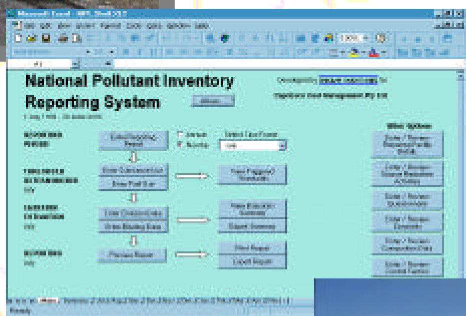
Department of Environmental Protection

Aggregated Emissions Inventory of NPI Substances for the Bunbury Regional Airshed

July 2003



Emissions Inventory Report

Final

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 Bunbury Regional 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 Bunbury Regional Airshed has been identified as a priority for aggregated emissions reporting as part of the NPI in 2002/2003. 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 aggregated emissions was undertaken largely through use of the techniques detailed in the various Emission Estimation Technique (EET) Manuals developed for the NPI. 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 NPI Guide (Environment Australia, 2002c). The emissions were totalled for each type of aggregated emission source and also allocated spatially to identify key source areas of NPI pollutants.

Emissions data are limited to estimates of substances released from specific locations. No comment is made on the "fate" the various emissions (eg. PM_{10}), or resulting exposures to various communities, or ambient air quality concentrations, since this is outside the scope of the work, and would require significant further information on local conditions such as wind direction, topography and other factors.

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 113,000 tonnes. Motor vehicles contribute 39.9% of all aggregate CO emissions, wildfires contribute 39.1% and domestic solid fuel burning 15.5%.
- Total PM_{10} emissions are 133,000 tonnes. The major sources of PM_{10} emissions are from paved and unpaved roads, which contributes 85.0% of the total emissions and windblown dust which accounts for 9.8% of emissions.
- Total NO_x emissions are 26,900 tonnes. 60.3% of these emissions are predominantly from "natural" sources with 56.5% from biogenic sources and 3.8% from wildfires. The next most significant emissions of NO_x are from motor vehicles, which contribute 20.3%.
- Total SO_2 emissions are 991 tonnes. Commercial shipping and boating dominate these emissions, with 55.4% of all aggregate SO_2. Fuel combustion sub reporting threshold is next with 22.1%.
- Total lead emissions are 391 tonnes. Emissions from paved and unpaved roads dominate with 97.6%.
- Total VOC emissions are 135,000 tonnes with these predominantly arising from natural sources, with biogenic sources contributing 88.1% and wildfires 3.3%.

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

With regards to anthropogenic emissions:

- Emissions of CO are dominated by motor vehicles, which contribute 65.2%, and domestic solid fuel burning which contributes 25.3%;
- Emissions of PM_{10} are dominated by dust from paved and unpaved roads (98.1%);
- Total NO_x emissions are dominated by motor vehicles, which contribute 50.9% and sub-threshold facility fuel combustion contributing 26.8%;
- Commercial shipping and boating dominate SO_2 emissions with contributions of 55.4% of all aggregate SO_2, with sub-threshold facility fuel combustion contributing 22.1%;
- Lead emissions are dominated by dust from paved and unpaved roads (99.9%); and
- The major sources of total VOC are 36.6% from motor vehicles and 27.1% from domestic solid fuel burning.

Recommendations

The following are recommended from the study:

- 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).
- Emissions from sub threshold facilities are uncertain. This is due to:
  - The large amount of diesel fuel used by sub threshold facilities. This usage may however occur on public roads as well as onsite therefore contributing to a double counting of emissions. It is considered that part of this diesel usage may be from haulage and earth moving companies. As such, it is recommended that the NPI section follow up with the fuel suppliers to determine all large diesel users in the Bunbury Regional Airshed and then determine from the relevant companies where the diesel is used. This will also assist the NPI section identify companies that should be submitting NPI reports.
- As the emissions of dust are very large from unpaved roads and wind erosion, the speciation of the soil/road dirt content is critical in determining the overall emissions of metals. Therefore, it is recommended that regional specific speciations be obtained for these categories.
- For ships emission estimation 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 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 aircraft it is recommended that LTOs be developed for a range of airports/airstrips, particularly to include small regional towns.
- For dry cleaning it is recommended the defaults be developed for both city and country areas as there are significant differences in the amount of dry cleaning conducted.

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Document History and Status

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1. 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 Bunbury Regional 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 Bunbury Regional Airshed has been identified as a priority for aggregated emissions reporting as part of the NPI in 2002/2003. The goals of the air emissions inventory is the:

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

The sources from which emissions were calculated 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, 2002c).

The most recent information available has been utilised to estimate emissions and it was assumed that this information would be representative of 2002/2003 data.

1.1 Study Area

The Bunbury Regional Airshed is defined by the following co-ordinates:

- Lower left corner Northing: 6,187,000 Easting: 295,000; and
- Upper right corner Northing: 6,421,000 Easting: 460,000.

The region encompasses an area approximately 165km by 234km, which corresponds to a total area of 38,610km^2 and a land area of 24,983km^2. Emissions were spatially allocated on a 3 by 3km grid. This approximates to 55 by 78 grid cells or a total of 4,290 data points across the spatial domain.

The study area comprises 22 Shires as shown in **Figure 1-1**. The Cities of Mandurah and Bunbury, and the Shires of Busselton, Pinjarra, Murray, Waroona, Harvey, Collie, Dardanup, Capel, Donnybrook-Balingup, Bridgetown-Greenbushes and Augusta-Margaret River lie completely within the Bunbury Regional Airshed. A number of other Shires/Cities are partially contained within the study area.

Populations in the Peel and Southwest regions increased between the 1991 and 1996 Census at an average annual growth rate of 5.3% for the Peel, and 2.9% for the Southwest, compared to the State growth rate of 1.5% (Regional Development Council, 2003). In this study, population census data from 2001 was used for spatial allocation. The total population in the study area is 201,105, and the total number of households in the study area is 72,588. The Shires and population figures within the Bunbury Regional Airshed are detailed in **Table 1-1**.

- **Table 1-1 Population centres in the Bunbury Regional Airshed**

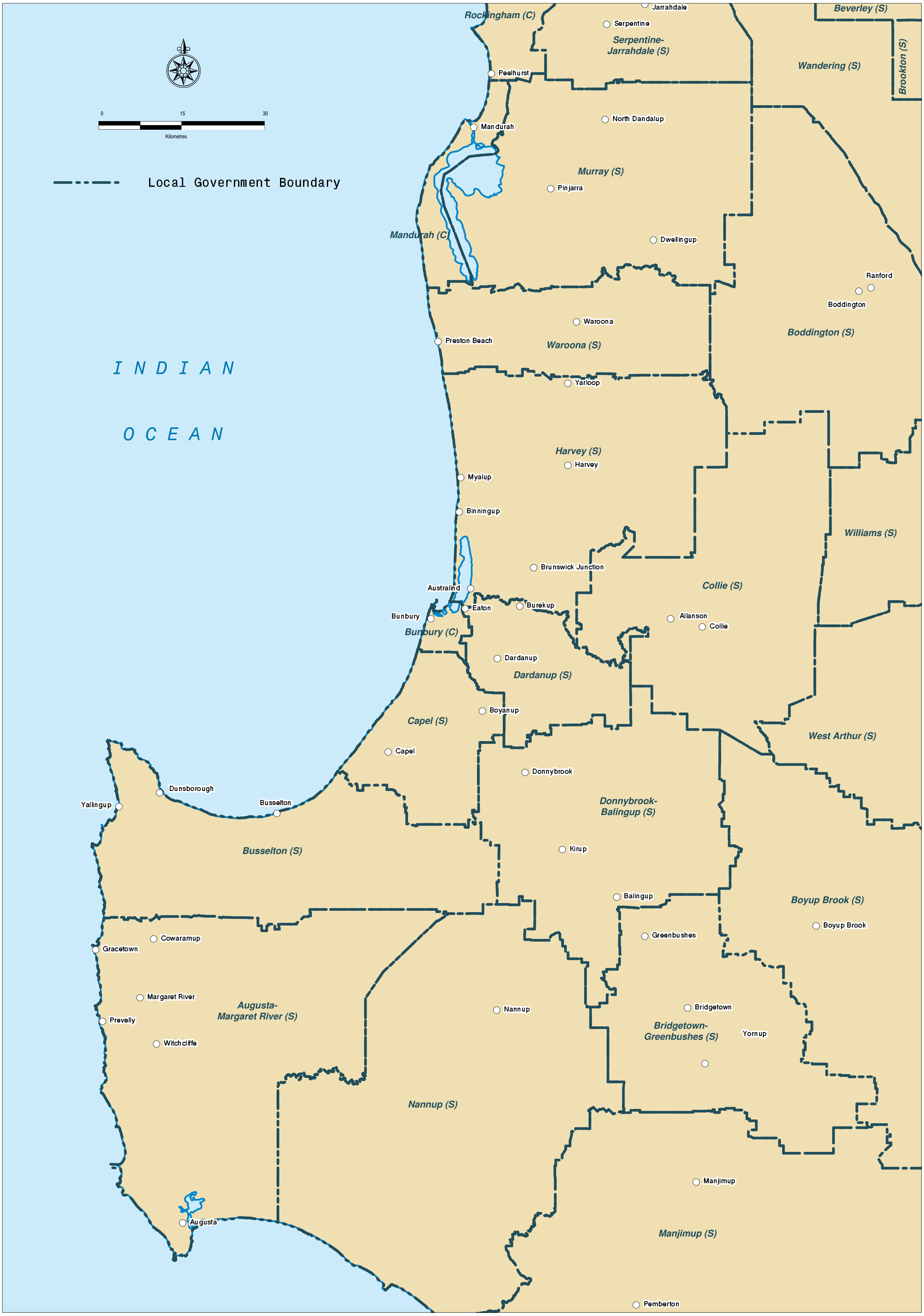
Shire/City	Population	Population in Airshed	No. of Households	No. of Households in Airshed
Augusta-Margaret River	9,851	9,851	3,416	3,416
Boddington	1,407	1,279	503	561
Boyup Brook	1,558	1,085	582	482
Bridgetown-Greenbushes	3,935	3,935	1,506	1,506
Brookton	1,016	10	459	5
Bunbury	28,682	28,682	10,891	10,891
Busselton	22,060	22,060	7,770	7,770
Capel	6,533	6,533	2,202	2,202
Collie	8,400	8,400	3,112	3,112
Dardanup	8,350	8,350	2,874	2,874
Donnybrook-Balingup	4,305	4,305	1,569	1,569
Harvey	17,272	17,272	5,881	5,881
Mandurah	46,936	46,936	17,381	17,381
Manjimup	10,030	7,874	3,461	2,797
Murray	10,061	10,061	3,877	3,877
Nannup	1,183	1,173	442	442
Serpentine-Jarrahdale	11,120	2,351	3,560	837
Wandering	318	76	121	56
Waroona	3,276	3,276	1,176	1,176
West Arthur	866	152	352	53
Williams	900	95	330	41
Rockingham	70,306	17,349	25,041	5,659
Total	**265,583**	**201,105**	**96,506**	**72,588**

Note:
Source Australian Bureau of Statistics (ABS) 2001 census.

For the study, the population and households were spatially allocated on the 3 by 3km grid using the locations of census districts. Areas where the 3 by 3km grid cell were completely covered by National Parks, remnant vegetation cover and water bodies were assigned zero population and household figures.

The major economic activities in the Bunbury Regional Airshed are very diverse and include mining, agriculture, tourism, forestry and manufacturing. The Bunbury Regional Airshed produces all of Western Australia's coal, and also produces alumina, mineral sands and other metals such as tin. Agricultural produce is diverse, with the region supporting beef and dairy cattle, fruit and vegetables, viticulture and wool. The fishery industry is smaller in the Bunbury Regional Airshed than other regions of Western Australia, with the main contributors being abalone, fin fish and commercial rock lobster operations.

The area has a typical Mediterranean climate with warm, dry summers and cool, wet winters and receives most of its rainfall between May and September.



Shires and Major Towns located within the Bunbury Regional Airshed

Figure 1-1

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2. Mobile Sources

2.1 Motor Vehicles

2.1.1 Introduction

Emissions from motor vehicles arise as 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, PM_{10} and trace metals such as lead. 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 aggregated emissions closely follows the approach documented in the EET Manual for Aggregated Emissions from Motor Vehicles (Environment Australia, 2000). Emission estimates have been prepared for the 2001/2002 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.

Lead replacement petrol was introduced in WA on 1 January 2000 and as such all leaded petrol vehicles are assumed to be using lead replacement petrol.

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.

2.1.2 Data Collection and Information Sources

Data collected for the estimation of emissions included:

- Traffic count data obtained from Main Roads WA;
- Traffic count data obtained from Local Councils in the Bunbury Regional Airshed;
- Vehicle registration information for the Bunbury Regional Airshed from the WA Department for Planning and Infrastructure (DPI);

- Motor vehicle usage information for WA from the Australian Bureau of Statistics (ABS);
- Fuel composition from BP; and
- Spatial road centrelines with road type information.

Previous experience with vehicle emissions studies in the Pilbara region and vehicle classification data from Main Roads WA (MRWA) was used to determine the proportions of the primary vehicle classes. 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) were determined using the defaults in the EET Manual.

Vehicle registration data was sourced from the DPI. Queries of the data supplied were performed to give cross tabulations of vehicle type, age and fuel type for vehicles in the Bunbury Regional Airshed.

Fuel product information was sourced from BP for diesel, unleaded, premium unleaded and lead replacement fuels. Data on LPG was 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 digital information AUSLIG 1:2,500,000 data. The classification of roads was undertaken using the same data set.

The road network (excluding tracks) for the Bunbury Regional Airshed is shown in **Figure 2-1**.

2.1.3 Emission Estimation

2.1.3.1 General Approach

The approach used for the estimation of motor vehicle aggregated emissions closely follows the approach documented in the EET Manual for Aggregated Emissions from Motor Vehicles (Environment Australia, 2000). The methodology estimates vehicle kilometres travelled (VKT) and applies emission rates for the various NPI substances emitted. The broad steps followed for this study were:

- Traffic volume estimates for this study were located on road centreline segments for each road in the Bunbury Regional Airshed;
- 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 calculated from the spatial road centreline information;
- Grid based VKT estimates were calculated (i.e. traffic volume × segment length in grid);
- Emission rates were developed for the representative vehicle class, fuel type, and road type categories; and
- Emission rates were applied to the grid based VKT including speciation of VOCs and PM_{10} emissions.

Road Network within the Bunbury Regional Airshed **Figure 2-1**

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

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

Where:

E_c	=	Annual emissions from motor vehicles in grid cell c (kg/yr)
$v_{r,c}$	=	Average daily VKT for road type r in grid cell c (km/day)
$\chi_{r,m,f}$	=	Relative VKT of vehicle type m and fuel type f on road type r (km/day)
$e_{r,m,f,p}$	=	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)
365	=	Conversion factor from day to year (days/yr)
0.001	=	Conversion factor from grams to kilograms (g/kg)

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

2.1.3.2 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 freeway, highway, main road, minor road and tracks, designated as sealed or unsealed as appropriate as detailed in **Table 2-1**.

Traffic counts obtained from MRWA and local councils were entered into the MapInfo centreline data set for the appropriate road segments. A flag was also added to indicate "Urban" or "Rural" environments.

Default traffic volumes were developed from this traffic count data by grouping the traffic counts into road hierarchy classifications as listed in **Table 2-1**. For the minor unsealed roads and tracks no count data was available with defaults determined based on estimates used in the Pilbara study (SKM, 2003). These default values were then assigned to all roads without actual count data.

■ **Table 2-1 Road Types and Default Vehicle Volume**

Road Hierarchy	Environment	Default Vehicle Volume (Vehicles/day)	Adopted EET Manual Road Type
Freeway	All	20,000	Freeway
Highway	Urban	4,000	Arterial
Main sealed	Urban	3,000	Arterial
Minor sealed	Urban	300	Residential
Minor unsealed	Urban	50	Residential
Track	Urban	5	Residential
Highway	Rural	2,000	Freeway
Main sealed	Rural	1,500	Freeway
Main unsealed	Rural	300	Freeway
Minor sealed	Rural	200	Residential
Minor unsealed	Rural	50	Freeway
Track	Rural	3	Residential

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.

The resultant vehicle traffic is listed in **Table 2-2** along with data from other Australian Airsheds.

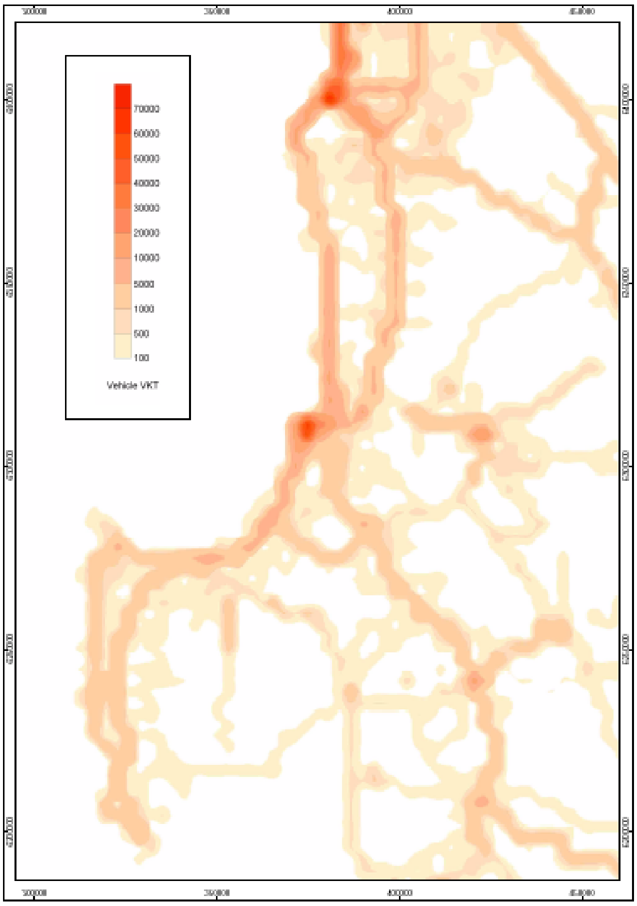
- **Table 2-2 Annual Vehicle Kilometre Travelled by Road Type**

Airshed	Population	Paved Road VKT (km x10^6)	Unpaved Road VKT (km x10^6)	Total VKT (km x10^6)	Paved Road (VKT/person)	Unpaved Road (VKT/person)	Total (VKT/person)
Bunbury Region	201,105	2,411	248.5	2,659.5	11,989	1,236	13,225
Perth[1]	1,310,355	-	-	14,465	-	-	11,042
Pilbara[2]	50,108	380	52.6	432.6	7,584	1,050	8,634
Kalgoorlie[3]	31,090	321.5	5.5	327	10,341	177	10,518
Darwin[4]	106,150	-	-	1,298	-	-	12,228
Alice Springs[4]	27,250	-	-	167.9	-	-	6,162

Note:
1) Source DEP (2002).
2) Source SKM (2003).
3) Source Coffey Geosciences (1999).
4) Source SKM, Wilkinson, S., personal communication (2003).

This indicates that approximately 9% of the traffic volume occurred on unpaved roads, with a total VKT per person of 13,225 km. The total VKT in the Bunbury Regional Airshed is slightly higher than for the other Airsheds presented, excepting Alice Springs which is expected to have much lower traffic as the study area only encompassed the city and therefore neglected any inter regional travel.

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 gridded VKT for paved roads are presented in **Figure 2-2**. These indicate the greatest VKT around Mandurah and lesser amounts at other regional centres such as Bunbury, Collie etc.



■ **Figure 2-2 Gridded VKT for Paved roads**

2.1.3.3 Relative VKT Per Vehicle Category

Traffic volume proportions obtained from the MRWA for the Bunbury Regional Airshed 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 Bunbury Regional Airshed. Vehicle fuel proportions were calculated from registration cross-tabulations.

The resulting proportions globally applied for traffic volume and fuel type are given in **Table 2-3**. 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 2-3 Traffic Volume and Fuel Type Proportions**

	Vehicle Class			
	Motorcycle	Passenger	Light Commercial	Heavy Duty
Traffic Volume Proportions [1]				
Arterial	1.10%	75.20%	14.20%	9.50%
Freeway	1.10%	80.60%	13.10%	5.20%
Residential	1.10%	89.75%	6.55%	2.60%
Fuel Type Proportions [2]				
Lead Replacement Petrol	31.33%	19.71%	19.71%	5.41%
Unleaded Petrol	68.67%	62.55%	62.55%	11.48%
Diesel	0.00%	16.88%	16.88%	83.11%
LPG/CNG	0%	0.87%	0.87%	0.00%

Notes:
1) Source Table 5 of EET Manual for Aggregated Emissions from Motor Vehicles (Environment Australia, 2000).
2) Source WADMR vehicle registrations for the Bunbury Regional Airshed 2001/2002.

2.1.3.4 Emission Factors for CO, NO_x and Total VOCs

The EET Manual describes a detailed methodology for the derivation of carbon monoxide (CO), oxides of nitrogen (NO_x) and Total Volatile Organic Compounds (VOCs) emission factors for the various vehicle class, road type and fuel type categories. Application of this detailed approach was not possible for the Bunbury Regional Airshed 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 2-4**.

Petrol values have been applied to all unleaded and lead replacement petrol. Evaporative emissions from diesel have not been estimated in accordance with the EET manual due to the comparatively low evaporative emissions from diesel due to its low volatility.

■ **Table 2-4 Emission Rates for CO, NO_x and VOCs**

Vehicle Class	Fuel Type	Emission Rate (g/km) by Road Type		
		Arterial	Freeway	Residential
CO				
Passenger	Petrol	19.3	18.8	22.3
	Diesel	0.637	0.516	1.13
	LPG	24.5	24.0	27.9
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
NO_x				
Passenger	Petrol	1.53	1.98	1.78
	Diesel	0.785	1.33	1.02
	LPG	1.1	1.37	1.23
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
Total VOCs (exhaust)				
Passenger	Petrol	1.26	1.24	1.45
	Diesel	0.331	0.31	0.513
	LPG	1.53	1.51	1.73
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
Total 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

Note:
1) Source Table 11 of EET Manual for Aggregated Emissions from Motor Vehicles (Environment Australia, 2000).

2.1.3.5 Emission Factors for PM_{10}, $S0_2$ and Lead

The default emission factors for particulate matter less than 10 µm (PM_{10}) have been adopted unchanged from the EET Manual (**Table 2-5**). Factors for buses have been ignored, as the proportion of buses in the Bunbury Regional Airshed 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 calculated using the emission factors given in the EET Manual (**Table 2-5**).

Table 2-5 Emission Factors for PM_{10}

Vehicle Type	Fuel	Emission Factor (g/km) by Road Type		
		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

Note:
1) Source Table 13 of EET Manual for Aggregated Emissions from Motor Vehicles (Environment Australia, 2000).

Emission factors for sulphur dioxide (SO_2) have been scaled from the default EET Manual values, which are for national average sulphur contents, by WA standards for fuel sulphur content (as given in the *Environmental Protection (Diesel and Petrol) Regulations 1999*), and are given in **Table 2-6**. For diesel the data indicates that local sulphur levels are significantly lower than the national average used in the EET Manual.

Table 2-6 Sulphur Contents of Fuels

Fuel	Sulphur Content (EET Manual)[1] (g/L)	Sulphur Content (Bunbury)[2] (g/L)	Maximum WA Fuel Sulphur Content[3] (ppm by weight)
Lead Replacement Petrol	0.155 (assuming leaded)	0.114	150
Unleaded Petrol	0.110	0.1125	150
Diesel	1.270	0.408	500
LPG	0.00784	Unavailable – Use EET Manual	Not Applicable

Notes:
1) Source Table 14 of EET Manual for Aggregated Emissions from Motor Vehicles (Environment Australia, 2000).
2) Based on WA Standards for fuel sulphur content.
3) Source *Environmental Protection (Diesel and Petrol) Regulations 1999*.

For LPG, similar comparisons of sulphur were not possible due to lack of suitable data. As such the national sulphur content value has been adopted for LPG.

The resulting emission factors for SO_2 based on the scaled defaults from the EET Manual are given in **Table 2-7**. 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 2-7 Emission Factors for SO_2

Vehicle Type	Fuel	Emission Factors (g/km)		
		Arterial	Freeway	Residential
Passenger	Lead replacement petrol	0.026274	0.018435	0.026274
	Unleaded petrol	0.024769	0.017411	0.024769
	Diesel	0.091559	0.063931	0.091559
	LPG	0.00273	0.00191	0.00273
Light commercial	Lead replacement petrol	0.030556	0.021411	0.030556
	Unleaded petrol	0.028189	0.019795	0.028189
	Diesel	0.09702	0.068107	0.09702
	LPG	0.00262	0.00183	0.00262
Heavy duty	Lead replacement petrol	0.068026	0.047642	0.068026
	Unleaded petrol	0.031526	0.022028	0.031526
	Diesel	0.289343	0.202265	0.289343
	LPG	0.007708	0.005393	0.007708
Motorcycle	Lead replacement petrol	0.012774	0.009	0.012774
	Unleaded petrol	0.013473	0.0094	0.013473

Notes:
1) Source Table 15 of EET Manual for Aggregated Emissions from Motor Vehicles (Environment Australia, 2000) with adjustments to reflect WA Standards for fuel sulphur content.

Emission factors for lead were obtained from the EET Manual as the default lead content of petrol (0.0001% by weight) is considered appropriate for WA fuels (BP Refinery, Lukatelich, R., personal communication, 2003). This low level of lead is due entirely to lead in the oil feedstock with no lead added to unleaded or lead replacement petrol. As for the SO_2 emission factors, 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 factors for lead based on the scaled defaults from the EET Manual are given in **Table 2-8**.

Neither diesel nor LPG fuelled vehicles emit lead compounds.

Table 2-8 Emission Rates for Lead

Vehicle Type	Fuel	Emission Rate (g/km)		
		Arterial	Freeway	Residential
Passenger	Leaded petrol[1]	0.0117	0.0082	0.0117
	Lead replacement petrol	0.000126	0.000088	0.000126
	Unleaded petrol	0.000118	0.000082	0.000118
Light commercial	Leaded petrol[1]	0.0136	0.0095	0.0136
	Lead replacement petrol	0.000146	0.000102	0.000146
	Unleaded petrol	0.000134	0.000094	0.000134
Heavy duty	Leaded petrol[1]	0.030275	0.02124	0.030275
	Lead replacement petrol	0.000326	0.000229	0.000326
	Unleaded petrol	0.000150	0.000105	0.000150
Motorcycles	Leaded petrol[1]	0.00571	0.00399	0.00571
	Lead replacement petrol	0.0000615	0.0000430	0.0000615
	Unleaded petrol	0.0000636	0.0000445	0.0000636

Notes:
1) The value for Leaded Petrol has been supplied for comparison purposes only.
2) Source Table 17 of EET Manual for Aggregated Emissions from Motor Vehicles (Environment Australia, 2000) with lead replacement petrol emissions modified from the unleaded emissions by the density difference of the two fuels.

2.1.3.6 Speciation Factors for VOCs and PM_{10}

Speciation of both VOCs and PM_{10} 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 2-9** and **Table 2-10**.

Table 2-9 VOC Speciation of Motor Vehicle Emissions

Substance	Weight Fraction			
	Petrol Exhaust	Petrol Evaporative	Diesel Exhaust	LPG Exhaust
Acetaldehyde	0.00437	-	0.155	0.000615
Acetone	0.00286	-	0.0815	-
Benzene	0.0658	0.017	0.0101	0.00000943
1,3-Butadiene	0.00649	0.0018	0.00115	0.0000552
Cyclohexane	0.0011	0.000713	0.000778	-
Ethylbenzene	0.015	0.0019	-	-
Formaldehyde	0.0156	-	0.0826	0.00178
n-Hexane	0.0155	0.0147	-	-
PAHs	0.00217	-	0.00667	-
Styrene	0.00213	0.000308	-	-
Toluene	0.105	0.0224	0.0147	-
Xylenes	0.0759	0.00992	0.0117	-

Note:
1) Source Table 18 of EET Manual for Aggregated Emissions from Motor Vehicles (Environment Australia, 2000).

Table 2-10 PM_{10} Speciation of Motor Vehicle Emissions

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

Note:
1) Source Table 19 of EET Manual for Aggregated Emissions from Motor Vehicles (Environment Australia, 2000).

2.1.4 Spatial Allocation

The spatial allocation was performed based on the grid based vehicle kilometres travelled estimates discussed in **Section 2.1.3.2**.

2.1.5 Emission Estimates

The emissions for the Bunbury Regional Airshed from motor vehicles for the 2001/2002 financial year calculated using the above methodology are given in **Table 2-11**.

Table 2-11 Emissions from Motor Vehicles

NPI Substance Name	Total Emissions (kg/yr)
Acetaldehyde	58,200
Acetone	32,300
Benzene	216,000
1,3-Butadiene (vinyl ethylene)	21,500
Cadmium & compounds	55.7
Carbon monoxide	45,100,000
Chromium (III) compounds	8.05
Chromium (VI) compounds	3.64
Cobalt & compounds	10.5
Copper & compounds	14.6
Cyclohexane	4,170
Ethylbenzene	46,800
Formaldehyde (methyl aldehyde)	70,900
n-Hexane	59,800
Lead & compounds	230
Manganese & compounds	12.8
Nickel & compounds	2.09
Oxides of nitrogen	5,460,000
Particulate matter (PM_{10})	145,000
PAHs	8,450
Styrene (ethenylbenzene)	6,670
Sulphur dioxide	103,000
Toluene (methylbenzene)	340,000
Total VOCs	4,250,000
Xylenes (individual or mixed isomers)	240,000
Zinc & compounds	504

2.1.6 Comparison to Other Studies

Comparisons of emissions from motor vehicles from the Bunbury Regional Airshed on a per capita basis with those from aggregated emissions studies for the Perth, Pilbara, Darwin, Alice Springs and Port Phillip Regional Airsheds are given in **Table 2-12**. Only NPI substances common to all areas have been compared. Generally the motor vehicle emissions estimates compare well for CO, NO_x, total VOC and PM_{10}. However, the speciated compounds of total VOCs and PM_{10} sometimes are different, notably acetaldehyde and acetone are lower in the other studies, significantly for the Alice Springs and Darwin Airsheds. These differences are considered primarily due to the different emission rates and speciations used in the earlier studies. For example the Pilbara study used the August 2000 version of the of EET Manual for Aggregated Emissions from Motor Vehicles, that was then updated and corrected to the current November 2000 version. It is noted that emissions of benzene for instance were increased by over a factor of 10 between the two versions of the EET manual.

For SO_2 and lead, in particular, the Bunbury Region Airshed emissions per capita are lower due to the introduction of cleaner fuel standards in WA.

- **Table 2-12 Comparison of Emissions from Motor Vehicles from Bunbury Regional Airshed with Other Airsheds**

NPI Substance Name	Emission Rates per Capita (kg/yr/person)					
	Bunbury Regional Airshed	Perth[1]	Pilbara[2]	Alice Springs[3]	Darwin[3]	Port Phillip Regional Airshed[4]
Acetaldehyde	0.289	0.0916	0.217	0.0207	0.0235	Not given
Acetone	0.161	0.0237	0.117	0.000402	0.000871	Not given
Benzene	1.07	0.606	0.089	0.0448	0.0897	1.104
1,3-Butadiene (vinyl ethylene)	0.107	0.001	0.0757	0.00432	0.0065	0.13
Carbon monoxide	224	153	58.5	54.8	101	162
Cyclohexane	0.207	Not given	0.0638	0.0091	0.0187	Not given
Ethylbenzene	0.233	0.214	0.0522	0.0345	0.074	Not given
Formaldehyde (methyl aldehyde)	0.352	0.214	0.176	0.0503	0.0602	0.237
n-Hexane	0.297	Not given	0.0668	0.0348	0.0756	Not given
Lead & compounds	0.00114	0.0328	0.0109	0.0349	0.0693	0.052
Oxides of nitrogen	27.2	21.4	14.2	27.3	52.3	15.6
Particulate matter (PM_{10})	0.721	1.22	0.549	0.539	0.647	1.01
PAHs	0.042	0.0003	0.0183	0.000221	0.000451	0.0318
Styrene (ethenylbenzene)	0.033	Not given	0.124	0.00621	0.013	Not given
Sulphur dioxide	0.512	0.56	1.5	0.923	1.14	0.637
Toluene (methylbenzene)	1.69	1.22	0.115	0.118	0.257	1.74
Total VOCs	21.1	15.3	8.01	5.68	9.98	18.2
Xylenes (individual or mixed isomers)	1.19	1.14	0.207	0.0996	0.228	1.28

Note:
1) Source DEP (2002).
2) Source SKM (2003).
3) Source NT Department of Infrastructure, Planning and Environment (2003).
4) Source EPAV (1998).

