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NAMOI REGION
REGIONAL AIRSHED MODELLING PROJECT

RAMBOLL ENVIRON

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EXECUTIVE SUMMARY

Purpose of the study

The study was commissioned to better understand temporal and spatial variations in ambient particle concentrations, provide a scientific basis for establishment of a regional air quality monitoring network and support improved cumulative air quality assessments for new proposals within the Namoi basin.

The study objectives are:

- To ensure that the NSW Government has a verified regional air shed modelling system for the modelling of particle concentrations within the Namoi region.
- To apply the air shed model developed to answer the following questions in regard to the base year (2013) and future year (2021):
    1. How do particle (PM_{10}, $PM_{2.5}$) concentrations vary spatially and temporally across the Gunnedah Basin, and how is this likely to change in the future as a result of land use changes?
    2. What particle concentrations occur within major population centres (Gunnedah, Narrabri) and within towns and villages (e.g. Werris Creek, Quirindi, Breeza, Caroona and Boggabri) in the region, and how is this likely to change in future as a result of land use changes?
    3. Which major sources contribute to airborne PM_{10} and $PM_{2.5}$ concentrations in the main population centres of Gunnedah and Narrabri and within towns and villages currently, and how is this likely to change in future as a result of land use changes?
    4. How are particle levels likely to vary between dry and wet years?
    5. Is there a requirement for a regional ambient air quality monitoring network taking into account current and projected future particle concentrations?
    6. If so, what is the optimum configuration of a regional ambient air quality monitoring network taking into account current and projected future particle concentrations?
    7. What further research should be undertaken to extend and improve the performance of cumulative air quality modelling for the region, following completion of the modelling system?

Overview of the methodology

The study methodology was developed in accordance with the study terms of reference (ToR) and in accordance with Australian and International guidance for the modelling and assessment of air pollutants. The study region is defined as the Namoi basin, comprising the local government areas (LGAs) of Narrabri, Gunnedah and Liverpool Plains.

Emissions inventories have been developed and reported for major sources within each LGA, for a base year (2013) and a future year (2021). The inventories focus on emissions of primary particles (PM_{10} and $PM_{2.5}$) for the main anthropogenic sources in the region (coal mines, industrial off road diesel, wood heaters, agriculture, transport (road and rail) and other industrial/commercial sources. Emission estimates for gaseous pollutants in the region are also presented but not included in the modelling.

Regional modelling for this study used a combination of TAPM, CALMET and CALPUFF modelling schemes. Surface observations were incorporated into both TAPM and CALMET modelling, with some stations excluded for the purpose of model evaluation. Meteorological model performance is evaluated by comparing summary statistics, visual analysis tools and statistical analysis.

Source apportionment modelling is used to quantify the contribution of each source group to annual average ambient PM_{10} and $PM_{2.5}$ concentrations in the major population centres of the study area. Model evaluation for the base year is presented to determine if the air quality model is acceptable as a means to inform the future year air quality projections, source contribution and suitable locations for monitoring stations.

Wet deposition (removal of particles from the air by rainfall) was excluded from the source apportionment modelling, however sensitivity analysis is presented to inform particle levels likely to vary between dry and wet years.

Emission estimates

Emission inventories presented for the Narrabri, Gunnedah and Liverpool Plains LGAs show that the dominant anthropogenic sources of PM_{10} and $PM_{2.5}$ emissions in the region are coal mines. In 2013, fugitive emissions from coal mines are estimated to contribute to approximately 76% of total PM_{10} emissions and 48% of the total $PM_{2.5}$ emissions. For the future year scenario (2021), the emission estimates for coal mines assume future operation at the maximum approved production rate, with the following exceptions:

- Sunnyside Coal Mine is in care and maintenance and is not included.
- Vickery Coal Mine is approved for 4.5 Million tonnes per annum (Mtpa), however a recent application for the Vickery Extension Project seeks an increase to 10 Mtpa, which is included for the 2021 modelling scenario.
- The proposed Caroona Coal Project is excluded, due to the recent cancellation of the Exploration Licence for this project.
- The proposed Watermark Coal Project is not yet approved, therefore two scenarios are presented for 2021, with and without this project.

Assuming the Watermark Coal Project does proceed, the contribution from coal mines is projected to increase to 87% in 2021 for PM_{10} and 58% for $PM_{2.5}$. The contribution from diesel equipment also increases significantly for $PM_{2.5}$ in 2021 (from 19% to 31%).

Other significant sources of $PM_{2.5}$ emissions in 2013 are agriculture (11%), wood heaters (10%) and rail transportation (5%). The relative contribution from these sources is projected to decrease in 2021, however, it is noted that a robust methodology for projecting emissions for certain sources in 2021 could not be found (i.e. agriculture) and therefore the relative contributions should be viewed with this in mind.

Model evaluation

To evaluate model performance against the monitoring data, it is important to account for 'non-modelled' components, by either subtracting from the monitoring data or adding to the modelling results. Particle characterisation data from the Upper Hunter Particle Characterisation Study was used to estimate the 'non-modelled' components, including the contribution from secondary and natural PM to the total measured mass in rural areas. For example, the derived contribution from non-modelled sources at Vickery is 55% of the total measured PM_{10} and 65% of the total measured $PM_{2.5}$. For Werris Creek the derived contribution from non-modelled sources is 55% of the measured PM_{10} mass and 60% of the measured $PM_{2.5}$ mass. These estimates appear to be consistent with the reported contribution of secondary PM in the literature (Chan et al, 2008; Cope, 2012) and similar in magnitude to the estimated secondary and natural PM derived for Singleton and Muswellbrook in the Upper Hunter Particle Model (Kellaghan et al, 2014).

With the 'non-modelled' component added to the modelling results, the base year model evaluation suggests an under-estimation in PM_{10} and $PM_{2.5}$ concentrations by approximately 30% - 40% at most sites. The modelling and the 'non-modelled' components do not necessarily account for regionally transported PM and therefore the results from the model evaluation are used to derive a combined regional background PM_{10} and $PM_{2.5}$ concentration of 11.1 μg/m³ and 6.8 μg/m³, which is combined with the modelling predictions to inform total PM_{10} and $PM_{2.5}$ concentrations for the town centres. While on the surface this 'background' contribution may appear high, analysis of monitoring data from sites where the influence of major anthropogenic sources are expected to be minor, shows PM_{10} and $PM_{2.5}$ concentrations similar in magnitude to these levels.

Study results and conclusions

For annual average PM_{10} in 2013, coal mine fugitive emissions are the single largest contributor at Boggabri (9.3%) and Werris Creek (8.0%). Wood heaters are estimated to be the single largest contributor to annual average PM_{10} at Gunnedah (7.0%), Narrabri (7.8%) and Quirindi (7.9%).

In 2021, the contribution to annual average PM_{10} from coal mine fugitive emissions increases at Boggabri (36.3%) and Werris Creek (21.0%) while at Gunnedah coal mine fugitive emissions overtake wood heaters at the single largest contributor (11.8%). While wood heaters remain the single largest contributor to annual average PM_{10} in 2021 at Narrabri (7.3%) and Quirindi (7.3%), the combined emissions from coal mines and coal mine diesel overtakes wood heaters as the largest source.

For annual average $PM_{2.5}$ in 2013, wood heaters are the single largest contributor at Quirindi (11.9%), Narrabri (11.9%), Gunnedah (10.7%), Boggabri (7.7%) and Werris Creek (2.9%). Wood heaters remain the single largest contributor in 2021 at Quirindi (11.4%), Narrabri (11.6%) and Gunnedah (10.1%). In 2021, the contribution to annual average $PM_{2.5}$ from coal mine fugitive emissions increases at Boggabri (14.5%) and Werris Creek (5.8%) to overtake wood heaters at the single largest source.

It is noted that the estimated secondary, natural and regionally transported PM remains constant for the 2021 projections and therefore the relative contributions should be viewed with this in mind.

A probabilistic risk based approach is used to investigate the probability of additional exceedances of the 24-hour average concentrations. Using this approach, the estimated additional exceedances for 24-hour PM_{10} ranges from one to seven additional days over the 50 $\mu g/m^3$ across all towns. Similar analysis for 24-hour average $PM_{2.5}$ estimates one to two additional days over 25 $\mu g/m^3$ across all towns.

Assuming the Watermark Coal Project does proceed, the largest increases in PM_{10} and $PM_{2.5}$ concentrations in 2021 are predicted in the towns of Werris Creek, Curlewis and Boggabri. If the Watermark Coal Project is excluded from the 2021 scenario, the largest percentage increase in occurs in the towns of Werris Creek, Boggabri and Baan Baa. Although definite comparisons cannot be made against ambient air quality standards, the modelling suggests that all towns would comply with the NEPM AAQ PM_{10} standard of 25 $\mu g/m^3$ for PM_{10} in 2021, however compliance with the NEPM AAQ $PM_{2.5}$ standard of 8 $\mu g/m^3$ may not be achieved at some towns.

The spatial distribution in annual average and 24-hour average PM_{10} and $PM_{2.5}$ shows significant concentrations gradients in the vicinity of existing and proposed coal mines, and to a lesser extent a concentration gradient around towns for annual average $PM_{2.5}$. There is also evidence that the increase in emissions in 2021 results in a more defined or connected regional airshed for the Namoi Region, particularly for annual average $PM_{2.5}$. The modelled source contributions to annual average ground level PM_{10} and $PM_{2.5}$ concentrations in 2013 and 2021 are presented in **Figure E1**.

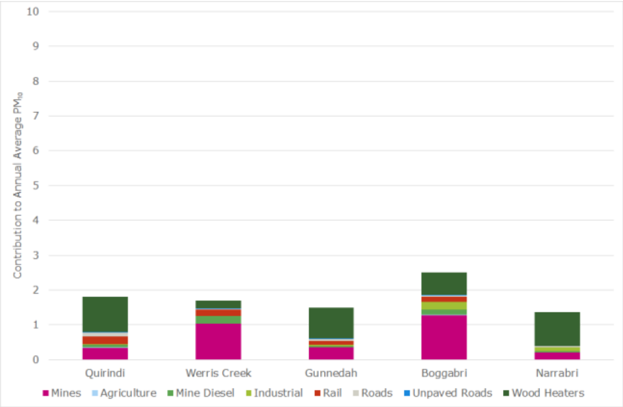
Recommendations for a regional monitoring network

Although extensive air quality monitoring already exists within the Namoi region, there are some significant limitations in the existing network. To inform prioritisation of a regional monitoring network, a summary of the base year (2013) and projected (2021) PM concentrations are presented for each town, along with the current population and the distance to the nearest existing monitoring site.

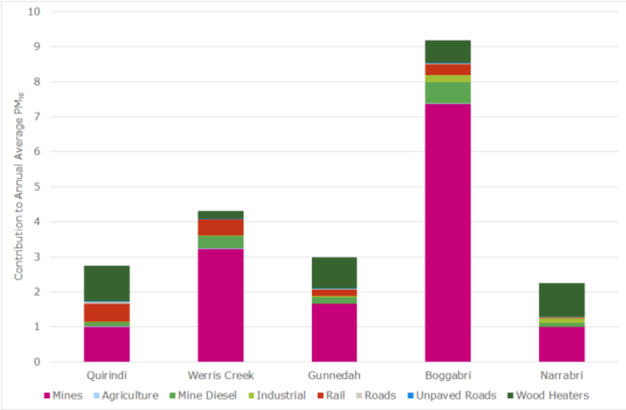
Recommendations for future work

The most significant source of uncertainty identified for this study relates to estimates of background from all sources not considered in the modelling, including secondary particles. Recommendations for future work include:

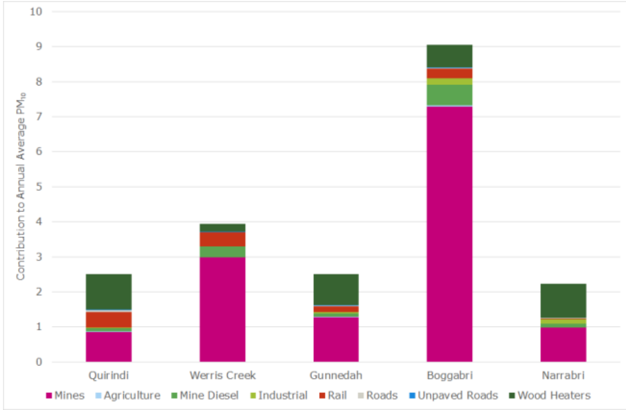
- Following commissioning of the proposed Namoi basin monitoring network and as soon as a year of data are collected, it is recommended that the modelling is updated to allow consideration of background and evaluation of the base case model.
- Refinement of the approach for estimating the contribution from 'non-modelled' PM.
- Refinement of the modelling to include additional prognostic modelling or the use of photochemical grid models to account for secondary particle formation.
- Improving the spatial resolution of certain sources may improve modelling predictions and reduce model uncertainty.



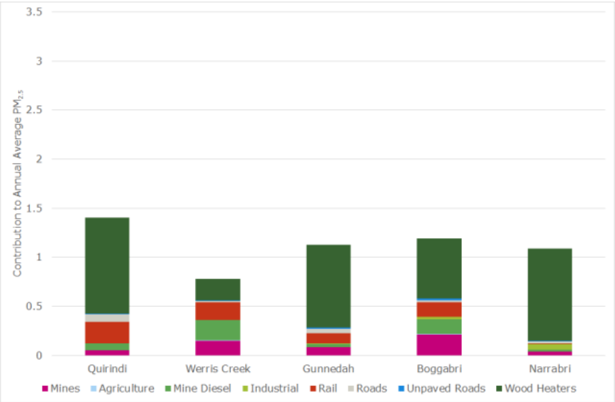
PM_{10} 2013



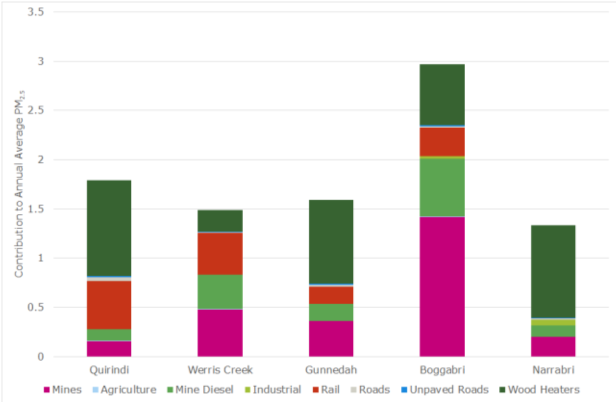
PM_{10} 2021



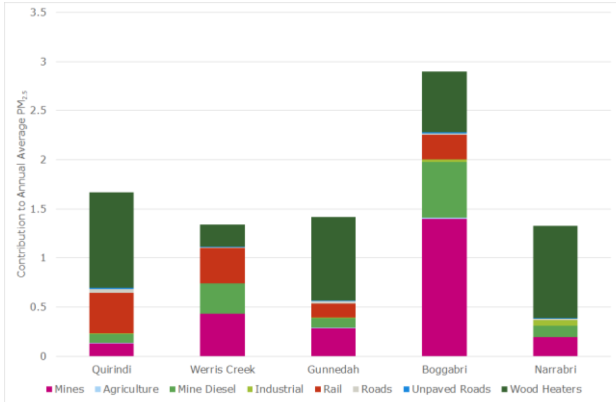
PM_{10} 2021 without Watermark Coal Project



$PM_{2.5}$ 2013



$PM_{2.5}$ 2021



PM_{10} 2021 without Watermark Coal Project

Figure E1: Modelled source contribution to annual average concentrations

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APPENDICES

1. INTRODUCTION

The New South Wales (NSW) Environment Protection Authority (EPA) has commissioned Ramboll Environ Australia Pty Ltd (Ramboll Environ) to develop a regional emission inventory and airshed model for the New England North West (Namoi basin) region in NSW. The study focuses on the most significant sources of primary anthropogenic[1] PM_{10} and $PM_{2.5}$[2] emissions within the local government areas (LGAs) of Narrabri, Gunnedah and Liverpool Plains.

The outcomes of the study will be used to better understand temporal and spatial variations in ambient particle levels, provide a scientific basis for establishment of a regional air quality monitoring network and support improved cumulative air quality assessments for new proposals within the basin.

1.1 Study scope and objectives

The study methodology has been developed in accordance with the terms of reference for the study and includes the following key tasks:

- Task 1. Develop emission inventories for the major sources in the region, for a base year (2013) and a future year (2021).
- Task 2. Develop a regional primary particle model for the region, incorporating all major emissions sources inventoried in Task 1, for the base year and future year.
- Task 3. Use the outcomes from the model outputs to address the questions outlined in the study objectives, and inform source contribution to PM_{10} and $PM_{2.5}$ concentrations in regional population centres for the base year and future year.

The study objectives and key outcomes are:

- To ensure that the NSW Government has a verified regional air shed modelling system for the modelling of particle concentrations within the Namoi region.
- To apply the air shed model developed to answer the following questions in regard to the base year (2013) and future year (2021):
    1. How do particle (PM_{10}, $PM_{2.5}$) concentrations vary spatially and temporally across the Namoi region, and how is this likely to change in the future as a result of land use changes?
    2. What particle concentrations occur within major population centres (Gunnedah, Narrabri) and within towns and villages (e.g. Werris Creek, Quirindi, Breeza, Caroona and Boggabri) in the region, and how is this likely to change in future as a result of land use changes?
    3. Which major sources contribute to airborne PM_{10} and $PM_{2.5}$ concentrations in the main population centres of Gunnedah and Narrabri and within towns and villages currently, and how is this likely to change in future as a result of land use changes?
    4. How are particle levels likely to vary between dry and wet years?
    5. Is there a requirement for a regional ambient air quality monitoring network taking into account current and projected future particle concentrations?
    6. If so, what is the optimum configuration of a regional ambient air quality monitoring network taking into account current and projected future particle concentrations?
    7. What further research should be undertaken to extend and improve the performance of cumulative air quality modelling for the region, following completion of the modelling system.

[1] Primary natural particulate matter (PM) is emitted directly into the atmosphere as a result of processes such as wind erosion and the production of marine aerosols (sea salt). Primary anthropogenic PM result from processes involving either combustion (e.g. industrial activity, domestic wood heaters, vehicle exhaust) or abrasion (e.g. mining for coal, road vehicle tyre wear). Secondary PM is not emitted directly, but is formed by chemical reactions involving gas-phase components of the atmosphere. The origin of secondary PM may be natural or anthropogenic.

[2] Particulate matter with an aerodynamic diameter of less than 10 and 2.5 micrometres

2. BACKGROUND AND CONTEXT

In 2012 the NSW Government issued the New England North West Strategic Regional Land Use Plan which included a commitment to the establishment of an air quality monitoring network in the region and the development of a cumulative impact assessment methodology for mining and coal seam gas development (NSW DPI, 2012). This study builds on previous work commissioned by the NSW EPA (TAS, 2013; OEH. 2013) by providing a scientific basis for the design of a regional air quality monitoring network.

2.1 Previous recommendations for regional air quality monitoring

Todoroski Air Sciences (TAS) was commissioned by the EPA to provide recommendations for regional air quality monitoring in the Namoi basin, based on a review of meteorology and the location of industrial emission sources in the region (TAS, 2013). The TAS study suggested 16 potential monitoring locations, grouping sites as "exposure" , "diagnostic" and "combination / background" monitoring sites. Exposure monitoring sites were defined as an approximation of NEPM performance monitoring sites while diagnostic sites were upwind or downwind of significant air pollution sources. The exposure monitoring sites were suggested in each of the main population centres while the diagnostic sites were proposed in the vicinity (upwind/downwind) of each mining projects. Regional background sites were also suggested, away from major sources but where exposure to dust from agricultural activities could be assessed.

The NSW Office of Environment and Heritage (OEH) has also advised the EPA on the establishment of an air quality monitoring network for the Namoi basin and provided a comprehensive review of population density, topography, climate, meteorology and existing and proposed sources of emissions within the region (OEH, 2013). The OEH report recommended that air quality monitoring sites be established at Gunnedah and Narrabri, employing continuous PM_{10} and $PM_{2.5}$ monitoring. Potential monitoring site locations were identified (near the Racetrack on Hunter St in Gunnedah and near the public swimming pool on Tibbereena St in Narrabri). These two suggested monitoring locations would measure exposure for 55% of the combined populations within the Gunnedah and Narrabri LGAs.

The OEH report also recommended that an emissions inventory and regional air quality model be developed for the Namoi basin to provide a more detailed understanding of spatial and temporal variations in ambient PM, now and into the future.

2.2 Requirements for monitoring networks

The need for air quality monitoring in the region was evaluated in OEH (2013), with findings supporting the need for implementation of the monitoring network. The need was supported because:

- There are a number of licenced premises contributing cumulatively to air pollutants in the region.
- There are some limitations to the existing monitoring network in the region.
- There is a potential for population exposure to particles to increase into the future.
- There is state and local government support for a regional monitoring network.

OEH, in their review, note that an air quality monitoring network established in the Namoi region would not meet the requirements for performance (compliance) monitoring under the National Environment Protection (Ambient Air Quality) Measure (AAQ NEPM) (OEH, 2013).

The technical requirements for air quality monitoring for the AAQ NEPM were outlined by the NEPM Peer Review Committee (PRC) in a series of guidance papers, which were used to generate the monitoring strategy for NSW[3].

[3] http://www.environment.nsw.gov.au/air/nepm/index.htm

The PRC guidance paper No.2 identifies three types of regions (listed below) which, for the purposes of performance monitoring, are geographical areas where air quality (for a particular pollutant) is determined either entirely or in a large part by the influence of a common collection of anthropogenic emission sources.

- Type 1 - A large urban or town complex with a population in excess of 25,000 requiring direct monitoring and contained within a single airshed.
- Type 2 - A region with no one population centre above 25,000 but with a total population above 25,000 and with significant point source or area based emissions so as to require a level of direct monitoring.
- Type 3 - A region with a population in excess of 25,000 but with no significant point or area based emissions, so that ancillary data can be used to infer that direct monitoring is not required.

Monitoring sites in NSW are typically performance or trend monitoring sites and meet the definition of a neighbourhood site in AS/ANZ 3580.1.1: 2007. The AAQ NEPM monitoring strategy for NSW identifies Type 1 and Type 3 regions for NSW only and adopts performance monitoring for Type 1 regions. The outcomes of this study may be useful to inform whether the Namoi region airshed could be classified as a Type 2 region for AAQ NEPM monitoring.

2.3 Ambient air quality standards

When first regulated, assessment of airborne particulate matter (PM) was based on concentrations of "total suspended particulate matter" (TSP). In practice, this typically referred to PM smaller than about 30-50 micrometers (µm) in diameter. As air sampling technology improved and the importance of particle size and chemical composition become more apparent, ambient air quality standards have been revised to focus on the smaller particle sizes, thought to be most dangerous to human health. Contemporary air quality assessment typically focuses on "fine" and "coarse" inhalable PM, based on health-based ambient air quality standards set for PM_{10} and $PM_{2.5}$[4].

Under the AAQ NEPM national reporting standards were initially prescribed for 24-hour average PM_{10} concentrations (NEPC, 1998). The AAQ NEPM was varied in 2003 to include 'advisory reporting standards' for $PM_{2.5}$ (NEPC, 2003) and again in 2015 to adopt these 'advisory reporting standards' as formal standards for $PM_{2.5}$ (NEPC, 2015).

The latest variation to the AAQ NEPM also introduces an annual reporting standard for PM_{10} and establishes long term goals for $PM_{2.5}$, to be achieved by 2025 (NEPC, 2015). The AAQ NEPM standards for PM are presented in **Table 2-1**.

The purpose of the AAQ NEPM is to attain '*ambient air quality that allows for the adequate protection of human health and wellbeing*', assessed through air quality monitoring data collected and reported by each State and Territory.

The AAQ NEPM standards are not necessarily applicable to the assessment of localised impacts of emissions sources on individual sensitive receivers. Local air quality impacts from discrete emission sources are typically assessed against impact assessment criteria prescribed in the *Approved Methods for the Modelling and Assessment of Air Pollutants in New South Wales* (the Approved Methods) (NSW EPA, 2005).

As described above, there are currently no AAQ NEPM monitoring sites within the Namoi region. Existing monitoring within the region has been established either to assess compliance for existing industry or to collect baseline data for proposed new industry.

Although the existing monitoring data cannot be assessed for compliance against AAQ NEPM standards, it is useful to provide some discussion of existing air quality within the region, with reference to the AAQ NEPM standards (**Section 3**).

Table 2-1: AAQ NEPM standards for PM (NEPC, 2015)

Pollutant	**Averaging period**	**Maximum concentration standard ($\mu g/m^3$)**
PM_{10}	1 day	50
	1 year	25
$PM_{2.5}$	1 day	25
		20[1]
	1 year	8
		7[1]

Note: [1] long term compliance goal for 2025

3. EXISTING AIR QUALITY MONITORING IN THE REGION

There is an extensive network of industry owned air quality monitoring stations in the Namoi region, including 17 PM_{10} High Volume Air Samplers (HVAS), seven PM_{10} TEOMs[5] and five $PM_{2.5}$ TEOMs. A more comprehensive summary of the existing air quality monitoring network within the region is provided in OEH (2013).

The annual mean and maximum 24-hour average PM_{10} and $PM_{2.5}$ concentrations for 2013 are presented in **Figure 3-1** and **Figure 3-2**. Also presented are the PM_{10} concentrations for OEH operated monitoring sites in the region.

There is significant variation in annual mean PM_{10} concentrations across the Namoi region, ranging from 9 µg/m³ to 26 µg/m³ for 2013. Similarly, OEH (2013) reviewed five years of data (2008-2012) and found annual average PM_{10} concentrations to generally be in the range of 8 µg/m³ to 18 µg/m³. Annual average concentrations for 2013 mostly fall within the range of 10 µg/m³ to 15 µg/m³, with an average of 14.1 µg/m³ across all sites. Some sites, for example located close to existing mining operations, recorded higher annual average PM_{10} concentrations in 2013.

Similar variation in evident in the maximum daily PM_{10} concentrations (**Figure 3-2**), ranging from 106 µg/m³ to 28 µg/m³. The highest 24-hour average PM_{10} concentrations in 2013 are not necessarily located close to existing mining operations. For example, the third highest 24-hour average PM_{10} concentration was measured at Wybong.

$PM_{2.5}$ is measured at five sites, however only the Vickery and Werris Creek sites represent a complete year of data for 2013. The annual mean $PM_{2.5}$ concentrations for 2013 varies from 5 µg/m³ to 7.5 µg/m³, with the highest concentrations measured at the Werris Creek Town site (7.5 µg/m³). These concentrations are similar in magnitude to the annual average $PM_{2.5}$ reported in OEH (2013) for Werris Creek and Breeza (7.3 µg/m³ and 7.6 µg/m³).

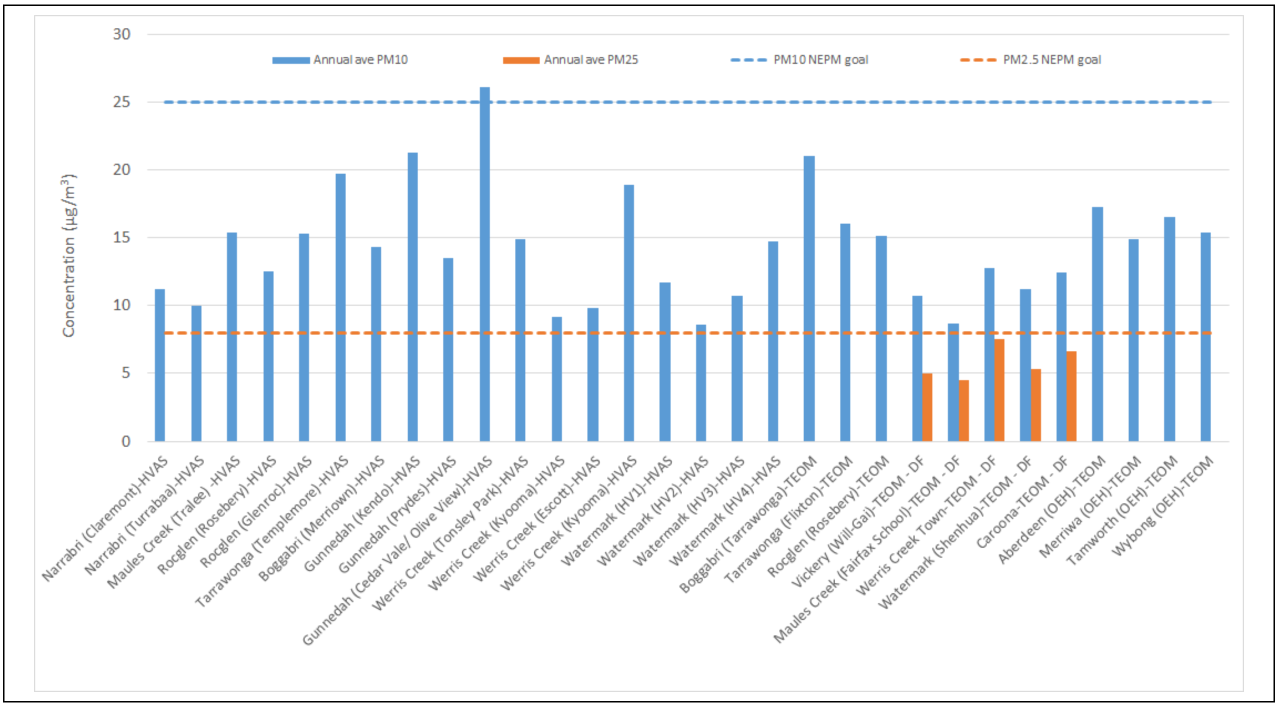


Figure 3-1: Annual mean PM_{10} and $PM_{2.5}$ concentrations for 2013 across the Namoi region

[5] TEOM = Tapered Element Oscillating Microbalance. TEOM-DF refers to a dichotomous model which measures both PM_{10} and $PM_{2.5}$.

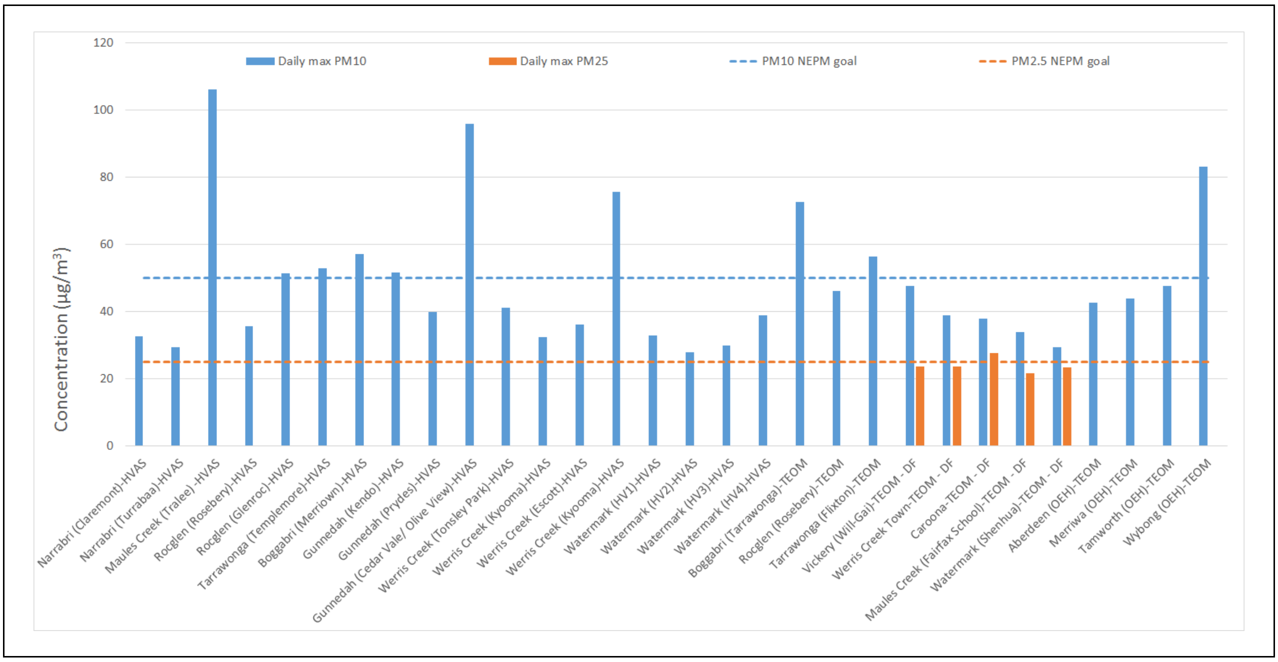


Figure 3-2: Daily maximum PM_{10} and $PM_{2.5}$ concentrations for 2013 across the Namoi region

3.1 Spatial variation in ambient PM

Figure 3-3 and **Figure 3-4** show the spatial variation in annual average and daily maximum PM_{10} and $PM_{2.5}$ concentrations across the region. The variation in concentration, from low to high, is shown by both the colour gradient and the size of the circle. For ease of presentation, some of the monitoring sites are combined, based on proximity. For example, at Rocglen (Roseberry) there is a co-located TEOM and HVAS, therefore the monitoring data is combined (averaged) to represent ambient PM_{10} concentrations for this area.

Figure 3-3 shows that potentially significant gradients in annual average PM_{10} concentrations occur across the Namoi region. PM_{10} concentrations are noticeably higher close to emissions sources (the major towns of Gunnedah and Tamworth and in the vicinity of coal mines). A similar picture is evident in **Figure 3-4**, showing higher daily maximum PM_{10} concentrations in the vicinity of the coal mines and within major towns. $PM_{2.5}$ monitoring is limited to 5 sites, only two of which have a complete year of data for 2013. Limited conclusions on spatial variation can be made, however based on the available data, $PM_{2.5}$ concentrations appear higher within towns (i.e. Werris Creek) compared with, for example, the rural setting of Vickery.

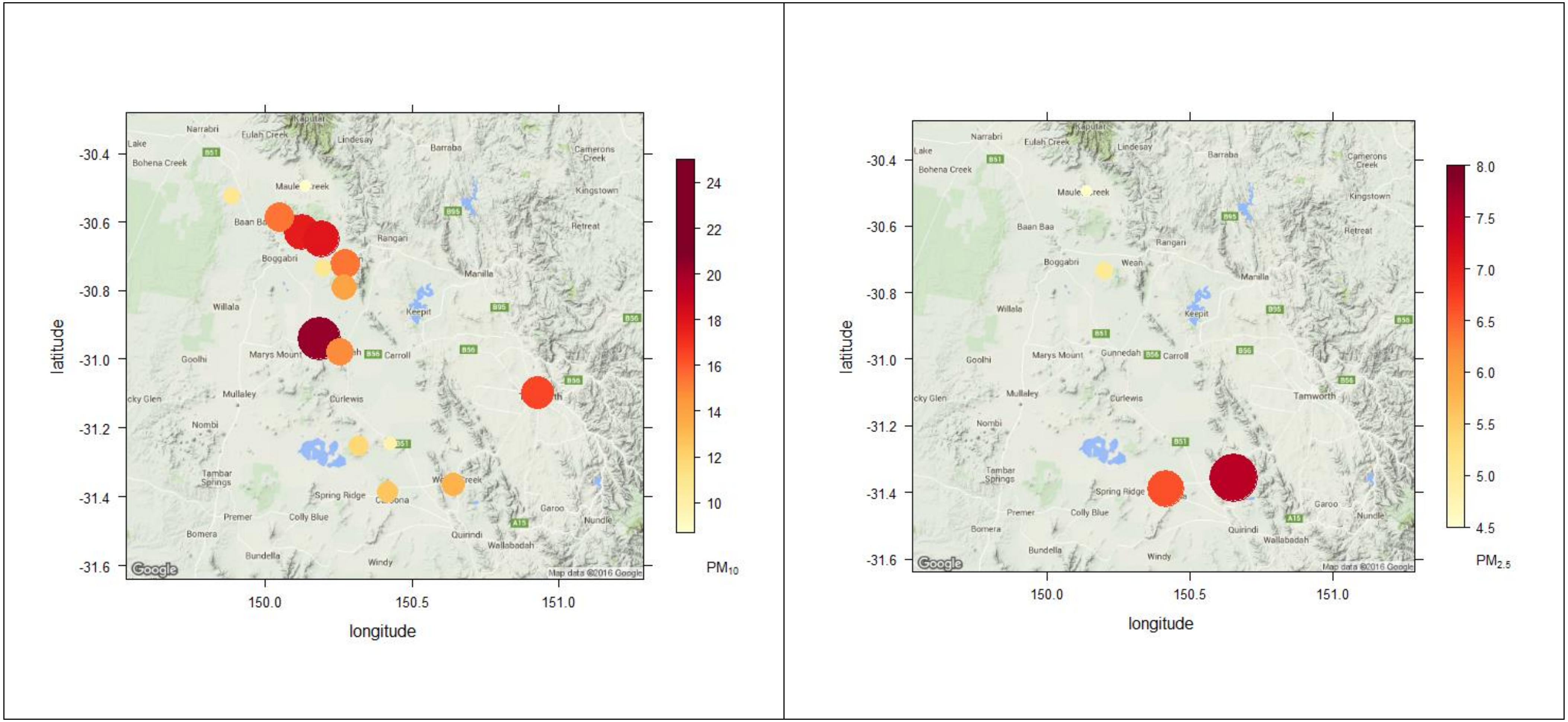


Figure 3-3: Spatial variation in annual average PM_{10} and $PM_{2.5}$ concentrations for 2013 across the Namoi region

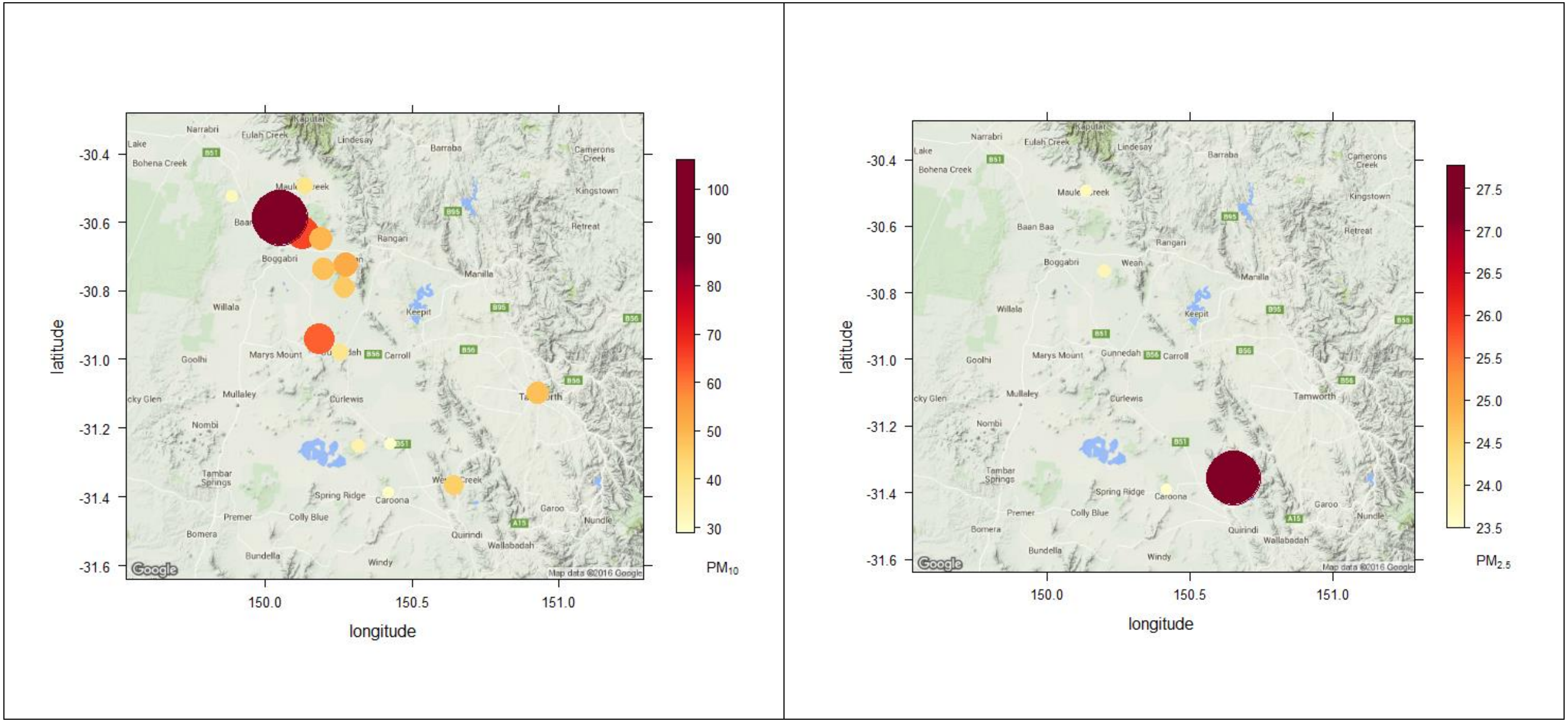


Figure 3-4: Spatial variation in maximum 24-hour PM_{10} and $PM_{2.5}$ concentrations for 2013 across the Namoi region

3.2 Temporal variation in ambient PM

Temporal variation (diurnal and seasonal) in ambient PM is presented for the Vickery (Wil-gai) TEOM and the Werris Creek Town TEOM. These are the only sites with a full year of data in 2013 for both PM_{10} and $PM_{2.5}$. Temporal variation is presented using the polar annulus function in openair (Carslaw et al, 2012; Carslaw, 2015). The plots shows how the PM concentrations vary temporally (by hour of the day and month of the year) and by wind direction (the darker the shade the higher the concentration).

Figure 3-5 shows the hourly mean PM_{10} and $PM_{2.5}$ concentrations for Werris Creek town, plotted by hour of the day and wind direction. For PM_{10} (left panel) the highest hourly mean concentrations (represented by the dark bands) occur when winds blow from the southwest through northeast and in the evening. There is also an early morning source to the southeast. For $PM_{2.5}$ the highest mean hourly concentrations occur at night when winds blow from the northeast. The Werris Creek data re-plotted in **Figure 3-6**, this time showing monthly variation. The influence of wind direction is less obvious but the highest concentrations are clearly associated with certain months of the year (October and December for PM_{10}, July, October and December for $PM_{2.5}$).

Figure 3-7 and **Figure 3-8** show the same analysis for Vickery. The highest mean hourly PM_{10} concentrations occur in the early morning (most wind directions) and evenings (from the northwest). For $PM_{2.5}$, there is a clear daytime signal for highest mean hourly $PM_{2.5}$ concentrations from the northwest. Similar to the Werris Creek data, certain months of the year are associated with higher mean hourly concentrations (March/April for PM_{10} and and September, October and December for $PM_{2.5}$).

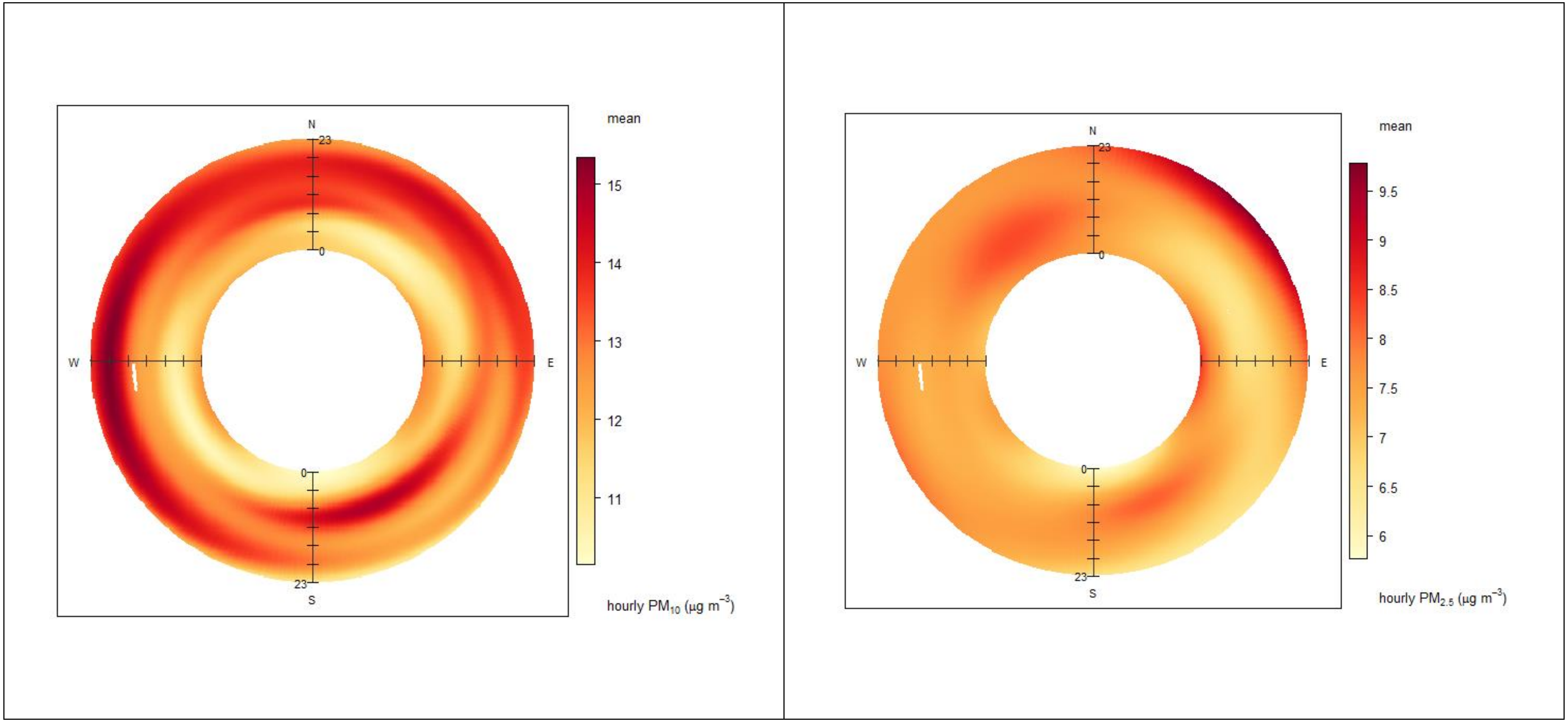


Figure 3-5: Polar plot of hourly PM concentration by wind direction at Werris Creek (2013)

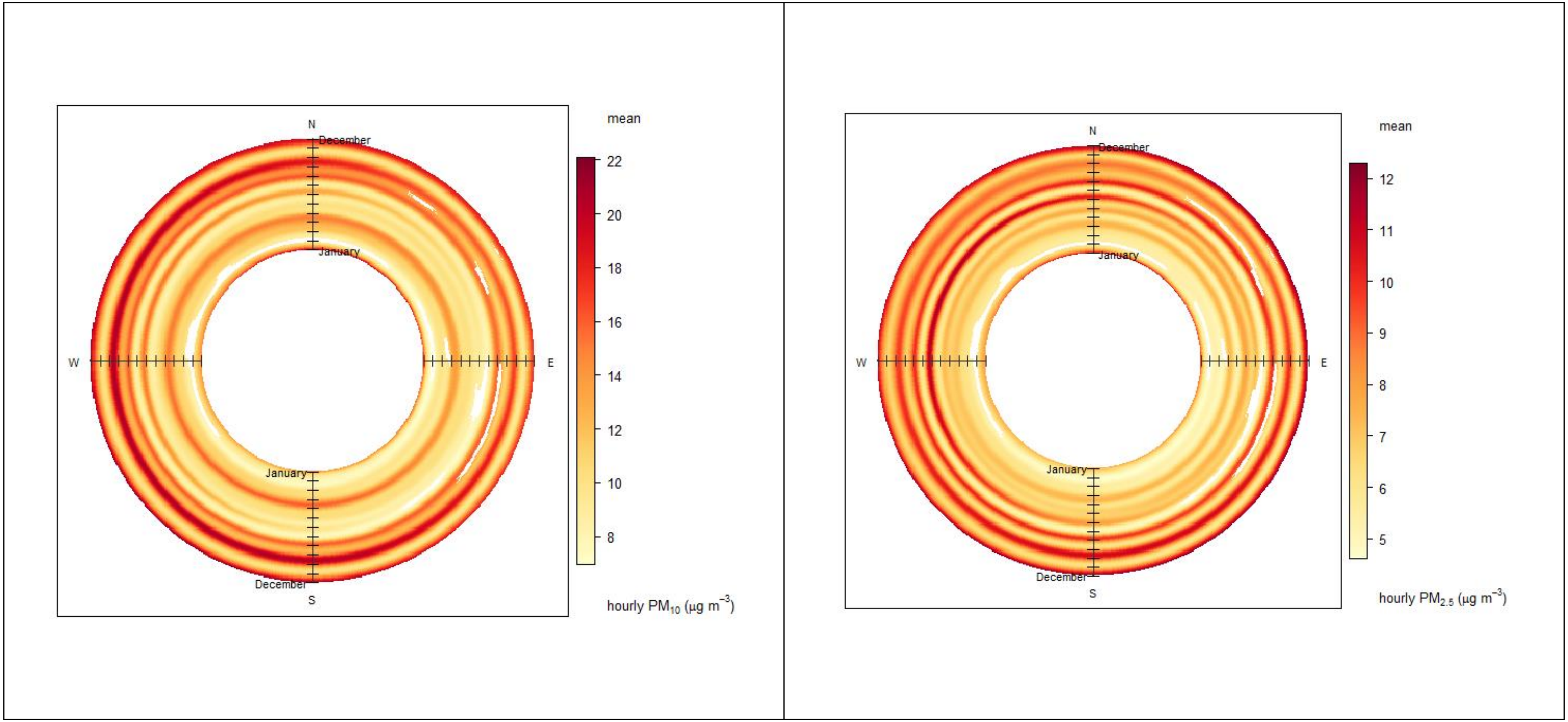


Figure 3-6: Polar plot of monthly PM concentration by wind direction at Werris Creek (2013)

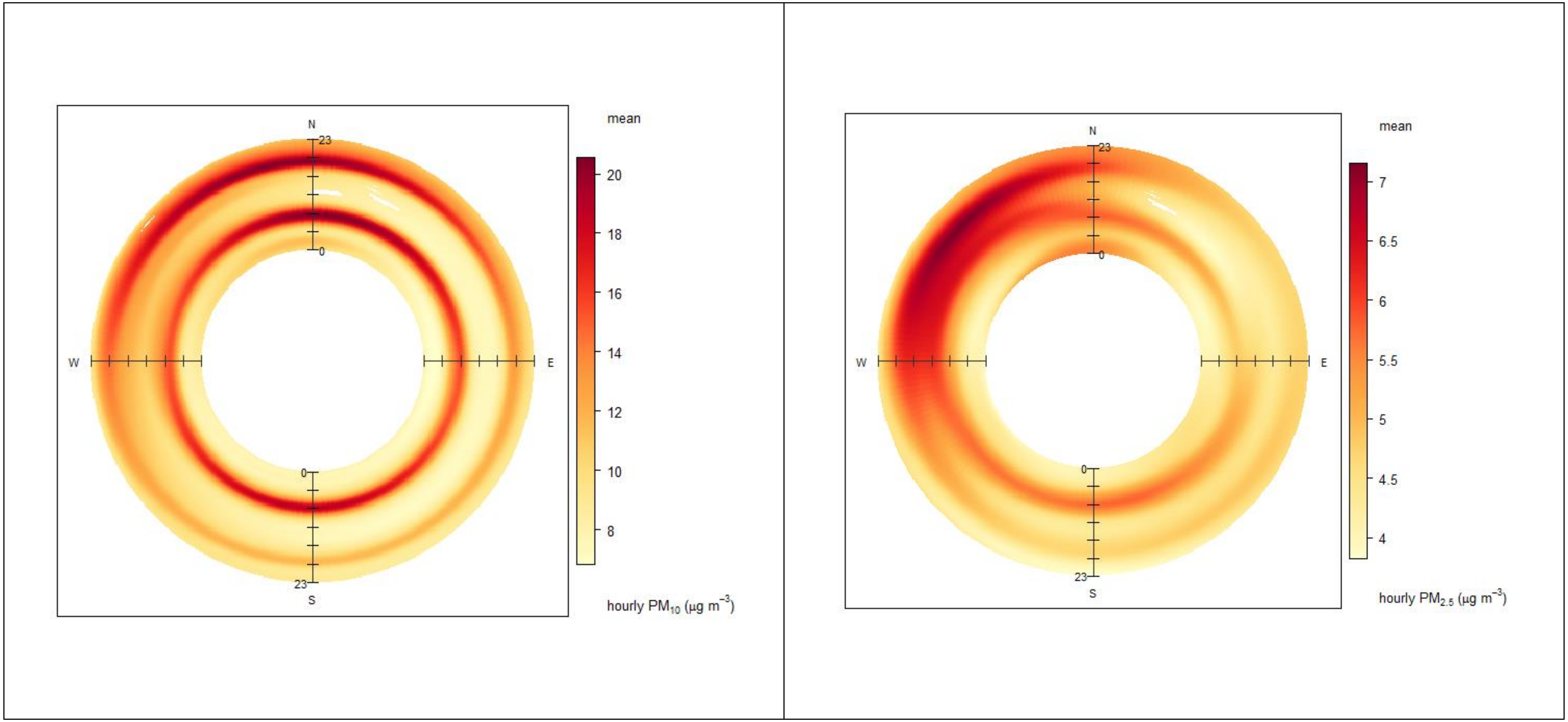


Figure 3-7: Polar plot of hourly PM concentration by wind direction at Vickery (2013)

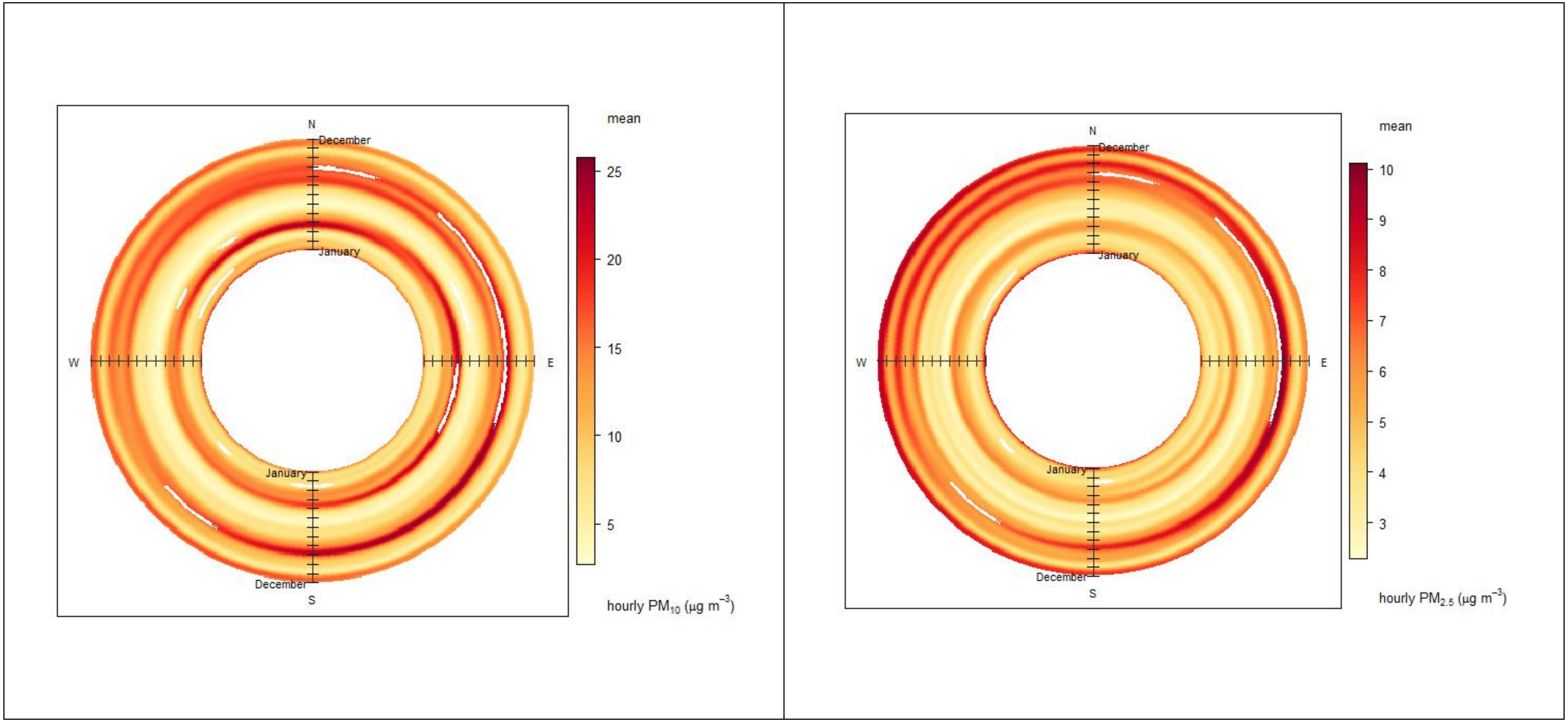


Figure 3-8: Polar plot of monthly PM concentration by wind direction at Vickery (2013)

3.3 Summary

Although extensive air quality monitoring already exists within the Namoi region, there are some limitations in the existing network. Many of the monitoring sites employ HVAS and collect samplers on a 1-in-6 day run cycle, which delays the reporting of results. Reporting of a single 24-hour average result also limits the ability to analyse the data with concurrent wind data.

