fraction [1]	Total Emissions (kg/yr)
PM10		36,400,000
TSP		141,000,000
Antimony and compounds	0.000013	1,120
Arsenic and compounds	0.000015	1,970
Cadmium and compounds	0.000019	3,090
Cobalt and compounds	0.000116	20,100
Copper and compounds	0.000161	12,400
Lead and compounds	0.000951	122,000
Manganese and compounds	0.000795	137,000
Mercury and compounds	0.000016	2,110
Nickel and compounds	0.000068	9,140
Selenium and compounds	0.000002	141
Zinc and compounds	0.000936	85,100

Notes:
1. Weight fraction is proportion of total TSP emissions

Total Paved and Unpaved Roads

As expected, unpaved roads emissions was the more dominant contributor from unpaved and paved roads. Total PM10 emissions were estimated at 37,100 tonnes with a 98.3% contribution from unpaved roads. A similar percentage contribution from unpaved roads was found for the remainder of the compounds (average of 97%) for which emission estimates were made. **Table 3-33** presents total emissions of each compound from paved and unpaved roads.

■ **Table 3-33 Total emissions from paved and unpaved roads**

Substance	Total Emissions (kg/yr)
PM10	37,100,000
TSP	144,000,000
Antimony and compounds	1,170
Arsenic and compounds	2,020
Cadmium and compounds	3,160
Cobalt and compounds	20,500
Copper and compounds	12,900
Lead and compounds	125,000
Manganese and compounds	140,000
Mercury and compounds	2,160
Nickel and compounds	9,370
Selenium and compounds	147
Zinc and compounds	88,200

3.15.3 Spatial Allocation

Total emissions from both paved and unpaved roads were spatially allocated in proportion to the length of unpaved and paved road VKT in each grid cell on a 2 km by 2km grid. This is thought to be far more realistic than evenly distributing the emissions over the whole Airshed as recommended in the manual.

3.15.4 Comparison to Other Studies

Emissions from the Kalgoorlie NPI trial and from California (CARB, 2000) are presented alongside estimates from this study in **Table 3-34**. These indicate that VKT per person are similar for the Kalgoorlie and Pilbara study for paved roads. For unpaved roads the Pilbara emissions per person are much higher, which is a result of the much higher VKTs travelled on unpaved roads in the Pilbara. Comparison to estimates for the state of California, indicate that California's emissions per person for both paved and unpaved roads are much lower than for the Pilbara. The lower paved road emission is due to much lower silt loadings used for the highly trafficked roads in most of California (0.02 to 0.04 g/m^2) instead of the high silt loading of 0.4 g/m^2 used for the low trafficked roads in the Pilbara. The much lower unpaved road emission is likely to be due to the low proportion of travel on unpaved roads in California.

- **Table 3-34 Paved and Unpaved road PM10 emissions**

Region	Paved Roads VKT/person	Paved Roads PM10 (tonnes/person)	Unpaved Roads VKT/person	Unpaved Roads PM10 (tonnes/person)
Pilbara	7,580	0.013	1,050	0.726
Kalgoorlie [1]	10,320	0.010	177	0.086
California [2]	-	0.00042	-	0.0066

Notes: Sources (Coffey Geosciences, 1999) [1] and CARB (2000) [2]

3.16 Fuel Combustion (Sub Threshold)

Emissions from sub threshold facilities can be significant, particularly if the number of these facilities is a significant fraction of the total number of facilities to report. Sub threshold facilities are defined in the EET Manual for Aggregated Emissions from Fuel Combustion (Sub-Threshold) (Environment Australia, 1999h) as "industrial and commercial sites that do not burn 400 or more tonnes of fuel or waste oil in a year". This also includes facilities that do trigger the threshold but fail to submit their reports. For the Pilbara this definition therefore does not include the many generators used at homesteads and aboriginal communities that are not on the interconnected grid as they are not industrial or commercial facilities. Of the small Western Power owned power stations, Marble Bar reported its emissions for 1998/1999 whilst the stations at Nullagine and Wittenoom were below the threshold (seen **Table 1-1** for the populations). Marble Bar's fuel usage for this period was estimated at 550 tonnes, whilst the other stations usage were below the threshold. As noted in **Table 3-11**, the Jigalong community has a substantial sized generator and used 250 tonnes of diesel. Additionally, the locality of Coral Bay has a number of small generators that are run privately by the local business that do not report their emissions.

Therefore, for localities not on the interconnected grid a population threshold for fuel generation combustion of 300 people may be appropriate. From **Table 1-1** this implies up to 6800 people may be using power from smaller generators that are not reporting.

3.16.1 Data Collection and Information Sources

Data required for the estimation of emissions in the EET Manual for Aggregated Emissions from Fuel Combustion (Sub-Threshold) (Environment Australia, 1999h) are fuel consumption by fuel type and by commercial/industrial facilities. The preferred source of data for fuel usage is from fuel suppliers. For this study the suppliers were contacted but none were willing to provide data in the categories that could be of assistance. The alternative to this suggested in the EET Manual is to

calculate fuel consumption based on population or employee numbers. This method was considered but discounted due primarily to the;

- Uncertainty in the number of industry and commercial sites that were not going to report for the 1999/2000 reporting period. This was due to the relatively low number that had reported in the initial year's reporting and the uncertainty in how many more industries would report in the first full year of reporting.
- That data on fuel consumption by sectors appropriate for elsewhere in Australia could not be scaled to the Pilbara with a different mix of industry and commercial sites; and
- The anticipated large contribution from small generators.

As such, given the large uncertainties for this reporting year in knowing which industries would be reporting a simple methodology based on:

- Scaling Perth's sub threshold reporting by the population in the Pilbara; and
- Adding the fuel combustion emissions from small diesel generators.

Fuel usage from sub threshold facilities in Perth was obtained from the WA DEP for 1998/1999 reporting year. Fuel usage for facilities that were known not to exist in the Pilbara such as lime and glass production were then subtracted from this estimate. The resultant fuel usage was then scaled by the relative population of the two study regions and is presented in **Table 3-35**.

Fuel usage for sub threshold diesel generators was estimated using an average diesel consumption of 1.5 m^3/person/year based on the Jigalong usage. The number of people not on the interconnected grid with generators that did not report was estimated at 6,800 from **Table 1-1**. The resultant fuel usage (**Table 3-35)** indicates diesel generators are by far the largest sub threshold fuel users in the Pilbara.

■ **Table 3-35 Estimated Pilbara sub Threshold fuel combustion**

Fuel	Units	Pilbara Sub Threshold Commercial Use	Small Diesel generators	Total Fuel Usage
Natural Gas	m^3	0	0	0
Distillate	Litres	117,000	10,200,00	11,337,000
LPG	Litres	110,000	0	110,000

3.16.2 Emission Estimation

Emission factors for sub threshold fuel usage were obtained from:

- Diesel engines emissions based on the EET Manual for Combustion engines for uncontrolled diesel engines less than 450 kW (expected to be the primary generator size); and
- LPG engines based on emission factors used in DEP (2000) with the VOC speciation based on the EET Manual for combustion in boilers for commercial LPG burners.

The estimated emissions are presented in **Table 3-36**.

■ **Table 3-36 Sub threshold combustion in the Pilbara**

Substance	Emissions (kg/year)
Arsenic & compounds	0.00251
Benzene	3,630
Cadmium & compounds	0.00131
Carbon monoxide	126,000
Chromium (III) compounds	0.00151
Chromium (VI) compounds	0.000248
Cobalt & compounds	0.00601
Fluoride compounds	0.0373
Lead & compounds	0.00426
Mercury & compounds	0.00103
Oxides of nitrogen	416,000
Nickel & compounds	0.085
Particulate matter <10 um	41,300
Polyclic aromatic hydrocarbons	28.4
Sulphur dioxide	50,200
Toluene	69.3
Xylene	48.2
Total VOC	40,900

3.16.3 Spatial Allocation

Emissions from sub threshold combustion were allocated by population across the study region. This is not strictly valid as sub-threshold facilities could be argued to be primarily concentrated in light industrial parks such as Wedgefield at Port Hedland and the Karratha light industrial park, and at the facilities that are likely not to report. However given that the estimate includes emissions from power generation, as a first estimate the emissions have been allocated by population.

3.16.4 Comparison with Other Studies

Comparison with emission estimates from the Perth study indicates the emissions per capita are generally comparable (**Table 3-37**). However, as the Perth estimates include facilities that are to report in subsequent years to 1998/1999, the true Perth sub threshold facility emissions will be lower.

■ **Table 3-37 Sub Threshold Emission Estimates for Selected Studies**

Substance	Pilbara (kg/person/year)	Perth (kg/person/year)
Carbon monoxide	2.5	1.3
Lead	8.5×10^{-3}	1.0×10^{-3}
Oxides of Nitrogen	8.3	4.3
PM10	0.82	1.7
Sulphur Dioxide	1.0	7.5
Total VOC	0.82	0.51

Notes: Perth estimates include facilities that will be reporting from 1999/2000 onwards and as such will overestimate the sub threshold component.

4. Natural Sources

4.1 Introduction

Emissions from natural sources cover the following categories:

- VOC emissions from vegetation;
- NO_x emissions from soil;
- Windblown dust emissions from natural windblown events; and
- Emissions from prescribed burning and wildfires.

In the NPI categorisation VOC emissions from vegetation and NO_x emissions from soil have been classified under the one category - Biogenics. These two sources are discussed separately in **Sections 4.2** and **4.3** but are presented as a single emission source in the NPI database. Wind blown dust emissions are discussed in **Section 4.4** and are estimated from open bare areas, including wind blown dust from roads. Burning and Wildfire emissions are classified under the commercial/agricultural section but for the sake of clarity and as a large proportion of the fires in this study area are due to nature (lightning strikes) are presented in **Section 4.5**.

4.2 Biogenics - VOC Emissions from Vegetation

4.2.1 Data Collection and Information Sources

The methodology adopted for the calculation of VOC emissions from vegetation is the same as that used in the Kalgoorlie NPI Trial (Coffey Geosciences, 1999) and for the Newcastle region in the NPI Trial (EPAV, 1996). This methodology is based on Lamb *et al* (1987) and estimates the major VOCs emitted (isoprene, cineole, and monoterpenes) from vegetation based on a temperature dependant function and a vegetation density index (see **Section 4.2.2**). This methodology is simpler than that adopted for other Australian studies such as MAQS (Carnovale *et al*, 1997), that used for Dandenong, Launceston and Port Pirie in the NPI Trial (EPAV, 1996) and for the Perth Photochemical Smog Study (EPAV, 1995). The methodology for these studies requires additional data on biomass density (mass on a dry basis of leaf per unit area of ground) as well as using more complicated temperature factor and a radiation factor that varies with the sun angle.

For this study, given that there are no biomass density data for the full study area and there are no specific VOC measurements for the vegetation types in the study region, the simpler (Lamb *et al*, 1987) approach will be sufficient for the first estimate.

Data required for emission estimates are vegetation types, classification of the vegetation density and meteorological data for the Pilbara region. The primary source of vegetation type and coverage (used to determine density) is a detailed map compiled by the Botany Department, Australian National University and AUSLIG geographers. Temperature data also required was obtained from the Bureau of Meteorology's automatic weather station and manual recording stations.

4.2.2 Emission Estimation

Emissions of VOC compounds from vegetation were calculated using **Equation 4-1** from Lamb *et al* (1987), as used in Coffey Geosciences (1999) and EPAV (1996).

$$E_j = pq10^r \qquad \textbf{Equation 4-1}$$

Where

E_j is the mass emission flux (g/m^2/hr) of a volatile organic compound j at an ambient temperature of T°C

p and r are empirical coefficients

q is the vegetation density index (ranging from 0 to 5)

The empirical constants used in Coffey Geosciences (1999) and EPAV (1996) are listed in **Table 4-1**. For this study the empirical scaling constant p was modified as new data (He *et al*, 1999; CSIRO, Cope, M., personal communication, 2000) indicates that the emissions from heavily wooded forest of eucalyptus trees (as used for a vegetation index of 5) are higher than that derived in MAQS and used in the above studies. In MAQS a maximum emission rate per land area of 1.8 mg/m^2/hr was used which equates to a p value of 0.0268. This value has subsequently been found to be too low with CSIRO (Cope, M., personal communication, 2000) indicating that a value up to twice this may be more appropriate for the Sydney area. Measurements by He *et al* (1999) for 15 Eucalypt species gave an average around 12 mg/m^2/hr (based on a leaf biomass density of 350 g/m^2, EPAV, 1995). These measurements were taken from small plants, that were well watered and fertilised and may be over-estimates of emissions from mature plants that undergo water stress. For the Perth Photochemical smog study values of around 4.7 to 5.7 g/m^2/hr are predicted using branch level isoprene values of 13.1 µgC/g/h as suggested by CSIRO (Cope, M., personal communication, 2000). These values were thought to result in emissions that were slightly higher than actual from comparison of predicted ozone levels (CSIRO, Cope, M., personal communication, 2000)). As such, based on the above Australian studies a value of 3.6 mg/m^2/hr (or a p value 2.0 times that quoted by EPAV, 1996) has been adopted for a dense canopy of trees in the study area.

■ **Table 4-1 Empirical equations for Biogenic VOCs from EPAV (1996)**

Pollutant	Time & Temperature	p	r
Isoprene	Day, T<40°C	0.0268	0.0416T – 3.109
	Day, T>40°C	3.52 – 0.064T	-3
	Night	0	n.a.
1,8-Cineole	Day/night	0.0302	0.0416T – 3.109
Monoterpenes	Day/night	0.0133	0.0416T – 3.109

Notes:
1. In this study p value 2 times these have been adopted.
2. Night was defined as from 6pm to 6am.

For areas with 100% grass coverage a value 0.4 mg/m^2/hr has been adopted from the open savanna measurements of Klinger *et al* (1998). This value is higher than values for temperate grasses as used in the US of 0.15 mg/m^2/hr (Carnovale *et al*, 1997), based on a quoted value of 300 µg/m^2/hr of total non-methane hydrocarbons consisting of 50% isoprene). The higher value is considered appropriate as the grasslands consist primarily of spinifex that are known to have a high oil content. With no measurements of such grasses in Australia the African savanna results have been adopted.

Vegetation densities (i.e. values of q from 0 to 5) were assigned based on the percentage of coverage of trees and percent coverage of grasses. For shrubs and trees with 50% coverage or less, it was assumed that the grasses underneath provided an additional 30% coverage (as a mid range figure for grass coverage).

As per EPAV (1996) mangroves were assumed to emit negligible isoprene and cineoles, whilst monoterpenes were emitted at approximately the same rate as for other isoprene emitting species. Therefore as an approximation to estimate total VOCs, emissions of isoprene, cineoles and monoterpenes were reduced by one third. For emissions, as mangroves were taken to have a biomass density half that of a forested area, a q factor of 0.83 was adopted. A description of each category is presented below (**Table 4-2**).

■ **Table 4-2 Vegetation categories**

Species	Description	% Cover	Vegetation Density Index (q)	Max. Isoprene Emission ($mg/m^2/hr$)
Acacia	Tall shrubs > 10.0m	30 – 70	2.69	2.2
Hummock	Grasses	30 – 70	0.31	0.225
Acacia	Tall shrubs > 10.0m	10 – 30	1.19	0.86
Chenopods	Low shrubs < 2.0m	10 – 30	1.19	0.86
Littoral	Mangroves	-	0.83	0.60
Eucalypts	Low trees < 10.0m	< 10%	0.44	0.32
Hummock	Grasses	10 – 30%	0.125	0.09
Acacia	Tall shrubs > 10.0m	< 10%	0.44	0.32
Chenopods	Low shrubs < 2.0m	< 10%	0.44	0.32
-	Water bodies	100%	0.0	0.0

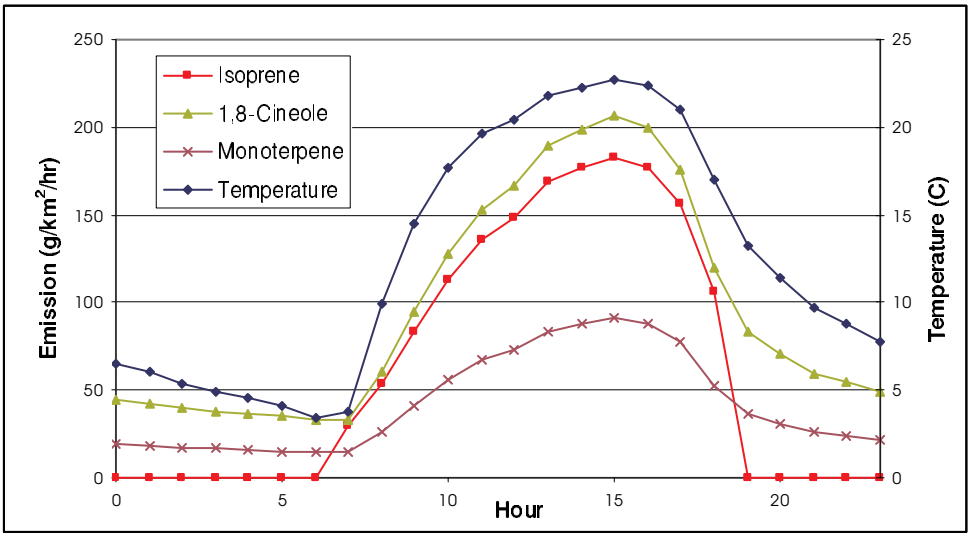
Notes
1. A vegetation index (q) of 5 corresponds to emissions of isoprene of 4.5 $mg/m^2/hr$
2. Emission rate normalised to 30 ^0C and photosynthetically active radiation of 1000 $\mu mol/m^2/s$.

Max emissions (q=5) were calculated using hourly temperatures at the following sites with hourly temperature data:

- Karratha;
- Newman;
- Onslow;
- Port Hedland; and
- Learmonth.

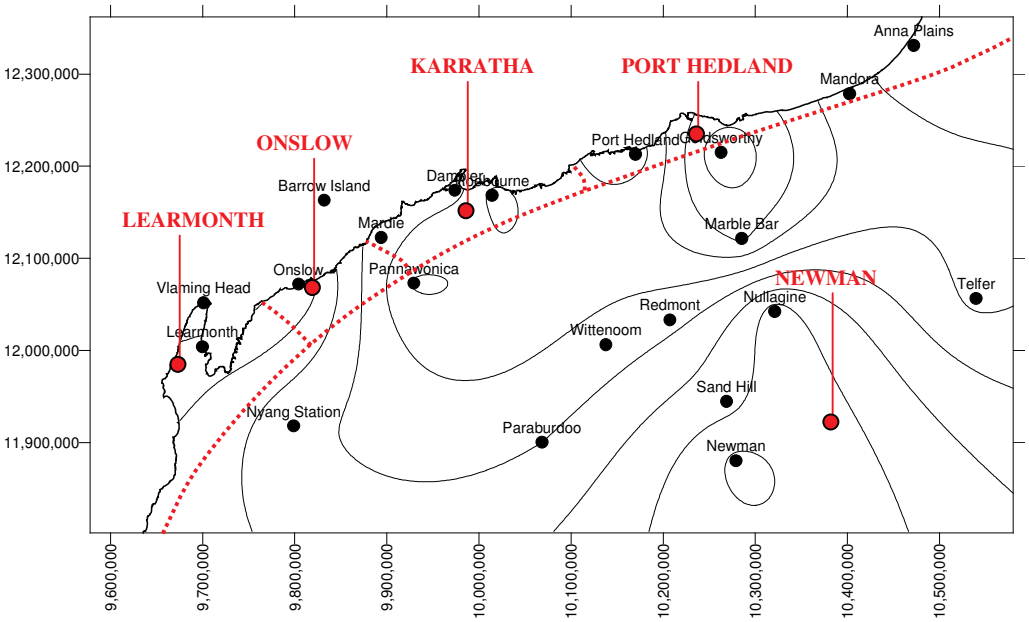
A typical 24-hr temperature profile and emissions of the various VOC compounds is illustrated in **Figure 4-1** for July at Newman.