2.2 Off-Road Vehicles (Agricultural Machinery)

2.2.1 Introduction

Off-road vehicles release emissions through the engine combustion process and through evaporation of the fuel itself. Off-road vehicles were classified as vehicles used on non-public roads, and did not include vehicles used on mine sites or industrial sites. The latter were covered by **Section 3.16**, which looks at sub-threshold industrial/commercial fuel consumption. Off-road sources therefore include agricultural equipment and personal four-wheel-drive vehicles.

Recreational four-wheel-drive vehicle usage in the Bunbury Regional Airshed was estimated from discussions with five four-wheel-drive clubs in the area. Usage estimates were very variable, and considered negligible in relation to the off-road use by agricultural vehicles.

As such, emissions from off-road vehicles were determined solely from agricultural vehicles and have been allocated to the category of Agriculture (Machinery).

2.2.2 Data Collection and Information Sources

Annual fuel sale information for automotive fuels in the Bunbury Regional Airshed was obtained from the fuel suppliers (Caltex, Shell, Gull, BP and Mobil) and is summarised in **Table 2-13**. This indicates that 18.2ML of diesel and 2.22ML of petrol (lead replacement and unleaded) was delivered directly to farms. This is approximately 8.5% and 2.8% of the total diesel and petrol used in the Bunbury Regional Airshed and therefore is a significant component of total fuel usage.

- **Table 2-13 Annual fuel supply to the Bunbury Regional Airshed**

	Unleaded (ML/yr)	Leaded (ML/yr)	Diesel (ML/yr)
Retail (Total)	**71.2**	**5.68**	**28.0**
Retail (Marine Bowser)	*0.168*	-	*4.12*
Commercial/Industrial (Total)	**0.589**	**0.012**	**167**
Commercial/Industrial (NPI Reporting facilities)	*0.380*	-	*95.4*
Commercial/Industrial (Sub threshold)	*0.209*	*0.012*	*65.7*
Locomotives	-	-	*6.26*
Agriculture	**2.14**	**0.077**	**18.2**
Total	**73.9**	**5.77**	**213.2**

Notes:
1) Marine bowsers assumed captured under total retail sales and locomotives under commercial/industrial.

Telephone surveys of people on rural properties/farmers in the Bunbury Regional Airshed were undertaken to determine the following information:

- Types of vehicles used for agricultural purposes;
- Type of fuel for each vehicle;
- The proportion of each fuel type that different vehicles used; and
- The proportion of on-road and off-road use per vehicle.

Information was collected from three property owners in Boyup Brook, Waroona and Collie. A summary of the types of vehicles, fuel types and percentages of off-road use for each vehicle is presented in **Table 2-14**.

- **Table 2-14 Summary of agricultural vehicle use survey**

Vehicle Type	No. of vehicles	Fuel Type	Average off-road use (%)
Tractor	6	Diesel	90
Ute	3	Diesel	60
Truck	1	Diesel	100
Car	9	Unleaded Petrol	3
Car	1	Lead Replacement Petrol	100
Motorbike	5	Unleaded Petrol	80

The number of registered tractors by postcodes was obtained from the Department of Planning and Infrastructure (DPI). This information was used to spatially allocate the emissions.

2.2.3 Emission Estimation

Emissions were calculated using the EET Manual for Combustion Engines (Environment Australia, 2002a) using a modified form of **Equation 2.2**, as follows:

$$E_{kpy,j} = F \times EF_i \qquad \textbf{Equation 2.2}$$

Where:
$E_{kpy,i}$ = emission of pollutant i for a specific type of engine, kpy (kg/yr)
F = vehicle fuel use, (L/yr)
EF_i = emission factor for pollutant i, for given engine and fuel type, (kg/L)
i = pollutant type

Here the load factor multiplier has been omitted, as this is considered inappropriate when multiplying fuel usage by emission factors.

The annual fuel use was calculated by the total fuel supplied to the Bunbury Regional Airshed for agricultural use, and the proportion of each fuel type used by different vehicle type. The proportion of fuel type used by each vehicle type was based on information from the telephone surveys such as estimates of hours used for each vehicle and fuel consumption rates. Annual fuel use for each vehicle type is shown in **Table 2-15**. Lead replacement petrol and unleaded petrol have been grouped together, and are assumed to have similar emissions. **Table 2-15** indicates that 88% of diesel and 57% of petrol supplied to the Bunbury Regional Airshed for agricultural purposes is used off-road.

- **Table 2-15 Proportion of fuel used for off-road vehicles**

Vehicle type	Annual fuel use by vehicle type (%)[1]		Annual off-road fuel use by vehicle type (%)		Annual off-road fuel use by vehicle type (L/yr)	
	Diesel	Petrol	Diesel	Petrol	Diesel	Petrol
Tractor	90	0	81	-	14,742,671	-
Ute/Truck	10	0	7	-	1,274,058	-
Car	0	40	-	9	-	195,547
Motorbike	0	60	-	48	-	1,066,619
Total	100	100	88	57	16,016,729	1,262,166

Notes:
1) Annual fuel use includes on-road and off-road use.

The emissions factors for the various vehicle types are shown in **Table 2-16**.

- **Table 2-16 Emission factors for off-road vehicle use**

Substance	Diesel Wheeled Tractor (kg/L)	Diesel Misc (utes, cars, trucks) (kg/L)	Petrol Misc (utes, cars, trucks) (kg/L)	Petrol Motorbikes (kg/L)[3]
Carbon monoxide	3.22E-02	1.84E-02	4.75E-01	8.26E-04
Formaldehyde	1.23E-03	8.13E-04	5.32E-04	-
Oxides of nitrogen	5.24E-02	4.41E-02	1.15E-02	5.22E-06
Particulate matter (PM_{10})	5.57E-03	3.61E-03	7.26E-04	3.78E-06
Sulphur dioxide	3.73E-03	3.73E-03	6.33E-04	1.04E-06
Total VOCs	7.74E-03	4.04E-03	1.56E-02	2.18E-04
Benzene	-	-	-	1.65E-06
1,3 Butadiene	-	-	-	6.43E-07

Notes:
1) Emission factors for diesel wheeled tractors and diesel miscellaneous vehicles were taken from Table 7 of the EET Manual for Combustion Engines (Environment Australia, 2002a).
2) Emission factors for petrol miscellaneous vehicles were taken from Table 10 from the EET Manual for Combustion Engines (Environment Australia, 2002a).
3) Emission factors for motorbikes were calculated based on Table 5 from the EET Manual for Combustion Engines (Environment Australia, 2002a), and converted from kg/km to kg/L using a conversion factor of 0.04 L/km which was based on the average fuel consumption for 250cc trail motorbike (obtained from current catalogues).

The total emissions from off-road vehicle use in the Bunbury Regional Airshed are shown in **Table 2-17**.

- **Table 2-17 Annual emissions from off-road vehicle use**

Substance	Total Emissions (kg/yr)
Carbon monoxide	592,000
Formaldehyde	19,300
Oxides of nitrogen	831,000
Particulate matter (PM_{10})	86,900
Sulphur dioxide	59,900
Total VOCs	123,000
Benzene	1.76
1,3 Butadiene	0.686

2.2.4 Spatial Allocation

Off-road vehicle emissions were allocated according to the number of registered tractors in postcode areas over the 3 by 3km grid. Tractors were used to define agricultural activity.

2.2.5 Comparison to Other studies

Table 2-18 gives a comparison of off-road vehicle emissions to other aggregated emission studies. The emissions for the Bunbury Regional Airshed are generally higher by around 1 to 2 times than the Kalgoorlie study and a factor of 100 times higher than that estimated for the Port Phillip Region. These differences are due to the estimation methodologies employed and importantly on the nature of the study region. The Port Phillip study region is dominated by the large urban population with relatively minor agricultural activities. The Kalgoorlie region too, has little agricultural activities, with the estimates of off-road emissions estimated by scaling the Perth 1994 data. The Perth 1994 estimates were based on estimating off-road emissions as a fraction on road emissions based on early US work. The 1998/1999 Perth inventory (SKM, 1999) included heavy machinery used for mining and construction works, as well as agricultural machinery and tractors or miscellaneous equipment used to mow golf courses, parks and verges. Therefore comparisons have not been made to the 1998/1999 Perth estimates.

- **Table 2-18 Comparison of Emissions from Off-Road Vehicles from Bunbury Regional Airshed with Other Airsheds**

Substance	Emissions from Airshed (kg/person/yr)		
	Bunbury Region	Kalgoorlie[1]	Port Phillip Region[2]
Carbon monoxide	2.94	0.92	0.008
Oxides of nitrogen	4.13	1.93	0.023
Particulate matter (PM_{10})	0.43	0.14	0.003
Sulphur dioxide	0.30	0.25	0.001
Total VOCs	0.61	0.16	0.004

Note:
1) Coffey Geosciences (1999).
2) Source EPAV (1998).

2.3 Railways

2.3.1 Introduction

Rail in the Bunbury Regional Airshed is used for freight, passenger services and tourism. These services provided by four rail operators:

- Western Australia Government Railways;
- Australian Railway Group;
- Hotham Valley Tourist Railways; and
- Pemberton Tramway Company.

Freight in the Bunbury Regional Airshed is run primarily by the Australian Railway Group and includes but is not limited to:

- Coal from the Ewington, Premier and Collie mines to Hamilton and Kwinana;
- Alumina from Pinjarra, Wagerup and Worsley refineries to either Bunbury Port or Kwinana;
- Mineral sands from Capel to Bunbury Port; and

- Woodchips from Lambert (near Pemberton) to Bunbury Port.

Western Australian Government Railways operates the ‘Australind’ country commuter service, which travels twice daily between Perth and Bunbury.

Hotham Valley Tourist Railways and the Pemberton Tramway Company operate diesel and steam locomotives primarily for tourism throughout the Bunbury Regional Airshed, although the Pemberton Tramway Company does conduct some commercial work in the southern end of the Bunbury Regional Airshed.

2.3.2 Data Collection and Information Sources

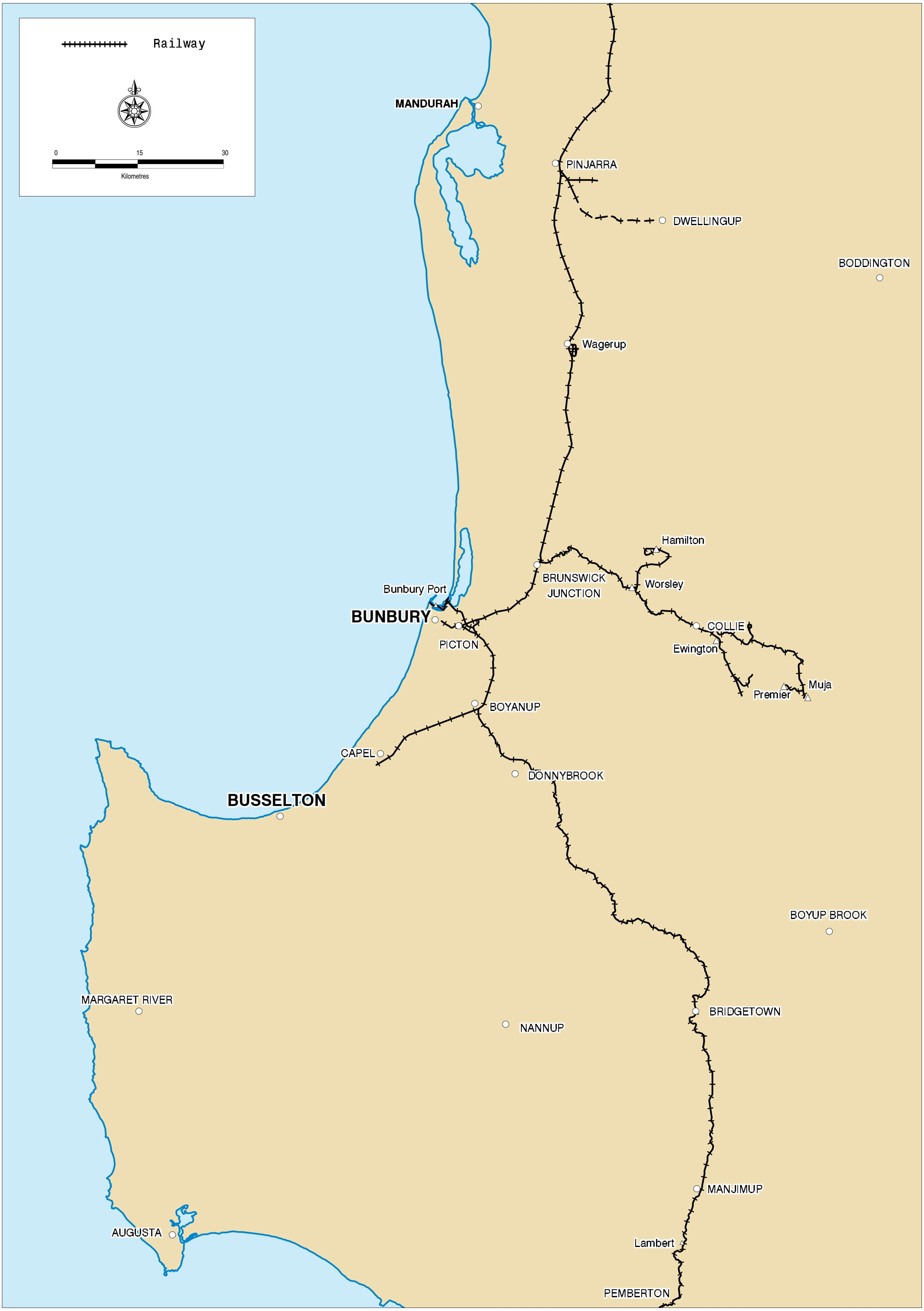
Electronic data sets of railways in the Bunbury Region Airshed were gridded over the 3 by 3km grid. **Figure 2-3** illustrates railway tracks in the Bunbury Regional Airshed. The total length of track within the Bunbury Regional Airshed is 977 km.

Data on fuel consumption was obtained from each of the companies operating in the Bunbury Regional Airshed. The estimated total fuel consumption by trains in the Bunbury Regional Airshed is 6,257,725kL of diesel. The total fuel consumption includes fuel that is used in shunting activities with shunting occurring around the three alumina refineries (Pinjarra, Wagerup and Worsley), the various coal mines and from Picton into the Bunbury Port. Shunting around the alumina refineries and the coal mines use line haul locomotives, whilst a dedicated smaller line haul locomotive is used for shunting activities from Picton into the Bunbury Port.

2.3.3 Emission Estimation

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

Emissions were calculated by multiplying the amount of fuel consumed by the appropriate emissions factors for NPI substances. Emissions factors for line haul locomotives and the total emissions from railways are summarised in **Table 2-19**. Note that due to the line haul locomotives being used for shunting operations, no separate shunting operation factors have been included.



SKM
Sinclair Knight Merz
263 Adelaide Tce
Perth WA 6001
Tel: 08-92684400

Rail Network within the Study Area

Figure 2-3

Table 2-19 Emission Factors for Line Haul Locomotives and Total Emissions

Substance	Emission Factor (g/L)	Total Emissions (kg/yr)
Acetaldehyde	0.0755	445
Antimony & compounds	1.92E-04	1.13
Arsenic & compounds	4.17E-06	0.0246
Benzene	0.044	260
1,3-Butadiene (vinyl ethylene)	0.0401	237
Cadmium & compounds	9.31E-05	0.549
Carbon monoxide	7.5	44,200
Chromium (III) compounds	8.84E-06	0.0522
Chromium (VI) compounds	3.67E-06	0.0217
Cobalt & compounds	8.34E-06	0.0492
Copper & compounds	4.17E-05	0.246
Ethylbenzene	0.00152	8.97
Formaldehyde (methyl aldehyde)	0.223	1,320
Lead & compounds	4.17E-05	0.246
Manganese & compounds	3.20E-05	0.189
Mercury & compounds	3.47E-05	0.205
n-Hexane	0.0358	211
Nickel & compounds	2.08E-05	0.123
Oxides of nitrogen	59.1	349,000
Particulate matter (PM_{10})	1.39	8,200
PAHs	0.0188	111
Selenium & compounds	5.56E-06	0.0328
Sulphur dioxide	2.59	15,300
Toluene (methylbenzene)	0.0445	263
Total VOCs	2.54	15,000
Xylenes (individual or mixed isomers)	0.00711	41.9
Zinc & compounds	5.56E-04	3.28

Notes:
1) Source Table 2 of EET Manual for Aggregated Emissions from Railways (Environment Australia, 1999l).

2.3.4 Spatial Allocation

Emissions from railways were calculated in proportion to the fuel used and length of track between towns, junctions or endpoints. The emissions were then spatially allocated in proportion to the length of track in each grid cell and the quantity of fuel used in that section.

2.3.5 Comparison to Other studies

Table 2-20 presents a selection of substances from this study compared to estimates obtained from other studies within Australia. This indicates for emissions on a unit fuel consumption basis, an excellent agreement with the other WA studies as expected using the same emission factors, while the Newcastle and Port Pirie studies show slightly lower emissions per unit fuel consumption.

Table 2-20 Comparison of Fuel Usage and Emissions from Railways from Bunbury Regional Airshed with Other Airsheds

Substance	Airshed				
	Bunbury Region	Pilbara [1]	Perth [2]	Newcastle [3]	Port Pirie [3]
Diesel Fuel (ML/yr)	5.90	99.1	13.44	1.01	0.16
NO_x (tpa)	349	5,860	794	48.2	6.93
CO (tpa)	44.2	743	101	17.5	2.52
PM_{10} (tpa)	8.20	138	18.7	1.81	0.26
SO_2 (tpa)	15.3	257	34.8	3.35	0.48
Total VOCs (tpa)	15.0	252	34.1	13.7	1.97

Notes:
1) Source SKM (2003).
2) Source SKM (1999).
3) Source EPAV (1996).

2.4 Aeroplanes

2.4.1 Introduction

In the Bunbury Regional Airshed the majority of airports are small strips that only cater for light aircraft, unlike other studies that include larger aircraft. No airstrips in the Bunbury Regional Airshed have the potential to cater for jets, with the exception of the Bunbury Airport. Emissions from aircraft result from combustion processes in the engines, and vary with engine size and mode of engine use e.g. landing, takeoff, taxiing and approaching airstrips.

2.4.2 Emission Estimation

Emissions from aeroplanes were calculated using a methodology derived from the best practice technique in the EET Manual for Aggregated Emissions from Aircraft (Environment Australia, 2001a) with modifications to account for a difference in the idle and take-off times by aircraft in the Bunbury Regional Airshed.

Emissions from aeroplanes were estimated using aircraft movements in the Bunbury Regional Airshed on a 3 by 3km grid up to a height of 1,000m. 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.

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 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 obtained by multiplying by the number of landings/take-offs at each airport;
- This is 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 Bunbury Regional Airshed, 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.

2.4.3 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 type of aircraft 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.

Detailed data on aircraft landings was available from only the Bunbury Airport which provided a detailed breakdown of landings by aircraft type. For the other smaller airports and airfields no such detailed breakdown exists. Therefore information on the number of landings/take offs was sourced from aircraft operators who fly in and out of the region as well as local operators. These include:

- Conservation and Land Management (CALM);
- Royal Flying Doctor Service (RFDS) operating out of Perth; and
- Private aircraft operators and private helicopter operators.

Activities not included were geophysical surveys, power line inspection work and crop dusting or application of fertiliser, as these operations typically occur below 100 to 200m, but are spread right across the study area and not at an airport/airfield.

The number of resolved flights is summarised in **Appendix A**. This indicates around 21,000 landing/take offs occur in the Bunbury Regional Airshed per annum. For comparison, the number of landing/take offs is similar to that recorded for the Pilbara (21,000 landing/take offs per year (SKM, 2003)), but well below Perth and Jandakot airports (110,000 and 450,000 landing/take offs per year respectively, SKM, (1999)).

2.4.4 Emission Estimation

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 detailed in the EET Manual were derived from scaling emissions from other similar aircraft by the engine power.

Time spent in each operating mode for light aircraft (single and twin engines) was derived from estimates obtained from the three major airstrips in the Bunbury Regional Airshed (Murrayfield, Manjimup and Collie). The comparison between the default mode times and the times used in the Bunbury study are presented in **Table 2-21**. This method is preferable to using the default times given in the EET Manual as these were obtained from the Melbourne Airport, which is significantly larger and busier than any airstrip in the Bunbury Regional Airshed. The estimates provided from the three strips for climb-out and approach were very close to those of the default estimates, which would be expected as they are not considered to vary widely by location and the size of the airport. All three airstrips provided estimates for take-off that were longer than those listed in the default figures while the estimates for taxi/idle are much lower than those listed in the defaults. This reflects that there is limited congestion at the strips in the Bunbury Regional Airshed.

■ **Table 2-21 Default and Estimated Time in Modes (minutes) for Aircraft**

	Aircraft Type	Taxi/Idle	Takeoff	Climbout	Approach
Default	Turboprop	26	0.5	2.5	4.5
	Piston	16	0.3	5	6
	Helicopter	35	1.4	6.5	6.5
Bunbury NPI	Turboprop	5	1	7	6
	Single engine piston	8.6	1	6.1	4.7
	Twin engine piston	10	1	4	3
	Helicopter	35	1.4	6.5	6.5

The results for all aircraft emissions estimated in the Bunbury Regional Airshed are summarised in **Table 2-22**.

■ **Table 2-22 Summary of aircraft emissions from landing, taxiing and take-off in the Bunbury Regional Airshed**

Substance	Total Emissions (kg/yr)
Carbon monoxide	137,000
Oxides of nitrogen	1,620
Sulphur dioxide	250
Total Suspended Particulates (TSP)[1]	0
Total VOCs	8,420
Acetaldehyde	364
Acetone	247
Benzene	151
1,3-Butadiene	132
Ethylbenzene	12.6
Formaldehyde	1,190
PAHs	80.0
Phenol	18.5
Styrene	31.1
Toluene	41.2
Xylenes	37.0

Note:
1) TSP and PM_{10} 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.

2.4.5 Spatial Allocation

Estimates of emissions for each airfield were allocated to the relevant airfield with emissions spatially allocated to only the grid cell containing the airfield.

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 Bunbury Regional Airshed, which would make the best practice methodology impractically long to undertake.

2.4.6 Comparison to Other Studies

A comparison of per capita aircraft emissions from the Bunbury Regional Airshed with the Perth and Pilbara aggregated emission studies is presented in **Table 2-23**. The emissions from aircraft from the Bunbury Regional Airshed are much lower than the emissions from these studies. This is due to the Bunbury Regional Airshed having a much lower number of landing/take offs per person per year than the other airports and not having any commercial jets operating at any airports within the Airshed.

- **Table 2-23 Comparison of Emissions from Aircraft from Bunbury Regional Airshed with Other WA Airsheds**

Substance	Emissions from Airshed (kg/person/yr)		
	Bunbury Regional	Pilbara [1]	Perth [2]
Oxides of nitrogen	0.008	1.718	0.314
Carbon monoxide	0.680	7.794	0.918
Sulphur dioxide	0.001	0.401	0.036
Total VOCs	0.042	2.601	0.112

Source:
1) SKM (2003)
2) SKM (1999)

2.5 Commercial Shipping and Boating

2.5.1 Introduction

The EET Manual for Aggregated Emissions from Commercial Ships/Boats and Recreational Boats (Environment Australia, 1999a) defines ships as cargo ships, passenger ships, chemical tankers 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.

Commercial Shipping in the Bunbury Regional Airshed only occurs from the Bunbury Port while Commercial Boating occurs from Mandurah, Port Bouvard, Bunbury and Port Geographe.

2.5.2 Data Collection and Information Sources

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.

2.5.2.1 Commercial Shipping

The only port with commercial shipping in the Airshed is located at Bunbury. The Bunbury Port Authority provided the following information for July 2001 to June 2002:

- Number of ships berthing;
- Tonnage of ships berthing;
- Cargo imported and exported;
- Last and next ports of each ship; and
- Average speed of 6 knots in the shipping channel (the NPI default of 14.6 knots was used for cruising).

The data from these sources is presented in **Table 2-24** along with data collected from previous aggregated emission studies in Western Australia. This indicates that a lower number of ships utilise Bunbury Port compared to the other ports with an associated lower total tonnage of imports and exports. Additionally the majority of the ships at Bunbury are bulk carriers which is similar to Dampier and Port Hedland but unlike Perth which has a high proportion of container vessels.

■ **Table 2-24 Comparison of Ship movements at Bunbury Port with Other WA Ports**

Port	Export Tonnes (tpa)	Import Tonnes (tpa)	Number of Ships of Tonnage Range Berthing per Year					Total Ships Berthing (per year)
			<1,000	1,000 – 5,000	5,000 – 10,000	10,000 – 50,000	>50,000	
Bunbury [1]	10,360,000	1,116,000	1	2	9	175	116	303
Perth [2]	12,782,000	9,019,000	20	15	25	265	170	495
Dampier [3]	81,282,900	227,000	607	484	81	132	764	2,063
Port Hedland [3]	65,147,200	284,100	11	37	15	129	433	625

Notes:
1) Source Bunbury Port Authority.
2) Source SKM (1999).
3) Source SKM (2003).

Time spent by the vessels travelling in the shipping channels was estimated from the channel length and average vessel speed in the channel, both of which were supplied by the Bunbury Port Authority. The shipping channel is 3.5 nautical miles in length and vessels travel at an estimated 6 knots in this channel. The distance that vessels travel from Bunbury Port to the extent of the study area was estimated by the previous port and next port information obtained from the Bunbury Port Authority. Travel time from the end of the shipping channel to outside the study area was estimated from this distance and an average speed of 15 knots as determined from Port staff.

2.5.2.2 Commercial Boating

Commercial boating within the Bunbury Regional Airshed includes:

- Commercial fishing vessels that operate out of Mandurah, Port Bouvard Marina, Bunbury and Port Geographe;
- Tug and line boat operators in Bunbury Port; and
- Tour boat operators (which include diving operators, fishing and houseboats).

Emissions from commercial boats depend on their fuel consumption. Information on commercial boating activity and fuel consumption by commercial boats was collected from the following sources:

- Fuel consumption from marine refuelling facilities obtained directly from the fuel suppliers or the marina; and
- For tugboats, fuel consumption was obtained directly from the operators.

2.5.3 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) with a few variations to account for local differences.

2.5.3.1 Commercial Shipping

Emission factors for commercial ships for the different tonnage ranges is presented in **Table 2-25**.

■ **Table 2-25 Emission Factors for Commercial Ships**

Substance	Emission Factor (kg/hr)				
	< 1,000	1,000 – 5,000	5,000 – 10,000	10,000 – 50,000	> 50,000
Main Engines					
Carbon monoxide	0.481	1.63	3.03	13.5	28.5
Oxides of nitrogen	1.44	11.3	32.5	167	334
Sulphur dioxide	0.432	2.59	35.0	127	254
TSP	0.0374	0.224	0.561	16.8	33.7
Total VOCs	0.174	0.6	1.13	3.41	6.82
Auxiliary Engines					
Carbon monoxide	1.19	1.19	1.19	1.19	1.19
Oxides of nitrogen	6.66	6.66	6.66	6.66	6.66
Sulphur dioxide	1.42	2.83	4.25	5.66	7.08
TSP	0.12	0.12	0.12	0.9	0.9
Total VOCs	0.436	0.436	0.436	0.436	0.436

Notes:
1) Source Table 4 of EET Manual for Aggregated Emissions from Commercial Ships/Boats and Recreational Boats (Environment Australia, 1999a).

For ship movements in the shipping channel, an average speed of 6 knots was used (Bunbury Port Authority, Evans, H., personal communication, 2003). This is substantially less than the default speed of 14.6 knots listed in the EET Manual. The default speed was used to estimate emissions outside the port channel to the extent of the study area.

As per the EET Manual, main engines were assumed to operate whenever the ships were in transit, with auxiliary engines operating at all times.

2.5.3.2 Commercial Boating

Emission factors used for estimating emissions from commercial boats are summarised in **Table 2-26**.

■ **Table 2-26 Emission factors for Commercial Boats**

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

Notes:
1) Source Table 6 of EET Manual for Aggregated Emissions from Commercial Ships/Boats and Recreational Boats (Environment Australia, 1999a)

2.5.4 Emission Estimates

Emissions from commercial ships are presented in **Table 2-27** with a breakdown of emissions for ships by are presented in **Appendix B**.

2.5.5 Spatial Allocation

Emissions from the shipping operations were estimated and allocated according to the following categories:

- At berth;
- In the shipping channel; and

- For travel from outside the shipping channel to outside the Bunbury Regional Airshed.

Shipping channel emissions and travel outside the shipping channel were distributed according to an estimate of the direction of travel based on previous and destination port information supplied by the Bunbury Port Authority.

Commercial boat emissions were determined by the total fuel usage. The emissions were spatially allocated across the entire study region ocean area and the emissions from tug boats were allocated to the Bunbury Port.

Table 2-27 Commercial Shipping and Commercial Boating Emissions (kg/yr)

Substance	Commercial Shipping Emissions (kg/yr)	Commercial Boating[1] Emissions (kg/yr)	Total Emissions (kg/yr)
Carbon monoxide	66,700	61,500	128,000
Oxides of nitrogen	688,000	127,000	815,000
Sulphur dioxide	540,000	8,330	548,000
PM_{10}	72,100	13,900	86,000
Total VOCs	18,500	26,100	44,600
VOC Speciation			
Acetaldehyde	605	826	1,430
Benzene	353	550	903
1,3-Butadiene	292	399	691
Cyclohexane	-	0	0
Ethylbenzene	12.2	34.2	46.4
Formaldehyde	1,790	2,370	4,160
n-Hexane	287	389	676
PAH	-	5.15	5.15
Styrene	-	2.38	2.38
Toluene	357	755	1,110
Xylenes	184	327	510
Particulate Speciation			
Antimony & compounds	2.22	0.933	3.15
Arsenic & compounds	6.23	0.972	7.20
Beryllium & compounds	4.47	3.43	7.90
Cadmium & Compounds	0.158	0.144	0.302
Chromium (III) compounds	1.57	0.308	1.88
Chromium (VI) compounds	0.654	0.156	0.810
Cobalt & compounds	4.04	0.705	4.75
Copper & compounds	3.89	9.64	13.5
Lead & compounds	1.22	0.952	2.17
Manganese & compounds	-	0.0511	0.0511
Mercury & compounds	0.146	0.279	0.425
Nickel & compounds	323	76.1	399
Particulate matter (PM_{10})	72,100	13,900	86,000
PAHs	0.600	1.55	2.15
Selenium & compounds	2.73	2.06	4.79
Zinc & compounds	7.17	9.06	16.2

Notes:
1) Commercial boating includes commercial fishing and tugs.

2.5.6 Comparison with Other Studies

A comparison of the emissions from the Bunbury Regional Airshed with the emissions from the Perth, Pilbara and Port Phillip Region Airsheds is presented in **Table 2-28**. The comparison is complicated in that the emissions are dependent on the number of ships, the size distribution of the ships and the size of the study area or port boundaries. Nevertheless it does indicate fair agreement between the studies with NO_x and SO_2 being the major pollutants in each Airshed. The comparisons between the Bunbury Regional Airshed (Bunbury Port) and the other ports indicate that the Bunbury Port has at most approximately half of the next largest port/region emissions of NO_x and SO_2. When the Bunbury Regional Airshed emissions are estimated for only a 30km port boundary (which is the approximate distance from the port to the edge of the Perth study region) the emissions are even smaller, with the NO_x emissions being a third lower and SO_2 being a fifth lower than the next largest port/region.

- **Table 2-28 Comparison of Emissions from Ships and Commercial Boats from the Bunbury Regional Airshed with Other Airsheds**

Substance	Emissions from Airshed (tpa)					
	Bunbury Region	Bunbury Region (Max 30km)[1]	Perth[2]	Pilbara[3]	Dampier Port[3]	Port Phillip Region[4]
Carbon monoxide	128	96	296	2,060	225	1,730
Oxides of nitrogen	814	442	2,593	10,700	1,450	4,540
Sulphur dioxides	549	263	1,607	6,250	1,160	3,225
Particulate matter (PM_{10})	86	48	83	1,070	161	421
Total VOCs	45	37	86	1,890	116	900

Notes:
1) This distance is the approximate distance from the port to the edge of the Perth study region. This value has been included so a comparison against the Perth Airshed emissions can be made.
2) Source SKM (1999).
3) Source SKM (2003).
4) Source EPAV (1998).

2.6 Recreational Boating

2.6.1 Introduction

Emissions from recreational boating were estimated using the EET Manual for Aggregated Emissions from Commercial Ships/Boats and Recreational Boats (Environment Australia, 1999a).

$$E = N \times \sum (c_i + p_i + e_i) \qquad \textbf{Equation 2.3}$$

Where:
E = annual emissions from recreational boats in the Airshed (kg/yr)
N = the number of households in the Airshed
c_i = the average fuel consumption of recreational boats with engine type i, 10^3 L/household/year
p_i = the number of households which own boats with engine/fuel type i
e_i = the emission factor for boats with engine/fuel type i (g/L)

Equation 2.3 was modified in the Pilbara study to include an additional factor (F) to account for non-local boat usage in the study area (SKM, 2003). This was defined as total boat usage divided by local usage. This was found to vary markedly in the Pilbara ranging from 1 to 5.6 with an average of 1.55. As such, a significant amount of boat usage from boat owners outside the region will not be captured from a survey of households within the Region. For this study a non-local usage factor could not be determined from data supplied by Department of Fisheries and as such, the default equation was used in this study. It is considered that the non-local usage factor will not have a significant influence on the emissions given the uncertainties in the estimates from fuel usage (as discussed in **Section 2.6.3**).

