

Urban Air Quality Assessment

Australian Capital Territory (ACT)

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Client: ACT Government, Environment, Planning and Sustainable Development Directorate (EPSDD)

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Executive Summary

AECOM Australia Pty Limited (AECOM) have been commissioned by ACT Government, Environment, Planning and Sustainable Development Directorate (EPSDD) to prepare an urban air quality assessment focusing on meteorology and air pollution levels within the urban area of the ACT. This report has been prepared to support a regulatory impact assessment focusing on the potential phasing out of domestic wood heaters in the ACT by 2045.

Objectives

Broadly the purpose of the study is to gain an understanding of the microclimatic conditions and their potential influence on air quality associated with emissions from potential sources of air pollution including woodfired heaters on current and future urban areas within the ACT. More specifically the objectives include:

- Establishing a clear understanding of the microclimate around the urban ACT area including the effects of terrain. Land use and cold air drainage flows.
- Provide an understanding of the existing air pollution levels in the ACT and:
 - Establish a clear understanding of the likely existing sources of air pollution
 - Identify the potential risks associated with the distribution of air pollution based on the existing climate and geographical settings.
 - Identify any potential future pollution sources that may arise in urban areas.
- Understanding the potential effects of regional climate change in relation to:
 - The influence on microclimate around urban areas
 - How potential changes in microclimate may influence air quality in urban areas.
- Based on an understanding of microclimatic conditions, air quality and pollutant dispersal provide guidance on:
 - The implications of current air quality, climate change and development created impacts on future land use and management.
 - Establish a clear understanding of the mitigation measures that could be used to reduce pollution levels from identified sources within the ACT urban areas, during development of new areas and for undeveloped urban areas.

Policy

The ACT Planning Strategy 2018 (the Planning Strategy) informs policy development and investment in Canberra and its districts. The strategy provides a vision for a more compact and efficient city and a strategic direction that the future urban growth will be supported by delivering up to 70% of new homes within Canberra's existing urban footprint. There are nine districts within Canberra and each one has their own strategy. The strategies help direct forecast growth towards 2038 and beyond 2050 to areas of Canberra that are best suited for it. They also outline what future services, transport and infrastructure is needed in those areas. The strategy for each district was utilised to estimate the air pollution effects due to development for each district.

Existing environment

Climate and meteorology were examined across the ACT, utilising monitoring data sourced from the Bureau of Meteorology and Icon Water, with the following findings:

- Wind patterns across the ACT urban areas are reasonably consistent with predominant winds presented on a northwest to southeast axis. A higher proportion of high winds are observed at the Canberra Airport site in comparison to the other locations, with high winds creating increased mechanical mixing which is favourable to pollutant dispersion. Significant variance in wind direction was observed at the Pierces Creek and Mt Ginini stations, which are situated close to the Brindabella Ranges to the west of the ACT urban areas. The terrain dominating the Brindabella ranges appear to be significantly affecting wind directions, particularly at the Pierces Creek station

which is situated within a valley and shows a much higher calm percentage than the Mt Ginini Station situated at the top of the ranges.

- Analysis of the calm conditions (where wind speed is less than 0.5 m/s) for the different stations showed that the highest calm percentages occur at Tuggeranong, followed by West Belconnen and Pierces Creek. These locations correspond with locations closer to the ranges to the south and west of the ACT urban areas. Calm conditions are generally associated with a stable atmosphere where pollutant dispersion is less effective.
- Differences were observed in average temperatures between the 2014, 2019 and 2023 years. In summer, 2019 data were significantly higher than those observed for 2014 and 2023 (although the 2014 temperatures were higher than the 2023 data during the day). In winter the trends reversed with the 2019 data having lower average temperatures across the day as compared with 2014 and 2023. Warmer weather can aid pollutant dispersion through the development of stronger convective mixing conditions and reducing atmospheric stability. Warmer years however are often associated with drier periods where dust generation can be higher, resulting in higher background dust concentrations.
- Significant differences were observed in average humidity levels between the 2014, 2019 and 2023 years. In summer, humidity levels were the lowest in 2014 with higher humidity levels observed for both 2019 and 2023 (with 2023 levels being the highest of the three). In winter the trend was less apparent with humidity levels during the nighttime being similar and daytime humidity levels showing the most variability. The highest humidity levels were observed in 2014, with the highest humidity observed during the winter months. Humidity can have different effects on pollutant dispersion, which can be both beneficial and detrimental. If humidity is high, pollutants can attach to water droplets and other particles in the air, causing them to be removed from the atmosphere.
- Analysis of the 10 years of data from Tuggeranong and Canberra Airport show similar trends across the year with peak rainfall periods occurring in summer and Autumn and lowest rainfall levels occurring in early-winter to mid-spring. Significant variability was observed for annual rainfall with the rainfall total for 2014, 2019 and 2023 being 684, 350 and 655mm respectively for Tuggeranong and 569, 347 and 698mm respectively for Canberra Airport. Rainfall was much lower for both stations for the 2019 period which was characterised by stronger El Nino patterns. Rainfall also causes wet deposition scavenging (reduction) of pollutants in the atmosphere, therefore in periods of increased rainfall air pollution would be expected to be improved.
- The stability class data shows that there are significant periods where Class F and Class G may result in inversions, with Tuggeranong having a slightly higher proportion than Canberra airport. Of importance to inversions beyond simple occurrence is also inversion strength and time of day which influences break-up time. From a domestic wood smoke perspective, when the inversions may occur is critical to understanding whether wood smoke effects may be exacerbated by micrometeorology. This indicates that wood smoke in the area has a strong likelihood of building up to higher concentrations during inversion conditions.
- There is a clear pattern of atmospheric pressure change across the year with highest pressure occurring during winter and lowest pressure occurring during summer. Pressure was similar between Tuggeranong and Canberra Airport, with the airport having slightly higher pressure over the year as compared with Tuggeranong. Diurnal pattern is clear and consistent across both the Tuggeranong and Airport stations. Air pressure is significantly different between summer and winter with winter being approximately 10hPa higher than in summer. High-pressure systems are generally associated with clear, calm weather, while low-pressure systems can bring clouds, wind, and precipitation, and therefore periods of high-pressure can be associated with poorer air pollutant dispersion.
- The topography of the ACT is dominated by the mountain range to the west and south of the ACT urban areas, the Murrumbidgee River running along the base of the range and the higher ground to the east of the ACT urban areas. Microclimatic effects have the potential to occur during periods of atmospheric stability that could lead to pollutant trapping and accumulation. During periods of stable air conditions, the mountain ranges or elevated terrain has the potential to generate katabatic flows, (drainage wind flows generated by cooler, higher density air being transported down a slope under the force of gravity) which may induce air flow downhill within the ACT. This may channel air

in several directions within the ACT urban area, such as toward and then along the Murrumbidgee River valley or along the Molonglo River valley. These drainage flows would be expected to flow down the elevated terrain to the base of the mountains and then along the river valley.

Existing air quality

Air quality in the ACT is generally considered to be quite good, particularly in comparison to other Australian capital cities, (mostly because the area has no significant heavy industry). The primary sources of air pollution in the ACT are motor vehicles, wood smoke, bushfires/dust storms and pollen events. Other sources include landfills, agriculture, sewerage treatment plants and pipelines, and gas fired power stations associated with landfill gas harvesting. Temperature inversions during winter can be associated with elevated particulate levels in some areas, particularly in urbanised valley areas such as Tuggeranong. High particulate levels can also occur in summer due to bush fires, hazard reduction burns and dust storms.

Since 1998 the ACT has operated an ambient air quality network and currently the network consists of three monitoring stations located at Monash, Civic and Florey, from which the following findings were derived:

- Monitoring data for the three monitoring stations showed broadly similar results, suggesting that the PM₁₀ concentrations in the ACT are not driven as much by local conditions and sources, rather they are more affected by regional effects such as dust storms or bush fires. PM₁₀ concentrations were affected by wood smoke in winter however not to the same degree as PM_{2.5}.
- Monitoring data from the Monash and Florey stations show significant PM_{2.5} concentrations across all calendar years. Data from Civic shows a much lower concentration (although concentrations are still elevated and at times above the criteria). This is thought to be due to the location of the Monash and Florey monitoring stations situated within residential areas where the use of wood fires is commonplace. The Civic monitoring station is situated within a commercial estate on the northern edge of Lake Burley Griffin. The commercial setting along with the microclimate generated by the proximity to the lake would be expected to affect the wood smoke concentration at this location.

The use of different criteria to examine the levels of pollution in the ACT result in different outcomes. Comparison against the NEPM 2022 criteria shows that the ACT air quality has generally been reasonable for PM₁₀ with poorer conditions observed for PM_{2.5} which showed a small number of exceedances across calendar years.

When the NEPM 2025 criteria are applied for PM_{2.5} (as no change is proposed for PM₁₀), it is observed that the number of exceedances increases significantly. This situation is made even worse if the WHO criteria are applied, which shows a large number of exceedances across all calendar years if the WHO criteria are applied.

If the NEPM 2025 or WHO criteria were applied to a future air pollution regulatory environment (which for the 2025 NEPM seems very likely, if not the WHO criteria), significant work would be needed to achieve compliance with those criteria. Significant reduction in PM_{2.5} concentrations would be needed across contributing sources of PM_{2.5} pollution.

Air emission sources

The 2023 ACT State of the Environment report (ACT CSE 2023) states that the pollutant of highest concern in the ACT is PM_{2.5}, with the main sources being:

1. Wood heaters, which have the greatest impacts on the ACT's air quality in non-bushfire years. It is estimated that up to 75% of all PM_{2.5} pollution is from wood heaters in the cooler months.
2. Bush fires and planned burns, with impacts being variable depending on the nature of the bush fire season. For example, around 40% of the ACT was burnt in the 2020 bushfires and 70% was burnt in the 2003 fires. The resultant quantities of air pollutants (primarily PM_{2.5}) would be vastly different between these two fire events and other years where bushfires were not as substantial or widespread.
3. Road transport vehicle emissions, which consistently contributes to pollution year-round.

The *ACT Zero Emissions Vehicles Strategy 2022 – 30* (the Strategy) (ACT Government 2022) outlines the ACT's plan to transition from internal combustion engines (ICE) to zero (tailpipe) emission vehicles (ZEVs) with targets for 80-90% of new light vehicle sales being ZEVs by 2030 and phasing out ICE vehicles from 2035. This would be expected to have a measurable benefit to air quality.

The largest potential source of additional pollution in the ACT is through the development of new residential areas. If these areas are allowed to use domestic wood fires for heating, there is the potential for significant increases in air pollution levels.

Given the significant contribution domestic wood smoke makes to PM_{2.5} in the ACT, it is expected that the elimination of wood smoke would significantly alter the PM_{2.5} concentrations in ACT airshed. To estimate the magnitude of the reduction, the monitoring data for Monash had data removed where wood heater emissions are at their highest, which was May to August for the hours 6pm to 6am, which removed the majority of the peak concentrations due to wood heater emissions. Annual average PM_{2.5} was recalculated on the modified dataset, which generally shows an improvement in annual average PM_{2.5} of 1-2 µg/m³ could be expected if nighttime emissions of wood heater smoke were eliminated. Similarly, the Borchers-Arriagada *et.al.* 2024 paper estimated that the annual average PM₁₀ concentration (of which most would be PM_{2.5}) attributed to woodfired heaters was estimated at 0.82µg/m³ within the ACT. If wood heater emissions were eliminated it could reasonably be expected that the ACT would meet the NEPM 2025 goals and go close to meeting the WHO 2021 guidelines.

Meteorological modelling

Meteorological and dispersion modelling was performed as a part of the study. Meteorology was assessed across the ACT by looking at a number of representative meteorological conditions whilst dispersion modelling used arbitrary emissions from each district in the ACT to understand dispersion patterns from each district as a way to assess microclimatic effects on air pollution.

The findings of the meteorological modelling of wind were:

- The urban areas of ACT have an effect on the wind speed and direction of the microclimate. Wind speeds are generally lower than areas outside of the urban land use areas. With the change in speed, the urban areas also appear to change the direction of the air flow across the urban areas.
- Under light wind speeds from the south (predominant wind condition during nighttime), air flow appears to either direct air from the Tuggeranong district either to the northwest toward the Western Edge Investigation Area (WEIA) or Weston Creek areas or to the north to north-northeast toward Woden Valley, Inner South and Inner North and City districts.
- There are wind flows observed where winds under low winds speeds are directed along the Murrumbidgee River valley toward the north. These conditions may be affected by katabatic drift as cool air in winter falls down the valleys from the Tuggeranong and Woden Valley areas to the north or west toward the Inner south or WEIA areas. This katabatic air movement is observed during very low wind speed conditions and would be expected to result in the transport of woodsmoke laden air under poor dispersion conditions (katabatic drift does not have significant vertical mixing occurring with the movement of air).
- The northern suburbs around Belconnen and Gungahlin do not appear to affect the wind flow as much as the southern suburbs and have wind conditions broadly similar to the conditions in the larger district. There is some evidence of katabatic drift to the western edge of Belconnen closer to the Murrumbidgee River valley but is less noticeable than for the southern districts around Tuggeranong.

Analysis of the vertical temperature profiles showed that there are inversions present in both summer and winter.

The inversion conditions in summer showed weaker inversions with higher inversion elevations as compared with July inversion which were very strong and at low elevations. The implications of this are that in summer months, inversions are weaker and break up faster and trap less pollution underneath the inversion. In addition, pollution levels from sources like wood fired heaters occur at a much lower elevation, meaning the implications of an inversion forming during summer are much less severe.

Winter conditions show very strong inversion conditions with low elevations for the inversions. With woodsmoke emissions common in winter, the inversion conditions would result in trapping of emissions

under a low inversion increasing the pollution concentrations in the mixing layer. This matches the observations made in relation to existing pollution concentrations.

Diurnal variation is observed in mixing height data, with the maximum heights observed in the afternoon and minimum mixing heights occurring during the early morning. Average mixing heights in the ACT urban area are typical for the region, with a maximum of around 1600 m and a minimum of around 150 m. Again, this is suggestive of higher pollutant concentrations at ground level if pollutants are present in the airshed. Summer and winter mixing heights are quite different with peak summer mixing heights observed around 2200m and a peak winter mixing height of 1200m. This large difference in mixing heights would be expected to result in higher concentrations of pollution in winter and the increased occurrence of inversions trapping an emitted pollution.

The effects of climate change on air quality were qualitatively assessed using NARClIM projections for the ACT, which examine the change in average temperatures, number of hot days (over 35°C), number of cold nights (less than 2°C) and high fire danger days.

The projections show that the ACT will experience a higher number of “hot” days, whilst the number of cold nights are projected to decrease with significantly less cold nights forecast in the near and far future (decrease of about 5-10 less cold days in the near future and over 40 less cold nights in the far future). The southern alpine areas are projected to have the largest decrease in cold nights. As temperature heavily influences micrometeorological conditions, any change would be expected to impact the meteorology and by inference pollution dispersion. Hotter temperatures increase convective mixing in the atmosphere. During the summer months, it is expected that the hotter conditions would result in meteorology with broadly improved overall pollution dispersion conditions.

Generally, rainfall is projected to decrease in spring and increase in autumn with the far future projection having a larger reduction than the near future. Overall, winter is also projected to experience drying where autumn and spring are generally projected to experience increased rainfall, aside from the near future summer projection for the western area of the ACT. Predicted seasonal fluctuations suggest there is a potential for increased wet deposition and higher soil moisture contents during summer and autumn which may potentially result in marginally lower ambient particulate concentrations. The reverse may be expected during winter and spring where there is less opportunity for particulates to be washed out of the atmosphere due to lower rain events; and lower soil moisture contents potentially giving rise to marginal increased risk in windblown dust from exposed surfaces.

Increased fire danger is projected on an annual basis for both the near future and far future projections, with the far future having the highest values. The figure also shows that fire danger is mostly associated with summer and spring, with autumn and winter projected to have only a small change.

Mean annual average wind speeds are generally projected to decrease by less than 2% within urban areas by 2020-2039 and by 4-6% by 2060-2070. A less than 2 percent increase is unlikely to have a material impact in pollutant dispersal in the short term; however further decreases in wind speed projected out into the far future may have a notable impact in pollutant dispersal.

The frequency of occurrence of near surface temperature inversions are expected to increase by up to 10% within the ACT by 2060-2070 and the strength of the temperature inversions in urban areas within the ACT are projected to increase between 20 and 30%. Both the increase in frequency and substantial increase in temperature inversion strength of near surface temperature inversions suggests that future inversion conditions may amplify poor air quality events.

Dispersion modelling

The findings from the dispersion modelling of pollutants within the ACT urban areas showed the following:

- Air pollution transport for the ACT urban areas generally showed a clear south to north transportation pattern. Pollution generated at Tuggeranong tended to move north or northwest transporting pollution through either the Woden Weston Creek districts toward the Inner south district or to the northwest toward the WEIA.
- Pollution transport through the inner south district was funnelled between the Black Mountain and Mt Ainslie elevated terrain channelling pollution into the inner north district. Pollution then migrated further north toward Gungahlin.

- Pollution moving through the WEIA and from the Molonglo Valley appeared to move along the Murrumbidgee River valley toward Belconnen. The pollution didn't appear to move into the older established areas of Belconnen but rather was transported around the western edge of the district (where new development is currently occurring).

Recommendations

Findings of this study identified several recommendations for urban development and for the control of particulate emissions, with further restrictions around wood heaters being key to improving PM_{2.5} concentrations especially during the colder months where heater use and emissions are highest.

Future studies were also recommended to enable a better understand air pollution distribution within the ACT. These studies would be aimed at understanding the patterns of usage for wood heaters in the ACT, more comprehensively understand the dispersion of pollution generated within the ACT and provide additional particulate monitoring stations in the WEIA, Woden Valley, Molonglo Valley and Gungahlin areas. Additionally, meteorology sensors are recommended for all existing and new pollution monitoring stations to enable more meaningful data analysis.

1.0 Introduction

AECOM Australia Pty Limited (AECOM) have been commissioned by the ACT Government, Environment, Planning and Sustainable Development Directorate (EPSDD) to prepare an urban air quality assessment focusing on meteorology and air pollution levels within the urban area of the ACT. This report has been prepared to support a regulatory impact assessment focusing on the potential elimination of domestic wood heaters in the ACT by 2045.

1.1 Background

Air pollution in urban areas of the ACT plays a large part in defining the health and wellbeing of communities living within urbanised areas. There are a range of air pollution sources that contribute to the overall pollution loading within an urban setting such as the ACT, including emission from vehicles, industry and naturally occurring sources of pollution such as bush fires and dust storms. Another common source of air pollution in urban areas is air pollution from domestic combustion of wood for either heating or cooking, which contributes significantly to the particulate load in many urban areas of the ACT within Australia.

As concluded in Wei *et al* (2024) there has been no safe threshold (level) of PM_{2.5} determined which has no impact on overall cardiovascular health. This study also states substantial health improvements could be attained through complying with the World Health Organisations recommended PM_{2.5} levels, which are lower than current Australian guidelines set by the National Environment Protection Measure's (NEPM). Given this situation, the ACT government are investigating different means to reduce particulate concentrations in the atmosphere within the ACT. As noted above, woodsmoke is a key contributor to particulate emissions across Australia and in the ACT in particular (given its cold winters). Reduction or elimination of domestic woodsmoke would be expected to have a significant effect on the concentration of particulates in the ACT.

This study aims to compliment historical studies and decisions made to ban the use of domestic wood heaters in new developments and extend the ban to existing areas within the ACT.

The ACT Government currently offers various programs to tackle emissions from domestic wood heaters. These initiatives include regulating the sale of commercial firewood to ensure it is seasoned and dry, banning wood heaters in new development areas where planning studies indicate negative effects on air quality, updating the Wood Heater Removal Program (WHRP) to eliminate old, inefficient heaters, and launching the new 'Burn Better' public education campaign.

The aim of this report is to build on incremental domestic wood heater air quality studies undertaken within the ACT and examine air quality across the ACT and identify any factors that need to be considered in the future with the target of ultimately banning wood heaters by 2045. Findings from this study would be used as part of a regulatory impact assessment targeting domestic wood heaters in the ACT.

1.2 Purpose of Study

1.2.1 Study Objectives

Broadly the purpose of the study is to gain an understanding of the microclimatic conditions and their potential influence on air quality associated with emissions from potential sources of air pollution including woodfired heaters on current and future urban areas within the ACT.

The evaluation of microclimatic conditions and their influence on pollutant dispersal within urban areas in the ACT would then be used to provide a better understanding potential impacts woodfire heaters may have on urban air quality. Further extension of this objective would be to identify what potential air quality mitigations may be available to reduce urban air quality impacts and identify hotspot areas for prioritising government intervention.

More specifically the study the objectives include:

- Establishing a clear understanding of the microclimate around the urban ACT area including the effects of terrain. Land use and cold air drainage flows.
- Provide an understanding of the existing air pollution levels in the ACT and:

- Establish a clear understanding of the likely existing sources of air pollution
- Identify the potential risks associated with the distribution of air pollution based on the existing climate and geographical settings.
- Identify any potential future pollution sources that may arise in urban areas.
- Understanding the potential effects of regional climate change in relation to:
 - The influence on microclimate around urban areas
 - How potential changes in microclimate may influence air quality in urban areas.
- Based on an understanding of microclimatic conditions, air quality and pollutant dispersal provide guidance on:
 - The implications of current air quality, climate change and development created impacts on future land use and management.
 - Establish a clear understanding of the mitigation measures that could be used to reduce pollution levels from identified sources within the ACT urban areas, during development of new areas and for undeveloped urban areas.

The findings of the study would be used to inform a Regulatory Impact Assessment concerning the phase-out of wood heaters in all urban areas of the ACT by 2045.

1.2.2 Assessment Scope

The following scope was development to provide an understanding of the microclimatic conditions and their potential influence on air quality on current and future urban areas within the ACT in line with study objectives provide in **Section 1.2.1**:

- A description of the study area including identification of existing and future identified urban development areas within the ACT (**Section 1.3** and **Section 3.2.2**).
- Identification relevant air quality Commonwealth and Territory legislation policy and plans (**Section 2.0**)
- Desktop review of topography land use and meteorological data to provide an understanding of the local climate and geographical setting within the study area (**Section 4.0**).
- A description of the existing air quality within the study area based on (**Section 5.0**):
 - Review of the ACT ambient air quality monitoring network observational data
 - Identification of existing air quality trends
 - Identification of existing air pollutant sources in urban areas and potential future sources.
- A description of the methodology used to conduct both meteorological and air dispersion modelling for the study (**Section 6.1**). The meteorological modelling at the macro scale was conducted using models CALMET and GRAMM. Micrometeorological modelling and air dispersion modelling was conducted using GRAL. All modelling was conducted in accordance with the following guidelines:
 - *Approved Methods for the Modelling and Assessment of Air Pollutants in New South Wales* (NSW EPA 2022)
 - Generic Guidance and Optimum Model Settings for the CALPUFF Modeling (sic) System for Inclusion into the ‘Approved Methods for the Modelling and Assessment of Air Pollutants in NSW, Australia’ (J. Barclay and J. Scire 2011)
 - GRAL Manual GRAL Graphical User Interface 22.09, Ottl et al 2022
- Analysis of predicted existing microclimatic conditions in the study area including (**Section 7.0**):
 - Wind speed and wind direction, predicted wind flow field patterns and katabatic flows¹.

¹ Wind that carries cold, high-density air from a higher elevation down a slope under the force of gravity

- Temperature: including regional and seasonal changes and vertical temperature profiles to identify likelihood of temperature inversions.
- Other parameters including relative humidity, rainfall, air pressure and atmospheric stability.
- Analysis of predicted existing air pollutant transport and dispersal patterns including identification of potential hotspot areas (**Section 8.0**).
- Description of regional climate change predictions and qualitative assessment of how it may influence local microclimatic conditions, air pollutant transport and dispersion (**Section 9.0**).
- Provide an understanding microclimatic conditions and pollutant transport and air dispersal patterns may be used to provide better air quality outcomes with regards to urban planning and design including:
 - A review of ACT government urban planning documents and identification of expected pollutant sources associated with future urban development **Section 0** and **Section 10.1**).
 - A discussion on how the existing and potential future air pollution may affect future land use and the management of those future area of growth.
 - Identification and high-level review of potential urban air quality mitigation measures based on their practicality, efficacy, and indicative cost.
 - Recommendations for future supporting studies.

1.3 Study Area

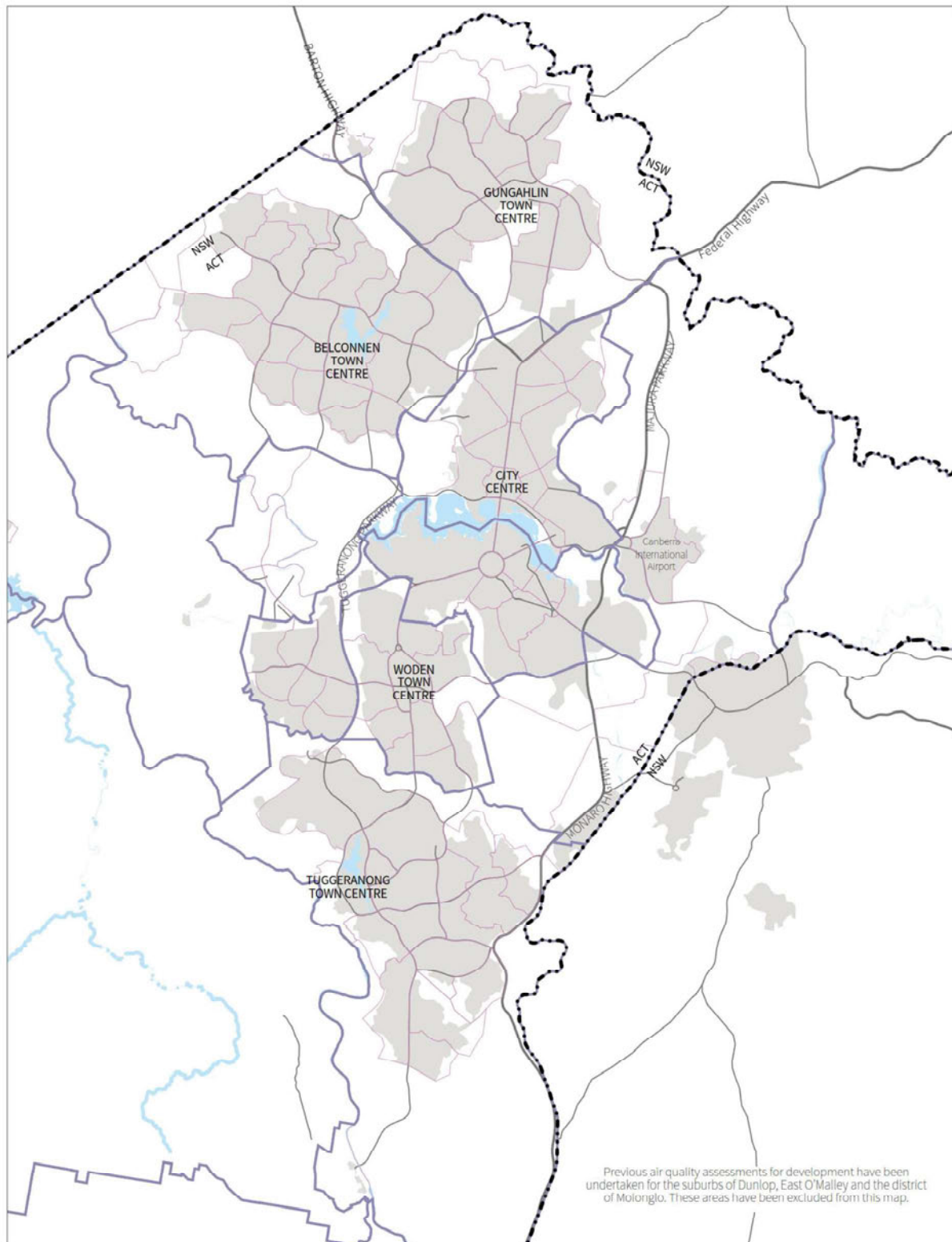
The study area includes encompasses existing urban areas and identified future urban development areas within the ACT. A total of 121 suburbs were identified as part of the study, with the location of the study area shown in **Figure 1**.

The ACT urban areas are broadly separated into the following regions, each with several suburbs within each region:

- Gungahlin Town Centre
- Belconnen Town Centre
- City Centre
- Woden Town Centre
- Tuggeranong Town Centre

In addition to these areas, there are several proposed areas which are expected to be developed over the next 20-50 years (such as the Western Edge Investigation Area to the west of the Woden Town Centre).

These regions have been further refined through the development of district strategies which outline the expected growth objectives and characteristics of each of the different urban areas within the regions outlined above. A more detailed discussion of the nine districts within the regions outlined above has been provided in **Section 3.2.1**. These districts have been used as the basis for the discussion of the microclimate data and pollution data presented in **Section 7.0**.