■ **Figure 4-1 Typical hourly temperature and emission profile for July at Newman**



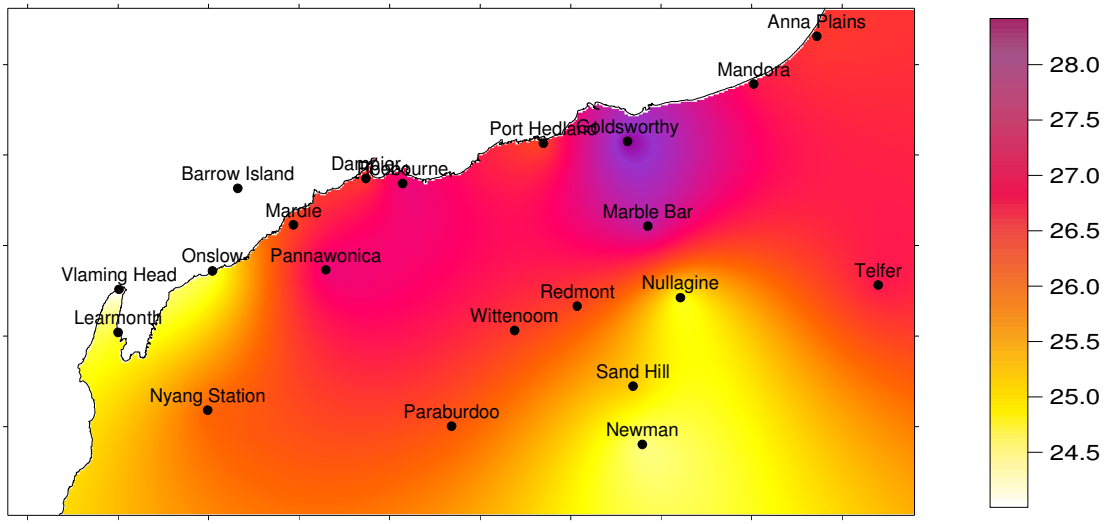
The temperature factors were then determined across the study region by dividing the area into a number of zones to coincide with the towns for which hourly temperature data was available. This zonation is presented in **Figure 4-2**.

■ **Figure 4-2 Temperature zones for the Pilbara**



Maximum emission potentials were then generated across the Pilbara based on the ratios of the annual temperatures at these stations to the sites with the hourly temperature data. The average annual temperatures are presented in **Figure 4-3**. No account of temperature change with height is necessary (as required in EPAV, 1996 and Carnovale *et al*, 1997) as the temperatures recorded at the inland sites include this.

■ **Figure 4-3 Average annual temperatures (°C)**



The resultant VOC emissions for each vegetation category (**Table 4-3**) were determined by multiplying the maximum emission potential for that grid by the vegetation density index.

■ **Table 4-3 Total VOC emissions and area of each category**

Species	Description	% Cover	Area (km^2)	VOC Emissions (t/yr)	Contribution (%)
Acacia	Tall shrubs > 10.0m	30 – 70	2,342	84,000	4.1
Hummock	Grasses	30 – 70	18,384	65,000	3.2
Acacia	Tall shrubs > 10.0m	10 – 30	53,378	593,000	29.4
Chenopods	Low shrubs < 2.0m	10 – 30	7,104	83,000	4.1
Littoral	Mangroves	-	2,965	27,000	1.3
Eucalypts	Low trees < 10.0m	< 10%	67,514	311,000	15.5
Hummock	Grasses	10 – 30%	21,470	27,000	1.3
Acacia	Tall shrubs > 10.0m	< 10%	181,809	795,000	39.4
Chenopods	Low shrubs < 2.0m	< 10%	7,197	33,000	1.7
-	Water bodies	100%	197,835	0	0.0
Total			**565,000**	**2,018,000**	**100.0**

4.2.3 Spatial Allocation

Emissions were estimated on a 10 km by 10 km grid, dependent on vegetation type, vegetation density and the temperatures, as described in **Section 4.2.2**.

4.2.4 Comparison to Other Studies

Emission estimates of VOC per square kilometre for other studies in Australia are presented in **Table 4-4** along with the Pilbara study for emissions from the land area. These indicate quite a large variation in emissions with those from the Pilbara being highest on a per kilometre basis. This is due to:

- The different methodologies used in the different studies;
- The large uncertainties in the emission rates and the assumptions involved; and
- The high temperatures in the Pilbara which result in much higher estimated emissions than would occur for more temperate climates.

Also the comparison indicates that Melbourne (Port Phillip Bay area) emissions are significantly lower. This may be due to the larger urban area in this study but the data appears questionable.

■ **Table 4-4 VOC emissions from vegetation for this and other Australian studies**

Region	VOC ($kg/km^2/yr$)
Pilbara	5,500
Dandenong [1]	727
Port Pirie [1]	1,356
Newcastle [1]	5,233
Launceston [1]	964
Melbourne [2]	36.7
Kalgoorlie [3]	5,090

Note: Sources (1), EPAV (1996) and (2) EPAV (1998), Coffey Geosciences (1999).

4.3 Biogenics - Emissions of NO_x from Soils

4.3.1 Data Collection and Information Sources

Data required for emission estimates are temperature and rainfall. These were obtained from the Bureau of Meteorology from their network of automatic weather stations and manual observations.

4.3.2 Emission Estimation

4.3.2.1 Background

One of the principal natural sources of NO_x has been found to be biogenic emissions from soils (e.g. Williams *et al*, 1987; Guenther *et al*, 2000). In rural areas, soil biogenic emissions of NO_x account for a larger fraction of the total NO_x source than anthropogenic emissions (Yienger and Levy, 1995).

NO_x emissions are strongly influenced by the landscape. In soil, NO_x emissions result from microbial and chemical processes from both denitrifying bacteria in anaerobic environments and nitrifying bacteria in aerobic environments (Williams *et al*, 1987). In water bodies, NO_x emissions result from nitrite photolysis. Guenther *et al* (2000) reports that in general, wetlands and tundra have low emissions, forests have moderate emissions, while agricultural and grasslands have the highest emission rates. Yienger and Levy (1995) believe that in general, grassland emissions are an order of magnitude greater than those of forests, while heavily fertilised soils are an order of magnitude greater than those of grasslands.

The emission activity can be seen to be a function of both short term and long term effects. Long term effects include soil texture, organic matter content, soil pH and nitrate levels. In the short term, the effects are primarily soil temperature and moisture content. Soil NO_x rates generally increase with the application of nitrogen based fertilisers, soil temperature and optimal soil moisture conditions (Guenther *et al*, 2000).

As there is a strong dependency of NO_x emission rates on atmospheric parameters, large regional, seasonal and diurnal variations in emission rates can be expected. Land use practices in agricultural land can also result in significant changes in emissions on time scales of a few years to a decade (Guenther *et al*, 2000).

Williams *et al* (1987) demonstrates that there is a strong relationship between the air temperature and the NO_x emission rate in the form of the following relationship.

$$\text{Log}_{10}(\text{NO flux}) = 0.0049T_A - 0.83 \qquad \textbf{Equation 4.2}$$

Where T_A is the ambient air temperature. Williams emphasises, however, that the above flux represents the total emission of NO_x from the soil and not a net flux to the atmosphere.

Guenther *et al* (2000) also finds that significant NO_x emissions can result from lightning through the dissociation of molecular nitrogen and reaction with oxygen to form NO. He finds the contribution from lightning to be as much as from soils.

Previous estimates of biogenic NO_x inventories in Australia including that adopted in the Victorian trial (EPAV, 1996), the Kalgoorlie Mining NPI Trial (Coffey Geosciences, 1999) and the MAQS study (Carnovale *et al*, 1997) have used the temperature dependence of NO_x emissions derived by Williams *et al* (1992) and a set of land use categories described below.

$$E_{NOx} = \alpha 10^{(0.049T - 0.83)} \qquad \textbf{Equation 4.3}$$

Where:

E_{NOx} = NO_x emission rate (kg/km^2/hr) at an ambient temperature of T°C
α = empirical coefficient (**Table 4-5**)

■ **Table 4-5 Land use categories**

Land Use	α
CBD, built up area, commercial/industrial	0.000
Residential	0.004
Mixed rangeland[1]	0.040
Forest	0.005
Water bodies (ocean, bays, lakes etc)[2]	0.002
Barren land[3]	0.028

Notes:
1. Includes pasture and agricultural land.
2. Above values are during daylight hours. At night-time α = 0.
3. Includes beaches, deserts, quarries and strip mines.

The above categories are not applicable for use in the Pilbara as the landscape is mostly tussocky grassland and spinifex grassland and acacia shrublands (AgWA, 2000). The high NO_x emission rate allocated above for mixed rangeland is believed to be due to the inclusion of agricultural land in the category which has a higher NO_x emission rate due to the application of nitrogen based fertilisers. The landscape in the Pilbara can neither be described as mixed rangeland or barren land.

The most authoritative, but practical approach for estimating NO_x emissions from soils is found in Yienger and Levy (1995) (USEPA, Pierce, T., personal communication, 2000). This approach incorporates both variations in soil temperature and soil moisture. Yienger and Levy describe the temperature dependence of NO_x emissions in dry as opposed to wet soils. In very dry soils, the strong exponential temperature dependence described by the equations above becomes weaker and more linear, with emissions 3-5 times lower than from comparable moist soils. However in extremely wet or inundated soils, emissions drop due to the suppression of nitrifying bacteria and/or clogging of soil pores.

The approach described by Yienger and Levy (1995) is attractive due to the introduction of a concept described as ‘pulsing’. When a very dry soil is wetted, a large burst or ‘pulse’ occurs and then decays rapidly over a period of time. Typically, the flux begins at 10-100 times the background level and decays over a period of a few

days to a few weeks, depending on the duration of dry period and amount of rainfall. Yienger and Levy (1995) believe that the strongest impact of pulsing will be in the tropics where there are extended dry seasons followed by wet seasons. One of the main features of the model developed by Yienger and Levy (1995) is the inclusion of a separate exponential temperature dependence for wet soils and linear dependence for dry soils, and an optimal temperature above which the NO_x emission rate becomes temperature independent. As such, in this study the method of Yienger and Levy (1995) has been adopted.

4.3.2.2 Adopted Methodology – Yienger and Levy (1995)

Emissions of NO_x for the Pilbara have been estimated using the empirical relationship used by Yienger and Levy (1995) as presented in **Equation 4.4**:

$$E_{NOx} = f_{w/d} \text{ (soil temperature, } A_{w/d}) \text{ x P (precipitation)} \qquad \textbf{Equation 4.4}$$

Where:

- $f_{w/d}$ is some function with the subscript w/d representing the soil moisture state, either dry or wet;
- $A_{w/d}$ is a coefficient used to distinguish between different landscapes;
- P is a function of the magnitude and duration of the precipitation, and is a scalar factor which varies between 1 and 15.

A soil is considered dry in the sense that it will pulse when wetted. A dry soil is classified as having received less than 1cm of precipitation in the previous 2 weeks.

The function f_w (w, when the soil is wet) is described by three soil temperature intervals: cold-linear (0-10°C), exponential (>10-30°C), and optimal (>30°C).

$$f_w = \begin{cases} 0.28A_w T & 0 < T < 10 \\ A_w e^{0.103T} & 10 < T < 30 \\ 21.97A_w & T > 30 \end{cases} \qquad \textbf{Equation 4.5}$$

Where f_w is measured in kg/km^2/hr, the parameter A_w is estimated as 1.296 x 10^{-3} kg/km^2/hr (the average of 13 grassland/savanna landscapes) and T is the soil temperature in °C. Soil temperature (T °C) is approximated by air temperature (T_A°C) after Williams *et al* (1992) by:

$$T = 0.66T_A + 8.8 \qquad \textbf{Equation 4.6}$$

In dry soils, two temperature regimes are defined: cold-linear (0-30°C) and optimal (>30°C):

$$f_d = \begin{cases} \dfrac{A_d T}{30} & 0 < T < 30 \\ A_d & T > 30 \end{cases} \qquad \textbf{Equation 4.7}$$

with A_d estimated at 9.54 x 10^{-3}.

Estimates of P are determined from the rainfall rate and determine the magnitude and duration of the VOC pulse.

■ **Table 4-6 VOC Emission as a Function of Rainfall**

Rain Rate (mm/day)	Pulse Description	Function
< 1.0	No pulse (assume evaporation)	P = 1.0
1.0 – 5.0	'sprinkle', a 3-day pulse with exponential decay starting x5	$P = 11.19e^{-0.805t}$ (1<t<3)
5.0 – 15	'shower', 1-week pulse with exponential decay starting x10	$P = 14.68e^{-0.384t}$ (1<t<7)
> 15	'heavy rain', 2-week pulse with exponential decay starting x15	$P = 18.46e^{-0.208t}$ (1<t<14)

For vegetation that is fertilised, Yienger and Levy (1995) define two functions that simulate fertiliser application and canopy reduction which acts to suppress soil NO_x emissions. These two functions are not required for the Pilbara region with minimal fertiliser application.

For water bodies, Yienger and Levy (1995) provide no methodology, as they are concerned with estimating a global biogenic inventory. For the purposes of this study, NO_x emissions from water bodies due to nitrite photolysis were calculated using Equation **4.8** as used by the Victorian trial (EPAV, 1996), the Kalgoorlie Mining NPI Trial (Coffey Geosciences, 1999) and the MAQS study (Carnovale *et al*, 1997).

$$E_{NOx} = 0.002[10^{(0.049T_A - 0.83)}] \qquad \textbf{Equation 4.8}$$

Where

T_A is the ambient air temperature.

4.3.2.3 Emission Estimates – Adopted Methodology

Emissions of NO_x were estimated using daily rainfall and average daily temperature data for each of the automatic weather station sites indicated in **Figure 4-2.** These were calculated using the equations given in **Section 4-3-2-2** on a daily time step and are presented in presented in **Table 4-7** for land and water.

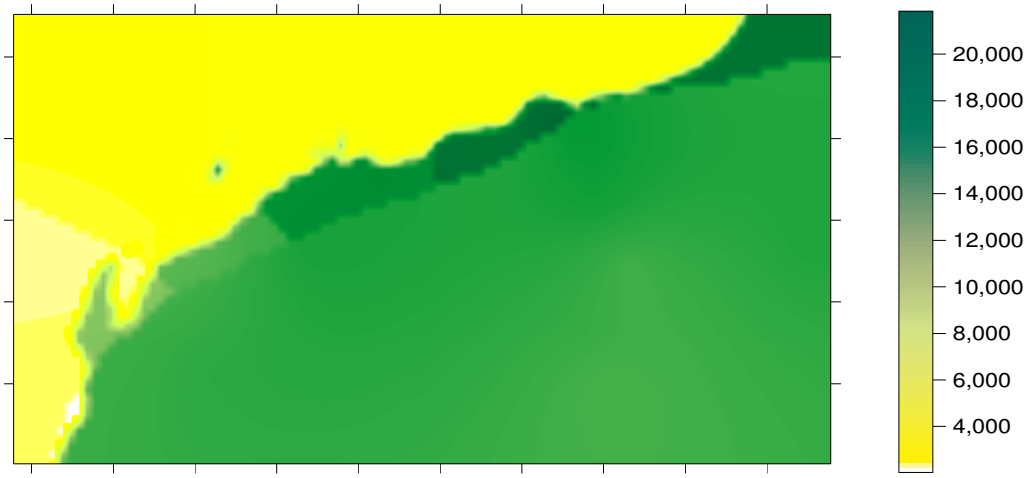
■ **Table 4-7 Average NO_x emission rates for each region**

Region	Land Emission Rate (kg/km^2)	Water Emission Rate (kg/km^2)	Average Emission Rate (kg/km^2)
Port Hedland	204.5	26.1	142.7
Karratha	178.4	26.9	125.9
Newman	145.3	19.9	101.9
Learmonth	123.5	23.0	88.7
Onslow	139.4	24.6	99.6
Study Region			112

Emissions throughout each of the five regions defined in **Figure 4-2** where then scaled linearly according to the temperature variation within the region. This linear scaling is an approximation as the temperature dependence of emissions is both linear and exponential, depending on whether the soil is wet/dry, and whether the landscape is water. However, as much of the study area is land and it is dry for most of the reporting period, this approximation is thought justified.

The resultant emission estimates across the study region are presented in **Figure 4.4** with total NO_x emissions from soils estimated at 6.23×10^4 tonnes/year, which is an average 112 kg/km^2.

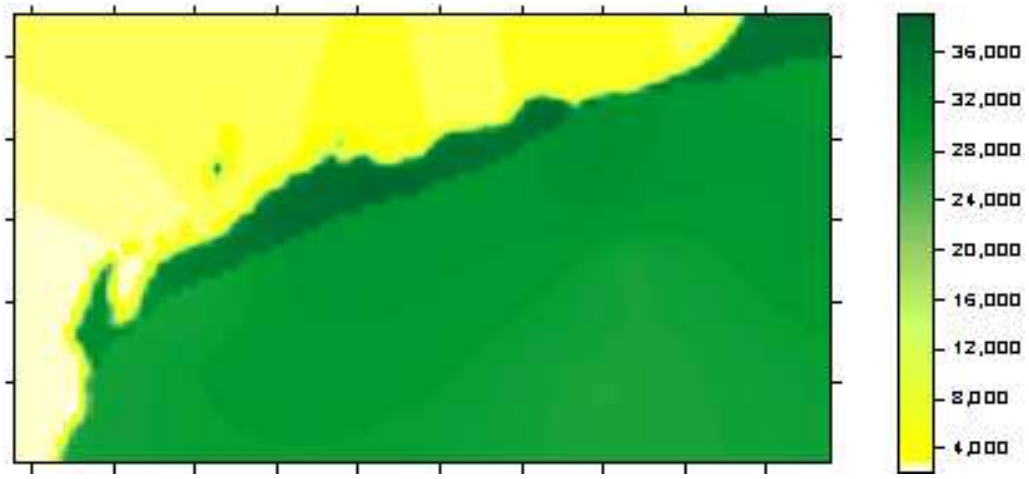
■ **Figure 4-4 Total NO_x emissions in the Pilbara study area (kg/year/grid cell)**



4.3.2.4 Emission Estimates – Methodology used in EPAV (1996)

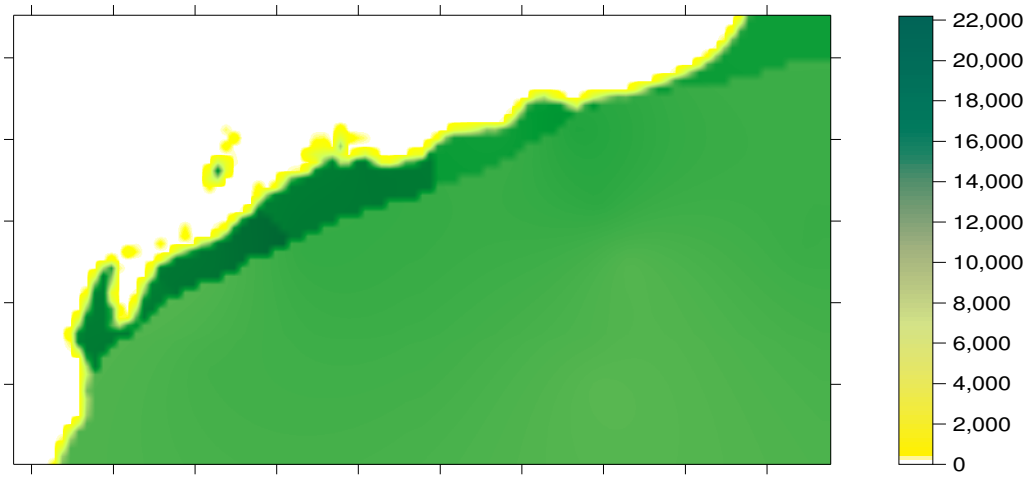
For purposes of comparison, estimates of NO_x emissions from soils were also calculated for the study area using the methodology adopted in the Victorian trial (EPAV, 1996), the Kalgoorlie Mining NPI Trial (Coffey Geosciences, 1999) and the MAQS study (Carnovale *et al*, 1997). The whole landscape was classified as 'barren land' in accordance with the set of classifications outlined in **Table 4-5**. The 'rangeland' classification was not selected for the Pilbara study area as the category includes pasture and agricultural land. The empirical factor therefore reflects the use of nitrogen based fertilisers which is not a true reflection of the land use in the Pilbara region. The resultant NO_x emissions are presented in **Figure 4-5**. With the total NO_x emissions estimated at 1.16×10^5 tonnes, which is on average 207 kg/km^2.