Emission factors used for recreational boating are summarised in **Table 2-29**.

Table 2-29 Emission Factors for Recreational Boats

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

Notes:
1) Source Table 7 of EET Manual for Aggregated Emissions from Commercial Ships/Boats and Recreational Boats (Environment Australia, 1999a).
2) Values for unleaded and lead replacement petrol.

2.6.2 Data Collection and Information Sources

Fuel consumption information was sourced from two methodologies. One from the domestic survey undertaken and the other from a survey of boat ramp usage conducted by Department of Fisheries.

The domestic survey conducted for five representative towns, Mandurah, Bunbury, Waroona, Collie and Augusta (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 (DoT) also provided recreational boat registrations by postcode and size of boat for the Bunbury Regional Airshed. Additionally, Department of Fisheries had information on use of boat ramps in the Bunbury Regional Airshed between Augusta and Mandurah.

2.6.3 Emission Estimation

Data for emissions from recreational boating was obtained from a domestic survey of five towns as detailed in **Section 3.1**. The survey of 240 households found a total of 59 vessels or an overall average boat ownership of 24.4%. Of these:
- All but one of the vessels was trailerable (a houseboat which was permanently moored);
- All respondents had one craft except for one who had three boats; and
- One respondent had not used their craft for several years.

This gives an estimate of 24.0% of households in the Bunbury Regional Airshed that own a trailerable craft, giving a total of 17,420 trailerable crafts in the Bunbury Regional Airshed. This compares to the number of households with registered trailerable boats in the Bunbury Regional Airshed of 15,652 or 21.6% of households where the number of trailerable boats was estimated from total boat registrations minus yachts and houseboats.

The average fuel consumption for engine and fuel type obtained from the survey of trailerable boats is summarised in **Table 2-30** along with data from the Pilbara Airshed.

■ **Table 2-30 Fuel consumption for recreational boats**

Engine/Fuel	Percentage of Boats (%)	Average Fuel Consumption (L/year)
Inboard Diesel	0 (9.5)	Na (905)
Inboard Petrol	3.4 (7.1)	960 (905)
Outboard Petrol	96.6 (83.4)	320 (294)
Total or Average	100.0	342 (378)

Notes:
1) Data in brackets from the Pilbara NPI study (SKM, 2003) for comparison.
2) 0% of inboards used lead replacement petrol whilst 3.6% of outboards used lead replacement petrol.

This indicates good agreement in the fuel consumption per boat between the two regions, though with a lower percentage of inboards surveyed for the Bunbury Regional Airshed, particularly diesel inboards.

The data from the survey is also summarised in **Table 2-31**.

■ **Table 2-31 Trailerable Boat and Fuel Usage Estimates for the Bunbury Regional Airshed and Comparison to other Airsheds**

Airshed	Engine	Percent of engine type (%)	Fuel per fill (F) or Fuel Use per trip (T) (L)	No. times tank was filled per year per boat (F), or No. trips (T)	Total Fuel consumption per year per boat (L/boat/yr)[1]	Percentage Households with trailerable boats (%)	Fuel Consumption for all households (L/yr)
Bunbury Region – Phone Survey	Inboard Outboard All Boats	3.4 96.6 100	101 (F) 48.9 (F) 50.6 (F)	9.5 (F) 6.55 (F) 6.65 (F)	960 320 342	0.83 23.17 24.0	8.0 74.1 82.1
Perth[5]	Total	100	20 (T) assumed	5.35 (T)	107 estimated[4]	7.1	7.6
Newcastle[6]	All Boats	100	Not known	Not known	142	12.8	18.2
Launceston[6]	All Boats	100	Not known	Not known	278	5.41	39.2
Port Pirie[6]	All Boats	100	Not known	Not known	297	14.1	38.0
Pilbara[7]	Inboard Outboard All Boats		Not known	Not known	905 294 395	3.97 19.93 23.9	35.9 (55.2)[3] 58.6 (90.2)[3] 94.5 (145.4)[3]
Bunbury Region – Boat Ramp Survey[2]	All Boats	100	25 (T) assumed	3.19 (T) estimated	80 estimated	21.6	17.3

Notes:
1) The fuel consumption for the Bunbury Regional and the Pilbara Airsheds was based on a survey of the number of fillings of the fuel tank per year. The values quoted assume that every fuel tank is filled 100%, which will be an overestimate. Note the basis for the Newcastle, Launceston and Port Pirie fuel consumption values are not known.
2) The alternative Bunbury Regional Airshed fuel usage estimates are based on the Department of Fisheries boat ramp survey, conservatively rounded to 50,000 trips, as data was not available for areas north of Mandurah and trips at inland areas such as skiing on dams. A fuel usage of 25 L/trip was used based on a revision of the estimate in the Perth study. With trailerable boat registrations of 15,652, this equates to 3.19 trips per registered trailerable boats/yr.
3) The Pilbara fuel consumption figure for all households is given for boats owned in that study area, whilst the second figure in brackets includes boats from outside the study area.
4) The Perth average fuel consumption per boat is based on Department of Fisheries boat ramp surveys (185,000 trips), divided by the total trailerable registration (34,600) and an assumed fuel consumption of 20L/trip from a brief survey. Note the survey indicated that 40L/trip was used for inboards, though this was not used in the estimation. Therefore, the Perth fuel consumption is expected to be on low side.
5) Source SKM (1999).
6) Source EPAV (1996).
7) Source SKM (2003).

A comparison of the data indicates that:

- The number of households with boats in the Bunbury Regional Airshed is similar to the Pilbara Airshed, but significantly higher than for the Perth Airshed; and
- The fuel usage per boat for the Bunbury Regional Airshed is similar to that in the Pilbara Airshed, slightly higher than for Newcastle, Launceston and Port Pirie, but much higher than for the Perth Airshed. The fuel usage for the Perth Airshed however appears to be underestimated, primarily due to the low fuel usage per trip of 20L.

An alternative estimate of the fuel usage can also be made based on the boat ramp usage survey of Department of Fisheries and an assumed fuel usage. The Department of Fisheries study of boat ramps indicated that there were 45,693 launchings in 2002 in the area from Mandurah to Augusta (Department of Fisheries, 2003). This however neglects boat launchings north of Mandurah, which were included in the Perth study, boat usage on dams used for skiing and boats launched from non-ramps. Additionally, trips from moored or temporary moored vessels particularly around Mandurah, which are not filled from the bowsers but from portable fuel tanks would be missed. As such, a value of 50,000 trips is assumed, though this may be low.

Using this value and a fuel usage of 25L/trip from the Perth study (when inboards are accounted for) **Table 2-31** indicates:

- The number of trips per registered boat is significantly different for the two methods. Noting that the number of boat trips may be greater than the number of times the tank is filled indicates that the boat survey derived trips per boat would even be higher than from the boat ramp survey. Therefore, there may be a higher number of boat trips in the region than estimated at 50,000.
- The fuel consumption per boat filling (50.6L) is approximately twice that from the estimate derived from Perth by trip (25L). However, these estimates per filled tank and per trip would be similar if it assumed that each tank fill was around 50% capacity of the tank.
- Based on the two methods the total recreational fuel usage would be 5.96ML based on the phone survey data and 1.16ML based on boat ramp usage.

For this study, the best estimate of the fuel by recreational trailerable boats was derived from:

- That the average fuel tank was filled 6.65 times per year (from the phone survey), with the tank topped up by 2/3 of the tank capacity, or an average of 33.7L/fill per boat, which equates to a total fuel usage per boat of 224L/year; and
- The number of trailerable boats in the Bunbury Regional Airshed of 15,652 from DoT registrations.

This resulted in a total recreational fuel consumption from trailerable boats of 3.5ML/year. According to **Table 2-13** this is 4.55% of the retail petrol sales (76.9 ML of petrol) within the Bunbury Regional Airshed.

Annual fuel usage by the different types of recreational boats is presented in **Table 2-32** using the above fuel usage and the breakdown by inboard petrol and diesel and outboard petrol engines in **Table 2-30**. These were supplemented with fuel usage for recreational boats from marine bowsers, which are assumed to be supplied to moored vessels not accounted for in the trailerable fuel usage estimates. The total fuel usage is summarised in **Table 2-32**.

■ **Table 2-32 Estimated Recreational Fuel Usage in the Bunbury Regional Airshed**

Boat type	Inboard Diesel (L/yr)	Inboard Petrol (L/yr)	Outboard Petrol (L/yr)
Trailerable (Survey)	0	119,000	3,381,000
Moored (Bowsers)	157,000	4,454	126,546
Total	**157,000**	**123,454**	**3,507,546**

The resultant emissions from recreational boating are presented in **Table 2-33**.

■ **Table 2-33 Emissions from Recreational boating from the Bunbury Regional Airshed**

Substance	Total Emissions (kg/yr)
Carbon monoxide	1,420,000
Lead and Compounds	5.92
Oxides of nitrogen	9,730
Sulphur dioxide	1,430
TSP	1,260
Antimony & compounds	0.351
Arsenic & Compounds	0.0367
Beryllium & compounds	0.134
Cadmium & Compounds	0.00381
Chromium (III) compounds	0.260
Chromium (VI) compounds	0.108
Cobalt & compounds	0.380
Copper & compounds	0.383
Lead & compounds	0.0359
Manganese & compounds	0.354
Mercury & compounds	0.00918
Nickel & compounds	3.37
Particulate matter (PM_{10})	1,073
PAHs	0.0599
Selenium & compounds	0.0797
Zinc & compounds	0.711
Total VOCs	
Acetaldehyde	8,850
Benzene	17,100
1,3-Butadiene	4,150
Cyclohexane	0
Ethylbenzene	3,290
Formaldehyde	13,400
n-Hexane	3,700
PAHs	916
Styrene	422
Toluene	52,800
Xylenes	16,200

2.6.4 Spatial Allocation

Emissions from trailerable marine craft were spatially allocated from the survey of boat ramp usage from Department of Fisheries.

2.6.5 Comparison to Other Studies

Emissions from the Bunbury Regional Airshed for certain substances along with estimates from other studies are presented in **Table 2-34**.

Table 2-34 Comparison of Emissions from Recreational Boating from Bunbury Regional Airshed with Other Airsheds

Substance	Emissions per capita from Airshed(kg/capita/year)			
	Bunbury Region	Perth[1]	Pilbara[2]	Port Philip Region[3]
Carbon monoxide	7.06	1.05	15.1	0.84
Lead and Compounds	0.00003	0.0002	0.0018	0.000075
Oxides of nitrogen	0.048	0.165	0.66	0.055
Sulphur dioxide	0.007	0.01	0.05	0.0035
Total VOCs	2.10	0.29	4.4	0.25
Particulate matter (PM_{10})	0.0028	0.03	0.048	0.004
Benzene	0.085	0.013	0.17	0.014

Notes:
1) Source SKM (1999).
2) Source SKM (2003).
3) Source EPAV (1998).

The comparison indicates a fair degree of scatter, with the Bunbury Regional and the Pilbara Airsheds having the highest emissions of CO, total VOCs and benzene. This is due to the higher usage of outboards in these regions which have higher emissions of these substances than other engine types. Emissions of NO_x are higher for Perth than the Bunbury Regional Airshed due to the higher usage of inboards in Perth, with emissions of lead lower in the Bunbury Regional Airshed with the decrease in lead in petrol since the Perth study. Note that this is only an estimate based upon a small survey sample and there is a fair degree of uncertainty in the results.

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 estimate emissions from domestic gaseous fuel burning, domestic solid fuel burning, domestic lawnmowing and recreational boat use, data on domestic fuel consumption was required. This was obtained through a domestic survey.

To account for the variation in climate and lifestyles, the Bunbury Regional Airshed was divided into five domestic survey sub-regions, represented by the following towns:

- Augusta, representative of southern coastal towns with cool climates, that are not connected to natural gas;
- Bunbury, representative of more northern coastal towns, connected to natural gas;
- Collie, representative of inland towns with ready access to firewood and no natural gas supply;
- Mandurah, representative of towns in the northern coastal section of the Bunbury Regional Airshed that are connected to natural gas and can be considered metropolitan; and
- Waroona, representative of towns between the coast and the Darling Scarp that are not connected to natural gas, but have a different climate to coastal towns (e.g. Augusta and Mandurah) and towns on the escarpment (e.g. Collie).

The five domestic survey sub-regions are shown in **Figure 3-1**. The towns of Harvey, Brunswick Junction and Pinjarra fall within the Waroona sub-region, but emissions were calculated independently for firewood, natural gas and LPG consumption. These three towns are connected to a reticulated natural gas system, and therefore considered to have different fuel consumption levels than Waroona, which is not connected to natural gas.

The survey targeted various domestic fuel consumption levels, including:

- Firewood;
- Coal;
- Gas (both natural and LPG);
- Petrol used in garden equipment; and
- Petrol used in trailerable marine craft.

The domestic survey was conducted via telephone over a four-week period, from the 29th January to the 24th February 2003, on both weeknights and weekends. Random numbers were taken from regional phone books. If households could not be contacted on the first attempt, a minimum of two more attempts were made over the course of sampling before an alternative household was phoned. A total of 240 surveys were completed. A minimum sample group of 42 dwellings were surveyed for each sub-region to achieve a 95% confidence level with a confidence interval of 15% (i.e. there is 95% certainty that the entire population would have given an answer within ±15% of the answer given). An example of the telephone survey used can be found in **Appendix C**.

3.3 Domestic/Commercial Solvent and Aerosol Use

3.3.1 Introduction

Products containing solvents are used in a wide range of domestic and commercial applications including:

- Personal hygiene;
- Household cleaning;
- Motor vehicle aftermarket products;
- Adhesive and sealant products;
- Pesticides and herbicides;
- Coatings and related products; and
- Various miscellaneous products.

VOCs are contained in these products either as active ingredients or function as propellants, solvents or co-solvents, and are emitted to the atmosphere during use. The recommended techniques in the EET Manual for estimating emissions from domestic and commercial solvent and aerosol use rely on default per capita usage for the various products. These factors have been derived from comprehensive research undertaken in the United States and are assumed to give reasonably accurate estimates of total VOCs released by the use of such products in Australia.

3.3.2 Data Collection and Information Sources

Population data was required for estimating emissions from this source, and was obtained from the ABS 2001 census.

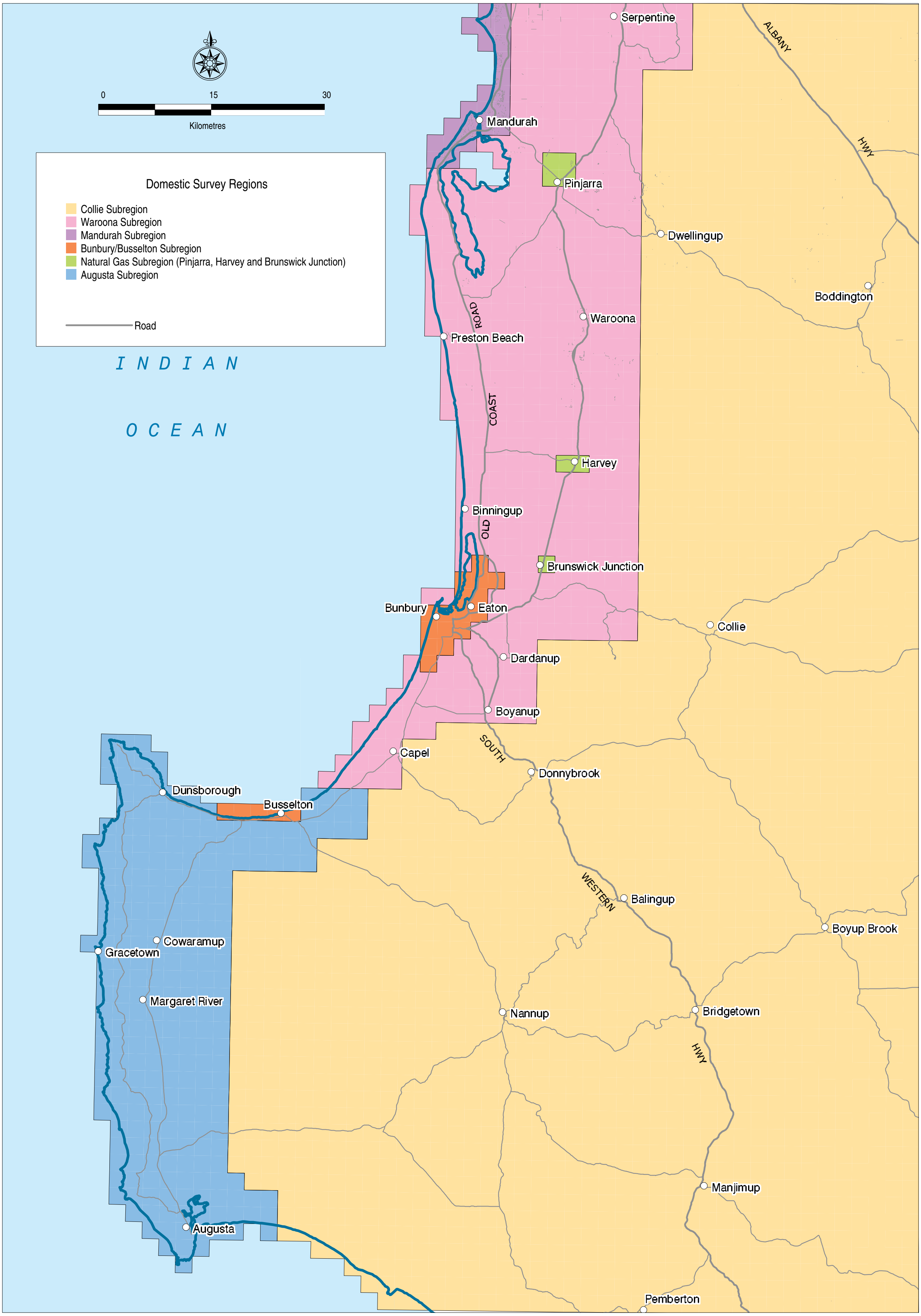
3.3.3 Emission Estimation

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 Bunbury Regional Airshed is 201,105 (ABS Census, 2001). Emissions were calculated using the following equation:

$$E_i = TEF_i \times P$$ **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/person/yr); 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.



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Survey Subregions within Bunbury Regional Airshed

Figure 3-1

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- **Table 3-1 Emission Factors and Total Emissions from Domestic/Commercial Solvent and Aerosol Use**

Substance	Emission Factor (kg/person/yr)[1]	Total Emissions (kg/yr)
Acrylic acid	1.79E-09	3.60E-04
Benzene	2.14E-06	0.430
Chloroform	4.49E-04	90.3
1,2-Dichloroethane	2.12E-06	0.426
Dichloromethane	0.0165	3,320
Ethylbenzene	9.42E-04	189
Ethylene glycol	0.0414	8,330
Ethylene oxide	6.85E-03	1,380
Fluoride compounds	6.44E-06	1.30
Formaldehyde	5.75E-04	116
n-Hexane	0.0391	7,860
Hydrochloric acid	7.94E-07	0.160
Methanol	0.319	64,200
Methyl ethyl ketone	0.0229	4,610
Methyl isobutyl ketone	3.44E-03	692
Tetrachloroethylene	0.0128	2,570
Toluene	0.194	39,000
Trichloroethylene	2.20E-04	44.2
Xylenes	0.0921	18,500
Total VOCs	5.15	1,040,000

Notes:
1) Source Table 2 of EET Manual for Aggregated Emissions from Domestic/Commercial Solvent and Aerosol Use (Environment Australia, 1999c)

3.3.4 Spatial Allocation

Emissions from domestic/commercial solvent and aerosol use were spatially allocated by population distribution on the 3 by 3km grid.

3.3.5 Comparison to Other Studies

As the emissions are derived from the NPI per capita emission factors, there should be no variation in studies using equivalent factors. This is true for the Pilbara Airshed study, which used the current 1999 EET Manual (SKM, 2003). However for the earlier Kalgoorlie and Perth Airshed estimates there are slight differences primarily in substances such as benzene and VOC that are due to different US emission factors being used (Coffey Geosciences, 1999; DEP, 2002).

3.4 Solvents Use (Sub-Threshold Facilities)

3.4.1 Introduction

Emission estimates in this category are solely concerned with solvent degreasing and surface cleaning as used in various industries such as metalworking. The majority of solvent degreasing processes occur in metalworking, which use various equipment for vapour degreasing, cold degreasing and conveyorised degreasing.

3.4.2 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 no longer supplies trichloroethylene to Western Australia and could not supply any sales data (Stelco Chemicals, Williams, V., personal communication, 2003). ABS could only quantify amounts of trichloroethylene entering Australia at various ports, but did not have information on distribution. Three companies were contacted in regards to trichloroethylene distribution in the south west of WA. None of the companies contacted knew of any sales to the Bunbury Regional Airshed and stated that all trichloroethylene they supplied to businesses remained in the Perth Metropolitan Area. It was suggested that new methods for degreasing and newer products, e.g. non-chlorinated solvents, have replaced the need for trichloroethylene.

3.4.3 Emissions Estimation

The default method outlined in the EET Manual uses emission factors based on the total population in the Bunbury Regional Airshed. Based on the information received from trichloroethylene distributors in Western Australia, it is believed that trichloroethylene is not used in the Bunbury Regional Airshed. Therefore to use the default method outlined in the EET Manual would result in gross overestimation of emissions. It is assumed that emissions for all compounds from sub-threshold industrial solvents are zero.

3.4.4 Spatial Allocation

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

3.5 Cutback Bitumen

3.5.1 Introduction

Roads are sealed with bitumen to protect the underlying road materials from excessive wear. A common method of applying the bitumen during road construction and maintenance is via spray sealing. Bitumen needs to be diluted for spray sealing, and this is achieved by blending solvents, such as kerosene, with the bitumen to produce cutback bitumen. The solvents are known as cutters or flux oils, depending on the type of solvent used. The amount of solvents added can vary from zero to 100 parts of cutter/flux oil per 100 parts of bitumen, depending on road construction methods, ambient conditions and expected traffic loads. Cutback bitumen releases VOCs from evaporation of cutters and flux oils. The largest source of VOC emissions comes from the road surfaces covered with cutback bitumen. Other types of bitumen only emit minor emissions.

3.5.2 Data Collection and Information Sources

MRWA maintenance and construction works in the Bunbury Regional Airshed are carried out by contractors, such as CSR Emoleum and Pioneer Road Services, whereas local shires such as the Shire of Collie tend to smaller roads. The quantity of cutter oil and flux oil supplied to the Bunbury Regional Airshed over a 12-month period was obtained from Malatesta, the primary supplier to the area.

3.5.3 Emission Estimation

Aggregated emission estimations were made for cutback bitumen using the EET Manual for Aggregated Emissions from Cutback Bitumen (Environment Australia, 1999b). Emission estimates were made using the best practice methodology outlined in the EET Manual. Total volumes of cutter oil and flux oil supplied to the Bunbury Regional Airshed over the past year are summarised in **Table 3-2**.

- **Table 3-2 Annual Cutter Oil and Flux Oil Consumption with Bunbury Regional Airshed**

	Cutter Oil	Flux Oil
Volume Supplied (L/yr)	75,000	18,000

Total VOC emissions from cutback bitumen were calculated using:

$$E_{VOC} = \left[T_c \times \left(d_c \times 10^{-2}\right) \times \rho_c\right] + \left[T_f \times \left(d_f \times 10^{-2}\right) \times \rho_f\right]$$ **Equation 3.2**

Where:

E_{VOC} = Total VOC emissions from use of cutback bitumen (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
T_f = Total flux oil consumption in the Airshed (L/yr)
d_f = Fraction of flux oil evaporated = 40%
ρ_f = Density of flux oil = 0.846 kg/L

Where the fraction evaporated and the density are the default values recommended by the EET Manual

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	Cutter Oil (Weight %)[1]	Cutter Oil Emissions (kg/yr)	Flux Oil (Weight %)[1]	Flux Oil Emissions (kg/yr)	Total Emissions (kg/yr)
Benzene	0.028	11.1	0.018	1.10	12.2
Biphenyl	0.07	27.7	0.040	2.44	30.2
Cumene	0.16	63	0.035	2.13	65.5
Cyclohexane	0.045	17.8	0.020	1.22	19.0
Ethylbenzene	0.21	83	0.053	3.23	86.5
n-Hexane	0.16	63.4	0.007	0.43	63.8
PAH's	0.59	234	0.240	14.6	248
Toluene	0.16	63.4	0.190	11.6	75.0
Xylenes	1.34	531	0.360	21.9	553
Total VOCs	100	39,600	100	6,090	45,700

Source:
1) Values from BP Refinery for kerosene and diesel composition (BP Refinery (Kwinana) Pty Ltd, 2003).

3.5.4 Spatial Allocation

Gridded VKT data for paved roads was used for the spatial allocation of emissions on the 3 by 3km grid. This assumes that roads with more traffic require proportionally more maintenance.

3.5.5 Comparison to Other Studies

Estimates of usage of cutter and flux oils for the Bunbury Regional Airshed and other WA regions are presented in **Table 3-4**.

- **Table 3-4 Comparison of Estimated Cutter and Flux Usage for Cutback Bitumen Operations within Bunbury Regional Airshed with Other WA Airsheds**

Airshed	Cutter Used (tpa)	Flux (tpa)
Bunbury Region	61	15.23
Perth[1]	31.2	7.2
Kalgoorlie[2]	9.6	8.4
Pilbara[3]	72	Negligible due to high temperatures

Notes:
1) Source DEP (2002).
2) Source Coffey Geosciences (1999).
3) Source SKM (2003).

The table indicates that higher volumes of cutter and flux oils are used in the Bunbury Regional and Pilbara Airsheds than in the Perth or Kalgoorlie Airsheds. This is due to the larger road networks in the Bunbury Regional and Pilbara Airsheds. Comparison of the Bunbury Regional Airshed to the Pilbara Airshed show similar volumes of cutter oil used in both Airsheds, although there is a significant difference in flux oil usage for the two areas, with negligible flux oil being used in the Pilbara Airshed. Flux oil is better suited to areas with cooler temperatures, whereas the high temperatures in the Pilbara Airshed result in cutter oil use only.

A comparison of the emissions of two substances (total VOCs and xylenes) from the Bunbury Regional Airshed with these other WA Airsheds is presented in **Table 3-5**.

- **Table 3-5 Comparison of VOC and Xylenes Emissions from Cutback Bitumen Operations from Bunbury Regional Airshed with Other WA Airsheds**

Airshed	Total VOC (kg/yr)	Total VOC (kg/person/yr)	Xylenes (kg/yr)	Xylenes (kg/person/yr)
Bunbury Region	45,700	0.227	553	0.00275
Perth[1]	23,100	0.018	4,400	0.0034
Kalgoorlie[2]	9,900	0.32	1,900	0.061
Pilbara[3]	50,200	1.0	713	0.014

Notes:
1) Source DEP (2002).
2) Source Coffey Geosciences (1999).
3) Source SKM (2003).

Table 3-5 indicates that the Bunbury Regional Airshed VOC emissions per capita are similar to the Kalgoorlie Airshed emissions but lower than the Pilbara emissions by a factor of 4 and higher than the Perth emissions by a factor of 1. Pilbara Airshed emissions were higher than the Bunbury Regional Airshed and Perth Airshed emissions were lower. This is consistent with the length of road per capita, varying from very high in the Pilbara Airshed, moderate in the Kalgoorlie Airshed and Bunbury Regional Airsheds, and low road length per capita in the Perth Airshed. Emissions of xylene (and other speciated compounds) show more variability which is due to the above factor, but also to different composition in the diesel and kerosene used.

3.6 Service Stations

3.6.1 Introduction

Petrol and diesel contain a mixture of VOCs, which release emissions to the atmosphere through evaporative fuel losses from service stations and fuel distribution activities due to the following:

- Transfer of fuel from delivery tankers to underground storage tanks at service stations via splash filling (outlet pipe above the static fuel level in the tank) and submerged filling (outlet pipe below the static fuel level);
- Refuelling of motor vehicles;
- Spillage; and
- Breathing of the underground fuel storage tanks due to changes in temperature and pressure.

3.6.2 Data Collection and Information Sources

Annual fuel sales information for automotive fuels in the Bunbury Regional Airshed was obtained from the fuel suppliers (Caltex, Shell, Gull, BP and Mobil). According to fuel suppliers, the transfer of fuel to underground tanks is undertaken via submerged filling. Filling of vehicle tanks in the Bunbury Regional Airshed is uncontrolled, in that vapour is freely released to the atmosphere (vapour recovery during underground tank filling is currently not a requirement for retail outlets outside Perth). Emissions are also released by fuel spills during vehicle filling, which can be caused by petrol spit-back, dripping nozzles and tank overflow.

It is estimated that there are 186 service stations in the Bunbury Regional Airshed. This information was taken from a list of facilities with Dangerous Goods licences and the Yellow Pages. The list included service stations, roadhouses and other facilities where fuel is sold. However it is recognised that some small private retailers may have been overlooked.

3.6.3 Emission Estimation

Emissions were calculated using the EET Manual for Aggregated Emissions from Service Stations (Environment Australia, 1999m), based on submerged filling and uncontrolled displacement losses during vehicle refuelling. Emission factors for total VOCs are summarised in **Table 3-6**.

- **Table 3-6 Total VOC Emission Factors for Emission Sources at Service Stations**

Emission Source	Total VOC Emission Factors[1] (mg/L of throughput)
PETROL	
Underground tank filling	
Submerged filling	880
Splash filling	1,380
Submerged filling & vapour balance	40
Underground tank breathing/emptying	120
Vehicle refuelling	
Displacement losses (uncontrolled)	1,320
Displacement losses (controlled)	132
Spillage	80
DIESEL (includes filling underground tanks, vehicle refuelling losses and tank breathing)	176
LPG	0.04

Notes:
1) Source Table 2 of EET Manual for Aggregated Emissions from Service Stations (Environment Australia, 1999m).

Details of the composition of petrol and the lead content of petrol and petrol vapour is summarised in **Table 3-7**. The composition apart from lead was obtained from BP (BP Refinery (Kwinana) Pty Ltd, 2003), as they are the major supplier of fuel in WA (supplying around 80 to 85% of the metropolitam and south-wests fuel). The aromatic composition of WA fuel is much lower than in eastern states fuels, which is the basis for the EET Manuals. For example, benzene comprises 0.65% by weight in ULP instead of around 3% by weight as given in the EET Manual.

For lead replacement petrol (LRP), BP advised that the LRP composition in WA is the same as PULP unlike in other states, where LRP composition is similar to leaded petrol, except for the lead content (BP Refinery, Lukatelich, R., personal communication, 2003). For the lead content in ULP and LRP fuel, a value of 0.0001% has been taken from the EET Manual for Aggregated Emissions from Service Stations (Environment Australia, 1999m) with this value given as the 1998 value of unleaded fuel. This is consistent with expectations for WA fuel, where no lead is added to fuel, and the lead in the fuel is solely due to the lead in the oil feedstock (BP Refinery, Lukatelich, R., personal communication, 2003). The composition in the vapour phase was supplied separately by BP based on their own calculations (BP Refinery, Connelly, A., personal communication, 2003).

- **Table 3-7 Composition of Motor Vehicle Fuels**

	Composite ULP		PULP or LRP		Diesel	
Species	% weight – Vapour[2]	% weight – Liquid[1]	% weight – Vapour[2]	% weight – Liquid[1]	% weight – Vapour[2]	% weight – Liquid[1]
Benzene	0.78	0.68	0.888	0.77	0.021	0.018
Biphenyl[5]	0	0	0	0	0.000018	0.04[(6)]
1,3 – Butadiene[5]	0.078	0.01	0.078	0.01	0	0
Cumene	0.017	0.3	0.023	0.33	0.002	0.035
Cyclohexane	2.563	1.4	1.01	0.86	0.024	0.02
Ethylbenzene	0.265	2.71	0.435	3.22	0.007	0.053
Lead	0.000012	0.0001	0.000012[(3)]	0.0001	ND[4]	ND[4]
n-Hexane	3.383	1.53	2.982	1.67	0.013	0.007
PAHs	0	0.14	0	0.15	0	0.24
Toluene	3.31	8.67	3.059	8.39	0.068	0.19
Xylenes	0.964	11.94	1.604	14.1	0.04	0.36

Notes:
1) Source BP Refinery (Kwinana) Pty Ltd (2003).
2) Source BP Refinery, Connelly, A., personal communication (2003).
3) Vapour lead contents from Tables 1 and 11 for PULP from the EET Manual for Fuel and Organic Liquid Storage (Environment Australia, 2002b).
4) ND: No data.
5) 1,3-Butadiene and biphenyl vapour weight percentages calculated from the percentage liquid weight and Equation 2 in the EET Manual for Aggregate Emissions from Service Stations (Environment Australia, 1999m).
6) Biphenyl composition from BP Refinery, Lukatelich, R., personal communication (2003).