LEGEND

- SUBURBS
- URBAN AREAS

Figure 1 ACT Urban Study Area

2.0 Air Quality Legislation and Policy

2.1 Overview

This section provides a brief overview of the relevant air quality legislation and ambient air quality criteria relevant to the assessment of key air pollutants for this study.

2.2 National Environmental Protection Council Act 1994

The *National Environment Protection Council Act 1994* (Cth) establishes and provides authority to the National Environment Protection Council (NEPC) to make National Environment Protection Measures (NEPMs) and to assess and report on their implementation and effectiveness in participating jurisdictions. NEPMs are a special set of national objectives designed to assist in protecting or managing aspects of the environment. Regarding concentrations of air pollutants, there are two relevant NEPMs:

- National Environment Protection (Ambient Air Quality) Measure 2021 (AAQ NEPM)
- National Environment Protection (Air Toxics) Measure 2004 (Air Toxics NEPM)

The AAQ NEPM was designed to create a nationally consistent framework for monitoring and reporting on common ambient air pollutants. The Air Toxics NEPM provides a framework for monitoring, assessing, and reporting on ambient levels of air toxics, and was designed to collect information to facilitate the development of standards for ambient air toxics. Of relevance to this study is the AAQ NEPM which is further discussed below in **Section 2.2.1**.

2.2.1 National Environment Protection (Ambient Air Quality) Measure

The AAQ NEPM standards aim to achieve adequate protection of human health and wellbeing and apply to air quality experienced by the general population within a region. Under this general exposure approach, the standards are applicable to urban sites away from specific sources of pollution such as heavily trafficked streets and industrial outlets.

In the Key Changes to the Ambient Air Quality Measure agreed by Ministers April 2021 in a statement issued by the NEPC (NEPC 2021a) it was asserted that the standards in the AAQ NEPM are not intended to be applied as an environmental standard by regulators without consideration of regulatory impacts in their jurisdictions. The statement clarifies this intent of the NEPM as a standard for reporting representative ambient air quality within an airshed, and not as a regulatory standard. However, state and territory environmental regulators may adopt the numerical standards as assessment criteria within their jurisdictions. The ACT Government had committed to meeting the NEPM standards under Section 5.5 of the Air Environment Protection Policy described in **Section 2.3**.

The AAQ NEPM standards, as amended on 18 May 2021 are shown in **Table 1**. Primary pollutants of interest for the study shown in **Table 1**.

Table 1 NEPM Ambient Air Quality Standards as updated 18 May 2021

Item	Pollutant	Averaging period	Maximum concentration standard	
			ppm	µg/m ³
1	Carbon monoxide (CO)	8 hours	9.0	11,250
2	Nitrogen dioxide (NO ₂)	1 hour	0.08	164
		1 year	0.015	31
3	Photochemical oxidants (as ozone)	8 hours	0.065	139
4	Sulfur dioxide (SO ₂)	1 hour	0.10	286
		1 day	0.02	57
5	Lead	1 year	-	0.50

Item	Pollutant	Averaging period	Maximum concentration standard	
			ppm	µg/m ³
6	Particles ≤ 10 micrometres in diameter (PM ₁₀)	1 day	-	50
		1 year	-	25
7	Particles ≤ 2.5 micrometres in diameter (PM _{2.5})	1 day	-	25
		1 year	-	8
ppm = parts per million µg/m ³ = micrograms per cubic metre (under standard temperature and pressure).				

In addition to the current standards in Table 2 reductions of the 24-hour and annual average PM_{2.5} standards are proposed as new national environment protection goals from 2025². The goal for particulates from 1 January 2025 will provide a framework for continuous improvement and facilitate a review of the PM_{2.5} standard.

Proposed national environment protection goals for 2025 are provided in Table 2.

Table 2 NEPM proposed national environment protection goals scheduled for 2025

Item	Pollutant	Averaging period	Goal	
			ppm	µg/m³
7	Particles ≤ 2.5 micrometres in diameter (PM _{2.5})	1 day	-	20
		1 year	-	7
ppm = parts per million µg/m³ = micrograms per cubic metre (under standard temperature and pressure).				

2.3 Air Environment Protection Policy 1999

The Air Environment Protection Policy 1999 (Air EPP) as prepared by the Environment Management Authority (EMA), now the Environment Protection Authority (EPA), to manage air emissions in the ACT such that the air quality standards in the Territory at least meet the NEPM standards. The AEPP provides guidance to assist people to meet their environmental obligations, but is not legally binding, and does not apply to motor vehicles operating on public streets, trains, or aircraft.

The major sources of air emissions in the ACT are transportation and fires from non-industrial activities. The AEPP recommends different strategies to control emissions for different types of activities, including:

- Restricting the purposes for which the activity may be undertaken;
- Requiring the activity to be undertaken in a particular way; and
- Requiring emissions from the activity to meet specified standards.

Transportation Activities

Emissions from motor vehicles are a major source of air pollution in the ACT. Urban planning, vehicle design and emission controls, and fuel composition are the primary means of mitigating the environmental impacts of their emissions. Emissions from motor vehicles being driven on public streets

² A reduction of the 1-hour maximum SO₂ standard to 0.075 ppm is also proposed for 2025 under the AAQ NEPM. SO₂ concentrations attributed to operation of the project are anticipated to be very low compared to the proposed NEPM standard due to stringent diesel and petrol fuel quantity standards in Australia that limit sulfur content. The quality of automotive fuels in Australia is regulated by the Fuel Quality Standards Act 2000, the Fuel Quality Standards Regulations 2001 and the Fuel Standard (Automotive Diesel) Determination 2001 (updated in 2019). The sulfur content in diesel fuel is limited to 10 ppm. The maximum sulfur content in fuel for petrol is currently 50 ppm with a further reduction of the standard to 10 ppm scheduled for 2027.

are subject to the relevant ADR, based on the vehicles year of manufacture, and fuel quality is legislated are set under the Fuel Quality Standards Act 2000.

Domestic, Social, Rural and Open Space Management Activities

The main air pollutants produced by these activities are smoke and fumes from fires, spray and fumes from the use of chemicals, and dust. Of these, domestic wood fires are the main source of air emissions.

Outdoor fires are controlled through the types of material that can be burned, when the fires may be lit, and in the allowable emissions, which are dependent on the purpose for which the fire was lit. Indoor fires are also restricted in the types of materials that can be burned and the way in which the fires are managed. Synthetic substances painted or chemically treated woods, chemicals, unseasoned wood, and wastes are not allowed to be burned, except in incinerators that hold an environmental authorisation to do so. Under section 12 of the Environment Protection Regulation 2005, a person must take “such steps as are practicable and reasonable to prevent or minimise the environmental harm caused, or likely to be caused, by the emission of pollutants into the air from the fire.” These steps include managing the fire such that excessive smoke is not produced.

3.0 ACT Planning Legislation, Development Plans and Strategies

3.1 Overview

As an objective of this study is to both identify future potential air emissions sources and understand development created impacts it is important to provide an understanding of planning legislation within the ACT and more specifically the underpinning strategies and plans that are expected to influence future development with the ACT. This both aids in the understanding in the identification of changes to air emission sources such as from changes to transport emissions and how future land use changes may influence both sensitive receptor density and dispersal conditions.

3.2 Planning Act 2023

The *Planning Act 2023* (the Planning Act) provides the legal foundation for the ACT planning system. Key elements of the Act that allow for the provision of planning instruments include:

- Section 36 which requires the provision of a planning strategy. The ACT Planning Strategy is discussed in **Section 3.2.1** and provides:
 - The long-term planning policy and goals for the ACT;
 - The overarching spatial vision.
 - Strategic directions and desired future planning outcomes.
- Section 38 allows for plans to be developed for individual districts (district strategies) which are discussed in **Section 3.2.3.1** to **Section 3.2.3.9** which include:
 - Strategies, spatial policies and desired future planning outcomes
 - Principles and policies for development areas including future urban areas
 - Identification of areas in the district for future detailed planning
 - Inclusion of other government strategies that may apply to a district.
- Section 45 allows for the provision of a Territory Plan as a notifiable instrument. The Territory Plan 2023 is discussed in **Section 3.2.1** and is required to:
 - Sets out a map that identifies both districts and land use zones
 - Sets out the planning principles and policies for giving effect to the object of the plan

3.2.1 The Territory Plan 2023

The Territory Plan 2023 (Territory Plan) is a notifiable planning instrument under Section 45 of the Planning Act and guides the planning and development in the ACT. The Territory plan sets out a statutory framework for the future development and conservation of land in the ACT.

The Territory Plan is divided into both District and Zone Policies. District policies detail the key assessment requirements and expected outcomes relevant to each specific district. Zone policies list the types of developments that can be built in specific zones.

There are ten district policies under the Territory Plan, one for each of the nine districts and an additional non-urban district policy.

3.2.2 National Capital Plan 1990

The National Capital Plan 1990 (and amendments) is the strategy and blueprint giving effect to the Commonwealth's interests for planning designing and developing Canberra and the Territory and is administered by the National Capital Authority on behalf of the Australian Government.

The National Capital Plan provides for the continuation of urban development in the ACT as separate and distinct towns set in broad landscaped valleys, with the immediate hills, ridges and other major open space providing separation between towns and the distant mountains providing a natural landscape backdrop.

3.2.3 ACT Planning Strategy 2018 and District Strategies

The ACT Planning Strategy 2018 (the Planning Strategy) informs policy development and investment in Canberra and its districts. The strategy provides a vision for a more compact and efficient city and a strategic direction that the future urban growth will be supported by delivering up to 70% of new homes within Canberra's existing urban footprint.

There are nine districts within Canberra and each one has their own strategy. The strategies help direct forecasted growth towards 2038 and beyond 2050 to areas of Canberra that are best suited for it. They also outline what future services, transport and infrastructure is needed in those areas. An overview of each District Strategy are described below in **Section 3.2.3.1** to **Section 3.2.3.9**. Further information on change areas and key sites identified in each district strategy is provided in **Appendix A**.

3.2.3.1 Belconnen District Strategy

The Belconnen District is in Canberra's northwest and is the most heavily populated of Canberra's nine districts. The Belconnen District Strategy (ACT Government 2023a) outlines the future development for the district. Future development would focus on infill areas, primarily in and around the Belconnen town centre and other central hubs within the district, Lawson North and in greenfield development as part of the Ginninderry in the west of the district. The strategy includes several change areas and key sites identified for development within the next 15 years and these are summarised in **Appendix A**.

An additional estimated additional 21,200 dwellings required within the Belconnen District to meet 2050 population growth projections. Land releases and redevelopment of brownfield sites will not be enough to meet housing needs with a projected shortfall of 14,000 to 15,000 dwellings by 2050 when expected development under existing plans and key sites and change areas identified above are accounted for. Housing density in existing suburbs would need to increase through urban regeneration areas. This includes replacement of low density housing with medium density housing in existing suburbs around centres and key transit routes including town housing, dual occupancies, duplexes, triplexes, and terrace housing.

Additional transport infrastructure would be required within the district to support increased population growth by 2050. This would include:

- Medium term strategic initiatives in the next ten years including:
 - Planning for additional rapid transport connections between Belconnen and Molonglo Valley
 - Investigate and invest in structural transport growth areas in Ginninderry and Kippax
 - Improve freight network and access around Kippax
 - Progressively implement upgrades to priority travel routes between:
 - Southern Cross Drive and Belconnen Way linking Kippax and Belconnen town centre
 - Lake Ginninderra Circuit path and connecting paths to the town centre and Southern Cross Drive via Florey
- Long term strategic initiative within the next 20 years to investigate and deliver the light rail network to Belconnen town centre including connecting the City Centre and Canberra Airport
- Longer term strategic initiative in over 20 years' time to investigate additional transport connections between west Belconnen and main employment centres in the east.

3.2.3.2 East Canberra District Strategy

The East Canberra District contains the aviation, freight and business hub of Canberra Airport and is a key employment district while also containing environmentally sensitive areas and threatened flora, fauna and ecological communities. The East Canberra District Strategy (ACT Government 2023b) outlines the future development for the district. Future development would focus on enhancing employment opportunities, while maintaining a modest development footprint to protect environmentally sensitive areas. The strategy includes several change areas identified for development within the next 15 years and these are summarised in **Appendix A**.

East Canberra District does not have any areas that will be investigated for potential urban regeneration.

The district is important for freight, logistics and facilitation of economic activity across the ACT and its gateway role to key industrial areas. Additional transport infrastructure would be required within the district to improve connectivity by 2050. This would include:

- Short term strategic initiatives within the next five years including:
 - Identification and protection of major road and rail corridors
 - Support cross-border infrastructure and road connectivity to accommodate anticipated employment and housing growth East Canberra District does not have any areas that will be investigated for potential urban regeneration.
- Medium term strategic initiatives in the next ten years including:
 - Planning for expansion of the light rail network
 - Investigate improvement to public transport access to East Canberra, from Inner South Hume and Tuggeranong District.
- Longer term strategic initiative in over 20 years' time to investigate potential for high speed rail connection through the district.

3.2.3.3 Gungahlin District Strategy

The Gungahlin District is in Canberra's northern most district and the ACT's major greenfield growth area over the past thirty years, including new suburbs Taylor and Jacka in the north and the soon to be established suburb of Kenny in the southeast. As one of the newer districts, Gungahlin has more compact forms of development and street layouts, though this differs between suburbs depending on when they were established. The district also houses a light industrial estate in the suburb of Mitchell. The operation of Stage 1 of the Canberra light rail network from Gungahlin town centre to the City Centre has stimulated housing growth and development along the corridor.

The Gungahlin District Strategy (ACT Government 2023c) outlines the future development for the district. The strategy includes several change areas and key sites identified for development within the next 15 years and these are summarised in **Appendix A**.

An additional estimated additional 17,900 dwellings required within the Gungahlin District to meet 2050 population growth projections. Land releases will not be enough to meet housing needs with a projected shortfall of 2,000 to 2,500 dwellings by 2050 when expected development under existing plans are accounted for. Housing density in existing suburbs would need to increase through urban regeneration areas. This includes replacement of low density housing with medium density housing in existing suburbs around centres and key transit routes including town housing, dual occupancies, duplexes, triplexes, and terrace housing.

The establishment of light rail from the town centre to the City Centre has been the most significant public transport project within Gungahlin District and patronage is expected to increase over the coming years. Ongoing capacity for freight and heavy vehicles on key roads into Mitchell to support its industrial and urban services function is expected to be maintained including the potential for extension of Morisset Drive to the Federal Highway to reduce road pressures and heavy vehicle traffic on Flemington Road. Other strategic transport initiatives identified for the district include:

- A short term initiative within the next five years to investigate progressive upgrades to priority active travel routes including along the Barton Highway adjacent to Palmerston and Crace, along Flemington Road and within Franklin and Gungahlin town centre.
- A medium term initiative within the next ten years to investigate new rapid transport services to the northern suburbs of the Gungahlin district connection the town centre to group centres in Casy, Moncrief and Amaroo.

3.2.3.4 Inner North and City District Strategy

The Inner North and City District is centrally located immediately north of Lake Burley Griffin. There is a central spine along Northbourne Avenue from the lake through to the Federal Highway and the ACT border with NSW to the north. The district is highly urbanised and includes the City Centre and several established suburbs. The Inner North District Strategy (ACT Government 2023d) outlines the future

development for the district. The district has seen significant population growth and development in recent years catalysed in part by the light rail corridor linking the Gungahlin District to the City Centre.

The strategy includes several change areas and key sites identified for development within the next 15 years and these are summarised in **Appendix A**.

An additional estimated additional 24,000 dwellings required within the Inner North District to meet 2050 population growth projections. Land releases and redevelopment of brownfield sites will not be enough to meet housing needs with a projected shortfall of 6,000 to 7,000 dwellings by 2050 when expected development under existing plans and key sites and change areas identified above are accounted for. Housing density in existing suburbs would need to increase through urban regeneration areas. This includes replacement of low density housing with medium density housing in existing suburbs around centres and key transit routes including town housing, dual occupancies, duplexes, triplexes, and terrace housing.

Additional transport infrastructure would be required within the district to support increased population growth by 2050. This would include:

- Short term strategic initiative within the next five years to deliver Stage 2a of the Canberra Light Rail from Alinga Street to Commonwealth Park.
- Medium term strategic initiative in the next ten years to continue investigations and planning for future light rail corridors including a potential link between Belconnen, Russel and Canberra Airport.
- Long term strategic initiatives within the next 20 years to:
 - Undertake detailed planning for the City Centre and its future as a multimodal transport hub
 - Investigate options for increasing the capacity of the public transport network to relieve demand pressures including Northbourne Avenue Corridor linkages.

3.2.3.5 Inner South District Strategy

The Inner South District is one of ACT's most established districts, extending from the Fyshwick industrial precinct in the east to Yarralumla and Deakin in the west. The Inner South District Strategy (ACT Government 2023e) outlines the future development for the district. The construction and operation of the proposed Stage 2b Canberra Light Rail Project extending from Commonwealth Avenue to Woden is expected to bring a positive transformation of the district.

The strategy includes several change areas and key sites identified for development within the next 15 years and these are summarised in **Appendix A**.

An additional estimated additional 7,000 dwellings required within the Inner South District to meet 2050 population growth projections. Land releases and redevelopment of brownfield sites will not be enough to meet housing needs with a projected shortfall of 3,500 to 4,000 dwellings by 2050 when expected development under existing plans and key sites and change areas identified above are accounted for. Housing density in existing suburbs would need to increase through urban regeneration areas. This includes replacement of low density housing with medium density housing in existing suburbs around centres and key transit routes including town housing, dual occupancies, duplexes, triplexes, and terrace housing.

In addition to current investigations and future delivery into the Canberra Light Rail from City Centre to Woden additional transport infrastructure would be required within the district to support increased population growth by 2050. This would include:

- Short term strategic initiatives within the next 5 years include:
 - Planning for Canberra Railway Station as a key element of the strategic investigation corridor from Parliamentary zone to Fyshwick
 - Ensure future development control plans around Kingston and Fyshwick support and maintain capacity for freight traffic in the district.
- Medium term strategic initiatives in the next ten years including:

- Improve public transport connections.
- Progressively deliver upgrades and additions to cycling network.
- Lake Ginninderra Circuit path and connecting paths to the town centre and Southern Cross Drive via Florey
- Long term strategic initiative within the next 20 years to investigate the long term potential for enhance public transport connections to Fyshwick.

3.2.3.6 Molonglo Valley District Strategy

The Molonglo Valley District is located less than 10km from the City Centre between the districts of Belconnen and Weston Creek; and is the newest of nine districts and the main greenfield development area within the ACT. It includes the new suburb of Whitlam and other future residential suburbs marked for future development. The suburb of Molonglo will also include the districts main commercial hub. The Molonglo District Strategy (ACT Government 2023f) outlines the future development for the district which will cater for a large proportion of the overall demand for low density detached dwellings in the ACT as well as future medium density residential dwellings including townhouses and apartments. The strategy includes several change areas identified for development within the next 15 years and these are summarised in **Appendix A**.

An additional estimated additional 24,000 dwellings required within the Molonglo Valley to meet 2050 population growth projections. Expected development under existing plans on greenfield sites are expected to meet this housing demands. No urban regeneration areas have been identified under the Molonglo Valley District Strategy.

Current road projects in the road network include construction of the remaining stage of the John Gorton Drive strategic investigation corridor, including a bridge over the Molonglo River. There are also two major road connections into the district including the east-west east-west arterial linking Denman Prospect and the Molonglo group centre in the west to the Tuggeranong Parkway in the east.

Additional transport infrastructure would be required within the district to support increased population growth by 2050 and provide adequate transport infrastructure to new land release areas and connections to other districts. This would include:

- Short term strategic initiatives within the next five years to implement priority upgrades to Molonglo Valley, including connections within the district and priority connections to adjacent districts.
- Medium term strategic initiative within the next ten years to plan for additional rapid transport connections between Belconnen and Molonglo Valley.
- Longer term strategic initiative in over 20 years' time to further enhance and plan for potential enhancements and additions to the rapid transport network to Molonglo Valley.

3.2.3.7 Tuggeranong District Strategy

The Tuggeranong District Strategy is the ACT's southernmost and second largest district. The Tuggeranong town centre is the main employment hub the district also has many local and group centres servicing low density residential suburbs. The Tuggeranong District Strategy (ACT Government 2023g) outlines the future development for the district which is expecting moderate population growth. The strategy includes several change areas and key sites identified for development within the next 15 years and these are summarised in **Appendix A**.

Modest population growth is forecasted for the Tuggeranong District with an estimated 1,100 dwellings required within the district to meet 2050 population growth projections. Future housing opportunities including expected development under existing plans, identified change areas and key sites and potential urban regeneration areas can provide a housing surplus within the district.

Additional transport infrastructure would be required within the district to support city growth by 2050. This would include:

- Short term strategic objectives within the next five years to:
 - Progressively implement upgrades to priority travel routes

- Investigate cross boarder infrastructure and road connectivity to accommodate housing growth in South Jerrabomberra
- Continue with duplication of Athllon Drive and upgrades to the Monaro Highway between Hume and Isabella Drive.
- Long term strategic initiative within the next twenty years to further investigate and deliver the light rail network to Tuggeranong town centre.

3.2.3.8 Weston Creek District Strategy

The Weston Creek District located south of the Molonglo Valley District is the smallest of ACTs district. It has a largely suburban character and is not expected to see substantial levels of new development, with only modest population growth forecast for the region. Potential opportunities investigated within the district are likely to focus on employment opportunities and longer term transport initiatives.

The Weston Creek District Strategy (ACT Government 2023h) outlines the future development for the district. The strategy includes several change areas identified for development within the next 15 years and these are summarised in **Appendix A**.

Modest population growth is forecasted for the Weston Creek District with only an estimated 300 dwellings required within the district to meet 2050 population growth projections. Future housing opportunities including expected development under existing plans and potential urban regeneration areas can provide a housing surplus within the district.

Additional transport infrastructure would be required within the district to support city growth by 2050. This would include:

- Short term strategic objective within the next five years to deliver upgrades to Streeton Drive intersections.
- A longer term strategic objective over 20 years or more is to investigate corridors for future rapid transit connections from Weston Creek to Woden and Molonglo Valley.

3.2.3.9 Woden District Strategy

The Woden district is north of the Tuggeranong District. The district itself houses a relatively small population. Woden town centre is the central employment hub for the district, it also poses a key transport hub for Canberra's South side.

The Woden District Strategy (ACT Government 2023i) outlines the future development for the district. Future development opportunities are expected to stem from the proposed extension of the light rail network from the City Centre to Woden; with population growth and increases in higher density dwelling types marked for this district. The strategy includes several change areas and key sites identified for development within the next 15 years and these are summarised in **Appendix A**.

Modest population growth is forecasted for the Woden District with only an estimated 3,400 dwellings required within the district to meet 2050 population growth projections. Future housing opportunities including expected development under existing plans and potential urban regeneration areas can provide a housing surplus within the district.

Additional transport infrastructure would be required within the district to support city growth by 2050 and address areas of the network already facing congestion. This would include:

- Short term strategic objectives within the next five years to:
 - Future planning of Athlon Drive identified as a multimodal transport and urban corridor.
 - Implement upgrades to priority travel routes.
- Medium term strategic objectives within the next 10 years to:
 - Deliver Stage2b of the light rail Project from the City Centre to Woden
 - Identify strategies to improve road corridors including Melrose Drive and Hindmarsh Drive
- A Longer-term strategic objective over 20 years or more is to investigate corridors for future rapid transit connections from Weston Creek to Woden and Molonglo Valley.

3.3 ACT Transport Strategy 2020

The ACT Transport Strategy 2020 (the Transport Strategy) has been developed alongside the ACT Planning Strategy (refer to **Section 3.2.1**) sets out the ACT Governments provides a framework for planning and investment into transport over the next 20 years and beyond. A copy of the ACT Transport Policy Map showing the conceptual transport network for 2045 is shown below in **Figure 2**. The conceptual plan shows key central links that focus on improving links between centres and urban intensification areas by public transport, walking or cycling. Orbital links support trips around and across the city for private vehicles and freight and regional links focus on enhancing connectivity between Canberra and Sydney, road freight connection routes to inland and coast regions and air routes.

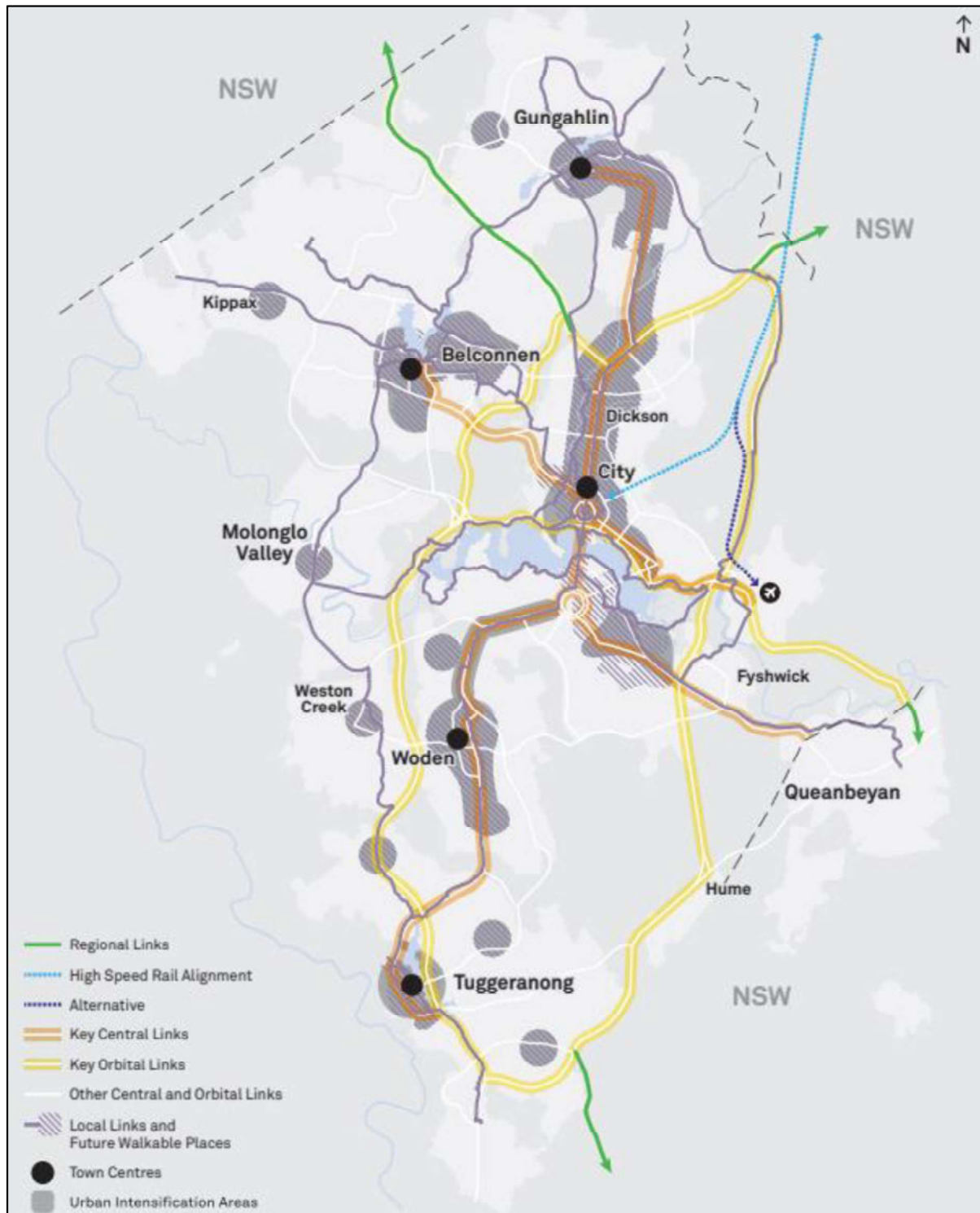


Figure 2 ACT Transport Policy: conceptual transport network for 2045

Source: ACT Transport Strategy 2020

3.4 ACT Strategies, Influencing Air Quality

3.4.1 Phase out of wood heaters by 2045

The ACT Government is moving towards phasing out wood heaters in urban areas of the ACT by 2045; and would extend to all suburbs within the ACT excluding rural areas. The ACT Government already offers incentives and support to remove old wood heaters and offers rebates and incentives to encourage uptake of electrical heating alternatives through the:

- Wood Heater Removal Program
- Home Energy Support Program
- Sustainable household Scheme

Firewood merchants are also regulated under the EPA Act 1997 and must comply with the requirements as set out in Section 14 of the Environment Protection Regulation 2005. These requirements include that the merchant must supply customers with seasoned wood, supplied by weight and customers are provided with an EPA pamphlet setting out the recommended wood burning practices and encourages compliance with those practices.

