Technical Report No. 2

Air Emissions Inventory for the Greater Metropolitan Region in New South Wales

2008 Calendar Year

Biogenic and Geogenic Emissions: Results

ACKNOWLEDGMENTS

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EXECUTIVE SUMMARY

An air emissions inventory project for biogenic and geogenic sources has taken over 2 years to complete. The base year of the biogenic and geogenic inventory represents activities that took place during the 2008 calendar year. The area included in the inventory covers the greater Sydney, Newcastle and Wollongong regions, known collectively as the Greater Metropolitan Region (GMR).

The inventory region defined as the GMR measures 210 km (east–west) by 273 km (north–south). The inventory region is defined in Table ES-1 and shown in Figure ES-1.

Table ES-1: Definition of Greater Metropolitan, Sydney, Newcastle and Wollongong regions

Region	South-west corner MGA[1] coordinates		North-east corner MGA coordinates	
	Easting (km)	Northing (km)	Easting (km)	Northing (km)
Greater Metropolitan	210	6159	420	6432
Sydney	261	6201	360	6300
Newcastle	360	6348	408	6372
Wollongong	279	6174	318	6201

The biogenic and geogenic air emissions inventory includes emissions from the following sources/activities:

- Agricultural burning;
- Bushfires;
- Prescribed burning;
- Fugitive/windborne from agricultural lands and unpaved roads;
- Microbial activity and chemical processes of nitrification and denitrification in soil;
- Fertiliser application to agricultural lands;
- Tree canopy and grass (i.e. cut and uncut); and
- Marine aerosol.

The pollutants inventoried include criteria pollutants specified in the Ambient Air Quality NEPM (NEPC, 2003), air toxics associated with the National Pollutant Inventory NEPM (NEPC, 2008) and the Air Toxics NEPM (NEPC, 2004), and any other pollutants associated with state-specific programs, i.e. Load Based Licensing (Protection of the Environment Operations (General) Regulation 2009 (PCO, 2010)) and the Protection of the Environment Operations (Clean Air) Regulation 2010 (PCO, 2011).

Load Based Licensing (Protection of the Environment Operations (General) Regulation 2009 (PCO, 2010)) and the Protection of the Environment Operations (Clean Air) Regulation 2010 (PCO, 2011).

Figure ES-1: Definition of Greater Metropolitan, Sydney, Newcastle and Wollongong regions

Table ES-2 presents total estimated annual emissions (for selected substances) from all biogenic and geogenic sources in the whole GMR and the Sydney, Newcastle and Wollongong regions. Total estimated annual emissions are also presented for the region defined as Non Urban. This region is the area of the GMR minus the combined areas of the Sydney, Newcastle and Wollongong regions. The selected substances were chosen because they:

- Are the most common air pollutants found in airsheds according to the National Pollutant Inventory NEPM (NEPC, 2008);
- Are referred to in National Environment Protection Measures (NEPMs) for Ambient Air Quality (NEPC, 2003) and Air Toxics (NEPC, 2004); and
- Have been classified as priority air pollutants (NEPC, 2006).

Table ES-2: Total estimated annual emissions from biogenic and geogenic sources in each region

Substance	Emissions (tonne/year)				
	Newcastle	Non Urban	Sydney	Wollongong	GMR
1,3-BUTADIENE	0.24	23	4.39	0.48	28
ACETALDEHYDE	16	865	201	14	1,095
CARBON MONOXIDE	301	28,545	5,484	603	34,934
LEAD & COMPOUNDS	0.10	2.16	0.46	8.89×10^{-3}	2.73
OXIDES OF NITROGEN	126	8,319	1,296	71	9,811
PARTICULATE MATTER ≤ 10 µm	689	28,719	3,901	327	33,635
PARTICULATE MATTER ≤ 2.5 µm	121	6,176	951	90	7,338
POLYCYCLIC AROMATIC HYDROCARBONS	8.44×10^{-2}	7.41	1.37	0.14	9.00
SULFUR DIOXIDE	2.72	259	50	5.49	317
TOTAL SUSPENDED PARTICULATE	2,422	99,401	12,940	1,096	115,859
TOTAL VOLATILE ORGANIC COMPOUNDS	3,404	130,284	32,468	3,482	169,637

Figure ES-2 shows the proportions of total estimated annual emissions (for selected substances) from biogenic and geogenic sources in the whole GMR and the Sydney, Newcastle, Wollongong and Non Urban regions.

Figure ES-2: Proportions of total estimated annual emissions from biogenic and geogenic sources in each region

Table ES-3, Table ES-4, Table ES-5, Table ES-6 and Table ES-7 present total estimated annual emissions (for selected substances) from each biogenic and geogenic source type in the whole GMR and the Sydney, Newcastle, Wollongong and Non Urban regions, respectively.

Figure ES-3, Figure ES-4, Figure ES-5, Figure ES-6 and Figure ES-7 show the proportions of total estimated annual emissions (for selected substances) from each biogenic and geogenic source type in the whole GMR and the Sydney, Newcastle, Wollongong and Non Urban regions, respectively.

Table ES-3: Total estimated annual emissions by biogenic and geogenic source type in the GMR

Substance	Emissions (tonne/year)										
	Agricultural burning	Bushfires	Prescribed burning	Agricultural lands (fugitive/ windborne)	Unpaved roads (fugitive/ windborne)	Soil nitrification and denitrification	Tree canopy	Uncut grass	Cut grass	Marine aerosol	Biogenic and Geogenic Total
1,3-BUTADIENE	0.28	5.87	22	-	-	-	-	-	-	-	28
ACETALDEHYDE	-	-	-	-	-	-	-	1,009	86	-	1,095
CARBON MONOXIDE	325	7,338	27,271	-	-	-	-	-	-	-	34,934
LEAD & COMPOUNDS	5.11×10^{-4}	7.37×10^{-2}	0.27	1.55×10^{-2}	2.36	-	-	-	-	-	2.73
OXIDES OF NITROGEN	12	217	806	-	-	8,778	-	-	-	-	9,811
PARTICULATE MATTER ≤ 10 µm	42	739	2,747	114	1,559	-	-	-	-	28,435	33,635
PARTICULATE MATTER ≤ 2.5µm	40	627	2,331	20	206	-	-	-	-	4,114	7,338
POLYCYCLIC AROMATIC HYDROCARBONS	0.73	1.75	6.52	-	-	-	-	-	-	-	9.00
SULFUR DIOXIDE	1.79	67	248	-	-	-	-	-	-	-	317
TOTAL SUSPENDED PARTICULATE	43	752	2,796	250	2,624	-	-	-	-	109,395	115,859
TOTAL VOLATILE ORGANIC COMPOUNDS	24	514	1,909	-	-	-	160,150	5,007	2,033	-	169,637

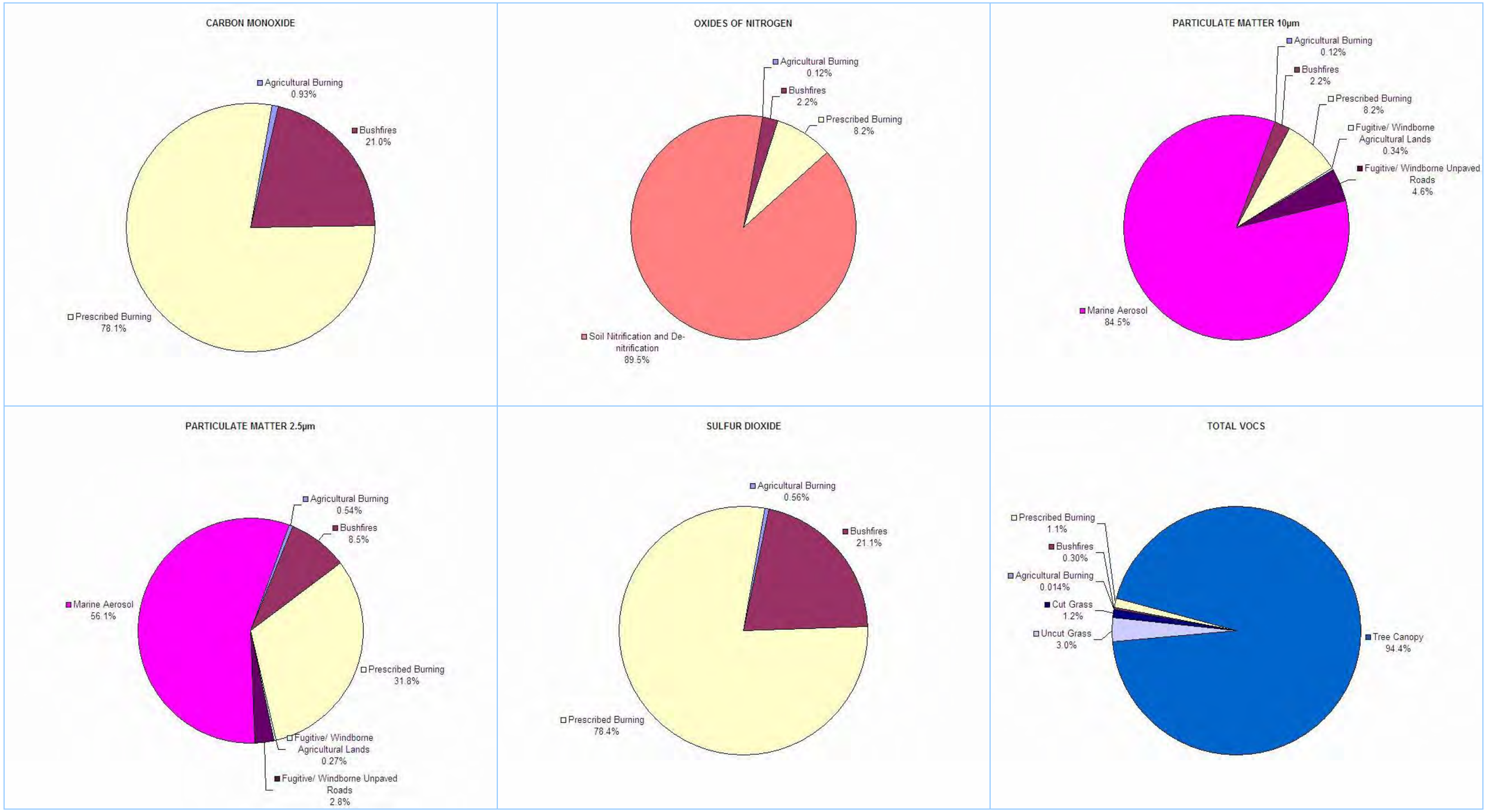


Figure ES-3: Proportions of total estimated annual emissions by biogenic and geogenic source type in the GMR

Table ES-4: Total estimated annual emissions by biogenic and geogenic source type in the Sydney region

Substance	Emissions (tonne/year)										
	Agricultural burning	Bushfires	Prescribed burning	Agricultural lands (fugitive/ windborne)	Unpaved roads (fugitive/ windborne)	Soil nitrification and denitrification	Tree canopy	Uncut grass	Cut grass	Marine aerosol	Biogenic and Geogenic Total
1,3-BUTADIENE	2.40×10^{-2}	0.64	3.72	-	-	-	-	-	-	-	4.39
ACETALDEHYDE	-	-	-	-	-	-	-	136	64	-	201
CARBON MONOXIDE	28	806	4,650	-	-	-	-	-	-	-	5,484
LEAD & COMPOUNDS	4.43×10^{-5}	8.10×10^{-3}	4.67×10^{-2}	1.40×10^{-3}	0.40	-	-	-	-	-	0.46
OXIDES OF NITROGEN	1.00	24	137	-	-	1,133	-	-	-	-	1,296
PARTICULATE MATTER ≤ 10 µm	3.63	81	468	10	263	-	-	-	-	3,074	3,901
PARTICULATE MATTER ≤ 2.5µm	3.46	69	397	1.77	35	-	-	-	-	445	951
POLYCYCLIC AROMATIC HYDROCARBONS	6.37×10^{-2}	0.19	1.11	-	-	-	-	-	-	-	1.37
SULFUR DIOXIDE	0.16	7.34	42	-	-	-	-	-	-	-	50
TOTAL SUSPENDED PARTICULATE	3.69	83	477	23	443	-	-	-	-	11,912	12,940
TOTAL VOLATILE ORGANIC COMPOUNDS	2.10	56	326	-	-	-	29,881	677	1,526	-	32,468

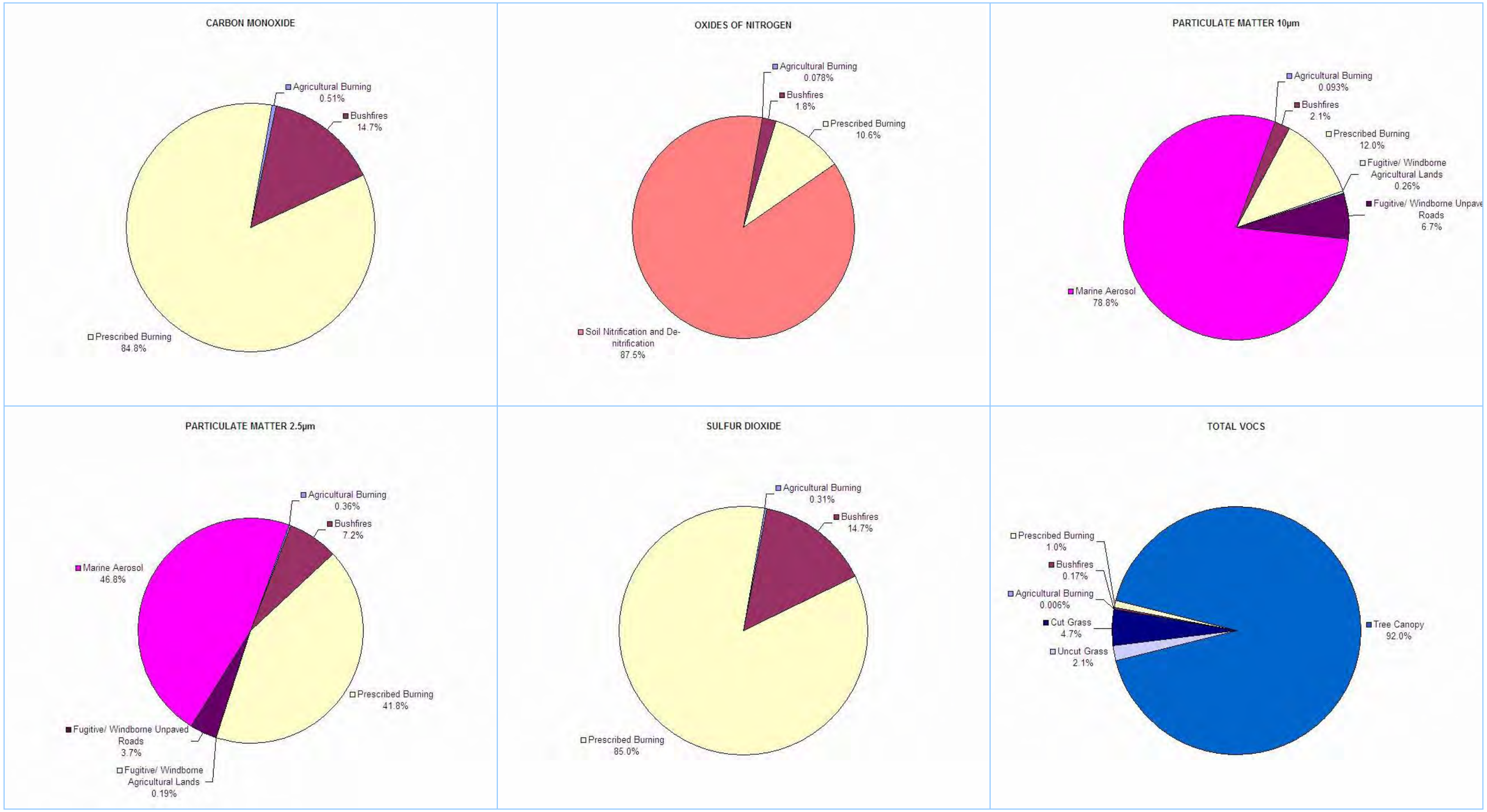


Figure ES-4: Proportions of total estimated annual emissions by biogenic and geogenic source type in the Sydney region

Table ES-5: Total estimated annual emissions by biogenic and geogenic source type in the Newcastle region

Substance	Emissions (tonne/year)										
	Agricultural burning	Bushfires	Prescribed burning	Agricultural lands (fugitive/ windborne)	Unpaved roads (fugitive/ windborne)	Soil nitrification and denitrification	Tree canopy	Uncut grass	Cut grass	Marine aerosol	Biogenic and Geogenic Total
1,3-BUTADIENE	5.21×10^{-3}	6.0×10^{-2}	0.18	-	-	-	-	-	-	-	0.24
ACETALDEHYDE	-	-	-	-	-	-	-	11	5.14	-	16
CARBON MONOXIDE	6.13	75	220	-	-	-	-	-	-	-	301
LEAD & COMPOUNDS	9.62×10^{-6}	7.54×10^{-4}	2.21×10^{-3}	1.17×10^{-3}	9.70×10^{-2}	-	-	-	-	-	0.10
OXIDES OF NITROGEN	0.22	2.22	6.50	-	-	117	-	-	-	-	126
PARTICULATE MATTER ≤ 10 µm	0.79	7.56	22	8.54	64	-	-	-	-	586	689
PARTICULATE MATTER ≤ 2.5µm	0.75	6.42	19	1.48	8.46	-	-	-	-	85	121
POLYCYCLIC AROMATIC HYDROCARBONS	1.38×10^{-2}	1.79×10^{-2}	5.26×10^{-2}	-	-	-	-	-	-	-	8.44×10^{-2}
SULFUR DIOXIDE	3.37×10^{-2}	0.68	2.00	-	-	-	-	-	-	-	2.72
TOTAL SUSPENDED PARTICULATE	0.80	7.70	23	19	108	-	-	-	-	2,264	2,422
TOTAL VOLATILE ORGANIC COMPOUNDS	0.46	5.26	15	-	-	-	3,207	53	122	-	3,404

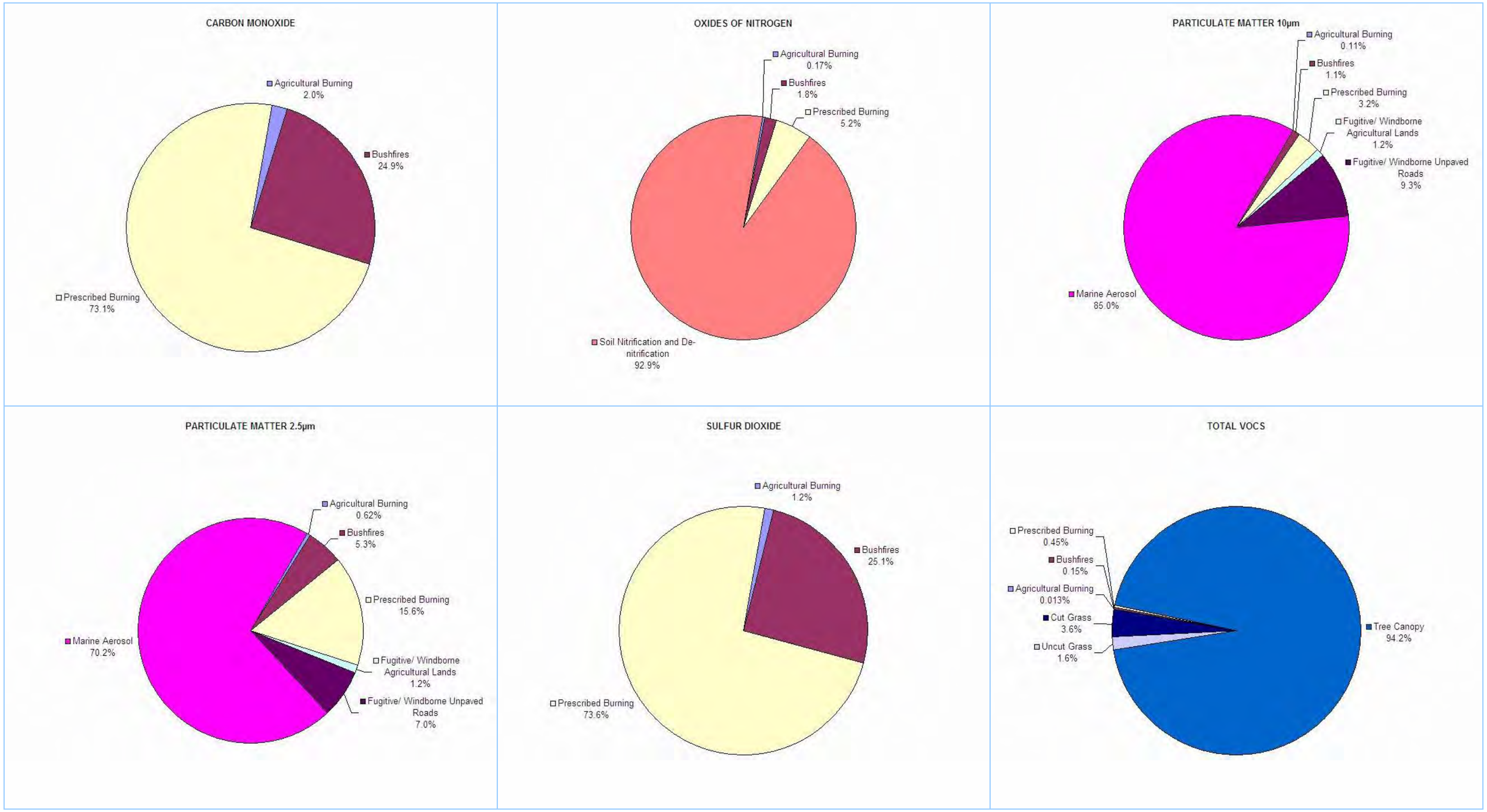


Figure ES-5: Proportions of total estimated annual emissions by biogenic and geogenic source type in the Newcastle region

Table ES-6: Total estimated annual emissions by biogenic and geogenic source type in the Wollongong region

Substance	Emissions (tonne/year)								
	Bushfires	Prescribed burning	Unpaved roads (fugitive/ windborne)	Soil Nitrification and denitrification	Tree canopy	Uncut grass	Cut grass	Marine aerosol	Biogenic and Geogenic Total
1,3-BUTADIENE	5.22×10^{-3}	0.48	-	-	-	-	-	-	0.48
ACETALDEHYDE	-	-	-	-	-	10	3.46	-	14
CARBON MONOXIDE	6.53	597	-	-	-	-	-	-	603
LEAD & COMPOUNDS	6.56×10^{-5}	5.99×10^{-3}	2.83×10^{-3}	-	-	-	-	-	8.89×10^{-3}
OXIDES OF NITROGEN	0.19	18	-	53	-	-	-	-	71
PARTICULATE MATTER ≤ 10 µm	0.66	60	1.86	-	-	-	-	264	327
PARTICULATE MATTER ≤ 2.5µm	0.56	51	0.25	-	-	-	-	38	90
POLYCYCLIC AROMATIC HYDROCARBONS	1.56×10^{-3}	0.14	-	-	-	-	-	-	0.14
SULFUR DIOXIDE	5.94×10^{-2}	5.43	-	-	-	-	-	-	5.49
TOTAL SUSPENDED PARTICULATE	0.67	61	3.14	-	-	-	-	1,031	1,096
TOTAL VOLATILE ORGANIC COMPOUNDS	0.46	42	-	-	3,307	51	82	-	3,482

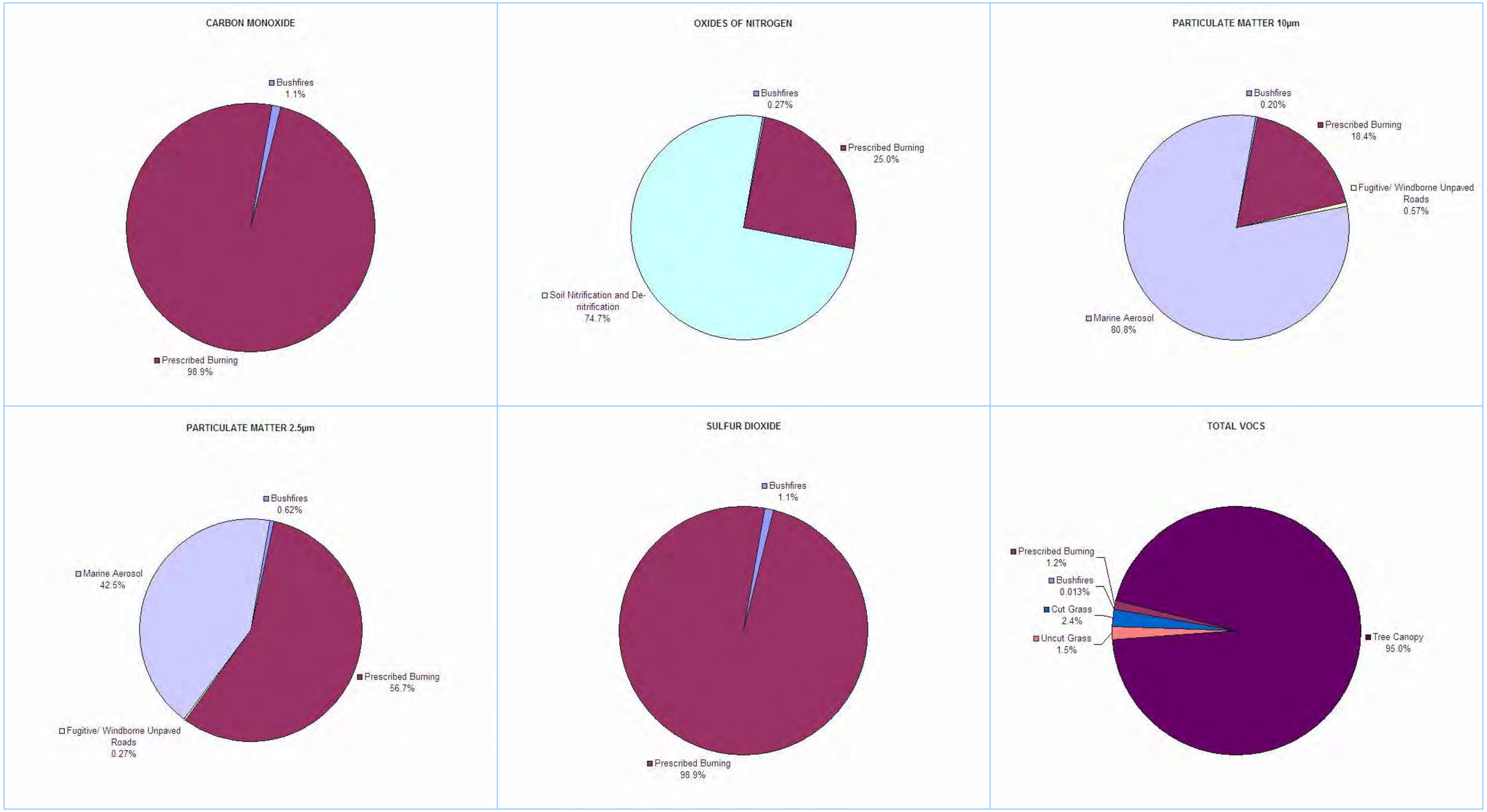
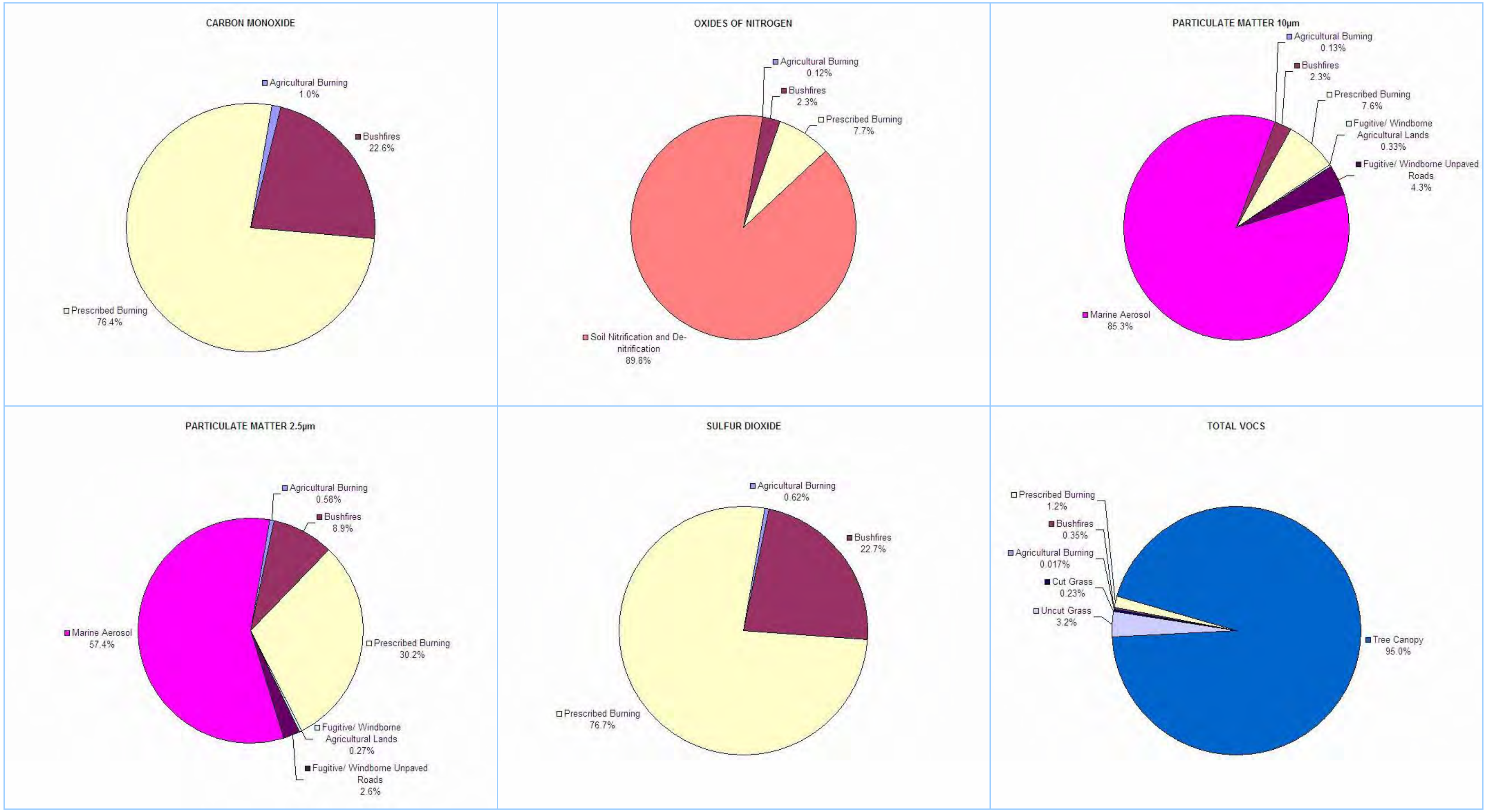


Figure ES-6: Proportions of total estimated annual emissions by biogenic and geogenic source type in the Wollongong region

Table ES-7: Total estimated annual emissions by biogenic and geogenic source type in the Non Urban region

Substance	Emissions (tonne/year)										
	Agricultural burning	Bushfires	Prescribed burning	Agricultural lands (fugitive/ windborne)	Unpaved roads (fugitive/ windborne)	Soil nitrification and denitrification	Tree canopy	Uncut grass	Cut grass	Marine aerosol	Biogenic and Geogenic Total
1,3-BUTADIENE	0.25	5.16	17	-	-	-	-	-	-	-	23
ACETALDEHYDE	-	-	-	-	-	-	-	852	13	-	865
CARBON MONOXIDE	291	6,451	21,803	-	-	-	-	-	-	-	28,545
LEAD & COMPOUNDS	4.57×10^{-4}	6.48×10^{-2}	0.22	1.29×10^{-2}	1.87	-	-	-	-	-	2.16
OXIDES OF NITROGEN	10	191	644	-	-	7,474	-	-	-	-	8,319
PARTICULATE MATTER ≤ 10 µm	37	650	2,196	95	1,230	-	-	-	-	24,511	28,719
PARTICULATE MATTER ≤ 2.5µm	36	551	1,864	16	163	-	-	-	-	3,546	6,176
POLYCYCLIC AROMATIC HYDROCARBONS	0.66	1.54	5.21	-	-	-	-	-	-	-	7.41
SULFUR DIOXIDE	1.60	59	198	-	-	-	-	-	-	-	259
TOTAL SUSPENDED PARTICULATE	38	661	2,235	209	2,070	-	-	-	-	94,188	99,401
TOTAL VOLATILE ORGANIC COMPOUNDS	22	452	1,526	-	-	-	123,756	4,226	303	-	130,284



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1 INTRODUCTION

An air emissions inventory project for biogenic and geogenic sources has taken over 2 years to complete. The base year of the biogenic and geogenic inventory represents activities that took place during the 2008 calendar year. The area included in the inventory covers the greater Sydney, Newcastle and Wollongong regions, known collectively as the Greater Metropolitan Region (GMR).

The purpose of this document is to present the emission estimation methodologies and results of the biogenic and geogenic air emissions inventory. The information is structured as follows:

- A description of the biogenic and geogenic air emissions inventory specification (Section 2) including:
    - The inventory year (Section 2.1);
    - A description of the inventory region (Section 2.2);
    - A description of the grid coordinate system (Section 2.3);
    - A description of emission sources considered (Section 2.4);
    - A description of the pollutants evaluated (Section 2.5); and
    - A broad discussion of the methodology (Section 2.6).
- The emission estimation methodology; and activity, spatial and temporal data presented by biogenic and geogenic source type (Section 3).
- An emission summary (for selected substances) presented by biogenic and geogenic source type in the whole GMR and the Sydney, Newcastle, Wollongong and Non Urban regions (Section 3).
- An emissions summary (for selected substances) presented for all biogenic and geogenic sources in the whole GMR and the Sydney, Newcastle, Wollongong and Non Urban regions (Section 4).
- A complete list of references (Section 5).
- Total biogenic and geogenic emissions of all substances emitted in the whole GMR and the Sydney, Newcastle, Wollongong and Non Urban regions (Appendix A: Estimated Annual Emissions of all Substances from Biogenic and Geogenic Sources).

2 INVENTORY SPECIFICATIONS

2.1 The Inventory Year

The biogenic and geogenic air emissions inventory results presented in this report are based on activities that took place in the 2008 calendar year.

2.2 The Inventory Region

The inventory region defined as the GMR measures 210 km (east-west) by 273 km (north-south). The inventory region is defined in Table 2-1 and shown in Figure 2-1.

Table 2-1: Definition of Greater Metropolitan, Sydney, Newcastle and Wollongong regions

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Greater Metropolitan	210	6159	420	6432
Sydney	261	6201	360	6300
Newcastle	360	6348	408	6372
Wollongong	279	6174	318	6201

[2] Map Grid of Australia based on the Geocentric Datum of Australia 1994 (GDA94) (ICSM, 2006).

Figure 2-1: Definition of Greater Metropolitan, Sydney, Newcastle and Wollongong regions

2.3 Grid Coordinate System

The grid coordinate system used for the biogenic and geogenic air emissions inventory uses 1 km by 1 km grid cells. The grid coordinates start from the bottom left corner having index number with

Easting (km) in the horizontal and Northing (km) in the vertical direction. The grid coordinate system is illustrated in Figure 2-2.

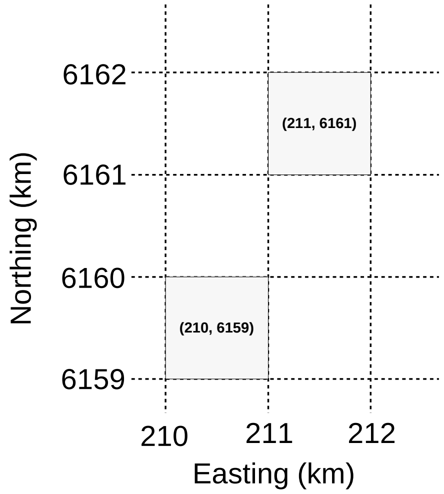

Figure 2-2: Grid coordinate system

2.4 Emission Sources Considered

The biogenic and geogenic air emissions inventory includes emissions from the following sources/activities:

- Agricultural burning;
- Bushfires;
- Prescribed burning;
- Fugitive/windborne from agricultural lands and unpaved roads;
- Microbial activity and chemical processes of nitrification and denitrification in soil;
- Fertiliser application to agricultural lands;
- Tree canopy and grass (i.e. cut and uncut); and
- Marine aerosol.

2.5 Pollutants Evaluated

The following pollutants have been considered:

- Substances included in the *National Environment Protection (National Pollutant Inventory) Measure* (NEPC, 2008);
- Pollutants included in the *National Environment Protection (Ambient Air Quality) Measure* (NEPC, 2003);

- Pollutants included in the *National Environment Protection (Air Toxics) Measure* (NEPC, 2004);
- Pollutants associated with the *Protection of the Environment Operations (Clean Air) Regulation 2010* (PCO, 2011);
- Air pollutants associated with the *Protection of the Environment Operations (General) Regulation 2009* (PCO, 2010);
- Speciation of oxides of nitrogen (i.e. NO and NO_2) for photochemical modelling (USEPA, 2003a)[3];
- Speciated organic compounds for photochemical modelling sourced from Carter (2010);
- Speciated particulate emissions (i.e. TSP (total suspended particulate), PM_{10} (particulate matter with an aerodynamic diameter ≤ 10 μm) and $PM_{2.5}$ (particulate matter with an aerodynamic diameter ≤ 2.5 μm));
- Environment Protection Authority of Victoria air toxic pollutants sourced from Hazardous Air Pollutants - A Review of Studies Performed in Australia and New Zealand (EPAV, 1999);
- Commonwealth Government Air Toxics Program Technical Advisory Group (13 March 2000) priority air pollutants (EA, 2001);
- U.S. Environmental Protection Agency list of 189 Hazardous Air Pollutants (USEPA, 2010a);
- Air pollutants included in the Office of Environmental Human Health Assessment (OEHHA)/Air Resources Board (ARB) 'hot spots' list (CARB, 2011);
- EPA regulated pollutants with design ground level concentrations (DEC, 2005);
- USEPA 16 priority polycyclic aromatic hydrocarbons (PAH) (Keith et. al., 1979);
- WHO97 polychlorinated dibenzo-p-dioxins (PCDD), polychlorinated dibenzofurans (PCDF) and polychlorinated biphenyls (PCB) (Van den Berg et. al., 1998); and
- Greenhouse gases (i.e. carbon dioxide, methane and nitrous oxide) included in the National Greenhouse Accounts (NGA) Factors (DCCEE, 2010).

2.6 Methodology Overview

This section contains a broad overview of the methodology used to develop the biogenic and geogenic air emissions inventory, while specific details are provided in Section 3.

The methodology used to develop the biogenic and geogenic air emissions inventory involves the following steps:

2.6.1 Identify Sources

Biogenic and geogenic sources considered in this report include all sources defined in Section 2.4 with the potential for air emissions in the GMR.

[3] The default NO_x speciation profile used in the inventory is 95% NO and 5% NO_2.

Biogenic and geogenic air emission sources have been identified from a number of different sources including:

- *ARB's Emissions Inventory, Area-Wide Source Methodologies, Index of Methodologies by Major Category* (CARB, 2008a);
- *EMEP/EEA air pollutant emission inventory guidebook 2009* (EEA, 2009);
- *USEPA AP 42, Fifth Edition, Compilation of Air Pollutant Emission Factors, Volume 1: Stationary Point and Area Sources* (USEPA, 1995a);
- *USEPA Emission Inventory Improvement Program, EIIP Technical Report Series, Volumes 1-10* (USEPA, 2007); and
- *USEPA 2008 National Emissions Inventory Data* (USEPA, 2011).

2.6.2 Select Emission Estimation Methodologies

Emissions have been estimated by combining activity data with emission factors. The emissions have been allocated spatially to each 1 km by 1 km grid cell, and temporally to months, weekdays/weekend days and hours. Emissions have been estimated using estimation methodologies and emission factors sourced from references provided in Table 2-2.

Table 2-2: Biogenic and geogenic estimation methodologies and emission factor data

Source type	Methodology or substance	Estimation methodologies and emission factor source
Agricultural Burning	Methodology	- *Area-Wide Source Methodologies, Section 7.17, Agricultural Burning and Other Burning Methodology* (CARB, 2005a) - *Australian Methodology for the Estimation of Greenhouse Gas Emissions and Sinks 2006, Agriculture* (DCC, 2007)
	Criteria pollutants: CO, NO_x, $PM_{2.5}$, PM_{10}, SO_2 & VOC	- *Area-Wide Source Methodologies, Section 7.17, Agricultural Burning and Other Burning Methodology* (CARB, 2005a)
	Criteria pollutants: TSP	- *California Emission Inventory and Reporting System (CEIDARS), Particulate Matter (PM) Speciation Profiles* (CARB, 2008b)
	Speciated NO_x	- *Technology Transfer Network - Clearinghouse for Inventories & Emissions Factors* (USEPA, 2003a)
	Speciated VOC	- *California Emission Inventory and Reporting System (CEIDARS), Organic Gas Speciation Profiles* (CARB, 2005b)
	Organic air toxics	- *California Emission Inventory and Reporting System (CEIDARS), Organic Gas Speciation Profiles* (CARB, 2005b)
	Metal air toxics	- *California Emission Inventory and Reporting System (CEIDARS), Particulate Matter (PM) Speciation Profiles* (CARB, 2007)
	Polycyclic aromatic hydrocarbons: PAH	- *Atmospheric Pollutant Emissions Factors from Open Burning of Agricultural and Forest Biomass by Wind Tunnel Simulations Volumes 1 and 2* (CARB, 1996a; and CARB, 1996b)
	Polychlorinated dibenzo-p-dioxins and	- *Australian Inventory of Dioxin Emissions 2004, National Dioxins Program Technical Report No. 3* (Bawden et. al., 2004)

Source type	Methodology or substance	Estimation methodologies and emission factor source
	Polychlorinated dibenzofurans: PCDD and PCDF	
	Ammonia	- *Area-Wide Source Methodologies, Section 7.17 Agricultural Burning and Other Burning Methodology* (CARB, 2005a)
	Greenhouse gases: CH_4, CO_2 and N_2O	- *California's 1990-2004 Greenhouse Gas Emissions Inventory and 1990 Emissions Level Technical Support Document* (CARB, 2009a) - *Annex 3D. Agricultural Residue Burning (IPCC 3C1B) to the Technical Support Document for California's Greenhouse Gas Emissions Inventory and the 1990 Emissions Level* (CARB, 2009b) - *AP 42, Fifth Edition, Volume I Chapter 2: Solid Waste Disposal, 2.5 Open Burning* (USEPA, 1992)
Bushfires	Methodology	- *Area-Wide Source Methodologies, Section 9.3 Wildfires* (CARB, 2004) - *Australian Methodology for the Estimation of Greenhouse Gas Emissions and Sinks 2006, Land Use, Land Use Change and Forestry* (DCC, 2008)
	Criteria pollutants: CO, NO_x, $PM_{2.5}$, PM_{10}, SO_2 & VOC	- *Area-Wide Source Methodologies, Section 9.3 Wildfires* (CARB, 2004) - *Wildland Fire Emissions Estimation System, Version 4* (VESTRA, 2003)
	Criteria pollutants: TSP	- *California Emission Inventory and Reporting System (CEIDARS), Particulate Matter (PM) Speciation Profiles* (CARB, 2008b)
	Speciated NO_x	- *Technology Transfer Network - Clearinghouse for Inventories & Emissions Factors* (USEPA, 2003a)
	Speciated VOC	- *California Emission Inventory and Reporting System (CEIDARS), Organic Gas Speciation Profiles* (CARB, 2005b)
	Organic air toxics	- *California Emission Inventory and Reporting System (CEIDARS), Organic Gas Speciation Profiles* (CARB, 2005b)
	Metal air toxics	- *California Emission Inventory and Reporting System (CEIDARS), Particulate Matter (PM) Speciation Profiles* (CARB, 2007)
	Polycyclic aromatic hydrocarbons: PAH	- *Atmospheric Pollutant Emissions Factors from Open Burning of Agricultural and Forest Biomass by Wind Tunnel Simulations Volumes 1 and 2* (CARB, 1996a; and CARB, 1996b)
	Polychlorinated dibenzo-p-dioxins and Polychlorinated dibenzofurans: PCDD and PCDF	- *Australian Inventory of Dioxin Emissions 2004, National Dioxins Program Technical Report No. 3* (Bawden et. al., 2004)
	Ammonia	- *Area-Wide Source Methodologies, Section 9.3 Wildfires* (CARB, 2004) - *Wildland Fire Emissions Estimation System, Version 4* (VESTRA, 2003)
	Greenhouse gases: CH_4, CO_2 and N_2O	- *Wildland Fire Emissions Estimation System, Version 4* (VESTRA, 2003)

Source type	Methodology or substance	Estimation methodologies and emission factor source
Prescribed Burning	Methodology	- *Area-Wide Source Methodologies, Section 7.16 Forest Management* (CARB, 2006) - *Australian Methodology for the Estimation of Greenhouse Gas Emissions and Sinks 2006, Land Use, Land Use Change and Forestry* (DCC, 2008)
	Criteria pollutants: CO, NO_x, $PM_{2.5}$, PM_{10}, SO_2 & VOC	- *Area-Wide Source Methodologies, Section 7.16 Forest Management* (CARB, 2006) - *Wildland Fire Emissions Estimation System, Version 4* (VESTRA, 2003)
	Criteria pollutants: TSP	- *California Emission Inventory and Reporting System (CEIDARS), Particulate Matter (PM) Speciation Profiles* (CARB, 2008b)
	Speciated NO_x	- *Technology Transfer Network - Clearinghouse for Inventories & Emissions Factors* (USEPA, 2003a)
	Speciated VOC	- *California Emission Inventory and Reporting System (CEIDARS), Organic Gas Speciation Profiles* (CARB, 2005b)
	Organic air toxics	- *California Emission Inventory and Reporting System (CEIDARS), Organic Gas Speciation Profiles* (CARB, 2005b)
	Metal air toxics	- *California Emission Inventory and Reporting System (CEIDARS), Particulate Matter (PM) Speciation Profiles* (CARB, 2007)
	Polycyclic aromatic hydrocarbons: PAH	- *Atmospheric Pollutant Emissions Factors from Open Burning of Agricultural and Forest Biomass by Wind Tunnel Simulations Volumes 1 and 2* (CARB, 1996a; and CARB, 1996b)
	Polychlorinated dibenzo-p-dioxins and Polychlorinated dibenzofurans: PCDD and PCDF	- *Australian Inventory of Dioxin Emissions 2004, National Dioxins Program Technical Report No. 3* (Bawden et. al., 2004)
	Ammonia	- *Area-Wide Source Methodologies, Section 7.16 Forest Management* (CARB, 2006) - *Wildland Fire Emissions Estimation System, Version 4* (VESTRA, 2003)
	Greenhouse gases: CH_4, CO_2 and N_2O	- *Wildland Fire Emissions Estimation System, Version 4* (VESTRA, 2003)
Fugitive/ Windborne from Agricultural Lands	Methodology	- *Area-Wide Source Methodologies, Section 7.12 Windblown Dust - Agricultural Lands* (CARB, 1997a)
	Criteria pollutants: $PM_{2.5}$ and PM_{10}	- *California Emission Inventory and Reporting System (CEIDARS), Particulate Matter (PM) Speciation Profiles* (CARB, 2008b)
	Criteria pollutants: TSP	- *Area-Wide Source Methodologies, Section 7.12 Windblown Dust - Agricultural Lands* (CARB, 1997a)
	Metal air toxics	- *California Emission Inventory and Reporting System (CEIDARS), Particulate Matter (PM) Speciation Profiles* (CARB, 2007)
Fugitive/ Windborne from Unpaved Roads	Methodology	- *Area-Wide Source Methodologies, Section 7.13 Windblown Dust - Unpaved Roads* (CARB, 1997b)
	Criteria pollutants: $PM_{2.5}$ and PM_{10}	- *California Emission Inventory and Reporting System (CEIDARS), Particulate Matter (PM) Speciation Profiles*

Source type	Methodology or substance	Estimation methodologies and emission factor source
		(CARB, 2008b)
	Criteria pollutants: TSP	- *Area-Wide Source Methodologies, Section 7.13 Windblown Dust - Unpaved Roads* (CARB, 1997b)
	Metal air toxics	- *California Emission Inventory and Reporting System (CEIDARS), Particulate Matter (PM) Speciation Profiles* (CARB, 2007)
Soil	Methodology	- *Biogenic Sources Preferred Methods, Technical Report Series Volume 5, Emission Inventory Improvement Program* (Radian, 1996) - *Review of Ammonia Emission Modeling Techniques for Natural Landscapes and Fertilized Soils* (Battye et. al., 2004) - *AP 42, Fifth Edition, Volume I, Chapter 14: Greenhouse Gas Biogenic Sources, 14.1 Emission from Soils - Greenhouse Gases* (USEPA, 2003b)
	Criteria pollutants: NO_x	- *Biogenic Sources Preferred Methods, Technical Report Series Volume 5, Emission Inventory Improvement Program* (Radian, 1996)
	Speciated NO_x	- *Biogenic Sources Preferred Methods, Technical Report Series Volume 5, Emission Inventory Improvement Program* (Radian, 1996)
	Ammonia	- *Review of Ammonia Emission Modeling Techniques for Natural Landscapes and Fertilized Soils* (Battye et. al., 2004)
	Greenhouse gases: N_2O	- *AP 42, Fifth Edition, Volume I, Chapter 14: Greenhouse Gas Biogenic Sources, 14.1 Emission from Soils - Greenhouse Gases* (USEPA, 2003b)
Tree Canopy	Methodology	- *Biogenic Emissions in the Greater Sydney Region* (Azzi et. al., 2004)
	Criteria pollutants: VOC	- *Biogenic Emissions in the Greater Sydney Region* (Azzi et. al., 2004) - *Biogenic Emissions Inventory GIS Version 3.02* (Huber, 2005)
	Speciated VOC	- *Biogenic Emissions in the Greater Sydney Region* (Azzi et. al., 2004) - *Biogenic Emissions Inventory GIS Version 3.02* (Huber, 2005)
	Organic air toxics	- *Biogenic Emissions in the Greater Sydney Region* (Azzi et. al., 2004) - *Biogenic Emissions Inventory GIS Version 3.02* (Huber, 2005)
Uncut Grass	Methodology	- *Biogenic Emissions in the Greater Sydney Region* (Azzi et. al., 2004)
	Criteria pollutants: VOC	- *Biogenic Emissions in the Greater Sydney Region* (Azzi et. al., 2004) - *Biogenic Emissions Inventory GIS Version 3.02* (Huber, 2005)
	Speciated VOC	- *Biogenic Emissions in the Greater Sydney Region* (Azzi et. al., 2004) - *Biogenic Emissions Inventory GIS Version 3.02* (Huber, 2005)
	Organic air toxics	- *Biogenic Emissions in the Greater Sydney Region* (Azzi et. al., 2004) - *Biogenic Emissions Inventory GIS Version 3.02* (Huber, 2005)
Cut Grass	Methodology	- *Biogenic Emissions in the Greater Sydney Region* (Azzi et. al., 2004)

Source type	Methodology or substance	Estimation methodologies and emission factor source
	Criteria pollutants: VOC	- *Biogenic Emissions in the Greater Sydney Region* (Azzi et. al., 2004)
	Speciated VOC	- *Emissions of Volatile Organic Compounds (Primarily Oxygenated Species) from Pasture* (Kirstine et. al., 1998)
	Organic air toxics	- *Emissions of Volatile Organic Compounds (Primarily Oxygenated Species) from Pasture* (Kirstine et. al., 1998)
Marine Aerosol	Methodology	- *Initial Applications of Sea Salt Aerosol Emissions and Chemistry Algorithms in the CMAQ v4.5 – AERO4 Module* (Shankar et. al., 2005) - *A Parameterization of Sea-Salt Aerosol Source Function for Sub- and Super-Micron Particles* (Gong, 2003) - *A Model of Marine Aerosol Generation via Whitecaps and Wave Disruption* (Monahan et. al., 1986) - *The Sea Spray Generation Function* (Smith et. al., 1998)
	Criteria pollutants: $PM_{2.5}$ and PM_{10}	- *A Parameterization of Sea-Salt Aerosol Source Function for Sub- and Super-Micron Particles* (Gong, 2003) - *A Model of Marine Aerosol Generation via Whitecaps and Wave Disruption* (Monahan et. al., 1986)
	Criteria pollutants: TSP	- *A Parameterization of Sea-Salt Aerosol Source Function for Sub- and Super-Micron Particles* (Gong, 2003) - *A Model of Marine Aerosol Generation via Whitecaps and Wave Disruption* (Monahan et. al., 1986) - *The Sea Spray Generation Function* (Smith et. al., 1998)

Detailed emission estimation methodologies for each biogenic and geogenic source are presented in Section 3.

2.6.3 Acquire Activity, Spatial and Temporal Data

Activity, spatial and temporal data have been acquired from a number of government departments and service providers. Emissions have been estimated using activity, spatial and temporal data sourced from the references provided in Table 2-3, Table 2-4 and Table 2-5.

Table 2-3: Biogenic and geogenic activity data

Source type	Activity data	Activity data source
Agricultural Burning	Crop harvest (tonne and ha) by NSW agronomy district	- *NSW Grains Report 2008* (NSW DPI, 2008)
Bushfires	Bushfire area (ha)	- *On-Park Wildfires 2008 Calendar Year* (DECCW, 2009a) - *Off-Park Wildfires 2008 Calendar Year* (RFS, 2009a)
Prescribed Burning	Prescribed burn area (ha)	- *On-Park Prescribed Burns Entered into BRIMS for the 2008 Calendar Year* (DECCW, 2009b) - *Off-Park Prescribed Burns Entered into BRIMS for the 2008 Calendar*

Source type	Activity data	Activity data source
		Year (RFS, 2009b)
Fugitive/ Windborne from Agricultural Lands	Crop area (ha) by NSW agronomy district	- *NSW Grains Report 2008* (NSW DPI, 2008)
	Soil erodibility (tonne/ha/year)	- *Digital Atlas of Australian* Soils (BRS , 1991)
	Hourly meteorological data (temperature (K), precipitation (mm) and wind speed (m/s)) required to calculate the climatic factor	- *The Air Pollution Model (TAPM) Version 3* (Hurley, 2005)
Fugitive/ Windborne from Unpaved Roads	Unpaved road length (m)	- *Unsealed Roads from the dtdb Cultural Lines Layer - Arc/Info Export Format* (DEC, 2004a)
	Unpaved road width (m)	- *Performance Based Standards Scheme Network Classification Guidelines* (NTC, 2007)
	Soil erodibility (tonne/ha/year)	- *Digital Atlas of Australian Soils* (BRS , 1991)
	Hourly meteorological data (temperature (K), precipitation (mm) and wind speed (m/s)) required to calculate the climatic factor	- *The Air Pollution Model (TAPM) Version 3* (Hurley, 2005)
Soil	Land use area (ha)	- *Land Use of Australia, Version 3 - 1996/1997* (BRS , 2006)
	Nitrogen fertiliser consumption (tonne/year)	- *Mean Annual Nitrogen Fertilisation (kgN ha-1 y-1)* (BRS, 2001; and NLWRA, 2001) - *Consumption of Nitrogen Fertilizers in Australia in 2008* (IFA ,2011)
	Hourly meteorological data (temperature (K)) required to calculate the temperature correction factor	- *The Air Pollution Model (TAPM) Version 3* (Hurley, 2005)
Tree Canopy	Genus specific speciated VOC emission rate (µg/g leaf biomass/h), leaf area index (LAI) (m^2/m^2), canopy height (m) and leaf biomass (g/m^2)	- *Biogenic Emissions in the Greater Sydney Region* (Azzi et. al., 2004) - *Biogenic Emissions Inventory GIS Version 3.02* (Huber, 2005)
	Hourly meteorological data (temperature (K)) required by the tree canopy model	- *The Air Pollution Model (TAPM) Version 3* (Hurley, 2005)
Uncut Grass	Genus specific speciated VOC emission rate (µg/g leaf biomass/h), leaf area index (LAI) (m^2/m^2) and leaf biomass (g/m^2)	- *Biogenic Emissions in the Greater Sydney Region* (Azzi et. al., 2004) - *Biogenic Emissions Inventory GIS Version 3.02* (Huber, 2005)
	Hourly meteorological data (temperature (K)) required by the uncut grass model	- *The Air Pollution Model (TAPM) Version 3* (Hurley, 2005)
Cut Grass	Residential lawn area (m^2) and annual lawn mowing frequency	- *Domestic Lawn Mowing Pollution Survey* (TR, 2009)
	Public open space lawn area (m^2) annual monthly lawn mowing frequency	- *Public Open Space Lawn Mowing Pollution Survey* (DECC, 2007)

Source type	Activity data	Activity data source
Marine Aerosol	Ocean area (m^2)	- *Gridded Ocean Area in the GMR* (DECCW, 2009c)
	Hourly meteorological data (wind speed (m/s)) required by the open-ocean sea-salt aerosol model	- *The Air Pollution Model (TAPM) Version 3* (Hurley, 2005)

Table 2-4: Biogenic and geogenic spatial data

Source type	Spatial data	Spatial data source
Agricultural Burning	GIS layer for crop area	- *Land Use of Australia, Version 3 - 1996/1997* (BRS , 2006)
Bushfires	Bushfire location (latitude and longitude)	- *On-Park Wildfires 2008 Calendar Year* (DECCW, 2009a) - *Off-Park Wildfires 2008 Calendar Year* (RFS, 2009a)
Prescribed Burning	Prescribed burn location (latitude and longitude)	- *On-Park Prescribed Burns Entered into BRIMS for the 2008 Calendar Year* (DECCW, 2009b) - *Off-Park Prescribed Burns Entered into BRIMS for the 2008 Calendar Year* (RFS, 2009b)
Fugitive/ Windborne from Agricultural Lands	GIS layer for crop area combined with GIS layer for soil erodibility and gridded 1 km x 1 km climatic factor estimates	- *Land Use of Australia, Version 3 - 1996/1997* (BRS , 2006) - *Digital Atlas of Australian Soils* (BRS , 1991) - *The Air Pollution Model (TAPM) Version 3* (Hurley, 2005)
Fugitive/ Windborne from Unpaved Roads	GIS layer for unpaved road area combined with GIS layer for soil erodibility and gridded 1 km x 1 km climatic factor estimates	- *Unsealed Roads from the dtdb Cultural Lines Layer - Arc/Info Export Format* (DEC, 2004a) - *Digital Atlas of Australian Soils* (BRS , 1991) - *The Air Pollution Model (TAPM) Version 3* (Hurley, 2005)
Soil	GIS layer for land use area combined with gridded 1 km x 1 km temperature correction factor estimates	- *Land Use of Australia, Version 3 - 1996/1997* (BRS , 2006) - *The Air Pollution Model (TAPM) Version 3* (Hurley, 2005)

Source type	Spatial data	Spatial data source
Tree Canopy	GIS layer for genus specific speciated VOC emission rate, leaf area index, canopy height and leaf biomass combined with gridded 1 km x 1 km temperature estimates	- *Biogenic Emissions in the Greater Sydney Region* (Azzi et. al., 2004) - *Biogenic Emissions Inventory GIS Version 3.02* (Huber, 2005) - *The Air Pollution Model (TAPM) Version 3* (Hurley, 2005)
Uncut Grass	GIS layer for genus specific speciated VOC emission rate, leaf area index and leaf biomass combined with gridded 1 km x 1 km temperature estimates	- *Biogenic Emissions in the Greater Sydney Region* (Azzi et. al., 2004) - *Biogenic Emissions Inventory GIS Version 3.02* (Huber, 2005) - *The Air Pollution Model (TAPM) Version 3* (Hurley, 2005)
Cut Grass	Gridded 1 km x 1 km free standing dwelling estimates for residential lawn mowing	- *Forecasts for Free Standing Dwelling from 2006 to 2036* (TDC, 2009)
	Gridded 1 km x 1 km population estimates (≥ 50 per grid cell) for public open space lawn mowing	- *Forecasts for Population from 2006 to 2036* (TDC, 2009)
Marine Aerosol	Gridded 1 km x 1 km ocean proportion combined with gridded 1 km x 1 km wind speed estimates	- *Gridded Ocean Area in the GMR* (DECCW, 2009c) - *The Air Pollution Model (TAPM) Version 3* (Hurley, 2005)

Table 2-5: Biogenic and geogenic temporal data

Source type	Temporal data	Temporal data source
Agricultural Burning	Monthly: Crop harvest time from crop calendar	- *Australia State Crop Calendars* (USDA, 2003)
	Daily: Average working days Hourly: Average working hours	- *Biogenic and Biomass Burning Emissions Inventory* (EPAV, 2002)
Bushfires	Monthly: Bushfire date Daily: Bushfire date	- *On-Park Wildfires 2008 Calendar Year* (DECCW, 2009a) - *Off-Park Wildfires 2008 Calendar Year* (RFS, 2009a)
	Hourly: Generic bushfire profile	- *Biogenic and Biomass Burning Emissions Inventory* (EPAV, 2002)
Prescribed Burning	Monthly: Prescribed burn date Daily: Prescribed burn date	- *On-Park Prescribed Burns Entered into BRIMS for the 2008 Calendar Year* (DECCW, 2009b) - *Off-Park Prescribed Burns Entered*

Source type	Temporal data	Temporal data source
		into BRIMS for the 2008 Calendar Year (RFS, 2009b)
	Hourly: Generic prescribed burn profile	- *Biogenic and Biomass Burning Emissions Inventory* (EPAV, 2002)
Fugitive/ Windborne from Agricultural Lands	Monthly, daily and hourly: Gridded 1 km x 1 km climatic factor combined with vegetative cover factor estimates	- *The Air Pollution Model (TAPM) Version 3* (Hurley, 2005) - *Australia State Crop Calendars* (USDA, 2003)
Fugitive/ Windborne from Unpaved Roads	Monthly, daily and hourly: Gridded 1 km x 1 km climatic factor estimates	- *The Air Pollution Model (TAPM) Version 3* (Hurley, 2005)
Soil	Monthly, daily and hourly: Gridded 1 km x 1 km temperature correction factor estimates	- *The Air Pollution Model (TAPM) Version 3* (Hurley, 2005)
Tree Canopy	Monthly, daily and hourly: Gridded 1 km x 1 km leaf temperature as a function of ambient temperature estimates	- *Biogenic Emissions in the Greater Sydney Region* (Azzi et. al., 2004) - *Biogenic Emissions Inventory GIS Version 3.02* (Huber, 2005) - *The Air Pollution Model (TAPM) Version 3* (Hurley, 2005)
Uncut Grass	Monthly, daily and hourly: Gridded 1 km x 1 km leaf temperature as a function of ambient temperature estimates	- *Biogenic Emissions in the Greater Sydney Region* (Azzi et. al., 2004) - *Biogenic Emissions Inventory GIS Version 3.02* (Huber, 2005) - *The Air Pollution Model (TAPM) Version 3* (Hurley, 2005)
Cut Grass	Monthly: Lawn mowing frequency combined with gridded 1 km x 1 km temperature correction factor estimates	- Domestic lawn mowing: *Domestic Lawn Mowing Pollution Survey* (TR, 2009) - Public open space lawn mowing: *Public Open Space Lawn Mowing Pollution Survey* (DECC, 2007) - *The Air Pollution Model (TAPM) Version 3* (Hurley, 2005) - *Modeling Terrestrial Biogenic Sources of Oxygenated Organic Emissions* (Potter et. al., 2003)
	Daily and hourly: Lawn mowing frequency combined with exponential decay for initial leaf wounding followed by leaf drying emission phases	- Domestic lawn mowing: *Domestic Lawn Mowing Pollution Survey* (TR, 2009) - Public open space lawn mowing: *Public Open Space Lawn Mowing Pollution Survey* (DECC, 2007) - *Biogenic Emissions in the Greater Sydney Region* (Azzi et. al., 2004) - *Emissions of Volatile Organic Compounds (Primarily Oxygenated*

Source type	Temporal data	Temporal data source
		Species) from Pasture (Kirstine et. al., 1998)
Marine Aerosol	Monthly, daily and hourly: Gridded 1 km x 1 km wind speed estimates	- *The Air Pollution Model (TAPM) Version 3* (Hurley, 2005)

A detailed discussion of the activity, spatial and temporal data acquired for each biogenic and geogenic source is presented in Section 3.

2.6.4 *Design and Implement Emission Estimation Techniques*

All emissions have been calculated within the *Biogenic and Geogenic Emissions Data Management System v1.0*, which is a Microsoft® Access™ 2003 relational database that includes all the data necessary for estimating emissions to air from biogenic and geogenic sources, including: activity data; emission factors; particulate matter (PM) and volatile organic compound (VOC) speciation profiles; spatial allocation data; and hourly, daily and monthly temporal variation data. The *Biogenic and Geogenic Emissions Data Management System v1.0* start-up form is shown in Figure 2-3.

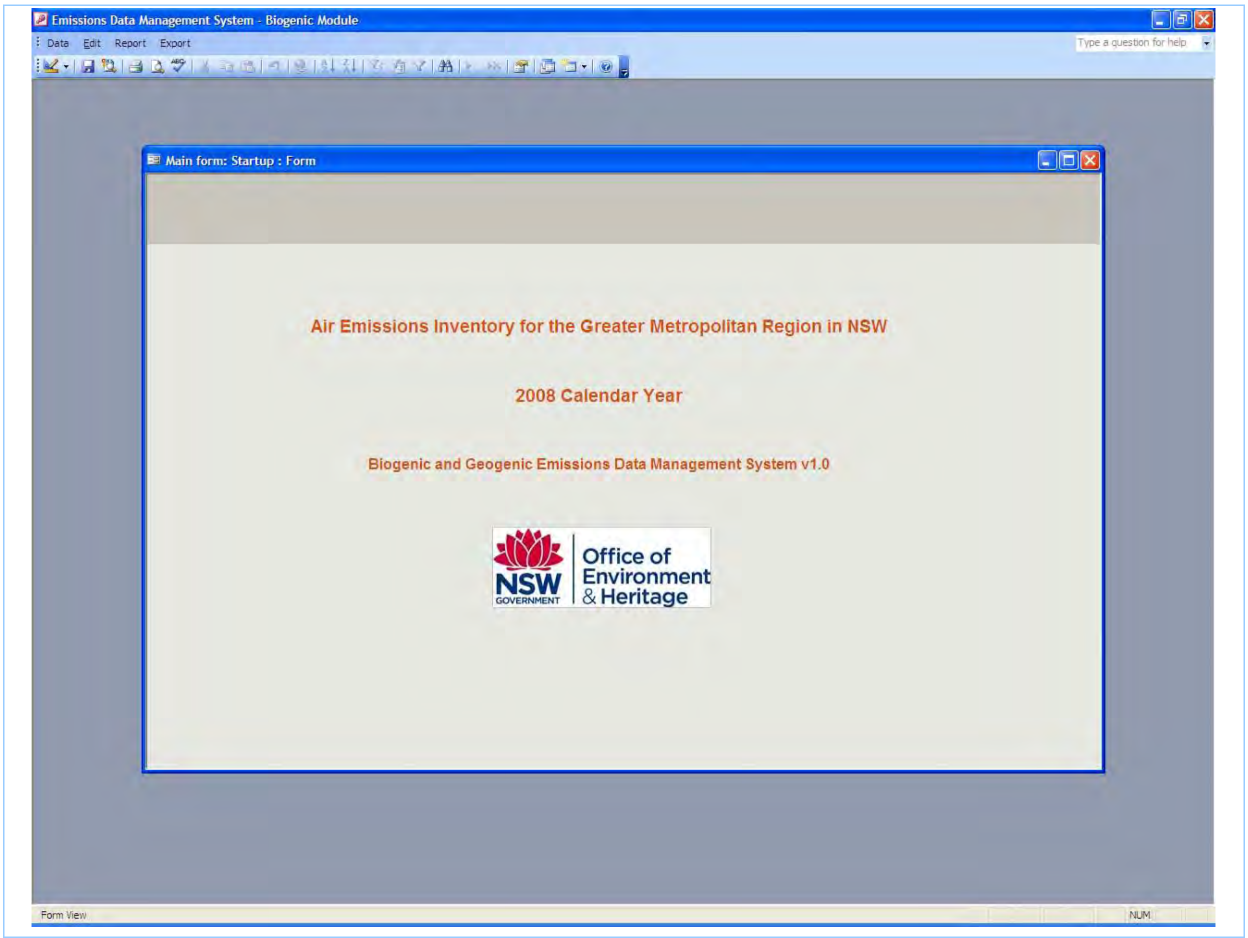

Figure 2-3: Biogenic and Geogenic Emissions Data Management System v1.0 start-up form

In general, emissions have been estimated using Equation 1:

$$E_{i,j} = A_j \times EF_{i,j} \times \left(1 - ER_{i,j} / 100\right)$$ **Equation 1**

where:			
$E_{i,j}$	=	Emissions of substance i from source j	(kg/year)
A_j	=	Activity rate for source j	(activity unit/year)
$EF_{i,j}$	=	Emission factor for substance i from source j	(kg/activity unit)
$ER_{i,j}$	=	Emission reduction efficiency for substance i for source j	(%)

Detailed emission estimation techniques for each biogenic and geogenic source are presented in Section 3.

3 DATA SOURCES AND RESULTS

This section presents the: detailed emission estimation methodologies; activity, spatial and temporal data sources used; and the associated emission estimates for the 2008 calendar year for the following biogenic and geogenic sources:

- Agricultural burning;
- Bushfires;
- Prescribed burning;
- Fugitive/windborne from agricultural lands and unpaved roads
- Microbial activity and chemical processes of nitrification and denitrification in soil;
- Fertiliser application to agricultural lands;
- Tree canopy and grass (i.e. cut and uncut); and
- Marine aerosol.

For each biogenic and geogenic source type, the information in this section is structured as follows:

- Emission Source Description;
- Emission Estimation Methodology;
- Activity Data;
- Emission and Speciation Factors;
- Spatial Distribution of Emissions;
- Temporal Variation of Emissions; and
- Emission Estimates.

Biogenic and geogenic emissions have been estimated by combining activity data with emission factors. The emissions have been allocated spatially to each 1 km by 1 km grid cell, and temporally to months, weekdays/weekend days and hours. Activity, spatial and temporal data have been acquired from a number of government departments and service providers. All emissions have been calculated within the *Biogenic and Geogenic Emissions Data Management System v1.0*, which is a Microsoft® Access™ 2003 relational database that includes all the data necessary for estimating emissions to air from biogenic and geogenic sources, including: activity data; emission factors; particulate matter (PM) and volatile organic compound (VOC) speciation profiles; spatial allocation data; and hourly, daily and monthly temporal variation data.

Where reference is made to:

- *Combustion products*, this includes CO, NO_x, $PM_{2.5}$, PM_{10}, TSP, SO_2 and VOC (total and speciated); and

- *Particulate matter*, this includes $PM_{2.5}$, PM_{10} and TSP.

In this section total estimated emissions are presented for each biogenic and geogenic source type in the whole GMR and the Sydney, Newcastle and Wollongong regions. Total estimated emissions are also presented for the region defined as Non Urban. This region is the area of the GMR minus the combined areas of the Sydney, Newcastle and Wollongong regions. Emissions are presented for the following pollutants only:

- 1,3-Butadiene
- Acetaldehyde
- Carbon monoxide (CO)
- Lead & compounds
- Oxides of nitrogen (NO_x)
- Particulate matter ≤ 10 µm (PM_{10})
- Particulate matter ≤ 2.5 µm ($PM_{2.5}$)
- Polycyclic aromatic hydrocarbons (PAH)
- Sulfur dioxide (SO_2)
- Total suspended particulate (TSP)
- Total volatile organic compounds (VOC).

These substances were selected since they:

- Are the most common air pollutants found in airsheds according to the National Pollutant Inventory NEPM (NEPC, 2008);

- Are referred to in National Environment Protection Measures (NEPMs) for Ambient Air Quality (NEPC, 2003) and Air Toxics (NEPC, 2004); and

- Have been classified as priority air pollutants (NEPC, 2006).

Total biogenic and geogenic emissions of all substances emitted in the whole GMR and the Sydney, Newcastle, Wollongong and Non Urban regions are presented in Appendix A: Estimated Annual Emissions of all Substances from Biogenic and Geogenic Sources.

3.1 Agricultural Burning

3.1.1 *Emission Source Description*

The biogenic and geogenic air emissions inventory includes emissions of combustion products from open burning of agricultural residues (i.e. crop stubble) after field crops are harvested.