The resultant total VOC emissions for the Bunbury Regional Airshed were calculated to be 1.89×10^5 kg/yr with 1.78×10^5 kg/yr contributed from petrol filling, 4.94×10^3 kg/yr from diesel filling and 6.15×10^3 kg/yr from spillage. A summary of the calculated emissions is presented in **Table 3-8**.

- **Table 3-8 Total Emissions from Service Stations within Bunbury Regional Airshed**

Species	Total Emissions (kg/yr)
Total VOCs	189,000
Benzene	1,450
Biphenyl	0.000887
1,3 – Butadiene	140
Cumene	49.8
Cyclohexane	4,450
Ethylbenzene	664
Lead	0.0276
n-Hexane	6,080
PAHs	8.66
Toluene	6,410
Xylenes	2,550

3.6.4 Spatial Allocation

Emissions from service stations were spatially allocated according to the number and of service stations in each grid cell, using the 3 by 3km grid.

3.6.5 Comparison to Other Studies

A comparison of petrol and diesel sales in the Bunbury Regional Airshed and other WA Airsheds is shown in **Table 3-9**. Diesel sales by service stations in the Bunbury Regional Airshed account for 26.7% of the total fuel sold. This is higher than the state average of 20.3%, but lower than both the Pilbara and Kalgoorlie Airsheds (32.3% and 39% respectively). The higher proportion of diesel sales in these rural areas is consistent with the higher prevalence of diesel vehicles used, including 4-wheel drive utilities, tractors, trucks and road trains, than in city areas. In terms of fuel used per person, the Bunbury Regional Airshed values are lower than the state average and other regional centres. This is at odds with the VKTs per person estimated in **Table 2-2**. A possible reason for this is a substantial amount of fuel is bought outside the study area and used on the study area roads. Another reason is that the fuel usage may be underestimated.

- **Table 3-9 Comparison of Annual retail fuel sales in the Bunbury Regional, Pilbara and Kalgoorlie Airsheds and WA**

Airshed	Total fuel sales (ML/yr)		Percentage of Sales in Region (%)		Average per capita consumption (L/person/yr)	
	Petrol	Diesel	Petrol	Diesel	Petrol	Diesel
Bunbury Region[1]	76.9	28.0	73	27	382	139
Pilbara[2]	27.0	12.9	68	32	531	253
Kalgoorlie[3]	47.2	30	61	39	1,520	965
Perth[4]	960	201	83	17	733	153

Notes:
1) Bunbury Regional Airshed values derived from data received from fuel suppliers.
2) Source SKM (2003).
3) Source Coffey Geosciences (1999). Figures were based on service station data supplied by one fuel distributor and have been used to estimate average throughput for retail sales. Therefore they are considered uncertain and likely an overestimate.
4) Source DEP (2002).

Emissions from service stations in the Bunbury Regional Airshed and other regions are summarised in **Table 3-10**. The VOC emissions per capita for Bunbury Regional Airshed are lower than the other airsheds. This is consistent with the lower fuel consumption figures per capita **Table 3-9**. The Perth emissions are only slightly higher per capita than the Bunbury Regional Airshed's even though they have a higher petrol usage per capita as in Perth filling of underground tanks uses submerged filling with vapour recovery.

- **Table 3-10 Comparison of VOC Emissions from Service Stations from Bunbury Regional Airshed with Other WA Airsheds**

	Total VOC emissions (kg/yr)	VOC emissions per capita (kg/person/yr)
Bunbury Regional Airshed	189,000	0.94
Pilbara[1]	67,300	1.34
Perth[2]	1,530,000	1.14
Kalgoorlie[3]	11,900	3.8

Notes:
1) Source SKM (2003).
2) Source DEP (2002).
3) Source Coffey Geosciences (1999).

3.7 Architectural Surface Coatings

3.7.1 Introduction

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.

3.7.2 Data Collection and Information Sources

Accurate sales and distribution data of architectural surface coatings are not available for the Bunbury Regional Airshed. As such, sales figures were obtained from national sales figures scaled by the proportion of dwellings in the study region to the national number of dwellings. National sales figures were obtained from the 2002 3rd quarter sales with dwelling data for the Bunbury Regional Airshed obtained from the ABS 2001 census.

3.7.3 Emission Estimation

Architectural surface coating emissions were calculated using the best practice method outlined in the EET Manual for Aggregated Emissions from Architectural Surface Coatings (Environment Australia, 2003a). The total number of dwellings in the Bunbury Regional Airshed is 90,409 (ABS census 2001), which is higher than the number of households (72,588) in the Bunbury Regional Airshed. Dwellings are defined as a structure intended to have people live in it, but may or may not be occupied whereas households focus on a person or a group of people living in a dwelling and therefore does not include unoccupied dwellings. The third quarter sales figures of surface coatings were 58.077 ML which was used to estimate annual sales of 232.31 ML. Using the EET manual default VOC contents for the various coatings an estimate of 77.669ML of VOC or 11.07 kg VOC/dwelling was obtained. This is slightly higher than the value of 9.506 kg/dwelling provided in the default method of the EET manual, which is based on the south east Queensland trial (Environment Australia, 2003a).

Table 3-11 summarises the total emissions for compounds emitted by architectural surface coatings.

■ **Table 3-11 Total Emissions from Architectural Surface Coatings**

Substance	Total Emissions (kg/yr)
Acetone	26,960
Benzene	474
Cyclohexane	174,400
Dichloromethane	8,700
Ethanol	5,050
2-Ethoxyethanol acetate	10,950
Ethylene glycol	5,850
n-Hexane	174,400
Methanol	32,900
Methyl ethyl ketone	47,200
Methyl isobutyl ketone	5,050
Toluene	43,800
Xylenes	21,900
Total VOCs	**1,000,729**

Notes:
1) Source Table 4 of EET Manual for Aggregated Emissions from Architectural Surface Coatings (Environment Australia, 2003a).

3.7.4 Spatial Allocation

Emissions from architectural surface coatings were spatially allocated according to the distribution of dwellings in the Bunbury Regional Airshed.

3.7.5 Comparison to Other Studies

A comparison of the emissions of VOC and benzene with that from other Airsheds is given in **Table 3-12**. The Pilbara study also used the default method as outlined in the EET Manual (SKM, 2003). On a per capita basis, the values are similar especially for benzene, with differences due to the different factors used in the different studies and different consumption figures per year.

■ **Table 3-12 Comparison of VOC and Benzene Emissions from Architectural Surface Coatings from Bunbury Regional Airshed with Other WA Airsheds**

Airshed	VOCs Emissions (kg/yr)	Benzene Emissions (kg/yr)	VOCs (kg/capita/yr)	Benzene (kg/capita/yr)
Bunbury Region	1,000,729	474	4.98	0.0024
Pilbara[1]	181,000	86	3.61	0.0017
Perth[2]	4,450,000	1,910	3.40	0.0015
Kalgoorlie[3]	193,000	46.4	6.21	0.0015

Notes:
1) Source SKM (2003).
2) Source DEP (2002).
3) Source Coffey Geosciences (1999).

3.8 Domestic Gaseous Fuel Burning

3.8.1 Introduction

Domestic gaseous fuel comes in the form of natural gas and liquefied petroleum gas (LPG). Households use gaseous fuels for activities such as cooking, heating and running hot water systems. Emissions are dependent on the type and amount of gaseous fuel burnt.

3.8.2 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), which involves calculating emissions from the volume of gaseous fuels burnt in the Airshed.

The average domestic gaseous fuel use data for households, obtained by the domestic survey of five towns in the Bunbury Regional Airshed and by natural gas usage provided by AlintaGas, has been summarised in **Table 3-13**. **Table 3-13** represents the average amount of fuel used by households who use that fuel.

- **Table 3-13 Summary of Domestic Gaseous Fuel Burning for households that use those fuels in the Bunbury Regional Airshed**

Town	LPG Usage (kg/household/year)	Natural Gas Usage (kg/household/year)
Augusta	206	-
Bunbury	58	392
Collie	170	-
Mandurah	65	392
Waroona	126	-

Notes:
1) Natural gas is from the mains and is estimated at 20 GJ/household per year for connected households (AlintaGas, Stubbs, M., personal communication, 2003). This compares to a figure of 14.3 GJ/household used in the 1998/1999 Perth inventory (DEP, 2002).
2) All averages are based on households that use that fuel.

Table 3-14 shows the percentage of households surveyed using particular fuel types. The highest percentage of LPG use was in Collie, whilst the highest natural gas use was in Bunbury. Mandurah had the lowest percentage of LPG usage.

- **Table 3-14 Percentage (%) of Households Surveyed Using Fuels**

Town	LPG	Natural Gas
Augusta	76	0
Bunbury	60	84
Collie	90	0
Mandurah	42	65
Waroona	83	0

A summary of domestic fuel usage per capita for all households in the Bunbury Regional Airshed by survey sub-region is given in **Table 3-15**.

Table 3-15 Summary of Domestic Fuel Usage for all Households in the Bunbury Regional Airshed by Survey Sub-region

	LPG Usage (kg/household/yr)	Natural Gas Usage (kg/household/yr)	Data Source
Region			
Augusta	156	0	Domestic survey
Bunbury	35	328	Domestic survey
Collie	153	0	Domestic survey
Mandurah	27	0	Domestic survey
Waroona	105	254	Domestic survey
Exceptions to the above regions			
Brunswick Junction	66	254	Average of Mandurah and Waroona, AlintaGas
Harvey	66	271	Average of Mandurah and Waroona, AlintaGas
Pinjarra	66	389	Average of Mandurah and Waroona, AlintaGas
Average for Airshed[1]	**84**	**176**	

Notes:
1) Averages based on the usage by all households within the study area, weighted to include households that don't use fuel.

Of the five towns surveyed, only Bunbury and Mandurah were connected to the natural gas network. Both these towns had lower LPG use than the remaining three towns surveyed. The highest average consumption of LPG for all households occurred in Augusta (156kg/household/yr), whilst Mandurah had the lowest (27kg/household/yr).

The above LPG usage includes that used by caravan owners in the Bunbury Regional Airshed. A summary of the caravan ownership and associated LPG usage for the Bunbury Regional Airshed is given in **Table 3-16**. Caravan ownership varied from 7.1% of households surveyed in Waroona, to 16.9% in Mandurah. LPG usage by caravans accounted for a small percentage of total LPG use in each survey town. A higher percentage of total LPG use came from caravans in Bunbury (7.5%) and Mandurah (12.5%), the two towns connected to natural gas. The three towns without natural gas relied on LPG for other gas appliances and therefore only 1.4% (Augusta) to 3.5% (Waroona) of total LPG consumption was used for caravans.

Table 3-16 Caravan Ownership and Associated LPG Usage in the Bunbury Regional Airshed

Caravan Owners	Percentage of Caravan ownership (%)	Annual LPG consumption by Caravans (kg/household/yr)	Percentage of total LPG use by caravans (%)
Augusta	16.7	2.1	1.4
Bunbury	9.5	3.4	7.5
Collie	16.7	3.6	2.4
Mandurah	16.9	3.4	12.5
Waroona	7.1	3.6	3.5
Average	**13.4**	**3.2**	**5.5**

3.8.3 Emission Estimation

Emissions from domestic gaseous fuel burning in the Bunbury Regional Airshed were calculated using the EET Manual for Aggregated Emissions from Domestic Gaseous Fuel Burning (Environment Australia, 1999d), and are summarised in **Table 3-17**.

- **Table 3-17 Emission Factors and Total Emissions from Domestic Gaseous Fuel Burning**

Substance	Emission Factor for Natural Gas[1] (kg 10^{-6}/m^3)	Emission Factor for LPG[1] (kg 10^{-3}/L)	Total Emissions (kg/yr)
Arsenic & compounds	0.0032	0	0.0526
Benzene	0.0336	0.00266	28.9
Beryllium & compounds	0.000096	0	0.00158
Cadmium & compounds	0.0176	0	0.289
Chromium (VI) compounds	0.0224	0.000264	3.18
Carbon monoxide	640	0.228	12,900
Cobalt & compounds	0.00134	0.00096	10.3
Copper & compounds	0.0136	0.000024	0.479
Cyclohexane	1.74	0.000713	36.2
Formaldehyde	1.2	0.00628	86.6
n-Hexane	28.8	0.000738	481
Lead & compounds	0.008	0.000024	0.387
Manganese & compounds	0.00608	0.000024	0.356
Mercury & compounds	0.00416	0	0.0662
Nickel & compounds	0.0336	0.000264	3.36
Oxides of nitrogen	1,500	1.68	42,500
Particulate matter (PM_{10})	122	0.048	2,520
PAHs	0.011	0	0.181
Selenium & compounds	0.000192	0.000264	2.82
Sulphur dioxide	8.36	9.45E-09	137
Toluene	0.054	0.00134	15.2
Total VOCs	88	0.036	1,830
Zinc & compounds	0.464	0.000264	10.4

Notes:
1) Source Table 3 of EET Manual for Aggregated Emissions from Domestic Gaseous Fuel Burning (Environment Australia, 1999d).

3.8.4 Spatial Allocation

Emissions were spatially allocated in the Bunbury Regional Airshed according to the five domestic survey sub-regions, as represented by Augusta, Bunbury, Collie, Mandurah and Waroona (**Figure 3-1**). For example the towns of Manjimup and Bridgetown were assigned the same fuel usage as Collie, which is representative of an inland site.

The exceptions to this approach were the towns of Busselton, Pinjarra, Harvey and Brunswick Junction, all of which are connected to reticulated natural gas. For these towns natural gas usage was determined using data from AlintaGas and the number of households in each town, as determined from the ABS 2001 census. The LPG was estimated as a mix of the survey regions dependent on the percentage of natural gas availability and climate.

For the town of Busselton, given its close proximity to Bunbury and its coastal position, the LPG usage of Bunbury was used. For the towns of Brunswick Junction, Harvey and Pinjarra, the LPG was taken as an average of usage in Mandurah and Waroona.

Margaret River has 50 households connected to a reticulated LPG system (Kleenheat, Carrigg, M., personal communication, 2003). Independent emissions were not calculated for these households because they account for a small percentage of households in Margaret River and are therefore not representative of the whole town. As such, Margaret River was assigned gaseous fuel usage after Augusta.

3.8.5 Comparison to Other Studies

Annual average domestic fuel consumption for various WA Airsheds is summarised in **Table 3-18**.

- **Table 3-18 Comparison of Domestic Fuel Usage within Bunbury Regional Airshed with Other WA Airsheds**

Fuel Type	Estimated Fuel Usage (kg/household/yr)[1]			
	Bunbury Region	Kalgoorlie[2]	Perth[3]	Pilbara Towns[4]
Natural Gas	172	47.4[(2]	280	0
LPG	76.4	185[(2)]	Not given	153

Notes:
1) Average across all households, not just those using the fuel.
2) Based on Table 7.1 Coffey Geosciences (1999). May also contain commercial usage.
3) Source DEP (2002). No LPG usage was estimated for Perth, as this was considered minor compared to natural gas consumption.
4) Source SKM (2003).

Natural gas consumption for the Bunbury Regional Airshed was higher than the Kalgoorlie Airshed but lower than the Perth Airshed. This was expected because the natural gas reticulation system is greater in Bunbury Regional Airshed than in Kalgoorlie, but smaller than the Perth metropolitan system.

The average LPG consumption of 84 kg/household/year was lower than LPG usage in the Kalgoorlie and the Pilbara Airsheds. 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 (Coffey Geosciences, 1999), which has not been included in the Bunbury Regional Airshed calculations. The Perth Airshed study did not calculate emissions from LPG since Perth has domestic natural gas reticulation, and it was assumed that LPG use was minimal (DEP, 2002).

Estimated emissions per capita for the Bunbury Regional Airshed are presented in **Table 3-19**. The Bunbury Regional Airshed shows similar emissions to the Perth study, and greater emissions than both the Kalgoorlie and Pilbara studies. The differences are primarily the result of different proportions of LPG and natural gas used in each region, with different emission factors for each gas quoted in the EET Manual resulting in variations in the total emissions.

- **Table 3-19 Comparison of Emissions per Capita from Domestic Gaseous Fuel Combustion from Bunbury Regional Airshed with Other WA Airsheds**

Substance	Emissions from Airshed (kg/person/yr)			
	Bunbury Region	Perth[1]	Kalgoorlie[2]	Pilbara[3]
Carbon monoxide	0.064	0.088	0.0081	0.013
Lead	1.9E-6	0.0	-	0.0
Oxides of nitrogen	0.21	0.21	0.0216	0.092
Particulate matter (PM_{10})	0.013	0.025	-	0.0026
Sulphur dioxide	0.0007	0.002	0.0002	0.0026
Total VOCs	0.009	0.016	-	0.002

Notes:
1) Source DEP (2002).
2) Source Coffey Geosciences (1999).
3) Source SKM (2003).

3.9 Domestic Solid Fuel Burning

3.9.1 Introduction

The main solid fuel used for domestic purposes in Western Australia is wood, although coal and briquettes are also used in small amounts. Emissions from wood burning are highly variable, and depend on the type of wood being burnt, the appliance used and operating practices.

3.9.2 Data Collection and Information Sources

The domestic survey collected data on domestic wood use in the Bunbury Regional Airshed. Domestic solid fuel burning by the five survey towns has been summarised in **Table 3-20**. None of the households surveyed used coal, indicating that there is no or negligible coal used in the Bunbury Regional Airshed. Communication with the collieries near Collie indicate that there are a small number of people who do use coal, with around 6 people within Collie and 2 to 3 dairy farmers from the coastal plain. These have not been captured by the survey and because of the low numbers have been omitted from the emission estimates.

- **Table 3-20 Summary of Domestic Wood Burning in the Bunbury Regional Airshed**

Town	Wood Usage in Households that Use Wood[1] (kg/household/yr)	Percentage (%) of Households Surveyed Using Wood	Average Wood Usage for all Households[2] (kg/household/yr)
Augusta	2,610	83	2,175
Bunbury	1,583	28	442
Collie	3,541	86	3,035
Mandurah	1,921	26	507
Waroona	2,000	88	1,762

Notes:
1) Based on households that use that wood.
2) Average usage for entire Bunbury Regional Airshed – i.e. include households that don't use wood.

The usage of wood shows large variation within the regions as expected, ranging from an average for all households from 3,035kg/yr at Collie to 442kg/yr at Bunbury. This variation reflects the availability of wood and gas at these centres. Mandurah and Bunbury are connected to natural gas, and therefore have much lower wood use, whereas other towns surveyed rely on wood and LPG for heating and cooking and have colder temperatures.

The appliances used for wood burning are presented in **Table 3-21**. The most popular wood appliances in all towns surveyed were slow combustion stoves/heaters, which also used the most wood of all the appliances. The least popular appliance was wood fuelled outdoor barbecues, which were only used by 7% of households surveyed in Augusta and 4.5% in Collie. Usage of open fireplaces and wood fuelled water heaters was also small, with water heaters being restricted to those towns not connected to natural gas.

■ **Table 3-21 Wood Usage by Appliances for all households**

Region	Wood Usage by Appliance (kg/household/yr)					
	Open Fireplace	Outdoor BBQ	Pot Belly Stove	Slow Comb Stove/Heater	Water Heater	All Appliances
Augusta	148	100	839	937	151	2,175
Bunbury	35	0	81	326	0	442
Collie	52	6	1,059	1,758	159	3,035
Mandurah	0	0	162	345	0	507
Waroona	71	0	333	1,145	212	1,762
Average Bunbury Regional Airshed	**61**	**21**	**495**	**902**	**105**	**1,584**

Note: Usage is the average over all households in the various regions.

3.9.3 Emission Estimation

Emission factors from the EET Manual for Aggregated Emissions from Domestic Solid Fuel Burning (Environment Australia, 1999f) were used to calculate the emissions from domestic solid fuel burning for the Bunbury Regional Airshed, as outlined in **Table 3-22**. Emissions for each sub-region were estimated from the emissions factors multiplied by estimated wood usage within the sub-region for appliance type (**Table 3-21**) and the number of households within that region (from 2001 ABS Census data). The total emissions for the Bunbury Regional Airshed were determined by summing the emissions from each of the sub-regions.

■ **Table 3-22 Emission Factors and Emissions from Domestic Solid Fuel Burning**

Substance	Wood 1[2] (Open) (g/kg)	Wood 2[3] (Conventional) (g/kg)	Wood 3[4] (Controlled) (g/kg)	Total Emissions (kg/yr)
Acetaldehyde	8.87	2.05	0.465	234,000
Acetone	6.56	1.52	0.344	173,000
Antimony & compounds	0.000113	7.22E-05	3.31E-05	9.48
Arsenic & compounds	0.0000752	4.81E-05	2.21E-05	6.32
Benzene	0	0.969	0.732	161,000
1,3-Butadiene	0.36	0	0	2,410
Cadmium & compounds	0.000094	1.10E-05	1.00E-05	2.72
Chromium (III) compounds	0	3.53E-07	3.53E-07	0.0721
Chromium (VI) compounds	0	1.47E-07	1.47E-07	0.0300
Carbon disulphide	0	0	0	0
Carbon monoxide	126.3	115.4	70.4	17,500,000
Cobalt & compounds	0.0000188	1.20E-05	5.52E-06	1.58
Formaldehyde	9.55	2.21	0.5	252,000
Lead & compounds	0.000301	1.93E-04	8.83E-05	25.3
Manganese & compounds	0.000545	8.50E-05	7.00E-05	18.7
Methyl ethyl ketone	0	0.145	0.031	12,100
Nickel & compounds	0	7.00E-07	1.00E-05	1.58
Oxides of nitrogen	1.3	1.4	1	233,000
PAHs	0.0008	0.365	0.25	56,800
Particulate matter (PM_{10})	17.3	12	5.5	1,570,000
Selenium & compounds	0.0000188	1.20E-05	5.52E-06	1.58
Sulphur dioxide	0.2	0.2	0.2	42,200
Styrene	0.175	0	0	1,170
Toluene	1.17	0.365	0.26	66,200
Total VOCs	114.5	26.5	6.75	3,140,000
Xylenes	0.71	0.101	0.093	24,200
Zinc & compounds	0.0139	8.92E-03	4.09E-03	1,170

Notes:
1) Source Table 2 of EET Manual for Aggregated Emissions from Domestic Solid Fuel Burning (Environment Australia, 1999f).
2) Wood 1 (Open) was applied to open fireplaces and outdoor barbecues. Outdoor barbeques were included in this category as barbeque emissions were not required to be reported as a separate category for this study and the emissions factors for barbeques and open fireplaces are the same (EET Manual for Aggregated Emission from Barbeques, September 1999).
3) Wood 2 (Conventional) was applied to pot belly stoves and water heaters.
4) Wood 3 (Controlled) was applied to slow combustion stoves/heaters.

3.9.4 Spatial Allocation

Emissions were spatially allocated in the Bunbury Regional Airshed according to the five domestic survey sub-regions, as represented by Augusta, Bunbury, Collie, Mandurah and Waroona (**Figure 3-1**).

The exceptions to this approach were the towns of Busselton, Pinjarra, Harvey and Brunswick Junction, all of which are connected to reticulated natural gas. For these towns, wood usage was estimated as a mix of the survey regions dependent on the percentage of natural gas availability, climate and proximity to source of wood.

For the town of Busselton, given its close proximity to Bunbury and its coastal position, the fuel usage of Bunbury was used. For the towns of Brunswick Junction, Harvey and Pinjarra, the wood usage were taken as an average of usage in Mandurah and Waroona.

3.9.5 Comparison to Other Studies

Domestic wood usage for studies in WA are presented in **Table 3-23**, which compares usage in the Bunbury, Perth, Kalgoorlie and Pilbara Regional Airsheds.

- **Table 3-23 Comparison of Domestic Wood Usage within Bunbury Regional Airshed with Other WA Airsheds**

	Units	Bunbury Region[1]	Perth[2]	Kalgoorlie[3]	Pilbara Inland Aboriginal Communities[4]	Pilbara Town[4]
Percentage Households using Wood	(%)	26 – 88 (51.9)	21.0 (primary)[5] 4.3 (secondary)[6]	60 (primary)[5]	100	1.76
Usage Per Household using Wood	(tonne/ household/yr)	1.6 – 3.5 (2.43)	2.0 (primary)[5] 0.2 (secondary)[6]	2.6	8	1.25
Overall Household Usage	(tonne/ household/yr)	0.44 – 3.0 (1.26)	0.428	1.56	8	0.022
Number of Households		72,588	488,869	10,255	165	48,100
Total Usage	**tpa**	**91,700**	**209,354**	**16,000**	**1,320**	**402**

Notes:
1) Bunbury Regional Airshed figures are given for the range of the 5 survey areas and for the average of the region in brackets.
2) Source DEP (2002). Usage this study is higher than the estimates of 175,000 and 172,000 tpa for "Perth" for 1997 and 1998/1999 by FIFWA, 1997 and Womble and Clark, 1999.
3) Source Coffey Geosciences (1999).
4) Source SKM (2003).
5) Wood used as primary source of heating.
6) Wood used as secondary source of heating.

This indicates a large variation in domestic wood consumption between regions in WA, ranging from 0.022 tonnes per household for Pilbara towns to 8 tonnes per household for Pilbara inland Aboriginal communities, who use open fires for cooking and heating. The Bunbury Regional Airshed is very similar to the Kalgoorlie Airshed in terms of annual tonnes of wood consumed per household, and approximately three times higher then the overall Perth Airshed usage per household.

Emissions per capita are presented in **Table 3-24**.

- **Table 3-24 Comparison of Emissions per Capita from Domestic Solid Fuel Burning from Bunbury Regional Airshed with Other WA Airsheds**

Substance	Emissions from Airshed (kg/person/yr)			
	Bunbury Region	Perth[1]	Kalgoorlie[2]	Pilbara[3]
Carbon monoxide	87.0	16.5	59	6.1
Lead	0.0001	0.0	0.0	0.00002
Oxides of nitrogen	1.16	0.19	0.72	0.063
Particulate matter (PM_{10})	7.81	1.8	4.4	0.81
Sulphur dioxide	0.21	0.032	0.064	0.016
Total VOCs	15.6	6.7	13.7	5.4

Notes:
1) Source DEP (2002).
2) Source Coffey Geosciences (1999).
3) Source SKM (2003).

The Bunbury Regional Airshed has the highest emissions for all substances, which is to be expected due to the high total usage of wood per capita and the relatively high percentage of open/uncontrolled burning (open fireplaces and outdoor wood barbecues) and conventional appliances (pot belly stoves and water heaters). Although only a relatively small percentage of these appliances were used in each survey region, the emissions are significantly higher than for other appliances, as demonstrated in **Table 3-24**. The effect of these appliances can be clearly seen when comparing the Perth Airshed with the Bunbury Regional Airshed. The emissions for the Perth Airshed are lower than the Bunbury Regional Airshed by a factor of 2 to 7, because the annual usage is less by a factor of 3 and because of a high usage of slow combustion and potbelly appliances in the Bunbury Regional Airshed. Similarly, despite having similar annual household usage of wood (Bunbury Regional Airshed 1.26 tonnes per year and Kalgoorlie Airshed 1.56 tonnes per year), Kalgoorlie Airshed emissions are also lower then the Bunbury Regional Airshed. The Kalgoorlie study used emission factors based on USEPA (1996) which are lower to the emission factors in the EET Manual (Coffey Geosciences, 1999).

3.10 Lawn Mowing

3.10.1 Introduction

Emissions of NPI substances are released from the use of petrol powered lawnmowers and other gardening equipment. The emissions vary depending on the type of fuel used, engine size and engine type (i.e. 2-stroke or 4-stroke). Generally, 4-stroke mowers have lower emissions of total VOCs, CO and PM_{10} but higher NO_x emissions. The fuel type will also affect emissions, particularly for the compounds lead and SO_2.

3.10.2 Data Collection and Information Sources

The domestic survey was used to gather information about domestic lawnmower use within the Bunbury Regional Airshed. The survey gathered information concerning the:

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

The range of fuel powered tools owned by households is summarised in **Table 3-25**. Of the households that own fuel powered gardening equipment, most people owned lawnmowers. The least owned tool was the rotary hoe, which was only recorded by 7.1% of households in Collie. Ownership of petrol or diesel powered gardening equipment varied between the five towns, ranging from 49.3% (Mandurah) to 85.7% (Augusta). Most respondents reported that they have one form or other of a garden power tool.

- **Table 3-25 Type and percentage of fuel powered gardening equipment owned by surveyed households.**

Town	% of households owning Blowers	% of households owning Chainsaws	% of households owning Edgers	% of households owning Lawnmowers	% of households owning Rotary Hoes	% of households owning Whipper Snippers	% Households owning power tools
Augusta	0	40.5	2.4	76.2	0	28.6	85.7
Bunbury	4.7	11.6	2.3	53.5	0	23.3	55.8
Collie	2.4	54.8	11.9	76.2	7.1	54.8	78.6
Mandurah	1.4	7	5.6	49.3	0	14.1	49.3
Waroona	0	38.1	4.8	78.6	0	42.9	78.6
Survey Average	**1.7**	**30.4**	**5.4**	**66.7**	**1.4**	**32.7**	**69.6**

The greatest variation between survey regions occurred in the ownership of chainsaws in Collie and Mandurah. Collie had the highest percentage of ownership of chainsaws of the five survey regions (57.1%), whilst Mandurah had the lowest (7%). Waroona had the highest percentage of lawnmower ownership at 81%, compared to the lowest percentage in Mandurah at 50.7%. Mandurah had low ownership for all gardening equipment. This may be due to different lifestyles or demographics in Mandurah compared to other regions, e.g. smaller properties with less gardening requirements.

The average annual hours of use for each type of tool, for a household using that tool, is summarised in **Table 3-26**. This shows that Collie had the most chainsaw use per household, averaging 20.3 hours per household per year. Bunbury had the least length of time for chainsaw use, at 1.8 hours per household per year, followed closely by Mandurah (1.9 hours per household per year)

- **Table 3-26 Average hours of use for fuel powered gardening equipment in the domestic survey regions**

Equipment	Average Hours of use (hrs/household/yr)					
	Augusta	Bunbury	Collie	Mandurah	Waroona	Average for Bunbury Regional Airshed
Blower	0	1.2	8.7	0.2	0	2.0
Chain saw	13.8	1.8	20.3	1.9	19.6	11.5
Edger	0.6	3.2	2.1	0.5	2.3	1.7
Lawn mower	15.8	14.2	15.7	1.3	23.1	14.0
Rotary Hoe	0	0	33.7	0	0	6.8
Whipper snipper	14.1	3.1	8.5	0.7	9.9	7.2

Notes:
1) Only for households using that tool.

The engine types and fuel types of the equipment owned by households surveyed are summarised in **Table 3-27**. This demonstrates, for example, that all the rotary hoes owned have 4-stroke engines and 66.7% of the rotary hoes use unleaded fuel. Equipment using unleaded fuel is much more popular than equipment using lead replacement fuel.

- **Table 3-27 Engine types and fuel types of fuel powered gardening equipment owned by households surveyed**

Average Usage	Engine Type		Fuel Type	
	% 4-stroke	% 2-stroke	% Unleaded	% Lead Replacement
Blower	0.0	100	83.3	16.7
Chain saw	6.9	93.1	94.7	5.3
Edger	38.0	62.0	75.0	25.0
Lawn mower	58.2	40.3	92.8	7.2
Rotary Hoe	100	0.0	66.7	33.3
Whipper snipper	11.9	88.1	93.5	6.5

Notes:
1) There was no diesel fuel usage reported by the households surveyed.

The percentage of households surveyed that use lawnmowers, or households surveyed that have their lawns mowed for them, is summarised in **Table 3-28**.

- **Table 3-28 Summary of domestic lawn mowing activity by surveyed households**

Town	Households that mow their own lawn (%)	Households that have their lawn mowed (%)	Total lawnmowing activity (%)
Augusta	76.2	14.3	88.1
Bunbury	53.5	37.2	90.7
Collie	76.2	19.0	95.2
Mandurah	49.3	42.3	90.1
Waroona	78.6	19.0	95.2

The majority of households surveyed in Augusta, Collie and Waroona mowed their own lawns, whilst approximately half of the households in Mandurah and Bunbury had their lawns mowed for them by a contractor. These differences may be due to demographic and social differences between the five towns. The total lawnmowing activity ranged from 88.1% in Augusta to 95.2% in Collie. These figures are similar to those obtained from the Perth and Kalgoorlie studies where 92.5% and 90% of respondents respectively had their lawns mowed (total mowing) (DEP, 2002; Coffey Geosciences, 1999).

The average annual hours of lawn mower usage for various studies have been summarised below in **Table 3-29**. The Bunbury Regional Airshed estimates are comparable to estimates of the Kalgoorlie study, but are lower than the Perth or Sydney studies.