■ **Figure 4-5 Total NO_x emissions in the Pilbara study area using the EPAV (1996) methodology (kg/year/grid cell)**



This estimate is approximately 86% higher than the estimates based on the methodology adopted for the study and is thought to result from this methodology not including the effects of precipitation and the resultant pulsing of emissions from soils. The difference in emissions between the EPAV (1996) and Yienger and Levy (1995) methodologies is shown in **Figure 4-6**.

■ **Figure 4-6 Difference in emission estimates of the two methods (kg/year/grid cell)**



4.3.3 Spatial Allocation

Emissions were estimated on a 10 km by 10 km grid, dependent on land/sea, air temperature and rainfall.

4.3.4 Comparison with Other Studies

Comparison to the estimate for this region and other studies are presented in **Table 4-8.**

■ **Table 4-8 NO_x emissions from soil for this and other Australian studies**

Region	NO_x ($kg/km^2/yr$)
Pilbara	112
Dandenong (1)	190
Port Pirie (1)	491
Newcastle (1)	135
Launceston (1)	122
Melbourne (2)	1.25
Kalgoorlie (3)	304

Note: Sources (1), EPAV (1996) and (2) EPAV (1998), Coffey Geosciences (1999).

Table 4-8 indicates that emissions are on the low side for the other studies excepting the estimates from the Melbourne (Port Phillip area) study, which appear in error. This difference between the various studies is due to:

- The methodologies used. This study has adopted the methodology of Yienger and Levy (1995) which it is believed provides a more accurate estimate of NO_x emissions, especially from the dry soils in the Pilbara region. The Yienger and Levy (1995) methodology estimates considerably lower emissions than the EPAV (1996) methodology previously adopted in Australia. For the entire Pilbara study area, including both land and sea, the estimated emissions are 86% less. Considering only the land areas, the estimated emissions are 100% less.
- The relatively barren soil and vegetation of the region, which would be characterised at the lower end of NO_x emitters according to the methodology as used in EPAV (1996), Carnovale *et al* (1997).

It is interesting to note that Yienger and Levy (1995) in their estimation of global soil NO_x emissions found Australia to be one of the three largest emitters of soil NO_x as the biogenic source dominates in remote and agricultural regions which are neither cultivated nor densely populated. They also found grassland/savanna to be the most important landscape in terms of NO_x emissions.

4.4 Windblown Dust

4.4.1 Data Collection and Information Sources

Windblown dust emissions from bare areas were estimated using a modified wind erosion equation (WEQ) as used by the USEPA (1974) and USEPA (1988) and with revisions in CARB (1997). This is also summarised by Dudley and Macintosh (2000) who recommended this scheme for use for estimating PM10 for the Bowen Basin.

This methodology was used to estimate windblown dust from two sources, un-vegetated open areas and from unpaved road as per CARB (1997).

Data required for this method include:

- Areas within the study area that are susceptible to wind erosion obtained from Agricultural Western Australia
- Unpaved road areas obtained from the length of unpaved roads in the study areas; and
- Wind, temperature and rainfall records obtained from the Bureau of Meteorology.

Areas of open bare area susceptible to wind erosion were obtained from the comprehensive surveys undertaken by the Agricultural Western Australia in the 1980s and 1990s. These surveys were conducted "in response to reports of degradation in the district and complaints of dust storms. These storms appear to be a result of the degradation, and affected the towns of Karratha, Wickham, Dampier and Roebourne. Also on a number of occasions in the 1980s, dust storms severely reduced visibility on the North West Coastal Highway" (Payne and Tille, 1992). These surveys mapped the vegetation types, soil types, condition reports of the rangeland with all severely degraded areas susceptible to wind erosion greater than about 400 by 400 m mapped. This study found that wind eroded areas occurred on the alluvial plains where over grazing and a run of poor seasons had contributed to large bare areas. When this overgrazing had occurred on soils with little stony mantle for protection from wind erosion, severe erosion had occurred with some evidence that soil loss was around 0.4 m due to wind action. Other areas of the study such as areas with stony plains and large rocky outcrops were not mapped, as there is little or zero potential for wind erosion given the type of bare surface. This data has recently been extended to cover the Pilbara (AgWA, 2000).

Bare erodible land was digitally obtained from AgWA for 250,000 km^2 of the 365,000 km^2 of land area in the study region. Not covered were areas to the south east, south west and west of the study region. As the condition of the Roebourne plain area has improved since the eighties when this area was studied, the area of susceptible land for this area has been reduced by 50% (AgWA, Payne, A., personal communication, 2000). The resultant total area of land greater than 400 by 400 m susceptible to wind erosion in the study area therefore is 352 km^2.

The area of unpaved roads was determined from the total length of unpaved roads in the study region of 8,511 km. Of these roads, 975 km are major unsealed, 4,834 km are minor unsealed and 2,702 km are tracks. Average widths for major unsealed, minor unsealed and tracks were taken as 10 m, (two 3.5m lanes and 1.5m shoulders), 8 m and 4 m (MRWA, 1999). This corresponds to areas of these road categories of 9.75, 38.7 and 10.8 km^2 or a total unpaved road area of 59.25 km^2.

4.4.2 Emission Estimation

Emissions were calculated after CARB (1997) according to:

$$E = kaIKCL'V' \qquad \textbf{Equation 4.9}$$

Where:

E = PM10 fraction of particulate wind erosion losses (t/acre/yr);
k = fraction of particulate emissions which is PM10 (assumed to be 0.5);
a = portion of total wind erosion losses that would be measured as suspended particulate (estimated to be 0.025);
I = soil erodibility (t/acre/yr) that would occur for that soil type for the climatic conditions at Garden City, Kansas;
K = surface roughness factor;
C = climatic factor;
L' = unsheltered field width factor; and
V' = vegetative cover factor.

The climatic factor was calculated using the following set of equations:

$$C = 0.0828\frac{W^3}{(PE)^2} \qquad PE = \sum_{i=1}^{12} PE_i = 1.644\left[\frac{P_i}{(T_i + 12.2)}\right]^{\frac{10}{9}} \qquad \textbf{Equation 4.10}$$

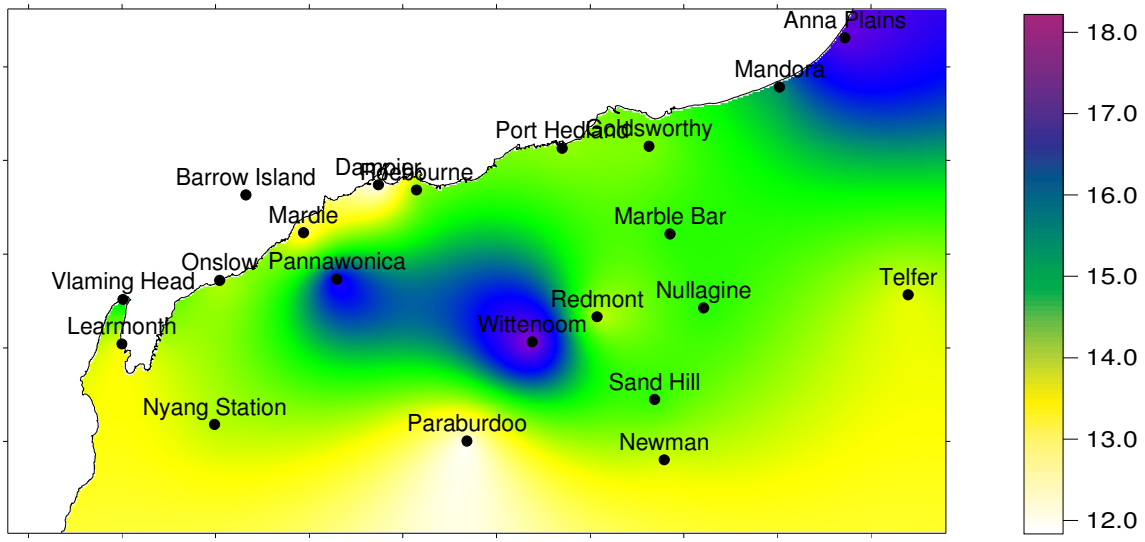
Where:

- W^3 is the mean annual wind speed cubed (where W is the wind speed at 10 m expressed as km/hr). In this report W^3 was evaluated as $(1/12)\sum W_i^3$. This monthly evaluation of the cube of the wind speed was used as it is thought to give a better representation of the wind potential at a site than the annual average (CARB, 1997).
- PE is the Thornthwaite's precipitation-evaporation index. Following CARB (1997) all months with precipitation less than 12.5 mm were assigned a value of 12.5 mm to restrict excessively small PE and therefore C values.
- P_i is the monthly rainfall (mm).
- T_i is the average temperature for that month (°C).
- i is the month of the year.

Wind data from the Bureau of Meteorology were available from five automatic weather stations in the Pilbara area. These stations were used as they provided hourly wind speeds that give the most accurate representation of monthly and annual wind speeds. Also they are sited in wide open areas at airports which provide true estimates of wind speeds in the region and are not subject to sheltering effects commonly found at other weather stations. To spatially vary the winds across the region, winds were assumed constant in the 5 zones in **Figure 4-2**. This is an approximation and does lead to step changes at zone boundaries, but with the lack of wind stations in the region was thought justifiable.

A Thornwaite precipitation- evaporation (PE) index grid was generated using precipitation and temperature data from 21 stations. This data is represented as an image map in **Figure 4-7**. A higher PE index represents less erodibility.

■ **Figure 4-7 PE Index image map**



Climate "C" factors were then derived using **Equation 4.10** for each grid cell. These are summarised in **Table 4-9** for the 5 automatic weather station sites and range from 0.99 at the inland site of Newman to 4.96 at Karratha. This wide variation is primarily due to the variation in average wind speed at the site, with the C factor being very sensitive to relatively small changes in annual wind speed. This indicates that the erosion potential is much greater near the coast, particularly in the region from Onslow to between Karratha and Port Hedland. This area corresponds to the region of the Roebourne plains that was frequented by dust storms in the eighties (Payne and Tille (1992).

■ **Table 4-9 Estimated PM10 potential erosion rates for selected sites in the Pilbara**

Station	Average Wind Speed @10m (m/s)	Annual PE value	C Factor	PM10 emission (t/acre/year)	PM10 emission (t/ha/year)
Port Hedland	4.6	14.1	1.96	2.06	5.63
Karratha	5.6	11.8	4.96	5.21	14.2
Onslow	5.5	13.9	3.68	3.86	10.5
Learmonth	5.0	13.4	2.95	3.09	8.44
Newman	3.5	13.7	0.99	1.04	2.84

4.4.2.1 Unvegetated Open Areas

Estimates of PM10 emissions from unvegetated open areas were made based on the following:

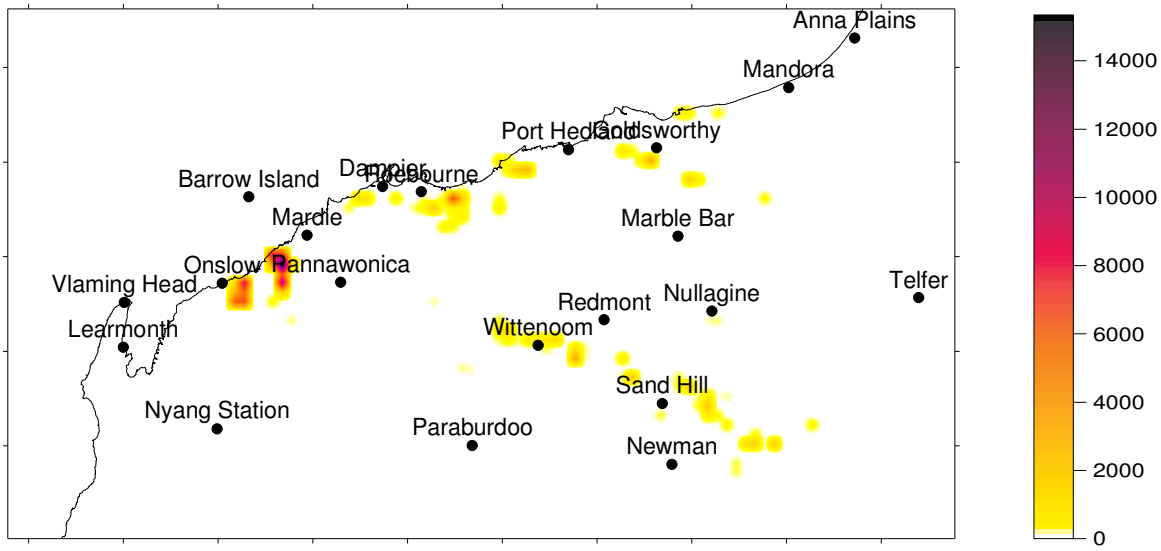
- Soil Erodibility Index. A value of 56 (t/acre/yr) was assumed. This corresponds to soil with 60% passing (or smaller than) 0.84 mm (USEPA, 1988 soil data). This is considered appropriate for the "red duplex and gradational soils with texture ranging from light sandy clay loams to sandy clay that exists on the alluvial plains that are highly susceptible to wind erosion (Payne and Tille, 1992).
- Surface roughness factor taken as 1, indicating no influence of small ridges, large clods to reduce wind speed.
- Unsheltered field width factor taken as 0.75 to account for some sheltering due to vegetation on the edges of the erodible area and that the areas are finite in size.
- Vegetative cover factor equal to 1 indicating no vegetation cover is present.

Using these factors and the climate factor, E factors (PM10 emissions per hectare per year) were calculated across the grid. These factors range from 2.8 to 14.2 tonne/ha/year (see **Table 4-9**). This erosion rate compares to the rate of 1.75 tonne/ha/year for PM10 from the EET Manual for Mining (Environment Australia, 2000c) and 0.85 tonne/ha/year from the EET Manual for Fugitive Emissions (Environment Australia, 1999p. These values are therefore higher corresponding to the high climatic "C" factors for the area and the erodible soils.

PM10 emissions from wind erosion calculated as E for the grid cell multiplied by the area susceptible to wind erosion are presented in **Figure 4-8**. This indicates that:

- High emissions occur along the coast from Onslow to Goldsworthy;
- Area of highest erosion between Onslow and Mardie with other areas near Dampier and Roebourne and along a line from Wittenoom through to SandHill.

■ **Figure 4-8 Wind blown PM10 emissions from open bare areas (tonne per grid cell)**



Total emissions of PM10 from the study area were estimated at 163,000 tonne/year.

4.4.2.2 Unpaved Roads

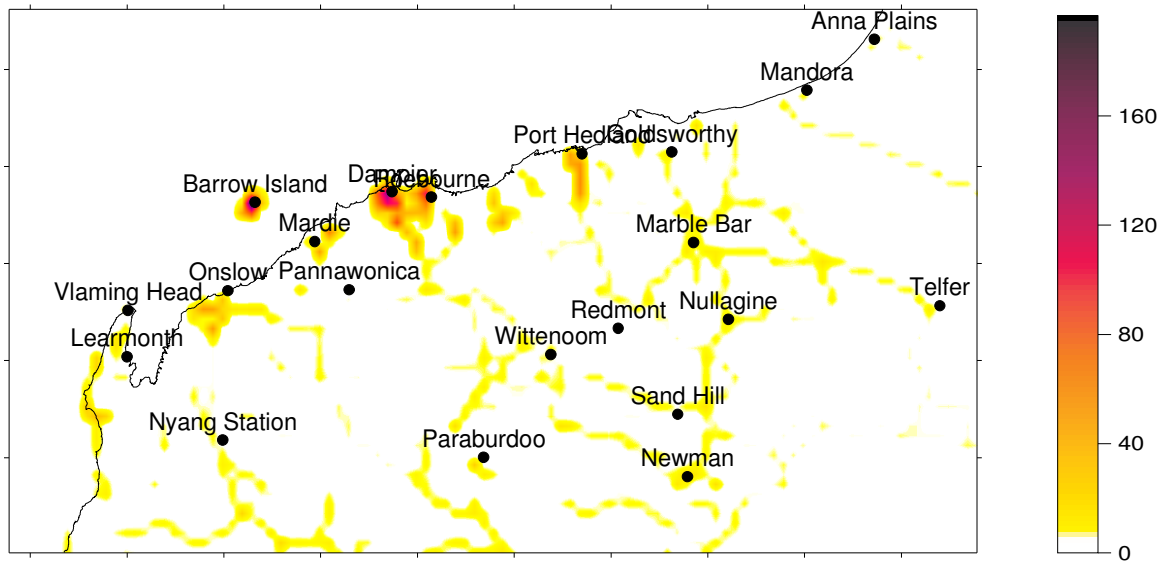
Windblown dust emissions from all unpaved roads are also estimated using **Equation 4-10** with the following assumptions to quantify the variables (CARB, 1997 and Countess, 1999):

- 'a' assumed to be 0.038 with the PM10 fraction 50%;
- 'I' soil characteristics assumed to be the same as roadside soil. For the study area this was taken as less than that for the open areas at 38 ton/acre/year;
- 'k' assumed to be 1.0 as most unpaved roads are flat;
- 'L' assumed to be 0.32; and
- 'V' assumed to be 1.0, as most unpaved roads have no vegetation.

The emissions per unit area from road surfaces are therefore 44% of that from large open unvegetated areas.

The resultant PM10 estimates from unpaved roads are presented in **Figure 4-9** with a total of 8760 tonnes of PM10 emitted annually. This shows a maximum around the Dampier and Roebourne areas and on Barrow Island with lesser maximums around Port Hedland due to high areas of unpaved roads in these regions.

■ **Figure 4-9 Wind blown PM10 from unpaved roads (tonne per grid cell)**



4.4.2.3 Total Emissions of Windblown PM10 and Metals

Taking into account both windblown emissions from bare erodible areas and from unpaved roads the total windblown PM10 emissions for the study area are estimated at 172,000 tonnes/year.

Emissions of metals and PM10 from the study are presented in **Table 4-10.** Metals emissions were estimated using the default unpaved road metal fractions in the EET Manual for paved and unpaved roads and wind blown dust from erodible areas from the soil fraction in the EET Manual for Mining (Environment Australia, 2000c).

■ **Table 4-10 Emissions from Windblown dust in the study area**

Substance	Emissions (kg/year)
Antimony and compounds	232
Arsenic and compounds	1,100
Beryllium and compounds	48.9
Boron and compounds	3,260
Cadmium and compounds	247
Chromium (III) compounds	11,400
Cobalt and compounds	2,540
Copper and compounds	5,650
Fluoride compounds	32,600
Lead and compounds	13,200
Manganese and compounds	171,000
Mercury and compounds	140
Nickel and compounds	8,720
Selenium and compounds	1,150
Zinc and compounds	67,000
PM10	172,000,000

4.4.3 Spatial Allocation

Estimates of PM10 and metals were derived on a 10 km by 10 km grid from the study area. Estimates were obtained for each grid cell based on the climatic factors for that cell and the areas of unvegetated, erodible land and unpaved roads.