3.4.2 Phase out of petrol and diesel light vehicle sales by 2035

The ACT Government is moving towards the phasing out of light internal combustion engine vehicles by 2035 in Canberra. The ACT is also aiming for 80 to 90% of new light vehicles sold in the ACT to be electric or hydrogen powered by 2030, ahead of the 2035 deadline.

3.4.3 Phase out of natural gas by 2045

The ACT Government is moving towards the phasing out natural gas by 2045. As the ACT is 100% renewable electricity, natural gas emissions make up around 20% of the ACT's emissions. To achieve this, new natural gas connections were banned from 2023 and gas infrastructure would be phased out by 2045.

3.5 ACT Bushfire Smoke and Air Quality Strategy 2021-25

The ACT Bushfire Smoke and Air Quality Strategy 2021-25 seeks to focus its efforts across all government authorities to reduce the effects of smoke pollution in the ACT. This Strategy represents a whole-of-government approach to effectively prevent, prepare for, respond to, and recover from significant bushfire smoke events in the future. It also outlines the coordinated actions that have been taken to manage smoke from wood heaters as well as future actions.

This document sets the vision for the future of air pollution in the ACT with regards to bushfires and wood smoke. The vision is as follows:

"Our vision is to support healthy communities by reducing the adverse effects of bushfire and woodfire smoke on human health"

The stages of the strategy are as follows:

- 1- Support the implementation of the Strategic Bushfire Management Plan to manage and reduce bushfire risks and consequences in the ACT
- 2- Strengthen measures to address the air quality impacts of wood heaters
- 3- Enhance air quality monitoring and forecasting
- 4- Consider the impact of air quality associated with bushfire smoke through all phases of the emergency management continuum
- 5- Support the development of buildings that are resilient to smoke pollution
- 6- Support the Health and Wellbeing of Canberrans affected by bushfire and wood smoke
- 7- Provide targeted support to vulnerable populations and workers during severe air pollution events
- 8- Provide economic supports to businesses, communities and individuals affected by severe bushfire smoke

These stages will be tracked and reported to ensure there is progress on the implementation of the strategy.

3.6 Commissioner for Sustainability and the Environment's report into Wood Heater Policy

The Commissioner for Sustainability and the Environment's report into Wood Heater Policy report examined the existing wood heater policy in the ACT. This report was commissioned following a community complaint into wood smoke which triggered an investigation into woodsmoke more broadly.

Findings of the investigation were that an investigation into the wood smoke policy framework was needed to ensure the problem is being dealt with appropriately.

The investigation examined a range of legislative instruments, reports and data sets to understand the wood smoke issue. The findings of the study were *"While the ACT Government is committed to strengthening wood heater emissions standards and phasing out older wood heaters that do not meet standards, this Investigation demonstrates that current policies, plans and strategies for managing wood heaters in the ACT are insufficient to protect human health and the environment of the Territory from issues arising from wood heaters"*

The specific areas of policy issues included:

- Inadequate emissions and efficiency standards
- Difficulty with enforcement of smoke standards
- Education campaigns have not improved air quality to safe levels in winter
- Wood heater replacement programs have not been effective
- Wood heater suburb restrictions have been limited to some greenfield areas

A range of recommendations were made, including:

- Phase out of wood heaters
- Improve education about wood heater risks
- Strengthen compliance powers

3.6.1 Government response to the recommendations of the report

Of the eight recommendations presented in the Commissioner's report, the ACT Government has agreed or agreed in principle with four and noted two.

The ACT government agreed to the following recommendations:

- To include explicit messaging about the health risks associated with wood heater usage in ACT Government education and communication activities (e.g., Burn Right Tonight program).
- Reconsider responses to the 2019 State of the Environment Report's recommendations 21 and 22:
 - 21 Increase the number of National Environment Protection (Ambient Air Quality) Measure compliance monitoring stations, and
 - 22 Urgently undertake an assessment of air pollutant emissions from diffuse sources to update the National Pollutant Inventory data (1999).

The ACT government agreed in principle to the following recommendations:

- Phase out wood heaters from ACT suburbs through the establishment of a target date for the replacement of wood heaters with electric alternatives in all ACT suburbs (excluding rural areas), as has been done for fossil-fuel gas. This should be supported through accessible financial support for lower income households.

- Ban the installation of new wood heaters in all ACT suburbs (excluding rural areas), for both new and existing builds.

The ACT government noted the following recommendations:

- Mandate the removal of wood heaters before a property in any ACT suburb (excluding rural areas) can be sold.
- Introduce mandatory labelling explaining the health risks associated with wood heater usage at point of sale for both wood heaters and firewood in ACT.

The ACT government did not agree the following recommendations:

- Establish a register of wood heaters in the ACT to determine the number and age of wood heaters.
- Develop and apply empirical criteria for determining environmental harm or nuisance from wood heater smoke, such as assessment of smoke composition and air quality monitoring at the affected sites, as part of EPA investigations.

4.0 Climate and Local Geographical Setting

When examining the potential effect of domestic wood smoke within the ACT is first worth examining the existing climatic conditions within the ACT and how the particular topographical and land use characteristics within the ACT may influence the wood smoke dispersion.

4.1 Meteorology

ACT meteorology on a regional scale is dominated by synoptic scale winds which are large-scale wind patterns that occur over extensive areas, typically spanning hundreds to thousands of kilometres. These winds are primarily influenced by major weather systems such as high-pressure and low-pressure areas, frontal systems, and jet streams. Synoptic scale winds are a key component of the Earth's atmospheric circulation, playing a crucial role in weather patterns and climate.

Micrometeorology refers to the atmospheric processes and phenomena that occur at small spatial scales, typically less than 1 kilometre in extent, and over shorter time periods, typically minutes to hours. This component of meteorology focuses on the interactions between the atmosphere and the Earth's surface, including vegetation, soil, water bodies, and man-made structures. Micrometeorology is of particular importance to urban air quality as the effects from manmade structures and land use changes are more pronounced.

The analysis of meteorology in this report has been focused on the micrometeorological patterns around the ACT. The following sections summarise the meteorological parameters observed at a range of locations around the ACT. Data has been sourced from the Australian Bureau of Meteorology (BOM) and from Icon Water, who are a public utility responsible for the operation of the ACT's water and wastewater assets.

4.1.1 Wind Speed and Direction

Wind speed and direction are crucial components in the study of micrometeorology due to their significant impact on various atmospheric and surface processes at small scales. These parameters influence the exchange of energy and mass between the surface and the atmosphere, affecting processes like evaporation, transpiration, and gas fluxes, which are key to understanding microclimates and local environmental conditions. In urban areas, wind patterns help predict the dispersion and concentration of pollutants, essential for air quality management, public health, and environmental protection.

Local wind patterns contribute to the formation of microclimates by affecting temperature and humidity distributions through processes like advection and mixing. In urban areas of the ACT, understanding wind speed and direction is important for managing the urban heat island effect, designing effective ventilation systems, and optimizing building placement to enhance natural ventilation and reduce energy consumption. Wind also plays a role in soil erosion and deposition processes, which is important for managing soil conservation efforts and predicting the movement of sand and dust.

Accurate measurements of wind speed and direction are essential for interpreting micrometeorological data and for developing and validating models that simulate local atmospheric conditions. Overall, wind speed and direction are integral to micrometeorology because they directly influence the microenvironment's thermal, moisture, and chemical characteristics, which are critical for understanding and managing various natural and human-made systems at small scales.

Meteorological data was obtained for the following locations:

- Bureau of Meteorology station locations:
 - Mt Ginini
 - Canberra Airport
 - Tuggeranong
- Icon Water meteorology station locations
 - Googong
 - West Belconnen

- Pierces Creek
- LMWQCC

The location of these meteorology stations with wind roses shown in **Figure 3**.

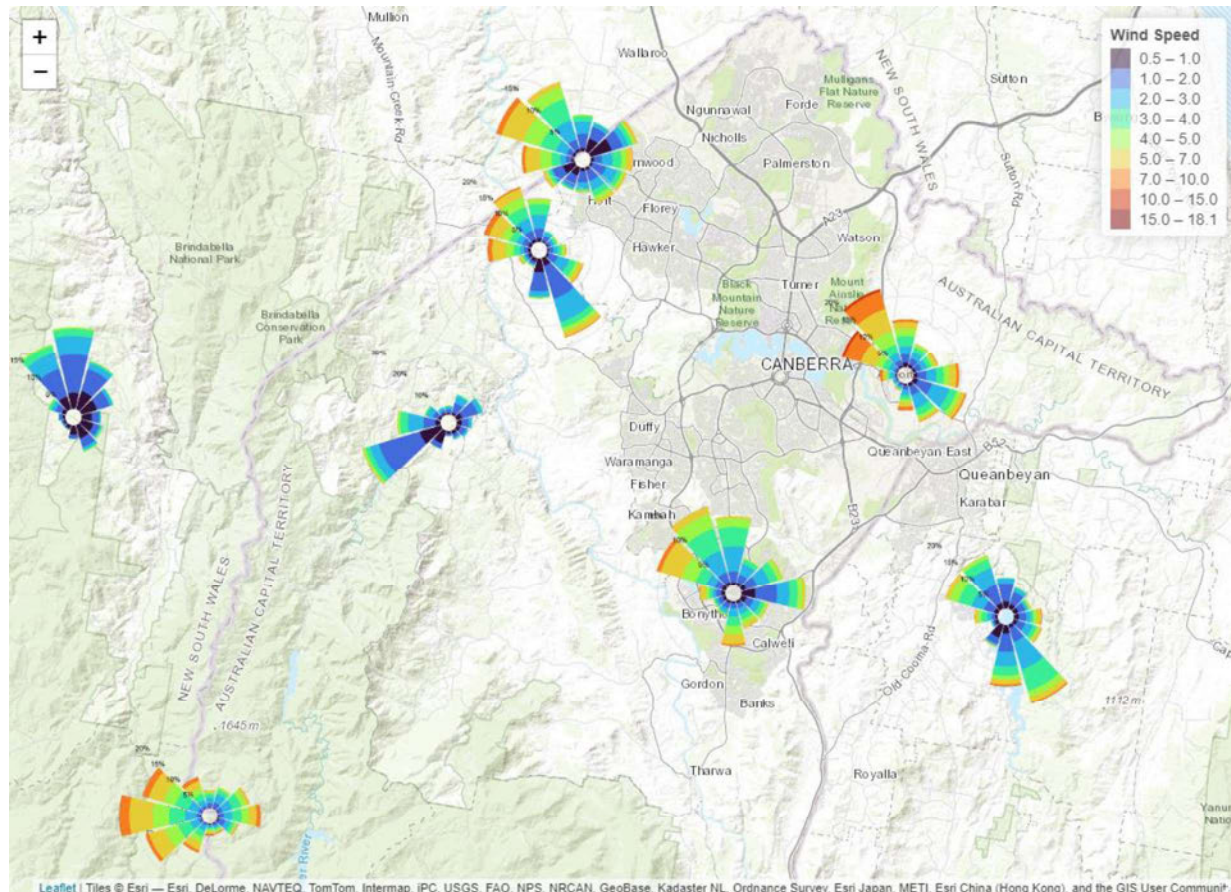


Figure 3 Wind roses for Meteorological Monitoring Stations considered for the study

Wind patterns across the ACT urban areas are reasonably consistent with predominant winds presented on a northwest to southeast axis. A higher proportion of high winds are observed at the Canberra Airport in comparison to the other locations, with high winds creating increased mechanical mixing which is favourable to pollutant dispersion. Significant variance in wind direction was observed at the Pierces Creek and Mt Ginini stations, which are situated close to the Brindabella Ranges to the west of the ACT urban areas. The terrain of the ranges appears to be significantly affecting the wind directions, particularly at the Pierces Creek station which is situated within a valley and shows a much higher calm percentage than the Mt Ginini Station situated at the top of the ranges.

An analysis of the variance in the wind speeds from the different stations was undertaken as a comparison of wind variability across the ACT. Several plots were generated for the analysis including wind speed variability by time of day, wind speed variability by day of the week and wind speed variability by month.

Wind Speed Variability by Time of Day

Figure 4 shows the variability in the wind speed for each hour of the day between January 2018 and December 2019. The wind speed trends show that overall, there is a common trend across all stations of lower wind speeds during the night and higher wind speeds during the day, with wind speed reaching its highest value around 2-3pm in the afternoon. The only station where this trend was not observed was the Mt Ginini station, which showed only minor variation in wind speed across the day with higher wind speeds observed during the night (although the difference between the highest and lowest wind speeds was small).

The station with the highest average wind speed was at Canberra Airport with the lowest wind speeds observed at the Pierces Creek station.

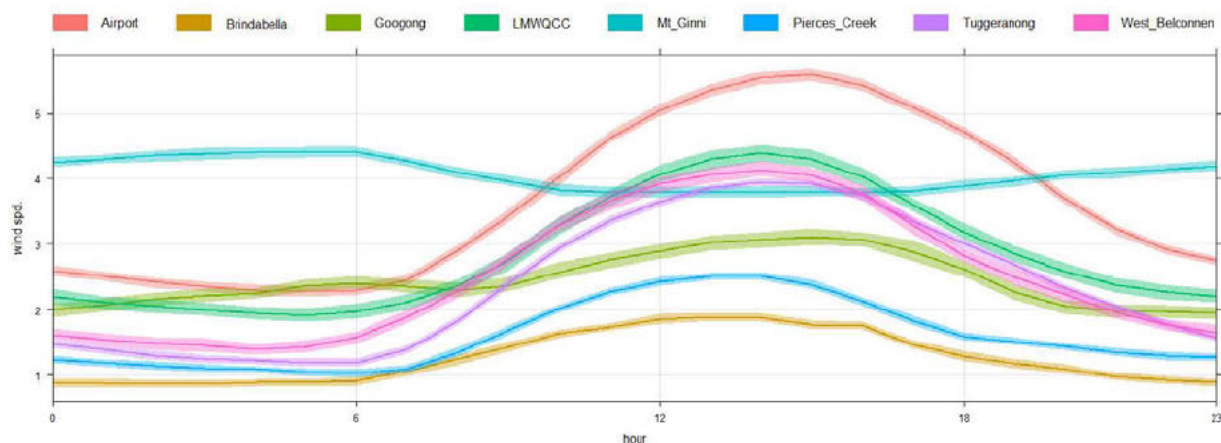


Figure 4 Wind speed (m/s) variance between stations by hour of day

Table 3 Calm Percentages

Station	Calm Percentage (all hours)
Canberra Airport	6.4
Googong	3.0
LMWQCC	4.1
Mt Ginini	0.9
Pierces Creek	7.2
Tuggeranong	22.6
West Belconnen	11.2

Analysis of the calm conditions, where wind speed is less than 0.5 m/s, for the different stations shows that the highest calm percentages occur at Tuggeranong, followed by West Belconnen and Pierces Creek. These locations correspond with locations closer to the ranges to the south and west of the ACT urban areas. Calm conditions are generally associated with a stable atmosphere where pollutant dispersion is less effective.

Wind Speed Variability by Month of Year

Figure 5 shows a similar trend across most of the meteorology stations examined by this assessment. There is a trend of higher winds in summer, winter and spring with lower wind speeds observed during autumn. This trend was again not observed for Mt Ginini, which showed a clear trend of higher winds during the cooler months and lower winds during the warmer months.

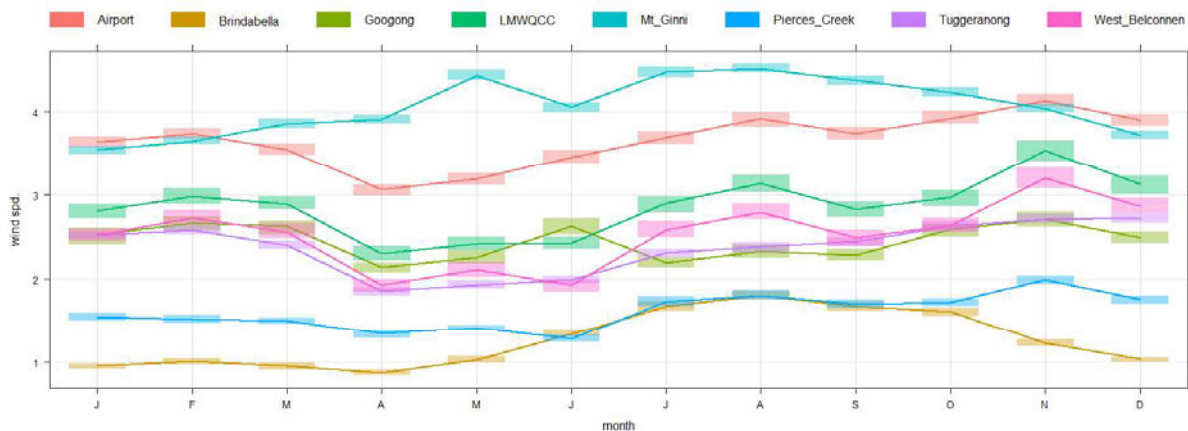


Figure 5 Wind speed (m/s) variance between stations by month

4.1.2 Temperature

Temperature is a fundamental factor when studying micrometeorology as it influences a range of atmospheric and surface processes. It plays a critical role in the exchange of energy between the surface and the atmosphere. Temperature differences drive the sensible heat flux, which involves the transfer of heat due to temperature gradients between the ground and the air. This process is essential for the regulation of the thermal environment of the boundary layer, the lowest part of the atmosphere that is directly influenced by the earth's surface.

In terms of weather patterns, temperature influences atmospheric stability and the formation of weather phenomena. Temperature gradients can lead to convection, where warmer air rises and cooler air sinks, driving the development of clouds and precipitation. This is particularly important for predicting local weather conditions and understanding the dynamics of thunderstorms and other convective systems.

Temperature also impacts human comfort and health. It is a key factor in determining the heat index, which combines air temperature and humidity to indicate how hot it feels to humans. Extreme temperatures, whether hot or cold, can pose health risks and affect human activities. Urban areas can experience higher temperatures due to the urban heat island effect, where the concentration of buildings, roads, and other infrastructure retains heat, leading to warmer conditions compared to surrounding rural areas.

Temperature plays a critical role in the formation and persistence of microclimates. Microclimates are localised climate conditions that differ from the surrounding areas, often influenced by factors such as topography, vegetation, and water bodies. Understanding temperature patterns at these small scales is important for various applications, including urban planning, agriculture, and natural resource management.

Temperature trends have been examined for two meteorological stations with long term data sets (Tuggeranong and Canberra Airport). Ten years of data was examined (2014-2023) to understand trends in temperature both between seasons and between years.

The first analysis of the data examined the diurnal variation across the full data set for different months of the year. The data in Figure 6 shows that there is a clear and consistent diurnal temperature trend which varies between seasons. There were only minor differences observed between the two monitoring station locations with the Tuggeranong station recording slightly higher temperatures than the Canberra Airport, with the differences mostly observed during the early hours of the morning.

In addition to a comparison for different seasons and time of day, the variance across different years was examined. Data are presented in Figure 7 and Figure 8 show a comparison of temperatures for January and June (Summer and Winter) for three years (2014, 2019 and 2023). Analysis of the data shows the following:

- Significant differences were observed in average temperatures between the 2014, 2019 and 2023 years.
- In summer, 2019 data were significantly higher than those observed for 2014 and 2023 (although the 2014 temperatures were higher than the 2023 data during the day).
- In winter the trends reversed with the 2019 data having lower average temperatures across the day as compared with 2014 and 2023.

The reasons behind the observed temperature trends are not clear but are likely to be due to changes to regional climate conditions. In particular, the change between El Nino to La Nina and the weather phenomenon is likely to influence the temperatures.

Figure 9 shows the southern oscillation index changes over time, which shows that for 2014 and 2023, the southern oscillation index was showing a weak El Nino event whereas the data for 2019 showed a much stronger El Nino. Stronger El Nino events are commonly associated with warmer temperatures in Eastern Australia which is generally supported by the observations of the temperature trends.

Warmer weather can aid pollutant dispersion by setting up stronger convective mixing and reducing atmospheric stability, however warmer years are often associated with drier periods where dust generation can be higher.

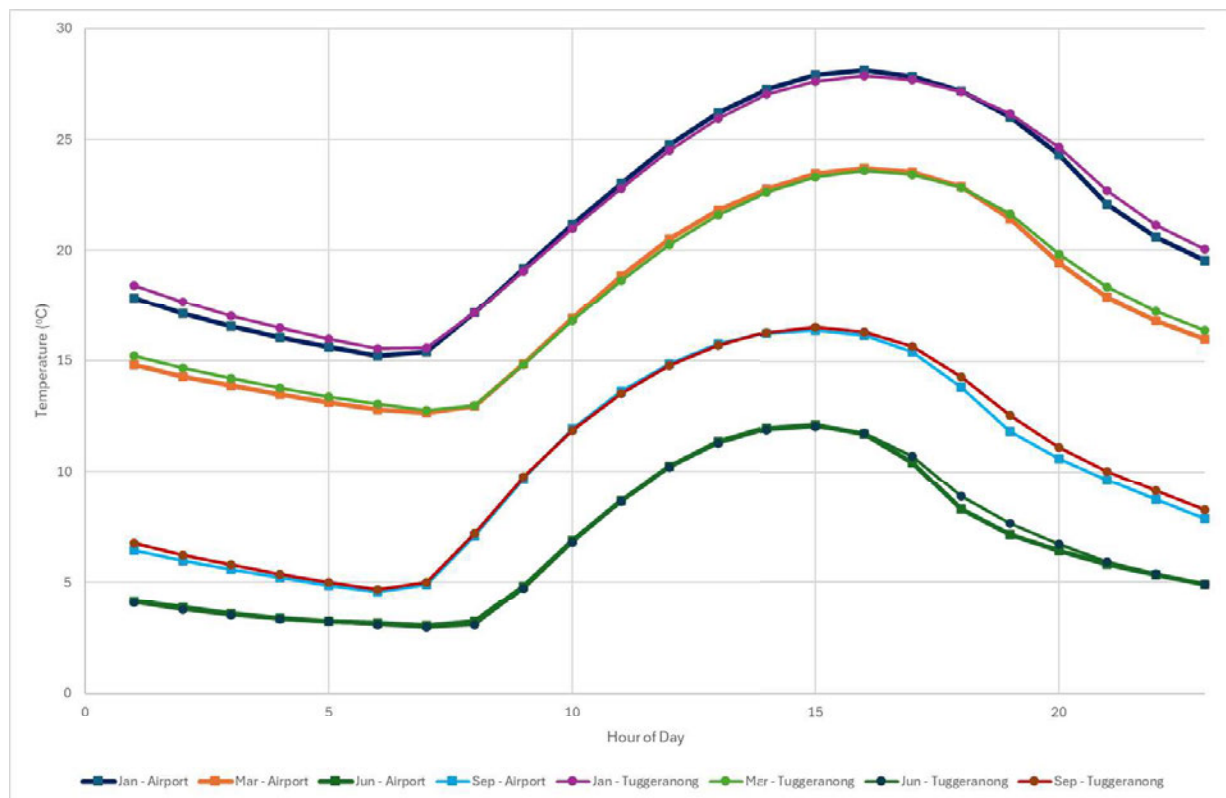


Figure 6 Diurnal Temperature Deviation across all seasons

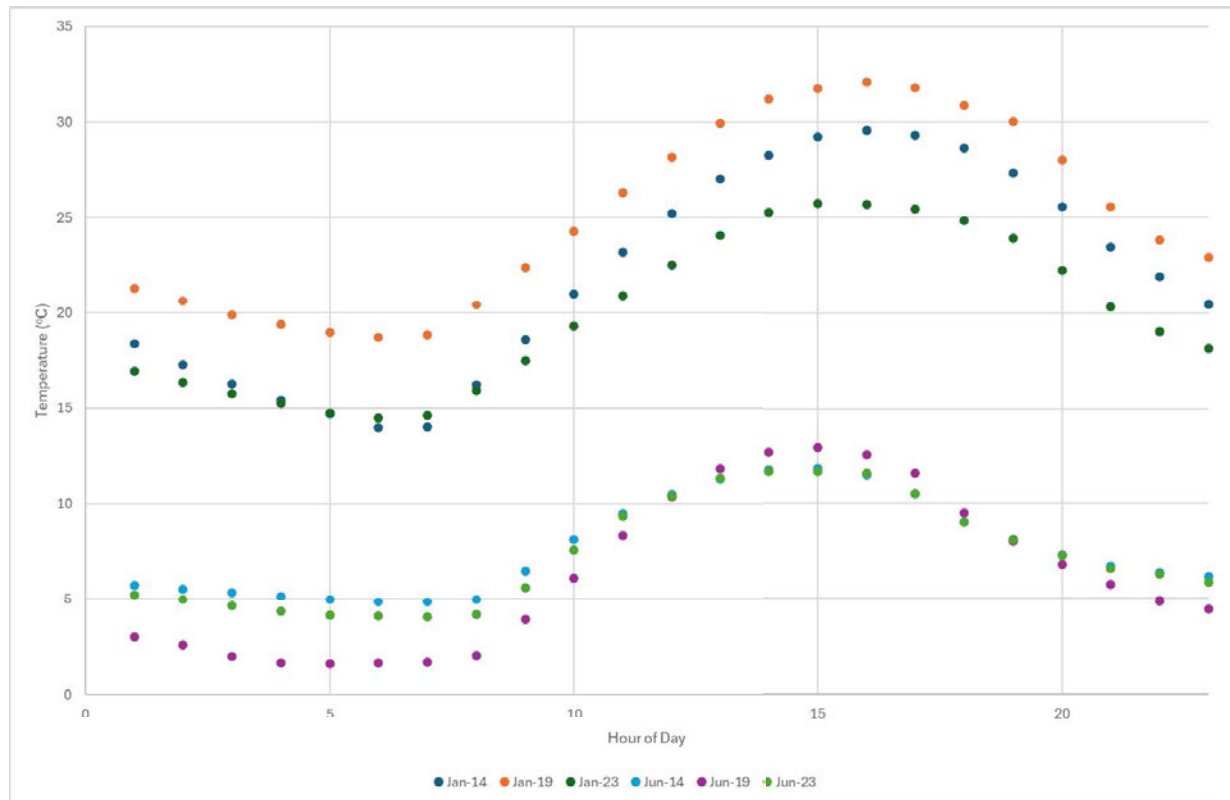


Figure 7 Diurnal Temperature Deviation across seasons (summer and winter) and years (Tuggeranong)

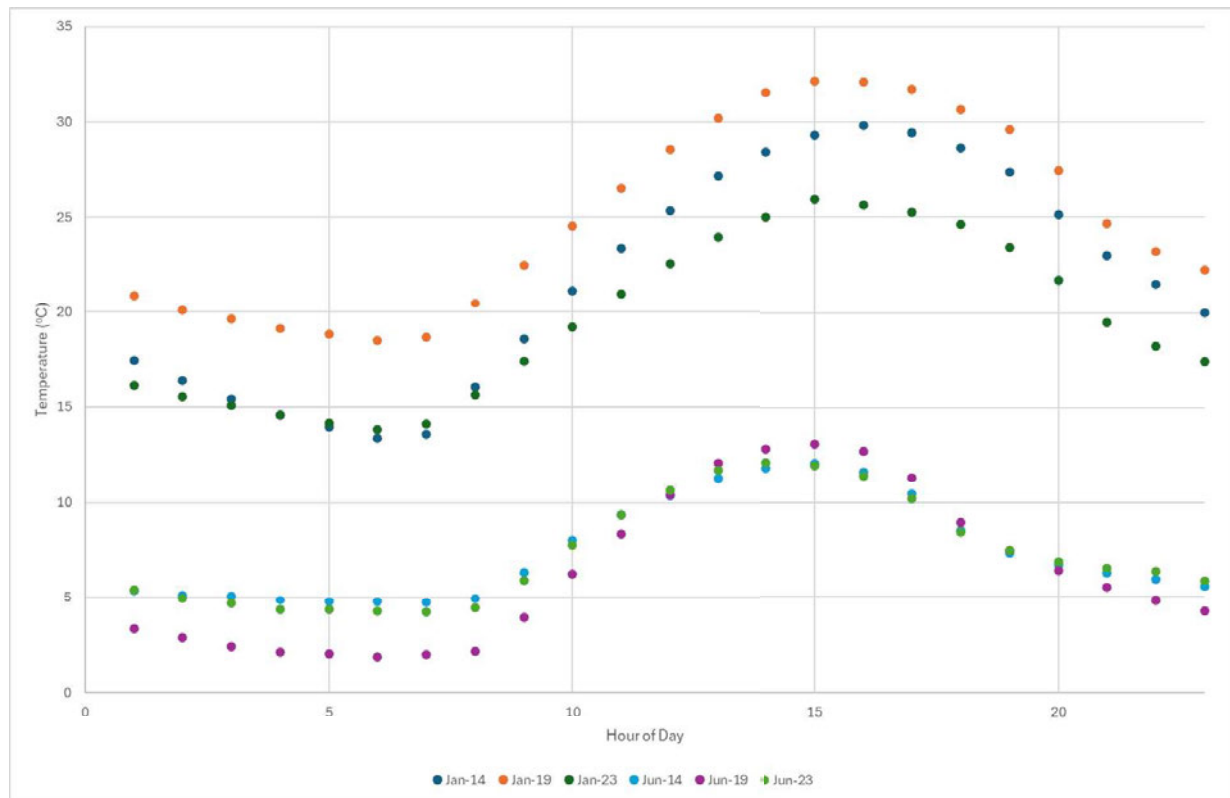


Figure 8 Diurnal Temperature Deviation across seasons (summer and winter) and years (Canberra Airport)

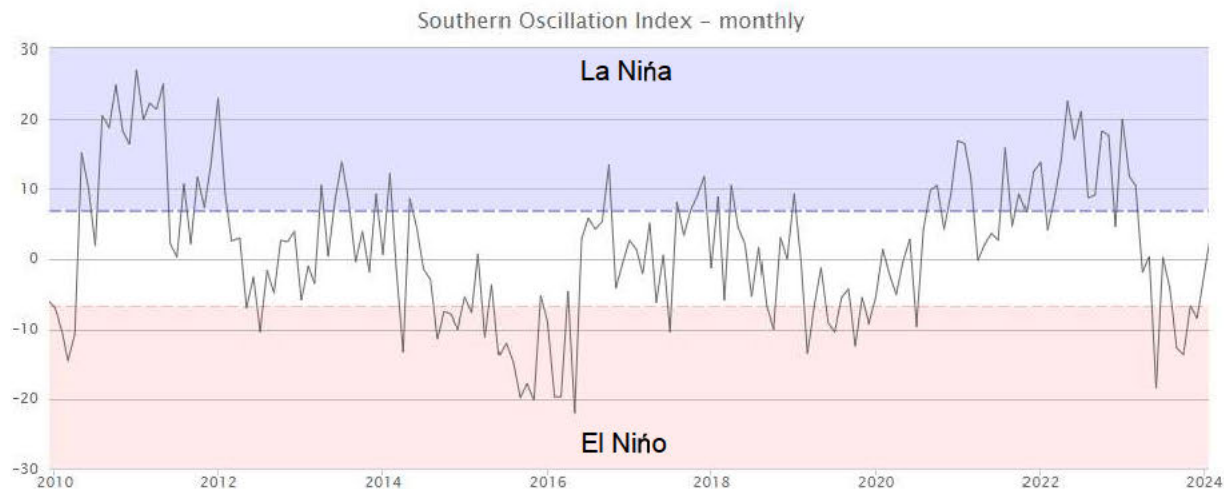


Figure 9 Monthly Southern Oscillation Index plot (2010-2024). Source: BoM

4.1.3 Humidity

Humidity is a critical factor when examining meteorological processes as it influences a wide range of atmospheric and surface processes at small scales. It affects the latent and sensible heat fluxes, which are essential for regulating temperature in the boundary layer of the atmosphere. Humidity also plays a crucial role in evapotranspiration, impacting plant processes, soil moisture levels, and the overall hydrological cycle. High humidity levels are necessary for cloud formation and subsequent precipitation, making it vital for predicting local weather patterns, including rainfall and the likelihood of fog or dew formation. Additionally, localised increases in humidity can lead to microclimatic effects, such as enhanced cloud cover and precipitation in specific areas.