- **Table 3-29 Average annual hours of lawnmowing for various studies**

Study	Average annual hours of lawn mower use (hrs/household/year)
Bunbury Regional Airshed	14
Kalgoorlie	13
Perth	18
Sydney	27

3.10.3 Emissions Estimation

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

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

$$T_{ifj} = (P_{if} \div 100) \times H_{if} \times N_a$$ **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 (hrs/yr)
N_a is the number of households in the Airshed

To account for contract mowing of private residences, the emissions for lawn mowing were then increased by a ratio of total mowing conducted to that undertaken by the householder. This factor was only applied to lawnmowers, not to any other appliances. This may underestimate emissions from whipper snippers and edgers, but is considered to be minor.

Emission factors for domestic lawn mowers based on engine and fuel type from the EET Manual are summarised in **Table 3-30**.

■ **Table 3-30 Emission factors for Lawn Mowers**

Substance	Emission Factor (g/hr)[1]	
	2-stroke Engine	**4-stroke Engine**
Benzene	17	2.3
1,3-Butadiene	2.16	0.292
Carbon monoxide	731	489
Chromium (III) compounds	0.00332	0.000219
Chromium (VI) compounds	0.00138	0.000091
Cobalt & compounds	0.0047	0.00031
Copper & compounds	0.0047	0.00031
Cyclohexane	0.517	0.07
Ethylbenzene	3.96	0.534
Formaldehyde	2.8	0.68
n-Hexane	0.548	0.74
Lead & compounds[2, 3]	0.00007	0.000035
Manganese & compounds	0.0047	0.00031
Nickel & compounds	0.0047	0.00031
Oxides of nitrogen	1.45	4.85
Particulate matter (PM_{10})	7.8	0.515
PAHs	0.895	0.121
Styrene	0.304	0.041
Sulphur dioxide[4]	0.265	0.1818
Toluene	28.6	3.87
Total VOCs	304	41.1
Xylenes	21	2.83
Zinc & compounds	0.0047	0.00031

Notes:
1) Source Table 3 of EET Manual for Aggregated Emissions from Domestic Lawn Mowing (Environment Australia, 1999e).
2) It was assumed that leaded and lead replacement petrol have the same speciation.
3) Lead content modified to 0.0001% for LRP and unleaded petrol based on the actual average for Australian fuels as given in from Table 1 of the EET Manual for Fuel and Organic Liquid Storage (Environment Australia, 2002b).
4) Sulphur dioxide modified by limit of 0.015% S for unleaded as per the legislated maximum for WA fuels (compared to EET Manual of 0.017%).

The EET Manual does not provide emission factors for the calculation of emissions from other fuel powered garden tools such as whipper snippers and chains saws. The emission factors in the EET Manual for Combustion Engines (Environment Australia, 2002a) relates to engines of larger size and were thought not appropriate for these smaller engines. Therefore, emission factors for fuel powered tools other than lawnmowers were determined by scaling the emission factors from given in **Table 3-30** by their engine power. The standard engine sizes used were:

- 1.25kW for blowers;
- 1.75kW for chainsaws;
- 0.75kW for edgers;
- 2.55kW for lawnmowers;
- 5.76kW for rotary hoes; and
- 0.75kW for whipper snippers.

Engine sizes were obtained from standard engine sizes in current catalogues, with the exception of lawnmower engine sizes, which was sourced from USEPA (1985). This procedure is adequate as long as variation in engine size is not too large, as it is known that emissions of total VOCs and CO especially increase with decreasing engine size (see European Environmental Agency, 1996). Note an alternative methodology would be to use the equations in European Environmental Agency (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 total VOCs emissions listed in the EET Manual and that in European Environmental Agency (1996) were substantially different, such that a mix of inconsistent factors would result.

Total emissions calculated for lawn mowers and the other gardening equipment are summarised in **Table 3-31**. This indicates that generally emissions from lawnmowers account for two-thirds of total domestic ‘lawnmowing’ emissions.

■ **Table 3-31 Total emissions from Domestic Lawn Mowing/Gardening**

Compound	Lawn Mowing (kg/yr)	Miscellaneous Garden Equipment (kg/yr)	Total Emissions (kg/yr)
Benzene	7,480	3,810	11,300
1,3-Butadiene	950	485	1,430
Carbon monoxide	516,000	202,000	718,000
Chromium (III) compounds	1.35	0.722	2.07
Chromium (VI) compounds	0.559	0.300	0.860
Cobalt & compounds	1.91	1.02	2.93
Copper & compounds	1.91	1.02	2.93
Cyclohexane	227	116	343
Ethylbenzene	1,740	888	2,630
Formaldehyde	1,380	658	2,040
n-Hexane	573	189	761
Lead & compounds	0.0435	0.0182	0.0617
Manganese & compounds	1.91	1.02	2.93
Nickel & compounds	1.91	1.02	2.93
Oxides of nitrogen	2,960	784	3,740
Particulate matter (PM_{10})	3,160	1,700	4,860
PAHs	394	201	594
Styrene	134	68.2	202
Sulphur dioxide	189	73.8	263
Toluene	12,600	6,420	19,000
Total VOCs	134,000	68,200	202,000
Xylenes	9,230	4,710	13,900
Zinc & compounds	1.91	1.02	2.93

3.10.4 Spatial Allocation

Emissions were spatially allocated in the Airshed by distribution of households in each domestic survey region (Augusta, Bunbury, Collie, Mandurah and Waroona).

3.10.5 Comparison to Other studies

A comparison of domestic lawnmowing emissions per capita with other studies is given in **Table 3-32**. The Bunbury Regional Airshed figures are comparable to the Perth, Newcastle and Pilbara studies. This indicates that the emissions are fairly similar for all four Airsheds.

■ **Table 3-32 Comparison of Emissions per Capita from Domestic Lawn Mowing from Bunbury Regional Airshed with Other Airsheds**

Airshed	NO_x Emissions (g/person/yr)	VOC Emissions (g/person/yr)	PM_{10} Emissions (g/person/yr)
Bunbury Region	18.6	1,004	24.2
Pilbara[1]	18	1,050	25.4
Perth[2]	20.7	1,050	25.1
Newcastle[3]	15.4	1,100	37.3

Notes:
1) Source SKM (2003).
2) Source DEP (2002).
3) Source EPAV (1996).

3.11 Lawn Mowing – Public Open Spaces

3.11.1 Introduction

Lawnmowing in public open spaces includes mowing activities carried out by local councils, schools and golf courses. As with domestic lawnmowing, emissions vary depending on the fuel type, engine size and engine type of equipment used.

3.11.2 Data Collection and Information Sources

Councils

Information was collected on mowing activity for a number of the councils in the Bunbury Regional Airshed (Bunbury, Augusta, Mandurah and Manjimup) and from a contractor in Bunbury. These local government areas were chosen to represent different climatic areas and local government areas of varying sizes. As expected, there was variation in the amount of lawnmowing undertaken in each local government area, which does not always scale to the size of the local government area. Average mowing activity data was calculated from these local government areas and then multiplied by the number of local government areas in the Bunbury Regional Airshed to determine total commercial lawnmowing activity for the study area.

Golf Courses

From a search of the Internet and Yellow Pages, there are a total of 32 golf courses in the Bunbury Regional Airshed.

Details of mowing frequency and duration was obtained from Dunsborough Lakes Resort Golf Course and Meadow Springs Golf and Country Club, and extrapolated to the remainder by the number of holes on each course.

Schools

Information on the number of schools and students in the Bunbury Regional Airshed was obtained from the Education Department WA (EDWA, 2000). There are a total of 89 schools in the Bunbury Regional Airshed with 28,712 students enrolled. Discussions with schools and councils found that schools are mowed by contractors, local councils or school gardeners. Details on mowing practices was obtained from two schools (one small primary and one large secondary school) and extrapolated by the number of students in the Bunbury Regional Airshed.

It is noted that the survey showed no small equipment usage such as edgers or whipper snippers which is surprising, but may be due to the small sample size. No correction for this has been undertaken in the study due to the small error it will introduce and the uncertainty in the amount of small equipment use.

Total mowing activity from councils, golf courses and schools in the Bunbury Regional Airshed is summarised in **Table 3-33**.

- **Table 3-33 Commercial 'mowing' activity in Bunbury Regional Airshed (hrs/yr)**

	Tractor (Diesel)	Mower ride on		Push mower (Petrol)	Whipper snipper	Edger	Chainsaw	Blower
		Petrol	Diesel					
Councils	44,187	4,290	115,401	70,785	101,244	10,940	30,690	37,752
Golf Courses	22,750	2,184	15,093	2,548	2,912	2,912	0	0
Schools	2,633	0	782	0	0	0	0	0
TOTAL	**69,570**	**6,474**	**131,276**	**73,333**	**104,156**	**13,852**	**30,690**	**37,752**

3.11.3 Emission Estimation

Emissions from lawn mowing of public open spaces were estimated using the method outlined in **Section 3.10.3**.

The EET Manual for Aggregated Emissions from Domestic Lawn Mowing (Environment Australia, 1999e) outlines emission factors for petrol pushmowers (as given in **Table 3-30**). Emissions for other petrol powered gardening tools were calculated by scaling emissions factors according to engine size as for domestic lawnmowing (**Section 3.10.3**).

Emission factors for diesel tractors were obtained from the USEPA (1985) and are given in **Table 3-34**. Emission factors for the diesel ride-on mowers were based on the tractor emission factors, and scaled according to the engine size. Engine sizes used for diesel tools were:

- 20kW for diesel and petrol ride-on mowers; and
- 52kW for diesel tractors.

As no details on whether 2-stroke or 4-stroke engines were used was available, petrol ride on mowers were assumed to be 4-stroke and the same proportion of 2-stroke and 4-stroke engines for other equipment as for the domestic use was assumed (see **Table 3-27**).

Table 3-34 Emission Factors for Diesel Tractors

Substance	Emission Factor (g/hr) Tractor (Diesel)
Acetaldehyde	1.02
Acetone	0.534
Benzene	0.0662
1,3-Butadiene	0.00753
Carbon monoxide	161
Chromium (III) compounds	0.0043
Chromium (VI) compounds	0.0019
Cobalt & compounds	0.0062
Copper & compounds	0.0062
Cyclohexane	0.0051
Ethylbenzene	0
Formaldehyde	0.541
n-Hexane	0
Lead & compounds	0.00618
Manganese & compounds	0.00618
Nickel & compounds	0
Oxides of nitrogen	452
Particulate matter (PM_{10})	61.8
PAH's	0.0437
Styrene	0
Sulphur dioxide	6.54
Toluene	0.0963
Total VOCs	6.55
Xylenes	0.0766
Zinc & compounds	0.043

Notes:
1) Source USEPA (1985) for a 52kW (70hp) tractor with PM10 emissions taken to equal the total particulate emissions for carbon monoxide,nitrogen oxides, sulphur dioxide, PM10 and total VOCs.
2) Lead content modified by 0.0001% for LRP/PULP, as stated in EET Manual for Fuel and Liquid Storage, and by 0.001% (0.739mg/L) as per the legislated maximum for WA fuels
3) Sulphur dioxide modified by limit of 0.015% S as per the legislated maximum for WA fuels (compared to EET Manual of 0.017%)
4) Speciations for metal and VOCs as per Table 19 and 20 of the EET Manual for Aggregated Emissions from Motor Vehicles (Environment Australia, 2000).

Total emissions from the mowing of golf courses, schools and councils are summarised in **Table 3-35**. This indicates that council lawnmowing activity is the largest source of emissions for commercial lawnmowing.

Table 3-35 Total emissions from lawn mowing of public open spaces

Compound	Emissions from Councils (kg/yr)	Emissions from Golf Courses (kg/yr)	Emissions from Schools (kg/yr)	Total Emissions (kg/yr)
Acetaldehyde	89.9	139	2.98	232
Acetone	47.3	72.9	1.57	122
Benzene	1,690	369	0.194	2,060
1,3-Butadiene	215	46.8	0.0221	261
Carbon monoxide	119,000	66,600	472	186,000
Chromium (III) compounds	0.6931	0.6440	0.0127	1.350
Chromium (VI) compounds	0.2931	0.2754	0.0054	0.574
Cobalt & compounds	0.9862	0.9197	0.0181	1.92
Copper & compounds	0.9862	0.9197	0.0181	1.92
Cyclohexane	52	12	0.01	63
Ethylbenzene	392	83.8	0	476
Formaldehyde	350	156	1.59	507
n-Hexane	109	61.2	0	170
Lead & compounds	0.556	0.848	0.0181	1.42
Manganese & compounds	0.986	0.920	0.0181	1.92
Nickel & compounds	0.439	0.0754	0	0.514
Oxides of nitrogen	40,600	62,100	1,330	104,000
Particulate matter (PM_{10})	6,200	8,570	181	15,000
PAH's	92.5	24.9	0.128	118
Styrene	30.1	6.43	0	36.5
Sulphur dioxide	618	910	19.2	1,550
Toluene	2,840	620	0.282	3,460
Total VOCs	30,700	7,340	19.2	38,100
Xylenes	2,090	455	0.225	2,550
Zinc & compounds	4	6	0.1	10

3.11.4 Spatial Allocation

Emissions from lawn mowing of public open spaces were spatially allocated proportionally to the number of households in the Bunbury Regional Airshed.

3.11.5 Comparison to Other Studies

Emissions from commercial lawnmowing for the Bunbury Regional Airshed, Perth Airshed and Pilbara study on a per capita basis are presented in **Table 3-36**.

Table 3-36 Comparison of Emissions per Capita from Commercial Lawn Mowing from Bunbury Regional Airshed with Other WA Airsheds

Substance	Emissions from Airshed (kg/person/yr)		
	Bunbury Region	Perth[1]	Pilbara[2]
Carbon monoxide	0.925	0.24	0.66
Lead	0.000007	0.00001	0.0000013
Oxides of nitrogen	0.517	0.073	0.091
Particulate matter (PM_{10})	0.0746	0.008	0.0012
Total VOCs	0.190	0.027	0.054

Notes:
1) Source DEP (2002).
2) Source SKM (2003).

Table 3-36 indicates that emissions per capita in the Bunbury Regional Airshed for CO, NO_x, PM_{10} and total VOCs are higher than the Pilbara and Perth Airshed emissions. These higher value may be the result of efficiencies achieved by councils and local government areas in Perth with much larger populations and relatively small area over which to maintain public open spaces and large number of golf courses in the Bunbury Regional Airshed. The higher values of PM_{10} and NO_x are also due to the high usage of diesel mowers for the commercial mowing in the Bunbury Regional Airshed. The lower emissions of lead are due to the lower lead content of fuel now used in WA.

3.12 Motor Vehicle Refinishing

3.12.1 Introduction

Motor vehicle refinishing emissions come from spray painters, smash repairers and panel beaters, who apply primers, topcoats and hardeners to motor vehicle surfaces. This protects the surfaces 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. Chemical reactions can also result in emissions being released during the refinishing, drying, curing and hardening phases.

3.12.2 Data Collection and Information Sources

National paint production figures, including data for automotive paints, enamels, clears and thinners, were provided by the Australian Paint Manufacturers' Federation, and scaled by the population in the Bunbury Regional Airshed.

3.12.3 Emission Estimation

Emissions from motor vehicle refinishing were calculated using the mass balance approach 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:

$$E = C_i \times EF_i$$ **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 3-37**.

- **Table 3-37 VOC content by surface coating type (EF_i)**

Substance	VOC Content[1] (kg/L)
Paint (solvent based)	0.672
Enamel	0.420
Lacquer	0.732
Primer	0.792
Thinner	0.883
Adhesive	0.528

Notes:
1) Source Table 3 of EET Manual for Aggregated Emissions from Motor Vehicle Refinishing (Environment Australia, 1999i).

The VOC emissions are then speciated using the speciation profile prescribed in the EET Manual as summarised in **Table 3-38**.

■ Table 3-38 VOC Speciation for Various Automotive Surface Coating Product Types

NPI Substance	Weight % Solvent Based Paint	Weight % Enamel	Weight % Thinner	Weight % Primer	Weight % Lacquer	Weight % Adhesive
Acetone	1.27	5.57				14.2
Cyclohexane	0.52	2.27				
Ethyl acetate	2.04	8.96				13.3
Ethylbenzene	0.54	2.36				
Methyl ethyl ketone	0.54	2.36	2.5			5.3
Methyl isobutyl ketone	0.36	1.57				4.3
Toluene	37.87	15.9	25	44.3	44.6	20.3
Xylenes	8.17	23.09	20	2.68	4.18	
Total VOCs	**51.3**	**63.08**	**47.5**	**46.9**	**48.8**	**57.4**

Notes:
2) Source Table 4 of EET Manual for Aggregated Emissions from Motor Vehicle Refinishing (Environment Australia, 1999i).

Total emissions were estimated using the best practice mass balance method as outlined in the EET Manual and are given in **Table 3-39**. This was based upon the National September 2003 quarter sales of paints, enamels and clears (3,393,442L) and thinners (1,771,961L), and used an Australian population of 18,972,350 and Bunbury Regional Airshed population of 201,105. A comparison was also made to the default method based on population as presented in **Table 3-39**.

■ Table 3-39 Total Emissions (kg/yr) from Motor Vehicle Refinishing

Substance	Emissions from best practice method (kg/yr)	Emissions from default methodology based on population[1, 2] (kg/yr)
Acetone	935	-
Cyclohexane	382	-
Ethyl acetate	1,500	-
Ethylbenzene	397	-
Methyl ethyl ketone	2,060	28,700
Methyl isobutyl ketone	264	5,070
Toluene	55,400	55,700
Xylenes	20,100	49,000
Total VOCs	164,000	169,000

Notes:
1) Calculated from default consumption figures given in Tables 2 and 5 of EET Manual for Aggregated Emissions from Motor Vehicle Refinishing (Environment Australia, 1999i).
2) Values included for comparison only.

Table 3-39 indicates fair agreement between the best practice and default estimates for total VOCs and toluene, but substantial difference for other species, such as methyl ethyl ketone and methyl isobutyl ketone emissions. These other species are much higher for the default methodology than the best practice method. This difference is due to the speciations and highlights the very indicative nature of the default speciation.

3.12.4 Spatial Allocation

Emissions from motor vehicle refinishing were spatially allocated in proportion to the number of premises in each grid cell, on a 3 by 3km grid. This is the preferred approach outlined in the EET Manual.

3.12.5 Comparison with Other Studies

Emissions per capita from motor vehicle refinishing for various WA studies are presented in **Table 3-40**.

- **Table 3-40 Comparison of Emissions per Capita from Motor Vehicle Refinishing from Bunbury Regional Airshed with Other WA Airsheds**

Substance	Emissions from Airshed (g/person/year)			
	Bunbury Region	Perth[1]	Kalgoorlie[2]	Pilbara[3]
Total VOCs	815	877	415	130
Toluene	275	237	21.6	43
Xylenes	100	231	10.8	38

Notes:
1) Source DEP (2002).
2) Source Coffey Geosciences (1999).
3) Source SKM (2003).

These indicate fair agreement between the Bunbury Regional and the Perth Airshed emissions on a per capita basis, whilst the emissions for the Bunbury Regional Airshed are much higher than estimated for the Kalgoorlie and Pilbara Airsheds. The Perth estimates have been based on the population methodology (DEP, 2002), whereas the Kalgoorlie and Pilbara were based on employee estimations (Coffey Geosciences, 1999; SKM, 2003).

3.13 Dry Cleaning

3.13.1 Introduction

The dry cleaning industry provides cleaning services for various fabric goods, including clothes, manchester and leather goods. There are two general types of cleaning fluids used in the dry cleaning industry; petroleum solvents and synthetic solvents. The principal synthetic solvent used is tetrachloroethylene, while only a small amount of petroleum solvents are generally used, such as white spirit. Petroleum solvents account for approximately 2 to 3% of national dry cleaning solvent usage (Environment Australia, 1999g). 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.

3.13.2 Data Collection and Information Sources

There were eight dry cleaning facilities in the Bunbury Regional Airshed. Telephone surveys of these facilities revealed that tetrachloroethylene came from two suppliers, both located in Perth. No facilities in the Bunbury Regional Airshed reported use of white spirits. The two suppliers gave details of the total sales figures for tetrachloroethylene to the Bunbury Regional Airshed (1,638L/year).

3.13.3 Emission Estimation

The best practice method given in the EET Manual for Aggregated Emissions from Dry Cleaning (Environment Australia, 1999g) was used to calculate emissions. 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 1.620m^3 for the compound. Therefore, the total annual emissions of tetrachloroethylene in the Airshed from dry cleaning operations were 2,654 kg/yr.

3.13.4 Spatial Allocation

Emissions from dry cleaning were spatially allocated according to the location of the facilities on a 3 by 3km grid.

3.13.5 Comparison to Other Studies

Table 3-41 provides a comparison of the emissions on a per capita basis from three other WA studies. This indicates that:

- The Bunbury Regional Airshed estimates of tetrachloroethylene (Perc) are lower (1.5 to 2 times) than other regional centres in WA, and significantly lower (8 times) than the Perth emissions. The lower usage in the Bunbury Regional Airshed may be due to lower dry cleaning requirements based on occupations and lifestyles here. All regional centres are however much lower than for Perth.
- The reported zero usage of white spirit is in agreement to that found for the Pilbara study, and similar to the Perth study which reported low usage.

Table 3-41 Comparison of Emissions from Dry Cleaning from Bunbury Regional Airshed with Other WA Airsheds

Airshed	Perc (kg/yr)	White Spirits (kg/yr)	Perc (kg/capita/yr)	White Spirits (kg/capita/yr)
Bunbury Region	2,654	0	0.0132	0
Perth[1]	133,000	8,000	0.102	0.0061
Kalgoorlie[2]	880	3,000	0.028	0.0965
Pilbara[3]	974	0	0.0194	0
Bunbury Region – Based on Default per capita	120,663	Not given	0.6	Not given
Bunbury Region – Based on Default per employee[4]	2,414	Not given	0.0120	Not given

Notes:
1) Source DEP (2002).
2) Source Coffey Geosciences (1999).
3) Source SKM (2003).
4) Per employee estimate based on an estimated average of 3 employees per facility that was determined from a phone survey and the default factor of 100.6 kg/employee/yr.

The comparison of emissions estimated using the mass balance approach and the emissions estimated using the default population and employee methods given in the EET Manual show that the default method based on population overestimates the emissions of Perc, while the default method based on employees gives a good agreement. This indicates the current NPI population based default method is not suitable for use in regional areas such as Bunbury Regional Airshed.

3.14 Bakeries

3.14.1 Introduction

Bread manufacturing involves the blending of ingredients such as flour, to produce bread and other related products. Many of these products are leavened by yeast, and it is the fermentation stage, where ingredients are blended with yeast and allowed to ferment before baking, that releases emissions such as ethanol and other VOCs.

3.14.2 Data Collection and Information Sources

There were 58 premises identified in the Bunbury Regional Airshed 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 Bunbury Regional Airshed. A telephone survey was undertaken of 20 bakeries, and was followed up with a commercial survey form issued to 8 bakeries by fax. From these approaches, only two bakeries provided information on the amount of bread baked. Of the others, particularly the large chain stores with bakeries or smaller private chains, no data was obtained due to concerns of commercial confidentiality. Therefore, with the large uncertainty in usage in the Bunbury Regional Airshed 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 bread consumed in the Bunbury Regional Airshed but baked elsewhere.

For bread consumption, a value of 45 kg of bread per capita per year was used, which was obtained from the Bread Research Institute (1999) for the Pilbara study (SKM, 2003). From a survey of the major two suppliers of bread (TipTop and Goodman Fielder) a total of 5.65 Mtpa of yeast products was imported into the Bunbury Regional Airshed. This equates to 28.1 kg/per capita. Therefore it is assumed that the local bakeries account for the remainder of 16.9 kg/per capita or 3.40 Mtpa (37.6%). Using these estimates and the Industry EET Manual for Bread Manufacturing (Environment Australia, 2003b) emissions were calculated as presented in **Table 3-42**.

- **Table 3-42 Emission Factors and Total Emissions from Bread Manufacturing**

Substance	Emission Factor[1] (kg/tonne of bread)	Total Emissions (kg/yr)
Ethanol	0.83	2,820
Total VOCs	0.832	2,830

Notes:
1) Source Table 2 of EET Manual for Bread Manufacturing (Environment Australia, 2003b).

3.14.3 Spatial Allocation

Emissions from bread manufacturing were spatially allocated in proportion to the number of bakeries per grid cell on a 3 by 3km grid.

3.14.4 Comparison to Other Studies

The bread usage and bakery emissions for various WA studies have been summarised in **Table 3-43**.

- **Table 3-43 Comparison of Bread Usage and Emissions from Bread Manufacturing from Bunbury Regional Airshed with Other WA Airsheds**

Airshed	Bread Manufactured in Region (kg/person/yr)	Ethanol Emissions (kg/person/yr)	Total VOC Emissions (kg/person/yr)
Bunbury Region	16.9	0.0140	0.0141
Perth[1]	Not estimated	-	-
Pilbara[2]	4.5	0.0124	0.0124
Kalgoorlie[34]	41.5	0.114	0.1145

Notes:
1) Source DEP (2002).
2) Source SKM (2003).
3) Source Coffey Geosciences (1999).

This indicates that the bread manufacture and subsequent emissions in the Bunbury Regional Airshed fall between the Pilbara and Kalgoorlie Airsheds. It should also be noted that different emission factors were used to calculate the emissions from the Pilbara and Kalgoorlie Airsheds (the EET Manual has been updated since these studies).

3.15 Paved and Unpaved Roads

3.15.1 Introduction

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.

3.15.2 Data Collection and Information Sources

Data was obtained from VKT estimates for paved and unpaved roads as detailed in **Section 2.1.2.2** and default values used in the EET Manual.

3.15.3 Emissions Estimation

Emissions were calculated using the prescribed methods in the EET Manual for Aggregated Emissions from Paved and Unpaved Roads (Environment Australia, 1999j).

Paved Roads

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

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

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)
k_{ip}	=	empirical factor for particle size category i and paved roads (kg/km) [PM_{10} = 0.0046 and TSP = 0.024]
sL	=	road surface silt loading (g/m^2)
AW	=	average weight of vehicles (tonnes)
VKT_p	=	Vehicle Kilometre Travelled (VKT) on paved roads in Airshed (km/yr)

The default road surface silt loading of 0.1 g/m^2 for high average daily traffic roads was adopted for all paved roads. An average vehicle weight of 3.1 tonnes for the Bunbury Regional Airshed was also used to calculate emission factors for PM_{10} and TSP as per the default value in the EET Manual. This results in emission factors of 0.689 g/km for PM_{10} and 3.6 g/km for TSP.

VKT on paved roads in the Bunbury Regional Airshed is estimated to be approximately 2,411 million km per year. Annual emissions of PM_{10} from paved roads in the Bunbury Regional Airshed are therefore estimated to be 1,662 tonnes (**Table 3-44**). A number of other NPI substances are also emitted in trace amounts. Emissions of these compounds are calculated using a weight fraction of the TSP emissions. A summary of the weight fraction of these compounds and total annual emissions is summarised below in **Table 3-44**.

■ Table 3-44 Total Emissions from Paved Roads

Substance	Weight Fraction[1]	Total Emissions (kg/yr)
Particulate matter (PM_{10})	-	1,660,000
TSP	-	8,670,000
Antimony & compounds	0.000013	113
Arsenic & compounds	0.000015	130
Cadmium & compounds	0.000019	165
Cobalt & compounds	0.000116	1,000
Copper & compounds	0.000161	1,400
Lead & compounds	0.000951	8,250
Manganese & compounds	0.000795	6,900
Mercury & compounds	0.000016	139
Nickel & compounds	0.000068	590
Selenium & compounds	0.000002	17
Zinc & compounds	0.000936	8,120

Notes:
1) Source Table 8 of EET Manual for Aggregated Emissions from Paved and Unpaved Roads (Environment Australia, 1999j). 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:

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

Where:

E_{iu}	=	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 6.4% (as provided for roads made out of gravel or crushed limestone from the EET Manual) was used and the default moisture content of 0.2%. As for the paved roads an average vehicle weight of 3.1 tonnes was used. Other empirical constants used to calculate emission factors for PM_{10} and TSP are summarised in **Table 3-45**.

■ Table 3-45 Empirical Constants for Unpaved Road Emissions

	PM_{10}	TSP
k_{iu}	0.733	2.82
A	0.8	0.8
B	0.4	0.5
C	0.3	0.4

Notes:
1) Source Table 5 of EET Manual for Aggregated Emissions from Paved and Unpaved Roads (Environment Australia, 1999j).

The above parameters result in an emission factor of 449 g/km for PM_{10} and 1,734 g/km for TSP. These factors are around 500 to 750 times greater than that for paved roads. Factors used in the Kalgoorlie trial resulted in a value of 486 g/km for PM_{10}. This lower value in the Kalgoorlie trial was because Coffey Geosciences (1999) used a correction to account for rain days (when zero dust is assumed to be emitted). This has been neglected here, as it is not incorporated in the EET methodology.

VKT on unpaved roads in the Bunbury Regional Airshed is estimated to be approximately 248.5 million km per year. Annual emissions of PM_{10} from unpaved roads in the Bunbury Regional Airshed are therefore estimated to be 111,600 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 3-46**.

- **Table 3-46 Total Emissions from Unpaved Roads**

Substance	Weight Fraction [1]	Total Emissions (kg/yr)
TSP	-	431,000,000
Particulate matter (PM_{10})	-	112,000,000
Antimony & compounds	0.000008	3,450
Arsenic & compounds	0.000014	6,030
Cadmium & compounds	0.000022	9,480
Cobalt & compounds	0.000143	61,600
Copper & compounds	0.000088	37,900
Lead & compounds	0.000867	374,000
Manganese & compounds	0.000973	419,000
Mercury & compounds	0.000015	6,460
Nickel & compounds	0.000065	28,000
Selenium & compounds	0.000001	431
Zinc & compounds	0.000605	261,000

Notes:
1) Source Table 8 of EET Manual for Aggregated Emissions from Paved and Unpaved Roads (Environment Australia, 1999j). Weight fraction is proportion of total TSP emissions.

Total Paved and Unpaved Roads

As expected, emission from unpaved roads was the more dominant contributor from unpaved and paved roads. Total PM_{10} emissions were estimated at 113,300 tonnes with a 98.5% contribution from unpaved roads. A similar percentage contribution from unpaved roads was found for the remainder of the compounds (average of 97.5%) for which emission estimates were made. **Table 3-47** presents total emissions of each compound from paved and unpaved roads.

- **Table 3-47 Total Emissions from Paved and Unpaved Roads**

Substance	Total Emissions (kg/yr)
TSP	439,400,000
Particulate matter (PM_{10})	113,300,000
Antimony & compounds	3,560
Arsenic & compounds	6,160
Cadmium & compounds	9,640
Cobalt & compounds	62,600
Copper & compounds	39,300
Lead & compounds	382,000
Manganese & compounds	426,000
Mercury & compounds	6,600
Nickel & compounds	28,600
Selenium & compounds	448
Zinc & compounds	269,000

3.15.4 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 3 by 3km grid. This is thought to be far more realistic than evenly distributing the emissions over the whole Airshed as recommended in the manual.

3.15.5 Comparison to Other Studies

Emissions from the Pilbara NPI Study (SKM, 2003), the Kalgoorlie NPI trial (Coffey Geosciences, 1999) and from California (CARB, 2002) are presented alongside estimates from this study in **Table 3-48**.

- **Table 3-48 Comparison of PM_{10} emissions from Paved and Unpaved Roads from Bunbury Regional Airshed with Other WA Airsheds**

Airshed	Paved Roads		Unpaved Roads	
	(VKT/person)	PM_{10} Emissions (tonnes/Person/yr)	(VKT/person)	PM_{10} Emissions (tonnes/person/yr)
Bunbury Region	11,989	0.0083	1,236	0.555
Pilbara [1]	7,580	0.013	1,050	0.726
Kalgoorlie [2]	10,320	0.010	177	0.086
California [3]	13,644	0.0041	-	0.0069

Notes:
1) Source SKM (2003).
2) Source Coffey Geosciences (1999).
3) Source CARB (2002) with the VKT/person being the total VKT for paved and unpaved roads.

Table 3-48 indicates that the PM_{10} emissions per capita from paved roads are slightly lower than both the Pilbara and Kalgoorlie studies even though the VKT/person is higher in the Bunbury Regional Airshed. The Pilbara and Kalgoorlie values are higher as higher silt loadings of 0.4g/m^2 were used for these areas compared to the 0.1g/m^2 used for the Bunbury Regional Airshed. Likewise the emissions per capita for Californian roads are lower as typically lower silt loadings are used for their highly trafficked roads.

For unpaved roads the estimated emissions of PM_{10} per capita for the Bunbury Regional Airshed are slightly lower than for the Pilbara region but are 6.45 times higher than estimated for the Kalgoorlie region and around 80 times higher than for the state of California. The difference in the emission estimates for Kalgoorlie and California is primarily due to the much lower VKT in these study regions. For example in California, though VKT figures for unpaved roads were not supplied, there are only 55,820 km of unpaved roads listed for the year 2000 population of 34.7 million (0.00161km/person) compared to the Bunbury Regional Airshed with 36,534 km of roads and tracks (0.182km/person).

3.16 Fuel Combustion (Sub Threshold)

3.16.1 Introduction

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.