4.4.4 Comparison to Other studies

Estimates of dust loss from wind erosion have been derived from dust measurements during wind storms in Australia. Raupach and McIainsh (1994) estimated dust loss from the 1983 dust storm that enveloped Melbourne at around 2 million tonnes. Knight *et al* (1995) estimated that for one dust storm in western Queensland that dust emissions in the size range (6.75-10.3 um) were between 5.5 and 6.3 million tonnes.

Shao and Leslie (1997) using a model also estimated emissions of dust of this magnitude, estimating for a period of extreme winds emissions of 6 million tonnes from Australia.

The numbers above are much greater than those estimated for the 1999/2000 reporting period in this study region. The lower estimates in the study region are thought to be due to: no major dust storms present in the reporting period, the methodology of WEQS which is to predict typical, average estimates and the neglect of erosion from bare areas less than 400 by 400 m. Therefore the estimates in this study will possibly be on the low side.

For comparison to another study that used the revised WEQ methodology, CARB (2000) for the state of California (area 411,000 km^2 that is similar to the Pilbara study area) estimated emissions of dust from bare agriculture ground to be 115,000 tonnes/year. This is similar to the emissions from the unvegetated, erodible area in the Pilbara.

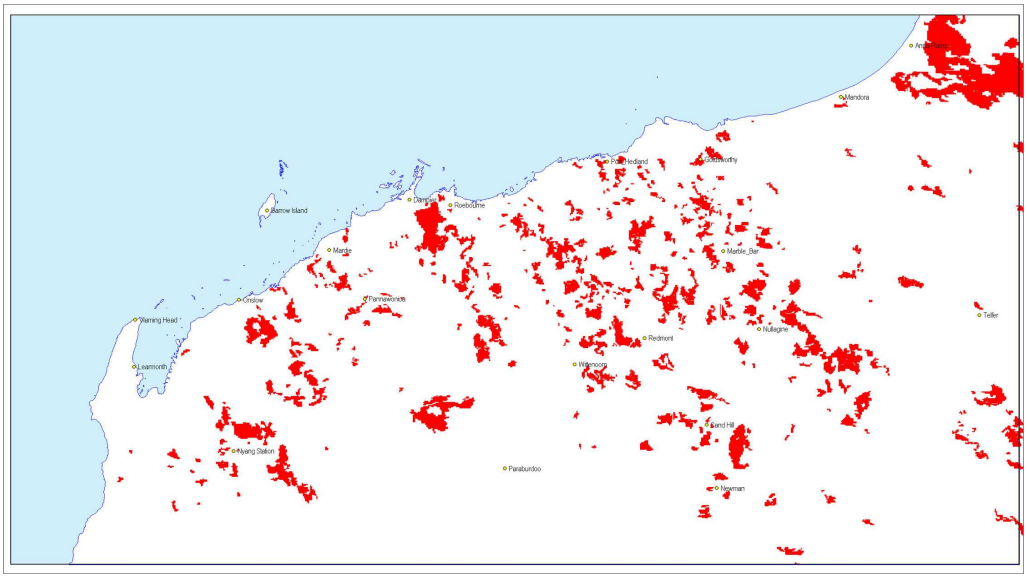
4.5 Burning and Wildfires

4.5.1 Data Collection and Information Sources

Areas burnt within the study area were sourced from the Firewatch project co-ordinated by the Remote Sensing Services Division of the Department of Land Administration (DOLA). This data is obtained from NOAA-AVHRR imagery on an approximate 1 km^2 pixel size. Fire scars are determined by changes in reflectance between two successive passes of the satellite due to the decreased reflectance of blackened burnt surfaces (Beringer *et al,* 1995). This technique for mapping areas is used by the National Greenhouse Inventory for estimating emissions of greenhouse gases from savanna burning (NGIC, 1999). The advantage of this method is that it provides data for large areas with little population, which is the best alternative due to the remoteness of the area. However, it is known that if there is a sufficiently long period between cloudless overpasses, fires may be missed if regeneration occurs (CALM, Craig, R., personal communication, 2000). For temperate regions with smaller fires and larger populations, the NGIC (1999) recommend the use of local fire protection officers to assess the area burned. The disadvantage of this system is that the coarse 1 km^2 pixels may over/underestimate the areas burned.

The fire scar map derived by DOLA for the study area between July 1999 and June 2000 is presented in **Figure 4-10.** For this period the total area burnt in the Pilbara was 27,059 km^2, which is approximately 4.8% of the study area and 7.5% of the land area in the study region.

■ **Figure 4-10 Fire scar areas – 1999/2000**



Fire scar maps for other years are not readily available, therefore annual variability in the area has not been addressed. Discussions with CALM officers (CALM, Leighton, K., personal communication, 2000) suggest that burning over the last few years has been below average. This occurs as spinifex that predominates in the region undergoes an approximate six year growth cycle, with the first three years being palatable to cattle. As such, pastoralists manage the quality of vegetation by fire burning. During 1997, due to a combination of inadequate burning in previous years and a dry season, there was well above the average area burned. This cycle according to CALM (Leighton, K., personal communication, 2000) is a feature of fires in the Pilbara region with the next dry season in the next few years likely to lead to another year with large area of land burned.

4.5.2 Emission Estimation

Emissions were calculated based on the methodology presented in the EET Manual for Aggregated Emissions from Prescribed Burning and Wildfires (Environment Australia, 1999k). This calculates emissions based on the following equation:

$$E_{ij} = A_{ik}L_{ik}EF_{jk} \times 10^{-3} \qquad \textbf{Equation 4.11}$$

Where:

E_{ij} = emissions of substance j from burn area i (kg)
A_{jk} = size of area i burned under fire type k (ha)
L_{ik} = fuel loading of burn area i for fire type k (kg/ha)
EF_{jk} = emission factor for substance j from fire type k (g/kg) (**Table 4-11**)

For fuel loading, the EET Manual specifies a default factor of 7.2 tonne/ha. This is assigned to a broad area of WA under the classification of temperate grassland and savanna. This value is thought to be a reasonable estimate for the spinifex areas, with values for fuel loading reported between 2.8 and 10.2 tonne/ha (Burrows *et al*, 1991). This value though may be dependent on the time since last burn and could possibly be better estimated by using a methodology as described by Denlay *et al* (2000) based on a narrower classification of vegetation type/landform and time since last burn.

Emission factors for the NPI substances, together with total emissions for the study area are summarised in **Table 4-11**.

■ **Table 4-11 Emission factors and total emissions from open burning**

Substance	Emission Factor (Grassland) (g/kg)	Total Emissions (kg/yr)
Antimony and compounds	$4.60x10^{-3}$	89,600
Arsenic and compounds	$3.00x10^{-5}$	584
1,3-Butadiene	$4.40x10^{-2}$	857,000
Cadmium and compounds	$6.20x10^{-4}$	12,100
Chromium (III) compounds	$2.19x10^{-4}$	4,270
Chromium (VI) compounds	$9.14x10^{-5}$	1,780
Carbon monoxide	83.6	1,630,000,000
Cobalt and compounds	$1.10x10^{-4}$	2,140
Copper and compounds	$2.20x10^{-4}$	4,290
Lead and compounds	$5.10x10^{-4}$	9,940
Manganese and compounds	$1.26x10^{-3}$	24,500
Mercury and compounds	$1.30x10^{-4}$	2,530
Nickel and compounds	$1.80x10^{-4}$	3,510
Oxides of Nitrogen	6.36	124,000,000
Particulate Matter (10.0µm)	10	195,000,000
Selenium and compounds	$5.00x10^{-5}$	974
Total volatile organic compounds	4.90	95,500,000
Zinc and compounds	$8.40x10^{-4}$	16,400

4.5.3 Spatial Allocation

Emissions were spatially allocated proportionally to the area burnt within each grid cell on a 10 km by 10 km grid.

4.5.4 Comparison with Other Studies

Emissions from the study area of PM10 and NO_x as a total and per unit land area are presented in **Table 4-12** along with data from other studies. These show that for PM10 the Northern Territory estimates are similar, with the emissions per area at Perth being lower as expected. The Pilbara estimate is higher than Perth due primarily to the higher percentage of land area burned (7.5% to 2%). For California the emissions are much lower per unit area due to the area burned being lower.

For NO_x, the Pilbara estimates per unit area are higher than for the Northern Territory and the Perth region. This much higher value is thought due to the high NO_x emission factor of 6.36 g/kg for grasslands in the EET Manual, compared to 2 g/kg for emissions from forests. Delmas *et al* (1995) in their review paper derived an emission rate for savanna fires of 3.1 g/kg that is less than half that used in the manual and indicates that the EET Manual figure may be a factor of 2 too high.

■ **Table 4-12 Emissions of PM10 and NO_x from various studies**

Region	Land Area (km^2)	Area Burned (km^2)	Land Area Burned (%)	PM10 Emissions (tonne)	PM10 Emissions (tonne/ km^2)	NO_x emissions (t/yr)	NO_x Emissions (tonne/km^2)
Pilbara	362,165	27,059	7.5	195,000	0.54	124,00	0.34
Perth Airshed	6450	126	1.95	1871	0.29	316	0.05
California	411,000	Not known	Not Known	33,400	0.081	3,340	0.0081
Northern Territory	1,347,224	73,729	5.5	620,000	0.46	110,000	0.08

Notes:
1. Northern Territory from Beringer *et al* (1993), California from CARB (2000) and Perth from SKM (1999)
2. Northern Territory PM10 estimates assuming all particulate matter is below 10 um.
3. Beringer *et al* (1992) claims that the 1992 estimates will be lower than usual due to a very dry year.

5. Summary

Emissions of all substances from aggregated sources in the Pilbara study region are presented in **Table 5-1**. Additionally **Table 5-2** presents this emission data from each source as a percentage of the total aggregated emissions with **Table 5-3** presenting the anthropogenic emissions as a percentage of the anthropogenic emissions**.**

Emissions of the six substances listed in the Ambient Air Quality NEPM (NEPC, 1998) (excluding ozone and including VOCs) are summarised below:

- Total emissions of CO are 1.64 million tonnes. These emissions of CO are dominated by that produced from wild fires which contribute 99.6% of all aggregate CO.
- Total PM_{10} emissions are 405,000 tonnes. Emissions of PM_{10} are dominated by "natural" sources with 48.1% from wild fires and 42.4% from windblown dust. These are followed by 9.1% from paved and unpaved roads and 0.3% from commercial ships and boats.
- Total NO_x emissions are 204,000 tonnes. These emissions are predominantly from "natural" sources with 60.8% and 30.6% from wild fires and biogenic emissions respectively. The next most significant emissions of NO_x are from commercial ships and boats, which contribute 5.2%.
- Total SO_2 emissions are 6,640 tonnes. These emissions are dominated by commercial shipping and boating, which contribute 94.1% of all aggregate SO_2. Railways are next highest, contributing 3.9%.
- Total lead emissions are 152 tonnes. These arise from dust emissions from paved and unpaved roads (82.1%), followed by windblown dust (8.7%) and wild fires (6.5%).
- Total VOC emissions are 217,000 tonnes with these predominantly arising from biogenic sources (95.3%) and wildfires (4.5%).

This indicates that natural emissions are the dominant source of CO, NOx, PM_{10} and total VOC in the Pilbara Airshed, whilst anthropogenic emissions are the dominant sources of SO_2 and lead.

With regards to anthropogenic emissions **Table 5–3** shows that:

- Emissions of CO are dominated by mobile sources, with motor vehicles contributing 40.3%, commercial shipping and boating 28.4%, recreational boating 10.4% and railways 10.2%.
- Emissions of PM_{10} are dominated by dust from paved and unpaved roads (96.6%), with commercial shipping and boating contributing 2.8%.
- Total NO_x emissions are dominated by mobile sources, with commercial shipping and boating contributing 60.2% and railways contributing 33.0%.
- SO_2 emissions are dominated by commercial shipping and boating, which contribute 94.1% of all aggregate SO_2. Railways are next highest, contributing 3.9%.
- Lead emissions are dominated by dust from paved and unpaved roads (96.7%), with railways contributing 2.7%.

- Total VOC emissions are mostly from mobile sources, including commercial shipping and boating (51.3%), motor vehicles (10.9%), railways (6.8%) and recreational boating (6.0%). However, domestic/commercial solvents/aerosols, solid fuel burning and architectural surface coatings also contribute 7.0%, 7.3% and 4.9% respectively.

Commercial and domestic transport is therefore the predominant anthropogenic source of aggregate emissions, through both mobile sources and dust emissions from roads.

■ Table 5-1 Emissions of NPI Substances in the Pilbara Region (Tonnes per Annum)

	MOBILE SOURCES					DOMMESTIC / COMMERCIAL SOURCES													NATURAL SOURCES			
	Motor vehicles	Railways	Aeroplanes	Commercial Shipping/Boating	Recreational Boating	Domestic/ Commercial solvents/ aerosols	Solid fuel burning (domestic)	Lawn Mowing	Lawn Mowing (public open spaces)	Service Stations	Architectural Surface Coatings	Motor Vehicle Refinishing	Dry Cleaning	Gaseous fuel burning (domestic)	Fuel Combustion – sub reporting threshold facilities	Paved/ Unpaved Roads	Cutback Bitumen	Bakeries	Biogenics	Windblown Dust	Burning / Wildfires	TOTAL EMISSIONS
Acetaldehyde	10.9	7.48	2.29				20.9															**41.5**
Acetone	5.84		1.21				15.4				4.88											**27.4**
Acrylic acid						8.97E-08																**8.97E-08**
Antimony & compounds		0.0190					2.66E-04									1.17				0.23	89.6	**91.0**
Arsenic & compounds		0.000413	0	0.0873	1.40E-04		1.85E-04							0	2.51E-06	2.02				1.10	0.58	**3.79**
Benzene	4.46	4.36	0.96	36.14	8.71	1.07E-04	5.22E-05	2.58	0.148	0.660	0.0859			7.33E-03	3.63		2.89E-03					**61.7**
Beryllium & compounds							1.25E-05							0						0.0489		**0.0489**
Biphenyl (1,1-biphenyl)																	8.53E-03					**0.0085**
1,3-Butadiene (vinyl ethylene)	3.79	3.97	0.886	29.90	2.25		0.847	0.328	0.0188												857	**899**
Boron & compounds																				3.26		**3.26**
Cadmium & compounds	0.0118	9.22E-03	0	3.61E-03	1.45E-05		2.24E-04							0	1.88E-03	3.16				0.25	12.1	**15.5**
Carbon disulphide							5.22E-06															**5.22E-06**
Carbon monoxide	2,930	743	147	2,063	759		308	165	33.0					0.628	126						1,628,764	**1,636,038**
Chloroform (trichloromethane)						0.0225																**0.0225**
Chromium (III) compounds	1.55E-03	8.76E-04	0				7.27E-06	4.72E-04	1.41E-05					5.15E-04	1.51E-06					11.4	4.27	**15.7**
Chromium (VI) compounds	6.74E-04	3.64E-04	0	9.37E-03	7.79E-05		3.17E-06	1.96E-04	5.86E-06					2.14E-04	2.48E-07						1.78	**1.79**
Cobalt & compounds	2.03E-03	8.26E-04		0.0577	3.09E-04		4.42E-05	6.69E-04	2.00E-05					2.65E-03	6.01E-06	20.50				2.54	2.14	**25.2**
Copper & compounds	2.62E-03	4.13E-03						6.69E-04	2.00E-05					6.61E-05		12.9				5.65	4.29	**22.9**
Cumene (1-methylethylbenzene)																	2.03					**2.03**
Cyanide (inorganic) compounds							1.00E-04															**1.00E-04**
Cyclohexane	3.20							0.0785	0.00451	0.0444	31.6			1.96E-03			1.26E-04					**34.9**
1,2-Dichloroethane						1.06E-04																**1.06E-04**
Dichloromethane						0.827	2.13E-05				1.58											**2.40**
Ethanol											0.913							0.620				**1.53**
2-Ethoxyethanol acetate											1.99											**1.99**
Ethylbenzene	2.62	3.17E-03	0.0837			0.0472	3.78E-06	0.601	0.0344	0.0931							0.140					**3.62**
Ethylene glycol (1,2-ethanediol)						2.07					1.06											**3.13**
Ethylene oxide						0.343																**0.343**
Di-(2-Ethylhexyl) phthalate (DEHP)							2.93E-06															**2.93E-06**
Fluoride compounds						3.23E-04	6.03E-03								3.73E-05					32.6		**32.6**
Formaldehyde (methyl aldehyde)	8.81	0.00344	7.39			0.0288	22.5	0.467	0.0438					0.0173								**39.2**
n-Hexane	3.35					1.96	2.69E-06	0.175	0.0477	1.16	31.6			2.03E-03			1.26E-04					**38.3**
Hydrochloric acid						3.98E-05	0.0482															**0.0483**
Lead & compounds	0.546	3.55	0	0.0309	0.0931		1.07E-03	7.37E-03	6.44E-05	3.46E-05				6.61E-05	4.26E-06	125				13.2	9.94	**152**
Manganese & compounds	2.40E-03	2.06E-03					1.43E-03	6.69E-04	2.00E-05					6.61E-05		140				171	24.5	**336**
Mercury & compounds				6.07E-03	3.49E-05		5.22E-06							0	1.03E-06	2.16				0.14	2.53	**4.84**
Methanol						16.0					5.94											**21.9**
Methyl ethyl ketone						1.15	1.57E-05				8.53	1.11										**10.8**
Methyl isobutyl ketone						0.172					0.913	0.195										**1.28**
Nickel & compounds	2.38E-04		0				1.04E-05	6.69E-04	2.00E-05					7.28E-04	8.50E-05	9.37				8.72	3.51	**21.6**
Oxides of Nitrogen	711	5,856	32.52	10,694	32.9		3.18	0.861	4.58					4.63	416				62,307		123,911	**203,973**
Particulate Matter 10.0 um	27.5	138	0	1,072	2.40		40.8	1.11	0.617					0.132	41.3	37,078				171,724	194,828	**404,953**
Phenol			0.118				6.43E-07															**0.118**
Polycyclic aromatic hydrocarbons	0.918	1.86	0.522	0.036	0.453		1.97E-03	0.136	7.80E-03					0	0.0284		0.161					**4.13**
Selenium & compounds		5.51E-04					9.65E-05							7.28E-04		0.147				1.15	0.97	**2.27**
Styrene (ethenylbenzene)	6.19		0.19				0.412	0.0461	2.64E-03	3.94E-03							4.02E-04					**6.85**
Sulphur dioxide	75.3	257	7.58	6,248	2.49		0.784	0.117	0.285					2.6044E-08	50.2							**6,641**
Tetrachloroethylene						0.641	1.73E-06						974									**975**
Toluene (methylbenzene)	5.77	4.41	0.256	36.5	26.4	9.72	2.75	4.34	0.249	0.904	7.92	2.15		3.69E-03	0.0693		0.0858					**102**
Trichloroethylene						0.011																**0.0110**
Xylenes (individual or mixed isomers)	10.4	0.70	0.236	18.8	8.13	4.61	1.67	3.19	0.182	0.537	3.95	1.89			0.0482		0.713					**55.0**
Zinc and compounds	0.0818	0.0551					0.0327	6.69E-04	2.00E-05					7.28E-04		88.2				67.0	16.4	**172**
Total Volatile Organic Compounds	401	252	49.2	1,892	222	258	270	46.1	2.71	67.3	181	6.51		0.099	40.9		50.2	0.621	2,018,035		95,466	**2,117,241**

■ **Table 5-2 Emissions of NPI Substances in the Pilbara Region (Percentage of Total Emissions)**