There are no continuous PM_{10} and $PM_{2.5}$ monitoring sites in the regional centres of Gunnedah and Narrabri, and generally $PM_{2.5}$ monitoring is limited. Finally, industry sites are operated independently, which introduces potential inconsistency in instrument type, maintenance, calibration and data validation.

4. STUDY APPROACH

4.1 Introduction

The study methodology has been developed in accordance with the terms of Reference (ToR) for the study. The ToR required the development of a Methodology Paper, which should be reviewed by a suitable independent peer reviewer. Ramboll Environ developed the Methodology Paper (ENVIRON, 2015) and commissioned Dr. Nigel Holmes for the independent peer review.

The following sections summarise the study approach and methodology. Further details can be found in ENVIRON (2015).

The main study tasks are as follows:

- Task 1. Develop emission inventories for the major sources in the region, for a base year (2013) and a future year (2021). The inventories will focus on emissions of primary particles (PM_{10} and $PM_{2.5}$) for the main anthropogenic sources in the region (coal mines, industrial off road diesel, wood heaters, agriculture, transport (road and rail) and other industry/commercial). Anthropogenic sources of gaseous pollutants, including sulphur dioxide (SO_2), oxides of nitrogen (NO_x), carbon monoxide (CO) and total volatile organic compounds (VOCs), for major industrial and mining sources, are also inventoried.
- Task 2. Develop a regional primary particle model for the region, incorporating all major emissions sources inventoried in Task 1, for the base year and future year, including evaluation of the performance of the base year model using existing monitoring data.
- Task 3. Use the outcomes from the model outputs to address the questions outlined in the study objectives, and inform source contribution to PM_{10} and $PM_{2.5}$ concentrations in regional population centres for the base year and future year.

The study has been prepared with reference to Australian and International best practice guidance for modelling and assessment of air pollutants (i.e. NSW EPA, 2005; TRC, 2011;US EPA 2005;US EPA, 2013; DEFRA, 2009; DEFRA, 2010; NZ MFE, 2004; AESRD, 2009).

4.2 Study region

The study region as the Namoi basin, comprising the local government areas (LGAs) of Liverpool Plains, Gunnedah and part of the Narrabri LGA. Emissions inventories have been developed and reported for major sources within each LGA.

Modelling predictions for PM_{10} and $PM_{2.5}$ focus on key populated areas of study area (Namoi basin), although the overall modelling domain extends beyond the LGAs to account for the dominant terrain features and the influence on regional dispersion meteorology. The geographical setting of the Narrabri, Gunnedah and Liverpool Plains LGAs and the study area boundary are illustrated in **Figure 4-1**.

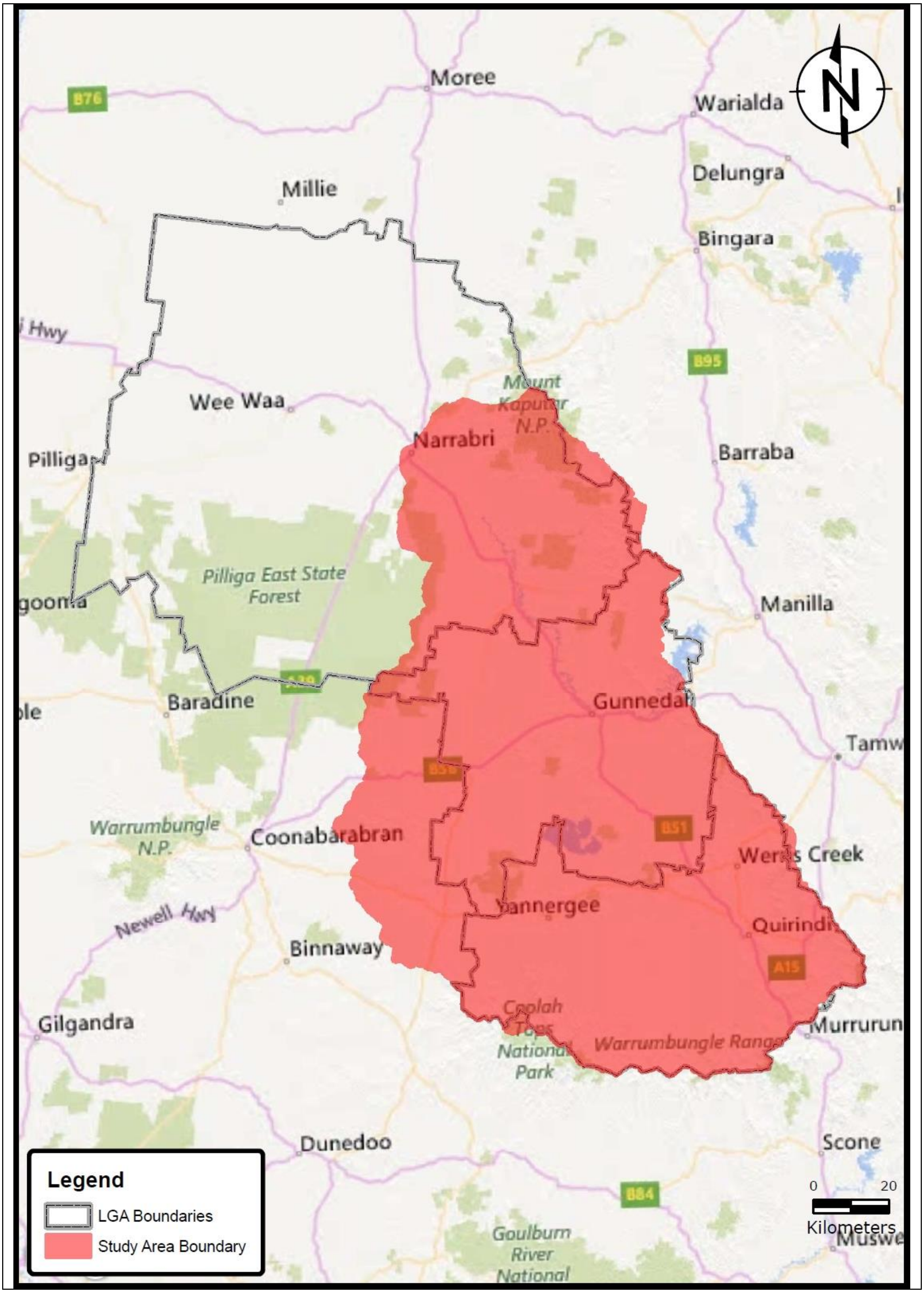


Figure 4-1: Study area boundary and geographical setting

4.3 Modelling system

The Approved Methods for the Modelling and Assessment of Air Pollutants in New South Wales (NSW EPA, 2005) provides guidance for air quality impact assessment in NSW, including recommendations for the use of dispersion models. The guidance typically relates to local air quality assessment although it does recommend suitable dispersion models for non-steady state conditions and far field dispersion.

The modelling for this study used a combination of TAPM, CALMET and CALPUFF modelling schemes, as follows:

- TAPM is used to generate gridded three-dimensional meteorological data for each hour of the model run period for input into CALMET (as '3D.dat') to drive the 'initial guess' of the meteorological field.
- CALMET, the meteorological pre-processor for the dispersion model CALPUFF, calculates fine resolution three-dimensional meteorological data using a combination of observed and prognostic (TAPM) surface and upper air meteorological inputs.
- CALPUFF then calculates the dispersion of plumes within this three-dimensional meteorological field.

CALPUFF and TAPM are commonly used in NSW for applications involving non-steady state conditions and far field dispersion. TAPM has been extensively used as a prognostic modelling tool, both in Australia and internationally (Wang et al., 2008; Soriano et al.; 2003; Mahmud, 2009;Zoras et al., 2010, Hurley et al., 2009).

It is noted that a recent update to the US EPA's "Guideline on Air Quality Models" has removed the CALPUFF modelling system as the EPA's preferred model for long-range transport (>50km) for Prevention of Significant Deterioration (PSD) permitting applications, mainly due to concerns about the management and maintenance of the model code. CALPUFF may be retained for screening approaches to support long transport in PSD increment assessments (US EPA. 2015).

4.4 Data assimilation

A significant number of surface meteorological observation stations are located in the Namoi basin region, including Bureau of Meteorology (BoM) Automatic Weather Stations (AWS), NSW Office of Environment and Heritage (OEH) air quality stations and stations at assorted industrial operations. The inclusion of surface observation data in the modelling (referred to as data assimilation) provides real-world observations and improves the accuracy of the wind field.

Surface observations are incorporated into both TAPM and CALMET modelling, with some stations excluded for the purpose of model evaluation. The surface observations sites included, and model evaluation sites excluded are shown in **Table 4-1**.

Table 4-1: Meteorological monitoring sites in study area

Operator	Site	Data assimilation	Station ID (Figure 4-2)
Bureau of Meteorology	Scone Airport	TAPM & CALMET	1
	Murrurundi Gap	TAPM & CALMET	2
	Moree Aero	TAPM & CALMET	3
	Tamworth Airport	TAPM & CALMET	4
	Merriwa (Rosscommon)	TAPM & CALMET	5
	Narrabri Airport	TAPM & CALMET	6
	Gunnedah Airport	TAPM & CALMET	7
	Coonabarabran Airport	TAPM & CALMET	8
Office of Environment and Heritage	Merriwa	CALMET	9
	Wybong	CALMET	10
	Aberdeen	CALMET	11
	Muswellbrook NW	N/A	12
	Tamworth	Evaluation site	13
Whitehaven Coal Limited	Maules Creek mine	CALMET	14
	Tarrawonga mine	N/A	15
	Rocglen mine	N/A	16
	Werris Creek mine	CALMET	17
	Sunnyside mine	N/A	18
	Vickery mine	Evaluation site	19
	Narrabri mine	CALMET	20
Idemitsu Australia Resources Pty Ltd	Boggabri mine site	CALMET	21
Shenhua Australia Holdings Pty Ltd	Watermark mine no. 1	CALMET	22
	Watermark mine no. 2	Evaluation site	23
BHP Billiton	Caroona mine site	N/A	24

N/A – not included due to incomplete data or if the site has significant influence from local scale terrain features

4.5 Prognostic modelling

The Air Pollution Model, or TAPM, is a three-dimensional meteorological and air pollution model developed by the CSIRO Division of Atmospheric Research. A detailed description of TAPM and its performance can be found in Hurley (2008) and Hurley et al. (2009). TAPM uses fundamental fluid dynamics and scalar transport equations to predict meteorology and (optionally) pollutant concentrations. It consists of coupled prognostic meteorological and air pollution concentration components. The model predicts airflows that are important to local-scale air pollution, such as sea breezes and terrain induced flows, against a background of larger scale meteorology provided by synoptic analyses.

TAPM was used to generate gridded three-dimensional meteorological data for each hour of the model run period, for input into CALMET (as '3D.dat') to drive the 'initial guess' of the meteorological field. TAPM was run with nested grids, according to the settings presented in **Appendix 1**. The inner grid spacing and grid points was selected to ensure coverage of the proposed CALMET modelling domain. The outer grid spacing was required to be limited to a 10km spacing, to remain within the maximum domain size recommended for TAPM (Hurley, 2008). Domains larger than 1500km x 1500km should be avoided as the model will not account for curvature of the earth.

The peer review noted that the choice of grid spacing is not in accordance within the recommended range for grid spacing ratios. It was recommended that either the approach is discussed with CSIRO or that a revised grid spacing is selected to better reflect the recommended ratios (such as 14km, 7km and 3km). Model sensitivity analysis using these grid spacing was found to have no significant impact on the resultant wind field and the original grid spacing was retained.

4.6 CALMET modelling

CALMET is a meteorological pre-processor that includes a wind field generator with treatments of slope flows, terrain effects and terrain blocking effects. The pre-processor produces fields of wind components, air temperature, relative humidity, mixing height and other micro-meteorological variables to produce the three-dimensional (3-D) meteorological fields that are used in the CALPUFF dispersion model. CALMET uses the meteorological inputs in combination with land use and geophysical information for the modelling domain to predict gridded meteorological fields for the region (Scire et al., 2000).

CALMET was used to calculate finer resolution three-dimensional meteorological data, incorporating surface observations and TAPM prognostic upper level meteorological data. The CALMET model settings are presented in in **Appendix 1**, selected in accordance with recommendations in TRC (2011).

Land-use is determined from Geographical Information System (GIS) data from the Australian Collaborative Land Use Mapping Program (ACLUMP) and updated using aerial photography from Google Earth. Terrain data for the modelling is sourced from Shuttle Radar Topographic Mission (SRTM) data. SRTM data for Australia is sampled at three arc seconds, resulting in an approximate resolution of 90 m.

Model gird spacing was chosen based on a compromise between computational time and ability to resolve significant terrain features. A grid spacing of 2 km was found to resolve significant terrain features and account for the dominant features of the valley, with manageable model run times.

Both TAPM and CALMET require the input of a radius of influence for surface observations. For TAPM modelling, the radius of influence can be varied for each station and suitable values were selected based on the surrounding terrain features for each station.

For the CALMET modelling, a fixed radius of influence is required. A CALMET RMAX value of 20km was selected, accounting for the distribution of monitoring stations between Narrabri and Murrurundi Gap and local topographical features. The CALMET observation weighting parameter *R*, also a fixed value, was set to 8 km (less than half the RMAX value) to enable a gradual reduction in influence of observations away from each station. Some observation stations are significantly influenced by local terrain, for example at Rocglen where winds are north-south aligned due to a localised valley. These local scale terrain features are not necessarily resolved at the regional scale modelling for this study and the observation sites are therefore excluded from the modelling.

The TAPM and CALMET modelling domains and observations sites are shown in **Figure 4-2**.

4.7 Sensitivity analysis for wet and dry years

Precipitation is important to air pollution since it impacts on dust generation potential and represents a removal mechanism for atmospheric pollutants. Some examples of how rainfall may influence particle levels are:

- The generation of fugitive emissions, from sources such as agriculture, mining, quarrying etc., may be higher during dry years and lower during wet years.

- Dryer periods may result in more frequent dust storms and bushfire activity, resulting in higher regional background dust.
- Rainfall acts as a removal mechanism for dust, lowering pollutant concentrations by removing them more efficiently than during dry periods.
- Rainfall forecasts for the region will dictate crop production levels or shift preference for certain types of crops sown for each region. This may in turn influence the amount of fugitive emissions generated from agricultural sources.

Wet deposition (removal of particles from the air by rainfall) was not included in the source apportionment modelling, however sensitivity analysis is presented in **Appendix 2** to inform particle levels likely to vary between dry and wet years.

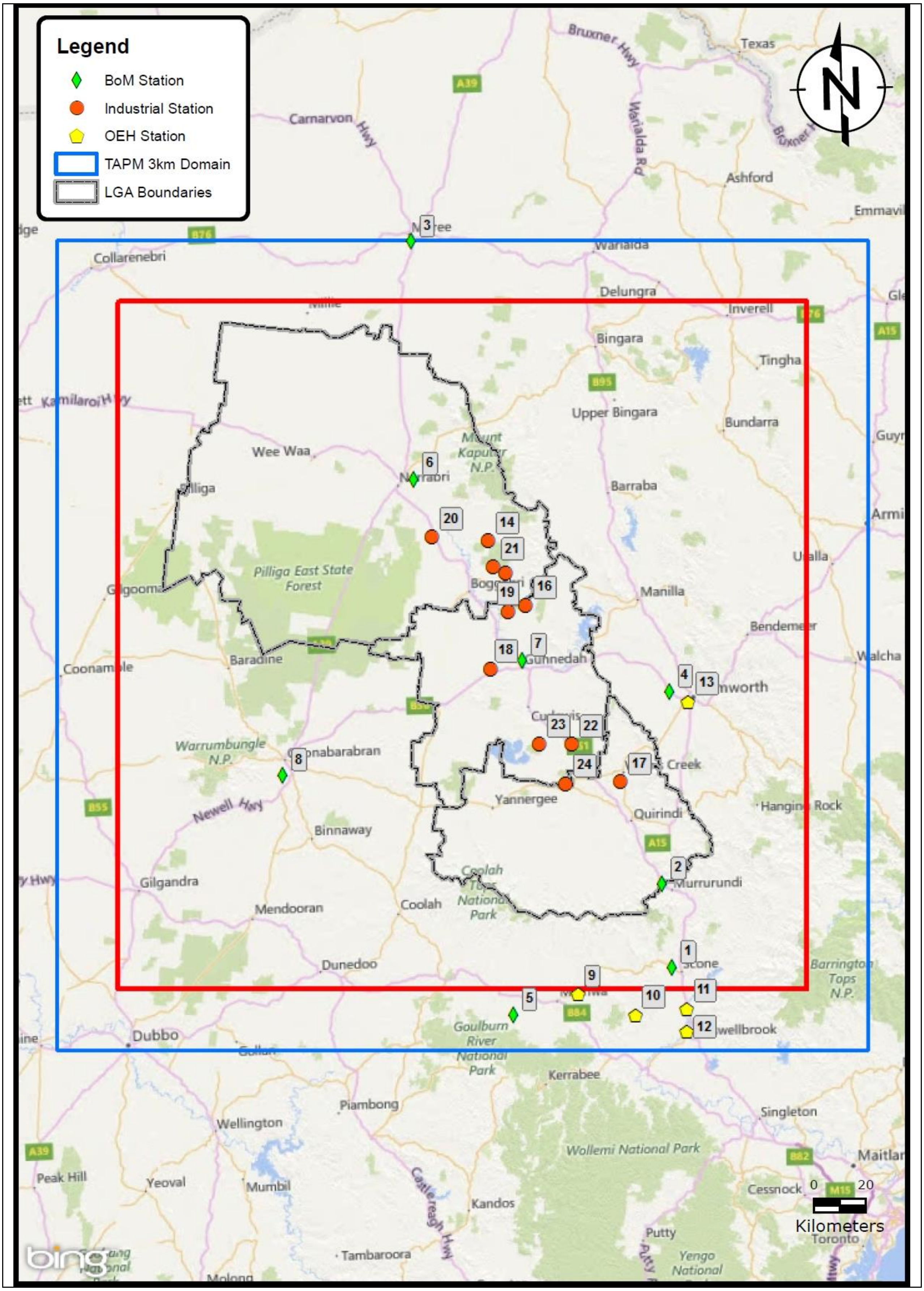


Figure 4-2: Prognostic and diagnostic modelling domain with assimilation sites identified by Station ID (Table 4-1)

5. EVALUATION OF METEOROLOGICAL MODELLING

5.1 Introduction

Meteorological model performance is critical to obtaining accurate PM model predictions because dispersion depends upon meteorological conditions and source-receptor relationships are determined by the 3-D wind fields.

Model performance is evaluated by comparing summary statistics, visual analysis tools (wind roses, time variation plots and scatter plots) and statistical analysis. Model evaluation is primarily based on three observation sites which were excluded from the modelling (described in **Table 4-1**). Summary statistics and wind rose plots are presented for all monitoring sites within the study CALPUFF model domain[6].

5.2 Summary statistics for all monitoring sites

Summary statistics for observed and modelled wind speed are presented in **Table 5-1** for all sites within the CALPUFF domain. The observation sites that were excluded from the modelling are shown in bold.

For all data assimilation sites, the predicted and observed annual mean wind speeds and percentage of calm winds (<=0.5 m/s) are very similar (tendency for predicted to be slightly lower than the observed at most sites).

At the Vickery mine evaluation site, the predicted and observed annual mean wind speeds and the percentage of calm winds are very similar, however at the Watermark No.2 and Tamworth OEH evaluation sites, there is a more significant difference between observed and predicted mean wind speeds. In the case of the Tamworth OEH site, the predicted annual mean wind speeds correlates better with the nearby Tamworth BoM data assimilation site.

Table 5-1: Summary statistics for observed and modelled wind speed

Site	Annual mean (m/s)		Percentage of calm winds	
	Observed	**Predicted**	**Observed**	**Predicted**
Narrabri Airport	4.0	3.9	8.8%	7.5%
Narrabri mine	3.2	3.1	3.3%	3.2%
Maules Creek mine	2.5	2.4	15.3%	15.6%
Boggabri mine	2.4	2.4	0.6%	1.8%
Vickery mine	**2.7**	**2.8**	**2.6%**	**3.2%**
Gunnedah Airport	3.6	3.5	10.7%	10.1%
Watermark mine No. 1	3.2	3.0	11.8%	11.1%
Watermark mine No. 2	**3.4**	**2.6**	**6.2%**	**5.4%**
Werris Creek mine	3.0	2.9	7.1%	6.2%
Tamworth Airport	3.4	3.3	9.8%	8.5%
Tamworth OEH	**1.8**	**2.9**	**9.1%**	**3.3%**
Coonabarabran Airport	4.3	4.2	1.1%	1.0%
Murrurundi Gap	6.3	6.1	1.3%	1.1%
Scone Airport	3.1	3.0	22.7%	20.3%

Note: Monitoring sites marked in bold were used as model evaluation sites

[6] Sites within the CALMET modelling but outside the sampling grid / CALPUFF domain are not included in the model evaluation

Summary statistics for observed and modelled temperature are presented in **Table 5-2** for all sites within the CALPUFF domain. The observation sites that were excluded from the modelling are shown in bold.

For all sites, the predicted and observed annual mean and the minimum and maximum hourly temperature are very similar (predicted are slightly lower than the observed at most sites). The only notable exception is the predicted minimum hourly temperature for Watermark No. 2, which is much closer to the observed minimum temperature at the Watermark No. 1 site (which is included in the modelling as an observation site).

Table 5-2: Summary statistics for observed and modelled temperature

Site	Minimum		Mean		Maximum	
	Observed	Predicted	Observed	Predicted	Observed	Predicted
Narrabri Airport	-3.0	-2.5	19.2	19.3	43.2	43.2
Narrabri mine	1.2	-1.3	20.0	18.8	41.0	42.4
Maules Creek mine	-2.6	-2.1	18.6	18.6	43.1	42.7
Boggabri mine	-2.1	-1.5	18.4	18.8	42.5	42.4
Vickery mine	**0.2**	**-1.4**	**19.4**	**18.5**	**41.3**	**42.1**
Gunnedah Airport	-4.5	-3.2	17.9	18.0	42.0	41.9
Watermark mine No. 1	-1.5	-1.1	17.4	18.0	40.6	40.9
Watermark mine No. 2	**-5.6**	**-0.7**	**17.4**	**17.8**	**42.4**	**40.6**
Werris Creek mine	0.8	0.7	18.4	18.2	39.7	40.0
Tamworth Airport	-4.4	-3.6	17.4	17.5	42.1	41.8
Tamworth OEH	**-2.8**	**-1.7**	**17.9**	**18.6**	**40.6**	**42.5**
Coonabarabran Airport	1.6	1.7	17.0	17.3	39.9	40.1
Murrurundi Gap	0.7	1.5	15.5	16.2	37.0	38.4
Scone Airport	-2.2	-1.4	17.1	17.1	43.4	42.6

Note: Monitoring sites marked in bold were used as model evaluation sites

5.3 Comparison of observed and predicted wind direction

A comparison of observed and predicted annual wind roses are presented in **Figure 5-4** to **Figure 5-7** for all sites.

The observed and predicted wind roses for all data assimilation sites compare very favourably. The CALMET predicted wind directions reflected the measured data in terms of dominant wind directions and the magnitude of wind speeds.

At the evaluation sites, the observed and predicted wind roses compare less favourably in terms of prevailing wind direction. At Vickery, the general patterns are similar with a slight shift in dominant wind direction evident in the CALMET data.

At the Watermark No. 2 site, CALMET winds are aligned along the northwest-southeast axis but there is a more clear southeast and northwest dominant component in the measured data.

At Tamworth OEH site, the predicted wind speeds are higher than observed (reflect more the wind speeds measured at Tamworth BoM) and there is a shift in dominant wind directions, however the general alignment along the northwest-southeast axis is evident.

A comparison of seasonal wind roses is presented in **Appendix 3**.

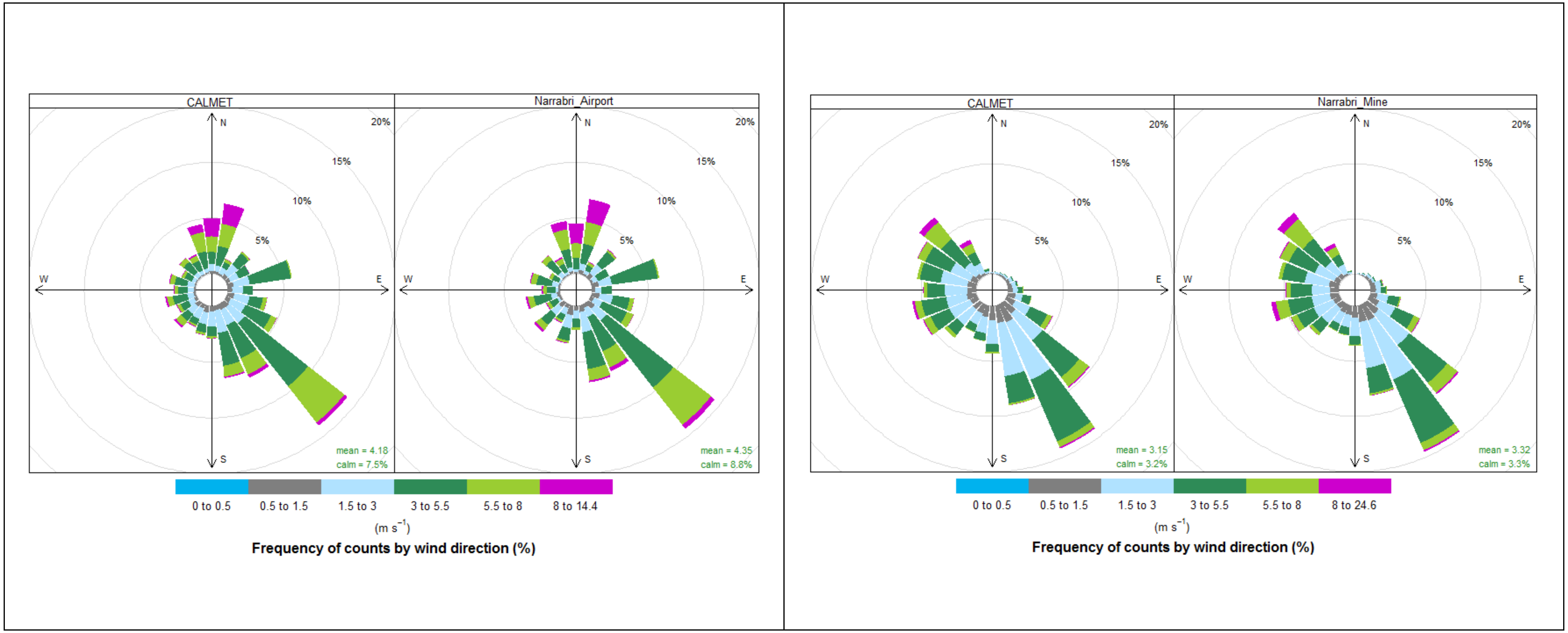


Figure 5-1: Wind rose comparison – Narrabri Airport and Narrabri Mine

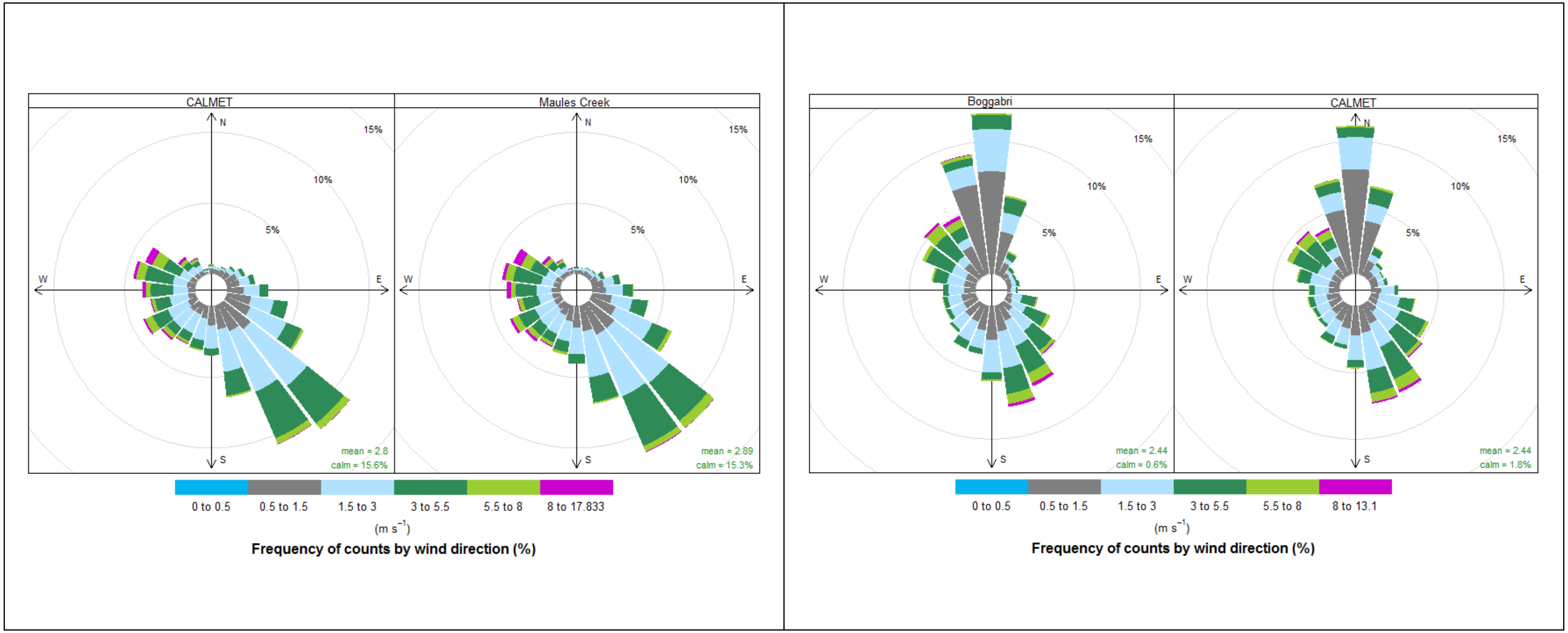


Figure 5-2: Wind rose comparison – Maules Creek and Boggabri

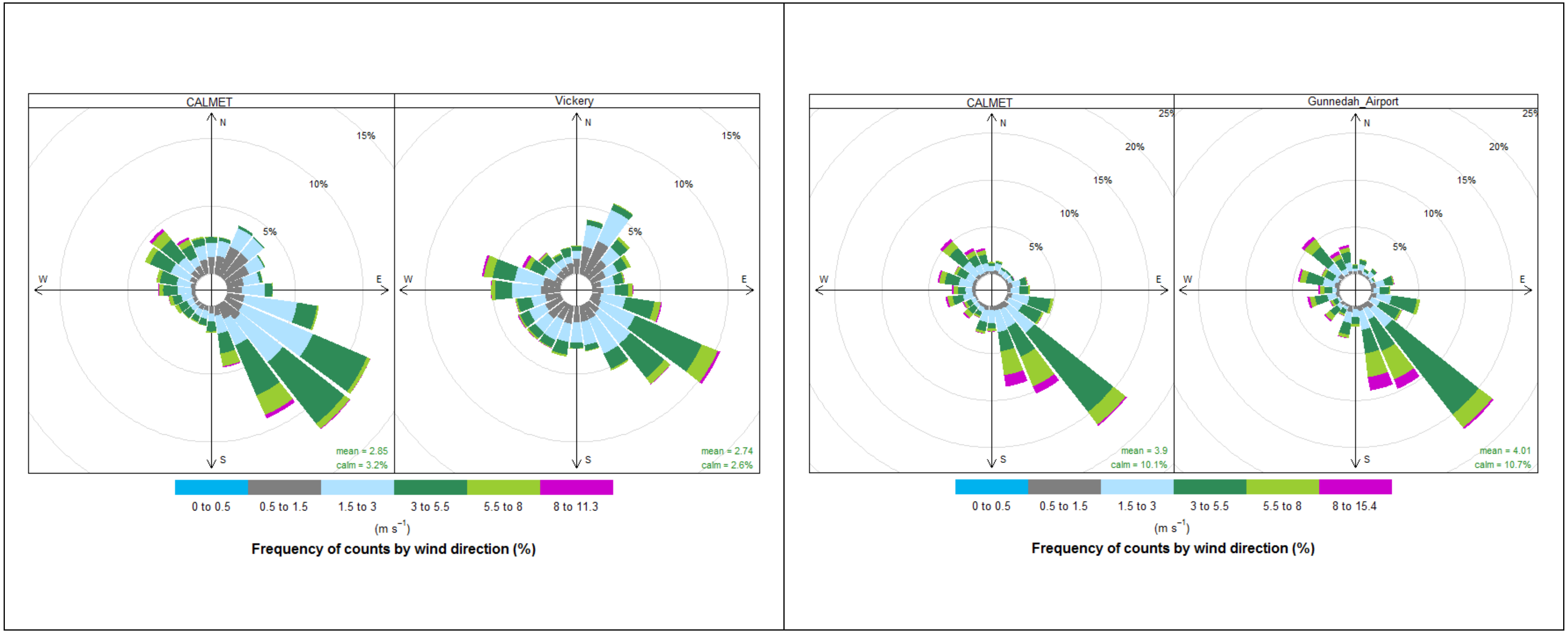
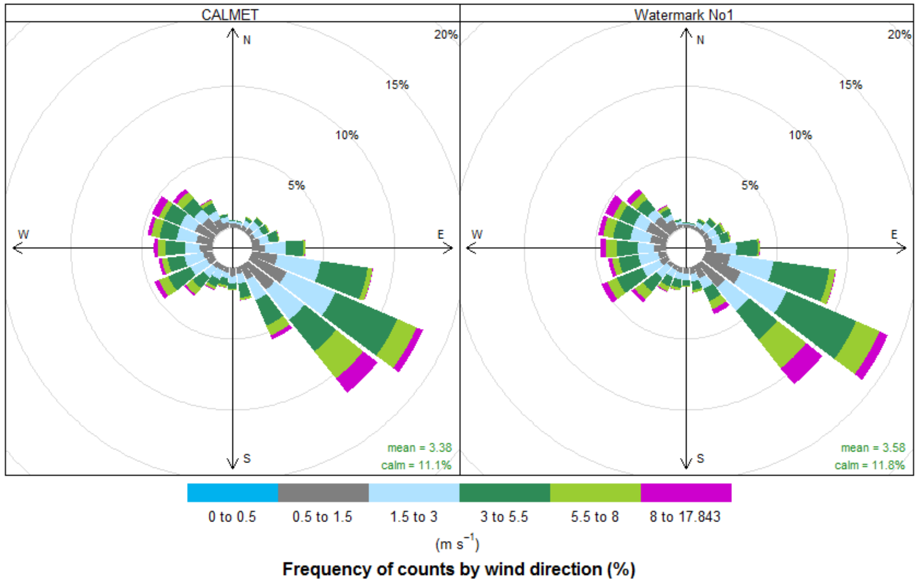


Figure 5-3: Wind rose comparison – Vickery and Gunnedah Airport



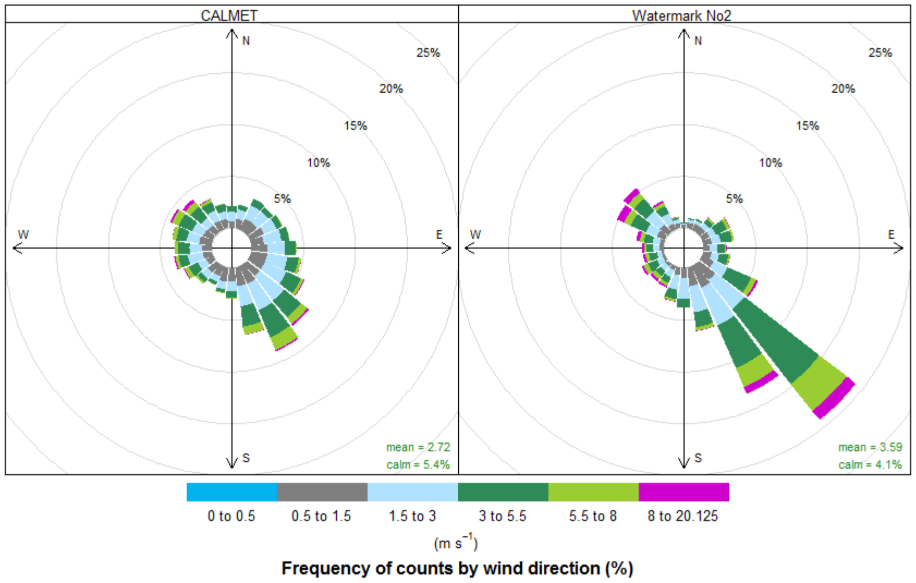


Figure 5-4: Wind rose comparison – Watermark No.1 and No.2

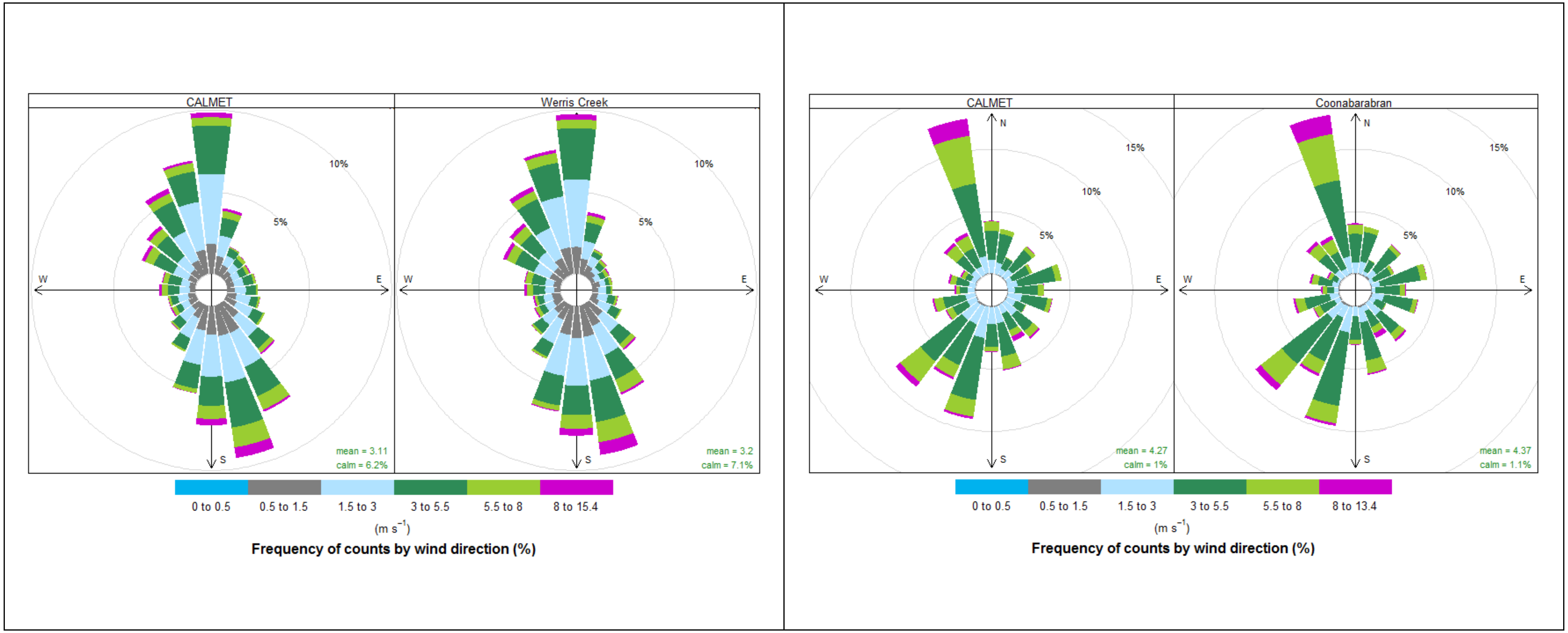


Figure 5-5: Wind rose comparison – Werris Creek and Coonabarabran

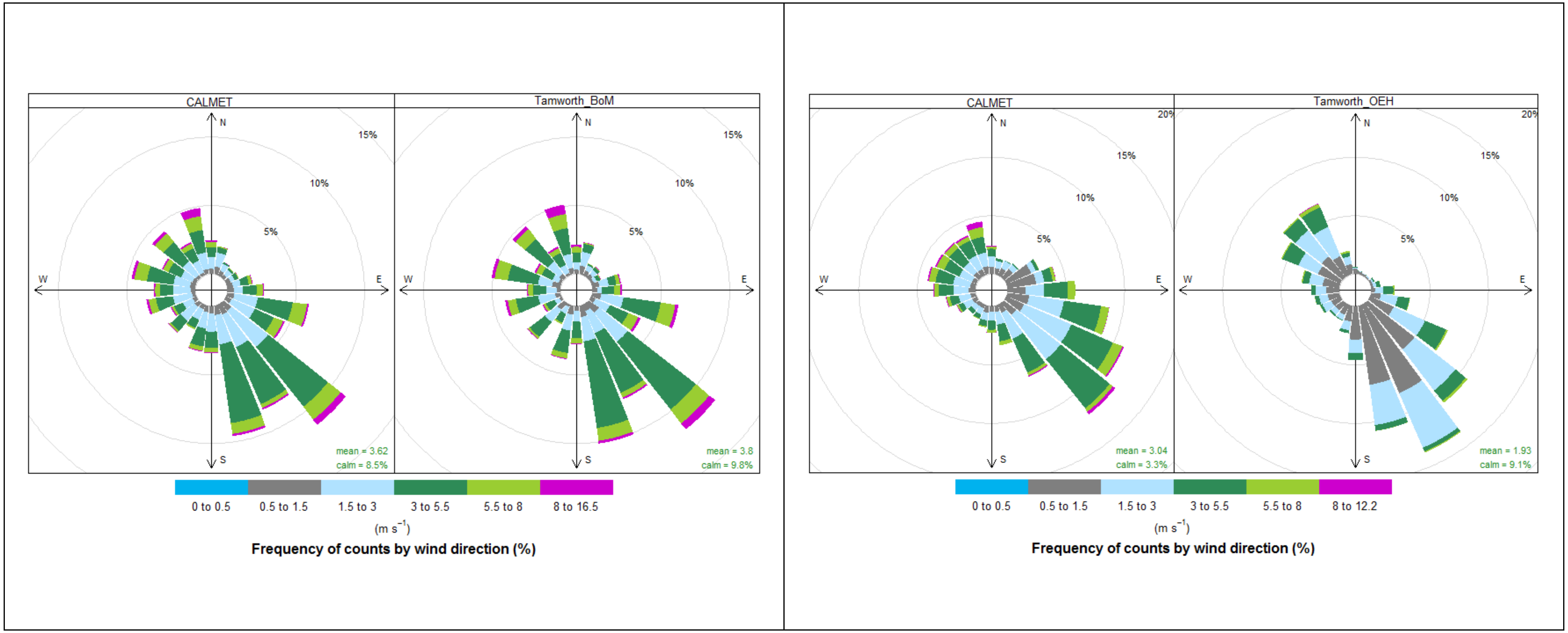


Figure 5-6: Wind rose comparison – Tamworth BoM and Tamworth OEH

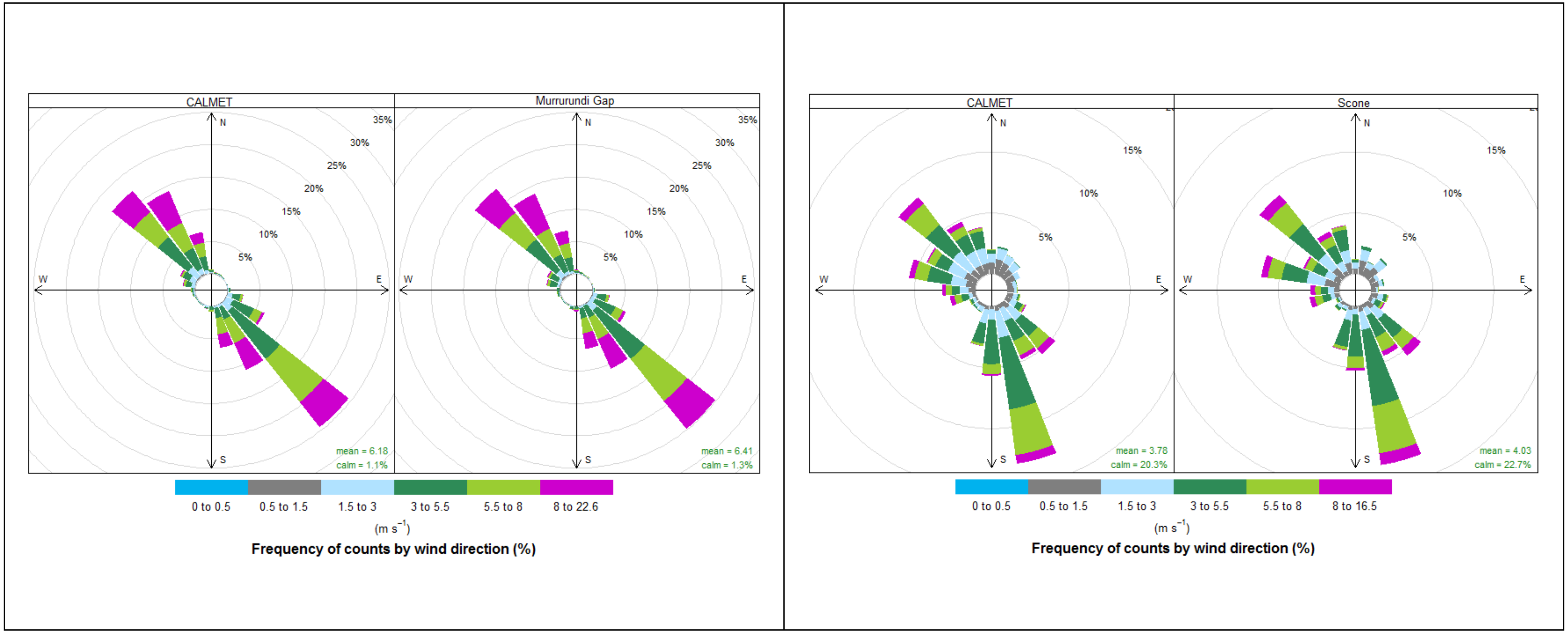


Figure 5-7: Wind rose comparison –Murrurundi Gap and Scone

5.4 Comparison of observed and predicted wind speed and temperature

Scatter plots of the observed and predicted hourly wind speed for the three evaluation sites are shown in **Figure 5-8**. Also plotted is the linear regression line (with 95% confidence limits) and correlation (R^2) is also displayed. In general, the model has a tendency to under predict lower wind speeds and over predict higher wind speeds. The correlation at Vickery and Watermark No.2 is reasonable (R^2 = of 0.62 and 0.61) and improved for the Tamworth OEH site (R^2 = 0.75).

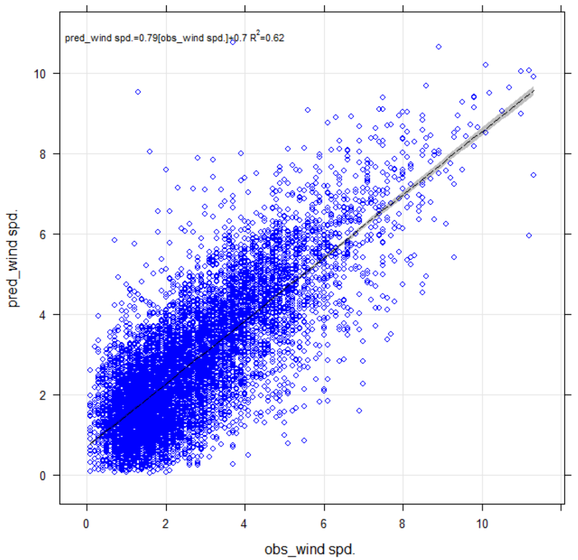
Scatter plots of the observed and predicted temperature for the evaluation sites are shown in **Figure 5-9**. The correlation is excellent for all sites (R^2 greater than 0.88).

Time variation plots for the observed and predicted wind speed at Vickery is presented in **Figure 5-10**. The mean hourly modelled wind speeds tend to be higher than observed during the afternoon and lower than observed during the early evening. Monthly mean wind speeds correlate well, with modelled wind speeds higher than observed for some months of the year.

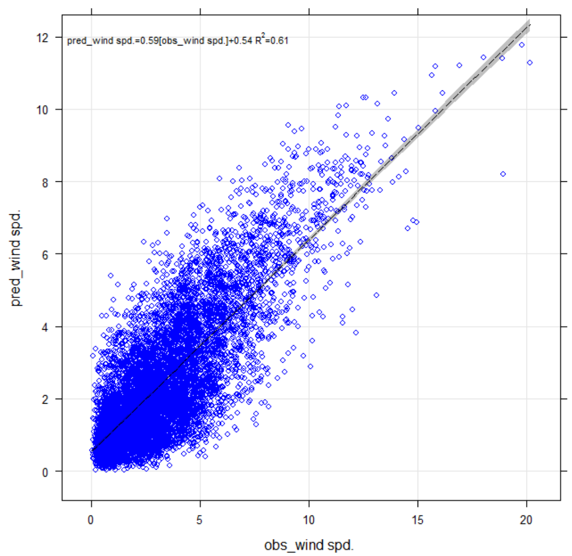
Time variation plots for the observed and predicted wind speed at Watermark No.2 is presented in **Figure 5-11**. The mean hourly and mean monthly modelled wind speeds tend to be consistently lower than observed.

Time variation plots for the observed and predicted wind speed at Tamworth is presented in **Figure 5-12**. In this case the observed and predicted wind speeds are presented for both the OEH and BoM sites. The mean hourly and mean monthly observed wind speeds at the BoM site tend to track well with the predicted winds speeds at both the BoM and OEH sites. The mean hourly and mean monthly observed wind speeds at the OEH site are noticeable lower than predicted.

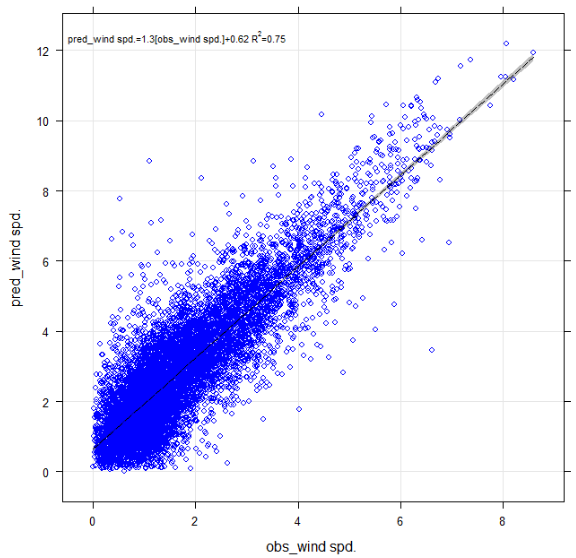
Time variation plots for observed and predicted temperature at the evaluation sites are presented in **Appendix 3.** The mean hourly and mean monthly modelled temperatures tend to track well with observed temperatures. At Vickery, mean hourly modelled temperature tends to be lower than observed while at Tamworth, the mean hourly modelled temperature tends to be higher during the day. At Watermark No.2, the mean hourly modelled temperature tends to be higher at night and early mornings and lower during the day.