3.16.2 Data Collection and Information Sources

Data required for the estimation of emissions in the EET Manual are fuel consumption by fuel type and by commercial/industrial facilities. Suppliers of coal, petrol, diesel, natural gas and LPG were contacted and provided data on the total fuel supplied, fuel supplied to commercial and industrial users, fuel supplied for farming and fuel supplied to service stations for the Bunbury Regional Airshed for 2002. Fuel consumption for reporting facilities in the region was obtained from the DEP NPI section for the 2001/2002 reporting year. Fuel consumption by sub-threshold, non-reporting facilities was determined as the difference between total commercial and industrial fuel supply to the Bunbury Regional Airshed and that used by reporting facilities (**Table 3-49**).

■ **Table 3-49 Sub-threshold Fuel Consumption**

	Natural Gas (tpa)	LPG (tpa)	Diesel (tpa)	Petrol (tpa)	Coal (tpa)
Annual Commercial/ Industrial Fuel Supply	1,833,256	5,613	134,660	445	5,253,163
Consumption by Reporting Facilities	1,733,371	2,261	79,770	283	5,253,163
Consumption by Subthreshold Facilities	99,885	3,352	54,890	162	-

The coal suppliers in the Bunbury Regional Airshed reported that most of the coal is distributed to large reporting facilities. One coal supplier mentioned that some coal goes to a handful of diary farmers and domestic users, but this amount is very small and therefore deemed negligible.

3.16.3 Emission Estimations

The following EET Manuals were used to calculate sub-threshold fuel consumption emissions:

- The EET Manual for Aggregated Emissions from Fuel Combustion (Sub-Threshold) (Environment Australia, 1999h) for natural gas emissions;
- The EET Manual for Combustion Engines (Environment Australia, 2002a) for uncontrolled diesel, petrol and LPG emissions;
- The EET Manual for Aggregated Emissions from Motor Vehicles (Environment Australia, 2000).

The emissions factors are summarised in **Table 3-50**. The total annual volume of fuel for each fuel type was multiplied by the appropriate emission factors to calculate annual emissions for the Bunbury Regional Airshed.

■ Table 3-50 Emission factors for sub-threshold fuel combustion

Substance	Natural Gas[1] (kg x 10^{-6} /m^3)	LPG[2] (kg/kg LPG)	Diesel[3,5] (kg/L)	Petrol[4,5] (kg/L)
Acetaldehyde	-	2.01E-05	6.26E-04	6.82E-05
Acetone	-	-	3.29E-04	4.46E-05
Arsenic & compounds	3.20E-03	-	-	-
Benzene	-	3.08E-07	4.08E-05	1.03E-03
Beryllium & compounds	3.40E-02	-	-	-
1,3 – Butadiene	1.90E-04	1.81E-06	4.65E-06	1.01E-04
Cadmium & compounds	1.80E-02	-	2.17E-06	-
Carbon monoxide	1.30E-03	3.00E-01	1.84E-02	4.75E-01
Chromium (VI) compounds	6.60E-03	-	1.08E-07	2.18E-08
Chromium (III) compounds	1.50E-02	-	2.53E-07	5.08E-08
Cobalt & compounds	1.30E-03	-	3.61E-07	-
Copper & compounds	1.40E-02	-	3.61E-07	2.18E-07
Cyclohexane	-	-	3.14E-06	1.73E-05
Dichloromethane	1.4	-	-	-
Ethylbenzene	-	-	-	2.34E-04
Formaldehyde	1.2	-	8.13E-04	5.32E-04
n-Hexane	2.90E+01	-	-	2.42E-04
Hydrochloric acid	-	5.82E-05	-	-
Lead & compounds	8.00E-03	-	3.61E-07	-
Manganese & compounds	6.10E-03	-	3.61E-07	1.45E-07
Mercury & compounds	4.20E-03	-	-	-
Nickel & compounds	3.40E-02	-	-	7.26E-08
Oxides of nitrogen	1.60E+03	1.50E-02	4.41E-02	1.15E-02
Particulate matter (PM_{10})	1.20E+02	-	3.61E-03	7.26E-04
PAHs	1.10E-02	-	2.69E-05	3.39E-05
Selenium & compounds	3.80E-04	-	-	-
Sulphur dioxide[2]	2.84[(6)]	-	3.73E-03	6.33E-04
Styrene	-	-	-	3.32E-05
Toluene	5.40E-02	-	5.94E-05	1.64E-03
Total VOCs	8.80E+01	3.27E-02	4.04E-03	1.56E-02
Xylenes	-	-	4.73E-05	1.18E-03
Zinc & compounds	4.60E-01	-	2.53E-06	3.70E-06

Notes:

1) Source Table 4 of the EET Manual for Aggregated Emissions from Fuel Combustion (Sub-Threshold) (Environment Australia, 1999h).
2) Source miscellaneous LPG industrial vehicle exhaust from Table 8 of the EET Manual for Combustion Engines (Environment Australia, 2002a).
3) Source miscellaneous diesel industrial vehicle exhaust from Table 7 of the EET Manual for Combustion Engines (Environment Australia, 2002a).
4) Source miscellaneous petrol industrial vehicles from Table 10 of the EET Manual for Combustion Engines (Environment Australia, 2002a).
5) The speciation of the above substances for diesel and petrol not included in the combustion engine manual were obtained from Tables 18 and 19 from the EET Manual for Aggregated Emissions from Motor Vehicles (Environment Australia, 2000).
6) Based on a sulphur content of 1.35 mg/m^3 (Western Power, 2002).

The estimated emissions are presented in **Table 3-51**.

Table 3-51 Sub threshold fuel combustion in the Bunbury Regional Airshed

Substance	**Total Emissions (kg/yr)**
Acetaldehyde	36,800
Acetone	19,300
Arsenic & compounds	0.411
Benzene	3,010
Beryllium & compounds	0.0244
1,3 - Butadiene	343
Cadmium & compounds	129
Carbon monoxide	3,340,000
Chromium (VI) compounds	7.19
Chromium (III) compounds	16.7
Cobalt & compounds	21.3
Copper & compounds	23.0
Cyclohexane	194
Dichloromethane	180
Ethylbenzene	141
Formaldehyde	48,000
n-Hexane	3,870
Hydrochloric acid	352
Lead & compounds	23.0
Manganese & compounds	22.0
Mercury & compounds	0.540
Nickel & compounds	4.41
Oxides of nitrogen	2,880,000
Particulate matter (PM_{10})	227,000
PAHs	1,600
Selenium & compounds	0.0488
Sulphur dioxide	219,000
Styrene	20.0
Toluene	4,460
Total VOCs	454,000
Xylenes	3,470
Zinc & compounds	209

3.16.4 Spatial Allocation

Industrial and commercial zoning was difficult to determine for the Bunbury Regional Airshed. Emissions from sub-threshold fuel combustion were therefore allocated to towns across the Bunbury Regional Airshed, in proportion to town populations within 3 by 3km grid cells.

3.16.5 Comparison with Other Studies

Comparison with emission estimates from the Perth and Pilbara Airsheds indicate the emissions per capita for the Bunbury Regional Airshed are generally much higher (**Table 3-52**). This is most probably due to the different techniques used to estimate fuel consumption. The methodology used here has assumed that all non-reported commercial/industrial fuel is used on commercial and industrial premises. This will be true for natural gas, which is likely used for boilers etc and LPG as used for forklifts etc. However diesel may also be used in vehicles on public roads. Examples of this are the large haulage and earthmoving companies in the south west that could use a significant fraction of diesel on public roads, therefore leading to a double counting of emissions as these are covered under motor vehicles.

Other reasons for the differences are the emission estimation methods used, with the Perth study based on a detailed survey of each industry and then the use of specific emission manuals for the sources identified.

Table 3-52 Comparison of Emissions per Capita from Sub-Threshold Fuel Combustion from Bunbury Regional Airshed with Other WA Airsheds

Substance	Emissions from Airshed (kg/person/yr)		
	Bunbury Region	Pilbara[1]	Perth[2]
Carbon monoxide	16.6	2.5	1.3
Lead	0.0001	8.5E-8	1.0E-3
Oxides of nitrogen	14.3	8.3	4.3
Particulate matter (PM_{10})	1.13	0.82	1.7
Sulphur dioxide	1.09	1.0	7.5
Total VOCs	2.26	0.82	0.51

Notes:
1) Source SKM (2003).
2) Source DEP (2002).

3.17 Natural/Town Gas Leakage

3.17.1 Introduction

Emissions of total VOCs and hydrogen sulphide (H_2S) can occur from natural/town gas distribution network through leakage. Within the Bunbury Regional Airshed, AlintaGas supplies reticulated natural gas to the towns of Mandurah, Harvey, Pinjarra, Brunswick Junction, Bunbury and Busselton and Kleenheat supplies reticulated liquefied petroleum gas (LPG) to the town of Margaret River.

Emissions can be released from natural gas distribution systems through leakages, losses due to accidental situations (e.g. burst pipes) and blowdown operations. Leakages account for the majority of losses (DEP, 2002).

Emissions were estimated from the AlintaGas natural gas network only as the LPG network is relatively new and as a consequence it was assumed that there were negligible losses due to routine operations (Kleenheat, Wilks, J., personal communication, 2003; Environment Australia, 1999o).

3.17.2 Emission Estimation

Emissions from gas losses were estimated using the methodology described in the Industry EET Manual for Gas Supply (Environment Australia, 1999o). This involves determination of the unaccounted for gas (UAFG) from the distribution network and assuming conservatively that all UAFG is line loss (UAFG could also be due to metering errors).

The VOC and hydrogen sulphide emissions were then determined from the concentration of VOC and H_2S in natural gas.

3.17.3 Data Collection and Information Sources

The amount of UAFG from the Bunbury Regional Airshed was not available, so this value was determined using an estimate of the gas delivered to the study area and the estimated percentage of UAFG for AlintaGas' entire network.

The total amount of gas supplied to the Bunbury Regional Airshed was determined by assuming that each household connected to the gas consumes 20GJ/yr of gas (AlintaGas, Stubbs, M., personal communication, 2003) and that 16% of the total gas consumed is used for domestic purposes (AlintaGas, 2002). The number of households connected to AlintaGas system in the towns of Bunbury, Busselton, Pinjarra, Harvey and Mandurah was given by AlintaGas (AlintaGas, Stubbs, M., personal communication, 2003). The total number of households in the Bunbury

Regional Airshed was determined from the households connected as supplied by AlintaGas and an estimate of number of residents connected to the system in the Bunbury Regional Airshed north of Mandurah, which was determined by assuming that 65% of the households in this area are connected to the system (this percentage was obtained from the domestic survey). The total number of households in these areas was obtained from the 2001 census data.

AlintaGas estimates that approximately 2.6% of the gas delivered is UAFG (AlintaGas, Stubbs, M., personal communication, 2003). This is consistent with the value given in the EET Manual of 2.5%.

Data on the density and heating value of natural gas was obtained from AlintaGas and the VOC content in the gas was obtained from Australian Greenhouse Office Workbook for Fugitive Fuel Emissions (National Greenhouse Gas Inventory Committee, 1998). The H_2S concentration of the gas was obtained from Western Power (2002).

3.17.4 Emission Estimation

A summary of the total VOC and H_2S emissions from natural gas leakage in the Bunbury Regional Airshed is given in **Table 3-53**.

- **Table 3-53 Emissions from Natural Gas Leakage**

Substance	Total Emissions (kg/yr)
Hydrogen sulphide	3,642
Total VOCs	454,000

3.17.5 Spatial Allocation

Emissions were spatially aggregated across the 3 by 3km grid by numbers of households within the AlintaGas distribution network.

3.17.6 Comparison with Other Studies

A comparison of the total VOC emissions from natural gas leakage from the Bunbury Regional Airshed with other aggregated emissions studies is given in **Table 3-54**. This table shows that the emissions are less than the emissions from Perth and Port Phillip Region, but higher than the other Airshed. The amount of gas supplied by the other regions is not known, so a meaningful comparison of leakage or UAFG cannot be undertaken.

- **Table 3-54 Comparison of VOC Emissions from Natural Gas Leakages from Bunbury Regional Airshed with Other Airsheds**

Airshed	Total Emission of Total VOCs (kg/yr)	Total Emission of Total VOCs per Capita (kg/person/yr)
Bunbury Regional Airshed	454,000	2.26
Perth[1]	1,451,000	1.11
Port Phillip Region[2]	3,100,000	0.898

Notes:
1) Source DEP (2002).
2) EPAV (1998).

Emissions of H_2S were not calculated for the other studies, so a comparison on the emissions of this substance could not be made.

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4. Biogenics and Other 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 the Bunbury Regional Airshed are wildfires the emission estimation is presented in **Section 4.5**.

4.2 Biogenics - VOC Emissions from Vegetation

4.2.1 Introduction

VOCs are emitted naturally from biogenic (living organisms), non-biogenic (bushfires) and anthropogenic sources (human). The impact that the biogenic emissions may have was first suggested by Went in 1955 who suggested that the formation of a 'blue haze' over forests may be a result of VOC emissions from vegetation (Kirstine *et al*, 1998). Subsequent investigations have shown that biogenic sources do emit a significant amount of hydrocarbons to the atmosphere (EPAV, 1996) with the majority of these emissions comprising isoprene and some monoterpenes (Kirstine *et al*, 1998).

4.2.2 Data Collection and Information Sources

The methodology adopted for the calculation of VOC emissions from vegetation is similar to that used in the South East Queensland Region 2000 NPI study (EPAV, 2002). This is a more complicated method than used in the Kalgoorlie NPI Trial (Coffey Geosciences, 1999), the Newcastle NPI Trial (EPAV, 1996) and the Pilbara study (SKM, 2003). This methodology is based on Lamb *et al* (1987) and estimates the total VOC emissions by determining isoprene, monoterpenes and other VOCs from vegetation based on a temperature dependant function, vegetation density index and solar radiation.

Data required for emission estimates are vegetation types and their spatial distribution, classification of the vegetation density and hourly temperature and solar radiation data. The primary source of vegetation type and coverage is a detailed map compiled by the WA Department of Agriculture. Total solar radiation data was obtained from the Alcoa automatic weather station located at the Wagerup refinery, with temperatures obtained from the Bureau of Meteorology station at Bunbury. These were assumed to be representative of the Bunbury Regional Airshed.

4.2.3 Emission Estimation

4.2.3.1 Methodology

To estimate VOC emissions from vegetation in the Bunbury Regional Airshed a modified version of the Biogenic Emission Inventory System (BEIS) was used. This system was developed by the USEPA and is widely used for biogenic inventory studies throughout the USA (EPAV, 2002). To estimate VOC emissions from vegetation, the BEIS system uses two methods. The first method is used to estimate emissions from forested areas (**Equation 4.1**) while the second is used to determine emissions from all other sources (**Equation 4.2**).

$$ER_i = \sum_j \mathrm{A_j} \times \mathrm{FF_j} \times 0.01 \times \mathrm{EF_{ij}} \times 10^{-6} \times \mathrm{C_L} \times \mathrm{C_T} \qquad \textbf{Equation 4.1}$$

$$ER_i = \sum_j \mathrm{A_j} \times \mathrm{EF_{ij}} \times 10^{-6} \times \mathrm{C_L} \times \mathrm{C_T} \qquad \textbf{Equation 4.2}$$

Where
ER_i = Emission rate of substance i (g/hr)
A = Area of vegetation unit j (m^2)
FF_j = Foliage cover (%)
EF_{ij} = Emission factor by land use ($\mu g/m^2/hr$)
C_L = Light (canopy) correction factor
C_T = Temperature correction factor

4.2.3.2 Emission Factors

The emission factors by land use (EF) are presented in **Table 4-1**. For this study the emission factors for crop, broadacre, horticulture and settlements were obtained from the South East Queensland Region study which are based on US values given in BEIS (EPAV, 2002). For pastures in this study, emission factors were derived from Kirstine *et al* (1998) whose work in estimating the VOC emissions from pastures found that total VOC emissions in warm sunny conditions can be best estimated at 650µg(C[1])/m²/hr (or 0.5µg(C)/g/hr). Of this, isoprene and monterpene emissions accounted for only 10%. To account for the variation in pasture biomass with season, the emissions per unit area were estimated using 0.5µg(C)/g/hr as the emission rate and a seasonal variation in grass biomass that varied from a maximum of 2,300g/m² to a minimum of 940g/m². For un-irrigated pasture the maximum and minimum biomass densities were assumed to occur during October and April respectively and fitted with a semi sinusoidal function. For irrigated pasture the biomass density was assumed at the maximum rate for the year. Therefore emission from pastures range from 470 to 1,150 µg(C)/m²/hr.

The emission factors for native vegetation and regrowth were determined using data from the study of He *et al* (1999a) on South West of Western Australia and other Australian Eucalypt species. He *et al* (1999a) conducted a study on fifteen Eucalypt species using small trees of age 12 to 24 months that were individually enclosed in transparent ventilated chambers. The air was analysed for isoprene and fourteen monoterpenes with emissions estimated on a leaf mass and leaf area basis. Of the fifteen species measured by He *et al* (1999a), only three; Jarrah (*Eucalyptus marginata*), Marri (*Eucalyptus calophylla*) and Tuart (*Eucalyptus gomphocephala*) occur significantly throughout the Bunbury Regional Airshed. In this study to

[1] Carbon

represent a generic forested area an average of the emissions from Jarrah, Marri and Tuart was used. This resulted in an average isoprene emission of 27.6µg/g/hr at the normalised conditions of 30°C leaf temperature and a Photosynthetically Active Radiation (PAR) flux of 1,000µmol/m^2/sec. A more rigorous scheme to estimate emissions based on individual species or individual forest types was neglected due to:

- Lack of data for other dominant species such as Karri;
- That there are complex seasonal variations in the emissions from these species (He *et al*, 1999b); and
- The uncertainties in factoring the emissions from He *et al* (1999a) that were derived from young, well watered and fertilised plants to mature plants that undergo water stress.

The derived isoprene emission rate of 27.6µg/g/hr is in good agreement to the leaf level estimates used in the Perth Photochemical Smog Study (PPSS) (Cope *et al*, 1996) that were based on overseas studies of 23.3 µg(C)/g/hr or 26.4 µg/g/hr. It is noted that in the actual emission estimates, Cope *et al* (1996) used branch level isoprene emissions of 15.1 µg/g/hr that implicitly includes foliage-shading effects and therefore used an equation without the light correction factor as in **Equation 4.1**.

To derive emission rates per unit land area for the generic forested area, a mean biomass density of 345 g/m^2 as used by Cope *et al* (1996) for a Jarrah/Marri forest was used. This results in an isoprene emission rate of 9,108 µg/m^2/hr for the standard conditions of 30°C leaf temperature and a PAR flux of 1,000µmol/m^2/sec. In the PPSS, Cope *et al* (1996) also considered a system using a dominant and subdominant genera with forest assigned a maximum coverage of 85%. Using this approach and the same non-dominant genera, a leaf level estimate of 7,062 µg/m^2/hr is derived. This is slightly lower than proposed in this study.

Likewise monoterpene and VOC emissions for a generic forested area were estimated in a similar fashion from the average of the three species with emissions under standard conditions of 480 µg/m^2/hr and 217 µg/m^2/hr respectively obtained.

■ Table 4-1 Emission Factors for VOC according to Land Use

Land Use	Emission factor [1] (µg/m^2/hr)			
	Isoprene	Monoterpenes	Other VOCs	Total VOCs
Pasture [2]	32.5	32.5	585	650
Crop [3]	55	80	48	183
Broadacre [3]	15	6	9	30
Horticulture [3]	38	95	57	190
Settlement [3]	409	162	201	772
Bare [3]	0	0	0	0
Water [3]	0	0	0	0
Native Vegetation [4]	9,556	480	175	10,200
Regrowth [4]	9,556	480	175	10,200
Pine Forests[5]	79	2,380	1,295	3,750

Notes:
1) Emission rate normalised to 30°C and photosynthetically active radiation of 1000 µmol/m^2/s.
2) Derived from Kirstine *et al* (1998).
3) Obtained from the South East Queensland Region NPI study (EPAV, 2002).
4) Derived from dominant local species after He *et al* (1999a).
5) Obtained from BEIS v2.3 (Radian Corporation, 1996).

4.2.3.3 Correction Factors

Studies by Lamb *et al* (1987) and Guenther *et al* (1993) highlight the fact that emissions of isoprenes from plants show a dependence on leaf temperature. Up to a leaf temperature of 30°C the emissions of isoprenes increased exponentially while over 40°C the emissions decrease. To account for this dependence on leaf temperature **Equation 4.3** is used to correct isoprene emissions. This equation has previously been used in other Australian emission inventory studies with the South East Queensland Region study (EPAV, 2002) being the most recent.

$$C_T = \frac{\exp\left[C_{T1} \times \left(T - T_S\right) \ / \ (R \times T_S \times T)\right]}{1 + \exp\left[C_{T2} \times \left(T - T_M\right) \ / \ (R \times T_S \times T)\right]}$$ **Equation 4.3**

Where:
C_T = Temperature correction factor
T = Leaf temperature (K)
T_s = Standard temperature (303K)
R = Ideal gas constant (8.314J/K/mol)
T_m = 314K
C_{T1} = 95,000J/mol
C_{T2} = 230,000J/mol

With monoterpenes, the emission mechanisms are poorly understood though it has been suggested that variations in both the long and short term appear to be controlled by temperature (Guenther *et al*, 1993). To account for this apparent variation in emissions, Guenther *et al* (1993) derived **Equation 4.4**. This equation has also been used in other Australian emission inventory studies with the South East Queensland Region study (EPAV, 2002) being the most recent.

$$C_T = \exp\left[\beta \times \left(T - T_S\right)\right]$$ **Equation 4.4**

Where:
C_T = Temperature correction factor
T = Leaf temperature (K)
T_s = Standard temperature (303K)
β = 0.09

Unlike monoterpene emissions, the emission rate of isoprenes is also dependent on solar radiation (Guenther *et al*, 1993). The dependence on solar radiation is very strong up to 50% of full sunlight, after which the emissions reach saturation. To account for this radiation dependence on isoprene emissions throughout a forest canopy, a five-layer canopy model is used as described in **Equation 4.5** and **Equation 4.6**.

$$C_L = \frac{C_{L1}}{5} \sum_{i=1}^{5} \frac{1}{\sqrt{1 + 1/(\alpha \times L_i)^2}}$$ **Equation 4.5**

Where:
C_L = Light correction factor
L_i = PAR flux at canopy level i (μmol/m^2/s)
α = 0.0027
C_{L1} = 1.066

$$L_i = L \times \exp\left[\frac{- E_L \times LAI \times (2 \times i - 1)}{10}\right]$$ **Equation 4.6**

Where:
L_I = PAR flux at canopy level i (μmol/m²/s)
L = above canopy PAR flux
E_L = Light extinction coefficient for PAR (0.42)
LAI = Leaf Area Index
I = Canopy number

To estimate the radiation flux (PAR) for the region, the Total Solar Radiation (TSR) measured at Wagerup was used. The TSR is converted to PAR by **Equation 4.7**.

$$PAR(\mu mol/m^2/sec) = (TSR(W/m^2) \times 0.49) \times 4.6$$ **Equation 4.7**

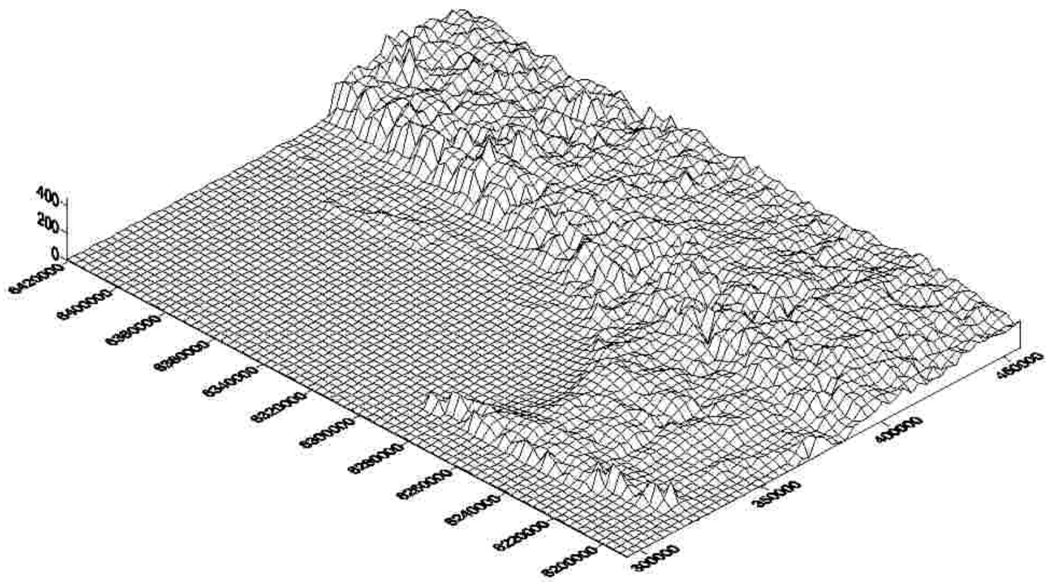
Where:
PAR = Photosynthetically Active Radiation. Note that *μ*mol is also known as *μ*E (10^{-6} Einstein's)
TSR = Total Solar Radiation

The multiplicative factor of 0.49, is the fraction of TSR in the wavelength band of 400nm to 700nm that is available for photosynthesis by plants. The factor 4.6 converts the units from W/m^2 to $\mu mol/m^2/sec$ for this wavelength band (CSIRO Division of Atmospheric Research, Cope, M., personal communication, 2003).

To account for the different temperatures that will occur with different elevations, a temperature correction was performed. The average height above sea level was calculated for each grid cell and this is presented in **Figure 4-1**. To avoid the complexities of correcting the temperature for every grid cell for every hour of the year, the elevations were separated into 100m intervals (100-200m, 200-300m) with the mid point being used in the actual calculations. The temperature was corrected for the difference in elevation over the Bunbury Regional Airshed by using **Equation 4.8** with a lapse rate of 0.01°C for every metre height change. Other methods that could be used to derive gridded temperatures, such as using a network of observations or predicted temperatures from a prognostic meteorological model like the CSIRO program TAPM have been neglected here due to time constraints.

$$T_i = T_o - 0.01 \times H_i - H_o$$ **Equation 4.8**

Where
T_I = Estimated Temperature (°C) at height H_I;
T_O = Observed Temperature (°C) at height H_o;
H_I = Height above sea level (m);
H_o = Height above sea level of observations.



■ **Figure 4-1 Ground Elevation of the Bunbury Regional Airshed**

4.2.3.4 Vegetation Classification

The emission factors for BEIS (as listed in **Table 4-1**) are based on a specific land usage. Land use in the Bunbury Regional Airshed was obtained from the Western Australian Agricultural Department for three levels of land use ranging from a primary (broad) to a tertiary (specific) classification. The three classifications were used to spatially assign percentage land usage to the appropriate BEIS land use as presented in **Table 4-2**.

■ **Table 4-2 BEIS Land Use Classification with Associated AgWA Descriptions**

BEIS Land Use	Classification		
	Primary	Secondary	Tertiary
Native Vegetation	Conservation & Natural Environment	Nature conservation, managed resource protection	National Parks, Strict nature reserves and Remnant cover
Regrowth	Production from Native Environment	Plantation Forestry	Hardwood plantation
Pine Plantations	Production from Dryland Agriculture and Plantations	Plantation Forestry	Softwood plantation
Pasture	Production from Dryland Agriculture	Grazing	Livestock grazing, Irrigated pastures, Hay and silage
Crop	Production from Dryland Agriculture	Cropping	Crops and cereals
Horticulture	Production from Irrigated Agriculture and Plantations Intensive uses	Irrigated perennial horticulture and intensive horticulture	Trees (fruit, nuts), vines, vegetables and glasshouses.
Settlement	Intensive uses	Manufacturing, residential and services	Urban and rural residential, recreation and manufacturing.
Bare	Mining	Mining	Mining
Water	Water	Conserved and managed natural and artificial water bodies	Water storage and treatment, aquaculture and conserved water areas.

4.2.3.5 Emission Estimation

The resultant land areas, VOC emissions for each land use type and total VOC emissions are presented in (**Table 4-3**).

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

Land Use types	Area (km^2)	VOC Emissions ($kg/km^2/year$)	VOC Emissions (t/yr)	Contribution (%)
Pasture	4,268	414	1,770	1.5
Crop	2,359	220	518	0.4
Horticulture	767	262	201	0.2
Settlement	283	1,018	288	0.2
Bare	100	0	0	0.0
Water	286	0	0	0.0
Pine Plantation	67	7,985	535	0.4
Native Vegetation	16,852	6,885	116,000	97.2
Total	24,983	4,776	119,000	100

It can be seen that native vegetation is by far the greatest contributor to VOC emissions due to its large area and very high VOC emission rate.

4.2.4 Spatial Allocation

Emissions were estimated on a 3 by 3km grid, dependent on vegetation type, vegetation spatial density and the temperatures, as described in **Section 4.2.3.3.**

4.2.5 Comparison to Other Studies

Emission estimates of VOC per square kilometre of land for the Bunbury Regional Airshed and other studies in Australia are presented in **Table 4-4**. These indicate quite a large variation in emissions with those from the South East Queensland Region study and Bunbury Regional Airshed studies being highest on a per kilometre basis. This is due to:

- The different methodologies used in the different studies with emission factors generally increasing over the years;
- Different mix of land categories for the different study area, and
- The large uncertainties in the emission rates and the assumptions involved.

- **Table 4-4 Comparison of VOC Emissions per Square Kilometre from Vegetation from Bunbury Regional Airshed with Other Airsheds**

Airshed	VOC Emissions from Airshed ($kg/km^2/yr$)
Bunbury Region (2002/2003)	4,780
Perth[1] (1998/1999)	2,480
Pilbara[2] (1999/2000)	5,500
Dandenong[3] (1994)	640
Port Pirie[3] (1994)	1,540
Newcastle[3] (1994)	4,920
Launceston[3] (1994)	800
Port Phillip Region[4] (1996)	36.7
Kalgoorlie[5] (1998/1999)	5,090
South East Queensland Region[6] (2000)	6,810

Notes:
1) Source DEP (2002).
2) Source SKM (2003).
3) Source EPAV (1996).
4) Source EPAV (1998).
5) Coffey Geosciences (1999).
6) Source EPAV (2002).

4.3 Biogenics – NO_x Emissions from Soils

4.3.1 Introduction

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.

4.3.2 Data Collection and Information Sources

Data required for emission estimates are temperature and landuse. The temperature data was obtained from the Bureau of Meteorology from their network of automatic weather stations while the landuse data was obtained from the WA Department of Agriculture.

4.3.3 Emission Estimation

Emission activity is 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).

4.3.3.1 Adopted Methodology – Modified BEIS2

Emissions of NO_x for the Bunbury Regional Airshed have been estimated using the modified BEIS2 system (Radian Corporation, 1996) that was used in the South East Queensland Region study (EPAV, 2002). This system was developed by the USEPA and is widely used for biogenic inventory studies throughout the USA. In Australia it has been used by the EPAV for the Port Phillip Region NPI inventory and with modifications for the South East Queensland Region study. The South East Queensland Region modifications were after the findings of Yienger and Levy (1995) that NO_x emissions are independent of soil temperature above 30°C. This method has been chosen over the empirical relationship developed by Yienger and Levy (1995) due to the complexities in obtaining reliable fertiliser usage of both tonnage application rates and spatial allocation and limited biomass burning data. The NO_x emission rate per grid cell is estimated using **Equation 4.9**.

Land use classifications used in BEIS2 and the associated emission factors are presented in **Table 4-5**. The land use in the Bunbury Regional Airshed was assigned to the appropriate areas as per the method described in **Section 4.2.3.4** using **Table 4-2**. It is noted that the emission factors for crops and pastures do not agree with the findings of Yienger and Levy (1995) mentioned in **Section 4.3.1** as it would be assumed that crops would be more heavily fertilised than pasture areas and therefore should have a higher NO_x emission factor.

- **Table 4-5 NO_x Emission Factors by Land Use (From BEIS2)**

Land Use	Emission Factor (µg/m²/hr)
Unclassified	58
Pasture	58
Crop	35
Broadacre	193
Horticulture	58
Settlement	13
Bare	0
Water	0
Regrowth	4.5
Native Vegetation	4.5

$$ER_{NO} = \begin{cases} \sum_j A_j \times EF_j \times 10^{-6} \times \exp\left[0.071 \times \left(T_j - 273\right)\right] & 273 < T_j < 303 \\ \sum_j A_j \times EF_j \times 10^{-6} \times \exp\left[0.071 \times 30\right] & T_j \geq 303 \\ 0 & T_j \leq 273 \end{cases}$$

Equation 4.9

Where:
ER_{NO} = NO emission rate per grid cell (g/hr);
A_j = Area of applicable land use cover (m^2);
EF_j = Emission factor for the land use (µg/m²/hr);
T_j = Soil temperature (K); and
j = Index of land use cover.