	MOBILE SOURCES					DOMMESTIC / COMMERCIAL SOURCES												NATURAL SOURCES			
	Motor vehicles	Railways	Aeroplanes	Commercial Shipping/Boating	Recreational Boating	Domestic/ Commercial solvents/ aerosols	Solid fuel burning (domestic)	Lawn Mowing	Lawn Mowing (public open spaces)	Service Stations	Architectural Surface Coatings	Motor Vehicle Refinishing	Dry Cleaning	Gaseous fuel burning (domestic)	Fuel Combustion – sub reporting threshold facilities	Paved/ Unpaved Roads	Cutback Bitumen	Bakeries	Biogenics	Windblown Dust	Burning / Wildfires	TOTAL
Acetaldehyde	26.24	18.01	5.51	-	-	-	50.23	-	-	-	-	-	-	-	-	-	-	-	-	-	-	100
Acetone	21.35	-	4.41	-	-	-	56.41	-	-	-	17.84	-	-	-	-	-	-	-	-	-	-	100
Acrylic acid	-	-	-	-	-	100.00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	100
Antimony & compounds	-	0.02	-	-	-	-	0.00	-	-	-	-	-	-	-	-	1.28	-	-	-	0.26	98.44	100
Arsenic & compounds	-	0.01	-	2.30	0.00	-	0.00	-	-	-	-	-	-	-	0.00	53.26	-	-	-	29.00	15.42	100
Benzene	7.22	7.06	1.55	58.54	14.11	0.00	0.00	4.18	0.24	1.07	0.14	-	-	0.01	5.88	-	0.00	-	-	-	-	100
Beryllium & compounds	-	-	-	-	-	-	0.03	-	-	-	-	-	-	-	-	-	-	-	-	99.97	-	100
Biphenyl (1,1-biphenyl)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	100.00	-	-	-	-	100
1,3-Butadiene (vinyl ethylene)	0.42	0.44	0.10	3.33	0.25	-	0.09	0.04	0.00	-	-	-	-	-	-	-	-	-	-	-	95.33	100
Boron & compounds	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	100.00	-	100
Cadmium & compounds	0.08	0.06	-	0.02	0.00	-	0.00	-	-	-	-	-	-	-	0.01	20.36	-	-	-	1.59	77.88	100
Carbon disulphide	-	-	-	-	-	-	100.00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	100
Carbon monoxide	0.18	0.05	0.01	0.13	0.05	-	0.02	0.01	0.00	-	-	-	-	0.00	0.01	-	-	-	-	-	99.56	100
Chloroform (trichloromethane)	-	-	-	-	-	100.00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	100
Chromium (III) compounds	0.01	0.01	-	-	-	-	0.00	0.00	0.00	-	-	-	-	0.00	0.00	-	-	-	-	72.78	27.20	100
Chromium (VI) compounds	0.04	0.02	-	0.52	0.00	-	0.00	0.01	0.00	-	-	-	-	0.01	0.00	-	-	-	-	-	99.39	100
Cobalt & compounds	0.01	0.00	-	0.23	0.00	-	0.00	0.00	0.00	-	-	-	-	0.01	0.00	81.19	-	-	-	10.07	8.49	100
Copper & compounds	0.01	0.02	-	-	-	-	-	0.00	0.00	-	-	-	-	0.00	-	56.49	-	-	-	24.73	18.75	100
Cumene (1-methylethylbenzene)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	100.00	-	-	-	-	100
Cyanide (inorganic) compounds	-	-	-	-	-	-	100.00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	100
Cyclohexane	9.17	-	-	-	-	-	-	0.22	0.01	0.13	90.46	-	-	0.01	-	-	0.00	-	-	-	-	100
1,2-Dichloroethane	-	-	-	-	-	100.00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	100
Dichloromethane	-	-	-	-	-	34.42	0.00	-	-	-	65.58	-	-	-	-	-	-	-	-	-	-	100
Ethanol	-	-	-	-	-	-	-	-	-	-	59.57	-	-	-	-	-	-	40.43	-	-	-	100
2-Ethoxyethanol acetate	-	-	-	-	-	-	-	-	-	-	100.00	-	-	-	-	-	-	-	-	-	-	100
Ethylbenzene	72.33	0.09	2.31	-	-	1.30	0.00	16.59	0.95	2.57	-	-	-	-	-	-	3.85	-	-	-	-	100
Ethylene glycol (1,2-ethanediol)	-	-	-	-	-	66.25	-	-	-	-	33.75	-	-	-	-	-	-	-	-	-	-	100
Ethylene oxide	-	-	-	-	-	100.00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	100
Di-(2-Ethylhexyl) phthalate (DEHP)	-	-	-	-	-	-	100.00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	100
Fluoride compounds	-	-	-	-	-	0.00	0.02	-	-	-	-	-	-	-	0.00	-	-	-	-	99.98	-	100
Formaldehyde (methyl aldehyde)	22.46	0.01	18.84	-	-	0.07	57.27	1.19	0.11	-	-	-	-	0.04	-	-	-	-	-	-	-	100
n-Hexane	8.75	-	-	-	-	5.12	0.00	0.46	0.12	3.04	82.51	-	-	0.01	-	-	0.00	-	-	-	-	100
Hydrochloric acid	-	-	-	-	-	0.08	99.92	-	-	-	-	-	-	-	-	-	-	-	-	-	-	100
Lead & compounds	0.36	2.33	-	0.02	0.06	-	0.00	0.00	0.00	0.00	-	-	-	0.00	0.00	82.05	-	-	-	8.66	6.52	100
Manganese & compounds	0.00	0.00	-	-	-	-	0.00	0.00	0.00	-	-	-	-	0.00	-	41.57	-	-	-	51.11	7.32	100
Mercury & compounds	-	-	-	0.13	0.00	-	0.00	-	-	-	-	-	-	-	0.00	44.68	-	-	-	2.88	52.31	100
Methanol	-	-	-	-	-	72.91	-	-	-	-	27.09	-	-	-	-	-	-	-	-	-	-	100
Methyl ethyl ketone	-	-	-	-	-	10.64	0.00	-	-	-	79.10	10.26	-	-	-	-	-	-	-	-	-	100
Methyl isobutyl ketone	-	-	-	-	-	13.45	-	-	-	-	71.30	15.24	-	-	-	-	-	-	-	-	-	100
Nickel & compounds	0.00	-	-	-	-	-	0.00	0.00	0.00	-	-	-	-	0.00	0.00	43.39	-	-	-	40.36	16.24	100
Oxides of Nitrogen	0.35	2.87	0.02	5.24	0.02	-	0.00	0.00	0.00	-	-	-	-	0.00	0.20	-	-	-	30.55	-	60.75	100
Particulate Matter 10.0 um	0.01	0.03	-	0.26	0.00	-	0.01	0.00	0.00	-	-	-	-	0.00	0.01	9.16	-	-	-	42.41	48.11	100
Phenol	-	-	100.00	-	-	-	0.00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	100
Polycyclic aromatic hydrocarbons	22.25	45.14	12.65	0.86	10.99	-	0.05	3.29	0.19	-	-	-	-	-	0.69	-	3.89	-	-	-	-	100
Selenium & compounds	-	0.02	-	-	-	-	0.00	-	-	-	-	-	-	0.03	-	6.48	-	-	-	50.60	42.86	100
Styrene (ethenylbenzene)	90.41	-	2.80	-	-	-	6.01	0.67	0.04	0.06	-	-	-	-	-	-	0.01	-	-	-	-	100
Sulphur dioxide	1.13	3.86	0.11	94.08	0.04	-	0.01	0.00	0.00	-	-	-	-	0.00	0.76	-	-	-	-	-	-	100
Tetrachloroethylene	-	-	-	-	-	0.07	0.00	-	-	-	-	-	99.93	-	-	-	-	-	-	-	-	100
Toluene (methylbenzene)	5.68	4.34	0.25	35.98	25.97	9.58	2.71	4.28	0.25	0.89	7.81	2.12	-	0.00	0.07	-	0.08	-	-	-	-	100
Trichloroethylene	-	-	-	-	-	100.00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	100
Xylenes (individual or mixed isomers)	18.90	1.28	0.43	34.11	14.77	8.39	3.03	5.79	0.33	0.97	7.18	3.43	-	-	0.09	-	1.30	-	-	-	-	100
Zinc and compounds	0.05	0.03	-	-	-	-	0.02	0.00	0.00	-	-	-	-	0.00	-	51.36	-	-	-	39.01	9.53	100
Total Volatile Organic Compounds	0.02	0.01	0.00	0.09	0.01	0.01	0.01	0.00	0.00	0.00	0.01	0.00	-	0.00	0.00	-	0.00	0.00	95.31	-	4.51	100

■ **Table 5-3 Emissions of NPI Substances in the Pilbara Region, Excluding Biogenic and Natural Sources (Percentage of Total Anthropogenic Emissions)**

	MOBILE SOURCES					DOMMESTIC / COMMERCIAL SOURCES													TOTAL
	Motor vehicles	Railways	Aeroplanes	Commercial Shipping/Boating	Recreational Boating	Domestic/ Commercial solvents/ aerosols	Solid fuel burning (domestic)	Lawn Mowing	Lawn Mowing (public open spaces)	Service Stations	Architectural Surface Coatings	Motor Vehicle Refinishing	Dry Cleaning	Gaseous fuel burning (domestic)	Fuel Combustion – sub reporting threshold facilities	Paved/ Unpaved Roads	Cutback Bitumen	Bakeries	
Acetaldehyde	26.24	18.01	5.51	-	-	-	50.23	-	-	-	-	-	-	-	-	-	-	-	100
Acetone	21.35	-	4.41	-	-	-	56.41	-	-	-	17.84	-	-	-	-	-	-	-	100
Acrylic acid	-	-	-	-	-	100.00	-	-	-	-	-	-	-	-	-	-	-	-	100
Antimony & compounds	-	1.60	-	-	-	-	0.02	-	-	-	-	-	-	-	-	98.38	-	-	100
Arsenic & compounds	-	0.02	-	4.14	0.01	-	0.01	-	-	-	-	-	-	-	0.00	95.82	-	-	100
Benzene	7.22	7.06	1.55	58.54	14.11	0.00	0.00	4.18	0.24	1.07	0.14	-	-	0.01	5.88	-	0.00	-	100
Beryllium & compounds	-	-	-	-	-	-	100.00	-	-	-	-	-	-	-	-	-	-	-	100
Biphenyl (1,1-biphenyl)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	100.00	-	100
1,3-Butadiene (vinyl ethylene)	9.02	9.46	2.11	71.19	5.37	-	2.02	0.78	0.04	-	-	-	-	-	-	-	-	-	100
Boron & compounds	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0
Cadmium & compounds	0.37	0.29	-	0.11	0.00	-	0.01	-	-	-	-	-	-	-	0.00	99.22	-	-	100
Carbon disulphide	-	-	-	-	-	-	100.00	-	-	-	-	-	-	-	-	-	-	-	100
Carbon monoxide	40.28	10.21	2.03	28.35	10.43	-	4.24	2.26	0.45	-	-	-	-	0.01	1.74	-	-	-	100
Chloroform (trichloromethane)	-	-	-	-	-	100.00	-	-	-	-	-	-	-	-	-	-	-	-	100
Chromium (III) compounds	45.11	25.49	-	-	-	-	0.21	13.74	0.41	-	-	-	-	15.00	0.04	-	-	-	100
Chromium (VI) compounds	6.18	3.33	-	85.93	0.71	-	0.03	1.80	0.05	-	-	-	-	1.96	0.00	-	-	-	100
Cobalt & compounds	0.01	0.00	-	0.28	0.00	-	0.00	0.00	0.00	-	-	-	-	0.01	0.00	99.69	-	-	100
Copper & compounds	0.02	0.03	-	-	-	-	-	0.01	0.00	-	-	-	-	0.00	-	99.94	-	-	100
Cumene (1-methylethylbenzene)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	100.00	-	100
Cyanide (inorganic) compounds	-	-	-	-	-	-	100.00	-	-	-	-	-	-	-	-	-	-	-	100
Cyclohexane	9.17	-	-	-	-	-	-	0.22	0.01	0.13	90.46	-	-	0.01	-	-	0.00	-	100
1,2-Dichloroethane	-	-	-	-	-	100.00	-	-	-	-	-	-	-	-	-	-	-	-	100
Dichloromethane	-	-	-	-	-	34.42	0.00	-	-	-	65.58	-	-	-	-	-	-	-	100
Ethanol	-	-	-	-	-	-	-	-	-	-	59.57	-	-	-	-	-	-	40.43	100
2-Ethoxyethanol acetate	-	-	-	-	-	-	-	-	-	-	100.00	-	-	-	-	-	-	-	100
Ethylbenzene	72.33	0.09	2.31	-	-	1.30	0.00	16.59	0.95	2.57	-	-	-	-	-	-	3.85	-	100
Ethylene glycol (1,2-ethanediol)	-	-	-	-	-	66.25	-	-	-	-	33.75	-	-	-	-	-	-	-	100
Ethylene oxide	-	-	-	-	-	100.00	-	-	-	-	-	-	-	-	-	-	-	-	100
Di-(2-Ethylhexyl) phthalate (DEHP)	-	-	-	-	-	-	100.00	-	-	-	-	-	-	-	-	-	-	-	100
Fluoride compounds	-	-	-	-	-	5.05	94.36	-	-	-	-	-	-	-	0.58	-	-	-	100
Formaldehyde (methyl aldehyde)	22.46	0.01	18.84	-	-	0.07	57.27	1.19	0.11	-	-	-	-	0.04	-	-	-	-	100
n-Hexane	8.75	-	-	-	-	5.12	0.00	0.46	0.12	3.04	82.51	-	-	0.01	-	-	0.00	-	100
Hydrochloric acid	-	-	-	-	-	0.08	99.92	-	-	-	-	-	-	-	-	-	-	-	100
Lead & compounds	0.42	2.74	-	0.02	0.07	-	0.00	0.01	0.00	0.00	-	-	-	0.00	0.00	96.73	-	-	100
Manganese & compounds	0.00	0.00	-	-	-	-	0.00	0.00	0.00	-	-	-	-	0.00	-	100.00	-	-	100
Mercury & compounds	-	-	-	0.28	0.00	-	0.00	-	-	-	-	-	-	-	0.00	99.72	-	-	100
Methanol	-	-	-	-	-	72.91	-	-	-	-	27.09	-	-	-	-	-	-	-	100
Methyl ethyl ketone	-	-	-	-	-	10.64	0.00	-	-	-	79.10	10.26	-	-	-	-	-	-	100
Methyl isobutyl ketone	-	-	-	-	-	13.45	-	-	-	-	71.30	15.24	-	-	-	-	-	-	100
Nickel & compounds	0.00	-	-	-	-	-	0.00	0.01	0.00	-	-	-	-	0.01	0.00	99.98	-	-	100
Oxides of Nitrogen	4.00	32.98	0.18	60.23	0.19	-	0.02	0.00	0.03	-	-	-	-	0.03	2.34	-	-	-	100
Particulate Matter 10.0 um	0.07	0.36	-	2.79	0.01	-	0.11	0.00	0.00	-	-	-	-	0.00	0.11	96.55	-	-	100
Phenol	-	-	100.00	-	-	-	0.00	-	-	-	-	-	-	-	-	-	-	-	100
Polycyclic aromatic hydrocarbons	22.25	45.14	12.65	0.86	10.99	-	0.05	3.29	0.19	-	-	-	-	-	0.69	-	3.89	-	100
Selenium & compounds	-	0.37	-	-	-	-	0.06	-	-	-	-	-	-	0.49	-	99.08	-	-	100
Styrene (ethenylbenzene)	90.41	-	2.80	-	-	-	6.01	0.67	0.04	0.06	-	-	-	-	-	-	0.01	-	100
Sulphur dioxide	1.13	3.86	0.11	94.08	0.04	-	0.01	0.00	0.00	-	-	-	-	0.00	0.76	-	-	-	100
Tetrachloroethylene	-	-	-	-	-	0.07	0.00	-	-	-	-	-	99.93	-	-	-	-	-	100
Toluene (methylbenzene)	5.94	-	0.26	37.61	27.15	10.01	2.83	4.47	0.26	0.93	8.16	2.21	-	0.00	0.07	-	0.09	-	100
Trichloroethylene	-	-	-	-	-	100.00	-	-	-	-	-	-	-	-	-	-	-	-	100
Xylenes (individual or mixed isomers)	18.90	1.28	0.43	34.11	14.77	8.39	3.03	5.79	0.33	0.97	7.18	3.43	-	-	0.09	-	1.30	-	100
Zinc and compounds	0.09	0.06	-	-	-	-	0.04	0.00	0.00	-	-	-	-	0.00	-	99.81	-	-	100
Total Volatile Organic Compounds	10.87	6.82	1.33	51.30	6.02	6.99	7.31	1.25	0.07	1.82	4.90	0.18	-	0.00	1.11	-	-	0.02	100

6. Recommendations

The following are recommended from the study:

- As wild fires are the dominant source for many substances, estimates of these emissions should be refined. This could be done using a system where fuel loading is classified by vegetation type across the study region and by considering the time since the last burn instead of the default constant factor. Such a technique may follow that used by Denlay *et al* (2000).

- As emissions from windblown sources are also predicted to be important, this estimate should be refined from the basic technique used here. It is considered that such estimates could most effectively be achieved by applying a model such as used by Shao *et al* (1996) for the whole Australian region (see Dudley and MacIntosh, 2000).

- Of the "man made" sources, emissions from ships are the major source in the study region. For these emissions it is recommended that:
  - The default EET Manual emissions from auxiliary engines be modified to specify engine size and emissions as a function of ship size;
  - The main engine emission equations developed in the EET Manual are improved. It is recommended that the linear relationship between engine maximum power and gross tonnage be replaced with a non-linear fit as power requirements taper off for larger gross tonnage vessels. Secondly, as there are marked differences in the power/gross tonnage relationships for different types of ships (e.g. container ships compared to bulk carriers) it is recommended that a best practice technique be implemented that provides separate equations for the different types of ships. Such data on these relationships can be found in SKM (1999).
  - A new emission factor for vessels travelling in shipping channels is introduced to account for the potentially lower engine power setting and therefore emissions per unit time. For the shipping channels and ships in this study the emissions per unit time were 65% of the open sea emissions.

- For the study region, helicopters were estimated to be a large source of aircraft emissions. However, there is little information available regarding the emissions for various types of helicopters and more data is required to refine the estimates. The default LTO cycles for helicopters also appear too large based on discussions with helicopter pilots. Additionally it is recommended that default LTO cycles be developed for large metropolitan airports and smaller regional airports such as Karratha as taxiing times at small regional airports are thought to be much less than the defaults developed for busy city airports in the USA.

- Sulphur dioxide emission factors for aircraft appear inconsistent. This and lead emissions would be better estimated based on fuel consumption figures.

- Estimates of VOC emissions from the study region are considered preliminary. To refine these estimates, measurements of VOC emissions from the various vegetation categories are required. This is particularly the case for the very high temperatures in the Pilbara, where the use of equations with temperature dependency developed in temperate climates predict apparently excessive VOC emissions.

- Emissions from sub threshold facilities are uncertain. This is due to:
  - The uncertainty in the facilities that will be reporting for this reporting year, which is the first year that many facilities are expected to report.
  - Fuel usage figures for sub threshold categories were not available as fuel companies were reluctant to provide this; and
  - The expected large fuel usage for small generators given that a significant percentage of the population is not connected to a centralised power grid. Emissions from this source have been estimated and are anticipated to be larger than from the "traditional" sub threshold sources in the EET Manual of small industrial and commercial facilities.

- A review of the surface coating emission estimation suggests that some of the substances listed in Australian paints in the EET Manual are no longer used. For example there is no benzene in water based paints. The current EET Manual is based on data contained in USEPA (1992) for US paints. Therefore it is recommended that this EET Manual be updated with data from Australian paint manufacturers.

- As non-local recreational boat usage can be a significant proportion of recreational boat usage, this needs to be included in the EET Manual methodology. It is suggested that this be incorporated by using a non-local boat usage factor in the EET Manual to increase the boat usage derived from the residential survey of local users.