For human comfort and health, humidity affects the perceived temperature, known as the heat index, which combines air temperature and relative humidity to indicate how hot it feels. High humidity can increase the heat index, impacting human comfort and health, and can exacerbate respiratory conditions and promote the growth of mould and dust mites, affecting indoor air quality. Humidity also influences the buoyancy of air parcels, impacting atmospheric stability and the development of convective weather patterns, such as thunderstorms. High humidity near the surface can lead to the formation of fog and mist, affecting visibility and local climate conditions.

Humidity impacts the transfer of energy and mass between the land surface and the atmosphere, including the exchange of water vapor, carbon dioxide, and other gases, which is critical for understanding local environmental conditions and climate feedback mechanisms. It also influences the structure and dynamics of the atmospheric boundary layer, the lowest part of the atmosphere directly influenced by the surface, which plays a key role in weather and climate processes. For environmental and ecological impacts, humidity affects the distribution and health of plant and animal species, influencing biodiversity and ecosystem dynamics. Certain species are highly sensitive to humidity levels and can serve as indicators of microclimatic conditions. Understanding humidity patterns is crucial for managing water resources, as it affects evaporation rates, water availability, and hydrological cycles.

Humidity trends have been examined for the same two meteorological stations used to examine temperature (Tuggeranong and Canberra Airport). Ten years of data were examined (2014-2023) to understand trends in temperature both between seasons and between years.

The first analysis of the data examined the diurnal humidity variation across the full data set for different months of the year. The data in Figure 10 shows that there is a clear and consistent diurnal humidity trend which varies between seasons. There were only minor differences observed between the two monitoring station locations with the Tuggeranong station recording slightly lower levels of humidity than the Canberra Airport.

In addition to a comparison for different seasons and time of day, the variance across different years was examined. Data are presented in Figure 11 show a comparison of humidity for January and June (Summer and Winter) for three years (2014, 2019 and 2023). Analysis of the data shows the following:

- Significant differences were observed in average humidity levels between the 2014, 2019 and 2023 years.
- In summer, humidity levels were the lowest in 2014 with higher humidity levels observed for both 2019 and 2023 (with 2023 levels being the highest of the three).
- In winter the trend was less apparent with humidity levels during the nighttime being similar and daytime humidity levels showing the most variability. The highest humidity levels were observed in 2014, with the highest humidity observed during the winter months.

Humidity can have different effects on pollutant dispersion, which can be both beneficial and detrimental. If humidity is high, pollutants can stick to water droplets and other particles in the air, causing them to be removed from the atmosphere.

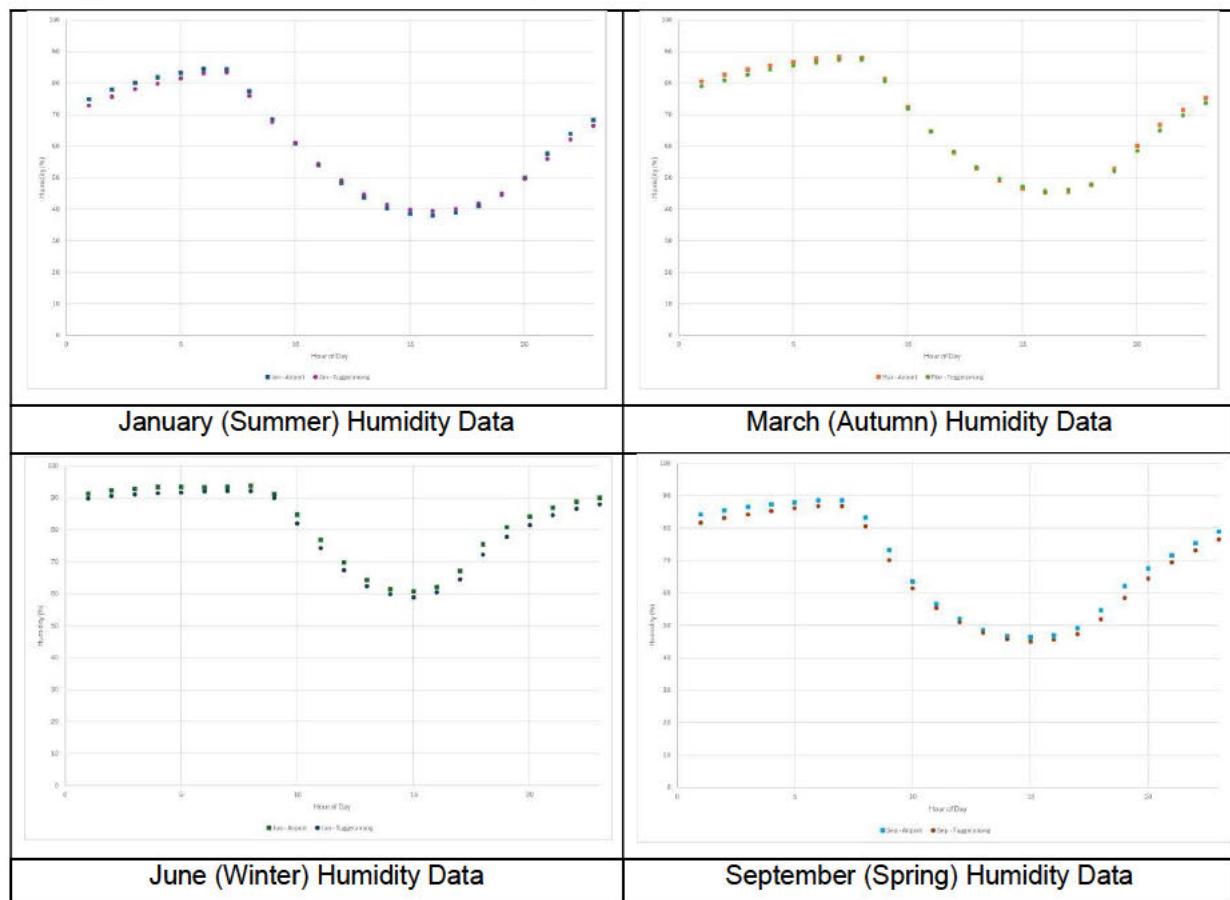
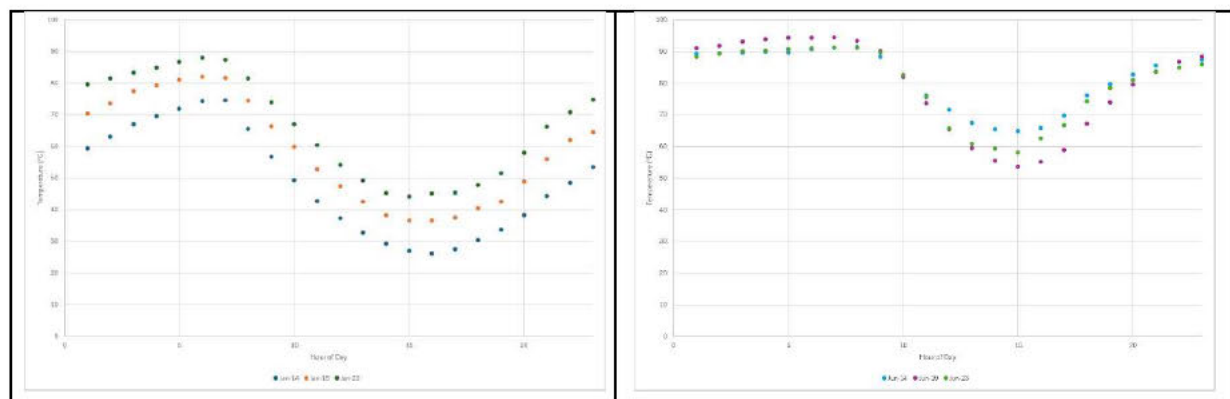


Figure 10 Humidity data comparison between Tuggeranong and Canberra Airport



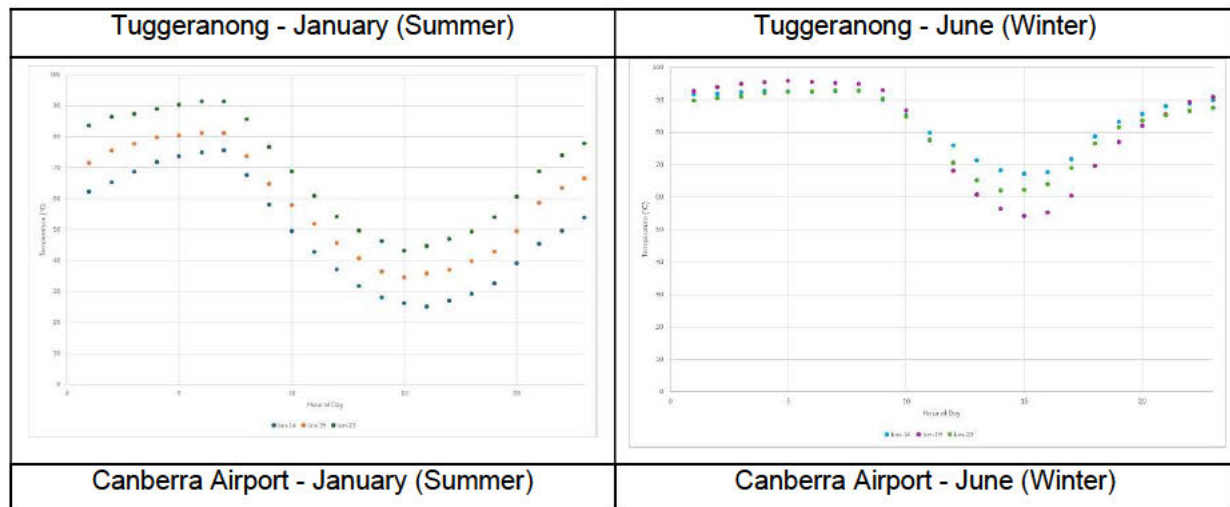


Figure 11 Diurnal Temperature Deviation across seasons and years (Tuggeranong and Canberra Airport)

4.1.4 Rainfall

Rainfall is important to study of meteorology as it affects how energy is distributed between sensible and latent heat fluxes. Wet surfaces, resulting from rainfall, enhance latent heat flux due to increased evaporation, which cools the surface. This process can moderate temperatures, particularly in arid and semi-arid regions, while the absence of rainfall can lead to higher surface temperatures due to reduced evaporative cooling.

Rainfall plays a key role in shaping local weather and climate patterns. It influences the formation of weather systems such as thunderstorms, cyclones, and frontal systems. The distribution and intensity of rainfall affect regional climate characteristics, including humidity levels, temperature variations, and wind patterns, making it essential for weather forecasting and climate modelling.

Analysis of the 10 years of data from Tuggeranong and Canberra Airport show similar trends across the year with peak rainfall periods occurring in summer and Autumn and lowest rainfall levels occurring in early-winter to mid-spring.

Significant variability was observed for annual rainfall with the rainfall total for 2014, 2019 and 2023 being 684, 350 and 655mm respectively for Tuggeranong and 569, 347 and 698mm respectively for Canberra Airport. Rainfall was much lower for both stations for the 2019 period which was characterised by stronger El Nino pattern discussed above.

Rainfall also causes wet deposition scavenging (reduction) of pollutants in the atmosphere, therefore in periods of increased rainfall air pollution would be expected to be improved.

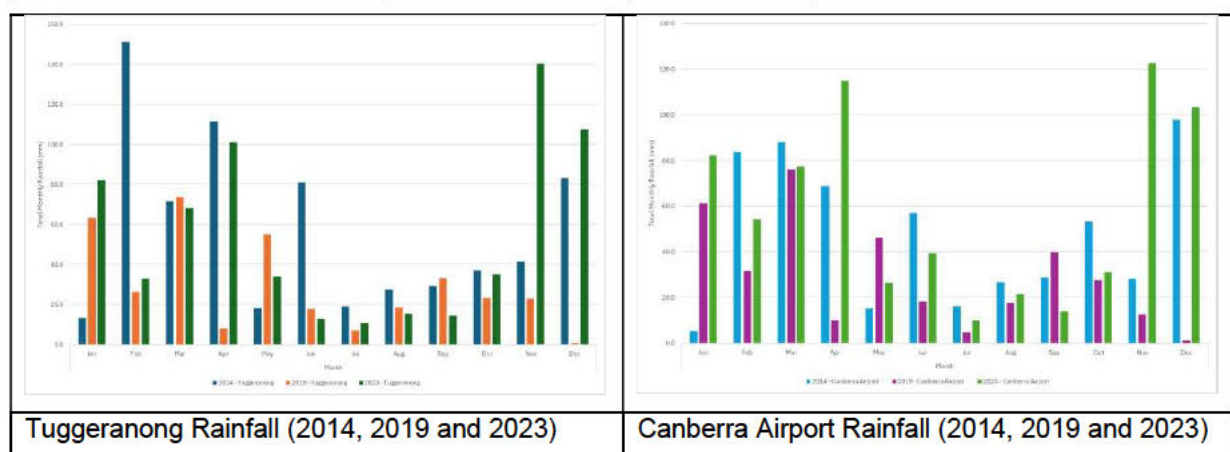


Figure 12 Monthly Rainfall Variability across years (Tuggeranong and Canberra Airport)

4.1.5 Atmospheric stability

Atmospheric stability class is a critical concept in the study of meteorology. Atmospheric stability categorizes the atmosphere based on its tendency to enhance or suppress vertical motion and turbulence. Stability classes range from very stable (Class G) to very unstable (Class A), with neutral stability (Class D) in between.

In a stable atmosphere, vertical motion is suppressed, leading to limited mixing and dispersion of pollutants, which can result in higher concentrations of contaminants near the surface. This often occurs during nighttime or in high-pressure systems. Conversely, an unstable atmosphere promotes vertical mixing and turbulence, enhancing the dispersion of pollutants and leading to more uniform air quality. This typically occurs during sunny, windy conditions with strong solar heating of the surface. Neutral stability, often found in overcast conditions or during strong winds, results in moderate mixing and dispersion.

Understanding atmospheric stability is essential for predicting the dispersion of pollutants, managing air quality, and modelling local weather patterns, as it directly influences the vertical movement of air and the distribution of heat, moisture, and contaminants in the atmosphere.

In addition to the simple relationship between turbulence and stability class, there is a relationship between atmospheric stability and temperature inversions. In stable conditions, vertical movement of air is suppressed, leading to minimal mixing of air layers. Temperature inversions, a specific type of stable atmosphere, occur when a layer of warmer air sits above a layer of cooler air near the surface, reversing the normal temperature gradient.

During a temperature inversion, the cooler air near the surface is trapped by the warmer air above, preventing it from rising. This suppression of vertical motion creates very stable atmospheric conditions. Inversions are common during the night or early morning, especially in winter, when the ground cools rapidly through radiation, cooling the air directly above it while the higher air layers remain warmer.

The stable conditions created by temperature inversions can have significant impacts. For example, they can lead to poor air quality because pollutants emitted near the ground, such as wood smoke emissions becoming trapped beneath the inversion layer. Without vertical mixing to disperse these pollutants, their concentrations can increase, leading to health and environmental concerns.

Temperature inversions also influence local weather patterns. They can limit cloud formation and precipitation by restricting upward movement of moist air. Conversely, breaking an inversion (often through heating of the surface during the day or by wind mixing) can lead to sudden changes in weather, including the dispersion of fog or smog and the onset of convection.

In terms of the analysis of the stability classes in the ACT, stability classes were calculated based on the sigma theta data provided by the Bureau of Meteorology. An analysis has focused on the occurrence of the class E, F and G stability classes, which have the potential to result in temperature inversions.

Stability class occurrence has been provided in **Table 4**. These data show that for the stability classes that are commonly associated with temperature inversions (classes F and G), occur about 21 to 27% of the time.

Table 4 Stability classes for Tuggeranong and Canberra Airport

Stability Class	Tuggeranong	Canberra Airport
A (very unstable)	19%	12%
B	7%	6%
C	12%	9%
D (neutral)	27%	42%
E	8%	8%
F	23%	17%
G (very stable)	4%	4%

The overall stability class data shows that there are significant periods where Class F and Class G may result in inversions, with Tuggeranong having a slightly higher proportion than Canberra airport. Of importance to inversions beyond simple occurrence is also inversion strength and time of day which influences break-up time. From a domestic wood smoke perspective, when the inversions may occur is critical to understanding whether wood smoke effects may be exacerbated by micrometeorology. **Figure 13** shows the occurrence of Class F and Class G stability classes for summer and winter (January and June months).

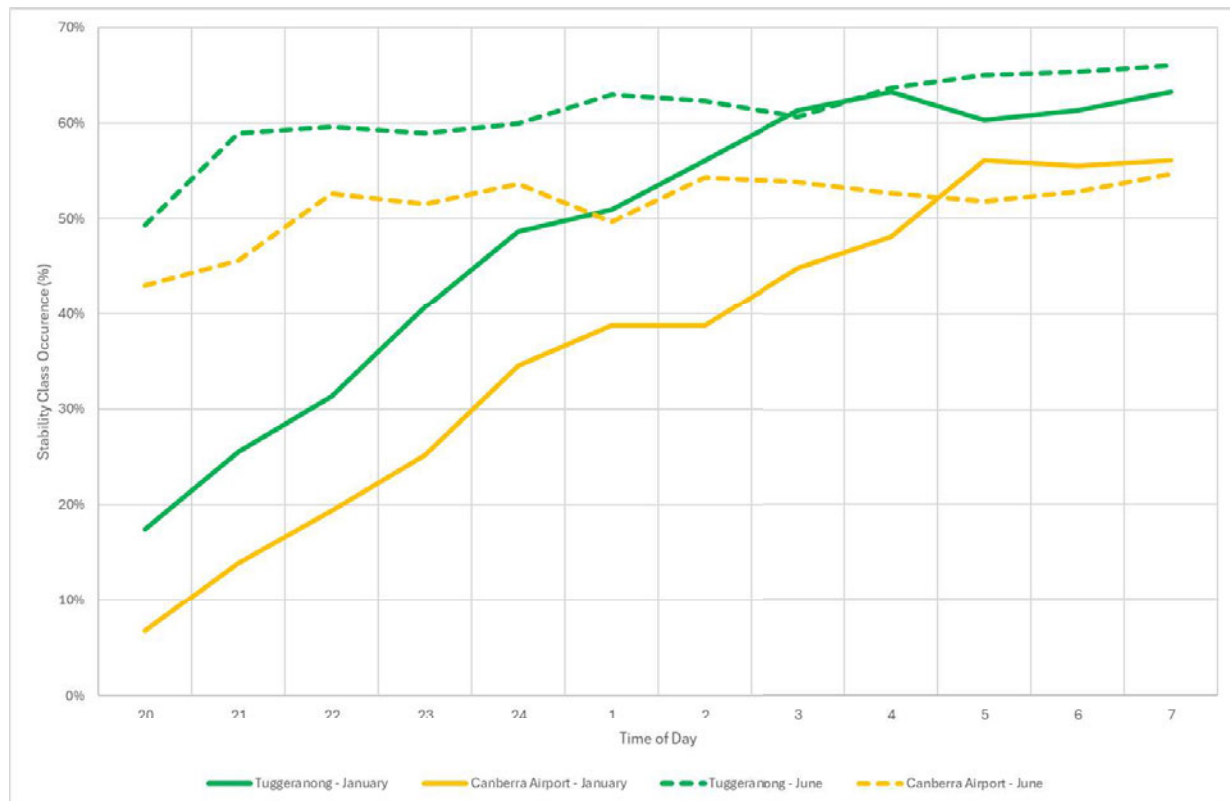


Figure 13 Stability Class Occurrence for Class F and G

Potential for inversion formation is lower in the early evening in summer as compared to winter, where Class F and Class G occurrence is high from early hours of the evening. Potential for inversions increases significantly during summer to a point after around 3am where summer and winter conditions are similar (in terms of stability class inversion potential). Inversion potential is significantly higher in the Tuggeranong area, with stability class occurrence about 5-10% higher for Tuggeranong as compared with the Canberra Airport station location.

The implications of the above data on domestic wood smoke are that in the Tuggeranong area, there are consistent meteorological conditions that are associated with inversion conditions across the hours of night. This suggests that any wood smoke in this area would have a high potential to accumulate to higher concentrations during inversion conditions.

4.1.6 Air Pressure

Air pressure is an important component of micrometeorological studies as it influences a variety of atmospheric processes and conditions at small scales. Its significance can be understood through several key aspects.

Firstly, air pressure variations are fundamental to the development of weather patterns and microclimates. High-pressure systems are generally associated with clear, calm weather, while low-pressure systems can bring clouds, wind, and precipitation. Understanding local air pressure variations helps in predicting weather changes, which is crucial for agriculture, outdoor activities, and various economic sectors.

Secondly, air pressure affects atmospheric stability, which in turn influences turbulence and vertical mixing. Stable conditions, often associated with high pressure, suppress vertical air movement, leading to less turbulence. Conversely, low-pressure systems can enhance vertical mixing and turbulence, impacting pollutant dispersion, cloud formation, and heat distribution.

Pressure gradients, or differences in air pressure across a region, drive wind patterns and speed. In micrometeorology, understanding these gradients is essential for predicting local wind conditions. Wind influences the transport of heat, moisture, and pollutants, affecting air quality, evaporation rates, and local climate conditions.

In micrometeorological studies, air pressure is crucial for understanding how pollutants disperse in the atmosphere. High-pressure conditions can lead to the accumulation of pollutants near the surface, while low-pressure conditions can facilitate their dispersion. This knowledge is vital for air quality management and public health.

Topography interacts with air pressure to create unique microclimates. For instance, valleys can experience higher air pressure and stable conditions, leading to temperature inversions and fog formation. Understanding these interactions helps in managing natural resources and planning urban development.

Air pressure has been examined through the analysis of pressure data from Canberra Airport and Tuggeranong. Average atmospheric pressure levels have been plotted in **Figure 14** and **Figure 15** and show the following:

- There is a clear pattern of atmospheric pressure change across the year with highest pressure occurring during winter and lowest pressure occurring during summer.
- Pressures are very similar between Tuggeranong and Canberra Airport, with the airport having slightly higher pressure over the year as compared with Tuggeranong.
- Diurnal pattern is clear and consistent across both the Tuggeranong and Airport stations. Air pressure is significantly different between summer and winter with winter being approximately 10hPa higher than in summer.