To estimate emissions from these sources, the following have been considered:

➢ *NSW grains report*

The NSW Grains Report contains crop production information highlights, seasonal conditions and outlook and information on specific summer and winter crops. The area and quantity of summer and winter field crops harvested in each NSW agronomy district have been obtained for the 2008 calendar year (NSW DPI, 2008) and used to estimate the quantity of crop stubble burned in the GMR.

➢ *Crop type*

The inventory includes emissions of combustion products from open burning of agricultural residues as follows:

Summer crops

- *Grain Sorghum;*
- *Maize; and*
- *Soybean.*

Winter crops

- *Barley;*
- *Canola.*
- *Lupin Angust;*
- *Oats;*
- *Triticale; and*
- *Wheat.*

3.1.2 *Emission Estimation Methodology*

Table 3-1 summarises the emission estimation methodologies used for agricultural burning.

Table 3-1: Agricultural burning emission estimation methodologies

Emission source	Emission estimation methodology source
Emissions of combustion products from open burning of agricultural residues	- *Area-Wide Source Methodologies, Section 7.17, Agricultural Burning and Other Burning Methodology* (CARB, 2005a) - *Australian Methodology for the Estimation of Greenhouse Gas Emissions and Sinks 2006, Agriculture* (DCC, 2007)

Emissions of combustion products from open burning of agricultural residues have been estimated using fuel consumption based emission factors combined with activity rates. Activity rates include crop type and quantity of agricultural residue burned (NSW DPI, 2008). Emissions have been determined using Equation 2 (CARB, 2005a; and DCC, 2007):

$$\mathbf{E_{i,j} = P_j \times R_j \times S_j \times DM_j \times Z_j \times F_j \times EF_{i,j}}$$ **Equation 2**

where:			
$E_{i,j}$	=	Emissions of substance i from crop type j	(kg/year)
P_j	=	Annual production of crop type j	(tonne/year)
R_j	=	Residue to crop ratio for crop type j (Table 3-2) (Appendix L, Table L.1; DCC, 2007)	(kg residue/kg crop)
S_j	=	Fraction of crop residue remaining at burning for crop type j (Table 3-2) (Appendix L, Table L.1; DCC, 2007)	(kg residue/kg residue)
DM_j	=	Dry matter content for crop type j (Table 3-2) (Appendix L, Table L.1; DCC, 2007)	(kg dry residue/kg residue)
Z	=	Residue burning efficiency for crop type j (Table 3-2) (Section 4F; DCC, 2007)	(kg residue burned/kg residue)
F_j	=	Fraction burned of the annual production of crop type j (Table 3-2) (Appendix L, Table L.1; DCC, 2007)	(ha burned/ha harvested)
$EF_{i,j}$	=	Emission factor for substance i and crop type j	(kg/tonne)
i	=	Substance (either "criteria pollutants", "speciated NO_x", "speciated VOC", "organic air toxics", "metal air toxics", "PAH", "PCDD and PCDF", "ammonia" or "greenhouse gases")	(-)
j	=	Crop type (either "grain sorghum", "maize", "soybean", "barley", "canola", "lupin angust", "oats", "triticale" or "wheat")	(-)

Table 3-2 presents crop attributes used to estimate emissions of combustion products from open burning of agricultural residues (DCC, 2007).

Table 3-2: Field crop attributes

Crop type	R (kg residue/kg crop)	S (kg residue/kg residue)	DM (kg dry residue/kg residue)	Z (kg residue burned/kg residue)	F (ha burned/ha harvested)
Grain Sorghum	1.5	0.5	0.8	0.96	0.23
Maize	1.5	1.0	0.8	0.96	0.30
Soybean	2.1	0.5	0.8	0.96	0.24
Barley	1.5	0.5	0.8	0.96	0.23
Canola	1.5	0.5	0.8	0.96	0.08
Lupin Angust	1.5	0.5	0.8	0.96	0.08
Oats	1.5	0.5	0.8	0.96	0.23
Triticale	1.5	0.5	0.8	0.96	0.23
Wheat	1.5	0.5	0.9	0.96	0.23

3.1.3 *Activity Data*

Table 3-3 summarises the activity data used for agricultural burning.

Table 3-3: Agricultural burning activity data

Activity data	Activity data source
Crop harvest (tonne and ha) by NSW agronomy district	- *NSW Grains Report 2008* (NSW DPI, 2008)

The area and quantity of summer and winter field crops harvested in each NSW agronomy district (i.e. North West, Central West, South West, Tablelands and Coastal) have been obtained for the 2008 calendar year (NSW DPI, 2008). Since the Tablelands agronomy district forms part of the GMR, 50% of the harvest area and quantity from this region has been used to estimate the quantity of crop stubble burned in the GMR. Table 3-4 presents the area and quantity of field crops harvested in the GMR.

Table 3-4: Field crop harvest in the GMR

Crop type	2008 harvest[4]	
	Area (ha)	Quantity (tonne)
Grain Sorghum	80	215
Maize	400	2,800
Soybean	125	162.5
Barley	175	397.5
Canola	650	1,100
Lupin Angust	500	1,000

[4] Crop harvest in the GMR assumes 50% of crop harvest in the Tablelands agronomy district (NSW DPI, 2008).

Crop type	2008 harvest[4]	
	Area (ha)	Quantity (tonne)
Oats	6,900	16,545
Triticale	2,785	7,525.5
Wheat	4,010	11,775
Grand Total	15,625	41,520.5

3.1.4 Emission and Speciation Factors

Table 3-5 summarises the emission and speciation factors used for agricultural burning.

Table 3-5: Agricultural burning emission and speciation factors

Substance	Emission source	Emission and speciation factor source
Criteria pollutants: CO, NO_x, $PM_{2.5}$, PM_{10}, SO_2 & VOC	Grain Sorghum	- *Sorghum - Area-Wide Source Methodologies, Section 7.17, Agricultural Burning and Other Burning Methodology* (CARB, 2005a)
	Maize	- *Corn - Area-Wide Source Methodologies, Section 7.17, Agricultural Burning and Other Burning Methodology* (CARB, 2005a)
	Soybean	- *Bean/Pea - Area-Wide Source Methodologies, Section 7.17, Agricultural Burning and Other Burning Methodology* (CARB, 2005a)
	Barley	- *Barley - Area-Wide Source Methodologies, Section 7.17, Agricultural Burning and Other Burning Methodology* (CARB, 2005a)
	Canola, Lupin Angust and Triticale	- *Other field crops - Area-Wide Source Methodologies, Section 7.17, Agricultural Burning and Other Burning Methodology* (CARB, 2005a)
	Oats	- *Oats - Area-Wide Source Methodologies, Section 7.17, Agricultural Burning and Other Burning Methodology* (CARB, 2005a)
	Wheat	- *Wheat - Area-Wide Source Methodologies, Section 7.17, Agricultural Burning and Other Burning Methodology* (CARB, 2005a)
Criteria pollutants: TSP	Grain Sorghum, Soybean, Canola, Lupin Angust, Triticale and Oats	- *PMPROF 430 - California Emission Inventory and Reporting System (CEIDARS), Particulate Matter (PM) Speciation Profiles* (CARB, 2008b)
	Maize	- *PMPROF 434 - California Emission Inventory and Reporting System (CEIDARS), Particulate Matter (PM) Speciation Profiles* (CARB, 2008b)
	Barley	- *PMPROF 433 - California Emission Inventory and Reporting System (CEIDARS), Particulate Matter (PM) Speciation Profiles* (CARB, 2008b)
	Wheat	- *PMPROF 432 - California Emission Inventory and Reporting System (CEIDARS), Particulate Matter (PM) Speciation Profiles* (CARB, 2008b)

Substance	Emission source	Emission and speciation factor source
Speciated NO_x	Grain Sorghum, Soybean, Canola, Lupin Angust, Triticale, Oats, Maize, Barley and Wheat	- *Technology Transfer Network - Clearinghouse for Inventories & Emissions Factors* (USEPA, 2003a)
Speciated VOC	Grain Sorghum, Soybean, Canola, Lupin Angust, Triticale, Oats, Maize, Barley and Wheat	- *ORGPROF 307 - California Emission Inventory and Reporting System (CEIDARS), Organic Gas Speciation Profiles* (CARB, 2005b)
Organic air toxics	Grain Sorghum, Soybean, Canola, Lupin Angust, Triticale, Oats, Maize, Barley and Wheat	- *ORGPROF 307 - California Emission Inventory and Reporting System (CEIDARS), Organic Gas Speciation Profiles* (CARB, 2005b)
Metal air toxics	Grain Sorghum, Soybean, Canola, Lupin Angust, Triticale, Oats, Maize, Barley and Wheat	- *PMPROF 430 - California Emission Inventory and Reporting System (CEIDARS), Particulate Matter (PM) Speciation Profiles* (CARB, 2007)
Polycyclic aromatic hydrocarbons: PAH	Grain Sorghum, Soybean, Canola, Lupin Angust, Triticale and Oats	- *Average of Barley Straw, Corn Stover, Rice Straw and Wheat Straw - Atmospheric Pollutant Emissions Factors from Open Burning of Agricultural and Forest Biomass by Wind Tunnel Simulations Volumes 1 and 2* (CARB, 1996a; and CARB, 1996b)
	Maize	- *Corn Stover - Atmospheric Pollutant Emissions Factors from Open Burning of Agricultural and Forest Biomass by Wind Tunnel Simulations Volumes 1 and 2* (CARB, 1996a; and CARB, 1996b)
	Barley	- *Barley Straw - Atmospheric Pollutant Emissions Factors from Open Burning of Agricultural and Forest Biomass by Wind Tunnel Simulations Volumes 1 and 2* (CARB, 1996a; and CARB, 1996b)
	Wheat	- *Wheat Straw - Atmospheric Pollutant Emissions Factors from Open Burning of Agricultural and Forest Biomass by Wind Tunnel Simulations Volumes 1 and 2* (CARB, 1996a; and CARB, 1996b)
Polychlorinated dibenzo-p-dioxins and Polychlorinated dibenzofurans: PCDD and PCDF	Grain Sorghum, Soybean, Canola, Lupin Angust, Triticale, Oats, Maize and Barley	- *Agricultural residue burning - coarse grains - Australian Inventory of Dioxin Emissions 2004, National Dioxins Program Technical Report No. 3* (Bawden et. al., 2004)
	Wheat	- *Agricultural residue burning – wheat - Australian Inventory of Dioxin Emissions 2004, National Dioxins Program Technical Report No. 3* (Bawden et. al., 2004)
Ammonia	Grain Sorghum	- *Sorghum - Area-Wide Source Methodologies, Section 7.17, Agricultural Burning and Other Burning Methodology* (CARB, 2005a)
	Maize	- *Corn - Area-Wide Source Methodologies, Section 7.17, Agricultural Burning and Other Burning Methodology* (CARB, 2005a)
	Soybean	- *Bean/Pea - Area-Wide Source Methodologies, Section 7.17, Agricultural Burning and Other Burning Methodology* (CARB, 2005a)
	Barley	- *Barley - Area-Wide Source Methodologies, Section 7.17,*

Substance	Emission source	Emission and speciation factor source
		Agricultural Burning and Other Burning Methodology (CARB, 2005a)
	Canola, Lupin Angust and Triticale	- *Other field crops - Area-Wide Source Methodologies, Section 7.17, Agricultural Burning and Other Burning Methodology* (CARB, 2005a)
	Oats	- *Oats - Area-Wide Source Methodologies, Section 7.17, Agricultural Burning and Other Burning Methodology* (CARB, 2005a)
	Wheat	- *Wheat - Area-Wide Source Methodologies, Section 7.17, Agricultural Burning and Other Burning Methodology* (CARB, 2005a)
Greenhouse gases: CH_4	Grain Sorghum	- *Sorghum - AP 42, Fifth Edition, Volume I Chapter 2: Solid Waste Disposal, 2.5 Open Burning* (USEPA, 1992)
	Maize	- *California's 1990-2004 Greenhouse Gas Emissions Inventory and 1990 Emissions Level Technical Support Document* (CARB, 2009a) - *Corn - Annex 3D. Agricultural Residue Burning (IPCC 3C1B) to the Technical Support Document for California's Greenhouse Gas Emissions Inventory and the 1990 Emissions Level* (CARB, 2009b)
	Soybean	- *Bean/Pea - AP 42, Fifth Edition, Volume I Chapter 2: Solid Waste Disposal, 2.5 Open Burning* (USEPA, 1992)
	Barley	- *California's 1990-2004 Greenhouse Gas Emissions Inventory and 1990 Emissions Level Technical Support Document* (CARB, 2009a) - *Barley - Annex 3D. Agricultural Residue Burning (IPCC 3C1B) to the Technical Support Document for California's Greenhouse Gas Emissions Inventory and the 1990 Emissions Level* (CARB, 2009b)
	Canola, Lupin Angust and Triticale	Average of Barley, Corn, Oats, Rice, Sorghum, Bean/Pea and Wheat: - *California's 1990-2004 Greenhouse Gas Emissions Inventory and 1990 Emissions Level Technical Support Document* (CARB, 2009a) - *Annex 3D. Agricultural Residue Burning (IPCC 3C1B) to the Technical Support Document for California's Greenhouse Gas Emissions Inventory and the 1990 Emissions Level* (CARB, 2009b) - *AP 42, Fifth Edition, Volume I Chapter 2: Solid Waste Disposal, 2.5 Open Burning* (USEPA, 1992)
	Oats	- *Oats - AP 42, Fifth Edition, Volume I Chapter 2: Solid Waste Disposal, 2.5 Open Burning* (USEPA, 1992)
	Wheat	- *California's 1990-2004 Greenhouse Gas Emissions Inventory and 1990 Emissions Level Technical Support Document* (CARB, 2009a) - *Wheat - Annex 3D. Agricultural Residue Burning (IPCC 3C1B) to the Technical Support Document for California's Greenhouse Gas Emissions Inventory and the 1990 Emissions Level* (CARB, 2009b)
Greenhouse gases: CO_2 and N_2O	Grain Sorghum, Soybean, Canola, Lupin Angust,	Average of Barley Straw, Corn Stover, Rice Straw and Wheat Straw:

Substance	Emission source	Emission and speciation factor source
	Triticale and Oats	- *California's 1990-2004 Greenhouse Gas Emissions Inventory and 1990 Emissions Level Technical Support Document* (CARB, 2009a) - *Annex 3D. Agricultural Residue Burning (IPCC 3C1B) to the Technical Support Document for California's Greenhouse Gas Emissions Inventory and the 1990 Emissions Level* (CARB, 2009b)
	Maize	- *California's 1990-2004 Greenhouse Gas Emissions Inventory and 1990 Emissions Level Technical Support Document* (CARB, 2009a) - *Corn - Annex 3D. Agricultural Residue Burning (IPCC 3C1B) to the Technical Support Document for California's Greenhouse Gas Emissions Inventory and the 1990 Emissions Level* (CARB, 2009b)
	Barley	- *California's 1990-2004 Greenhouse Gas Emissions Inventory and 1990 Emissions Level Technical Support Document* (CARB, 2009a) - *Barley - Annex 3D. Agricultural Residue Burning (IPCC 3C1B) to the Technical Support Document for California's Greenhouse Gas Emissions Inventory and the 1990 Emissions Level* (CARB, 2009b)
	Wheat	- *California's 1990-2004 Greenhouse Gas Emissions Inventory and 1990 Emissions Level Technical Support Document* (CARB, 2009a) - *Wheat - Annex 3D. Agricultural Residue Burning (IPCC 3C1B) to the Technical Support Document for California's Greenhouse Gas Emissions Inventory and the 1990 Emissions Level* (CARB, 2009b)

Table 3-6 presents emission factors for agricultural burning by crop type.

Table 3-6: Agricultural burning emission factors

Emission source	Emission factors (kg/tonne)											
	NO_x	N_2O	NH_3	SO_2	PM_{10}	$PM_{2.5}$	VOC	CH_4	CO	CO_2	PAH	PCDF and PCDF
Grain Sorghum	2.25	0.150	0.608	0.300	8.85	8.45	2.55	1.00	38.49	1,207.18	0.1081	8.20×10^{-10}
Maize	1.65	0.100	0.560	0.200	5.70	5.45	3.30	1.75	35.44	1,309.65	0.0533	8.20×10^{-10}
Soybean	2.60	0.150	1.169	0.050	6.85	6.50	7.10	3.86	73.98	1,207.18	0.1081	8.20×10^{-10}
Barley	2.55	0.200	1.451	0.050	7.15	6.90	7.50	2.47	91.83	1,169.69	0.1417	8.20×10^{-10}
Canola	2.24	0.150	0.900	0.305	7.95	7.59	5.36	2.08	56.96	1,207.18	0.1081	8.20×10^{-10}
Lupin Angust	2.24	0.150	0.900	0.305	7.95	7.59	5.36	2.08	56.96	1,207.18	0.1081	8.20×10^{-10}
Oats	2.25	0.150	1.074	0.300	10.35	9.85	5.15	2.95	67.98	1,207.18	0.1081	8.20×10^{-10}
Triticale	2.24	0.150	0.900	0.305	7.95	7.59	5.36	2.08	56.96	1,207.18	0.1081	8.20×10^{-10}
Wheat	2.15	0.100	0.976	0.450	5.30	5.05	3.80	1.82	61.78	1,189.68	0.2183	8.20×10^{-10}

3.1.5 Spatial Distribution of Emissions

Table 3-7 summarises the data used for spatially allocating emissions from agricultural burning.

Table 3-7: Agricultural burning spatial data

Emission source	Spatial data	Spatial data source
Emissions of combustion products from open burning of agricultural residues	GIS layer for crop area	- *Land Use of Australia, Version 3 - 1996/1997* (BRS , 2006)

Emissions from agricultural burning have been spatially distributed according to the proportion of cropping area in each 1 km by 1 km grid cell (BRS, 2006). The proportion of cropping area by LGA and region is presented in Table 3-8 and shown in Figure 3-1.

Table 3-8: Agricultural burning spatial distribution of cropping area by LGA and region

LGA	2008 proportion of cropping area (%)			
	Newcastle	Non Urban	Sydney	Grand Total
Blue Mountains	-	-	1.39	1.39
Camden	-	-	1.73	1.73
Cessnock	1.42	1.03	-	2.45
Dungog	-	1.76	-	1.76
Gosford	-	-	9.31×10^{-2}	9.31×10^{-2}
Goulburn Mulwaree	-	0.25	-	0.25
Hawkesbury	-	0.70	2.78	3.48
Hornsby	-	-	0.26	0.26
Kiama	-	0.34	-	0.34
Lithgow	-	28.04	-	28.04
Maitland	0.11	1.30	-	1.41
Mid-western Regional	-	3.87	-	3.87
Muswellbrook	-	15.40	-	15.40
N/A	4.45×10^{-3}	-	-	4.45×10^{-3}
Newcastle	1.70×10^{-2}	-	-	1.70×10^{-2}
Oberon	-	2.14	-	2.14
Port Stephens	0.33	0.46	-	0.79
Shellharbour	-	0.69	-	0.69
Singleton	-	6.42	-	6.42
Upper Hunter	-	4.11	-	4.11
Upper Lachlan	-	12.91	-	12.91
Wingecarribee	-	9.66	0.10	9.76
Wollondilly	-	-	2.33	2.33
Wyong	-	0.35	-	0.35
Grand Total	1.88	89.43	8.68	100.00

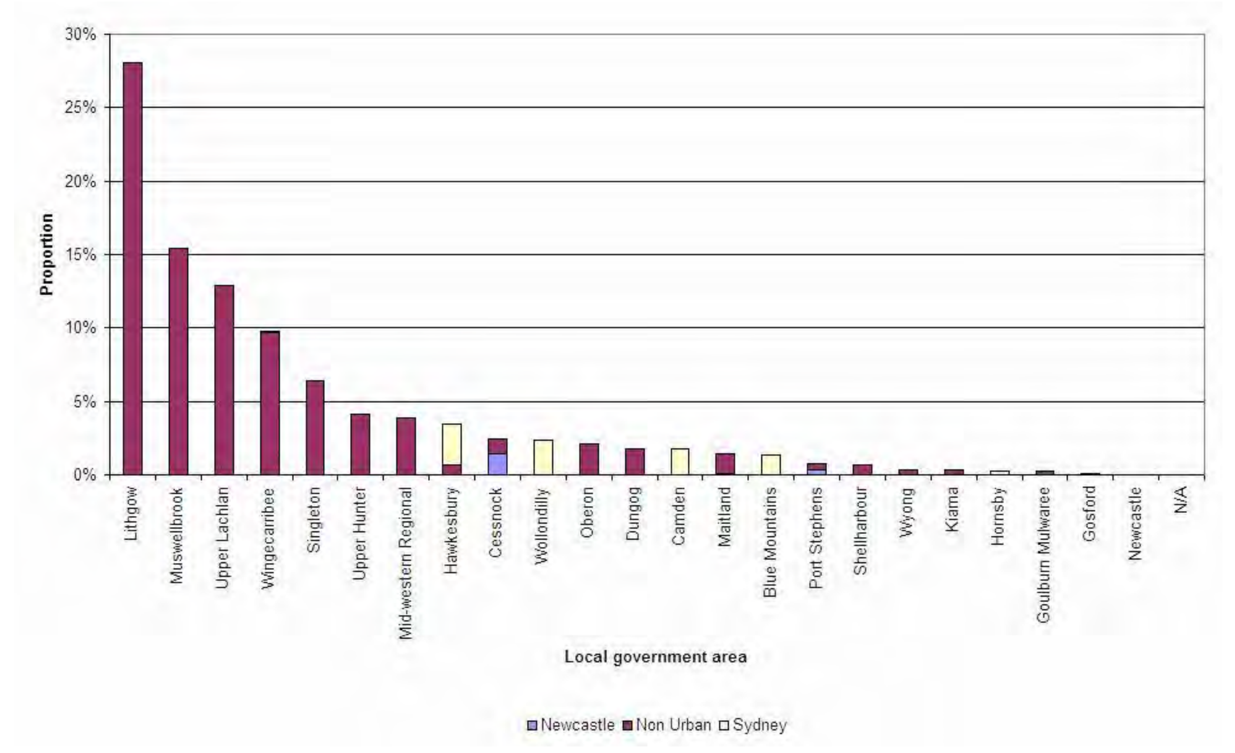

Figure 3-1: Agricultural burning spatial distribution of cropping area by LGA and region

Figure 3-2 shows the spatial distribution of agricultural burning emissions.

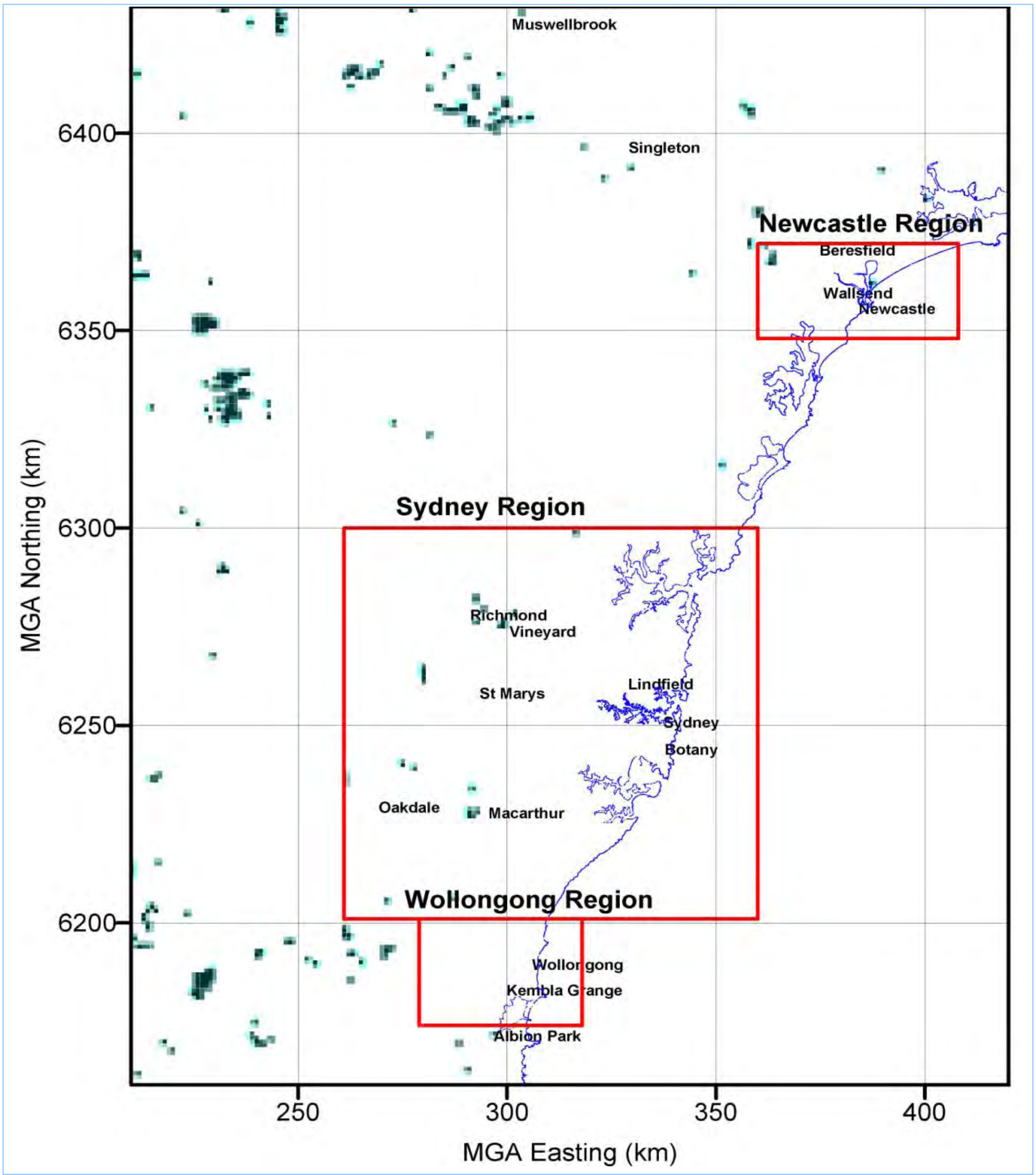

Figure 3-2: Agricultural burning spatial distribution of emissions

3.1.6 Temporal Variation of Emissions

Table 3-9 summarises the data used to estimate the temporal variation in emissions from agricultural burning.

Table 3-9: Agricultural burning temporal data

Emission source	Temporal data	Temporal data source
Emissions of combustion products from open burning of agricultural residues	Monthly: Crop harvest time from crop calendar	- *Australia State Crop Calendars* (USDA, 2003)
	Daily: Average working days Hourly: Average working hours	- *Biogenic and Biomass Burning Emissions Inventory* (EPAV, 2002)

The monthly temporal variation in emissions from agricultural burning have been estimated from NSW crop calendar data (USDA, 2003), while the daily and hourly temporal variation in emissions have been estimated from generic temporal profiles (EPAV, 2002).

Since open burning of agricultural residues occurs at crop harvesting, agricultural burning emissions have been allocated to the harvest months for each field crop. The harvest period for each field crop is presented in Table 3-10 and shown in Figure 3-3 for selected field crops.

Table 3-10: Field crop harvest period in NSW

Crop type	Harvest period		
	Start	End	Duration (month)
Grain Sorghum	March	June	4
Maize	January	July	7
Soybean	March	April	2
Barley	October	December	3
Canola	August	September	2
Lupin Angust	August	September	2
Oats	October	December	3
Triticale	August	September	2
Wheat	November	January	3

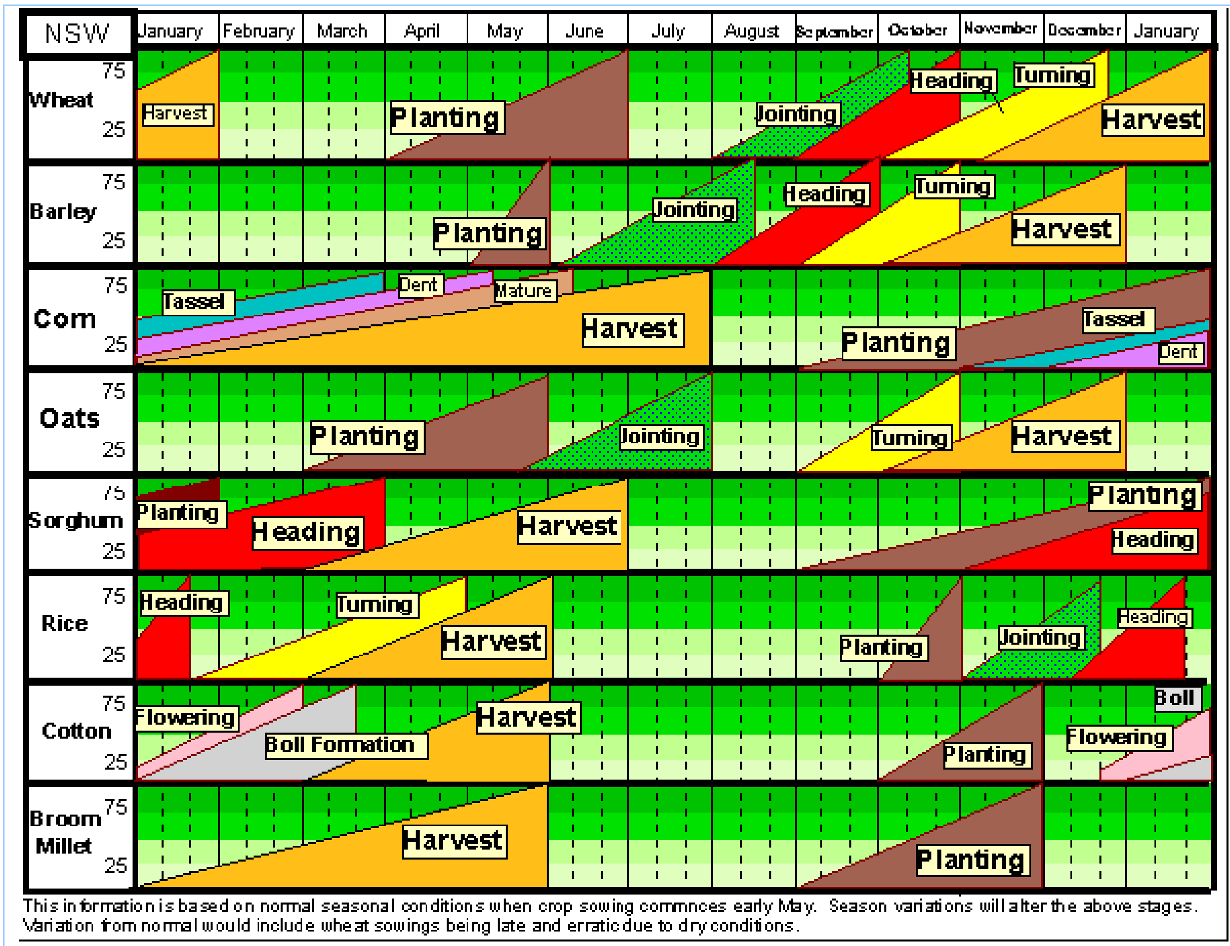

Figure 3-3: Field crop harvest period in NSW for selected crops

Weekend day emissions are estimated to be 80% of weekday emissions, while hourly emissions are constant between 8 am and 8 pm. This is based on information obtained from Grains Council of Australia and Agforce Queensland (EPAV, 2002).

Hourly temporal variation profiles are presented in Table 3-11 and shown in Figure 3-4.

Table 3-11: Agricultural burning hourly temporal profile

Hour	Week day and weekend proportion (%)	Hour	Week day and weekend proportion (%)
1	-	13	8.33
2	-	14	8.33
3	-	15	8.33
4	-	16	8.33
5	-	17	8.33
6	-	18	8.33
7	-	19	8.33
8	-	20	8.33
9	8.33	21	-
10	8.33	22	-
11	8.33	23	-
12	8.33	24	-

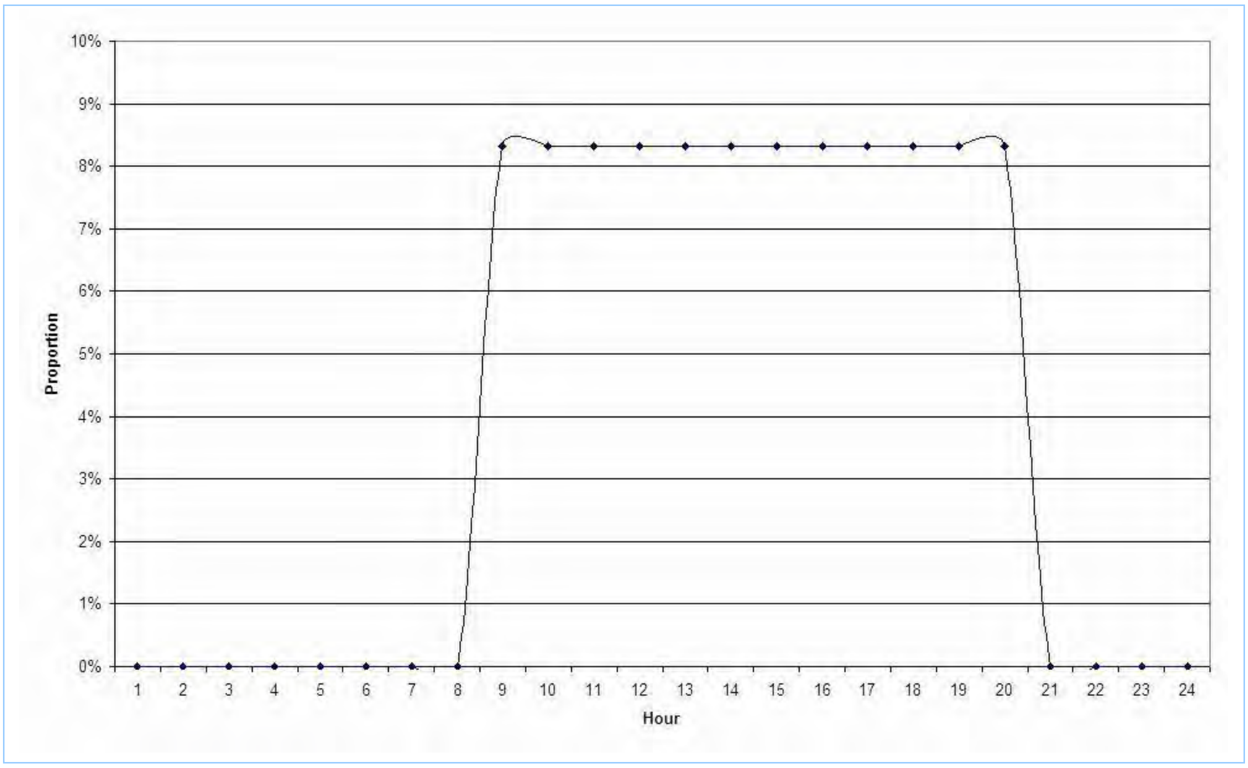

Figure 3-4: Agricultural burning hourly temporal profile

Daily temporal variation profiles are presented in Table 3-12 and shown in Figure 3-5.

Table 3-12: Agricultural burning daily temporal profile

Day	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Proportion (%)	15.15	15.15	15.15	15.15	15.15	12.12	12.12

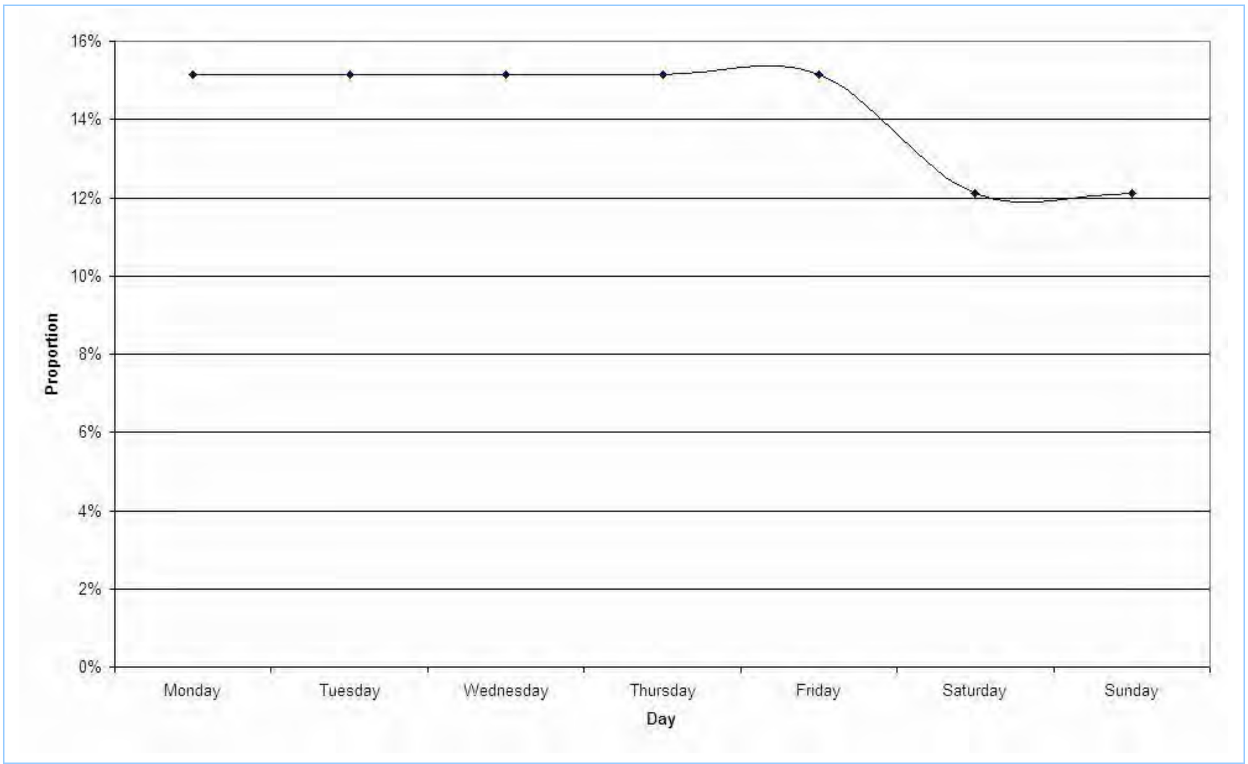

Figure 3-5: Agricultural burning daily temporal profile

Monthly temporal variation profiles are presented in Table 3-13 and shown in Figure 3-6.

Table 3-13: Agricultural burning monthly temporal profile

Month	Crop type								
	Barley	Canola	Grain Sorghum	Lupin Angust	Maize	Oats	Soybean	Triticale	Wheat
January	-	-	-	-	14.29	-	-	-	33.33
February	-	-	-	-	14.29	-	-	-	-
March	-	-	25.00	-	14.29	-	50.00	-	-
April	-	-	25.00	-	14.29	-	50.00	-	-
May	-	-	25.00	-	14.29	-	-	-	-
June	-	-	25.00	-	14.29	-	-	-	-
July	-	-	-	-	14.29	-	-	-	-
August	-	50.00	-	50.00	-	-	-	50.00	-
September	-	50.00	-	50.00	-	-	-	50.00	-
October	33.33	-	-	-	-	33.33	-	-	-
November	33.33	-	-	-	-	33.33	-	-	33.33
December	33.33	-	-	-	-	33.33	-	-	33.33
Grand Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

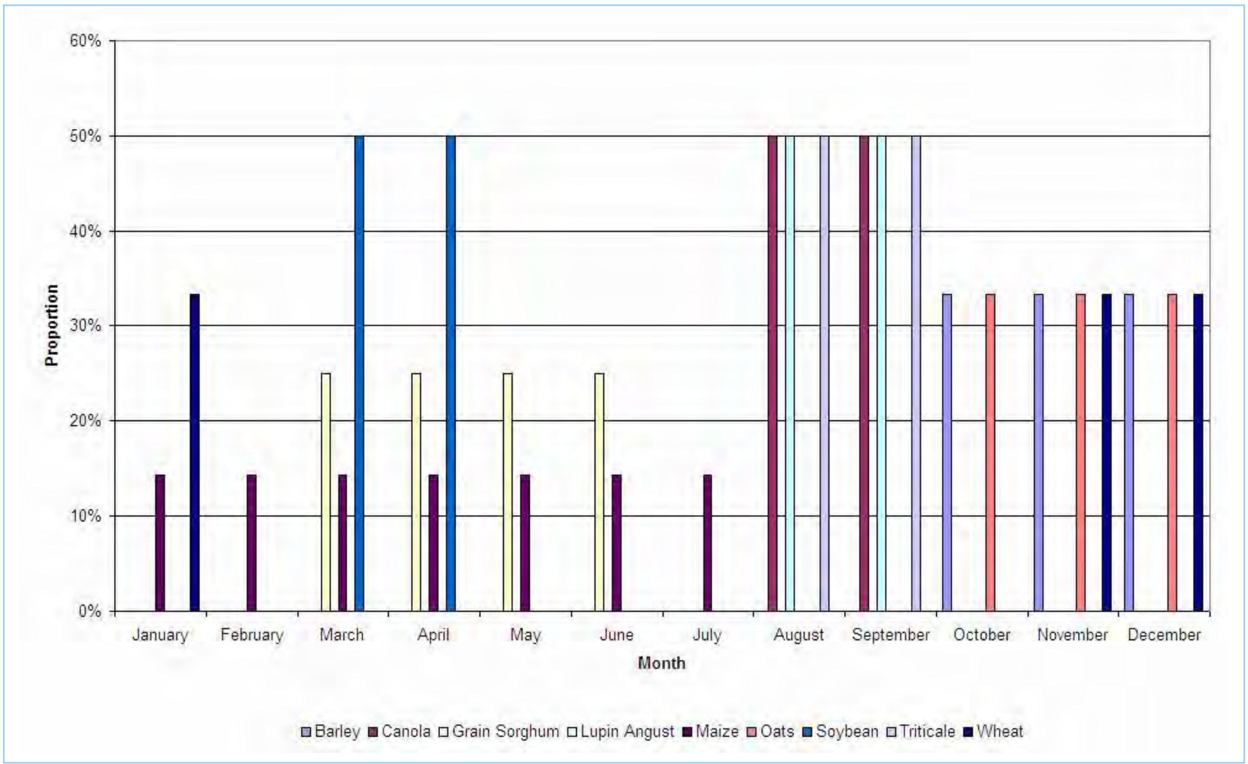

Figure 3-6: Agricultural burning monthly temporal profile

3.1.7 Emission Estimates

Table 3-14 presents annual emissions of selected substances from agricultural burning by activity.

Table 3-14: Agricultural burning emissions by activity

Activity	Substance	Emissions (kg/year)			
		Newcastle	Non Urban	Sydney	GMR
Agricultural Burning	1,3-BUTADIENE	5.21	247	24	277
	CARBON MONOXIDE	6,128	290,886	28,238	325,252
	LEAD & COMPOUNDS	9.62×10^{-3}	0.46	4.43×10^{-2}	0.51
	OXIDES OF NITROGEN	218	10,351	1,005	11,574
	PARTICULATE MATTER ≤ 10 µm	789	37,439	3,634	41,862
	PARTICULATE MATTER ≤ 2.5 µm	752	35,676	3,463	39,891
	POLYCYCLIC AROMATIC HYDROCARBONS	14	656	64	733
	SULFUR DIOXIDE	34	1,599	155	1,788
	TOTAL SUSPENDED PARTICULATE	802	38,058	3,694	42,554
	TOTAL VOLATILE ORGANIC COMPOUNDS	456	21,656	2,102	24,214

Table 3-15 presents annual emissions of selected substances from agricultural burning by source type.

Table 3-15: Agricultural burning emissions by source type

Source type	Substance	Emissions (kg/year)			
		Newcastle	Non Urban	Sydney	GMR
Summer Crop	1,3-BUTADIENE	0.75	36	3.46	40
	CARBON MONOXIDE	711	33,732	3,274	37,717
	LEAD & COMPOUNDS	1.37×10^{-3}	6.52×10^{-2}	6.33×10^{-3}	7.29×10^{-2}
	OXIDES OF NITROGEN	33	1,558	151	1,742
	PARTICULATE MATTER ≤ 10 µm	113	5,350	519	5,982
	PARTICULATE MATTER ≤ 2.5 µm	108	5,113	496	5,717
	POLYCYCLIC AROMATIC HYDROCARBONS	1.09	52	5.04	58
	SULFUR DIOXIDE	3.84	182	18	204
	TOTAL SUSPENDED PARTICULATE	114	5,432	527	6,073
	TOTAL VOLATILE ORGANIC COMPOUNDS	66	3,120	303	3,488
Winter Crop	1,3-BUTADIENE	4.46	212	21	237
	CARBON MONOXIDE	5,417	257,154	24,963	287,535
	LEAD & COMPOUNDS	8.25×10^{-3}	0.39	3.80×10^{-2}	0.44
	OXIDES OF NITROGEN	185	8,793	854	9,832
	PARTICULATE MATTER ≤ 10 µm	676	32,089	3,115	35,880
	PARTICULATE MATTER ≤ 2.5 µm	644	30,563	2,967	34,173
	POLYCYCLIC AROMATIC HYDROCARBONS	13	604	59	675
	SULFUR DIOXIDE	30	1,417	138	1,585
	TOTAL SUSPENDED PARTICULATE	687	32,626	3,167	36,481
	TOTAL VOLATILE ORGANIC COMPOUNDS	390	18,536	1,799	20,726

3.2 Bushfires and Prescribed Burning

3.2.1 *Emission Source Description*

The biogenic and geogenic air emissions inventory includes emissions of combustion products from bushfires and prescribed burning. Bushfires are large-scale events where a variety of vegetation is burnt as a result of natural (e.g. lightning strike) or human (e.g. arson) activity. Prescribed burning or hazard reduction burning is a planned vegetation management fire that is conducted during favourable weather conditions.

To estimate emissions from these sources, the following have been considered:

- *On-Park DECCW and off-park RFS wildfire data*

On-park (DECCW, 2009a) and off-park (RFS, 2009a) bushfires activity data for the 2008 calendar year has been obtained for NSW. The bushfires activity data includes: ignition date; local government area (LGA); area burned; and location (i.e. easting and northing coordinates).

- *On-Park DECCW and off-park RFS BRIMS prescribed burn data*

On-park (DECCW, 2009b) and off-park (RFS, 2009b) prescribed burning activity data for the 2008 calendar year has been obtained for NSW. The bushfire activity data includes: ignition date; local government area (LGA); area burned; and location (i.e. easting and northing coordinates).

- *Fire type*

The inventory includes emissions of combustion products from:

  - *Bushfires; and*
  - *Prescribed burning.*

3.2.2 *Emission Estimation Methodology*

Table 3-16 summarises the emission estimation methodologies used for bushfires and prescribed burning.

Table 3-16: Bushfires and prescribed burning emission estimation methodologies

Emission source	Emission estimation methodology source
Emissions of combustion products from bushfires	- *Area-Wide Source Methodologies, Section 9.3 Wildfires* (CARB, 2004) - *Australian Methodology for the Estimation of Greenhouse Gas Emissions and Sinks 2006, Land Use, Land Use Change and Forestry* (DCC, 2008)
Emissions of combustion products from prescribed burning	- *Area-Wide Source Methodologies, Section 7.16 Forest Management* (CARB, 2006) - *Australian Methodology for the Estimation of Greenhouse Gas Emissions and Sinks 2006, Land Use, Land Use Change and Forestry* (DCC, 2008)

Emissions of combustion products from bushfires and prescribed burning have been estimated using fuel consumption based emission factors combined with activity rates. Activity rates include fire type and area burned (DECCW, 2009a; DECCW, 2009b; RFS, 2009a; and RFS, 2009b). Emissions have been determined using Equation 3 (CARB, 2004; CARB, 2006; and DCC, 2008):

$$E_{i,j} = A_j \times FL_j \times Z_j \times EF_{i,j} \qquad \textbf{Equation 3}$$

where:			
$E_{i,j}$	=	Emissions of substance i from fire type j	(kg/year)
A_j	=	Annual area burned by fire type j	(ha/year)
FL_j	=	Fuel loading for fire type j (Table 3-17) (Section 5V, Table 3 and Table 4; DCC, 2008)	(tonne dry vegetation burned/ha vegetation)
Z_j	=	Vegetation burning efficiency for fire type j (Table 3-17) (Section 5V, Table 5; DCC, 2008)	(kg vegetation burned/kg vegetation)
$EF_{i,j}$	=	Emission factor for substance i and fire type j	(kg/tonne)
i	=	Substance (either "criteria pollutants", "speciated NO_x", "speciated VOC", "organic air toxics", "metal air toxics", "PAH", "PCDD and PCDF", "ammonia" or "greenhouse gases")	(-)
j	=	Fire type (either "bushfires" or "prescribed burning")	(-)

Table 3-17 presents fuel loads and burning efficiencies used to estimate emissions of combustion products from bushfires and prescribed burning (DCC, 2008).

Table 3-17: Fuel loads and burning efficiencies for bushfires and prescribed burning

Fire type	FL (tonne dry vegetation burned/ha vegetation)	Z (kg vegetation burned/kg vegetation)
Bushfires	36.4	0.72
Prescribed burning	18.2	0.42

3.2.3 *Activity Data*

Table 3-18 summarises the activity data used for bushfires and prescribed burning.

Table 3-18: Bushfires and prescribed burning activity data

Activity data	Activity data source
Bushfire area (ha)	- *On-Park Wildfires 2008 Calendar Year* (DECCW, 2009a) - *Off-Park Wildfires 2008 Calendar Year* (RFS, 2009a)
Prescribed burn area (ha)	- *On-Park Prescribed Burns Entered into BRIMS for the 2008 Calendar Year* (DECCW, 2009b) - *Off-Park Prescribed Burns Entered into BRIMS for the 2008 Calendar Year* (RFS, 2009b)

The areas burned by bushfires and prescribed burning in NSW have been obtained for the 2008 calendar year (DECCW, 2009a; DECCW, 2009b; RFS, 2009a; and RFS, 2009b). The local government area (LGA) and location (i.e. easting and northing coordinates) of each fire type have been used to estimate the vegetation area burned by bushfires and prescribed burning in the GMR, while fuel loading and vegetation burning efficiency by fire type (DCC, 2008) have been used to estimate the vegetation quantity burned by bushfires and prescribed burning in the GMR. Table 3-19 presents the vegetation area and quantity burned by bushfires and prescribed burning in the GMR.

Table 3-19: Bushfires and prescribed burning area and quantity in the GMR

Fire type	2008 statistics	
	Area (ha)	Quantity[5] (tonne)
Bushfires	2,248	58,910
Prescribed burning	28,640	218,923
Grand Total	30,888	277,833

3.2.4 *Emission and Speciation Factors*

Table 3-20 summarises the emission and speciation factors used for bushfires and prescribed burning.

Table 3-20: Bushfires and prescribed burning emission and speciation factors

Substance	Emission source	Emission and speciation factor source
Criteria pollutants: CO, NO_x, $PM_{2.5}$, PM_{10}, SO_2 & VOC	Bushfires	- *Area-Wide Source Methodologies, Section 9.3 Wildfires* (CARB, 2004) - *Wildland Fire Emissions Estimation System, Version 4* (VESTRA, 2003)
	Prescribed burning	- *Area-Wide Source Methodologies, Section 7.16 Forest Management* (CARB, 2006) - *Wildland Fire Emissions Estimation System, Version 4* (VESTRA, 2003)
Criteria pollutants: TSP	Bushfires and Prescribed burning	- *PMPROF 460 - California Emission Inventory and Reporting System (CEIDARS), Particulate Matter (PM) Speciation Profiles* (CARB, 2008b)
Speciated NO_x	Bushfires and Prescribed burning	- *Technology Transfer Network - Clearinghouse for Inventories & Emissions Factors* (USEPA, 2003a)
Speciated VOC	Bushfires and Prescribed burning	- *ORGPROF 307 - California Emission Inventory and Reporting System (CEIDARS), Organic Gas Speciation Profiles* (CARB, 2005b)
Organic air toxics	Bushfires and	- *ORGPROF 307 - California Emission Inventory and Reporting System*

[5] ($Quantity_j = A_j \times FL_j \times Z_j$). where: A_j = Annual area burned by fire type j (ha/year); FL_j = Fuel loading for fire type j (tonne dry vegetation burned/ha vegetation); and Z_j = Vegetation burning efficiency for fire type j (kg vegetation burned/kg vegetation); and j = Fire type (either "bushfires" or "prescribed burning") (DCC, 2008).

Substance	Emission source	Emission and speciation factor source
	Prescribed burning	*(CEIDARS), Organic Gas Speciation Profiles* (CARB, 2005b)
Metal air toxics	Bushfires and Prescribed burning	- *PMPROF 460 - California Emission Inventory and Reporting System (CEIDARS), Particulate Matter (PM) Speciation Profiles* (CARB, 2007)
Polycyclic aromatic hydrocarbons: PAH	Bushfires and Prescribed burning	- *Average of Douglas Fir Slash and Ponderosa Pine Slash - Atmospheric Pollutant Emissions Factors from Open Burning of Agricultural and Forest Biomass by Wind Tunnel Simulations Volumes 1 and 2* (CARB, 1996a; and CARB, 1996b)
Polychlorinated dibenzo-p-dioxins and Polychlorinated dibenzofurans: PCDD and PCDF	Bushfires	- *Wildfires – forest fuel - Australian Inventory of Dioxin Emissions 2004, National Dioxins Program Technical Report No. 3* (Bawden et. al., 2004)
	Prescribed burning	- *Prescribed burning – forest fuel - Australian Inventory of Dioxin Emissions 2004, National Dioxins Program Technical Report No. 3* (Bawden et. al., 2004)
Ammonia	Bushfires	- *Area-Wide Source Methodologies, Section 9.3 Wildfires* (CARB, 2004) - *Wildland Fire Emissions Estimation System, Version 4* (VESTRA, 2003)
	Prescribed burning	- *Area-Wide Source Methodologies, Section 7.16 Forest Management* (CARB, 2006) - *Wildland Fire Emissions Estimation System, Version 4* (VESTRA, 2003)
Greenhouse gases: CH_4 , CO_2 and N_2O	Bushfires	- *Area-Wide Source Methodologies, Section 9.3 Wildfires* (CARB, 2004) - *Wildland Fire Emissions Estimation System, Version 4* (VESTRA, 2003)
	Prescribed burning	- *Area-Wide Source Methodologies, Section 7.16 Forest Management* (CARB, 2006) - *Wildland Fire Emissions Estimation System, Version 4* (VESTRA, 2003)

Table 3-21 presents emission factors for bushfires and prescribed burning.

Table 3-21: Bushfires and prescribed burning emission factors

Emission source	Emission factors (kg/tonne)											
	NO_x	N_2O	NH_3	SO_2	PM_{10}	$PM_{2.5}$	VOC	CH_4	CO	CO_2	PAH	PCDF and PCDF
Bushfires	3.68	0.217	1.246	1.134	12.55	10.65	8.72	4.98	124.57	1,557.64	0.0298	4.40×10^{-10}
Prescribed burning	3.68	0.217	1.246	1.134	12.55	10.65	8.72	4.98	124.57	1,557.64	0.0298	8.50×10^{-10}

3.2.5 Spatial Distribution of Emissions

Table 3-22 summarises the data used for spatially allocating emissions from bushfires and prescribed burning.

Table 3-22: Bushfires and prescribed burning spatial data

Emission source	Spatial data	Spatial data source
Emissions of combustion products from bushfires	Bushfire location (latitude and longitude)	- *On-Park Wildfires 2008 Calendar Year* (DECCW, 2009a) - *Off-Park Wildfires 2008 Calendar Year* (RFS, 2009a)
Emissions of combustion products from prescribed burning	Prescribed burn location (latitude and longitude)	- *On-Park Prescribed Burns Entered into BRIMS for the 2008 Calendar Year* (DECCW, 2009b) - *Off-Park Prescribed Burns Entered into BRIMS for the 2008 Calendar Year* (RFS, 2009b)

Emissions from bushfires and prescribed burning have been spatially distributed according to the area burned at each fire location (DECCW, 2009a; DECCW, 2009b; RFS, 2009a; and RFS, 2009b). The latitude and longitude (i.e. geographical coordinates) have been converted to MGA easting and northing in km (i.e. gridded coordinates) using Redfearn's formula (ICSM, 2006) and then assigned to each 1 km by 1 km grid cell. The bushfire area by LGA and region is presented in Table 3-23 and shown in Figure 3-7.

Table 3-23: Bushfires spatial distribution of area burned by LGA and region

LGA	2008 bushfire area (ha)				
	Newcastle	Non Urban	Sydney	Wollongong	Grand Total
Port Stephens	-	676.00	-	-	676.00
Wyong	-	629.80	-	-	629.80
Great Lakes	-	320.00	-	-	320.00
Lithgow	-	125.00	-	-	125.00
Wingecarribee	-	111.30	-	-	111.30
Wollondilly	-	10.50	92.00	-	102.50
Cessnock	-	89.30	-	-	89.30
Gosford	-	-	75.01	-	75.01
Penrith	-	-	40.00	-	40.00
Hawkesbury	-	10.00	19.25	-	29.25
Newcastle	23.00	-	-	-	23.00
Blue Mountains	-	4.00	2.50	-	6.50
Campbelltown	-	-	6.00	-	6.00
Liverpool	-	-	6.00	-	6.00
Ku-ring-gai	-	-	3.00	-	3.00
Camden	-	-	2.00	-	2.00
Wollongong	-	-	-	2.00	2.00
Sutherland	-	-	1.00	-	1.00
Ryde	-	-	0.13	-	0.13
Grand Total	23.00	1,975.90	246.89	2.00	2,247.79

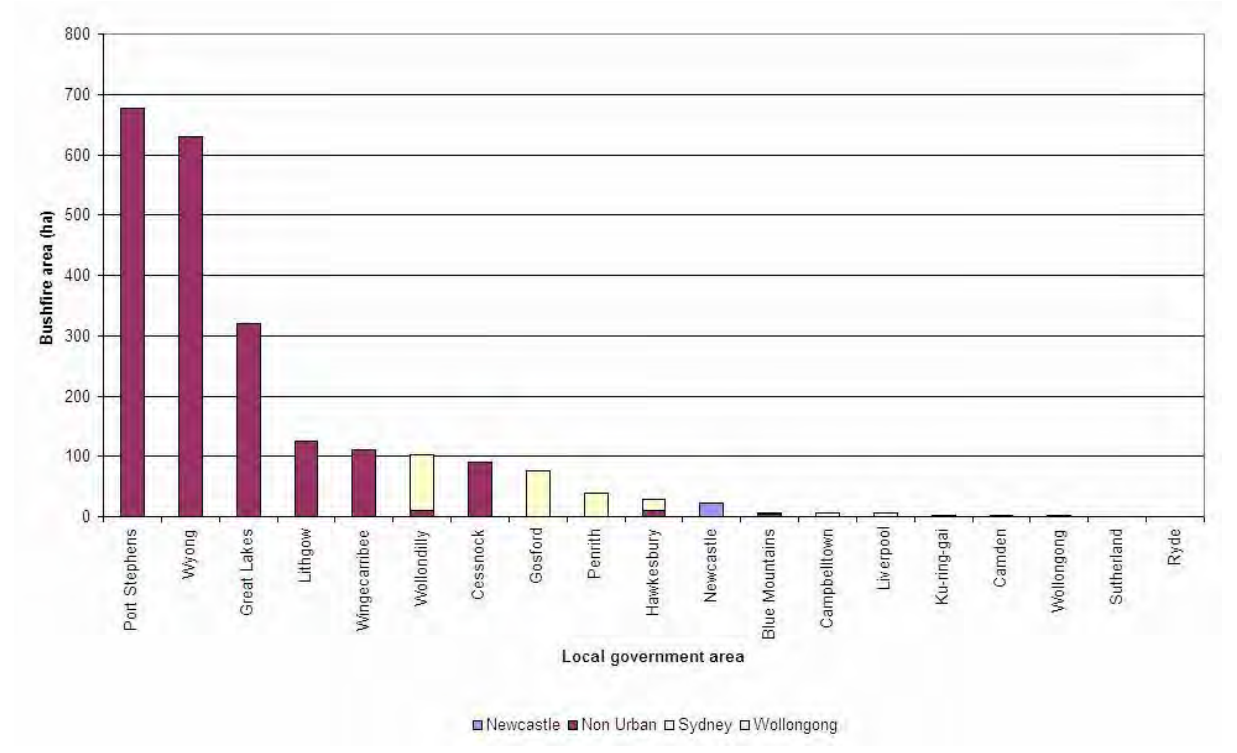

Figure 3-7: Bushfires spatial distribution of area burned by LGA and region

The prescribed burning area by LGA and region is presented in Table 3-24 and shown in Figure 3-8.

Table 3-24: Prescribed burning spatial distribution of area burned by LGA and region

LGA	2008 prescribed burning area (ha)				
	Newcastle	Non Urban	Sydney	Wollongong	Grand Total
Lithgow	-	6,770.86	-	-	6,770.86
Muswellbrook	-	5,068.01	-	-	5,068.01
Hawkesbury	-	4,342.70	122.08	-	4,464.78
Blue Mountains	-	-	3,697.62	-	3,697.62
Oberon	-	3,138.58	-	-	3,138.58
Wingecarribee	-	1,147.89	-	626.60	1,774.49
Upper Hunter	-	1,046.83	-	-	1,046.83
Bathurst Regional	-	604.12	-	-	604.12
Gosford	-	361.73	133.24	-	494.97
Warringah	-	-	378.43	-	378.43
Singleton	-	251.00	-	-	251.00
Cessnock	207.83	42.54	-	-	250.37
Wollondilly	-	-	166.95	-	166.95
Wyong	-	105.43	-	-	105.43
Baulkham Hills	-	-	92.22	-	92.22
Penrith	-	-	85.43	-	85.43
Hornsby	-	-	76.91	-	76.91
Campbelltown	-	-	54.22	-	54.22
Ku-ring-gai	-	-	29.50	-	29.50

LGA	2008 prescribed burning area (ha)				
	Newcastle	Non Urban	Sydney	Wollongong	Grand Total
Port Stephens	23.43	3.97	-	-	27.40
Sutherland	-	-	21.33	-	21.33
Blacktown	-	-	15.69	-	15.69
Lake Macquarie	-	14.59	-	-	14.59
Camden	-	-	4.42	-	4.42
Wollongong	-	-	2.78	-	2.78
Willoughby	-	-	0.91	-	0.91
Pittwater	-	-	0.85	-	0.85
Parramatta	-	-	0.81	-	0.81
Liverpool	-	-	0.32	-	0.32
Grand Total	231.26	22,898.24	4,883.69	626.60	28,639.80

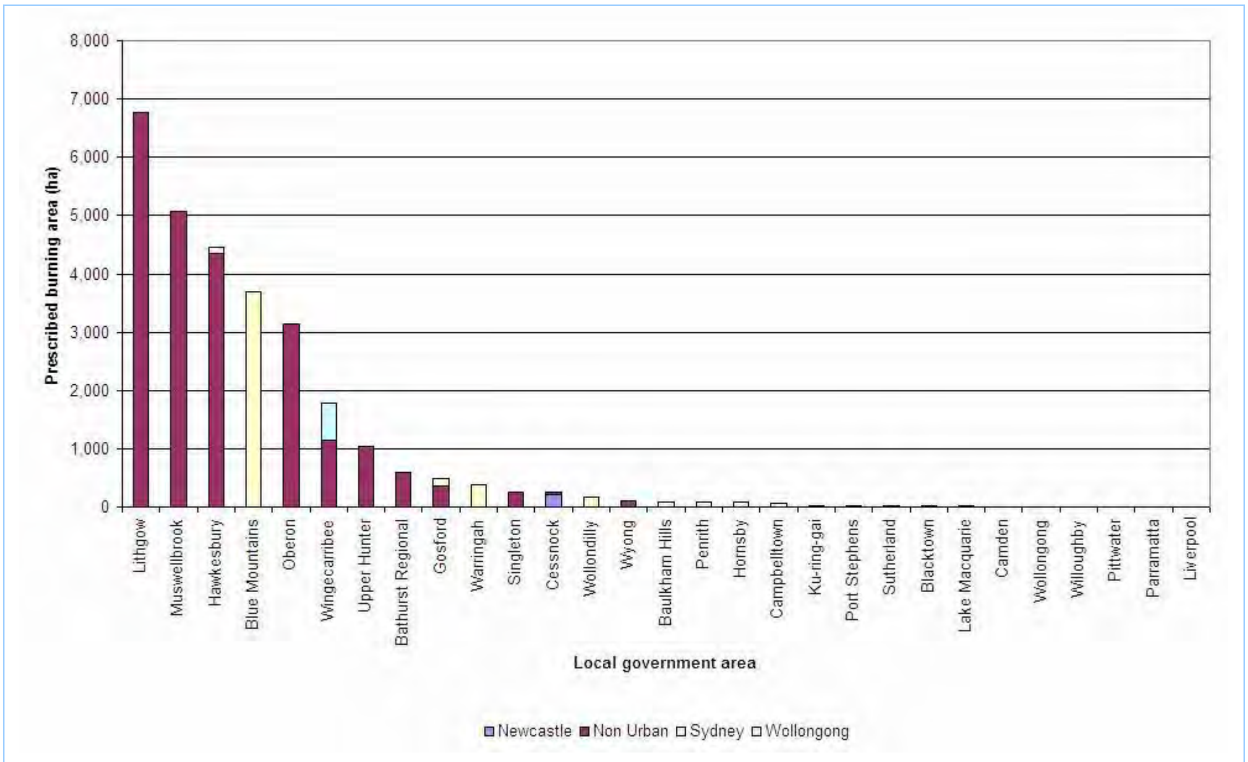

Figure 3-8: Prescribed burning spatial distribution of area burned by LGA and region

Figure 3-9 and Figure 3-10 show the spatial distribution of bushfires and prescribed burning emissions.

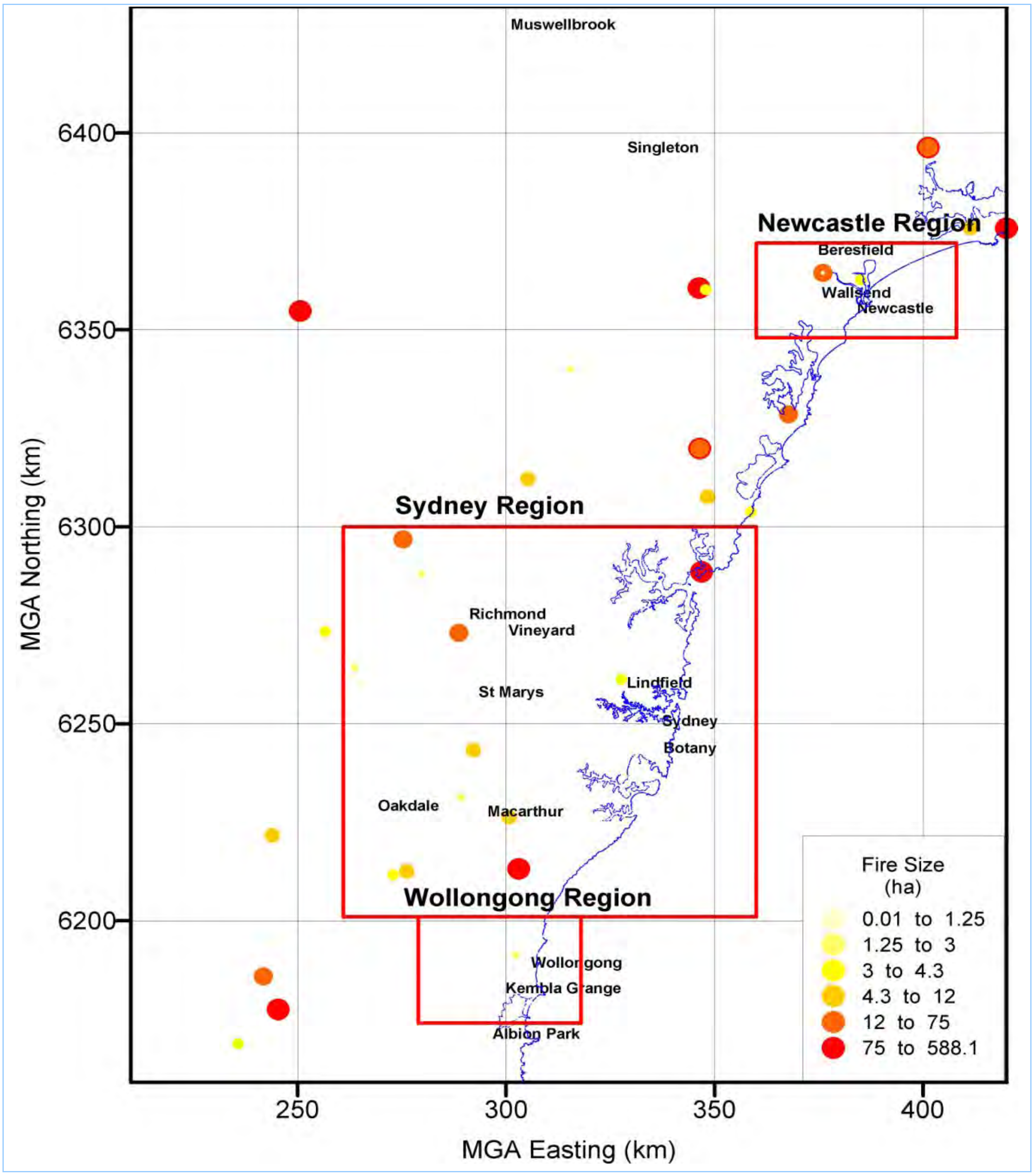

Figure 3-9: Bushfires spatial distribution of emissions

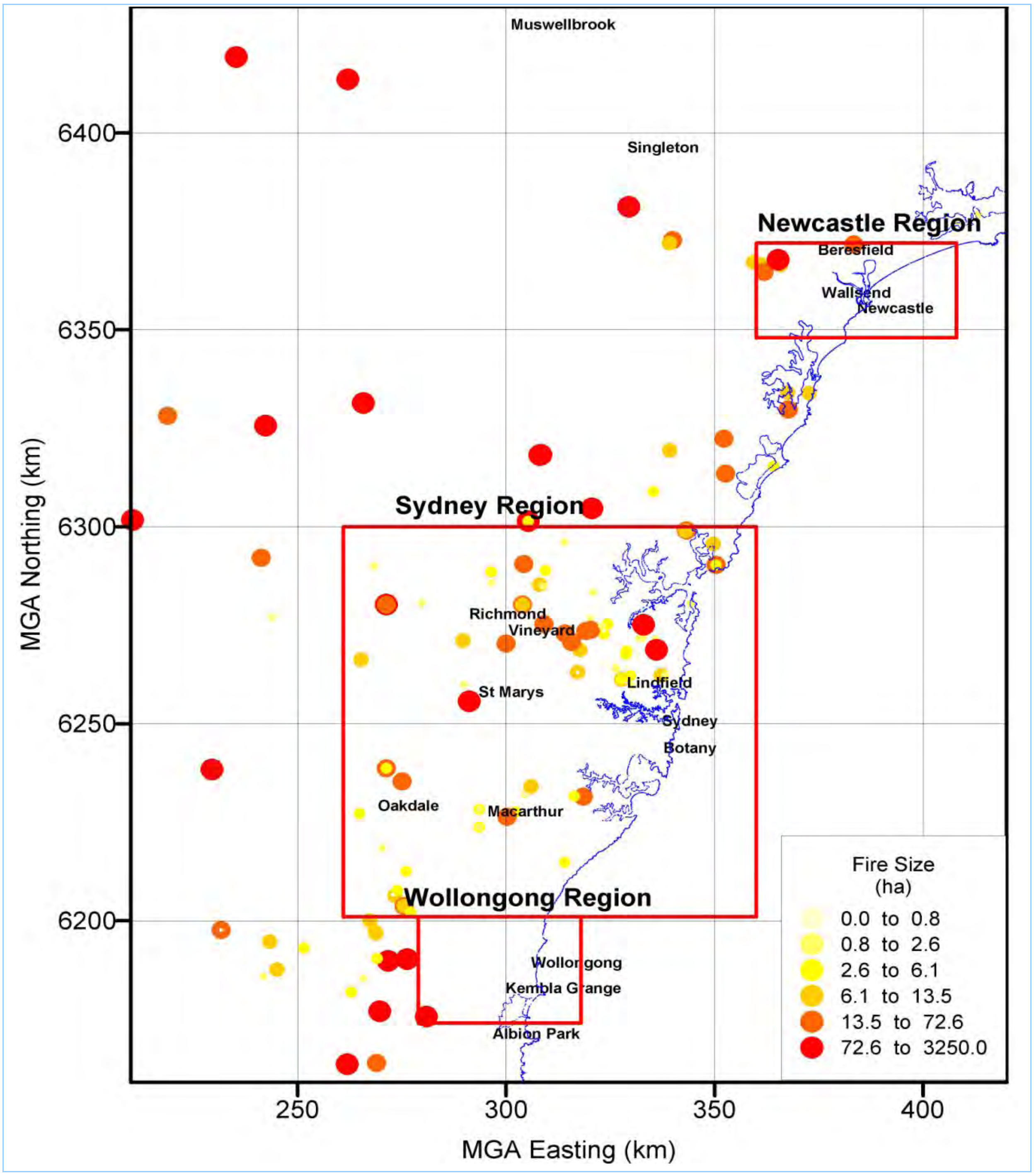

Figure 3-10: Prescribed burning spatial distribution of emissions

3.2.6 Temporal Variation of Emissions

Table 3-25 summarises the data used to estimate the temporal variation in emissions from bushfires and prescribed burning.