- For estimating NO_x from soils the methodology of Yienger and Levy (1995) is recommended. This methodology appears to be more scientifically valid than those used in previous Australian inventory studies as it incorporates the effects of soil wetting. For the Pilbara, estimated NO_x emissions were one half that estimated using the alternative methodology.

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Appendix A Pilbara Aircraft Emission Estimates

Annual Aircraft Movements in the Pilbara Region

Aircraft Type	Port Hedland	Karratha	Exmouth / Learmouth	Para-burdoo	Telfer	Dampier	Newman	Yandi	Coral Bay	Onslow	Roeburne	Shay Gap	Nullagine	Marble Bar	Barrow Island	Varanus Island	Woodside Platforms	Point Samson	Panna-wonica	Jiggalong	Brock-man	Punmu	TOTAL
Turbofan/Jet																							
BAe146	732	1152	104	572			624								200								**3,384**
F28	132	168																					**300**
A320	48																						**48**
737	60	432																					**492**
Canadair RJ-70					208																		**208**
Cessna Citation		6	2	2			26			2	2												**40**
Turboprop																							
F27	180																						**180**
F50	12		365																				**377**
Dash 8								104													52		**156**
Beechcraft King Air	591	56	17	17	15		405	104		17	17	156	15	15					15	15			**1,455**
Cessna Conquest	429	118	37	37	37		37			37	37		37	37					37	37			**917**
Piston Engine																							
Twin Engine	285	160	238	734	4		420	525	24	191	12			260	730						365		**3,948**
Single Engine	303		182				104			73									730	104		104	**1,600**
Helicopters																							
Superpuma AS 332L		728															852						**1,580**
Sikorski S76		1456													1853		1703						**5,012**
Bell Long Ranger																626							**626**
Bell Jet Ranger	72	12	3			365												365					**817**
TOTAL	**2,844**	**4,288**	**948**	**1,362**	**264**	**365**	**1,616**	**733**	**24**	**320**	**68**	**156**	**52**	**312**	**2,783**	**626**	**2,555**	**365**	**782**	**156**	**417**	**104**	**21,140**

1) Twin piston engine aircraft includes Beech Baron/ Cessna 310/ Piper Chieftan, Seneca, Navaho
2) Single piston engine aircraft includes Piper Lane/ Cessna 150, 172, 206, 210
3) Tom Price flight data ignored - no runway
4) Dampier flights, except for helicopters, are included in Karratha figures

Carbon Monoxide (CO) Emissions in kg per annum

Aircraft Type	Port Hedland	Karratha	Exmouth / Learmouth	Para-burdoo	Telfer	Dampier	Newman	Yandi	Coral Bay	Onslow	Roeburne	Shay Gap	Nullagine	Marble Bar	Barrow Island	Varanus Island	Woodside Platforms	Point Samson	Panna-wonica	Jiggalong	Brock-man	Punmu	TOTAL
Turbofan/Jet																							
BAe146	5,868	9,235	834	4,586	0	0	5,002	0	0	0	0	0	0	0	1,603	0	0	0	0	0	0	0	**27,129**
F28	3,233	4,115	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**7,348**
A320	887	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**887**
737	510	3,675	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**4,186**
Canadair RJ-70	0	0	0	0	1,667	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**1,667**
Cessna Citation	0	46	15	15	0	0	201	0	0	15	15	0	0	0	0	0	0	0	0	0	0	0	**309**
Turboprop																							
F27	279	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**279**
F50	20	0	601	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**621**
Dash 8	0	0	0	0	0	0	0	161	0	0	0	0	0	0	0	0	0	0	0	0	81	0	**242**
Beechcraft Twin Air	4,396	416	126	126	112	0	3,012	773	0	126	126	1,160	112	112	0	0	0	0	112	112	0	0	**10,821**
Cessna Conquest	3,191	878	275	275	275	0	275	0	0	275	275	0	275	275	0	0	0	0	275	275	0	0	**6,820**
Piston Engine																							
Twin Engine	4,266	2,395	3,563	10,987	60	0	6,287	7,859	359	2,859	180	0	0	3,892	10,927	0	0	0	0	0	5,464	0	**59,098**
Single Engine	1,983	0	1,191	0	0	0	681	0	0	478	0	0	0	0	0	0	0	0	4,779	681	0	681	**10,473**
Helicopters																							
Superpuma AS 332L	0	4,697	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5,494	0	0	0	0	0	**10,191**
Sikorski S76	0	5,067	0	0	0	0	0	0	0	0	0	0	0	0	6,449	0	5,928	0	0	0	0	0	**17,443**
Bell Long Ranger	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	721	0	0	0	0	0	0	**721**
Bell Jet Ranger	54	9	2	0	0	272	0	0	0	0	0	0	0	0	0	0	0	272	0	0	0	0	**608**
TOTAL	**24,687**	**30,534**	**6,608**	**15,990**	**2,114**	**272**	**15,459**	**8,793**	**359**	**3,754**	**597**	**1,160**	**387**	**4,279**	**18,979**	**721**	**11,422**	**272**	**5,165**	**1,068**	**5,544**	**681**	**158,844**

1) Twin piston engine aircraft includes Beech Baron/ Cessna 310/ Piper Chieftan, Seneca, Navaho
2) Single piston engine aircraft includes Piper Lane/ Cessna 150, 172, 206, 210
3) Tom Price flight data ignored - no runway
4) Dampier flights, except for helicopters, are included in Karratha figures

Hydrocarbon (HC) Emissions in kg per annum

Aircraft Type	Port Hedland	Karratha	Exmouth / Learmouth	Para-burdoo	Telfer	Dampier	Newman	Yandi	Coral Bay	Onslow	Roeburne	Shay Gap	Nullagine	Marble Bar	Barrow Island	Varanus Island	Woodside Platforms	Point Samson	Panna-wonica	Jiggalong	Brock-man	Punmu	TOTAL
Turbofan/Jet																							
BAe146	719	1,132	102	562	0	0	613	0	0	0	0	0	0	0	196	0	0	0	0	0	0	0	**3,325**
F28	3,157	4,018	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**7,174**
A320	56	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**56**
737	28	204	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**232**
Canadair RJ-70	0	0	0	0	204	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**204**
Cessna Citation	0	16	5	5	0	0	68	0	0	5	5	0	0	0	0	0	0	0	0	0	0	0	**105**
Turboprop																							
F27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-
F50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-
Dash 8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-
Beechcraft Twin Air	3,742	355	108	108	95	0	2,564	658	0	108	108	988	95	95	0	0	0	0	95	95	0	0	**9,212**
Cessna Conquest	2,716	747	234	234	234	0	234	0	0	234	234	0	234	234	0	0	0	0	234	234	0	0	**5,806**
Piston Engine																							
Twin Engine	146	82	122	375	2	0	215	269	12	98	6	0	0	133	373	0	0	0	0	0	187	0	**2,019**
Single Engine	23	0	14	0	0	0	8	0	0	6	0	0	0	0	0	0	0	0	56	8	0	8	**122**
Helicopters																							
Superpuma AS 332L	0	4,501	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5,265	0	0	0	0	0	**9,766**
Sikorski S76	0	4,855	0	0	0	0	0	0	0	0	0	0	0	0	6,180	0	5,680	0	0	0	0	0	**16,715**
Bell Long Ranger	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	691	0	0	0	0	0	0	**691**
Bell Jet Ranger	51	9	2	0	0	260	0	0	0	0	0	0	0	0	0	0	0	260	0	0	0	0	**582**
TOTAL	**10,638**	**15,917**	**587**	**1,285**	**536**	**260**	**3,702**	**927**	**12**	**450**	**353**	**988**	**329**	**462**	**6,749**	**691**	**10,945**	**260**	**385**	**337**	**187**	**8**	**56,009**

1) Twin piston engine aircraft includes Beech Baron/ Cessna 310/ Piper Chieftan, Seneca, Navaho
2) Single piston engine aircraft includes Piper Lane/ Cessna 150, 172, 206, 210
3) Tom Price flight data ignored - no runway
4) Dampier flights, except for helicopters, are included in Karratha figures

Nitrogen Oxides (NOx) Emissions in kg per annum

Aircraft Type	Port Hedland	Karratha	Exmouth / Learmouth	Para-burdoo	Telfer	Dampier	Newman	Yandi	Coral Bay	Onslow	Roeburne	Shay Gap	Nullagine	Marble Bar	Barrow Island	Varanus Island	Woodside Platforms	Point Samson	Panna-wonica	Jiggalong	Brock-man	Punmu	TOTAL
Turbofan/Jet																							
BAe146	2,439	3,839	347	1,906	0	0	2,079	0	0	0	0	0	0	0	667	0	0	0	0	0	0	0	**11,277**
F28	511	650	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**1,160**
A320	559	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**559**
737	410	2,955	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**3,366**
Canadair RJ-70	0	0	0	0	693	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**693**
Cessna Citation	0	3	1	1	0	0	11	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	**17**
Turboprop																							
F27	388	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**388**
F50	28	0	865	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**893**
Dash 8	0	0	0	0	0	0	0	224	0	0	0	0	0	0	0	0	0	0	0	0	112	0	**337**
Beechcraft Twin Air	216	21	6	6	5	0	148	38	0	6	6	57	5	5	0	0	0	0	5	5	0	0	**533**
Cessna Conquest	157	43	14	14	14	0	14	0	0	14	14	0	14	14	0	0	0	0	14	14	0	0	**336**
Piston Engine																							
Twin Engine	17	10	14	44	0	0	25	32	1	11	1	0	0	16	44	0	0	0	0	0	22	0	**237**
Single Engine	4	0	2	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	10	1	0	1	**21**
Helicopters																							
Superpuma AS 332L	0	3,400	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3,978	0	0	0	0	0	**7,378**
Sikorski S76	0	3,668	0	0	0	0	0	0	0	0	0	0	0	0	4,669	0	4,292	0	0	0	0	0	**12,629**
Bell Long Ranger	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	522	0	0	0	0	0	0	**522**
Bell Jet Ranger	39	6	2	0	0	197	0	0	0	0	0	0	0	0	0	0	0	197	0	0	0	0	**440**
TOTAL	**4,770**	**14,595**	**1,250**	**1,971**	**712**	**197**	**2,279**	**294**	**1**	**33**	**21**	**57**	**19**	**35**	**5,379**	**522**	**8,270**	**197**	**29**	**20**	**134**	**1**	**40,787**

1) Twin piston engine aircraft includes Beech Baron/ Cessna 310/ Piper Chieftan, Seneca, Navaho
2) Single piston engine aircraft includes Piper Lane/ Cessna 150, 172, 206, 210
3) Tom Price flight data ignored - no runway
4) Dampier flights, except for helicopters, are included in Karratha figures

Sulphur Dioxide (SO_2) Emissions in kg per annum

Aircraft Type	Port Hedland	Karratha	Exmouth / Learmouth	Para-burdoo	Telfer	Dampier	Newman	Yandi	Coral Bay	Onslow	Roeburne	Shay Gap	Nullagine	Marble Bar	Barrow Island	Varanus Island	Woodside Platforms	Point Samson	Panna-wonica	Jiggalong	Brock-man	Punmu	TOTAL
Turbofan/Jet																							
BAe146	937	1,475	133	732	0	0	799	0	0	0	0	0	0	0	256	0	0	0	0	0	0	0	**4,332**
F28	54	68	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**122**
A320	61	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**61**
737	47	335	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**382**
Canadair RJ-70	0	0	0	0	266	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**266**
Cessna Citation	0	1	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**4**
Turboprop																							
F27	42	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**42**
F50	3	0	90	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**93**
Dash 8	0	0	0	0	0	0	0	24	0	0	0	0	0	0	0	0	0	0	0	0	12	0	**37**
Beechcraft Twin Air	58	5	2	2	1	0	40	10	0	2	2	15	1	1	0	0	0	0	1	1	0	0	**143**
Cessna Conquest	42	12	4	4	4	0	4	0	0	4	4	0	4	4	0	0	0	0	4	4	0	0	**90**
Piston Engine																							
Twin Engine	1	1	1	2	0	0	1	2	0	1	0	0	0	1	2	0	0	0	0	0	1	0	**13**
Single Engine	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	**2**
Helicopters																							
Superpuma AS 332L	0	534	0	0	0	0	0	0	0	0	0	0	0	0	0	0	625	0	0	0	0	0	**1,159**
Sikorski S76	0	576	0	0	0	0	0	0	0	0	0	0	0	0	733	0	674	0	0	0	0	0	**1,983**
Bell Long Ranger	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	82	0	0	0	0	0	0	**82**
Bell Jet Ranger	6	1	0	0	0	31	0	0	0	0	0	0	0	0	0	0	0	31	0	0	0	0	**69**
TOTAL	**1,251**	**3,008**	**230**	**740**	**271**	**31**	**847**	**36**	**0**	**6**	**6**	**15**	**5**	**6**	**992**	**82**	**1,299**	**31**	**6**	**5**	**13**	**0**	**8,880**

1) Twin piston engine aircraft includes Beech Baron/ Cessna 310/ Piper Chieftan, Seneca, Navaho
2) Single piston engine aircraft includes Piper Lane/ Cessna 150, 172, 206, 210
3) Tom Price flight data ignored - no runway
4) Dampier flights, except for helicopters, are included in Karratha figures

Total Suspended Particulates (TSP) Emissions in kg per annum

Aircraft Type	Port Hedland	Karratha	Exmouth / Learmouth	Para-burdoo	Telfer	Dampier	Newman	Yandi	Coral Bay	Onslow	Roeburne	Shay Gap	Nullagine	Marble Bar	Barrow Island	Varanus Island	Woodside Platforms	Point Samson	Panna-wonica	Jiggalong	Brock-man	Punmu	TOTAL
Turbofan/Jet																							
BAe146	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-
F28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-
A320	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-
737	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-
Canadair RJ-70	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-
Cessna Citation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-
Turboprop																							
F27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-
F50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-
Dash 8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-
Beechcraft Twin Air	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-
Cessna Conquest	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-
Piston Engine																							
Twin Engine	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-
Single Engine	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-
Helicopters																							
Superpuma AS 332L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-
Sikorski S76	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-
Bell Long Ranger	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-
Bell Jet Ranger	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-
TOTAL	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

1) Twin piston engine aircraft includes Beech Baron/ Cessna 310/ Piper Chieftan, Seneca, Navaho
2) Single piston engine aircraft includes Piper Lane/ Cessna 150, 172, 206, 210
3) Tom Price flight data ignored - no runway
4) Dampier flights, except for helicopters, are included in Karratha figures

Aircraft Emissions in the Pilbara Region, by Airfield/Helopad

Airfield	CO	HC	NOx	SO2	TSP	VOCs
Port Hedland	24,687	10,638	4,770	1,251	0	11,624
Karratha	30,534	15,917	14,595	3,008	0	17,392
Exmouth/Learmouth	6,608	587	1,250	230	0	641
Paraburdoo	15,990	1,285	1,971	740	0	1,404
Telfer	2,114	536	712	271	0	585
Dampier/East Intercourse Isl.	272	260	197	31	0	284
Newman	15,459	3,702	2,279	847	0	4,046
Yandi	8,793	927	294	36	0	1,013
Coral Bay	359	12	1	0	0	13
Onslow	3,754	450	33	6	0	492
Roeburne	597	353	21	6	0	386
Shay Gap	1,160	988	57	15	0	1,079
Nullagine	387	329	19	5	0	360
Marble Bar	4,279	462	35	6	0	505
Barrow Island	18,979	6,749	5,379	992	0	7,375
Varanus Island	721	691	522	82	0	755
Woodside Platforms	11,422	10,945	8,270	1,299	0	11,960
Point Samson	272	260	197	31	0	284
Pannawonica	5,165	385	29	6	0	420
Jiggalong	1,068	337	20	5	0	368
Brockman	5,544	187	134	13	0	204
Punmu	681	8	1	0	0	9
TOTAL (minus Woodside)	**147,423**	**45,064**	**32,517**	**7,582**	**0**	**49,242**
REGIONAL TOTAL	**158,844**	**56,009**	**40,787**	**8,880**	**0**	**61,201**

Appendix B Commercial Shipping, Boating and Recreational Boating

Emissions from Commercial Shipping (kg in 1999/2000) - Summary by Harbour

		BERTH EMISSIONS					CHANNEL EMISSIONS					ANCHORAGE EMISSIONS					DEEPWATER EMISSIONS				
LOCATION	Number of Vessels	CO	NOX	SO2	TSP	VOC's	CO	NOX	SO2	TSP	VOC's	CO	NOX	SO2	TSP	VOC's	CO	NOX	SO2	TSP	VOC's
Port Hedland	625	30,078	168,336	164,099	21,661	11,020	48,156	543,656	418,666	54,568	12,199	44,514	249,130	264,841	33,666	16,309	96,486	1,104,909	848,011	110,606	24,132
Woodside	223	12,738	71,289	74,353	9,634	4,667	12,235	138,968	106,912	14,169	3,034	15,922	89,111	92,941	12,042	5,834	65,828	756,424	579,624	76,842	16,144
EEI, MI	345	20,240	113,273	110,967	15,182	7,415	24,278	276,565	212,625	28,199	6,112	25,061	140,260	137,858	18,954	9,182	88,274	1,019,486	780,955	103,516	21,946
Parker Point	298	17,022	95,265	90,912	12,874	6,237	18,898	215,822	165,790	22,048	4,793	21,277	119,081	113,640	16,092	7,796	68,560	794,762	608,415	80,820	17,162
Port Walcott	196	11,432	63,979	67,706	8,646	4,188	17,164	194,851	149,926	19,862	4,246	3,126	17,493	18,490	2,364	1,145	60,541	695,080	532,669	70,603	14,818
Barrow Island	15	857	4,795	5,098	648	314	485	5,508	4,239	561	120	0	0	0	0	0	6,199	71,127	54,511	7,224	1,515
Varanus Island	29	309	1,728	1,837	234	113	0	0	0	0	0	0	0	0	0	0	11,039	126,656	97,068	12,864	2,698
Airlie Island	1	19	105	112	14	7	37	416	320	42	9	0	0	0	0	0	500	5,740	4,399	583	122
Thevenard Island	18	1,028	5,754	6,117	778	377	1,048	11,898	9,156	1,213	259	0	0	0	0	0	10,179	116,798	89,513	11,863	2,488
Wandoo	20	382	2,135	2,270	289	140	0	0	0	0	0	0	0	0	0	0	5,003	57,401	43,992	5,830	1,223
Stag	20	382	2,135	2,270	289	140	0	0	0	0	0	0	0	0	0	0	5,655	64,888	49,730	6,590	1,382
Griffin FPSO	23	739	4,136	4,397	559	271	0	0	0	0	0	0	0	0	0	0	11,506	132,021	101,180	13,409	2,812
Cossack Pioneer	55	3,170	17,742	18,861	2,398	1,162	0	0	0	0	0	0	0	0	0	0	6,036	69,255	53,077	7,034	1,475
TOTAL	1868	98,394	550,673	548,998	73,203	36,050	122,300	1,387,685	1,067,634	140,663	30,771	109,901	615,074	627,771	83,118	40,266	435,808	5,014,545	3,843,144	507,785	107,915

Notes

1) Dampier Public Wharf (DPW) and King Bay (KB) are included under the figures for Commercial Boating
2) Assume 20 vessels per year for Wandoo

Harbour Emissions from Commercial Shipping and Support Vessels (kg in 1999/2000)