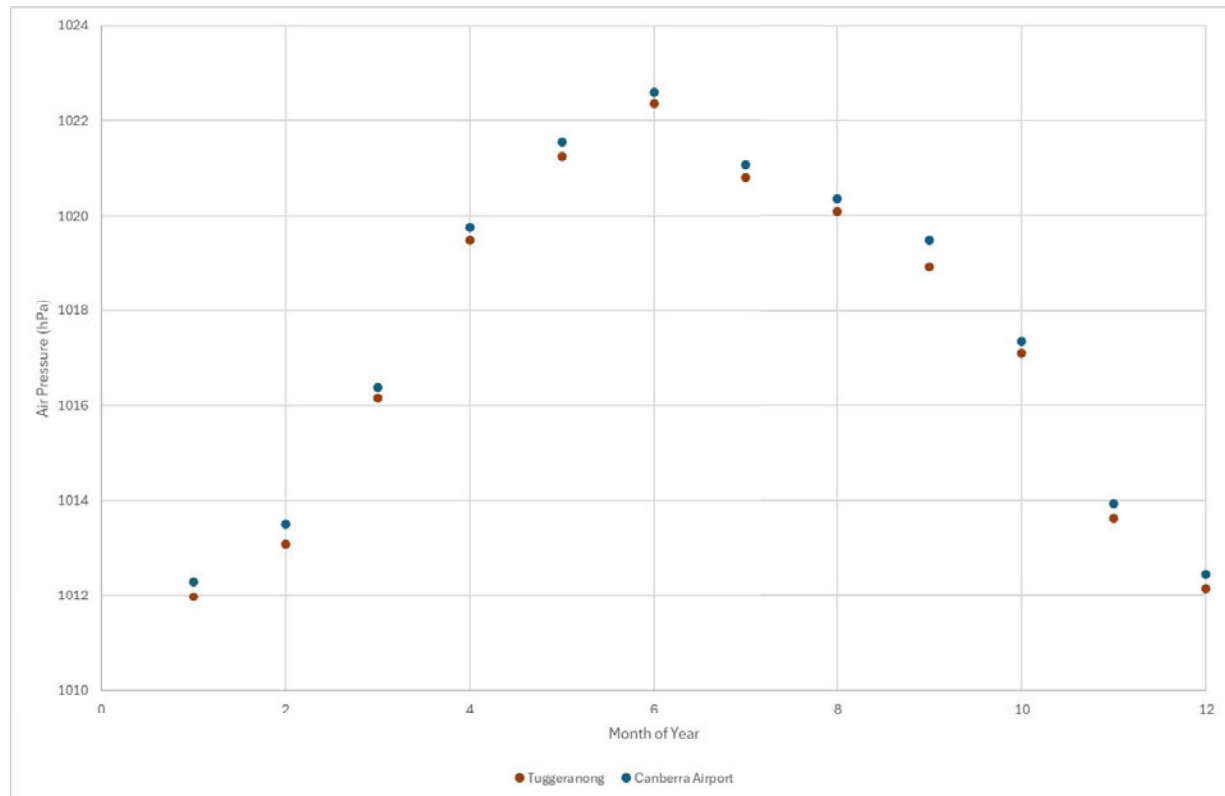


Figure 14 Monthly Air Pressure Data – Tuggeranong and Canberra Airport

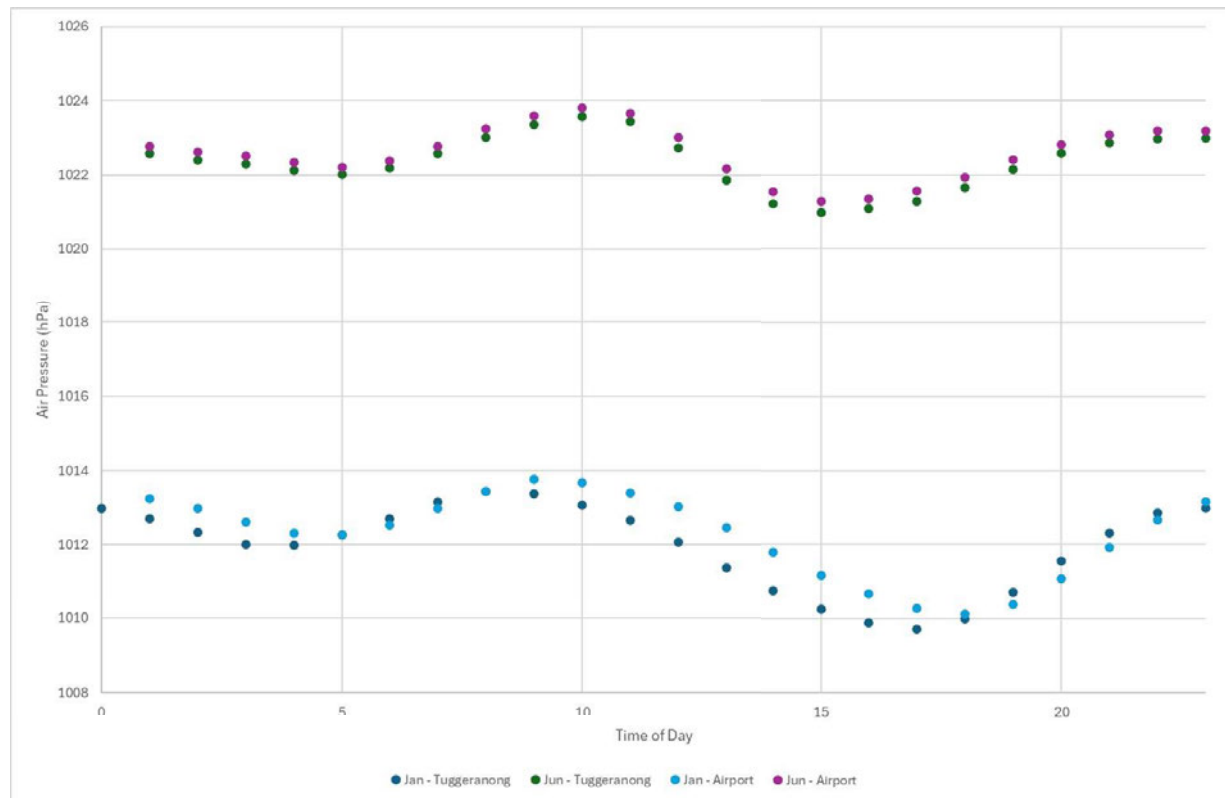


Figure 15 Hour of Day Air Pressure Data – Tuggeranong and Canberra Airport

4.1.7 Katabatic Flows

The topography of the ACT is dominated by the mountain range to the west and south of the ACT urban areas, the Murrumbidgee River running along the base of the range and the higher ground to the east of the ACT urban areas.

Microclimatic effects have the potential to occur during periods of atmospheric stability that could lead to pollutant trapping and accumulation. During periods of stable air conditions, the mountain ranges or elevated terrain has the potential to generate katabatic flows, (drainage wind flows generated by cooler, higher density air being transported down a slope under the force of gravity) which may induce air flow downhill within the ACT. This may lead in several directions within the ACT urban area, such as toward and then along the Murrumbidgee River valley or along the Molonglo River valley. These drainage flows would be expected to flow down the elevated terrain to the base of the mountains and then along the river valley.

Katabatic flows have been examined as part of the microclimatic analysis in **Section 7.0**.

4.2 Topography

The terrain of Canberra, the surrounding suburbs and the ACT more broadly is complex with significant topographical features influencing the meteorological patterns in the territory. Generally, central Canberra and suburbs range from around 500 – 600 m in elevation, with the lowest points being the CBD near Lake Burley Griffin, Tuggeranong and Belconnen areas, refer **Figure 17**. In most directions away from the centre of Canberra the terrain increases, except for to the north-west along the Molonglo River.

Complex terrain can create microclimate effects due to:

- **Wind blocking** - refers to the phenomenon where physical structures or natural features obstruct and alter the flow of wind. This can significantly impact the local microclimate by creating areas with reduced wind speeds and changing wind direction. Features like hills, mountains, and dense forests can block and redirect wind, leading to varied wind patterns in their vicinity.
- **Wind tunnelling** – is a phenomenon where wind is funnelled through narrow passages, such as between buildings, mountains, or other obstacles, leading to an increase in wind speed. This effect is also known as the Venturi effect.
- **Solar access** - refers to the availability of sunlight to a specific area or structure. It is a critical consideration in micrometeorology due to its influence on temperature, energy efficiency, plant growth, and overall microclimate. Solar access can be affected by natural features like topography and vegetation, as well as by human-made structures. This is particularly important in areas with tall mountains that block sunlight until later in the day, delaying the breakup of cooler nighttime conditions such as inversions.
- **Calm condition phenomena such as inversions and katabatic flows** - also known as katabatic winds or drainage winds, are a type of wind that occurs when cold, dense air moves downslope under the influence of gravity. These winds typically occur in regions with significant topographic relief, such as mountainous or glaciated areas. Katabatic flows are an important phenomenon in micrometeorology because they influence local climate, weather patterns, and environmental conditions.

The above microclimate effects can have a range of influences on pollution dispersion and air quality, which have been discussed briefly below.

When analysing the effects of topography in an area, it is important to first consider the broader context of the topographical features affecting that area. As shown in **Figure 16**, the ACT is situated to the east of the Great Dividing range and occupies a large proportion of the Namadgi National Park, Uriarra State Forrest and the Brindabella National Parks running along the western portion and edge of the ACT. Elevations to the east of the Brindabella ranges change to a lower elevation landform characterised by rolling hills and flat pasturelands within the broader Murrumbidgee River valley. The elevated land along the western side of the ACT also transitions to a lower elevation landform to the northeast of the ranges leading to lower rolling hills around the Lake George catchment.

When examined on a closer scale (as shown in **Figure 17**), topographical features within the ACT showing a general decrease in elevation from the southwest to the northeast generally following line of the Murrumbidgee River. Elevated terrain of the ranges gives way to rolling hills around the Tuggeranong area and other urban areas of the ACT.

A closer examination of the urban areas of the ACT (refer **Figure 18**) shows that generally, there is only minor change in topography from the south to the north of the city, with the major features being the Black Mountain Reserve and Mt Ainslie Nature reserve. These features have the potential to result in wind tunnelling as wind move through the ACT. There are also minor topographical features around the Red Hill and Fadden areas, with elevated terrain potentially channelling or blocking the flow of air through the Tuggeranong district.

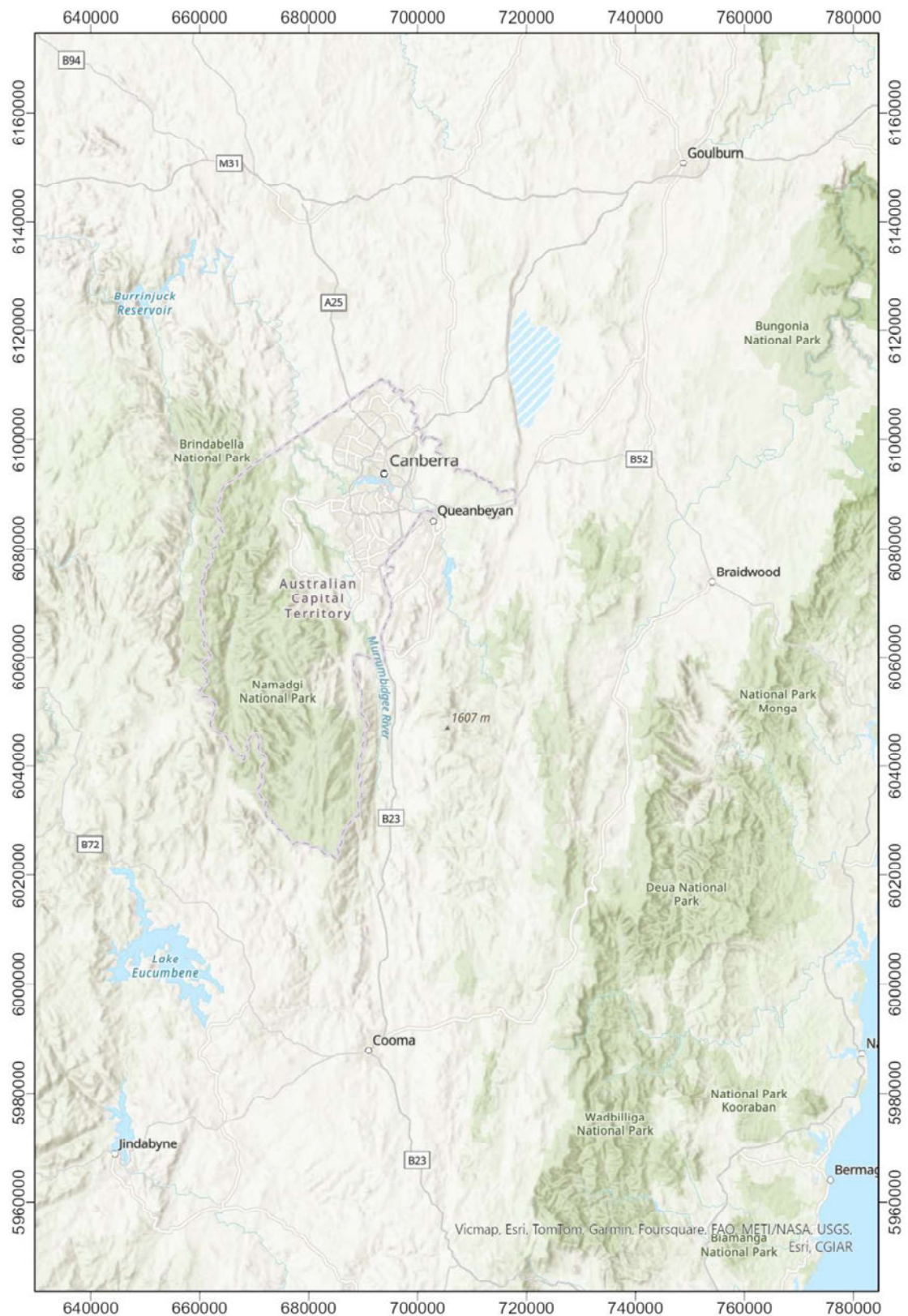


Figure 16 Broader topographical context of the ACT

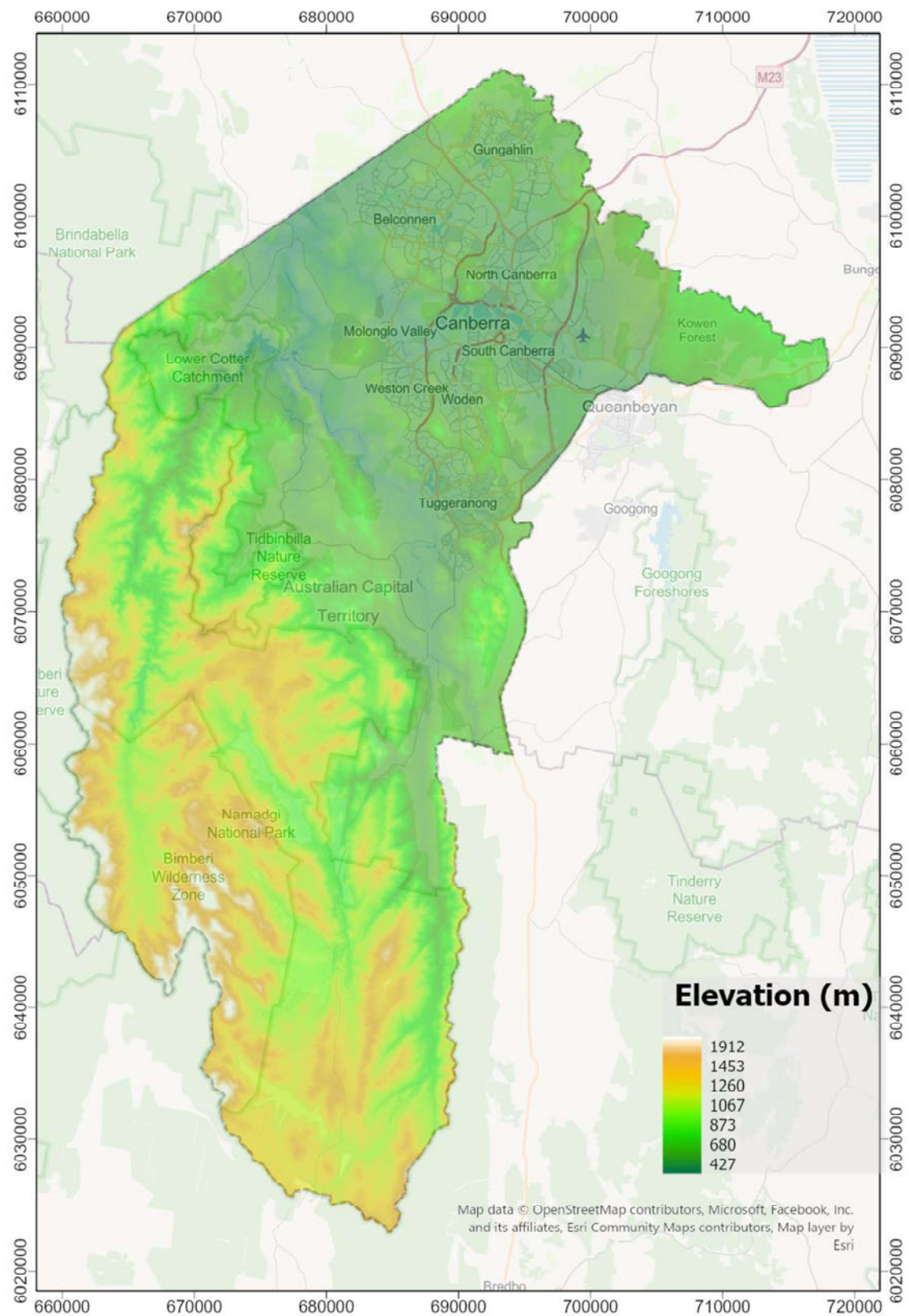


Figure 17 Terrain elevations – ACT

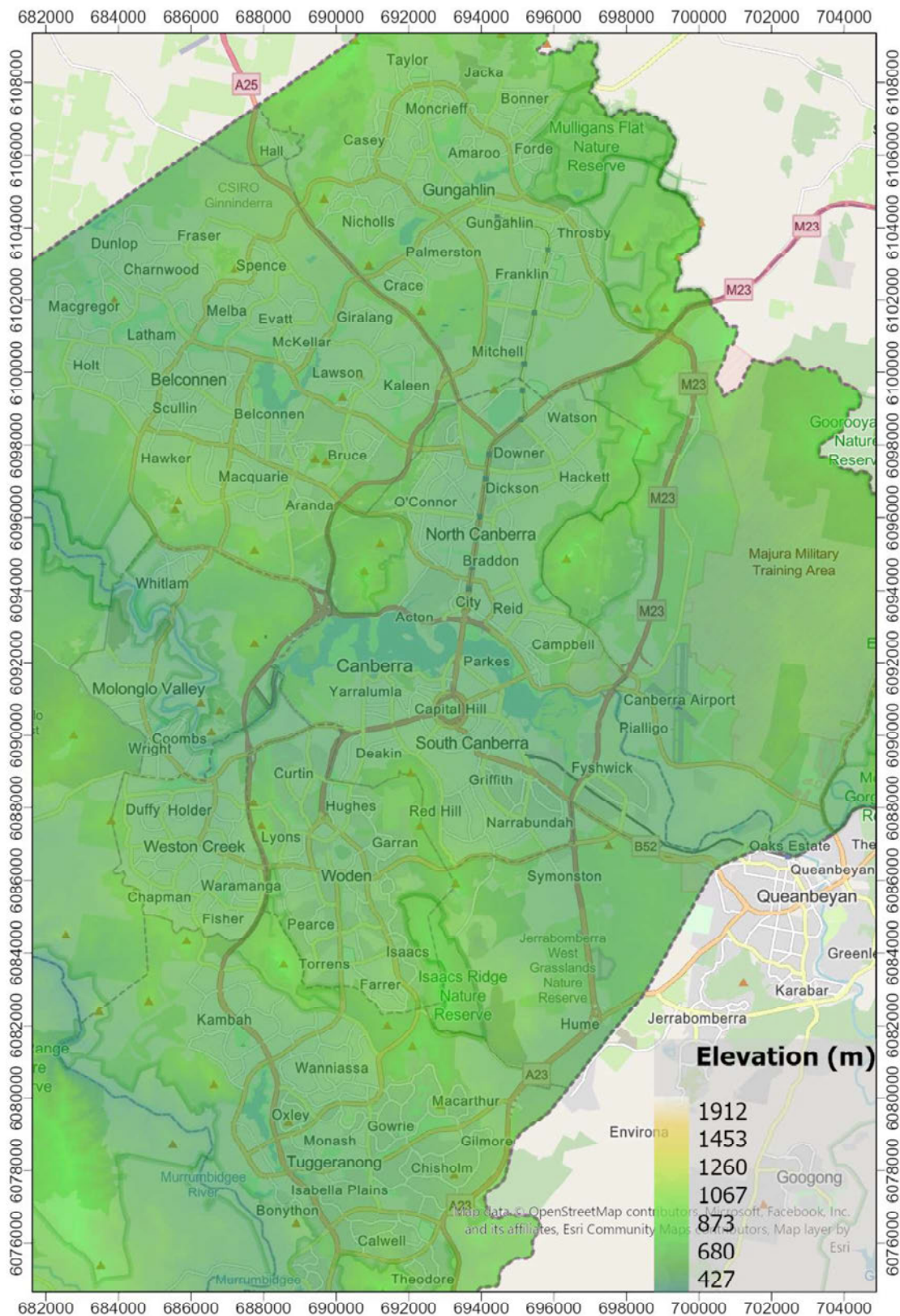


Figure 18 Terrain elevations – Urban ACT

4.3 Land Use

Land use in the ACT ranges from high density urban near the Canberra CBD to agricultural and nature conservation surrounding the outer suburbs, out to the ACT border, refer **Figure 19**. As shown in the Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES) land use data for the ACT, the urban areas are concentrated in the northeastern portion of the ACT. The majority of the ACT is dominated by Nature Conservation areas (best characterised as bushland) and by Grazing land and pastureland.

The implications of the land use on the micrometeorology in the ACT is that effects from the variable land use caused by the urban environment is only expected to affect a small area of the ACT, confined to the northeastern third of the territory.

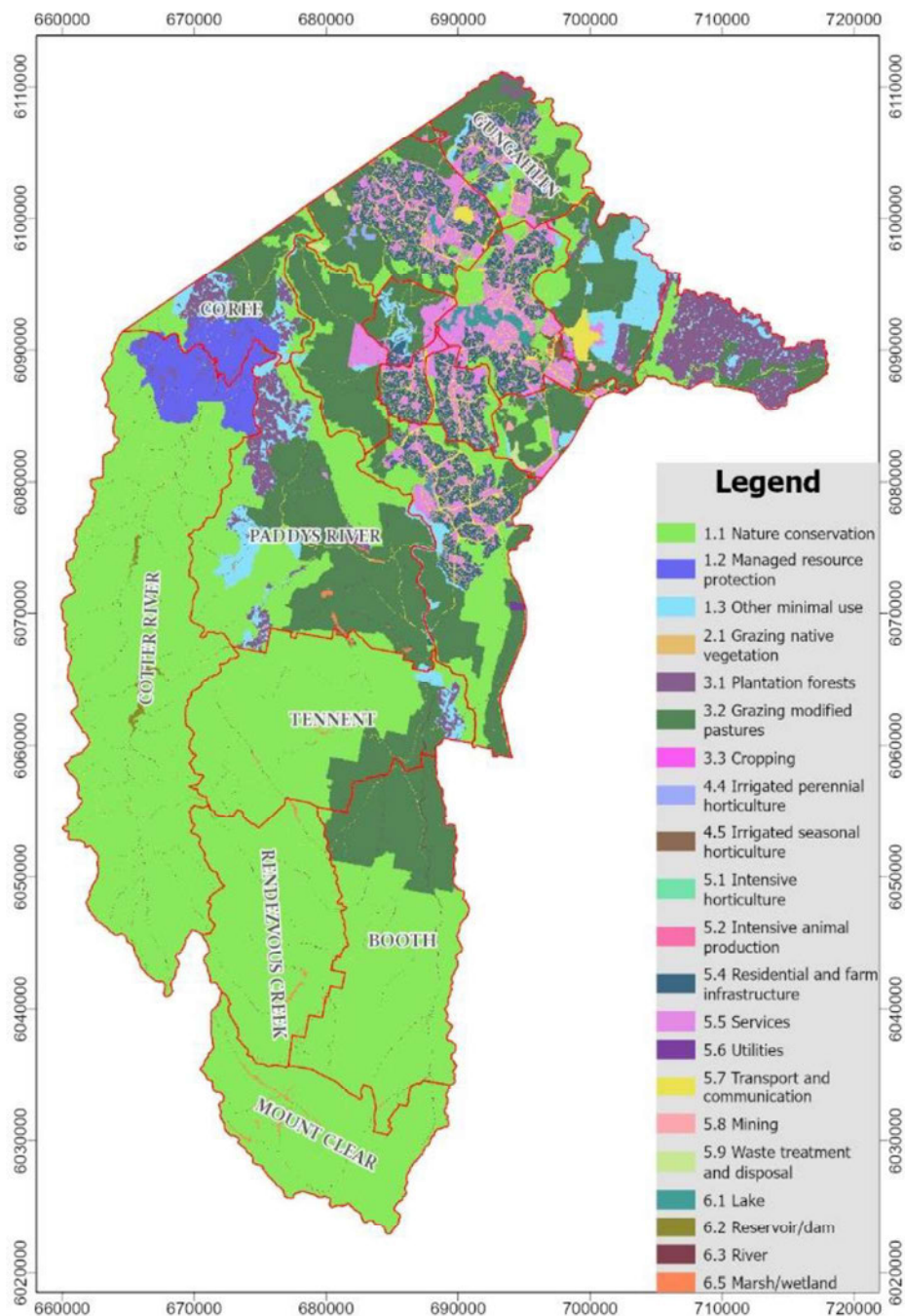


Figure 19 ACT Land use. Source: ABARES (2020)

5.0 Existing Air Quality

Air quality in the ACT is generally considered to be quite good, particularly in relation to other Australian capital cities, mainly because the area has no significant heavy industry. The primary sources of air pollution in the ACT are motor vehicles, wood smoke, bushfires/dust storms and pollen events. Other sources include landfills, agriculture, sewerage treatment plants and pipelines, and gas fired power stations associated with landfill gas harvesting, refer to **Section 5.4** for a list of air pollution sources in the ACT.

Temperature inversions during winter can be associated with elevated particulate levels in some areas, particularly in urbanised valley areas such as Tuggeranong. High particulate levels can also occur in summer due to bush fires; hazard reduction burns and dust storms.

5.1 Air Quality Monitoring

Since 1998 the ACT has operated an ambient air quality network. Currently the network consists of three monitoring stations:

- **Monash:** located approximately 300 m west of Cockcroft Avenue in the district sporting fields.
- **Civic:** located at the northern end of the carpark on the western side of the Olympic swimming pool adjacent to Allara Street.
- **Florey:** located at the end of Neumann Place.

The three monitoring locations are shown in **Figure 20**. Note that Monash and Florey are sited to comply with Australian Standard 3580.1.1:2016 (AS), however Civic does not comply for the following reasons:

- Minimum distance to support structure
- Clear sky angle of 120 degrees
- Unrestricted air flow
- 20m from trees

Though the Civic AQMS does not strictly meet the AS it is expected to generally represent the air quality conditions of Canberra CBD.

The pollutants monitored by the ACT air quality monitoring stations (AQMS) are:

- Particulate matter less than 2.5µm (PM_{2.5})
- Particulate matter less than 10µm (PM₁₀)
- Ozone (O₃)
- Nitrogen dioxide (NO₂)
- Carbon monoxide (CO)

Note the dates for all pollutants being monitored at each station varies depending on when each station was commissioned.

Lead has not been monitored since 2002 due to the phase out of leaded fuel, while sulphur dioxide has never been monitored due to the lack of heavy industry (ACT EPA, 2018).

All three AQMS's are located in urban areas and therefore are unlikely to be representative of more isolated or rural locations within the ACT.

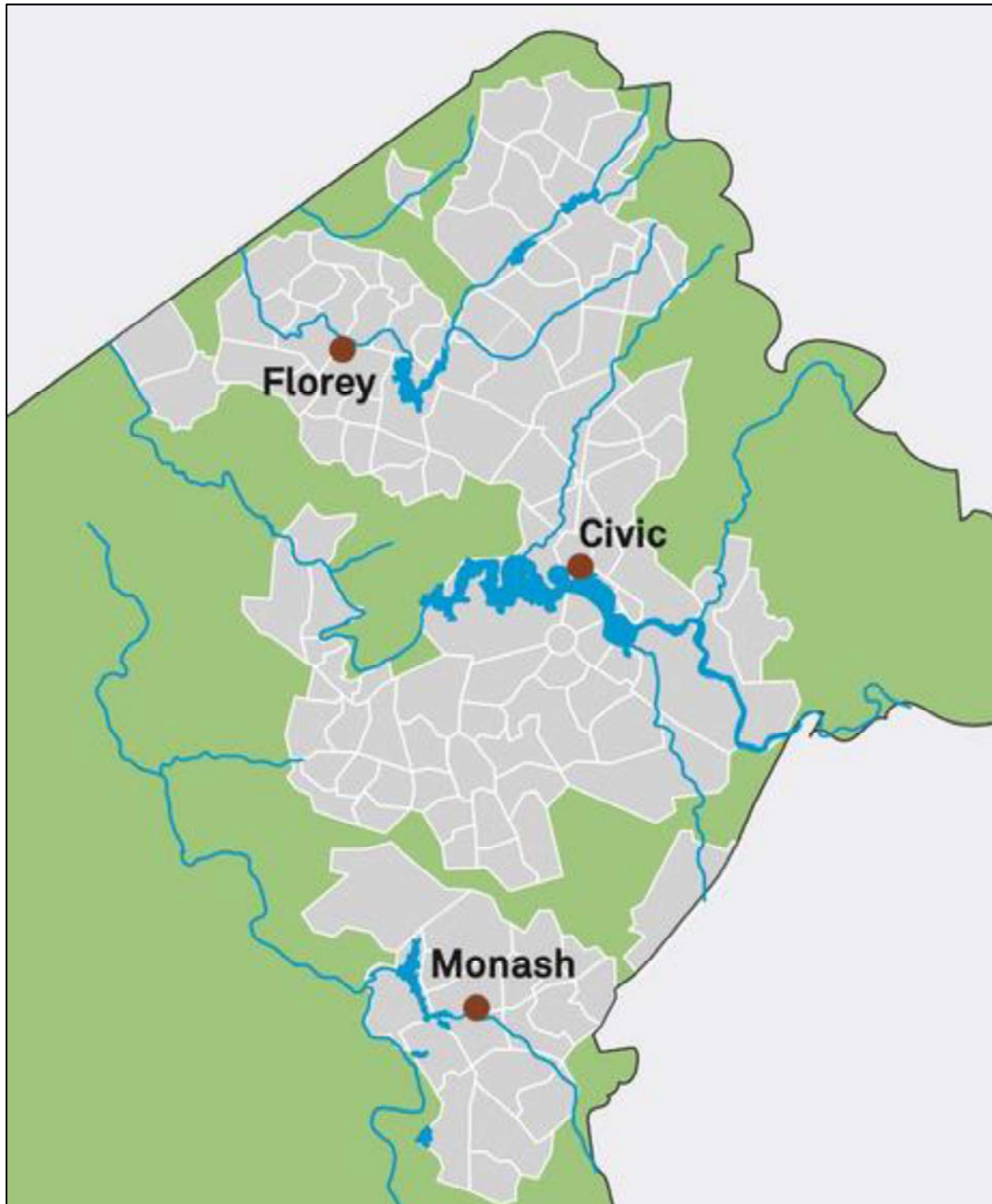


Figure 20 Ambient air quality monitoring locations

5.1.1 Particulate Matter (PM₁₀ and PM_{2.5})

Particulate matter is the term for solid or liquid particles found in the air. Some particles are large or dark enough to be seen such as soot or smoke, but fine particulate matter is tiny and is generally not visible to the naked eye. Particulate matter is produced by the mechanical breakup of larger solid particles. The larger or coarse fraction can include dust from roads, agricultural processes, uncovered soil or mining operations, as well as non-combustible materials released when burning fossil fuels. Pollen grains, mould spores, and plant and insect parts can also contribute to the coarse fraction.