The soil temperature (T_j) is estimated from one of the three following equations which are based on the most appropriate land usage. The soil temperature chosen for each land usage is presented in **Table 4-6**.

$$Where\, T_j = \begin{cases} Grassland = 0.66 \times T_A + 101.67 \\ Forest = 0.84 \times T_A + 47.31 \\ Agricultural = 1.03 \times T_A - 5.29 \end{cases}$$

Equation 4.10

Where:
T_A = is the ambient air temperature (K).

As seen from **Table 4-5,** the BEIS2 methodology assumes that NO_x emission from water bodies is negligible. This assumption is made as "the global contribution of NO_x to the troposphere is estimated to be 2 percent" (Radian Corporation, 1996), with much of this coming from tropical waters. This methodology differs from some of the other Austrlaian studies (the National Pollutant Inventory trial (EPAV, 1996) and the New South Wales Metropolitan Air Quality Study (MAQS) study (Carnovale *et al*, 1997)) that estimated the NO_x emissions from water bodies due to nitrite photolysis.

In this study in keeping with the BEIS2 methodology, the minor contribution from the relatively cool waters off the south west has been neglected.

Fertiliser application is incorporated into the BEIS2 emission factors listed in **Table 4-5** with higher NO_x emissions from fertilised lands (pastures, crops, broadacre and horticulture) compared to that from native vegetation.

The soil temperature was calculated using the ambient temperature data from four Bureau of Meteorology monitoring stations and **Equation 4.10** for each hour and for each of the three land usages. The NO_x emission rate was then calculated as the sum of the emission from the various areas within each grid cell.

- **Table 4-6 Soil Temperature Classification**

Land Use	Soil Temperature Land Usage
Unclassified	Grassland
Pasture	Grassland
Crop	Agricultural
Broadacre	Agricultural
Horticulture	Agricultural
Settlement	Agricultural
Bare	-
Water	-
Regrowth	Forest
Native Vegetation	Forest

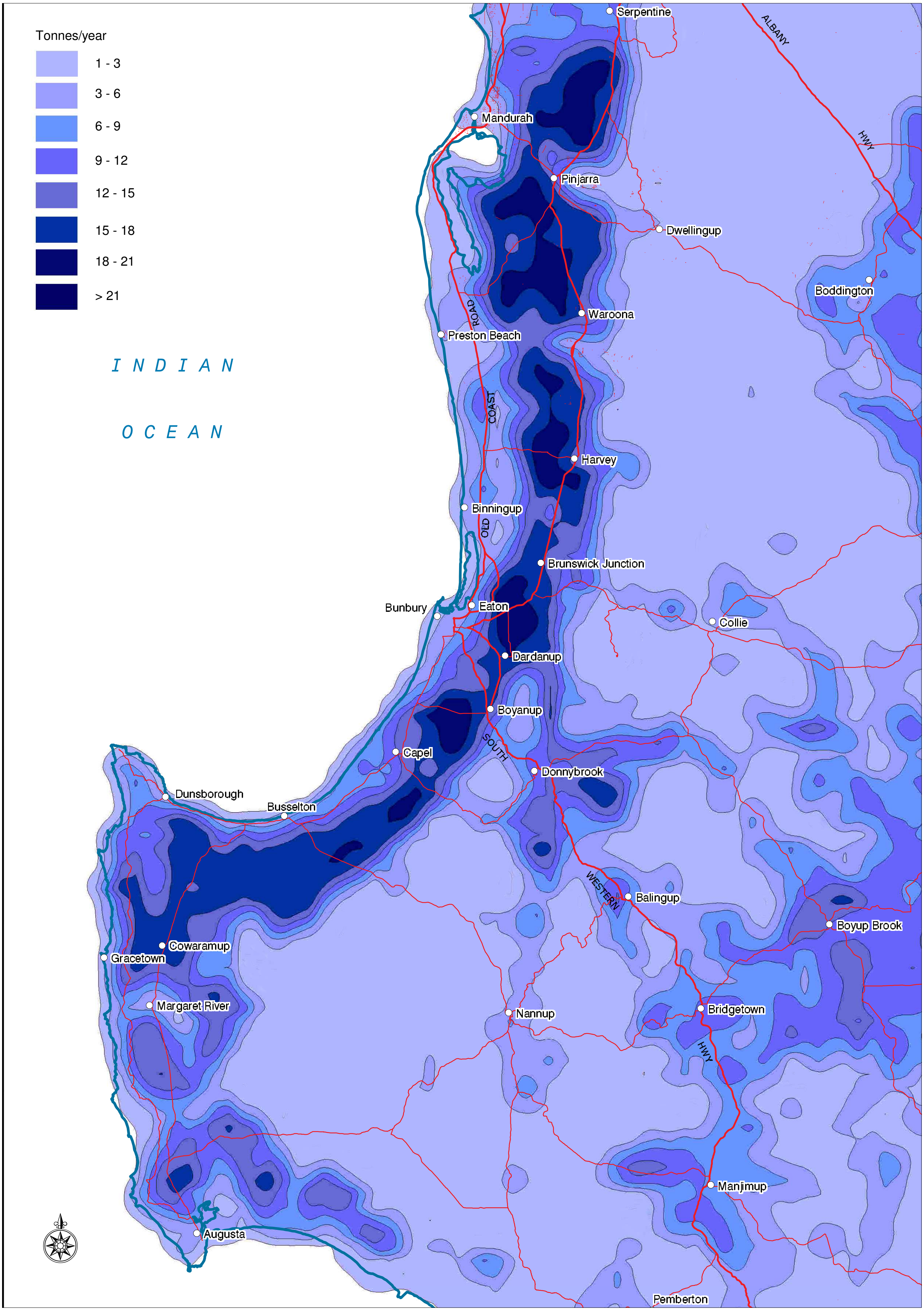
The resultant land areas, VOC emissions for each land use type and total VOC emissions are presented in **Table 4-7**.

- **Table 4-7 Total NO_x Emissions and Area for Each Category**

Land Use types	Area (km^2)	NO_x Emissions ($kg/km^2/year$)	NO_x Emissions (t/yr)	Contribution (%)
Pasture	4,268	1,619	6,909	45.4
Crop	2,359	1,533	3,617	23.8
Horticulture	767	2,948	2,261	14.9
Settlement	283	176	135	0.9
Bare	100	0	0	0.0
Water	286	0	0	0.0
Native Vegetation	16,919	136	2,300	15.0
Total	**24,983**	**609**	**15,222**	**100**

4.3.4 Spatial Allocation

Emissions were estimated on a 3 by 3km grid, dependent on air temperature and land use. This is presented in **Figure 4-2**.



SKM
SINCLAIR KNIGHT MERZ
Sinclair Knight Merz
263 Adelaide Tce
Perth WA 6001
Tel: 08-92684400

**NOx Soil Emissions (tonnes/yr)
within Study Area**

Figure 4-2

K:\Wves\02400\Wv02428\100\Gis\NOx_level_map.wor

4.3.5 Comparison with Other Studies

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

- **Table 4-8 Comparison of Nox Emissions from Soil from Bunbury Regional Airshed with Other Airsheds**

Airshed	NO_x Emissions ($kg/km^2/yr$)
Bunbury Region	609
Pilbara[1]	112
South East Queensland Region[2]	255
Dandenong[3]	190
Port Pirie[3]	491
Newcastle[3]	135
Launceston[3]	122
Port Phillip Region[4]	1.25
Kalgoorlie[5]	304

Notes:
1) Source SKM (2003).
2) Source EPAV (2002).
3) Source EPAV (1996).
4) Source EPAV (1998).
5) Coffey Geosciences (1999).

Table 4-8 indicates that emissions are higher than other Australian studies. This difference between the various studies is due to land use and climate within the Airsheds and the methodologies employed.

4.4 Windblown Dust

4.4.1 Introduction

Windblown dust (PM_{10}) emissions arise from the action of wind which suspends the finer fractions of soil into the air and may be a significant cause of elevated dust levels. This source is generally the largest fugitive dust source (i.e. from a non-controlled source such as a stack), excepting from fires. Other sources of fugitive PM_{10} include dust generated from farming operations such as ploughing, dust from cattle feed lots and dust from construction and demolition activities. These sources can be accounted for in a detailed inventory (see the California inventory, (CARB, 2002)), but are not part of this study.

4.4.2 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 PM_{10} for the Bowen Basin.

This methodology was used to estimate windblown dust from two sources, wind erosion from agricultural sources and from unpaved road as per CARB (1997). Wind erosion from bare areas (generally mining areas) within the study region were discounted as they are covered by the individual facilities estimates (e.g. Alcoa's mine sites).

Data required for this method include:

- Areas within the Bunbury Regional Airshed that are used for cropping were obtained from Agricultural Western Australia;

- Unpaved road areas obtained from the length of unpaved roads in the Bunbury Regional Airsheds; and
- Wind, temperature and rainfall records obtained from the Bureau of Meteorology.

The area of unpaved roads was determined from the total length of unpaved roads in the Bunbury Regional Airshed of 36,534 km. Of these roads, 42km are major unsealed, 10,062 km are minor unsealed and 26,430 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 0.42, 80.5 and 106 km^2 or a total unpaved road area of 186.9 km^2.

4.4.3 Emission Estimation

Emissions were calculated after CARB (1997) according to:

$$E = k \times a \times l \times K \times C \times L' \times V'$$ **Equation 4.11**

Where:
E = PM_{10} fraction of particulate wind erosion losses (t/acre/yr);
k = fraction of particulate emissions which is PM_{10} (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:

$$C = 0.0828 \times \frac{W^3}{(PE)^2}$$ **Equation 4.12**

$$PE = \sum_{i=1}^{12} PE_i = 1.644 \left[\frac{P_i}{(T_i + 12.2)} \right]^{\frac{10}{9}}$$

Where:
C = climatic factor
W^3 = 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 = 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 = monthly rainfall (mm).
T_I = average temperature for that month (°C).
I = month of the year.

Wind data from the Bureau of Meteorology was available from four automatic weather stations in the Bunbury Regional Airshed. These stations were used as they provided hourly wind speeds that gave 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 4 zones. This is an approximation and does lead to step changes at zone boundaries, but with the lack of good quality wind stations in the region was thought justifiable. It is noted that sites such as Cape Leuwin and Cape Naturaliste were rejected as these sites suffer substantial wind speed up effects being on elevated, exposed sites.

A Thornwaite precipitation- evaporation (PE) index grid was generated using precipitation and temperature data from the four stations. A higher PE index represents less erodibility.

Climate "C" factors were then derived using **Equation 4.12** for each grid cell. These are summarised in **Table 4-9** for the 4 automatic weather station sites and range from 0.36 at the inland site of Bridgetown to 1.23 at Bunbury. This wide variation is primarily due to the variation in average wind speed at the sites, with the C factor being very sensitive to relatively small changes in annual wind speed.

- **Table 4-9 Estimated PM_{10} Potential Erosion Rates for Selected Sites in the Bunbury Regional Airshed**

Station	Average Wind Speed @10m (m/s)	Annual PE value	C Factor
Dwellingup	4.5	60.1	1.01
Bunbury	4.3	49.5	1.23
Witchcliffe	4.5	72.0	0.68
Bridgetown	2.6	42.3	0.36

4.4.3.1 Wind Erosion from Agricultural Areas

Estimates of PM_{10} emissions from agricultural areas were made based on the following:

- The area for cropping supplied by Agricultural Western Australia, with this area assumed cropped once every two years. That is, the area subject to wind erosion was halved. Dust from bare areas (mining areas) were neglected as they would be covered under the individual mine reporting, whilst that from horticultural land was neglected as generally any bare areas occur within rows of well vegetated trees or vines, that will tend to suppress dust lift-off;
- Soil Erodibility Index. A value of 86 (t/acre/yr) was assumed. This corresponds to soil with a Sandy loam texture;
- Surface roughness factor taken as 0.6 which is the USEPA default factor for wheat;
- Unsheltered field width factor taken as 0.6 to account for some sheltering due to vegetation on the edges of the agricultural areas, the undulating topography and that the areas are finite in size; and
- Vegetative cover factor equal to 0.125 (1.5 months of the year) to account for the time after tillage when the land is subject to wind erosion.

Using these factors and the climate factor, E factors (PM_{10} emissions per hectare per year) were calculated across the grid. Emissions of PM_{10} from wind erosion from agricultural areas within the Bunbury Regional Airshed were estimated at 8,332 tonnes/yr. Most of this was estimated to occur for the eastern portion of the study region corresponding to the wheatbelt.

4.4.3.2 Unpaved Roads

Windblown dust emissions from all unpaved roads are also estimated using **Equation 4.11** with the following assumptions to quantify the variables (CARB, 1997 and Countess, 1999):

- 'a' assumed to be 0.038 with the PM_{10} fraction 50%;
- 'I' soil characteristics assumed to be the same as roadside soil. For the Bunbury Regional Airshed this was taken as less than that for the open areas at 38 ton/acre/year;
- 'k' assumed to be 0.8 to account for the undulating topography in the inland regions of the Bunbury Regional Airshed (**Figure 4-1**);
- 'L' assumed to be 0.3; and
- 'V' assumed to be 0.7 as even though the roads themselves tend not to have any vegetation the majority of the unsealed roads in this Bunbury Regional Airshed are tracks which are relatively enclosed.

The resultant PM_{10} estimates from unpaved roads are estimated to be 4,773 tonnes of PM_{10} emitted annually.

4.4.3.3 Total Emissions of Windblown PM_{10} and Metals

Taking into account both windblown emissions from bare erodible areas and from unpaved roads the total windblown PM_{10} emissions for the Bunbury Regional Airshed are estimated at 13,105 tonnes/year, with 63.6% from wind erosion and 36.4% from unpaved roads.

Emissions of metals and PM_{10} from the study are presented in **Table 4-10**. Metal emissions were estimated using the default unpaved road metal fractions in the NPI paved and unpaved road manual and wind blown dust from erodible areas from the soil fraction in the EET Manual for Mining (Environment Australia, 2001b).

- **Table 4-10 Emissions from Windblown Dust in the Bunbury Regional Airshed**

Substance	Total Emissions (kg/yr)
Antimony & compounds	93.0
Arsenic & compounds	234
Beryllium & compounds	5.00
Boron & compounds	333
Cadmium & compounds	216
Chromium (III) compounds	1,170
Cobalt & compounds	1,500
Copper & compounds	1,340
Fluoride compounds	3,330
Lead & compounds	8,860
Manganese & compounds	26,000
Mercury & compounds	144
Nickel & compounds	1,450
Particulate matter (PM_{10})	13,100,000
Selenium & compounds	126
Zinc & compounds	59,300

4.4.4 Spatial Allocation

Estimates of PM_{10} and metals were derived on a 3 by 3km grid from the Bunbury Regional Airshed. Estimates were obtained for each grid cell based on the climatic factors for that cell and the areas of that are subjected to cropping and unpaved roads.

4.4.5 Comparison to Other studies

Estimates of dust loss from wind erosion have been derived from dust measurements during windstorms in Australia. Raupach *et al* (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 dust emissions in the size range (6.75-10.3 μm) 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 wind emissions of 6 million tonnes from Australia.

A comparison to other studies that used the revised WEQ methodology is presented in **Table 4-11**. This Table indicates that per unit area that the Bunbury Regional Airshed emissions are 1.1 and 1.9 times that from the Pilbara and Californian regions. The higher emissions in this study are considered to result from the high area of cropping in the eastern part of the region and high length of unpaved roads, but may also indicate an over-prediction due to the uncertainty in some of the assumptions.

- **Table 4-11 Estimated Windblown PM_{10} Emissions**

Region	Wind Blown PM_{10} Emissions (tpa)			Wind Blown PM_{10} Emissions (tpa/km^2)
	Agricultural Areas	Unpaved Roads	Total	
Bunbury Regional Airshed	8,330	4,770	13,100	0.52
Pilbara [1]	163,240	8,760	172,000	0.47
California [2]	66,400	44,100	110,500	0.27

Notes:
1) Source SKM (2003).
2) Source CARB (2002). Note for this study agricultural practices such as tillage, harvesting, growing and livestock were estimated to add another 80,970 tpa or 0.20 tpa/km^2.

4.5 Burning and Wildfires

4.5.1 Data Collection and Information Sources

Areas burnt within the Bunbury Regional Airshed were sourced from the Department of Conservation and Land Management (CALM). This information was spatially supplied as the area burnt by either wildfires or prescribed burns on the 3 by 3km grid cell basis used in this study.

For roadside burning, agricultural burning and burning conducted under permits the chief fire control officer from each shire in the Bunbury Regional Airshed was contacted. Information from all shires was that roadside burning is not conducted and that burning as part of an agricultural regime is decreasing with some shires saying the practice has ceased completely. Unfortunately although a list of the number of permits issued each year is kept there was little information on the purpose of and the size of the burn.

For this period the total area burnt in the Bunbury Regional Airshed was 52,170 ha, which is approximately 1.4% of the Bunbury Regional Airshed and 2.1% of the land area. A breakdown of the area burned by type of fire is given in **Table 4-12**.

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:

$$E_{ij} = A_{ik} \times L_{ik} \times EF_{jk} \times 10^{-3}$$ **Equation 4.15**

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))

For fuel loading and burn efficiency rates from the EET Manual default factors for Western Australia were used as presented in **Table 4-12**. CALM was contacted on these default values and indicated that they were generally appropriate for forest fires, but that a total fuel loading of 3,000 kg/ha was more appropriate for grassland (CALM, Sneeuwjagt, R., personal communication, 2003). More accurate values could be obtained, but this would require considerable resources to estimate.

■ **Table 4-12 Default Loadings for Western Australia and areas burned**

	Forest Wildfires	Forest Prescribed Burning	Temperate Grassland [3]
Total Fuel Loading (kg/ha)[1]	41,100	12,000	10,000 (3,000)
Burn Efficiency Rates (%)[2]	72	42	72
Fuel Loading of Burn (kg/ha)[2]	29,600	5,040	7,200 (2,160)
Area Burned (ha)[4]	9,760	42,410	Negligible

Notes:
1) Source DEST (1996)
2) Source Table 2 of EET Manual for Aggregated Emissions from Prescribed Burning and Wildfires (Environment Australia, 1999k).
3) Values in brackets are suggested by CALM, Sneeuwjagt, R., personal communication (2003).
4) Source CALM.

The emission factors used to calculate the emissions (from the EET Manual) are summarised in **Table 4-13** along with the resultant emission factors in terms of g/ha and the derived total emissions in **Table 4-14**.

Table 4-13 Emission factors from open burning

Substance	Forest Wildfires[1] (g/kg)	Prescribed Forest Burning[1] (g/kg)	Grassland[1] (g/kg)
Antimony & compounds	$3.91x10^{-4}$	$8.28x10^{-4}$	$4.60x10^{-3}$
Arsenic & compounds	$2.55x10^{-5}$	$5.4x10^{-5}$	$3.00x10^{-5}$
1,3-Butadiene	$9.48x10^{-2}$	$5.73x10^{-2}$	$4.40x10^{-2}$
Cadmium & compounds	$5.27x10^{-4}$	$1.12x10^{-3}$	$6.20x10^{-4}$
Chromium (VI) compounds	$2.64x10^{-4}$	$5.58x10^{-4}$	$3.10x10^{-4}$
Carbon monoxide	70	112	83.6
Cobalt & compounds	$9.35x10^{-5}$	$1.98x10^{-4}$	$1.10x10^{-4}$
Copper & compounds	$1.87x10^{-4}$	$3.96x10^{-4}$	$2.20x10^{-4}$
Lead & compounds	$4.34x10^{-4}$	$9.18x10^{-4}$	$5.10x10^{-4}$
Manganese & compounds	$1.07x10^{-3}$	$2.27x10^{-3}$	$1.26x10^{-3}$
Mercury & compounds	$1.11x10^{-4}$	$2.34x10^{-4}$	$1.30x10^{-4}$
Nickel & compounds	$1.53x10^{-4}$	$3.24x10^{-4}$	$1.80x10^{-4}$
Oxides of nitrogen	2	2	6.36
Particulate matter (PM_{10})	7.48	12	10
Selenium & compounds	$4.25x10^{-5}$	$9.0x10^{-5}$	$5.00x10^{-5}$
Total VOCs	10.6	6.4	4.90
Zinc & compounds	$7.14x10^{-4}$	$1.52x10^{-3}$	$8.40x10^{-4}$

Notes:
1) Source Table 4 of EET Manual for Aggregated Emissions from Prescribed Burning and Wildfires (Environment Australia, 1999k).

Table 4-14 shows that even though the emission factors for PM_{10} are higher per kg of fuel burnt for prescribed burning versus wildfires, the overall emissions per hectare are much greater from the wildfires due to the much higher fuel consumption.

Table 4-14 Calculated total emissions for open burning

Substance	Forest Wildfires (kg/ha)	Prescribed Forest Burning (kg/ha)	Grassland (kg/ha)	Total Emissions (kg/yr)
Antimony & compounds	0.012	0.004	0.033	290
Arsenic & compounds	0.0008	0.0003	0.0002	18.9
1,3-Butadiene	2.806	0.289	0.317	39,600
Cadmium & compounds	0.016	0.006	0.004	392
Chromium (VI) compounds	0.008	0.003	0.002	196
Carbon monoxide	2,072	564	602	44,200,000
Cobalt & compounds	0.003	0.001	0.001	69.3
Copper & compounds	0.006	0.002	0.002	139
Lead & compounds	0.013	0.005	0.004	322
Manganese & compounds	0.032	0.011	0.009	794
Mercury & compounds	0.003	0.001	0.001	82.1
Nickel & compounds	0.005	0.002	0.001	113
Oxides of nitrogen	59.2	10.1	45.8	1,010,000
Particulate matter (PM_{10})	221	60.5	72.0	4,730,000
Selenium & compounds	0.001	0.0005	0.0004	31.5
Total VOCs	314	32.3	35.3	4,430,000
Zinc & compounds	0.021	0.008	0.006	531

4.5.3 Spatial Allocation

Emissions were spatially allocated proportionally to the area burnt within each grid cell on a 3 by 3km grid.

4.5.4 Comparison with Other Studies

Emissions from the Bunbury Regional Airshed of PM_{10} and NO_x as a total and per unit land area are presented in **Table 4-15** along with data from other studies. These show that the Bunbury Regional Airshed estimates are similar to Perth estimates on an area basis as approximately the same percentage land area is burned. The emissions from both these studies are less than that from the Pilbara and Northern territory on a land area basis, due to the high percentage of the land area that is burned in the northern areas of Australia. Considering the total emissions, the Pilbara and Northern Territory emissions are both much greater than the Bunbury or Perth Regional Airshed emissions, due to the large area of these regions.

- **Table 4-15 Comparison of PM_{10} and NO_x Emissions from Open Burning from Bunbury Regional Airshed with Other Airsheds**

Airshed	Land Area (km^2)	Area Burned (km^2)	Land Area Burned (%)	PM_{10} Emissions (tonne)	PM_{10} Emissions (tonnes/ km^2)	NO_x emissions (tpa)	NO_x Emissions (tonnes/km^2)
Bunbury Region	24,983	521	2.1	4,730	0.19	1,010	0.04
Pilbara[1]	362,165	27,059	7.5	195,000	0.54	124,000	0.34
Perth[2]	6,450	126	1.95	1,871	0.29	316	0.05
California[3]	411,000	Not known	Not Known	33,400	0.081	3,340	0.0081
Northern Territory[4]	1,347,224	73,729	5.5	620,000	0.46	110,000	0.08

Notes:

1) Source SKM (2003). The area reported burned in SKM (2003) is below average, with the percentage area burned over the period 1996 to 2002 ranging from 0.9% to 26.2% with an average of 11.2% (DOLA, Tovar, M., personal communication, 2003).
2) Source DEP (2002).
3) Source CARB (2000).
4) Source Beringer *et al* (1995). PM_{10} estimates assume all particulate matter is below 10 um. Beringer *et al* (1995) claims that the 1992 estimates will be lower than usual due to a very dry year.

Note: CALM prescribed burning activities are normally undertaken when forecast weather conditions will transport the emissions away from populated areas, significantly reducing the exposure of the community.

5. Summary

Emissions of all substances from aggregated sources in the Bunbury Regional Airshed 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 individual anthropogenic emissions as a percentage of the total 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 113,000 tonnes. Motor vehicles contribute 39.9% of all aggregate CO emissions, wildfires contribute 39.1% and domestic solid fuel burning 15.5%.
- Total PM_{10} emissions are 133,000 tonnes. The major sources of PM_{10} emissions are from paved and unpaved roads, which contributes 85.0% of the total emissions and windblown dust which accounts for 9.8% of emissions.
- Total NO_x emissions are 26,900 tonnes. 60.3% of these emissions are predominantly from "natural" sources with 56.5% from biogenic sources and 3.8% from wildfires. The next most significant emissions of NO_x are from motor vehicles, which contribute 20.3%.
- Total SO_2 emissions are 991 tonnes. Commercial shipping and boating dominate these emissions, with 55.4% of all aggregate SO_2. Fuel combustion sub reporting threshold is next with 22.1%.
- Total lead emissions are 391 tonnes. Emissions from paved and unpaved roads dominate with 97.6%.
- Total VOC emissions are 135,000 tonnes with these predominantly arising from natural sources, with biogenic sources contributing 88.1% and wildfires 3.3%.

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

With regards to anthropogenic emissions:

- Emissions of CO are dominated by motor vehicles, which contribute 65.2%, and domestic solid fuel burning which contributes 25.3%;
- Emissions of PM_{10} are dominated by dust from paved and unpaved roads (98.1%);
- Total NO_x emissions are dominated by motor vehicles, which contribute 50.9% and sub-threshold facility fuel combustion contributing 26.8%;
- Commercial shipping and boating dominate SO_2 emissions with contributions of 55.4% of all aggregate SO_2, with sub-threshold facility fuel combustion contributing 22.1%;
- Lead emissions are dominated by dust from paved and unpaved roads (99.9%); and
- The major sources of total VOC are 36.6% from motor vehicles and 27.1% from domestic solid fuel burning.

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■ **Table 5-1 Emissions of NPI Substances in the Bunbury Regional Airshed (Tonnes per Annum)**

	MOBILE SOURCES						DOMESTIC / COMMERCIAL SOURCES														NATURAL SOURCES			
	Motor vehicles	Agriculture (Machinery)	Railways	Aeroplanes	Commercial Shipping/Boating	Recreational Boating	Domestic/ Commercial solvents/ aerosols	Gaseous fuel burning (domestic)	Lawn Mowing	Lawn Mowing (public open spaces)	Service Stations	Architectural Surface Coatings	Motor Vehicle Refinishing	Dry Cleaning	Solid fuel burning (domestic)	Fuel Combustion – sub reporting threshold facilities	Natural Gas Leakages	Paved/ Unpaved Roads	Cutback Bitumen	Bakeries	Biogenics	Windblown Dust	Burning / Wildfires	TOTAL EMISSIONS
Acetaldehyde	58.2	0	0.445	0.364	1.43	8.85	0	0	0	0.232	0	0	0	0	234	36.8	0	0	0	0	0	0	0	**340**
Acetone	32.3	0	0	0.247	0	0	0	0	0	0.122	0	26.96	0.935	0	173	19.3	0	0	0	0	0	0	0	**253**
Acrylic acid	0	0	0	0	0	0	3.60E-07	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Antimony & compounds	0	0	0.00113	0	0.00315	3.51E-05	0	0	0	0	0	0	0	0	0.00948	0	0	3.56	0	0	0	0.093	0.290	**3.96**
Arsenic & compounds	0	0	2.46E-05	0	0.00720	3.67E-05	0	5.26E-05	0	0	0	0	0	0	0.00632	4.11E-04	0	6.16	0	0	0	0.234	0.0189	**6.43**
Benzene	215.9	0.00176	0.260	0.151	0.903	17.1	4.30E-04	0.0289	11.3	2.06	1.45	0.474	0	0	161	3.01	0	0	0.0122	0	0	0	0	**414**
Beryllium & compounds	0	0	0	0	0.00790	1.34E-04	0	1.58E-06	0	0	0	0	0	0	0	2.44E-05	0	0	0	0	0	0.00500	0	**0.0131**
Biphenyl (1,1-biphenyl)	0	0	0	0	0	0	0	0	0	0	8.87E-07	0	0	0	0	0	0	0	0.0302	0	0	0	0	**0.0302**
1,3-Butadiene (vinyl ethylene)	21.5	6.86E-04	0.237	0.132	0.691	4.15	0	0	1.43	0.261	0.140	0	0	0	2.41	0.343	0	0	0	0	0	0	39.6	**70.9**
Boron & compounds	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.33	0	**0.333**
Cadmium & compounds	0.0557	0	5.49E-04	0	3.02E-04	3.81E-06	0	2.89E-04	0	0	0	0	0	0	0.00272	0.129	0	9.64	0	0	0	0.216	0.392	**10.0**
Carbon disulphide	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Carbon monoxide	45,100	592	44.2	137	128	1,420	0	12.9	718	186	0	0	0	0	17,500	3,340	0	0	0	0	0	0	44,200	**113,000**
Chloroform (trichloromethane)	0	0	0	0	0	0	0.0903	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0.0903**
Chromium (III) compounds	0.00805	0	5.22E-05	0	0.00188	2.60E-04	0	0	0.00207	0.00135	0	0	0	0	7.21E-05	0.0167	0	0	0	0	0	1.17	0	**1.20**
Chromium (VI) compounds	0.00364	0	2.17E-05	0	8.10E-04	1.08E-04	0	0.00318	8.60E-04	0.000574	0	0	0	0	3.00E-05	0.00719	0	0	0	0	0	0	0.196	**0.21**
Cobalt & compounds	0.0105	0	4.92E-05	0	0.00475	3.80E-04	0	0.0103	0.00293	0.00192	0	0	0	0	0.00158	0.0213	0	62.6	0	0	0	1.50	0.0693	**64.2**
Copper & compounds	0.0146	0	2.46E-04	0	0.0135	3.83E-04	0	4.79E-04	0.00293	0.00192	0	0	0	0	0	0.0230	0	39.3	0	0	0	1.34	0.139	**40.8**
Cumene (1-methylethylbenzene)	0	0	0	0	0	0	0	0	0	0	0.0498	0	0	0	0	0	0	0	0.0655	0	0	0	0	**0.115**
Cyanide (inorganic) compounds	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Cyclohexane	4.17	0	0	0	0	0	0	0.0362	0.343	0.063	4.45	174.4	0.382	0	0	0.194	0	0	0.0191	0	0	0	0	**184.1**
1,2-Dichloroethane	0	0	0	0	0	0	4.26E-04	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**4.26E-04**
Dichloromethane	0	0	0	0	0	0	3.32	0	0	0	0	8.70	0	0	0	0.180	0	0	0	0	0	0	0	**12.2**
Ethanol	0	0	0	0	0	0	0	0	0	0	0	5.056	0	0	0	0	0	0	0	2.82	0	0	0	**7.88**
2-Ethoxyethanol acetate	0	0	0	0	0	0	0	0	0	0	0	10.95	0	0	0	0	0	0	0	0	0	0	0	**10.95**
Ethyl Acetate	0	0	0	0	0	0	0	0	0	0	0	0	1.50	0	0	0	0	0	0	0	0	0	0	**1.50**
Ethylbenzene	46.8	0	0.00897	0.0126	0.0464	3.29	0.189	0	2.63	0.476	0.664	0	0.397	0	0	0.141	0	0	0.0865	0	0	0	0	**54.7**
Ethylene glycol (1,2-ethanediol)	0	0	0	0	0	0	8.33	0	0	0	0	5.85	0	0	0	0	0	0	0	0	0	0	0	**14.18**
Ethylene oxide	0	0	0	0	0	0	1.38	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**1.38**
Di-(2-Ethylhexyl) phthalate (DEHP)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Fluoride compounds	0	0	0	0	0	0	0.00130	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3.3	0	**3.33**
Formaldehyde (methyl aldehyde)	70.9	19.3	1.32	1.19	4.16	13.4	0.116	0.0866	2.04	0.507	0	0	0	0	252	48.0	0	0	0	0	0	0	0	**413**
n-Hexane	59.8	0	0.211	0	0.676	3.70	7.86	0.481	0.761	0.170	6.08	174.4	0	0	0	3.87	0	0	0.0638	0	0	0	0	**258**
Hydrochloric acid	0	0	0	0	0	0	1.60E-04	0	0	0	0	0	0	0	0	0.352	0	0	0	0	0	0	0	**0.352**
Hydrogen sulphide	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3.64	0	0	0	0	0	0	**3.64**
Lead & compounds	0.230	0	2.46E-04	0	0.00217	0.00592	0	3.87E-04	6.17E-05	0.00142	2.76E-05	0	0	0	0.0253	0.0230	0	382	0	0	0	8.9	0.322	**391**
Manganese & compounds	0.0128	0	1.89E-04	0	5.11E-05	3.54E-04	0	3.56E-04	0.00293	0.00192	0	0	0	0	0.0187	0.0220	0	426	0	0	0	26.0	0.794	**453**
Mercury & compounds	0	0	2.05E-04	0	4.25E-04	9.18E-06	0	6.62E-05	0	0	0	0	0	0	0	5.40E-04	0	6.60	0	0	0	0.144	0.0821	**6.83**
Methanol	0	0	0	0	0	0	64.2	0	0	0	0	32.86	0	0	0	0	0	0	0	0	0	0	0	**97.1**
Methyl ethyl ketone	0	0	0	0	0	0	4.61	0	0	0	0	47.19	2.06	0	12.1	0	0	0	0	0	0	0	0	**65.9**
Methyl isobutyl ketone	0	0	0	0	0	0	0.692	0	0	0	0	5.056	0.264	0	0	0	0	0	0	0	0	0	0	**6.01**
Nickel & compounds	0.00209	0	1.23E-04	0	0.399	0.00337	0	0.00336	0.00293	5.14E-04	0	0	0	0	0.00158	0.00441	0	28.6	0	0	0	1.45	0.113	**30.6**
Oxides of nitrogen	5,460	831	349	1.62	815	9.73	0	42.5	3.74	104	0	0	0	0	233	2,880	0	0	0	0	15,200	0	1,010	**26,900**
Particulate Matter <10.0 um (PM_{10})	145	86.9	8.20	0	86.0	1.07	0	2.52	4.86	15.0	0	0	0	0	1,570	227	0	113,000	0	0	0	13,100	4,730	**133,000**
Phenol	0	0	0	0.0185	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0.0185**
Polycyclic aromatic hydrocarbons (PAHs)	8.45	0	0.111	0.0800	0.00731	0.916	0	1.81E-04	0.594	0.118	0.00866	0	0	0	56.8	1.60	0	0	0.248	0	0	0	0	**70.0**
Selenium & compounds	0	0	3.28E-05	0	0.00479	7.97E-05	0	0.00282	0	0	0	0	0	0	0.00158	4.88E-05	0	0.448	0	0	0	0.126	0.0315	**0.615**
Styrene (ethenylbenzene)	6.67	0	0	0.0311	0.00238	0.422	0	0	0.202	0.0365	0	0	0	0	1.17	0.0200	0	0	0	0	0	0	0	**8.56**
Sulphur dioxide	103	59.9	15.3	0.250	548	1.43	0	0.137	0.263	1.55	0	0	0	0	42.2	219	0	0	0	0	0	0	0	**991**
Tetrachloroethylene	0	0	0	0	0	0	2.57	0	0	0	0	0	0	2.65	0	0	0	0	0	0	0	0	0	**5.22**
Toluene (methylbenzene)	340	0	0.263	0.0412	1.11	52.8	39.0	0.0152	19.0	3.46	6.41	43.81	55.4	0	66.2	4.46	0	0	0.0750	0	0	0	0	**632**
Trichloroethylene	0	0	0	0	0	0	0.0442	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0.0442**
Xylenes (individual or mixed isomers)	240	0	0.0419	0.0370	0.510	16.2	18.5	0	13.9	2.55	2.55	21.91	20.1	0	24.2	3.47	0	0	0.553	0	0	0	0	**365**
Zinc & compounds	0.504	0	0.00328	0	0.0162	7.11E-04	0	0.0104	0.00293	0.0104	0	0	0	0	1.17	0.209	0	269	0	0	0	59.3	0.531	**330**
Total Volatile Organic Compounds	4,250	123	15.0	8.42	44.6	423	1,040	1.83	202	38.1	189	1,001	164	0	3,140	454	454	0	45.7	2.83	119,000	0	4,430	**135,000**