NPI Substance	Port Hedland	Woodside	EEI, MI	Parker Point	King Bay / DPW	Port Walcott	Barrow Island	Varanus Island	Airlie Island	Thevenard Island	Wandoo	Stag	Griffin	Cossack Pioneer
Carbon Monoxide (CO)	53,224	36,738	39,535	17,022	8,649	23,005	857	309	19	1,028	382	382	739	3,170
Nitrogen Oxides (NOx)	224,160	129,171	159,810	95,265	48,405	91,891	4,795	1,728	105	5,754	2,135	2,135	4,136	17,742
Sulphur Dioxide (SO2)	166,958	77,318	113,350	90,912	31,430	69,136	5,098	1,837	112	6,117	2,270	2,270	4,397	18,861
Total Susp. Part. (TSP)	26,426	14,575	19,155	12,874	1,172	11,029	648	234	14	778	289	289	559	2,398
Volatile Organics (VOC)	40,974	35,726	32,387	6,237	3,169	19,166	314	113	7	377	140	140	271	1,162
VOC Speciation														
benzene	*783*	*682*	*619*	*119.12*	*60.52*	*366*	*5.996*	*2.161*	*0.131*	*7.195*	*2.670*	*2.670*	*5.171*	*22.185*
1,3-Butadiene	*647*	*564*	*512*	*98.54*	*50.07*	*303*	*4.960*	*1.788*	*0.108*	*5.952*	*2.209*	*2.209*	*4.278*	*18.352*
PAHs	*see below*	*see below*	*see below*	*see below*	*see below*	*see below*	*see below*	*see below*	*see below*	*see below*	*see below*	*see below*	*see below*	*see below*
Toluene	*791*	*690*	*625*	*120.37*	*61.16*	*370*	*6.059*	*2.184*	*0.133*	*7.270*	*2.698*	*2.698*	*5.226*	*22.417*
Xylenes	*406*	*354*	*321*	*61.87*	*31.43*	*190*	*3.114*	*1.123*	*0.068*	*3.737*	*1.387*	*1.387*	*2.686*	*11.522*
Particulate Speciation														
Arsenic & cpds	*2.1893*	*1.1619*	*1.5767*	*1.1123*	*0.1012*	*0.9059*	*0.0560*	*0.0202*	*0.0012*	*0.0672*	*0.0249*	*0.0249*	*0.0483*	*0.2072*
Cadmium & cpds	*0.0805*	*0.0554*	*0.0608*	*0.0282*	*0.0026*	*0.0355*	*0.0014*	*0.0005*	*0.0000*	*0.0017*	*0.0006*	*0.0006*	*0.0012*	*0.0053*
Chromium (VI) cpds	*0.2336*	*0.1257*	*0.1686*	*0.1169*	*0.0106*	*0.0969*	*0.0059*	*0.0021*	*0.0001*	*0.0071*	*0.0026*	*0.0026*	*0.0051*	*0.0218*
Cobalt & cpds	*1.4401*	*0.7737*	*1.0392*	*0.7222*	*0.0657*	*0.5975*	*0.0364*	*0.0131*	*0.0008*	*0.0436*	*0.0162*	*0.0162*	*0.0314*	*0.1345*
Lead & cpds	*0.6751*	*0.4845*	*0.5145*	*0.2163*	*0.0197*	*0.3008*	*0.0109*	*0.0039*	*0.0002*	*0.0131*	*0.0048*	*0.0048*	*0.0094*	*0.0403*
Mercury & cpds	*0.1229*	*0.1018*	*0.0967*	*0.0257*	*0.0023*	*0.0571*	*0.0013*	*0.0005*	*0.0000*	*0.0016*	*0.0006*	*0.0006*	*0.0011*	*0.0048*
PM < 10um	*26,426*	*14,575*	*19,155*	*12,874*	*1,172*	*11,029*	*648*	*234*	*14*	*778*	*289*	*289*	*559*	*2,398*
PAHs	*0.6968*	*0.6175*	*0.5574*	*0.1054*	*0.0096*	*0.3305*	*0.0053*	*0.0019*	*0.0001*	*0.0064*	*0.0024*	*0.0024*	*0.0046*	*0.0196*

Note: Harbour emissions includes those from ships, commercial boats used for servicing the oil and gas industry and tugs.

Channel Emissions from Commercial Shipping and Support Vessels(kg in 1999/2000

NPI Substance	Port Hedland	Dampier Port Channels	Port Walcott	Barrow Island	Airlie Island	Thevenard Island
Carbon Monoxide (CO)	48,156	60,768	17,164	485	37	1,048
Nitrogen Oxides (NOx)	543,656	664,826	194,851	5,508	416	11,898
Sulphur Dioxide (SO2)	418,666	499,734	149,926	4,239	320	9,156
Total Susp. Part. (TSP)	54,568	65,432	19,862	561	42	1,213
Volatile Organics (VOC)	12,199	15,865	4,246	120	9	259
VOC Speciation						
benzene	*233*	*303*	*81*	*2.290*	*0.173*	*4.946*
1,3-Butadiene	*193*	*251*	*67*	*1.894*	*0.143*	*4.092*
PAHs	*see below*	*see below*	*see below*	*see below*	*see below*	*see below*
Toluene	*235*	*306*	*81.96*	*2.314*	*0.175*	*4.998*
Xylenes	*121*	*157*	*42.12*	*1.189*	*0.090*	*2.569*
Particulate Speciation						
Arsenic & cpds	*4.7147*	*5.6533*	*1.7161*	*0.0485*	*0.0037*	*0.1048*
Cadmium & cpds	*0.1195*	*0.1433*	*0.0435*	*0.0012*	*0.0001*	*0.0027*
Chromium (VI) cpds	*0.4955*	*0.5941*	*0.1804*	*0.0051*	*0.0004*	*0.0110*
Cobalt & cpds	*3.0613*	*3.6707*	*1.1143*	*0.0315*	*0.0024*	*0.0680*
Lead & cpds	*0.9167*	*1.0993*	*0.3337*	*0.0094*	*0.0007*	*0.0204*
Mercury & cpds	*0.1091*	*0.1309*	*0.0397*	*0.0011*	*0.0001*	*0.0024*
PM < 10um	*54,568*	*65,432*	*19,862*	*561*	*42*	*1,213*
PAHs	*0.4469*	*0.5359*	*0.1627*	*0.0046*	*0.0003*	*0.0099*

Notes

1) Dampier Port Channels includes Woodside, Parker Pt, East Intercourse and Mistaken Islands, King Bay and Dampier Public Wharf
2) Varanus Island, FPSOs and platforms do not have approach channels.

Anchorage Emissions from Commercial Shipping Vessels(kg in 1999/2000)

NPI Substance	Port Hedland	Dampier Port Anchorage	Port Walcott
Carbon Monoxide (CO)	44,514	62,832	3,126
Nitrogen Oxides (NOx)	249,130	351,648	17,493
Sulphur Dioxide (SO2)	264,841	347,156	18,490
Total Susp. Part. (TSP)	33,666	47,520	2,364
Volatile Organics (VOC)	16,309	23,021	1,145
VOC Speciation			
benzene	*312*	*440*	*21.87*
1,3-Butadiene	*258*	*364*	*18.09*
PAHs	*see below*	*see below*	*see below*
Toluene	*315*	*444*	*22.10*
Xylenes	*162*	*228*	*11.36*
Particulate Speciation			
Arsenic & cpds	*2.9088*	*4.1057*	*0.2042*
Cadmium & cpds	*0.0737*	*0.1041*	*0.0052*
Chromium (VI) cpds	*0.3057*	*0.4315*	*0.0215*
Cobalt & cpds	*1.8887*	*2.6659*	*0.1326*
Lead & cpds	*0.5656*	*0.7983*	*0.0397*
Mercury & cpds	*0.0673*	*0.0950*	*0.0047*
PM < 10um	*33,666*	*47,520*	*2,364*
PAHs	*0.2757*	*0.3892*	*0.0194*

Notes

1) Dampier Port Anchorage includes Woodside, Parker Pt, East Intercourse and Mistaken Islands, King Bay and Dampier Public Wharf
2) Barrow, Varanus, Airlie and Thevenard Islands do not have anchorages
3) FPSOs and platforms do not have anchorages

Deepwater Emissions from Commercial Shipping Vessels(kg in 1999/2000)

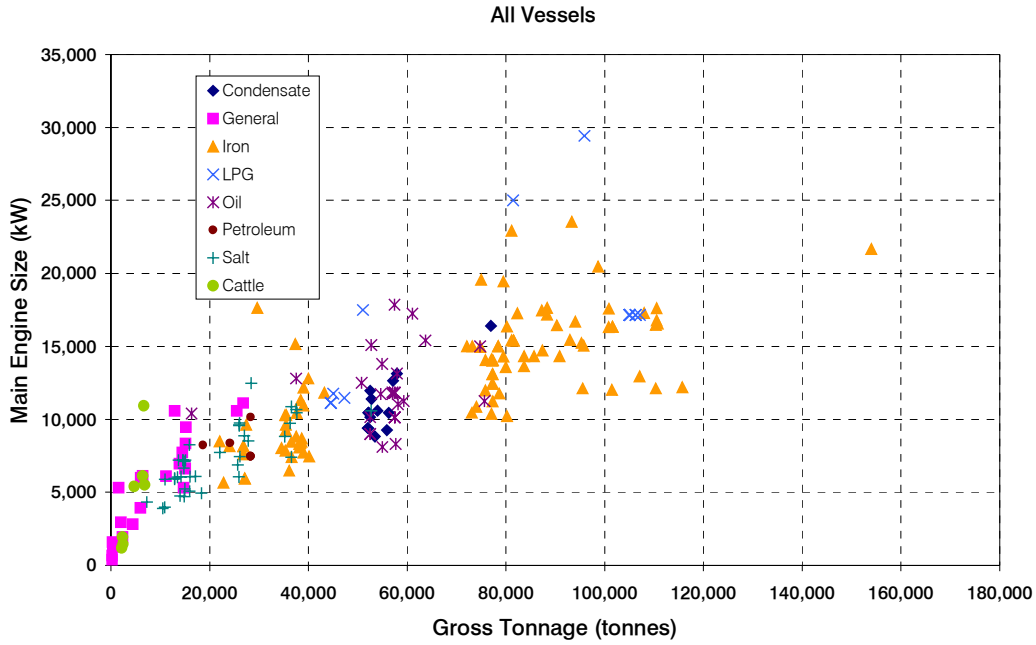
NPI Substance	Port Hedland	Dampier Port	King Bay / DPW	Port Walcott	Barrow Island	Varanus Island	Airlie Island	Thevenard Island	Wandoo	Stag	Griffin	Cossack Pioneer
Carbon Monoxide (CO)	96,486	222,663	724,848	60,541	6,199	11,039	500	10,179	5,003	5,655	11,506	6,036
Nitrogen Oxides (NOx)	1,104,909	2,570,672	1,698,248	695,080	71,127	126,656	5,740	116,798	57,401	64,888	132,021	69,255
Sulphur Dioxide (SO2)	848,011	1,968,995	42,787	532,669	54,511	97,068	4,399	89,513	43,992	49,730	101,180	53,077
Total Susp. Part. (TSP)	110,606	261,178	149,615	70,603	7,224	12,864	583	11,863	5,830	6,590	13,409	7,034
Volatile Organics (VOC)	24,132	55,251	951,599	14,818	1,515	2,698	122	17,162	1,223	1,382	2,812	1,475
VOC Speciation												
benzene	*461*	*1,055*	*18175.54*	*283*	*28.936*	*51.527*	*2.335*	*327.788*	*23.352*	*26.398*	*53.710*	*28.175*
1,3-Butadiene	*381*	*873*	*15035.26*	*234*	*23.937*	*42.624*	*1.932*	*271.154*	*19.317*	*21.837*	*44.430*	*23.307*
PAHs	*see below*	*see below*	*see below*	*see below*	*see below*	*see below*	*see below*	*see below*	*see below*	*see below*	*see below*	*see below*
Toluene	*466*	*1066*	*18365.86*	*285.98*	*29.239*	*52.066*	*2.360*	*331.220*	*23.597*	*26.674*	*54.272*	*28.470*
Xylenes	*239*	*548*	*9439.86*	*146.99*	*15.029*	*26.762*	*1.213*	*170.244*	*12.128*	*13.710*	*27.895*	*14.633*
Particulate Speciation												
Arsenic & cpds	*9.5564*	*22.5658*	*12.9267*	*6.1001*	*0.6242*	*1.1115*	*0.0504*	*1.0250*	*0.5037*	*0.5694*	*1.1585*	*0.6077*
Cadmium & cpds	*0.2422*	*0.5720*	*0.3277*	*0.1546*	*0.0158*	*0.0282*	*0.0013*	*0.0260*	*0.0128*	*0.0144*	*0.0294*	*0.0154*
Chromium (VI) cpds	*1.0043*	*2.3715*	*1.3585*	*0.6411*	*0.0656*	*0.1168*	*0.0053*	*0.1077*	*0.0529*	*0.0598*	*0.1218*	*0.0639*
Cobalt & cpds	*6.2050*	*14.6521*	*8.3934*	*3.9608*	*0.4053*	*0.7217*	*0.0327*	*0.6655*	*0.3271*	*0.3697*	*0.7522*	*0.3946*
Lead & cpds	*1.8582*	*4.3878*	*2.5135*	*1.1861*	*0.1214*	*0.2161*	*0.0098*	*0.1993*	*0.0979*	*0.1107*	*0.2253*	*0.1182*
Mercury & cpds	*0.2212*	*0.5224*	*0.2992*	*0.1412*	*0.0144*	*0.0257*	*0.0012*	*0.0237*	*0.0117*	*0.0132*	*0.0268*	*0.0141*
PM < 10um	*110,606*	*261,178*	*149,615*	*70,603*	*7,224*	*12,864*	*583*	*11,863*	*5,830*	*6,590*	*13,409*	*7,034*
PAHs	*0.9059*	*2.1390*	*1.2253*	*0.5782*	*0.0592*	*0.1054*	*0.0048*	*0.0972*	*0.0477*	*0.0540*	*0.1098*	*0.0576*

Notes

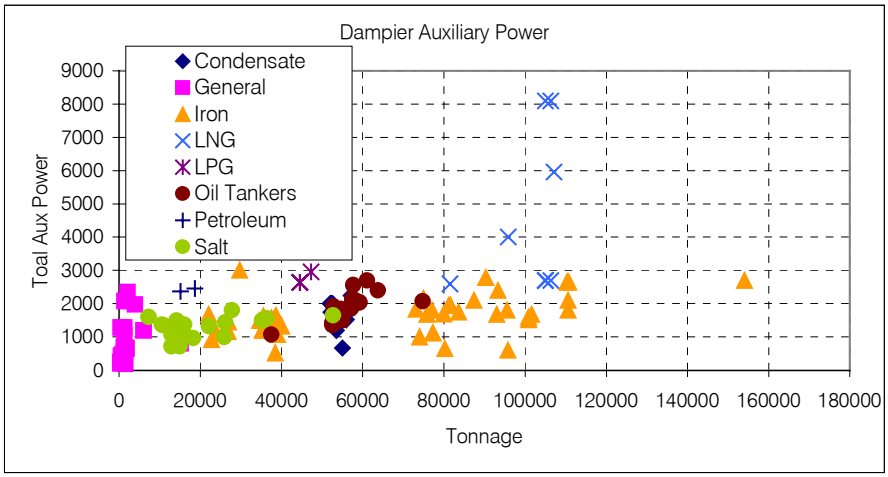
1) Dampier Port Anchorage includes Woodside, Parker Pt, East Intercourse and Mistaken Islands
2) King Bay and Dampier Public Wharf emissions calculated as follows:

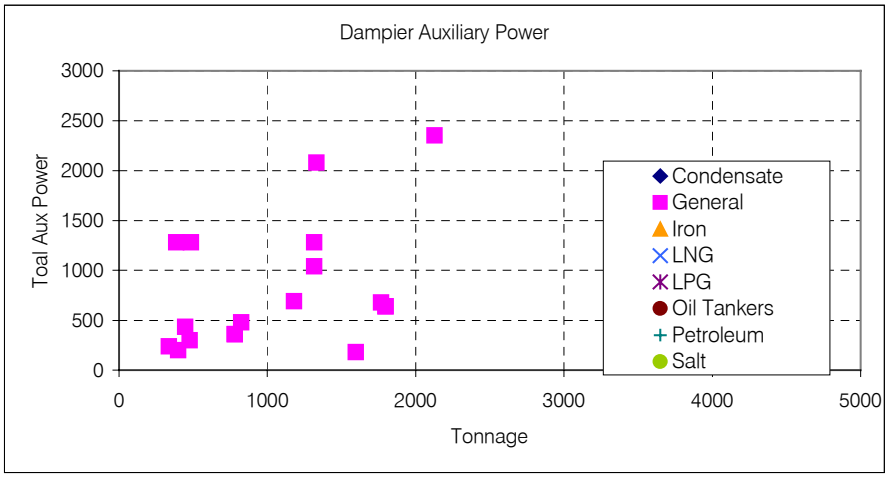
Deepwater emissions = (Comm. Boating Emissions based on fuel usage) - (Berth + Channel + Anchorage)