Table 3-25: Bushfires and prescribed burning temporal data

Emission source	Temporal data	Temporal data source
Emissions of combustion products from bushfires	Monthly: Bushfire date Daily: Bushfire date	- *On-Park Wildfires 2008 Calendar Year* (DECCW, 2009a) - *Off-Park Wildfires 2008 Calendar Year* (RFS, 2009a)
	Hourly: Generic bushfire profile	- *Biogenic and Biomass Burning Emissions Inventory* (EPAV, 2002)
Emissions of combustion products from prescribed burning	Monthly: Prescribed burn date Daily: Prescribed burn date	- *On-Park Prescribed Burns Entered into BRIMS for the 2008 Calendar Year* (DECCW, 2009b) - *Off-Park Prescribed Burns Entered into BRIMS for the 2008 Calendar Year* (RFS, 2009b)
	Hourly: Generic prescribed burn profile	- *Biogenic and Biomass Burning Emissions Inventory* (EPAV, 2002)

The monthly and daily temporal variation in emissions from bushfires and prescribed burning have been estimated from NSW ignition date data (DECCW, 2009a; DECCW, 2009b; RFS, 2009a; and RFS, 2009b), while the hourly temporal variation in emissions have been estimated from generic temporal profiles (EPAV, 2002).

Hourly temporal variation profiles for bushfires are presented in Table 3-26 and shown in Figure 3-11.

Table 3-26: Bushfires hourly temporal profile

Hour	Week day and weekend proportion (%)	Hour	Week day and weekend proportion (%)
1	4.00	13	3.97
2	3.88	14	4.29
3	3.71	15	4.51
4	3.58	16	5.01
5	3.45	17	5.28
6	3.45	18	5.36
7	3.41	19	5.31
8	3.39	20	5.13
9	3.55	21	4.78
10	3.53	22	4.63
11	3.55	23	4.41
12	3.71	24	4.09

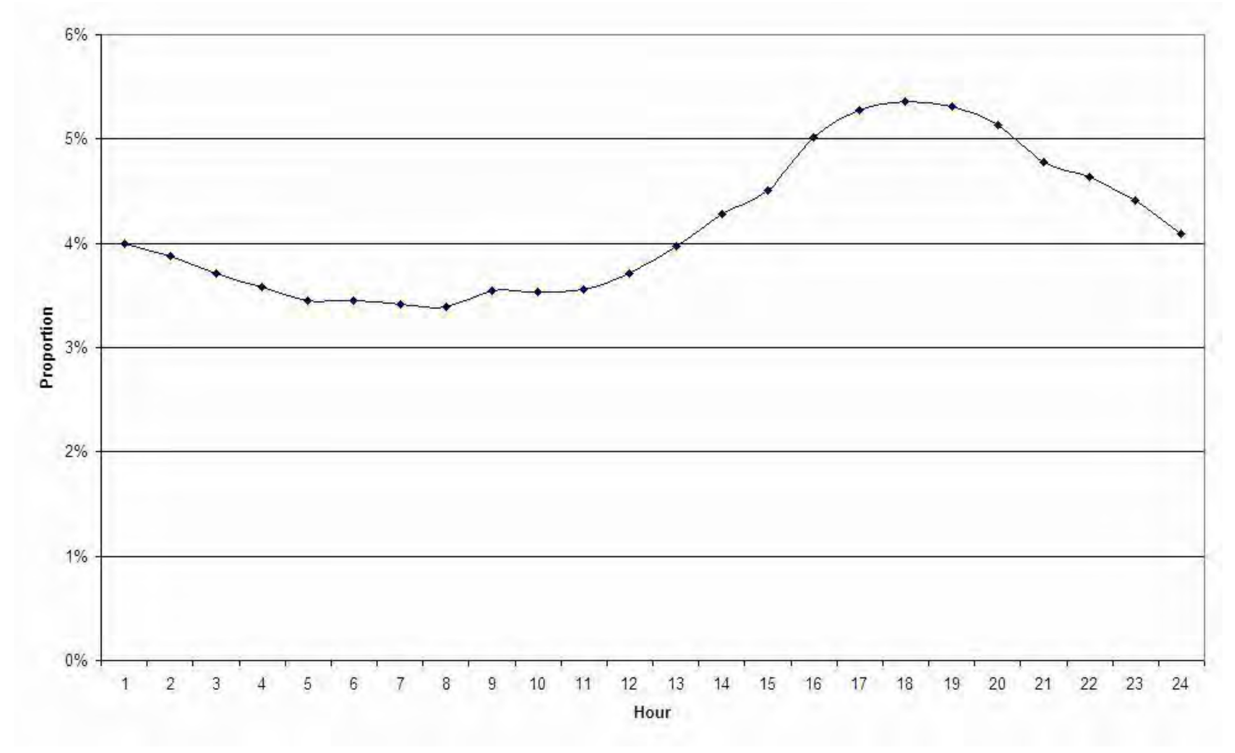

Figure 3-11: Bushfires hourly temporal profile

Hourly temporal variation profiles for prescribed burning are presented in Table 3-27 and shown in Figure 3-12.

Table 3-27: Prescribed burning hourly temporal profile

Hour	Week day and weekend proportion (%)	Hour	Week day and weekend proportion (%)
1	1.88	13	5.35
2	1.79	14	5.96
3	1.76	15	3.70
4	1.73	16	3.07
5	1.70	17	2.84
6	1.64	18	2.65
7	1.57	19	2.49
8	1.53	20	2.41
9	1.46	21	2.31
10	1.43	22	2.21
11	1.41	23	2.12
12	1.40	24	2.02

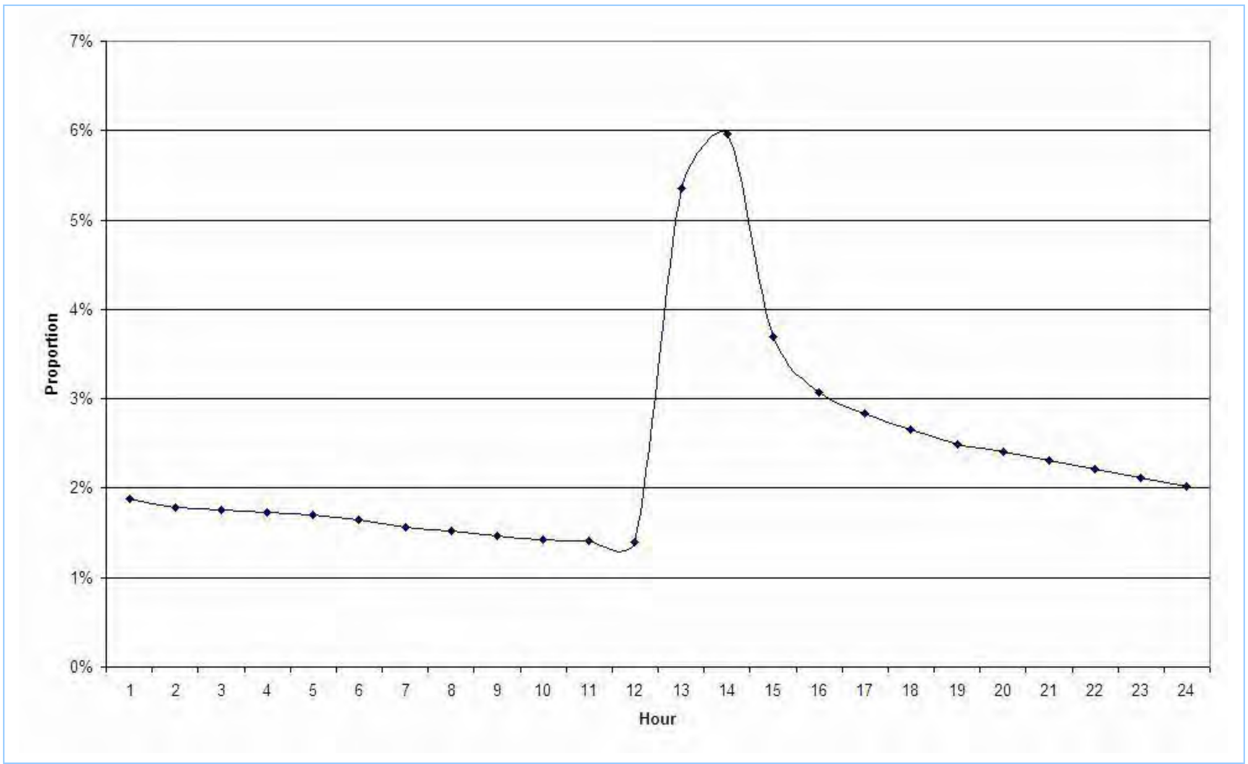

Figure 3-12: Prescribed burning hourly temporal profile

Figure 3-13 shows the daily temporal variation in bushfire area in the GMR.

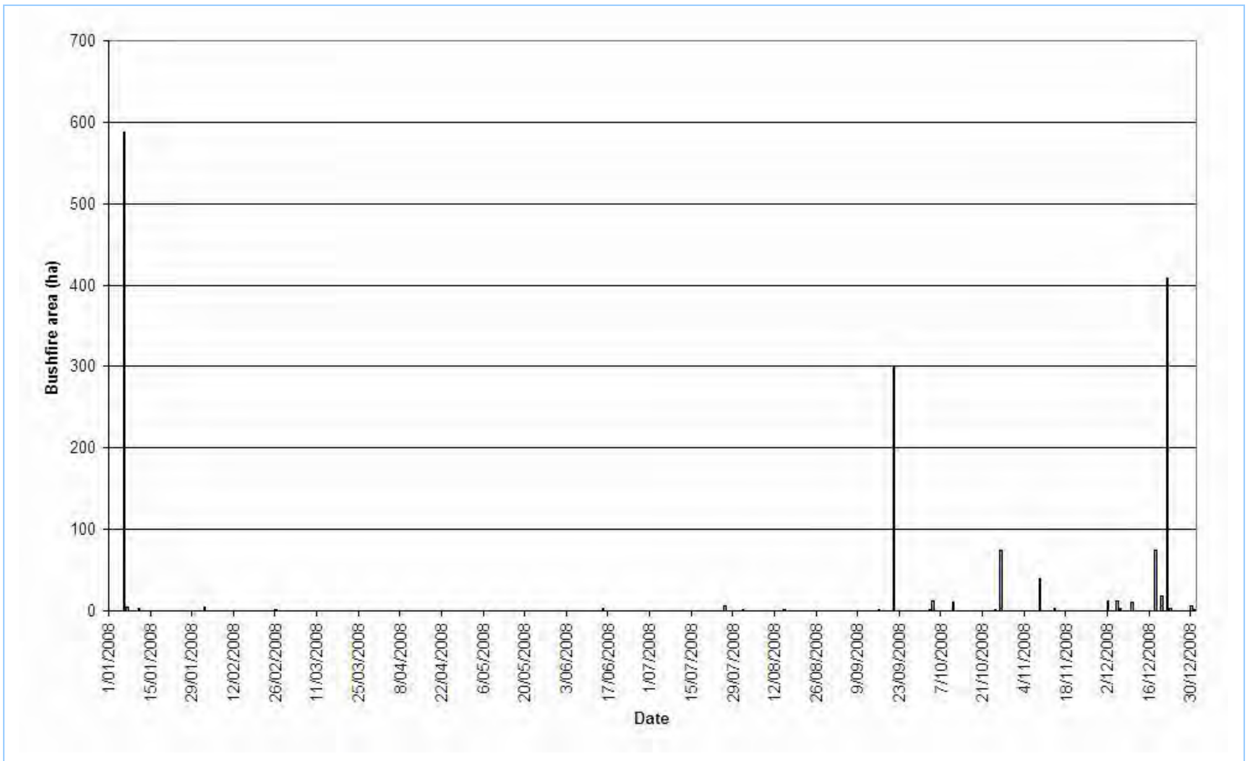

Figure 3-13: Bushfire area daily temporal variation in the GMR

Figure 3-14 shows the daily temporal variation in prescribed burning area in the GMR.

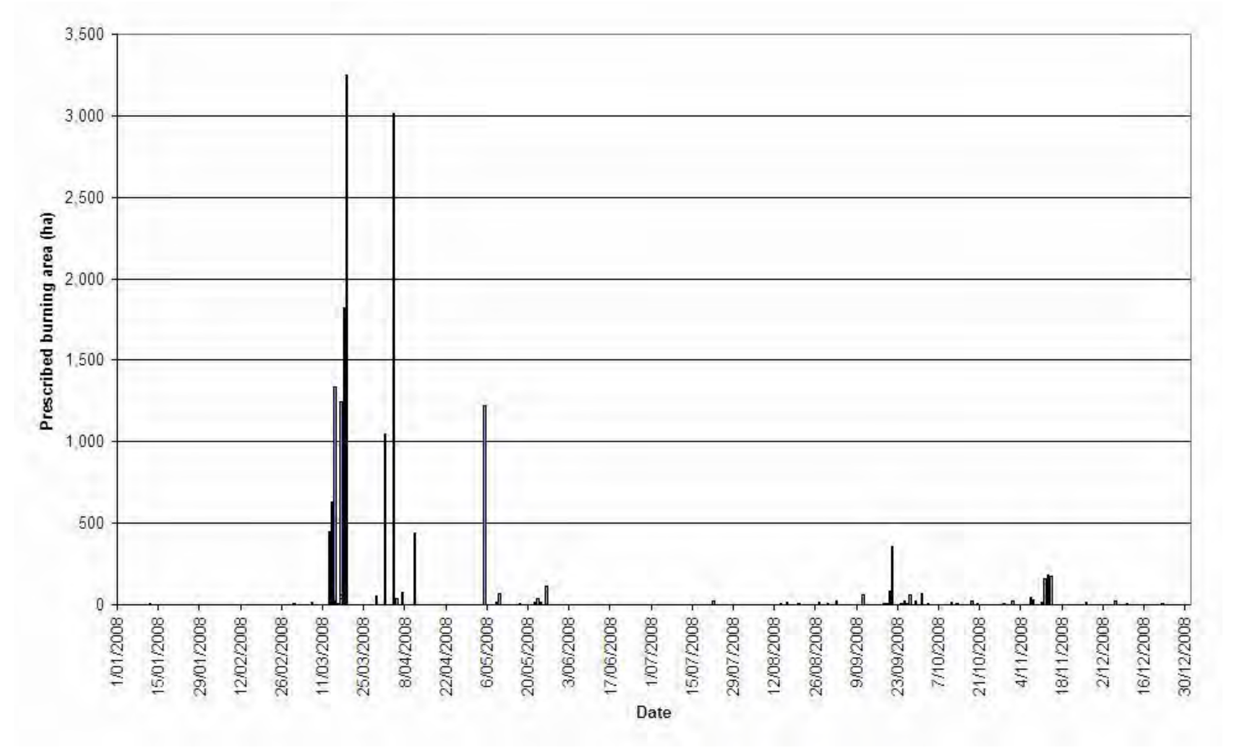

Figure 3-14: Prescribed burning area daily temporal variation in the GMR

The monthly temporal variation in bushfire area in the GMR is presented in Table 3-28 and shown in Figure 3-15.

Table 3-28: Bushfire area monthly temporal variation in the GMR

Month	2008 bushfire area (ha)
January	849.00
February	6.50
March	-
April	-
May	-
June	3.00
July	6.00
August	3.50
September	321.30
October	104.00
November	43.63
December	910.86
Grand Total	2,247.79

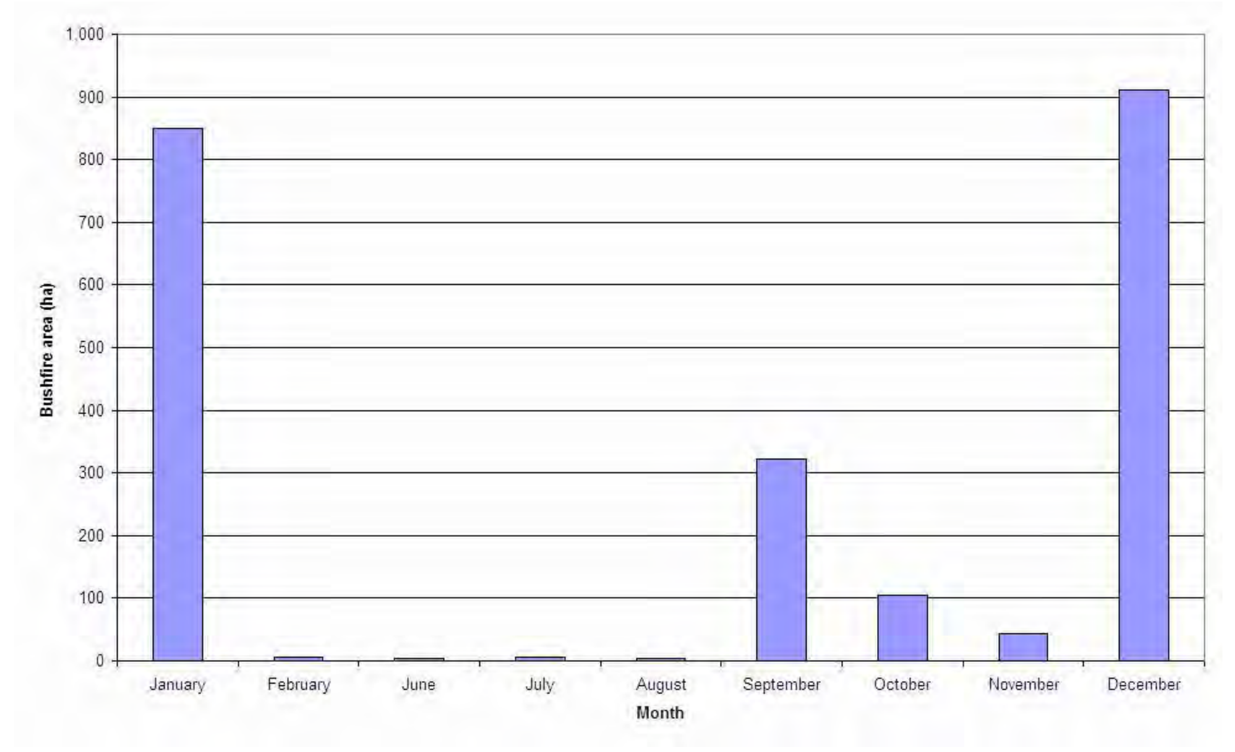

Figure 3-15: Bushfire area monthly temporal variation in the GMR

The monthly temporal variation in prescribed burning area in the GMR is presented in Table 3-29 and shown in Figure 3-16.

Table 3-29: Prescribed burning area monthly temporal variation in the GMR

Month	2008 prescribed burning area (ha)
January	7.11
February	0.39
March	14,521.08
April	10,766.11
May	1,503.38
June	1.06
July	23.87
August	61.71
September	824.05
October	200.04
November	696.58
December	34.39
Grand Total	28,639.80

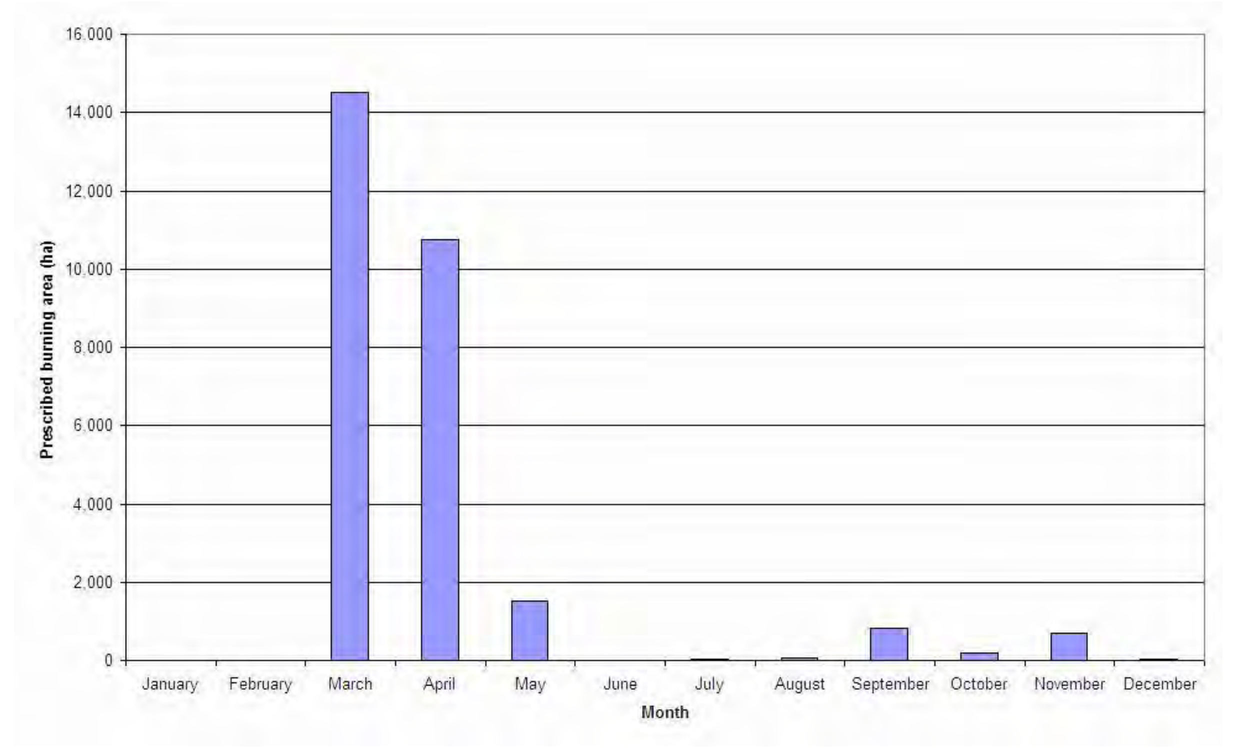

Figure 3-16: Prescribed burning area monthly temporal variation in the GMR

3.2.7 *Emission Estimates*

Table 3-30 presents annual emissions of selected substances from bushfires and prescribed burning by activity.

Table 3-30: Bushfires and prescribed burning emissions by activity

Activity	Substance	Emissions (kg/year)				
		Newcastle	Non Urban	Sydney	Wollongong	GMR
Bushfires and Prescribed Burning	1,3-BUTADIENE	236	22,595	4,363	482	27,677
	CARBON MONOXIDE	295,289	28,254,084	5,456,211	603,172	34,608,757
	LEAD & COMPOUNDS	2.97	284	55	6.06	348
	OXIDES OF NITROGEN	8,723	834,624	161,176	17,818	1,022,340
	PARTICULATE MATTER ≤ 10 µm	29,742	2,845,817	549,562	60,753	3,485,874
	PARTICULATE MATTER ≤ 2.5 µm	25,239	2,414,976	466,362	51,555	2,958,132
	POLYCYCLIC AROMATIC HYDROCARBONS	71	6,752	1,304	144	8,271
	SULFUR DIOXIDE	2,688	257,151	49,659	5,490	314,987
	TOTAL SUSPENDED PARTICULATE	30,272	2,896,505	559,351	61,835	3,547,963
	TOTAL VOLATILE ORGANIC COMPOUNDS	20,670	1,977,786	381,935	42,222	2,422,613

Table 3-31 presents annual emissions of selected substances from bushfires and prescribed burning by source type.

Table 3-31: Bushfires and prescribed burning emissions by source type

Source type	Substance	Emissions (kg/year)				
		Newcastle	Non Urban	Sydney	Wollongong	GMR
Bushfires	1,3-BUTADIENE	60	5,159	645	5.22	5,868
	CARBON MONOXIDE	75,087	6,450,621	806,009	6,529	7,338,247
	LEAD & COMPOUNDS	0.75	65	8.10	6.56×10^{-2}	74
	OXIDES OF NITROGEN	2,218	190,551	23,809	193	216,771
	PARTICULATE MATTER ≤ 10 µm	7,563	649,721	81,183	658	739,125
	PARTICULATE MATTER ≤ 2.5 µm	6,418	551,357	68,892	558	627,226
	POLYCYCLIC AROMATIC HYDROCARBONS	18	1,542	193	1.56	1,754
	SULFUR DIOXIDE	683	58,709	7,336	59	66,788
	TOTAL SUSPENDED PARTICULATE	7,698	661,294	82,629	669	752,290
	TOTAL VOLATILE ORGANIC COMPOUNDS	5,256	451,543	56,421	457	513,677
Prescribed Burning	1,3-BUTADIENE	176	17,436	3,719	477	21,808
	CARBON MONOXIDE	220,202	21,803,463	4,650,202	596,643	27,270,510
	LEAD & COMPOUNDS	2.21	219	47	5.99	274
	OXIDES OF NITROGEN	6,505	644,073	137,367	17,625	805,569
	PARTICULATE MATTER ≤ 10 µm	22,179	2,196,095	468,379	60,095	2,746,749
	PARTICULATE MATTER ≤ 2.5 µm	18,821	1,863,619	397,469	50,997	2,330,906
	POLYCYCLIC AROMATIC HYDROCARBONS	53	5,211	1,111	143	6,517
	SULFUR DIOXIDE	2,004	198,441	42,323	5,430	248,199
	TOTAL SUSPENDED PARTICULATE	22,574	2,235,211	476,722	61,166	2,795,673
	TOTAL VOLATILE ORGANIC COMPOUNDS	15,414	1,526,242	325,514	41,765	1,908,936

3.3 Fugitive/Windborne from Agricultural Lands and Unpaved Roads

3.3.1 *Emission Source Description*

The biogenic and geogenic air emissions inventory includes emissions of fugitive windborne particulate matter from agricultural lands and unpaved roads.

To estimate emissions from these sources, the following have been considered:

- *Soil erosion*

Soil erosion occurs when wind forces overcome the gravitational and cohesive forces of soil particles on the ground surface. The wind transports these soil particles in three ways, depending on their size:

- *Creep* occurs when soil particles greater than 0.5 mm diameter are too heavy to be lifted, so they are rolled along the ground surface by wind drag or moved by collision with other soil particles;
- *Saltation* is the main process of suspending soil particles in the range 0.1 to 0.5 mm diameter, where they are lifted then fall back to the ground while moving in a hopping or bouncing fashion. These particles cause abrasion of the soil surface where they break into smaller particles in a process called attrition; and
- *Suspension* takes place when soil particles less than 0.1 mm diameter are ejected into the air by saltation and remain suspended.

Figure 3-17 shows the Aeolian processes involved in wind erosion of soil particles (OEH, 2011).

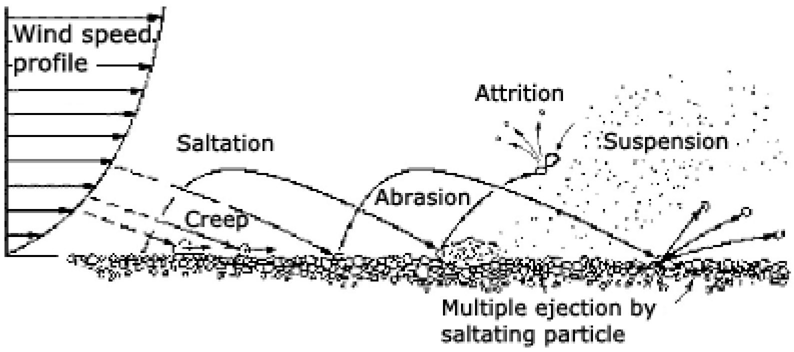

Figure 3-17: Aeolian processes involved in wind erosion of soil particles

- *NSW grains report*

The *NSW Grains Report* contains crop production information highlights, seasonal conditions and outlook and information on specific summer and winter crops. The area of summer and winter field crops grown in each NSW agronomy district have been obtained for the 2008 calendar year (NSW DPI, 2008) and used to estimate the area of agricultural lands in the GMR.

- *Unsealed roads*

Unsealed roads GIS data has been used to estimate the total length of unpaved roads in the GMR (DEC, 2004a), while the average unpaved road width (NTC, 2007) has been used to estimate the area of unpaved roads in the GMR.

- *Digital atlas of Australian soils*

Soil type GIS data has been used to estimate the soil erodibility of agricultural lands and unpaved roads in the GMR (BRS, 1991).

- *Meteorological data*

Hourly average meteorological data including temperature, precipitation and wind speed have been generated for the GMR at 2 km by 2 km grid cells with *TAPM* (Hurley, 2005) and used to estimate Thornthwaite's precipitation-evaporation index (Thornthwaite, 1931) and the climatic factor (CARB, 1997a; and CARB, 1997b) at 1 km by 1 km grid cells.

- *Source type*

The inventory includes emissions of fugitive windborne particulate matter from agricultural lands and unpaved roads as follows:

Summer crops

- *Grain Sorghum;*
- *Maize; and*
- *Soybean.*

Winter crops

- *Barley;*
- *Canola.*
- *Lupin Angust;*
- *Oats;*
- *Triticale; and*
- *Wheat.*

Unpaved roads

3.3.2 Emission Estimation Methodology

Table 3-32 summarises the emission estimation methodologies used for fugitive windborne particulate matter from agricultural lands and unpaved roads.

Table 3-32: Agricultural lands and unpaved roads emission estimation methodologies

Emission source	Emission estimation methodology source
Fugitive windborne particulate matter from agricultural lands	- *Area-Wide Source Methodologies, Section 7.12 Windblown Dust - Agricultural Lands* (CARB, 1997a)
Fugitive windborne particulate matter from unpaved roads	- *Area-Wide Source Methodologies, Section 7.13 Windblown Dust - Unpaved Roads* (CARB, 1997b)

Emissions of fugitive windborne particulate matter from agricultural lands and unpaved roads have been estimated using the wind erosion equation (WEQ) combined with the area of agricultural lands (NSW DPI, 2008) and unpaved roads (DEC, 2004a; and NTC, 2007), soil erodibility (BRS, 1991) and meteorological data (Hurley, 2005) within Equation 4 (CARB, 1997a; and CARB, 1997b):

$$E_{i,j} = A_i \times I_j \times K_i \times C \times L'_i \times V'_{i,k} \times H_i \times 1000 \qquad \textbf{Equation 4}$$

where:			
$E_{i,j}$	=	Emissions of TSP from source type i and soil type j	(kg/year)
A_i	=	Portion of total wind erosion losses that would be measured as TSP for source type i – 0.025 and 0.038 for agricultural lands and unpaved roads, respectively (CARB, 1997a; and CARB, 1997b)	(-)
I_j	=	Soil erodibility for soil type j (Table 3-33) (Table A-1; USEPA, 1974)	(tonne/ha/year)
K_i	=	Surface roughness factor for source type i (Table 3-34) (Table A-2; USEPA, 1974)	(-)
C	=	Climatic factor (Equation 5)	(-)
L'_i	=	Unsheltered field width factor for source type i (Table 3-34) (Equation 7)	(-)
$V'_{i,k}$	=	Vegetative cover factor for source type i and month k (Equation 8 and Equation 9)	
H_i	=	Area of source type i	(ha)
i	=	Source type (either "grain sorghum", "maize", "soybean", "barley", "canola", "lupin angust", "oats", "triticale", "wheat" or "unpaved roads")	(-)
j	=	Soil type (either "brown duplex", "cracking clay", "gley duplex", "lake", "loams", "massive earths", "red duplex", "sands" or "yellow duplex")	(-)
k	=	Month (either "January", "February", "March", "April", "May", "June", "July", "August", "September", "October", "November" or "December")	(-)
1000	=	Conversion factor	(kg/tonne)

Table 3-33 presents soil erodibility by soil type used to estimates emissions of fugitive windborne particulate matter from agricultural lands and unpaved roads (USEPA, 1974).

Table 3-33: Soil erodibility by soil type

Soil type	Erodibility	
	Ton/acre/year	tonne/ha/year
Brown Duplex	86	193
Cracking Clay	56	126
Gley Duplex	86	193
Lake	-	-
Loams	56	126
Massive Earths	38	85
Red Duplex	86	193
Sands	220	493
Yellow Duplex	86	193

The climatic factor has been estimated using annual average wind speed from *TAPM* (Hurley, 2005) and annual Thornthwaite's precipitation-evaporation index (Thornthwaite, 1931) from Equation 6 within Equation 5 (CARB, 1997a; and CARB, 1997b):

$$C = 0.0828 \times \left(WS^3 / PE^2\right)$$ **Equation 5**

where:			
C	=	Climatic factor	(-)
WS	=	Annual average wind speed	(km/h)
PE	=	Annual Thornthwaite's precipitation-evaporation index (Equation 6)	(-)

Thornthwaite's precipitation-evaporation index (Thornthwaite, 1931) has been estimated using monthly average precipitation and temperature from *TAPM* (Hurley, 2005) within Equation 6 (CARB, 1997a; and CARB, 1997b):

$$PE = \sum_{i=1}^{12} PE_i = \sum_{i=1}^{12} \left\{ 1.64 \times \left(\frac{P_i}{T_i + 12.2} \right)^{10/9} \right\}$$ **Equation 6**

where:			
PE	=	Annual Thornthwaite's precipitation-evaporation index	(-)
PE_i	=	Thornthwaite's precipitation-evaporation index for month i	(-)
P_i	=	Average monthly precipitation (where all values less than 12.5 mm have been assigned the value of 12.5 mm)	(mm)
T_i	=	Average monthly temperature	(°C)
i	=	Month (either "January", "February", "March", "April", "May", "June", "July", "August", "September", "October", "November" or "December")	(-)

The unsheltered field width factor for agricultural lands has been estimated using the unsheltered field width and the product of soil erodibility and surface roughness within Equation 7 (USEPA, 1974):

$$-\log_{10}(1-L'_i) = 1.8467\times10^{-7}(I_jK_i)^2L_i - 6.1213\times10^{-6}(I_jK_i)L_i + 6.8760\times10^{-4}L_i + 3.3161\times10^{-3}(I_jK_i) + 0.0336$$ **Equation 7**

where:

L'_i	=	Unsheltered field width factor for source type i (Table 3-34)	(-)
I_j	=	Soil erodibility for soil type j (Table 3-33) (Table A-1; USEPA, 1974)	(tonne/ha/year)
K_i	=	Surface roughness factor for source type i (Table 3-34) (Table A-2; USEPA, 1974)	(-)
L_i	=	Unsheltered field width for source type i (Table 3-34) (Table A-2; USEPA, 1974)	(m)
i	=	Source type (either "grain sorghum", "maize", "soybean", "barley", "canola", "lupin angust", "oats", "triticale", "wheat" or "unpaved roads")	(-)
j	=	Soil type (either "brown duplex", "cracking clay", "gley duplex", "lake", "loams", "massive earths", "red duplex", "sands" or "yellow duplex")	(-)

Table 3-34 presents surface roughness factor, unsheltered field width and unsheltered field width factor by source type used to estimates emissions of fugitive windborne particulate matter from agricultural lands and unpaved roads (CARB, 1997a; CARB, 1997b; NTC, 2007; and USEPA, 1974).

Table 3-34: Surface roughness factor, unsheltered field width and unsheltered field width factor by source type

Source type	K (surface roughness factor)	L (unsheltered field width) (ft)	L (unsheltered field width) (m)	L' (unsheltered field width factor)
Barley	0.6	2,000	610	0.9376
Canola	0.5	1,000	305	0.7926
Grain Sorghum	0.5	2,000	610	0.9066
Lupin Angust	0.5	1,000	305	0.7926
Maize	0.6	2,000	610	0.9376
Oats	0.8	2,000	610	0.9708
Soybean	0.6	2,000	610	0.9376
Triticale	0.6	2,000	610	0.9376
Wheat	0.6	2,000	610	0.9376
Unpaved Road	1.0	25.86	7.88	0.3200

The vegetative cover factor for agricultural lands has been estimated using the crop canopy cover during the growing season within Equation 8 (CARB, 1997a):

$$V'_{i,k} = \exp\left(-0.201 \times CC_k^{0.7366}\right)$$ **Equation 8**

where:

$V'_{i,k}$	=	Vegetative cover factor for source type i and month k	(-)

where:			
CC_k	=	Proportion of ground covered by crop canopy	(%)
i	=	Source type (either "grain sorghum", "maize", "soybean", "barley", "canola", "lupin angust", "oats", "triticale", "wheat" or "unpaved roads")	(-)
k	=	Month (either "January", "February", "March", "April", "May", "June", "July", "August", "September", "October", "November" or "December")	(-)

The vegetative cover factor for agricultural lands has been estimated using the postharvest soil cover during the harvest season within Equation 9 (CARB, 1997a):

$$V'_{i,k} = \exp\left(-0.0438 \times SC_k\right) \qquad \textbf{Equation 9}$$

where:			
$V'_{i,k}$	=	Vegetative cover factor for source type i and month k	(-)
SC_k	=	Proportion of ground covered by vegetative debris	(%)
i	=	Source type (either "grain sorghum", "maize", "soybean", "barley", "canola", "lupin angust", "oats", "triticale", "wheat" or "unpaved roads")	(-)
k	=	Month (either "January", "February", "March", "April", "May", "June", "July", "August", "September", "October", "November" or "December")	(-)

3.3.3 Activity Data

Table 3-35 summarises the activity data used for fugitive windborne particulate matter from agricultural lands and unpaved roads.

Table 3-35: Agricultural lands and unpaved roads activity data

Activity data	Activity data source
Crop area (ha) by NSW agronomy district	- *NSW Grains Report 2008* (NSW DPI, 2008)
Unpaved road length (m)	- *Unsealed Roads from the dtdb Cultural Lines Layer - Arc/Info Export Format* (DEC, 2004a)
Unpaved road width (m)	- *Performance Based Standards Scheme Network Classification Guidelines* (NTC, 2007)
Soil erodibility (tonne/ha/year)	- *Digital Atlas of Australian Soils* (BRS , 1991)
Hourly meteorological data (temperature (K), precipitation (mm) and wind speed (m/s)) required to calculate the climatic factor	- *The Air Pollution Model (TAPM) Version 3* (Hurley, 2005)

The area of summer and winter field crops harvested in each NSW agronomy district (i.e. North West, Central West, South West, Tablelands and Coastal) have been obtained for the 2008 calendar year (NSW DPI, 2008). Since the Tablelands agronomy district forms part of the GMR, 50% of the harvest area from this region has been used to estimate the area of agricultural lands in the GMR. Unsealed roads GIS data has been used to estimate the total length of unpaved roads in the GMR (DEC, 2004a), while the average unpaved road width (NTC, 2007) has been used to estimate the area of unpaved roads in the GMR. Table 3-36 presents the area of agricultural lands and unpaved roads in the GMR.

Table 3-36: Agricultural lands and unpaved roads area in the GMR

Source type		2008 area (ha)
Agricultural Lands[6]	Grain Sorghum	80
	Maize	400
	Soybean	125
	Barley	175
	Canola	650
	Lupin Angust	500
	Oats	6,900
	Triticale	2,785
	Wheat	4,010
Agricultural Lands Total		15,625
Unpaved Roads Total[7]		29,727
Grand Total		45,352

Soil erodibility is a function of soil particle diameter, which has been estimated for various soil types (USEPA, 1974). Soil type GIS data has been used to estimate the soil erodibility of agricultural lands and unpaved roads in the GMR (BRS, 1991). The proportion of land area covered by each soil type in each region is presented in Table 3-37 and shown in Figure 3-18.

Table 3-37: Area by soil type and region

Soil type	Proportion of soil type (%)				
	Newcastle	Non Urban	Sydney	Wollongong	Grand Total
Brown Duplex	-	3.17×10^{-3}	-	-	3.17×10^{-3}
Cracking Clay	-	0.30	-	-	0.30
Gley Duplex	-	-	0.53	2.64×10^{-3}	0.54
Lake	-	2.02×10^{-2}	4.76×10^{-2}	9.44×10^{-2}	0.16
Loams	0.49	7.85	0.68	6.59×10^{-2}	9.09
Massive Earths	6.57×10^{-2}	41.82	9.12	1.61	52.61
Red Duplex	-	5.71	4.17	-	9.88
Sands	0.33	1.15	0.33	6.50×10^{-2}	1.87
Yellow Duplex	0.94	21.24	3.34	2.74×10^{-2}	25.54
Grand Total	1.82	78.10	18.22	1.86	100.00

[6] Crop harvest in the GMR assumes 50% of crop harvest in the Tablelands agronomy district (NSW DPI, 2008).
[7] The unpaved road length has been estimated to be 37,709 km (DEC, 2004a), while the average unpaved road width of 7.88 m (NTC, 2007) has been used to estimate the area of 29,727 ha.

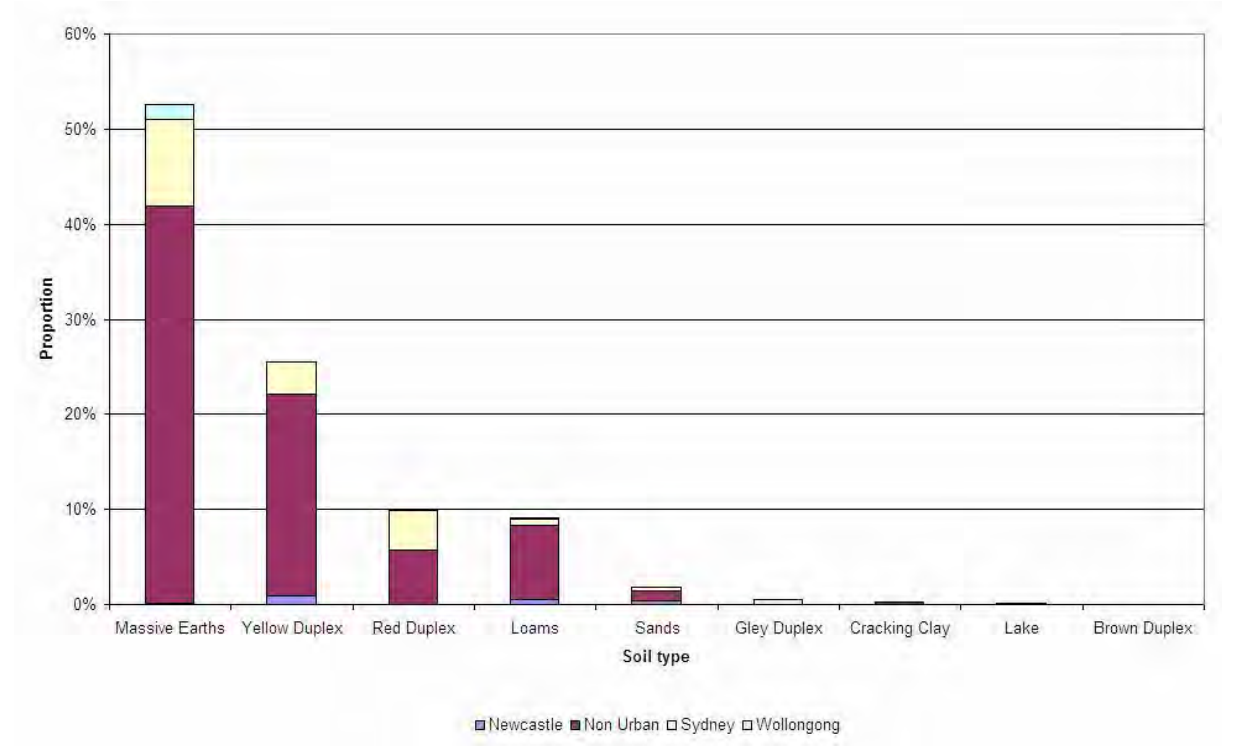

Figure 3-18: Area by soil type and region

Figure 3-19 shows the spatial distribution of soil type in the GMR.

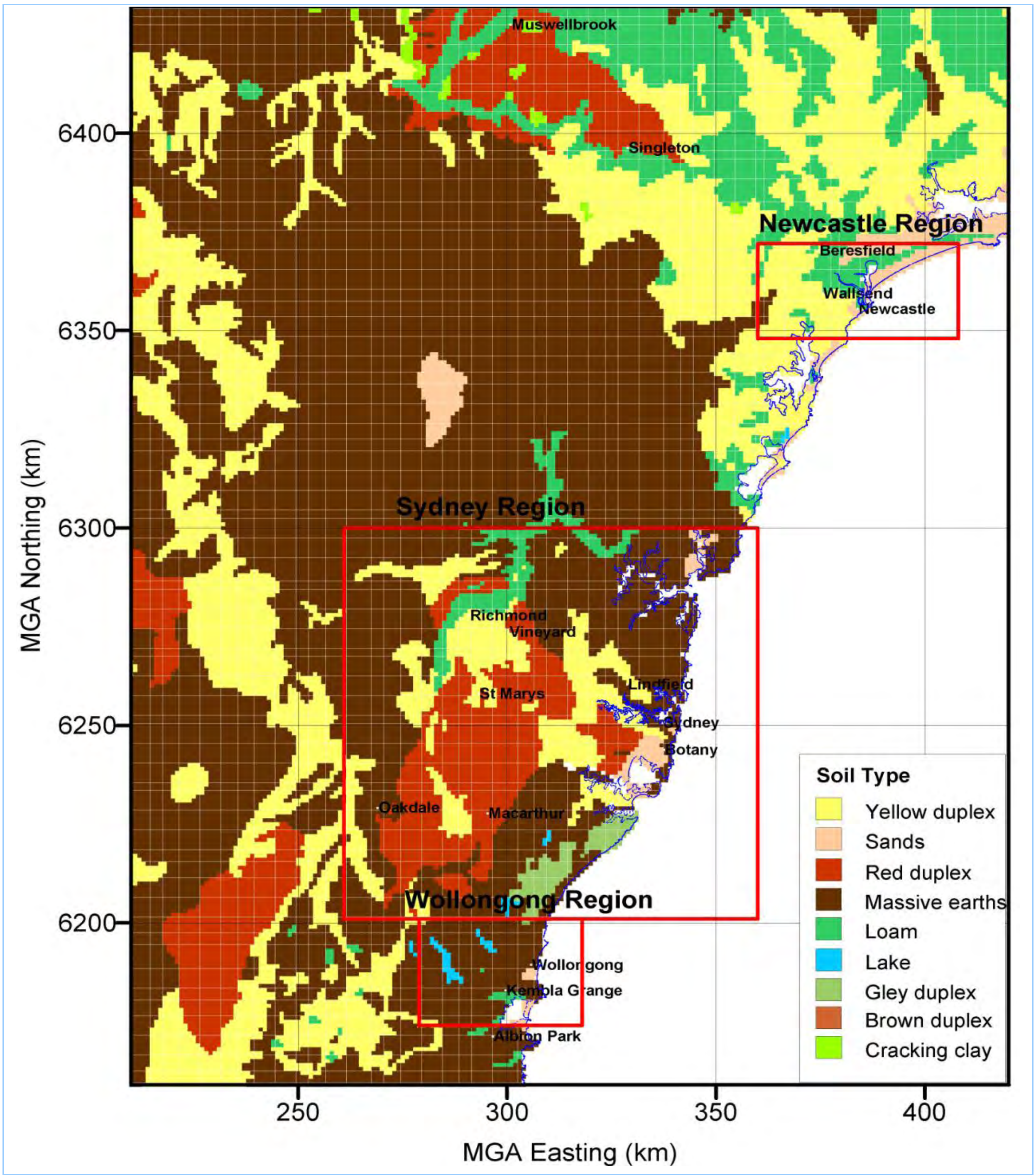

Figure 3-19: Spatial distribution of soil type in the GMR

Hourly average meteorological data including temperature, precipitation and wind speed have been generated for the GMR at 2 km by 2 km grid cells with *TAPM* (Hurley, 2005) and used to estimate Thornthwaite's precipitation-evaporation index (Thornthwaite, 1931) and the climatic factor (CARB, 1997a; and CARB, 1997b) at 1 km by 1 km grid cells.

Monthly average temperature, precipitation, wind speed, Thornthwaite's precipitation-evaporation index (Thornthwaite, 1931) and the climatic factor (i.e. month-as-a-year and annual) in the GMR are presented in Table 3-38 and shown in Figure 3-20, Figure 3-21 and Figure 3-22.

Table 3-38: Monthly average meteorological data in the GMR

Month	Monthly average meteorological data									
	Temperature (°C)		Precipitation (mm)		Wind speed (km/h)		Thornthwaite's precipitation-evaporation index (PE)		Month-as-a-year climatic factor (C)[8]	
January	24.5		113		13.1		6.8		0.1775	
February	23.2		542		12.4		38.5		0.0019	
March	19.2		268		10.8		20.5		0.0198	
April	14.9		327		10.7		30.1		0.0029	
May	11.9		336		11.8		33.5		0.0054	
June	9.7		74		12.8		6.8		0.0285	
July	8.3		66		12.7		6.5		0.0473	
August	9.0		98		13.8		10.2		0.0274	
September	11.9		13		16.5		1.3		0.5712	
October	15.1		109		13.5		8.2		0.0157	
November	19.8		159		12.7		10.9		0.0205	
December	24.4		71		12.9		3.7		0.0819	
Grand Total	Mean	16.0	Mean	181	Mean	12.8	Sum	176.9	Annual climatic factor Sum	0.0405

[8] When calculating the annual C factor, the monthly PE values have been summed for all of the months in the year. However, to calculate the month-as-a-year C factor, each month's PE has been multiplied by 12. Then each month's PE x 12 has been input into the C factor equation along with the mean monthly wind speed for that same month. The result is a C factor which would apply if the climate for that month were instead the year round climate. By then summing all of the monthly C factors for the year and then dividing each individual month by the sum, the month-as-a-year C factor has been normalised to 1. These normalised monthly numbers provide the climate based temporal profile. They have been multiplied by the annual WEQ results to produce monthly emissions (CARB, 1997a).

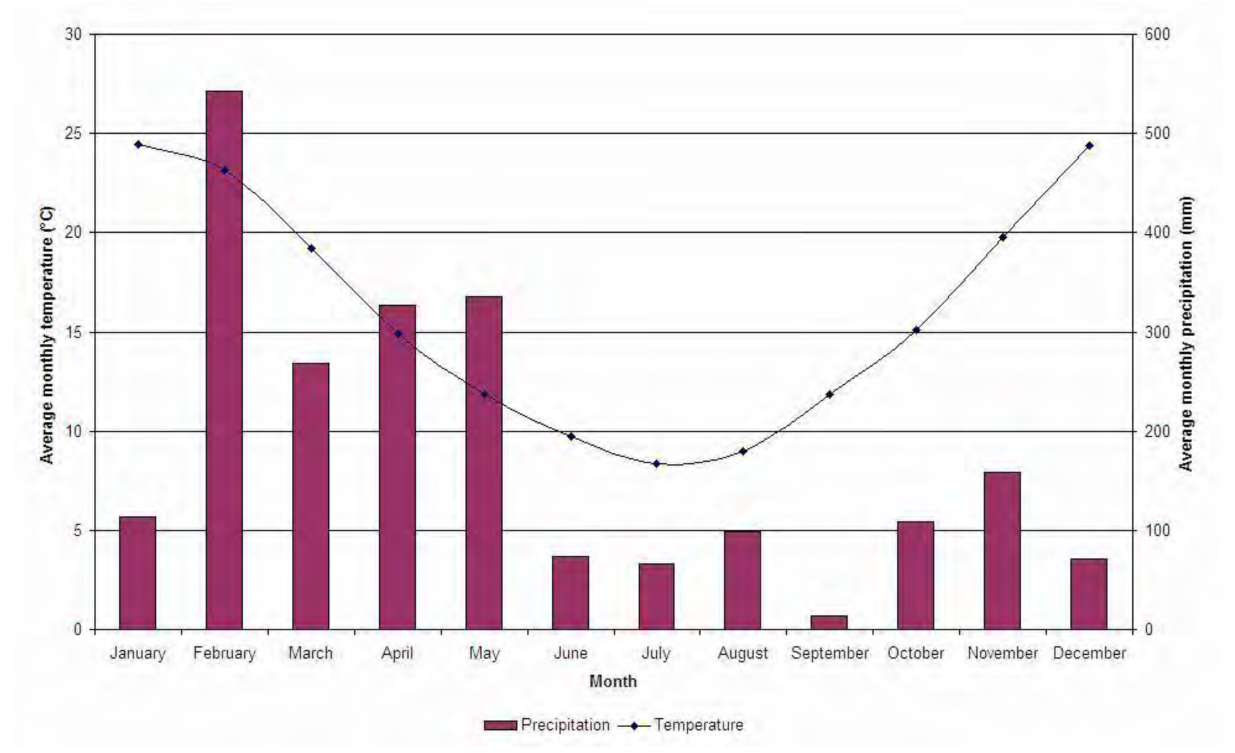

Figure 3-20: Monthly average temperature and precipitation in the GMR

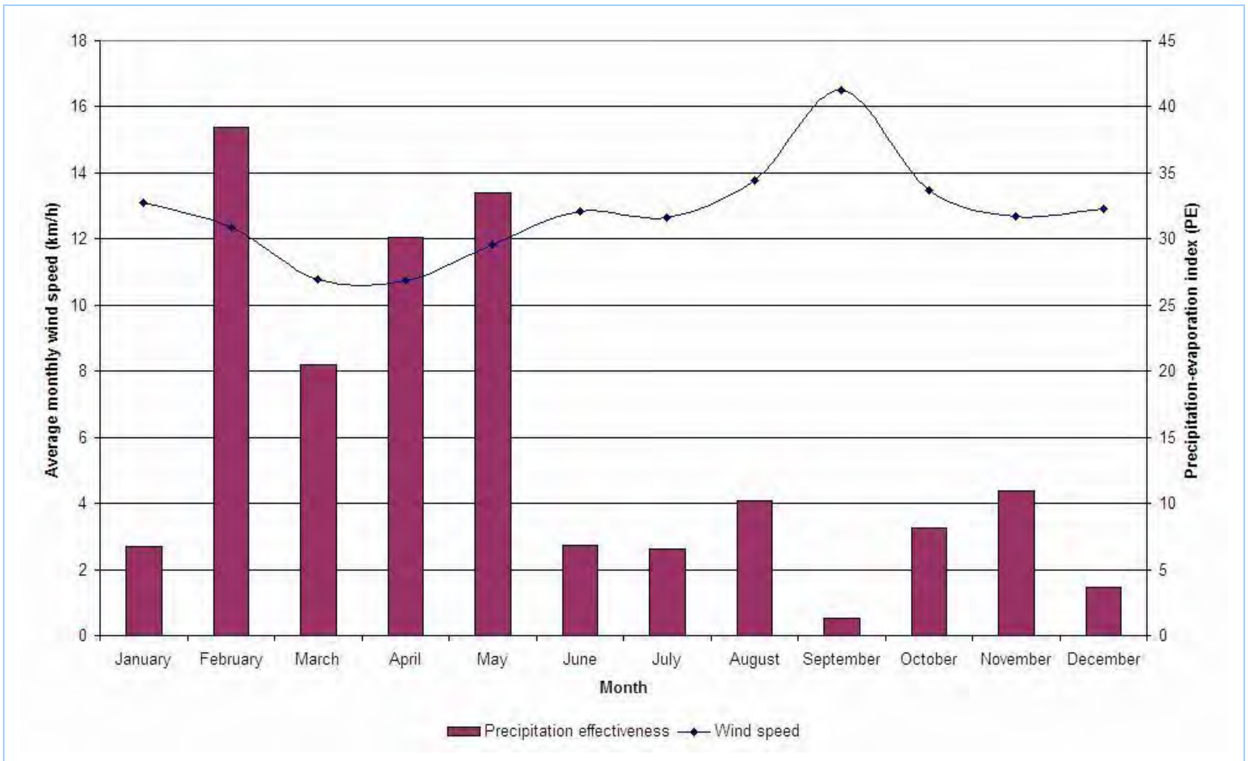

Figure 3-21: Monthly average wind speed and Thornthwaite's precipitation-evaporation index in the GMR

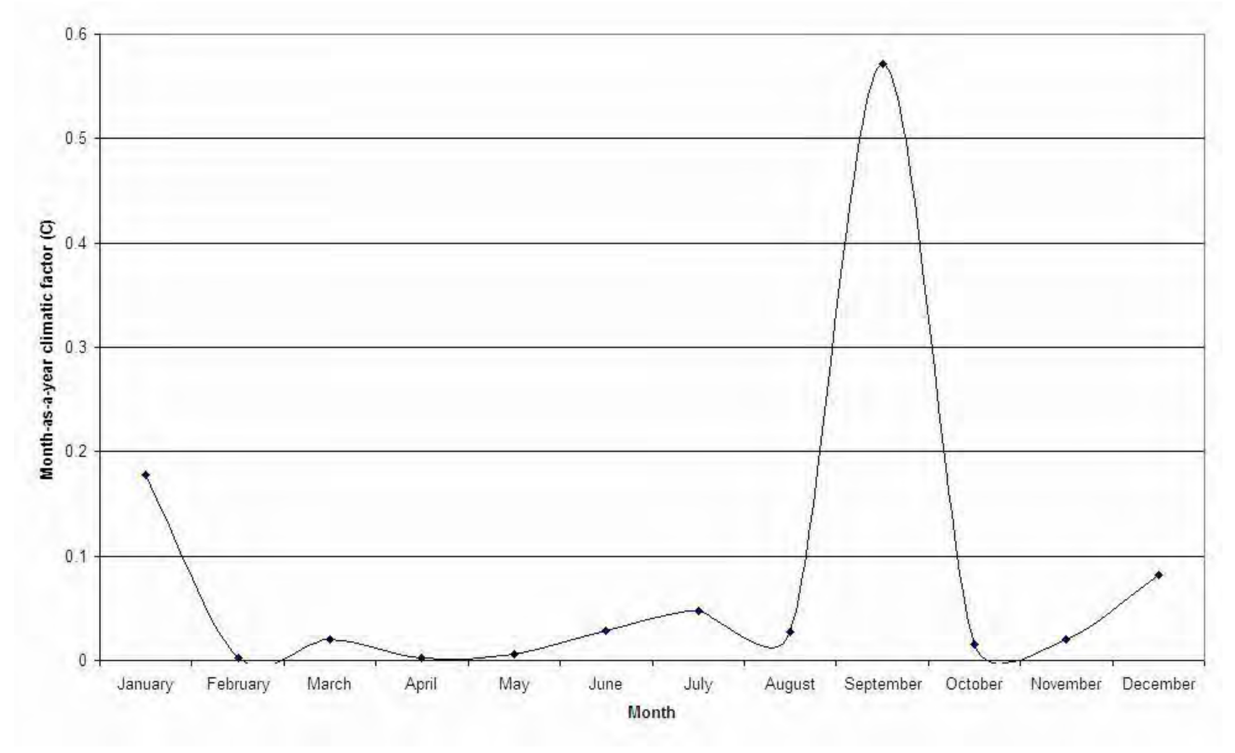

Figure 3-22: Month-as-a-year climatic factor in the GMR

Annual average temperature, precipitation, wind speed, Thornthwaite's precipitation-evaporation index and the climatic factor by region are presented in Table 3-39, while the gridded annual average is shown in Figure 3-23, Figure 3-24, Figure 3-25, Figure 3-26 and Figure 3-27 for the GMR.

Table 3-39: Annual average meteorological data by region

Region	Annual average meteorological data				
	Temperature (°C)	Precipitation (mm)	Wind speed (km/h)	Thornthwaite's precipitation-evaporation index (PE)	Annual climatic factor (C)
Non Urban	15.7	203	13.3	202.1	0.0420
Newcastle	18.6	75	10.7	56.1	0.0450
Sydney	16.9	90	11.2	73.2	0.0374
Wollongong	16.6	261	11.5	244.8	0.0042
Grand Total	16.0	181	12.8	176.9	0.0405

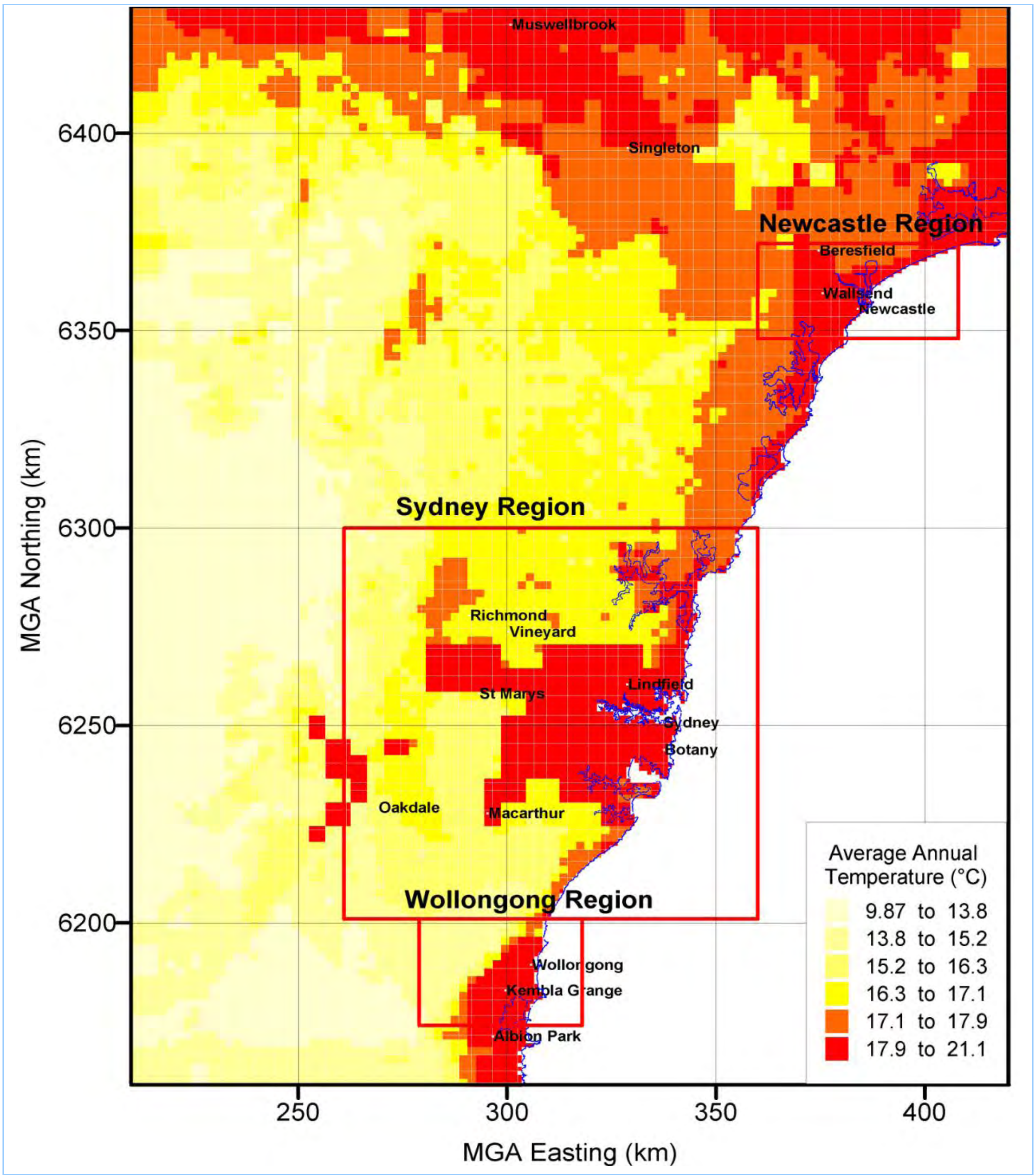

Figure 3-23: Gridded annual average temperature

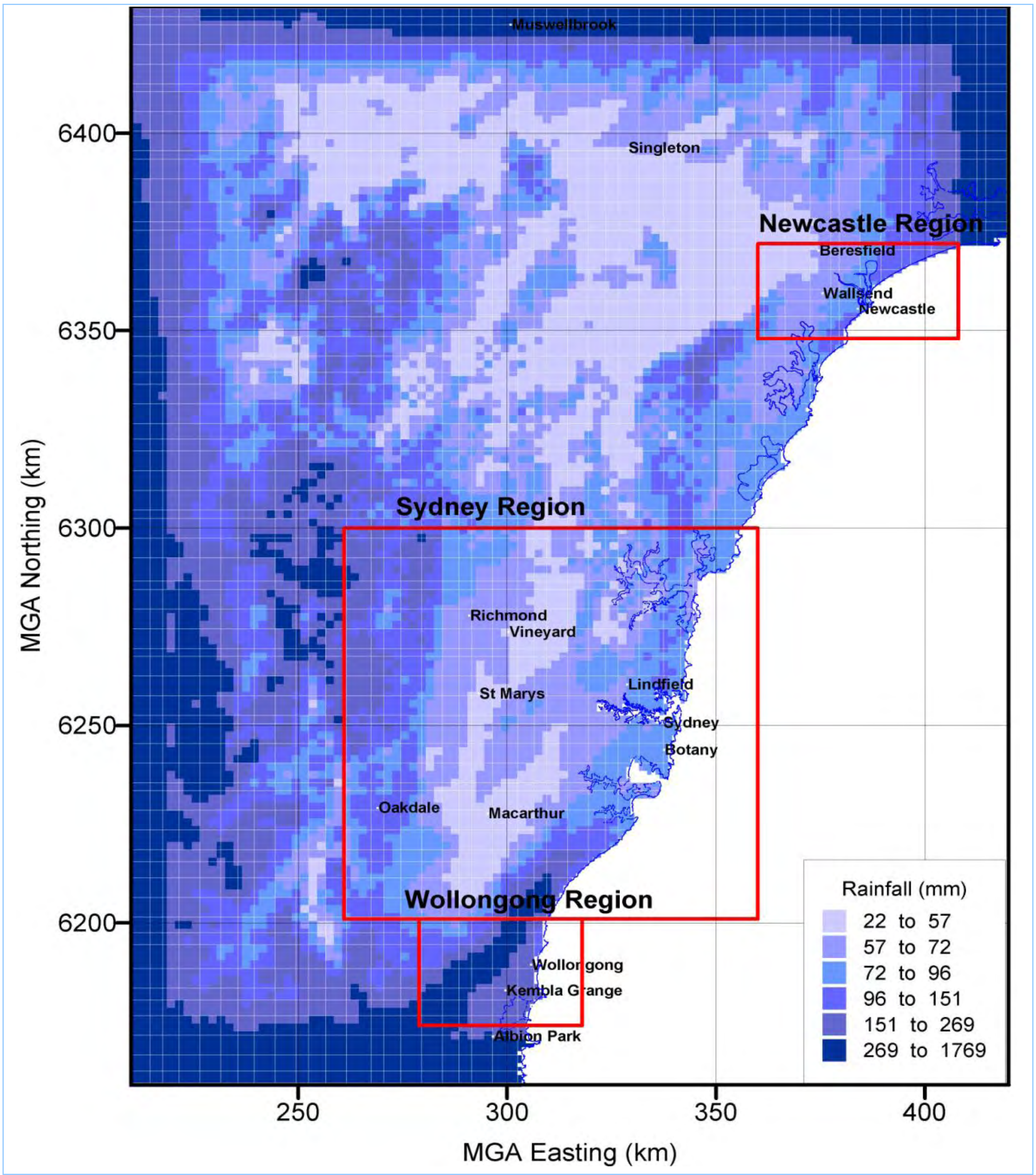

Figure 3-24: Gridded annual average precipitation

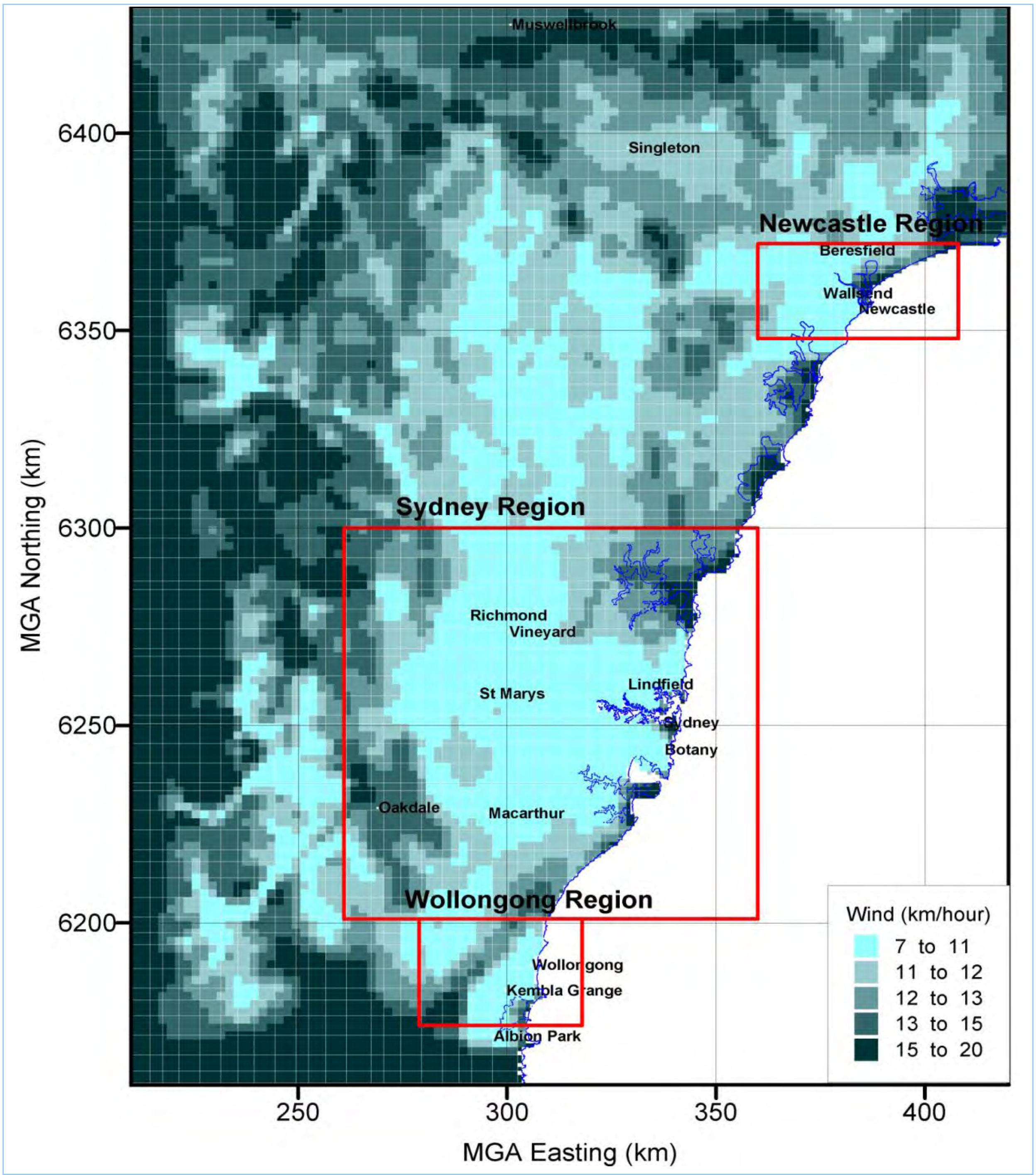

Figure 3-25: Gridded annual average wind speed

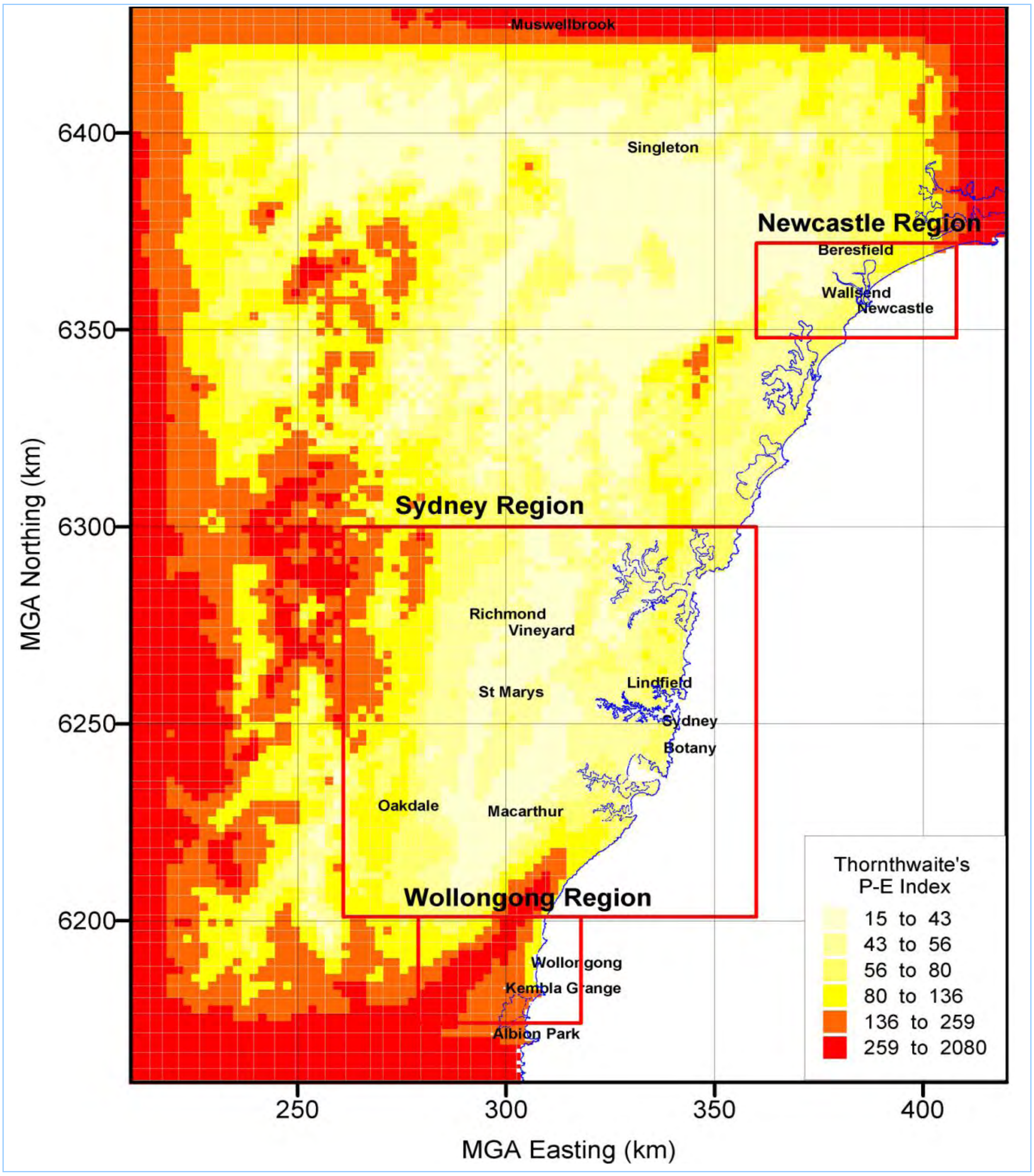

Figure 3-26: Gridded annual Thornthwaite's precipitation-evaporation index

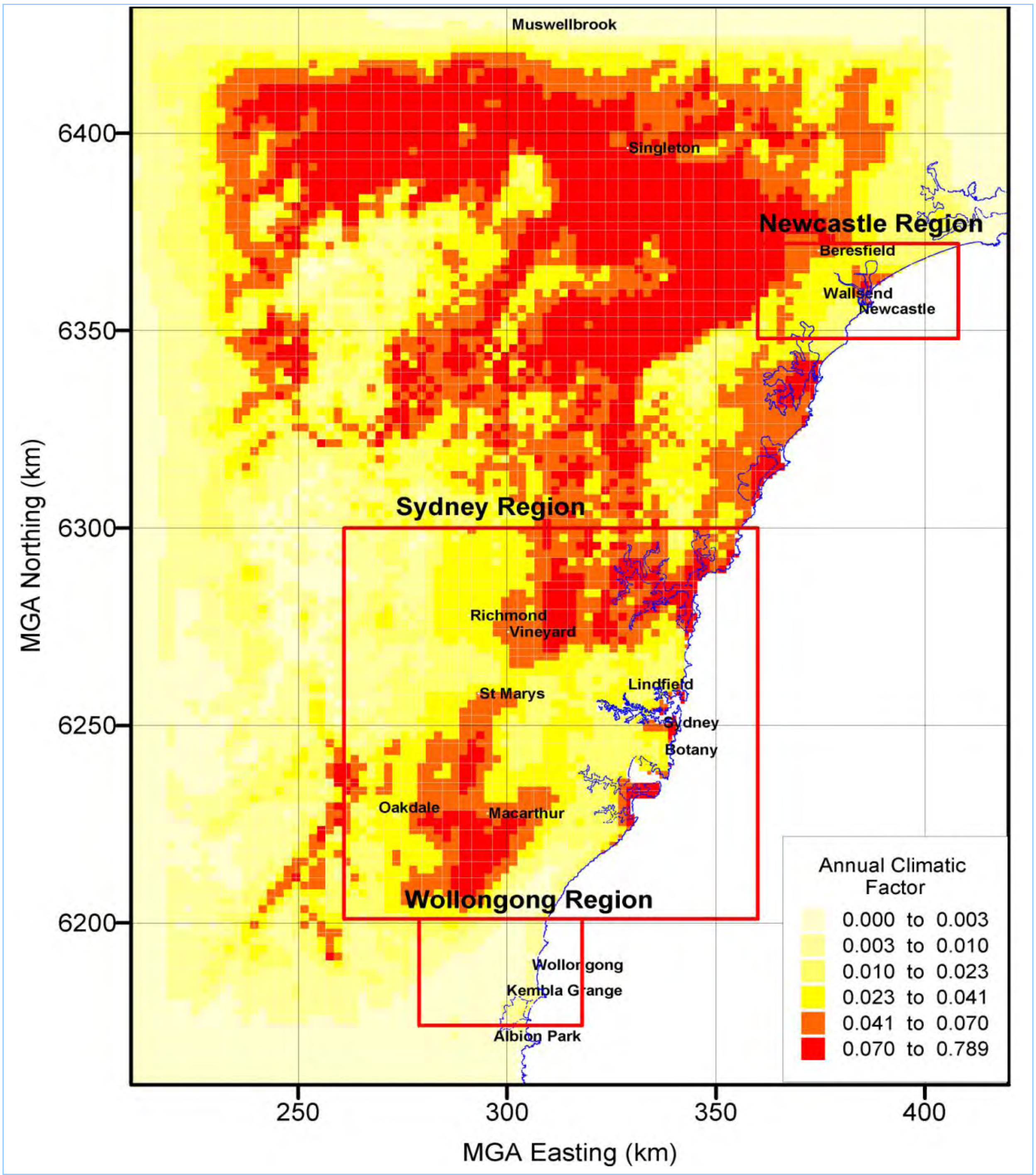

Figure 3-27: Gridded annual climatic factor

The monthly average crop canopy cover or postharvest soil cover by source type is presented in Table 3-40 and shown in Figure 3-28 and Figure 3-29 for summer and winter crops, respectively.