Vickery

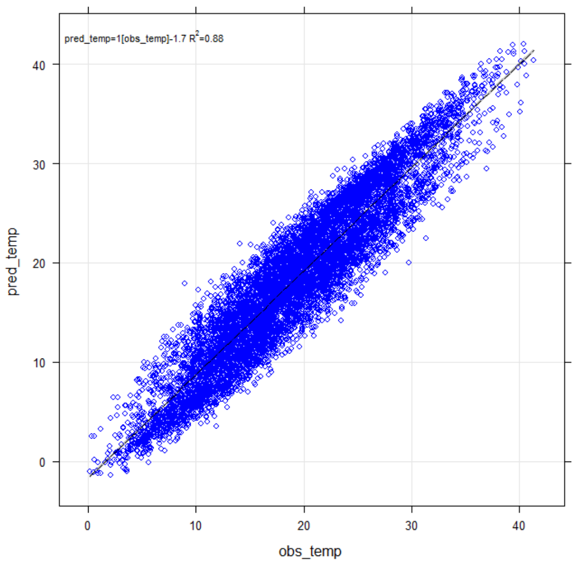


Watermark No. 2

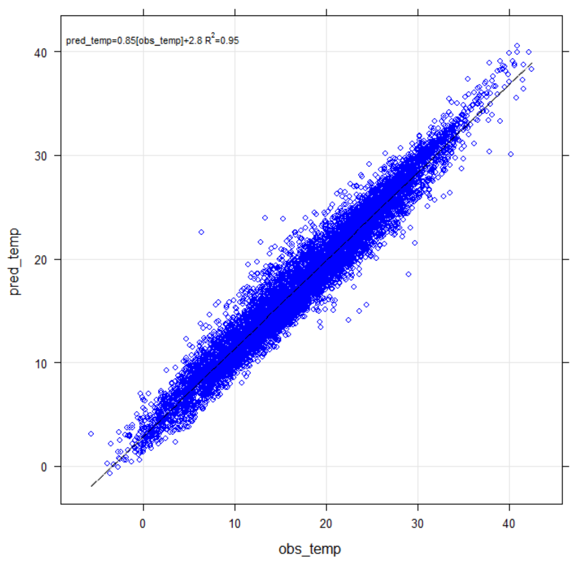


Tamworth OEH

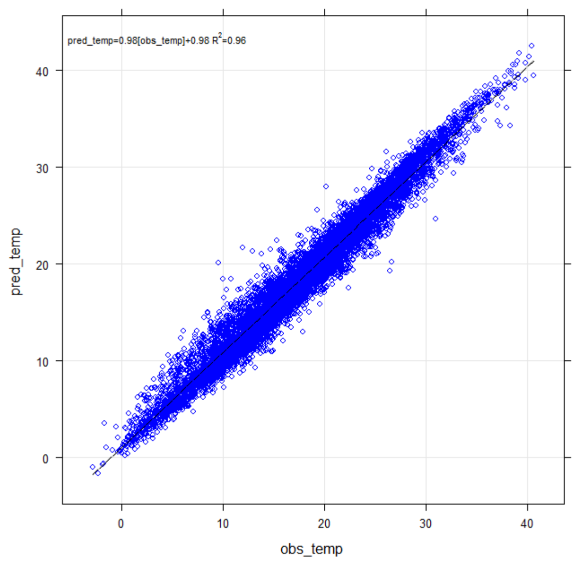
Figure 5-8: Scatter plots of observed and predicted wind speeds



Vickery



Watermark No. 2



Tamworth OEH

Figure 5-9: Scatter plots of observed and predicted temperature

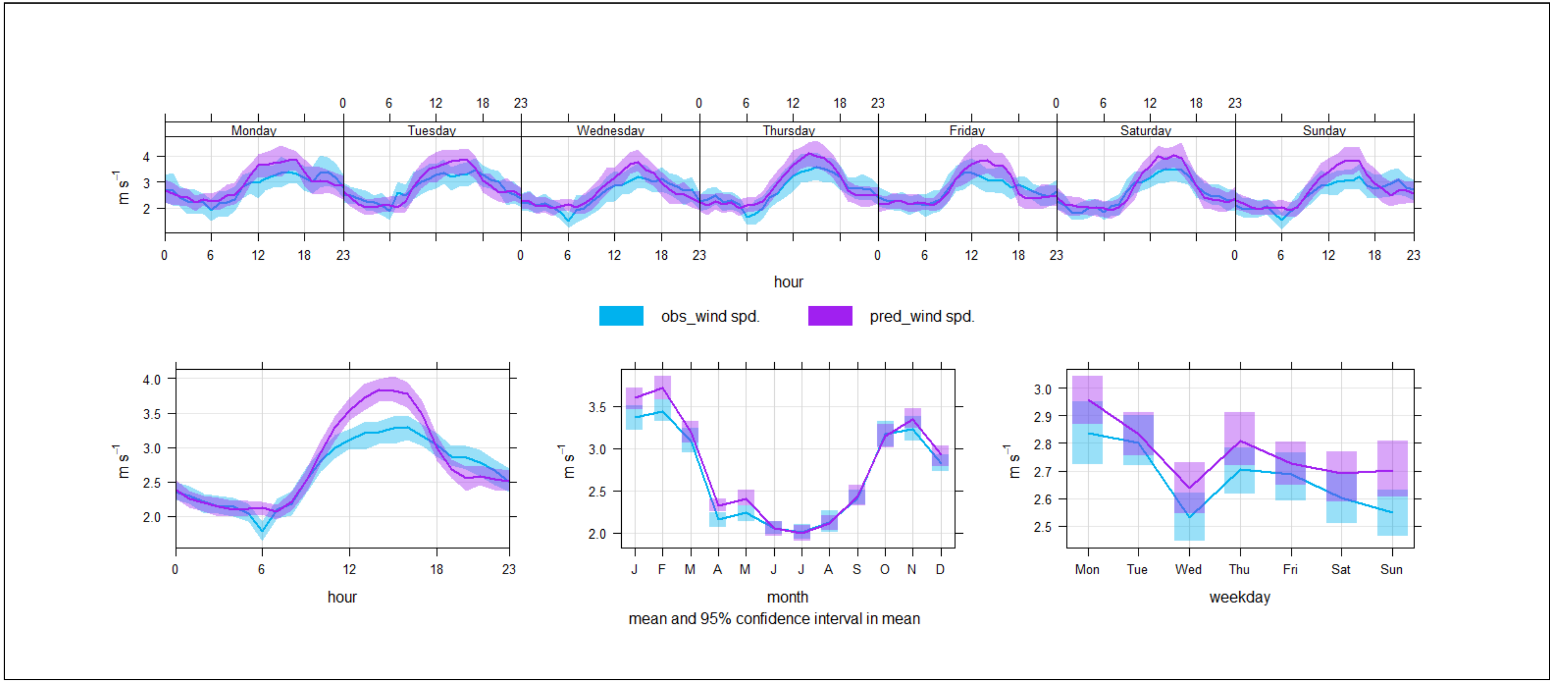


Figure 5-10: Time variation of observed and predicted wind speed for Vickery

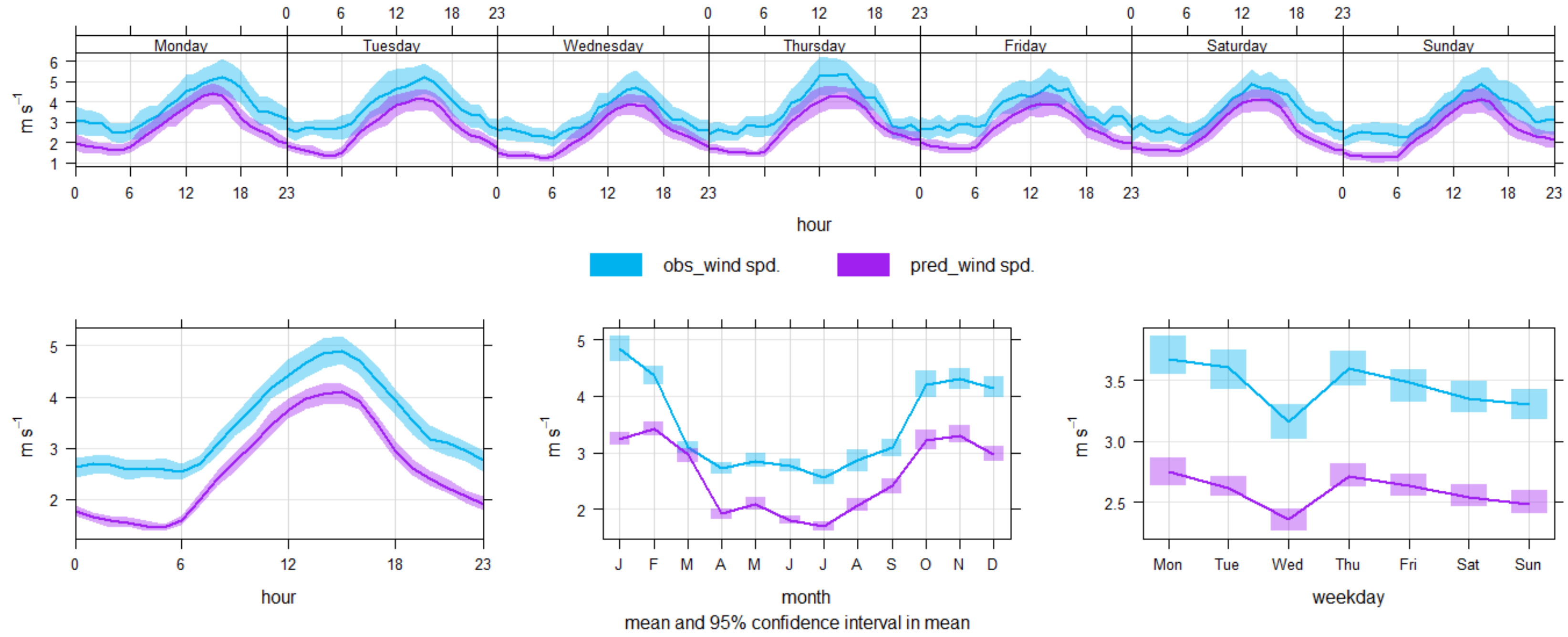


Figure 5-11: Time variation of observed and predicted wind speed for Watermark No2

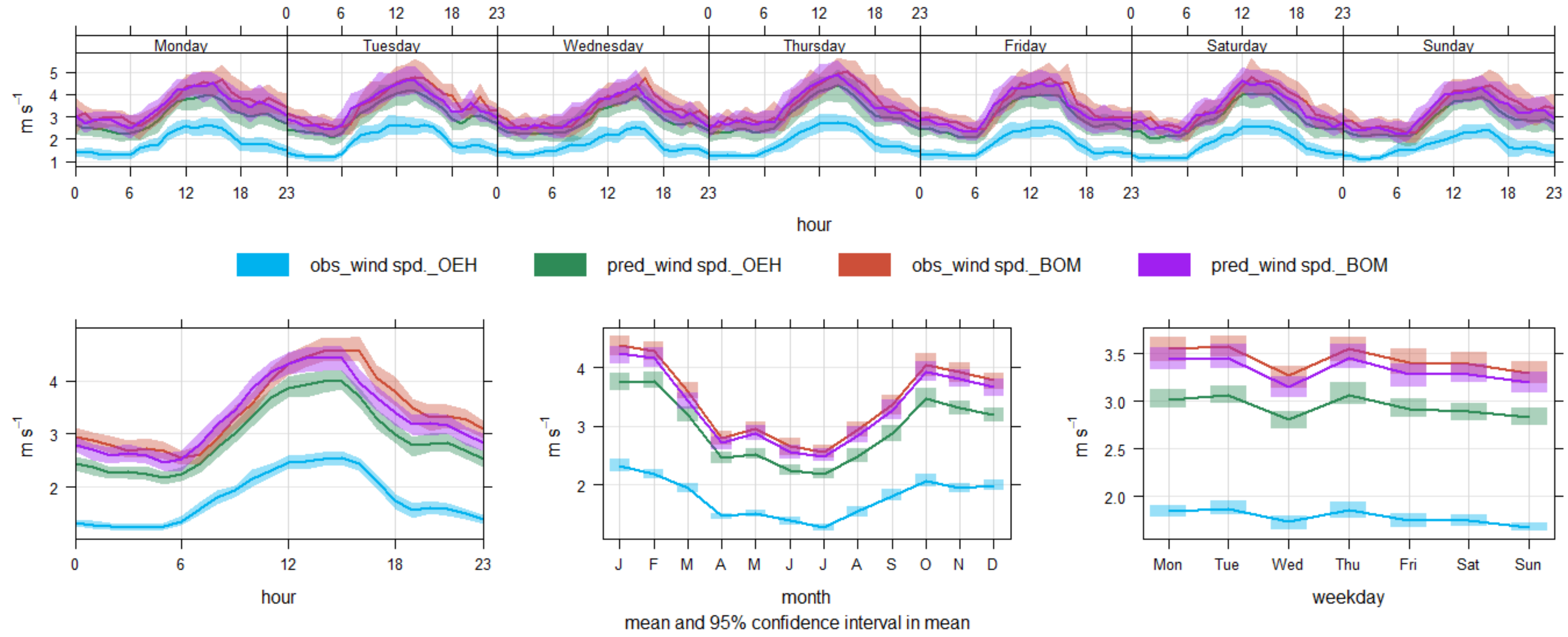


Figure 5-12: Time variation of observed and predicted wind speed for Tamworth (BoM and OEH)

5.5 Statistical evaluation

Model performance is assessed based on the evaluation methods described in **Table 5-3**. Indicative performance benchmarks for bias and error are provided, based on Emery et al. (2001). The purpose of these benchmarks was not to give a passing or failing grade to any one particular meteorological model application, but rather to put the model's results into the proper context of other models and meteorological data sets. Since 2001, the benchmarks have been promoted by the EPA-sponsored National Ad Hoc Meteorological Modeling Group and have been consistently relied upon to evaluate Pennsylvania State University / National Center for Atmospheric Research (MM5) and WRF model performance in many regulatory modelling projects throughout Texas and the U.S.

Table 5-3: Statistical evaluation for model performance

Statistical test	Form	Description
FAC2	$0.5 \leq \frac{M_i}{O_i} \geq 0.5$	Fraction of model predictions (M) within a factor of 2 of the observed values (O)
Mean bias (MB)	$\boldsymbol{MB = \frac{1}{n}\sum_{i=1}^{N} M_i - O_i}$	MB provides an indication of the mean over or under estimate of model predictions and is expressed in the same units as the quantities being considered. Indicative performance benchmark for wind speed is ≤±0.5 m/s, for wind direction ≤± 10 degrees and for temperature is ≤± 0.5 K.
Mean Gross Error (MGE)	$\boldsymbol{MGE = \frac{1}{N}\sum_{i=1}^{N} \lvert M_i - O_i \rvert}$	MGE provides an indication of the mean error regardless of whether it is an over or under estimate and is in the same units as the quantities being considered. Indicative performance benchmark for wind speed is ≤ 2.0 m/s, for wind direction ≤± 30 degrees and for temperature is ≤ 2.0 K.
Pearson correlation coefficient (r)	$r = \frac{1}{n-1}\sum_{i=1}^{N}\left(\frac{M_i - \bar{M}}{\sigma_M}\right)\left(\frac{O_I - \bar{O}}{\sigma_O}\right)$	The (Pearson) correlation coefficient is a measure of the strength of the linear relationship between two variables. If there is perfect linear relationship with positive slope between the two variables, r = 1.
Index of Agreement (IOA)	$IOA = 1 - \frac{\sum_{i=1}^{N} \lvert M_i - O_i \rvert}{c\sum_{i=1}^{N} \lvert O_i - \bar{O} \rvert}$	Values approaching +1 representing better model performance. (Willmott et al. 2011).

A summary of the model evaluation statistics for wind speed, wind direction and temperature at each of the evaluation sites is presented in **Table 5-4**, **Table 5-5** and **Table 5-6**. All sites demonstrate favourable FAC2 and high correlation for wind speed and temperature. The IOA is also high for wind speed and temperature at all sites except wind speed at the Tamworth OEH site. With the exception of wind direction, model bias and error is low and generally within the specified performance benchmarks.

Evaluation statistics for all assimilation sites are presented in **Appendix 4**. All sites demonstrate favourable FAC2 and high correlation and IOA, with model bias and error is low and generally within the specified performance benchmarks.

Table 5-4: Statistical evaluation of wind speed

Test	Benchmark / Ideal Score	Vickery	Watermark No2	Tamworth OEH
Fraction of predictions within a factor of 2 (FAC2)	≥ 0.5	0.8	0.7	0.7
Mean bias (MB)	≤± 0.5 m/s	0.1	-0.8	1.2
Mean Gross Error (MGE)	≤± 2.0 m/s	0.8	1.3	1.2
Pearson correlation coefficient (r)	1	0.8	0.8	0.9
Index of Agreement (IOA)	1	0.7	0.7	0.3

Table 5-5: Statistical evaluation of wind direction

Test	Benchmark / Ideal Score	Vickery	Watermark No2	Tamworth OEH
Fraction of predictions within a factor of 2 (FAC2)	≥ 0.5	0.8	0.8	0.9
Mean bias (MB)	≤± 10 degrees	-0.3	0.9	-23
Mean Gross Error (MGE)	≤± 30 degrees	60	58	44
Pearson correlation coefficient (r)	1	0.5	0.4	0.7
Index of Agreement (IOA)	1	0.6	0.6	0.7

Table 5-6: Statistical evaluation of temperature

Test	Benchmark / Ideal Score	Vickery	Watermark No2	Tamworth OEH
Fraction of predictions within a factor of 2 (FAC2)	≥ 0.5	1.0	1.0	1.0
Mean bias (MB)	≤± 0.5 K	-0.9	0.2	0.7
Mean Gross Error (MGE)	≤± 2.0 K	2.5	1.4	1.3
Pearson correlation coefficient (r)	1	0.9	1.0	1.0
Index of Agreement (IOA)	1	0.8	0.9	0.9

5.6 Summary

Overall, it is concluded that CALMET simulates the meteorology for the Namoi basin with an acceptable degree of accuracy, based on an analysis of all monitoring locations within the CALPUFF model domain. General wind patterns in the observation data were reflected well and wind speeds and temperature compares favourably. A statistical evaluation of the modelling predictions showed good correlation for wind speed, direction and temperature. It is noted that, although there is some slight differences in the observed and modelled parameters for the model evaluation sites, the observed and modelled data at the assimilation sites compare well. There is excellent coverage of data assimilation across the modelling domain, therefore the differences for the evaluation sites are not expected to have implications for the regional scale modelling.

6. EMISSIONS ESTIMATION

6.1 Introduction

The emission inventories developed for modelling focus on emissions of primary particles (PM_{10} and $PM_{2.5}$) for the main anthropogenic sources in the region. Emissions of gaseous pollutants, including sulphur dioxide (SO_2), oxides of nitrogen (NO_x), carbon monoxide (CO) and total volatile organic compounds (VOCs), while not included in the regional model, are presented in **Section 7** for the major industrial and mining sources.

The scope of the study did not include detailed information gathering (for example through industry surveys) and the emission inventories, therefore, are developed based on existing available information. The sources included in the study are identified with reference to the 2008 NSW EPA Air Emission Inventory for the Greater Metropolitan Region in NSW (GMR Inventory), (NSW EPA, 2012a), focusing on the main anthropogenic sources in the region, as follows:

- Major industrial premises (EPA-licenced coal mines).
- Non-road vehicles and equipment (diesel equipment used at coal mines, locomotives).
- Domestic (wood heaters).
- Other industrial / commercial premises (EPA-licenced quarries, cotton gins and cattle feedlots).
- Biogenic/Geogenic (agricultural sources).
- On-road transport (registered cars, trucks and buses).

NSW EPA (2012a) reports that for non-urban areas of the GMR, biogenic/geogenic sources account for 30% of the total emissions of PM_{10} while anthropogenic sources account for 70%. Similarly, for $PM_{2.5}$, biogenic/geogenic sources account for 27% of the total emissions while man-made sources account for 73% (NSW EPA, 2012a). It is noted that biogenic/geogenic sources include both natural (bushfires, marine aerosol) and anthropogenic sources of emissions (agricultural burning, fugitive dust from cropping area/unsealed roads).

The top 20 contributors to PM_{10} for non-urban areas of the GMR in the 2008 inventory are presented in **Table 6-1**, which shows that the majority (~95%) of the applicable non-urban GMR sources are included in this study. The exceptions are bushfires/burning (3%), waste disposal (0.2%) and bird accommodation (0.1%). Similarly for $PM_{2.5}$, 83% of the applicable non-urban GMR emission inventory sources are included in this study. The exceptions for $PM_{2.5}$ are bushfires/burning (10.4%), boats (0.2%) and agricultural burning (0.2%).

At the project commencement meeting, it was agreed that bushfires and prescribed burning would be excluded from the emission inventory, as projections for the future year would be difficult. This is likely to be the largest source of $PM_{2.5}$ emissions that has not been inventoried. It is noted that attempts have been made to "remove" the contribution from bushfire smoke (and other measured but non-modelled components) present in the monitoring data, for the purpose of assessing model performance for the base year.

Crop burning has been in general decline in the region as agriculture has seen a shift to management techniques that maintain organic material to improve soil heath, fertility and structure. Although crop burning still occurs on occasion, no accurate figures are available on the frequency or extent of such burning and emissions are therefore not included in the emission inventory. Regardless, it is expected that this would be a relatively minor source of PM for the region.

It is also noted that for some of the activities groups, not every emission source is inventoried. For example, the emission estimates for non-road vehicles and equipment includes coal mines only, which are assumed to account for the majority of non-road diesel consumption for the region. This assumption is based on 'Mining for Coal' alone accounting for 84% of the total diesel consumption for industrial facilities in the GMR and all other commercial activity (quarries, agriculture etc.), accounting for less than 1% of the 'Mining for Coal' activity in the GMR (NSW EPA, 2012c).

Similarly, estimates of fugitive windborne dust are made for cropping areas, unsealed roads and exposed areas at mines, quarries and feedlots. It is possible that exposed areas at other sites may also contribute to windborne dust.

Table 6-1: Top 20 contributors to PM_{10} for non-urban areas of the GMR (NSW EPA, 2012a)

Module	Activity	Proportion (%)	Source included
Industrial	Mining for coal	53.16	Yes
Biogenic-Geogenic	Marine Aerosol	25.95	N/A
Industrial	Generation of electrical power from coal	6.9	N/A
Biogenic-Geogenic	Bushfires and Prescribed Burning	3.01	No
Industrial	Land-based extractive activity	2.44	Yes
Off-Road	Mobile Industrial Vehicles and Equipment	1.92	Yes
Biogenic-Geogenic	Fugitive-Windborne	1.4	Yes
Domestic-Commercial	Solid Fuel Burning (Domestic)	1.26	Yes
Industrial	Cement or lime production	0.67	N/A
Commercial	Gravel and Sand Quarrying	0.66	Yes
Industrial	Mining for minerals	0.47	Yes
Industrial	Aluminium production (alumina)	0.22	N/A
On-Road	Mobile All - Non-Exhaust PM	0.2	Yes
Industrial	Waste disposal (application to land)	0.19	No
Industrial	Ceramics production	0.18	N/A
Industrial	Coal works	0.18	Yes
On-Road	Mobile Heavy Duty Commercial Diesel - Exhaust	0.17	Yes
Off-Road	Mobile Ships	0.17	N/A
Industrial	Bird accommodation	0.0858	No
Off-Road	Mobile Locomotives	0.0773	Yes

Table 6-2: Top 20 contributors to $PM_{2.5}$ for non-urban areas of the GMR (NSW EPA, 2012a)

Module	Activity	Proportion (%)	Source included
Industrial	Mining for coal	36.41	Yes
Biogenic-Geogenic	Marine Aerosol	15.25	N/A
trial	Generation of electrical power from coal	14.34	N/A
Biogenic-Geogenic	Bushfire and Prescribed Burning	10.39	No
Off-Road	Mobile Industrial Vehicles and Equipment	7.59	Yes
Domestic-Commercial	Solid Fuel Burning (Domestic)	4.92	Yes
Industrial	Cement or lime production	2.34	N/A
Industrial	Land-based extractive activity	1.99	Yes
Biogenic-Geogenic	Fugitive-Windborne	0.77	Yes
On-Road Mobile	Heavy Duty Commercial Diesel - Exhaust	0.68	Yes
Off-Road	Mobile Ships	0.62	N/A
Commercial	Gravel and Sand Quarrying	0.58	Yes
Industrial	Aluminium production (alumina)	0.58	N/A
Industrial	Ceramics production	0.49	N/A
On-Road	Mobile All - Non-Exhaust PM	0.44	Yes
Industrial	Mining for minerals	0.34	Yes
Off-Road	Mobile Locomotives	0.3	Yes
Off-Road	Mobile Commercial Boats Exhaust	0.24	N/A
Off-Road	Mobile Recreational Boats Exhaust	0.24	No
Biogenic-Geogenic	Agricultural Burning	0.15	No

6.2 Coal mines

There are eight approved coal mining operations in the Namoi basin, plus a Coal Handling and Preparation Plant (CHPP) in Gunnedah. Most of the approved mines are currently in production, the exceptions being the Sunnyside Coal Mine, which is in care and maintenance and the Vickery Coal Mine, which is approved but not yet developed. In January 2016, Whitehaven Coal submitted a request for Secretary's Environment Assessment Requirements (SEARs), seeking approval for a run-of-mine (ROM) production increase at the Vickery Coal Mine, from the currently approved 4.5 Million tonnes per annum (Mtpa) to a proposed maximum production rate of 10 Mtpa. Although not approved, the Vickery Extension Project is considered a reasonably foreseeable future development and is included for the 2021 modelling scenario.

There are two other proposed but not approved coal mining operations in the Namoi basin; the Caroona Coal Project and the Watermark Coal Project. BHP Billiton has recently agreed to cease progression of the Caroona Coal Project, through the cancellation of their Exploration Licence (EL) 6505 and this project is therefore excluded from this study. The Watermark Coal Project is not yet approved but is considered a reasonably foreseeable future development for the purpose of this assessment, although two scenarios are presented for the future year (2021); with and without the Watermark Coal Project.

A summary of the all coal mining operations in the Namoi basin and the 2013 and 2021 ROM production assumed for modelling is presented in **Table 6-3**.

Table 6-3: ROM coal production estimates for modelling

Mine	ROM production (tpa)		Source of ROM production estimate
	2013	2021	
Narrabri Mine	5,390,572	8,000,000	2013 – Whitehaven supplied production rate 2021 – Approved maximum production
Tarrawonga Coal Mine	2,073,051	3,000,000	2013 – Whitehaven supplied production rate 2021 – Approved maximum production
Maules Creek Coal Mine	-	13,000,000	2013 – N/A - not commenced 2021 – Approved maximum production
Rocglen Coal Mine	1,298,958	-	2013 – Whitehaven supplied production rate 2021 – Scheduled to have ceased production
Werris Creek Coal Mine	1,872,316	2,500,000	2013 – Whitehaven supplied production rate 2021 – Approved maximum production
Boggabri Coal Mine	4,063,000	7,800,000	2013 – 2013-2014 AEMR 2021 – Approved maximum production
Vickery Extension Project	-	10,000,000	2013 – N/A - not commenced 2021 – Proposed maximum production
Sunnyside Coal Mine	-	-	N/A - In care and maintenance
Whitehaven CHPP [1]	*2,936,000*	*3,000,000*	*2013 – 2013 Coal transport records* *2021 – Approved maximum production*
Watermark Coal Project	-	10,000,000	2013 – N/A - not commenced 2021 – Proposed maximum production
Caroona coal Project	-	-	N/A – Project ceased and mining lease surrendered
TOTAL (Mtpa)	**14.7**	**54.3**	

Note: [1] *Whitehaven CHPP receives coal from Tarrawonga and Rocglen and is not included in the ROM production total to avoid double counting*

6.2.1 Emission estimates

Existing emissions inventories are available for most mines in the Namoi basin. Air Quality Assessments (AQA) prepared as part of an Environment Assessment (EA) provide detailed emission inventories for existing and proposed mines and for multiple assessment years. Also, in 2012, the EPA's "dust stop" pollution reduction programme (PRP) required all existing mines to develop emissions inventories and identify best practice emission reduction options for key sources.

The emission inventories prepared for the EA process are considered a better source of information for this study, for the following reasons:

- The AQA inventories present more detailed disaggregation of emission sources allowing wind sensitive, wind insensitive and wind erosion sources to be clearly identified.
- The AQA inventories (generally) include best practice haul road controls, appropriate for the modelling years in this study.
- The AQA inventories include multiple years, whereas the PRP present a single year, typically 2011.
- AQA inventories are available for proposed as well as existing mines.

The existing emissions inventories are used to derive emissions for the study years, by scaling emissions according to the actual (2013) or proposed (2021) ROM production. Each AQA presents multiple assessment years and the closest available emissions inventory to the study years are selected for the assessment. For example, in the Tarrawonga AQA (PAEHolmes, 2012) the Year 2 emissions inventory (2014) is scaled for 2013 and the Year 6 emissions inventory (2018) is scaled for 2021.

For each available emission inventory year, the ratio of PM emissions (kg/annum) to ROM coal (tonnes/annum) is calculated for each mine (i.e. PM_{10}/ROM and $PM_{2.5}$/ROM ratios). This provides a site specific emission factor, expressed as kg PM generated per tonne of ROM mined. The PM/ROM ratios are then used to calculate the annual PM emissions for 2013 and 2021 at each mine[7], based on the ROM production for that year. The PM/ROM ratios tend to be similar for different inventory year, although by calculating site-specific ratios for each mine and each available inventory year, variations in stripping ratios are accounted for by using the closest available inventory year to 2013 and 2021.

The average PM_{10}/ROM and $PM_{2.5}$/ROM ratios derived for this study are 0.3 and 0.04. The ratios are similar to the 2008 NSW EPA Air Emission Inventory for the Greater Metropolitan Region in NSW (GMR Inventory) (Mining for Coal) which reports a PM_{10}/ROM ratio of 0.25 and $PM_{2.5}$/ROM ratio of 0.04.

The annual emissions are also split into wind-dependent, wind-independent and wind erosion sources and these splits are used to proportion emissions into these categories so that hourly emission files can be developed for modelling, varied according to the local wind speed (refer **Section 6.2.2**).

ROM production data for existing mines in 2013 are taken from the published production rates in Annual Environment Monitoring Reports (AEMRs). Future ROM production for 2021 is based on the maximum approved (or proposed) production.

SEARs for the Vickery Extension Project (SSD 16-7480) were issued in February 2016, however at the time of writing the Environmental Impact Statement (EIS) was not publically available. Therefore, emissions inventories presented in the AQA for the Vickery Coal Project have been used to derive the PM/ROM ratios and applied to the increased production rate proposed for the Vickery Extension Project.

There are no existing emission inventories for the Gunnedah CHPP. The activities at the Gunnedah CHPP are similar to surface activities at the Narrabri Coal Mine (coal handling, dozers on stockpile maintenance, wind erosion etc.). In the absence of detailed activity data for the Gunnedah CHPP (i.e. dozer hours, stockpile areas) the PM/ROM ratios derived for Narrabri Coal Mine are used to derive emissions, and applied to the actual throughput at the Gunnedah CHPP.

The total estimated PM emissions for each mine (kg PM/annum) are presented in **Table 6-4**. Detailed emission calculations are presented in **Appendix 5**.

[7] Detailed activity data were not available to develop detailed bottom up emission inventories for each study year, however the PM/ROM ratios are based on detailed bottom up emission inventories specific to each mine (for a year close to the assessment year), and therefore estimates of total PM emissions are considered to have a good degree of accuracy.

Table 6-4: Summary of coal mine emission estimates

Mine	Estimated emissions (kg/annum)			
	2013		2021	
	PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$
Whitehaven CHPP	59,424	12,395	60,716	12,664
Narrabri Mine	109,098	22,756	161,909	33,771
Werris Creek Coal Mine	425,390	46,433	568,000	62,000
Rocglen Coal Mine	491,557	59,087	-	-
Tarrawonga Coal Mine	750,148	90,171	1,118,684	134,471
Boggabri Coal Mine	1,645,344	197,778	2,903,693	349,037
Watermark Coal Project	-	-	2,225,764	267,547
Vickery Extension Project	-	-	3,159,318	514,334
Maules Creek Coal Mine	-	-	3,173,520	381,472
TOTAL	**3,480,961**	**428,620**	**13,371,604**	**1,755,296**

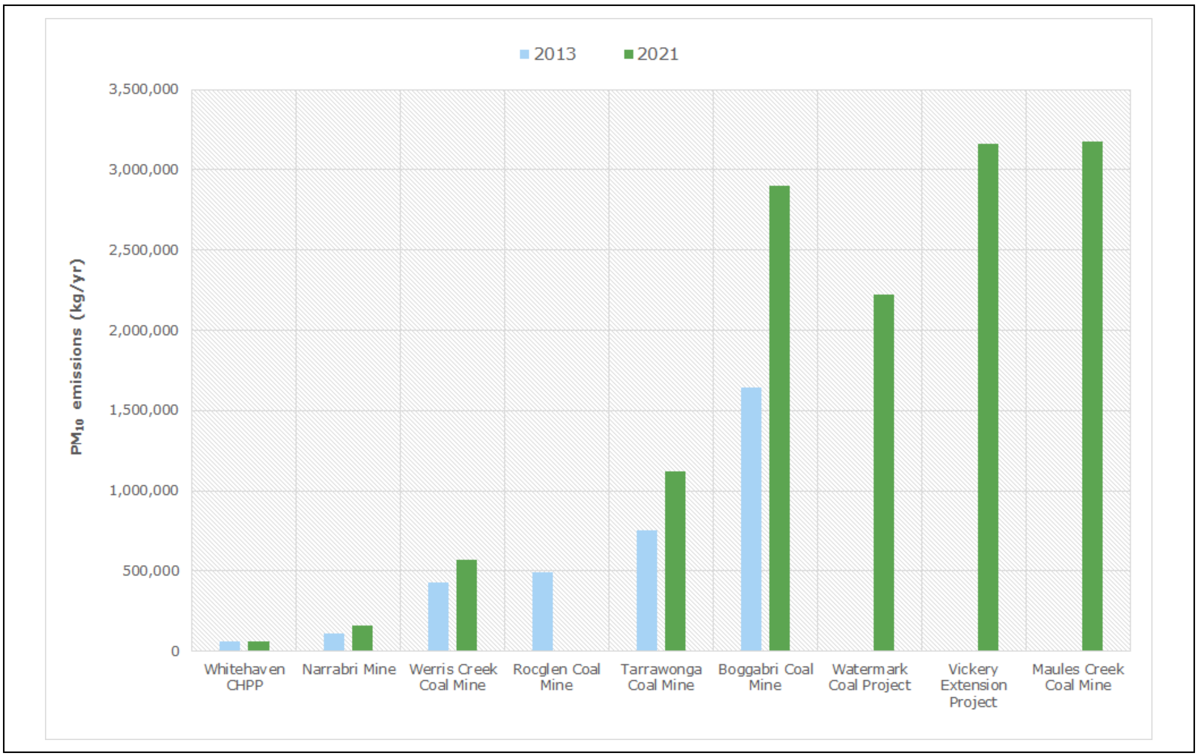


Figure 6-1: Estimated PM_{10} emissions for 2013 and 2021

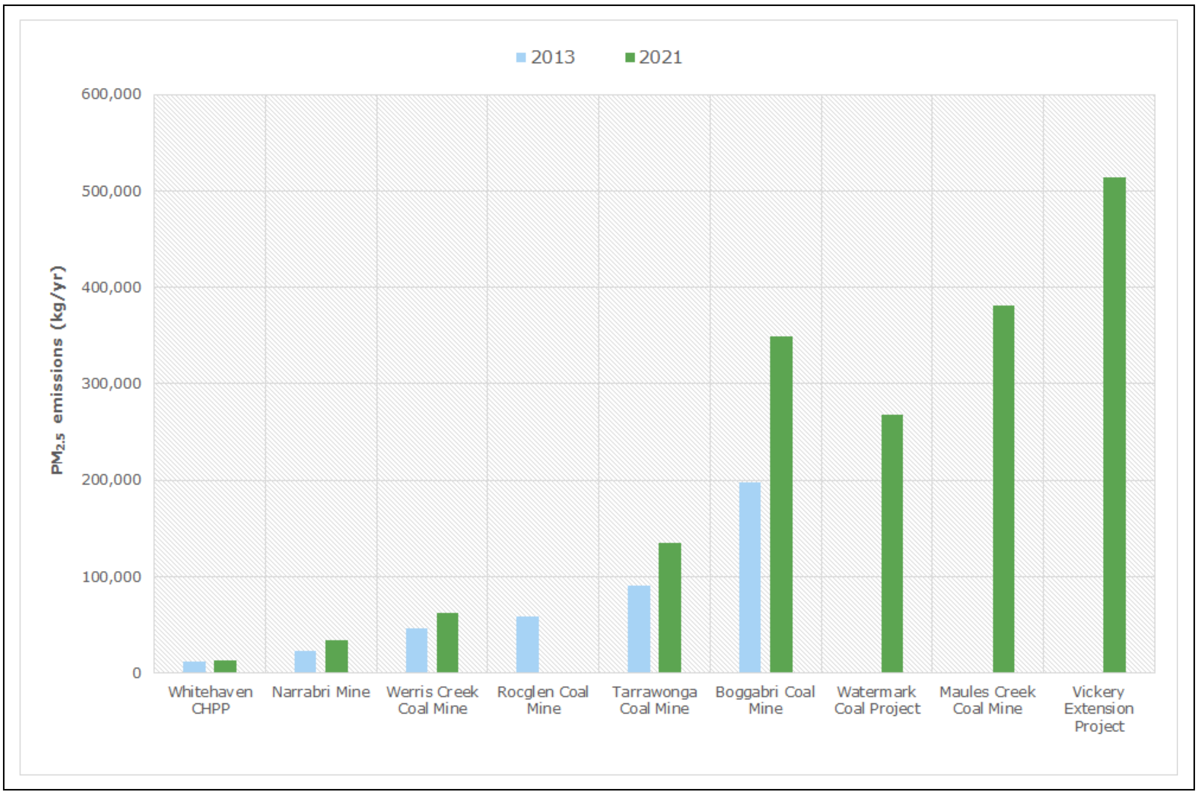


Figure 6-2: Estimated $PM_{2.5}$ emissions for 2013 and 2021

6.2.2 Hourly varying emissions

Annual emission totals are split into three emission source categories, as follows:

- Wind-insensitive sources (where the emission rate is independent of the wind speed).
- Wind-sensitive sources (where there is a relationship between the emission rate and wind speed).
- Wind erosion sources (where the emission is dependent on the wind speed).

Splitting the annual emissions into these source categories allows an hourly varying emission rate, adjusted according to the local wind speed for the wind-sensitive and wind erosion categories.

The annual emissions are assigned to each category based on the contribution of each category to the total mine emissions, calculated by adding together emissions from each individual source type that falls into the categories above and dividing by the mines total emissions.

The average category splits (across all mines) derived for this study are as follows:

- 73% of emissions are generated independent of wind speed.
- 6% of emissions are dependent on wind speed (such as loading and dumping).
- 21% of emissions are wind erosion sources.

The average category splits derived for this study are similar to an analysis of mine dust inventories for the Hunter Valley, presented in the Mount Arthur North Environmental Impact Statement (EIS) (**URS, 2000**), as follows:

- 73% for emissions that are independent of wind speed.
- 14% for emissions that depend on wind speed (such as loading and dumping).
- 13% for wind erosion sources.

Sources that are independent of wind speed contribute most to total mine emissions. This is reflected in the recently completed "dust stop' PRPs which consistently identified wheel generated dust from hauling as the largest dust source[8]. The emissions for these wind independent sources are evenly apportioned for each hour of the year, as it is assumed that all coal mines operate 24 hours a day for seven days a week.

Hourly varying emissions for wind erosion sources are derived using equation 1, adjusted according to the cube of the hourly average wind speed and normalised so that the total emission over all hours in the year adds up to the estimated annual total emission.

$$E_i = E_{annual} \times \frac{U_i^3}{\sum_{i=1}^{N} U_i^3} \qquad \text{eq.1}$$

Where: $E_i = emissions\ for\ hour\ i$

$E_{annual} = annual\ emissions$

$U_i^3 = wind\ speed\ cubed\ for\ hour\ i$

$N = number\ of\ hours\ of\ wind\ speed$

(Skidmore, 1998)

The emissions for wind-sensitive sources are converted to hourly emissions in a similar manner, however the wind speed adjustment is made based on equation 2:

$$E_i = E_{annual} \times \frac{\left(\frac{U}{2.2}\right)^{1.3}}{\sum_{i=1}^{N} \left(\frac{U}{2.2}\right)^{1.3}} \qquad \text{eq.2}$$

Where: $E_i = emissions\ for\ hour\ i$

$E_{annual} = annual\ emissions$

$\left(\frac{U}{2.2}\right)^{1.3} = wind\ speed/2.2\ \ to\ the\ power\ of\ 1.3\ for\ each\ hour\ i$

$N = number\ of\ hours\ of\ wind\ speed$

(US EPA, 1987)

An example of the resultant hourly varying emissions profiles is presented in **Figure 6-3**. The plot shows a constant emission rate for wind-insensitive sources (evenly apportioned across the year) compared with a diurnal and seasonal profile for wind erosion, with higher emission occurring in October through March and peaking each afternoon, when higher wind speeds are recorded.

[8] http://www.environment.nsw.gov.au/resources/ MinMedia/MinMedia13032201.pdf

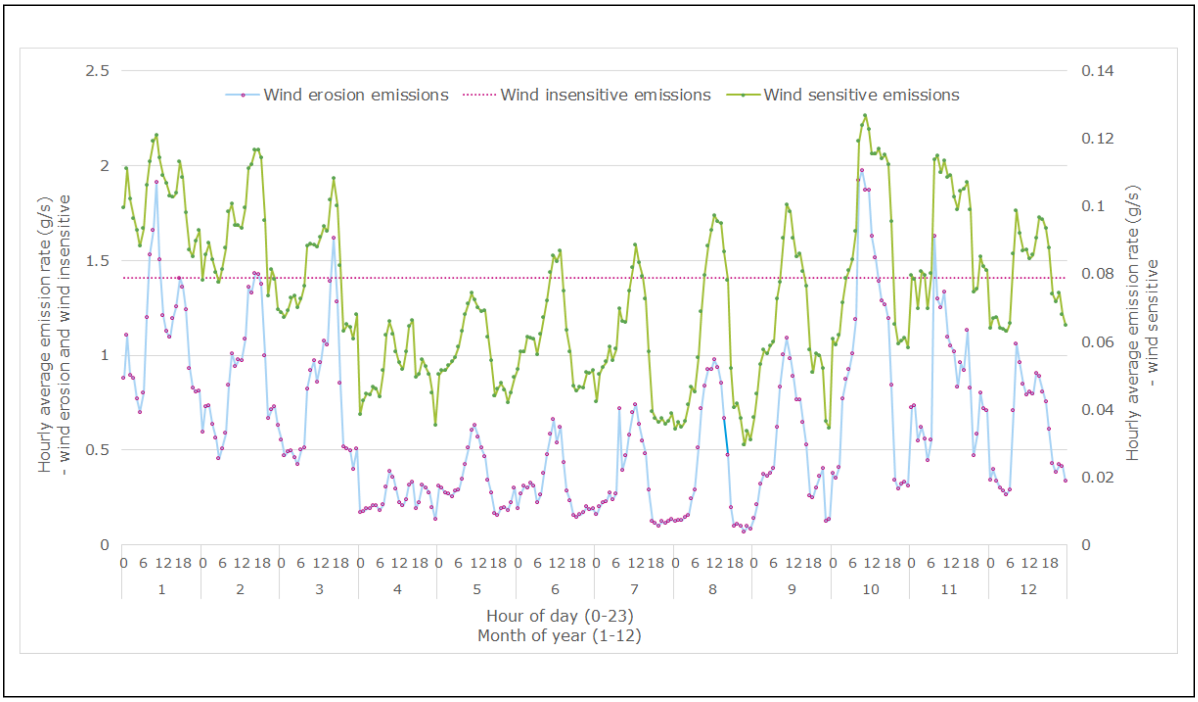


Figure 6-3: Example of an hourly varying emissions profile for PM_{10}

6.3 Non-road diesel emissions (coal mines)

As part of an initiative to manage diesel emissions from non-road vehicles, the EPA surveyed all licenced coal mines in NSW to obtain detailed information about the composition and use of their diesel fleet, their maintenance and engine replacement schedules, fleet projections and fuel use (NSW EPA, 2014).

The EPA has provided diesel consumption and ROM production data for 2012, allowing a site specific diesel intensity factor (kL diesel per tonne ROM) to be derived for each mine.

The 2012 diesel intensity factor varies from 0.0003 kL/tonne for the Narrabri underground mine to 0.008 kL/tonne, the average of all existing open cut mines.

The EPA has also estimated site specific PM_{10} and $PM_{2.5}$ emissions for each mine for 2012, based on, among other things, the composition and use of their diesel fleet. When combined with the 2012 diesel consumption, site specific PM_{10} and $PM_{2.5}$ emission factors (kg/kL) can be derived.

The annual PM_{10} and $PM_{2.5}$ emissions for 2013 and 2021 are then estimated based on actual and projected ROM production, as per equation 3:

$$E = P \times I \times EF \qquad \text{eq.3}$$

Where $E = Emissions_{\ (kg/year)}$

$P = ROM\ Production_{(tpa)}$

$I = Diesel\ intensity\ factor_{\ (kL/t\ ROM)}$

$EF = Emission\ Factor_{\ (kg/kL.year)}$

The estimated diesel emissions for are presented in **Table 6-5**. It is assumed that all coal mine operate 24/7 and the annual emissions are evenly distributed for each hour of the year. It is noted that the US EPA AP-42 emission factors used in the coal mine emissions inventories do not separate PM emissions from mechanical processes (i.e. crustal material) and diesel exhaust (combustion). Therefore, there may be an element of double counting when the emissions from diesel exhaust from coal mine vehicles are estimated separately.

Table 6-5: Non road diesel emission estimates (coal mines)

Mine	Estimated emissions (kg/annum)			
	2013		2021	
	PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$
Narrabri Mine	1,614	1,565	2,395	2,323
Tarrawonga Coal Mine	26,044	25,263	37,689	36,559
Maules Creek Coal Mine	-	-	312,878	303,492
Rocglen Coal Mine	15,163	14,708	0	0
Werris Creek Coal Mine	31,358	30,417	41,870	40,614
Vickery Extension Project	-	-	116,732	113,230
Boggabri Coal Mine	97,787	94,854	187,727	182,095
Watermark Coal Project	-	-	240,675	233,455
Whitehaven CHPP	879	853	898	871
TOTAL	**172,844**	**167,659**	**943,858**	**915,542**

6.4 Wood heaters

Emissions from the combustion of wood fuel in residential space heaters are estimated using the methodology described in the NSW EPA's Air Emissions Inventory for the GMR (NSW EPA, 2012d). Emissions are estimated based on the equation 4, presented in Pechan (2009c).

$$E_{i,j} = C_j \times EF_{i,j} \qquad \text{eq.4}$$

Where: $E_{i,j} = Emissions\ for\ substance\ i\ from\ residential\ space\ heater\ type\ j\ (kg/year)$

$C_j = Wood\ fuel\ consumption\ for\ residential\ space\ heater\ type\ j\ (tonnes/year)$

$EF_{i,j} = Emission\ factor\ for\ substance\ i\ from\ residential\ space\ heater\ type\ j\ (kg/tonne)$

j = *Type of wood heater - "slow combustion heater with compliance plate", "slow combustion heater without compliance plate", "open fireplace" or "potbelly stove"*

Emissions factors for each wood heater type are provided in NSW EPA (2012d). The activity data required for emissions estimation includes wood heater type, number in operation and fuel consumption. The number of wood heaters in use, by LGA, is determined from population estimates published by the Australian Bureau of Statistics (ABS)[9], based on data collected during their 2011 census.

The ABS provide estimates of occupied and unoccupied dwellings for a number of different reporting levels, including LGA level, statistical area level, state suburb level and urban centre level. For the larger urban centres, dwelling estimates are provided at both the urban centre and

[9] http://www.abs.gov.au/websitedbs/censushome.nsf/home/quickstats

state suburb level. For example, 86% of the dwellings in Gunnedah are concentrated within the urban centre.

Not every dwelling contains a wood heater and assumptions on wood heater ownership are required. The literature suggests that wood heater ownership in rural NSW ranges from 16% to 43%. For example, the economic analysis for wood heater measures (AECOM, 2014) estimates 43% for "*Richmond-Tweed and Mid-North Coast*" region, 23.1% for "*Northern, North Western and Central West*" and 30.6% for the "*Hunter*" region. The ABS report a state average of 19.2% (for areas outside capital cities) (ABS, 2014a) while the NSW EPA (2012d) reports a non-urban value of 16.3% for the GMR.

Wood heater ownership is likely to vary depending on how cold an area gets and also the availability of natural gas for heating. Heating degree days (HDD) can be used as a proxy for the energy demand needed to heat a building[10]. An analysis of the HDD in 2013 for various regions in NSW is presented in **Figure 6-5** and compared with wood heater ownership presented in AECOM (2014). The analysis shows a similar HDD value between Singleton and Gunnedah. As described previously, AECOM reports a wood heater ownership value of approximately 30% for the Hunter region and on this basis a value of 30% ownership is adopted for the Namoi basin.

Average wood consumption (tonnes/heater/year) and PM_{10} and $PM_{2.5}$ emission factors (kg/tonne) are provided in NSW EPA (2012d), by wood heater type. These are combined to create an emission factor in kg/heater/year. Also presented in NSW EPA (2012d) is the percentage of wood heater ownership, by type, for non-urban areas. These ownership percentages are normalised to 1 and then used to derive an adjusted PM_{10} and $PM_{2.5}$ emission factor (kg/heater/year) by normalised ownership proportion for each wood heater type. The sum of the adjusted PM_{10} and $PM_{2.5}$ emission factor is combined with the wood heater numbers for each LGA, state suburb and urban centre to generated annual emissions.

Temporal variation in emissions from wood heaters have been estimated from profiles reported in NSW EPA (2012d). Monthly, daily and hourly (weekday and weekend) profiles are provided and are combined to create a full year of hourly varying scaling factors to describe the temporal variation in emissions. The resultant temporal profile is presented in **Figure 6-4**, showing monthly variation averaged by hour of the day. The temporal profile re-allocates annual emissions so that peak emissions occur during cooler months, predominately May to September. A daily peak also occurs at 6 pm (hour 18) each day, with a much smaller peak in hour 6, as wood heaters are re-ignited each morning.

[10] Heating degree days are determined by the difference between the average daily temperature and the comfort level temperature, which is taken as 12 and 18 degrees Celsius. http://www.bom.gov.au/jsp/ncc/climate_averages/degree-days/index.jsp

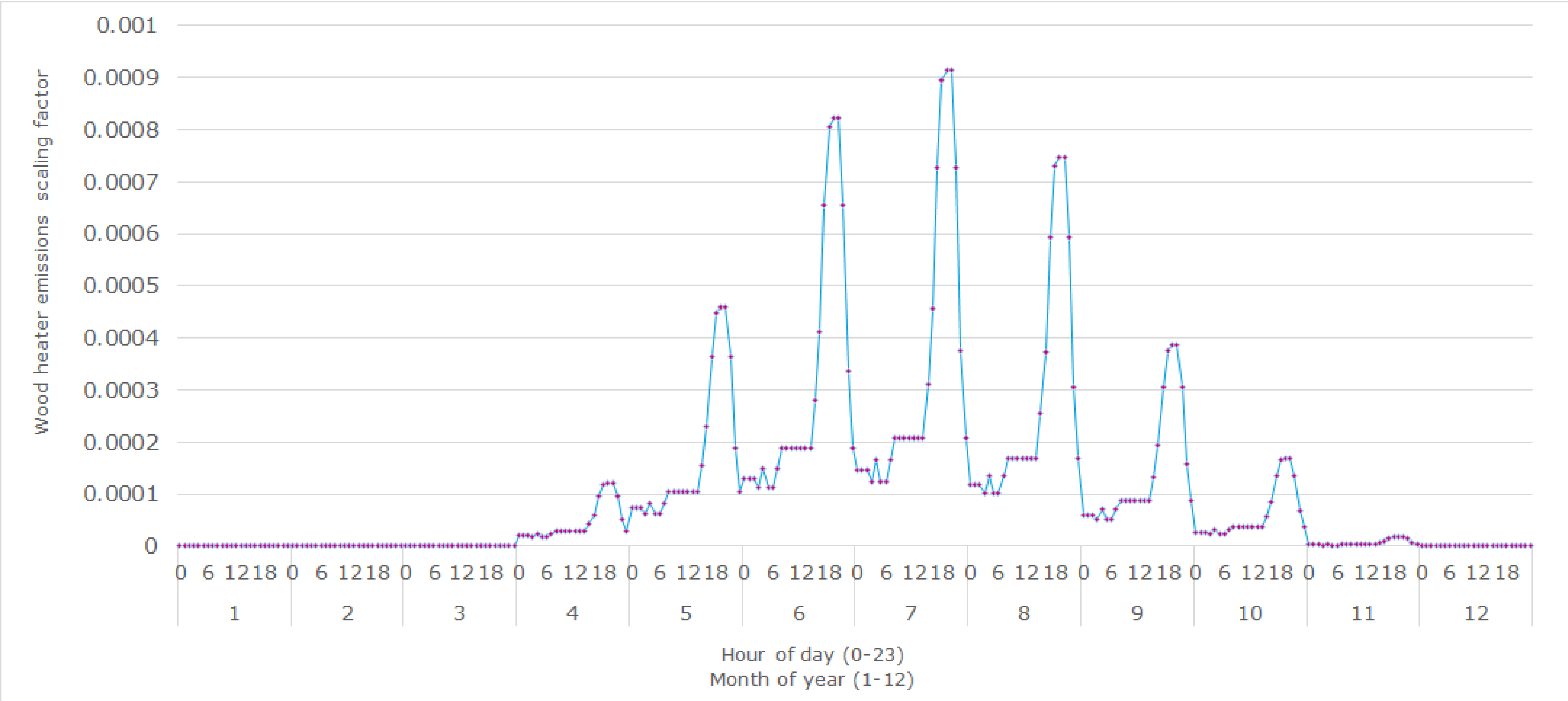


Figure 6-4: Temporal profile for wood heater emissions

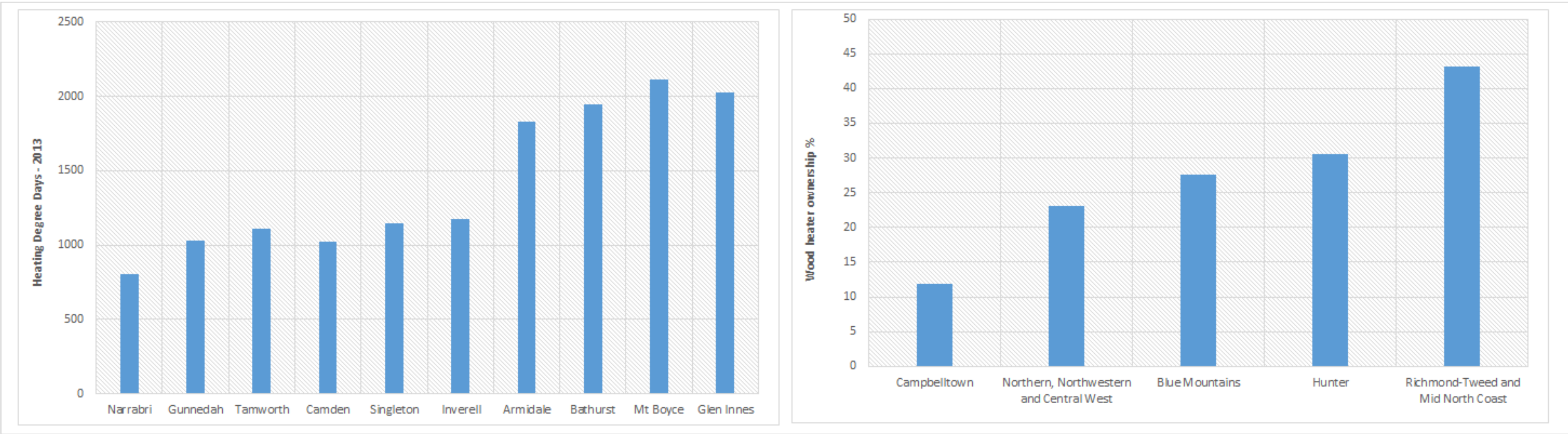


Figure 6-5: Analysis of HDD and wood heater ownership (based on AECOM, 2014)

6.5 Agriculture

Emissions estimates for wind erosion from cropping areas and unsealed roads are based on the NSW EPA’s Air Emissions Inventory for the GMR.

6.5.1 Fugitive emissions from cropping areas

Fugitive windborne particulate matter emissions from agricultural lands are estimated using the methodology described in the NSW EPA’s Air Emissions Inventory for the GMR (NSW EPA, 2012e) which is based on the California Air Resources Board (CARB) *Area-Wide Source Methodologies* for *Windblown Dust - Agricultural Lands* (CARB, 1997).

Emissions are estimated based on the wind erosion equation (WEQ) (equation 5) and the equation variables outlined in **Table 6-6**.

$$E_{i,j} = A_i \times I_j \times K_i \times C \times L'_i \times V'_{i,k} \times H_i \times 1000 \qquad \text{eq.5}$$

Table 6-6: WEQ variables

Variable	Description	Reference
$E_{i,j}$	Emissions of TSP from source type i and soil type j (kg/year)	NSW EPA, 2012e
A_i	Portion of total wind erosion losses that would be measured as TSP for source type i	Value of 0.025 applied, as per NSW EPA, 2012e
I_j	Soil erodibility for soil type j	Values provided for 9 NSW soil types in NSW EPA, 2012e
K_i	Surface roughness factor for source type i	Values for 9 crop types provided in NSW EPA, 2012e
C	Climatic factor	Derived based on wind speed and Thornthwaite’s PE index
L'_i	Unsheltered field width factor for source type i	Values for 9 crop types provided in NSW EPA, 2012e
$V'_{i,j}$	Vegetative cover factor for source type i and month k	Values for each month of the year and for 9 crop types provided in NSW EPA, 2012e
H_i	Area of source type i	Summer and Winter Crop Prospects for 2013 - NSW grains report (DPI, 2013)

6.5.1.1 Soil erodibility

The Digital Atlas of Australia Soils[11] provides data on soil types for the Liverpool Plains, Gunnedah and Narrabri LGAs. The soil types in the Digital Atlas of Australia Soils are matched, as closely as possible, to the categories for which soil erodibility factors (tonnes per hectare (ha) per year) are provided in NSW EPA 2012e. GIS data for soil categories are then combined with the Catchment Scale Land Use of Australia (CLUM) GIS data (ABARES, 2015) to determine the proportion of each soil types within the CLUM *dryland cropping* and *irrigated cropping* areas of each LGA.

As shown in **Table 6-7**, the highest proportion, by area, for each LGA, is cracking clay, followed by brown duplex, sands and loams. This seems to be consistent with reports in the literature (i.e. Scott et al, 2004, NSW Agriculture, 1998).

The soil erodibility factors are weighted according to the proportion of each soil type in each LGA cropping area and a combined (weighted) soil erodibility factor is calculated for each LGA cropping area. For example, the soil erodibility factor for cracking clay is 126 tonnes/ha/year and 85% of Narrabri cropping area has cracking clay as the dominant soil type. Therefore the weighted soil erodibility factor is 126 x 85% = 122 tonnes/ha/year.

[11] http://www.asris.csiro.au/themes/Atlas.html

Table 6-7: Proportion of soil types by cropping area						
Soil Type	**Proportion of soil type by dryland and irrigated cropping area for each LGA**			**Soil erodibility factor (tonnes/ha/yr)**		
	Liverpool Plains	**Gunnedah**	**Narrabri**	**NSW GMR EF**	**Weighted Gunnedah**	**Weighted Narrabri**
Brown Duplex	0%	0%	10%	193	0.0	18.6
Cracking Clay	95%	98%	85%	126	121.8	106.6
Loams	3%	0%	1%	126	2.1	0.6
Red Duplex	1%	0%	2%	193	1.4	3.3
Sands	0%	1%	4%	493	4.5	17.3
Total					**129.9**	**146.5**

6.5.1.2 Crop prospects for NSW

The major communities for the study area include cotton, cereals and pastures for stock feed. Crop prospects for 2013 are outlined in the NSW grains report newsletter. The accompanying statistics lists the summer and winter crop prospects (at April 2013) for each Agronomist District of NSW. In the northwest region, the Gunnedah Agronomist District includes the Liverpool Plains subregion (NSW DPI, 2004), therefore areas of winter and summer crops are combined for the Gunnedah and Liverpool LGA. Crop prospect areas for 2013, for the summer and winter crop types referenced in NSW EPA (2012e) are summarised in **Table 6-8**.

The crop types inventoried for this study represent 50% of the total dryland and irrigated CLUM cropping areas for Gunnedah, Narrabri and Liverpool Plains.

Estimate of cropping area for cotton are made based on information presented in the annual reports produced by Cotton Australia, which reports a total of 68,000 ha for the Namoi valley in 2013-2014 (Cotton Australia, 2014). Previous annual reports indicate that the Lower Namoi produces more cotton that the Upper Namoi, however it is not possible to clearly assign these Namoi districts to the agronomist districts of Gunnedah and Narrabri.