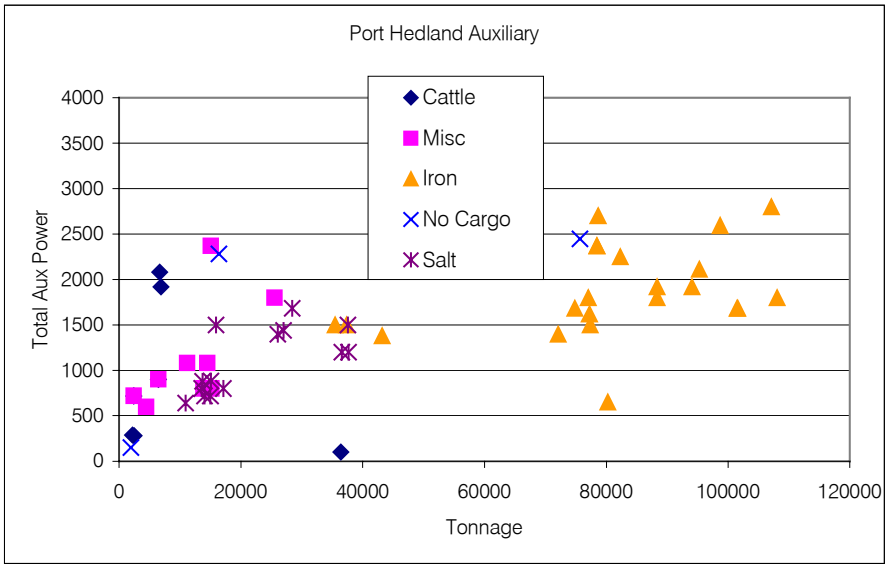
Emissions From Vessels



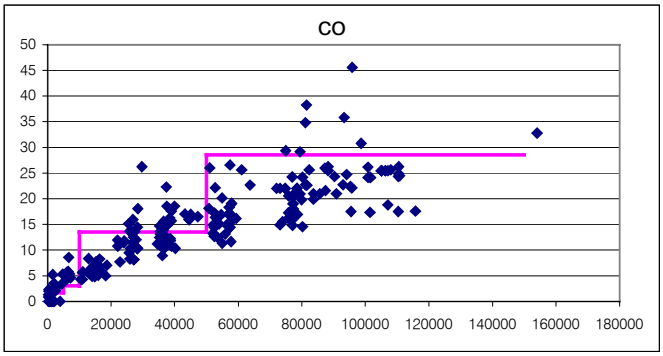
Emissions From Vessels

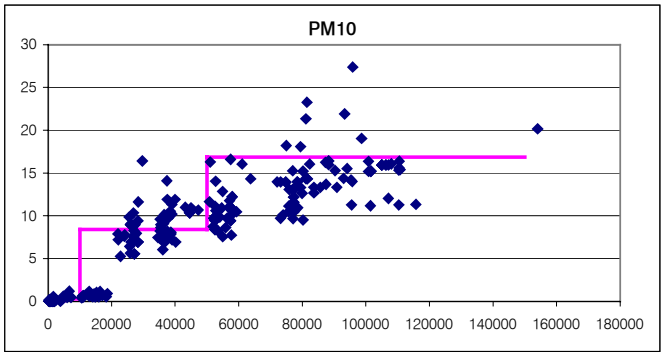


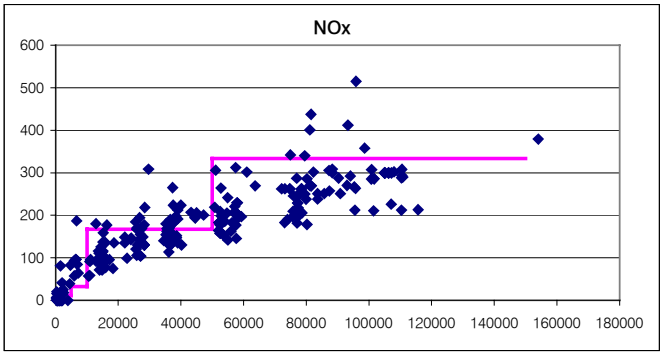


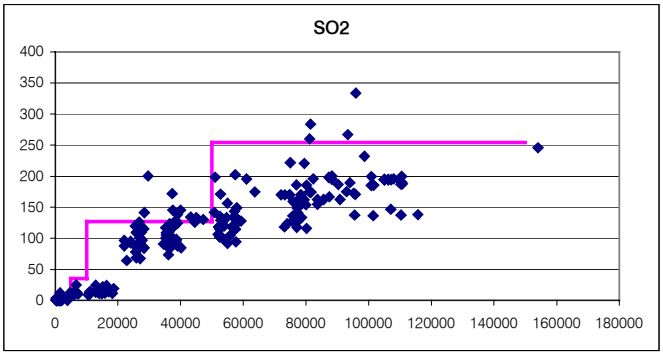


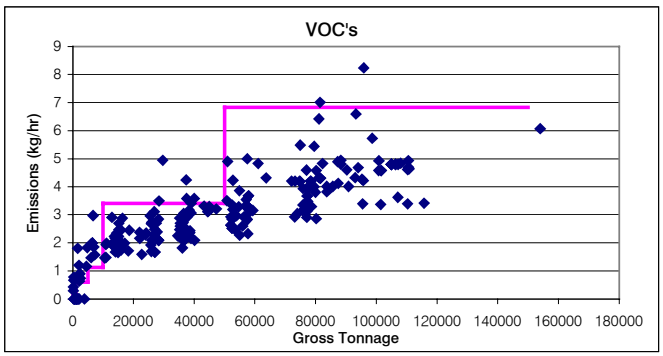
Emissions From Vessels











Appendix C Domestic Survey

PILBARA AIR QUALITY

CLIENT: ***SINCLAIR KNIGHT MERZ***

CLIENT CONTACT: ***BARBARA BROWN***

PMR CONTACT: ***MR KEITH PATTERSON***

JULY 2000

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1.0 SURVEY OVERVIEW

This report is based on a telephone survey conducted of 227 residents of the northwest of Western Australia. Two hundred and seven residents were surveyed from the town of Port Hedland, and 20 from the inland town of Marble Bar. Sampling for both towns was conducted by means of a random dial process of an electric database of the "white pages" telephone listings for those regions.

Under normal circumstances a sample of 227 interviews will provide survey data which is ± 6.5% at the 95% level of confidence.

No attempt has been made to weight the data to reflect the community profiles of these regions because the survey requirement was for the respondent to be the person "most associated with or responsible for the supply of fuels for heating and cooking for the household".

The survey purpose was to provide an indication of the usage of liquid and solid fuels in a range of activities, covering:

- Heating
- Cooking
- Barbeque activities
- Garden/landscaping equipment (domestic, or recreational)
- Marine engines
- LPG gas fuelled recreational equipment such as caravans

The survey was conducted on the weekend of the 8th and 9th July 2000. Households which were not able to be contacted on the first attempt were called a minimum of two further occasions over the course of the interviewing schedule. Fourteen interviewers worked on the project, and all fourteen had 10% of their work validated by means of a callback validation interview. Thirty validation interviews were completed.

1.1 SUMMARY OF FINDINGS

As may have been expected, very few households in northern Western Australia use combustible fuels for heating. However, LPG gas bottles were widely used to power cooking appliances.

Approximately six out of ten households have one or more petrol powered gardening appliance, ranging from lawn mowers and brush cutters through to chain saws and garden blowers. The survey also found that approximately one in five households have a recreational motor boat, and these appear to be used an average of 12 times per annum.

The detailed findings from this report provide the estimate of the proportions of respondents that own and use these various forms of equipment and power sources. The appendix to this report includes the questionnaire which was utilised, and the computer printout of results on which this report has been based. An electronic copy of the computer output is also available.

2.0 DETAILED FINDINGS

The survey was conducted by telephone over the weekend of July 15 and 16. A total of 227 interviews were conducted, 20 of which were conducted in Marble Bar and 207 in Port Hedland. Interviews were conducted with the person "most involved in monitoring the use of fuel for heating and cooking for this household".

2.1 FIREWOOD AND COAL

Only 2% of respondents indicated that they use firewood or coal for cooking, heating or hot water. One respondent indicated that they used coal for cooking, and four respondents indicated that they use firewood for cooking, two indicated that they use firewood for heating, and one indicated that they used firewood for hot water services.

The coal user (0.4% of households) indicated throughout the course of the year, the household uses approximately one tonne of coal.

Three of the four firewood users (1.3% of households) indicated that they use one tonne per annum and the single remaining firewood user (0.4% of households) indicated that they used two tonnes per annum of firewood.

2.2 WOOD AND COAL FIRED APPLIANCES

Two respondents (0.9% of households) indicated that they have an open fire and four (1.3%) indicated that they have an outdoor barbeque which is fired by wood or coal. Both the "open fire" households indicated that they each had one open fire only. Three of the four outdoor barbeque owners that they had one such barbeque only and one indicated that they had three outdoor barbeques.

Both open fireplaces were fuelled by firewood. One of the open fires was seven years old and the other was 20 years old.

One of the four respondents who had an outdoor barbeque indicated that the barbeque was coal fired and the remaining three indicated that the barbeque was wood fired.

2.2.1 Types of Wood Used

Four of the five "wood burning" respondents indicated that they used hard wood and one indicated that he used soft wood. The hard wood usage per annum was:

- Three of the four hardwood users indicated that they use 1 tonne per annum and one indicated that he used 2 tonnes per annum

2.3 OTHER FUEL COMBUSTIONS

Fifty-two percent of respondents indicated that they use LPG gas, 1% reported that they have natural gas (mains gas) (all three respondents reporting mains gas access were in Port Hedland) and 3% of respondents (all from Port Hedland) indicated that they used a diesel generator for power.

2.3.1 Applications of LPG Gas

As noted, 52% of respondents indicated that they use LPG gas in and around their home. The usage of that gas was:

- 81% reported usage in their stove top/oven
- 31% in and outdoor barbeque
- 4% in a flued heater (with a vent outside)
- 1% in an unflued heater (vented inside)
- 28% reported that they used LPG gas for other applications around the home

(These figures add beyond 100% due to multiple application usage)

All respondents who reported usage of natural gas claimed their usage was in a stove top or oven application.

2.3.2 Size of Gas Cylinder

The average size of the gas cylinder was 49.5 kilograms, and they were filled an average of 3.1 times per annum.

2.4 HEATING OIL

No respondents indicated that they used heating oil as a fuel.

2.5 CARAVAN OWNERSHIP

Five percent of respondents (12 respondents) reported that they own or live in a caravan (all of these respondents were from Port Hedland). Almost all of the caravan owners (92%) indicated that the caravan uses LPG fuel, and they filled the LPG gas bottle an average of 2.6 times per annum. The average weight of a caravan gas cylinder was 8 kilograms.

2.6 LAWNMOWERS, WHIPPER SNIPPERS AND OTHER POWER TOOLS

A total of 62% of respondents reported that they have one form or other of a garden power tool fuelled by either two or four stroke fuel. The range of power tools held was:

- 52% have a lawn mower
- 35% a whipper snipper or brush cutter
- 10% a chain saw
- 4% a garden blower
- 2% referred to some other form of powered garden appliance
- 38% reported that they have no petrol powered garden tools

(These figures add beyond 100% due to ownership of multiple categories of power garden tools).

2.6.1 Lawn Mower Engine Categories

One hundred and eighteen respondents (52% of the survey) indicated that they had a lawn mower. Fifty-eight percent of those lawn mowers were four stroke and 40% were two stroke. (The residual of 2% of lawn mowers were some other form of power).

A further 24% of respondents indicated that they have their lawn mowed for them in winter (which means that effectively 24% can be added to the 52% reported lawn mower ownership, to arrive at a net approximate 75% or 76% of respondents who have lawn mowing activity on their properties.

Sixty-eight percent of lawn mowers reported unleaded fuel, 30% reported leaded fuel with the residual unsure.

The summer and winter usage rates for lawn mowers were 2.8 times per month in summer and 1.9 times a month in winter. The average duration of each event in summer was 0.6 hours and in winter 0.5 hours.

2.6.2 Whipper Snipper/Brushcutters

Of the 80 respondents (35%) who indicated that they had a whipper snipper or brush cutter, 86% reported that their motor was two stroke, 6% were four stroke and 5% indicated that they had some other form of power. (These figures are of the 35% of respondents who had a whipper snipper or brush cutter).

Sixty-nine percent of whipper snipper/brush cutters were unleaded (20% had leaded fuel with the residual unsure).

Whipper snipper/brush cutters were used an average of 2.8 times a month in summer and 1.8 times a month in winter. The average duration of each whipper snipper/brush cutter usage was 0.6 hours in summer and 0.5 hours in winter.

2.6.3 Power Blower

Of the 4% of respondents (9 individuals) who reported that they have some form of power blower, three reported that the motor for the blower is a two stroke and the residual either were unsure or reported that it was some other form of power for the blower (possibly electrical).

Of the nine respondents who reported that they had a garden blower, we found three to be unleaded petrol, one to be of leaded fuel and the residual (five) of some other power source (possibly electric).

The usage of blowers in summer (amongst the nine respondents who reported using them) was an average of 4.1 times per month in the summer and 3.6 times a month in winter. The duration of each event in summer was 0.8 hours and in winter 1.1 hours (reflecting the need to clean up fallen leaves etc).

2.6.4 Chain Saws

Of the 10% of respondents (23 individuals) who reported that they had a chain saw, 78% reported that the motor for their chain saw was two stroke, 9% indicated that it was a four stroke with the residual unsure or reporting some other form of power (possibly electric).

Of the 23 respondents who reported that they had a chain saw, 52% (12) indicated that they used unleaded fuel, 30% (7 respondents) reported using leaded fuel with the residual reporting some other form of fuel.

The usage of chain saws amongst the 23 respondents who reported using chain saws was an average of 0.9 times a month in summer and an average of 0.5 times a month in winter. Each usage event took an average of 1.6 hours in summer and an average of 1.4 hours in winter.

2.6.5 Other Equipment

Of the other uncategorised garden implements (five respondents) we found two reporting that the implement was powered by leaded fuel, one that it was powered by unleaded fuel with the remaining two respondents indicating that it was not powered by either forms of petrol, presumably indicating that they were electric powered).

2.7 MARINE CRAFT

Nineteen percent of respondents indicated that they own a boat with an engine. This represented 42 respondents, and of that group, 83% reported that the engine was an outboard with 17% reporting an in-board engine.

2.7.1 Fuel Type

Sixty-two percent of marine motors report using unleaded petrol (29% use of leaded petrol) and the residual diesel.

2.7.2 Fuel Consumption

Fuel tanks are refilled on an average of 9.5 times per annum, and the average tank size was 77.7 litres. However, when asked to indicate the average litres used “per top up”, we found an average of only 33.7 litres. We believe that this is a more accurate estimation of fuel usage, as motor boat drivers very rarely run their fuel to “an empty tank state”, and tend to leave the fuel tanks in a “topped up” condition to minimise the risk of running out of fuel whilst at sea.

2.7.3 Estimated Frequency of Usage

Boat owners report using the boat on an average of once every 4.8 weeks in summer and an average of once every 4.1 weeks in winter. This converts to an average 11.8 trips per annum. However, when respondents were asked to estimate the number of boating trips per annum, they estimated an average 33 times per annum.

2.7.4 Duration of Usage

The average duration of usage for the motor on each occasion was 3.2 hours. The average motor size in terms of the horsepower rating was 72. This was based on:

- 29% having a motor size of up to 15 horsepower
- 31% reported from 15 to 75 horsepower
- 19% report from 75 to 150 horsepower
- 15% from 150 to 230 horsepower

(There were some “don’t know” responses to round out the total to 100%).

APPENDIX A

QUESTIONNAIRE

PMR Q02 Pilbara Air Quality

TIME COMMENCED: _____

TIME COMPLETED: _____

TOTAL MINUTES: _____

INTRO My name is ……..... from Patterson Market Research, the West Australian opinion polling company. We're conducting a survey about energy usage and air pollution in the Pilbara for the Department of Environmental Protection and would like to survey the views of this household.

REGION **Pt Hedland** 1
Marble bar 2
OTHER 3

Could I please speak to the person most involved in monitoring the use of fuel for heating and cooking for this household.
The survey is about energy usage and air pollution in the Pilbara region, covering both domestic and recreational activities.

O>TERMINATE
1>Q1
2>BIRTHDAY

IF SELECTED PERSON UNAVAILABLE, ASK WHEN THEY WILL BE AVAILABLE AND RECORD THE CALL BACK ON CALL SHEET

NAME _____ PH. _____

If necessary, once correct person comes to phone:

The survey is about energy usage and air pollution in the Pilbara region.

Q1. Do you use either firewood or coal in your home?

Firewood 1
Coal 2
Neither 3>Q8

Q2. Do you use (fuel type) for :

	Coal	***Firewood***
Heating	1	1
Cooking	2	2
Hot water	3	3

Other_____

_____

_____

Q3. About how much (fuel type) do you use each year?

Coal Tonnes (_____)

Firewood Tonnes (_____)

(N.B. Need Average conversion of trailer loads to tonnes)

Q4. Do you have any of the following appliances?

READ OUT	***Use***	***Q5a***	***Items - Q5b***		***Q5c***
		# Items	***Coal***	***Wood***	***Age***
Open fire place	1	(_____)	1	2	
Pot Betty stove	2	(_____)	1	2	
Slow Combustion heater	3	(_____)	1	2	
Simple box stove	4	(_____)	1	2	
Outdoor BBQ	5	(_____)	1	2	

Other _____

Q5. For each used:

Q5a. How many (items) do you have? (**CODE IN ITEMS BRACKETS ABOVE**)

Q5b. Which type of fuel do you use for that? (**CODE ABOVE**)

Q5c. How old is that appliance? (**CODE ABOVE**)

Q6. **If you use wood:**
What proportion of your (**TONNES FROM Q3)** do you use in: **(READ OUT APPLICABLE APPLIANCES)**

Open Fire place	(_____)
Pot Belly stove	(_____)
Slow combustion stove	(_____)
Simple box stove	(_____)
Outdoor BBQ	(_____)
	100%

Q7a. What types of wood do you burn?

	Q7a	***Q7b tonnes used***
Hardwood (eg eucalyptus stumps)	1	_____
Soft wood (eg Pine)	2	_____
Other_____		_____
_____		
	Total:	_____
Don't know	99	_____

Q7b. For each type – about how many tonnes do you use per annum?

Other fuel combustion:

Q8. Do you use any other fuel types in your home?

Gas (LPG tanks)	1
Gas Natural – (mains)	2
Oil	3
No	4>Q12a

Q9. For each fuel type, what appliances to you use (fuel type) for?

	LPG GAS	NATURAL GAS	OIL
Stove top/oven	1	1	1
Flued heater (vented outside)	2	2	2
Unflued heater (vented inside)	3	3	3
Outdoor BBQ	4	4	4
Other	5	5	5

Q10. **LPG ONLY – OTHERS SKIP TO Q11.**

Q10a. How big is your Gas Cylinder (kgs) (_____)

Q10b. How many times is it filled/changed per annum? (_____)

Q11. **OIL ONLY – OTHERS SKIP TO Q12a.**

How many litres of oil do you use per annum? (_____)
(IF GALS MULTIPLY BY 4.5 FOR LITRES)

Q12a. Do you own or live in a caravan?

Yes	1
No	2>Q13

Q12b. Does the caravan use LPG fuel?

Yes	1
No	2>Q13

Q12c. If yes, how many times do you fill your cylinder per year? (_____)

Q12d. How much does your cylinder weigh? (_____)

Section 3 Lawnmowers, whipper snippers, leaf blowers, chainsaws and other tools that run on petrol

Q13. Do use a petrol powered garden appliance (eg lawnmower, whipper snipper or leaf blower)?

Appliance	*Q13 Have?*	*Q14a*		*Q14b*		*Q15*	
		Engine		*Fuel*		*Use/Month*	
		2-Stroke	*4-Stroke*	*Leaded Fuel*	*Unleaded Fuel*	*Summer*	*Winter*
Lawnmower	1	1	2	1	2	( )	( )
Whipper snipper/brushcutter	2	1	2	1	2	( )	( )
Blower	3	1	2	1	2	( )	( )
Other	4					( )	( )
None	5>Q17					( )	( )

Q14a. What type of engine? **(CODE ABOVE FOR EACH APPLIANCE FROM Q13)**

Q14b. What type of fuel does the appliance use? **(CODE ABOVE FOR EACH FROM Q13)**

Q15. How often do you use your appliance per month? (**CODE ABOVE FOR EACH)**

Q16. How long is the appliance used for? (**PLEASE SPECIFY HOURS USED PER EVENT).**

Appliance	**In summer**	**In winter**
Lawnmower		
Whipper snipper/whipper snipper		
Blower		

Q17. Do you have your lawn mowed for you?

Yes	1
No	2

Section 4 Marine Craft

Q18. Do you own a boat with an engine?

Yes	1
No	2>Demographics

Q19. What type of engine does your boat have?

Q19a.

2-Stroke	1
4-Stroke	2
Diesel	3
Don't know	4

Q19b.

Inboard	1
Outboard	2

Q20. What type of fuel does it use?

Leaded	1
Unleaded	2
Diesel	3

Q21. How often do you fill your boat's petrol tank? _____per month of year

How big is the tank? _____ litres or gallons

Q22. How often do you use your boat?

In summer once every _____weeks

In winter once every _____ weeks

Estimate of usage per annum _____

Q23. For how many hours do you run the engine on the boat per use? (**AVERAGE)**

_____ hours

Q24. What is the size of the engine on your boat? _____ horsepower

----------DEMOGRAPHICS ----------

THANK YOU. Now to check that we have a good cross section
of the community: Could you please tell me your approx age (_____)

CODE SEX	MALE	1
	FEMALE	2

D1. Which of the following best describes your household structure:

READ OUT	YOUNG SINGLE	1
	YOUNG COUPLE - NO CHILDREN	2
	YOUNG FAMILY - YOUNGEST UNDER 10	3
	MIDDLE FAMILY - YOUNGEST UNDER 17	4
	LATER FAMILY - YOUNGEST 17+	5
	OLDER COUPLE - NO CHILDREN AT HOME	6
	OLDER SINGLE (WIDOW, ETC)	7
	REFUSED	8

Thank you for your time. Just to remind you my name is _____ from Patterson Market Research.
If you have any questions about this research you can telephone our office on 08 9316 2322.
That completes the actual survey, but in case my supervisor needs to check my work could I please have your:

Name _____ PH No. _____ Date _____

INTERVIEWER NAME _____ INT NUMBER _____

I hereby certify that these interviews are accurate and complete, taken in accordance with my instructions and the ICC/ESOMAR international code.

INTERVIEWER SIGNATURE _____