Evaporation of sea spray can produce large particles near coasts. The smaller or fine particulates are largely formed by the oxidation of primary gases. Particulate matter can be emitted from natural sources (bushfires, dust storms, pollens and sea spray) or as a result of human activities such as combustion activities (motor vehicle emissions, power generation and incineration), excavation works, bulk material handling, crushing operations, unpaved roads and, of particular importance to this project, wood heaters.

Airborne particles are commonly differentiated according to size based on their equivalent aerodynamic diameter. Particles with a diameter of less than or equal to 50 micrometres (μm) are collectively referred to as total suspended particulates (TSP). TSP primarily cause aesthetic impacts associated with coarse particles settling on surfaces, which also causes soiling and discolouration. These large particles, however, can cause some irritation of mucosal membranes and can increase health risks from ingestion if contaminated.

Deposited dust refers to the larger fractions that fall from the air and deposit on exposed surfaces. While deposited dust generally has an aerodynamic diameter of greater than about 20 μm , there is no sharp size cut off between these particles and the smaller particles that remain suspended in the air for long periods. Larger dust particles are generally responsible for nuisance (amenity) effects, including vegetation damage and surface soiling. Depending on its physical or chemical characteristics, dust may also cause surface deterioration of materials due to its abrasive or corrosive properties. If the dust composition is dangerous, the dust is considered a hazardous air pollutant (and may contain toxic material).

Particles with diameters less than or equal to 10 μm (known as PM_{10}) and particles with diameters less than or equal to 2.5 μm (known as $\text{PM}_{2.5}$) tend to remain suspended in the air for longer periods than larger particles and can penetrate into human lungs.

$\text{PM}_{2.5}$ can penetrate deeper into human lungs than PM_{10} and are considered to have more significant health impacts due to their deeper penetration. Epidemiological studies show a correlation between exposure to particles and adverse health effects. No safe threshold for particle exposure has been established.

5.1.2 Nitrogen Dioxide

Nitrogen dioxide (NO_2) is a brownish gas with a pungent odour. It exists in the atmosphere in equilibrium with nitric oxide. The mixture of these two gases is commonly referred to as nitrogen oxides (NO_x). Nitrogen oxides are a product of combustion processes. In urban areas, motor vehicles and industrial combustion processes are the major sources of ambient nitrogen oxides.

Nitrogen dioxide can cause damage to the human respiratory tract, increasing a person's susceptibility to respiratory infections and asthma. Sensitive populations, such as the elderly, children, and people with existing health conditions are most susceptible to the adverse effects of nitrogen dioxide exposure. Nitrogen dioxide can also cause damage to plants, especially in the presence of other pollutants such as ozone and sulphur dioxide. Nitrogen oxides are also primary ingredients in the reactions that lead to photochemical smog formation. Very high levels of Nitrogen oxides can aid the formation of acid rain.

5.1.3 Ozone

Photochemical oxidants (often referred to as photochemical smog) are a complex mixture of chemicals produced in the atmosphere by the action of sunlight. The principal component of photochemical oxidants is ozone (O_3). Ozone measurements are commonly used as a surrogate for photochemical oxidants. Ozone is a colourless, highly reactive gas with a distinctive sharp odour. At ground level, elevated concentrations of ozone can cause respiratory problems and cardiovascular disease in humans and can affect the healthy normal population as well as sensitive sub-populations. It can worsen bronchitis, emphysema, and asthma. Ozone can also affect the growth of vegetation and damage materials and ecosystems. At ground level, ozone is created by a chemical reaction between nitrogen oxides and volatile organic compounds (VOCs) in the presence of sunlight. As such, nitrogen oxides and volatile organic compounds are referred to as ozone precursors. Motor vehicle exhaust, industrial emissions, gasoline vapours, chemical solvents as well as natural sources (such as bushfires) emit ozone precursors. The highest concentrations of ozone normally occur on summer afternoons, downwind of major sources of ozone precursors. Elevated concentrations are most likely to occur on warm sunny days in areas where the surrounding topography prevents the precursors from dispersing.

Carbon Monoxide

Carbon monoxide (CO) is a colourless, odourless gas produced by the incomplete combustion of fuels containing carbon (e.g. oil, gas, coal and wood). Carbon monoxide is absorbed through the lungs of humans, where it reacts to reduce the blood's oxygen-carrying capacity. In the ACT, motor vehicles are the primary source of all CO emissions.

5.2 Air Pollution Criteria

Air pollution criteria have been discussed above in **Section 2.2.1**. This lists the 2022 NEPM air pollution standards and the 2025 NEPM air pollution goals. In addition, the World Health Organization (WHO) has released some Air Quality Guidelines for use when assessing air pollution throughout the world. These guideline values have not been adopted by any Australian regulatory authority but represent the lowest concentrations currently used around the world. The 2021 WHO values could be used as drivers for continuous improvement beyond what is already in the NEPM. The criteria adopted for the analysis of the existing air pollution levels is shown in **Table 5**.

Table 5 Project Air Quality Guidelines ($\mu\text{g}/\text{m}^3$)

Pollutant	Averaging Period	2022 NEPM Standards	2025 NEPM Goals	2021 WHO Guidelines
PM ₁₀	24-Hour Max	50	-	45
	Annual	25	-	15
PM _{2.5}	24-Hour Max	25	20	15
	Annual	8	7	5
NO ₂	1-Hour Max	164	-	-
	Annual	31	-	10
CO	1-hour Max	30,000	-	10,000
	8-hour Max	10,000	-	4,000
O ₃	8-hour Max	139	-	100

5.3 Air Quality Monitoring Data

All ambient monitoring data from the three monitoring stations has been summarised for the available data between 2011 to 2023. These have been compared with criteria for the current NEPM, future NEPM and the WHO guidelines for PM_{2.5}. Results of air pollution monitoring at the ACT monitoring stations have been summarised with the results presented in **Table 6**, **Table 7** and **Table 8** for Monash, Civic and Florey respectively.

Results have been compared with three sets of concentrations drawn from the NEPM and WHO.

Given that particulates are the primary pollutant of concern for the discussion of domestic wood heater use and smoke reduction, a more detailed analysis of the monitoring results for the three stations has been undertaken as follows:

- **Monash Monitoring data:**

- **PM₁₀ Particulates** – PM₁₀ particulates have been consistently below the 24-hour maximum 2022 NEPM criteria of 50 $\mu\text{g}/\text{m}^3$ from 2011 until 2023.

The only exception to this observation was in 2018, 2019 and 2020, where maximum PM₁₀ concentrations all exceeded the 2022 NEPM criteria. The exceedances noted in November 2018 and February 2019 were due to dust storm events. Exceedances of the criteria observed in 2019 and 2020 were due to the black summer bushfires which affected air pollution concentrations across western NSW and ACT.

It is noted that the 2018 annual average PM₁₀ concentration was only slightly higher than the longer term maximum 24-hour average concentration from 2011 until 2017, suggesting that

the 2018 event was an isolated event during an otherwise typical year in terms of PM₁₀ air pollution concentrations.

The number of exceedances were calculated for PM₁₀ for the 2018, 2019 and 2020 periods and are shown in Table 9. The number and timing of the exceedances calculated for PM₁₀ reflect dust storms in November 2018 and the black summer bushfires in December 2019 and January 2020.

When the WHO criteria are considered, there is one additional exceedance noted in 2013 as well as a small number of additional exceedances noted in 2019 and 2020.

Annual average PM₁₀ concentrations were below the annual average 2022 NEPM criteria of 25µg/m³ from 2011 until 2023.

When the annual average PM₁₀ WHO criteria are considered, only 2019 and 2020 exceeded the lower criteria.

- **PM_{2.5} Particulates** – PM_{2.5} particulates have been consistently above the 24-hour maximum 2022 NEPM criteria of 25µg/m³ from 2015 until 2023. The only year of monitoring without an exceedance of the 24-hour criteria was in 2022, which had a maximum concentration of 24.6µg/m³.

Maximum 24-hour average PM_{2.5} concentrations were consistently around the 35 µg/m³ range between 2015 and 2018 and rose to very high concentrations in 2019 and 2020 following the black summer bushfires. Concentrations decreased to levels lower than historical averages in 2021 to 2023.

The number of exceedances were calculated for PM_{2.5} for the 2015-2023 periods and are shown in Table 9. There were consistent number of exceedances of the 24-hour PM_{2.5} criteria between 2015 to 2017, with a slight decrease in exceedance numbers in 2018 before a large rise in exceedances corresponding with the 2019 and 2020 black summer bushfire event. Exceedances were much lower between 2021 and 2023 with no exceedances observed in 2022 and only 4 and 1 exceedances noted in 2021 and 2023 respectively.

When the NEPM 2025 criteria are considered, the pattern of exceedance is worse than is described above, with exceedances now occurring across all monitored years between 2011 and 2023. A significant increase in exceedances was noted with the lower PM_{2.5} 24-hour criteria with most exceedances increasing by more than double between 2015 and 2018. Exceedances noted in 2011 to 2023 are also much higher with exceedances increasing from 4, 0 and 1 exceedances in 2021, 2022 and 2023 respectively to 18, 2 and 7 exceedances in 2021, 2022 and 2023 respectively.

When the WHO 24-hour PM_{2.5} criterion is considered, there are a large number of additional exceedances with the number of exceedances increasing by 50-100% or higher for most monitoring years.

Annual average PM_{2.5} concentrations were generally below the annual average 2022 NEPM criteria of 8µg/m³ from 2015 until 2023 with the exception of 2015, 2019 and 2020.

Concentrations since the black summer bushfires have been consistently well below the annual average concentration criterion with values of 6.9, 5.1 and 6.8 µg/m³ for 2021, 2022 and 2023 respectively.

When the 2025 NEPM annual average criteria is considered, the number of years exceeding the criterion increases from 3 to 5 years, with two additional years (in 2016 and 2017) where concentrations are above the criterion.

When the annual average PM_{2.5} WHO criterion is considered, all periods between 2015 and 2023 exceed the criteria.

- **Civic Monitoring data:**

- **PM₁₀ Particulates** – PM₁₀ particulate concentrations have been variable at the Civic monitoring station with some exceedances of the 24-hour maximum 2022 NEPM criteria of 50µg/m³ from observations between 2011 and 2023.

Maximum PM₁₀ concentrations in 2015, 2017, 2018, 2019 and 2020 all exceeded the 2022 NEPM criteria. As discussed above, the exceedance noted in 2018 was due to a dust storm event occurring in November of 2018. Exceedances of the criteria observed in 2019 and 2020 were due to the black summer bushfires which affected air pollution concentrations across western NSW and ACT. The reasons for the exceedances in 2015 and 2017 are not clear, with no regionally significant event identified to occur during those time periods.

As with Monash, the 2018 annual average PM₁₀ concentration was only slightly higher than the longer-term maximum 24-hour average concentration from 2014 until 2017, suggesting that the 2018 dust storm event was an isolated event during an otherwise typical year in terms of PM₁₀ air pollution concentrations.

The number of exceedances were calculated for PM₁₀ for the 2015, 2017, 2018, 2019 and 2020 periods and are shown in Table 10. The number and timing of the exceedances calculated for PM₁₀ reflect dust storms in November 2018 and the black summer bushfires in December 2019 and January 2020.

When the WHO criteria are considered, there is no additional exceedance noted in 2015, 2017 or 2018, with only a small number of additional exceedances noted in 2019 and 2020.

Annual average PM₁₀ concentrations were below the annual average 2022 NEPM criteria of 25µg/m³ from 2014 until 2023.

When the annual average PM₁₀ WHO criteria are considered, only 2019 and 2020 exceeded the lower criteria.

- **PM_{2.5} Particulates** – PM_{2.5} particulates at Civic were consistently lower than the concentrations observed at Monash, with only 2017, 2018, 2019 and 2020 having PM_{2.5} concentrations that exceeded the 24-hour maximum 2022 NEPM criteria of 25µg/m³. The calendar years since the black summer bushfires have shown consistently lower PM_{2.5} concentrations, with the 2022 concentration only being 4.1 µg/m³, which is the lowest concentration monitored since 2015.

Maximum 24-hour average PM_{2.5} concentrations were variable with concentrations around or lower than 20 µg/m³ between 2015 and 2016 and 2021 to 2023. 24-hour maximum PM_{2.5} concentrations rose to very high concentrations in 2019 and 2020 following the black summer bushfires. Concentrations decreased to levels lower than historical averages in 2021 to 2023.

The number of exceedances were calculated for PM_{2.5} for the 2015-2023 periods and are shown in Table 10. There were consistently low numbers of exceedances of the 24-hour PM_{2.5} criteria noted for all years except for 2019 to 2020 corresponding with the 2019 and 2020 black summer bushfire event. No exceedances were observed between 2015 and 2016 as well as 2021 to 2023.

When the NEPM 2025 criteria are considered, the pattern of exceedance is worse than is described above, with exceedances now occurring across all monitored years between 2015 and 2021, with no exceedances still observed in 2022 and 2023. A significant increase in exceedances was noted with the NEPM 2025 PM_{2.5} 24-hour criteria with most exceedances increasing between 2015 and 2018.

When the WHO 24-hour PM_{2.5} criterion is considered, there are a large number of additional exceedances with the number of exceedances increasing by 50-100% or higher for most monitoring years. The 2022 monitoring year is the only calendar year that does not have a 24-hour period that exceeds the WHO criterion.

Annual average PM_{2.5} concentrations were below the annual average 2022 NEPM criteria of 8µg/m³ from 2015 until 2023 with the exception of 2019 and 2020 due to the influence of the black summer bushfires. Concentrations since the black summer bushfires have been

consistently well below the annual average concentration criterion with values of 4.9, 4.1 and 5.5 $\mu\text{g}/\text{m}^3$ for 2021, 2022 and 2023 respectively.

When the 2025 NEPM annual average criteria is considered, the number of calendar years exceeding the criterion is unchanged.

When the annual average $\text{PM}_{2.5}$ WHO criterion is considered, all periods between 2015 and 2023 exceed the criteria with the exception of 2021 and 2022.

- **Florey Monitoring data:**

- **PM₁₀ Particulates** – PM_{10} particulate concentrations have been variable at the Florey monitoring station with some exceedances of the 24-hour maximum 2022 NEPM criteria of 50 $\mu\text{g}/\text{m}^3$ from observations between 2014 and 2023.

Maximum PM_{10} concentrations in 2015, 2018, 2019 and 2020 all exceeded the 2022 NEPM criteria. As discussed above, the exceedance noted in 2018 was due to a dust storm event occurring in November of 2018. Exceedances of the criteria observed in 2019 and 2020 were due to the black summer bushfires which affected air pollution concentrations across western NSW and ACT. The reasons for the exceedances in 2015 are not clear, with no regionally significant event identified to occur during those time periods.

As with Monash and Civic, the 2018 annual average PM_{10} concentration was only slightly higher than the longer-term maximum 24-hour average concentration from 2014 until 2017, suggesting that the 2018 dust storm event was an isolated event during an otherwise typical year in terms of PM_{10} air pollution concentrations.

The number of exceedances were calculated for PM_{10} for the 2015, 2018, 2019 and 2020 periods and are shown in **Table 11**. The number and timing of the exceedances calculated for PM_{10} reflect dust storms in November 2018 and the black summer bushfires in December 2019 and January 2020.

When the WHO criteria are considered, there is no additional exceedance noted in 2015 or 2018, with only a small number of additional exceedances noted in 2019 and 2020.

Annual average PM_{10} concentrations were below the annual average 2022 NEPM criteria of 25 $\mu\text{g}/\text{m}^3$ from 2014 until 2023.

When the annual average PM_{10} WHO criteria are considered, only 2019 and 2020 exceeded the lower criteria.

- **PM_{2.5} Particulates** – $\text{PM}_{2.5}$ particulates at Florey were generally lower than the concentrations observed at Monash, but higher than concentrations observed for Civic. Maximum 24-hour $\text{PM}_{2.5}$ concentrations for 2014 to 2021 all had maximum $\text{PM}_{2.5}$ concentrations that exceeded the 24-hour maximum 2022 NEPM criteria of 25 $\mu\text{g}/\text{m}^3$. The calendar years since the black summer bushfires have shown generally lower $\text{PM}_{2.5}$ concentration.

Maximum 24-hour average $\text{PM}_{2.5}$ concentrations were above the NEPM 2025 criterion with concentrations around 30-40 $\mu\text{g}/\text{m}^3$ between 2015 and 2018. 24-hour maximum $\text{PM}_{2.5}$ concentrations rose to very high concentrations in 2019 and 2020 following the black summer bushfires. Concentrations decreased to levels lower than historical averages in 2021 to 2023 (although still exceeding the NEPM 2022 criterion for 2021).

The number of exceedances were calculated for $\text{PM}_{2.5}$ for the 2014-2023 periods and are shown in **Table 11**. There were consistently low numbers of exceedances (less than 4 exceedance in a calendar year) of the 24-hour $\text{PM}_{2.5}$ criteria noted for all years except for 2019 to 2020 corresponding with the 2019 and 2020 black summer bushfire event. No exceedances were observed between 2022 to 2023.

When the NEPM 2025 criteria are considered, the pattern of exceedance is much worse than is described above, with exceedances now occurring across all monitored years between 2014 and 2023. A significant increase in exceedances was noted with the NEPM 2025 $\text{PM}_{2.5}$ 24-hour criteria with most exceedances increasing between 2015 and 2018 and between 2021 and 2023.

When the WHO 24-hour PM_{2.5} criterion is considered, there are a large number of additional exceedances with the number of exceedances increasing by 50-100% or higher for all monitoring years.

Annual average PM_{2.5} concentrations were below the annual average 2022 NEPM criteria of 8µg/m³ from 2014 until 2023 with the exception of 2019 and 2020 due to the influence of the black summer bushfires. Concentrations since the black summer bushfires have been consistently well below the annual average concentration criterion with values of 6.1, 5.0 and 6.3 µg/m³ for 2021, 2022 and 2023 respectively.

When the 2025 NEPM annual average criteria is considered, the number of calendar years exceeding the criterion increases from 2 calendar year exceedances to 5 calendar year exceedances.

When the annual average PM_{2.5} WHO criterion is considered, all periods between 2014 and 2023 exceed the criteria with the exception of the 2022 calendar year.

Overall, the findings of the PM₁₀ and PM_{2.5} analysis were as follows:

- Monitoring data for the three monitoring stations showed broadly similar results, suggesting that the PM₁₀ concentrations in the ACT are not driven as much by local conditions and sources, rather they are more affected by regional effects such as dust storms or bush fires. PM₁₀ concentrations were affected by wood smoke in winter however not to the same extent as PM_{2.5}.
- Monitoring data from the Monash and Florey stations show significant PM_{2.5} concentrations across all calendar years in winter. Data from Civic shows a much lower concentration (although concentrations are still elevated and at times above the criteria. This is expected to be due to the location of the Monash and Florey monitoring stations situated within residential areas where the use of wood fires is commonplace. The Civic monitoring station is situated within a commercial estate on the northern edge of Lake Burley Griffin. The commercial area along with the microclimate generated by the proximity to the lake would be expected to affect the wood smoke.
- The use of different criteria to examine the levels of pollution in the ACT result in different outcomes. Comparison against the NEPM 2022 standards shows that the ACT air quality has generally been reasonable for PM₁₀ with poorer conditions observed for PM_{2.5} which showed a small number of exceedances across calendar years.

When the NEPM 2025 goals are applied for PM_{2.5} (as no change is proposed for PM₁₀), it is observed that the number of exceedances increases significantly. This situation is made even worse if the WHO guidelines are applied, which shows a large number of exceedances across all calendar years.

When the NEPM 2025 goals or if the WHO guidelines are applied to a future air pollution policy environment significant work would be needed to achieve compliance. Significant reduction in PM_{2.5} concentrations would be needed across all emitting sectors.

Given the significant contribution domestic wood smoke makes to PM_{2.5} overall in the ACT, it is expected that the elimination of wood smoke would significantly alter the PM_{2.5} concentrations in ACT airshed.

Table 6 Monash Monitoring Data Results (2011-2023)

Year	PM ₁₀		PM _{2.5}		NO ₂		CO		O ₃
	24-hr	Annual	24-hr	Annual	1-hr	Annual	1-hr	8-hr	
2011	40.1	10.3	nd	nd	88.2	11.5	2788	2528	332.9
2012	40.9	10.4	nd	nd	67.7	11.4	2525	2418	8.9
2013	45.8	9.8	nd	nd	75.9	10.7	2638	2425	9.3
2014	38.8	10.0	nd	nd	73.8	9.9	2250	1948	11.7
2015	44.7	10.0	34.6	8.6	65.6	9.1	2413	2250	8.7
2016	33.4	9.8	34.4	7.2	73.8	8.1	2188	2005	8.9
2017	28.4	9.7	37.6	7.7	63.6	9.2	2013	1763	10.4
2018	136.7	11.8	31.3	6.9	80.0	8.5	1988	1803	10.7
2019	310.8	18.8	231.8	14.2	172.2	9.6	13313	4022	20.5
2020	1096.8	22.6	1197.1	18.0	237.8	8.4	27500	23934	17.1
2021	37.6	10.3	27.9	6.9	73.8	6.5	1625	1434	8.4
2022	26.9	7.5	24.6	5.1	61.5	6.0	1688	1516	8.6
2023	31.9	10.5	28.5	6.8	63.6	7.2	1525	1375	10.0
NEPM 2022	50	25	25	8	164	31	30000	10000	139
NEPM 2025	-	-	20	7	-	-	-	-	-
WHO 2021	45	15	15	5	-	10	10000	4000	100

Note 1: "nd" = no data available

Note 2: Exceedances are colour coded

Table 7 Civic Monitoring Data Results (2011-2023)

Year	PM ₁₀		PM _{2.5}		NO ₂		CO		O ₃
	24-hr	Annual	24-hr	Annual	1-hr	Annual	1-hr	8-hr	
2011	nd	nd	nd	nd	nd	nd	2450	2081	9.3
2012	nd	nd	nd	nd	nd	nd	2188	1491	8.0
2013	nd	nd	nd	nd	nd	nd	1838	1381	7.8
2014	32.4	10.0	nd	nd	nd	nd	600	438	8.9
2015	57.4	11.1	21.0	6.3	nd	nd	nd	nd	7.9
2016	35.9	10.7	21.5	5.5	nd	nd	nd	nd	8.3
2017	53.1	10.1	53.9	6.0	nd	nd	nd	nd	8.9
2018	174.2	13.4	34.9	6.5	nd	nd	nd	nd	10.2
2019	349.5	22.7	230.1	12.5	nd	nd	nd	nd	17.1
2020	1067.2	21.6	971.6	14.6	nd	nd	nd	nd	14.2
2021	28.6	8.8	21.9	4.9	nd	nd	nd	nd	8.3
2022	21.2	6.7	10.3	4.1	nd	nd	nd	nd	7.6
2023	40.0	9.7	17.9	5.5	nd	nd	nd	nd	8.5
Criteria	NEPM 2022	25	25	8	164	31	30000	10000	139
	NEPM 2025	-	20	7	-	-	-	-	-
	WHO 2021	45	15	5	-	10	10000	4000	100

Note 1: "nd" = no data available

Note 2: Exceedances are colour coded

Table 8 Florey Monitoring Data Results (2011-2023)

Year	PM ₁₀		PM _{2.5}		NO ₂		CO		O ₃
	24-hr	Annual	24-hr	Annual	1-hr	Annual	1-hr	8-hr	
2011	nd	nd	nd	nd	nd	nd	nd	nd	nd
2012	nd	nd	nd	nd	nd	nd	nd	nd	nd
2013	nd	nd	nd	nd	nd	nd	nd	nd	nd
2014	40.8	10.6	25.7	6.0	92.3	11.6	2688	1903	7.0
2015	60.7	10.6	43.0	6.7	67.7	10.9	2475	2263	7.2
2016	29.7	10.1	28.0	7.1	69.7	10.0	2338	2116	9.1
2017	29.1	9.8	28.2	7.4	67.7	10.8	2288	2033	10.7
2018	152.8	12.1	33.5	7.3	80.0	10.2	1900	1714	10.8
2019	340.6	23.5	314.7	15.1	127.1	9.7	10325	6103	20.1
2020	1163.7	23.7	1065.1	17.6	350.6	8.5	18300	14028	16.6
2021	40.6	9.7	28.0	6.1	69.7	7.5	1550	1361	9.3
2022	26.6	7.6	24.4	5.0	53.3	7.3	1800	1597	8.6
2023	24.3	10.0	22.2	6.3	61.5	8.1	1400	1278	10.2
Criteria	NEPM 2022	25	25	8	164	31	30000	10000	139
	NEPM 2025	-	20	7	-	-	-	-	-
	WHO 2021	45	15	5	-	10	10000	4000	100

Note 1: "nd" = no data available

Note 2: Exceedances are colour coded

Table 9 Monash Monitoring Data Exceedances (2011-2023)

Year	PM ₁₀		PM _{2.5}			NO ₂		CO		O ₃	
Criteria	NEPM 2022	WHO 2021	NEPM 2022	NEPM 2025	WHO 2021	NEPM 2022	WHO 2021	NEPM 2022	WHO 2021	NEPM 2022	WHO 2021
2011	0	0	nd	nd	nd	0	0	0	0	3.0	4.0
2012	0	0	nd	nd	nd	0	0	0	0	0	0
2013	0	1	nd	nd	nd	0	0	0	0	0	0
2014	0	0	nd	nd	nd	0	0	0	0	0	0
2015	0	0	8	21	34	0	0	0	0	0	0
2016	0	0	8	21	36	0	0	0	0	0	0
2017	0	0	14	27	44	0	0	0	0	0	0
2018	4	4	1	17	34	0	0	0	0	0	0
2019	22	24	31	49	74	1	0	0	0	0	0
2020	22	23	35	47	64	2	0	0	0	0	0
2021	0	0	4	18	37	0	0	0	0	0	0
2022	0	0	0	2	9	0	0	0	0	0	0
2023	0	0	1	7	31	0	0	0	0	0	0

"nd" : no data available

Table 10 Civic Monitoring Data Exceedances (2011-2023)

Year	PM ₁₀		PM _{2.5}			NO ₂		CO		O ₃	
Criteria	NEPM 2022	WHO 2021	NEPM 2022	NEPM 2025	WHO 2021	NEPM 2022	WHO 2021	NEPM 2022	WHO 2021	NEPM 2022	WHO 2021
2011	nd	nd	nd	nd	nd	nd	0	0	0	0.0	0.0
2012	nd	nd	nd	nd	nd	nd	0	0	0	0.0	0.0
2013	nd	nd	nd	nd	nd	nd	0	0	0	0.0	0.0
2014	0	0	nd	nd	nd	nd	0	0	0	0.0	0.0
2015	1	1	0	1	3	nd	nd	nd	nd	0.0	0.0
2016	0	0	0	2	7	nd	nd	nd	nd	0.0	0.0
2017	1	1	1	2	6	nd	nd	nd	nd	0.0	0.0
2018	6	6	1	2	4	nd	nd	nd	nd	0.0	0.0
2019	28	30	28	35	39	nd	nd	nd	nd	0.0	0.0
2020	24	25	22	27	30	nd	nd	nd	nd	0.0	0.0
2021	0	0	0	2	5	nd	nd	nd	nd	0.0	0.0
2022	0	0	0	0	0	nd	nd	nd	nd	0.0	0.0
2023	0	0	0	0	2	nd	nd	nd	nd	0.0	0.0

"nd" : no data available

Table 11 Florey Monitoring Data Exceedances (2011-2023)

Year	PM ₁₀		PM _{2.5}			NO ₂		CO			O ₃	
Criteria	NEPM 2022	WHO 2021	NEPM 2022	NEPM 2025	WHO 2021	NEPM 2022	WHO 2021	NEPM 2022	WHO 2021	NEPM 2022	WHO 2021	WHO 2021
2011	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
2012	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
2013	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
2014	0	0	1	3	14	0	0	0	0	0	0	0
2015	1	1	2	17	35	0	0	0	0	0	0	0
2016	0	0	1	8	24	0	0	0	0	0	0	0
2017	0	0	2	12	36	0	0	0	0	0	0	0
2018	4	4	4	9	31	0	0	0	0	0	0	0
2019	29	30	30	38	62	0	0	0	0	0	0	0
2020	22	22	28	44	68	0	0	0	0	0	0	0
2021	0	0	2	8	24	0	0	0	0	0	0	0
2022	0	0	0	2	9	0	0	0	0	0	0	0
2023	0	0	0	1	13	0	0	0	0	0	0	0

"nd" : no data available

Historical monitoring has shown the main pollutant of concern are particulates (ACT EPA, 2018). Trends for each monitoring analyte, for all available data at the time of reporting however with the east coast bushfire influenced data removed (September 2019 to February 2020 inclusive), are presented and discussed below.