Table 3-40: Monthly average crop canopy cover or postharvest soil cover by source type

Month	Crop canopy cover or postharvest soil cover (%)[9]									
	Summer crop			Winter crop						Unpaved Roads
	Grain Sorghum	Maize	Soybean	Barley	Canola	Lupin Angust	Oats	Triticale	Wheat	
January	50	67	75	5#	5#	5#	5#	100	100	-
February	75	67	75	5#	5#	5#	5#	5#	5#	-
March	88	67	100	5#	5#	5#	25	5#	5#	-
April	100	88	100	5#	25	25	25	25	25	-
May	100	88	5#	25	25	25	25	25	25	-
June	100	100	5#	50	25	25	50	25	25	-
July	5#	100	5#	50	100	100	75	25	25	-
August	5#	5#	5#	75	100	100	75	50	50	-
September	25	25	5#	75	5#	5#	75	75	75	-
October	25	25	5#	88	5#	5#	88	75	75	-
November	50	50	25	100	5#	5#	100	88	88	-
December	50	50	25	100	5#	5#	100	88	88	-

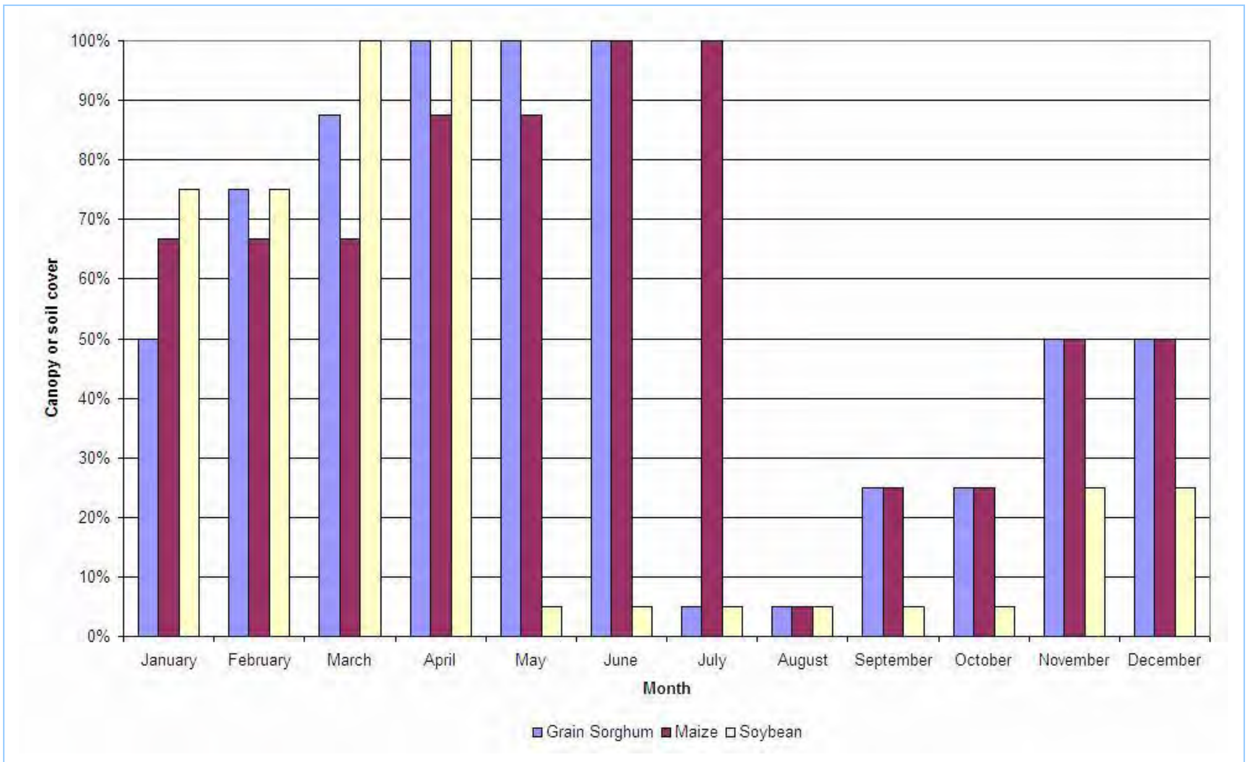

Figure 3-28: Crop canopy cover or postharvest soil cover for summer crop

[9] These values are monthly average crop canopy cover, except those values marked with a hash (#) which are monthly average postharvest soil cover (CARB, 1997a).

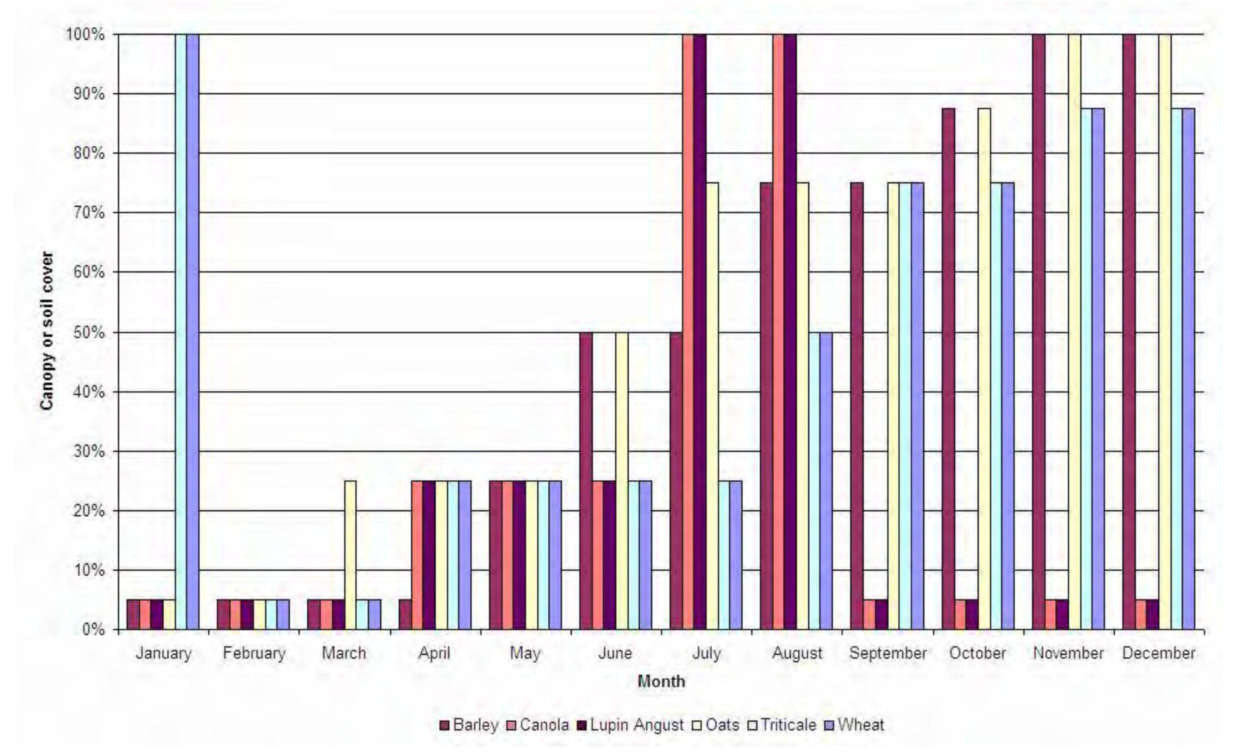

Figure 3-29: Crop canopy cover or postharvest soil cover for winter crop

Figure 3-30 shows the crop harvest area weighted crop canopy cover or postharvest soil cover for summer and winter crops.

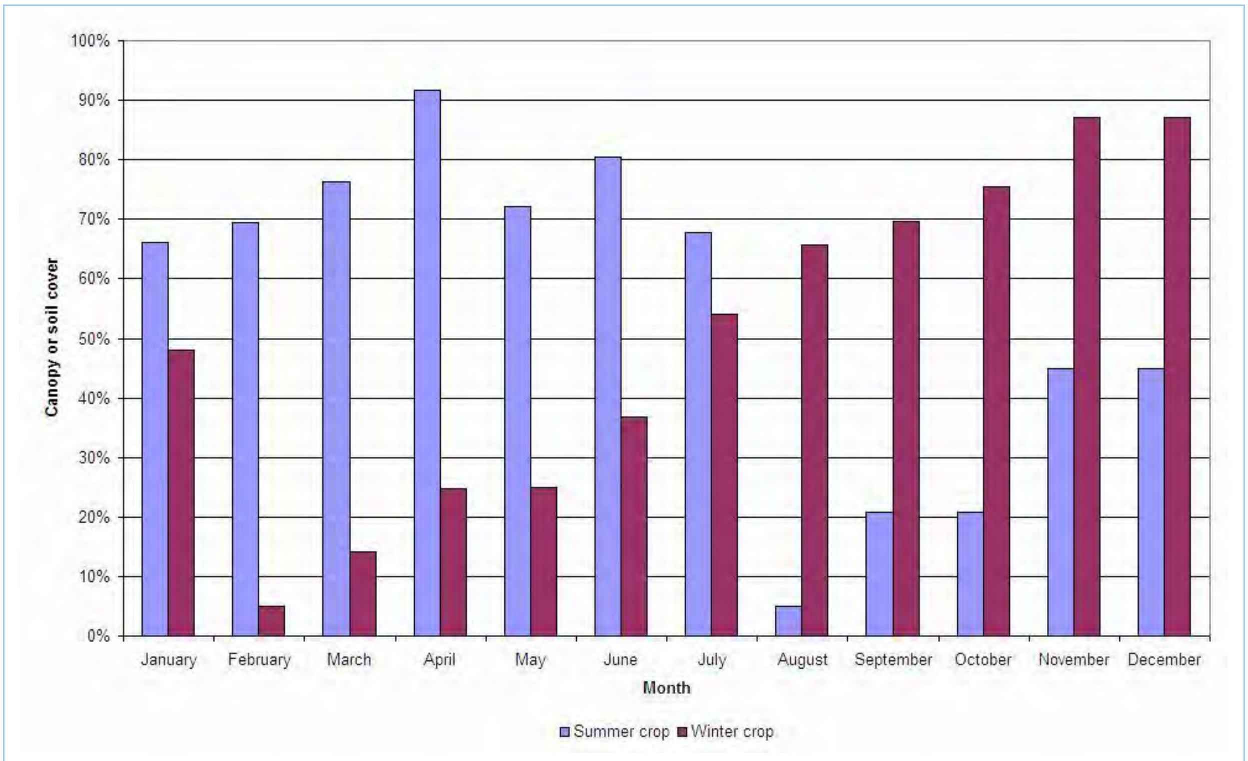

Figure 3-30: Crop canopy cover or postharvest soil cover for summer crop and winter crop

The monthly average vegetative cover factor by source type is presented in Table 3-41 and shown in Figure 3-31 and Figure 3-32 for summer and winter crops, respectively.

Table 3-41: Monthly average vegetative cover factor by source type

Month	Vegetative cover factor[10]									
	Summer crop			Winter crop						Unpaved Roads
	Grain Sorghum	Maize	Soybean	Barley	Canola	Lupin Angust	Oats	Triticale	Wheat	
January	0.0277	0.0119	0.0079	0.8033	0.8033	0.8033	0.8033	0.0025	0.0025	1.0000
February	0.0079	0.0119	0.0079	0.8033	0.8033	0.8033	0.8033	0.8033	0.8033	1.0000
March	0.0044	0.0119	0.0025	0.8033	0.8033	0.8033	0.1162	0.8033	0.8033	1.0000
April	0.0025	0.0044	0.0025	0.8033	0.1162	0.1162	0.1162	0.1162	0.1162	1.0000
May	0.0025	0.0044	0.8033	0.1162	0.1162	0.1162	0.1162	0.1162	0.1162	1.0000
June	0.0025	0.0025	0.8033	0.0277	0.1162	0.1162	0.0277	0.1162	0.1162	1.0000
July	0.8033	0.0025	0.8033	0.0277	0.0025	0.0025	0.0079	0.1162	0.1162	1.0000
August	0.8033	0.8033	0.8033	0.0079	0.0025	0.0025	0.0079	0.0277	0.0277	1.0000
September	0.1162	0.1162	0.8033	0.0079	0.8033	0.8033	0.0079	0.0079	0.0079	1.0000
October	0.1162	0.1162	0.8033	0.0044	0.8033	0.8033	0.0044	0.0079	0.0079	1.0000
November	0.0277	0.0277	0.1162	0.0025	0.8033	0.8033	0.0025	0.0044	0.0044	1.0000
December	0.0277	0.0277	0.1162	0.0025	0.8033	0.8033	0.0025	0.0044	0.0044	1.0000

[10] The monthly average vegetative factor has been calculated from the data in Table 3-40 using Equation 8 for crop canopy cover and Equation 9 for postharvest soil cover (CARB, 1997a).

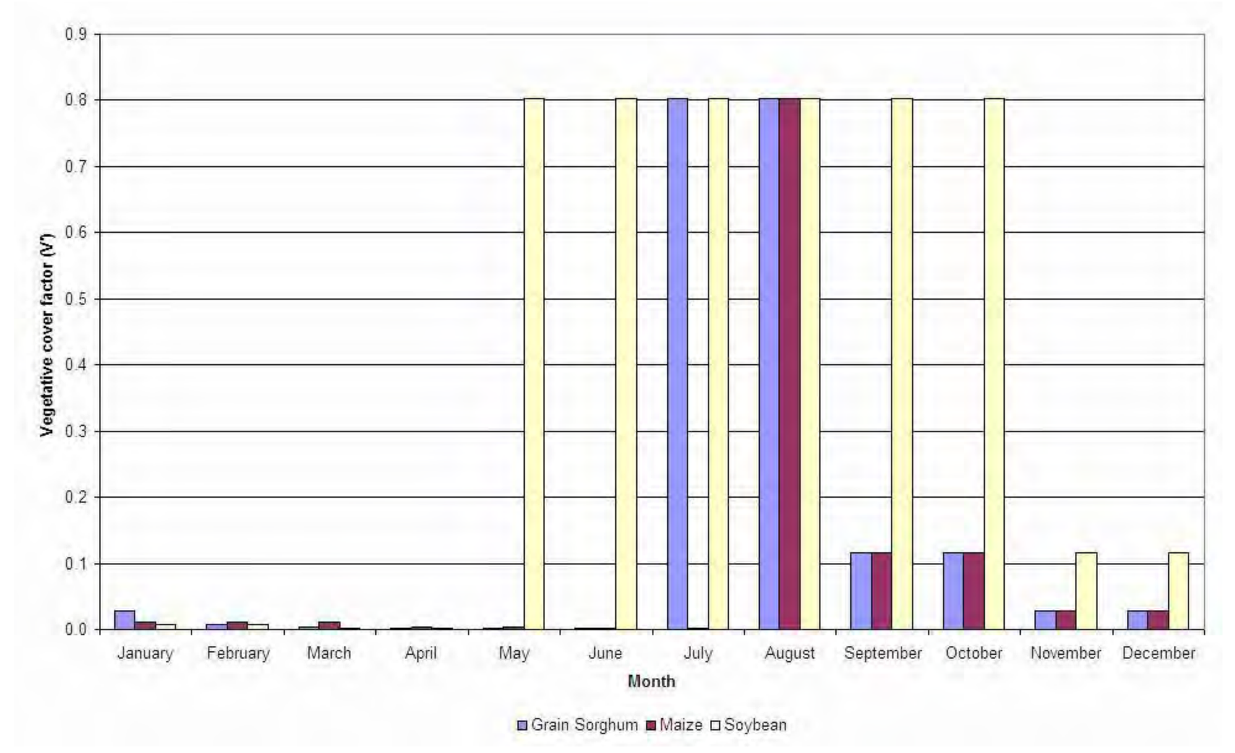

Figure 3-31: Vegetative cover factor for summer crop

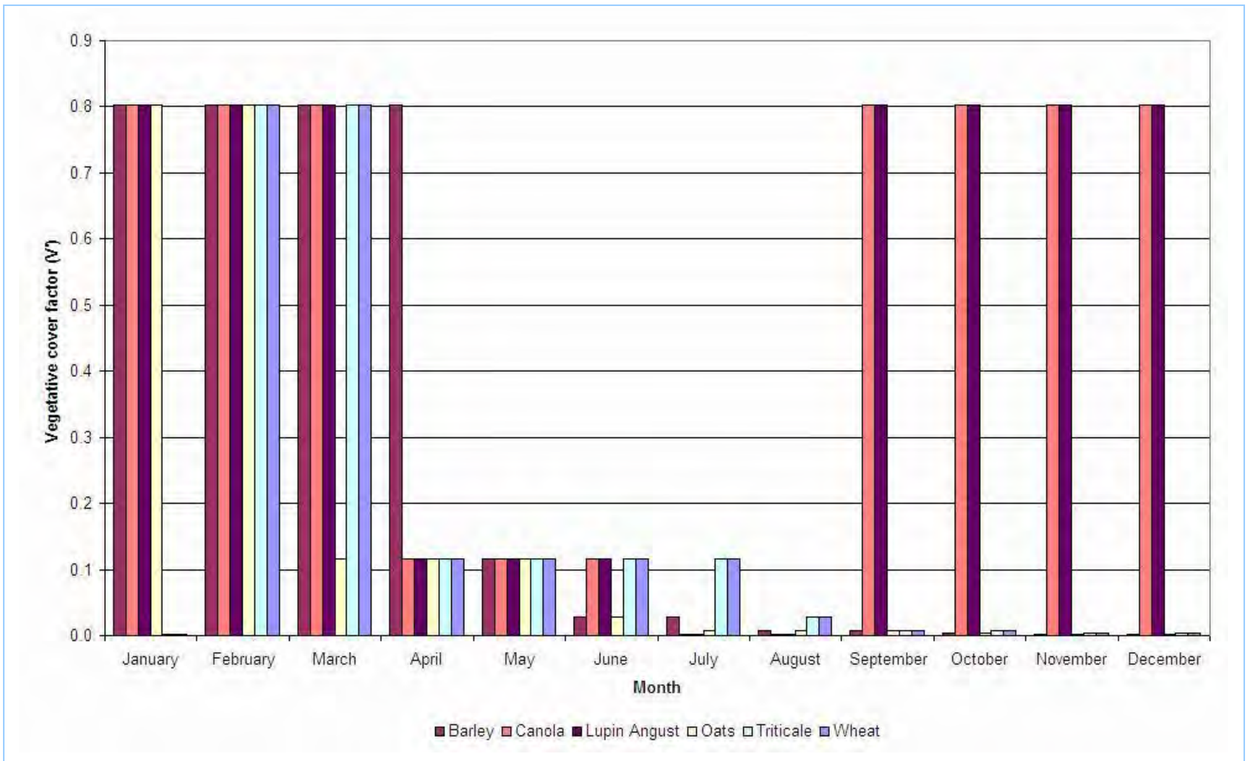

Figure 3-32: Vegetative cover factor for winter crop

Figure 3-33 shows the crop harvest area weighted vegetative cover factor for summer and winter crops.

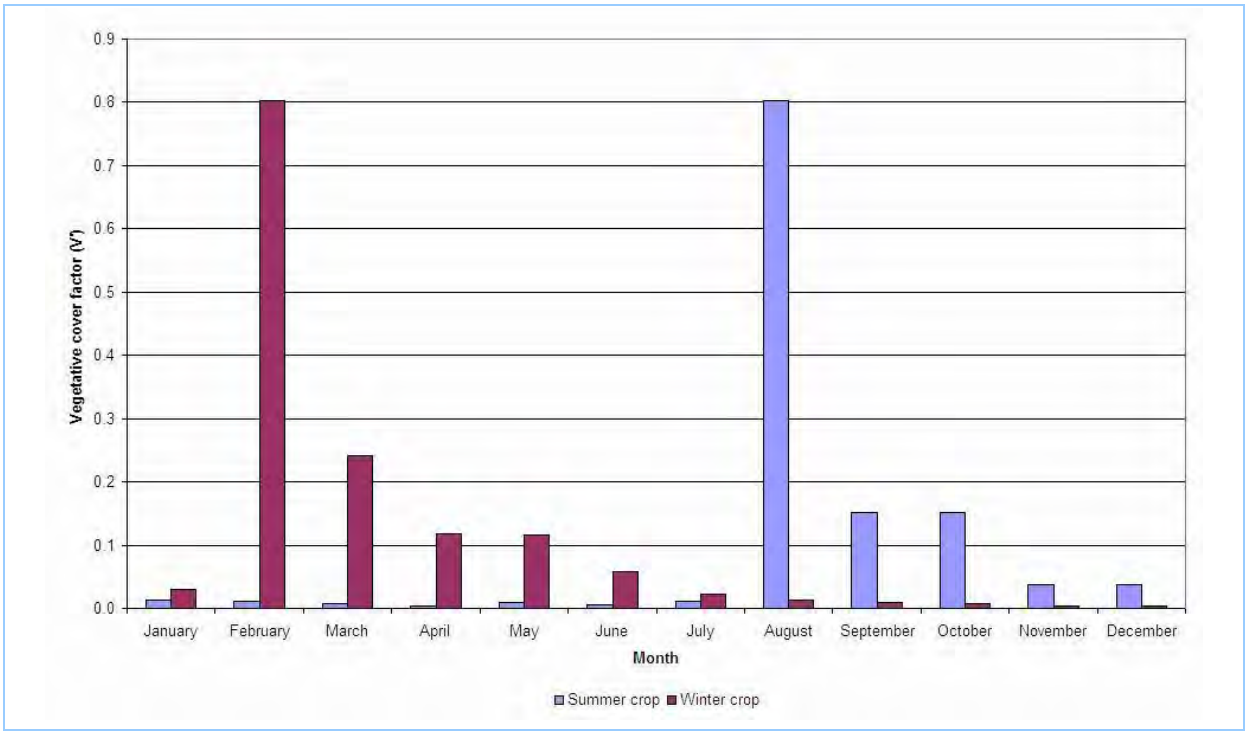

Figure 3-33: Vegetative cover factor for summer crop and winter crop

3.3.4 *Emission and Speciation Factors*

Table 3-42 summarises the emission and speciation factors used for fugitive windborne particulate matter from agricultural lands and unpaved roads.

Table 3-42: Agricultural lands and unpaved roads emission and speciation factors

Substance	Emission source	Emission and speciation factor source
Criteria pollutants: $PM_{2.5}$ and PM_{10}	Fugitive windborne particulate matter from agricultural lands	- *PMPROF 418 - California Emission Inventory and Reporting System (CEIDARS), Particulate Matter (PM) Speciation Profiles* (CARB, 2008b)
Criteria pollutants: TSP		- *Area-Wide Source Methodologies, Section 7.12 Windblown Dust - Agricultural Lands* (CARB, 1997a)
Metal air toxics		- *PMPROF 418 - California Emission Inventory and Reporting System (CEIDARS), Particulate Matter (PM) Speciation Profiles* (CARB, 2007)
Criteria pollutants: $PM_{2.5}$ and PM_{10}	Fugitive windborne particulate matter from unpaved roads	- *PMPROF 416 - California Emission Inventory and Reporting System (CEIDARS), Particulate Matter (PM) Speciation Profiles* (CARB, 2008b)
Criteria pollutants: TSP		- *Area-Wide Source Methodologies, Section 7.13 Windblown Dust - Unpaved Roads* (CARB, 1997b)
Metal air toxics		- *PMPROF 416 - California Emission Inventory and Reporting System (CEIDARS), Particulate Matter (PM) Speciation Profiles* (CARB, 2007)

Table 3-43 presents emission factors for fugitive windborne particulate matter from agricultural lands and unpaved roads.

Table 3-43: Agricultural lands and unpaved roads emission factors

Emission source	Emission factors (kg/ha/year)		
	$PM_{2.5}$	PM_{10}	TSP
Fugitive windborne particulate matter from agricultural lands	0.3568	2.0621	4.5390
Fugitive windborne particulate matter from unpaved roads	6.9371	52.4517	88.2579

3.3.5 *Spatial Distribution of Emissions*

Table 3-44 summarises the data used for spatially allocating emissions of fugitive windborne particulate matter from agricultural lands and unpaved roads.

Table 3-44: Agricultural lands and unpaved roads spatial data

Emission source	Spatial data	Spatial data source
Fugitive windborne particulate matter from agricultural lands	GIS layer for crop area combined with GIS layer for soil erodibility and gridded 1 km x 1 km climatic factor estimates	- *Land Use of Australia, Version 3 - 1996/1997* (BRS , 2006) - *Digital Atlas of Australian Soils* (BRS , 1991) - *The Air Pollution Model (TAPM) Version 3* (Hurley, 2005)
Fugitive windborne particulate matter from unpaved roads	GIS layer for unpaved road area combined with GIS layer for soil erodibility and gridded 1 km x 1 km climatic factor estimates	- *Unsealed Roads from the dtdb Cultural Lines Layer - Arc/Info Export Format* (DEC, 2004a) - *Digital Atlas of Australian Soils* (BRS , 1991) - *The Air Pollution Model (TAPM) Version 3* (Hurley, 2005)

Emissions of fugitive windborne particulate matter from agricultural lands have been spatially distributed according to the proportion of cropping area in each 1 km by 1 km grid cell (BRS, 2006). The proportion of cropping area by LGA and region is presented in Table 3-45 and shown in Figure 3-34.

Table 3-45: Agricultural lands spatial distribution by LGA and region

LGA	2008 proportion of cropping area (%)			
	Newcastle	Non Urban	Sydney	Grand Total
Blue Mountains	-	-	1.39	1.39
Camden	-	-	1.73	1.73
Cessnock	1.42	1.03	-	2.45
Dungog	-	1.76	-	1.76

LGA	2008 proportion of cropping area (%)			
	Newcastle	Non Urban	Sydney	Grand Total
Gosford	-	-	9.31×10^{-2}	9.31×10^{-2}
Goulburn Mulwaree	-	0.25	-	0.25
Hawkesbury	-	0.70	2.78	3.48
Hornsby	-	-	0.26	0.26
Kiama	-	0.34	-	0.34
Lithgow	-	28.04	-	28.04
Maitland	0.11	1.30	-	1.41
Mid-western Regional	-	3.87	-	3.87
Muswellbrook	-	15.40	-	15.40
N/A	4.45×10^{-3}	-	-	4.45×10^{-3}
Newcastle	1.70×10^{-2}	-	-	1.70×10^{-2}
Oberon	-	2.14	-	2.14
Port Stephens	0.33	0.46	-	0.79
Shellharbour	-	0.69	-	0.69
Singleton	-	6.42	-	6.42
Upper Hunter	-	4.11	-	4.11
Upper Lachlan	-	12.91	-	12.91
Wingecarribee	-	9.66	0.10	9.76
Wollondilly	-	-	2.33	2.33
Wyong	-	0.35	-	0.35
Grand Total	1.88	89.43	8.68	100.00

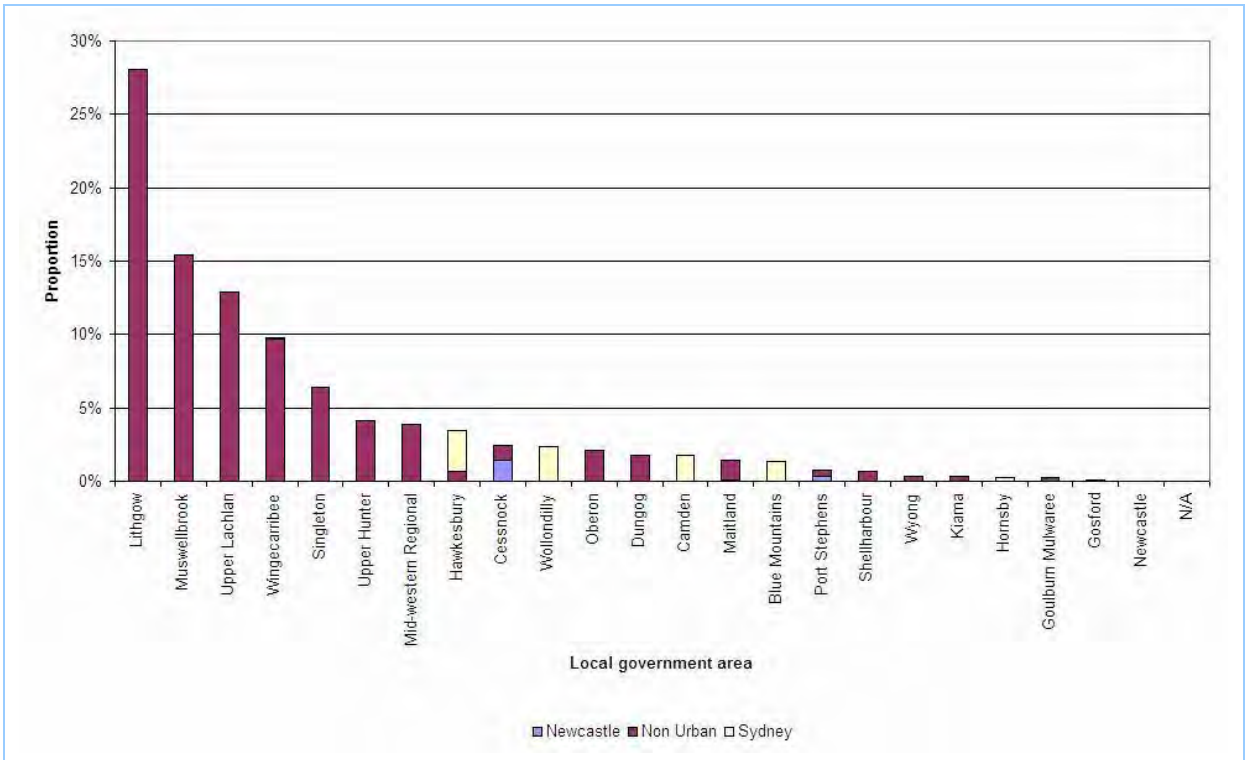

Figure 3-34: Agricultural lands spatial distribution by LGA and region

Figure 3-35 shows the spatial distribution of fugitive windborne particulate matter emissions from agricultural lands.

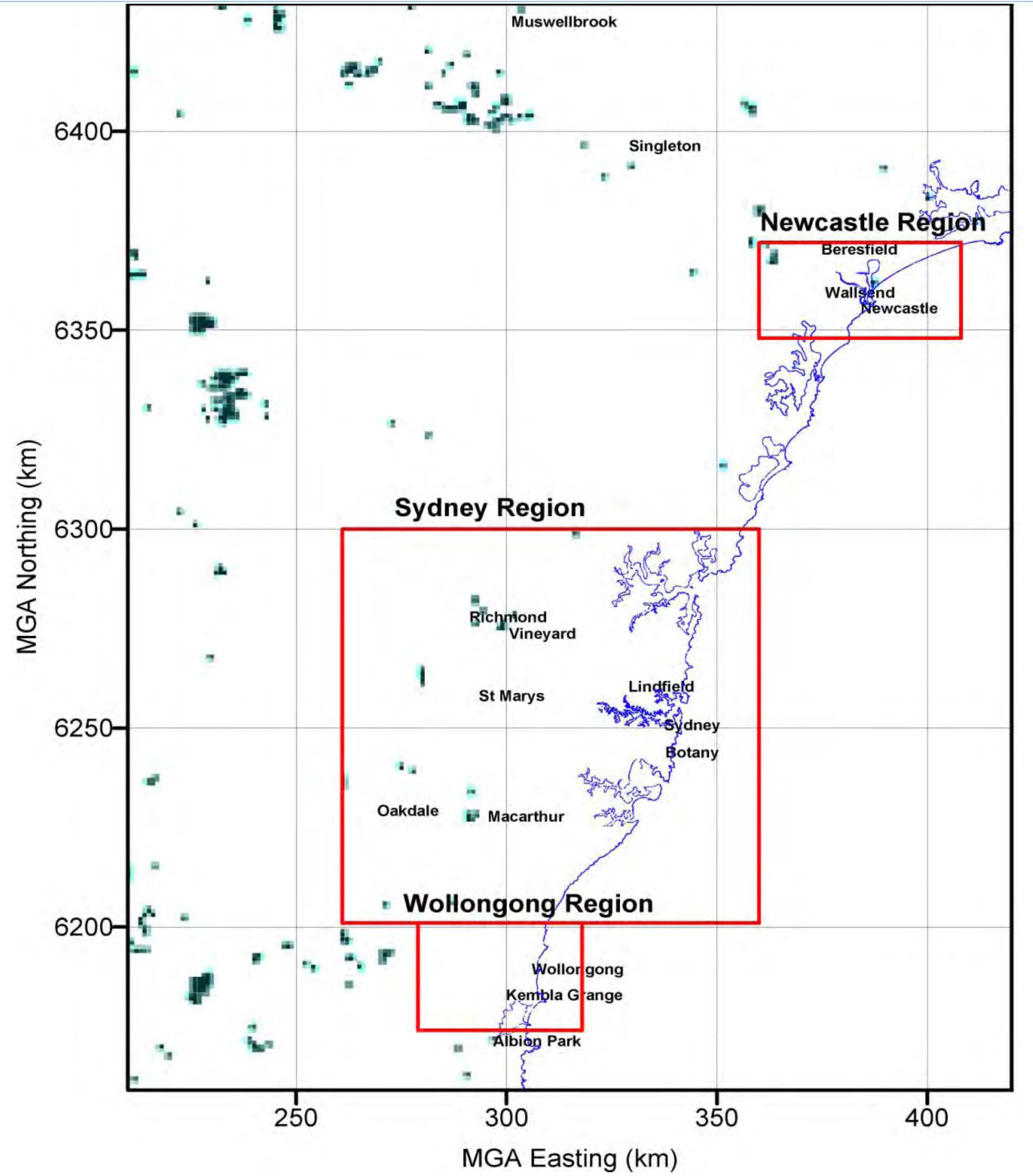

Figure 3-35: Agricultural lands spatial distribution of emissions

Emissions of fugitive windborne particulate matter from unpaved roads have been spatially distributed according to the proportion of unpaved road length in each 1 km by 1 km grid cell (DEC, 2004a). The proportion of unpaved road length by LGA and region is presented in Table 3-46 and shown in Figure 3-36.

Table 3-46: Unpaved roads spatial distribution by LGA and region

LGA	2008 proportion of unpaved road length (%)				
	Newcastle	Non Urban	Sydney	Wollongong	Grand Total
Ashfield	-	-	1.84×10^{-2}	-	1.84×10^{-2}
Auburn	-	-	5.28×10^{-2}	-	5.28×10^{-2}
Bankstown	-	-	6.70×10^{-2}	-	6.70×10^{-2}
Bathurst Regional	-	0.19	-	-	0.19
Baulkham Hills	-	1.67×10^{-2}	1.02	-	1.04
Blacktown	-	-	0.47	-	0.47
Blue Mountains	-	2.13	1.43	-	3.57
Botany Bay	-	-	1.28×10^{-2}	-	1.28×10^{-2}
Burwood	-	-	6.80×10^{-3}	-	6.80×10^{-3}
Camden	-	-	0.65	-	0.65
Campbelltown	-	-	1.25	-	1.25
Canada Bay	-	-	5.25×10^{-2}	-	5.25×10^{-2}
Canterbury	-	-	4.57×10^{-2}	-	4.57×10^{-2}
Cessnock	0.59	7.30	-	-	7.89
Dungog	-	5.14	-	-	5.14
Fairfield	-	-	0.20	-	0.20
Gosford	-	2.30	0.95	-	3.25
Goulburn Mulwaree	-	0.38	-	-	0.38
Great Lakes	-	4.87	-	-	4.87
Hawkesbury	-	2.91	2.80	-	5.71
Holroyd	-	-	6.79×10^{-2}	-	6.79×10^{-2}
Hornsby	-	4.42×10^{-2}	1.28	-	1.32
Hunters Hill	-	-	3.91×10^{-3}	-	3.91×10^{-3}
Hurstville	-	-	9.63×10^{-3}	-	9.63×10^{-3}
Kiama	-	0.44	-	-	0.44
Kogarah	-	-	2.34×10^{-2}	-	2.34×10^{-2}
Ku-ring-gai	-	-	0.28	-	0.28
Lake Macquarie	1.02	3.24	-	-	4.26
Lane Cove	-	-	4.82×10^{-2}	-	4.82×10^{-2}
Leichhardt	-	-	9.54×10^{-3}	-	9.54×10^{-3}
Lithgow	-	9.26	-	-	9.26
Liverpool	-	-	0.82	-	0.82
Maitland	8.14×10^{-2}	1.08	-	-	1.16
Manly	-	-	3.75×10^{-2}	-	3.75×10^{-2}
Marrickville	-	-	2.83×10^{-2}	-	2.83×10^{-2}
Mid-western Regional	-	4.08	-	-	4.08
Mosman	-	-	7.58×10^{-3}	-	7.58×10^{-3}
Muswellbrook	-	3.09	-	-	3.09
N/A	7.12×10^{-3}	4.78×10^{-2}	8.86×10^{-2}	1.38×10^{-2}	0.16
Newcastle	0.50	-	-	-	0.50
North Sydney	-	-	1.52×10^{-2}	-	1.52×10^{-2}
Oberon	-	3.81	-	-	3.81
Parramatta	-	-	7.19×10^{-2}	-	7.19×10^{-2}

LGA	2008 proportion of unpaved road length (%)				
	Newcastle	Non Urban	Sydney	Wollongong	Grand Total
Penrith	-	-	1.27	-	1.27
Pittwater	-	-	0.21	-	0.21
Port Stephens	0.45	2.84	-	-	3.28
Randwick	-	-	9.96×10^{-2}	-	9.96×10^{-2}
Rockdale	-	-	4.45×10^{-2}	-	4.45×10^{-2}
Ryde	-	-	0.11	-	0.11
Shellharbour	-	0.30	-	2.48×10^{-2}	0.32
Shoalhaven	-	0.14	-	-	0.14
Singleton	-	7.97	-	-	7.97
Strathfield	-	-	1.34×10^{-2}	-	1.34×10^{-2}
Sutherland	-	-	1.28	-	1.28
Sydney	-	-	5.85×10^{-2}	-	5.85×10^{-2}
Unincorporated	-	-	7.0×10^{-2}	-	7.0×10^{-2}
Upper Hunter	-	0.82	-	-	0.82
Upper Lachlan	-	1.62	-	-	1.62
Warringah	-	-	0.47	-	0.47
Waverley	-	-	2.64×10^{-2}	-	2.64×10^{-2}
Willoughby	-	-	4.98×10^{-2}	-	4.98×10^{-2}
Wingecarribee	-	6.35	0.25	0.39	6.98
Wollondilly	-	1.14	3.95	7.77×10^{-2}	5.17
Wollongong	-	-	0.86	1.34	2.20
Woollahra	-	-	2.33×10^{-2}	-	2.33×10^{-2}
Wyong	-	3.37	-	-	3.37
Grand Total	2.66	74.89	20.61	1.85	100.00

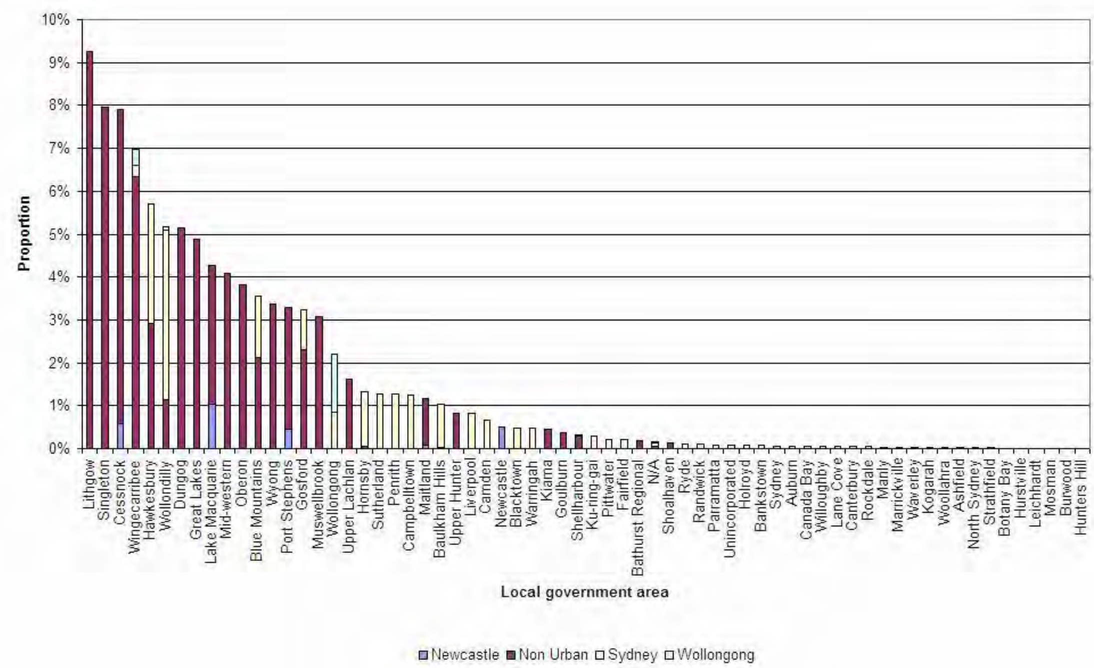

Figure 3-36: Unpaved roads spatial distribution by LGA and region

Figure 3-37 shows the spatial distribution of fugitive windborne particulate matter emissions from unpaved roads.

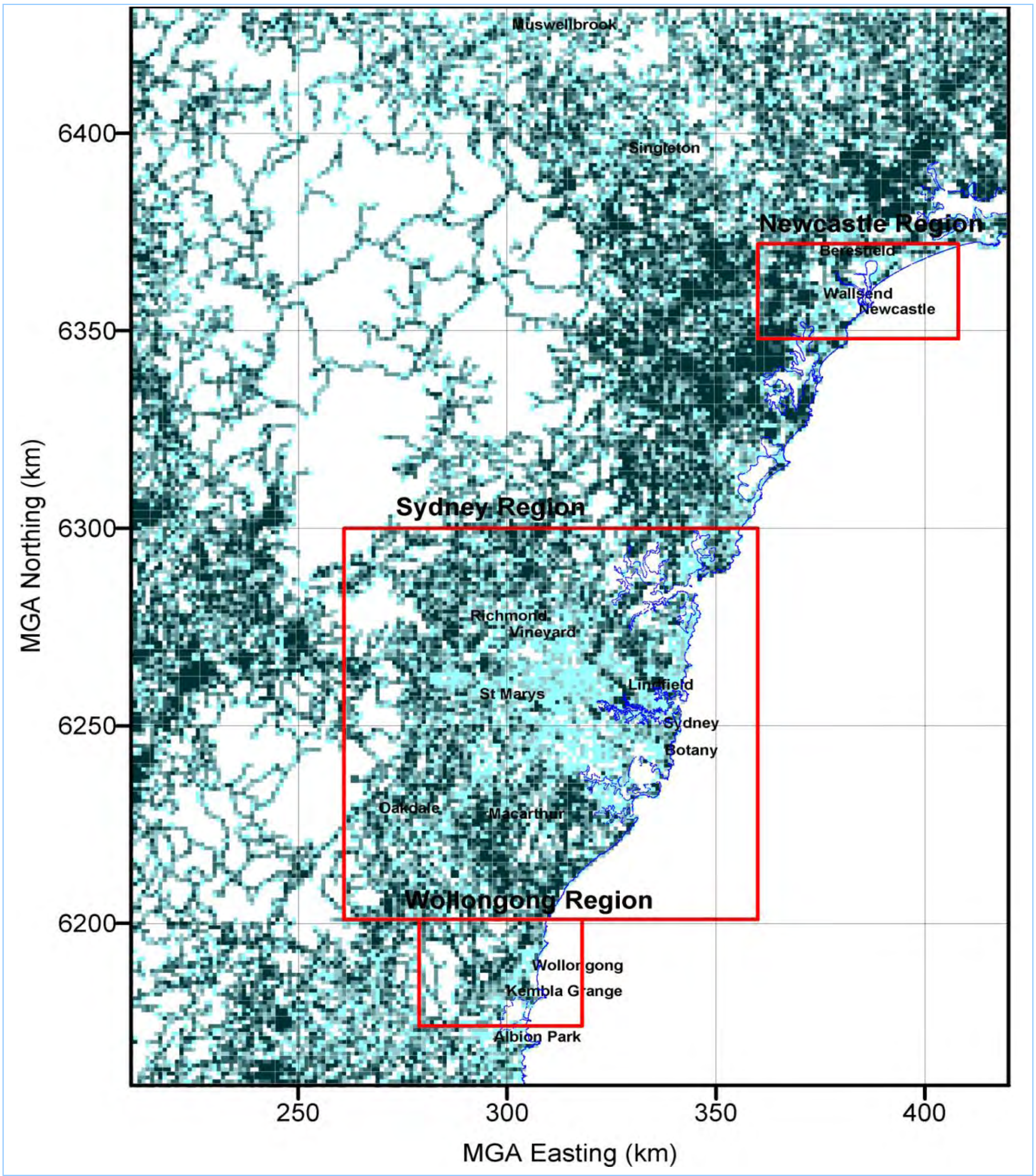

Figure 3-37: Unpaved roads spatial distribution of emissions

3.3.6 *Temporal Variation of Emissions*

Table 3-47 summarises the data used to estimate the temporal variation in fugitive windborne particulate matter emissions from agricultural lands and unpaved roads.

Table 3-47: Agricultural lands and unpaved roads temporal data

Emission source	Temporal data	Temporal data source
Fugitive windborne particulate matter from agricultural lands	Monthly, daily and hourly: Gridded 1 km x 1 km climatic factor combined with vegetative cover factor estimates	- *The Air Pollution Model (TAPM) Version 3* (Hurley, 2005) - *Australia State Crop Calendars* (USDA, 2003)
Fugitive windborne particulate matter from unpaved roads	Monthly, daily and hourly: Gridded 1 km x 1 km climatic factor estimates	- *The Air Pollution Model (TAPM) Version 3* (Hurley, 2005)

Hourly average meteorological data including temperature, precipitation and wind speed have been generated for the GMR at 2 km by 2 km grid cells with *TAPM* (Hurley, 2005) and used to estimate Thornthwaite's precipitation-evaporation index (Thornthwaite, 1931) and the climatic factor (CARB, 1997a; and CARB, 1997b) at 1 km by 1 km grid cells. The climatic factor has been combined with vegetative cover estimates (USDA, 2003) to determine the temporal variation in emissions from agricultural lands, while the climatic factor alone has been used to determine the temporal variation in emissions from unpaved roads.

Annual emissions from agricultural lands and unpaved roads have been estimated using the annual climatic factor within Equation 4 (CARB, 1997a). To calculate the annual climatic factor, the monthly Thornthwaite's precipitation-evaporation index values have been summed for all of the months in the year using Equation 5 (CARB, 1997a).

Monthly emissions from agricultural lands and unpaved roads have been estimated using the month-as-a-year climatic factor within Equation 4 (CARB, 1997a). To calculate the month-as-a-year climatic factor, each month's Thornthwaite's precipitation-evaporation index has been multiplied by 12. Each month's Thornthwaite's precipitation-evaporation index x 12 has been input into Equation 5 (CARB, 1997a) along with the mean monthly wind speed for that same month. The result is a climatic factor which would apply if the climate for that month were instead the year round climate. By then summing all of the monthly climatic factors for the year and then dividing each individual month by the sum, the month-as-a-year climatic factor has been normalised to 1. These normalised monthly numbers provide the climate based temporal profile. They have been multiplied by the annual emissions to produce monthly emissions (CARB, 1997a).

Hourly emissions from agricultural lands and unpaved roads have been estimated using the hour-as-a-year climatic factor within Equation 4 (CARB, 1997a). To calculate the hour-as-a-year climatic factor, each month's Thornthwaite's precipitation-evaporation index has been multiplied by 12 and then by 24. Each hour's Thornthwaite's precipitation-evaporation index x 12 x 24 has been input into Equation 5 (CARB, 1997a) along with the mean hourly wind speed for that same hour. The result is a climatic factor which would apply if the climate for that hour were instead the year round climate. By then summing all of the hourly climatic factors for the year and then dividing each individual hour by the sum, the hour-as-a-year climatic factor has been normalised to 1. These normalised hourly numbers provide the climate based temporal profile. They have been multiplied by the annual emissions to produce hourly emissions (CARB, 1997a).

While the temporal variation in emissions is different for each 1 km by 1 km grid cell where there are fugitive windborne particulate matter emissions from agricultural lands and unpaved roads, Figure 3-38, Figure 3-39, Figure 3-40, Figure 3-41, Figure 3-42 and Figure 3-43 show the hourly, daily and monthly variation in $PM_{2.5}$, PM_{10} and TSP emissions, respectively, in the GMR for all agricultural lands and unpaved roads.

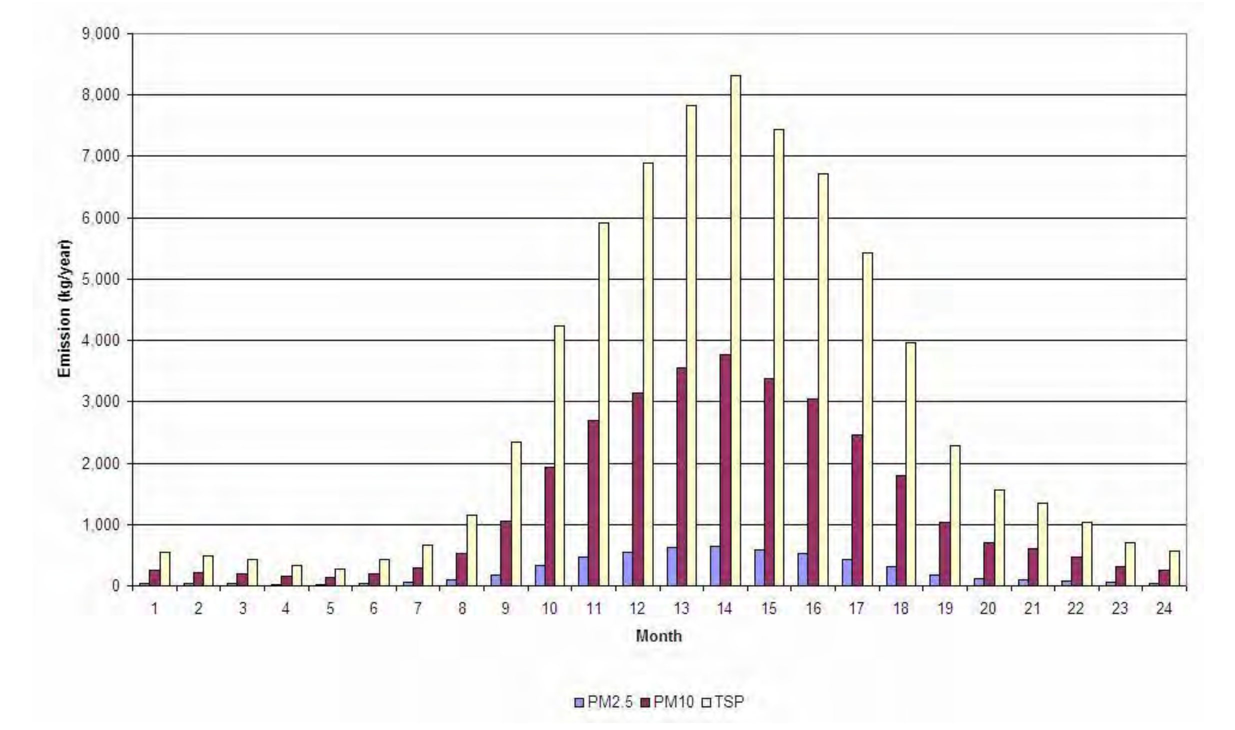

Figure 3-38: Agricultural lands hourly variation in particulate matter emissions

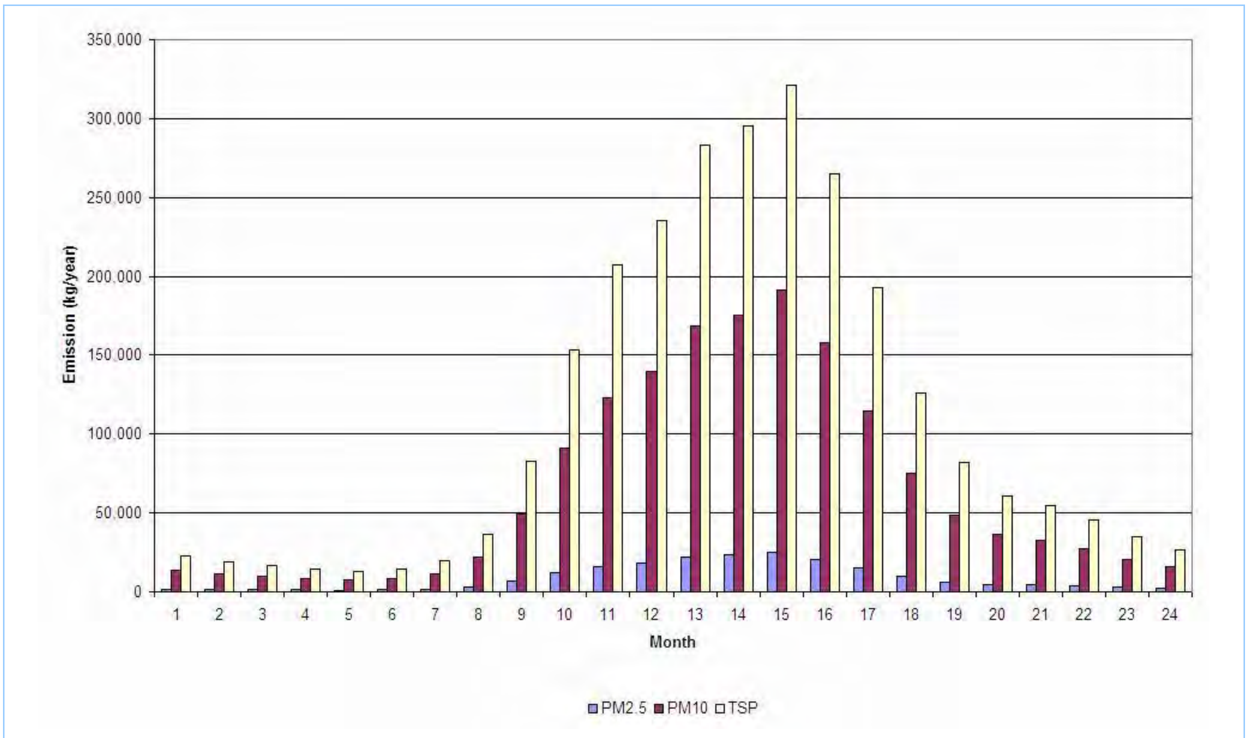

Figure 3-39: Unpaved roads hourly variation in particulate matter emissions

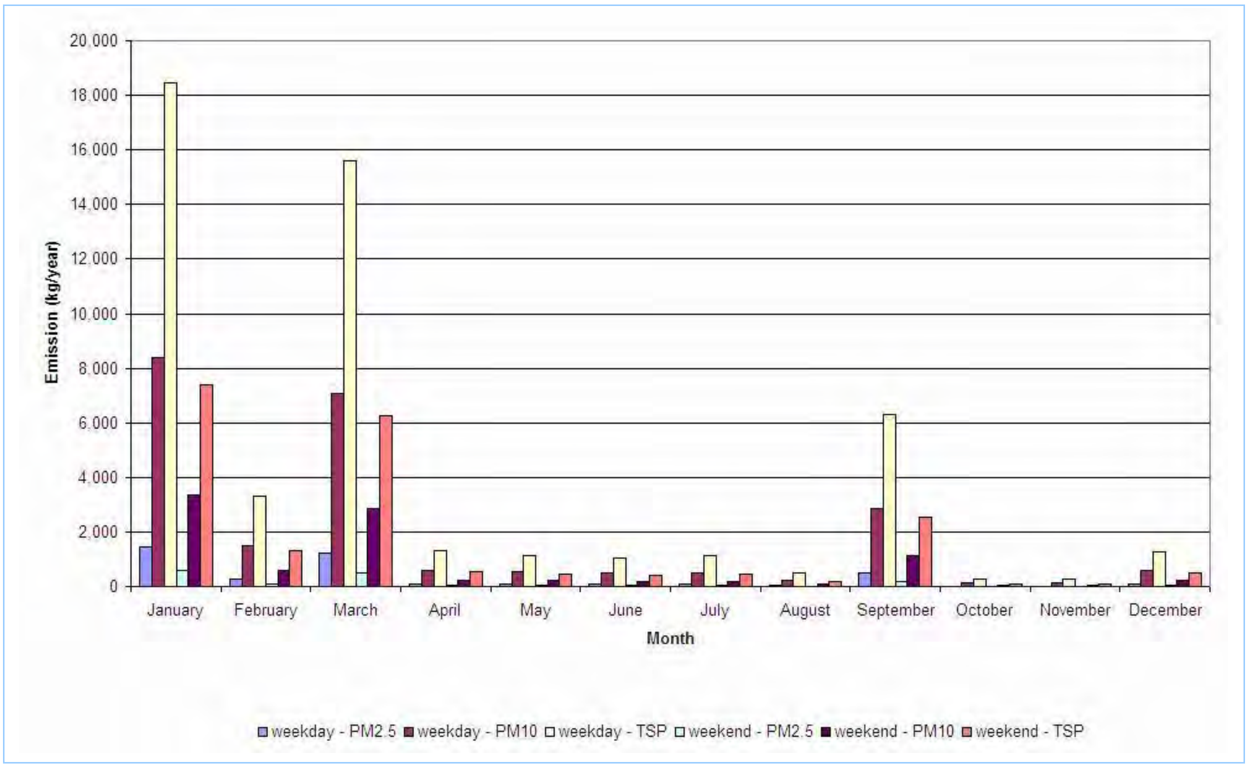

Figure 3-40: Agricultural lands daily variation in particulate matter emissions

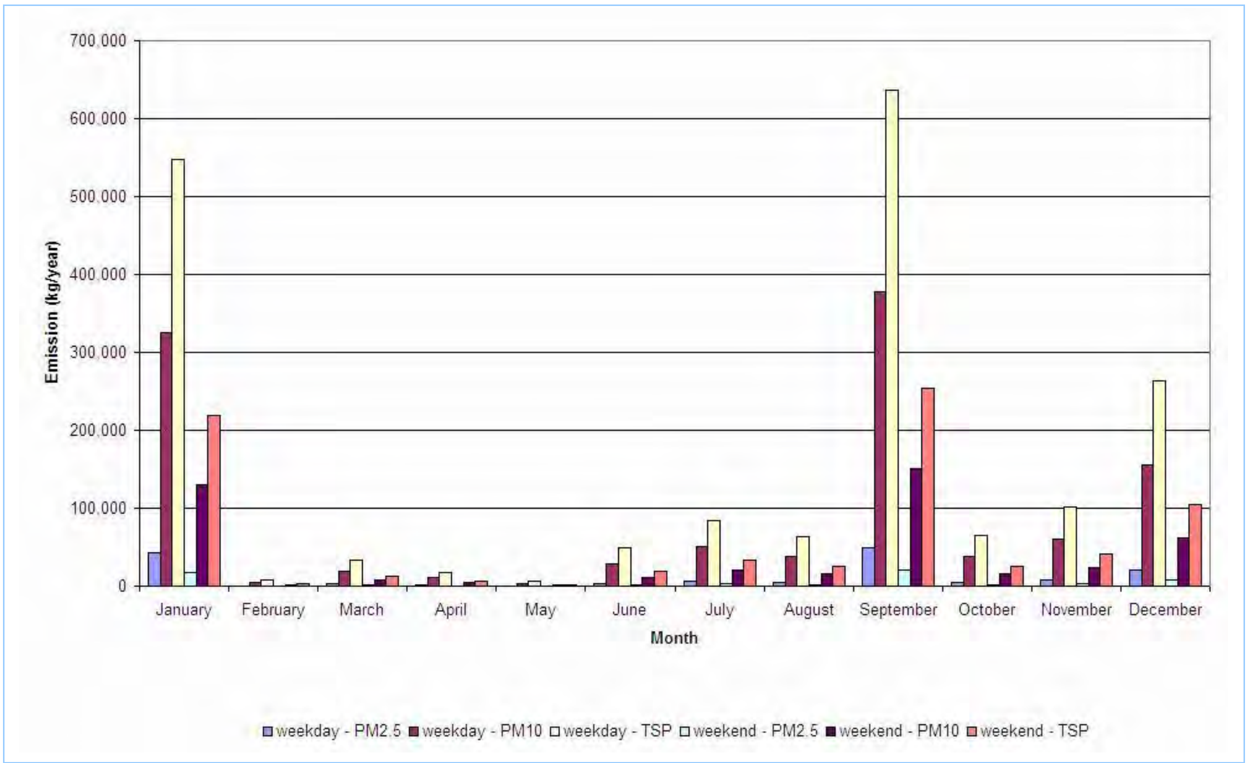

Figure 3-41: Unpaved roads daily variation in particulate matter emissions

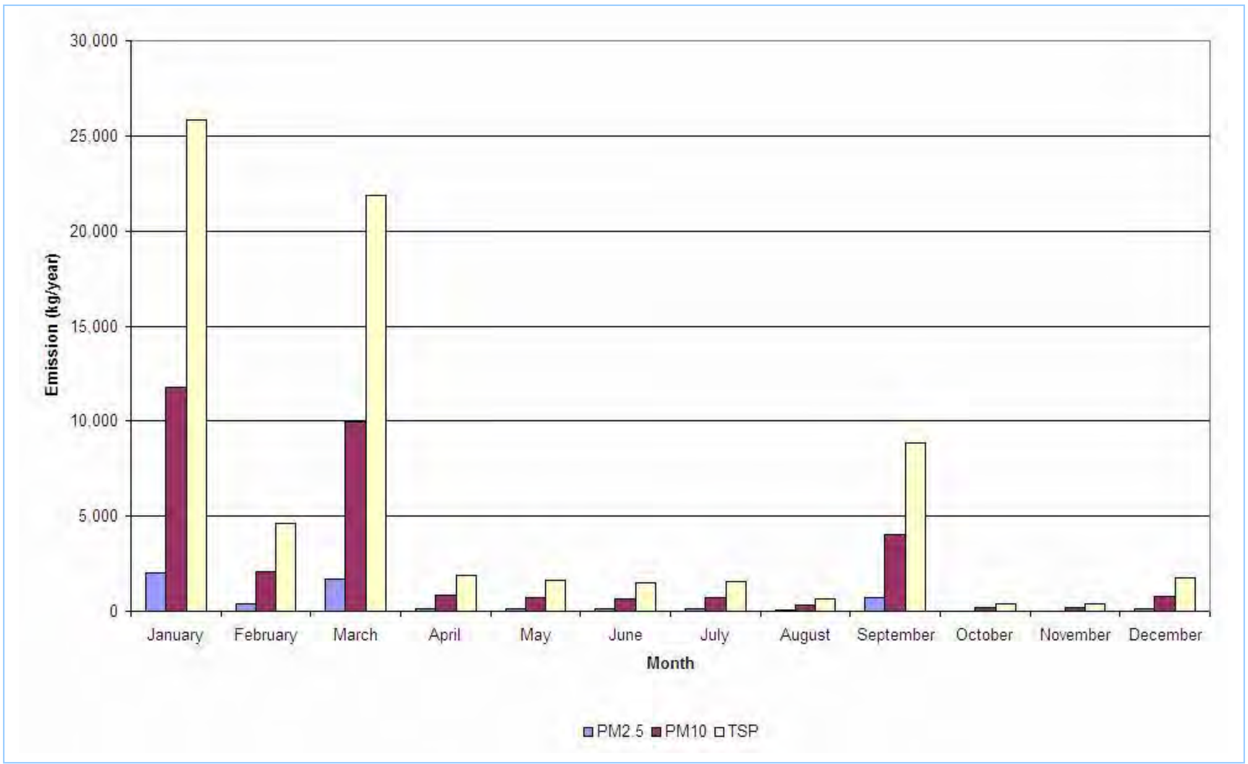

Figure 3-42: Agricultural lands monthly variation in particulate matter emissions

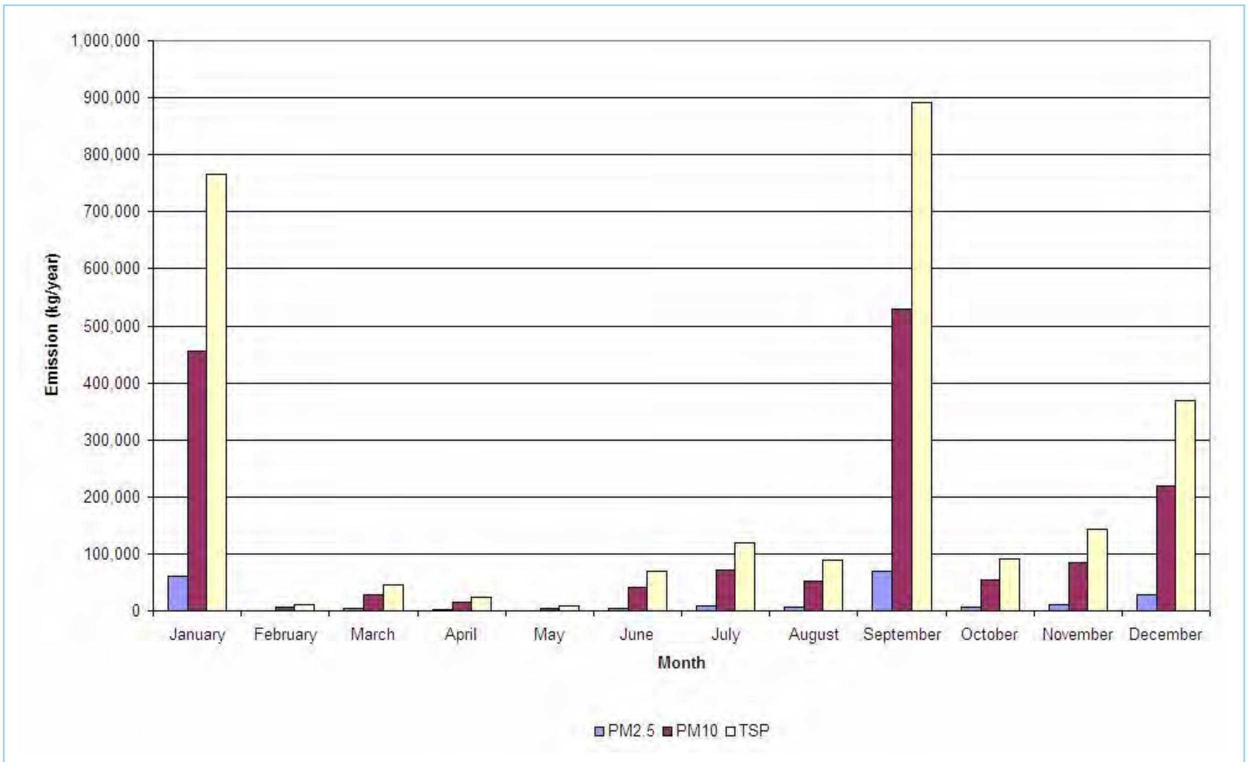

Figure 3-43: Unpaved roads monthly variation in particulate matter emissions

3.3.7 Emission Estimates

Table 3-48 presents annual fugitive windborne emissions of selected substances from agricultural lands and unpaved roads by activity.