Therefore, for the purposes of emission estimation 50,000 ha of cotton cropping is allocated to the Narrabri district with the remaining 18,000 ha allocated to the Gunnedah district. Assigning the majority of emissions to the Narrabri district is also consistent with the number of Cotton Gins licenced in the Narrabri LGA (six) when compared to Gunnedah (one).

Table 6-8: Crop areas for crops considered in this study			
Agronomist District	**Season**	**Crop**	**Area (ha)**
Gunnedah	Winter	Wheat	60,000
		Barley	20,000
		Oats	6,000
		Triticale	500
		Lupin Angust	100
		Canola	5,000
	Summer	Grain Sorghum	55,000
		Maize	2,000
		Soybean	2,000
		Cotton	34,150
	Total		**184,750**
Narrabri	Winter	Wheat	90,000
		Barley	10,000
		Oats	3,000

Table 6-8: Crop areas for crops considered in this study

Agronomist District	Season	Crop	Area (ha)
		Triticale	0
		Lupin Angust	0
		Canola	6,000
	Summer	Grain Sorghum	10,000
		Maize	200
		Soybean	380
		Cotton	34,150
	Total		**153,730**

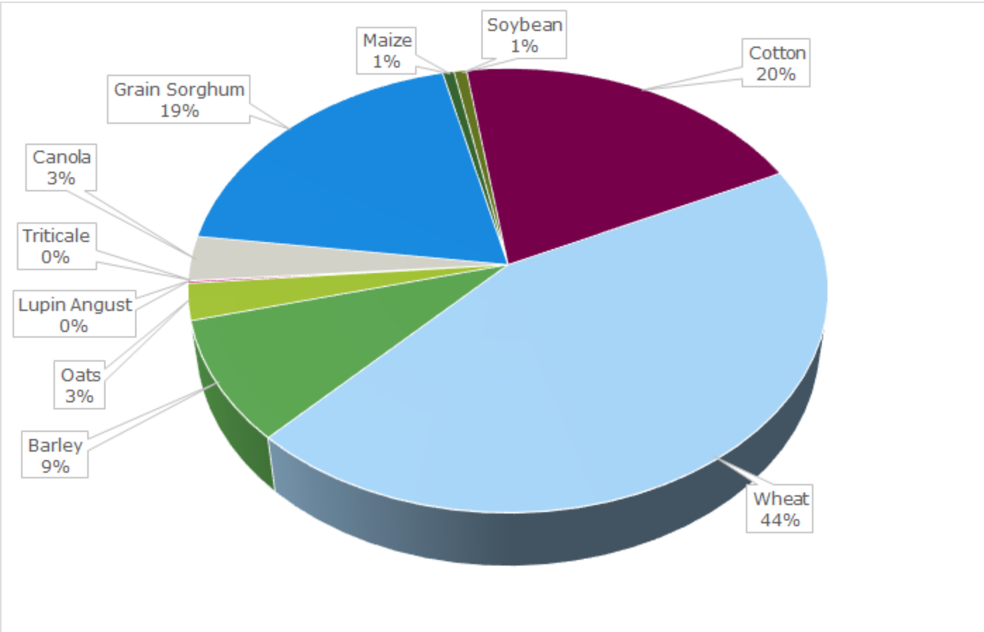


Figure 6-6: Estimated proportion of crop types for Gunnedah and Narrabri combined

6.5.1.3 Climate factor

A monthly climate factor is calculated based on the procedures described in NSW EPA (2012e), modified from CARB (1997). The climate factor (C) is a function of annual wind speed (WS) and annual Thornthwaite's precipitation-evaporation index (PE) (equation 6).

$$C = 0.0828 \times (WS^3|PE^2) \qquad \text{eq.6}$$

A monthly Thornthwaite's precipitation-evaporation index (PE), is derived based on the monthly precipitation (P) and average monthly temperature (equation 7), and summed to generate the annual PE index:

$$PE = \left\{1.64 \times \left(\frac{P}{T + 12.2}\right)^{10/9}\right\} \qquad \text{eq.7}$$

Similar to the approach used in in NSW EPA (2012e), a monthly varying (month-as-a-year) climate factor is derived by multiplying the monthly PE by 12, substituting this into the climate factor equation and normalising back to 1. This provides for a climate based temporal profile when used in the wind erosion equation.

6.5.1.4 Emissions estimates

Other inputs for the wind erosion equation (surface roughness, unsheltered field width, vegetative cover factors) are taken from NSW EPA (2012e). Values for surface roughness and unsheltered field width varying according to each crop type, while values for vegetative cover vary by crop type and month. For cotton, which is not reported in NSW EPA (2012e), values of surface roughness and unsheltered field width for wheat, barley and soybean are have been adopted for cotton. The vegetative cover factor depends on the proportion of ground covered by the crop canopy during the growing season and the proportion of ground covered by debris during harvest periods. A monthly vegetative cover factor is derived for cotton based on a modified monthly profile for another summer crop (sorghum) taking into account the cotton growing/harvesting window of September/October to March/April. The vegetative cover factor for cotton differs from sorghum by having an earlier harvesting window and therefore higher potential for fugitive emissions during the months of May to August.

The wind erosion equation is used to derive total fugitive dust emissions, in the TSP size metric. To estimate PM_{10} and $PM_{2.5}$ emissions, ratios of TSP/PM_{10} and PM_{10}/$PM_{2.5}$ were derived based on the default emission factors (kg/ha/annum) presented in NSW EPA (2012e). Based on these ratios, PM_{10} is assumed to be 45% of TSP and $PM_{2.5}$ is assumed to be 17% of PM_{10}. A breakdown of the estimated annual PM_{10} and $PM_{2.5}$ emissions by agronomist district and crop type is presented in **Table 6-9**.

The Gunnedah Agronomist District incorporates both the Liverpool Plains and Gunnedah agricultural areas. Emissions estimates are apportioned to these LGAs according to the relative size of the CLUM dryland cropping and irrigated cropping areas of each (43% for Liverpool Plains and 57% for Gunnedah).

A summary of the estimated annual PM_{10} and $PM_{2.5}$ emissions by agronomist district and crop type is presented in **Table 6-10**.

Table 6-9: Annual PM_{10} and $PM_{2.5}$ emissions from agriculture by crop type and region

Agronomist District	Season	Crop	Area (ha)	PM_{10} emissions (kg/annum)	$PM_{2.5}$ emissions (kg/annum)
Gunnedah	Winter	Wheat	60,000	47,205	8,168
		Barley	20,000	46,163	7,988
		Oats	6,000	5,733	992
		Triticale	500	393	68
		Lupin Angust	100	660	114
		Canola	5,000	33,000	5,710
	Summer	Grain Sorghum	55,000	77,505	13,411
		Maize	2,000	3,060	529
		Soybean	2,000	13,830	2,393
		Cotton	18,000	41,489	7,179
	Total		**168,600**	**269,038**	**46,551**
Narrabri	Winter	Wheat	90,000	53,645	9,282
		Barley	10,000	12,657	2,190
		Oats	3,000	2,168	375
		Triticale	-	-	-
		Lupin Angust	-	-	-
		Canola	6,000	49,364	8,541
	Summer	Grain Sorghum	10,000	19,682	3,406
		Maize	200	435	75
		Soybean	380	3,527	610
		Cotton	50,000	129,959	22,487
	Total		**169,580**	**271,438**	**46,966**

Table 6-10: Annual PM_{10} and $PM_{2.5}$ emissions from agriculture by LGA

LGA	Estimated emissions (kg/annum)			
	2013		2021	
	PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$
Liverpool Plains	114,648	19,837	114,648	19,837
Gunnedah	154,390	26,714	154,390	26,714
Narrabri	271,438	46,966	271,438	46,966
TOTAL	**540,476**	**93,517**	**540,476**	**93,517**

GIS data for individual crop types are not available to allocate emissions by crop type, therefore the aggregated emissions totals (in **Table 6-10**) are allocated to the CLUM cropping areas for each LGA.

Variations in monthly emissions are based on a monthly climate factor (which takes into account rainfall and wind speed) and a monthly vegetative cover factor. An example of the aggregated monthly variation in emissions is presented in **Figure 6-7**. The monthly emissions are further adjusted according to the cube of the hourly average wind speed and normalised to the total emissions over all hours (refer equation 1 in **Section 6.2.2**). An example of the adjusted average hourly emissions are presented in **Figure 6-8**, showing a peak in emissions during afternoon hours when wind speeds are highest.

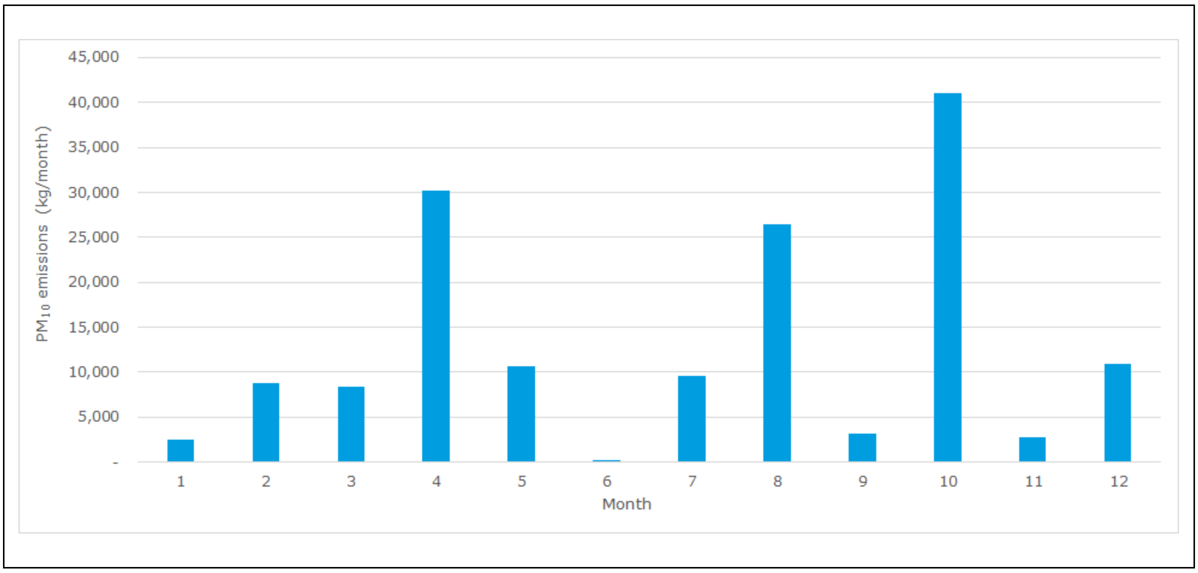


Figure 6-7: Monthly total PM_{10} emissions (kg) for the Gunnedah district

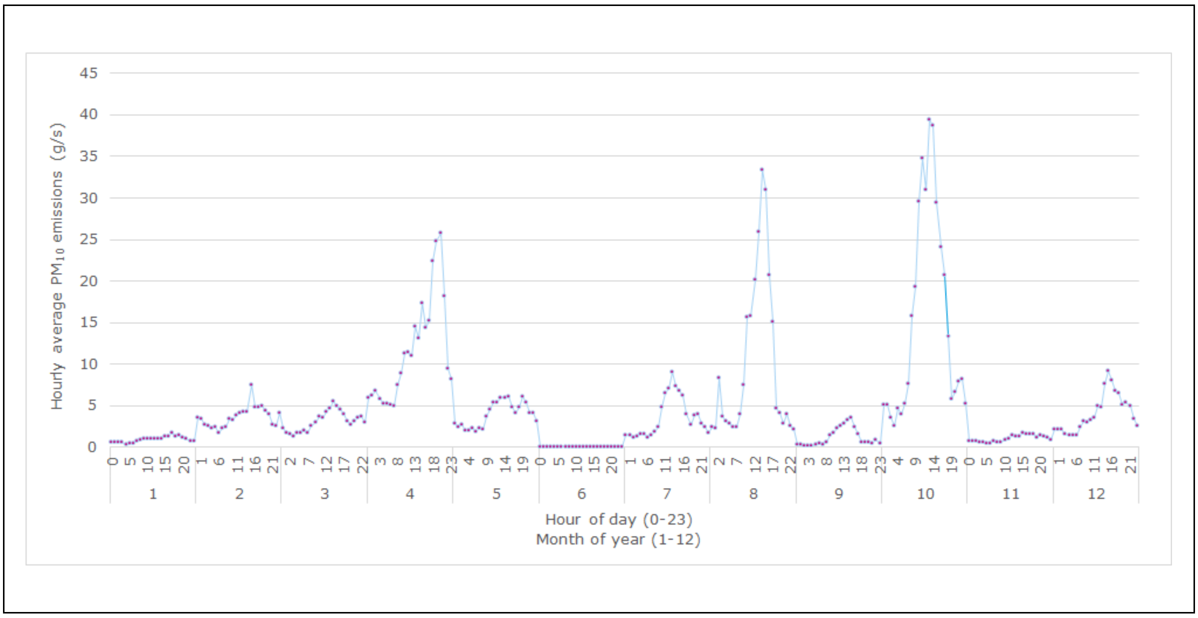


Figure 6-8: Average hourly PM_{10} emissions (g/s) for all LGAs combined

6.5.2 Fugitive emissions from unpaved roads

Fugitive windborne particulate matter emissions from unpaved roads are estimated in the same manner as agricultural lands using the wind erosion equation (equation 5). Surface roughness and vegetative cover are taken as 1 (i.e. no adjustment) and the unsheltered field width is taken from NSW EPA (2012e).

GIS data for unsealed roads for all of NSW are available from Geosciences Australia and the total unsealed road lengths for each LGA is extracted and used to estimate the total exposed areas for wind erosion. The GIS data includes minor roads, secondary roads and tracks, however for the purpose of this assessment, secondary roads and tracks are not considered.

The lengths and estimated exposed areas are presented in **Table 6-11**. The estimated emissions, based on the wind erosion equation, are presented in **Table 6-12**. Similar to the approach used for wind-blown dust from cropping areas, hourly varying emissions are generated for modelling, according to the cube of the hourly average wind speed.

Table 6-11: Unsealed road lengths for minor roads and estimated exposed areas for each LGA

LGA	Length (km)	Width (m)	Area (ha)
Liverpool Plains	702.9	7.88	807.4
Gunnedah	1024.6		553.8
Narrabri	1638.1		1290.8

Table 6-12: Annual PM_{10} and $PM_{2.5}$ emissions from unsealed roads by LGA

LGA	Estimated emissions (kg/annum)			
	2013		2021	
	PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$
Liverpool Plains	4,787	828	4,787	828
Gunnedah	6,979	1,207	6,979	1,207
Narrabri	12,592	2,179	12,592	2,179
TOTAL	**24,357**	**4,214**	**24,357**	**4,214**

6.6 Other commercial / industrial sources

Industrial sources within each LGA have been identified through a search of facilities that either report under the National Environment Protection (National Pollutant Inventory) Measure (NPI NEPM) or are EPA licenced facilities under the Protection of Environment Operations (POEO) Act.

A list of the identified facilities is provided in **Table 6-13**.

Table 6-13: Other industrial facilities in study area

LGA	Type of facility	Facility Name	NPI
Liverpool Plains	Quarry	Ardglen Quarry	No
		Willow Tree Gravels	No
		Boral Resources- Currabubula	Yes
		Zeolite Australia	No
		Castle Mountain Zeolite Quarry	No
		Warrah Ridge Quarry	No
	Cattle feedlot	Killara Feedlot	Yes
		Caroona Feedlot	Yes
Gunnedah	Quarry	Gunnedah Quarry Products Marys Mount Quarry	No
	Cotton Gin	Carroll Cotton Company	No
Narrabri	Cotton Gin	Queensland Cotton Company	No
		Auscott	No
		Namoi Cotton - Boggabri Cotton Gin	No
		Namoi Cotton – Merah North Cotton Gin	No
		Namoi Cotton – Yarraman Cotton Gin	No
	Quarry	Boral Resources Narrabri Quarry	Yes
		Johnstone Concrete and Landscape Supplies	No
		Pinebark Quarry (G&S Lein Earthmoving)	No
		Forest View Quarry (Boggabri Coal)	No
	Coal seam gas	Narrabri CSG Project	Yes
	Cotton seed processing	Cargill Processing Narrabri	Yes

Facilities that report to the NPI have publically available emissions estimates, however only five of the facilities in **Table 6-13** reported for 2013 to 2014. The NPI emissions reported for the Narrabri CSG Project and the Cargill Processing plant are taken from their NPI reports. In the case of the Narrabri CSG Project, no emissions of PM are reported. Emissions are assumed to remain constant for 2021.

Alternative emissions estimation methodologies are used for all other industrial facilities, described below.

6.6.1 Cotton ginning

Emissions from cotton gins have been calculated using a spreadsheet developed by the Texas Commission on Environmental Quality (TCEQ). The TCEQ emission factors are based on the "Seven Gin Study" which provided updated emission factors for cotton gins based on direct sampling of cyclones and particle size distribution (PSD) analysis for PM_{10} and $PM_{2.5}$ (Buser et al., 2012, Buser et al., 2013a, Buser et al., 2013b etc.).

Emission factors (EF) are provided for each process within a cotton gin (i.e. lint cleaning, mote system etc.), however in the absence of detailed operational data for the cotton gins within the study area, a facility total EF (kg/bale) is used to estimate emissions from each cotton gin.

Cotton Australia (2013) reports a production total of 602,750 bales for 2013/2014 for the Namoi district. Combining this with a PM_{10} EF of 0.2 kg/bale and a $PM_{2.5}$ EF of 0.01 kg/bale provides an estimate of total emissions for the Namoi district. For the purpose of this assessment, the emissions are distributed evenly across the seven cotton gins located in the study area.

Temporal variation is considered by distributing emissions across the ginning season, from April to September. A robust methodology for forecasting cotton production for 2021 could not be found, therefore emissions are assumed to remain constant.

6.6.2 Quarrying

NPI emissions are reported for three of the larger quarries in the study area. For all other quarries, emissions have been estimated using publically available emissions inventories for three hard rock quarries and two sand quarries. The PM_{10} emission factor for these five facilities varied from 0.02 kg PM_{10}/tonne to 0.12 kg PM_{10}/tonne with an average of 0.06 kg PM_{10}/tonne.

This average EF is used with the approved production rate to estimate annual emissions for each quarry. The majority of emissions are assumed to be from wind-independent sources (i.e. hauling), therefore emissions are evenly distributed across each hour of the year (and not varied according to wind speed).

Emissions for 2021 are generally assumed to remain constant, as they are estimated based on approved production rates. For the Gunnedah Quarry Products quarry and the Johnstone Concrete and Landscape Supplies quarry, future production for 2021 was increased based development applications for expansions which have been recommended for approval by the Joint Regional Planning Panel (JRPP).

According to the Ardglen Quarry website, production has currently ceased, therefore no emissions are assumed for 2013. However, future emissions for 2021 are assumed based on the currently approved production.

6.6.3 Feedlots

NPI emissions are reported for the two feedlots within the study area (the Killara and Caroona Feedlots). The two facilities being approved for a similar head of cattle (20,000 and 23,500, respectively), however the emission estimates are vastly different. For the reporting period 2012/2013, the Killara feedlot reported 170,000 kg of PM_{10} and 13 kg of $PM_{2.5}$. The Caroona feedlot reported 660 kg of PM_{10} and 630 kg of $PM_{2.5}$.

The NPI estimates are not used for modelling and emissions are estimated using a US EPA emission factor of 17 tons of PM_{10} per 1000 head of cattle, while $PM_{2.5}$ emissions are derived using a $PM_{2.5}/PM_{10}$ ratio of 0.15[12].

6.6.4 Summary

The annual emissions for other industrial facilities are summarised in **Table 6-14**.

[12] http://www.epa.gov/ttnchie1/eiip/techreport/volume09/feedlots.pdf

Table 6-14: Estimated emissions from other industrial facilities

Facility	Estimated emissions (kg/annum)			
	2013		2021	
	PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$
Ardglen Quarry	-	-	28,214	3,642
Willow Tree Gravels	11,285	1,457	11,285	1,457
Boral Resources- Currabubula	11,285	1,457	11,285	1,457
Zeolite Australia	1,693	219	1,693	219
Castle Mountain Zeolite Quarry	1,693	219	1,693	219
Warrah Ridge Quarry	5,643	728	5,643	728
Killara Feedlot	340	51	340	51
Caroona Feedlot	400	60	400	60
Gunnedah Quarry Products Marys Mount Quarry	2,821	364	20,314	2,622
Carroll Cotton Company	17,638	1,125	17,638	1,125
Queensland Cotton Company	17,638	1,125	17,638	1,125
Auscott	17,638	1,125	17,638	1,125
Namoi Cotton - Boggabri Cotton Gin	17,638	1,125	17,638	1,125
Namoi Cotton – Merah North Cotton Gin	17,638	1,125	17,638	1,125
Namoi Cotton – Yarraman Cotton Gin	17,638	1,125	17,638	1,125
Boral Resources Narrabri Quarry	5,643	728	5,643	728
Johnstone Concrete and Landscape Supplies	1,693	219	11,285	1,457
Pinebark Quarry (G&S Lein Earthmoving)	2,821	364	2,821	364
Forest View Quarry (Boggabri Coal)	11,285	1,457	-	-
Narrabri CSG Project	-	-	-	-
Cargill Processing Narrabri	36,743	11,948	36,743	11,948
TOTAL	**199,176**	**26,019**	**243,189**	**31,701**

6.7 Transportation

6.7.1 Rail

Emissions from locomotives were estimated using US EPA diesel locomotive emission factors and fuel. US EPA emission factors, expressed in g/kW-hr (grams of pollutant emissions per kilowatt-hour), were converted to g/litre (grams of pollutant per litre of fuel combusted) and adjusted for local sulfur content of automotive diesel oil (ADO) (ENVIRON, 2013). The emissions performance of the existing fleet in Australia is dominated by Pre Tier 0 locomotives (80.7%), followed by 2.8% meeting Tier 0, 16.1% meeting Tier 1 and 0.3% meeting Tier 2 (ENVIRON, 2013). The PM_{10} emission performance for large line haul locomotives is unchanged for Pre Tier 0, Tier 0 and Tier 1 and therefore suitable for use in this assessment as it represents the emissions performance of more than 99% of the Australian fleet. $PM_{2.5}$ emissions were taken to comprise 97% of PM_{10} emissions based on the speciation given by the US-EPA for diesel locomotives (ENVIRON, 2013).

The adopted emission factors are presented in **Table 6-15**. It is assumed that there would be no significant upgrade to the locomotive fleet from 2013 to 2021 and the same emission factors are applied.

Table 6-15: Locomotive emission factors

PM_{10} emission factor (g/L)	$PM_{2.5}$ emission factor (g/L)
1.32	1.28

Fuel consumption is estimated based on gross tonne kilometres (GTK) and the average fuel consumption rate of 4.03 L/kt-km. The average fuel consumption is derived from the 2008 GTK and annual diesel consumption for NSW (NSW EPA, 2012c).

For haulage of coal by rail, GTK is estimated for each section of rail between mine loading facilities, for loaded and unloaded trips. GTK for unloaded trips is estimated based on an average empty train weight, the number of trains per annum required to haul the product coal added at each loading facility and the travel distance from that loading point. GTK for loaded trains combines unloaded trips with the product coal hauled from each loading facility. The combined GTK is used to estimate fuel consumption and PM_{10} and $PM_{2.5}$ emissions from locomotives associated with coal haulage for each section of track.

Estimates are also presented for fugitive emissions from coal haulage, to account for coal loss as fugitive dust during travel. Emissions are estimated based on an emission factor (g/km/wagon) derived from Ferreira et al (2013). The combined emissions for coal haulage by rail by section of track are presented in **Table 6-16**.

Table 6-16: Estimated emissions from coal haulage by rail

Rail link	Estimated emissions (kg/annum)			
	2013		2021	
	PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$
Narrabri loop to Boggabri loop	920	770	1,366	1,142
Maules Creek to Boggabri loop	-	-	1,686	1,372
Boggabri Mine to Boggabri loop	-	-	2,488	1,992
Boggabri loop to Gunnedah loop	3,069	2,751	11,787	10,565
Gunnedah loop to Watermark Jct	3,448	3,044	10,747	9,488
Watermark Jct to Werris Creek	6,021	5,239	22,832	19,867
Werris Creek loop to Scone	10,490	9,837	36,887	34,590
TOTAL	**23,948**	**21,640**	**87,793**	**79,016**

Emission estimates for non-coal freight and passenger trains also requires estimates of GKT, however this is generally reported at state level and not disaggregated for the study LGAs. Similarly, activity data such as grain tonnages by LGA, does not provide a complete picture.

The ARTC 2015-2024 Hunter Valley Corridor Capacity Strategy (ARTC, 2015) estimates up to seven trains per day for non coal traffic (passenger, grain, flour and cotton), each way between Narrabri and Scone. This is similar to the number of trains needed to haul coal in 2013 (based on total product coal production and average train capacity).

This observation is supported in the NSW freight and Ports strategy (TfN, 2013) which presents freight volumes for major commodity groups (Figure 13) and shows that mining and agriculture have a similar proportion of freight task within the Northern statistical division of NSW. Furthermore, ENVIRON (2013) reports that coal-related rail activities account for 67% of the GTK within the GMR and 48% of the GTK across NSW.

Therefore, for 2013, we have assumed that GTK for all other rail traffic is equivalent to coal haulage GTK, based on the 48% reported in ENVIRON (2013) for coal-related rail activities across NSW. For 2021, coal haulage is expected to grow more than other sectors of rail travel and therefore rather than assuming the same 48% split, coal haulage GKT is assumed to represent 67% of the total freight task (based on estimates for the GMR, which includes the Hunter Valley mining area, presented in ENVIRON (2013).

Emission from locomotives for all non-coal trains are estimated based on the average fuel consumption rate of 4.03 L/kt-km and the derived values for GTK. Fugitive emissions for non-coal freight are not estimated.

The estimated emissions from rail transportation are summarised in **Table 6-17**.

Table 6-17: Summary of estimated emissions for rail

Source	Estimated emissions (kg/annum)			
	2013		2021	
	PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$
Coal train locomotive emissions	22,009	21,349	80,301	77,892
Coal train fugitive emissions	1,938	291	7,492	1,124
All other trains - locomotive emissions	23,844	23,128	39,551	38,365
TOTAL	**47,791**	**44,768**	**127,345**	**117,381**

Temporal variation in emissions from rail transportation has been estimated from profiles reported in NSW EPA (2012c). The assumptions applied in NSW EPA (2012c), for example passenger train priority during peak periods and daily and monthly GTK statistics for the GMR are assumed to be applicable for the study LGAs.

6.7.2 Road traffic

Emissions from road traffic were estimated using NSW EPA Air Quality Appraisal Tool (AQAT). The AQAT calculates road traffic emissions by defined road link by combining average daily traffic rates, length of road link, road type, road grade and traffic speed. Major highways, arterial roads and coal mine product transportation routes were included in the calculation of emissions. Daily traffic volume were resourced from the public domain, principally through traffic impact assessments, NSW Roads and Maritime Services traffic count data and council traffic counts. A 0% road grade was assumed across the study area, while travel speeds were selected by signed road travel speeds.

The estimated emissions from road transportation are summarised in **Table 6-18**.

Table 6-18: Summary of estimated emissions for on-road

Source	Estimated emissions (kg/annum)			
	2013		2021	
	PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$
On-road mobile	40,367	29,930	21,629	16,037

6.8 Summary of estimated PM emissions

A summary of the estimated annual emissions for the key sources included in the modelling is presented in **Table 6-19**. The percentage contribution of each source is shown in **Figure 6-9**. The spatial allocation of emissions from all sources is presented in **Appendix 6**.

Table 6-19: Summary of estimated emissions for key sources

Source	Estimated emissions (tonnes/annum)			
	2013		2021	
	PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$
Coal mines	3,481	429	13,372	1,755
Non road diesel (coal mines)	173	168	944	916
Wood heaters	96	93	92	89
On road mobile	40	30	22	16
Rail transportation	48	45	127	117
Industry	199	26	243	32
Agriculture	540	94	540	94
Unsealed roads	24	4	24	4

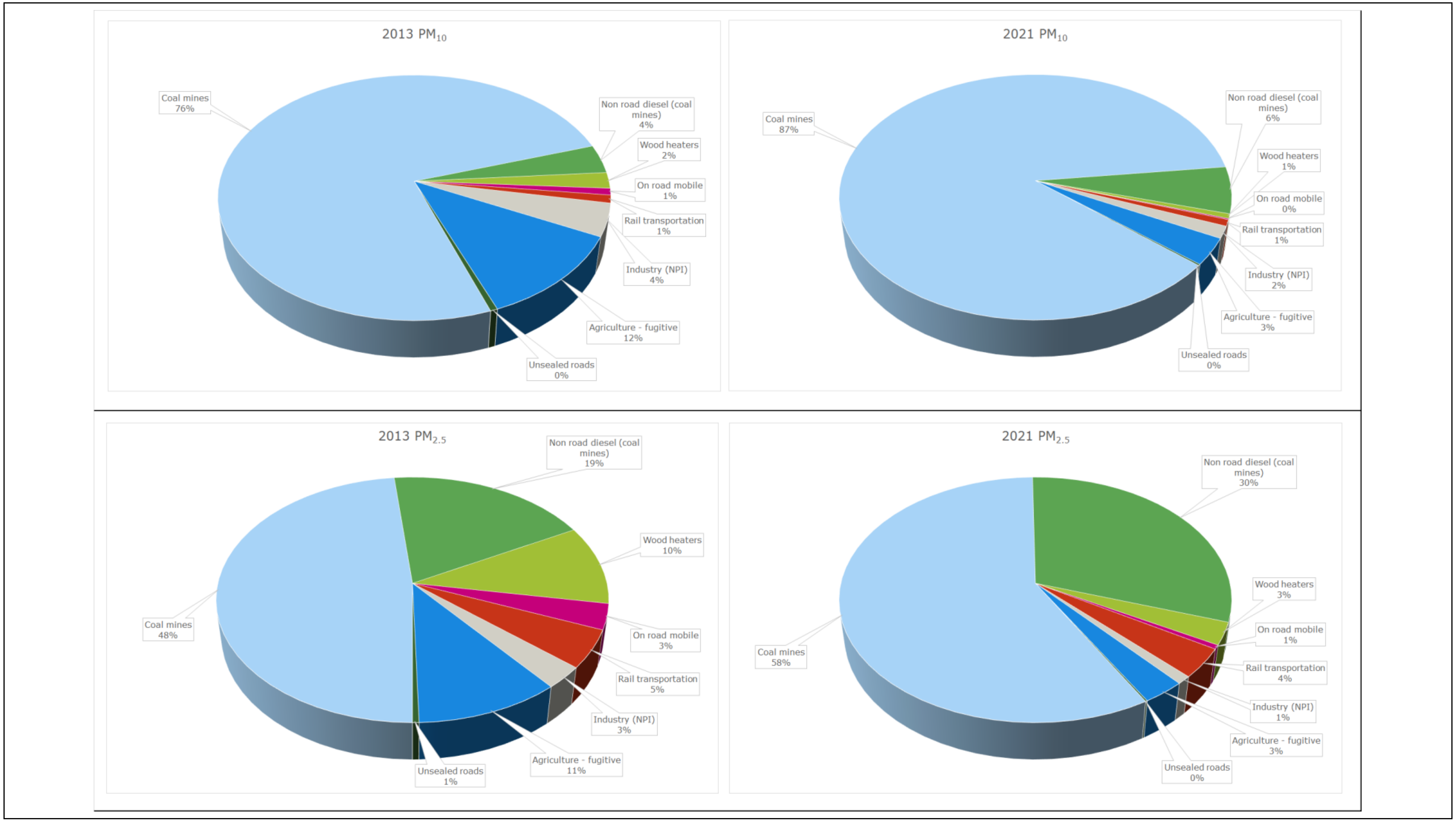


Figure 6-9: Summary of estimated annual emissions by source

7. INVENTORY OF GASEOUS EMISSION FROM INDUSTRY

The scope of work for the study requires development of an emissions inventory of gaseous pollutants for industrial and mining sources in the region. It is noted that these gaseous emissions are not included in the modelling.

The pollutants to be included are sulphur dioxide (SO_2), oxides of nitrogen (NO_x), carbon monoxide (CO) and total volatile organic compounds (VOCs) and the following activities / sources have been inventoried:

- Coal mines - diesel combustion and blasting.
- Coal transportation - diesel locomotives.
- Quarrying - diesel combustion.
- Cotton ginning - gas combustion.
- All other NPI facilities – coal/diesel/gas combustion.

7.1 Coal mines

Emissions for operating coal mines are presented using two methodologies. Coal mines are required to report their annual emissions under the National Environment Protection (National Pollutant Inventory) Measure (NPI NEPM). Reported emissions for the 2012/2013 are summarised in **Table 7-1**.

Table 7-1: Reported NPI emissions for operating coal mines

Facility	Estimated emissions (kg/annum)			
	NO_x	CO	SO_2	VOCs
Narrabri coal mine	82,000	25,000	35	6,100
Tarrawonga coal mine	390,000	160,000	260	28,000
Rocglen coal mine	190,000	73,000	110	14,000
Werris Creek coal mine	330,000	130,000	200	25,000
Boggabri coal mine	730,000	320,000	470	65,000
Gunnedah CHPP	27,000	9,600	17	2,400

Emissions are also inventoried for existing and proposed coal mines based on the actual (2013) and projected (2021) diesel consumption (derived in **Section 6.3**). Site specific emission factors for each mining fleet were not available, therefore emission estimates are presented based on the US EPA Tier 0 emission factors (kg/kL) presented in NSW EPA (2012c).

The fuel consumption based emission estimates presented in **Table 7-2**. It is noted that the site specific emission factors used for estimates of PM_{10} and $PM_{2.5}$ (**Section 6.3**) indicate that the fleet average emission performance for existing mines is closer to US EPA Tier 1, therefore the use of Tier 0 emission factors provides a conservative estimate of emissions for existing and especially the proposed coal mines. This this explain why these fuel based emissions estimates are significantly higher than the reported NPI emissions.

Table 7-2: Estimated gaseous emissions from coal mines based on fuel consumption

Facility	Estimated emissions (kg/annum)							
	NO_x		CO		SO_2		VOCs	
	2013	2021	2013	2021	2013	2021	2013	2021
Narrabri coal mine	55,193	81,910	31,489	46,731	112	167	5,415	8,036
Tarrawonga coal mine	682,453	987,606	389,351	563,447	1,389	2,011	66,956	96,895
Maules Creek Coal Mine	-	4,958,781	-	2,829,072	-	10,095	-	486,513
Rocglen coal mine	347,092	-	198,022	-	707	-	34,054	-
Werris Creek coal mine	720,277	961,746	410,931	548,693	1,466	1,958	70,667	94,358
Vickery Extension Project	-	2,672,082	-	1,540,470	-	5,440	-	262,908
Boggabri coal mine	1,549,821	2,975,269	884,200	1,697,443	3,155	6,057	152,055	291,908
Watermark Coal Project	-	3,814,447	-	2,176,209	-	7,765	-	374,241
Gunnedah CHPP	30,063	30,716	17,151	17,524	61	63	2,950	3,014

7.1.1 Emissions from blasting

Emissions from blasting are estimated using the NPI emission factors for explosive detonation (ANFO, mixed on site), expressed in kg per tonne of explosive used. Emissions of NO_x, CO and SO_2 are estimated for 2013 based on explosive usage reported in AEMRs for the 2012/2013 or 2013/2014 period. To estimate projected explosive usage for 2021, an intensity factor is derived, based on existing explosive usage and production statistics in the AEMRs for Boggabri, Tarrawonga and Werris Creek. The quantity of explosive reported varies from 0.2 to 0.7 kg per m^3 of waste rock, with an average of 0.5 kg/m^3 across the three sites.

An estimate of the explosive usage for 2021 is derived by multiplying this average usage factor by the projected waste volumes reported in each of the mine site's EA. The estimated emissions from blasting are presented in **Table 7-3**.

Table 7-3: Estimated gaseous emissions from blasting at open cut coal mines

Facility	Estimated emissions (kg/annum)							
	NO_x		CO		SO_2		VOCs	
	2013	2021	2013	2021	2013	2021	2013	2021
Tarrawonga Coal Mine	82	144	349	611	0.6	1.1	-	-
Maules Creek Coal Mine	-	324		1,376		2.4	-	-
Rocglen Coal Mine	16	-	67	-	0.1	-	-	-
Werris Creek Coal Mine	77	53	328	227	0.6	0.4	-	-
Vickery Extension Project	-	414	-	1,760	-	3.1	-	-
Boggabri Coal Mine	262	196	1,115	835	2.0	1.5	-	-
Watermark Coal Project	-	129	-	579	-	1.0	-	-

7.2 Coal transportation

Similar to approach for PM emissions, gaseous pollutants from coal transportation are estimated using US EPA diesel locomotive emission factors and fuel consumption. US EPA emission factors, expressed in g/kW-hr (grams of pollutant emissions per kilowatt-hour), were converted to g/litre (grams of pollutant per litre of fuel combusted) and adjusted for local sulfur content of automotive diesel oil (ADO) (ENVIRON, 2013). The emissions performance is assumed to be Pre Tier 0 and fuel consumption is estimated based on gross tonne kilometres (GTK) and the average fuel consumption rate of 4.03 L/kt-km.

The total emissions for coal transportation, from Narrabri to Scone, is presented in **Table 7-4**.

Table 7-4: Estimated gaseous emissions from coal transportation

Facility	Estimated emissions (kg/annum)							
	NO_x		CO		SO_2		VOCs	
	2013	2021	2013	2021	2013	2021	2013	2021
Coal transportation (Narrabri to Scone)	999,088	3,645,169	98,590	359,707	230	840	103,816	378,771

7.3 Cotton gins

LPG fuel consumption for cotton gins in Australia ranges from 2 to 6 litres per bale (Ismail, 2009). For this assessment an average of 4 litres per bale is assumed. As previously presented, Cotton Australia (2013) reports a production total of 602,750 bales for 2013/2014 for the Namoi district, which is used to estimate the annual fuel consumption for the region (2,411 kL).

Emissions from LPG combustion for cotton gins are estimated using the NPI emission factors for Combustion in Boilers (LPG Propane), expressed as kg/kL and the aggregated emissions for cotton gins in 2013/2014 are presented in **Table 7-5**. A robust methodology for forecasting cotton production for 2021 could not be found, therefore emissions are assumed to remain constant.

Table 7-5: Estimated emissions for cotton gins				
Facility	**Estimated emissions (kg/annum)**			
	NO_x	**CO**	**SO_2**	**VOCs**
All cotton gins	5,545	916	504	74

7.4 Quarries and land based extraction

Only three of the quarries in the study area are required to report emissions under the NPI. Therefore, emissions estimates are presented based on a derived fuel consumption. A review of publically available greenhouse gas assessment for three hard rock quarries and two sand quarries indicates that diesel consumption ranges from 0.0013 kl/tonne to 0.0016 kl/tonne (average of 0.0014 kl/tonne). This average diesel intensity factor is used in combination with the approved production rates for existing quarries to derived annual fuel consumption.

Emissions are estimated using US EPA Tier 0 emission factors (kg/kL) presented in NSW EPA (2012c) and summarised in **Table 7-6**.

Table 7-6: Estimated gaseous emissions for quarries and land based extraction								
Facility	**Estimated emissions (kg/annum)**							
	NO_x		**CO**		**SO_2**		**VOCs**	
	2013	**2021**	**2013**	**2021**	**2013**	**2021**	**2013**	**2021**
Ardglen Quarry	-	28,164	-	16,068	-	57	-	2,763
Willow Tree Gravels	11,265	11,265	6,427	6,427	23	23	1,105	1,105
Boral Resources-Currabubula	11,265	11,265	6,427	6,427	23	23	1,105	1,105
Zeolite Australia	1,690	1,690	964	964	3	3	166	166
Castle Mountain Zeolite Quarry	1,690	1,690	964	964	3	3	166	166
Warrah Ridge Quarry	5,633	5,633	3,214	3,214	11	11	553	553
Gunnedah Quarry Products Marys Mount Quarry	2,816	20,278	1,607	11,569	6	41	276	1,989
Boral Resources Narrabri Quarry	5,633	5,633	3,214	3,214	11	11	553	553
Johnstone Concrete and Landscape Supplies	1,690	11,265	964	6,427	3	23	166	1,105
Pinebark Quarry (G&S Lein Earthmoving)	2,816	2,816	1,607	1,607	6	6	276	276
Forest View Quarry (Boggabri Coal)	11,265	-	6,427	-	23	-	1,105	0

7.5 Other NPI facilities

Emissions estimates for all other facilities are presented based on the annual emissions for the NPI reporting year 2012/2013. A robust methodology for forecasting emissions for 2021 could not be found, therefore emissions are assumed to remain constant.

Table 7-7: Reported NPI emissions for all other facilities

Facility	Estimated emissions (kg/annum)			
	NO_x	CO	SO_2	VOCs
Killara Feedlot	1,200	290	8.2	12
Caroona Feedlot	3,100	3,800	19	300
Narrabri CSG Project	2,500	13,000	84	25,000
Willga Park Power Station	12,000	8,100	11	1,700
Cargill Processing Narrabri	41,000	32,000	80,000	750
Lowes Petroleum Narrabri Depot	-	-	-	1,300
Bowland Petroleum Narrabri Depot	-	-	-	1,200
Gunnedah Depot	-	-	-	5,900

7.6 Summary of estimated emissions

A summary of the estimated annual gaseous emissions by source is presented in **Table 7-8**.

Table 7-8: Summary of estimated gaseous emissions

Facility	Estimated emissions (tonnes/annum)							
	NO_x		CO		SO_2		VOCs	
	2013	2021	2013	2021	2013	2021	2013	2021
Coal mine diesel	3,385	18,066	1,931	10,307	7	37	332	1,773
Coal mine blasting	0.4	1.3	1.9	5.4	0.003	0.01	-	-
Coal transportation	999	3,645	99	360	0.2	0.8	104	379
Cotton gins	6	-	0.9	-	0.5	-	0.1	-
Quarries	56	100	32	57	0.1	0.2	5	10
Other NPI facilities	60	-	57	-	80	-	36	-

8. OVERVIEW OF SOURCE APPORTIONMENT MODELLING

Source apportionment modelling is used to quantify the contribution of each source group to annual average ambient PM_{10} and $PM_{2.5}$ concentrations in the major population centres of the study area. Each major source group is modelled separately and the individual contribution to total ground level concentrations is presented in **Section 9.3**. The following sections provide the technical details on model configuration.

Similar modelling was performed for the Upper Hunter (Upper Hunter Particle Model [Kellaghan et al, 2014]) and some of the outcomes from sensitivity analysis presented in that study are adopted in the technical descriptions below.

A key component of the study is to evaluate the performance of the model for base year emissions (2013), to provide confidence in the projected source contributions. The performance of the model is evaluated in **Section 9** by comparing model predictions with monitoring data for 2013, collected from industry operated monitoring sites. However, not every source of PM_{10} and $PM_{2.5}$ are modelled and therefore a direct comparison between modelled and measured PM cannot be made. For example, regionally transported PM from outside the modelling domain and secondary PM are not modelled but are, depending on the instrument, measured at the monitoring sites. Accounting for the non-modelled component is described further in **Section 8.8**.

8.1 Coal mines

Activities at each individual mine are represented as a series of volume sources spaced at 500m intervals within the boundary or extent of mining operations.

For modelling volume sources, estimates of horizontal spread (initial sigma y (σy)) and vertical spread (initial sigma z (σz)) need to be assigned. Values for σy are assigned based on source separation divided by 4.3. The approach aims to smear the total emissions, by source category (refer **Section 6.2.2**), across the nominated number of volume sources and assumes that emissions from various types of mining equipment are released from each volume source location. For example, a volume source located in the pit may include emissions from a dozer, an excavator loading trucks, hauling and wind erosion.

The vertical spread (initial sigma z (σz)) was chosen based on recommendations made in the US EPA Haul Road Workgroup (US EPA, 2012) as follows.

- Vertical spread calculated as plume height divided by 2.15.
- Plume height was determined based on vehicle height times 1.7.
- Vertical spread was calculated to be 4.7 based on a vehicle height of 6 m and assumed for all mining equipment.

Modelling will be completed for two size fractions, fine and coarse. Fine particles will be modelled using $PM_{2.5}$ emissions rates with a particle geometric mean diameter of 1.5 µm. The coarse fraction will be modelled using $PM_{2.5-10}$ emission rates (PM_{10} emissions minus $PM_{2.5}$ emissions) with a particle geometric mean diameter of 5.94 µm.

The particle mass mean diameters were determined from particle size distribution data for various coal mining activities (presented in SPCC (1986)).

8.2 Off-road diesel

Emissions from off-road diesel have been inventoried for coal mines only. The estimated coal mine diesel emissions are represented as volume sources and spatially distributed across the same source locations used to represent the coal mine fugitive emissions and modelled in the same way.

A particle geometric mean diameter of 1 µm is chosen for both PM_{10} and $PM_{2.5}$ (on the basis that US EPA AP-42 for Industrial Diesel Engines indicates all PM is sub 2.5 µm).

8.3 Wood heaters

Wood heater emissions are represented as volume sources with emissions assigned to urban centre boundaries defined by the ABS. The initial plume horizontal spread (σy) is assigned a value based on resolution (source spacing divided by 4.3). This essentially spreads the wood heater emissions for each 2 km x 2 km grid cell across a Gaussian distribution with initial spread defined by 465 m in the horizontal.

The US EPA AP-42 chapter for Residential Wood Stoves (US EPA, 1996) notes that 95% of the particles emitted from a wood stove are less than 0.4 microns in size, although the background documentation notes that the size distribution of wood smoke aerosol are dependent on burning conditions, fuel type and stove type. For cool burning stoves, for example, up to 50% of measured particles were in the range 0.6 – 1.2 microns (Rau, 1989). In the absence of size distribution data for Australian wood heaters, a particle geometric mean diameter of 1 μm is chosen for both PM_{10} and $PM_{2.5}$ from this source.

8.4 Transport emission - road

Road emissions were allocated as a series of line volume sources, allocated along the major highway, arterial roads and coal product transportation routes in the region.

For model source configuration, the US EPA guidance for modelling vehicle movements using line volume sources was adopted where possible. In order to balance between model limits, model run time and an even distribution of emissions and dispersion, a source side length of 500m was selected. Emission source release height and vertical dimension were configured based on the US EPA guidance for mobile sources.

For exhaust emissions, a particle geometric mean diameter of 1 μm were chosen for both PM_{10} and $PM_{2.5}$.

8.5 Transport emissions -rail

Rail emissions were be modelled by allocating volume sources along the Main Northern Railway between the Narrabri Coal mine and Scone. Emission sources were configured in the same way as roadway sources (**Section 8.5**). A particle geometric mean diameter of 1 μwas chosen for both PM_{10} and $PM_{2.5}$.

8.6 Other industry

Emissions from other industries (quarries, cotton gins, stockyards, etc) were be represented volume sources located at the site of each individual operation. The particle size distribution applied for coal mining emission sources was adopted for the release of industrial emissions.

8.7 Agriculture

Agricultural emissions were represented in the modelling using a grid of volume sources, located based on the CLUM GIS data for dryland cropping and irrigated cropping areas of each LGA. In order to balance model run time and ensure an even distribution of emissions, a 5 km grid resolution was selected with and initial plume horizontal spread (σy) assigned based on resolution (source spacing divided by 4.3). This essentially spreads the emissions for each 5 km x 5 km grid cell across a Gaussian distribution with initial spread defined by 1,163 m in the horizontal.

The Upper Hunter Particle Model (Kellaghan et al, 2014) tested the sensitivity of source configuration in modelling large area based emissions sources, using either a volume source or an area source configuration. The sensitivity analysis found that volume source configuration predicted higher concentrations and improvements in model evaluation occurred when a volume source configuration was used in lieu of an area source configuration.

8.8 Accounting for non-modelled sources

The sources modelled in this study include primary anthropogenic PM only and emission sources located within the geographical boundaries of the study area (most of the Narrabri, Gunnedah and Liverpool Plains LGAs).

However, the monitoring data presented in **Section 3** includes, depending on the instrument, both primary and secondary, natural and anthropogenic, local and regionally transported PM[13].

To evaluate model performance against the monitoring data, it is important to account for these 'non-modelled' components, by either subtracting from the monitoring data or adding to the modelling results.

Only measurements made at TEOM sites equipped with the Filter Dynamic Measurement System (FDMS) were used in the model evaluation (Vickery (Wil-gai), Werris Creek Town, Maules Creek (Fairfax School), Caroona and Watermark). These are the only sites which measure both PM_{10} and $PM_{2.5}$ and also, unlike the conventional TEOM, the TEOM-FDMS is assumed to measure the semi-volatile component of PM, and therefore report total PM mass (**Grover *et al.*, 2005**).

The components of PM that are assumed to be present in the monitoring data, but not modelled are:

- Regionally transported fugitive PM, from natural sources.
- Regionally transported marine aerosol and aged marine aerosol.
- Regionally transported secondary PM (sulphates and nitrates).
- Bushfires and other biomass smoke.
- Minor sources of local primary natural and anthropogenic PM.

These non-modelled components of PM can make up a significant percentage of total measured PM mass. Chan et al (2008) found that marine aerosol and secondary sulphates/nitrates alone make up 45% and 57% of the fine ($PM_{2.5}$) and coarse ($PM_{2.5-10}$) fractions in urban areas of Australia. A study by CSIRO (Cope, 2012) estimated that the primary PM component (i.e. what we modelled in this study) constitutes just 30% of the total $PM_{2.5}$ mass in summer and 50% in winter for the Sydney area.

To account for the non-modelled PM component, information on particle composition is needed. The closest available PM composition / characterisation data were collected as part of the Upper Hunter Fine Particle Characterisation Study (UHPCS) (Hibberd et al, 2013). The study reports chemical composition of $PM_{2.5}$ mass for Singleton and Muswellbrook and identifies a number of "factors", using positive matrix factorisation techniques (PMF), to describe each component of $PM_{2.5}$ mass.

In the absence of particle composition data specific to the Namoi region, Muswellbrook data are used to identify the contribution that each factor makes to the total $PM_{2.5}$ mass. A discussion of the uncertainty associated with using these data is provided in **Section 9.3**.

Table 8-1 identifies which components of the Muswellbrook 'factors' were modelled in this study. It is noted that only local anthropogenic sources of PM are modelled and therefore regionally transported PM from distant sources is not accounted for in this analysis. This is discussed further in the base year model evaluation presented in **Section 9**.

[13] This can be instrument specific, for example Beta Attenuation Monitors (BAM) measure secondary aerosol, but conventional TEOMs may not. TEOM sites equipped with the Filter Dynamic Measurement System (FDMS) are assumed to measure the semi-volatile component of PM.

Table 8-1: Factor analysis for UHPCS and estimated modelled and non modelled components

$PM_{2.5}$ Factor	Component modelled?	Measured by TEOM FDMS?
Wood smoke	Yes	Yes
Vehicle/ Industry	Yes	Yes
Soil	Yes	Yes
Secondary sulfate	No	Yes
Biomass smoke	No	Yes
Industry aged sea salt	No	Yes
Sea salt	No	Yes
Secondary nitrate	No	Yes

The monthly measured $PM_{2.5}$ mass by factor and the combined $PM_{2.5}$ mass (µg/m³) are presented in **Table 8-2**. The percentage contribution of the assumed 'non-modelled' component of $PM_{2.5}$ (factors identified in **Table 8-1**) is also presented.

These percentages are used to scale the Namoi region TEOM-FDMS monitoring data to estimate the 'non-modelled' component, which is then added to the modelling results for model evaluation.

The data are also expressed monthly to account for seasonal variation. For example the percentage contribution of non-modelled $PM_{2.5}$ is high in summer, due to the dominance of secondary sulphate and industry aged sea salt (which is not modelled) and significantly lower in winter months, due to the dominant of wood smoke (which is modelled).

The UHPCS does not include particle characterisation data for PM_{10} and therefore an estimate of PM_{10} composition is made based on the average contribution that marine aerosol and secondary sulphates and nitrates make to total mass of fine and coarse aerosol in Australian cities (Chan et al., 2008). For biomass smoke, it is assumed that it is all $PM_{2.5}$.

Table 8-2: Factor analysis for UHPCS and estimated percentage contribution of non modelled $PM_{2.5}$ to total $PM_{2.5}$ mass

	PM2.5 mass (μg/m³) based on UHPCS Muswellbrook data									Percentage contribution of non-modelled $PM_{2.5}$ to total $PM_{2.5}$
	Wood smoke	Vehicle/ Industry	Secondary sulfate	Biomass Smoke	Industry aged sea salt[14]	Soil	Sea salt	Secondary nitrate	Sum of factor contributions	
Jan	0.0	0.2	1.2	0.6	2.0	0.8	0.3	0.3	5.5	82.4%
Feb	0.0	0.4	3.0	0.5	1.1	0.9	0.1	0.1	6.1	78.9%
Mar	0.0	0.4	1.6	0.6	1.2	0.8	0.1	0.1	4.9	80.0%
Apr	0.6	0.9	2.1	0.7	0.7	1.2	0.1	0.4	6.7	60.3%
May	6.6	1.2	1.2	0.9	0.4	1.3	0.1	0.6	12.1	26.2%
Jun	6.3	0.8	1.1	0.3	0.2	0.8	0.1	0.7	10.3	23.1%
Jul	9.1	1.0	0.6	0.4	0.1	1.0	0.2	0.8	13.3	15.7%
Aug	6.4	1.0	0.5	1.4	0.4	0.6	0.4	0.8	11.4	29.5%
Sep	1.1	0.9	0.9	1.9	1.0	0.8	0.2	0.5	7.4	59.5%
Oct	0.3	0.4	1.3	1.2	1.6	0.7	0.6	0.6	6.7	79.8%
Nov	0.0	0.3	1.7	1.3	1.3	0.6	0.7	0.5	6.4	89.0%
Dec	0.1	0.2	1.6	1.3	2.1	0.6	0.4	0.3	6.6	90.6%

[14] Industry aged sea salt is sea salt which has, over time, displaced the chloride ion molecule with SO_4 from industry sources

9. BASE YEAR MODEL EVALUATION

9.1 Introduction

Model evaluation is presented to determine if the air quality model is acceptable as a means to inform the future year air quality projections, source contribution and suitable locations for monitoring stations. Model evaluation focuses on the industry operated TEOM-FDMS sites, because they measure both PM_{10} and $PM_{2.5}$ and they are assumed to measure total PM mass (as discussed in **Section 8.8**).

Of the five TEOM-FDMS sites, only Vickery and Werris Creek have a complete year of data for 2013. At all of the other sites, monitoring data are available for approximately half of the year.

It is also noted that raw data was received from industry and preliminary evaluation was performed on the data prior to model evaluation. For example, all hours with negative hourly averaged PM_{10} or $PM_{2.5}$ data or significant outliers (greater than 350 µg/m³) were removed. Hours where the ratio of $PM_{2.5}/PM_{10}$ ratio was greater than 1 were removed. Therefore the annual averages presented in this report may differ from annual averages reported elsewhere.

As discussed previously, to evaluate model performance against the monitoring data, it is important to account for the 'non-modelled' components of PM_{10} and $PM_{2.5}$. The estimated percentage of non-modelled PM to total PM (based on Muswellbrook PM characterisation data) is applied to the monitoring data at each site to estimate this component.

For example, the derived contribution from non-modelled sources at Vickery is 55% of the total measured PM_{10} and 65% of the total measured $PM_{2.5}$. For Werris Creek the derived contribution from non-modelled sources is 55% of the measured PM_{10} mass and 60% of the measured $PM_{2.5}$ mass.

These estimates appear to be consistent with the reported contribution of secondary PM in the literature (Chan et al, 2008; Cope, 2012) and similar in magnitude to the estimated secondary and natural PM derived for Singleton and Muswellbrook in the Upper Hunter Particle Model (Kellaghan et al, 2014).

The estimated 'non-modelled' PM_{10} and $PM_{2.5}$ for Vickery and Werris Creek are compared with the Upper Hunter Particle Model estimates in **Table 9-1**.

Table 9-1: Estimates of the 'non-modelled' components of PM_{10} and $PM_{2.5}$ and comparisons to the Upper Hunter Particle Model

	PM_{10}		$PM_{2.5}$	
	Non-modelled component mass (µg/m³)	% of total PM mass (µg/m³)	Non-modelled component mass (µg/m³)	% of total PM mass (µg/m³)
Estimated non-modelled PM (µg/m³) - Vickery (Wil-gai)	5.9	55%	3.3	65%
Estimated non-modelled PM (µg/m³) - Werris Creek Town	7.0	55%	4.6	60%
Estimated secondary and natural PM (µg/m³) - Muswellbrook	7.6	35%[1]	4.3	53%
Estimated secondary and natural PM (µg/m³) – Singleton	9.3	42%[1]	4.2	64%

Note: [1] estimated as a percentage of measured PM_{10} at the Muswellbrook OEH site, as opposed to $PM_{2.5}$ which is based on the UHPCS.