5.3.1 Particulate matter <2.5µm trends

PM_{2.5} is monitored at each AQMS which enables a comparison of trends by hour of day, day of the week and month. These trends are presented in **Figure 21** with the following observed:

- Concentrations are generally highest during the night and lowest during the daytime hours, however there are also trends during the day which correlate with peak hour traffic, particularly at the Civic monitoring station. Civic experiences similar concentrations to the other monitors during the day but lower concentrations at night compared to Florey and Monash. This is likely due to the use of domestic wood heaters in the residential areas around Florey and Monash.
- Noting this data does not include the effects of the east coast fires of 2019-2020, average concentrations are highest in the colder months. Average monthly data for Monash, Florey and Civic are generally similar in terms of concentration in the warmer months, however Florey and Monash experience significantly higher concentrations during the colder months compared to Civic.
- There are no significant PM_{2.5} trends observed for the weekend.
- Additionally, average monthly concentrations including the 2019-2020 east coast bushfire data were also analysed to show the effects of bushfires on the ACT. Figure 22 shows that extreme bushfires can have a significant effect on PM_{2.5} concentrations experienced in the ACT as compared with the long-term data in Figure 21.

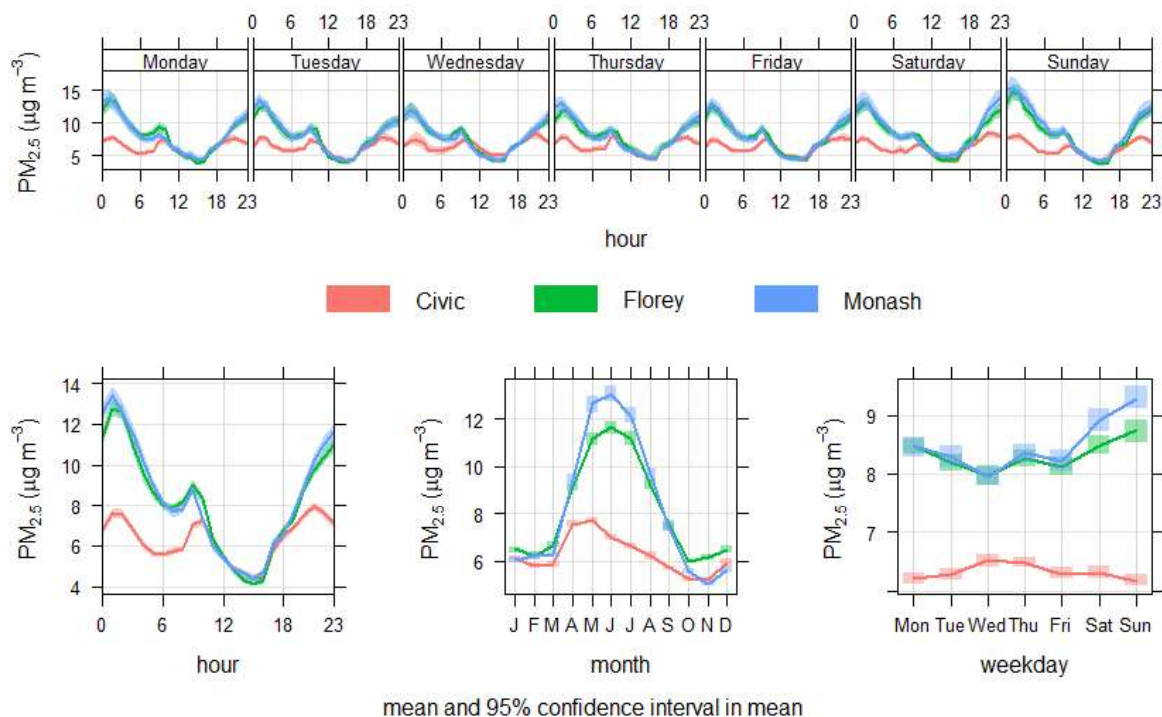


Figure 21 Mean PM_{2.5} variation by hour of day, month and day of the week

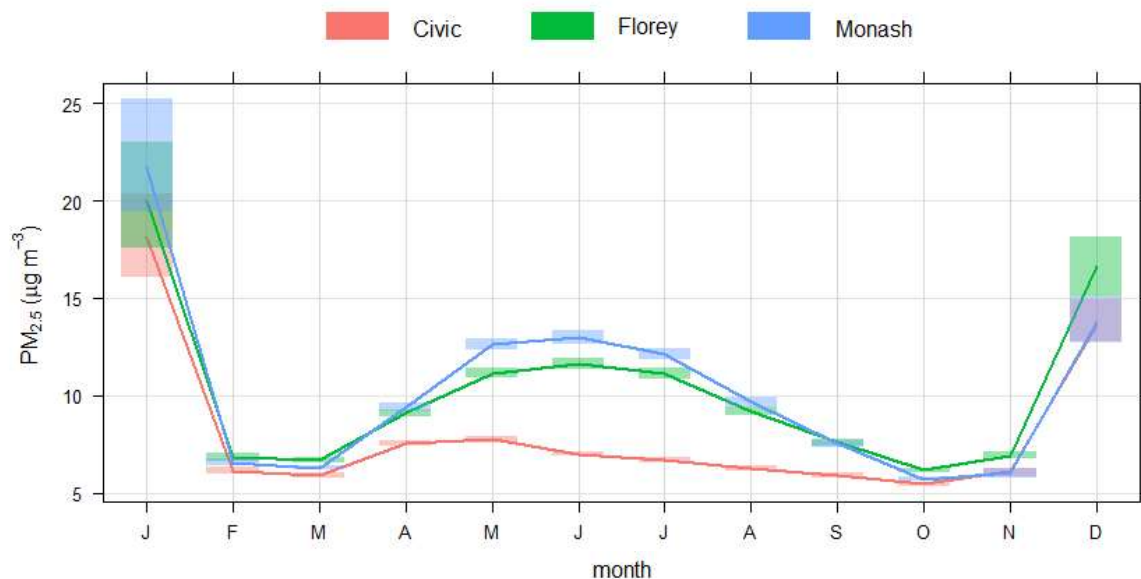


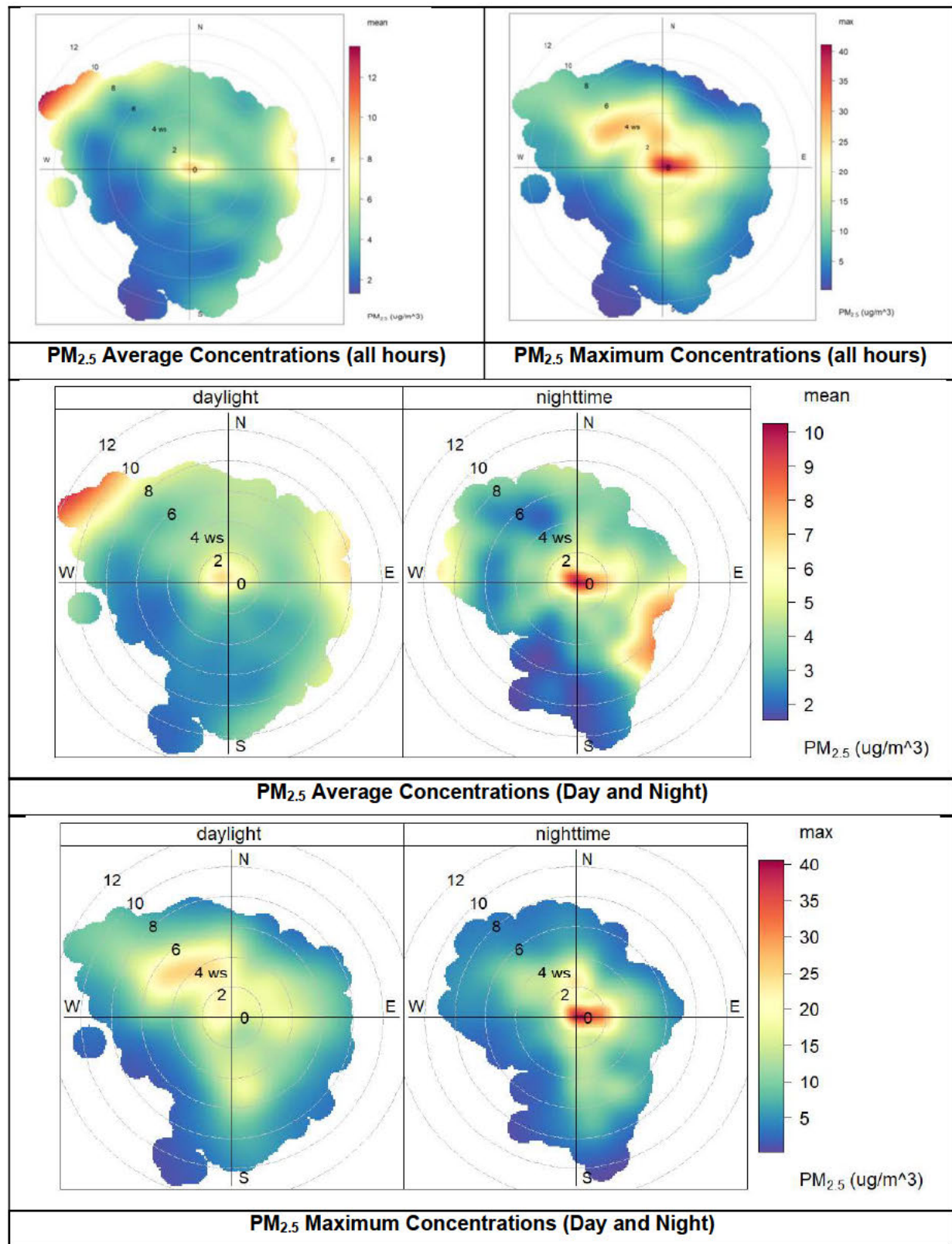
Figure 22 PM_{2.5} average monthly concentrations, east coast fire data included

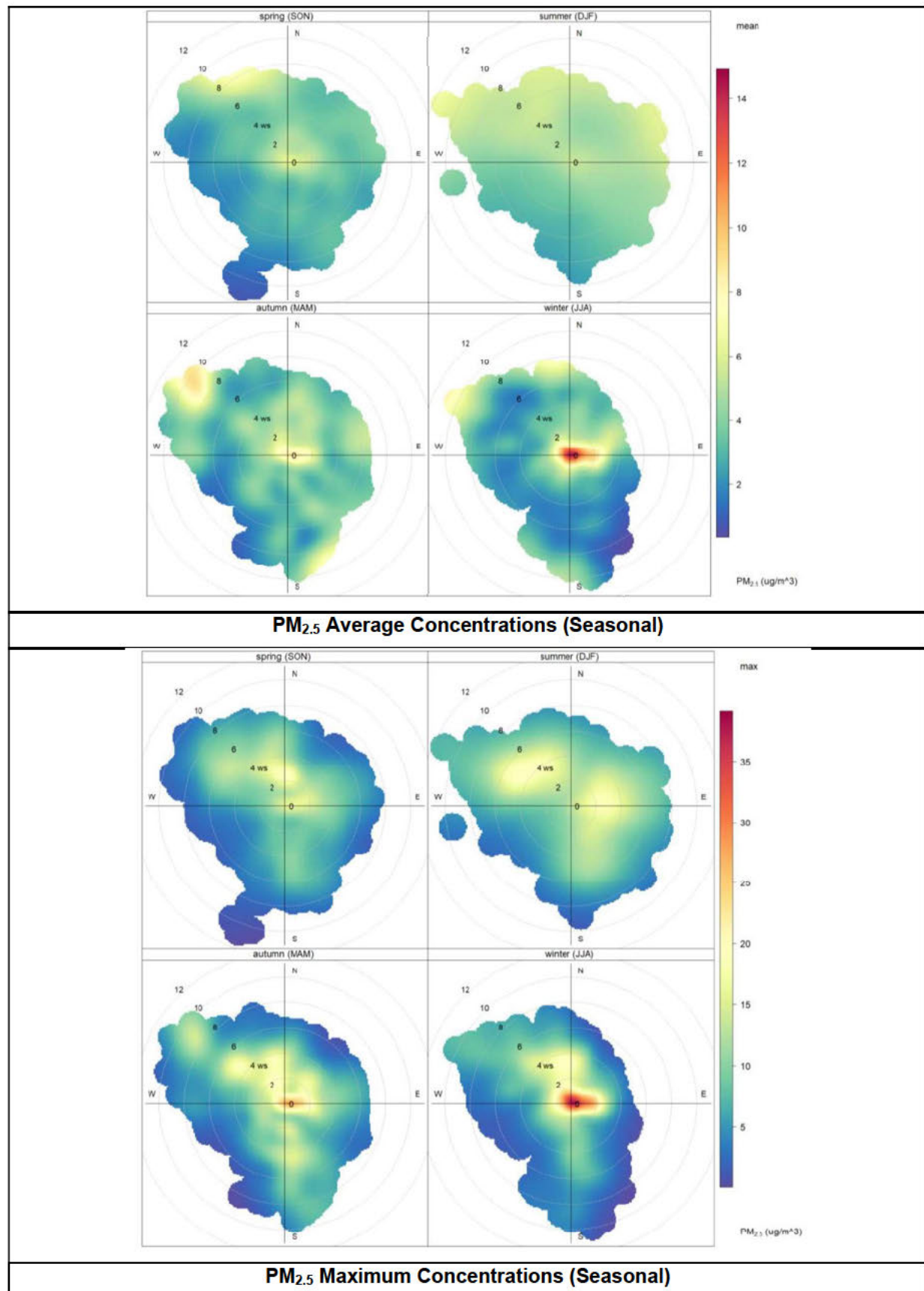
Pollution concentrations over time are a useful tool in understanding seasonal or diurnal trends. These types of time-series analysis however do not provide directionality to the data, meaning that an additional layer of understanding of the pollution concentrations can be missed. In an effort to understand more clearly where the pollution is coming from and under what conditions do peak concentrations occur, polar plots have been prepared for the hourly concentration data. Although the Monash, Civic and Florey pollution monitoring stations do not monitor for wind speed and direction, data from nearby meteorology monitoring stations can be used to provide additional meaning behind the monitoring data. Pollution and meteorology data were combined for the following stations:

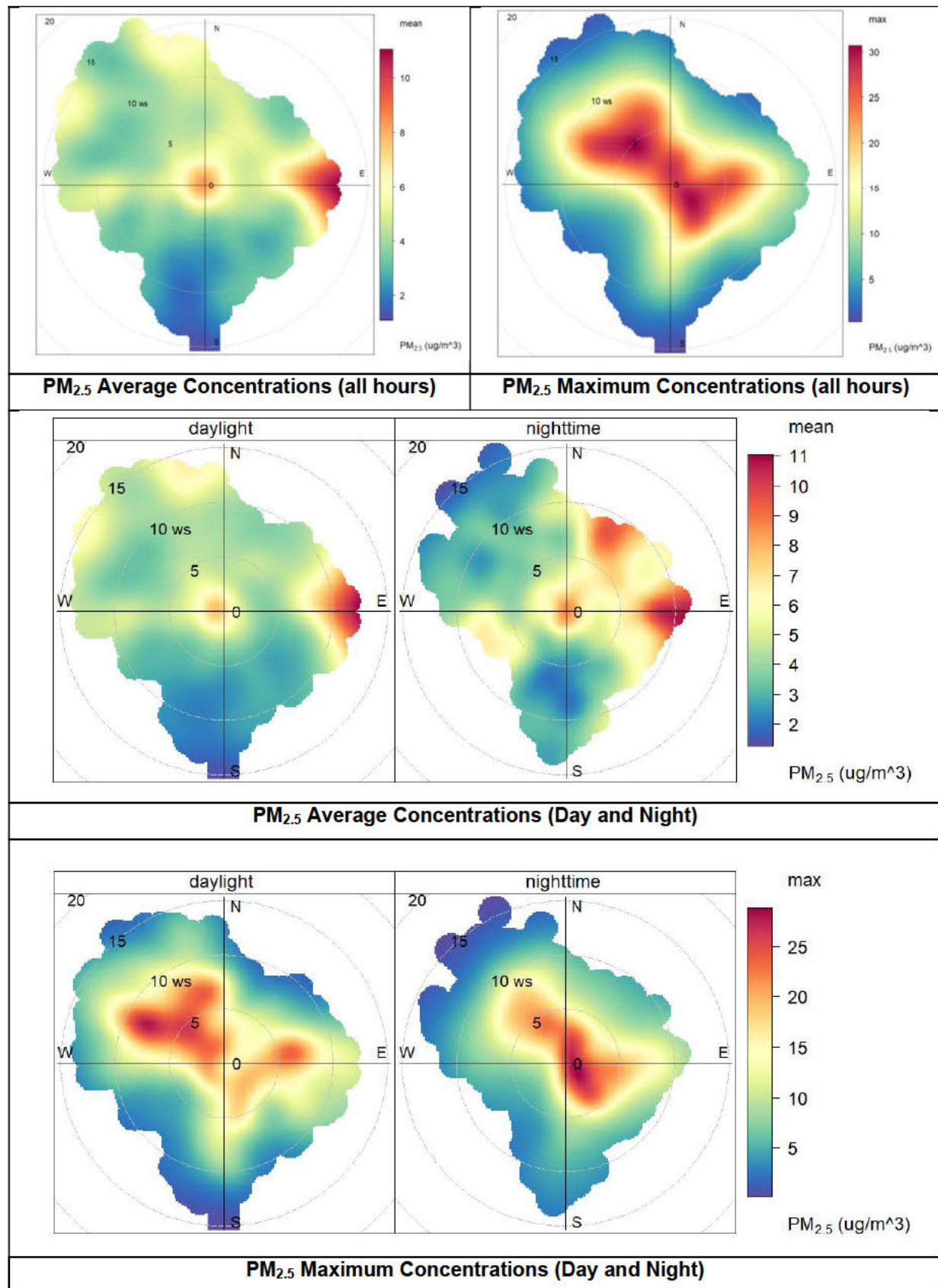
- **Monash Polar:** Monash pollution data with Tuggeranong meteorology data
- **Civic Polar:** Civic pollution data with Airport meteorology data
- **Florey Polar:** Florey pollution data with West Belconnen meteorology data.

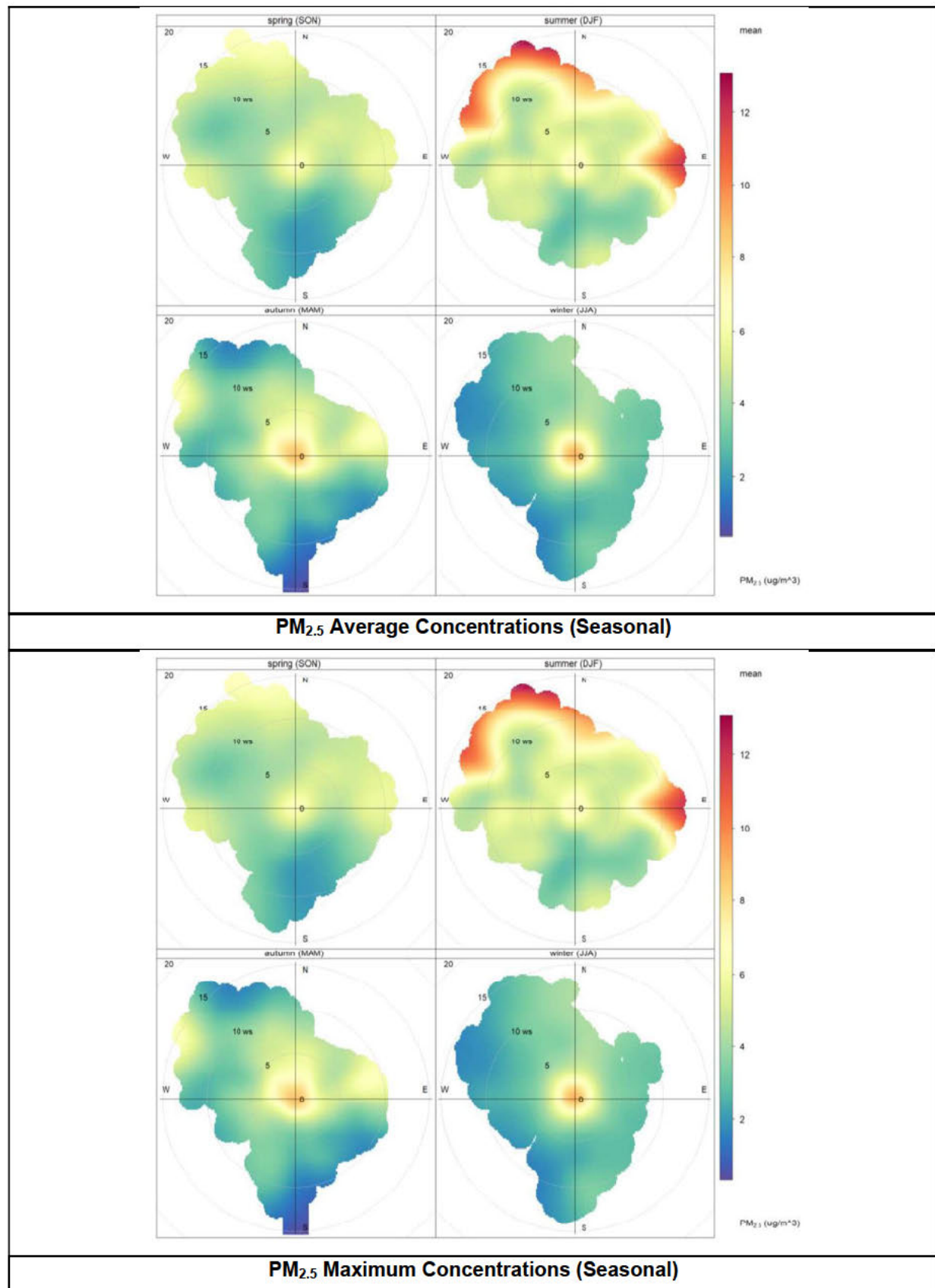
As the Tuggeranong BOM meteorology station is co-located with the Monash pollution monitoring station, there is a high degree of confidence in the correlation of pollution and meteorology. The other two stations use meteorological data at distance from the pollution stations and as such need to be treated with caution.

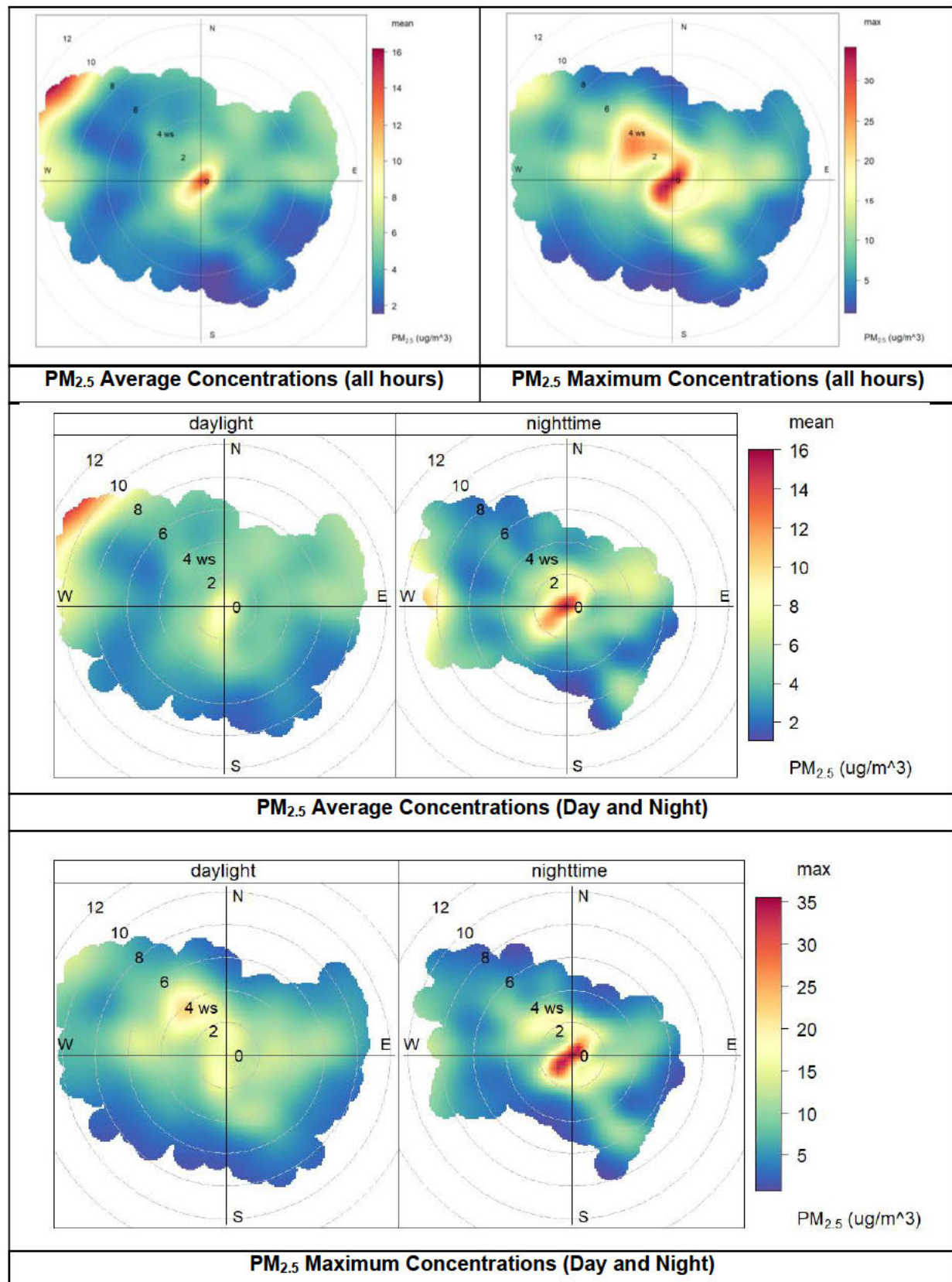
Polar plots for the Monash, Civic and Florey pollution stations for PM_{2.5} are as shown in **Figure 23** to **Figure 28**. Note that Ozone was not considered for Polar plots as ozone is not a key indicator of the pollution from domestic wood heaters.