Table 3-48: Agricultural lands and unpaved roads emissions by activity

Activity	Substance	Emissions (kg/year)				
		Newcastle	Non Urban	Sydney	Wollongong	GMR
Fugitive Windborne Particulate Matter from Agricultural Lands and Unpaved Roads	LEAD & COMPOUNDS	98	1,878	400	2.83	2,379
	PARTICULATE MATTER ≤ 10 µm	72,502	1,325,123	273,311	1,865	1,672,801
	PARTICULATE MATTER ≤ 2.5 µm	9,937	179,118	36,565	247	225,866
	TOTAL SUSPENDED PARTICULATE	126,425	2,278,852	465,204	3,138	2,873,619

Table 3-49 presents annual fugitive windborne emissions of selected substances from agricultural lands and unpaved roads by source type.

Table 3-49: Agricultural lands and unpaved roads emissions by source type

Source type	Substance	Emissions (kg/year)				
		Newcastle	Non Urban	Sydney	Wollongong	GMR
Summer Crop	LEAD & COMPOUNDS	3.38×10^{-2}	0.37	4.03×10^{-2}	-	0.45
	PARTICULATE MATTER ≤ 10 µm	248	2,728	296	-	3,272
	PARTICULATE MATTER ≤ 2.5 µm	43	472	51	-	566
	TOTAL SUSPENDED PARTICULATE	545	6,005	651	-	7,201
Winter Crop	LEAD & COMPOUNDS	1.13	13	1.36	-	15
	PARTICULATE MATTER ≤ 10 µm	8,295	92,022	9,959	-	110,275
	PARTICULATE MATTER ≤ 2.5 µm	1,435	15,921	1,723	-	19,079
	TOTAL SUSPENDED PARTICULATE	18,258	202,557	21,922	-	242,737
Unpaved Roads	LEAD & COMPOUNDS	97	1,865	399	2.83	2,364
	PARTICULATE MATTER ≤ 10 µm	63,960	1,230,373	263,056	1,865	1,559,254
	PARTICULATE MATTER ≤ 2.5 µm	8,459	162,725	34,791	247	206,221
	TOTAL SUSPENDED PARTICULATE	107,622	2,070,290	442,631	3,138	2,623,681

3.4 Soil Nitrification and Denitrification

3.4.1 Emission Source Description

The biogenic and geogenic air emissions inventory includes emissions of nitrogen compounds (i.e. ammonia (NH_3), nitric oxide (NO) and nitrous oxide (N_2O)) from agricultural lands and natural landscapes.

To estimate emissions from these sources, the following have been considered:

- *The nitrogen cycle*

The nitrogen cycle refers to the circulation of nitrogen compounds through the earth's atmosphere, hydrosphere, biosphere and pedosphere. Nitrogen is added to soils mainly as chemical fertiliser and manure and through biological nitrogen fixation. Other sources of nitrogen may include man-made emissions from the combustion of fossil fuels and natural emissions from lightning (IFA, 2004).

Within the nitrogen cycle, nitrogen moves from the soil to the plant, and back from the plant to the soil, often with animals or humans as intermediaries. During each stage of the nitrogen cycle, nitrogen compounds undergo a number of transformations in the soil (e.g. mineralisation, immobilisation, fixation, nitrification and denitrification). These compounds are exchanged between the soil and the atmosphere (e.g. volatilisation, denitrification, biological nitrogen fixation and atmospheric deposition) and between the soil and the hydrosphere (e.g. leaching, erosion/runoff, drainage and irrigation). These fluxes and transformations constitute the nitrogen cycle (IFA, 2004).

In agricultural lands, the nitrogen cycle is significantly altered since substantial amounts of nitrogen are fixed in harvested products. As a result, nitrogen fertilisers are essential to balance nitrogen inputs and outputs, maintain or improve soil fertility and increase crop yield (IFA, 2004).

In natural ecosystems, the nitrogen cycle is a largely closed system, with balanced nitrogen inputs and outputs. However, the relatively small amount of nitrogen in most natural ecosystems limits biomass production (IFA, 2004).

Figure 3-44 shows the nitrogen cycle (IFA, 2004).

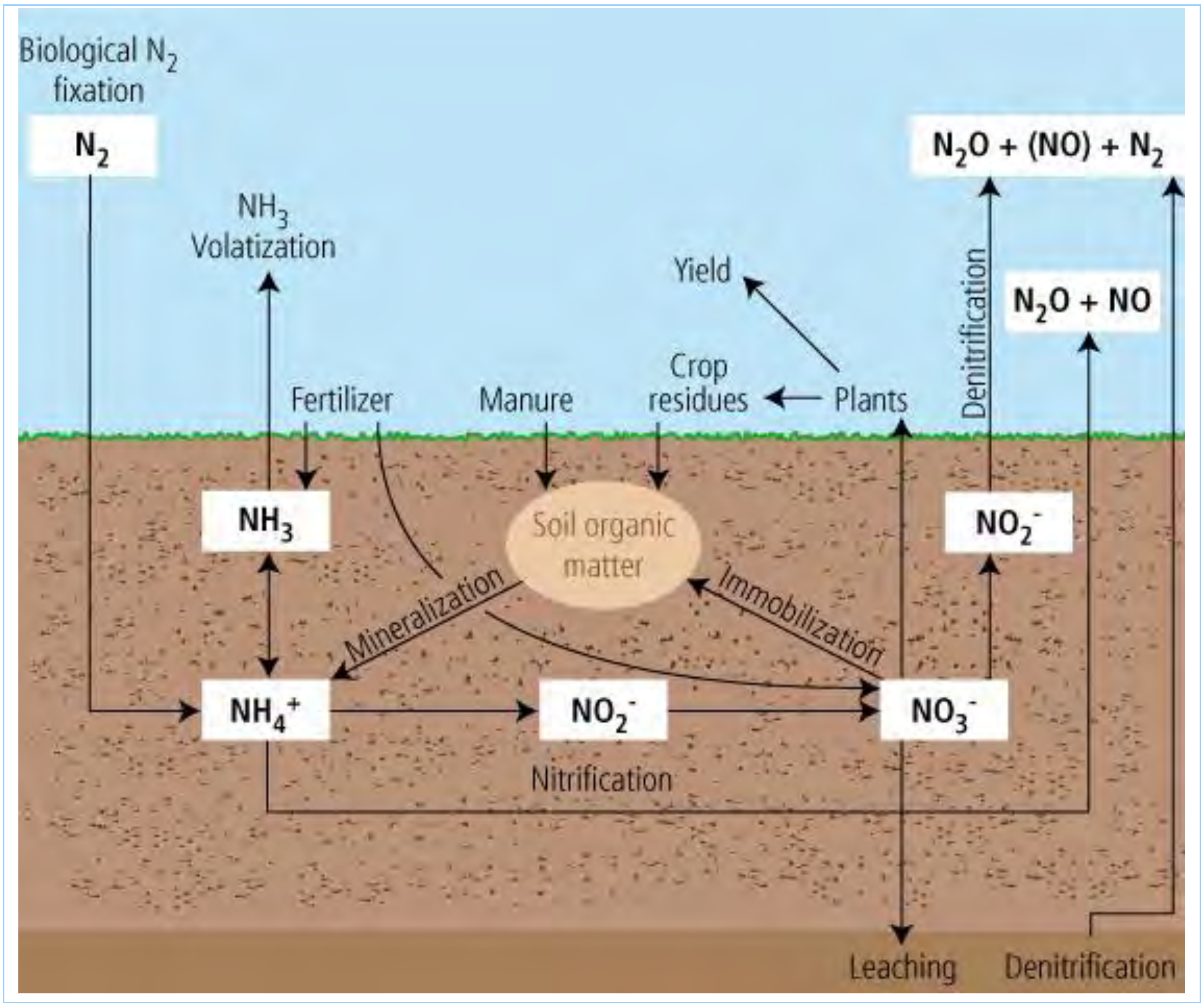

Figure 3-44: The nitrogen cycle

➢ *Land use of Australia*

Land use GIS data has been used to derive emission factors for nitrogen compounds (i.e. ammonia (NH_3), nitric oxide (NO) and nitrous oxide (N_2O)) from agricultural lands and natural landscapes (BRS, 2006). Table 3-50 presents the landuse types, while Figure 3-45 shows the landuse categories in the GMR.

Table 3-50: Landuse types in the GMR

Landuse category	Landuse type
Agricultural	Cropping
	Irrigated cropping
	Irrigated perennial horticulture
	Irrigated seasonal horticulture
	Perennial horticulture
	Seasonal horticulture
Forest	Managed resource protection
	Nature conservation

Landuse category	Landuse type
	Other minimal use
	Plantation forestry
	Production forestry
Grassland	Grazing modified pastures
	Irrigated modified pastures
	Livestock grazing
Urban	Intensive use
	Residential
	Transport and communication
Water	Estuary/coastal waters
	Lake
	Reservoir
	River
Wetland	Marsh/wetland

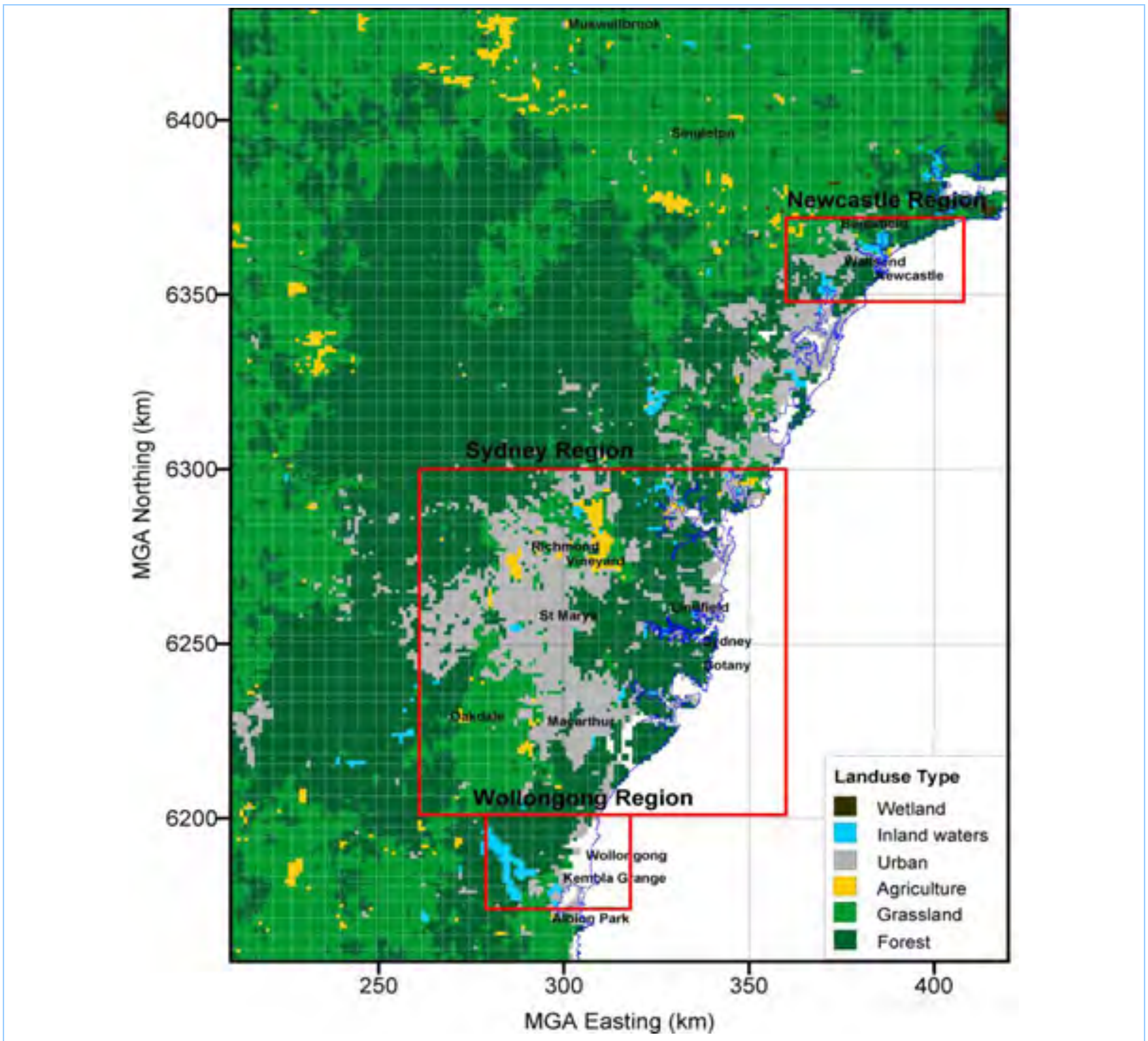

Figure 3-45: Landuse categories in the GMR

- *Nitrogen fertiliser consumption*

The quantities of nitrogen fertilisers consumed in Australia have been obtained for the 2008 calendar year (IFA, 2011). Mean annual nitrogen fertilisation GIS data (BRS, 2001; and NLWRA, 2001) have been used to estimate the proportion of nitrogen fertilisers consumed in the GMR. The inventory considers nitrogen fertiliser types as follows (Battye et. al., 2004; and IFA, 2011):

  - *Ammonium nitrate;*
  - *Ammonium sulfate;*
  - *Anhydrous ammonia;*
  - *Calcium ammonium nitrate;*
  - *Mix;*
  - *Monoammonium phosphate;*
  - *Nitrogen solutions (urea & ammonium nitrate);*
  - *Potassium nitrate; and*
  - *Urea.*

- *Meteorological data*

Hourly average meteorological data including temperature have been generated for the GMR at 2 km by 2 km grid cells with *TAPM* (Hurley, 2005) and used to estimate: soil temperature as a function of ambient temperature and landuse type; and the nitrogen compounds (i.e. ammonia (NH_3), nitric oxide (NO) and nitrous oxide (N_2O)) flux rate variation with temperature (USEPA, 1995b; and Radian, 1996) at 1 km by 1 km grid cells.

3.4.2 Emission Estimation Methodology

Table 3-51 summarises the emission estimation methodologies used for emissions of nitrogen compounds from agricultural lands and natural landscapes.

Table 3-51: Soil nitrification and denitrification emission estimation methodologies

Emission source	Emission estimation methodology source
Emissions of nitrogen compounds from agricultural lands and natural landscapes	- *Biogenic Sources Preferred Methods, Technical Report Series Volume 5, Emission Inventory Improvement Program* (Radian, 1996) - *Review of Ammonia Emission Modeling Techniques for Natural Landscapes and Fertilized Soils* (Battye et. al., 2004) - *AP 42, Fifth Edition, Volume I, Chapter 14: Greenhouse Gas Biogenic Sources, 14.1 Emission from Soils - Greenhouse Gases* (USEPA, 2003b)

Emissions of nitric oxide (NO) from agricultural lands and natural landscapes have been estimated using the *PCBEIS Version 2* methodology (USEPA, 1995b) combined with the area of each landuse category (BRS, 2006) and hourly average temperature data (Hurley, 2005) in Equation 10 (Radian, 1996):

$$E_{NO,i} = \sum_{j=1}^{8760} \left(A_i \times EF_{NO,i} \times CF_i \times 10^{-9} \right) \qquad \textbf{Equation 10}$$

where:			
$E_{NO,i}$	=	Emissions of NO from landuse category i	(kg/year)
A_i	=	Area of landuse category i	(m^2)
$EF_{NO,i}$	=	Emission factor for NO and landuse category i	(µg/m^2/h)
CF_i	=	Soil temperature correction factor for landuse category i (Equation 11)	(-)
i	=	Landuse category (either "agricultural", "forest", "grassland", "urban", "water" or "wetland")	(-)
j	=	Time interval	(h/year)
10^{-9}	=	Conversion factor	(kg/µg)

The soil temperature correction factor for each landuse category has been estimated using soil temperature within Equation 11 (Radian, 1996):

$$CF_i = \exp\left(0.071 \times T_{s,i}\right) \qquad \textbf{Equation 11}$$

where:			
CF_i	=	Soil temperature correction factor for landuse category i	(-)
$T_{s,i}$	=	Soil temperature for landuse category i (Equation 12)	(°C)
i	=	Landuse category (either "agricultural", "forest", "grassland", "urban", "water" or "wetland")	(-)

The soil temperature for each landuse category has been estimated using ambient temperature (Hurley, 2005) within Equation 12 (USEPA, 1995b):

$$T_{s,i} = K_{1,i} \times T_a + K_{2,i} \qquad \textbf{Equation 12}$$

where:			
$T_{s,i}$	=	Soil temperature for landuse category i	(°C)
$K_{1,i}$	=	Constant 1 for landuse category i (Table 3-51) (USEPA, 1995b)	(-)
T_a	=	Ambient temperature	(°C)
$K_{2,i}$	=	Constant 2 for landuse category i (Table 3-51) (USEPA, 1995b)	(°C)
i	=	Landuse category (either "agricultural", "forest", "grassland", "urban", "water" or "wetland")	(-)

Table 3-52 presents soil temperature correction factor constants by landuse category.

Table 3-52: Soil temperature correction factor constants by landuse category

Landuse category	$K_{1,i}$	$K_{2,i}$
Agricultural	1.03	2.9
Forest	0.84	3.6
Grassland	0.66	8.8
Urban	0.66	8.8
Water	-	-
Wetland	0.92	4.4

Table 3-53 presents nitric oxide emission factors for agricultural lands and natural landscapes by landuse type, which have been derived for the GMR.

Table 3-53: Nitric oxide emission factors for agricultural lands and natural landscapes by landuse type

<table>
<tr><th>Landuse category</th><th>Landuse type</th><th>Emission factor[11] (µg NO/m²/h)</th></tr>
<tr><td rowspan="6">Agricultural</td><td>Cropping</td><td rowspan="2">203.1</td></tr>
<tr><td>Irrigated cropping</td></tr>
<tr><td>Irrigated perennial horticulture</td><td rowspan="4">35.0</td></tr>
<tr><td>Irrigated seasonal horticulture</td></tr>
<tr><td>Perennial horticulture</td></tr>
<tr><td>Seasonal horticulture</td></tr>
<tr><td rowspan="5">Forest</td><td>Managed resource protection</td><td rowspan="5">4.5</td></tr>
<tr><td>Nature conservation</td></tr>
<tr><td>Other minimal use</td></tr>
<tr><td>Plantation forestry</td></tr>
<tr><td>Production forestry</td></tr>
<tr><td rowspan="3">Grassland</td><td>Grazing modified pastures</td><td rowspan="3">58.0</td></tr>
<tr><td>Irrigated modified pastures</td></tr>
<tr><td>Livestock grazing</td></tr>
<tr><td rowspan="3">Urban</td><td>Intensive use</td><td rowspan="3">19.8</td></tr>
<tr><td>Residential</td></tr>
<tr><td>Transport and communication</td></tr>
<tr><td rowspan="4">Water</td><td>Estuary/coastal waters</td><td rowspan="4">-</td></tr>
<tr><td>Lake</td></tr>
<tr><td>Reservoir</td></tr>
<tr><td>River</td></tr>
<tr><td>Wetland</td><td>Marsh/wetland</td><td>0.2</td></tr>
</table>

Emissions of ammonia (NH_3) from agricultural lands have been estimated using nitrogen fertiliser consumption based emission factors combined with activity rates. Activity rates include the quantity

[11] NO emission factors have been standardized to 30 °C and bright sunlight (USEPA, 1995b; and Radian, 1996).

of nitrogen fertiliser applied (BRS, 2001; NLWRA, 2001; and IFA, 2011) and the fraction applied to each landuse type (DCC, 2009). Emissions have been determined using Equation 13 (Battye et. al., 2004):

$$E_{NH_3,i} = NFC_j \times EF_{NH_3,j} \times F_i$$ **Equation 13**

where:			
$E_{NH3,i}$	=	Emissions of NH_3 from landuse type i	(kg/year)
NFC_j	=	Consumption of nitrogen fertiliser type j	(tonne N/year)
$EF_{NH3,j}$	=	Emission factor for NH_3 and nitrogen fertiliser type j (Table 3-54) (Executive Summary, Table S3; Battye et. al., 2004)	(kg/tonne N)
F_i	=	Fraction of nitrogen fertiliser applied to landuse type i (Table 3-55) (Appendix 6.H: Synthetic Fertilisers, Table 6.H2; DCC, 2009)	(tonne N/tonne N)
i	=	Landuse type (either "cropping", "irrigated cropping", "irrigated perennial horticulture", "irrigated seasonal horticulture", "perennial horticulture", "seasonal horticulture", "grazing modified pastures" or "irrigated modified pastures")	(-)
j	=	Fertiliser type (either "ammonium nitrate", "ammonium sulfate", "anhydrous ammonia", "calcium ammonium nitrate", "mix", "monoammonium phosphate", " nitrogen solutions (urea & ammonium nitrate", "potassium nitrate" or "urea")	(-)

Table 3-54 presents ammonia emission factors by nitrogen fertiliser type and soil type (Battye et. al., 2004). Ammonia emission factors for Group II soil type have been used for the GMR (BRS, 1991).

Table 3-54: Ammonia emission factors by nitrogen fertiliser type and soil type

Nitrogen fertiliser type	Emission factor (kg NH_3/tonne N)		
	Group I soil	Group II soil	Group III soil
Ammonium nitrate	36	24	12
Ammonium sulphate	182	121	61
Anhydrous ammonia	48	48	48
Calcium ammonium nitrate	36	24	12
Mix	36	24	12
Monoammonium phosphate	61	61	61
Nitrogen solutions (urea & ammonium nitrate)	97	97	97
Potassium nitrate	12	12	12
Urea	242	182	182

Group I soil: Warm temperate areas with a large proportion of calcareous soils
Group II soil: Temperate and warm-temperate areas with some calcareous soils (or managed with soil pH>7) but with large areas of acidic soils
Group III soil: Temperate and cool-temperate areas with largely acidic soils

Table 3-55 presents the fraction of nitrogen fertiliser applied to each landuse type (DCC, 2009).

Table 3-55: Fraction of nitrogen fertiliser applied to each landuse type

Landuse category	Landuse type	Fraction (tonne N/tonne N)
Agricultural	Cropping	0.20903
	Irrigated cropping	0.24272
	Irrigated perennial horticulture	0.13222
	Irrigated seasonal horticulture	
	Perennial horticulture	
	Seasonal horticulture	
Grassland	Grazing modified pastures	0.32034
	Irrigated modified pastures	0.09569
Grand Total		1.00000

Table 3-57 presents ammonia emission factors for agricultural lands by landuse type, which have been derived for the GMR.

Table 3-56: Ammonia emission factors for agricultural lands by landuse type

Landuse category	Landuse type	Emission factor (ng $NH_3/m^2/s$)
Agricultural	Cropping	22.1
	Irrigated cropping	256.2
	Irrigated perennial horticulture	10.3
	Irrigated seasonal horticulture	
	Perennial horticulture	
	Seasonal horticulture	
Grassland	Grazing modified pastures	5.1
	Irrigated modified pastures	6.6

Emissions of ammonia (NH_3) from natural landscapes have been estimated using area based emission factors combined with the area of each landuse type (BRS, 2006). Emissions have been determined using Equation 14 (Battye et. al., 2004):

$$E_{NH_3,i} = EF_{NH_3,i} \times A_i \times 3.1536 \times 10^7 \times 10^{-12} \qquad \textbf{Equation 14}$$

where:			
$E_{NH3,i}$	=	Emissions of NH_3 from landuse type i	(kg/year)
$EF_{NH3,j}$	=	Emission factor for NH_3 and landuse type i (Table 3-57) (Executive Summary, Table S1; Battye et. al., 2004)	($ng/m^2/s$)
A_i	=	Area of landuse type i	(m^2)
i	=	Landuse type (either "managed resource protection", "nature conservation", "other minimal use", "plantation forestry", "production forestry", "livestock grazing", "intensive use", "residential", "transport and communication", "estuary/coastal waters", "lake", "reservoir", "river" or "marsh/wetland")	(-)
3.1536 x 10^7	=	Time interval	(s/year)

where:			
10^{-12}	=	Conversion factor	(kg/ng)

Table 3-57 presents ammonia emission factors for natural landscapes by landuse type, which have been derived for the GMR.

Table 3-57: Ammonia emission factors for natural landscapes by landuse type

Landuse category	Landuse type	Emission factor (ng NH_3/m²/s)
Forest	Managed resource protection	1.2
	Nature conservation	
	Other minimal use	
	Plantation forestry	
	Production forestry	
Grassland	Livestock grazing	0.9
Urban	Intensive use	0.31[12]
	Residential	
	Transport and communication	
Water	Estuary/coastal waters	-
	Lake	
	Reservoir	
	River	
Wetland	Marsh/wetland	-

Emissions of nitrous oxide (N_2O) from agricultural lands have been estimated using nitrogen fertiliser consumption based emission factors combined with activity rates. Activity rates include the quantity of nitrogen fertiliser applied (BRS, 2001; NLWRA, 2001; and IFA, 2011) and the fraction applied to each landuse type (DCC, 2009). Emissions have been determined using Equation 15 (USEPA, 1996):

$$E_{N_2O,i} = NFC_j \times EF_{N_2O,j} \times F_i \qquad \textbf{Equation 15}$$

where:			
$E_{N2O,i}$	=	Emissions of N_2O from landuse type i	(kg/year)
NFC_j	=	Consumption of nitrogen fertiliser type j	(tonne N/year)
$EF_{N2O,j}$	=	Emission factor for N_2O and nitrogen fertiliser type j (Table 3-58) (Section 14.1.2; USEPA, 1996)	(kg/tonne N)
F_i	=	Fraction of nitrogen fertiliser applied to landuse type i (Table 3-59) (Appendix 6.H: Synthetic Fertilisers, Table 6.H2; DCC, 2009)	(tonne N/tonne N)

[12] The GMR urban landuse category includes 1,014.9 km² domestic lawn area (TR, 2009) and 201.9 km² public open space lawn area (DECC, 2007). The total urban landuse category area is 3,569.3 km² (BRS, 2006) so the urban landuse category NH_3 emission factor is 1,216.9 x 0.9/3,569.3 = 0.31 ng/m²/s, where 0.9 ng/m²/s applies to grassland (Battye et. al., 2004).

where:			
i	=	Landuse type (either "cropping", "irrigated cropping", "irrigated perennial horticulture", "irrigated seasonal horticulture", "perennial horticulture", "seasonal horticulture", "grazing modified pastures" or "irrigated modified pastures")	(-)
j	=	Fertiliser type (either "ammonium nitrate", "ammonium sulfate", "anhydrous ammonia", "calcium ammonium nitrate", "mix", "monoammonium phosphate", " nitrogen solutions (urea & ammonium nitrate", "potassium nitrate" or "urea")	(-)

Table 3-58 presents the nitrous oxide emission factors for nitrogen fertilisers (USEPA, 1996).

Table 3-58: Nitrous oxide emission factor for nitrogen fertilisers

Nitrogen fertiliser type	Emission factor (kg N_2O/tonne N)
All	0.0184

Table 3-59 presents the fraction of nitrogen fertiliser applied to each landuse type (DCC, 2009).

Table 3-59: Fraction of nitrogen fertiliser applied to each landuse type

Landuse category	Landuse type	Fraction (tonne N/tonne N)
Agricultural	Cropping	0.20903
	Irrigated cropping	0.24272
	Irrigated perennial horticulture	0.13222
	Irrigated seasonal horticulture	
	Perennial horticulture	
	Seasonal horticulture	
Grassland	Grazing modified pastures	0.32034
	Irrigated modified pastures	0.09569
Grand Total		1.00000

Table 3-60 presents nitrous oxide emission factors for agricultural lands by landuse type, which have been derived for the GMR.

Table 3-60: Nitrous oxide emission factors for agricultural lands by landuse type

Landuse category	Landuse type	Emission factor (kg N_2O/ha/year)
Agricultural	Cropping	0.986
	Irrigated cropping	11.461
	Irrigated perennial horticulture	0.459
	Irrigated seasonal horticulture	
	Perennial horticulture	
	Seasonal horticulture	
Grassland	Grazing modified pastures	0.229
	Irrigated modified pastures	0.294

Emissions of nitrous oxide (N_2O) from natural landscapes have been estimated using area based emission factors combined with the area of each landuse type (BRS, 2006). Emissions have been determined using Equation 16 (USEPA, 1996):

$$E_{N_2O,i} = EF_{N_2O,i} \times A_i$$ **Equation 16**

where:			
$E_{N2O,i}$	=	Emissions of N_2O from landuse type i	(kg/year)
$EF_{N2O,j}$	=	Emission factor for N_2O and landuse type i (Table 3-61) (Table 14.1.2; USEPA, 1996)	(kg/ha/year)
A_i	=	Area of landuse type i	(ha)
i	=	Landuse type (either "managed resource protection", "nature conservation", "other minimal use", "plantation forestry", "production forestry", "livestock grazing", "intensive use", "residential", "transport and communication", "estuary/coastal waters", "lake", "reservoir", "river" or "marsh/wetland")	(-)

Table 3-61 presents nitrous oxide emission factors for natural landscapes by landuse type, which have been derived for the GMR.

Table 3-61: Nitrous oxide emission factors for natural landscapes by landuse type

Landuse category	Landuse type	Emission factor (kg N_2O/ha/year)
Forest	Managed resource protection	0.631
	Nature conservation	
	Other minimal use	
	Plantation forestry	
	Production forestry	
Grassland	Livestock grazing	1.685
Urban	Intensive use	0.574[13]
	Residential	
	Transport and communication	
Water	Estuary/coastal waters	-
	Lake	
	Reservoir	
	River	
Wetland	Marsh/wetland	-

[13] The GMR urban landuse category includes 1,014.9 km^2 domestic lawn area (TR, 2009) and 201.9 km^2 public open space lawn area (DECC, 2007). The total urban landuse category area is 3,569.3 km^2 (BRS, 2006) so the urban landuse category N_2O emission factor is 1,216.9 x 1.685/3,569.3 = 0.574 kg/ha/year, where 1.685 kg/ha/year applies to grassland (USEPA, 1996).

3.4.3 Activity Data

Table 3-62 summarises the activity data used for emissions of nitrogen compounds from agricultural lands and natural landscapes.

Table 3-62: Soil nitrification and denitrification activity data

Activity data	Activity data source
Land use area (ha)	- *Land Use of Australia, Version 3 - 1996/1997* (BRS , 2006)
Nitrogen fertiliser consumption (tonne/year)	- *Mean Annual Nitrogen Fertilisation (kgN ha-1 y-1)* (BRS, 2001; and NLWRA, 2001) - *Consumption of Nitrogen Fertilizers in Australia in 2008* (IFA ,2011)
Hourly meteorological data (temperature (K)) required to calculate the temperature correction factor	- *The Air Pollution Model (TAPM) Version 3* (Hurley, 2005)

Land use GIS data has been used to derive emission factors for nitrogen compounds (i.e. ammonia (NH_3), nitric oxide (NO) and nitrous oxide (N_2O)) from agricultural lands and natural landscapes (BRS, 2006). The area of agricultural lands and natural landscapes in the GMR by landuse type are presented in Table 3-63 and shown in Figure 3-46.

Table 3-63: Landuse area in the GMR by landuse type

Landuse category	Landuse type	Area (ha)
Agricultural	Cropping	26,883
	Irrigated cropping	2,687
	Irrigated perennial horticulture	8,717
	Irrigated seasonal horticulture	11,942
	Perennial horticulture	15,500
	Seasonal horticulture	407
Agricultural Total		66,137
Forest	Managed resource protection	579,650
	Nature conservation	705,930
	Other minimal use	403,974
	Plantation forestry	6,404
	Production forestry	136,605
Forest Total		1,832,562
Grassland	Grazing modified pastures	177,466
	Irrigated modified pastures	41,272
	Livestock grazing	1,487,796
Grassland Total		1,706,535
Urban	Intensive use	269,053
	Residential	74,436
	Transport and communication	13,440
Urban Total		356,930
Water	Estuary/coastal waters	3,993

Landuse category	Landuse type	Area (ha)
	Lake	6,845
	Reservoir	14,927
	River	8,102
Water Total		33,868
Wetland	Marsh/wetland	3,875
Wetland Total		3,875
Grand Total		3,999,906

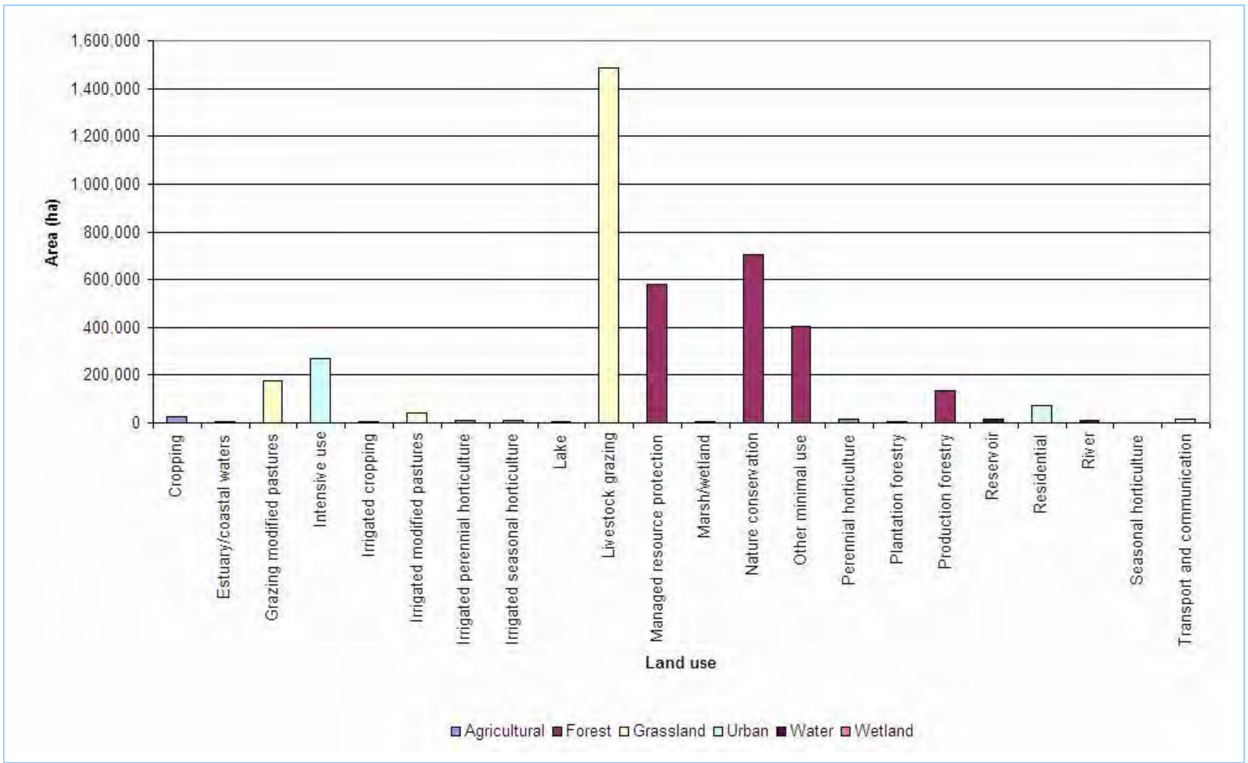

Figure 3-46: Landuse area in the GMR by landuse type

The quantities of nitrogen fertilisers consumed in Australia have been obtained for the 2008 calendar year (IFA, 2011). Mean annual nitrogen fertilisation GIS data (BRS, 2001; and NLWRA, 2001) have been used to estimate the proportion of nitrogen fertilisers consumed in the GMR. The consumption of nitrogen fertilisers in the GMR is approximately 0.8% of the total consumption in Australia. Table 3-64 presents nitrogen fertiliser consumption in Australia and the GMR by fertiliser type.

Table 3-64: Nitrogen fertiliser consumption in Australia and the GMR by fertiliser type

Fertiliser type	Nitrogen fertiliser consumption in 2008 (tonne N)	
	Australia	GMR
Ammonium sulphate	69,000	570
Anhydrous ammonia	30,000	248
Calcium ammonium nitrate	2,000	17
Mix	48,000	397
Monoammonium phosphate	160,000	1,322

Fertiliser type	Nitrogen fertiliser consumption in 2008 (tonne N)	
	Australia	GMR
Nitrogen solutions (urea & ammonium nitrate)	95,000	785
Potassium nitrate	1,000	8
Urea	430,000	3,553
Grand Total	835,000	6,900

Figure 3-47 shows the spatial distribution of nitrogen fertiliser consumption in agricultural lands (i.e. crops and pastures) across Australia (BRS, 2001; and NLWRA, 2001).

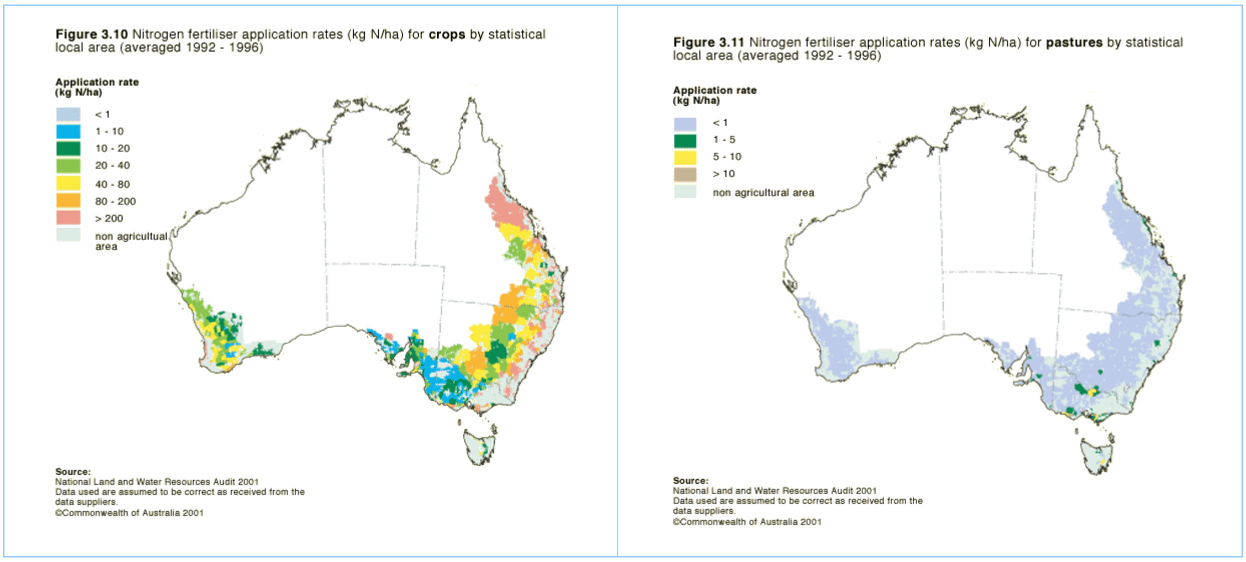

Figure 3-47: Spatial distribution of nitrogen fertiliser consumption in agricultural lands

Hourly average meteorological data including temperature have been generated for the GMR at 2 km by 2 km grid cells with *TAPM* (Hurley, 2005) and used to estimate: soil temperature as a function of ambient temperature and landuse type; and the nitrogen compounds (i.e. ammonia (NH_3), nitric oxide (NO) and nitrous oxide (N_2O)) flux rate variation with temperature (USEPA, 1995b; and Radian, 1996) at 1 km by 1 km grid cells. Figure 3-48 shows the monthly average temperature in the GMR by hour of day.

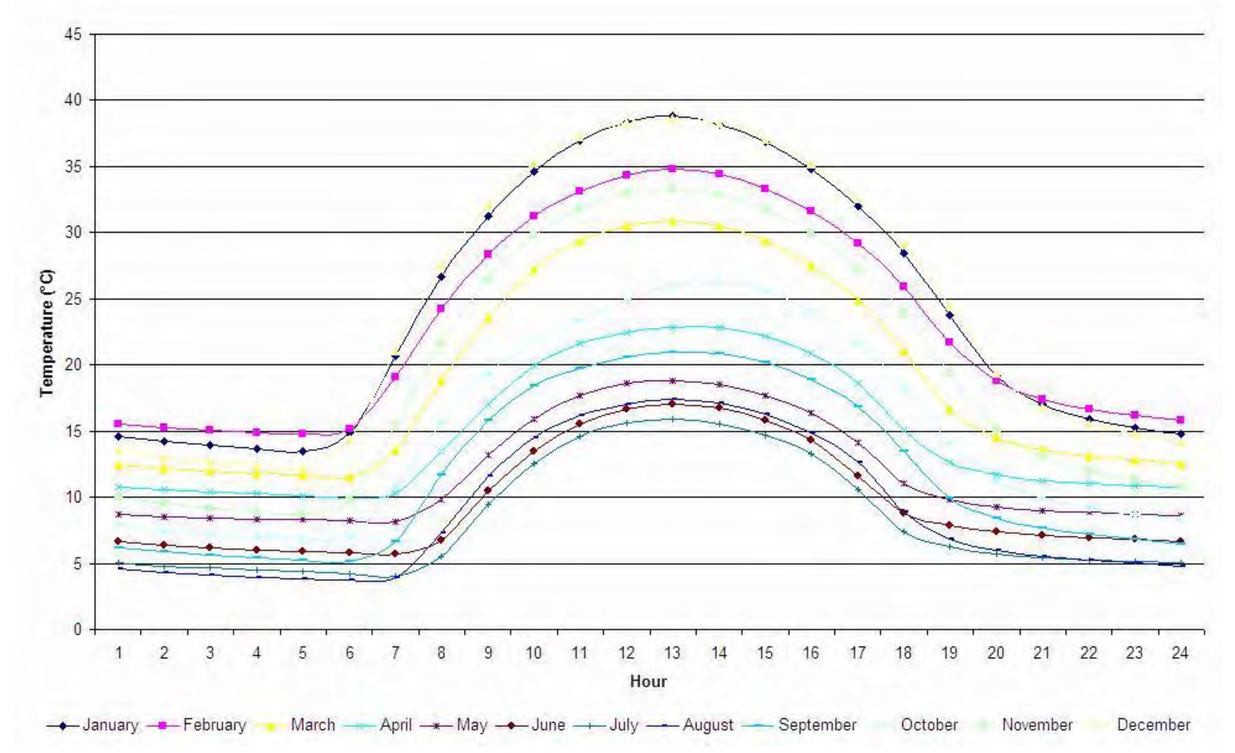

Figure 3-48: Monthly average temperature in the GMR by hour of day

Monthly average temperatures are presented in Table 3-65, while the gridded annual average temperature is shown in Figure 3-49 for the GMR.

Table 3-65: Monthly average temperature in the GMR

Month	Temperature (°C)
January	24.5
February	23.2
March	19.2
April	14.9
May	11.9
June	9.7
July	8.3
August	9.0
September	11.9
October	15.1
November	19.8
December	24.4
Grand Total	16.0

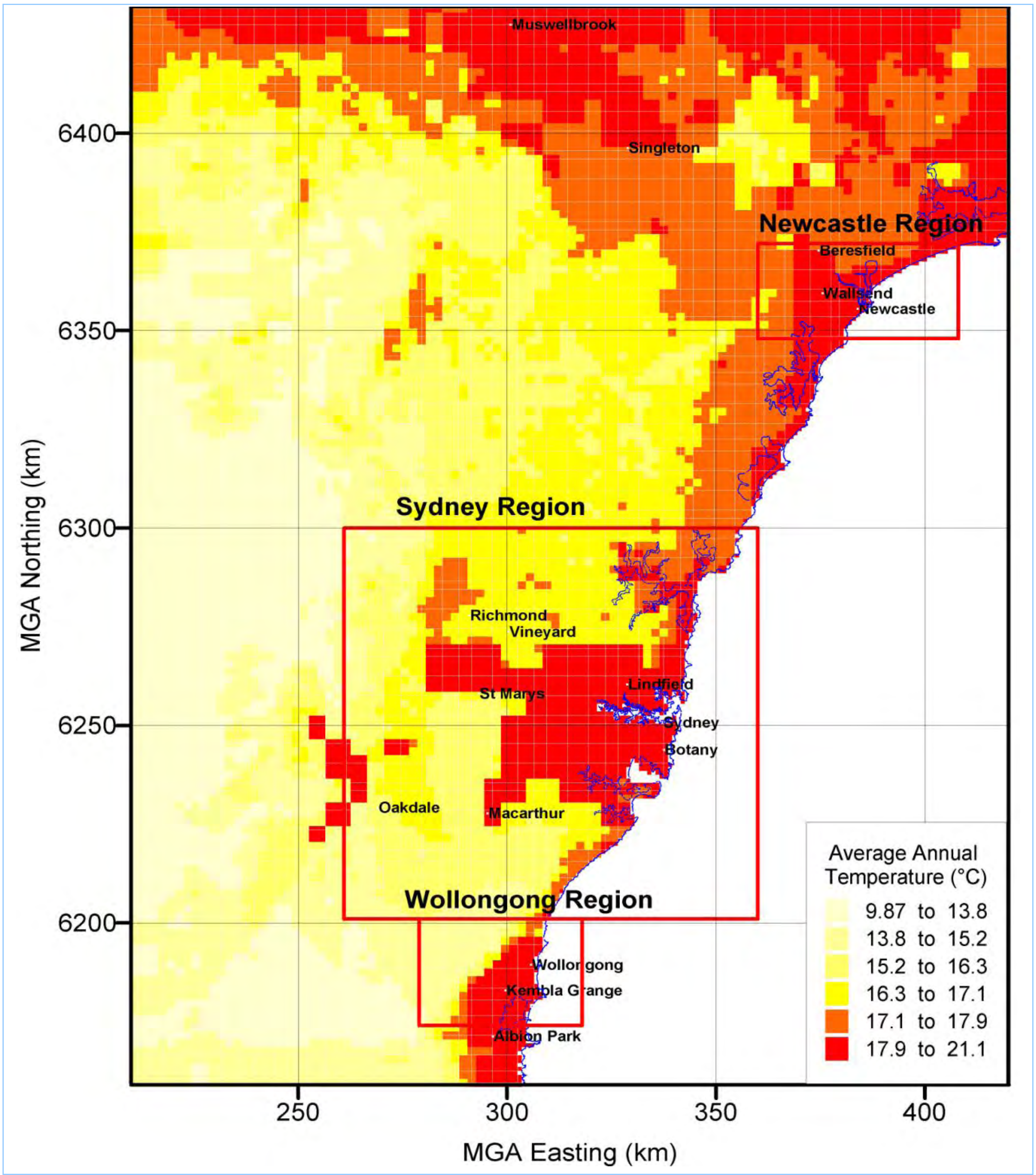

Figure 3-49: Gridded annual average temperature

3.4.4 *Emission and Speciation Factors*

Table 3-66 summarises the emission and speciation factors used for nitrogen compounds from agricultural lands and natural landscapes.

Table 3-66: Soil nitrification and denitrification emission and speciation factors

Emission source	Substance	Emission and speciation factor source
Emissions of nitrogen compounds from agricultural lands and natural landscapes	Criteria pollutants: NO_x	- *Biogenic Sources Preferred Methods, Technical Report Series Volume 5, Emission Inventory Improvement Program* (Radian, 1996)
	Speciated NO_x	- *Biogenic Sources Preferred Methods, Technical Report Series Volume 5, Emission Inventory Improvement Program* (Radian, 1996)
	Ammonia	- *Review of Ammonia Emission Modeling Techniques for Natural Landscapes and Fertilized Soils* (Battye et. al., 2004)
	Greenhouse gases: N_2O	- *AP 42, Fifth Edition, Volume I, Chapter 14: Greenhouse Gas Biogenic Sources, 14.1 Emission from Soils - Greenhouse Gases* (USEPA, 2003b)

Table 3-67 presents emission factors for nitrogen compounds from agricultural lands and natural landscapes by landuse type

Table 3-67: Soil nitrification and denitrification emission factors

Landuse category	Emission factors[14] ($\mu g/m^2/h$)		
	NO_x	N_2O	NH_3
Forest	6.90	4.32	7.20
Grassland	88.93	5.31	17.12
Agricultural	168.89	90.16	12.79
Wetland	0.31	-	-
Water	-	-	-
Urban	30.32	1.10	6.56

3.4.5 *Spatial Distribution of Emissions*

Table 3-68 summarises the data used for spatially allocating emissions of nitrogen compounds from agricultural lands and natural landscapes.

Table 3-68: Soil nitrification and denitrification spatial data

Emission source	Spatial data	Spatial data source
Emissions of nitrogen compounds from agricultural lands and natural landscapes	GIS layer for land use area combined with gridded 1 km x 1 km temperature correction factor estimates	- *Land Use of Australia, Version 3 - 1996/1997* (BRS , 2006)

[14] NO_x emission factors have been standardized to 30 °C and bright sunlight (USEPA, 1995b; and Radian, 1996). N_2O and NH_3 emission rates are hourly average (Battye et. al., 2004 and USEPA, 2003b).

Emission source	Spatial data	Spatial data source
		- *The Air Pollution Model (TAPM) Version 3* (Hurley, 2005)

Emissions of nitrogen compounds from agricultural lands and natural landscapes have been spatially distributed according to the proportion of each landuse category area in each 1 km by 1 km grid cell (BRS, 2006). The proportion of each landuse category area by LGA and region is presented in Table 3-69 and shown in Figure 3-50.

Table 3-69: Landuse category spatial distribution by LGA and region

Landuse category	LGA	2008 proportion of landuse category area (%)				
		Newcastle	Non Urban	Sydney	Wollongong	Grand Total
Agricultural	Baulkham Hills	-	-	0.21	-	0.21
	Blue Mountains	-	-	1.28×10^{-2}	-	1.28×10^{-2}
	Camden	-	-	1.28×10^{-2}	-	1.28×10^{-2}
	Cessnock	2.42×10^{-2}	8.78×10^{-2}	-	-	0.11
	Dungog	-	1.30×10^{-2}	-	-	1.30×10^{-2}
	Gosford	-	2.98×10^{-3}	3.08×10^{-2}	-	3.38×10^{-2}
	Goulburn Mulwaree	-	1.86×10^{-3}	-	-	1.86×10^{-3}
	Hawkesbury	-	9.93×10^{-3}	3.67×10^{-2}	-	4.66×10^{-2}
	Hornsby	-	-	1.07×10^{-2}	-	1.07×10^{-2}
	Kiama	-	3.14×10^{-3}	-	-	3.14×10^{-3}
	Lithgow	-	0.21	-	-	0.21
	Maitland	2.65×10^{-3}	2.77×10^{-2}	-	-	3.04×10^{-2}
	Mid-western Regional	-	3.12×10^{-2}	-	-	3.12×10^{-2}
	Muswellbrook	-	0.35	-	-	0.35
	N/A	3.29×10^{-5}	-	4.29×10^{-5}	-	7.58×10^{-5}
	Newcastle	1.26×10^{-4}	-	-	-	1.26×10^{-4}
	Oberon	-	1.58×10^{-2}	-	-	1.58×10^{-2}
	Penrith	-	-	5.10×10^{-2}	-	5.10×10^{-2}
	Port Stephens	5.03×10^{-3}	3.38×10^{-3}	-	-	8.41×10^{-3}
	Shellharbour	-	7.03×10^{-3}	-	-	7.03×10^{-3}
	Singleton	-	0.19	-	-	0.19
	Upper Hunter	-	3.04×10^{-2}	-	-	3.04×10^{-2}
	Upper Lachlan	-	9.68×10^{-2}	-	-	9.68×10^{-2}
	Wingecarribee	-	8.67×10^{-2}	7.43×10^{-4}	-	8.75×10^{-2}
	Wollondilly	-	1.82×10^{-2}	7.44×10^{-2}	-	9.26×10^{-2}
	Wyong	-	7.76×10^{-3}	-	-	7.76×10^{-3}
Agricultural Total		3.21×10^{-2}	1.19	0.44	-	1.65
Forest	Ashfield	-	-	2.36×10^{-2}	-	2.36×10^{-2}
	Auburn	-	-	5.48×10^{-2}	-	5.48×10^{-2}
	Bankstown	-	-	0.15	-	0.15
	Bathurst Regional	-	2.17×10^{-2}	-	-	2.17×10^{-2}
	Baulkham Hills	-	1.15×10^{-2}	0.27	-	0.28

Landuse category	LGA	2008 proportion of landuse category area (%)				
		Newcastle	Non Urban	Sydney	Wollongong	Grand Total
	Blacktown	-	-	0.15	-	0.15
	Blue Mountains	-	1.64	0.81	-	2.45
	Botany Bay	-	-	2.90×10^{-2}	-	2.90×10^{-2}
	Burwood	-	-	1.75×10^{-2}	-	1.75×10^{-2}
	Camden	-	-	6.32×10^{-3}	-	6.32×10^{-3}
	Campbelltown	-	-	0.16	-	0.16
	Canada Bay	-	-	3.41×10^{-2}	-	3.41×10^{-2}
	Canterbury	-	-	8.39×10^{-2}	-	8.39×10^{-2}
	Cessnock	4.94×10^{-2}	2.18	-	-	2.23
	Dungog	-	0.41	-	-	0.41
	Fairfield	-	-	0.16	-	0.16
	Gosford	-	0.68	0.40	-	1.09
	Goulburn Mulwaree	-	2.31×10^{-2}	-	-	2.31×10^{-2}
	Great Lakes	-	0.82	-	-	0.82
	Hawkesbury	-	4.28	1.09	-	5.37
	Holroyd	-	-	8.89×10^{-2}	-	8.89×10^{-2}
	Hornsby	-	1.04×10^{-2}	0.88	-	0.89
	Hunters Hill	-	-	6.06×10^{-3}	-	6.06×10^{-3}
	Hurstville	-	-	5.95×10^{-2}	-	5.95×10^{-2}
	Kiama	-	0.13	-	-	0.13
	Kogarah	-	-	3.79×10^{-2}	-	3.79×10^{-2}
	Ku-ring-gai	-	-	0.18	-	0.18
	Lake Macquarie	0.26	0.40	-	-	0.66
	Lane Cove	-	-	2.52×10^{-2}	-	2.52×10^{-2}
	Leichhardt	-	-	1.30×10^{-2}	-	1.30×10^{-2}
	Lithgow	-	6.25	6.25×10^{-2}	-	6.31
	Liverpool	-	-	9.89×10^{-2}	-	9.89×10^{-2}
	Maitland	5.35×10^{-4}	1.20×10^{-2}	-	-	1.25×10^{-2}
	Manly	-	-	1.83×10^{-3}	-	1.83×10^{-3}
	Marrickville	-	-	4.17×10^{-2}	-	4.17×10^{-2}
	Mid-western Regional	-	2.30	-	-	2.30
	Mosman	-	-	1.39×10^{-2}	-	1.39×10^{-2}
	Muswellbrook	-	2.76	-	-	2.76
	N/A	2.52×10^{-3}	2.23×10^{-3}	8.03×10^{-3}	-	1.28×10^{-2}
	Newcastle	0.18	-	-	-	0.18
	North Sydney	-	-	1.95×10^{-2}	-	1.95×10^{-2}
	Oberon	-	2.14	-	-	2.14
	Parramatta	-	-	0.14	-	0.14
	Penrith	-	-	5.38×10^{-2}	-	5.38×10^{-2}
	Pittwater	-	-	8.74×10^{-2}	-	8.74×10^{-2}
	Port Stephens	0.23	0.65	-	-	0.88
	Randwick	-	-	5.89×10^{-2}	-	5.89×10^{-2}
	Rockdale	-	-	5.70×10^{-2}	-	5.70×10^{-2}
	Ryde	-	-	9.17×10^{-2}	-	9.17×10^{-2}

Landuse category	LGA	2008 proportion of landuse category area (%)				
		Newcastle	Non Urban	Sydney	Wollongong	Grand Total
	Shellharbour	-	3.33×10^{-2}	-	2.69×10^{-3}	3.60×10^{-2}
	Shoalhaven	-	7.66×10^{-2}	-	-	7.66×10^{-2}
	Singleton	-	4.42	-	-	4.42
	Strathfield	-	-	3.23×10^{-2}	-	3.23×10^{-2}
	Sutherland	-	-	0.39	-	0.39
	Sydney	-	-	5.77×10^{-2}	-	5.77×10^{-2}
	Unincorporated	-	-	1.39×10^{-2}	-	1.39×10^{-2}
	Upper Hunter	-	0.12	-	-	0.12
	Upper Lachlan	-	0.82	-	-	0.82
	Warringah	-	-	0.19	-	0.19
	Waverley	-	-	1.68×10^{-2}	-	1.68×10^{-2}
	Willoughby	-	-	4.51×10^{-2}	-	4.51×10^{-2}
	Wingecarribee	-	2.31	0.13	0.40	2.84
	Wollondilly	-	2.65	1.44	6.21×10^{-2}	4.15
	Wollongong	-	-	0.31	0.49	0.80
	Woollahra	-	-	1.81×10^{-2}	-	1.81×10^{-2}
	Wyong	-	0.84	-	-	0.84
Forest Total		0.73	36.01	8.13	0.95	45.82
Grassland	Bankstown	-	-	1.95×10^{-2}	-	1.95×10^{-2}
	Bathurst Regional	-	8.33×10^{-2}	-	-	8.33×10^{-2}
	Baulkham Hills	-	1.93×10^{-3}	0.19	-	0.19
	Blacktown	-	-	2.70×10^{-2}	-	2.70×10^{-2}
	Blue Mountains	-	6.07×10^{-2}	7.13×10^{-2}	-	0.13
	Camden	-	-	0.32	-	0.32
	Campbelltown	-	-	1.75×10^{-2}	-	1.75×10^{-2}
	Cessnock	0.19	2.16	-	-	2.35
	Dungog	-	3.64	-	-	3.64
	Fairfield	-	-	3.88×10^{-3}	-	3.88×10^{-3}
	Gosford	-	0.49	7.73×10^{-2}	-	0.57
	Goulburn Mulwaree	-	0.32	-	-	0.32
	Great Lakes	-	2.18	-	-	2.18
	Hawkesbury	-	0.14	0.43	-	0.57
	Hornsby	-	1.96×10^{-2}	5.32×10^{-2}	-	7.28×10^{-2}
	Kiama	-	0.25	-	-	0.25
	Ku-ring-gai	-	-	5.14×10^{-3}	-	5.14×10^{-3}
	Lake Macquarie	6.46×10^{-3}	5.30×10^{-2}	-	-	5.95×10^{-2}
	Lithgow	-	4.15	-	-	4.15
	Liverpool	-	-	7.05×10^{-2}	-	7.05×10^{-2}
	Maitland	4.86×10^{-2}	0.83	-	-	0.88
	Mid-western Regional	-	4.04	-	-	4.04
	Muswellbrook	-	4.34	-	-	4.34
	N/A	-	1.79×10^{-4}	7.65×10^{-4}	-	9.44×10^{-4}
	Newcastle	6.75×10^{-2}	-	-	-	6.75×10^{-2}
	Oberon	-	1.15	-	-	1.15

Landuse category	LGA	2008 proportion of landuse category area (%)				
		Newcastle	Non Urban	Sydney	Wollongong	Grand Total
	Penrith	-	-	9.51×10^{-2}	-	9.51×10^{-2}
	Port Stephens	6.85×10^{-2}	0.84	-	-	0.91
	Ryde	-	-	5.14×10^{-3}	-	5.14×10^{-3}
	Shellharbour	-	0.23	-	1.67×10^{-2}	0.25
	Shoalhaven	-	2.46×10^{-2}	-	-	2.46×10^{-2}
	Singleton	-	7.40	-	-	7.40
	Sutherland	-	-	7.24×10^{-3}	-	7.24×10^{-3}
	Upper Hunter	-	1.43	-	-	1.43
	Upper Lachlan	-	1.70	-	-	1.70
	Wingecarribee	-	3.05	5.96×10^{-2}	1.10×10^{-2}	3.12
	Wollondilly	-	0.15	1.65	-	1.80
	Wollongong	-	-	-	0.16	0.16
	Wyong	-	0.27	-	-	0.27
Grassland Total		0.39	38.99	3.11	0.18	42.66
Urban	Ashfield	-	-	6.93×10^{-4}	-	6.93×10^{-4}
	Auburn	-	-	2.11×10^{-2}	-	2.11×10^{-2}
	Bankstown	-	-	2.57×10^{-2}	-	2.57×10^{-2}
	Baulkham Hills	-	4.03×10^{-3}	0.31	-	0.32
	Blacktown	-	-	0.42	-	0.42
	Blue Mountains	-	0.20	0.78	-	0.98
	Botany Bay	-	-	5.94×10^{-3}	-	5.94×10^{-3}
	Camden	-	-	0.15	-	0.15
	Campbelltown	-	-	0.60	-	0.60
	Canada Bay	-	-	5.89×10^{-3}	-	5.89×10^{-3}
	Canterbury	-	-	1.07×10^{-3}	-	1.07×10^{-3}
	Cessnock	3.92×10^{-2}	0.17	-	-	0.21
	Dungog	-	2.05×10^{-2}	-	-	2.05×10^{-2}
	Fairfield	-	-	9.32×10^{-2}	-	9.32×10^{-2}
	Gosford	-	0.35	0.19	-	0.53
	Hawkesbury	-	0.17	0.75	-	0.92
	Holroyd	-	-	1.11×10^{-2}	-	1.11×10^{-2}
	Hornsby	-	-	0.14	-	0.14
	Hurstville	-	-	8.01×10^{-3}	-	8.01×10^{-3}
	Kiama	-	1.42×10^{-2}	-	-	1.42×10^{-2}
	Kogarah	-	-	2.39×10^{-3}	-	2.39×10^{-3}
	Ku-ring-gai	-	-	2.87×10^{-2}	-	2.87×10^{-2}
	Lake Macquarie	0.15	0.52	-	-	0.67
	Lane Cove	-	-	1.71×10^{-4}	-	1.71×10^{-4}
	Leichhardt	-	-	5.22×10^{-3}	-	5.22×10^{-3}
	Lithgow	-	0.11	-	-	0.11
	Liverpool	-	-	0.60	-	0.60
	Maitland	3.19×10^{-3}	3.87×10^{-2}	-	-	4.19×10^{-2}
	Manly	-	-	1.79×10^{-2}	-	1.79×10^{-2}
	Marrickville	-	-	3.30×10^{-3}	-	3.30×10^{-3}

Landuse category	LGA	2008 proportion of landuse category area (%)				
		Newcastle	Non Urban	Sydney	Wollongong	Grand Total
	Mid-western Regional	-	7.80×10^{-3}	-	-	7.80×10^{-3}
	Muswellbrook	-	1.30×10^{-2}	-	-	1.30×10^{-2}
	N/A	-	2.84×10^{-3}	6.68×10^{-4}	6.16×10^{-6}	3.51×10^{-3}
	Newcastle	0.20	-	-	-	0.20
	North Sydney	-	-	3.74×10^{-3}	-	3.74×10^{-3}
	Oberon	-	0.23	-	-	0.23
	Parramatta	-	-	8.43×10^{-3}	-	8.43×10^{-3}
	Penrith	-	-	0.78	-	0.78
	Pittwater	-	-	6.62×10^{-2}	-	6.62×10^{-2}
	Port Stephens	2.62×10^{-2}	2.74×10^{-2}	-	-	5.36×10^{-2}
	Randwick	-	-	6.32×10^{-3}	-	6.32×10^{-3}
	Rockdale	-	-	1.65×10^{-3}	-	1.65×10^{-3}
	Ryde	-	-	8.12×10^{-3}	-	8.12×10^{-3}
	Shellharbour	-	3.49×10^{-2}	-	1.55×10^{-2}	5.04×10^{-2}
	Shoalhaven	-	1.26×10^{-3}	-	-	1.26×10^{-3}
	Singleton	-	3.12×10^{-2}	-	-	3.12×10^{-2}
	Strathfield	-	-	1.82×10^{-4}	-	1.82×10^{-4}
	Sutherland	-	-	0.19	-	0.19
	Sydney	-	-	7.13×10^{-3}	-	7.13×10^{-3}
	Unincorporated	-	-	1.13×10^{-2}	-	1.13×10^{-2}
	Upper Lachlan	-	2.56×10^{-3}	-	-	2.56×10^{-3}
	Warringah	-	-	0.14	-	0.14
	Waverley	-	-	1.69×10^{-4}	-	1.69×10^{-4}
	Willoughby	-	-	2.11×10^{-3}	-	2.11×10^{-3}
	Wingecarribee	-	5.66×10^{-2}	-	8.48×10^{-3}	6.51×10^{-2}
	Wollondilly	-	7.30×10^{-2}	0.23	4.40×10^{-4}	0.31
	Wollongong	-	-	9.41×10^{-2}	0.15	0.25
	Woollahra	-	-	3.63×10^{-4}	-	3.63×10^{-4}
	Wyong	-	0.54	-	-	0.54
Urban Total		0.42	2.61	5.72	0.18	8.92
Water	Auburn	-	-	9.23×10^{-4}	-	9.23×10^{-4}
	Baulkham Hills	-	-	6.0×10^{-3}	-	6.0×10^{-3}
	Blacktown	-	-	5.24×10^{-4}	-	5.24×10^{-4}
	Campbelltown	-	-	7.56×10^{-3}	-	7.56×10^{-3}
	Canada Bay	-	-	4.50×10^{-3}	-	4.50×10^{-3}
	Cessnock	4.29×10^{-4}	6.15×10^{-3}	-	-	6.58×10^{-3}
	Dungog	-	5.11×10^{-3}	-	-	5.11×10^{-3}
	Fairfield	-	-	2.04×10^{-3}	-	2.04×10^{-3}
	Gosford	-	6.35×10^{-2}	3.0×10^{-2}	-	9.36×10^{-2}
	Great Lakes	-	4.94×10^{-3}	-	-	4.94×10^{-3}
	Hawkesbury	-	3.66×10^{-3}	1.20×10^{-2}	-	1.57×10^{-2}
	Hornsby	-	-	2.56×10^{-2}	-	2.56×10^{-2}
	Hunters Hill	-	-	2.64×10^{-3}	-	2.64×10^{-3}
	Kogarah	-	-	3.71×10^{-3}	-	3.71×10^{-3}

Landuse category	LGA	2008 proportion of landuse category area (%)				
		Newcastle	Non Urban	Sydney	Wollongong	Grand Total
	Lake Macquarie	5.20×10^{-2}	1.30×10^{-2}	-	-	6.50×10^{-2}
	Lithgow	-	7.74×10^{-3}	-	-	7.74×10^{-3}
	Mosman	-	-	8.64×10^{-6}	-	8.64×10^{-6}
	Muswellbrook	-	7.83×10^{-3}	-	-	7.83×10^{-3}
	Newcastle	4.83×10^{-2}	-	-	-	4.83×10^{-2}
	North Sydney	-	-	4.06×10^{-5}	-	4.06×10^{-5}
	Penrith	-	-	1.54×10^{-2}	-	1.54×10^{-2}
	Port Stephens	2.16×10^{-2}	7.70×10^{-2}	-	-	9.86×10^{-2}
	Ryde	-	-	6.65×10^{-4}	-	6.65×10^{-4}
	Singleton	-	1.05×10^{-2}	-	-	1.05×10^{-2}
	Sutherland	-	-	1.67×10^{-2}	-	1.67×10^{-2}
	Unincorporated	-	-	4.17×10^{-3}	-	4.17×10^{-3}
	Warringah	-	-	2.60×10^{-4}	-	2.60×10^{-4}
	Willoughby	-	-	4.69×10^{-3}	-	4.69×10^{-3}
	Wingecarribee	-	3.75×10^{-2}	-	0.15	0.18
	Wollondilly	-	5.85×10^{-2}	1.33×10^{-2}	-	7.17×10^{-2}
	Wollongong	-	-	1.26×10^{-4}	0.11	0.11
	Wyong	-	1.86×10^{-2}	-	-	1.86×10^{-2}
Water Total		0.12	0.31	0.15	0.26	0.85
Wetland	Cessnock	-	2.60×10^{-3}	-	-	2.60×10^{-3}
	Great Lakes	-	3.97×10^{-2}	-	-	3.97×10^{-2}
	Maitland	-	7.79×10^{-3}	-	-	7.79×10^{-3}
	Port Stephens	-	4.67×10^{-2}	-	-	4.67×10^{-2}
Wetland Total		-	9.69×10^{-2}	-	-	9.69×10^{-2}
Grand Total		1.68	79.21	17.54	1.57	100.00

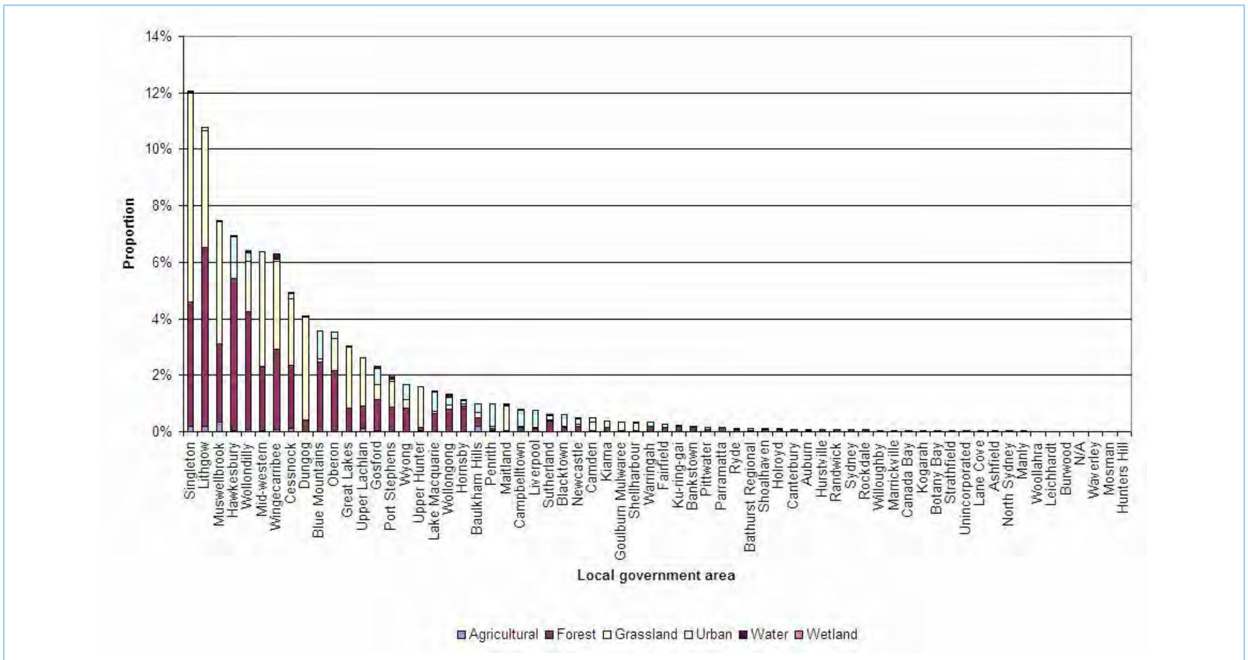

Figure 3-50: Landuse category spatial distribution by LGA and region

Figure 3-51 shows the spatial distribution of nitrogen compounds emissions from agricultural lands and natural landscapes.