9.2 Model evaluation

The observed and predicted annual average PM_{10} and $PM_{2.5}$ at are presented in **Table 9-2** and **Table 9-3**. It is noted that only Vickery and Werris Creek have a complete year of data for 2013 and the comparison for other sites is based on approximately 6 months of data.

At most sites, the predicted PM_{10} and $PM_{2.5}$ concentrations are approximately 30% to 40% lower than observed. The exception is Vickery, where the predicted PM_{10} is close to the observed and the predicted $PM_{2.5}$ is approximately 10% lower than observed.

As discussed previously, while we assume that certain components of PM have been modelled (for example the 'soil' factor), this in only true for local sources of PM. The modelling (or estimates of non-modelled components) does not necessarily account for regionally transported PM. In the Upper Hunter Particle Model, for example, an additional annual average of 1 µg/m³ to 4 µg/m³ of PM_{10} and 1 µg/m³ to 2 µg/m³ of $PM_{2.5}$ is added to the modelling results to account for a regional boundary flux, flowing into the modelling domain.

There are insufficient monitoring sites at the boundary of the modelling domain for this study to adopt a similar approach and therefore an alternative approach to assigning background is discussed in **Section 10.1**.

Table 9-2: Observed and predicted annual average PM_{10} (µg/m³)

Site	Observed	Modelled sources	Non-modelled sources	Total predicted	Predicted / observed (%)
Vickery (Wil-gai)	10.7	5.1	5.9	10.9	101%
Werris Creek Town	12.8	1.7	7.0	8.7	68%
Maules Creek	8.7	0.8	4.7	5.6	64%
Caroona	12.4	0.4	6.7	7.1	57%
Watermark	11.2	0.2	7.5	7.5	67%

Table 9-3: Observed and predicted annual average $PM_{2.5}$ (µg/m³)

Site	Observed	Modelled sources	Non-modelled sources	Total predicted	Predicted / observed (%)
Vickery (Wil-gai)	5.0	1.2	3.3	4.5	89%
Werris Creek Town	7.5	0.8	4.6	5.4	71%
Maules Creek	4.5	0.3	3.1	3.4	75%
Caroona	6.6	0.2	4.3	4.6	70%
Watermark	5.3	0.1	3.5	3.6	68%

Additional statistic evaluation if presented for Vickery and Werris Creek, which have a complete year of data for 2013. Scatter plots and percentile plots of paired observed and predicted 24-hour average PM_{10} and $PM_{2.5}$ concentrations provide a useful evaluation of model performance and are presented in **Figure 9-1** to **Figure 9-4**.

The scatter plots indicate that the majority of model predictions fall within a factor of 2 of the observations (the so called FAC2 test), shown by the dashed lines either side of the line of perfect fit.

The percentile plots indicate a general over prediction at Vickery for low PM_{10} concentrations (above the dashed line) and general under prediction for higher PM_{10} concentrations. $PM_{2.5}$ at Vickery demonstrates a general under prediction. At Werris Creek there is a more pronounced under prediction (below the dashed line).

It is noted that an under or over prediction may be a result of the modelling, the estimated non-modelled component or could even be an artefact of the monitoring data.

Statistical measures for FAC2 and model bias (normalised mean bias (NMB)) are presented in **Table 9-4**. Similar to what is observed in the scatter plots, FAC2 is greater than 0.5 for all sites and size metrics. Model bias is low for Vickery for both size metrics but Werris Creek does not meet the performance benchmark for NMB. As discussed above and evident in the percentile plots, bias is negative for Werris Creek, indicating an under prediction at this site.

Table 9-4: Statistical evaluation of model predictions

Test	Benchmark	Vickery		Werris Creek	
		PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$
FAC2	≥ 0.5	0.9	0.9	0.9	0.7
Normalised Mean bias (NMB)	≤± 0.2	0.0	-0.1	-0.3	-0.3

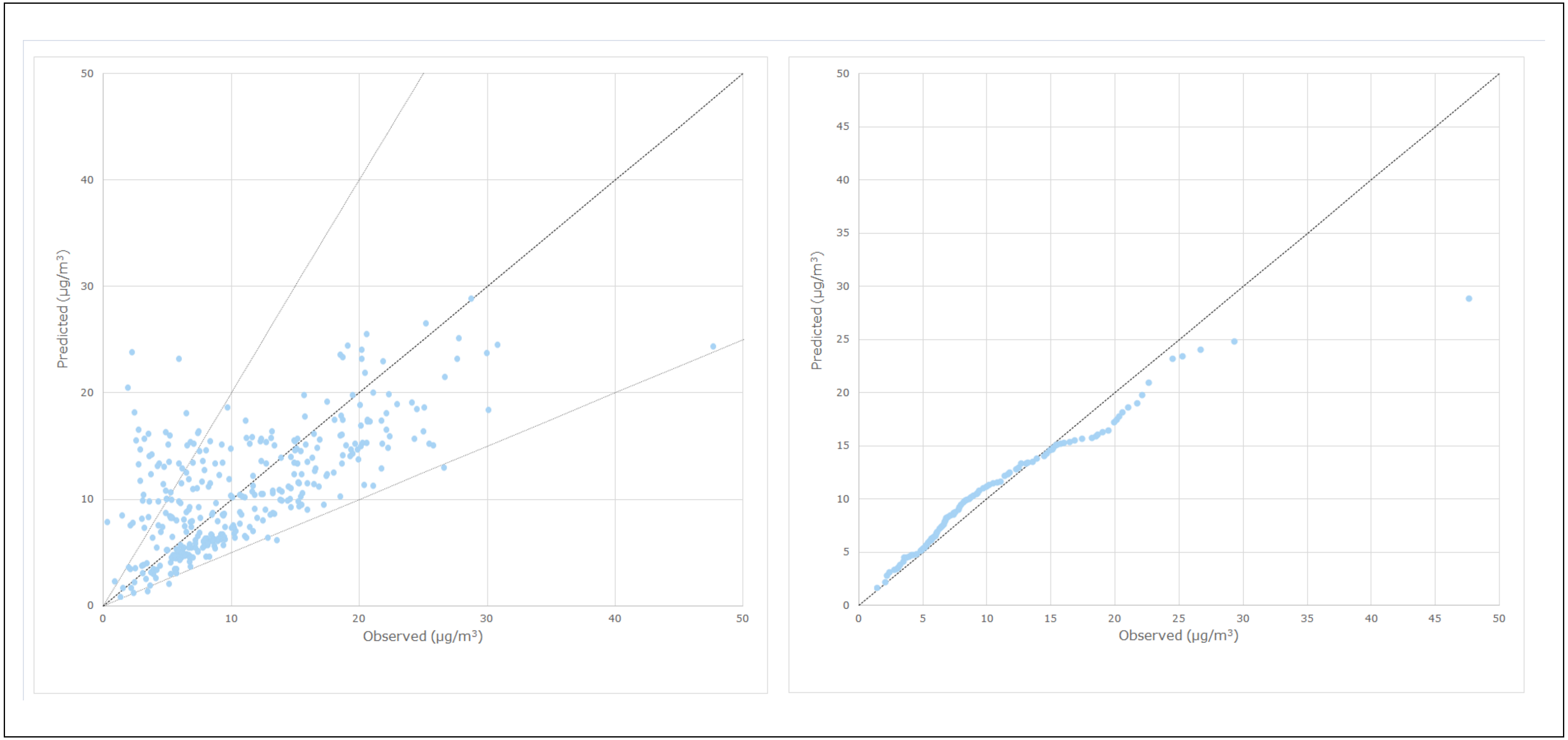


Figure 9-1: Scatter and percentile plots of observed and predicted PM_{10} for Vickery

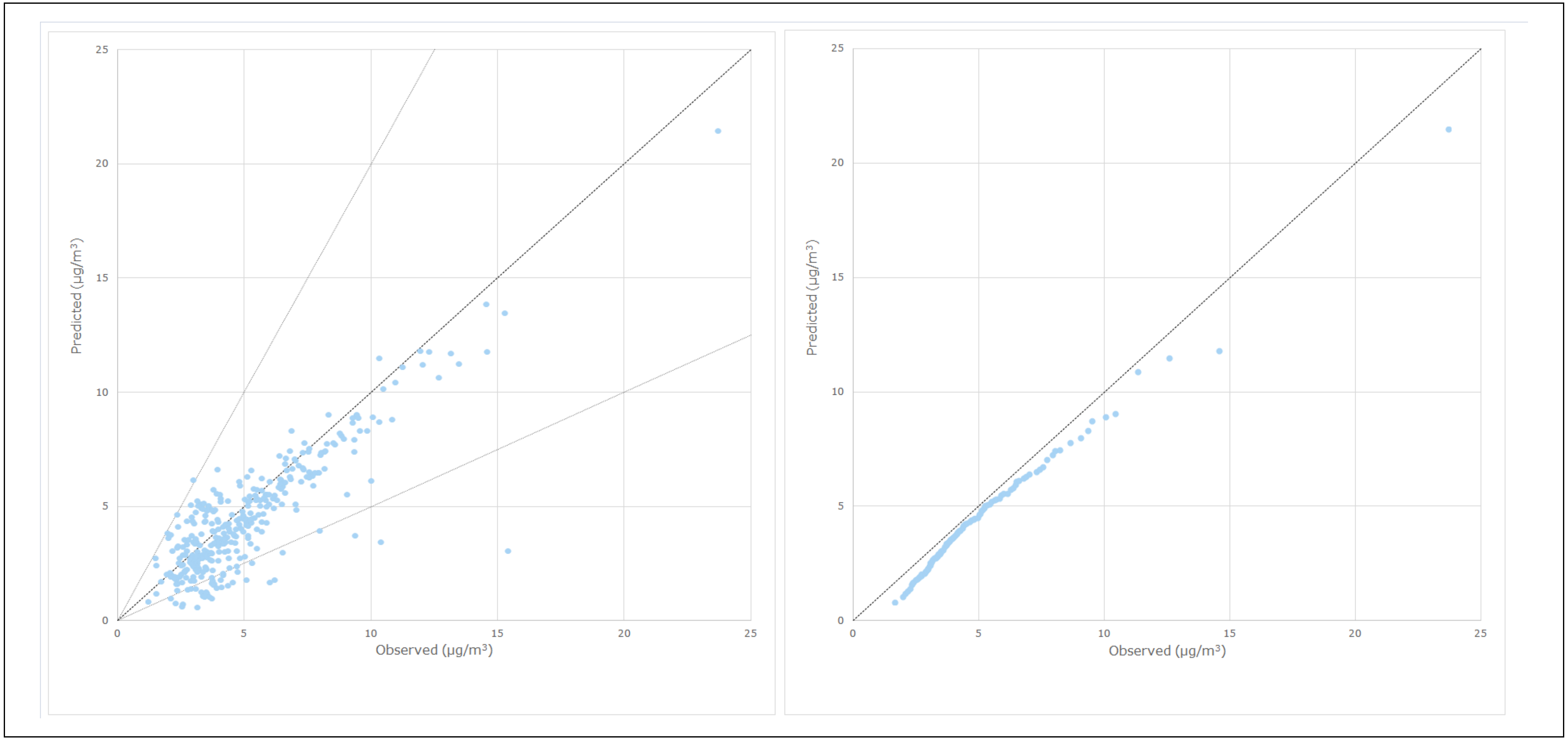


Figure 9-2: Scatter and percentile plots of observed and predicted $PM_{2.5}$ for Vickery

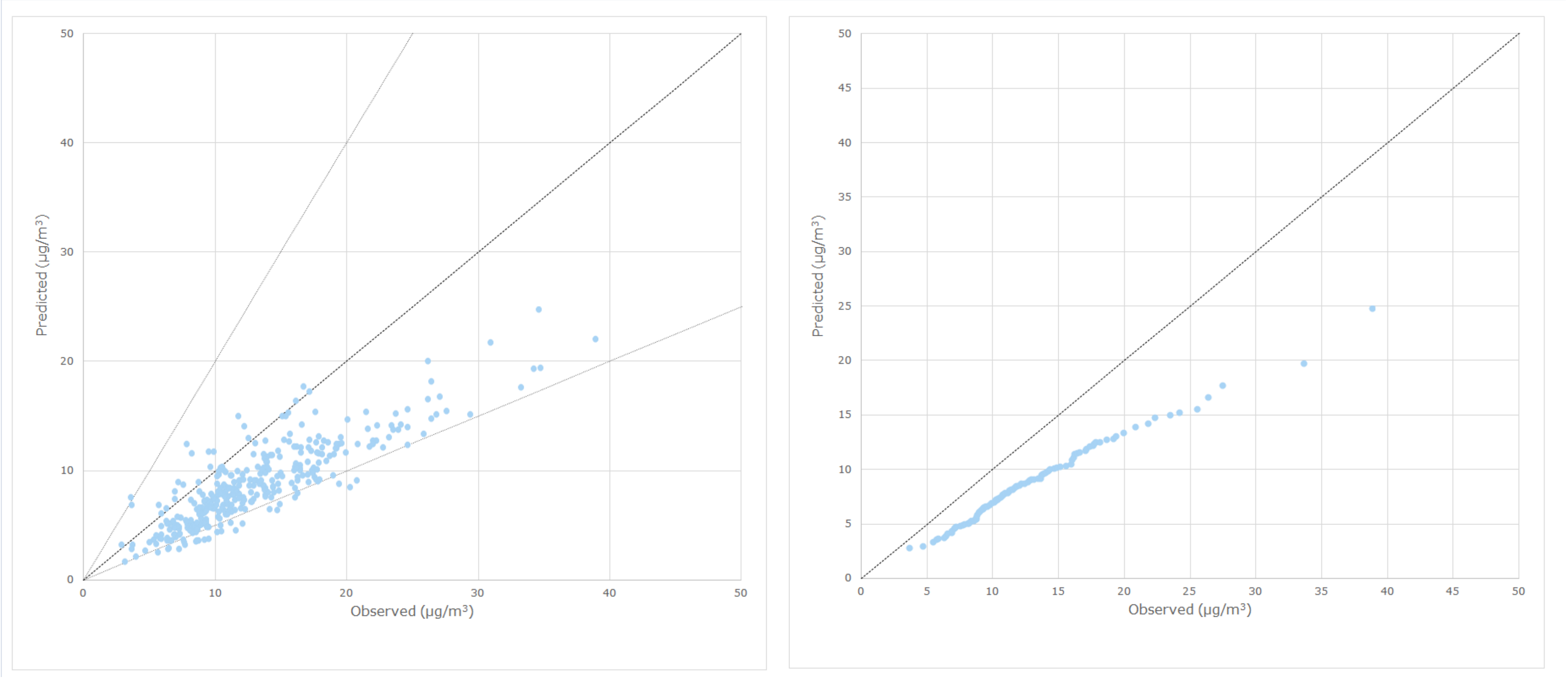


Figure 9-3: Scatter and percentile plots of observed and predicted PM_{10} for Werris Creek

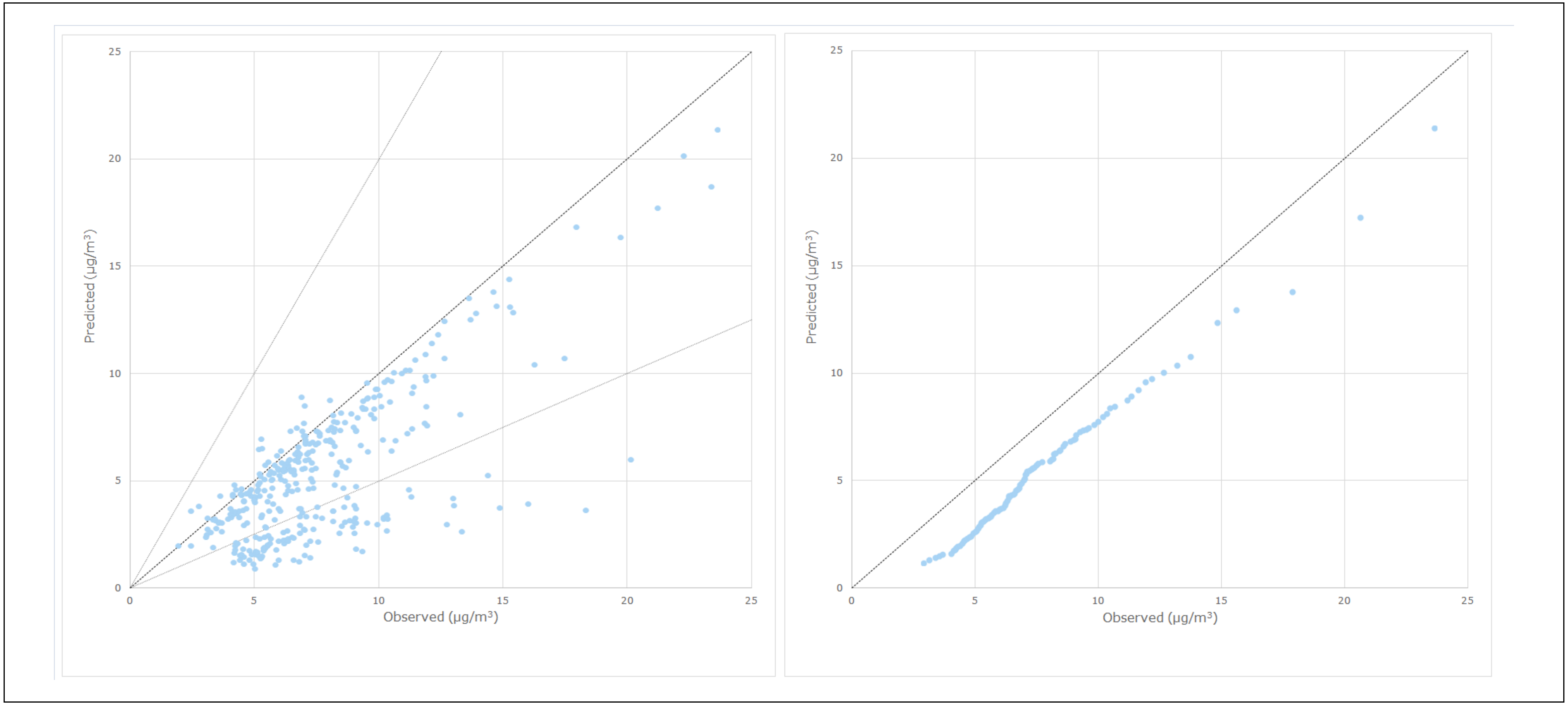


Figure 9-4: Scatter and percentile plots of observed and predicted $PM_{2.5}$ for Werris Creek

9.3 Uncertainty

In evaluating and considering model performance, it is important to understand that the predictions presented have an inherent uncertainty, both in the modelling predictions and the estimate of the non-modelled component (secondary PM and other natural and anthropogenic sources).

Uncertainty in the dispersion model predictions can result from emission estimates, meteorological inputs, source characterisation and model formulation. Leaving aside data input errors, model uncertainty has been reported to result in up to 50% error in predicted ground level concentrations in flat terrain, while uncertainty in the measured wind direction of 5 to 10 degrees can result in predicted ground-level concentration errors of 20% to 70% for a particular time and location (US EPA, 2005; Pasquill, 1974).

There is also a degree of uncertainty in the measured PM_{10} and $PM_{2.5}$ data. Uncertainties in measurement data (particularly for $PM_{2.5}$) make them far from ideal for comparison with models (AQEG, 2012). The difficulties in measuring $PM_{2.5}$ are reflected by the fact that measurement uncertainty, as required by the EU Air Quality Directive, is ± 25%, making it difficult to draw conclusions about small changes to predicted $PM_{2.5}$ concentrations (AQEG, 2012), as seen in this study.

The TEOM-FDMS used to measure $PM_{2.5}$ at the industry operated monitoring sites are complex technical instruments, requiring regular maintenance and calibration and extensive data ratification, including ratification of the base (non-volatile and) and reference (volatile) measurement channels (AQEG, 2012). Raw (unratified) measurement data was made available for this study however, in most cases, the base and reference measurement channels were not provided. Therefore, ratification of the monitoring data was not possible and only a simplified data validation process (removal of negatives, outliers) was performed. There is significant variation in the measured $PM_{2.5}$ concentrations across the four industry monitoring sites, however it is difficult to conclude whether this variation is real or an artefact of the measurement method.

There are also limitations in the approach to accounting for non-modelled PM, in that we have assumed that the percentage contribution of the various components of $PM_{2.5}$ mass at Muswellbrook are valid across the study area. The potential factors that might result in differences in PM characterisation at Muswellbrook are:

- Proximity to the coast – expected higher contribution from sea salt at Muswellbrook.
- Influence of local emissions – high density of wood heaters, intensity of mining and power stations in the Hunter Valley are expected to influence PM characterisation in Muswellbrook more so that the Namoi region.
- Topography - may act as a barrier to regional dispersion of emissions that influence the Muswellbrook monitoring site.

While the use of Muswelbrook data is recognised as a limitation, it is noted that long term ANSTO monitoring data indicates that generally, $PM_{2.5}$ characterisation displays similar patterns across different sites. Furthermore, in the absence of particle characterisation data for PM_{10} we are forced to use $PM_{2.5}$ characterisation data and estimate each component of PM_{10} based on a PM_{10}:$PM_{2.5}$ ratio reported for urban airsheds (Chan et al., 2008). Finally, it is not possible to disaggregate the 'soil' component in the UHPCS data from what we have modelled for fugitive dust.

9.4 Summary

As is evident from the potential uncertainty described above, it is difficult to provide a definitive indication of model performance based on the base year evaluation. However, the evaluation provides us with an opportunity to account for potential under-prediction at town centres, which can be addressed for future model predictions presented in **Section 9.3**.

10. AIR QUALITY PREDICTIONS

10.1 Introduction

The base year model evaluation suggests an under-estimation in PM_{10} and $PM_{2.5}$ concentrations by approximately 30% - 40% at most sites. The exception is Vickery which is more likely than other sites to be impacted by the anthropogenic emission sources included in the modelling (in this case coal mining). It is also a rural site and the focus of this study is on future air quality predictions for towns.

It is difficult to resolve the reasons for the model under-prediction, given the uncertainty described in **Section 9.3**. The model under prediction at Werris Creek (30%) corresponds to an annual average PM_{10} and $PM_{2.5}$ of 4.1 µg/m³ and 2.2 µg/m³ respectively. It is noted that these concentrations are similar in magnitude to the upper range of values for boundary flux added to the Upper Hunter Particle Model.

Combining the estimate of non-modelled source contribution with this under prediction gives a 'background' PM_{10} and $PM_{2.5}$ concentration of 11.1 µg/m³ and 6.8 µg/m³ respectively. On the surface, this 'background' contribution may appear high. However, analysis of monitoring data collected at the Caroona TEOM site supports these background values. The influence of the major anthropogenic sources that are modelled in this study are expected to contribute very little to the Caroona monitoring data in 2013 (there no major anthropogenic sources in the vicinity of this monitoring site[15]). The period averages for available PM_{10} and $PM_{2.5}$ data in 2013 are 12.4 µg/m³ and 6.6 µg/m³ respectively, similar in magnitude to the derived 'background' described above. Further discussion of the Caroona TEOM data is presented in **Appendix 7**.

In the absence of suitable PM_{10} and $PM_{2.5}$ monitoring data across all towns, a constant regional background is applied to all towns in inform the future air quality projections, based on the model evaluation for Werris Creek described above.

10.2 Predicted annual average PM concentrations in town centres

Adopting a constant value as regional background for the towns in the region, the modelled only and total predicted PM_{10} and $PM_{2.5}$ concentrations for the town centres, for 2013 and 2021 are presented in **Table 10-1**. The % increase from 2013 to 2021 is presented in **Table 10-2**. Two future scenarios are shown, with and without the Watermark Coal Project (WCP).

The modelled anthropogenic sources in 2021 contribute most to annual average PM_{10} in the town of Boggabri, followed by Werris Creek, Baan Baa and Curlewis. Modelled anthropogenic sources in 2021 contribute most to annual average $PM_{2.5}$ in the town of Boggabri followed by Quirindi, Gunnedah, Werris Creek and Narrabri. If the WCP is excluded from the 2021 scenario, the modelled anthropogenic source contribution is reduced at most towns but most significantly at Curlewis and Caroona.

The largest percentage increase in PM_{10} and $PM_{2.5}$ concentrations in 2021 occurs in the towns of Caroona, Curlewis and Boggabri. If the WCP is excluded from the 2021 scenario, the largest percentage increase in occurs in the towns of Boggabri and Baan Baa.

Although definite comparisons cannot be made against ambient air quality standards, due to the uncertainties described above, the modelling suggests that all towns would comply with the NEPM AAQ standard of 25 µg/m³ for PM_{10} in 2021. This is not the case for $PM_{2.5}$ modelling which suggests that compliance with the NEPM AAQ standard of 8 µg/m³ may not be achieved at some towns, with or without the WCP.

[15] The modelling of anthropogenic sources predicts PM_{10} and $PM_{2.5}$ concentrations of 0.3 µg/m³ and 0.2 µg/m³ respectively in Caroona town, which supports the assumption that the Caroona TEOM site is not influenced strongly by anthropogenic sources.

Table 10-1: Modelled and total predicted annual average PM_{10} and $PM_{2.5}$ at town centres

Town	PM_{10}						$PM_{2.5}$					
	Modelled sources			Total predicted			Modelled sources			Total predicted		
	2013	2021 with WCP	2021 without WCP	2013	2021 with WCP	2021 without WCP	2013	2021 with WCP	2021 without WCP	2013	2021 with WCP	2021 without WCP
Willow Tree	0.3	0.5	0.4	11.4	11.6	11.5	0.2	0.3	0.3	7.0	7.1	7.1
Wallabadah	0.2	0.3	0.2	11.3	11.4	11.3	0.1	0.2	0.1	6.9	7.0	6.9
Quirindi	1.8	2.8	2.5	12.9	13.9	13.6	1.4	1.8	1.7	8.2	8.6	8.5
Werris Creek	1.7	4.3	3.9	12.8	15.4	15.0	0.8	1.5	1.3	7.5	8.3	8.1
Caroona	0.3	1.3	0.5	11.4	12.4	11.6	0.2	0.5	0.3	7.0	7.3	7.1
Curlewis	0.7	3.1	1.0	11.8	14.2	12.1	0.6	1.3	0.7	7.4	8.1	7.5
Carroll	0.4	1.2	0.9	11.5	12.3	12.0	0.2	0.4	0.3	7.0	7.2	7.1
Gunnedah	1.5	3.0	2.5	12.6	14.1	13.6	1.1	1.6	1.4	7.9	8.4	8.2
Mullaley	0.2	0.8	0.5	11.3	11.9	11.6	0.1	0.3	0.2	6.9	7.1	7.0
Boggabri	2.5	9.2	9.1	13.6	20.3	20.2	1.2	3.0	2.9	8.0	9.8	9.7
Baan Baa	1.0	3.2	3.1	12.1	14.3	14.2	0.5	1.1	1.1	7.3	7.9	7.9
Narrabri	1.4	2.2	2.2	12.5	13.3	13.3	1.1	1.3	1.3	7.9	8.1	8.1

Table 10-2: Modelled and total predicted % increase in annual average PM_{10} and $PM_{2.5}$ at town centres from 2013 to 2021

Town	PM_{10}				$PM_{2.5}$			
	Modelled sources with WCP	Modelled sources without WCP	Total predicted with WCP	Total predicted without WCP	Modelled sources with WCP	Modelled sources without WCP	Total predicted with WCP	Total predicted without WCP
Willow Tree	86%	53%	2%	1%	57%	34%	2%	1%
Wallabadah	110%	62%	1%	1%	46%	23%	1%	0.3%
Quirindi	53%	40%	7%	6%	28%	19%	5%	3%
Werris Creek	153%	132%	20%	18%	91%	71%	9%	7%
Caroona	372%	70%	9%	2%	188%	45%	5%	1%
Curlewis	334%	46%	20%	3%	134%	17%	10%	1%
Carroll	229%	160%	7%	5%	124%	80%	3%	2%
Gunnedah	100%	68%	12%	8%	41%	26%	6%	4%
Mullaley	235%	94%	5%	2%	113%	43%	2%	1%
Boggabri	266%	261%	49%	48%	148%	142%	22%	21%
Baan Baa	222%	216%	18%	18%	116%	111%	8%	8%
Narrabri	63%	62%	7%	7%	23%	22%	3%	3%

10.3 Source contribution to annual average PM concentrations in town centres

The estimated source contributions to annual average PM_{10} in the town centres is presented in **Table 10-3**. For annual average PM_{10} in 2013, coal mine fugitive emissions are the single largest contributor at Boggabri (9.3%) and Werris Creek (8.0%). Wood heaters are estimated to be the single largest contributor to annual average PM_{10} at Gunnedah (7.0%), Narrabri (7.8%) and Quirindi (7.9%).

In 2021, the contribution to annual average PM_{10} from coal mine fugitive emissions is more dominant at Boggabri (36.3%) and Werris Creek (21.0%) while at Gunnedah and Narrabri, coal mine fugitive emissions overtake wood heaters at the single largest contributor (11.8% and 7.5% respectively). While wood heaters remain the single largest contributor to annual average PM_{10} in 2021 at Quirindi (7.3%), the combined emissions from coal mines and coal mine diesel overtakes wood heaters. It is noted that the estimated secondary, natural and regionally transported PM is assumed to remain constant for the 2021 projections.

The estimated source contributions to annual average $PM_{2.5}$ in the town centres is presented in **Table 10-4**. For annual average $PM_{2.5}$ in 2013, wood heaters are the single largest contributor at Quirindi (11.9%), Narrabri (11.9%), Gunnedah (10.7%) and Boggabri (7.7%). The largest source at Werris Creek is coal mining (fugitive dust and diesel combined). Wood heaters remain the single largest contributor in 2021 at Quirindi (11.4%), Narrabri (11.6%) and Gunnedah (10.1%). In 2021, the contribution to annual average $PM_{2.5}$ from coal mine fugitive emissions increases at Boggabri (14.5%) to overtake wood heaters at the single largest source.

The predicted source contributions are presented graphically in **Figure 10-1** and **Figure 10-2** for modelled sources only.

Table 10-3: Estimated source contribution (%) to annual average PM_{10} at town centres

Source	Quirindi			Werris Creek			Gunnedah			Boggabri			Narrabri		
	2013	2021 with WCP	2021 without WCP	2013	2021 with WCP	2021 without WCP	2013	2021 with WCP	2021 without WCP	2013	2021 with WCP	2021 without WCP	2013	2021 with WCP	2021 without WCP
Agriculture	0.1%	0.1%	0.1%	0.05%	0.04%	0.04%	0.1%	0.05%	0.05%	0.3%	0.2%	0.2%	0.03%	0.02%	0.02%
Mine Diesel	0.5%	0.8%	0.7%	1.7%	2.3%	2.1%	0.2%	1.2%	0.7%	1.1%	2.9%	2.9%	0.2%	0.9%	0.9%
Industrial	0.1%	0.1%	0.1%	0.05%	0.05%	0.05%	0.3%	0.2%	0.3%	1.5%	1.0%	1.0%	1.0%	1.0%	1.0%
Mines	2.6%	7.2%	6.3%	8.0%	21.0%	19.8%	2.8%	11.8%	9.4%	9.3%	36.3%	36.2%	1.7%	7.5%	7.4%
Rail	1.8%	3.8%	3.3%	1.5%	3.0%	2.6%	0.9%	1.3%	1.2%	1.2%	1.6%	1.3%	0.01%	0.03%	0.02%
Roads	0.8%	0.4%	0.4%	0.1%	0.05%	0.05%	0.4%	0.2%	0.2%	0.2%	0.1%	0.1%	0.3%	0.1%	0.1%
Unpaved Roads	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.2%	0.1%	0.1%	0.03%	0.02%	0.02%
Wood Heaters	7.9%	7.3%	7.5%	1.8%	1.5%	1.5%	7.0%	6.3%	6.5%	4.7%	3.2%	3.2%	7.8%	7.3%	7.3%
Estimated 2ndry, natural & regional PM	86%	80%	82%	87%	72%	74%	88%	79%	82%	82%	55%	55%	89%	83%	83%

Table 10-4: Estimated source contribution (%) to annual average $PM_{2.5}$ at town centres

Source	Quirindi			Werris Creek			Gunnedah			Boggabri			Narrabri		
	2013	2021 with WCP	2021 without WCP	2013	2021 with WCP	2021 without WCP	2013	2021 with WCP	2021 without WCP	2013	2021 with WCP	2021 without WCP	2013	2021 with WCP	2021 without WCP
Agriculture	0.05%	0.04%	0.04%	0.03%	0.02%	0.02%	0.03%	0.03%	0.03%	0.1%	0.1%	0.1%	0.02%	0.02%	0.02%
Mine Diesel	0.8%	1.3%	1.1%	2.8%	4.2%	3.8%	0.4%	2.0%	1.2%	1.8%	6.0%	5.9%	0.3%	1.4%	1.4%
Industrial	0.04%	0.04%	0.04%	0.02%	0.02%	0.02%	0.1%	0.1%	0.1%	0.3%	0.3%	0.3%	0.7%	0.7%	0.7%
Mines	0.6%	1.9%	1.6%	2.0%	5.8%	5.3%	1.1%	4.3%	3.5%	2.7%	14.5%	14.4%	0.5%	2.5%	2.4%
Rail	2.6%	5.6%	4.9%	2.3%	5.1%	4.4%	1.4%	2.0%	1.8%	1.9%	3.0%	2.6%	0.02%	0.04%	0.03%
Roads	0.9%	0.5%	0.5%	0.1%	0.1%	0.1%	0.5%	0.3%	0.3%	0.3%	0.1%	0.1%	0.3%	0.2%	0.2%
Unpaved Roads	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.2%	0.2%	0.2%	0.03%	0.03%	0.03%
Wood Heaters	11.9%	11.4%	11.5%	2.9%	2.7%	2.7%	10.7%	10.1%	10.3%	7.7%	6.3%	6.4%	11.9%	11.6%	11.6%
Estimated 2ndry, natural & regional PM	83%	79%	80%	90%	82%	84%	86%	81%	83%	85%	70%	70%	86%	84%	84%

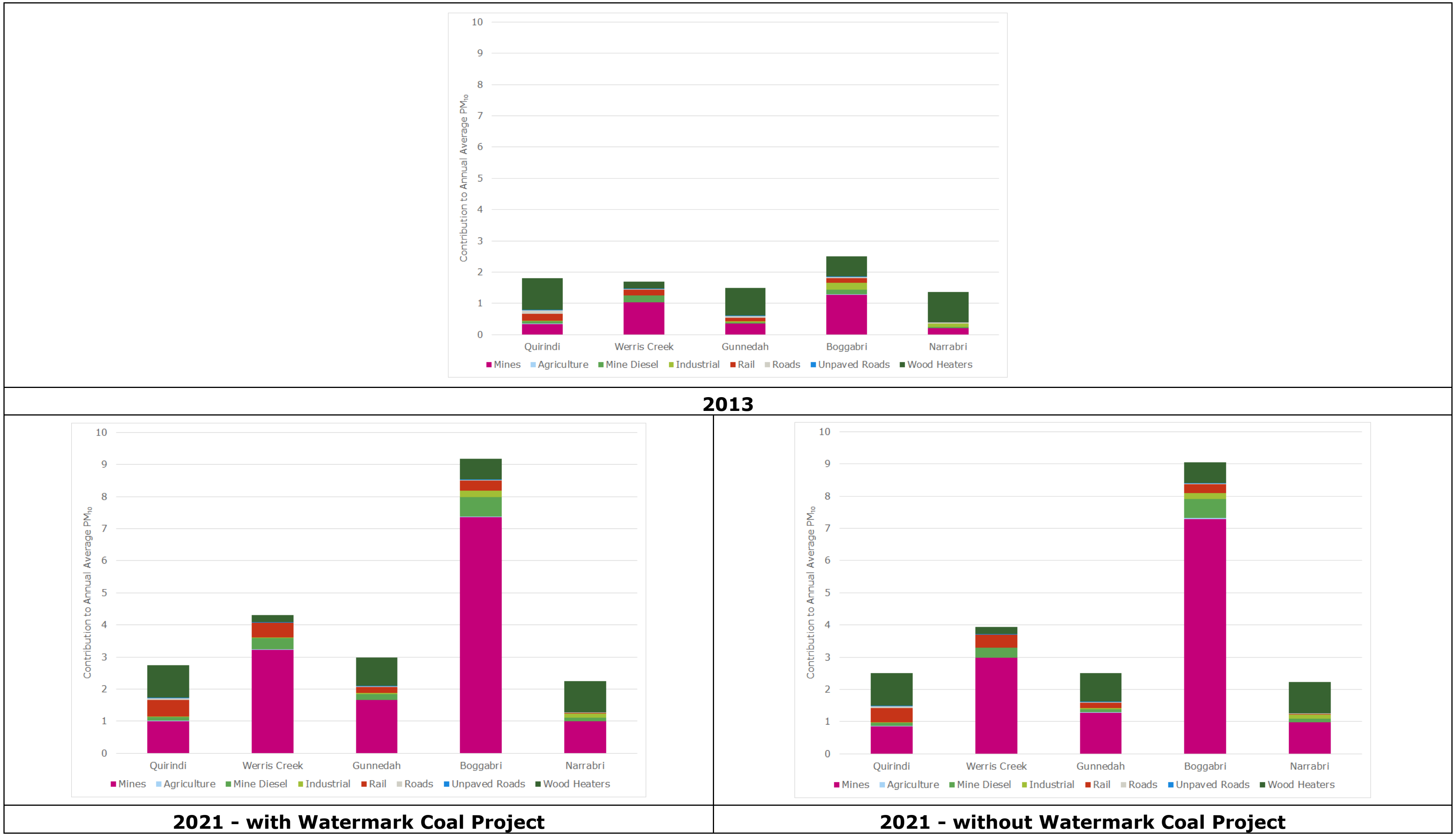


Figure 10-1: Modelled source contribution to annual average PM_{10} concentration for modelled sources

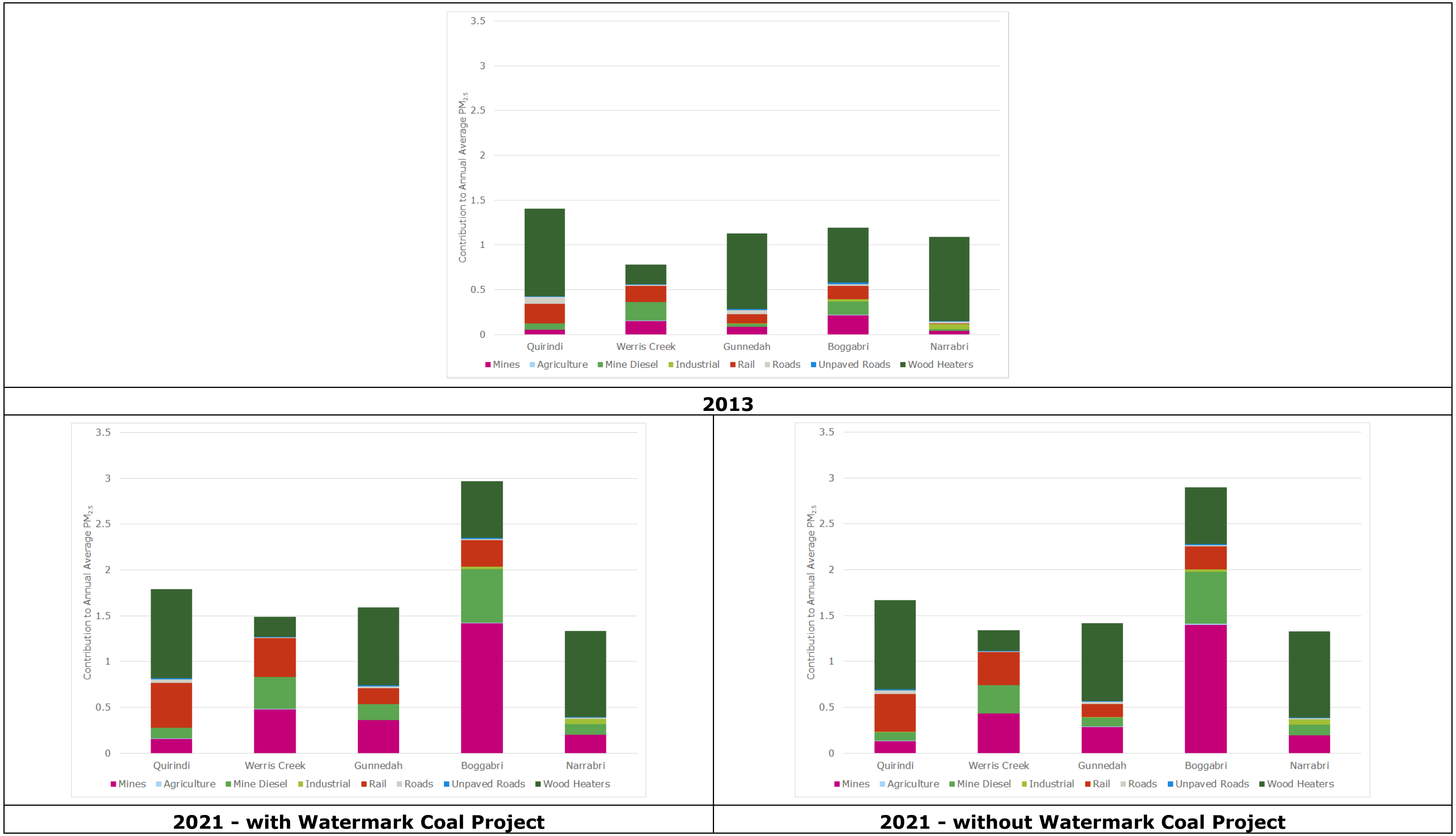


Figure 10-2: Modelled source contribution to annual average $PM_{2.5}$ concentration for modelled sources

10.4 Probability of additional exceedances of 24-hour average PM_{10} and $PM_{2.5}$

The review of monitoring data presented in **Figure 3-2** shows a number of sites recorded 24-hour PM_{10} concentrations above 50 µg/m³ during 2013. For the monitoring sites which operate HVAS, the number of daily exceedances for the year cannot be determined (as HVAS only run every 6th day).

For the continuous (TEOM) monitoring sites, only Boggabri and Tarrawonga recorded 24-hour PM_{10} concentrations above 50 µg/m³. By combining all data from the continuous monitoring sites into a frequency distribution, a worst case probability of days above 50 µg/m³ can be derived for the region and compared with the likelihood of additional exceedances for 2021, using a probabilistic risk based approach.

A frequency distribution of cumulative impact for each town is derived using every possible combination of predicted increase in concentrations for 2021 and existing background concentrations for 2013. In other words, every modelling prediction is added to all available background values. For background, we use all existing continuous monitoring data, which includes existing sources and therefore an element of double counting.

Using this approach, additional exceedances of the 24-hour PM_{10} and 24-hour $PM_{2.5}$ standards can be estimated, and are shown in **Table 10-5** for selected towns.

Table 10-5: Estimated additional days over the 24-hour average PM_{10} and $PM_{2.5}$ goals at town centres

Town	PM_{10}		$PM_{2.5}$	
	2021 with WCP	**2021 without WCP**	**2021 with WCP**	**2021 without WCP**
Quirindi	1	1	1	1
Werris Creek	2	2	1	1
Gunnedah	1	1	1	1
Boggabri	7	7	1	1
Narrabri	1	1	2	2

10.5 Temporal variation

The study objectives sought to determine how particle concentrations vary temporally across the Namoi region. Of the modelled sources included in this study, temporal variation is most influenced by wood heaters, which have the strongest temporal profile in emissions. However, the total predicted concentrations in town centres incorporate our estimates of non-modelled PM (secondary, natural and regionally transported PM), which can be a significant component of total PM_{10} and $PM_{2.5}$.

Due to uncertainties in accounting for the non-modelled components (as discussed in **Section 9.3**), there is limited value in presenting temporal analysis of total concentrations. In the absence of data specific to the Namoi region we have used particle composition data for Muswellbrook, and while this assumption is reasonable for annual average concentrations, presenting the diurnal and seasonal variation based on Muswellbrook data may misrepresent temporal variation for towns within the Namoi region.

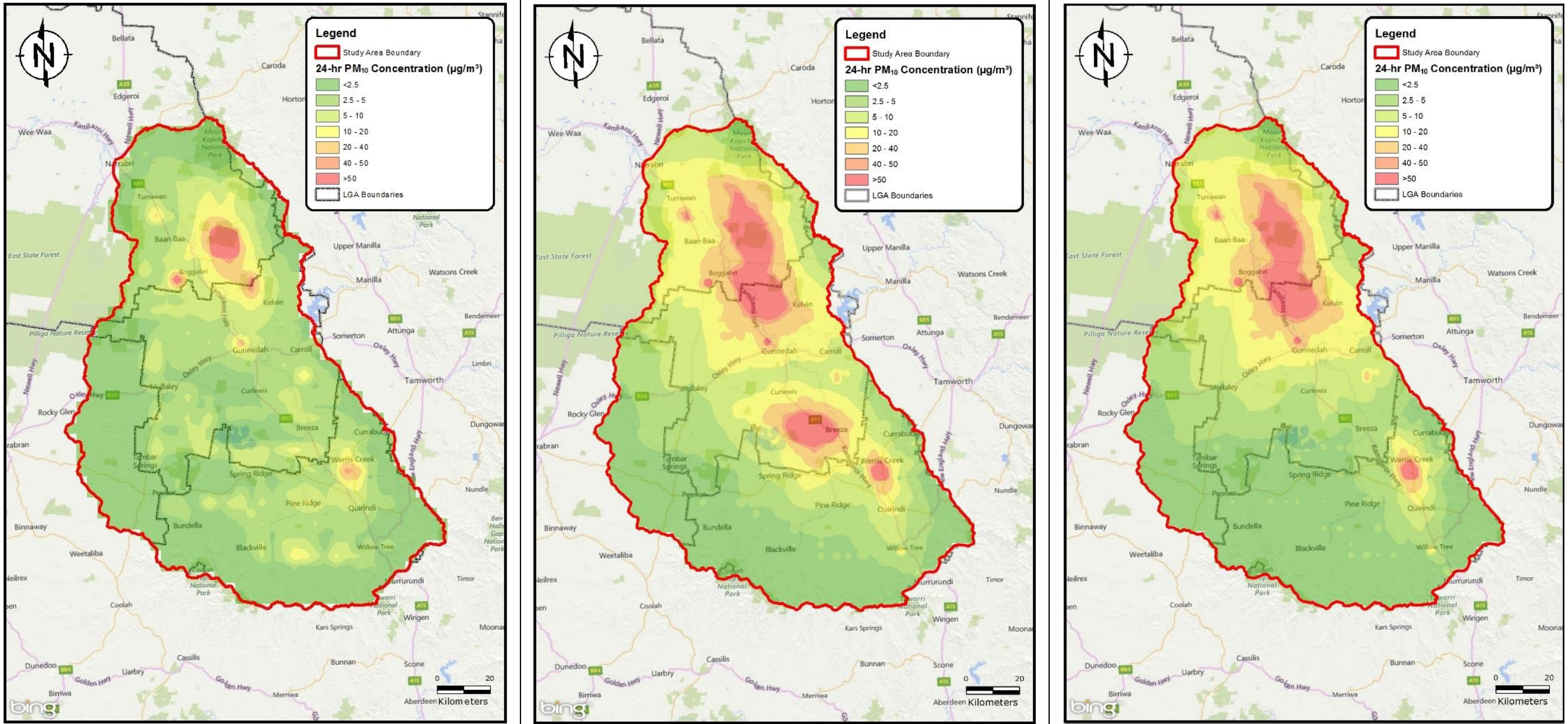
10.6 Spatial distribution of PM concentrations in study area

Contour plots showing the spatial distribution of maximum 24-hour and annual average PM_{10} and $PM_{2.5}$ for modelled sources are presented in **Figure 10-3** to **Figure 10-6**.

Contour plots for 2013 and 2021 (with and without Watermark Coal Project) are presented side by side to illustrate the change in spatial distribution between the two years. The annual average contour plots provide an indication of the spatial distribution of concentrations averaged across the entire modelling period. However, it is important to note that the maximum 24-hour average contour plots do not represent 24-hour average concentrations on any given day, rather, they are a composite of the highest day across the modelling domain for the complete modelling period. The actual 24-hour average concentrations on any given day would look very different, as the highest concentrations at one location would not occur on the same day as the highest concentrations at another location.

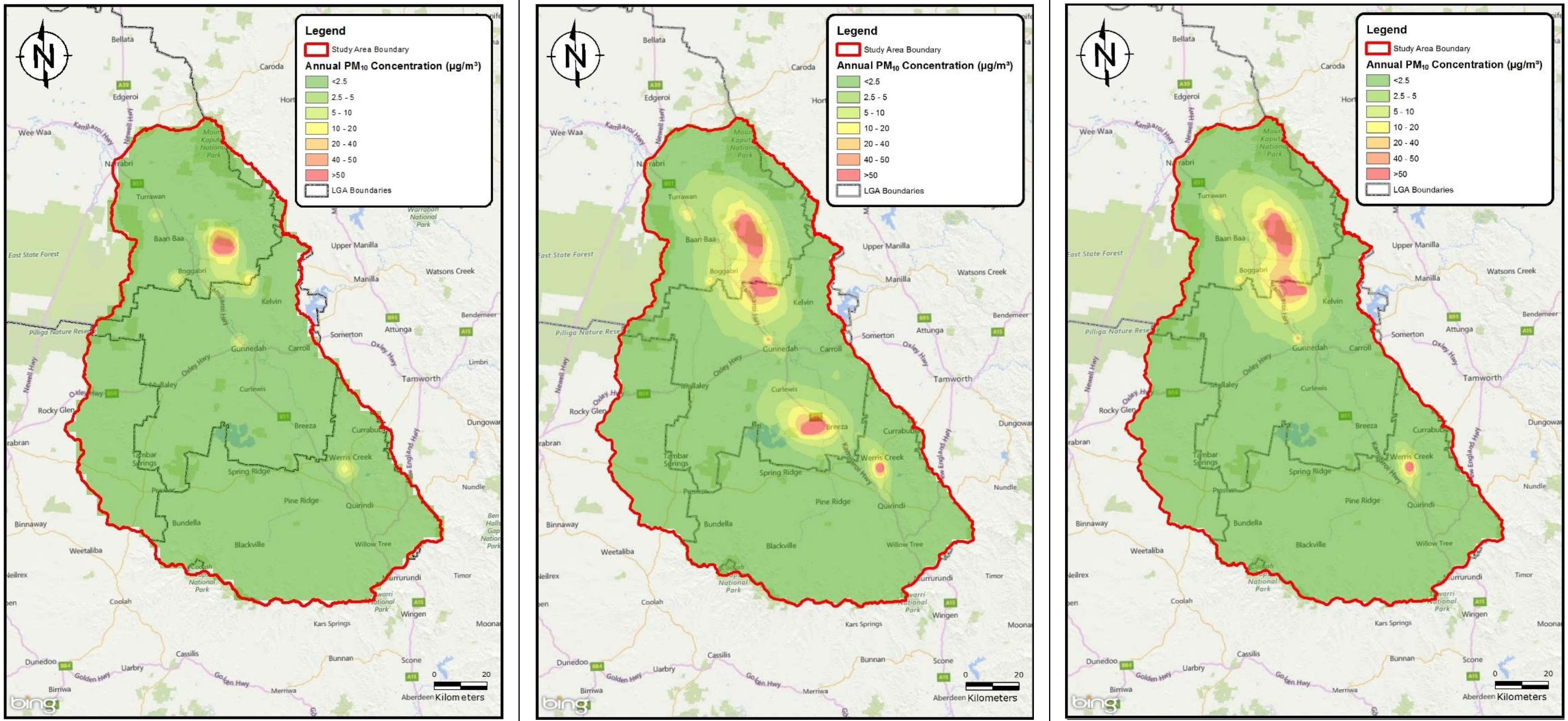
The contour plots show significant concentration gradients in annual average and 24-hour average PM_{10} and $PM_{2.5}$ in the vicinity of existing and proposed coal mines. Coal mining is the dominant emissions source for the region and projected to increase significantly in 2021 (**Section 6.8**).

This is reflected in the contour plots with the concentration gradients also increasing significantly in 2021. There is a less distinct concentration gradient around towns which is more evident in the annual average contours for $PM_{2.5}$. This reflects the stronger influence from wood heaters for the fine particle fraction. There is also evidence in the annual average contours that the increase in emissions in 2021 results in a defined or connected regional airshed, particularly for $PM_{2.5}$.