■ **Table 5-2 Emissions of NPI Substances in the Bunbury Regional Airshed (Percentage of Total Emissions)**

	MOBILE SOURCES						DOMESTIC / COMMERCIAL SOURCES														NATURAL SOURCES			
	Motor vehicles	Agriculture (Machinery)	Railways	Aeroplanes	Commercial Shipping/Boating	Recreational Boating	Domestic/ Commercial solvents/ aerosols	Gaseous fuel burning (domestic)	Lawn Mowing	Lawn Mowing (public open spaces)	Service Stations	Architectural Surface Coatings	Motor Vehicle Refinishing	Dry Cleaning	Solid fuel burning (domestic)	Fuel Combustion – sub reporting threshold facilities	Natural Gas Leakages	Paved/ Unpaved Roads	Cutback Bitumen	Bakeries	Biogenics	Windblown Dust	Burning / Wildfires	Total
Acetaldehyde	17.09	-	0.13	0.11	0.42	2.60	-	-	-	0.07	-	-	-	-	68.76	10.82	-	-	-	-	-	-	-	100
Acetone	12.75	-	-	0.10	-	-	-	-	-	0.05	-	10.65	0.37	-	68.46	7.63	-	-	-	-	-	-	-	100
Acrylic acid	-	-	-	-	-	-	100.00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	100
Antimony & compounds	-	-	0.03	-	0.08	0.00	-	-	-	-	-	-	-	-	0.24	-	-	89.97	-	-	-	2.35	7.33	100
Arsenic & compounds	-	-	0.00	-	0.11	0.00	-	0.00	-	-	-	-	-	-	0.10	0.01	-	95.85	-	-	-	3.64	0.29	100
Benzene	52.14	0.00	0.06	0.04	0.22	4.13	0.00	0.01	2.73	0.50	0.35	0.11	-	-	38.98	0.73	-	-	0.00	-	-	-	-	100
Beryllium & compounds	-	-	-	-	60.50	1.03	-	0.01	-	-	-	-	-	-	-	0.19	-	-	-	-	-	38.27	-	100
Biphenyl (1,1-biphenyl)	-	-	-	-	-	-	-	-	-	-	0.00	-	-	-	-	-	-	-	100.00	-	-	-	-	100
1,3-Butadiene (vinyl ethylene)	30.26	0.00	0.33	0.19	0.97	5.86	-	-	2.02	0.37	0.20	-	-	-	3.40	0.48	-	-	-	-	-	-	55.92	100
Boron & compounds	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	100.00	-	100
Cadmium & compounds	0.53	-	0.01	-	0.00	0.00	-	0.00	-	-	-	-	-	-	0.03	1.24	-	92.37	-	-	-	2.07	3.75	100
Carbon disulphide	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0
Carbon monoxide	39.91	0.52	0.04	0.12	0.11	1.26	-	0.01	0.64	0.16	-	-	-	-	15.49	2.96	-	-	-	-	-	-	39.12	100
Chloroform (trichloromethane)	-	-	-	-	-	-	100.00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	100
Chromium (III) compounds	0.67	-	0.00	-	0.16	0.02	-	-	0.17	0.11	-	-	-	-	0.01	1.40	-	-	-	-	-	97.45	-	100
Chromium (VI) compounds	1.72	-	0.01	-	0.38	0.05	-	1.50	0.41	0.27	-	-	-	-	0.01	3.39	-	-	-	-	-	-	92.26	100
Cobalt & compounds	0.02	-	0.00	-	0.01	0.00	-	0.02	0.00	0.00	-	-	-	-	0.00	0.03	-	97.48	-	-	-	2.33	0.11	100
Copper & compounds	0.04	-	0.00	-	0.03	0.00	-	0.00	0.01	0.00	-	-	-	-	-	0.06	-	96.24	-	-	-	3.28	0.34	100
Cumene (1-methylethylbenzene)	-	-	-	-	-	-	-	-	-	-	43.19	-	-	-	-	-	-	-	56.81	-	-	-	-	100
Cyanide (inorganic) compounds	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0
Cyclohexane	2.27	-	-	-	-	-	-	0.02	0.19	0.03	2.42	94.75	0.21	-	-	0.11	-	-	0.01	-	-	-	-	100
1,2-Dichloroethane	-	-	-	-	-	-	100.00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	100
Dichloromethane	-	-	-	-	-	-	27.22	-	-	-	-	71.31	-	-	-	1.48	-	-	-	-	-	-	-	100
Ethanol	-	-	-	-	-	-	-	-	-	-	-	64.20	-	-	-	-	-	-	-	35.80	-	-	-	100
2-Ethoxyethanol acetate	-	-	-	-	-	-	-	-	-	-	-	100.00	-	-	-	-	-	-	-	-	-	-	-	100
Ethyl Acetate	-	-	-	-	-	-	-	-	-	-	-	-	100.00	-	-	-	-	-	-	-	-	-	-	100
Ethylbenzene	85.49	-	0.02	0.02	0.08	6.01	0.35	-	4.81	0.87	1.21	-	0.73	-	-	0.26	-	-	0.16	-	-	-	-	100
Ethylene glycol (1,2-ethanediol)	-	-	-	-	-	-	58.76	-	-	-	-	41.24	-	-	-	-	-	-	-	-	-	-	-	100
Ethylene oxide	-	-	-	-	-	-	100.00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	100
Di-(2-Ethylhexyl) phthalate (DEHP)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0
Fluoride compounds	-	-	-	-	-	-	0.04	-	-	-	-	-	-	-	-	-	-	-	-	-	-	99.96	-	100
Formaldehyde (methyl aldehyde)	17.17	4.67	0.32	0.29	1.01	3.24	0.03	0.02	0.49	0.12	-	-	-	-	61.01	11.62	-	-	-	-	-	-	-	100
n-Hexane	23.17	-	0.08	-	0.26	1.43	3.05	0.19	0.29	0.07	2.36	67.58	-	-	-	1.50	-	-	0.02	-	-	-	-	100
Hydrochloric acid	-	-	-	-	-	-	0.05	-	-	-	-	-	-	-	-	99.95	-	-	-	-	-	-	-	100
Hydrogen sulphide	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	100.00	-	-	-	-	-	-	100
Lead & compounds	0.06	-	0.00	-	0.00	0.00	-	0.00	0.00	0.00	0.00	-	-	-	0.01	0.01	-	97.58	-	-	-	2.26	0.08	100
Manganese & compounds	0.00	-	0.00	-	0.00	0.00	-	0.00	0.00	0.00	-	-	-	-	0.00	0.00	-	94.08	-	-	-	5.73	0.18	100
Mercury & compounds	-	-	0.00	-	0.01	0.00	-	0.00	-	-	-	-	-	-	-	0.01	-	96.67	-	-	-	2.11	1.20	100
Methanol	-	-	-	-	-	-	66.14	-	-	-	-	33.86	-	-	-	-	-	-	-	-	-	-	-	100
Methyl ethyl ketone	-	-	-	-	-	-	6.99	-	-	-	-	71.59	3.13	-	18.29	-	-	-	-	-	-	-	-	100
Methyl isobutyl ketone	-	-	-	-	-	-	11.51	-	-	-	-	84.09	4.40	-	-	-	-	-	-	-	-	-	-	100
Nickel & compounds	0.01	-	0.00	-	1.31	0.01	-	0.01	0.01	0.00	-	-	-	-	0.01	0.01	-	93.51	-	-	-	4.75	0.37	100
Oxides of nitrogen	20.30	3.09	1.30	0.01	3.03	0.04	-	0.16	0.01	0.39	-	-	-	-	0.87	10.71	-	-	-	-	56.51	-	3.75	100
Particulate Matter <10.0 um (PM_{10})	0.11	0.07	0.01	-	0.06	0.00	-	0.00	0.00	0.01	-	-	-	-	1.18	0.17	-	84.96	-	-	-	9.85	3.56	100
Phenol	-	-	-	100.00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	100
Polycyclic aromatic hydrocarbons (PAHs)	12.26	-	0.16	0.12	0.01	1.33	-	0.00	0.86	0.17	0.01	-	-	-	82.41	2.32	-	-	0.36	-	-	-	-	100
Selenium & compounds	-	-	0.01	-	0.78	0.01	-	0.46	-	-	-	-	-	-	0.26	0.01	-	72.84	-	-	-	20.52	5.12	100
Styrene (ethenylbenzene)	77.97	-	-	0.36	0.03	4.93	-	-	2.36	0.43	-	-	-	-	13.69	0.23	-	-	-	-	-	-	-	100
Sulphur dioxide	10.35	6.04	1.54	0.03	55.37	0.14	-	0.01	0.03	0.16	-	-	-	-	4.26	22.07	-	-	-	-	-	-	-	100
Tetrachloroethylene	-	-	-	-	-	-	49.20	-	-	-	-	-	-	50.80	-	-	-	-	-	-	-	-	-	100
Toluene (methylbenzene)	53.78	-	0.04	0.01	0.18	8.35	6.17	0.00	3.01	0.55	1.01	6.93	8.77	-	10.48	0.71	-	-	0.01	-	-	-	-	100
Trichloroethylene	-	-	-	-	-	-	100.00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	100
Xylenes (individual or mixed isomers)	65.87	-	0.01	0.01	0.14	4.43	5.07	-	3.82	0.70	0.70	6.01	5.51	-	6.62	0.95	-	-	0.15	-	-	-	-	100
Zinc & compounds	0.15	-	0.00	-	0.00	0.00	-	0.00	0.00	0.00	-	-	-	-	0.35	0.06	-	81.32	-	-	-	17.93	0.16	100
Total Volatile Organic Compounds	3.15	0.09	0.01	0.01	0.03	0.31	0.77	0.00	0.15	0.03	0.14	0.74	0.12	-	2.33	0.34	0.34	-	0.03	0.00	88.15	-	3.28	100

Table 5-3 Emissions of NPI Substances in the Bunbury Regional Airshed, Excluding Biogenic and Natural Sources (Percentage of Total Anthropogenic Emissions)

	MOBILE SOURCES						DOMESTIC / COMMERCIAL SOURCES														
	Motor vehicles	Agriculture (Machinery)	Railways	Aeroplanes	Commercial Shipping/Boating	Recreational Boating	Domestic/ Commercial solvents/ aerosols	Gaseous fuel burning (domestic)	Lawn Mowing	Lawn Mowing (public open spaces)	Service Stations	Architectural Surface Coatings	Motor Vehicle Refinishing	Dry Cleaning	Solid fuel burning (domestic)	Fuel Combustion – sub reporting threshold facilities	Natural Gas Leakages	Paved/ Unpaved Roads	Cutback Bitumen	Bakeries	Total
Acetaldehyde	17.09%	-	0.13%	0.11%	0.42%	2.60%	-	-	-	0.07%	-	-	-	-	68.76%	10.82%	-	-	-	-	100%
Acetone	12.75%	-	-	0.10%	-	-	-	-	-	0.05%	-	10.65%	0.37%	-	68.46%	7.63%	-	-	-	-	100%
Acrylic acid	-	-	-	-	-	-	100.00%	-	-	-	-	-	-	-	-	-	-	-	-	-	100%
Antimony & compounds	-	-	0.03%	-	0.09%	0.00%	-	-	-	-	-	-	-	-	0.27%	-	-	99.61%	-	-	100%
Arsenic & compounds	-	-	0.00%	-	0.12%	0.00%	-	0.00%	-	-	-	-	-	-	0.10%	0.01%	-	99.77%	-	-	100%
Benzene	52.14%	0.00%	0.06%	0.04%	0.22%	4.13%	0.00%	0.01%	2.73%	0.50%	0.35%	0.11%	-	-	38.98%	0.73%	-	-	0.00%	-	100%
Beryllium & compounds	-	-	-	-	98.01%	1.66%	-	0.02%	-	-	-	-	-	-	-	0.30%	-	-	-	-	100%
Biphenyl (1,1-biphenyl)	-	-	-	-	-	-	-	-	-	-	0.00%	-	-	-	-	-	-	-	100.00%	-	100%
1,3-Butadiene (vinyl ethylene)	68.64%	0.00%	0.76%	0.42%	2.21%	13.28%	-	-	4.59%	0.84%	0.45%	-	-	-	7.71%	1.10%	-	-	-	-	100%
Boron & compounds	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0%
Cadmium & compounds	0.57%	-	0.01%	-	0.00%	0.00%	-	0.00%	-	-	-	-	-	-	0.03%	1.31%	-	98.08%	-	-	100%
Carbon disulphide	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0%
Carbon monoxide	65.19%	0.86%	0.06%	0.20%	0.19%	2.05%	-	0.02%	1.04%	0.27%	-	-	-	-	25.30%	4.83%	-	-	-	-	100%
Chloroform (trichloromethane)	-	-	-	-	-	-	100.00%	-	-	-	-	-	-	-	-	-	-	-	-	-	100%
Chromium (III) compounds	26.43%	-	0.17%	-	6.17%	0.85%	-	-	6.79%	4.43%	-	-	-	-	0.24%	54.92%	-	-	-	-	100%
Chromium (VI) compounds	22.16%	-	0.13%	-	4.94%	0.66%	-	19.38%	5.24%	3.50%	-	-	-	-	0.18%	43.81%	-	-	-	-	100%
Cobalt & compounds	0.02%	-	0.00%	-	0.01%	0.00%	-	0.02%	0.00%	0.00%	-	-	-	-	0.00%	0.03%	-	99.91%	-	-	100%
Copper & compounds	0.04%	-	0.00%	-	0.03%	0.00%	-	0.00%	0.01%	0.00%	-	-	-	-	-	0.06%	-	99.85%	-	-	100%
Cumene (1-methylethylbenzene)	-	-	-	-	-	-	-	-	-	-	43.19%	-	-	-	-	-	-	-	56.81%	-	100%
Cyanide (inorganic) compounds	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0%
Cyclohexane	2.27%	-	-	-	-	-	-	0.02%	0.19%	0.03%	2.42%	94.75%	0.21%	-	-	0.11%	-	-	0.01%	-	100%
1,2-Dichloroethane	-	-	-	-	-	-	100.00%	-	-	-	-	-	-	-	-	-	-	-	-	-	100%
Dichloromethane	-	-	-	-	-	-	27.22%	-	-	-	-	71.31%	-	-	-	1.48%	-	-	-	-	100%
Ethanol	-	-	-	-	-	-	-	-	-	-	-	64.20%	-	-	-	-	-	-	-	35.80%	100%
2-Ethoxyethanol acetate	-	-	-	-	-	-	-	-	-	-	-	100.00%	-	-	-	-	-	-	-	-	100%
Ethyl Acetate	-	-	-	-	-	-	-	-	-	-	-	-	100.00%	-	-	-	-	-	-	-	100%
Ethylbenzene	85.49%	-	0.02%	0.02%	0.08%	6.01%	0.35%	-	4.81%	0.87%	1.21%	-	0.73%	-	-	0.26%	-	-	0.16%	-	100%
Ethylene glycol (1,2-ethanediol)	-	-	-	-	-	-	58.76%	-	-	-	-	41.24%	-	-	-	-	-	-	-	-	100%
Ethylene oxide	-	-	-	-	-	-	100.00%	-	-	-	-	-	-	-	-	-	-	-	-	-	100%
Di-(2-Ethylhexyl) phthalate (DEHP)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0%
Fluoride compounds	-	-	-	-	-	-	100.00%	-	-	-	-	-	-	-	-	-	-	-	-	-	100%
Formaldehyde (methyl aldehyde)	17.17%	4.67%	0.32%	0.29%	1.01%	3.24%	0.03%	0.02%	0.49%	0.12%	-	-	-	-	61.01%	11.62%	-	-	-	-	100%
n-Hexane	23.17%	-	0.08%	-	0.26%	1.43%	3.05%	0.19%	0.29%	0.07%	2.36%	67.58%	-	-	-	1.50%	-	-	0.02%	-	100%
Hydrochloric acid	-	-	-	-	-	-	0.05%	-	-	-	-	-	-	-	-	99.95%	-	-	-	-	100%
Hydrogen sulphide	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	100.00%	-	-	-	100%
Lead & compounds	0.06%	-	0.00%	-	0.00%	0.00%	-	0.00%	0.00%	0.00%	0.00%	-	-	-	0.01%	0.01%	-	99.92%	-	-	100%
Manganese & compounds	0.00%	-	0.00%	-	0.00%	0.00%	-	0.00%	0.00%	0.00%	-	-	-	-	0.00%	0.01%	-	99.99%	-	-	100%
Mercury & compounds	-	-	0.00%	-	0.01%	0.00%	-	0.00%	-	-	-	-	-	-	-	0.01%	-	99.98%	-	-	100%
Methanol	-	-	-	-	-	-	66.14%	-	-	-	-	33.86%	-	-	-	-	-	-	-	-	100%
Methyl ethyl ketone	-	-	-	-	-	-	6.99%	-	-	-	-	71.59%	3.13%	-	18.29%	-	-	-	-	-	100%
Methyl isobutyl ketone	-	-	-	-	-	-	11.51%	-	-	-	-	84.09%	4.40%	-	-	-	-	-	-	-	100%
Nickel & compounds	0.01%	-	0.00%	-	1.38%	0.01%	-	0.01%	0.01%	0.00%	-	-	-	-	0.01%	0.02%	-	98.56%	-	-	100%
Oxides of nitrogen	50.89%	7.74%	3.25%	0.02%	7.60%	0.09%	-	0.40%	0.03%	0.97%	-	-	-	-	2.17%	26.84%	-	-	-	-	100%
Particulate Matter <10.0 um (PM_{10})	0.13%	0.08%	0.01%	-	0.07%	0.00%	-	0.00%	0.00%	0.01%	-	-	-	-	1.36%	0.20%	-	98.14%	-	-	100%
Phenol	-	-	-	100.00%	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	100%
Polycyclic aromatic hydrocarbons (PAHs)	12.26%	-	0.16%	0.12%	0.01%	1.33%	-	0.00%	0.86%	0.17%	0.01%	-	-	-	82.41%	2.32%	-	-	0.36%	-	100%
Selenium & compounds	-	-	0.01%	-	1.05%	0.02%	-	0.62%	-	-	-	-	-	-	0.35%	0.01%	-	97.96%	-	-	100%
Styrene (ethenylbenzene)	77.97%	-	-	0.36%	0.03%	4.93%	-	-	2.36%	0.43%	-	-	-	-	13.69%	0.23%	-	-	-	-	100%
Sulphur dioxide	10.35%	6.04%	1.54%	0.03%	55.37%	0.14%	-	0.01%	0.03%	0.16%	-	-	-	-	4.26%	22.07%	-	-	-	-	100%
Tetrachloroethylene	-	-	-	-	-	-	49.20%	-	-	-	-	-	-	50.80%	-	-	-	-	-	-	100%
Toluene (methylbenzene)	53.78%	-	0.04%	0.01%	0.18%	8.35%	6.17%	0.00%	3.01%	0.55%	1.01%	6.93%	8.77%	-	10.48%	0.71%	-	-	0.01%	-	100%
Trichloroethylene	-	-	-	-	-	-	100.00%	-	-	-	-	-	-	-	-	-	-	-	-	-	100%
Xylenes (individual or mixed isomers)	65.87%	-	0.01%	0.01%	0.14%	4.43%	5.07%	-	3.82%	0.70%	0.70%	6.01%	5.51%	-	6.62%	0.95%	-	-	0.15%	-	100%
Zinc & compounds	0.19%	-	0.00%	-	0.01%	0.00%	-	0.00%	0.00%	0.00%	-	-	-	-	0.43%	0.08%	-	99.29%	-	-	100%
Total Volatile Organic Compounds	36.65%	1.06%	0.13%	0.07%	0.38%	3.65%	8.97%	0.02%	1.74%	0.33%	1.63%	8.63%	1.41%	-	27.08%	3.92%	3.92%	-	0.39%	0.02%	100%

6. Recommendations

The following are recommended from the study:

- As emissions from windblown sources are 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).
- Emissions from sub threshold facilities are uncertain. This is due to:
  - The large amount of diesel fuel used by sub threshold facilities. This usage may however occur on public roads as well as onsite therefore contributing to a double counting of emissions. It is considered that part of this diesel usage may be from haulage and earth moving companies. As such, it is recommended that the NPI section follow up with the fuel suppliers to determine all large diesel uses in the Bunbury Regional Airshed and then determine from the relevant companies where the diesel is used. This will also assist the NPI section identify companies that should be submitting NPI reports.
- As the emissions of dust are very large from unpaved roads and wind erosion, the speciation of the soil/road dirt content is critical in determining the overall emissions of metals. Therefore, it is recommended that regional specific speciations be obtained for these categories.
- For ships emission estimation it is recommended that:
  - The default EET Manual emission factors for 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 based on the speed in the shipping channel. It is found that in the Bunbury, Perth and Pilbara Regional Airshed studies, the speeds travelled in the shipping are much lower speeds than the default of 15 knots, which is derived from the Port Phillip Region study.
- For aircraft it is recommended that LTOs be developed for a range of airports/airstrips, particularly to include small regional towns.
- For dry cleaning it is recommended that defaults be developed for both city and country areas as there are significant differences in the amount of dry cleaning conducted.

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8. Study Team

The study team for Sinclair Knight Merz comprised the following personnel:

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The study team for the Department of Environmental Protection comprised the following personnel:

- Mr Greg Mueller
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Appendix A Aircraft Emission Estimates

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Annual Aircraft movements in the Bunbury Regional Airshed

Aircraft Type	Augusta	Boyup Brook	Bunbury	Busselton	Bridgetown	Carbanup River	Collie	Dunsborough	Dwellingup	Harvey	Kirup	Margaret River	Mt Cook	Mandurah	Manjimup	Murrayfield	Nannup	North Dandalup	Pemberton	Pinjarra	TOTAL
Turbofan/Jet																					-
Hercules C130H	0		10	0			0					0			0	0	0				**10**
																					-
Turboprop																					-
Beechcraft King Air	6		230	180			20					18									**454**
Cessna Conquest			155	15								10			30				10		**220**
Pilatis PC-12	10	3	0	0			20					10			60						**103**
																					-
Piston Engine																					-
Twin Engine	3		150	174								2			240						**569**
Single Engine	142		8269	1332			216		574			114			2216	6195	85				**19,143**
																					-
Helicopters																					-
Superpuma AS 332L																					-
Sikorski S76																					-
Bell Long Ranger																					-
Bell Jet Ranger			110		3		8			5		10	5					3			**144**
Robinson R22			100																		**100**
Robinson R44			50																		**50**
Aerospatiale AS 332			100																		**100**
Aerospatiale AS 350			135	4		8	20	5			10	4			20		20			200	**426**
Kawasaki 47G			50											12							**62**
																					-
TOTAL	**161**	**3**	**9,359**	**1,705**	**3**	**8**	**284**	**5**	**574**	**5**	**10**	**168**	**5**	**12**	**2,566**	**6,195**	**105**	**3**	**10**	**200**	**21,063**

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

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Aircraft emissions in the Bunbury Regional Airshed by Airfield (kg/yr)

Airfield	CO	HC	NOx	SO2	TSP	VOCs
Augusta	1073.36535	116.851479	8.21894308	1.74680488	0	127.683611
Boyup Brook	22.3137	19.02345	1.09974	0.29391	0	20.7869238
Bunbury	58432.5486	3804.48363	1010.21562	156.206443	0	4157.15926
Busselton	12051.2573	1393.0694	105.77369	21.3992719	0	1522.20694
Bridgetown	2.23203	2.13888	1.61601	0.25377	0	2.33715418
Carbanup River	9.08975796	8.71041227	6.58106735	1.03345738	0	9.51786749
Collie	1724.30107	302.964526	38.7991835	7.44042895	0	331.049337
Dunsborough	5.68109872	5.44400767	4.11316709	0.64591086	0	5.94866718
Dwellingup	3715.34415	58.0346288	8.96597328	0.69428888	0	63.4144388
Harvey	3.72005	10.8880153	8.22633419	1.29182173	0	11.8973344
Kirup	11.3621974	10.8880153	8.22633419	1.29182173	0	11.8973344
Margaret River	1012.24314	236.379379	26.0430041	5.04937659	0	258.291748
Mt Cook	3.72005	3.5648	2.69335	0.42295	0	3.89525696
Mandurah	5.53372294	5.30278236	4.00646569	0.62915502		5.79435029
Manjimup	17716.6464	814.265226	99.5655485	14.144874	0	889.747612
Murrayfield	40098.5314	626.349347	96.7669067	7.49323969	0	684.411931
Nannup	572.90602	30.3700088	17.7803822	2.68645626	0	33.1853086
North Dandalup	2.23203	2.13888	1.61601	0.25377		2.33715418
Pemberton	28.5098	35.02791	5.2186	0.80016	0	38.2749973
Pinjarra	227.243949	217.760307	164.526684	25.8364345	0	237.946687
TOTAL	**136718.78**	**7703.6551**	**1620.053**	**249.61435**	**0**	**8417.7839**

Appendix B Commercial Shipping Emissions

Emissions from commercial shipping

Substance	Berth	Inner Channel	Outer Channel	TOTAL
CO	14414.8627	7,091	45,215	66,721
NOx	80674.7778	82,263	524,599	687,537
SO2	75225.1678	63,030	401,932	540,187
TSP	10652.397	8,329	53,114	72,096
VOC's	5281.41188	1,792	11,431	18,504
Acetaldehyde	172.702	58.600	373.780	605
Benzene	100.875	34.228	218.324	353
1,3-Butadiene	83.446	28.315	180.603	292
Ethylbenzene	3.491	1.185	7.556	12
Formaldehyde	511.241	173.471	1106.481	1,791
n-Hexane	81.862	27.777	177.174	287
Toluene	101.931	34.587	220.610	357
Xylene	52.392	17.777	113.391	184
Antimony	0.328	0.256	1.632	2
Arsenic	0.920	0.719	4.588	6
Beryllium	0.665	0.516	3.292	4
Cadmium	0.024	0.018	0.117	0
Chromium (III)	0.232	0.182	1.158	2
Chromium (IV)	0.097	0.076	0.482	1
Cobalt	0.597	0.467	2.979	4
Copper	0.590	0.447	2.854	4
Lead	0.181	0.140	0.895	1
Mercury	0.022	0.017	0.107	0
Nickel	47.762	37.322	238.006	323
PM10	10652.397	8328.980	53114.484	72,096
PAH	0.091	0.069	0.440	1
Selenium	0.406	0.315	2.008	3
Zinc	1.073	0.827	5.271	7

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Appendix C Domestic Survey

INTRO My name is ……...... from SKM, We're conducting a survey about energy usage and air pollution in the South West for the Department of Environmental Protection. The survey takes 5 to 10 minutes. Could I please speak to the person who would know the most about fuel usage for heating, gardening equipment and boating in this household?

Fuel usage

Q1. Do you use either firewood or coal in your home?
Coal 1, Firewood 2, Neither 3 >Q8, Both 4

Q2. Do you use (fuel type) for :
Heating 1C/1F, Cooking 2C/2F, Hot water 3C/3F, Other

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

Q4. Do you have any of the following appliances?
Open fire place, Pot Belly or Wood stove, Slow Combustion stove/heater, Outdoor BBQ, Water Heater, Other
Yes 1, No 2

Q5a. How many (items) do you have?

Q5b. Which type of fuel do you use for that?
Coal 1, Firewood 2, Both 3

Q5c. How old is that appliance?

Q6. **If you use wood:** What % of your (**TONNES FROM Q3)** do you use in:
Open fire place, Pot Belly stove, Slow Combustion stove/heater, Outdoor BBQ, Water Heater, Other

Q7a. What types of wood do you burn?
Hardwood (e.g. Jarrah, Marri, Mallee roots) 1, Soft wood (e.g. Pine) 2, Other

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

Q8. Do you use any other fuel types in your home?
Gas (LPG tanks) 1, Natural Gas (mains) 2, Oil 3, No >Q12a

Q9. For each fuel type, what appliances to you use (fuel type) for?
Stove top/oven 1LPG/1NG/1OL, Flued heater (vented outside) 2LPG/2NG/2OL, Unflued heater (vented inside) 3LPG/3NG/3OL, Outdoor BBQ 4LPG/4NG/4OL, Other 5LPG/5NG/5OL

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

Q10a. How big is your Gas Cylinder (kgs/size)

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)

Caravan Fuel Use

Q12a. Do you own or live in a caravan?
Yes 1, No 2 >Q31

Q12b. Does the caravan use LPG fuel?
Yes 1, No 2 >Q31

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

Q12d. How much does your cylinder weigh/size?

Gardening Equipment

Q13. Do use a petrol powered garden appliance (e.g. lawnmower, whipper snipper or leaf blower) or do you use a lawnmower man (Q17)?
Lawnmower 1, whipper shipper 2, leaf blower 3, other 4

Q14a. What type of engine?
2-stroke 1, 4-stroke 2, Unsure 3 (if unsure, what brand engine/do you mix oil and fuel (i.e. 2-stroke)?)

Q14b. What type of fuel does the appliance use?
Leaded fuel 1, Unleaded fuel 2, Unsure 3

Q15. How often do you use your appliance per month (summer/winter)?

Q16. How long is the appliance used for (hrs summer/winter)?

Q17. Do you have your lawn mowed for you?
Yes 1, No 2

Marine Craft

Q18. Do you own a boat with an engine?
Yes 1, No 2

Q19. What is the size of the engine on your boat? (horsepower)

Q20. Is the engine inboard or outboard?
Inboard 1, Outboard 2

Q21. What type of fuel does it use?
2-stroke 1, Leaded 2, Unleaded 3, Diesel 4

Q22. How often do you fill your boat's fuel tank? (per month of year)

How big is the tank? (litres or gallons)

Q23. How much fuel do you use annually? (litres)

Q24. What location(s) do you normally go boating?

THANK YOU. Now to check that we have a good cross section of the community:
Could you please tell me your approx. age?
Do you live on a farm or in town?

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 SKM. If you have any questions about this research you can telephone our office on 08 9268 4400.