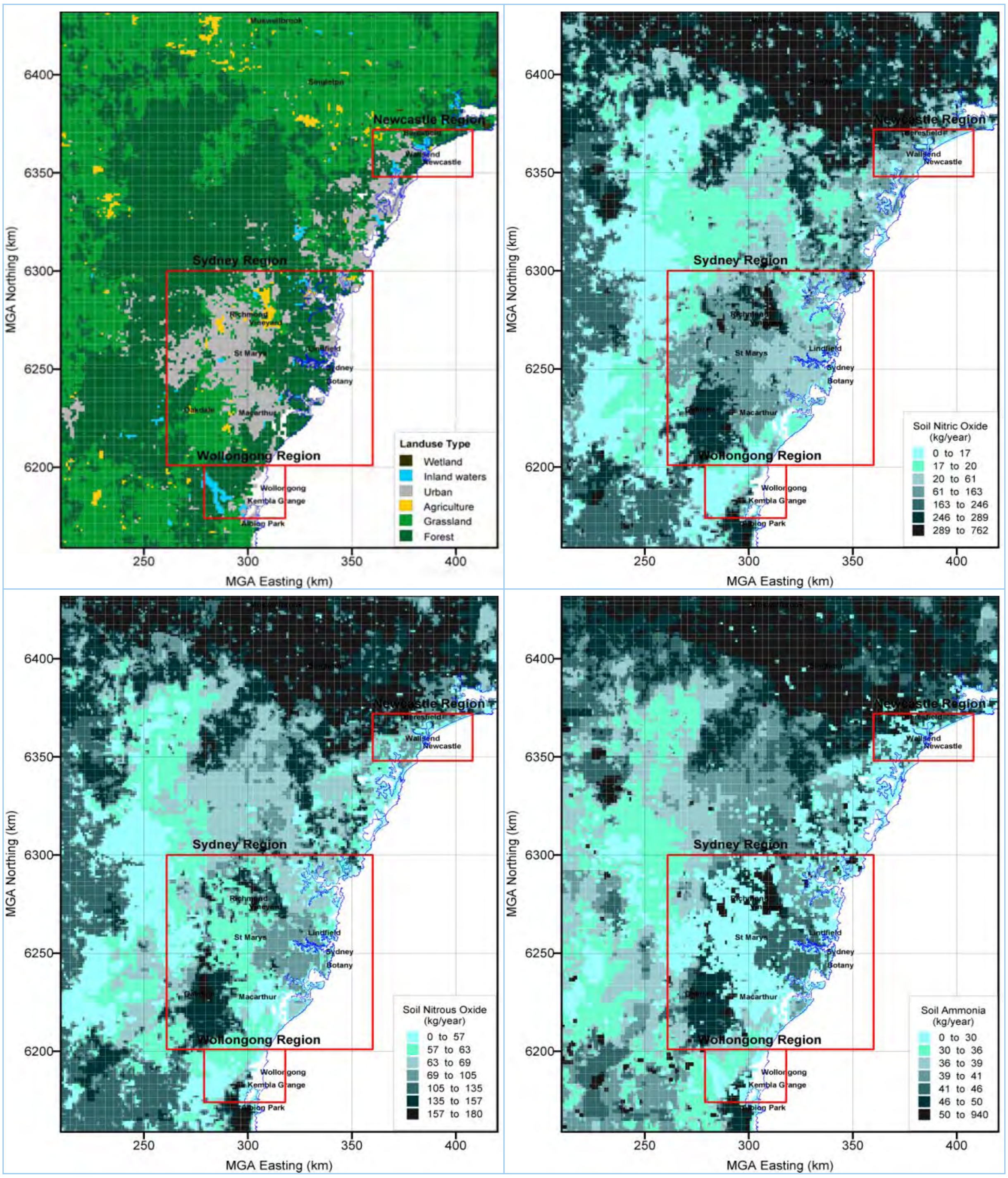

Figure 3-51: Soil nitrification and denitrification spatial distribution of emissions

3.4.6 *Temporal Variation of Emissions*

Table 3-47 summarises the data used to estimate the temporal variation in emissions of nitrogen compounds from agricultural lands and natural landscapes.

Table 3-70: Soil nitrification and denitrification temporal data

Emission source	Temporal data	Temporal data source
Emissions of nitrogen compounds from agricultural lands and natural landscapes	Monthly, daily and hourly: Gridded 1 km x 1 km temperature correction factor estimates	- *The Air Pollution Model (TAPM) Version 3* (Hurley, 2005)

Hourly average meteorological data including temperature have been generated for the GMR at 2 km by 2 km grid cells with *TAPM* (Hurley, 2005) and used to estimate: soil temperature as a function of ambient temperature and landuse type; and the nitrogen compounds (i.e. ammonia (NH_3), nitric oxide (NO) and nitrous oxide (N_2O)) flux rate variation with temperature (USEPA, 1995b; and Radian, 1996) at 1 km by 1 km grid cells.

Annual emissions of nitric oxide (NO) from agricultural lands and natural landscapes have been estimated using the soil temperature correction factor within Equation 10 (Radian, 1996). Hourly emissions are calculated first and then summed to estimate annual, monthly and daily emissions.

Annual emissions of ammonia (NH_3) and nitrous oxide (N_2O) from agricultural lands and natural landscapes have been estimated using annual nitrogen fertiliser consumption data (IFA, 2011; BRS, 2001; and NLWRA, 2001) and area based emission factors by landuse type within Equation 13 (Battye et. al., 2004)/ Equation 15 (USEPA, 1996) and Equation 14 (Battye et. al., 2004)/Equation 16 (USEPA, 1996), respectively.

Hourly emissions of ammonia (NH_3) and nitrous oxide (N_2O) from agricultural lands and natural landscapes have been estimated by multiplying the results of Equation 13 (Battye et. al., 2004)/ Equation 15 (USEPA, 1996) and Equation 14 (Battye et. al., 2004)/Equation 16 (USEPA, 1996), respectively with the normalised hourly soil temperature correction factor. By summing all of the hourly soil temperature correction factors for the year and then dividing each individual hour by the sum, the hourly soil temperature correction factor has been normalised to 1. These normalised hourly numbers provide the temperature based temporal profile. Annual emissions are calculated first and then multiplied by the normalised hourly soil temperature correction factor to estimate monthly, daily and hourly emissions.

While the temporal variation in emissions is different for each 1 km by 1 km grid cell where there are emissions of nitrogen compounds from agricultural lands and natural landscapes, Figure 3-52, Figure 3-53 and Figure 3-54 show the hourly, daily and monthly variation in NH_3, NO and N_2O emissions, respectively in the GMR for all agricultural lands and natural landscapes.

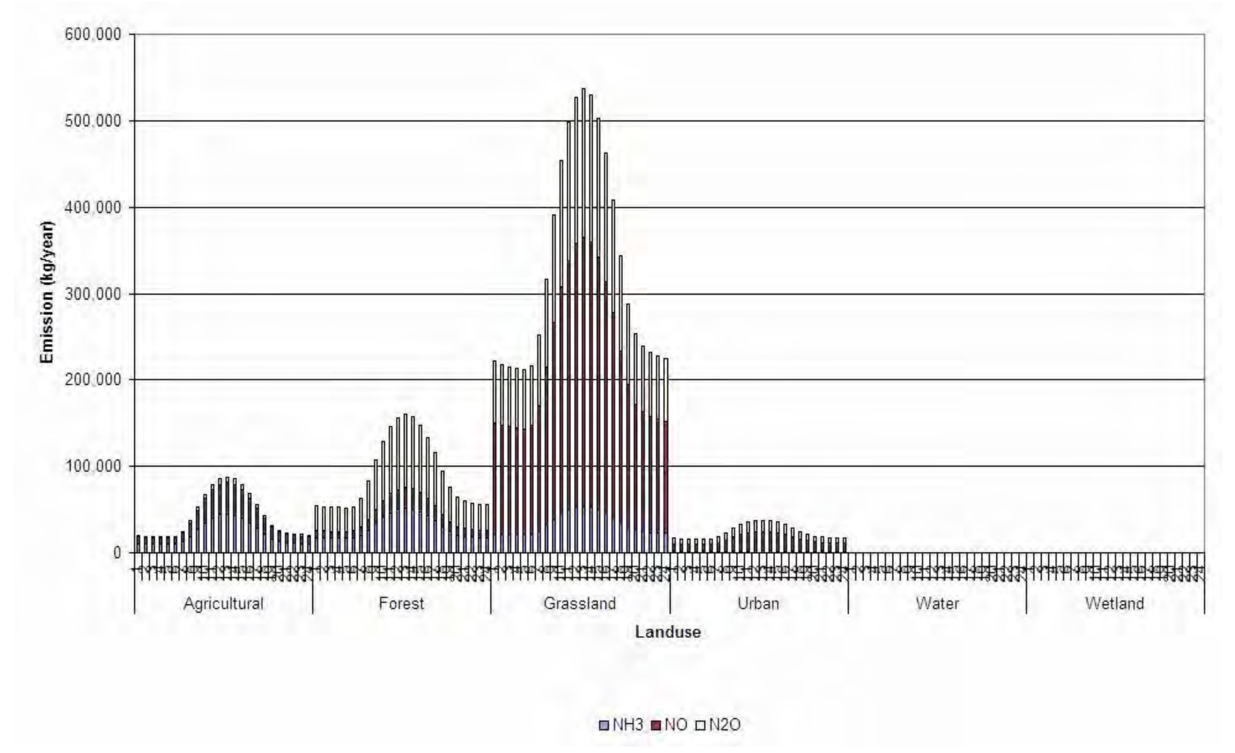

Figure 3-52: Soil nitrification and denitrification hourly variation in nitrogen compounds emissions

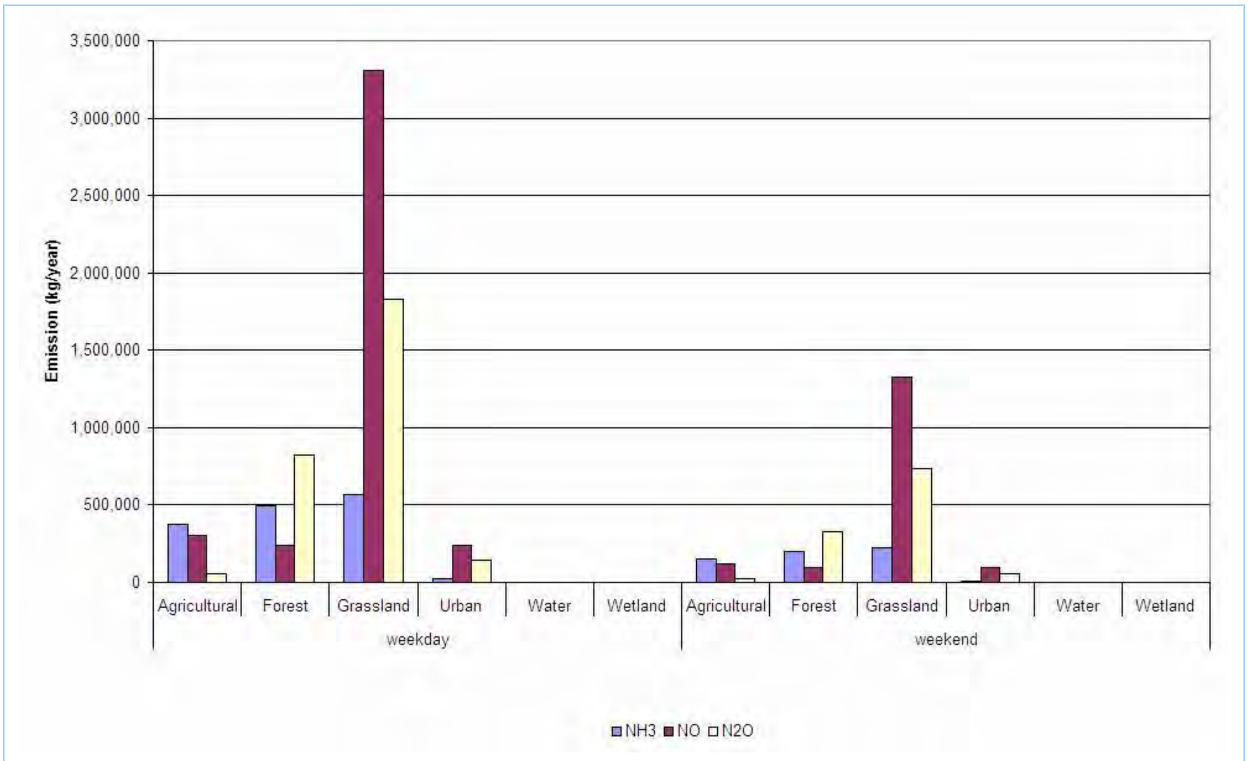

Figure 3-53: Soil nitrification and denitrification daily variation in nitrogen compounds emissions

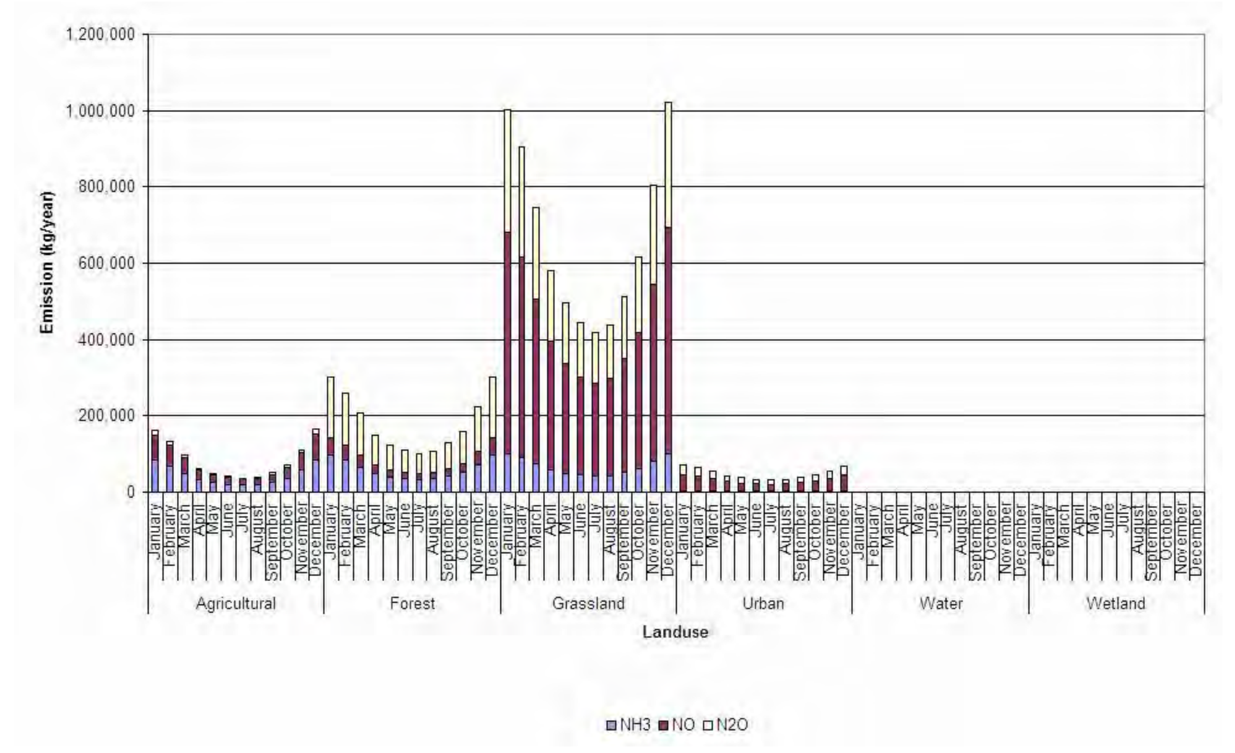

Figure 3-54: Soil nitrification and denitrification monthly variation in nitrogen compounds emissions

3.4.7 *Emission Estimates*

Table 3-71 presents annual soil nitrification and denitrification emissions of selected substances from agricultural lands and natural landscapes by activity.

Table 3-71: Soil nitrification and denitrification emissions by activity

Activity	Substance	Emissions (kg/year)				
		Newcastle	Non Urban	Sydney	Wollongong	GMR
Soil Nitrification and Denitrification	OXIDES OF NITROGEN	116,947	7,474,416	1,133,469	52,686	8,777,518

Table 3-72 presents annual soil nitrification and denitrification emissions of selected substances from agricultural lands and natural landscapes by source type.

Table 3-72: Soil nitrification and denitrification emissions by source type

Source type	Substance	Emissions (kg/year)				
		Newcastle	Non Urban	Sydney	Wollongong	GMR
Agricultural	OXIDES OF NITROGEN	13,237	461,357	175,246	-	649,841
Forest	OXIDES OF NITROGEN	9,231	394,807	95,562	10,059	509,659
Grassland	OXIDES OF NITROGEN	68,616	6,472,294	528,030	32,097	7,101,037
Urban	OXIDES OF NITROGEN	25,863	145,893	334,631	10,530	516,917
Water	OXIDES OF NITROGEN	-	-	-	-	-
Wetland	OXIDES OF NITROGEN	-	65	-	-	65

3.5 Tree Canopy, Uncut Grass and Cut Grass

3.5.1 Emission Source Description

The biogenic and geogenic air emissions inventory includes emissions of VOC from vegetation (i.e. tree canopy, uncut grass and cut grass).

To estimate emissions from these sources, the following have been considered:

- *CSIRO Investigation Report ET/IR 686R and Biogenic Emissions Inventory GIS Version 3.02*

The *CSIRO Investigation Report ET/IR 686R* (Azzi et. al., 2004) documents three models for estimating emissions of VOC from vegetation (i.e. tree canopy, uncut grass and cut grass).

The models for estimating emissions from tree canopy and uncut grass are incorporated into the *Biogenic Emissions Inventory GIS Version 1.01 (*BEI-GIS v1.01) software package (Azzi et. al., 2004) and the *Chemical Transport Model* (Cope et. al., 2009). The *BEI-GIS v3.02* software package (Huber, 2005) is based on *BEI-GIS v1.01* and includes additional features as follows:

- Spatial extent includes GMR as option;
- Import *TAPM* meteorological data in either Microsoft® Windows *.csv or Microsoft® Access™ 2003 *.mdb format; and
- Simulate any period of time from 1 day to 1 year.

To estimate tree canopy and uncut grass emissions, *BEI-GIS v3.02* requires the following GIS data:

- Genus specific speciated VOC emission rate (Q_{leaf});
- Leaf area index (LAI);
- Leaf biomass (B_m);
- Canopy height (h_c);
- Temperature (T);
- Geographical (i.e. latitude and longitude) or gridded (i.e. MGA easting and northing); and
- Time and date.

Figure 3-55 shows the hierarchy of tree canopy and uncut grass emission estimation within the *BEI-GIS v3.02* software package, which uses information collected at leaf level scale to estimate data at canopy, landscape and regional scales.

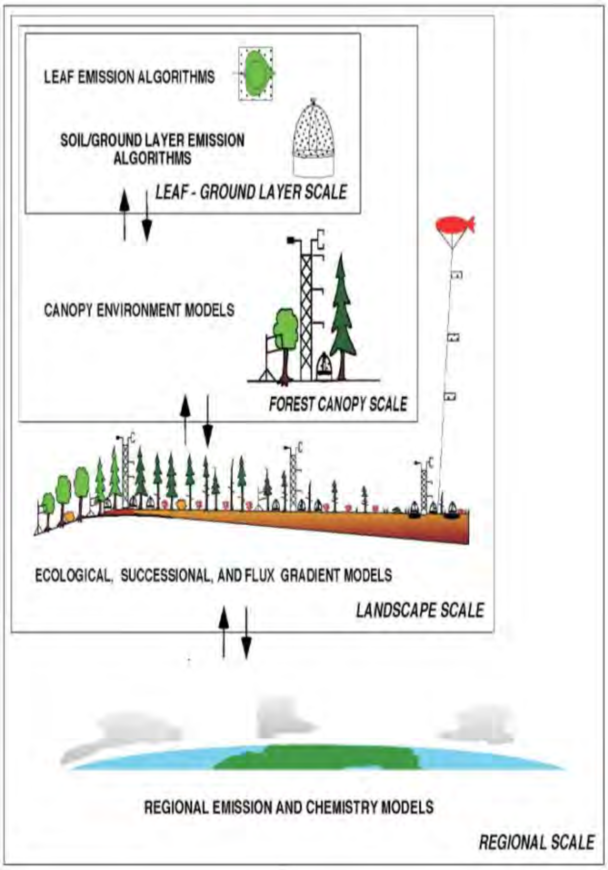

Figure 3-55: Hierarchy of tree canopy and uncut grass emission estimation

The model for estimating emissions from cut grass is incorporated into the *Biogenic and Geogenic Emissions Data Management System v1.0*, which is a Microsoft® Access™ 2003 relational database. Domestic (TR, 2009) and commercial (DECC, 2007b) survey data have been used to determine lawn mowing and garden equipment frequency and duration of use on an hourly, daily, monthly and annual basis and the lawn area mowed so that cut grass emissions can be estimated (Azzi et. al., 2004).

- *Domestic survey*

A domestic survey of lawn mowing and garden equipment ownership and usage has been conducted, which includes each of the 64 local government areas (LGA)[15] located in the GMR. The survey results include data about: equipment type, number and age; engine type and fuel used; frequency and duration of equipment use by hour, day and season; lawn area; and proportion of private and commercial usage (TR, 2009). The survey data have been used to determine residential lawn mowing and garden equipment frequency and duration of use on an hourly, daily, monthly and annual basis and the lawn area mowed so that cut grass emissions[16] can be estimated (Azzi et. al., 2004).

[15] The GMR includes 64 local government areas (LGA), plus two areas designated N/A and unincorporated. N/A areas are those located near the coastline and the majority area within the 1 km by 1 km grid cell lies over water. Unincorporated areas are those areas which are not under the responsibility of an incorporated local government.
[16] Emissions have been estimated for 64 LGA plus the two areas designated N/A and unincorporated.

➢ *Commercial survey*

A commercial survey of lawn mowing and garden equipment ownership and usage has been conducted, which includes 5 golf courses and 9 LGA located in the GMR. The survey results include data about: equipment type, number and age; engine type and fuel used; and frequency and duration of equipment use by hour, day and season (DECC, 2007b). The survey data have been used to determine public open space lawn mowing and garden equipment frequency and duration of use on an hourly, daily, monthly and annual basis and the lawn area mowed so that cut grass emissions[17] can be estimated (Azzi et. al., 2004).

➢ *Meteorological data*

Hourly average meteorological data including temperature have been generated for the GMR at 2 km by 2 km grid cells with *TAPM* (Hurley, 2005) and used to estimate: leaf temperature as a function of ambient temperature and flux rate variation with temperature for tree canopy and uncut grass (Azzi et. al., 2004; and Cope et. al., 2009); and flux rate variation with temperature for cut grass (Potter et. al., 2003) at 1 km by 1 km grid cells.

➢ *Source type*

The inventory includes emissions of includes emissions of VOC from vegetation as follows:

- *Tree canopy;*
- *Uncut grass; and*
- *Cut grass.*

3.5.2 Emission Estimation Methodology

Table 3-73 summarises the emission estimation methodologies used for emissions of VOC from vegetation (i.e. tree canopy, uncut grass and cut grass).

Table 3-73: Tree canopy, uncut grass and cut grass emission estimation methodologies

Emission source	Emission estimation methodology source
Emissions of VOC from tree canopy	- *Biogenic Emissions in the Greater Sydney Region* (Azzi et. al., 2004)
Emissions of VOC from uncut grass	- *Biogenic Emissions in the Greater Sydney Region* (Azzi et. al., 2004)
Emissions of VOC from cut grass	- *Biogenic Emissions in the Greater Sydney Region* (Azzi et. al., 2004)

Emissions of VOC from tree canopy and uncut grass have been estimated using *BEI-GIS v3.02* combined with hourly average temperature data (Hurley, 2005) in Equation 17 (Azzi et. al., 2004; and Cope et. al., 2009):

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[17] Emissions have been estimated for 59 LGA plus the two areas designated N/A and unincorporated.

$$E_{i,j} = \sum_{k=1}^{8760}\left(A_j \times B_{m,j} \times EF_{i,j} \times f\left(LAI_j, PAR_j, T_j\right) \times 10^{-9}\right)$$ **Equation 17**

where:			
$E_{i,j}$	=	Emissions of substance i from vegetation type j	(kg/year)
A_j	=	Area of vegetation type j	(m^2)
$B_{m,j}$	=	Leaf biomass for vegetation type j	(g leaf biomass/m^2)
$EF_{i,j}$	=	Emission factor for substance i from vegetation type j	(µg/g leaf biomass/h)
$f(LAI_j, PAR_j, T_j)$	=	Equations which account for leaf area index (LAI), photosynthetically active radiation (PAR) and temperature (T)	(-)
i	=	Substance (either "VOC", "speciated VOC" or "organic air toxics")	(-)
j	=	Vegetation type (either "tree canopy" or "uncut grass")	(-)
k	=	Time interval	(h/year)
10^{-9}	=	Conversion factor	(kg/µg)

Emissions of VOC from cut grass have been estimated using leaf biomass based emission factors combined with activity rates. Activity rates include residential (TR, 2009) and public open space (DECC, 2007b) lawn mowing and garden equipment frequency and duration of use on an hourly, daily, monthly and annual basis and the lawn area mowed. Emissions have been determined using Equation 18 (Azzi et. al., 2004):

$$E_{i,j} = A_j \times \left(B_m - B_m^o\right) \times EF_i \times 10^{-3}$$ **Equation 18**

where:			
$E_{i,j}$	=	Emissions of substance i from source type j	(kg/year)
A_j	=	Area of lawn mowed for source type j	(m^2/year)
B_m	=	Maximum potential leaf biomass before lawn mowing (Table 3-74) (Table 6.3; Azzi et. al., 2004)	(g leaf biomass/m^2)
B^o_m	=	Basal leaf biomass after lawn mowing (Table 3-74) (Table 6.3; Azzi et. al., 2004)	(g leaf biomass/m^2)
EF_i	=	Emission factor for substance i (Table 3-74) (Table 6.3; Azzi et. al., 2004)	(g/g leaf biomass/mow)
i	=	Substance (either "VOC", "speciated VOC" or "organic air toxics")	(-)
j	=	Source type (either "residential lawn area" or "public open space lawn area")	(-)
10^{-3}	=	Conversion factor	(kg/g)

The maximum potential leaf biomass has been estimated using Equation 19 (Azzi et. al., 2004):

$$B_m = D \times f + B_m^o \qquad \textbf{Equation 19}$$

where:			
B_m	=	Maximum potential leaf biomass before lawn mowing (Table 3-74) (Table 6.3; Azzi et. al., 2004)	(g leaf biomass/m²)
D	=	Leaf biomass removed (Table 3-74) (Table 6.3; Azzi et. al., 2004)	(g leaf biomass/m²/mow)
f	=	Frequency of lawn mowing	(mow/year)
B_m^o	=	Basal leaf biomass after lawn mowing (Table 3-74) (Table 6.3; Azzi et. al., 2004)	(g leaf biomass/m²)

Table 3-74 presents lawn attributes used to estimate emissions of VOC from domestic and public open space cut grass (Azzi et. al., 2004).

Table 3-74: Lawn attributes

Parameter	Measure	Units of measure
Maximum potential leaf biomass before lawn mowing (B_m)	936	g leaf biomass/m²
Basal leaf biomass after lawn mowing (B^o_m)	100	g leaf biomass/m²
Leaf biomass removed (D)	40	g leaf biomass/m²/mow
Emission factor for VOC (EF_{VOC})	0.002	g VOC/g leaf biomass/mow

3.5.3 *Activity Data*

Table 3-75 summarises the activity data used for emissions of VOC from vegetation (i.e. tree canopy, uncut grass and cut grass).

Table 3-75: Tree canopy, uncut grass and cut grass activity data

Activity data	Activity data source
Genus specific speciated VOC emission rate (µg/g leaf biomass/h), leaf area index (LAI) (m²/m²), canopy height (m) and leaf biomass (g/m²) required by the tree canopy and uncut grass models	- *Biogenic Emissions in the Greater Sydney Region* (Azzi et. al., 2004) - *Biogenic Emissions Inventory GIS Version 3.02* (Huber, 2005)
Hourly meteorological data (temperature (K)) required by the tree canopy, uncut grass and cut grass models	- *The Air Pollution Model (TAPM) Version 3* (Hurley, 2005)
Residential lawn area (m²) and annual lawn mowing frequency required by the cut grass model	- *Domestic Lawn Mowing Pollution Survey* (TR, 2009)
Public open space lawn area (m²) and annual lawn mowing frequency required by the cut grass model	- *Public Open Space Lawn Mowing Pollution Survey* (DECC, 2007)

Figure 3-56 shows how activity data are used within *BEI-GIS v3.02* to develop an inventory of tree canopy and uncut grass emissions.

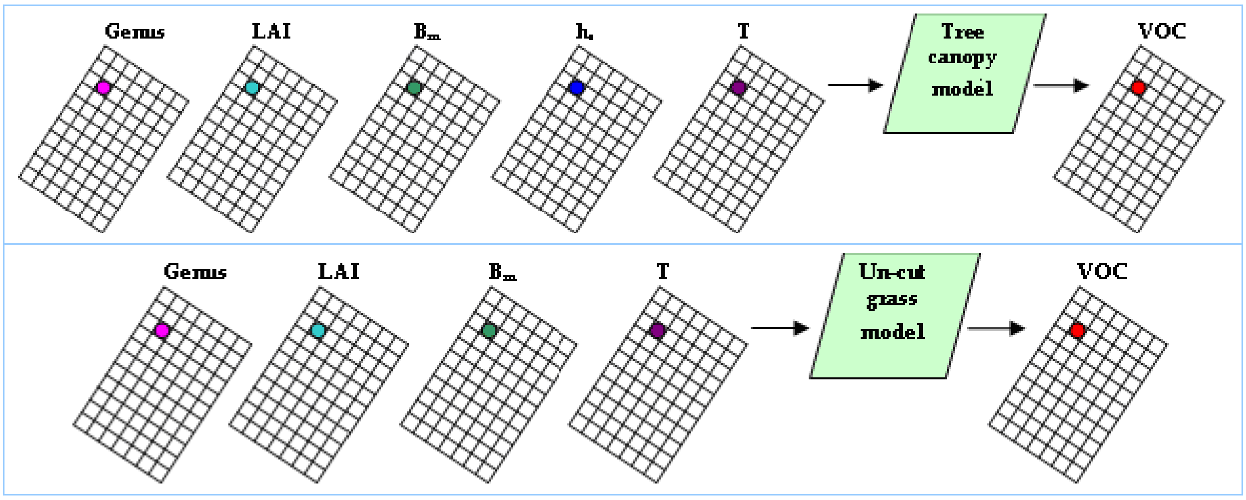


Figure 3-56: Tree canopy and uncut grass models – use of GIS data

Figure 3-57 shows the GIS data for genus specific speciated VOC emission rate, leaf area index, canopy height and leaf biomass within *BEI-GIS v3.02* for the GMR.

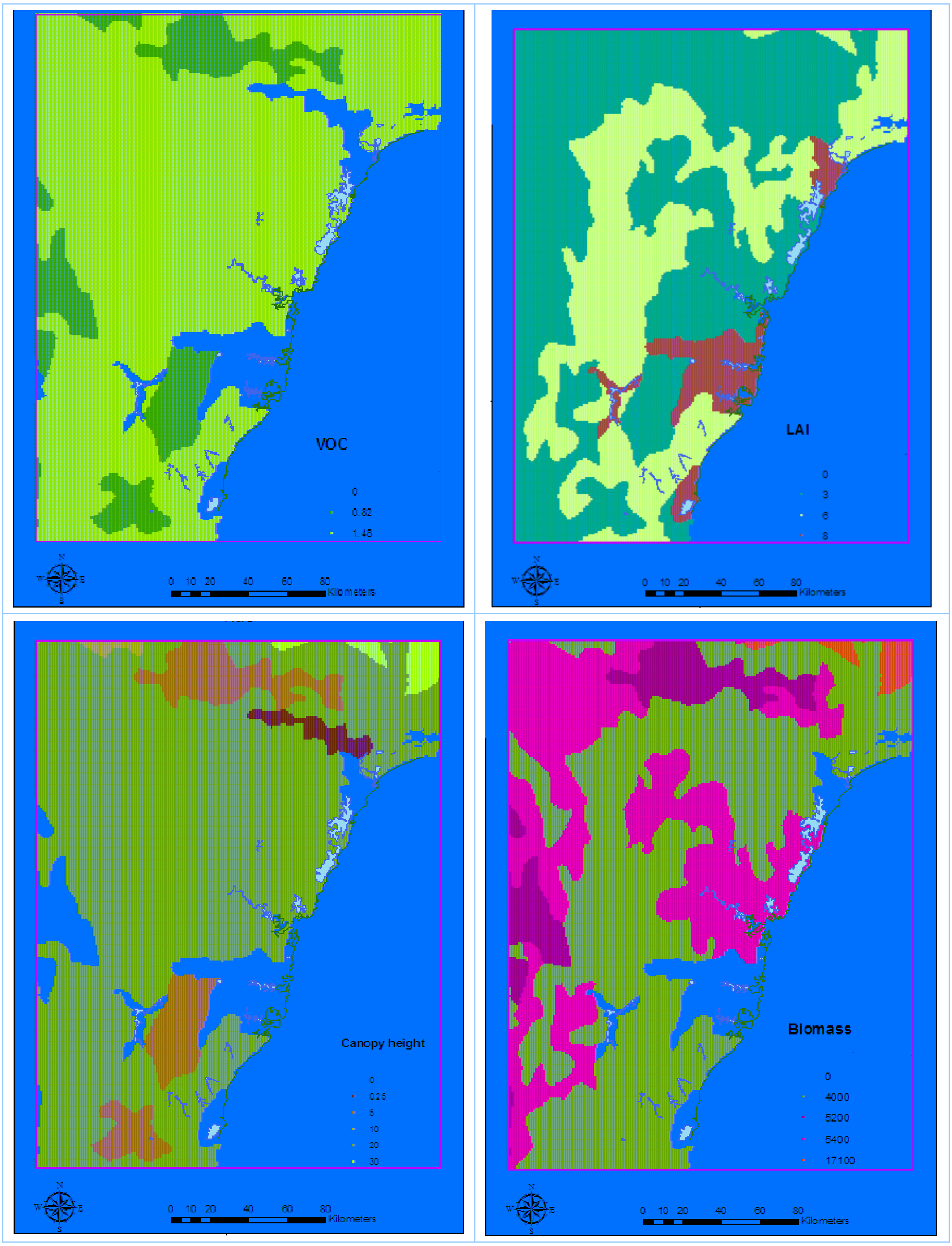


Figure 3-57: BEI-GIS v3.02 genus specific speciated VOC emission rate, leaf area index, canopy height and leaf biomass

Hourly average meteorological data including temperature have been generated for the GMR at 2 km by 2 km grid cells with *TAPM* (Hurley, 2005) and used to estimate: leaf temperature as a function of ambient temperature and flux rate variation with temperature for tree canopy and uncut grass (Azzi et. al., 2004; and Cope et. al., 2009); and flux rate variation with temperature for cut grass (Potter et. al., 2003) at 1 km by 1 km grid cells.

Figure 3-58 shows the monthly average temperature in the GMR by hour of day.

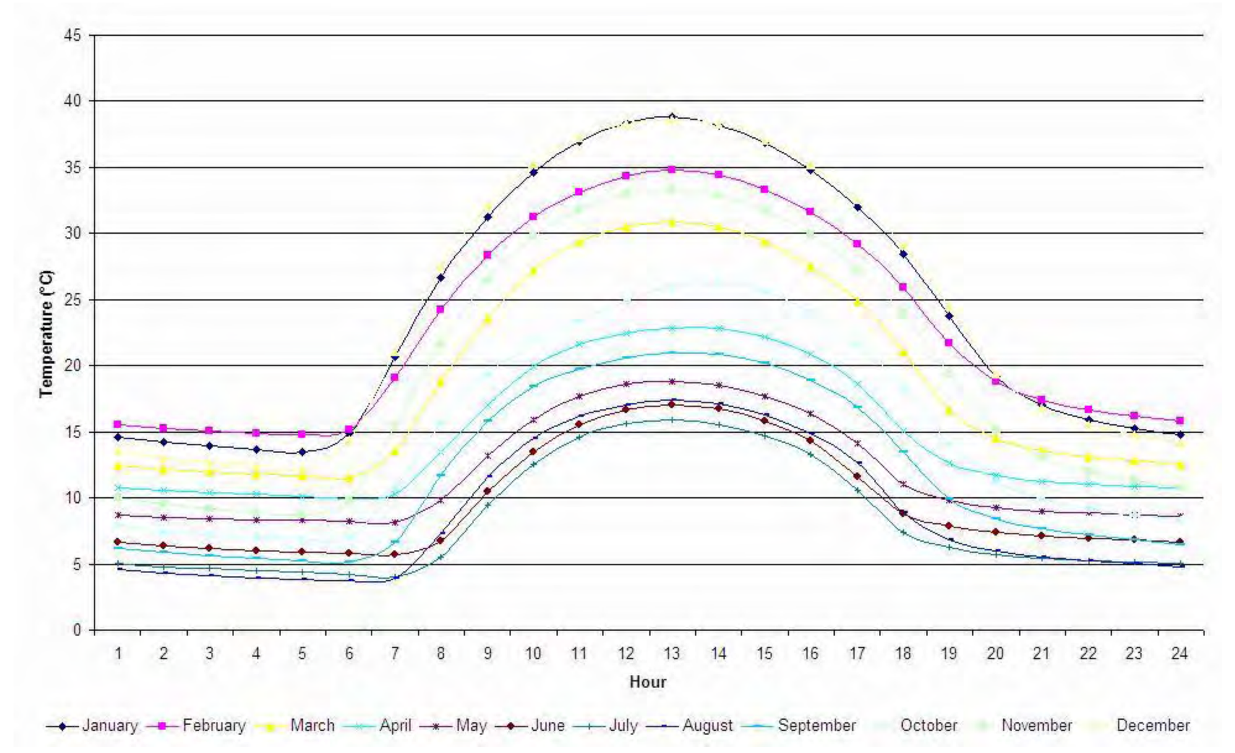


Figure 3-58: Monthly average temperature in the GMR by hour of day

Monthly average temperatures are presented in Table 3-76, while the gridded annual average temperature is shown in Figure 3-59 for the GMR.

Table 3-76: Monthly average temperature in the GMR

Month	Temperature (°C)
January	24.5
February	23.2
March	19.2
April	14.9
May	11.9
June	9.7
July	8.3
August	9.0
September	11.9
October	15.1
November	19.8
December	24.4
Grand Total	16.0

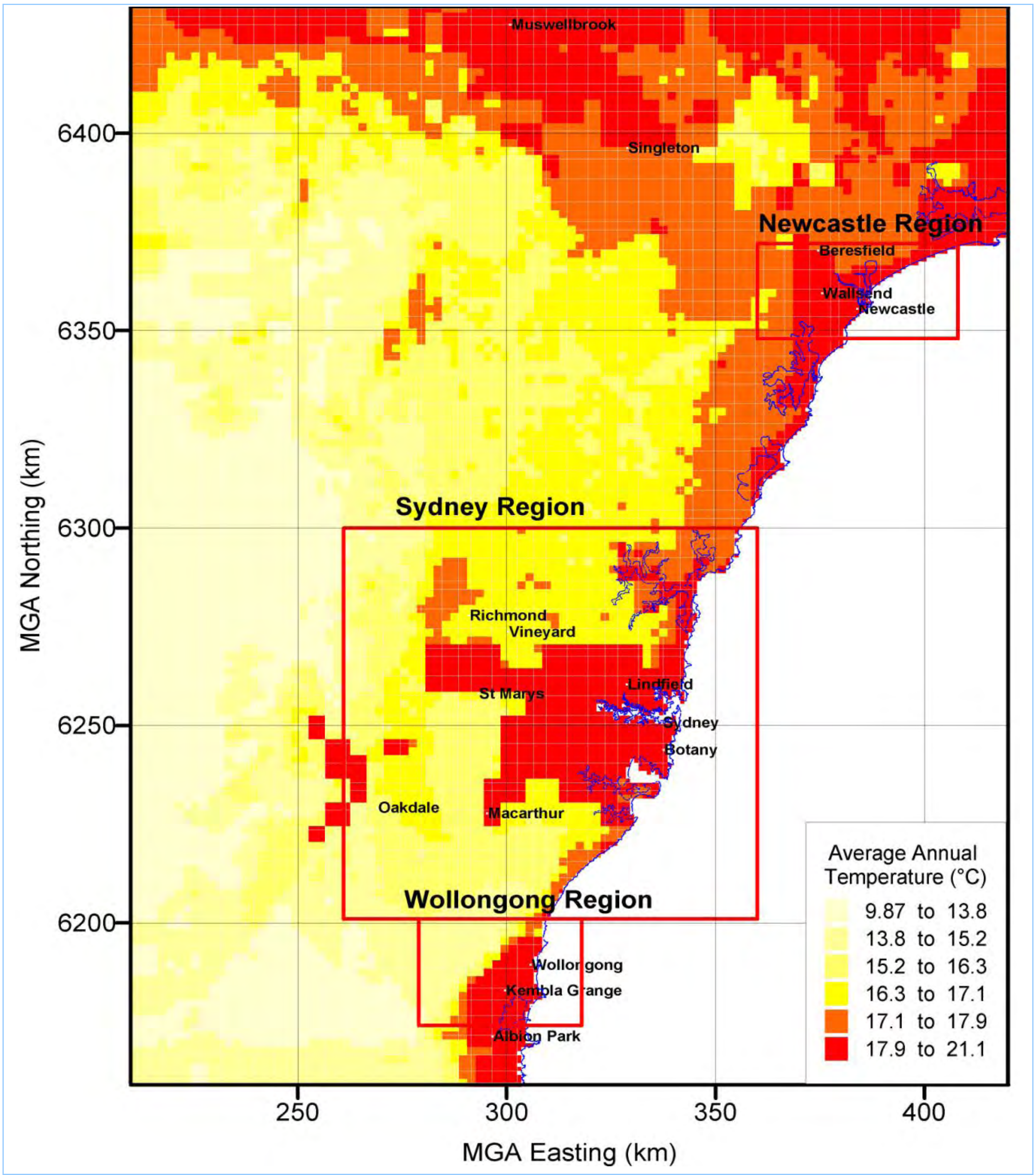


Figure 3-59: Gridded annual average temperature

Emissions of VOC from tree canopy and uncut grass have been estimated using GIS data for genus specific speciated VOC emission rate, leaf area index, canopy height and leaf biomass (Azzi et. al., 2004) data combined with hourly average temperature data (Hurley, 2005) within *BEI-GIS v3.02* (Azzi et. al., 2004).

Figure 3-60 shows the *BEI-GIS v3.02* model options selected for tree canopy and uncut grass emission estimation simulation.

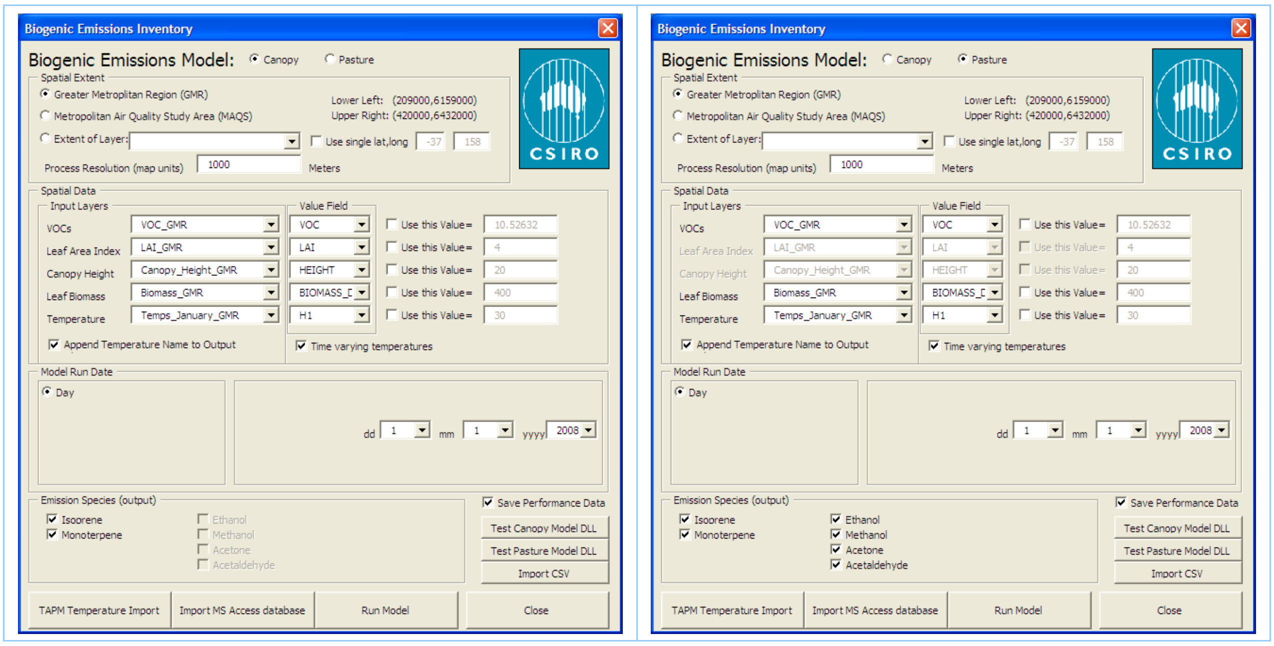


Figure 3-60: BEI-GIS v3.02 tree canopy and uncut grass model options

A domestic survey of lawn mowing and garden equipment ownership and usage has been conducted, which includes each of the 64 local government areas (LGA) located in the GMR. The survey results include data about: equipment type, number and age; engine type and fuel used; frequency and duration of equipment use by hour, day and season; lawn area; and proportion of private and commercial usage (TR, 2009). Gridded 1 km by 1 km dwelling estimates (TDC, 2009) have been used to scale-up the lawn mowing and garden equipment survey results (TR, 2009). A detailed discussion about the activity data for residential lawn mowing and garden equipment is presented in the *Air Emissions Inventory for the Greater Metropolitan Region in New South Wales, 2008 Calendar Year Domestic-Commercial Emissions: Results* report.

The domestic survey data have been used to determine residential lawn mowing and garden equipment frequency and duration of use on an hourly, daily, monthly and annual basis and the lawn area mowed so that cut grass emissions can be estimated (Azzi et. al., 2004).

A commercial survey of lawn mowing and garden equipment ownership and usage has been conducted, which includes 5 golf courses and 9 LGA located in the GMR. The survey results include data about: equipment type, number and age; engine type and fuel used; and frequency and duration of equipment use by hour, day and season (DECC, 2007b). A detailed discussion about the activity data for public open space lawn mowing and garden equipment is presented in the *Air Emissions Inventory for the Greater Metropolitan Region in New South Wales, 2008 Calendar Year Domestic-Commercial Emissions: Results* report.

The 5 golf courses surveyed include Castle Hill Country Club, Killara Golf Club, Manly Golf Club, Pennant Hills Golf Course and St Michaels Golf Club (DECC, 2007b). The golf course survey results (DECC, 2007b) have been used to scale-up activity data to the 162 golf courses in the GMR (Iseekgolf.com, 2011) using the average activity levels for each golf course.

The 9 LGA surveyed include Auburn, Bankstown, Canada Bay, Great Lakes, Kiama, Ku-ring-gai, Newcastle, Port Stephens and Strathfield (DECC, 2007b). While the GMR includes 64 local government areas (LGA), plus two areas designated N/A and unincorporated, the LGA survey results (DECC, 2007b) have been used to scale-up activity data to 59 LGA, plus the two areas designated N/A and unincorporated, using a linear regression of activity levels for each LGA.

The commercial survey data have been used to determine public open space lawn mowing and garden equipment frequency and duration of use on an hourly, daily, monthly and annual basis and the lawn area mowed so that cut grass emissions can be estimated (Azzi et. al., 2004).

Table 3-77 presents the residential and public open space lawn area and annual mowing frequency used to estimate emissions of VOC from cut grass.

Table 3-77: Residential and public open space lawn area and annual lawn mowing frequency

Activity	Lawn area		Lawn mowing frequency (mow/year)
	m^2	ha	
Residential cut-grass	1,014,914,751	101,491	20.89
Public open space cut-grass	201,942,433	20,194	20.89
Grand Total	1,216,857,184	121,686	20.89

3.5.4 *Emission and Speciation Factors*

Table 3-78 summarises the emission and speciation factors used for VOC from vegetation (i.e. tree canopy, uncut grass and cut grass).

Table 3-78: Tree canopy, uncut grass and cut grass emission and speciation factors

Emission source	Substance	Estimation and speciation factor source
Emissions of VOC from tree canopy	Criteria pollutants: VOC	- *Biogenic Emissions in the Greater Sydney Region* (Azzi et. al., 2004) - *Biogenic Emissions Inventory GIS Version 3.02* (Huber, 2005)
	Speciated VOC	- *Biogenic Emissions in the Greater Sydney Region* (Azzi et. al., 2004) - *Biogenic Emissions Inventory GIS Version 3.02* (Huber, 2005)
	Organic air toxics	- *Biogenic Emissions in the Greater Sydney Region* (Azzi et. al., 2004) - *Biogenic Emissions Inventory GIS Version 3.02* (Huber, 2005)
Emissions of VOC from uncut grass	Criteria pollutants: VOC	- *Biogenic Emissions in the Greater Sydney Region* (Azzi et. al., 2004) - *Biogenic Emissions Inventory GIS Version 3.02* (Huber, 2005)
	Speciated VOC	- *Biogenic Emissions in the Greater Sydney Region* (Azzi et. al., 2004) - *Biogenic Emissions Inventory GIS Version 3.02* (Huber, 2005)
	Organic air toxics	- *Biogenic Emissions in the Greater Sydney Region* (Azzi et. al., 2004) - *Biogenic Emissions Inventory GIS Version 3.02* (Huber, 2005)
Emissions of VOC from cut grass	Criteria pollutants: VOC	- *Biogenic Emissions in the Greater Sydney Region* (Azzi et. al., 2004)
	Speciated VOC	- *Emissions of Volatile Organic Compounds (Primarily Oxygenated Species) from Pasture* (Kirstine et. al., 1998)
	Organic air toxics	- *Emissions of Volatile Organic Compounds (Primarily Oxygenated Species) from Pasture* (Kirstine et. al., 1998)

Figure 3-61 shows the estimated annual emission of VOC, speciated VOC and organic air toxics for tree canopy and uncut grass in the GMR using BEI-GIS v3.02.

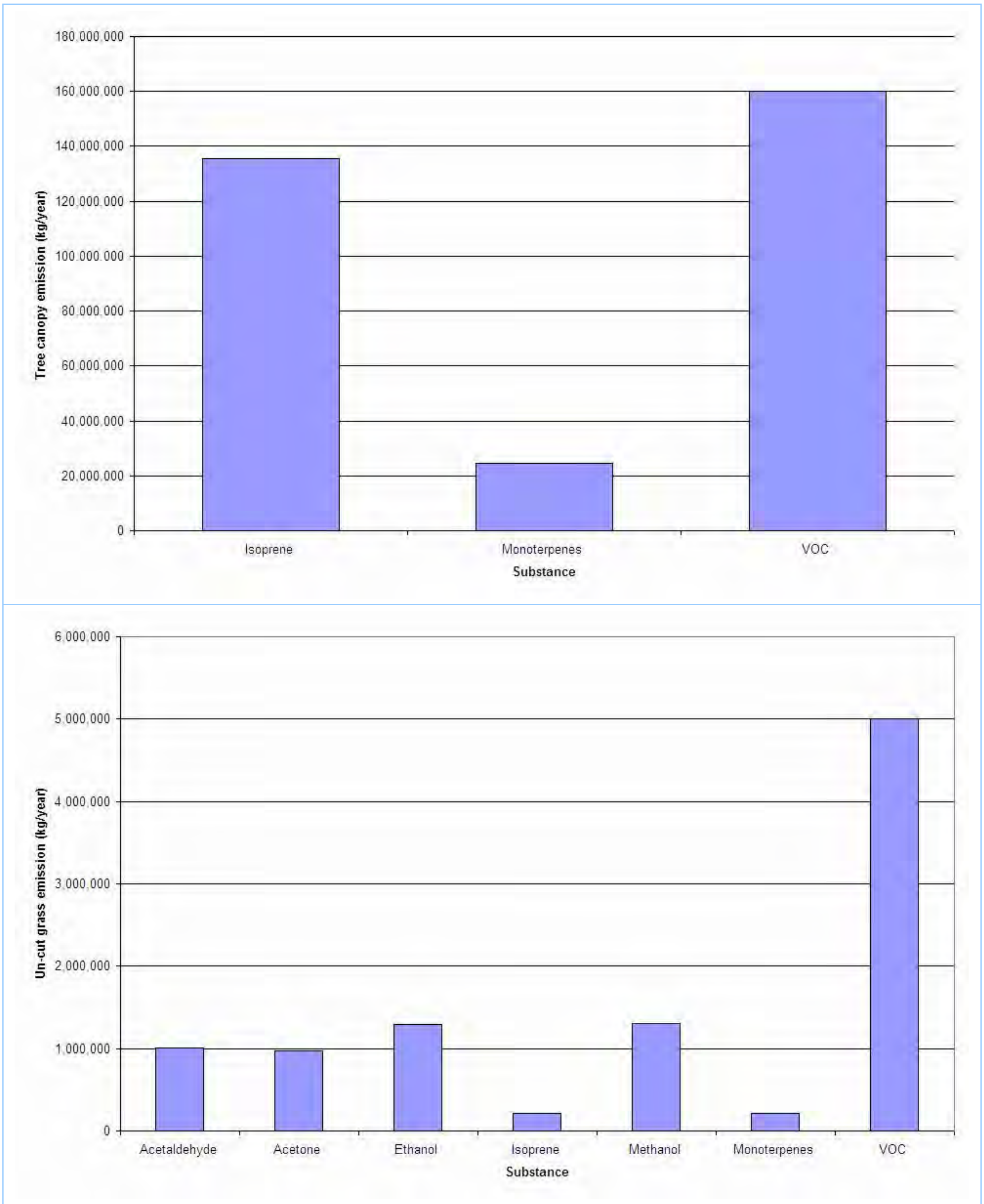


Figure 3-61: BEI-GIS v3.02 tree canopy and uncut grass annual emission of VOC, speciated VOC and organic air toxics in the GMR

Table 3-79 presents the cut grass VOC emission factor (Kirstine et al., 1998).

Table 3-79: Cut grass VOC emission factor

Emission factor	Units of measure
0.0020	g VOC/g leaf biomass/mow

Table 3-80 presents the cut grass VOC and organic air toxic speciation factors (Kirstine et al., 1998).

Table 3-80: Cut grass VOC and organic air toxic speciation factors

Substance	Carbon (%)	VOC (%)
(E)-2-Hexenal	7.50	6.51
(Z)-2-Hexen-1-ol	0.50	0.44
(Z)-2-Hexenyl acetate	0.80	0.75
(Z)-3-Hexen-1-ol	8.90	7.88
(Z)-3-Hexenal	12.70	11.02
(Z)-3-Hexenyl acetate	39.50	37.26
1-Octen-3-ol	1.20	1.02
1-Penten-3-ol	1.20	1.10
3-Pentanone	0.10	0.09
Acetaldehyde	3.60	4.21
Acetone	1.50	1.54
Butanone	0.60	0.57
Ethanol	0.50	0.61
Hexanal	1.60	1.42
Methanol	9.40	15.98
Nonanal	0.80	0.67
Propanol	0.90	0.96
Unidentified	8.70	7.96
Total	100.00	100.00

3.5.5 Spatial Distribution of Emissions

Table 3-68 summarises the data used for spatially allocating emissions of VOC from vegetation (i.e. tree canopy, uncut grass and cut grass).

Table 3-81: Tree canopy, uncut grass and cut grass spatial data

Emission source	Spatial data	Spatial data source
Emissions of VOC from tree canopy	GIS layer for genus specific speciated VOC emission rate, leaf area index, canopy height and leaf biomass combined with gridded 1 km x 1 km temperature estimates	- *Biogenic Emissions in the Greater Sydney Region* (Azzi et. al., 2004) - *Biogenic Emissions Inventory GIS Version 3.02* (Huber, 2005) - *The Air Pollution Model (TAPM) Version 3* (Hurley, 2005)
Emissions of VOC from uncut grass	GIS layer for genus specific speciated VOC emission rate, leaf area index and leaf biomass combined with gridded 1 km x 1 km temperature estimates	- *Biogenic Emissions in the Greater Sydney Region* (Azzi et. al., 2004) - *Biogenic Emissions Inventory GIS Version 3.02* (Huber, 2005) - *The Air Pollution Model (TAPM) Version 3* (Hurley, 2005)
Emissions of VOC from cut grass	Gridded 1 km x 1 km free standing dwelling estimates for residential lawn mowing	- *Forecasts for Free Standing Dwelling from 2006 to 2036* (TDC, 2009)
	Gridded 1 km x 1 km population estimates (≥ 50 per grid cell) for public open space lawn mowing	- *Forecasts for Population from 2006 to 2036* (TDC, 2009)

Emissions of VOC from tree canopy and uncut grass have been spatially distributed using GIS layers for genus specific speciated VOC emission rate, leaf area index, canopy height and leaf biomass combined with gridded 1 km x 1 km temperature estimates.

Figure 3-62 and Figure 3-63 show the spatial distribution of VOC emissions from tree canopy and uncut grass, respectively.

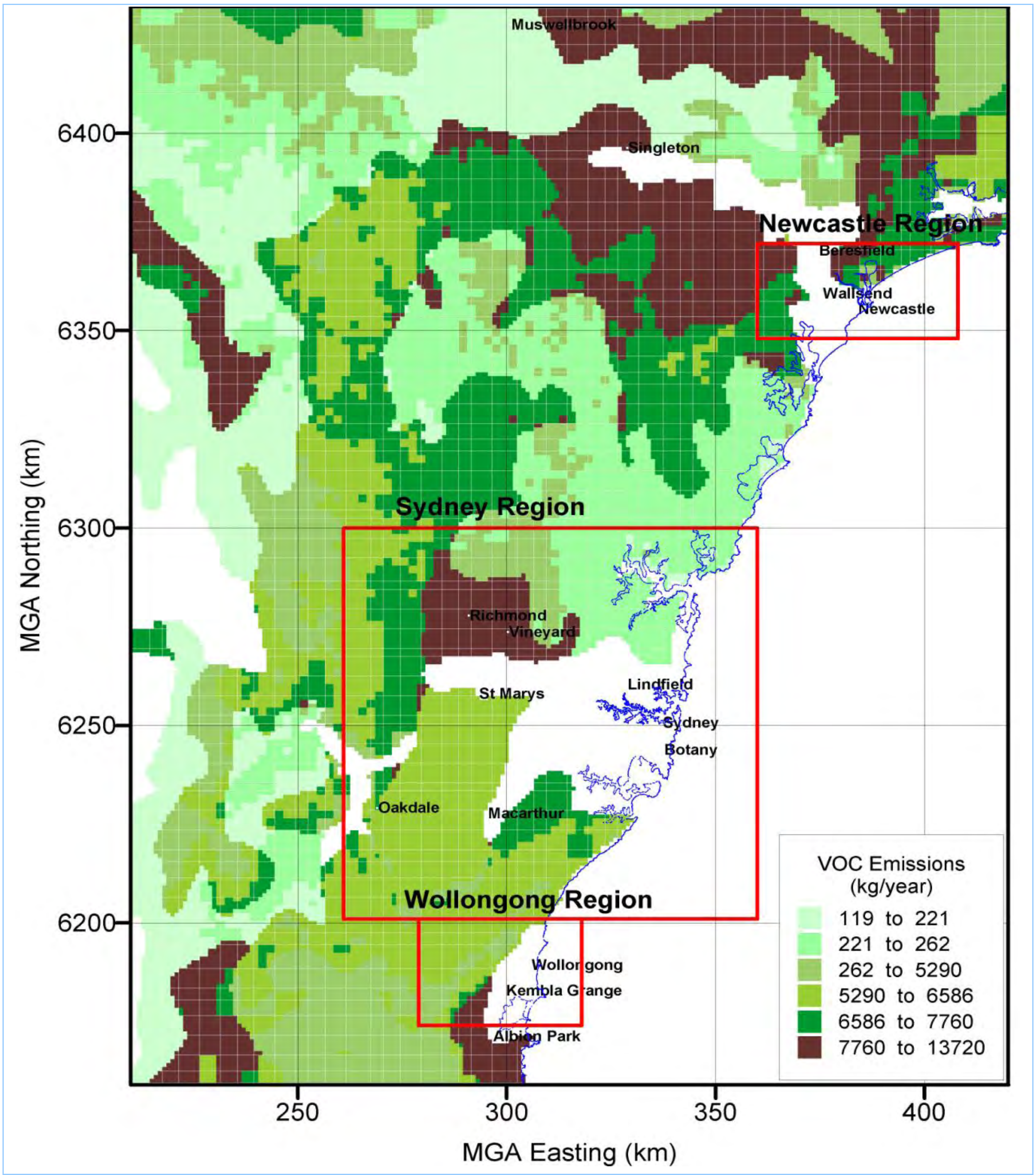


Figure 3-62: Tree canopy spatial distribution of emissions

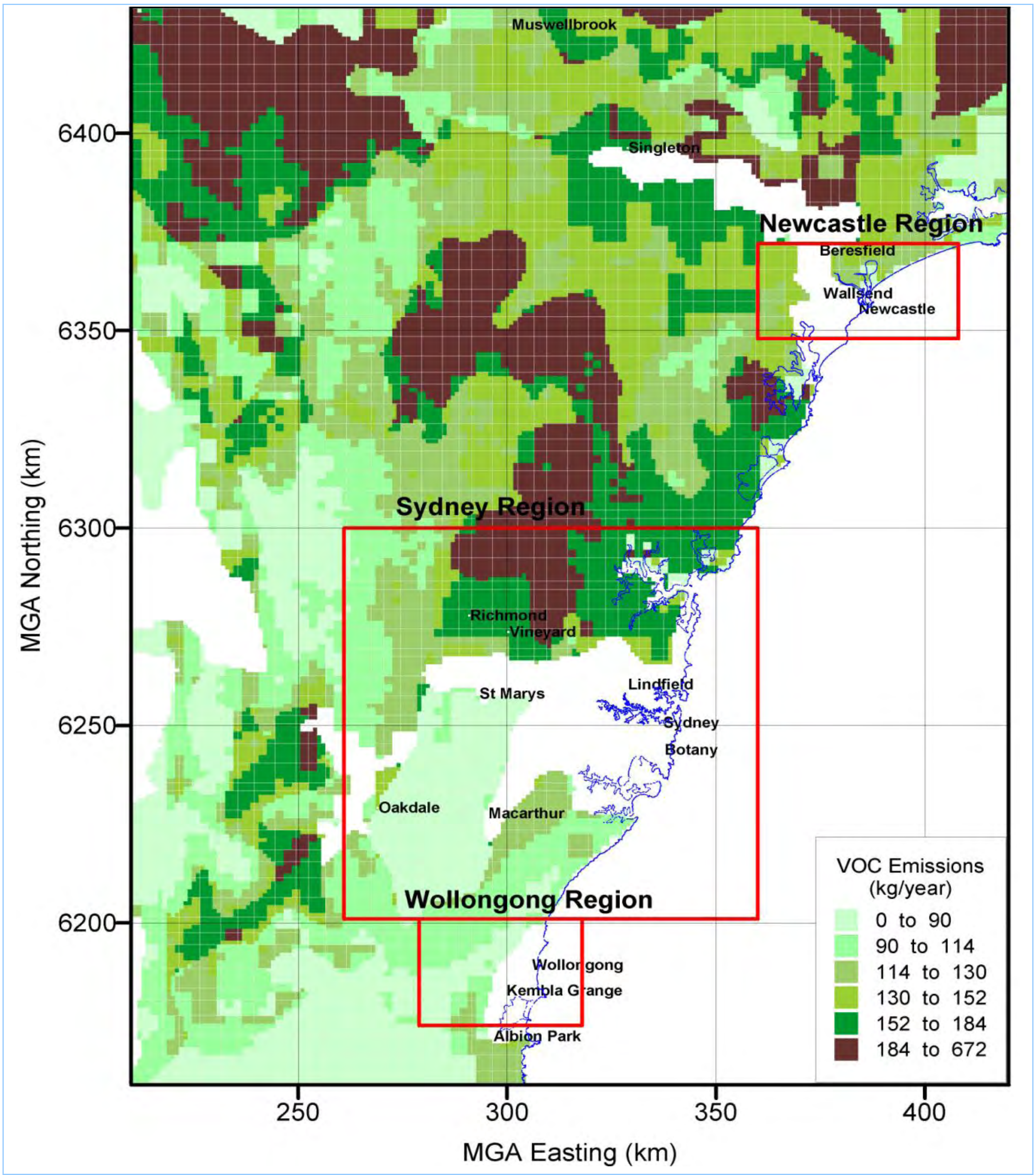


Figure 3-63: Uncut grass spatial distribution of emissions

Emissions of cut grass VOC from residential lawn mowing have been spatially distributed according to lawn area, which is proportional to free standing dwellings in each 1 km by 1 km grid cell (TDC, 2009). The lawn area by LGA and region is presented in Table 3-82 and shown in Figure 3-64.

Table 3-82: Residential cut grass spatial distribution of lawn area by LGA and region

LGA	2008 proportion of lawn area (%)				
	Newcastle	Non Urban	Sydney	Wollongong	Grand Total
Ashfield	-	-	0.72	-	0.72
Auburn	-	-	0.94	-	0.94
Bankstown	-	-	3.37	-	3.37
Bathurst Regional	-	2.78×10^{-3}	-	-	2.78×10^{-3}
Baulkham Hills	-	2.50×10^{-3}	3.50	-	3.50
Blacktown	-	-	5.92	-	5.92
Blue Mountains	-	0.70	1.28	-	1.97
Botany Bay	-	-	0.53	-	0.53
Burwood	-	-	0.47	-	0.47
Camden	-	-	1.19	-	1.19
Campbelltown	-	-	3.26	-	3.26
Canada Bay	-	-	1.06	-	1.06
Canterbury	-	-	2.08	-	2.08
Cessnock	4.90×10^{-2}	1.11	-	-	1.15
Dungog	-	0.18	-	-	0.18
Fairfield	-	-	3.39	-	3.39
Gosford	-	1.06	2.87	-	3.93
Goulburn Mulwaree	-	5.41×10^{-3}	-	-	5.41×10^{-3}
Great Lakes	-	8.49×10^{-2}	-	-	8.49×10^{-2}
Hawkesbury	-	2.90×10^{-2}	1.34	-	1.37
Holroyd	-	-	1.77	-	1.77
Hornsby	-	4.26×10^{-3}	3.07	-	3.08
Hunters Hill	-	-	0.15	-	0.15
Hurstville	-	-	1.50	-	1.50
Kiama	-	0.32	-	-	0.32
Kogarah	-	-	0.92	-	0.92
Ku-ring-gai	-	-	2.14	-	2.14
Lake Macquarie	2.46	2.21	-	-	4.66
Lane Cove	-	-	0.43	-	0.43
Leichhardt	-	-	0.83	-	0.83
Lithgow	-	0.45	-	-	0.45
Liverpool	-	-	3.26	-	3.26
Maitland	0.12	1.39	-	-	1.51
Manly	-	-	0.49	-	0.49
Marrickville	-	-	1.51	-	1.51
Mid-western Regional	-	6.41×10^{-2}	-	-	6.41×10^{-2}
Mosman	-	-	0.42	-	0.42
Muswellbrook	-	0.31	-	-	0.31
N/A	1.46×10^{-2}	6.58×10^{-2}	0.27	3.05×10^{-2}	0.38
Newcastle	3.48	-	-	-	3.48
North Sydney	-	-	0.55	-	0.55
Oberon	-	2.87×10^{-2}	-	-	2.87×10^{-2}
Parramatta	-	-	2.50	-	2.50
Penrith	-	-	3.81	-	3.81
Pittwater	-	-	1.16	-	1.16

LGA	2008 proportion of lawn area (%)				
	Newcastle	Non Urban	Sydney	Wollongong	Grand Total
Port Stephens	7.89×10^{-2}	1.31	-	-	1.39
Randwick	-	-	1.69	-	1.69
Rockdale	-	-	1.39	-	1.39
Ryde	-	-	1.90	-	1.90
Shellharbour	-	1.10	-	0.34	1.44
Shoalhaven	-	2.06×10^{-3}	-	-	2.06×10^{-3}
Singleton	-	0.44	-	-	0.44
Strathfield	-	-	0.50	-	0.50
Sutherland	-	-	4.15	-	4.15
Sydney	-	-	1.53	-	1.53
Unincorporated	-	-	0.54	-	0.54
Upper Lachlan	-	8.65×10^{-4}	-	-	8.65×10^{-4}
Warringah	-	-	2.39	-	2.39
Waverley	-	-	0.64	-	0.64
Willoughby	-	-	0.99	-	0.99
Wingecarribee	-	1.10	6.02×10^{-3}	1.94×10^{-3}	1.11
Wollondilly	-	1.49×10^{-2}	0.93	4.83×10^{-4}	0.95
Wollongong	-	-	0.33	3.72	4.05
Woollahra	-	-	0.50	-	0.50
Wyong	-	3.57	-	-	3.57
Grand Total	6.20	15.55	74.16	4.09	100.00

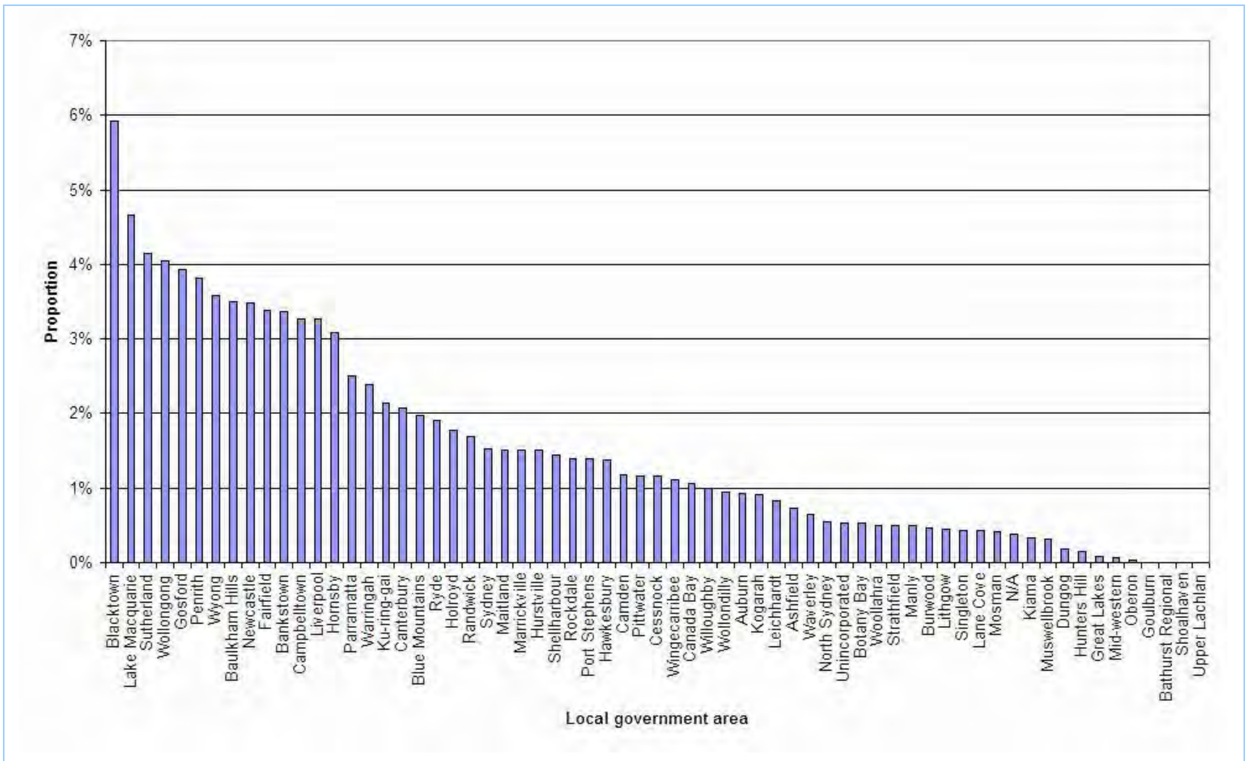


Figure 3-64: Residential cut grass spatial distribution of lawn area by LGA and region

Figure 3-65 shows the spatial distribution of residential cut grass emissions.