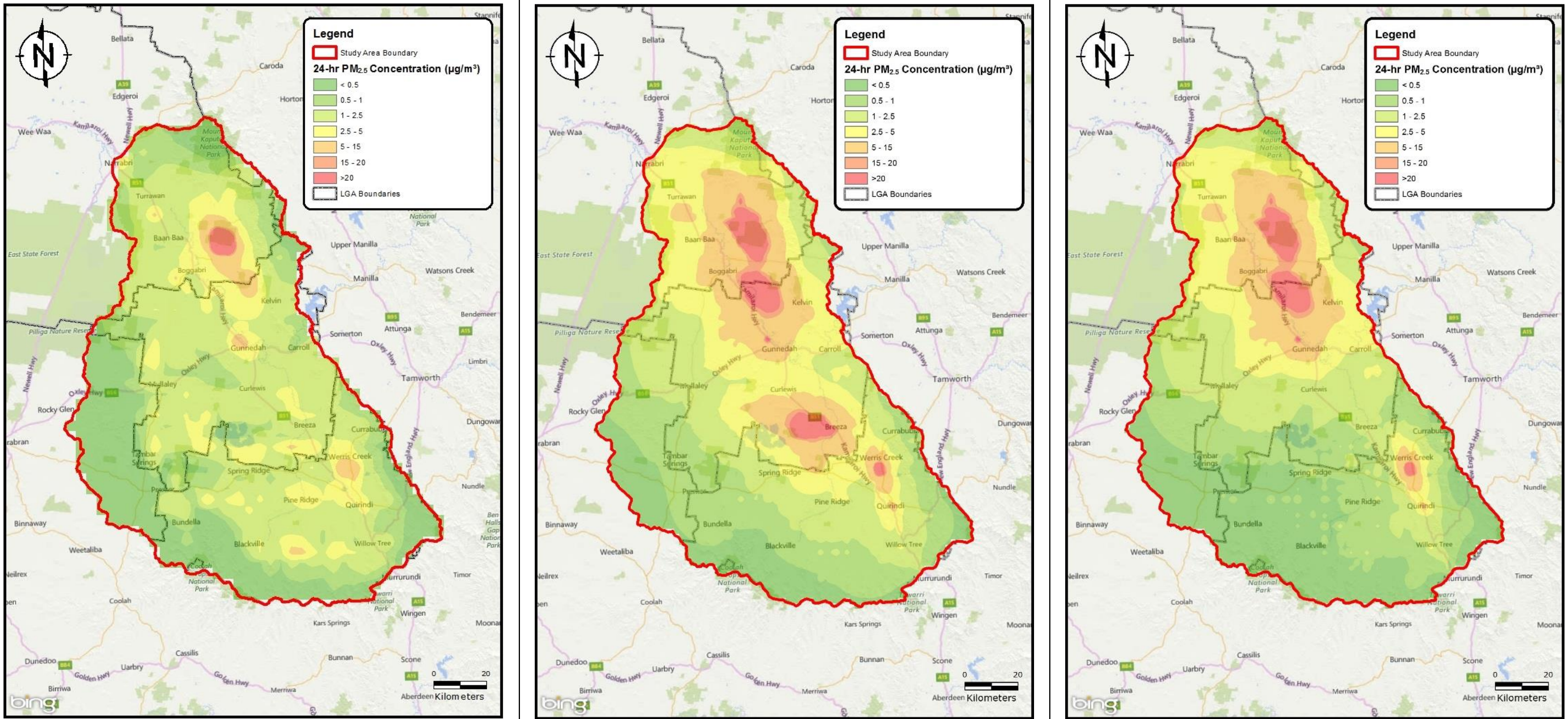
2013	2021 - with Watermark Coal Project	2021 - without Watermark Coal Project

Figure 10-3: Modelled spatial variation in maximum 24-hour average PM_{10} concentrations for modelled sources



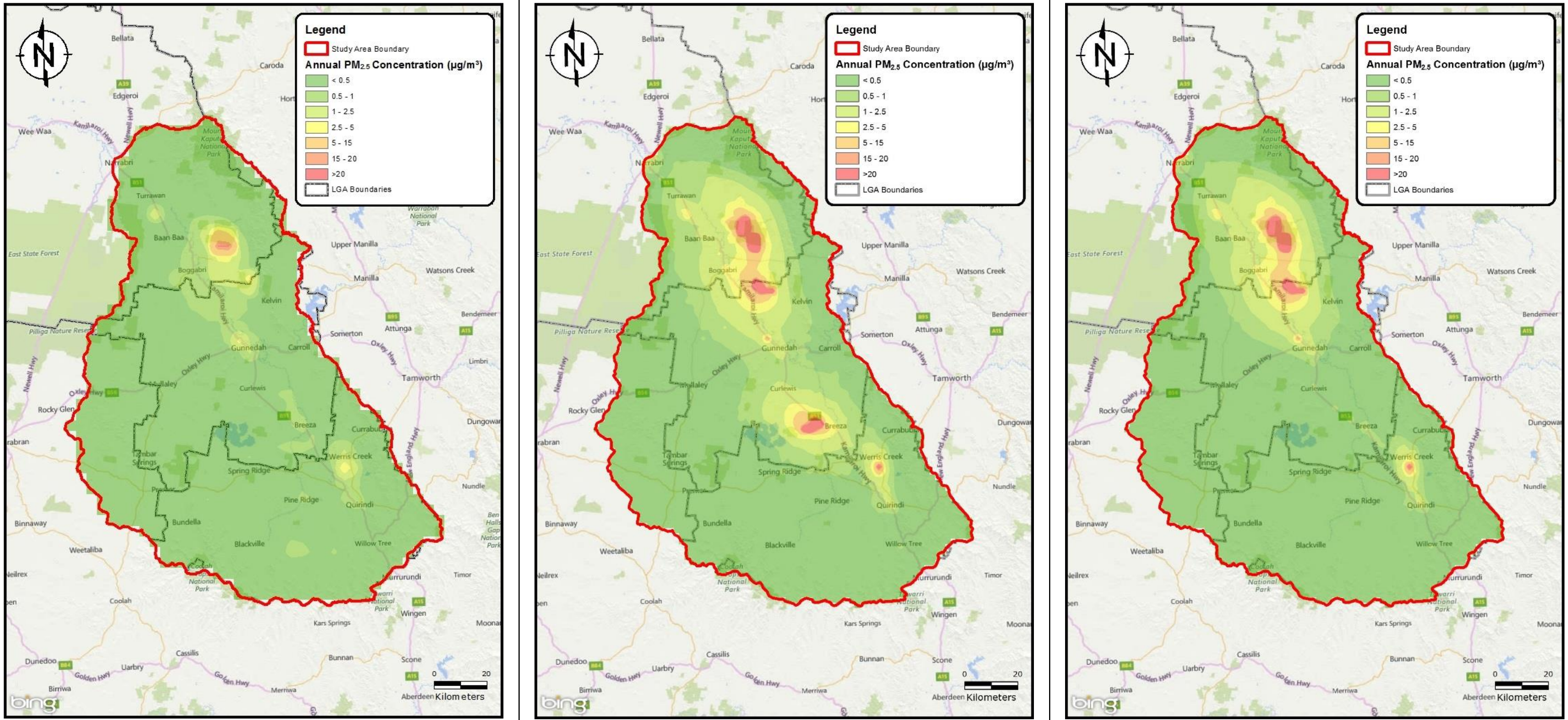
2013	2021 - with Watermark Coal Project	2021 - without Watermark Coal Project

Figure 10-4: Modelled spatial variation in annual average PM_{10} concentrations for modelled sources



2013	2021 - with Watermark Coal Project	2021 - without Watermark Coal Project

Figure 10-5: Modelled spatial variation in maximum 24-hour average $PM_{2.5}$ concentrations for modelled sources



2013	2021 - with Watermark Coal Project	2021 - without Watermark Coal Project

Figure 10-6: Modelled spatial variation in annual average $PM_{2.5}$ concentrations for modelled sources

11. CONCLUSION AND RECOMMENDATIONS

Emission inventories presented for the Narrabri, Gunnedah and Liverpool Plains LGAs show that the dominant anthropogenic sources of PM_{10} and $PM_{2.5}$ emissions in the region are coal mines. In 2013, fugitive emissions from coal mines are estimated to contribute to approximately 76% of total PM_{10} emissions and 48% of the total $PM_{2.5}$ emissions. Other significant sources of $PM_{2.5}$ emissions in 2013 are diesel equipment at coal mines (19%), agriculture (11%), wood heaters (10%) and rail transportation (5%). The contribution from coal mines is projected to increase to 87% in 2021 for PM_{10} and 58% for $PM_{2.5}$, assuming all mines operate at approved or proposed maximum production. It is noted that a robust methodology for projecting emissions for certain sources in 2021 could not be found (i.e. agriculture) and the relative contributions should be viewed with this in mind.

Model evaluation for the base year is presented to determine if the air quality model is acceptable as a means to inform the future year air quality projections, source contribution and suitable locations for monitoring stations. To evaluate model performance against the monitoring data, it is important to account for 'non-modelled' components and particle characterisation data from the Upper Hunter Particle Characterisation Study was used to estimate these 'non-modelled' components, including the contribution from secondary and natural PM to the total measured mass in rural areas. With the 'non-modelled' component added to the modelling results, the base year model evaluation suggests an under-estimation in PM_{10} and $PM_{2.5}$ concentrations by approximately 30% - 40% at most sites. The modelling and the 'non-modelled' components do not necessarily account for regionally transported PM and therefore the results from the model evaluation are used to derive a combined regional background to predict total PM_{10} and $PM_{2.5}$ concentrations for the town centres.

For annual average PM_{10} in 2013, coal mine fugitive emissions are the single largest contributor at Boggabri (9.3%) and Werris Creek (8.0%). Wood heaters are estimated to be the single largest contributor to annual average PM_{10} at Gunnedah (7.0%), Narrabri (7.8%) and Quirindi (7.9%). In 2021, the contribution to annual average PM_{10} from coal mine fugitive emissions increases at Boggabri (36.3%) and Werris Creek (21.0%) while at Gunnedah coal mine fugitive emissions overtake wood heaters at the single largest contributor (11.8%). While wood heaters remain the single largest contributor to annual average PM_{10} in 2021 at Quirindi (7.3%), the combined emissions from coal mines and coal mine diesel overtake wood heaters.

For annual average $PM_{2.5}$ in 2013, wood heaters are the single largest contributor at Quirindi (11.9%), Narrabri (11.9%), Gunnedah (10.7%), Boggabri (7.7%) and Werris Creek (2.9%). Wood heaters remain the single largest contributor in 2021 at Quirindi (11.3%), Narrabri (11.6%) and Gunnedah (10.2%). In 2021, the contribution to annual average $PM_{2.5}$ from coal mine fugitive emissions increases at Boggabri (14.5%) and Werris Creek (5.8%) to overtake wood heaters at the single largest source.

The largest percentage increase in PM_{10} and $PM_{2.5}$ concentrations in 2021 occur at the towns of Caroona, Curlewis, and Boggabri. If the WCP is excluded from the 2021 scenario, the largest percentage increase in occurs in the towns of Boggabri and Baan Baa. Although definite comparisons cannot be made against ambient air quality standards, due to the uncertainties described above, the modelling suggests that all towns would comply with the NEPM AAQ standard of 25 µg/m³ for PM_{10} in 2021. This is not the case for $PM_{2.5}$ modelling which suggests that compliance with the NEPM AAQ standard of 8 µg/m³ may not be achieved at some towns.

11.1 Recommendations for monitoring locations

To inform prioritisation of the regional monitoring network, a summary of the base year (2013) and projected (2021) PM concentrations for each towns is presented in **Table 11-1**. Also shown is the current population and the distance to the nearest existing monitoring site.

Table 11-1: Summary of the estimated base year (2013) and projected (2021) town centre concentrations and closest existing monitoring sites

Town	Population	PM_{10} concentration ($\mu g/m^3$) - 2013	PM_{10} concentration ($\mu g/m^3$) - 2021		$PM_{2.5}$ concentration ($\mu g/m^3$) - 2013	$PM_{2.5}$ concentration ($\mu g/m^3$) - 2021		Nearest existing monitoring site	Distance
			with WCP	without WCP		with WCP	without WCP		
Willow Tree	422	11.4	11.6	11.5	7.0	7.1	7.1	Glenara HVAS (PM_{10}) Werris Creek Town TEOM (PM_{10} and $PM_{2.5}$)	25 km 33 km
Wallabadah	229	11.3	11.4	11.3	6.9	7.0	6.9	Glenara HVAS (PM_{10}) Werris Creek Town TEOM (PM_{10} and $PM_{2.5}$)	21 km 26 km
Quirindi	3,523	12.9	13.9	13.6	8.2	8.6	8.5	Glenara HVAS (PM_{10}) Werris Creek Town TEOM (PM_{10} and $PM_{2.5}$)	9 km 17 km
Werris Creek	1,729	12.8	15.4	15.0	7.5	8.3	8.1	Werris Creek Town TEOM (PM_{10} and $PM_{2.5}$)	n/a
Caroona	90	11.4	12.4	11.6	7.0	7.3	7.1	Caroona Mine TEOM (PM_{10} and $PM_{2.5}$)	2 km
Curlewis	969	11.8	14.2	12.1	7.4	8.1	7.5	Watermark HVAS Gunnedah (PM_{10}) Watermark TEOM (PM_{10} and $PM_{2.5}$)	15 km 23 km
Carroll	176	11.5	12.3	12.0	7.0	7.2	7.1	Watermark HVAS Gunnedah (PM_{10}) Vickery Wil-gai TEOM (PM_{10} and $PM_{2.5}$)	18 km 36 km
Gunnedah	9,340	12.6	14.1	13.6	7.9	8.4	8.2	Watermark HVAS Gunnedah (PM_{10}) Vickery Wil-gai TEOM (PM_{10} and $PM_{2.5}$)	n/a 28 km
Mullaley	540[1]	11.3	11.9	11.6	6.9	7.1	7.0	Sunnyside HVAS (PM_{10}) Watermark TEOM (PM_{10} and $PM_{2.5}$)	24 km 54 km
Boggabri	1,189	13.6	20.3	20.2	8.0	9.8	9.7	Boggabri Mine TEOM (PM_{10}) Vickery Wil-gai TEOM (PM_{10} and $PM_{2.5}$)	11 km 15 km
Baan Baa	525	12.1	14.3	14.2	7.3	7.9	7.9	Maules Creek HVAS (PM_{10}) Maules Creek TEOM (PM_{10} and $PM_{2.5}$)	9 km 21 km
Narrabri	7,392	12.5	13.3	13.3	7.9	8.1	8.1	Narrabri mine HVAS (PM_{10}) Maules Creek TEOM (PM_{10} and $PM_{2.5}$)	25 km 38 km

Note: [1] Includes Tambar Springs

11.2 Recommendations for future work

The most significant source of uncertainty identified for this study relates to estimates of secondary, natural and regionally transported PM from all sources not considered in the modelling. The modelling results suggest that these combined components of PM represent a significant proportion of the total measured PM mass across the region.

There are limited monitoring sites outside the modelling domain to accurately estimate regional background. A recommendation for future work would be to better account for regional background, either through monitoring data collected as part of the proposed Namoi basin monitoring network or by using continental scale modelling to derive boundary conditions.

The contribution of secondary PM to annual average PM_{10} and $PM_{2.5}$ can be significant and in the absence of characterisation data for the Namoi basin region, this study references the Upper Hunter Particle Characterisation Study data. While some components of secondary PM are well described in these data, there are limitations to this approach and particle characterisation data for PM_{10} are not available. Potential future work could refine this approach, for example by developing a secondary particle model.

Some further recommendations for future work are:

- Following commissioning of the proposed Namoi basin monitoring network and as soon as a year of data are collected, it is recommended that the modelling is updated to allow better model evaluation and consideration of background.
- Refinement of the modelling approach might include additional prognostic modelling using the advanced Weather Research Forecast (WRF) model to further refine the resolution of wind field or the use of photochemical grid models (PGM) to account for secondary particles.
- Improving the spatial resolution of certain sources may improve modelling predictions and reduce model uncertainty.

12. REFERENCES

ABS (2014).
http://www.abs.gov.au/websitedbs/censushome.nsf/home/quickstats?opendocument&navpos=220

ABS (2014a). 4602.0.55.001 - Environmental Issues: Energy Use and Conservation, Australian Bureau of Statistics, March 2014

AECOM (2014). Wood Smoke Control Measures Cost Benefit Analysis. Prepared for the NSW EPA, 19 December 2014.

AESRD (2013). Air Quality Model Guideline. Alberta Environment and Sustainable Resource Development. Effective October 1st 2013.

ARTC (2014). 2014-2023 Hunter Valley Corridor Capacity Strategy. July 2014.

ARTC (2015). 2015-2024 Hunter Valley Corridor Capacity Strategy. June 2015.

AQEG (2005). Particulate matter in the United Kingdom. Report of the Air Quality Expert Group. Published by the Department for Environment, Food and Rural Affairs, London, UK.

AQEG (2012). Fine Particulate Matter (PM2.5) in the United Kingdom. Report of the Air Quality Expert Group. Published by the Department for Environment, Food and Rural Affairs, London, UK.

Boulter, P., Kulkarni, K. (2013). Economic analysis to inform the National Plan for Clean Air (Particles). Prepared for NEPC Service Corporation on behalf of Council of Australian Governments (COAG) Standing Council on Environment and Water. August 2013.

Buser M. D., Whitelock D. P., Boykin J. C., Holt G. A., (2012). Engineering and Ginning. Characterisation of Cotton Gin Particulate Matter Emissions – Project Plan. The Journal of Cotton Science 16: 105–116 (2012).

Buser M. D., Whitelock D. P., Boykin J. C., Holt G. A., (2013a). Engineering and Ginning. Unloading System PM2.5 Emission Factors and Rates for Cotton Gins: Method 201A Combination PM10 and PM2.5 Sizing Cyclones. The Journal of Cotton Science 17: 309–319 (2013).

Buser M. D., Whitelock D. P., Boykin J. C., Holt G. A., (2013b). Engineering and Ginning. Third Stage Seed Cotton Cleaning System PM2.5 Emission Factors and Rates for Cotton Gins: Method 201A Combination PM10 and PM2.5 Sizing Cyclones. The Journal of Cotton Science 17: 309–319 (2013).

Buser M. D., Whitelock D. P., Boykin J. C., Holt G. A., (2013c). Engineering and Ginning. First Stage Lint Cleaning System PM2.5 Emission Factors and Rates for Cotton Gins: Method 201A Combination PM10 and PM2.5 Sizing Cyclones. The Journal of Cotton Science 17: 368–379 (2013).

Buser M. D., Whitelock D. P., Boykin J. C., Holt G. A., (2013d). Engineering and Ginning. Second Stage Lint Cleaning System PM2.5 Emission Factors and Rates for Cotton Gins: Method 201A Combination PM10 and PM2.5 Sizing Cyclones. The Journal of Cotton Science 17: 380–390 (2013).

Buser M. D., Whitelock D. P., Boykin J. C., Holt G. A., (2013e). Engineering and Ginning. Battery Condenser System PM2.5 Emission Factors and Rates for Cotton Gins: Method 201A Combination PM10 and PM2.5 Sizing Cyclones. The Journal of Cotton Science 17: 402–413 (2013).

Buser M. D., Whitelock D. P., Boykin J. C., Holt G. A., (2013f). Engineering and Ginning. First Stage Mote System PM2.5 Emission Factors and Rates for Cotton Gins: Method 201A Combination PM10 and PM2.5 Sizing Cyclones. The Journal of Cotton Science 17: 425–435 (2013).

Buser M. D., Whitelock D. P., Boykin J. C., Holt G. A., (2013g). Engineering and Ginning. Second Stage Mote System PM2.5 Emission Factors and Rates for Cotton Gins: Method 201A Combination PM10 and PM2.5 Sizing Cyclones. The Journal of Cotton Science 17: 436–446 (2013).

Buser M. D., Whitelock D. P., Boykin J. C., Holt G. A., (2013h). Engineering and Ginning. Combined Mote System PM2.5 Emission Factors and Rates for Cotton Gins: Method 201A Combination PM10 and PM2.5 Sizing Cyclones. The Journal of Cotton Science 17: 447-456 (2013).

Buser M. D., Whitelock D. P., Boykin J. C., Holt G. A., (2013i). Engineering and Ginning. Mote Trash System PM2.5 Emission Factors and Rates for Cotton Gins: Method 201A Combination PM10 and PM2.5 Sizing Cyclones. The Journal of Cotton Science 17: 479-488 (2013).

Buser M. D., Whitelock D. P., Boykin J. C., Holt G. A., (2013j). Particle Size Distribution Characteristics of Cotton Gin 1st Stage Lint Cleaning System Total Particulate Emissions. Part of the National Characterization of Cotton Gin Particulate Matter. Emissions Project Final Report: OSU13-06, December 2013.

Buser M. D., Whitelock D. P., Boykin J. C., Holt G. A., (2013k). Particle Size Distribution Characteristics of Cotton Gin 2nd Stage Lint Cleaning System Total Particulate Emissions. Part of the National Characterization of Cotton Gin Particulate Matter. Emissions Project Final Report: OSU13-07, December 2013.

Buser M. D., Whitelock D. P., Boykin J. C., Holt G. A., (2013l). Particle Size Distribution Characteristics of Cotton Gin Mote Trash System Total Particulate Emissions. Part of the National Characterization of Cotton Gin Particulate Matter. Emissions Project Final Report: OSU13-16, December 2013. Buser M. D., Whitelock D. P., Boykin J. C., Holt G. A., (2013m). Particle Size Distribution Characteristics of Cotton Gin 1st Stage Seed Cleaning System Total Particulate Emissions. Part of the National Characterization of Cotton Gin Particulate Matter. Emissions Project Final Report: OSU13-02, December 2013.

Buser M. D., Whitelock D. P., Boykin J. C., Holt G. A., (2013n). Particle Size Distribution Characteristics of Cotton Gin 2nd Stage Seed Cleaning System Total Particulate Emissions. Part of the National Characterization of Cotton Gin Particulate Matter. Emissions Project Final Report: OSU13-03, December 2013.

Buser M. D., Whitelock D. P., Boykin J. C., Holt G. A., (2013o). Particle Size Distribution Characteristics of Cotton Gin 3rd Stage Seed Cleaning System Total Particulate Emissions. Part of the National Characterization of Cotton Gin Particulate Matter. Emissions Project Final Report: OSU13-04, December 2013.

Buser M. D., Whitelock D. P., Boykin J. C., Holt G. A., (2013p). Particle Size Distribution Characteristics of Cotton Gin Cyclone Robber System Total Particulate Emissions. Part of the National Characterization of Cotton Gin Particulate Matter. Emissions Project Final Report: OSU13-13, December 2013.

Buser M. D., Whitelock D. P., Boykin J. C., Holt G. A., (2013q). Particle Size Distribution Characteristics of Cotton Gin Battery Condenser System Total Particulate Emissions. Part of the National Characterization of Cotton Gin Particulate Matter. Emissions Project Final Report: OSU13-09, December 2013.

Buser M. D., Whitelock D. P., Boykin J. C., Holt G. A., (2013r). Particle Size Distribution Characteristics of Cotton Gin Overflow System Total Particulate Emissions. Part of the National Characterization of Cotton Gin Particulate Matter. Emissions Project Final Report: OSU13-05, December 2013.

Buser M. D., Whitelock D. P., Boykin J. C., Holt G. A., (2013s). Particle Size Distribution Characteristics of Cotton Gin 1st Stage Mote System Total Particulate Emissions. Part of the

National Characterization of Cotton Gin Particulate Matter. Emissions Project Final Report: OSU13-10, December 2013.

Buser M. D., Whitelock D. P., Boykin J. C., Holt G. A., (2013t). Particle Size Distribution Characteristics of Cotton Gin 1st Stage Mote System Total Particulate Emissions. Part of the National Characterization of Cotton Gin Particulate Matter. Emissions Project Final Report: OSU13-10, December 2013.

Buser M. D., Whitelock D. P., Boykin J. C., Holt G. A., (2013u). Particle Size Distribution Characteristics of Cotton Gin 2nd Stage Mote System Total Particulate Emissions. Part of the National Characterization of Cotton Gin Particulate Matter. Emissions Project Final Report: OSU13-11, December 2013.

Carslaw, D.C. and K. Ropkins, (2012). openair — an R package for air quality data analysis. Environmental Modelling & Software. Volume 27-28, pp. 52–61.

Carslaw, D.C. (2015). The openair manual — open-source tools for analysing air pollution data. Manual for version 1.1-4, King's College London.

CARB (1997), Area-Wide Source Methodologies, Section 7.12 Windblown Dust - Agricultural Lands, Californian Air Resources Board, 1001 "I" Street P.O. Box 2815 Sacramento, CA 95812, USA.

Cotton Australia (2014). Securing our future. Annual report 2013/2014.

Chan Y. C., Cohen D. D., Hawas O., Stelcer E., Simpson R., Denison L., Wong N., Hodge M., Comino E. and Carswell S. (2008). Apportionment of sources of fine and coarse particles in four major Australian cities by positive matrix factorisation. Atmospheric Environment, Vol. 42, Issue 2, pp. 374–389.

Cope, M (2012), 'Reflections on Domestic Wood Smoke Emissions – Effects, Concerns, Progress and Opportunities', presentation to NSW/ACT Branch Technical Meeting, Monday, 10 September 2012, Macquarie University.

DEFRA (2009). Local Air Quality Management - Technical Guidance LAQM.TG(09). Febraury 2009.

DEFRA (2010). Evaluating the Performance of Air Quality Models, Issue 3 June 2010, Department for Environment Food and Rural Affairs.

DSEWPC (2011), State of the air in Australia 1999–2008, Australian Department of Sustainability, Environment, Water, Population and Communities, Canberra, ACT.

ENVIRON (2013). Locomotive Emissions Project. Potential Measures to Reduce Emissions from New and In-service Locomotives in NSW and Australia. Prepared for NSW Office of Environment and Heritage. March 2013.

ENVIRON (2015). Airshed modelling for the Gunnedah basin. Prepared for NSW EPA. 13/05/2015.

Emery, C., E. Tai, and G. Yarwood, (2001). Enhanced Meteorological Modeling and Performance Evaluation for Two Texas Ozone Episodes, report to the Texas Natural Resources Conservation Commission, prepared by ENVIRON, International Corp, Novato, CA.

Ferreira A D, Viegas D X and Sousa A C M (2003). Full-scale measurements for evaluation of coal dust release from train wagons with two different shelter covers, Journal of Wind Engineering and Industrial Aerodynamics, 91 (2003), 1271 – 1283.

Ferreira AD and Vaz PA (2004), "Wind tunnel study of coal dust release from train wagons", Journal of Wind Engineering and Industrial Aerodynamics 92 (2004) 565-577.

Grover B D, Kleinman M, Eatough N L, Eatough D J, Hopke P K, Long R W, Wilson W E, Meyer M B and Ambs J L (2005). Measurement of total $PM_{2.5}$ mass (nonvolatile plus semivolatile) with the

Filter Dynamic Measurement System tapered element oscillating microbalance monitor, *Journal of Geophysical Research*, 110, D07S03, doi:10.1029/2004JD004995.

Hibberd, M., Selleck, P., Keywood, M., Cohen, D., Stelcer, E., Atanacio, A. (2013). Upper Hunter Valley Particle Characterisation Study. Final Report. 17 September 2013. CSIRO Marine & Atmospheric Research and Institute for Environmental Research, ANSTO.

Hanna, S.R., Briggs, G.A., Hosker, R.P. (1982). Handbook on Atmospheric Diffusion. Atmospheric Turbulence and Diffusion Laboratory National Oceanic and Atmospheric Administration, prepared for Office of Health and Environmental Research, Office of Energy, U.S. Department of Energy.

Hurley, P. (2008) "TAPM V4. Part 1: Technical Description, CSIRO Marine and Atmospheric Research Paper".

Hurley, P., M. Edwards. (2009) "Evaluation of TAPM V4 for Several Meteorological and Air Pollution Datasets." Air Quality and Climate Change 43(3): 19.

Ismail, S. A. (2009). Assessment of energy usage for cotton gins in Australia. Thesis presented for PhD. University of Southern Queensland. http://eprints.usq.edu.au/19847/

Katestone Environmental (2011). NSW Coal Mining Study: International Best Practice Measures to Prevent and/or Minimise Emissions of Particulate Matter from Coal Mining, Report compiled on behalf of NSW Department of Environment, Climate Change and Water.

Kellaghan, R., Manansala, F., Hill, K. (2014). Upper Hunter Particle Model. Prepared for the NSw Environment Protection Authority. 9 October 2014.

Mahmud, M. (2009) Mesoscale equatorial wind prediction in Southeast Asia during a haze episode of 2005. GEOFIZIKA VOL. 26 No. 1.

NCOPL (2014). Annual Environmental Management Report (ML 1609) and Annual Review (PA 08_0144 MOD 2) for the Narrabri Mine 1 April 2013 – 31 March 2014. Narrabri Coal Operations, June 2014.

NEPC (2003). National Environmental Protection Measure (Ambient Air Quality) Measure, as amended. National Environmental Protection Council

NEPC (2011). National Environment Protection (Ambient Air Quality) Measure Review. National Environment Protection Council Service Corporation, Level 5 81 Flinders Street, Adelaide, South Australia.

NEPC (2014). Draft Variation to the National Environment protection (ambient Air Quality) Measure Impact Statement. Prepared for National Environmental Protection Council. July 2014.

NSW Agriculture (1998). Soilpak-
http://www.dpi.nsw.gov.au/agriculture/resources/soils/guides/soilpak/cotton

NSW DPI (2004). Farming Systems in the Northern Cropping Region of NSW: An Economic Analysis Economic. Research Report No. 20. Department of Primary Industries.

NSW DPI (2013). NSW grains report. April 2013. Department of Primary Industries. Newsletter and accompanying statistics.

NSW EPA (2005). Approved Methods for the Modelling and Assessment of Air Pollutants in New South Wales, prepared by Department of Environment and Conservation, 2005.

NSW EPA (2012). NSW State of the Environment 2012. NSW Environment Protection Authority.

NSW EPA (2012a). 2008 Calendar Year Consolidated Natural and Human-Made Emissions: Results.

NSW EPA (2012b). Technical Report No.5 - Air Emissions Inventory for the Greater Metropolitan Region in New South Wales. 2008 Calendar Year. Industrial Emissions: Results.

NSW EPA (2012c). Technical Report No. 6. Air Emissions Inventory for the Greater Metropolitan Region in New South Wales. 2008 Calendar Year. Off Road Mobile Emissions: Results

NSW EPA (2012d). Technical Report No. 4 - Air Emissions Inventory for the Greater Metropolitan Region in New South Wales. 2008 Calendar Year. Domestic-Commercial Emissions: Results.

NSW EPA (2012e). Technical Report No. 4 - Air Emissions Inventory for the Greater Metropolitan Region in New South Wales. 2008 Calendar Year. Biogenic-Geogenic: Results.

NSW EPA (2012e). Technical Report No. 4 - Air Emissions Inventory for the Greater Metropolitan Region in New South Wales. 2008 Calendar Year. Biogenic-Geogenic: Results.

NSW EPA (2014). NSW Coal Mining Benchmarking Study. Best-practice measures for reducing non-road diesel exhaust emissions. Final draft report. December 2014.

OEH (2013). Advice on Air Quality Monitoring within the New England North West (Gunnedah Basin) Coal Mining Region

Pasquill, F. (1974). Atmospheric Diffusion, 2nd Edition. John Wiley and Sons, New York, NY; 479pp.

PAEHolmes (2012). Tarrawonga Coal Project – Air Quality and Greenhouse Gas Assessment. Tarrawonga Coal Pty Ltd. 9 January 2012.

Scott, G.J., Farquharson, R.J., Mullen, J.D. (2004). Farming Systems in the Northern Cropping Region of NSW: An Economic Analysis. NSW Department of Primary Industries, Orange. Economic Research Report No. 20, September 2004.

Scire, J.S., Strimaitis, D.G. & Yamartino, R.J. (2000) A User's Guide for the CALPUFF Dispersion Model (Version 5), Earth Tech, Inc., Concord.

Soriano, C., Soler, R.M., Pino, D., Alarcon, M., Physick, B., and Hurley, P. (2003). Modelling different meteorological situations in Catalunya, Spain, with MM5 and TAPM mesoscale models: a comparative study, International Journal of Environment and Pollution, 20(1-6), 256-268.

Skidmore, E.L. (1998). Wind Erosion Processes, USDA-ARS Wind Erosion Research Unit, Kansas State University. Wind Erosion in Africa and West Asia: Problems and Control Strategies. Proceedings of the expert group meeting 22-25 April 1997, Cairo, Egypt.

SPCC (1986). Particle size distributions in dust from open cut coal mines in the Hunter Valley, Report Number 10636-002-71, Prepared for the State Pollution Control Commission of NSW (now EPA) by Dames & Moore, 41 McLaren Street, North Sydney, NSW 2060.

TAS (2013). New England North West (Gunnedah Basin) Coal Mining Region Consideration for Monitoring Network Design.

TfN (2013). NSW Freight and Ports Strategy. Transport for NSW, November 2013.

TRC (2011). Generic Guidance and Optimum Model Settings for the CALPUFF Modelling System for Inclusion into the Approved Methods for Modelling and Assessment of Air Pollutants in NSW, Australia. prepared for NSW Department of Environment, Climate Change and Water.

Wang W C, Chen K S. (2008) Modeling and Analysis of Source Contribution of PM10 during Severe Pollution Events in Southern Taiwan. Aerosol and Air Quality Research, Vol. 8, No. 3, pp. 319-338, 2008

URS (2000)"Mount Arthur North Coal Project" EIS produced for COAL Australia Pty Ltd by URS Australia Pty Ltd, Level 22, and 127 Creek Street, Brisbane, Queensland 4000.

US EPA (1986). Compilation of Air Pollutant Emissions Factors, AP-42, Fourth Edition, Volume 1 chapter 1: External combustion Source. Section 1.10 Residential Wood Stoves, Final Section, October 1996.

US EPA (1987). Update of fugitive dust emission factors in AP-42 Section 11.2, EPA Contract No. 68-02-3891, Midwest Research Institute, Kansas City, MO, July 1987.

US EPA (1998). AP-42 Emission Factor Database, Chapter 11.9 Western Surface Coal Mining, United States Environmental Protection Agency, 1998.

US EPA (2004). User's Guide for the AMS/EPA Regulatory Model - AERMOD.

US EPA (2005). Revision to the Guideline on Air Quality Models: Adoption of a Preferred General Purpose (Flat and Complex Terrain) Dispersion Model and Other Revisions; Final Rule. Federal Register Part III Environmental Protection Agency 40 CFR Part 51.

US EPA (2006). AP-42 Emission Factor Database, Chapter 13.2.5 Industrial Wind Erosion, United States Environmental Protection Agency, November 2006.

US EPA (2013). Draft Guidance for $PM_{2.5}$ Permit Modelling. United States Environmental Protection Agency, Office of Air Quality Planning and Standards, Research Triangle Park, North Carolina 27711, March 2013.

US EPA (2015). Revision to the Guideline on Air Quality Models: Enhancements to the AERMOD Dispersion Modeling System and Incorporation of Approaches To Address Ozone and Fine Particulate Matter; Proposed Rule. 40 CFR Part 51. Vol 80. No. 145. July 29, 2015.

Zoras, S., Evagelopoulos, V., Pytharoulis, I., and Kallos, G. (2010). Development and validation of a novel-based combination operational air quality forecasting system in Greece, Meteorology and Atmospheric Physics, 106(3-4), 127-133.

APPENDIX 1
MODEL SETTINGS

Table A1-1: TAPM settings

Parameter	Setting
Model Version	TAPM v.4.0.4
Number of grids (spacing)	3 (10 km, 6 km, 3 km)
Number of grid points	105 x 105
Vertical grids / vertical extent	25 / 8000m (~400mb)
Centre of analysis (local coordinates)	214000E, 6578000S
Year of analysis	2013
Terrain and landuse	Default TAPM values based on land-use and soils data sets from Geoscience Australia and the US Geological Survey, Earth Resources Observation Systems (EROS) Data Center Distributed Active Archive Center (EDC DAAC).

Table A1-2: CALMET settings

Parameter	Setting
Grid domain	265 km x 265 km
Grid resolution	2 km
Number of grid points	265 x 265
Vertical grids / vertical extent	11 cell heights / 4,000m
Upper air meteorology	Prognostic 3D.dat extracted from TAPM at 3 km grid

Table A1-3: CALMET model options

Flag	Description	Default	Value used
NOOBS	Meteorological data options	No Default	1 (combination of surface and prognostic data)
ICLOUD	Cloud Data Options – Gridded Cloud Fields	No Default (4 recommended)	4 -Gridded cloud cover from Prognostic relative humidity at all levels (MM5toGrads algorithm)
IEXTRP	Extrapolate surface wind observations to upper layers	Similarity theory	Applied
BIAS (NZ)	Relative weight given to vertically extrapolated surface observations vs. upper air data	NZ * 0	Applied. Layers in lower levels of model (<160m) will have stronger weighting towards surface, higher levels will be have stronger weighting to upper air data
TERRAD	Radius of influence of terrain	No default (typically 5-15km)	5 km
RMAX1 and RMAX2	Maximum radius of influence over land for observations in layer 1 and aloft	No Default	20 km
R1 and R2	Distance from observations in layer 1 and aloft at which observations and Step 1 wind fields are weighted equally	No Default	R1 - 8 km, R2 – 20 km

Table A1-4: CALPUFF model options

Flag	Description	Value used	Description
MCHEM	Chemical Transformation	0	Not modelled
MDRY	Dry Deposition	1	Yes
MWET	Wet Deposition	0	Not modelled
MTRANS	Transitional plume rise allowed?	1	Yes
MTIP	Stack tip downwash?	1	Yes
MRISE	Method to compute plume rise	1	Briggs plume rise
MSHEAR	Vertical wind Shear	0	Vertical wind shear not modelled
MPARTL	Partial plume penetration of elevated inversion?	1	Yes
MSPLIT	Puff Splitting	0	No puff splitting
MSLUG	Near field modelled as slugs	0	Not used
MDISP	Dispersion Coefficients	2	Based on micrometeorology
MPDF	Probability density function used for dispersion under convective conditions	1	Yes
MROUGH	PG sigma y,z adjusted for z	0	No
MCTADJ	Terrain adjustment method	3	Partial Plume Adjustment
MBDW	Method for building downwash	1	ISC Method

APPENDIX 2
SENSITIVITY ANALYSIS FOR WET AND DRY YEARS

Introduction

One of the questions that the study seeks to answer is how particle levels are likely to vary between dry and wet years. There are a number of mechanisms by which rainfall might influence particle concentrations across the study area and is not possible or practical to account for every variable in conducting a sensitivity analysis.

Some examples of how rainfall may influence particle levels are:

- The generation of fugitive emissions, from sources such as agriculture, mining, quarrying etc., may be higher during dry years and lower during wet years.
- Dryer periods may result in more frequent dust storms and bushfire activity, resulting in higher regional background dust.
- Rainfall acts as a removal mechanism for dust, lowering pollutant concentrations by removing them more efficiently than during dry periods.
- Rainfall forecasts for the region will dictate crop production levels or shift preference for certain types of crops sown for each region. This may in turn influence the amount of fugitive emissions generated from agricultural sources.

The following analysis is presented to provide an indication of how particle levels are likely to vary between for wet and dry years.

Long term trends in ambient PM_{10}

The sensitivity of ambient PM_{10} concentrations to wet and dry years is investigated by looking at the long terms trends in PM_{10} concentrations at Tamworth over a period of 14 years. **Figure A2-1** presents the trend (and 95% confidence intervals) in monthly PM_{10} concentrations, plotted using the smooth trend function in Openair (Carslaw, 2015; Carslaw and Ropkins, 2012[16]).

The plot shows a cyclical pattern in monthly PM_{10}. The pattern is more obvious in the higher percentiles, therefore the data are re-plotted in **Figure A2-2** showing the 50th percentile only. This shows the cyclical pattern is evident also in the monthly median concentration.

The Bureau of Meteorology (BoM) publish a Southern Oscillation Index (SOI) to provide an indication of the intensity of El Niño or La Niña events. Sustained negative values below negative 8 often indicate El Niño episodes, resulting in reduced rainfall in winter and spring over much of eastern Australia. Sustained positive above 8 are typical of La Niña and results in increased probability that eastern Australia will be wetter than normal[17]. A plot of the SOI is shown in **Figure A2-3**.

The El Niño Southern Oscillation (ENSO) can be compared with the trend in PM_{10} concentrations across the same period, and in some years is indicative of a difference in PM_{10} concentrations for wet and dry years. For example, between 2010 and 2012 a dip in PM_{10} concentrations is evident, corresponding to development of La Nina conditions and above average rainfall in 2010 and 2011. In 2013 PM_{10} concentrations increase again, corresponding to period of low rainfall and the warmest year on record for NSW.

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[16] Carslaw, D.C. (2015). The openair manual — open-source tools for analysing air pollution data. Manual for version 1.1-4, King's College London

Carslaw, D.C. and K. Ropkins, (2012). openair — an R package for air quality data analysis. Environmental Modelling & Software. Volume 27-28, pp. 52–61.

[17] http://www.bom.gov.au/watl/about-weather-and-climate/australian-climate-influences.shtml?bookmark=enso

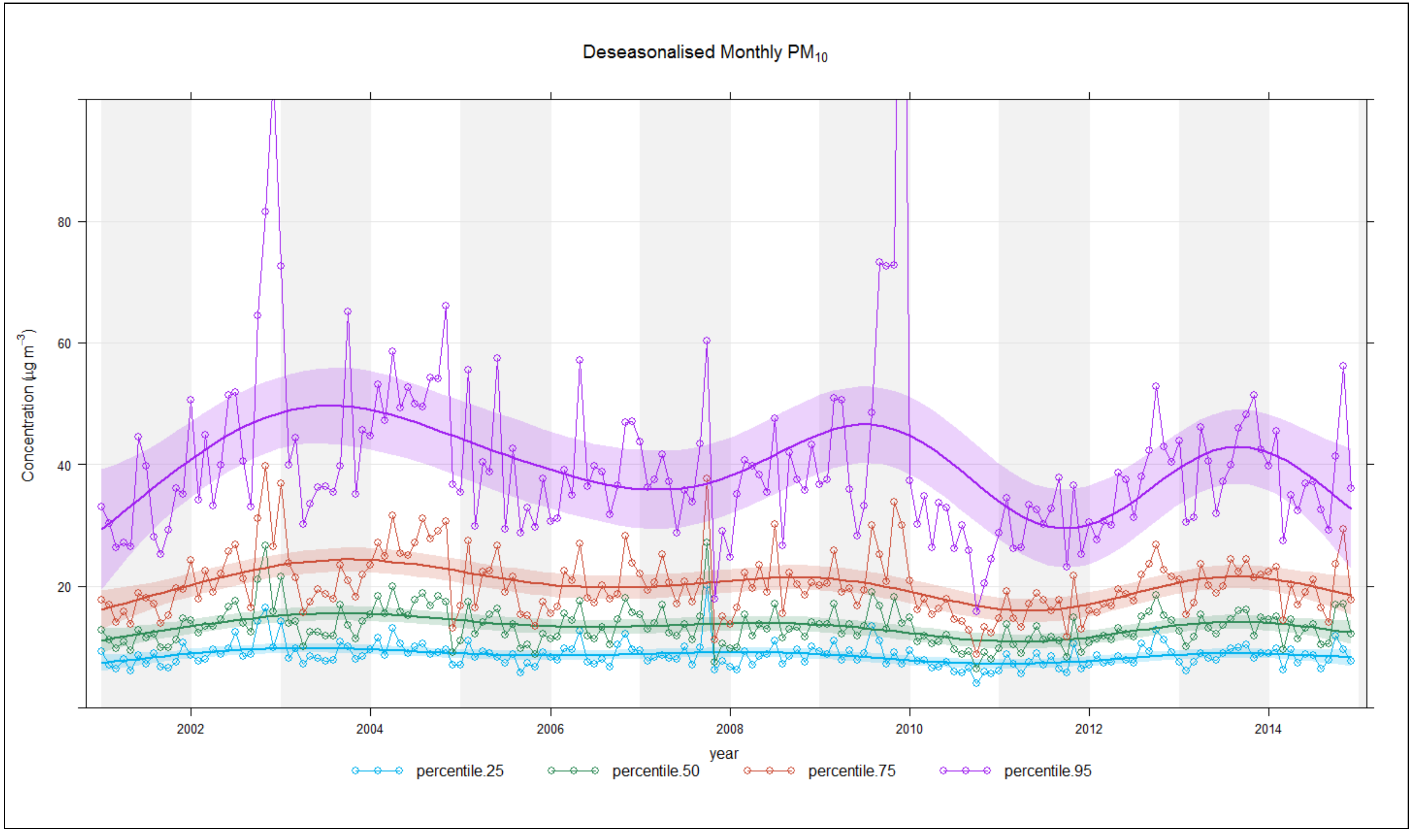


Figure A2-1: Monthly PM_{10} concentrations for Tamworth - 2001 to 2014

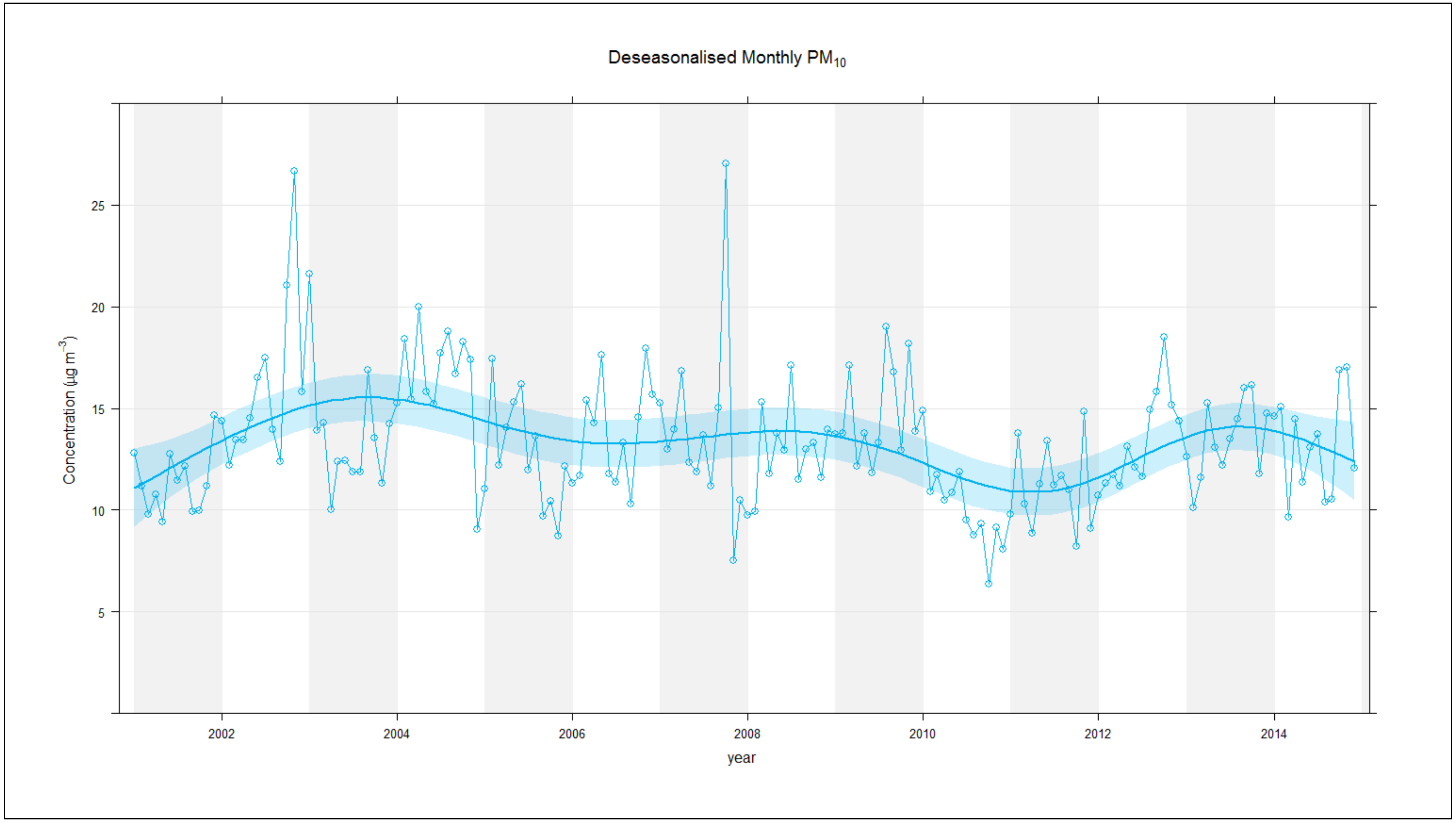


Figure A2-2: Monthly median PM_{10} concentrations for Tamworth - 2001 to 2014

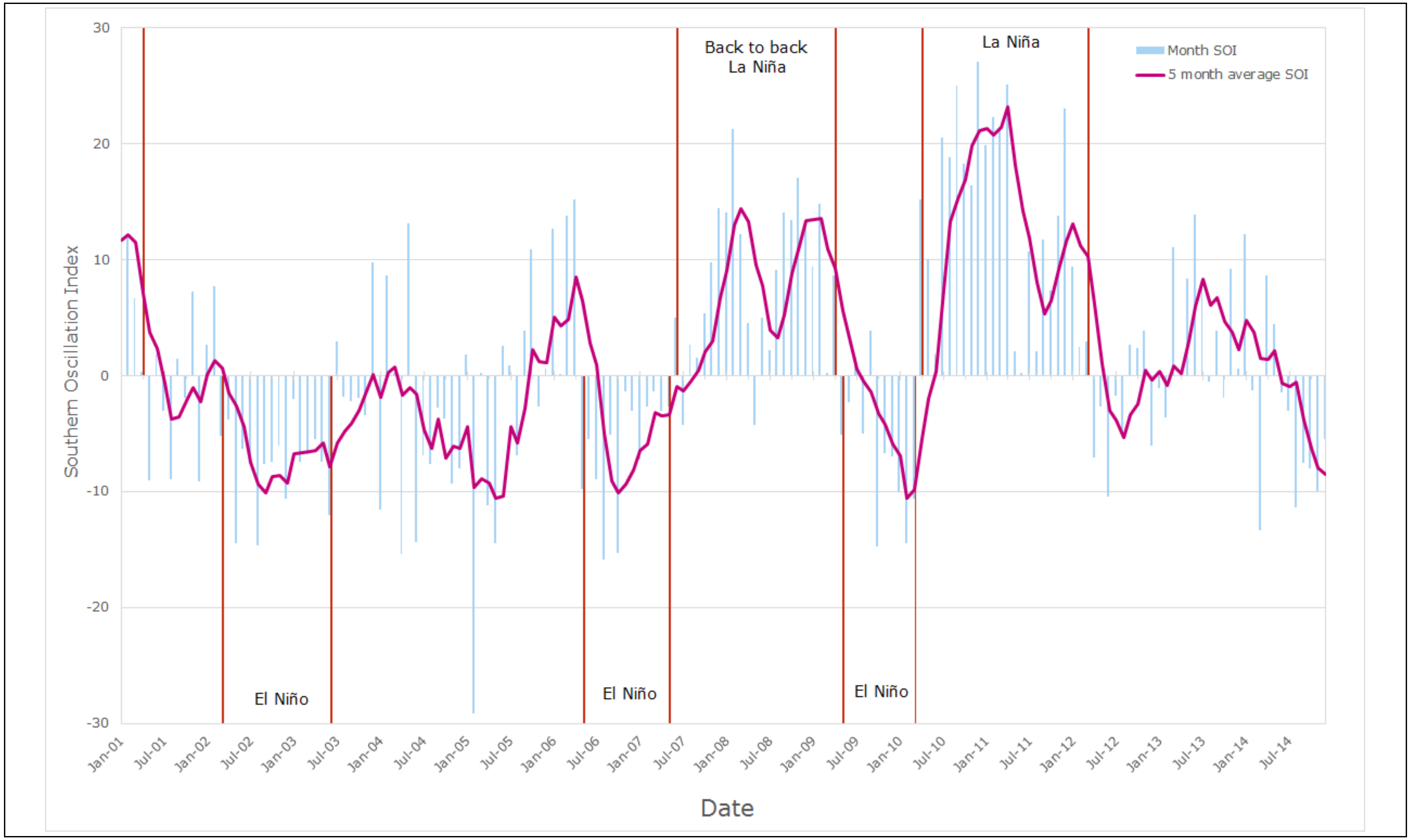


Figure A2-3: Southern Oscillation Index and ENSO cycles - 2001 to 2014

Fugitive emissions from agriculture for wet and dry years

A review of recent rainfall records collected by BoM at six locations across the Gunnedah basin show that notably drier years occurred in 2002 and 2006, while notably wetter years occurred in 2004 and 2010. The annual rainfall for Gunnedah and Narrabri for the previous 13 years is presented in **Figure A2-4**.

The average rainfall across the region is approximately 650 mm and the study year (2013) is slightly below average, with a rainfall range across the region of 490 mm - 650 mm.

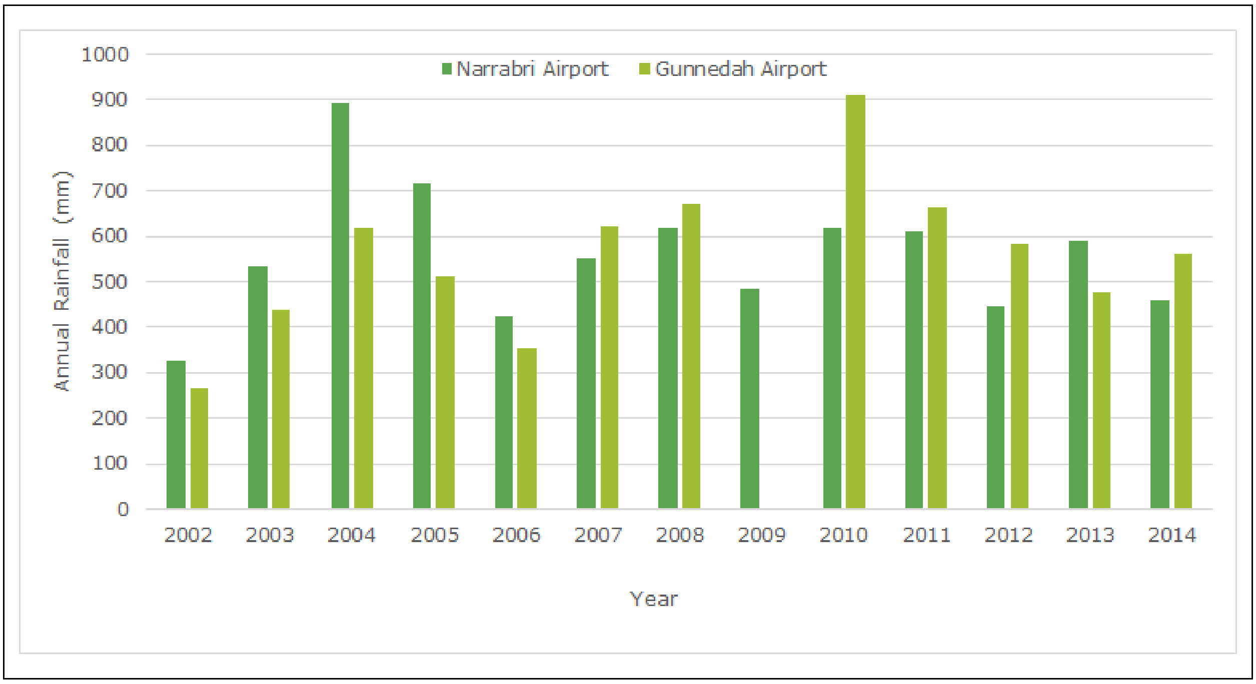


Figure A2-4: Annual rainfall – Gunnedah and Narrabri

As described in **Section 5**, fugitive emission estimates for agriculture are estimated using the CARB wind erosion equation (WEQ), which incorporates a climate factor, derived from monthly rainfall (and temperature, wind speed). By altering monthly rainfall within the emission calculation, variations in fugitive emissions can be estimated for wet and dry years.

This analysis is presented in **Table A2-1**, showing annual emissions and % change from 2013 for a low and high rainfall year. The analysis shows that emission estimation is much more sensitive to lower rainfall years. For just a 44% reduction in annual rainfall, the estimated emission increase by over 300%. Conversely for higher rainfall years, a significant increase in rainfall (53%) results in a moderate decrease in emissions (-8%).

Modelling predictions presented in **Section 10** indicate that fugitive dust from agricultural does not contribute significantly to annual average PM_{10} or $PM_{2.5}$ at the main towns within the study area.

Therefore, although emissions may increase significantly in a low rainfall year, it is not expected that this would necessarily translate to significant ground level concentrations in town centres (in absolute terms).

Table A2-1: Annual PM_{10} and $PM_{2.5}$ emissions from agriculture for wet and dry years

Scenario	Annual rainfall – Gunnedah (mm)	% change from 2013	Estimated emissions (tonnes/annum)		
			PM_{10}	$PM_{2.5}$	% change from 2013
2013 rainfall (slightly below average)	582	N/A	540	94	N/A
Low rainfall year	327	-44%	2362	409	337%
High rainfall year	891	53%	498	86	-8%

Fugitive emissions from mining and quarry operations for wet and dry years

The US EPA AP-42 emission factor documentation for unsealed roads (Chapter 13.2.2) describes a 'natural mitigation' factor due to rainfall and other precipitation, based on the assumption that annual emissions are inversely proportional to the number of days with measureable rain, defined as the number of days with greater than 0.25 mm recorded (P), as follows:

$$[(365 - P)/365]$$

An analysis of 5 years of hourly data at Narrabri and Gunnedah indicates that the number of annual rain days ranges from 50 to 96 (average of 69) with a resultant natural mitigation factor of 0.86 to 0.74 (average 0.81).

The majority of the emission inventories developed for coal mines in the region have not applied this natural mitigation factor. The total coal mine emissions for 2013, presented in this report, may be reduced by approximately 15% if the natural mitigation factor is applied to all sources.

The number of rain days recorded for Gunnedah and Narrabri is only calculated for the previous five years, and 2013 is the lowest of these recent years. However, there is a very strong relationship between the number of rain days and the annual precipitation for these years ($R^2 \geq 0.9$) which allows indicative rain days to be calculated for the wettest and driest years over a longer period.

The revised 'controlled' emissions for 2013 are compared with 'controlled' emissions for a wet and dry year and presented in **Table A2-2**. The analysis shows that wet and dry years might influence coal mine emissions by approximately ± 10%, which would result in a similar magnitude of change in the predicted ground level concentrations.

Table A2-2: Annual PM_{10} and $PM_{2.5}$ emissions from coal mines for wet and dry years

Scenario	Indicative annual rain days	Estimated emissions (tonnes/annum)		
		PM_{10}	$PM_{2.5}$	% change from 2013
Revised 2013 with natural mitigation	62	2,952	363	N/A
Low rainfall year	40	3,097	381	7%
High rainfall year	97	2,555	315	-12%

Modelling wet removal of particles

As a compromise to model run times, wet removal (depletion) was not modelled in this study. Modelling wet (and dry) depletion causes particle mass to be removed from the plume, as it deposited on surfaces, resulting in lower ground level concentrations as the plume travels.

Therefore, by not including wet depletion in the modelling, the ground level concentrations presented in this report may have been overestimated, particularly for larger size fractions. Previous modelling for coal mines sources in the Upper Hunter Valley (Kellaghan et al, 2014) compared CALPUFF predictions with and without wet deposition and found that the inclusion of wet deposition may reduce PM_{10} concentrations by approximately 20% to 50% and $PM_{2.5}$ concentrations by approximately 20% to 30%.