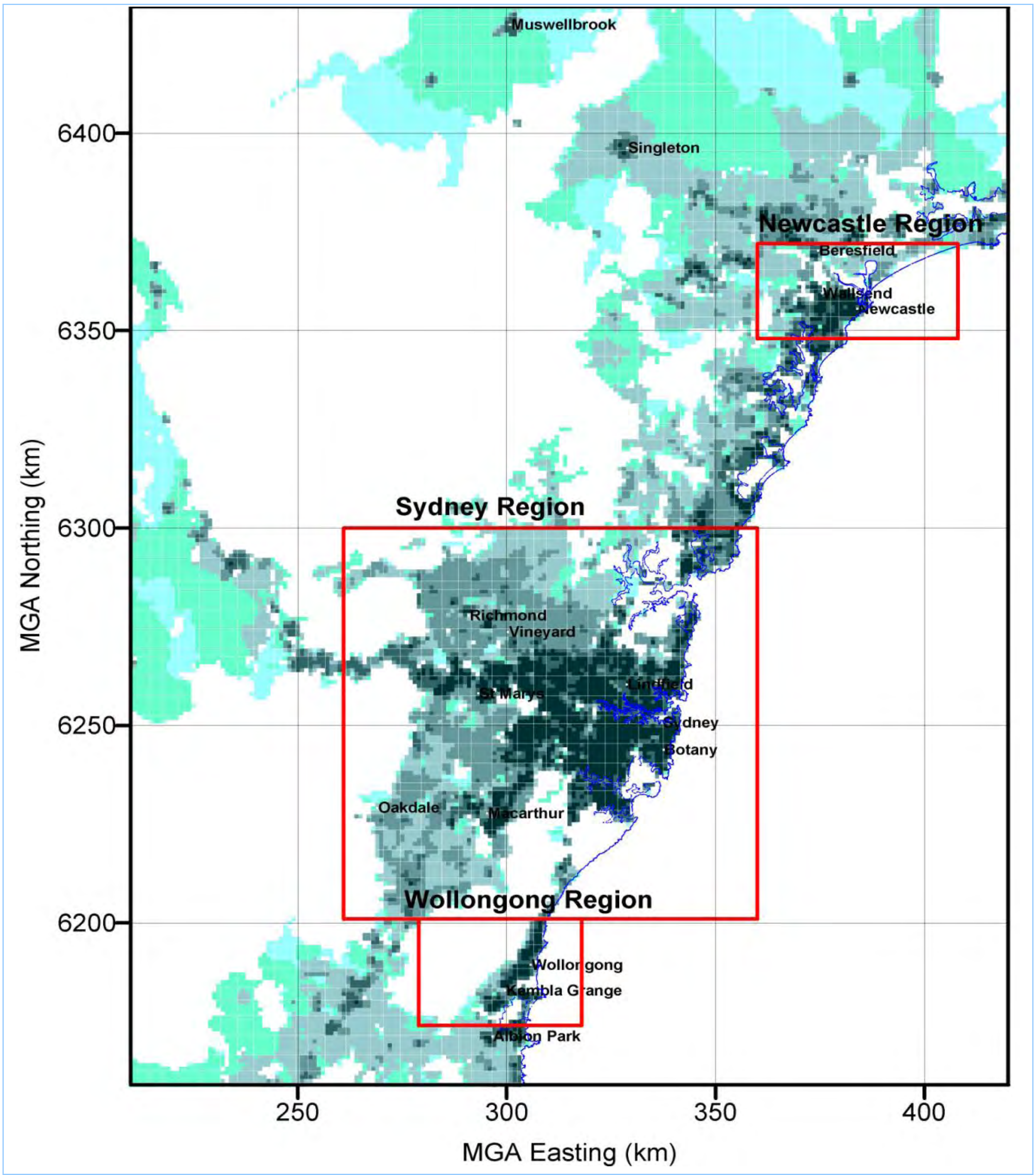


Figure 3-65: Residential cut grass spatial distribution of emissions

Emissions of cut grass VOC from public open space lawn mowing have been spatially distributed according to lawn area, which is proportional to population ≥ 50 persons in each 1 km by 1 km grid cell (TDC, 2009). The lawn area by LGA and region is presented in Table 3-83 and shown in Figure 3-66.

Table 3-83: Public open space cut grass spatial distribution of lawn area by LGA and region

LGA	2008 proportion of lawn area (%)				
	Newcastle	Non Urban	Sydney	Wollongong	Grand Total
Ashfield	-	-	0.92	-	0.92
Auburn	-	-	1.34	-	1.34
Bankstown	-	-	3.36	-	3.36
Baulkham Hills	-	-	3.23	-	3.23
Blacktown	-	-	5.51	-	5.51
Blue Mountains	-	0.48	1.00	-	1.48
Botany Bay	-	-	0.64	-	0.64
Burwood	-	-	0.58	-	0.58
Camden	-	-	1.04	-	1.04
Campbelltown	-	-	2.88	-	2.88
Canada Bay	-	-	1.14	-	1.14
Canterbury	-	-	2.67	-	2.67
Cessnock	3.36×10^{-2}	0.79	-	-	0.83
Dungog	-	6.63×10^{-2}	-	-	6.63×10^{-2}
Fairfield	-	-	3.64	-	3.64
Gosford	-	0.85	2.22	-	3.06
Great Lakes	-	3.15×10^{-2}	-	-	3.15×10^{-2}
Hawkesbury	-	5.14×10^{-3}	1.04	-	1.04
Holroyd	-	-	1.84	-	1.84
Hornsby	-	-	3.06	-	3.06
Hunters Hill	-	-	0.18	-	0.18
Hurstville	-	-	1.58	-	1.58
Kiama	-	0.26	-	-	0.26
Kogarah	-	-	1.11	-	1.11
Ku-ring-gai	-	-	2.06	-	2.06
Lake Macquarie	1.98	1.72	-	-	3.70
Lane Cove	-	-	0.55	-	0.55
Leichhardt	-	-	0.77	-	0.77
Lithgow	-	0.29	-	-	0.29
Liverpool	-	-	3.40	-	3.40
Maitland	0.10	1.11	-	-	1.21
Manly	-	-	0.65	-	0.65
Marrickville	-	-	1.68	-	1.68
Mid-western Regional	-	3.67×10^{-2}	-	-	3.67×10^{-2}
Mosman	-	-	0.60	-	0.60
Muswellbrook	-	0.23	-	-	0.23
N/A	2.48×10^{-2}	5.06×10^{-2}	0.36	6.08×10^{-2}	0.49
Newcastle	2.90	-	-	-	2.90
North Sydney	-	-	1.04	-	1.04
Oberon	-	1.64×10^{-2}	-	-	1.64×10^{-2}
Parramatta	-	-	2.94	-	2.94
Penrith	-	-	3.36	-	3.36
Pittwater	-	-	1.05	-	1.05
Port Stephens	3.70×10^{-2}	0.98	-	-	1.02
Randwick	-	-	2.53	-	2.53

LGA	2008 proportion of lawn area (%)				
	Newcastle	Non Urban	Sydney	Wollongong	Grand Total
Rockdale	-	-	1.73	-	1.73
Ryde	-	-	2.03	-	2.03
Shellharbour	-	0.94	-	0.30	1.24
Singleton	-	0.30	-	-	0.30
Strathfield	-	-	0.75	-	0.75
Sutherland	-	-	4.10	-	4.10
Sydney	-	-	3.23	-	3.23
Unincorporated	-	-	0.82	-	0.82
Warringah	-	-	2.72	-	2.72
Waverley	-	-	1.10	-	1.10
Willoughby	-	-	1.34	-	1.34
Wingecarribee	-	0.73	1.48×10^{-3}	-	0.73
Wollondilly	-	1.10×10^{-2}	0.60	-	0.61
Wollongong	-	-	0.29	3.41	3.70
Woollahra	-	-	0.86	-	0.86
Wyong	-	2.72	-	-	2.72
Grand Total	5.08	11.62	79.53	3.77	100.00

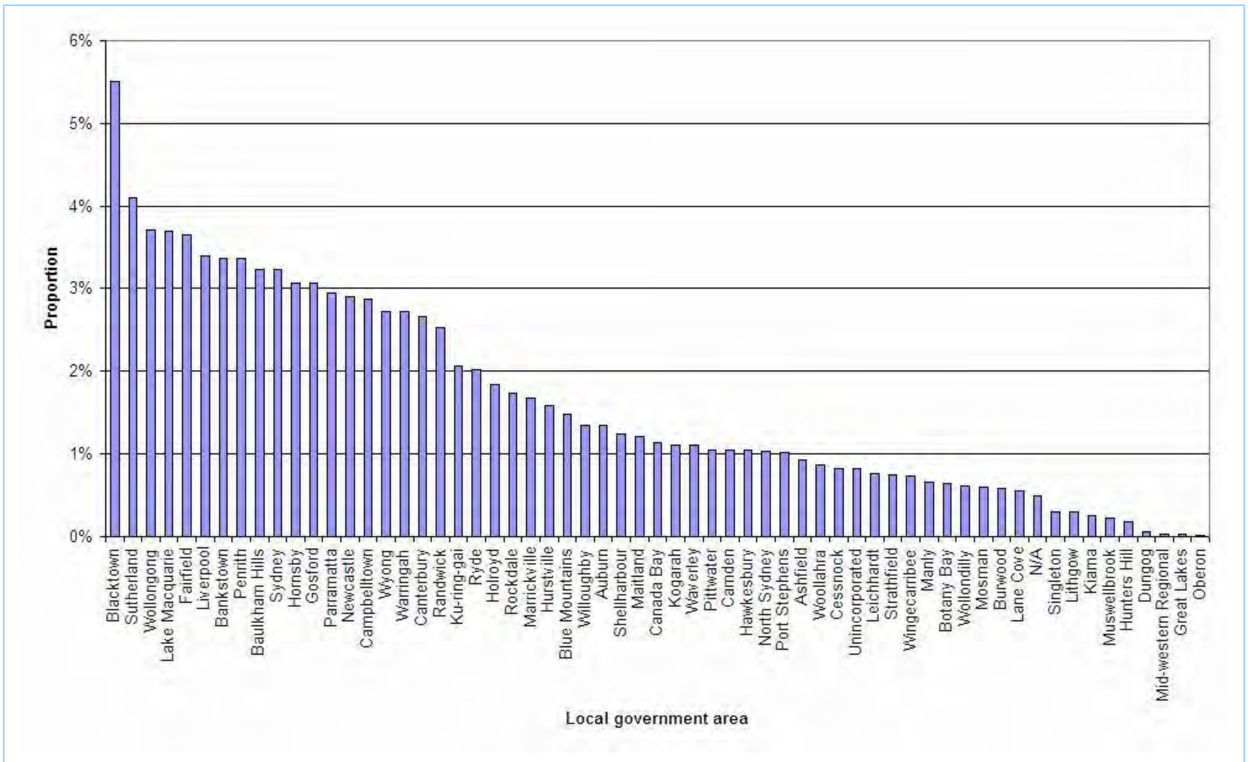


Figure 3-66: Public open space cut grass spatial distribution of lawn area by LGA

Figure 3-67 shows the spatial distribution of public open space cut grass emissions.

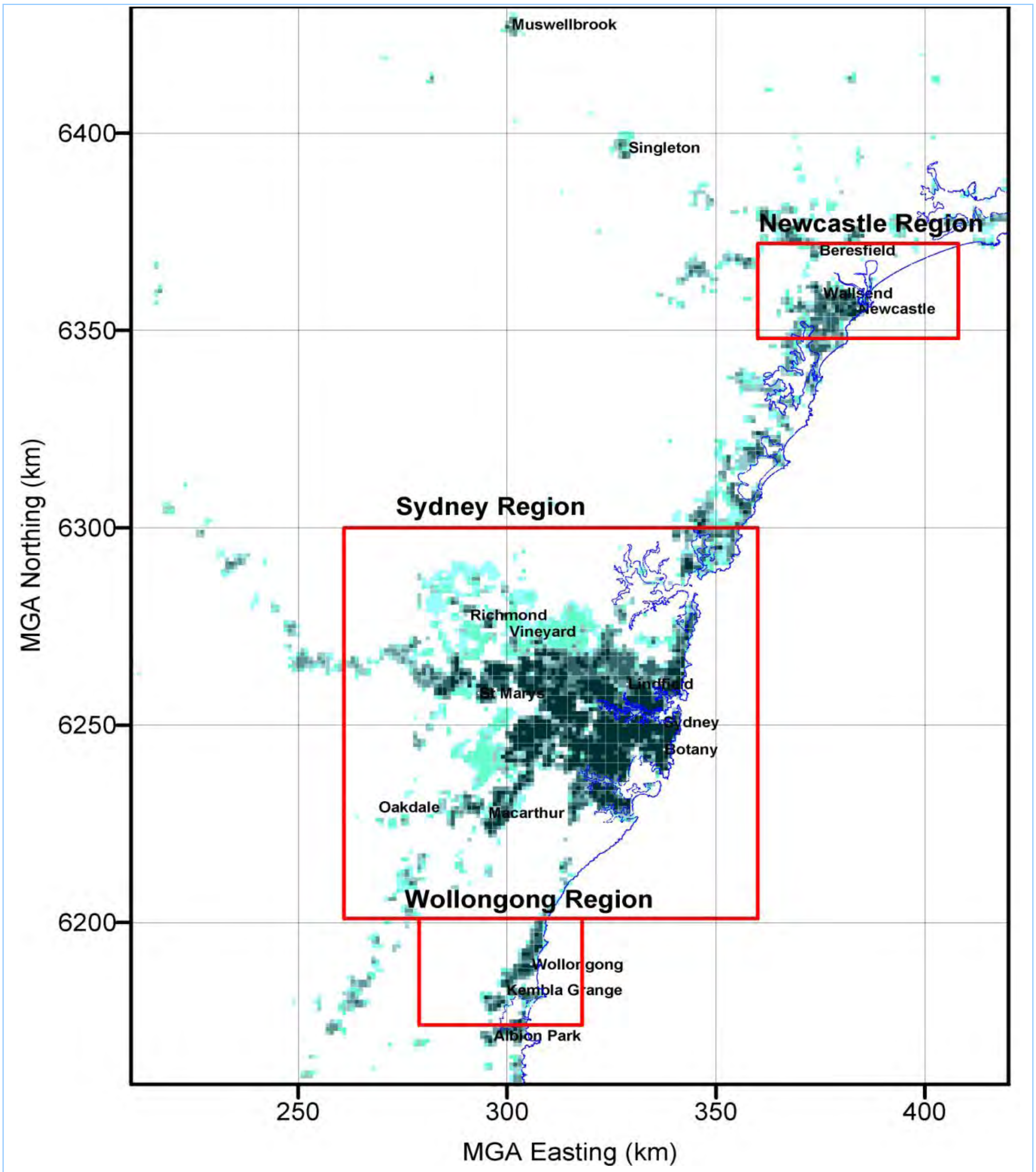


Figure 3-67: Public open space cut grass spatial distribution of emissions

3.5.6 *Temporal Variation of Emissions*

Table 3-84 summarises the data used to estimate the temporal variation in emissions of VOC from vegetation (i.e. tree canopy, uncut grass and cut grass).

Table 3-84: Tree canopy, uncut grass and cut grass temporal data

Emission source	Temporal data	Temporal data source
Emissions of VOC from tree canopy	Monthly, daily and hourly: Gridded 1 km x 1 km leaf temperature as a function of ambient temperature estimates	- *Biogenic Emissions in the Greater Sydney Region* (Azzi et. al., 2004) - *Biogenic Emissions Inventory GIS Version 3.02* (Huber, 2005) - *The Air Pollution Model (TAPM) Version 3* (Hurley, 2005)
Emissions of VOC from uncut grass	Monthly, daily and hourly: Gridded 1 km x 1 km leaf temperature as a function of ambient temperature estimates	- *Biogenic Emissions in the Greater Sydney Region* (Azzi et. al., 2004) - *Biogenic Emissions Inventory GIS Version 3.02* (Huber, 2005) - *The Air Pollution Model (TAPM) Version 3* (Hurley, 2005)
Emissions of VOC from cut grass	Monthly: Lawn mowing frequency combined with gridded 1 km x 1 km temperature correction factor estimates	- Domestic lawn mowing: *Domestic Lawn Mowing Pollution Survey* (TR, 2009) - Public open space lawn mowing: *Public Open Space Lawn Mowing Pollution Survey* (DECC, 2007) - *The Air Pollution Model (TAPM) Version 3* (Hurley, 2005) - *Modeling Terrestrial Biogenic Sources of Oxygenated Organic Emissions* (Potter et. al., 2003)
	Daily and hourly: Lawn mowing frequency combined with exponential decay for initial leaf wounding followed by leaf drying emission phases	- Domestic lawn mowing: *Domestic Lawn Mowing Pollution Survey* (TR, 2009) - Public open space lawn mowing: *Public Open Space Lawn Mowing Pollution Survey* (DECC, 2007) - *Biogenic Emissions in the Greater Sydney Region* (Azzi et. al., 2004) - *Emissions of Volatile Organic Compounds (Primarily Oxygenated Species) from Pasture* (Kirstine et. al., 1998)

Hourly average meteorological data including temperature have been generated for the GMR at 2 km by 2 km grid cells with *TAPM* (Hurley, 2005) and used to estimate leaf temperature as a function of ambient temperature and flux rate variation with temperature for tree canopy and uncut grass (Azzi et. al., 2004; and Cope et. al., 2009) at 1 km by 1 km grid cells.

While the temporal variation in emissions is different for each 1 km by 1 km grid cell where there are emissions of VOC from tree canopy and uncut grass, Figure 3-68, Figure 3-69 and Figure 3-70 show the hourly, daily and monthly variation in VOC, speciated VOC and organic air toxics emissions in the GMR for all areas with tree canopy and uncut grass.

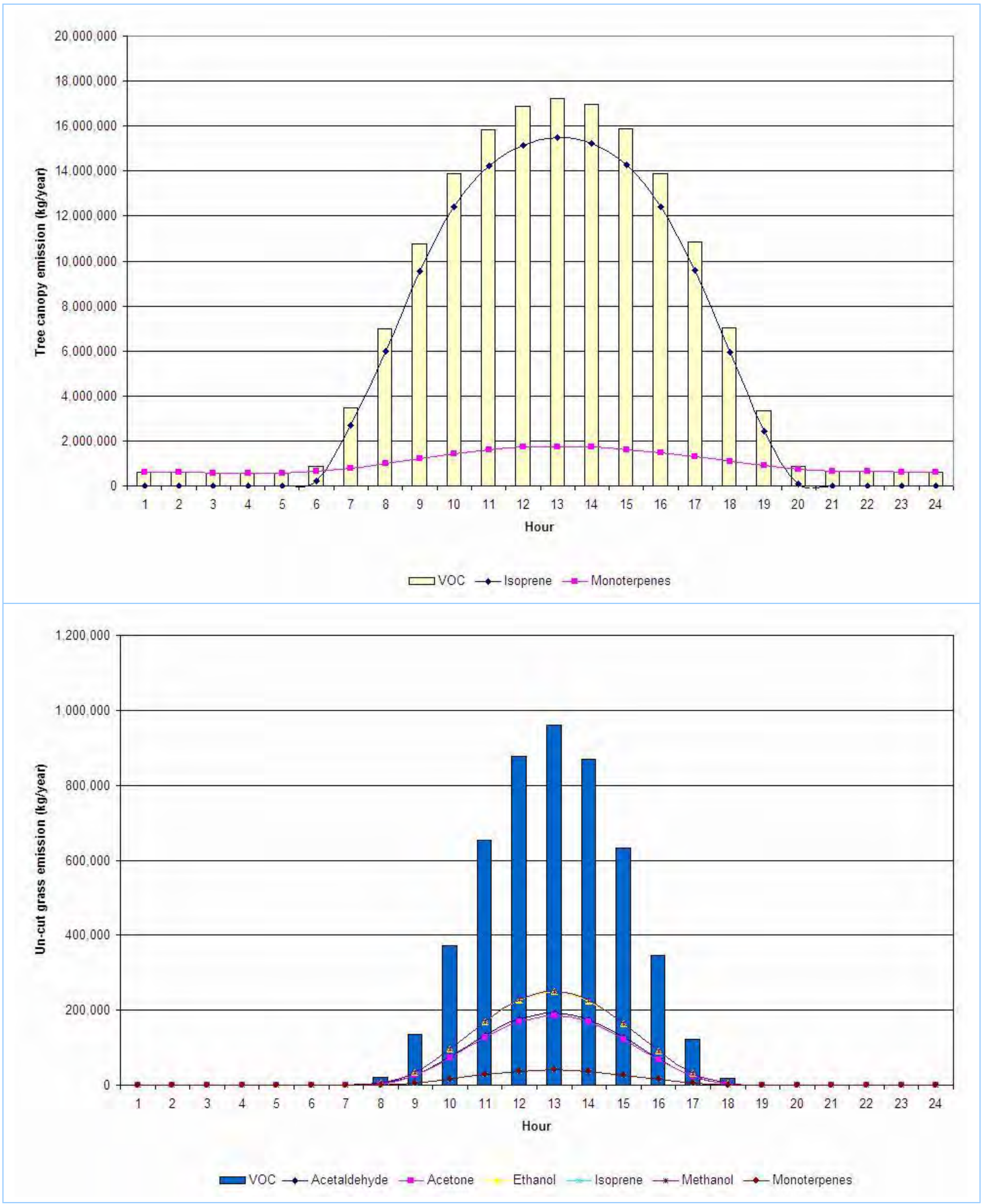


Figure 3-68: Tree canopy and uncut grass hourly variation in VOC, speciated VOC and organic air toxics emissions

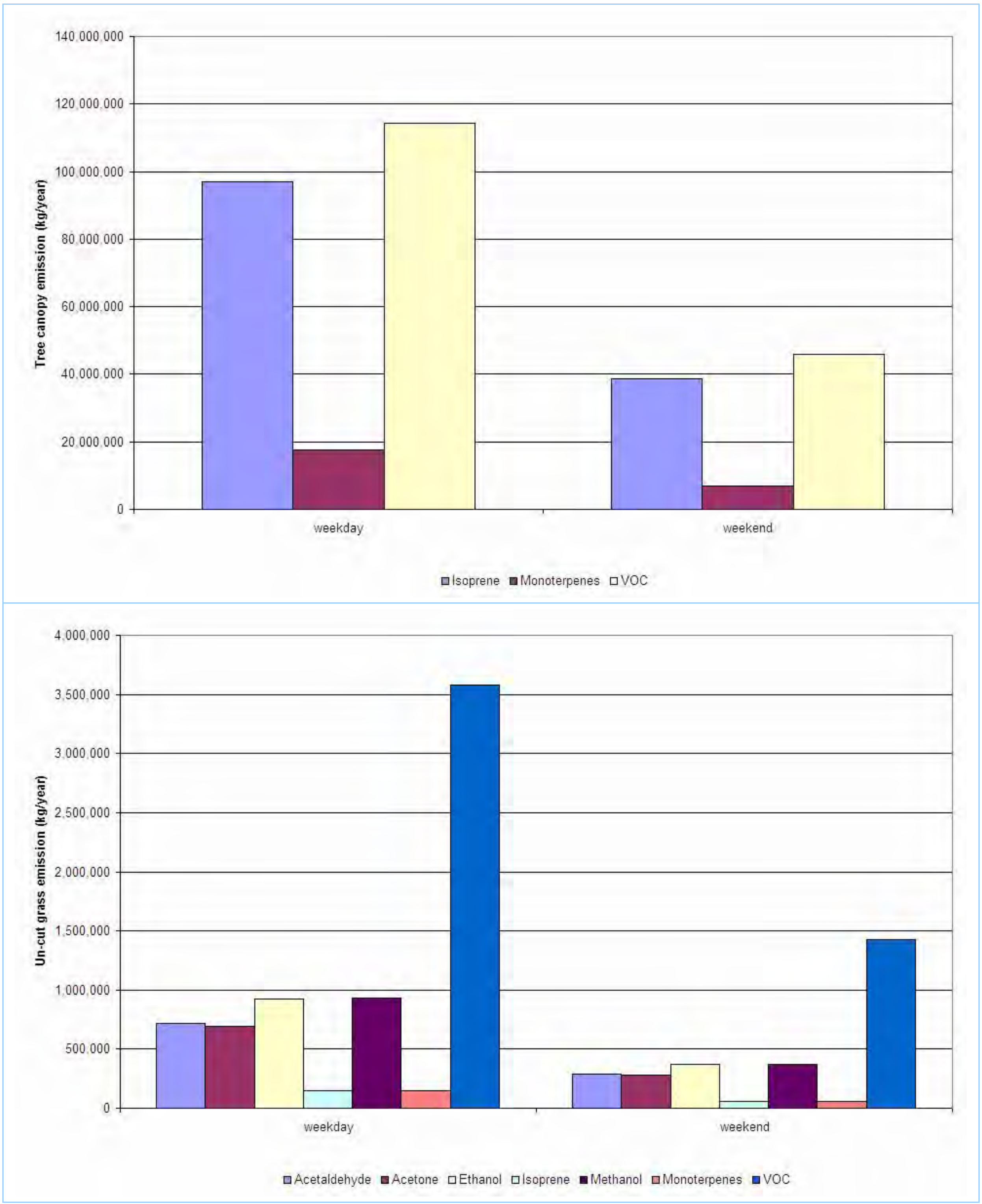


Figure 3-69: Tree canopy and uncut grass daily variation in VOC, speciated VOC and organic air toxics emissions

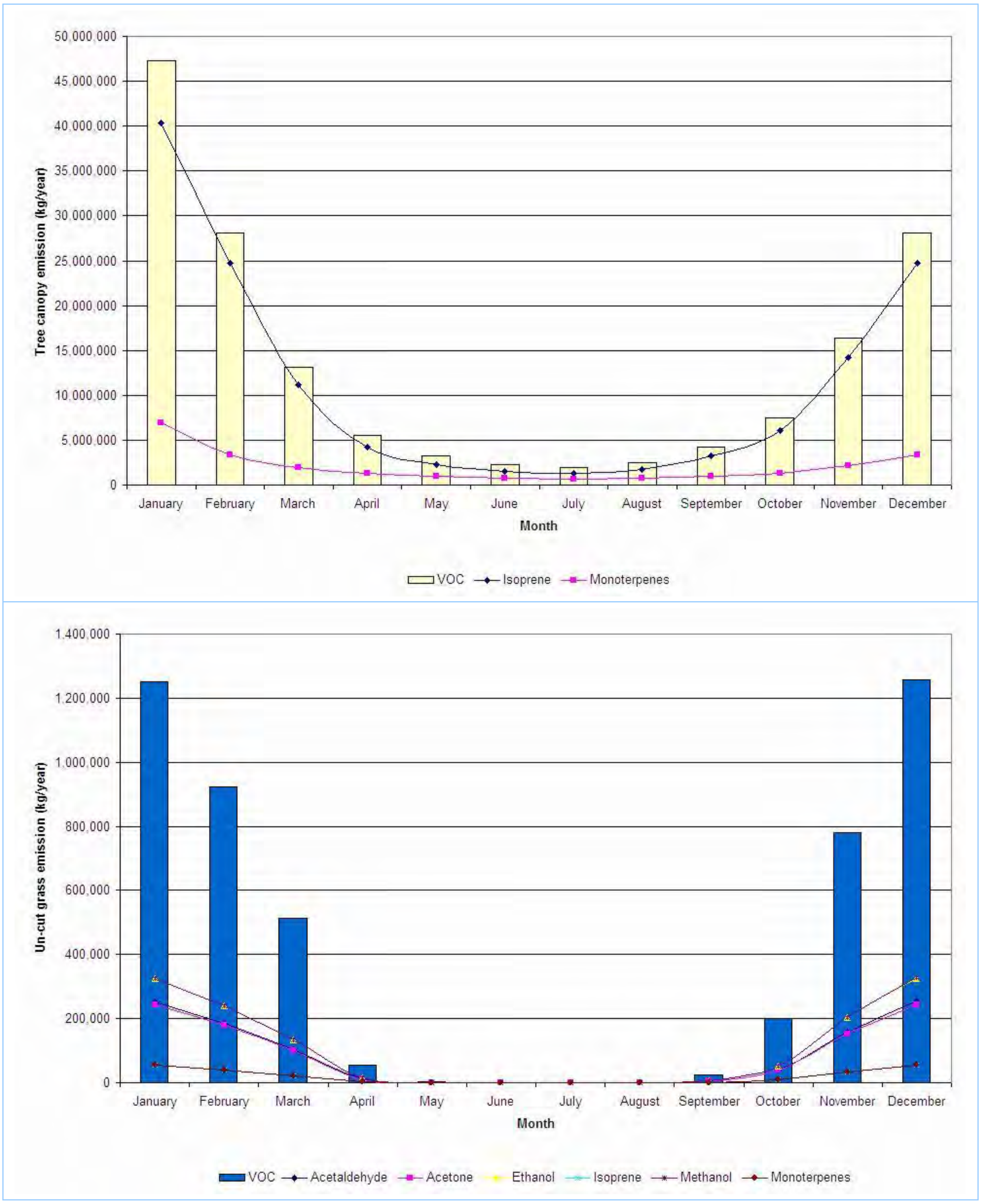


Figure 3-70: Tree canopy and uncut grass monthly variation in VOC, speciated VOC and organic air toxics emissions

Domestic (TR, 2009) and commercial (DECC, 2007b) survey data have been used to determine lawn mowing and garden equipment frequency and duration of use on an hourly, daily and monthly basis so the temporal variation in cut grass emissions can be estimated.

The hourly and daily temporal variation in emissions from cut grass has been estimated by combining the hourly and daily frequency and duration of lawn mowing and garden equipment use with the cut grass event based model results presented in Table 3-85, Table 3-86 and Table 3-87.

Monthly emissions of VOC, speciated VOC and organic air toxics from residential and public open space cut grass have been estimated by multiplying the results of Equation 18 (Azzi et. al., 2004) with the normalised monthly cut grass temperature correction factor. By summing all of the monthly cut grass temperature correction factors for the year and then dividing each individual month by the sum, the cut grass temperature correction factor has been normalised to 1. These normalised monthly numbers provide the temperature based temporal profile. Annual emissions are calculated first and then multiplied by the normalised monthly cut grass temperature correction factor to estimate monthly emissions.

The monthly temporal variation in emissions from cut grass has been estimated by combining the monthly frequency and duration of lawn mowing and garden equipment use with the cut grass temperature correction factor. The cut grass temperature correction factor for each month has been estimated using ambient temperature within Equation 20 (Potter et. al., 2003):

$$CF_{i,j} = P_{i,j} \times 0.00192 \times \exp\left[0.11\left(T_{a,i,j} - 303\right)\right] \Big/ \sum_{i=1}^{24}\left(\sum_{j=1}^{12}\left(P_{i,j} \times 0.00192 \times \exp\left[0.11\left(T_{a,i,j} - 303\right)\right]\right)\right) \quad \textbf{Equation 20}$$

where:			
$CF_{i,j}$	=	Cut grass temperature correction factor for hour i and month j	(-)
$P_{i,j}$	=	Proportion of total VOC emission rate for hour i and month j	(number)
$T_{a,i,j}$	=	Temperature of ambient air for hour i and month j	(K)
i	=	Hour (from "1" to "24")	(number)
j	=	Month (from "1" to "12")	(number)

During the primary leaf wounding phase (commencing at t = 0 h), VOC emissions from cut grass exponentially decay at the rate of -0.3 h^{-1} and 0.0 h^{-1} during day 1 to 2 and day 3 to 7, respectively, while cumulative VOC emissions during this phase make up approximately 33% of the total for both phases (Azzi et. al., 2004; and Kirstine et. al., 1998). The secondary leaf drying phase (commencing at t = 3 h) exhibits exponential decay rates of -0.0438 h^{-1}, -0.1141 h^{-1} and 0.0 h^{-1} during day 1, day 2 and day 3 to 7, respectively, while cumulative VOC emissions during this phase make up approximately 67% of the total for both phases (Azzi et. al., 2004; and Kirstine et. al., 1998).

VOC emissions from cut grass have been estimated to be 2 x 10^{-3} kg/kg leaf biomass/mow, 8 x 10^{-5} kg/m^2/mow or 1.67 x 10^{-3} kg/m^2 based on an annual mowing frequency of 20.89 (DECC, 2007b; and TR, 2009).

Table 3-85, Table 3-86 and Table 3-87 present key parameters for estimating the hourly and daily temporal variation in VOC emission rate from cut grass, while Figure 3-71 shows the cut grass event based hourly and daily variation in VOC emission rate.

Table 3-85: Cut grass hourly and daily temporal variation in VOC emission rate during primary leaf wounding and secondary drying phase

Grass cutting phase	Time period (day)	Exponential decay rate (h^{-1})	Proportion of VOC (%)
Leaf wounding	1 to 2	-0.3000	33.33
	3 to 7	0.0000	7.80×10^{-4}
Leaf drying	1	-0.0438	46.69
	2	-0.1141	9.98
	3 to 7	0.0000	10.00

Table 3-86: Cut grass event based hourly temporal variation in VOC emission rate

Hour	Leaf wounding		Leaf drying		Grand Total	
	VOC emission rate (kg/m²/mow/h)	Proportion of VOC (%)	VOC emission rate (kg/m²/mow/h)	Proportion of VOC (%)	VOC emission rate (kg/m²/mow/h)	Proportion of VOC (%)[18]
1	6.91×10^{-6}	10.80	-	-	6.91×10^{-6}	10.80
2	5.12×10^{-6}	8.00	-	-	5.12×10^{-6}	8.00
3	3.79×10^{-6}	5.93	2.59×10^{-6}	4.04	6.38×10^{-6}	9.97
4	2.81×10^{-6}	4.39	2.48×10^{-6}	3.87	5.29×10^{-6}	8.26
5	2.08×10^{-6}	3.25	2.37×10^{-6}	3.71	4.45×10^{-6}	6.96
6	1.54×10^{-6}	2.41	2.27×10^{-6}	3.55	3.81×10^{-6}	5.96
7	1.14×10^{-6}	1.79	2.17×10^{-6}	3.39	3.31×10^{-6}	5.18
8	8.46×10^{-7}	1.32	2.08×10^{-6}	3.25	2.93×10^{-6}	4.57
9	6.27×10^{-7}	0.98	1.99×10^{-6}	3.11	2.62×10^{-6}	4.09
10	4.64×10^{-7}	0.73	1.90×10^{-6}	2.98	2.37×10^{-6}	3.70
11	3.44×10^{-7}	0.54	1.82×10^{-6}	2.85	2.17×10^{-6}	3.39
12	2.55×10^{-7}	0.40	1.75×10^{-6}	2.73	2.00×10^{-6}	3.12
13	1.89×10^{-7}	0.30	1.67×10^{-6}	2.61	1.86×10^{-6}	2.90
14	1.40×10^{-7}	0.22	1.60×10^{-6}	2.50	1.74×10^{-6}	2.72
15	1.04×10^{-7}	0.16	1.53×10^{-6}	2.39	1.63×10^{-6}	2.55
16	7.68×10^{-8}	0.12	1.46×10^{-6}	2.29	1.54×10^{-6}	2.41
17	5.69×10^{-8}	8.89×10^{-2}	1.40×10^{-6}	2.19	1.46×10^{-6}	2.28
18	4.21×10^{-8}	6.58×10^{-2}	1.34×10^{-6}	2.10	1.38×10^{-6}	2.16
19	3.12×10^{-8}	4.88×10^{-2}	1.28×10^{-6}	2.01	1.32×10^{-6}	2.06
20	2.31×10^{-8}	3.61×10^{-2}	1.23×10^{-6}	1.92	1.25×10^{-6}	1.96
21	1.71×10^{-8}	2.68×10^{-2}	1.18×10^{-6}	1.84	1.19×10^{-6}	1.86
22	1.27×10^{-8}	1.98×10^{-2}	1.13×10^{-6}	1.76	1.14×10^{-6}	1.78
23	9.40×10^{-9}	1.47×10^{-2}	1.08×10^{-6}	1.68	1.09×10^{-6}	1.70
24	6.97×10^{-9}	1.09×10^{-2}	1.03×10^{-6}	1.61	1.04×10^{-6}	1.62
Grand Total	2.66×10^{-5}	41.63	3.74×10^{-5}	58.37	6.40×10^{-5}	100.00

[18] Proportion of VOC (%) relate to the grand total VOC emission rate integrated over the first 24 hours.

Table 3-87: Cut grass event based daily temporal variation in VOC emission rate

Day	Grand Total VOC emission rate ($kg/m^2/mow/day$)[19]	Proportion of VOC (%)
1	6.40×10^{-5}	80.00
2	8.00×10^{-6}	10.00
3	1.60×10^{-6}	2.00
4	1.60×10^{-6}	2.00
5	1.60×10^{-6}	2.00
6	1.60×10^{-6}	2.00
7	1.60×10^{-6}	2.00
Grand Total	8.00×10^{-5}	100.00

[19] Grand Total VOC emission rate ($kg/m^2/mow/day$) includes both the leaf wounding and leaf drying phases.

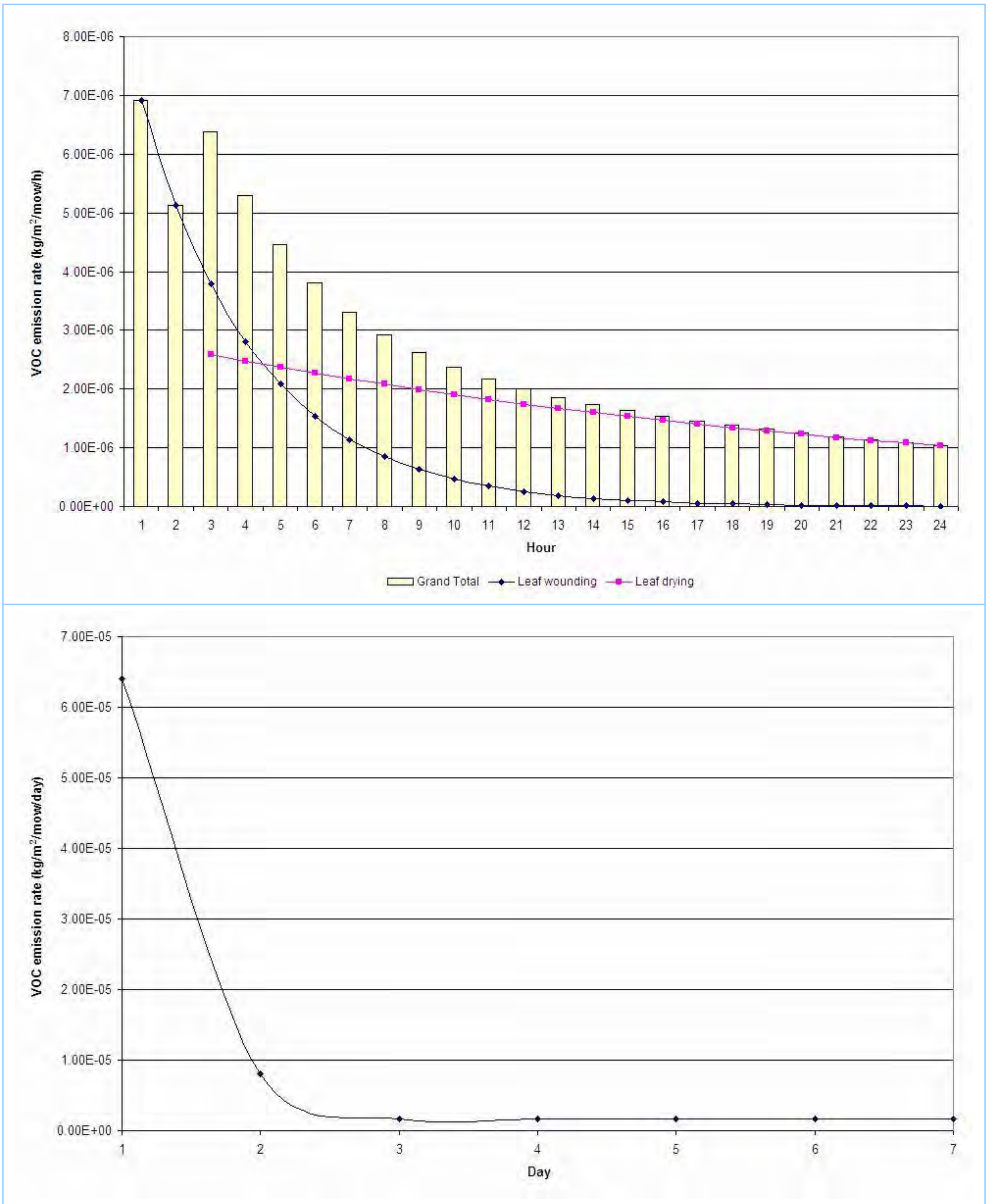


Figure 3-71: Residential and public open space cut grass event based hourly and daily variation in VOC emission rate

While the temporal variation in emissions is different for each 1 km by 1 km grid cell where there are emissions of VOC from cut grass, Figure 3-72, Figure 3-73 and Figure 3-74 show the hourly, daily and monthly variation in lawn mowing rate and VOC emission rate in the GMR for all areas with residential and public open space cut grass.

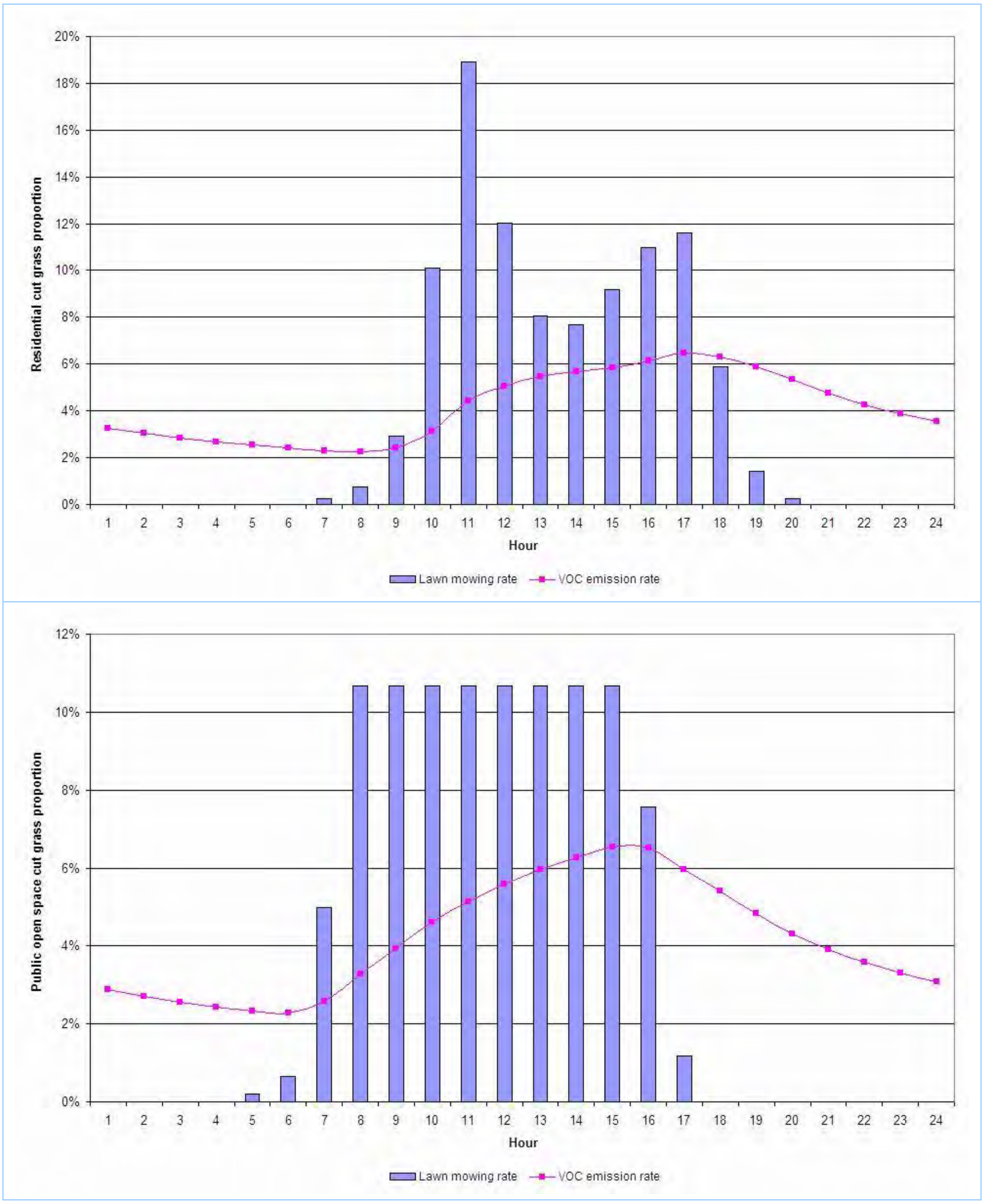


Figure 3-72: Residential and public open space cut grass hourly variation in lawn mowing rate and VOC emission rate

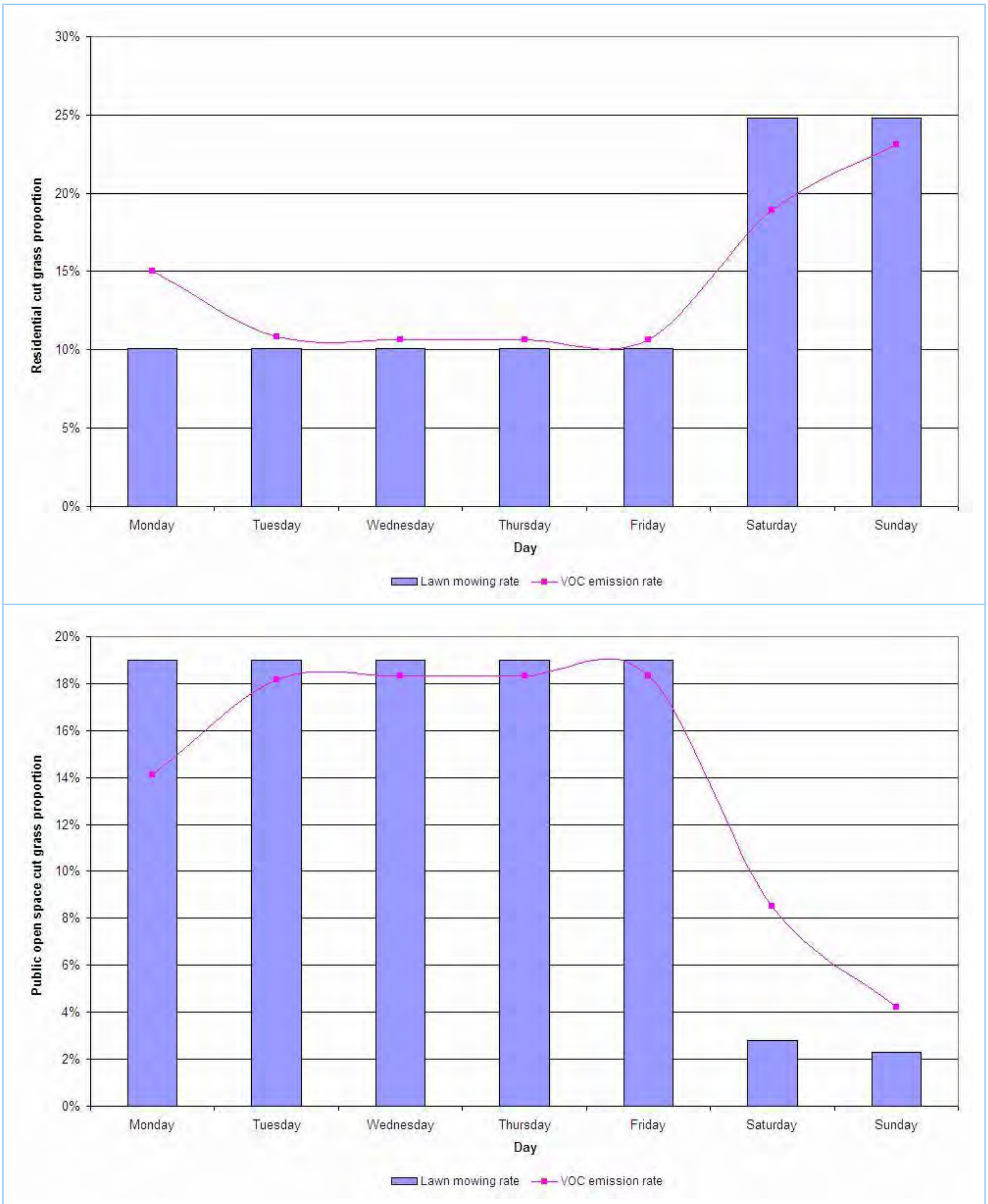


Figure 3-73: Residential and public open space cut grass daily variation in lawn mowing rate and VOC emission rate

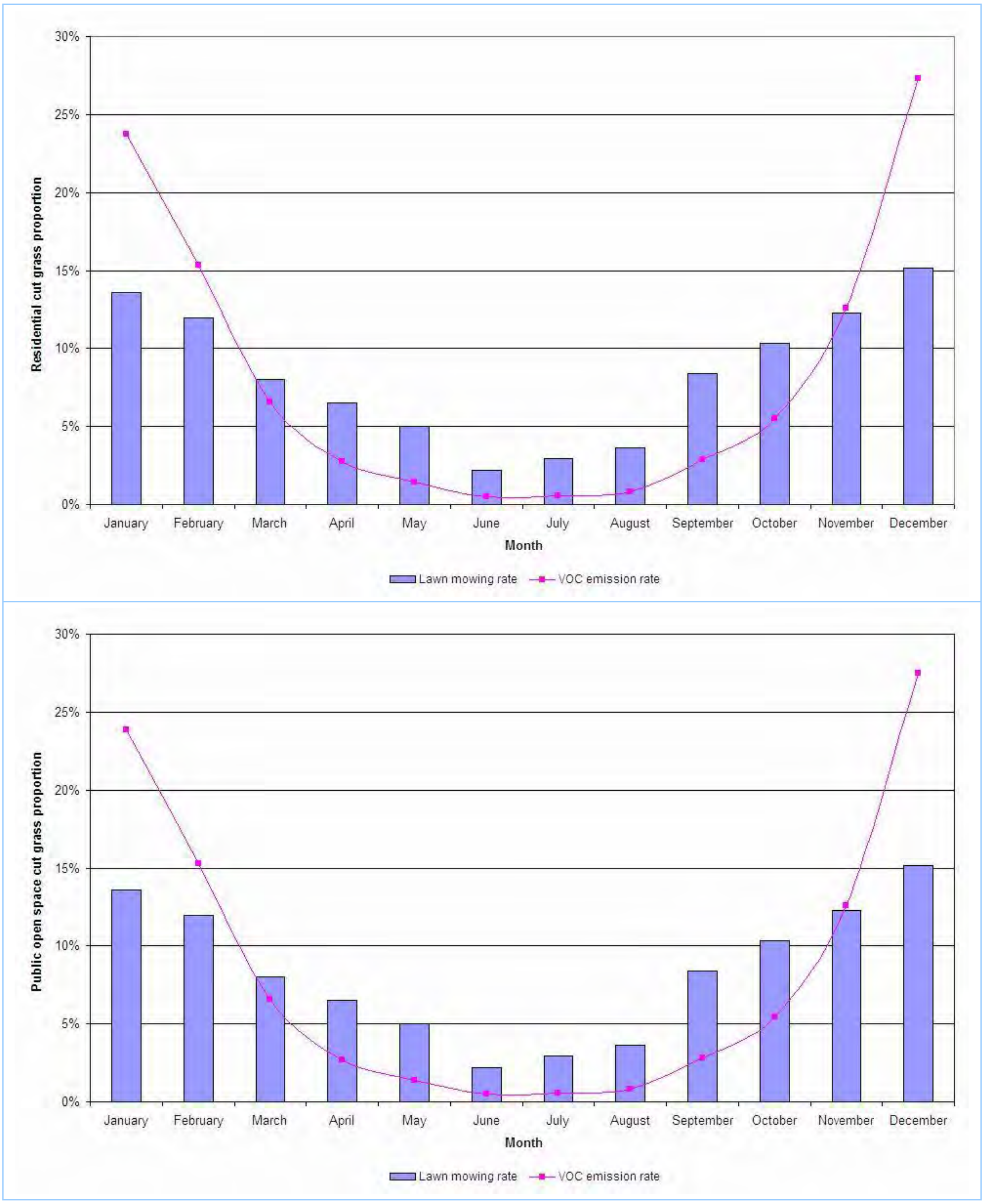


Figure 3-74: Residential and public open space cut grass monthly variation in lawn mowing rate and VOC emission rate

3.5.7 Emission Estimates

Table 3-88 presents annual emissions of selected substances from vegetation (i.e. tree canopy, uncut grass and cut grass) by activity.

Table 3-88: Tree canopy, uncut grass and cut grass emissions by activity

Activity	Substance	Emissions (kg/year)				
		Newcastle	Non Urban	Sydney	Wollongong	GMR
Vegetation	ACETALDEHYDE	15,888	864,530	200,615	13,696	1,094,729
	TOTAL VOLATILE ORGANIC COMPOUNDS	3,382,641	128,284,925	32,083,583	3,439,484	167,190,633

Table 3-89 presents annual emissions of selected substances from vegetation (i.e. tree canopy, uncut grass and cut grass) by source type.

Table 3-89: Tree canopy, uncut grass and cut grass emissions by source type

Source type	Substance	Emissions (kg/year)				
		Newcastle	Non Urban	Sydney	Wollongong	GMR
Tree Canopy	TOTAL VOLATILE ORGANIC COMPOUNDS	3,207,096	123,755,940	29,880,726	3,306,558	160,150,320
Uncut Grass	ACETALDEHYDE	10,745	851,781	136,401	10,240	1,009,167
	TOTAL VOLATILE ORGANIC COMPOUNDS	53,311	4,225,977	676,735	50,805	5,006,828
Cut Grass (Domestic)	ACETALDEHYDE	4,422	11,099	52,920	2,920	71,362
	TOTAL VOLATILE ORGANIC COMPOUNDS	105,100	263,786	1,257,727	69,407	1,696,020
Cut Grass (Public Open Space)	ACETALDEHYDE	721	1,650	11,293	535	14,199
	TOTAL VOLATILE ORGANIC COMPOUNDS	17,134	39,221	268,395	12,715	337,465

3.6 Marine Aerosol

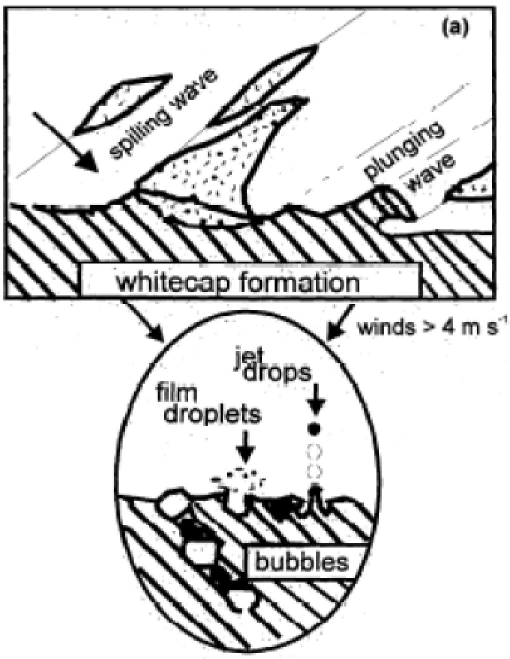
3.6.1 Emission Source Description

The biogenic and geogenic air emissions inventory includes emissions of sea-salt aerosols from the action of surface wind on the open-ocean.

To estimate emissions from this source, the following have been considered:

- *Generation of sea-salt aerosols*

The generation of sea-salt aerosols has been attributed to various physical processes (Blanchard, 1983). The most significant process is when entrained air bubbles burst during the formation of whitecaps through surface wind action, which ejects jet and film droplets from the sea surface (Monahan et. al., 1986). Most of the bubbles are formed when air is trapped through breaking waves. Since the energy dissipated in breaking waves is derived from surface wind action, the number of breaking waves is proportional to wind speed and the generation of sea-salt aerosols is proportional to whitecap coverage. The generation of sea-salt aerosols by either splash or bubbles, which are produced from precipitation, are of lesser significance than those generated when entrained air bubbles burst during the formation of whitecaps (Gong et. al., 1997). While sea-salt aerosols can be generated in the open-ocean and surf-zone, the inventory includes indirect production by bubbles (i.e. whitecaps) and direct production by spumes (i.e. breaking waves) in open-ocean. Figure 3-75 shows the physical processes involved in the generation of sea-salt aerosols (Monahan et. al., 1986).



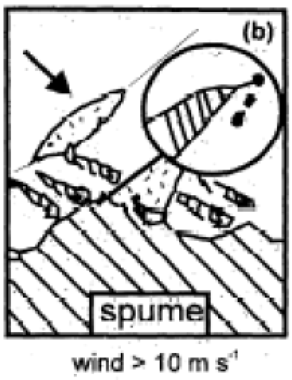


Figure 3-75: Physical processes involved in the generation of sea-salt aerosols include (a) indirect production by bubbles and (b) direct production by spumes

➢ *Ocean area*

The sea-salt aerosol source functions (Gong, 2003; Monahan et. al., 1986; and Smith et. al., 1998) express the rate of droplet generation per unit area of open-ocean, per increment of droplet radius and per unit of time (i.e. droplet number/m^2.µm.s). The open-ocean area in each 1 km by 1 km grid cell (DECCW, 2009c) has been used to estimate the emissions of sea-salt aerosols in the GMR.

➢ *Meteorological data*

The sea-salt aerosol source functions (Gong, 2003; Monahan et. al., 1986; and Smith et. al., 1998) are proportional to the wind speed raised to a power (i.e. wind speed $^{(3 \text{ to } 3.5)}$).kg/m^2.s)[20]. Hourly average meteorological data including wind speed have been generated for the GMR at 2 km by 2 km grid cells with *TAPM* (Hurley, 2005) and used to estimate the emissions of sea-salt aerosols in the GMR at 1 km by 1 km grid cells.

3.6.2 *Emission Estimation Methodology*

Table 3-90 summarises the emission estimation methodologies used for emissions of sea-salt aerosols from the action of surface wind on the open-ocean.

Table 3-90: Marine aerosol emission estimation methodologies

Emission source	Emission estimation methodology source
Emissions of sea-salt aerosols from the action of surface wind on the open-ocean	- *Initial Applications of Sea Salt Aerosol Emissions and Chemistry Algorithms in the CMAQ v4.5 – AERO4 Module* (Shankar et. al., 2005) - *A Parameterization of Sea-Salt Aerosol Source Function for Sub- and Super-Micron Particles* (Gong, 2003) - *A Model of Marine Aerosol Generation via Whitecaps and Wave Disruption* (Monahan et. al., 1986) - *The Sea Spray Generation Function* (Smith et. al., 1998)

Emissions of sea-salt aerosols have been estimated using the *CMAQ v4.5 – AERO4 Module* methodology (Shankar et. al., 2005). The comparison of three sea-salt aerosol flux parameterisations concludes (Shankar et. al., 2005):

➢ GM03 (Gong, 2003) performs best for 0.06 µm $\leq r_{80} <$ 1 µm[21];

➢ M86 (Monahan et. al., 1986) performs best for 1 µm $\leq r_{80} <$ 10 µm; and

➢ SH98 (Smith et. al., 1998) performs best for 10 µm $\leq r_{80} <$ 150 µm.

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[20] Wet sea-salt droplet number generation is proportional to the wind speed at 10 m raised to a power varying from 3 to 3.5 (Gong, 2003; Monahan et. al., 1986; and Smith et. al., 1998).

[21] r_{80} is the wet sea-salt droplet radius (µm) at a reference relative humidity of 80% (Gong, 2003; Monahan et. al., 1986; and Smith et. al., 1998).

The number of wet sea-salt droplets has been estimated using the GM03, M86 and SH98 flux parameterisations as piecewise functions (i.e. the range over which each parameterisation performs best) within Equation 21 (Gong, 2003; Monahan et. al., 1986; and Smith et. al., 1998):

$$\left.\begin{array}{lll} \dfrac{dF^{G03}_{N-open-ocean}}{dr_{80}} = & 1.373U_{10}^{3.41}r_{80}^{-A_{G03}}\left(1+0.057r_{80}^{3.45}\right)\times 10^{1.19e^{-B_{G03}^{2}}} & \text{for } 0.06\ \mu m \le r_{80} < 1\ \mu m \\ \dfrac{dF^{M86}_{N-open-ocean}}{dr_{80}} = & 1.373U_{10}^{3.41}r_{80}^{-3}\left(1+0.057r_{80}^{1.05}\right)\times 10^{1.19e^{-B_{M86}^{2}}} & \text{for } 1\ \mu m \le r_{80} < 10\ \mu m \\ \dfrac{dF^{SH98}_{N-open-ocean}}{dr_{80}} = & \sum_{i=1}^{2} A^{i}_{SH98}\exp\left\{-f_i\left[\ln\left(\dfrac{r_{80}}{r_{0i}}\right)\right]^2\right\} & \text{for } 10\ \mu m \le r_{80} < 150\ \mu m \end{array}\right\} \quad \textbf{Equation 21}$$

where:			
$\dfrac{dF^{G03,M86 \text{ or } SH98}_{N-open-ocean}}{dr_{80}}$	=	**Wet sea-salt droplet generation per unit area of open-ocean, per increment of droplet radius at a reference relative humidity of 80% and per unit of time**	**(droplet number/m².µm.s)**
U_{10}	=	**Hourly average wind speed at an elevation of 10 m from the water surface**	**(m/s)**
A_{G03}	=	$4.7\left(1+30r_{80}\right)^{-0.017r_{80}^{-1.44}}$	**(-)**
B_{G03}	=	$\left(0.433-\log_{10}r_{80}\right)/\,0.433$	**(-)**
B_{M86}	=	$\left(0.380-\log_{10}r_{80}\right)/\,0.650$	**(-)**
A^{1}_{SH98}	=	$0.2U_{10}^{3.5}$	**(-)**
A^{2}_{SH98}	=	$6.8\times 10^{-3}U_{10}^{3}$	**(-)**
f_1	=	1.5	**(-)**
f_2	=	1.0	**(-)**
r_{01}	=	3	**(µm)**
r_{02}	=	30	**(µm)**

The mass emissions of dry sea-salt particles with an aerodynamic equivalent diameter up to 2.5 µm ($PM_{2.5}$) have been estimated by integrating and summing each of the GM03 and M86 flux parameterisations using Simpson's rule. The limits of integration for wet sea-salt droplet radii (r_{80}) using G03 and M86 are 0.06 to 1.00 µm and 1.00 to 1.76 µm, respectively and these include dry sea-salt aerodynamic equivalent particle diameters ($d_{dry-aero}$) up to 2.5 µm. The GM03 and M86 integrals have been combined with the open-ocean area (DECCW, 2009c) and hourly average wind speed data (Hurley, 2005) in each 1 km by 1 km grid cell using Equation 22 (Gong, 2003; and Monahan et. al., 1986):

$$E_{ss}^{G03} = \frac{4 \times \pi \times \rho_{ss}}{3 \times C_{80}^{3}} \times 10^{-15} \times \int_{r_{80,i}=0.06}^{r_{80,i+1}=1.00} \left(r_{80}^{3} \times \frac{dF_{N-open-ocean}^{G03}}{dr_{80}} dr_{80} \right)$$

$$E_{ss}^{M86} = \frac{4 \times \pi \times \rho_{ss}}{3 \times C_{80}^{3}} \times 10^{-15} \times \int_{r_{80,i}=1.00}^{r_{80,i+1}=1.76} \left(r_{80}^{3} \times \frac{dF_{N-open-ocean}^{M86}}{dr_{80}} dr_{80} \right)$$

Equation 22

where:			
$E_{ss}^{G03} + E_{ss}^{M86}$	=	**Mass emissions of dry sea-salt particles with aerodynamic equivalent diameters of 2.5 µm ($PM_{2.5}$)**	**(kg/m².s)**
$\frac{dF_{N-open-ocean}^{G03\,or\,M86}}{dr_{80}}$	=	**Wet sea-salt droplet generation per unit area of open-ocean, per increment of droplet radius at a reference relative humidity of 80% and per unit of time**	**(droplet number/m².µm.s)**
ρ_{ss}	=	**Density of sea-salt - 2,165 (Lewis et. al., 2006)**	**(kg/m³)**
C_{80}	=	r_{80}/r_{dry}	**(-)**
r_{80}	=	**Wet sea-salt droplet radius at a reference relative humidity of 80%**	**(µm)**
r_{dry}	=	**Dry sea-salt particle radius**	**(µm)**

The mass emissions of dry sea-salt particles with an aerodynamic equivalent diameter up to 10 µm (PM_{10}) have been estimated by integrating and summing each of the GM03 and M86 flux parameterisations using Simpson's rule. The limits of integration for wet sea-salt droplet radii (r_{80}) using G03 and M86 are 0.06 to 1.00 µm and 1.00 to 7.25 µm, respectively and these include dry sea-salt aerodynamic equivalent particle diameters ($d_{dry-aero}$) up to 10 µm. The GM03 and M86 integrals have been combined with the open-ocean area (DECCW, 2009c) and hourly average wind speed data (Hurley, 2005) in each 1 km by 1 km grid cell using Equation 23 (Gong, 2003; and Monahan et. al., 1986):

$$E_{ss}^{G03} = \frac{4 \times \pi \times \rho_{ss}}{3 \times C_{80}^{3}} \times 10^{-15} \times \int_{r_{80,i}=0.06}^{r_{80,i+1}=1.00} \left(r_{80}^{3} \times \frac{dF_{N-open-ocean}^{G03}}{dr_{80}} dr_{80} \right)$$

$$E_{ss}^{M86} = \frac{4 \times \pi \times \rho_{ss}}{3 \times C_{80}^{3}} \times 10^{-15} \times \int_{r_{80,i}=1.00}^{r_{80,i+1}=7.25} \left(r_{80}^{3} \times \frac{dF_{N-open-ocean}^{M86}}{dr_{80}} dr_{80} \right)$$

Equation 23

where:			
$E_{ss}^{G03} + E_{ss}^{M86}$	=	**Mass emissions of dry sea-salt particles with aerodynamic equivalent diameters of 10 µm (PM_{10})**	**(kg/m².s)**
$\frac{dF_{N-open-ocean}^{G03\,or\,M86}}{dr_{80}}$	=	**Wet sea-salt droplet generation per unit area of open-ocean, per increment of droplet radius at a reference relative humidity of 80% and per unit of time**	**(droplet number/m².µm.s)**
ρ_{ss}	=	**Density of sea-salt – 2,165 (Lewis et. al., 2006)**	**(kg/m³)**
C_{80}	=	r_{80}/r_{dry}	**(-)**
r_{80}	=	**Wet sea-salt droplet radius at a reference relative humidity of 80%**	**(µm)**
r_{dry}	=	**Dry sea-salt particle radius**	**(µm)**

The mass emissions of dry sea-salt particles with aerodynamic equivalent diameters up to 30 µm (TSP)[22] have been estimated by integrating and summing each of the GM03, M86 and SH98 flux parameterisations using Simpson's rule. The limits of integration for wet sea-salt droplet radii (r_{80}) using G03, M86 and SH98 are 0.06 to 1.00 µm, 1.00 to 10.00 µm and 10.00 to 22.33 µm, respectively and these include dry sea-salt aerodynamic equivalent particle diameters ($d_{dry\text{-}aero}$) up to 30 µm. The GM03, M86 and SH98 integrals have been combined with the open-ocean area (DECCW, 2009c) and hourly average wind speed data (Hurley, 2005) in each 1 km by 1 km grid cell using Equation 24 (Gong, 2003; Monahan et. al., 1986; and Smith et. al., 1998):

$$E_{ss}^{G03} = \frac{4 \times \pi \times \rho_{ss}}{3 \times C_{80}^{3}} \times 10^{-15} \times \int_{r_{80,i}=0.06}^{r_{80,i+1}=1.00} \left(r_{80}^{3} \times \frac{dF_{N-open-ocean}^{G03}}{dr_{80}} dr_{80} \right)$$

$$E_{ss}^{M86} = \frac{4 \times \pi \times \rho_{ss}}{3 \times C_{80}^{3}} \times 10^{-15} \times \int_{r_{80,i}=1.00}^{r_{80,i+1}=10.00} \left(r_{80}^{3} \times \frac{dF_{N-open-ocean}^{M86}}{dr_{80}} dr_{80} \right)$$

$$E_{ss}^{SH98} = \frac{4 \times \pi \times \rho_{ss}}{3 \times C_{80}^{3}} \times 10^{-15} \times \int_{r_{80,i}=10.00}^{r_{80,i+1}=22.33} \left(r_{80}^{3} \times \frac{dF_{N-open-ocean}^{SH98}}{dr_{80}} dr_{80} \right)$$

Equation 24

where:

$E_{ss}^{G03} + E_{ss}^{M86} + E_{ss}^{SH98}$	=	**Mass emissions of dry sea-salt particles with aerodynamic equivalent diameters of 30 µm (TSP)**	**(kg/m².s)**
$\frac{dF_{N-open-ocean}^{G03,\ M86\ or\ SH98}}{dr_{80}}$	=	**Wet sea-salt droplet generation per unit area of open-ocean, per increment of droplet radius at a reference relative humidity of 80% and per unit of time**	**(droplet number/m².µm.s)**
ρ_{ss}	=	**Density of sea-salt - 2,165 (Lewis et. al., 2006)**	**(kg/m³)**
C_{80}	=	r_{80}/r_{dry}	**(-)**
r_{80}	=	**Wet sea-salt droplet radius at a reference relative humidity of 80%**	**(µm)**
r_{dry}	=	**Dry sea-salt particle radius**	**(µm)**

The integration between $r_{80,i}$ and $r_{80,i+1}$ has been performed over 2N + 1 points (i.e. 1001) with Simpson's rule[23] using Equation 25:

[22] Particles ranging in size from 0.1 micrometer to about 30 micrometer in diameter are referred to as total suspended particulate matter (TSP). TSP includes a broad range of particle sizes including fine, coarse, and supercoarse particles (USEPA, 2010b).

[23] Technique adapted from 4.2.7. Emissions, Integration, pp 97 – 98 (Sportisse, et. al., 2006). Original formulation by Johannes Keppler in 1615 (1571 – 1630). Additional people involved include Roger Cotes (1682 – 1716), Isaac Newton (1642 – 1726) and Thomas Simpson (1710 – 1761).

$$\int_{r_{80,i}}^{r_{80,i+1}} \left(r_{80}^3 \times \frac{dF_N}{dr_{80}} dr_{80} \right) = \frac{h}{3} \left(a_0^3 \times \frac{dF_N}{dr_{80}}(a_0) + 4a_1^3 \times \frac{dF_N}{dr_{80}}(a_1) + 2a_2^3 \times \frac{dF_N}{dr_{80}}(a_2) + ... + 2a_{2N-2}^3 \times \frac{dF_N}{dr_{80}}(a_{2N-2}) + 4a_{2N-1}^3 \times \frac{dF_N}{dr_{80}}(a_{2N-1}) + a_N^3 \times \frac{dF_N}{dr_{80}}(a_N) \right) \quad \text{Equation 25}$$

where:

$\frac{dF_N}{dr_{80}}$	=	**Wet sea-salt droplet generation per unit area of open-ocean, per increment of droplet radius at a reference relative humidity of 80% and per unit of time**	**(droplet number/m²·µm.s)**
r_{80}	=	**Wet sea-salt droplet radius at a reference relative humidity of 80%**	**(µm)**
a_j	=	$r_{80,i} + \left(r_{80,i+1} - r_{80,i}\right) \times \frac{j}{2N}$	**(µm³)**
j	=	$\left(0, 1, ..., 2N-1, 2N\right)$	**(-)**

The ratio (C_{80}) of dry sea-salt particle radius (r_{dry}) to wet sea-salt droplet radius (r_{80}) is approximately 0.5 to within 1% (Lewis et. al., 2006). However, for each point over the interval of integration for wet sea-salt droplet radii ($r_{80,i}$ to $r_{80,i+1}$), the corresponding dry sea-salt particle radii ($r_{dry,i}$ to $r_{dry,i+1}$) have been iteratively estimated using an empirical relationship (Gerber, 1985) in order to calculate the ratio C_{80} ($C_{80,i}$ to $C_{80,i+1}$). The dry sea-salt particle radius (r_{dry}) has been estimated from wet sea-salt droplet radius (r_{80}) using Equation 26:

$$r_{80} = \left(\frac{C_1 \times r_{dry}^{C_2}}{C_3 \times r_{dry}^{C_4} - \log_{10}\left(RH/100\right)} + r_{dry}^3 \right)^{1/3} \quad \text{Equation 26}$$

where:

r_{80}	=	**Wet sea-salt droplet radius at a reference relative humidity of 80%**	**(µm)**
r_{dry}	=	**Dry sea-salt particle radius**	**(µm)**
C_1	=	**0.7674**	**(-)**
C_2	=	**3.079**	**(-)**
C_3	=	**2.5730×10^{-11}**	**(-)**
C_4	=	**-1.4240**	**(-)**
RH	=	**Relative humidity**	**(%)**

Figure 3-76 shows a scatter plot of the modelled relationship and line of best fit between dry sea-salt particle radius (r_{dry}) and wet sea-salt droplet radius (r_{80}). The ratio (C_{80}) of dry sea-salt particle radius (r_{dry}) to wet sea-salt droplet radius (r_{80}) is approximately 0.46, with a coefficient of determination (R^2) of approximately 0.99. For wet sea-salt droplet radii (r_{80}) ranging from 0.06 to 22.33 µm, the corresponding dry sea-salt particle radii (r_{dry}) range from 0.03 to 10.19 µm. This corresponds with dry sea-salt aerodynamic equivalent particle diameters ($d_{dry\text{-}aero}$) ranging from to 0.09 to 30 µm.

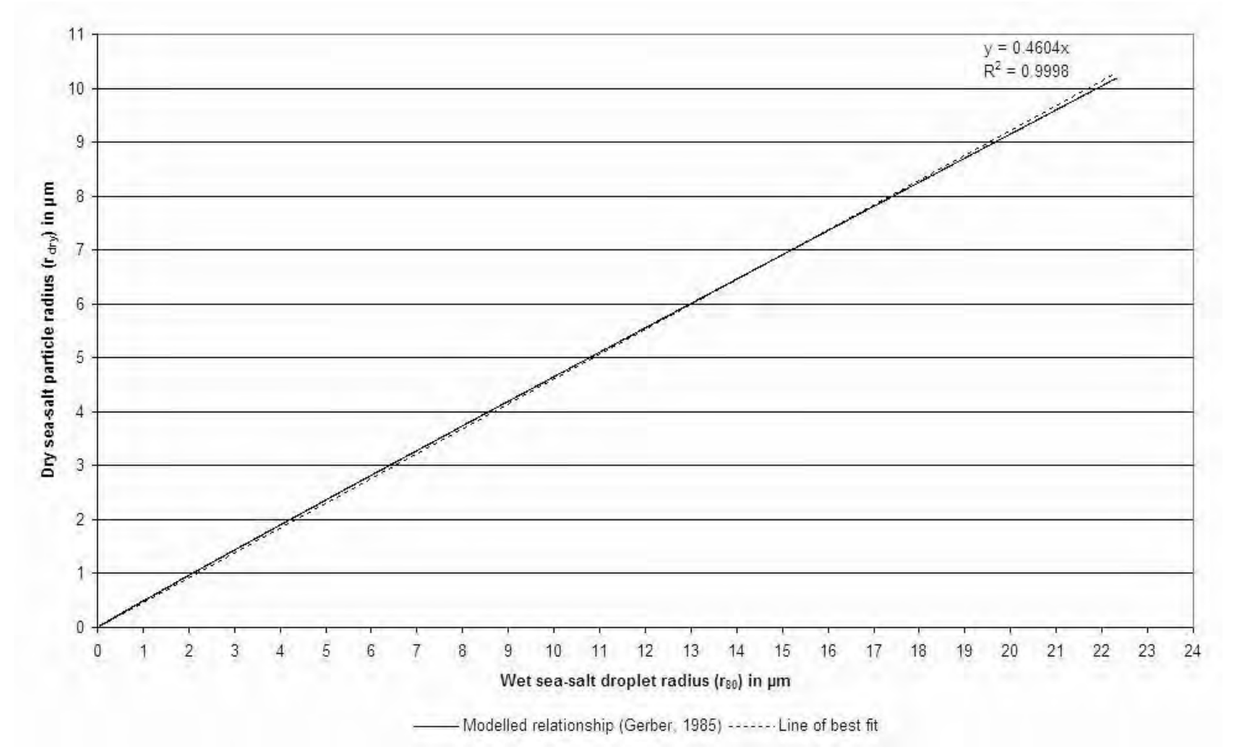

Figure 3-76: Modelled relationship and line of best fit between dry sea-salt particle radius (r_{dry}) and wet sea-salt droplet radius (r_{80})

The GM03, M86 and SH98 flux parameterisations are expressed as functions of the wet sea-salt droplet radius (r_{80}), which is then converted to dry sea-salt particle radius (r_{dry}) using Equation 26. The dry sea-salt particle radius (r_{dry}) is then converted to dry sea-salt aerodynamic equivalent particle diameter ($d_{dry\text{-}aero}$) using Equation 27 in order to estimate emissions of $PM_{2.5}$, PM_{10} and TSP (USEPA, 2010c):

$$d_{i-aero} = r_i \times 2 \times \sqrt{\rho_i \;/\; 1000} \qquad \textbf{Equation 27}$$

where:			
d_{i-aero}	=	**Aerodynamic equivalent particle diameter for particle type i**	**(µm)**
r_i	=	**Particle radius for particle type i**	**(µm)**
ρ_i	=	**Density of particle type i – 1,182 for wet sea-salt droplet (Tang et. al., 1997; and Zhang et. al., 2005) and 2,165 for dry sea-salt particle (Lewis et. al., 2006)**	**(kg/m^3)**
i	=	**Particle type (either "wet sea-salt droplet" or "dry sea-salt particle")**	**(-)**

Table 3-91 presents the limits of integration for the G03, M86 and SH98 flux parameterisations for dry sea-salt $PM_{2.5}$, PM_{10} and TSP, which have been used within Equation 22, Equation 23 and Equation 24.

Table 3-91: Limits of integration for the G03, M86 and SH98 flux parameterisations for dry sea-salt $PM_{2.5}$, PM_{10} and TSP

Particle size	Flux parameterisation	Limits of integration (µm)			
		r_{80}	$d_{80\text{-aero}}$	r_{dry}	$d_{dry\text{-aero}}$
$PM_{2.5}$	G03	0.06 to 1.00	0.13 to 2.17	0.03 to 0.49	0.09 to 1.44
	M86	1.00 to 1.76	2.17 to 3.82	0.49 to 0.85	1.44 to 2.50
PM_{10}	G03	0.06 to 1.00	0.13 to 2.17	0.03 to 0.49	0.09 to 1.44
	M86	1.00 to 7.25	2.17 to 15.77	0.49 to 3.40	1.44 to 10.00
TSP	G03	0.06 to 1.00	0.13 to 2.17	0.03 to 0.49	0.09 to 1.44
	M86	1.00 to 10.00	2.17 to 21.75	0.49 to 4.65	1.44 to 13.69
	SH98	10.00 to 22.33	21.75 to 48.56	4.65 to 10.19	13.69 to 30.00

Figure 3-77 shows predicted particle number and mass using the G03, M86 and SH98 flux parameterisations for dry sea-salt $PM_{2.5}$, PM_{10} and TSP at a wind speed of 1 m/s using Equation 22, Equation 23 and Equation 24. Total particle mass and particle number are calculated by summing the area under each curve.

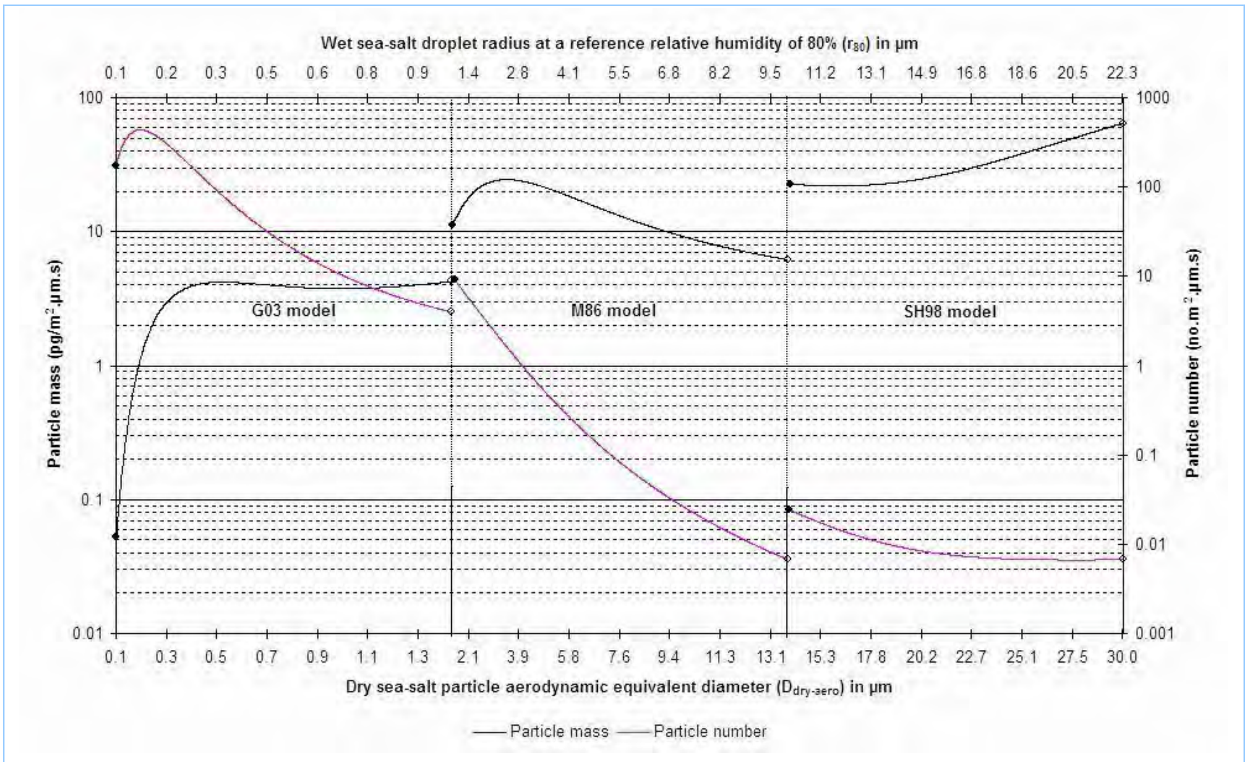

Figure 3-77: Predicted particle mass and particle number using the G03, M86 and SH98 flux parameterisations for dry sea-salt $PM_{2.5}$, PM_{10} and TSP at a wind speed of 1 m/s

3.6.3 Activity Data

Table 3-92 summarises the activity data used for emissions of sea-salt aerosols from the action of surface wind on the open-ocean.

Table 3-92: Marine aerosol activity data

Activity data	Activity data source
Ocean area (m^2)	- *Gridded Ocean Area in the GMR* (DECCW, 2009c)
Hourly meteorological data (wind speed (m/s)) required by the open ocean marine aerosol model	- *The Air Pollution Model (TAPM) Version 3* (Hurley, 2005)

The sea-salt aerosol source functions (Gong, 2003; Monahan et. al., 1986; and Smith et. al., 1998) express the rate of droplet generation per unit area of open-ocean, per increment of droplet radius and per unit of time (droplet number/m^2.μm.s). The open-ocean area in each 1 km by 1 km grid cell (DECCW, 2009c) has been used to estimate the sea-salt aerosol flux rate in the GMR. Figure 3-78 shows the open-ocean area in the GMR, which covers an area of 1,677,752 ha (DECCW, 2009c).

Figure 3-78: Open-ocean area in the GMR

The sea-salt aerosol source functions (Gong, 2003; Monahan et. al., 1986; and Smith et. al., 1998) are proportional to the wind speed raised to a power (wind speed$^{(3 \text{ to } 3.5)}$).kg/m^2.s)[24]. Hourly average meteorological data including wind speed have been generated for the GMR at 2 km by 2 km grid cells with *TAPM* (Hurley, 2005) and used to estimate the sea-salt aerosol flux rate in the GMR at 1 km by 1 km grid cells. Figure 3-79 shows the monthly average wind speed in the GMR by hour of day.

[24] Wet sea-salt droplet number generation is proportional to the wind speed at 10 m raised to a power varying from 3 to 3.5 (Gong, 2003; Monahan et. al., 1986; and Smith et. al., 1998).

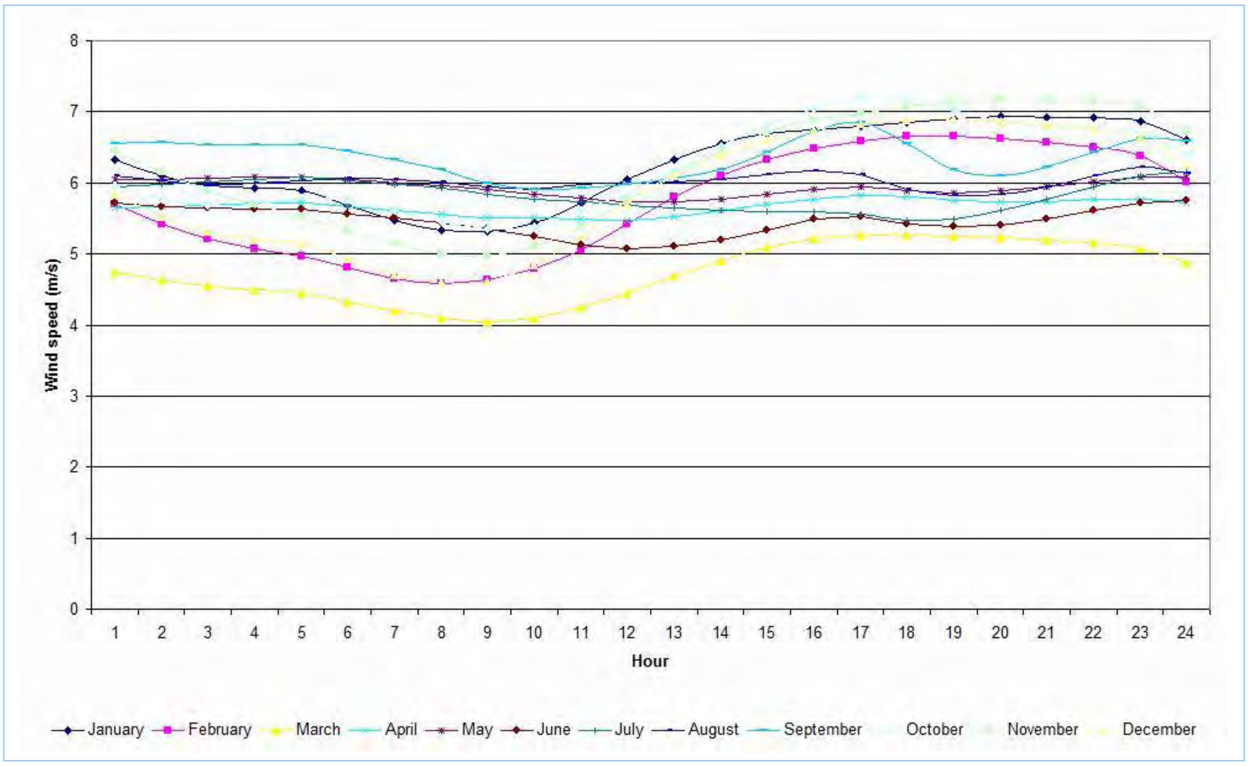

Figure 3-79: Monthly average wind speed in the GMR by hour of day

Monthly average wind speed is presented in Table 3-93, while the gridded annual average wind speed is shown in Figure 3-80 for the GMR.

Table 3-93: Monthly average wind speed in the GMR

Month	Wind speed (m/s)
January	6.26
February	5.71
March	4.73
April	5.67
May	5.94
June	5.46
July	5.81
August	6.02
September	6.35
October	6.22
November	6.21
December	5.90
Grand Total	5.86

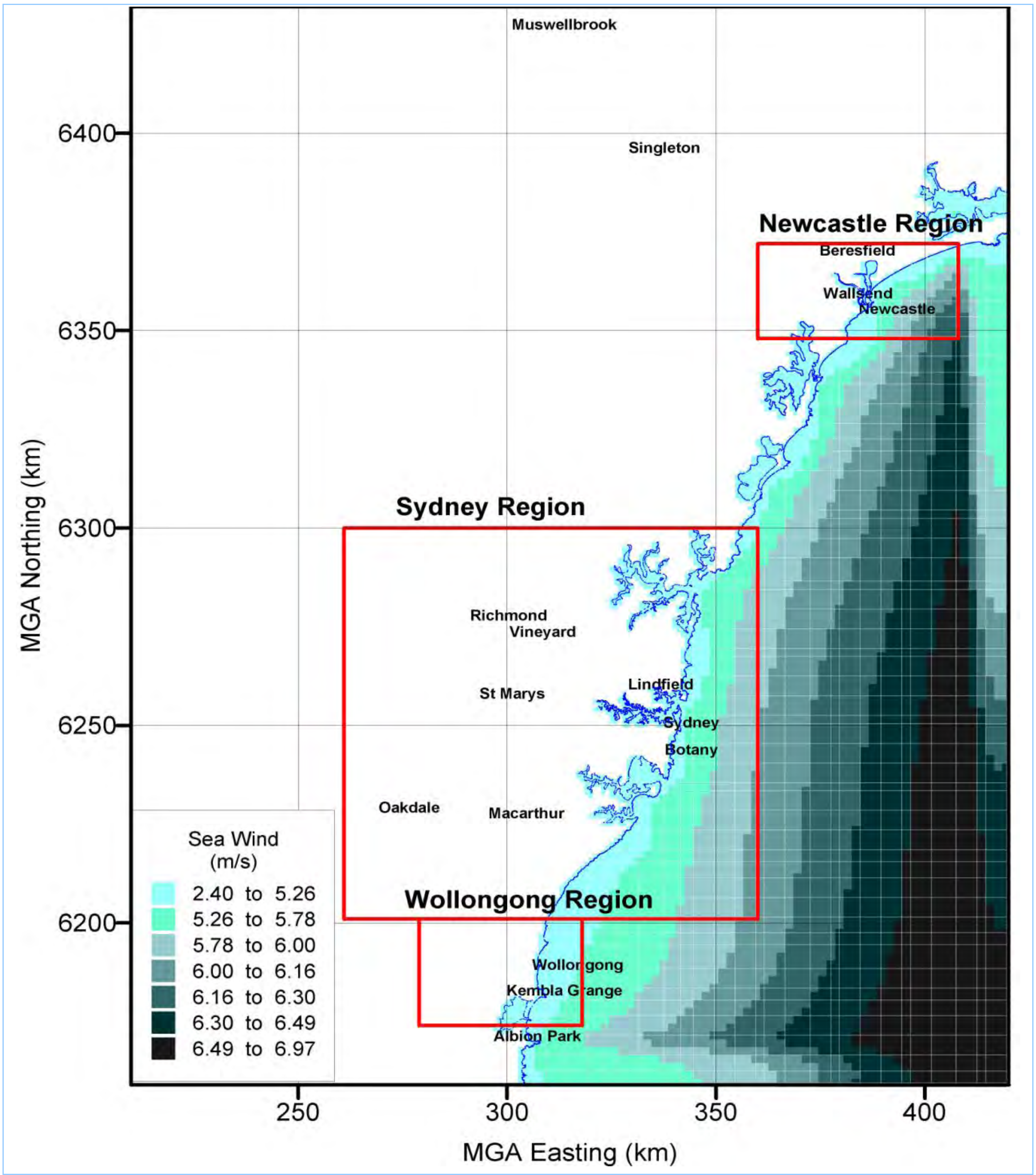

Figure 3-80: Gridded annual average wind speed

3.6.4 *Emission and Speciation Factors*

Table 3-94 summarises the emission and speciation factors used for sea-salt aerosols from the action of surface wind on the open-ocean.

Table 3-94: Marine aerosol emission and speciation factors

Emission source	Substance	Emission and speciation factor source
Emissions of sea-salt aerosols from the action of surface wind on the open-ocean	Criteria pollutants: $PM_{2.5}$ and PM_{10}	- *A Parameterization of Sea-Salt Aerosol Source Function for Sub- and Super-Micron Particles* (Gong, 2003) - *A Model of Marine Aerosol Generation via Whitecaps and Wave Disruption* (Monahan et. al., 1986)
	Criteria pollutants: TSP	- *A Parameterization of Sea-Salt Aerosol Source Function for Sub- and Super-Micron Particles* (Gong, 2003) - *A Model of Marine Aerosol Generation via Whitecaps and Wave Disruption* (Monahan et. al., 1986) - *The Sea Spray Generation Function* (Smith et. al., 1998)

Table 3-95 presents emission factors for sea-salt aerosols by wet droplet radius and dry particle diameter.

Table 3-95: Dry sea-salt $PM_{2.5}$, PM_{10} and TSP emission factors by wet droplet radius and dry particle diameter

Particle size	Flux parameterisation	Wet droplet (r_{80})	Dry particle ($d_{dry\text{-}aero}$)	Emission factors ($kg/m^2.s$)[25]
$PM_{2.5}$	G03	0.06 to 1.00	0.09 to 1.44	$3.31 \times 10^{-15}U^{3.41}$
	M86	1.00 to 1.76	1.44 to 2.50	$1.26 \times 10^{-14}U^{3.41}$
$PM_{2.5}$ Total		0.06 to 1.76	0.09 to 2.50	$1.59 \times 10^{-14}U^{3.41}$
PM_{10}	G03	0.06 to 1.00	0.09 to 1.44	$3.31 \times 10^{-15}U^{3.41}$
	M86	1.00 to 7.25	1.44 to 10.00	$1.06 \times 10^{-13}U^{3.41}$
PM_{10} Total		0.06 to 7.25	0.09 to 1.44	$1.10 \times 10^{-13}U^{3.41}$
TSP	G03	0.06 to 1.00	0.09 to 1.44	$3.31 \times 10^{-15}U^{3.41}$
	M86	1.00 to 10.00	1.44 to 13.69	$1.27 \times 10^{-13}U^{3.41}$
	SH98	10.00 to 22.33	13.69 to 30.00	$1.40 \times 10^{-13}U^{3.5} + 2.70 \times 10^{-13}U^{3}$
TSP Total		0.06 to 22.33	0.09 to 30.00	$1.30 \times 10^{-13}U^{3.41} + 1.40 \times 10^{-13}U^{3.5} + 2.70 \times 10^{-13}U^{3}$

Figure 3-81 shows the variation in emission factors for sea-salt aerosols as a function of wind speed.

[25] U is the hourly average wind speed at an elevation of 10 m from the water surface (Gong, 2003; Monahan et. al., 1986; and Smith et. al., 1998).

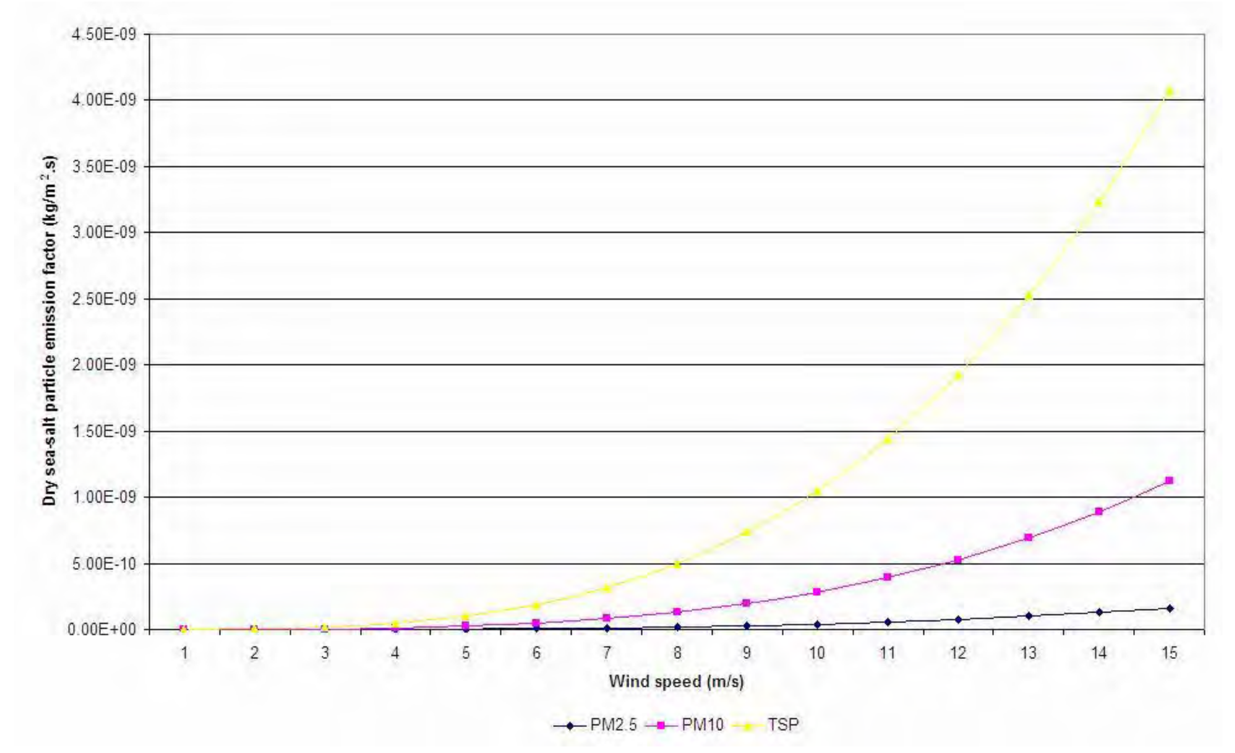

Figure 3-81: Dry sea-salt $PM_{2.5}$, PM_{10} and TSP emission factors by wind speed

3.6.5 Spatial Distribution of Emissions

Table 3-96 summarises the data used for spatially allocating emissions of sea-salt aerosols from the action of surface wind on the open-ocean.

Table 3-96: Marine aerosol spatial data

Emission source	Spatial data	Spatial data source
Emissions of sea-salt aerosols from the action of surface wind on the open-ocean	Gridded 1 km x 1 km ocean proportion combined with gridded 1 km x 1 km wind speed estimates	- *Gridded Ocean Area in the GMR* (DECCW, 2009c) - *The Air Pollution Model (TAPM) Version 3* (Hurley, 2005)

Emissions of sea-salt aerosols from the action of surface wind on the open-ocean have been spatially distributed according to the proportion of open-ocean area in each 1 km by 1 km grid cell (DECCW, 2009c). The open-ocean area and proportion by region are presented in Table 3-97.

Table 3-97: Open-ocean area spatial distribution by region

Region	Open-ocean area statistics	
	Open-ocean area (ha)	Proportion of open-ocean area (%)
Newcastle	45,509	2.71
Non Urban	1,348,422	80.37

Region	Open-ocean area statistics	
	Open-ocean area (ha)	Proportion of open-ocean area (%)
Sydney	252,568	15.05
Wollongong	31,252	1.86
Grand Total	1,677,752	100.00

Figure 3-82 shows the spatial distribution of sea-salt aerosol emissions from the action of surface wind on the open-ocean.

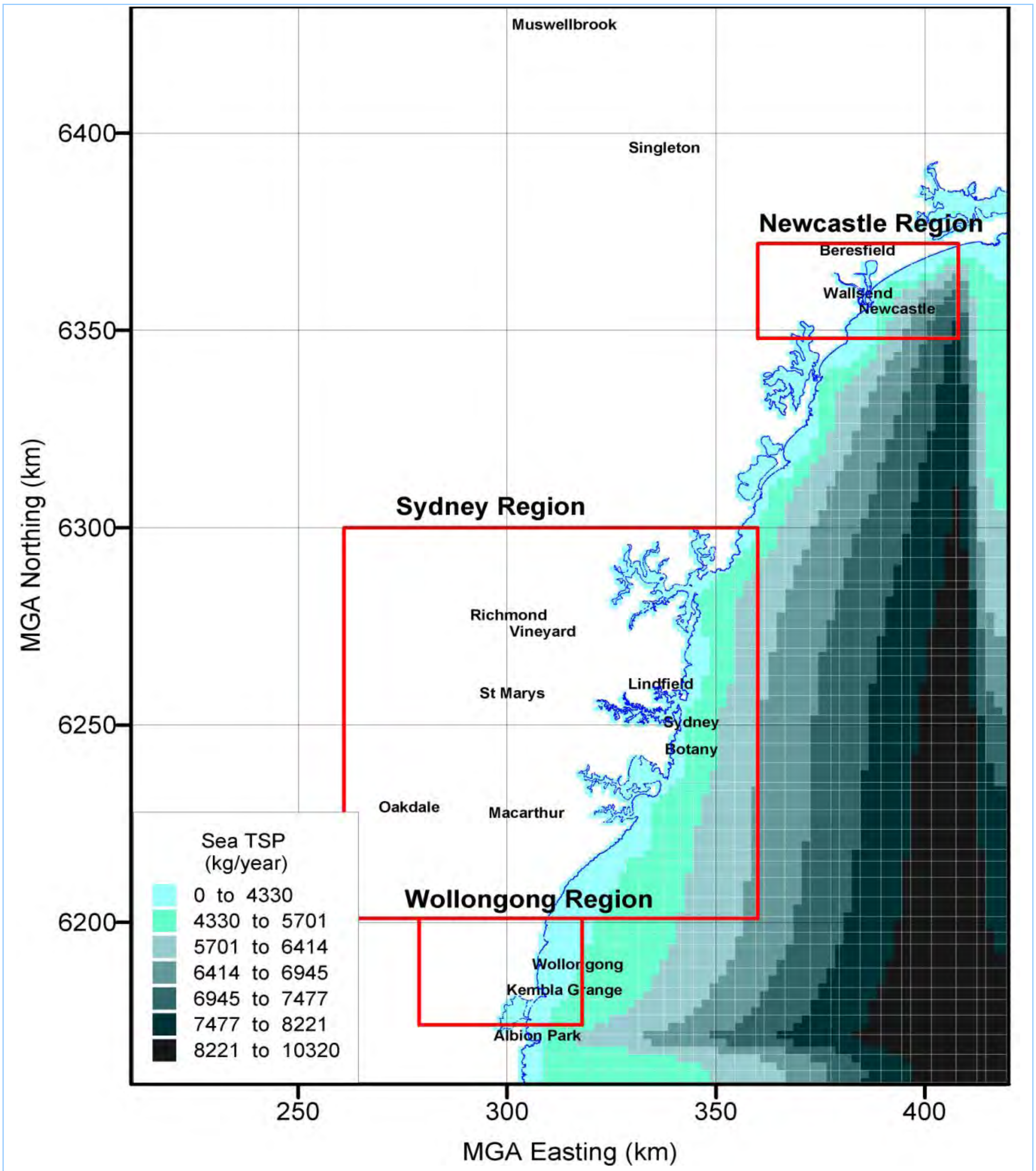

Figure 3-82: Marine aerosol spatial distribution of emissions

3.6.6 Temporal Variation of Emissions

Table 3-98 summarises the data used to estimate the temporal variation in emissions of sea-salt aerosols from the action of surface wind on the open-ocean.

Table 3-98: Marine aerosol temporal data

Emission source	Temporal data	Temporal data source
Emissions of sea-salt aerosols from the action of surface wind on the open-ocean	Monthly, daily and hourly: Gridded 1 km x 1 km wind speed estimates	- *The Air Pollution Model (TAPM) Version 3* (Hurley, 2005)

Hourly average meteorological data including wind speed have been generated for the GMR at 2 km by 2 km grid cells with *TAPM* (Hurley, 2005) and used to estimate the sea-salt aerosol flux rate variation with wind speed (Gong, 2003; Monahan et. al., 1986; and Smith et. al., 1998) at 1 km by 1 km grid cells.

Annual emissions of $PM_{2.5}$, PM_{10} and TSP have been estimated using hourly average wind speed within Equation 22, Equation 23 and Equation 24 (Gong, 2003; Monahan et. al., 1986; and Smith et. al., 1998). Hourly emissions are calculated first and then summed to estimate annual, monthly and daily emissions.

While the temporal variation in emissions is different for each 1 km by 1 km grid cell where there are emissions of sea-salt aerosols from the action of surface wind on the open-ocean, Figure 3-83, Figure 3-84 and Figure 3-85 show the hourly, daily and monthly variation in $PM_{2.5}$, PM_{10} and TSP emissions, respectively in the GMR for all open-ocean areas.

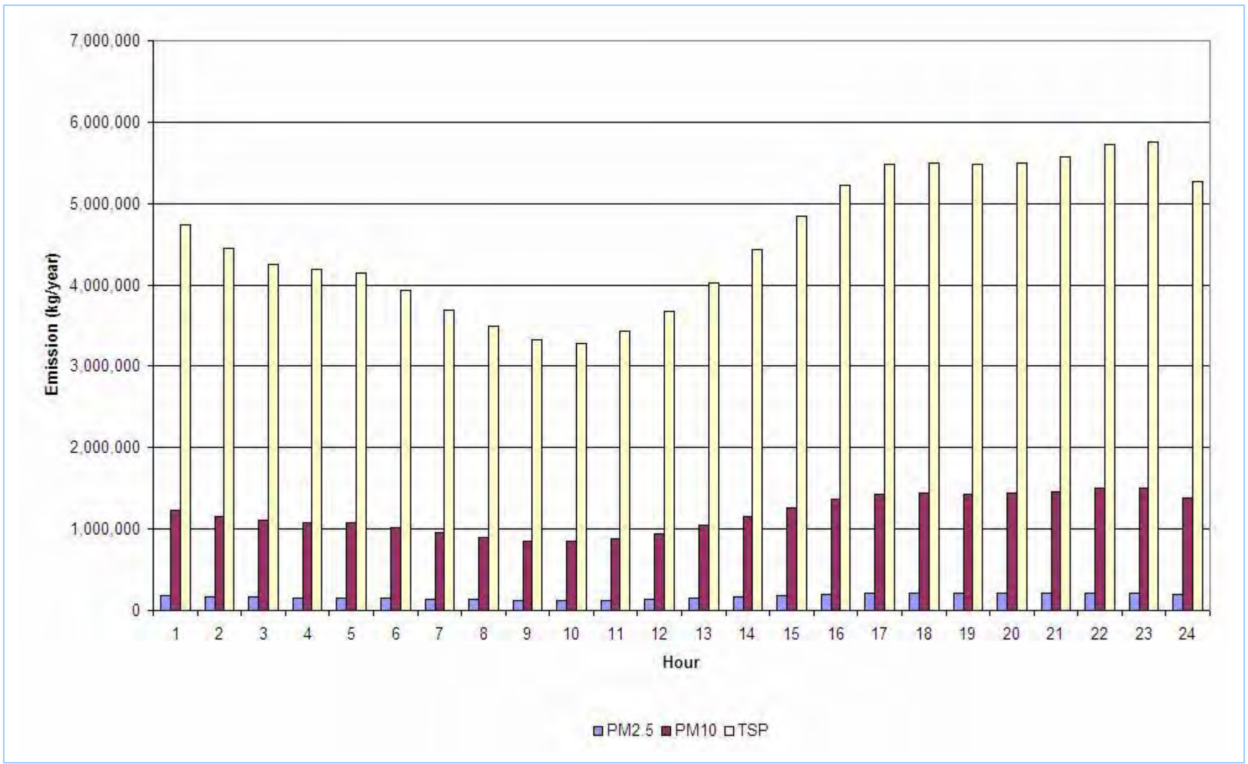

Figure 3-83: Marine aerosol hourly variation in $PM_{2.5}$, PM_{10} and TSP emissions

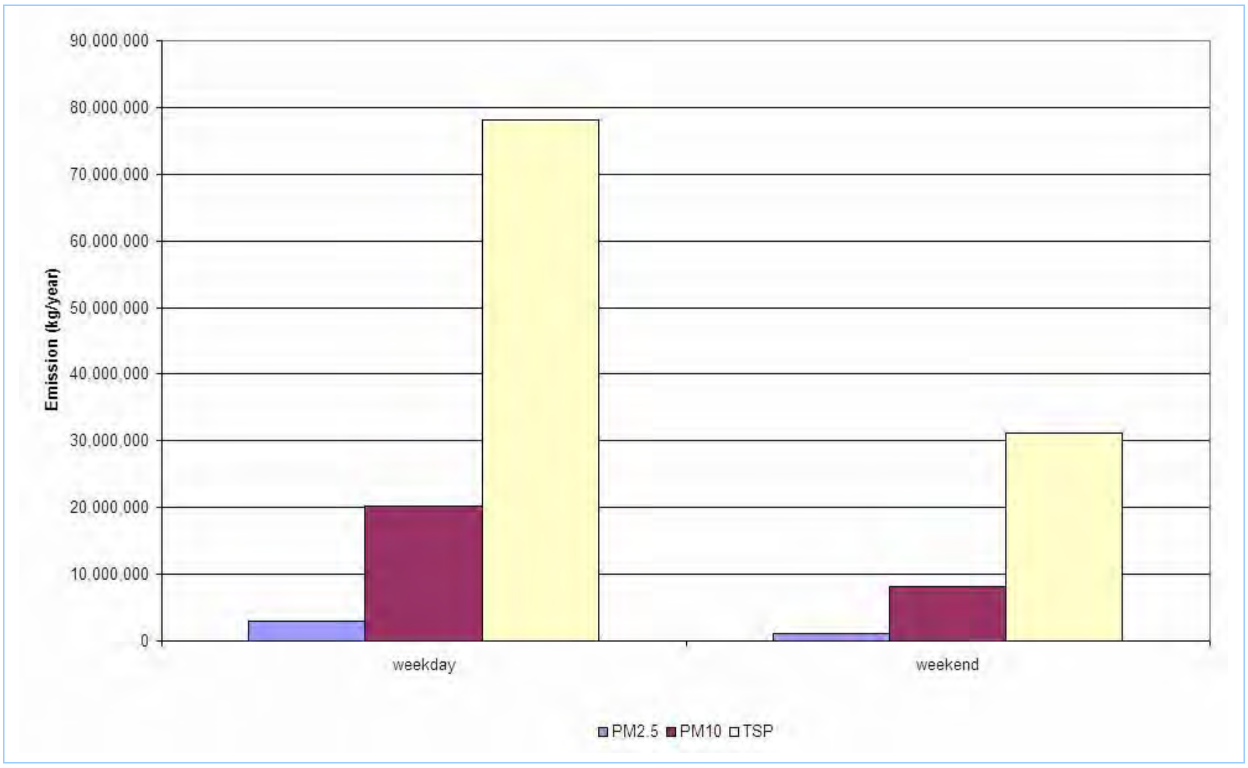

Figure 3-84: Marine aerosol daily variation in $PM_{2.5}$, PM_{10} and TSP emissions

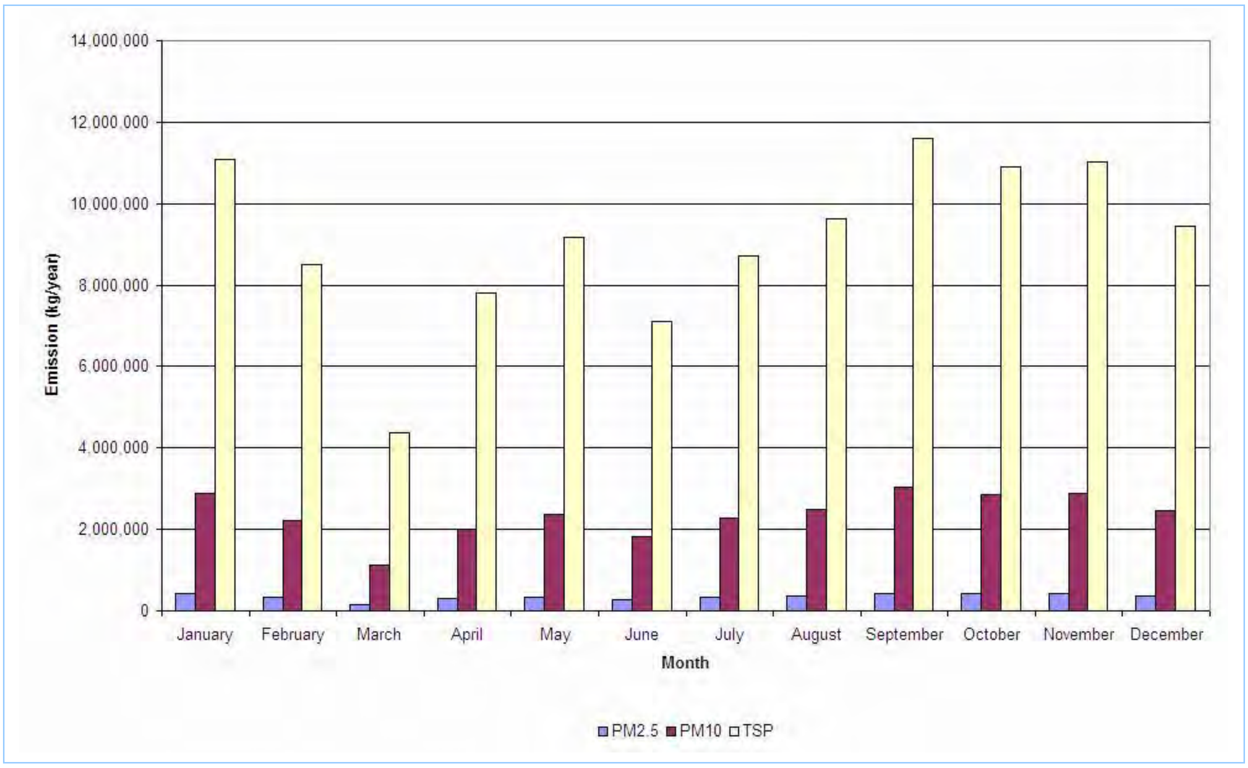

Figure 3-85: Marine aerosol monthly variation in $PM_{2.5}$, PM_{10} and TSP emissions

3.6.7 *Emission Estimates*

Table 3-99 presents annual sea-salt aerosol emissions of selected substances from the action of surface wind on the open-ocean by activity.

Table 3-99: Marine aerosol emissions by activity

Activity	Substance	Emissions (kg/year)				
		Newcastle	Non Urban	Sydney	Wollongong	GMR
Marine Aerosol	PARTICULATE MATTER ≤ 2.5 µm	84,741	3,546,495	444,783	38,215	4,114,234
	PARTICULATE MATTER ≤ 10 µm	585,671	24,510,801	3,074,017	264,111	28,434,601
	TOTAL SUSPENDED PARTICULATE	2,264,165	94,187,920	11,911,676	1,030,846	109,394,607

4 EMISSIONS SUMMARY

The biogenic and geogenic air emissions inventory has been developed for the 2008 calendar year, which incorporates an area covering the greater Sydney, Newcastle and Wollongong regions, known collectively as the Greater Metropolitan Region (GMR).

The biogenic and geogenic air emissions inventory includes emissions from the following sources:

- Agricultural burning;
- Bushfires;
- Prescribed burning;
- Fugitive/windborne from agricultural lands and unpaved roads;
- Microbial activity and chemical processes of nitrification and denitrification in soil;
- Fertiliser application to agricultural land;
- Tree canopy and grass (i.e. cut and uncut); and
- Marine aerosol.

The pollutants inventoried include criteria pollutants specified in the Ambient Air Quality NEPM (NEPC, 2003), air toxics associated with the National Pollutant Inventory NEPM (NEPC, 2008) and the Air Toxics NEPM (NEPC, 2004) and any other pollutants associated with state-specific programs, i.e. Load Based Licensing (Protection of the Environment Operations (General) Regulation 2009 (PCO, 2010)) and Protection of the Environment Operations (Clean Air) Regulation 2010 (PCO, 2011).

Table 4-1 presents total estimated annual emissions (for selected substances) from all biogenic and geogenic sources in the whole GMR and the Sydney, Newcastle, Wollongong and Non Urban regions.

Figure 4-1 shows the proportions of total estimated annual emissions (for selected substances) from all biogenic and geogenic sources in the whole GMR and the Sydney, Newcastle, Wollongong and Non Urban regions.

Table 4-1: Total estimated annual emissions from biogenic and geogenic sources in each region

Substance	Emissions (tonne/year)				
	Newcastle	Non Urban	Sydney	Wollongong	GMR
1,3-BUTADIENE	0.24	23	4.39	0.48	28
ACETALDEHYDE	16	865	201	14	1,095
CARBON MONOXIDE	301	28,545	5,484	603	34,934
LEAD & COMPOUNDS	0.10	2.16	0.46	8.89×10^{-3}	2.73
OXIDES OF NITROGEN	126	8,319	1,296	71	9,811
PARTICULATE MATTER ≤ 10 µm	689	28,719	3,901	327	33,635
PARTICULATE MATTER ≤ 2.5 µm	121	6,176	951	90	7,338
POLYCYCLIC AROMATIC HYDROCARBONS	8.44×10^{-2}	7.41	1.37	0.14	9.00
SULFUR DIOXIDE	2.72	259	50	5.49	317
TOTAL SUSPENDED PARTICULATE	2,422	99,401	12,940	1,096	115,859
TOTAL VOLATILE ORGANIC COMPOUNDS	3,404	130,284	32,468	3,482	169,637

Figure 4-1: Proportions of total estimated annual emissions from biogenic and geogenic sources in each region

Table 4-2, Table 4-3, Table 4-4, Table 4-5 and Table 4-6 present total estimated annual emissions (for selected substances) from each biogenic and geogenic source type in the whole GMR and the Sydney, Newcastle, Wollongong and Non Urban regions, respectively.

Figure 4-2, Figure 4-3, Figure 4-4, Figure 4-5 and Figure 4-6 show the proportions of total estimated annual emissions (for selected substances) from each biogenic and geogenic source type in the whole GMR and the Sydney, Newcastle, Wollongong and Non Urban regions, respectively.

Table 4-2: Total estimated annual emissions by biogenic and geogenic source type in the GMR

Substance	Emissions (tonne/year)										
	Agricultural burning	Bushfires	Prescribed burning	Agricultural lands (fugitive/ windborne)	Unpaved roads (fugitive/ windborne)	Soil nitrification and denitrification	Tree canopy	Uncut grass	Cut grass	Marine aerosol	Biogenic and Geogenic Total
1,3-BUTADIENE	0.28	5.87	22	-	-	-	-	-	-	-	28
ACETALDEHYDE	-	-	-	-	-	-	-	1,009	86	-	1,095
CARBON MONOXIDE	325	7,338	27,271	-	-	-	-	-	-	-	34,934
LEAD & COMPOUNDS	5.11×10^{-4}	7.37×10^{-2}	0.27	1.55×10^{-2}	2.36	-	-	-	-	-	2.73
OXIDES OF NITROGEN	12	217	806	-	-	8,778	-	-	-	-	9,811
PARTICULATE MATTER ≤ 10µm	42	739	2,747	114	1,559	-	-	-	-	28,435	33,635
PARTICULATE MATTER ≤ 2.5µm	40	627	2,331	20	206	-	-	-	-	4,114	7,338
POLYCYCLIC AROMATIC HYDROCARBONS	0.73	1.75	6.52	-	-	-	-	-	-	-	9.00
SULFUR DIOXIDE	1.79	67	248	-	-	-	-	-	-	-	317
TOTAL SUSPENDED PARTICULATE	43	752	2,796	250	2,624	-	-	-	-	109,395	115,859
TOTAL VOLATILE ORGANIC COMPOUNDS	24	514	1,909	-	-	-	160,150	5,007	2,033	-	169,637

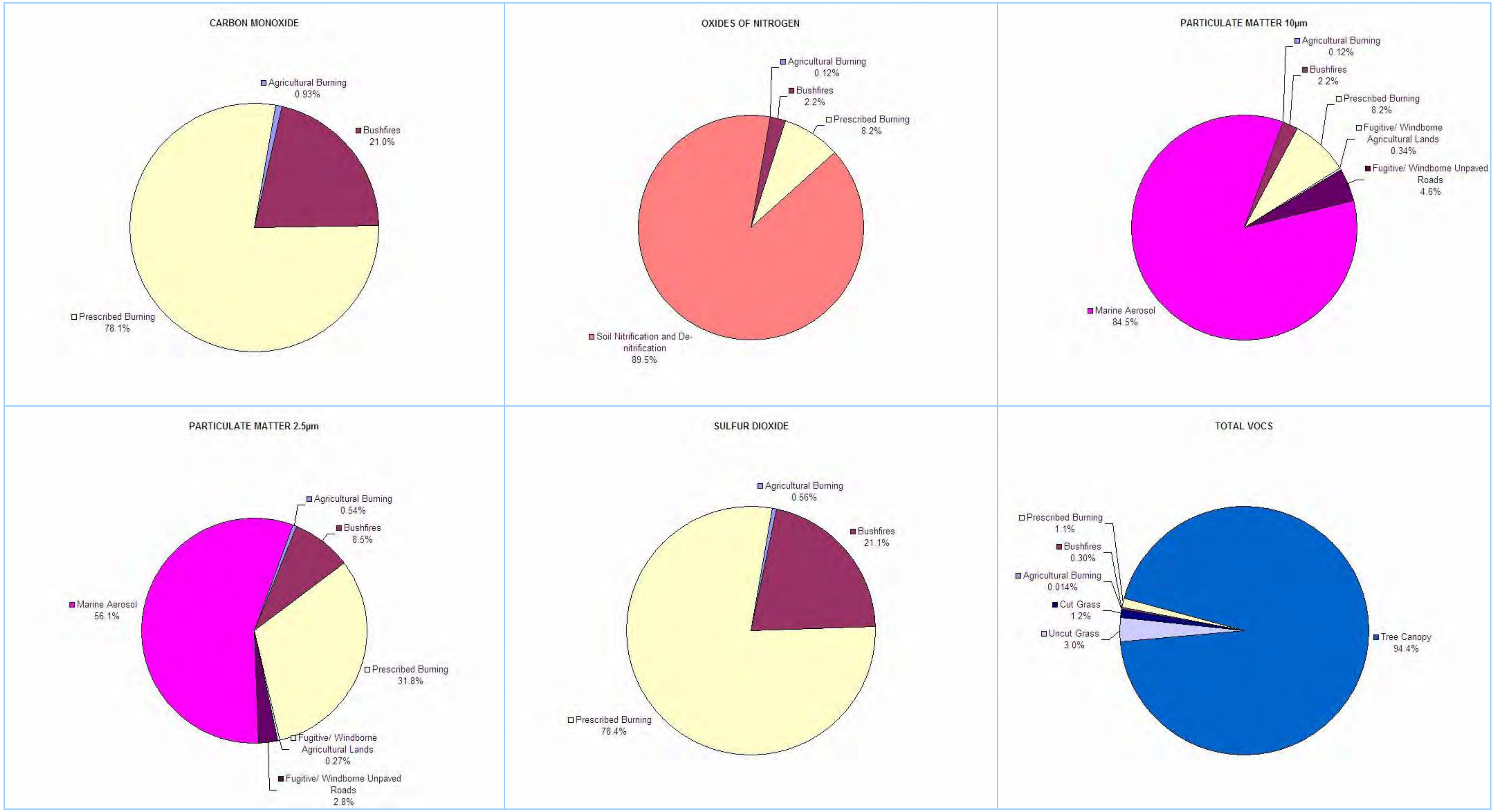

Figure 4-2: Proportions of total estimated annual emissions by biogenic and geogenic source type in the GMR

Table 4-3: Total estimated annual emissions by biogenic and geogenic source type in the Sydney region

Substance	Emissions (tonne/year)										
	Agricultural burning	Bushfires	Prescribed burning	Agricultural lands (fugitive/ windborne)	Unpaved roads (fugitive/ windborne)	Soil nitrification and denitrification	Tree canopy	Uncut grass	Cut grass	Marine aerosol	Biogenic and Geogenic Total
1,3-BUTADIENE	2.40×10^{-2}	0.64	3.72	-	-	-	-	-	-	-	4.39
ACETALDEHYDE	-	-	-	-	-	-	-	136	64	-	201
CARBON MONOXIDE	28	806	4,650	-	-	-	-	-	-	-	5,484
LEAD & COMPOUNDS	4.43×10^{-5}	8.10×10^{-3}	4.67×10^{-2}	1.40×10^{-3}	0.40	-	-	-	-	-	0.46
OXIDES OF NITROGEN	1.00	24	137	-	-	1,133	-	-	-	-	1,296
PARTICULATE MATTER ≤ 10 µm	3.63	81	468	10	263	-	-	-	-	3,074	3,901
PARTICULATE MATTER ≤ 2.5 µm	3.46	69	397	1.77	35	-	-	-	-	445	951
POLYCYCLIC AROMATIC HYDROCARBONS	6.37×10^{-2}	0.19	1.11	-	-	-	-	-	-	-	1.37
SULFUR DIOXIDE	0.16	7.34	42	-	-	-	-	-	-	-	50
TOTAL SUSPENDED PARTICULATE	3.69	83	477	23	443	-	-	-	-	11,912	12,940
TOTAL VOLATILE ORGANIC COMPOUNDS	2.10	56	326	-	-	-	29,881	677	1,526	-	32,468

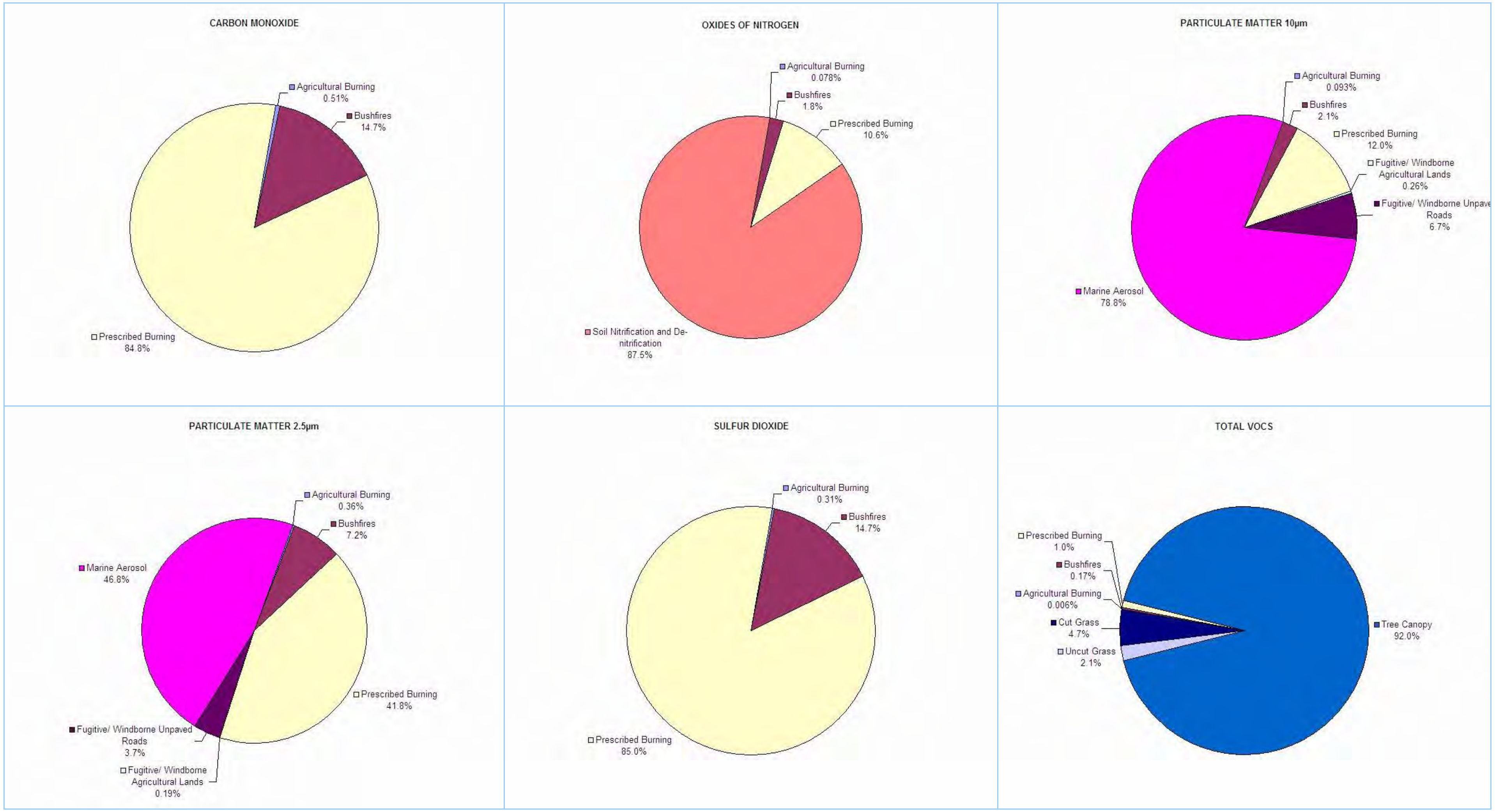

Figure 4-3: Proportions of total estimated annual emissions by biogenic and geogenic source type in the Sydney region

Table 4-4: Total estimated annual emissions by biogenic and geogenic source type in the Newcastle region

Substance	Emissions (tonne/year)										
	Agricultural burning	Bushfires	Prescribed burning	Agricultural lands (fugitive/ windborne)	Unpaved roads (fugitive/ windborne)	Soil nitrification and denitrification	Tree canopy	Uncut grass	Cut grass	Marine aerosol	Biogenic and Geogenic Total
1,3-BUTADIENE	5.21×10^{-3}	6.0×10^{-2}	0.18	-	-	-	-	-	-	-	0.24
ACETALDEHYDE	-	-	-	-	-	-	-	11	5.14	-	16
CARBON MONOXIDE	6.13	75	220	-	-	-	-	-	-	-	301
LEAD & COMPOUNDS	9.62×10^{-6}	7.54×10^{-4}	2.21×10^{-3}	1.17×10^{-3}	9.70×10^{-2}	-	-	-	-	-	0.10
OXIDES OF NITROGEN	0.22	2.22	6.50	-	-	117	-	-	-	-	126
PARTICULATE MATTER ≤ 10 µm	0.79	7.56	22	8.54	64	-	-	-	-	586	689
PARTICULATE MATTER ≤ 2.5 µm	0.75	6.42	19	1.48	8.46	-	-	-	-	85	121
POLYCYCLIC AROMATIC HYDROCARBONS	1.38×10^{-2}	1.79×10^{-2}	5.26×10^{-2}	-	-	-	-	-	-	-	8.44×10^{-2}
SULFUR DIOXIDE	3.37×10^{-2}	0.68	2.00	-	-	-	-	-	-	-	2.72
TOTAL SUSPENDED PARTICULATE	0.80	7.70	23	19	108	-	-	-	-	2,264	2,422
TOTAL VOLATILE ORGANIC COMPOUNDS	0.46	5.26	15	-	-	-	3,207	53	122	-	3,404

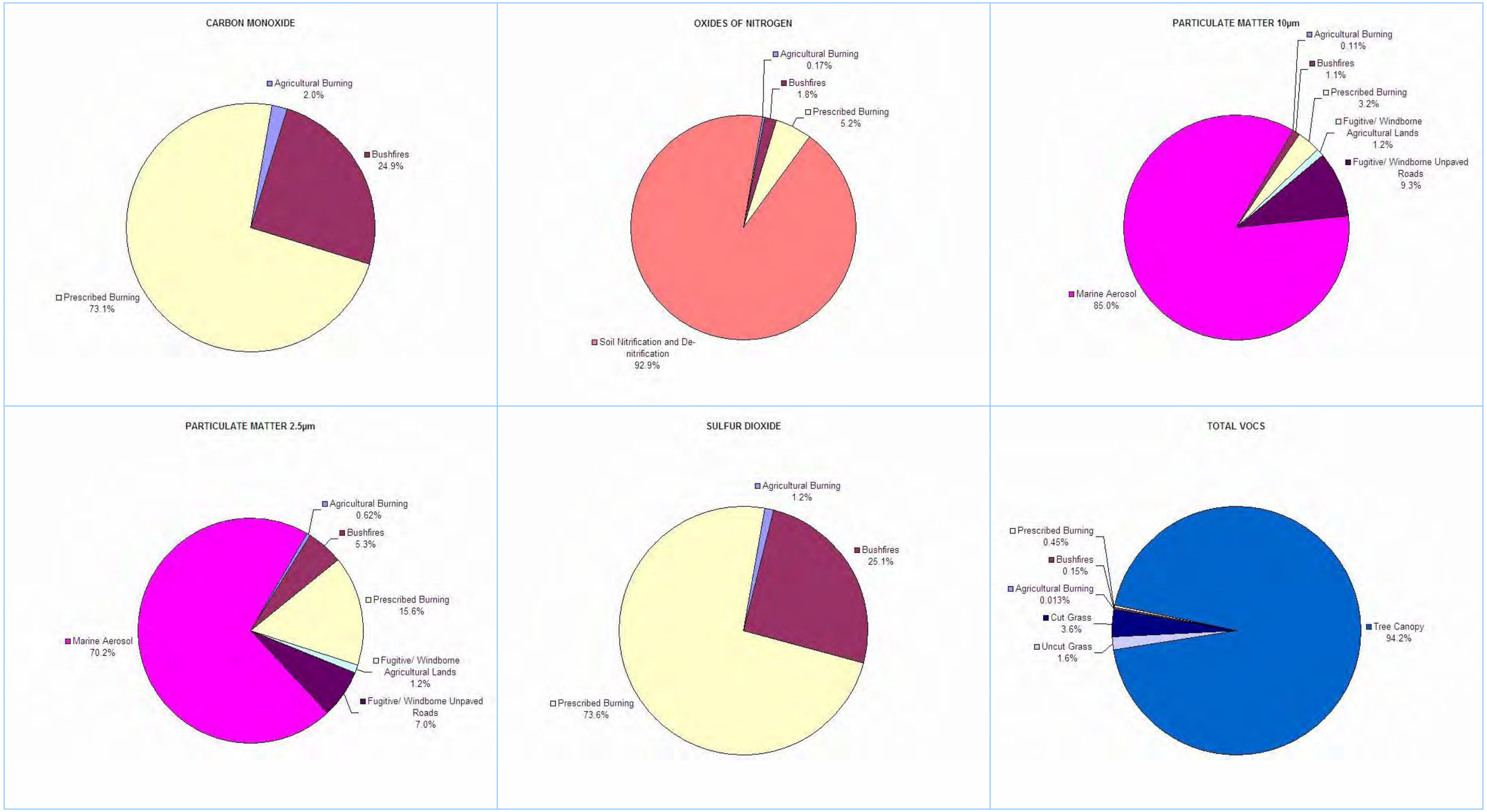

Figure 4-4: Proportions of total estimated annual emissions by biogenic and geogenic source type in the Newcastle region

Table 4-5: Total estimated annual emissions by biogenic and geogenic source type in the Wollongong region

Substance	Emissions (tonne/year)								
	Bushfires	Prescribed burning	Unpaved roads (fugitive/ windborne)	Soil nitrification and denitrification	Tree canopy	Uncut grass	Cut grass	Marine aerosol	Biogenic and Geogenic Total
1,3-BUTADIENE	5.22×10^{-3}	0.48	-	-	-	-	-	-	0.48
ACETALDEHYDE	-	-	-	-	-	10	3.46	-	14
CARBON MONOXIDE	6.53	597	-	-	-	-	-	-	603
LEAD & COMPOUNDS	6.56×10^{-5}	5.99×10^{-3}	2.83×10^{-3}	-	-	-	-	-	8.89×10^{-3}
OXIDES OF NITROGEN	0.19	18	-	53	-	-	-	-	71
PARTICULATE MATTER ≤ 10 µm	0.66	60	1.86	-	-	-	-	264	327
PARTICULATE MATTER ≤ 2.5 µm	0.56	51	0.25	-	-	-	-	38	90
POLYCYCLIC AROMATIC HYDROCARBONS	1.56×10^{-3}	0.14	-	-	-	-	-	-	0.14
SULFUR DIOXIDE	5.94×10^{-2}	5.43	-	-	-	-	-	-	5.49
TOTAL SUSPENDED PARTICULATE	0.67	61	3.14	-	-	-	-	1,031	1,096
TOTAL VOLATILE ORGANIC COMPOUNDS	0.46	42	-	-	3,307	51	82	-	3,482

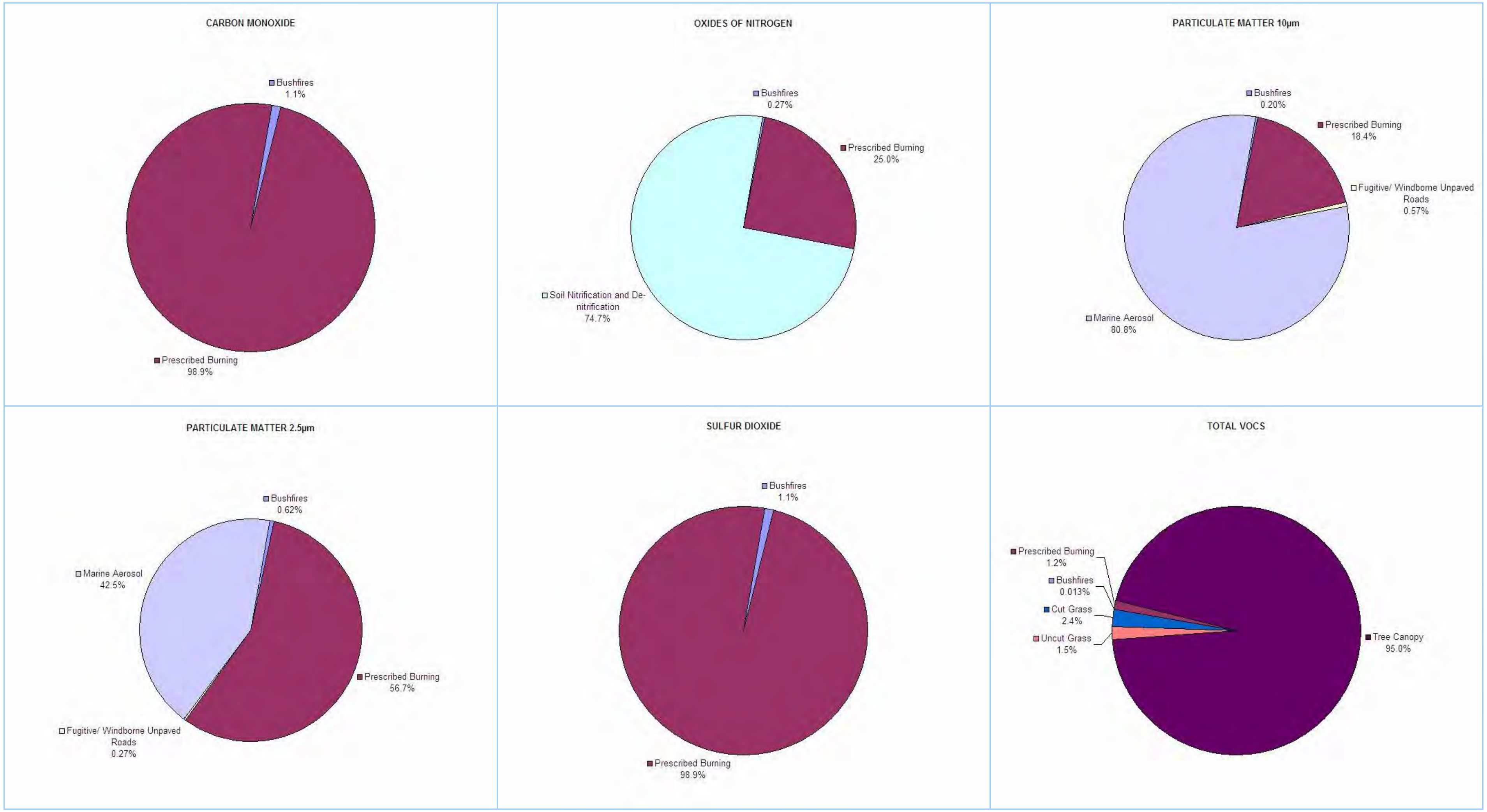

Figure 4-5: Proportions of total estimated annual emissions by biogenic and geogenic source type in the Wollongong region

Table 4-6: Total estimated annual emissions by biogenic and geogenic source type in the Non Urban region

Substance	Emissions (tonne/year)										
	Agricultural burning	Bushfires	Prescribed burning	Agricultural lands (fugitive/ windborne)	Unpaved roads (fugitive/ windborne)	Soil nitrification and denitrification	Tree canopy	Uncut grass	Cut grass	Marine aerosol	Biogenic and Geogenic Total
1,3-BUTADIENE	0.25	5.16	17	-	-	-	-	-	-	-	23
ACETALDEHYDE	-	-	-	-	-	-	-	852	13	-	865
CARBON MONOXIDE	291	6,451	21,803	-	-	-	-	-	-	-	28,545
LEAD & COMPOUNDS	4.57×10^{-4}	6.48×10^{-2}	0.22	1.29×10^{-2}	1.87	-	-	-	-	-	2.16
OXIDES OF NITROGEN	10	191	644	-	-	7,474	-	-	-	-	8,319
PARTICULATE MATTER ≤ 10 µm	37	650	2,196	95	1,230	-	-	-	-	24,511	28,719
PARTICULATE MATTER ≤ 2.5 µm	36	551	1,864	16	163	-	-	-	-	3,546	6,176
POLYCYCLIC AROMATIC HYDROCARBONS	0.66	1.54	5.21	-	-	-	-	-	-	-	7.41
SULFUR DIOXIDE	1.60	59	198	-	-	-	-	-	-	-	259
TOTAL SUSPENDED PARTICULATE	38	661	2,235	209	2,070	-	-	-	-	94,188	99,401
TOTAL VOLATILE ORGANIC COMPOUNDS	22	452	1,526	-	-	-	123,756	4,226	303	-	130,284

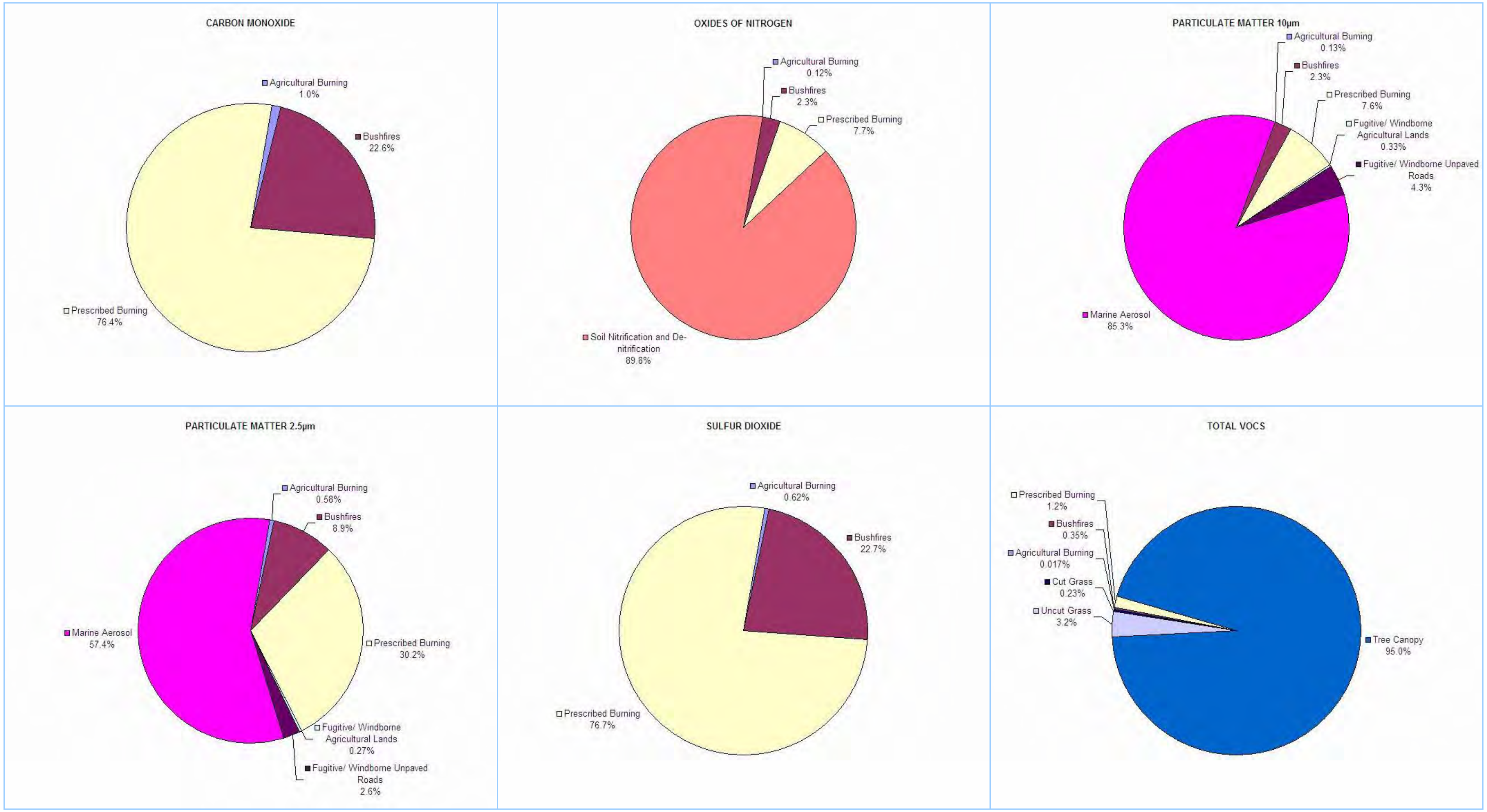

Figure 4-6: Proportions of total estimated annual emissions by biogenic and geogenic source type in the Non Urban region

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