APPENDIX 3
SEASONAL WIND ROSE AND TIME VARIATION PLOTS OF TEMPERATURE AT EVALUATION SITES

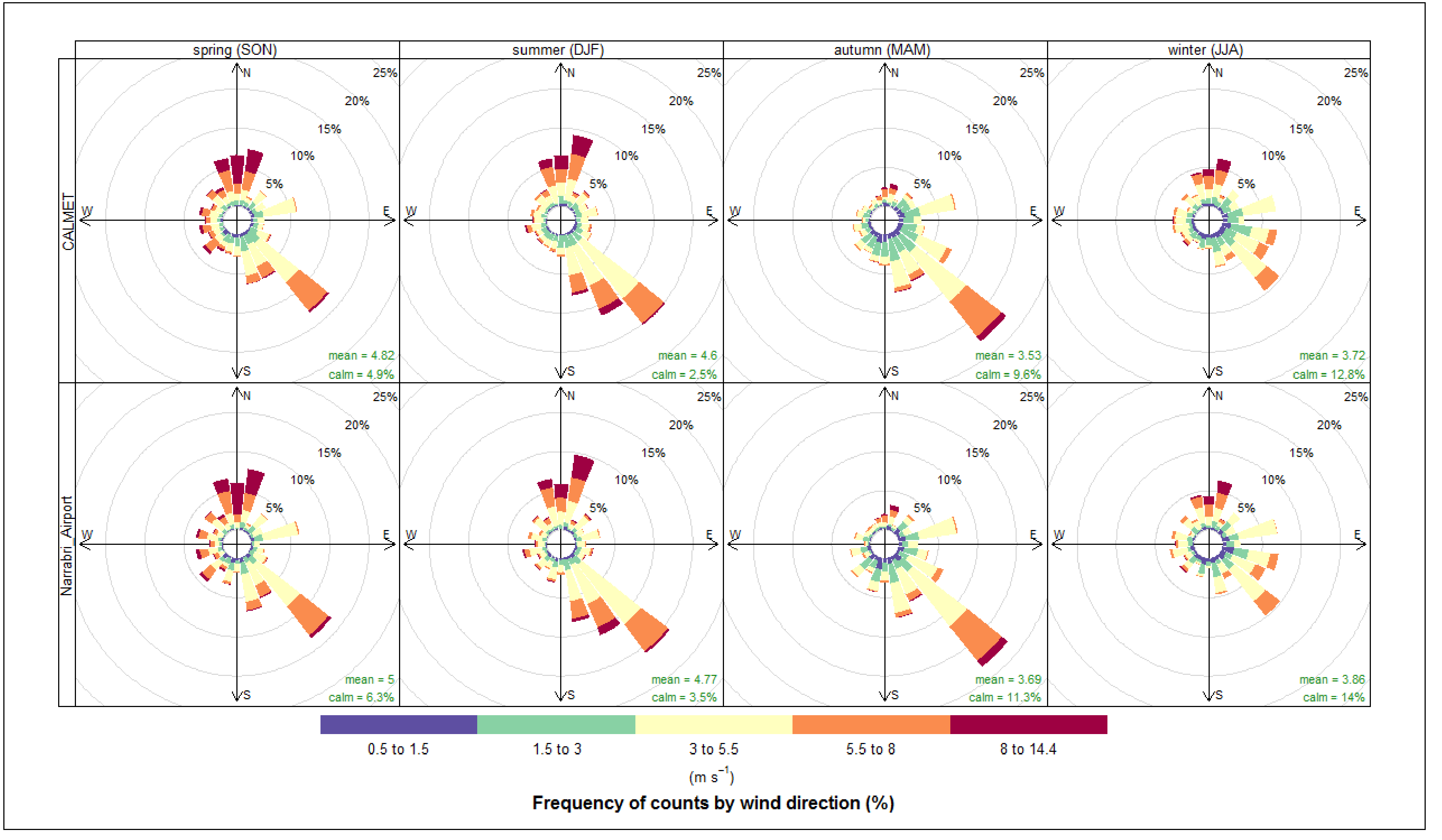


Figure A3-1: Seasonal wind rose comparison for Narrabri Airport

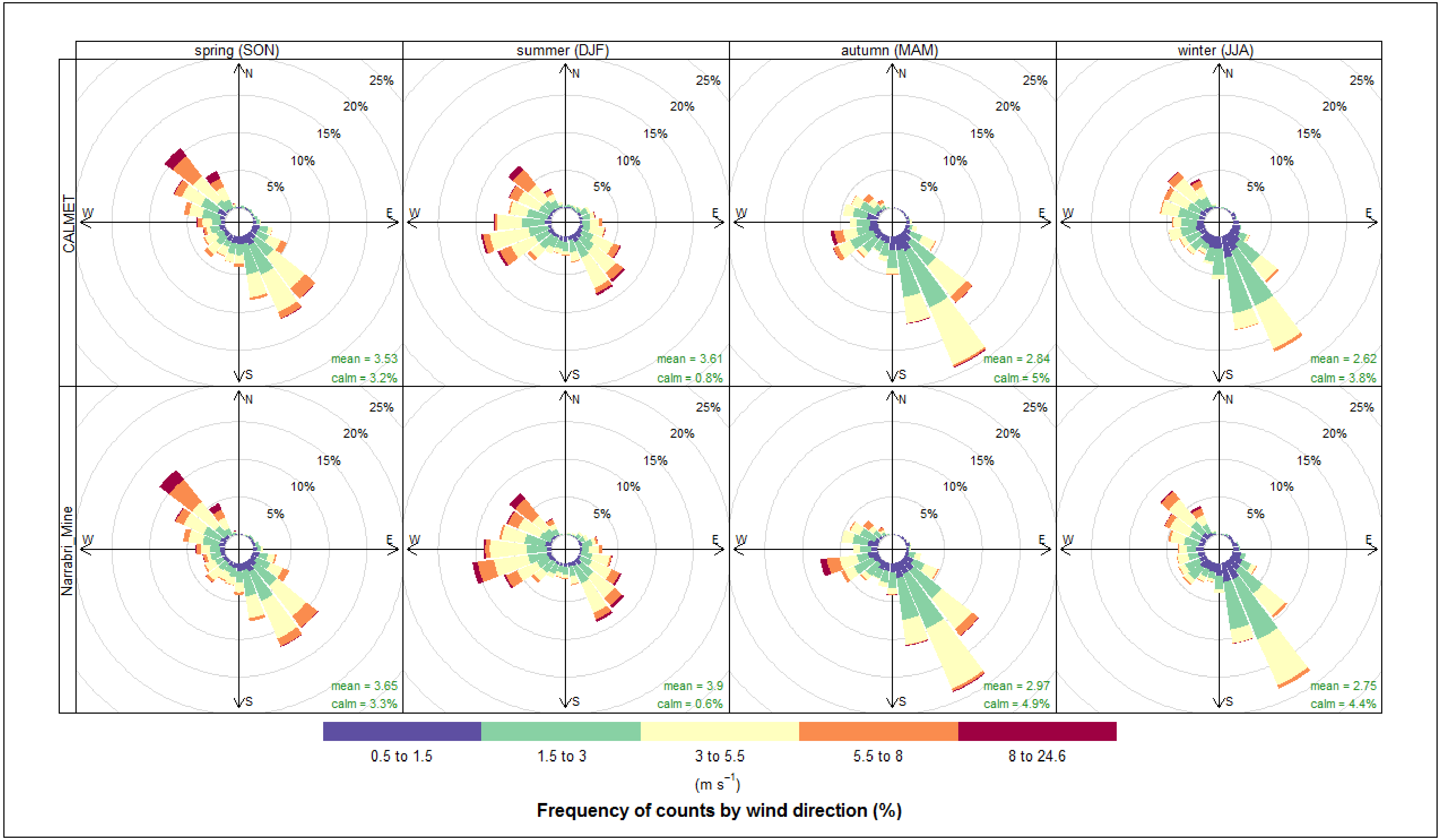


Figure A3-2: Seasonal wind rose comparison for Narrabri Mine

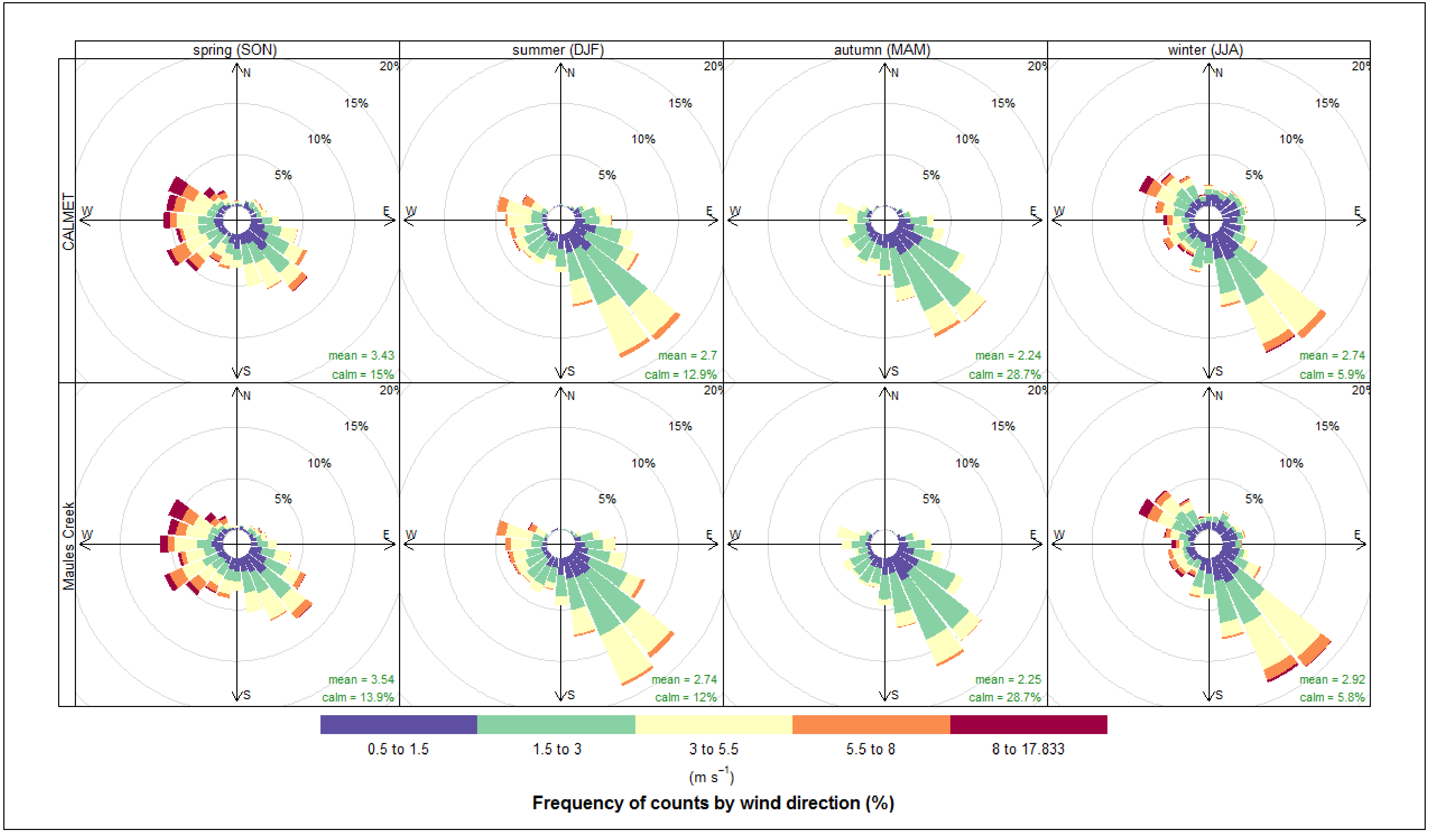


Figure A3-3: Seasonal wind rose comparison for Maules Creek mine

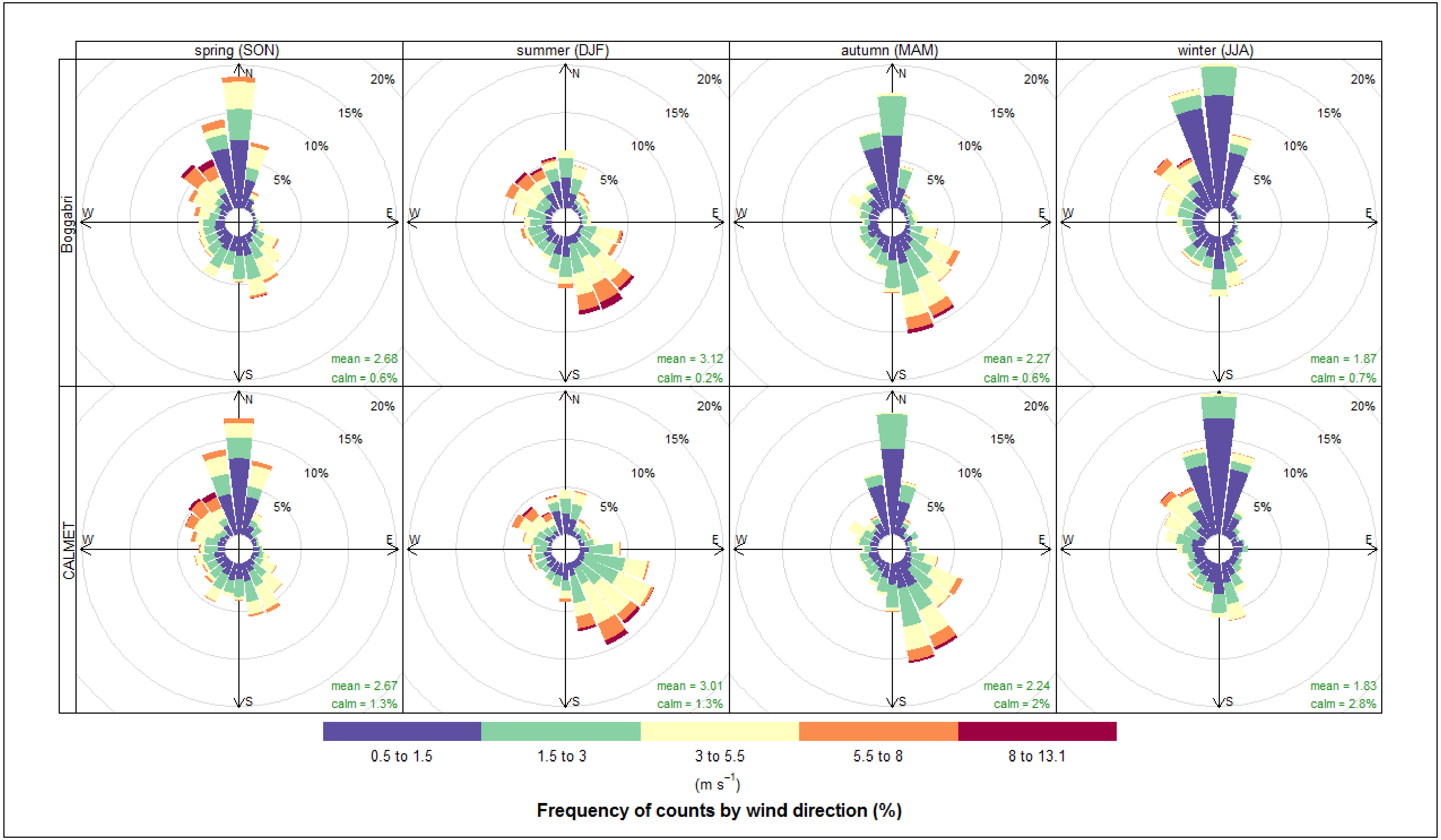


Figure A3-4: Seasonal wind rose comparison for Boggabri mine

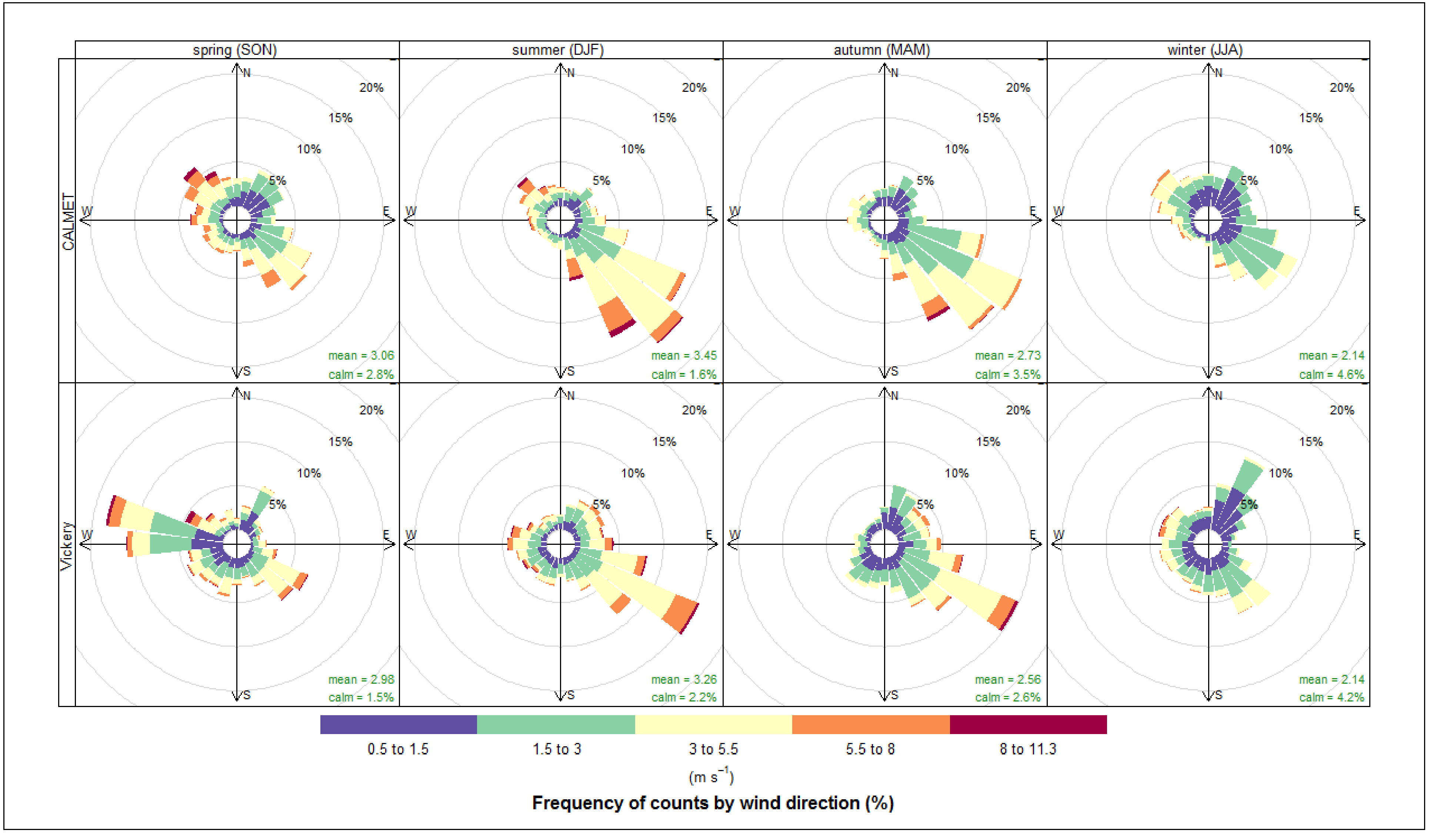


Figure A3-5: Seasonal wind rose comparison for Vickery mine

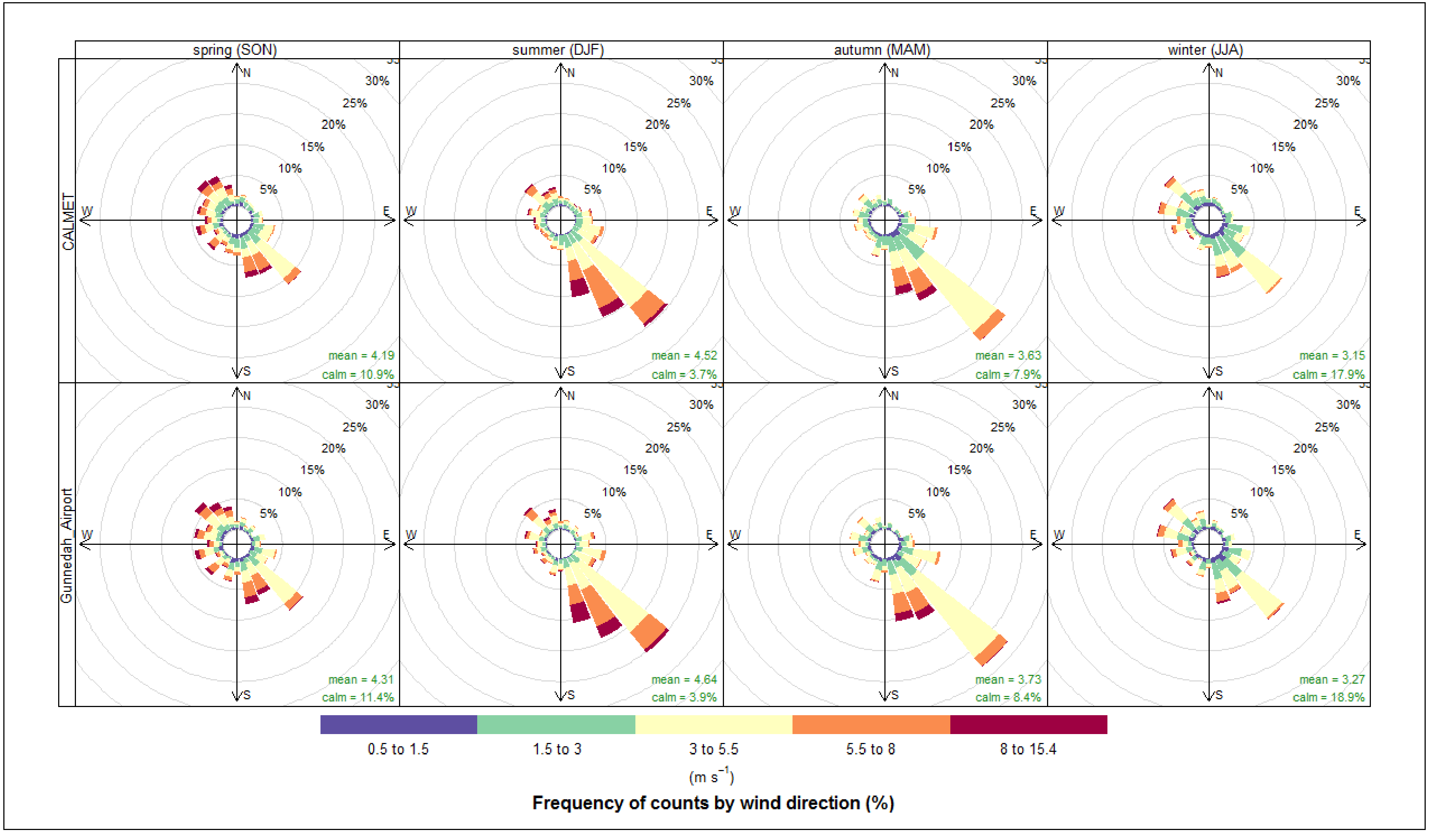


Figure A3-6: Seasonal wind rose comparison for Gunnedah Airport

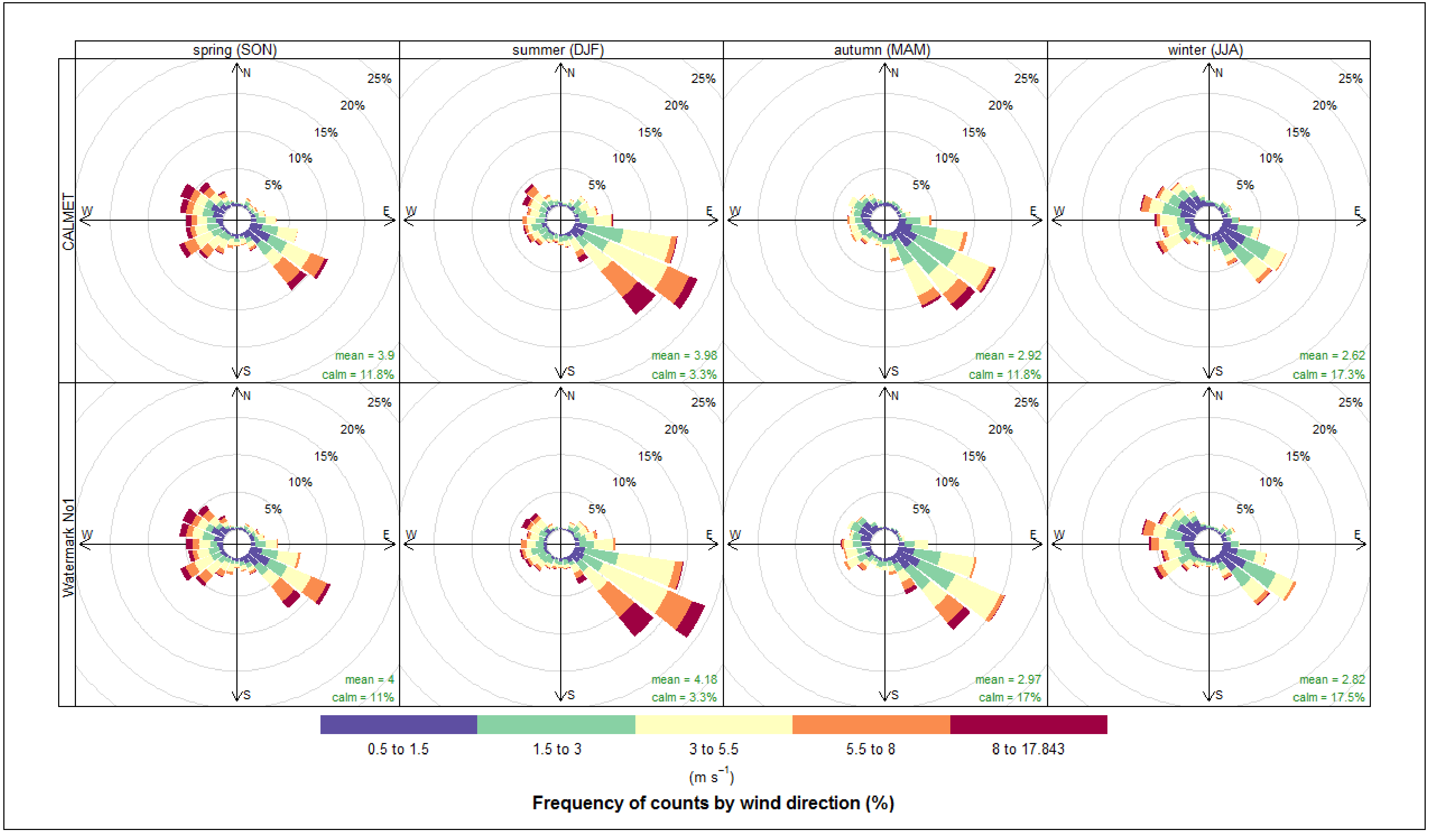


Figure A3-7: Seasonal wind rose comparison for Watermark No.1

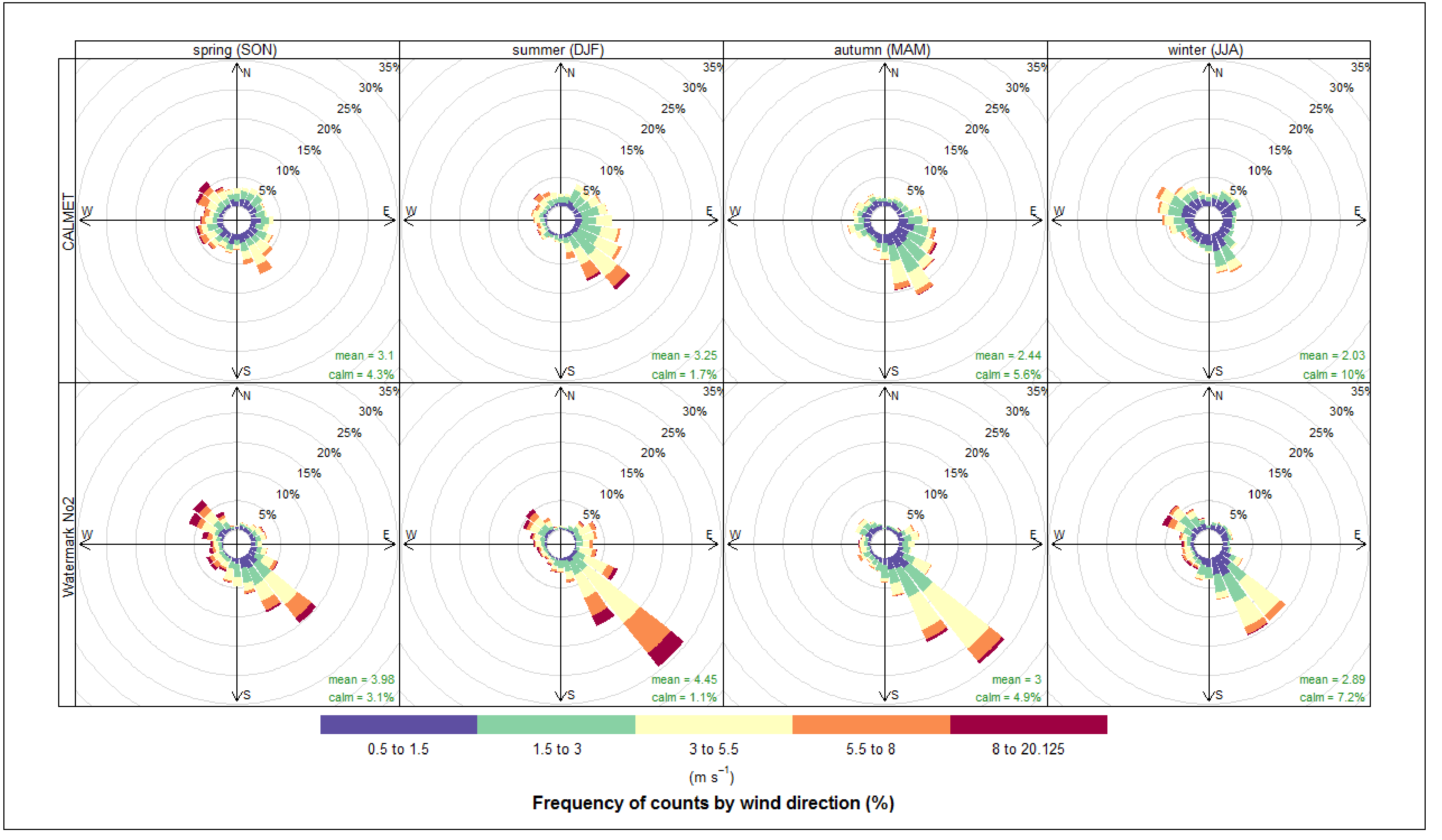


Figure A3-8: Seasonal wind rose comparison for Watermark No.2

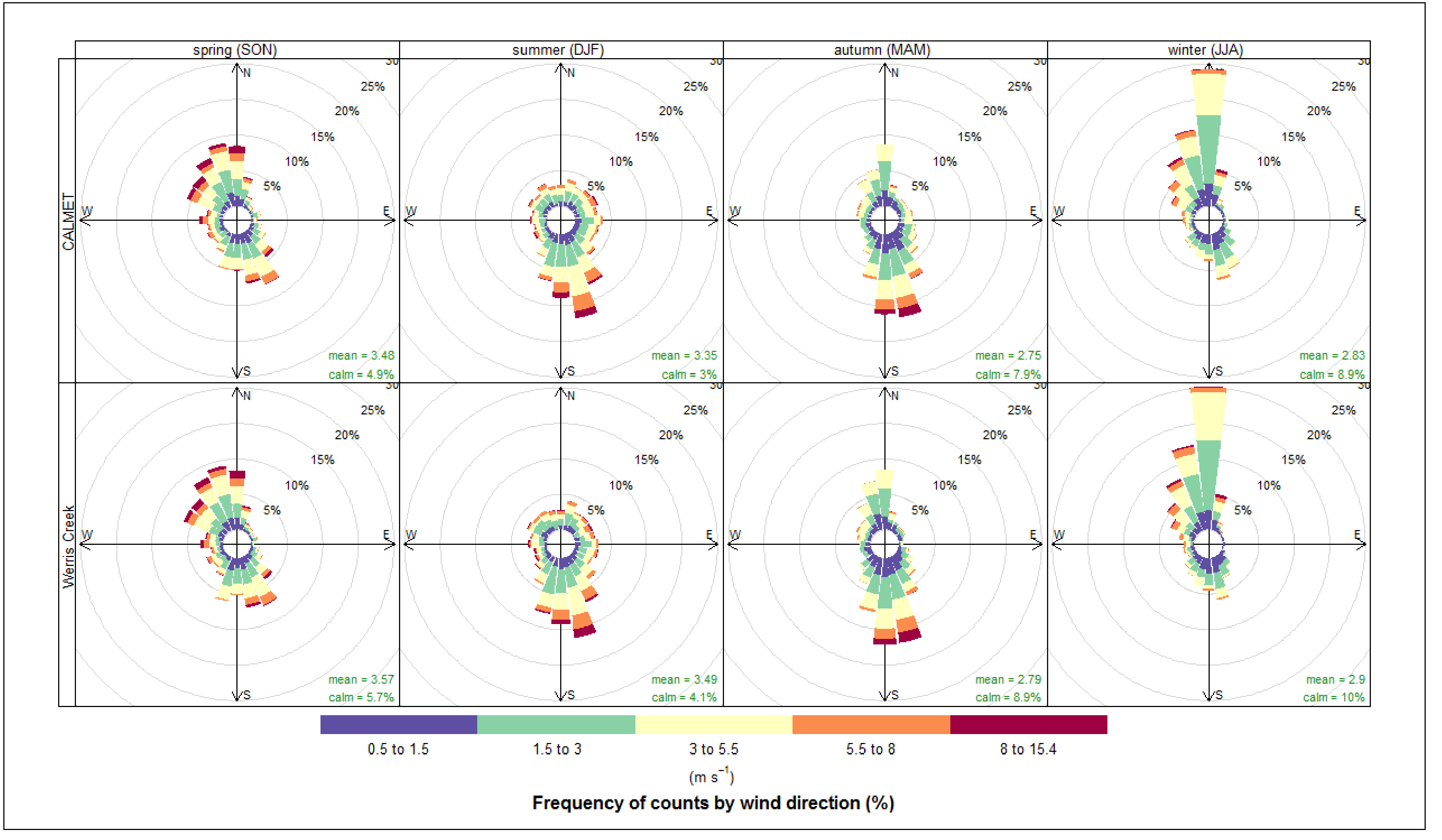


Figure A3-9: Seasonal wind rose comparison for Werris Creek

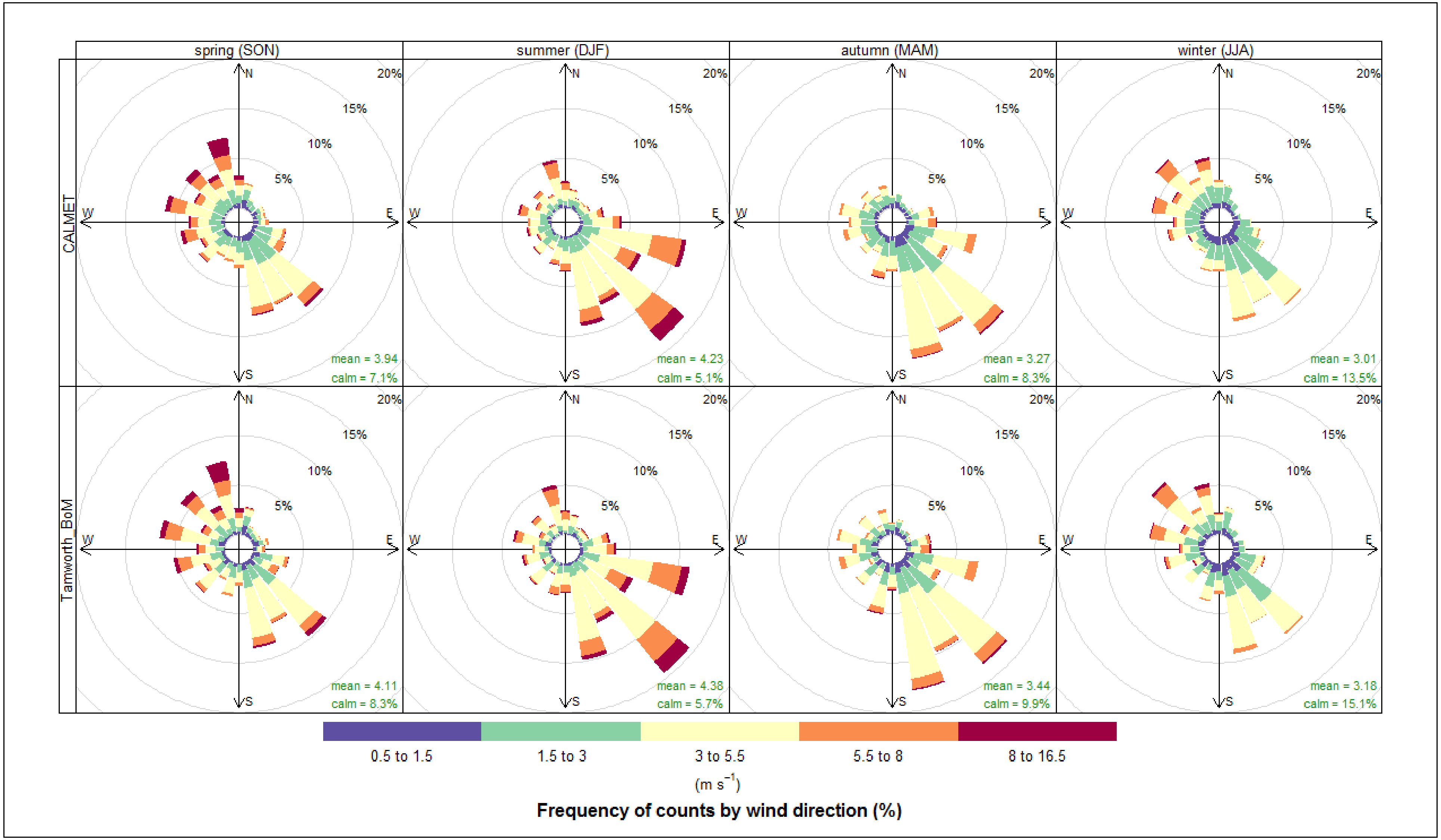


Figure A3-10: Seasonal wind rose comparison for Tamworth BoM

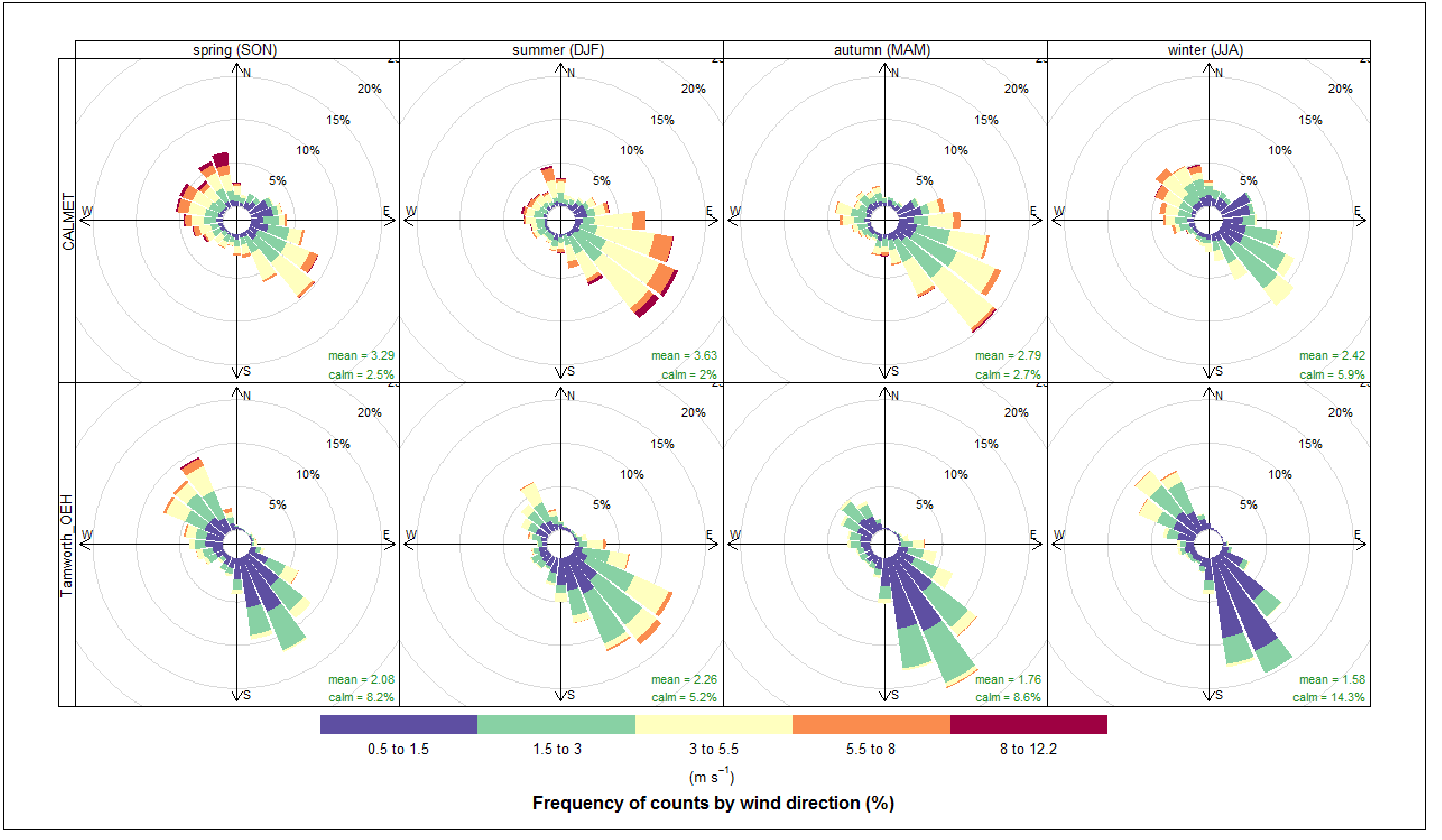


Figure A3-11: Seasonal wind rose comparison for Tamworth OEH

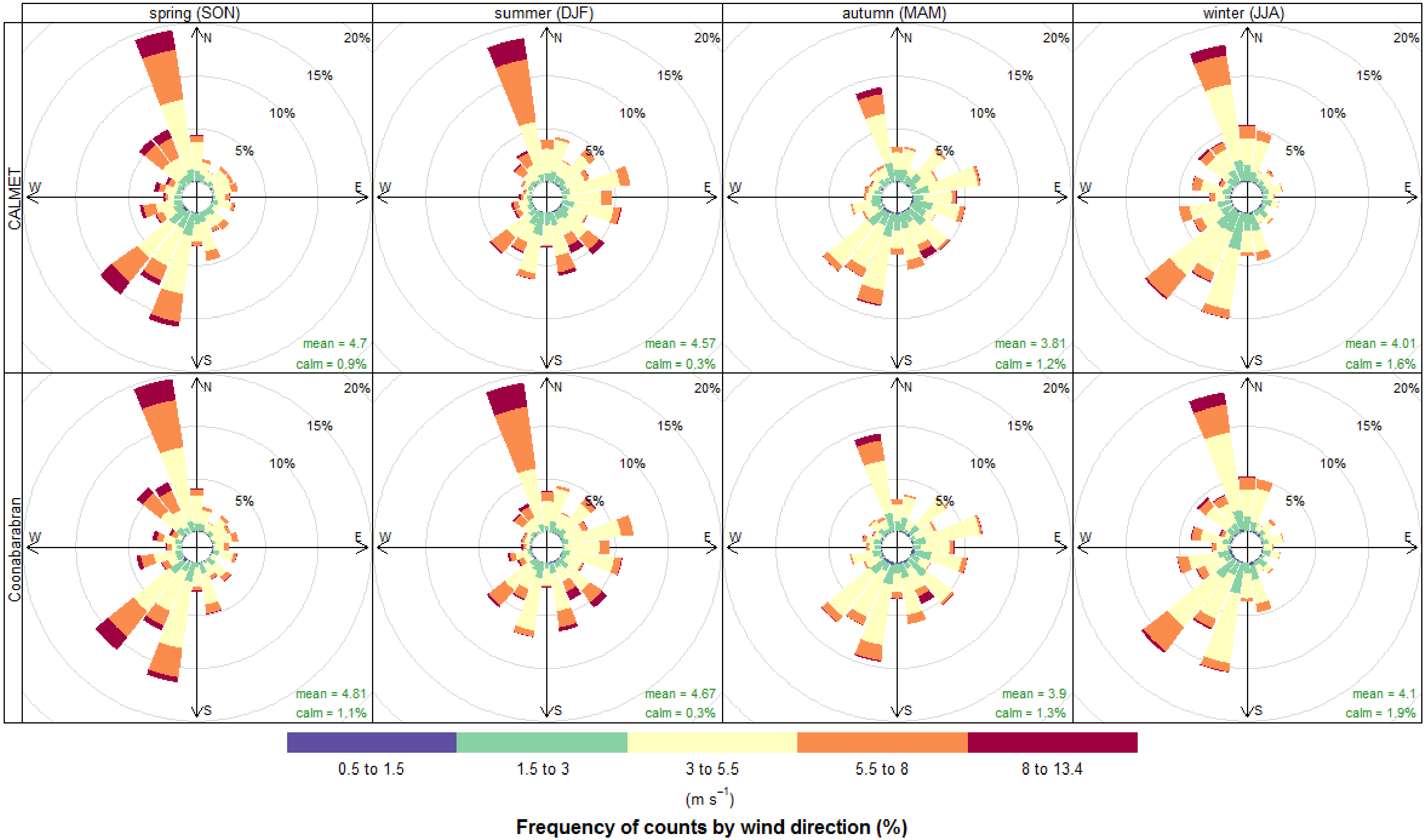


Figure A3-12: Seasonal wind rose comparison for Coonabarabran

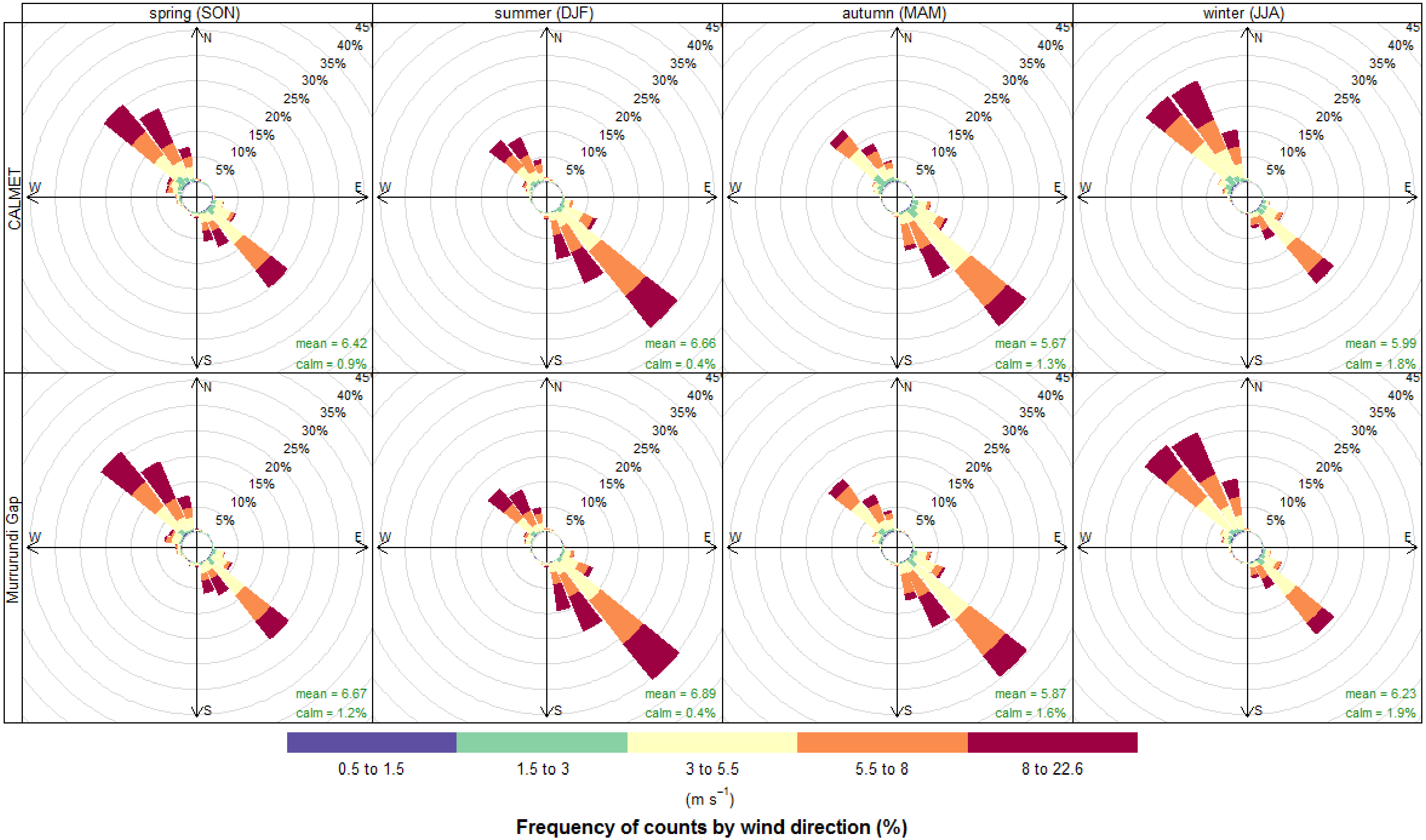


Figure A3-13: Seasonal wind rose comparison for Murrurundi Gap

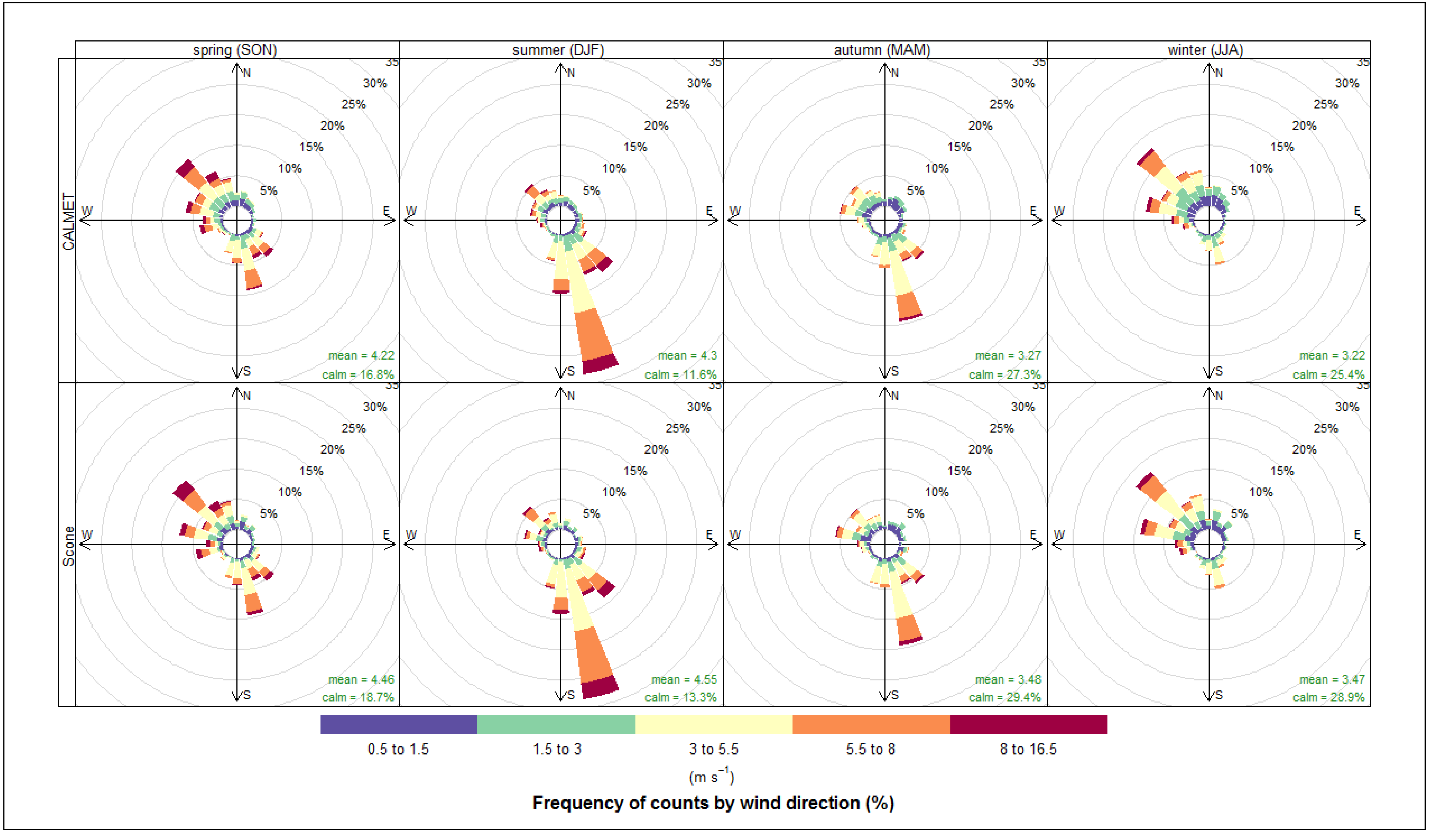


Figure A3-14: Seasonal wind rose comparison for Scone Airport

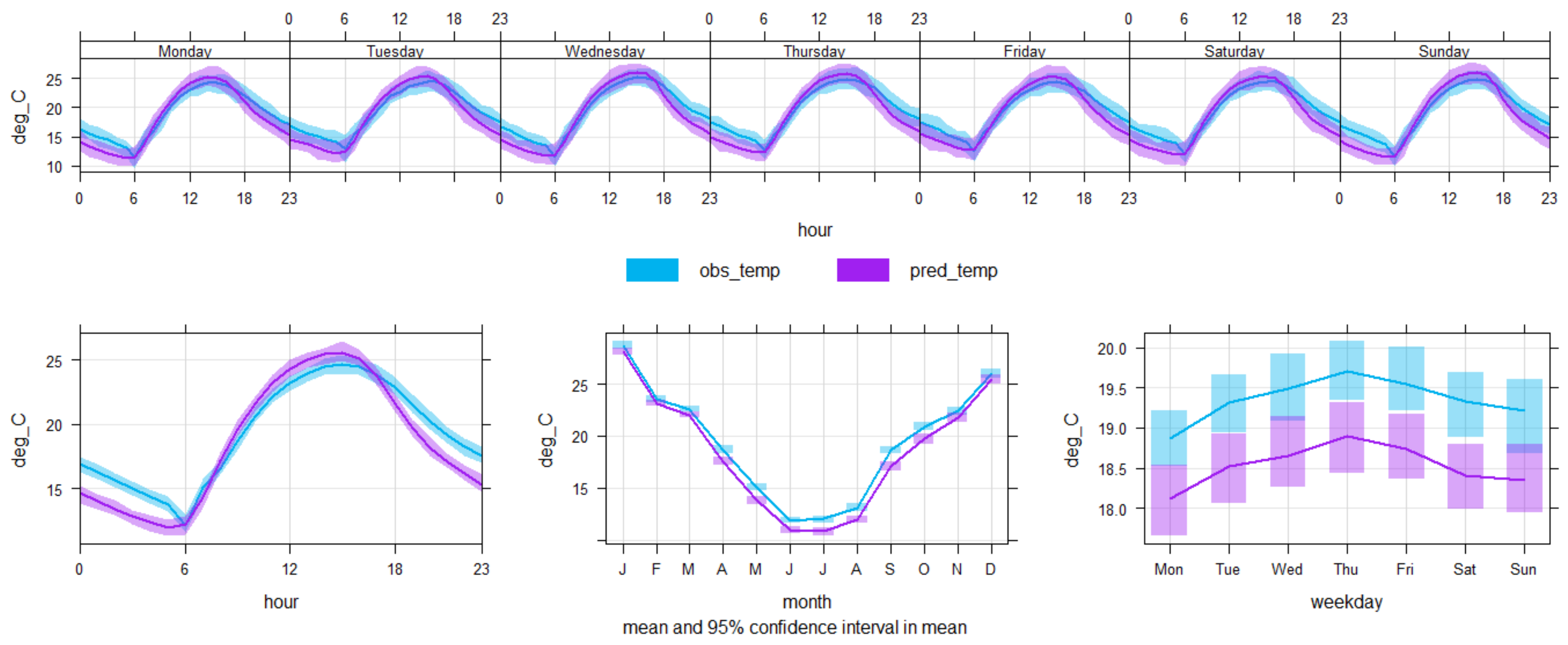


Figure A3-15: Time variation of observed and predicted temperature for Vickery

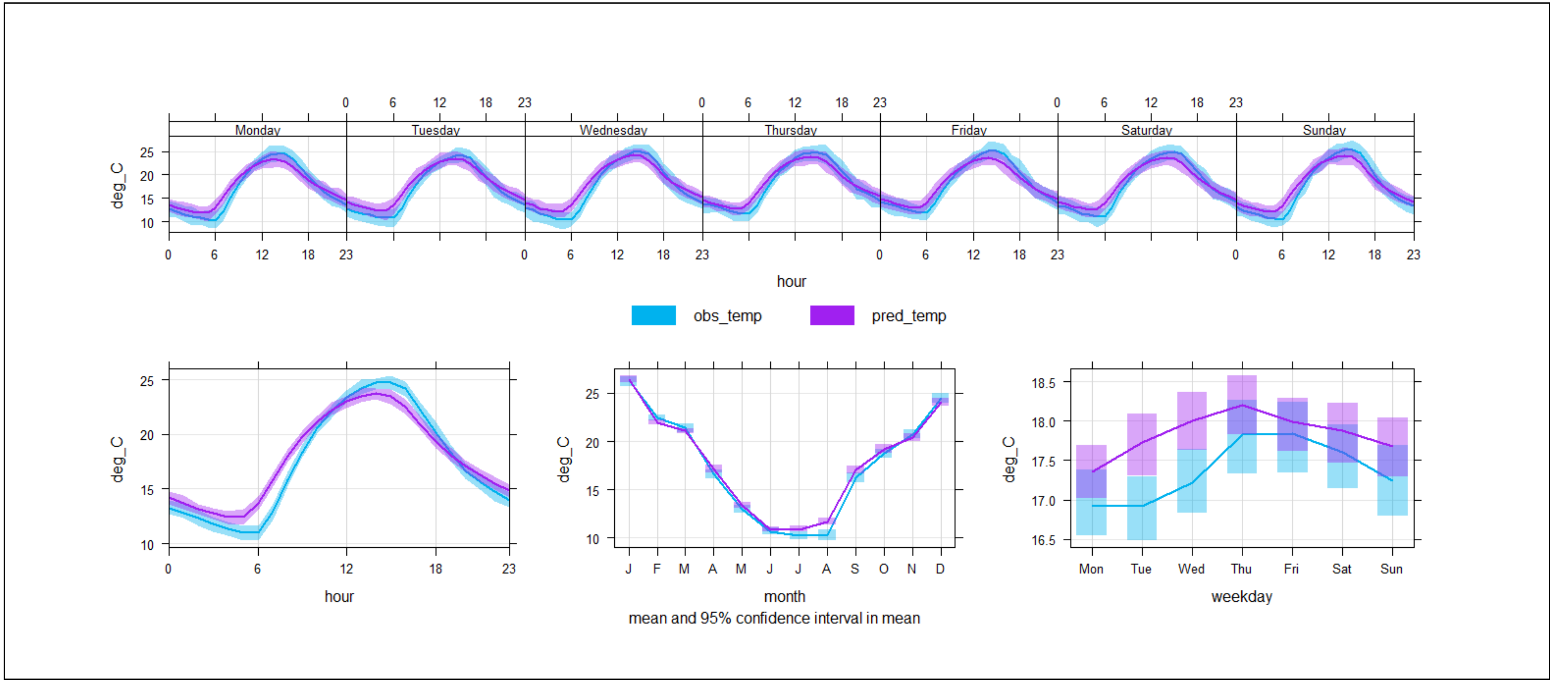


Figure A3-16: Time variation of observed and predicted temperature for Watermark No2

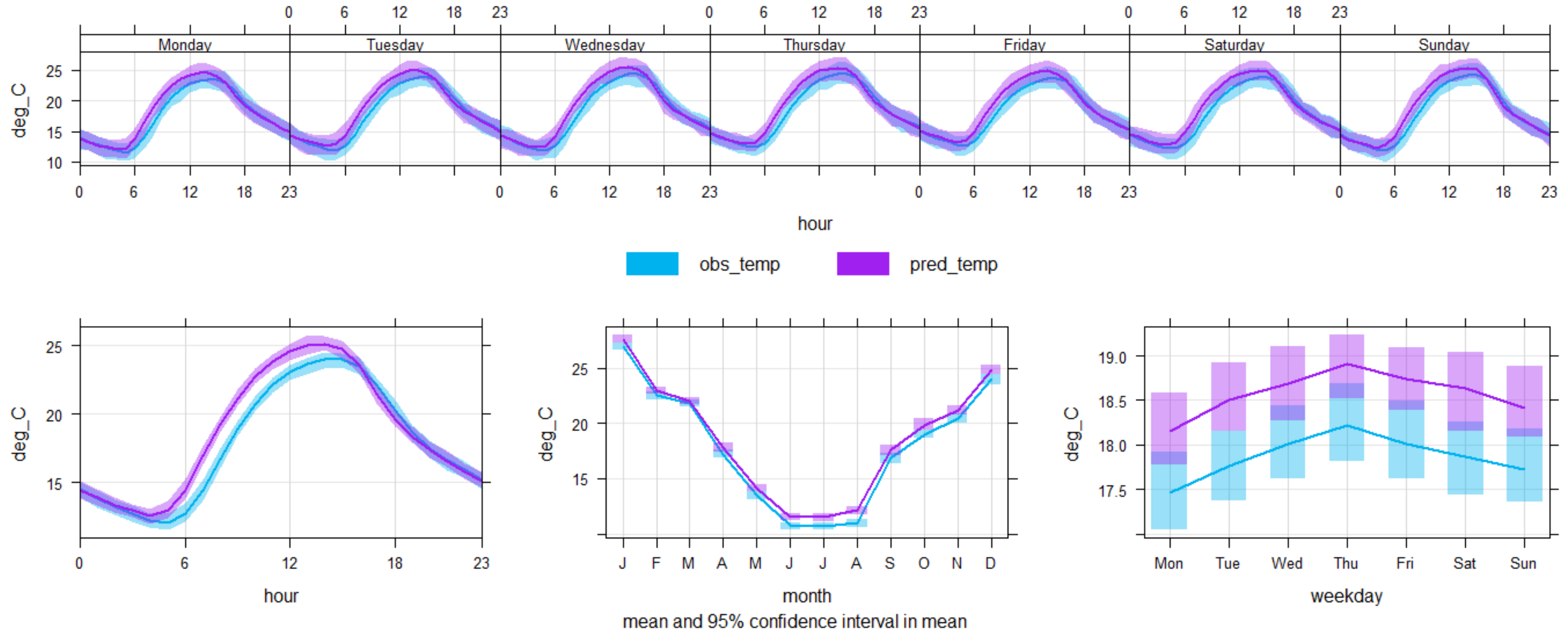


Figure A3-17: Time variation of observed and predicted temperature for Tamworth OEH

APPENDIX 4
STATISTICAL EVALUATION FOR DATA ASSIMILATION SITES

Table A4-1: Statistical evaluation of wind speed												
Test	**Benchmark / Ideal Score**	**Watermark No1**	**Tamworth BoM**	**Narrabri Airport**	**Narrabri Mine**	**Boggabri**	**Maules Creek**	**Gunnedah Airport**	**Werris Creek**	**Murrurundi Gap**	**Scone**	**Coonabarabran**
FAC2	≥ 0.5	0.8	0.8	0.8	0.9	0.9	0.8	0.8	0.8	0.9	0.6	1.0
MB	≤± 0.5 m/s	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.2	-0.1	-0.1
MGE	≤± 2.0 m/s	0.8	1.0	1.1	0.7	0.6	0.7	0.9	0.8	1.0	1.0	0.8
r	1	0.9	0.8	0.8	0.9	0.9	0.9	0.8	0.9	0.9	0.8	0.8
IOA	1	0.8	0.7	0.7	0.8	0.8	0.8	0.7	0.8	0.8	0.8	0.7

Table A4-2: Statistical evaluation of wind direction												
Test	**Benchmark / Ideal Score**	**Watermark No1**	**Tamworth BoM**	**Narrabri Airport**	**Narrabri Mine**	**Boggabri**	**Maules Creek**	**Gunnedah Airport**	**Werris Creek**	**Murrurundi Gap**	**Scone**	**Coonabarabran**
FAC2	≥ 0.5	0.9	0.8	0.8	1.0	0.8	0.9	0.8	0.8	1.0	0.7	0.9
MB	≤± 10 degrees	1.4	7.5	-4.2	1.3	-9.0	-3.0	10.0	-5.2	0.0	18.6	-6.6
MGE	≤± 30 degrees	42	50	48	24	70	39	44	54	23	63	32
r	1	0.6	0.6	0.6	0.8	0.3	0.6	0.6	0.5	0.8	0.5	0.7
IOA	1	0.7	0.7	0.7	0.8	0.6	0.7	0.7	0.7	0.9	0.7	0.8

Table A4-3: Statistical evaluation of temperature

Test	Benchmark / Ideal Score	Watermark No1	Tamworth BoM	Narrabri Airport	Narrabri Mine	Boggabri	Maules Creek	Gunnedah Airport	Werris Creek	Murrurundi Gap	Scone	Coonabarabran
FAC2	≥ 0.5	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
MB	≤± 0.5 K	0.1	0.2	0.0	-1.1	0.0	0.2	0.2	-0.1	0.7	0.0	0.3
MGE	≤± 2.0 K	1.2	1.3	1.4	2.7	1.4	1.3	1.4	1.1	1.2	1.3	1.0
r	1	1.0	1.0	1.0	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0
IOA	1	0.9	0.9	0.9	0.8	0.9	0.9	0.9	0.9	0.9	0.9	0.9

APPENDIX 5
DETAILED COAL MINE EMISSION CALCULATIONS

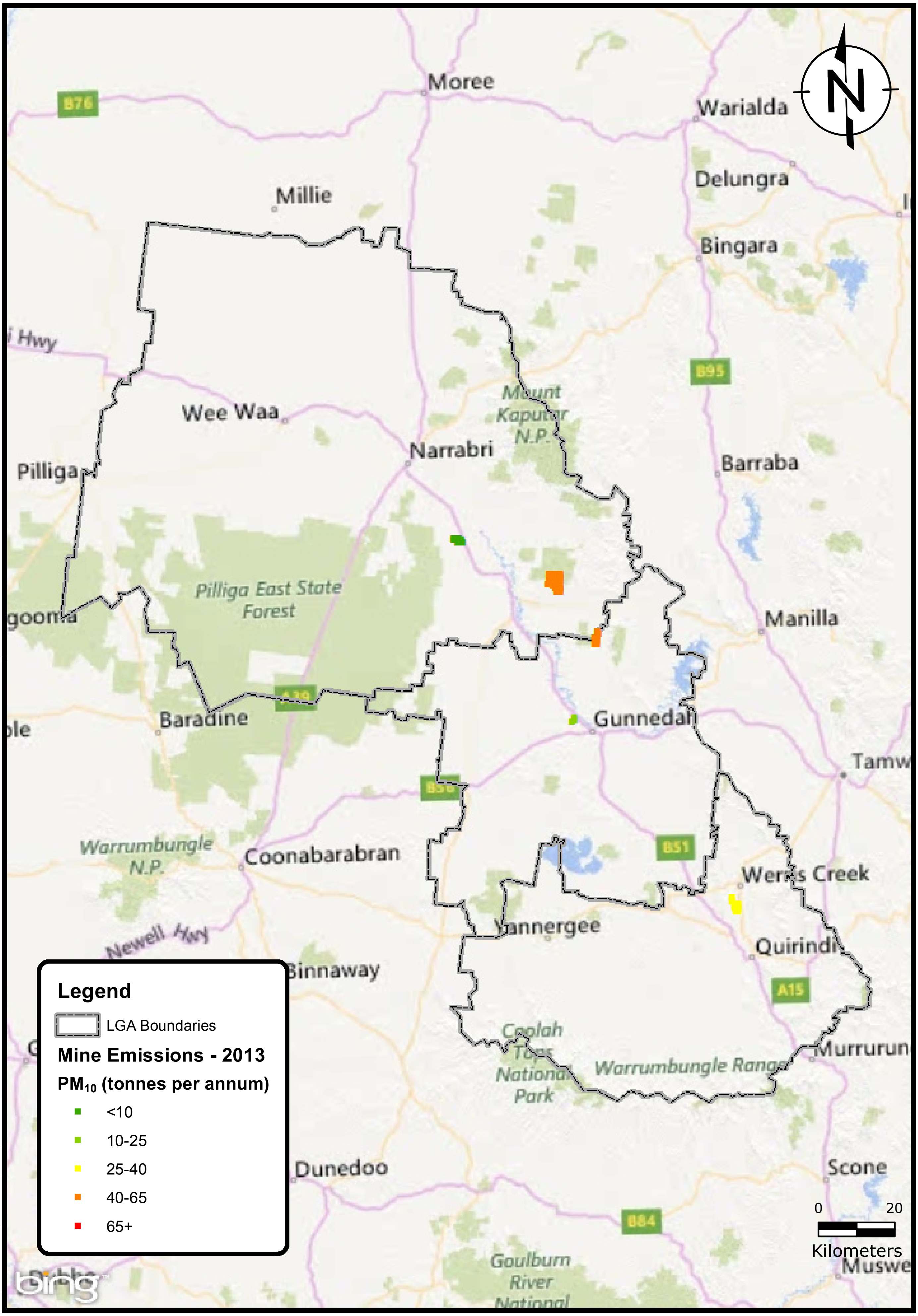
Mine	EA Assessment Year	EA ROM (t)	EA Waste (Mtpa)	EA Emissions (kg/annum)			kg PM / t ROM			PM ratios		Splits			2013 ROM (t)	2013 Emissions (kg/annum)		2013 Emissions (kg/annum)			2013 Emissions (kg/annum)		
																PM10	PM2.5	PM10			PM2.5		
				TSP	PM10	PM2.5	TSP/ ROM	PM10 /ROM	PM2.5 /ROM	PM10 /TSP	PM2.5 /PM1	WE	WS	WI				WE	WS	WI	WE	WS	WI
Narrabri	N/A	8,000,000	N/A	414,673	161909	33771	0.1	0.0	0.00	0.4	0.2	0.3	0.04	0.7	5,390,572	109,098	22,756	32,502	3,822	72,774	6,779	797	15,179
Tarrawonga	Year 2 (2014)	3,000,000	67.9	2,776,396	1,085,571	130,490.6	0.9	0.4	0.04	0.4	0.1	0.1	0.05	0.8	2,073,051	750,148	90,171	106,717	33,970	609,461	12,828	4,083	73,260
	Year 4 (2016)	3,000,000	64.4	2,855,504	1,116,502	134,208.7	1.0	0.4	0.04	0.4	0.1												
	Year 6 (2018)	3,000,000	75.9	2,861,085	1,118,684	134,471.0	1.0	0.4	0.04	0.4	0.1	0.1	0.05	0.8									
	Year 16 (2028)	3,000,000	71.3	2,719,719	1,063,410	127,826.8	0.9	0.4	0.04	0.4	0.1												
Maules Creek	Year 5 (2016)	12,400,000	170.9	6,584,245	2,574,440	309,460	0.5	0.2	0.02	0.4	0.1				Not commenced								
	Year 10 (2021)	12,700,000	170.9	7,929,117	3,100,285	372,668	0.6	0.2	0.03	0.4	0.1	0.2	0.08	0.7									
	Year 15 (2026)	11,200,000	170.9	7,589,496	2,967,493	356,706	0.7	0.3	0.03	0.4	0.1												
	Year 21 (2032)	13,000,000	196.5	7,655,684	2,993,372	359,817	0.6	0.2	0.03	0.4	0.1												
Rocglen	Year 1 (2011)	1,500,000	16.2	1,171,386	458,012	55,055	0.8	0.3	0.04	0.4	0.1												
	Year 5 (2015)	1,500,000	18.6	1,451,755	567,636	68,232	1.0	0.4	0.05	0.4	0.1	0.4	0.03	0.6	1,298,958	491,557	59,087	182,620	14,787	294,151	21,952	1,777	35,358
	Year 10 (2020)	1,500,000	27.3	1,534,888	600,141	72,140	1.0	0.4	0.05	0.4	0.1												
Werris Creek	Year 3 Mod	2,500,000	28.2	2,073,000	568,000	62,000	0.8	0.2	0.02	0.3	0.1	0.03	0.1	0.8	1,872,316	425,390	46,433	14,798	57,700	352,892	1,615	6,298	38,520
	Year 7	2,500,000	28.2	1,445,000	500,000	74,000	0.6	0.2	0.03	0.3	0.1												
	Year 15	2,500,000	28.2	1,553,000	592,000	85,000	0.6	0.2	0.03	0.4	0.1												
Vickery Extension Project	Year 2 (2015)	1,500,000	57.5	3,584,806	918,646	137,319	2.4	0.6	0.09	0.3	0.1				Not commenced								
	Year 7 (2020)	4,500,000	67.5	5,585,833	1,421,693	231,450	1.2	0.3	0.05	0.3	0.2	0.2	0.05	0.8									
	Year 17 (2030)	4,500,000	69	5,415,774	1,413,473	227,143	1.2	0.3	0.05	0.3	0.2												
	Year 26 (2039)	4,500,000	76.66	6,234,577	1,653,679	255,454	1.4	0.4	0.06	0.3	0.2												
Boggabri	Year 1 (2012)	2,500,000	43.0	3,509,469	1,372,202	164,945	1.4	0.5	0.07	0.4	0.1												
	Year 5 (2016)	6,970,000	136.4	7,218,763	2,822,536	339,282	1.0	0.4	0.05	0.4	0.1	0.3	0.03	0.7	4,063,029	1,645,344	197,778	584,428	41,966	1,018,950	70,251	5,045	122,482
	Year 10 (2021)	7,890,000	103.7	7,512,014	2,937,197	353,065	1.0	0.4	0.04	0.4	0.1	0.4	0.03	0.6									
	Year 21 (2032)	7,230,000	107.8	8,395,716	3,282,725	394,599	1.2	0.5	0.05	0.4	0.1												
Watermark	Year 1 (2014)	100,000	9.7	97,534	38,136	4,584	1.0	0.4	0.05	0.4	0.1				Not commenced								
	Year 2 (2015)	2,700,000	27.3	2,565,377	1,003,062	120,573	1.0	0.4	0.04	0.4	0.1												
	Year 5 (2018)	10,000,000	43.4	3,749,302	1,465,977	176,217	0.4	0.1	0.02	0.4	0.1												
	Year 10 (2023)	10,000,000	68.2	5,692,490	2,225,764	267,547	0.6	0.2	0.03	0.4	0.1	0.1	0.07	0.8									
	Year 15 (2028)	9,800,000	68	5,546,335	2,168,617	260,678	0.6	0.2	0.03	0.4	0.1												
	Year 21 (2034)	9,800,000	68.2	4,714,770	1,843,475	221,594	0.5	0.2	0.02	0.4	0.1												
	Year 25 (2038)	10,000,000	63.5	6,475,901	2,532,077	304,367	0.6	0.3	0.03	0.4	0.1												
	Year 30 (2043)	1,900,000	6.9	955,596	373,638	44,913	0.5	0.2	0.02	0.4	0.1												
Gunnedah CHPP															2,936,187	59,424	12,395	17,704	2,082	39,639	3,693	434	8,268

Figure A5-1: Detailed emission calculations for coal mines - 2013

Mine	EA Assessment Year	EA ROM (t)	EA Waste (Mtpa)	EA Emissions (kg/annum)			kg PM / t ROM			PM ratios		Splits			2021 ROM (t)	2021 Emissions (kg/annum)		2021 Emissions (kg/annum)			2021 Emissions (kg/annum)		
																PM10	PM2.5	PM10			PM2.5		
				TSP	PM10	PM2.5	TSP/ ROM	PM10 /ROM	PM2.5 /ROM	PM10 /TSP	PM2.5 /PM1	WE	WS	WI				WE	WS	WI	WE	WS	WI
Narrabri	N/A	8,000,000	N/A	414,673	161909	33771	0.1	0.0	0.00	0.4	0.2	0.3	0.04	0.7	8,000,000	161,909	33,771	48,235	5,672	108,001	10,061	1,183	22,527
Tarrawonga	Year 2 (2014)	3,000,000	67.9	2,776,396	1,085,571	130,490.6	0.9	0.4	0.04	0.4	0.1	0.1	0.05	0.8									
	Year 4 (2016)	3,000,000	64.4	2,855,504	1,116,502	134,208.7	1.0	0.4	0.04	0.4	0.1												
	Year 6 (2018)	3,000,000	75.9	2,861,085	1,118,684	134,471.0	1.0	0.4	0.04	0.4	0.1	0.1	0.05	0.8	3,000,000.0	1,118,684	134,471.0	121,913	54,938	941,834	14,655	6,604	113,213
	Year 16 (2028)	3,000,000	71.3	2,719,719	1,063,410	127,826.8	0.9	0.4	0.04	0.4	0.1												
Maules Creek	Year 5 (2016)	12,400,000	170.9	6,584,245	2,574,440	309,460	0.5	0.2	0.02	0.4	0.1												
	Year 10 (2021)	12,700,000	170.9	7,929,117	3,100,285	372,668	0.6	0.2	0.03	0.4	0.1	0.2	0.08	0.7	13,000,000	3,173,520	381,472	771,335	267,963	2,134,221	92,718	32,210	256,543
	Year 15 (2026)	11,200,000	170.9	7,589,496	2,967,493	356,706	0.7	0.3	0.03	0.4	0.1												
	Year 21 (2032)	13,000,000	196.5	7,655,684	2,993,372	359,817	0.6	0.2	0.03	0.4	0.1												
Rocglen	Year 1 (2011)	1,500,000	16.2	1,171,386	458,012	55,055	0.8	0.3	0.04	0.4	0.1				Production to cease in FY2016								
	Year 5 (2015)	1,500,000	18.6	1,451,755	567,636	68,232	1.0	0.4	0.05	0.4	0.1	0.4	0.03	0.6									
	Year 10 (2020)	1,500,000	27.3	1,534,888	600,141	72,140	1.0	0.4	0.05	0.4	0.1												
Werris Creek	Year 3 Mod	2,500,000	28.2	2,073,000	568,000	62,000	0.8	0.2	0.02	0.3	0.1	0.03	0.1	0.8	2,500,000	568,000	62,000	19,759	77,044	471,197	2,157	8,410	51,434
	Year 7	2,500,000	28.2	1,445,000	500,000	74,000	0.6	0.2	0.03	0.3	0.1												
	Year 15	2,500,000	28.2	1,553,000	592,000	85,000	0.6	0.2	0.03	0.4	0.1												
Vickery Extension Project	Year 2 (2015)	1,500,000	57.5	3,584,806	918,646	137,319	2.4	0.6	0.09	0.3	0.1												
	Year 7 (2020)	4,500,000	67.5	5,585,833	1,421,693	231,450	1.2	0.3	0.05	0.3	0.2	0.2	0.05	0.8	10,000,000	3,159,318	514,334	616,652	164,156	2,378,510	100,390	26,724	387,219
	Year 17 (2030)	4,500,000	69	5,415,774	1,413,473	227,143	1.2	0.3	0.05	0.3	0.2												
	Year 26 (2039)	4,500,000	76.66	6,234,577	1,653,679	255,454	1.4	0.4	0.06	0.3	0.2												
Boggabri	Year 1 (2012)	2,500,000	43.0	3,509,469	1,372,202	164,945	1.4	0.5	0.07	0.4	0.1												
	Year 5 (2016)	6,970,000	136.4	7,218,763	2,822,536	339,282	1.0	0.4	0.05	0.4	0.1	0.3	0.03	0.7									
	Year 10 (2021)	7,890,000	103.7	7,512,014	2,937,197	353,065	1.0	0.4	0.04	0.4	0.1	0.4	0.03	0.6	7,800,000	2,903,693	349,037	1,031,395	74,062	1,798,237	123,978	8,903	216,156
	Year 21 (2032)	7,230,000	107.8	8,395,716	3,282,725	394,599	1.2	0.5	0.05	0.4	0.1												
Watermark	Year 1 (2014)	100,000	9.7	97,534	38,136	4,584	1.0	0.4	0.05	0.4	0.1												
	Year 2 (2015)	2,700,000	27.3	2,565,377	1,003,062	120,573	1.0	0.4	0.04	0.4	0.1												
	Year 5 (2018)	10,000,000	43.4	3,749,302	1,465,977	176,217	0.4	0.1	0.02	0.4	0.1												
	Year 10 (2023)	10,000,000	68.2	5,692,490	2,225,764	267,547	0.6	0.2	0.03	0.4	0.1	0.1	0.07	0.8	10,000,000	2,225,764	267,547	226,049	151,792	1,847,923	27,172	18,246	222,129
	Year 15 (2028)	9,800,000	68	5,546,335	2,168,617	260,678	0.6	0.2	0.03	0.4	0.1												
	Year 21 (2034)	9,800,000	68.2	4,714,770	1,843,475	221,594	0.5	0.2	0.02	0.4	0.1												
	Year 25 (2038)	10,000,000	63.5	6,475,901	2,532,077	304,367	0.6	0.3	0.03	0.4	0.1												
	Year 30 (2043)	1,900,000	6.9	955,596	373,638	44,913	0.5	0.2	0.02	0.4	0.1												
Gunnedah CHPP															3,000,000	60,716	12,664	18,088	2,127	40,500	3,773	444	8,448

Figure A5-2: Detailed emission calculations for coal mines - 2021

APPENDIX 6
SPATIAL ALLOCATION OF EMISSIONS



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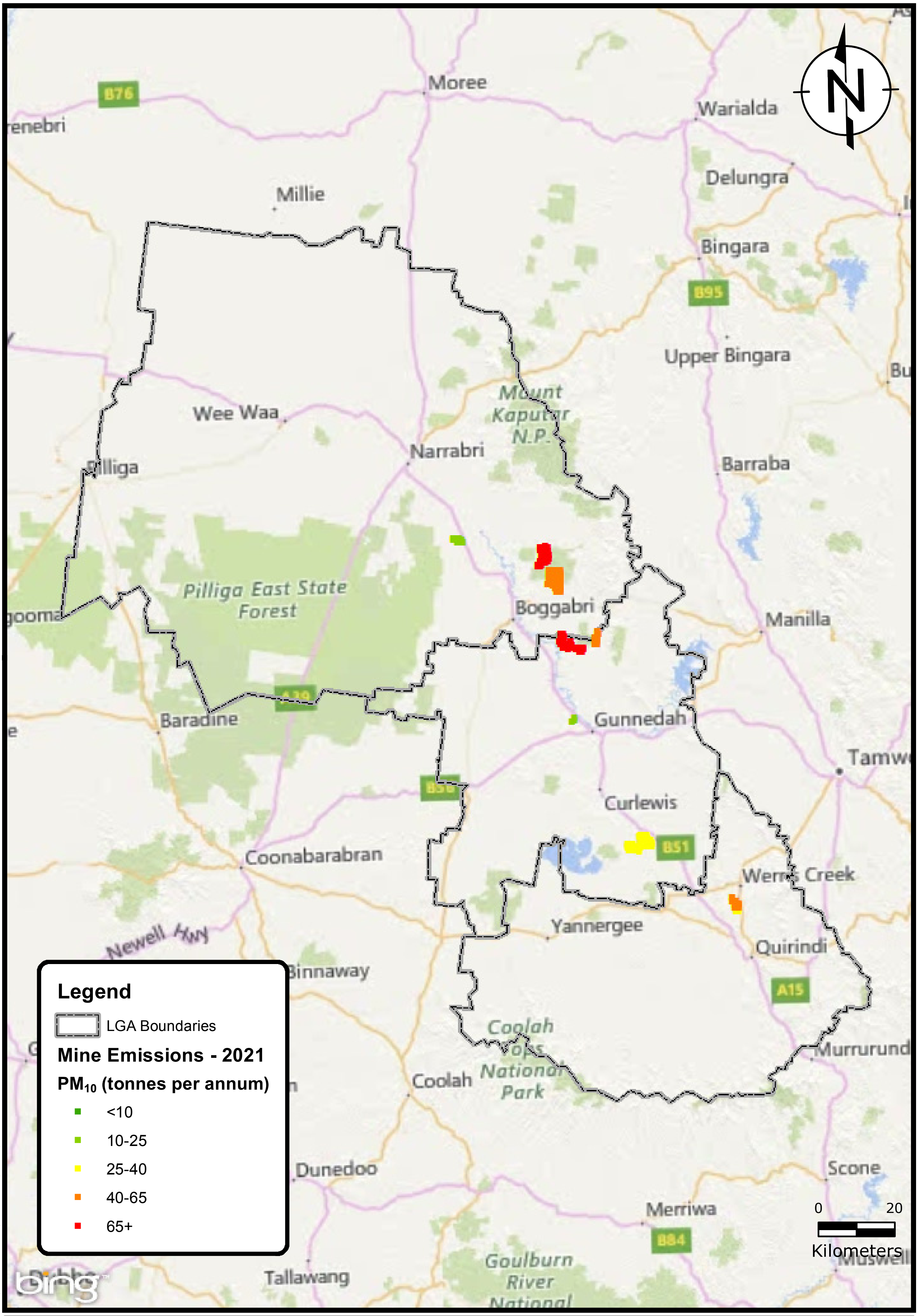
RAMBOLL ENVIRON

Mine Emissions - 2013

FIGURE **A6-1**

DRAFTED BY: SF | DATE: 20/07/2015 | AS121844

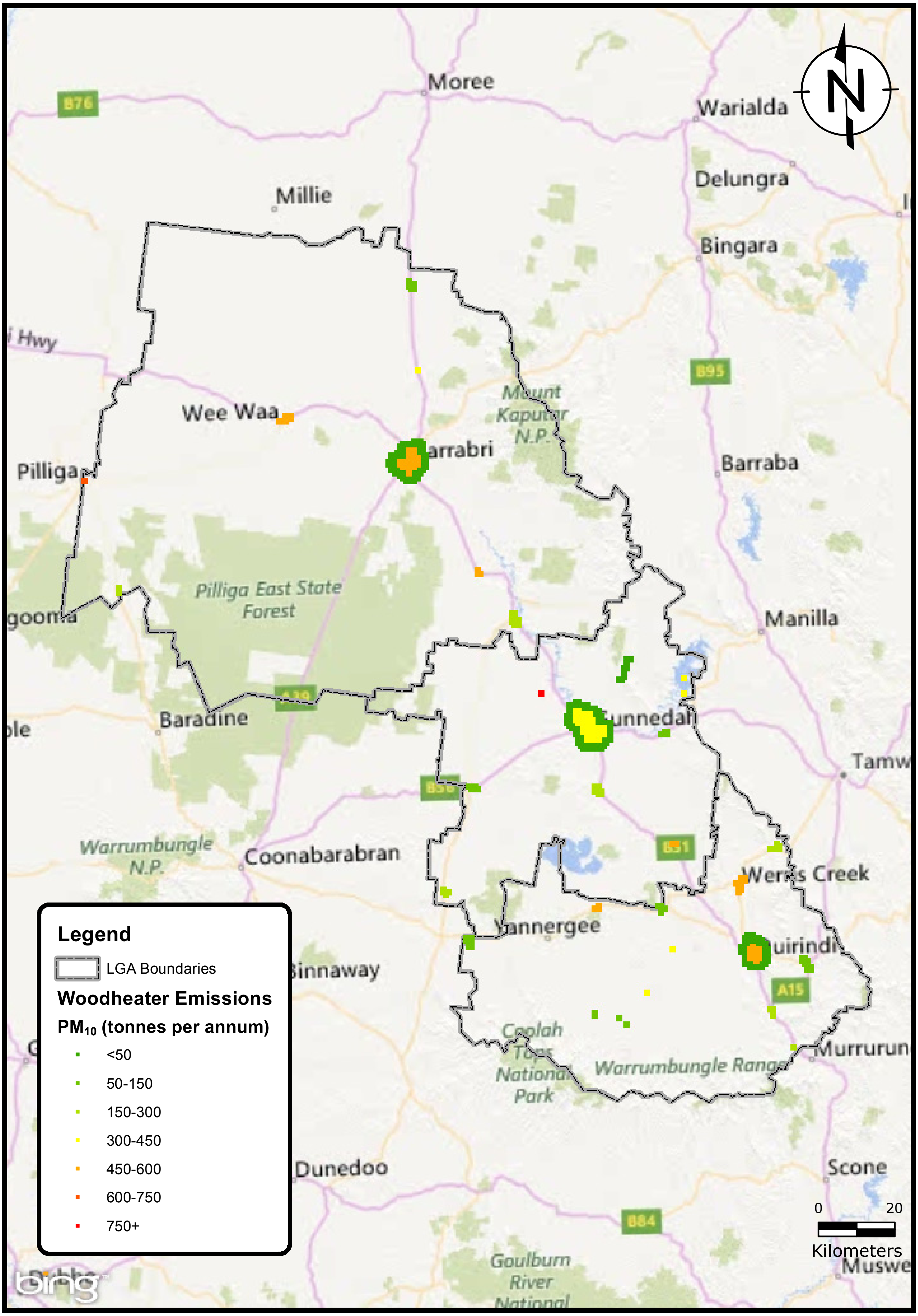


RAMBOLL ENVIRON

Mine Emissions - 2021

FIGURE **A6-2**

DRAFTED BY: SF | DATE: 8/11/2016 | AS121844



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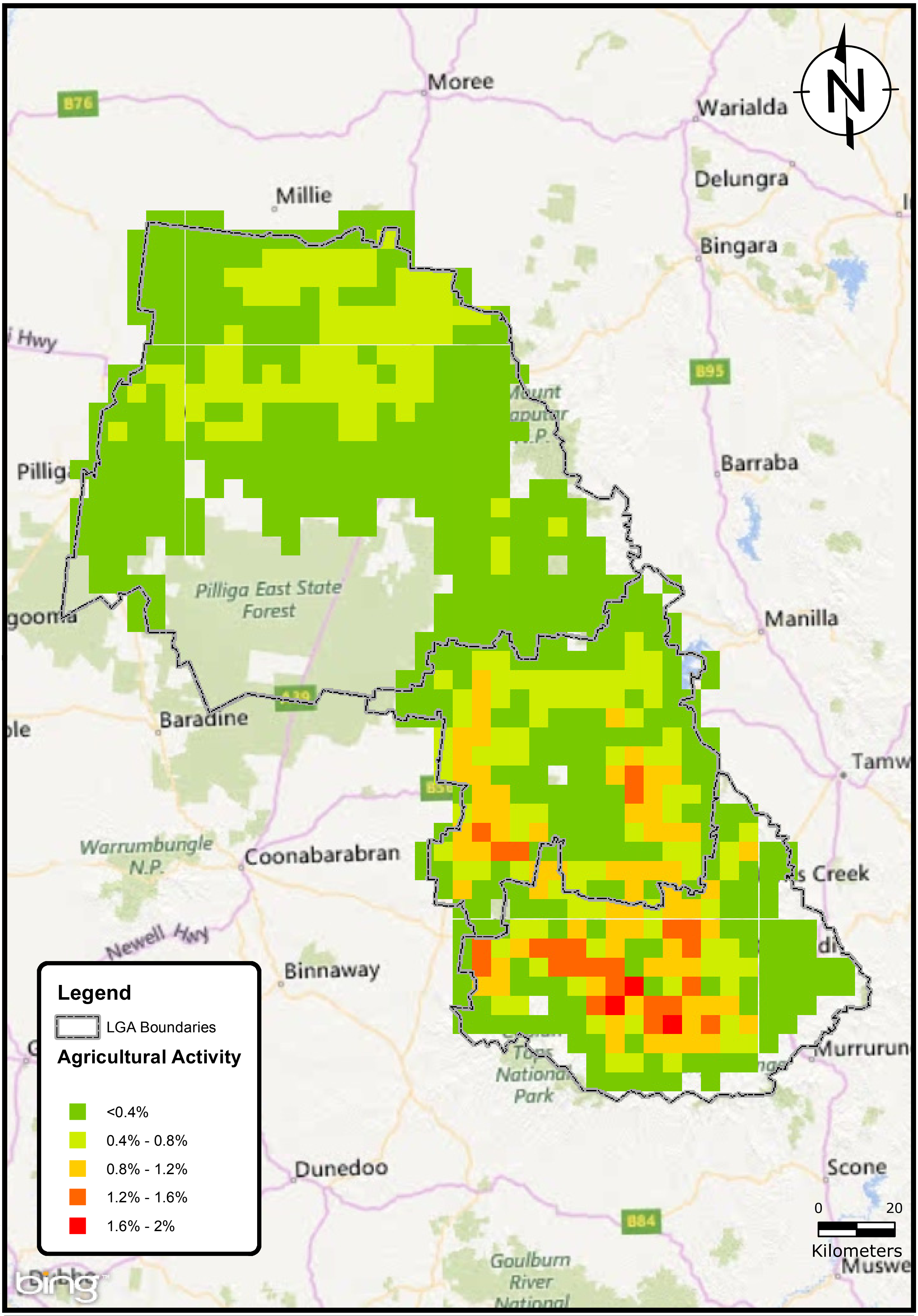
RAMBOLL ENVIRON	**Wood Heater Emissions**	FIGURE **A6-3**
DRAFTED BY: SF — DATE: 20/07/2015		AS121844



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RAMBOLL ENVIRON

Agricultural Emissions Acitivity Distribution

FIGURE

A6-4

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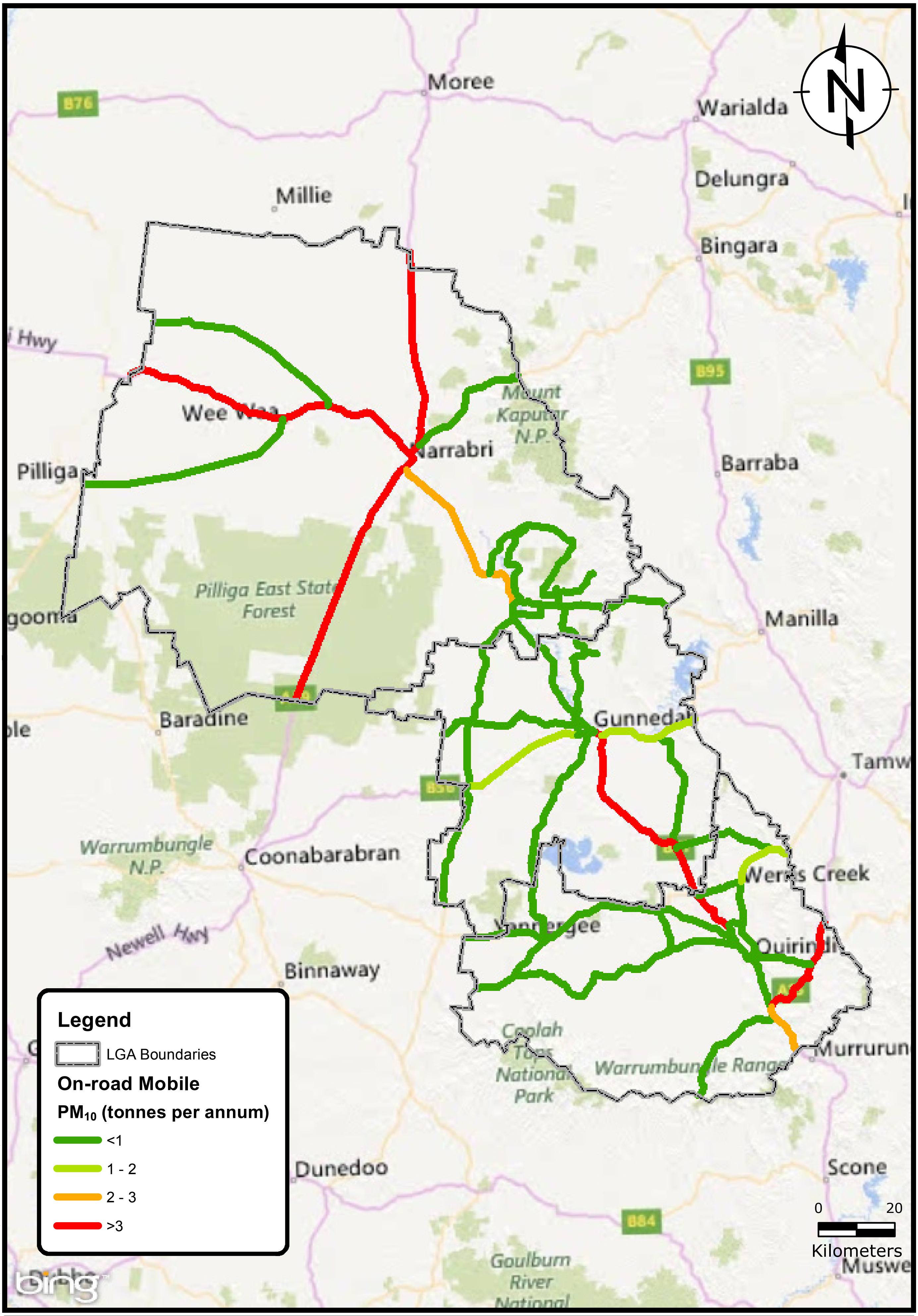


RAMBOLL ENVIRON

On-road Mobile Emissions

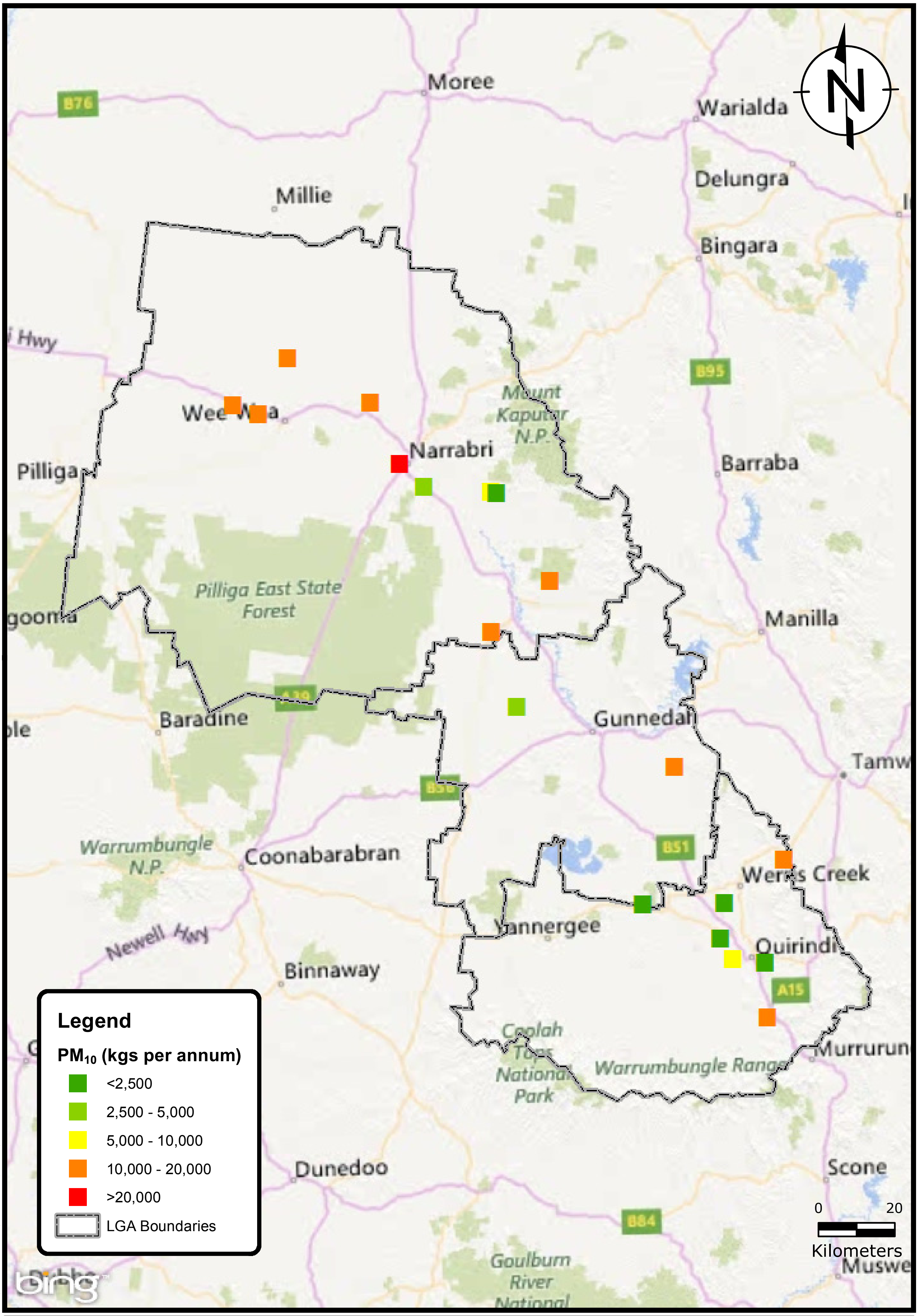
FIGURE

A6-5

DRAFTED BY: SF

DATE: 20/07/2015

PROJECT



RAMBOLL ENVIRON

Industrial Emissions - 2013

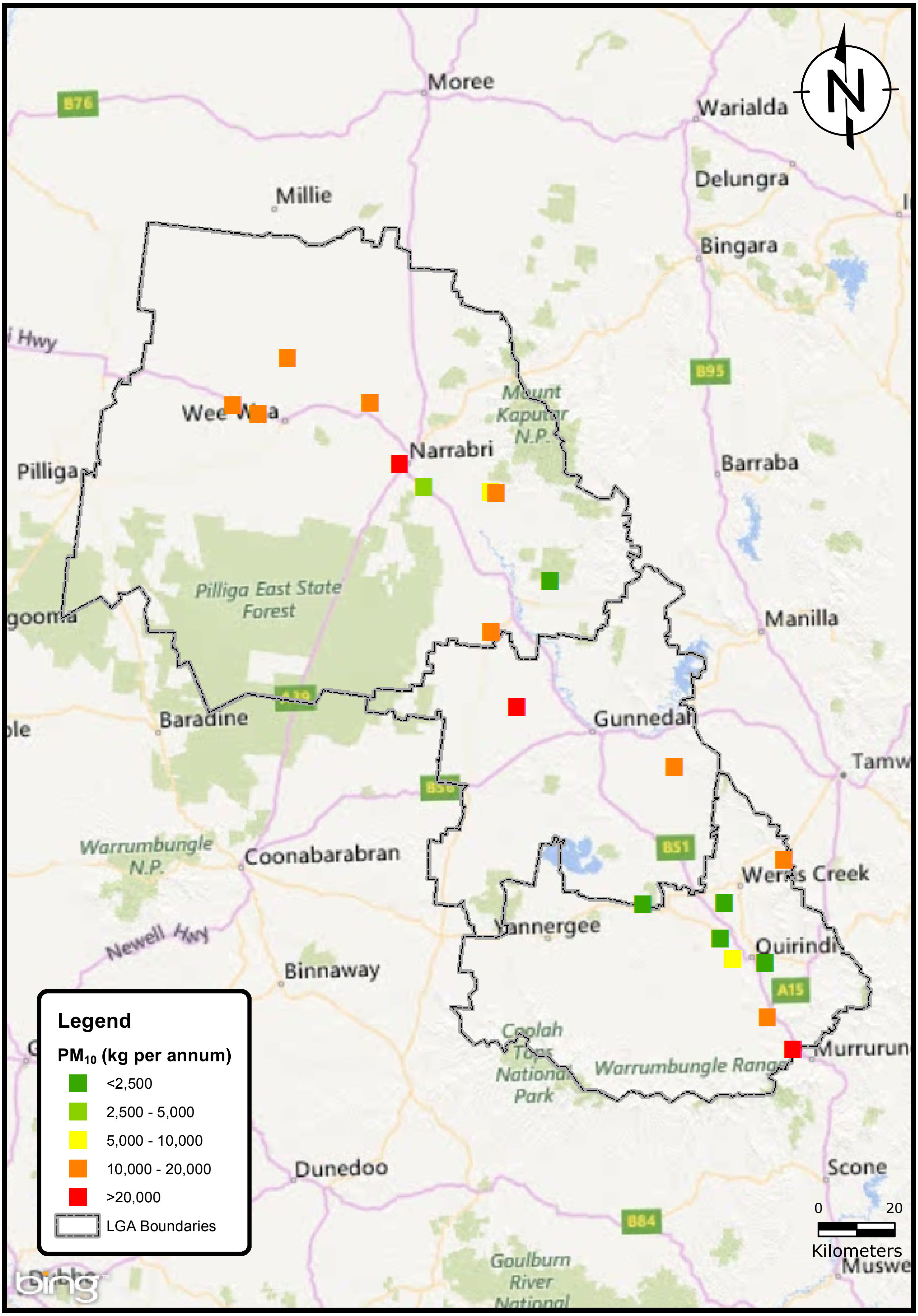
FIGURE

A6-6

DRAFTED BY: SF

DATE: 20/07/2015

PROJECT



RAMBOLL ENVIRON

Industrial Emissions - 2021

FIGURE

A6-7

DRAFTED BY: SF

DATE: 20/07/2015

PROJECT

APPENDIX 7
ANALYSIS OF REGIONAL BACKGROUND CONCENTRATIONS

In order to investigate potential inter-regional transportation of particulate matter concentrations into the Gunnedah Basin air shed, concurrent observations at the Caroona and Werris Creek mine air quality monitoring stations have been compared with the closest NSW OEH air quality monitoring stations.

The Caroona air quality monitoring station is considered the most representative site for background air quality, of the air quality monitoring stations collated in this study. The Caroona station is remotely sited away from significant mining, residential or transportation emissions sources. The Werris Creek air quality monitoring station is influenced by both mining and urban (residential and transportation) emission sources.

Daily average PM_{10} and $PM_{2.5}$ concentration data for Caroona is available for the period between July and December 2013. Concurrent observations from the Werris Creek station and NSW OEH stations at the Tamworth (PM_{10}), Merriwa (PM_{10}), Muswellbrook ($PM_{2.5}$) and Singleton ($PM_{2.5}$) have been paired with the Caroona data. Daily-varying PM_{10} and $PM_{2.5}$ concentrations are presented in **Figure A7-1** and **Figure A7-2** respectively.

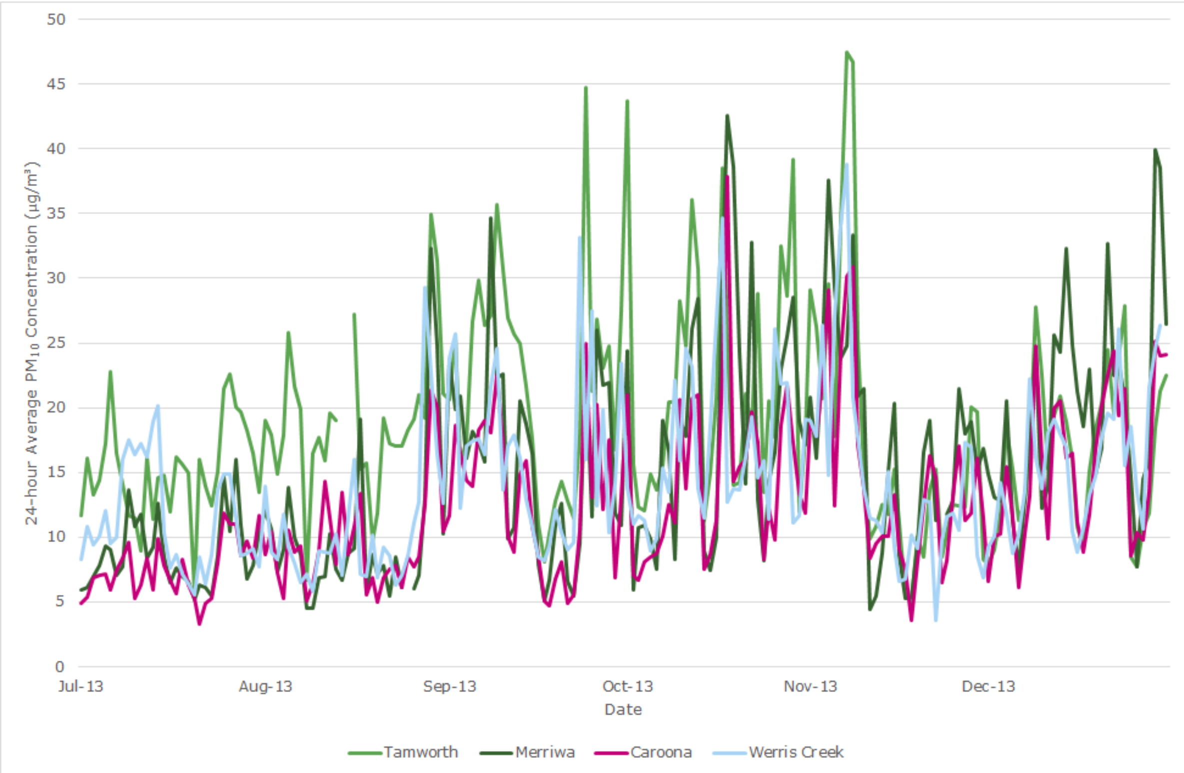


Figure A7-1: Daily-varying PM_{10} Concentrations – Tamworth, Merriwa, Caroona and Werris Creek

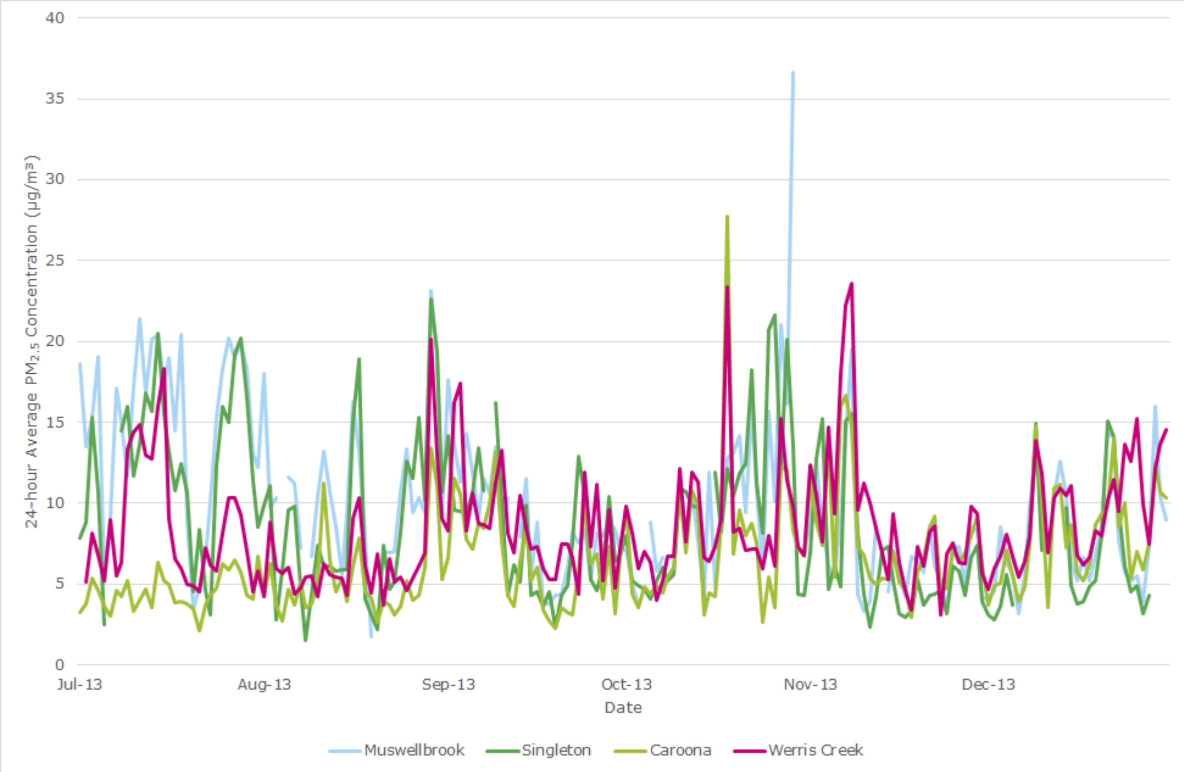


Figure A7-1: Daily-varying $PM_{2.5}$ Concentrations – Muswellbrook, Singleton, Caroona and Werris Creek

The following points are noted from **Figure A7-1** and **A7-2**:

- Between July and September 2013, PM_{10} and $PM_{2.5}$ concentrations at the Caroona station are consistently lower than the corresponding concentrations at the other selected stations. A possible cause of this difference is the influence of localised wood heater emissions at the other comparison stations. Another factor is the winter northwesterly air flow dominant at the southern end of the Gunnedah Basin (see Werris Creek and Scone seasonal wind roses, **Appendix 3**);
- Following the winter period, concentrations at the Werris Creek and Caroona stations are very comparable. This is likely a function of reduced residential wood fire heater use.
- The period between October and November 2013 experienced notable bushfire events across NSW. Concentrations through this period are variable across all stations, however it is noted that the Caroona and Werris Creek stations follow a comparable daily varying trend;
- Concentrations across all stations between November and December 2013 show generally good agreement on a daily basis.

It is considered that the above data illustrates that the concentrations recorded at the Caroona are an appropriate indicator of regional background concentrations, excluding the significant influence of primary localised sources of emissions (mining, transportation, residential wood fire heaters).