Figure 23 Monash PM_{2.5} Polar Plots – All Data and Night and Day Data

Figure 24 Monash PM_{2.5} Polar Plots – Seasonal Data

Figure 25 Civic PM_{2.5} Polar Plots – All Data and Night and Day Data

Figure 26 Civic PM_{2.5} Polar Plots – Seasonal Data

Figure 27 Florey PM_{2.5} Polar Plots – All Data and Night and Day Data

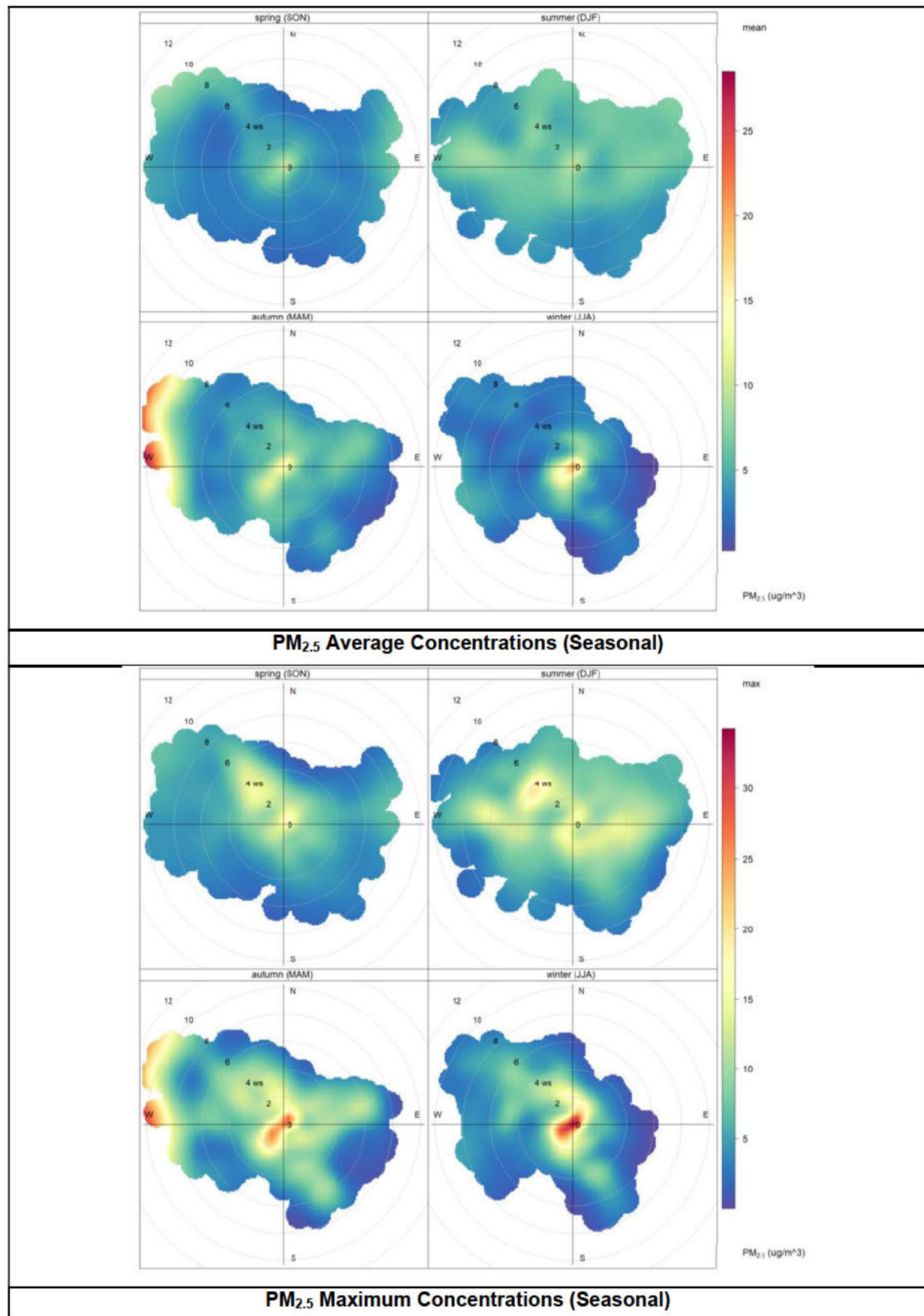


Figure 28 Florey PM_{2.5} Polar Plots – Seasonal Data

5.3.2 Particulate matter <10µm trends

PM₁₀ is monitored at each AQMS which enables a comparison of trends by hour of day, day of the week and month. These trends are presented in **Figure 29** with the following observed:

- Concentrations are generally highest during the night and lowest during the daytime hours, however there are also trends during the day which correlate with peak hour traffic, especially at Civic. Civic experiences higher concentrations during the day and lower at night compared to Florey and Monash, typical of traffic sources at Civic and wood heater sources at Florey and Monash.
- Average concentrations are highest in the colder months for Florey and Monash and follow a similar trend and value to PM_{2.5}, suggesting that the majority of PM₁₀ in these months is PM_{2.5}. Civic experiences higher PM₁₀ values in the warmer months and lower in the cooler months, suggesting PM_{2.5} does not make up the majority of PM₁₀ at Civic.
- There are no obvious trends for the weekend for Florey and Monash however Civic does record lower values on the weekend.

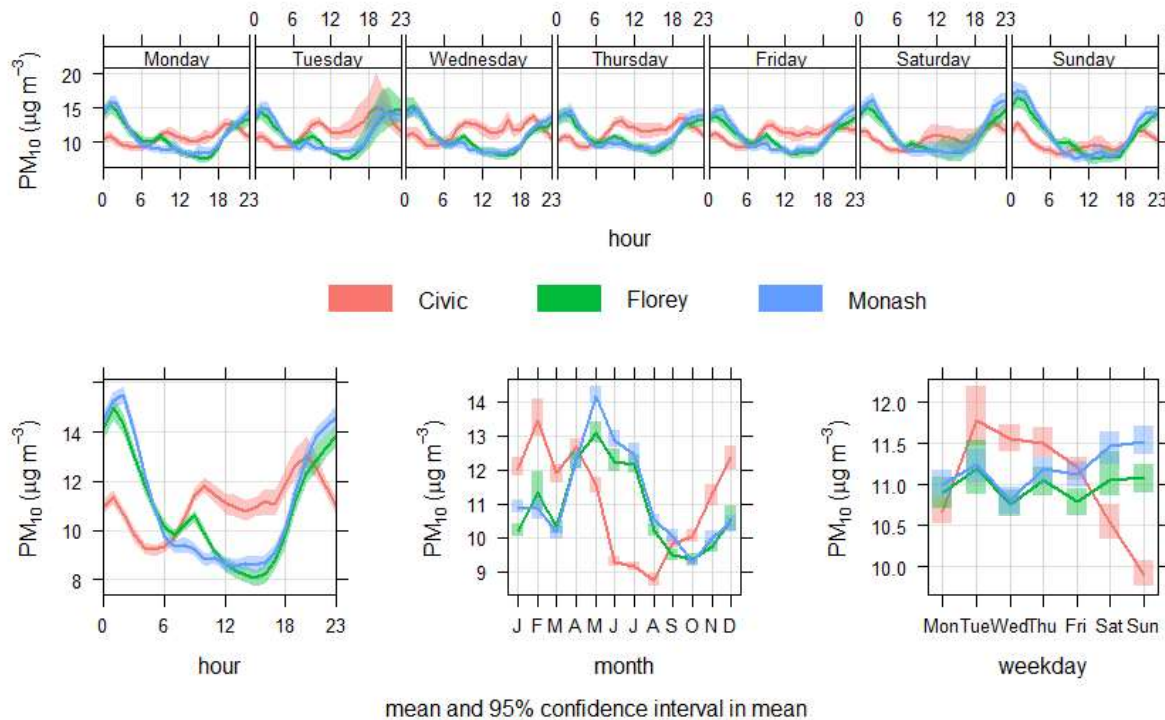
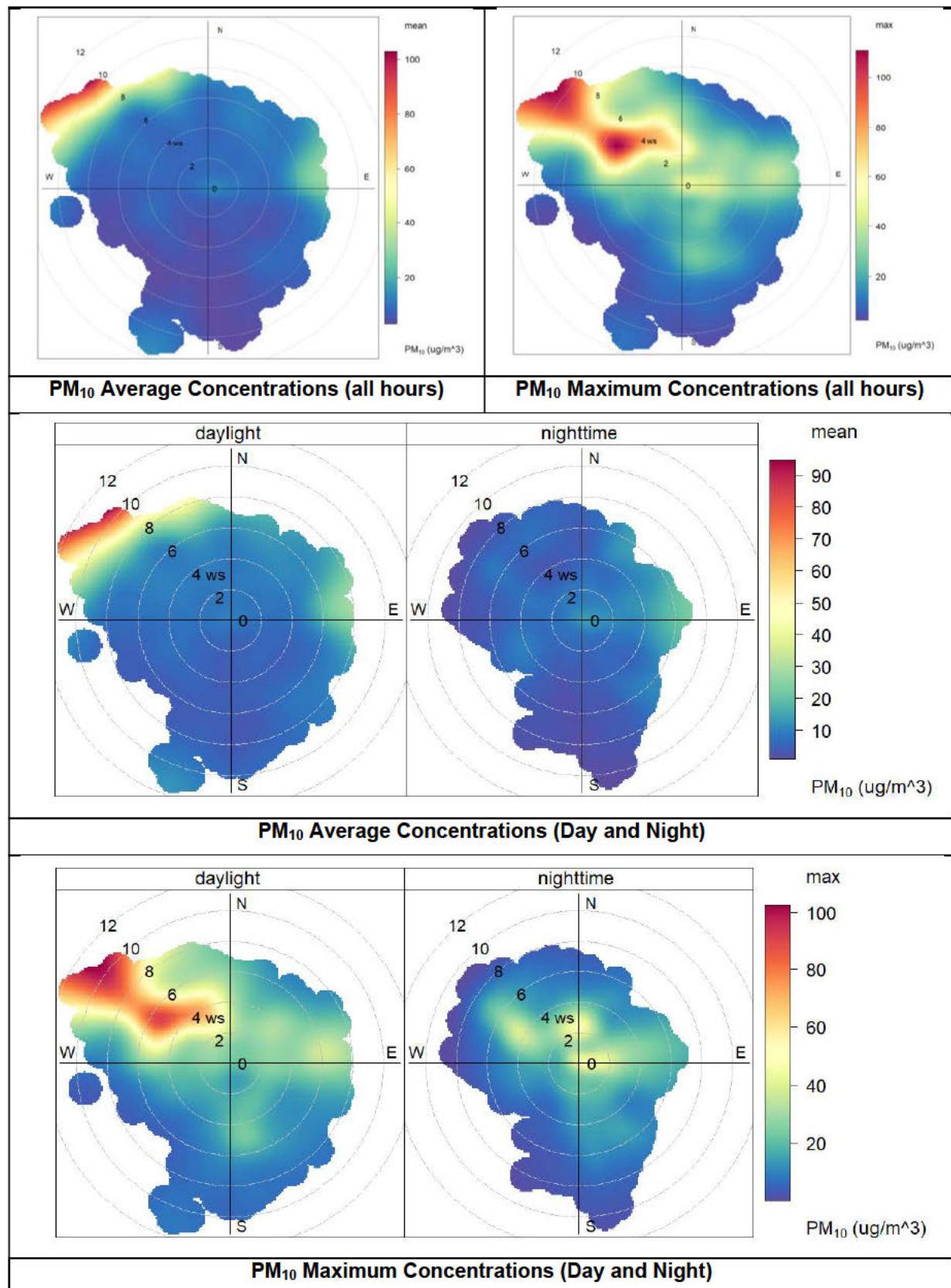
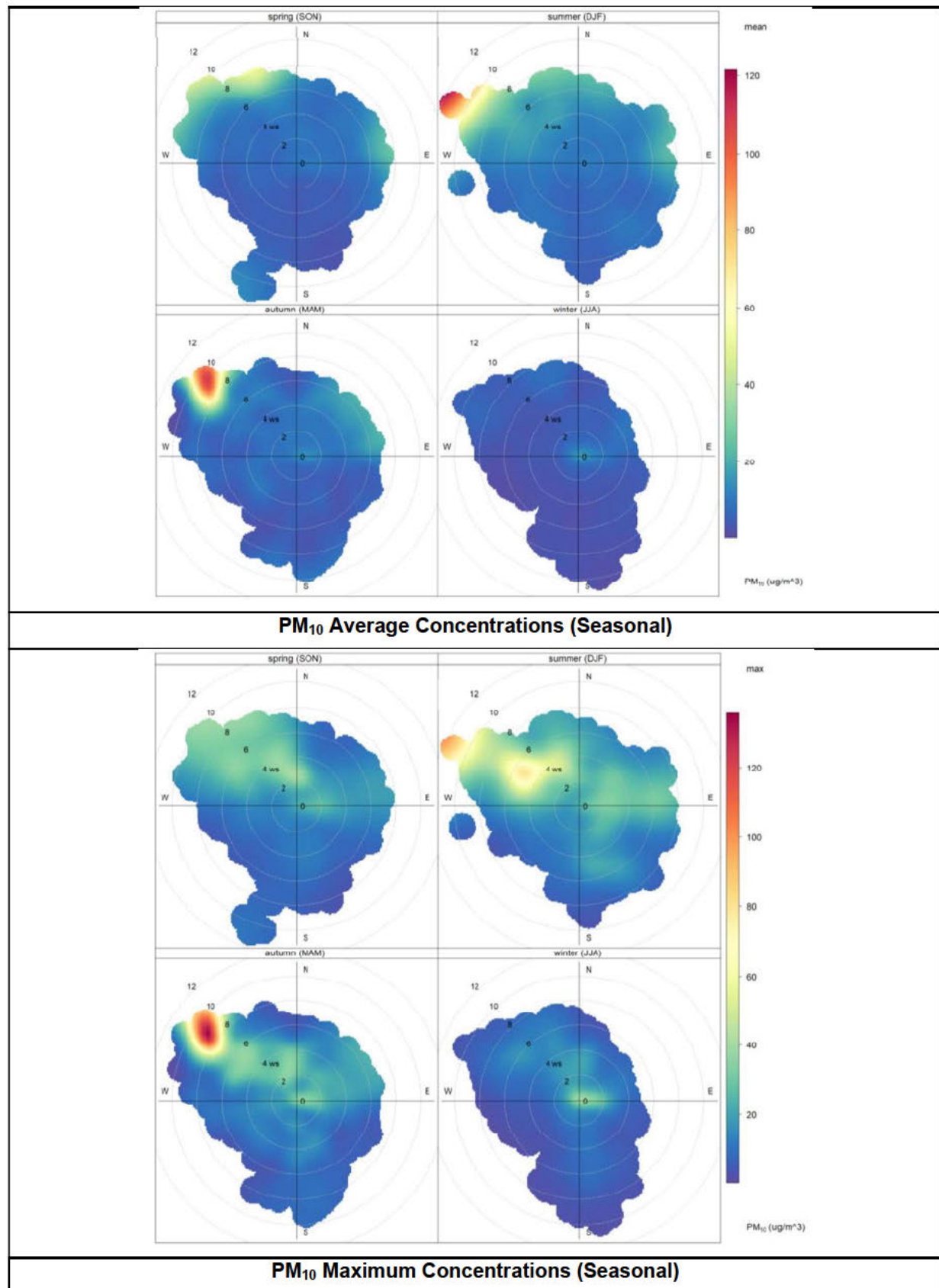
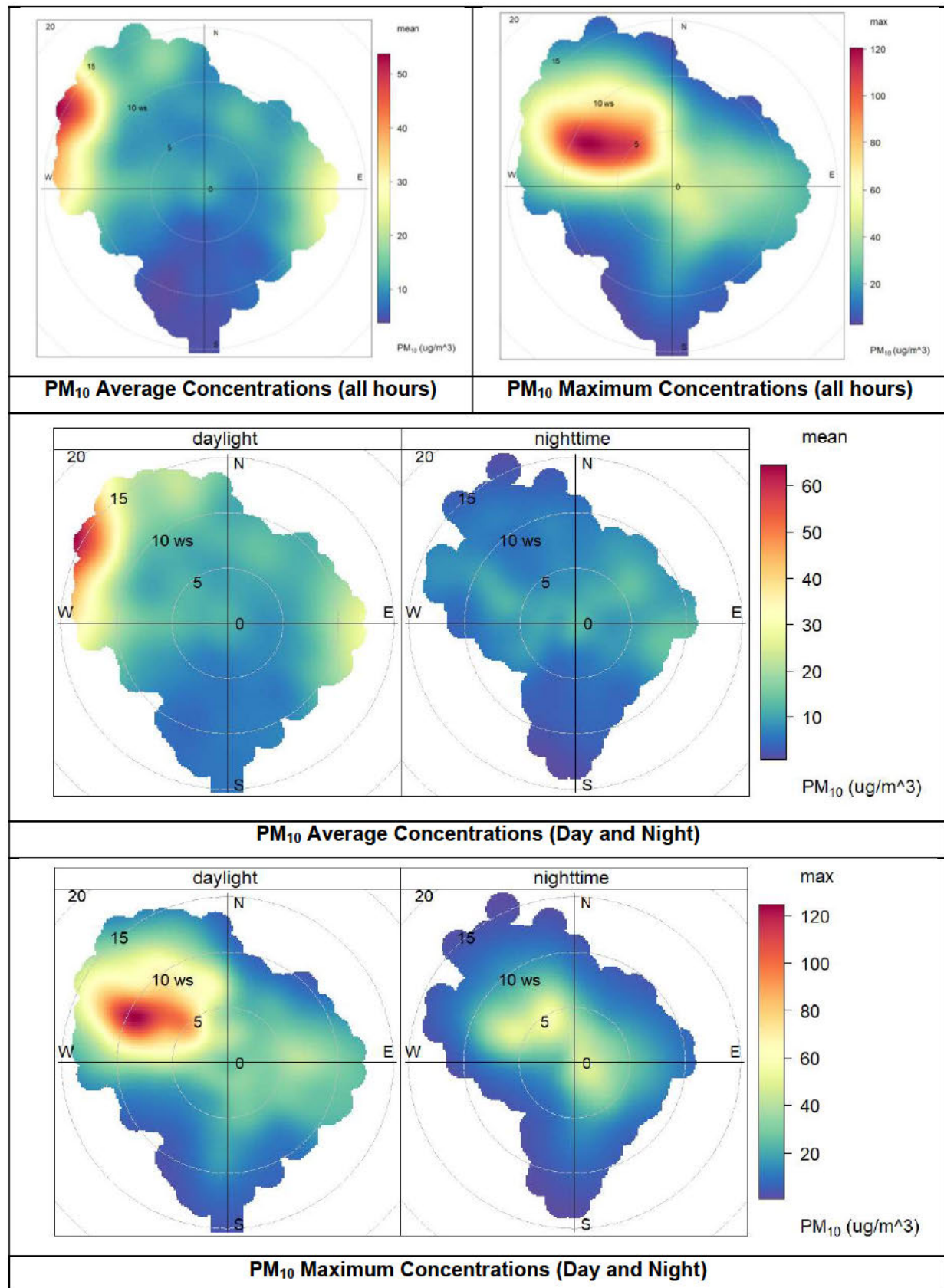


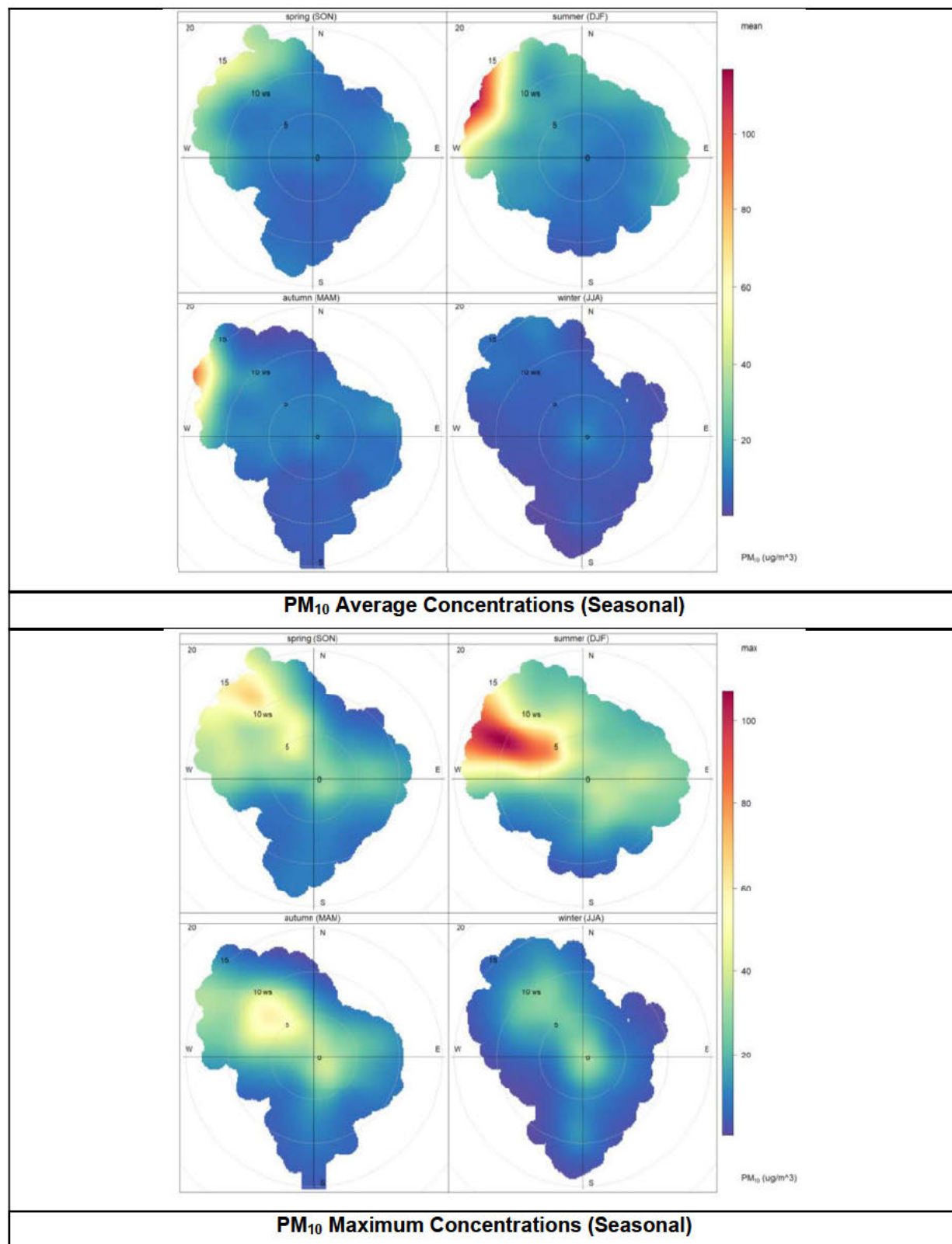
Figure 29 Mean PM₁₀ variation by hour of day, month and day of the week

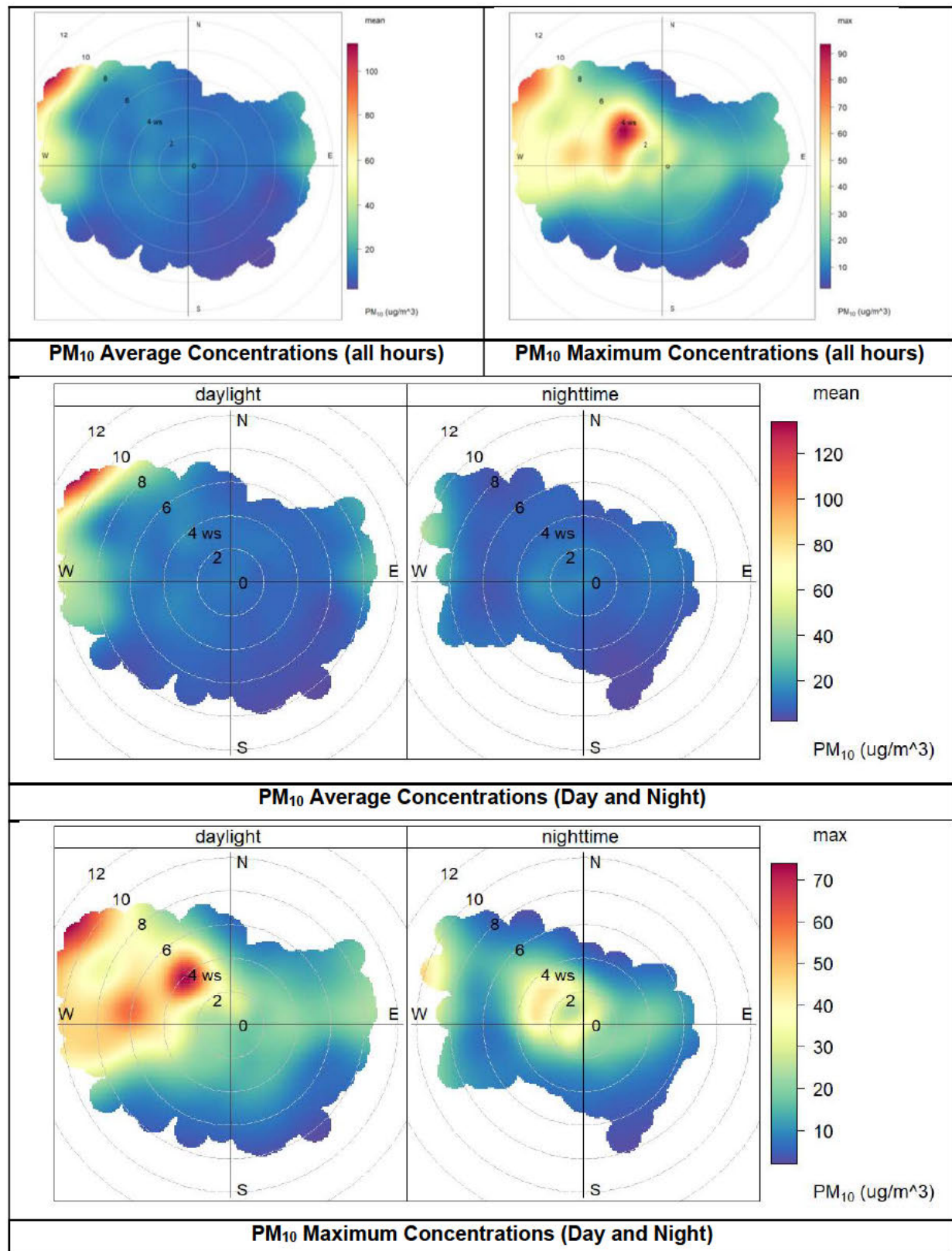
Polar plots for the Monash, Civic and Florey pollution stations for PM₁₀ are as shown in **Figure 30** to **Figure 35**.

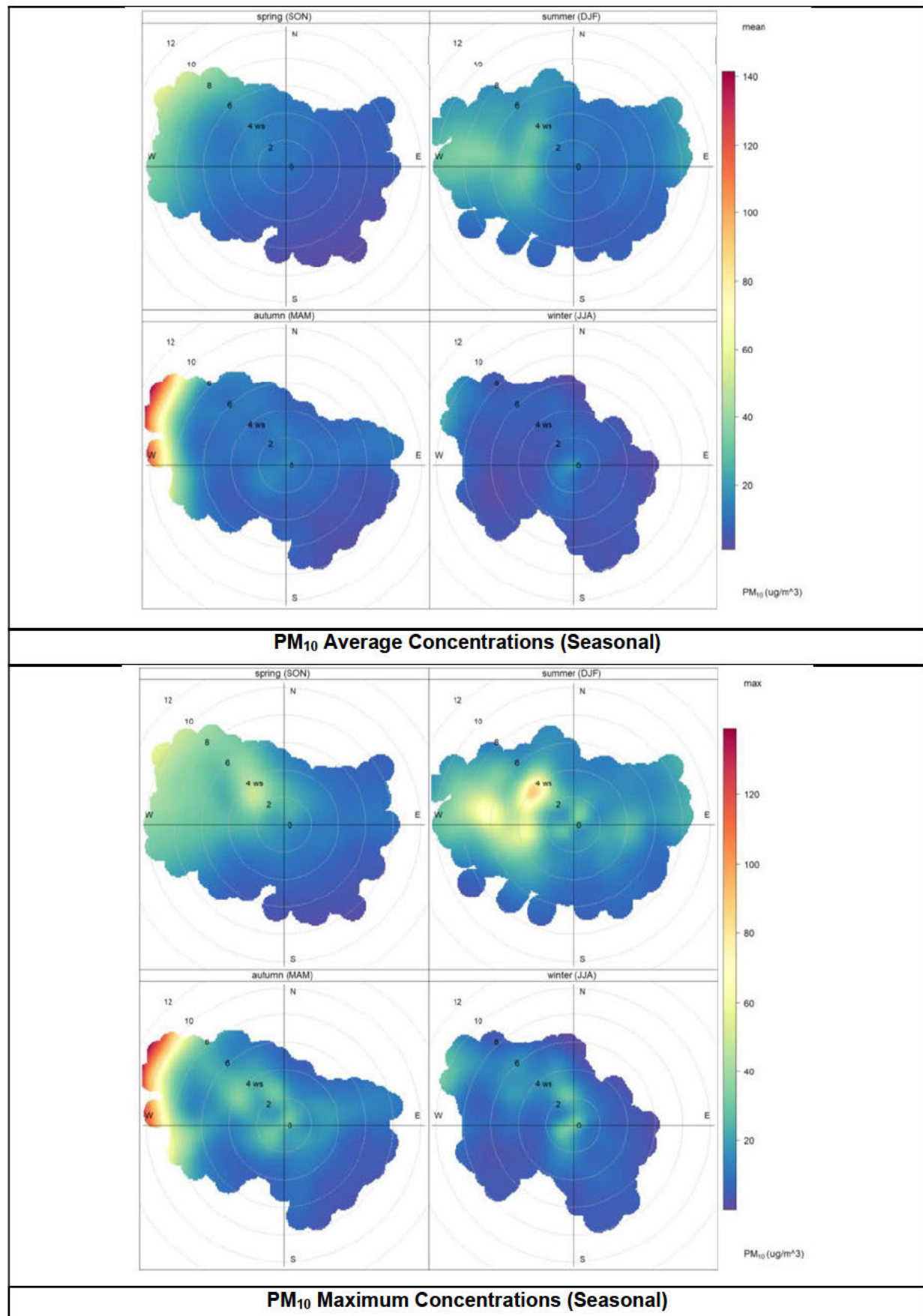
Figure 30 Monash PM₁₀ Polar Plots – All Data and Night and Day Data

Figure 31 Monash PM₁₀ Polar Plots – Seasonal Data

Figure 32 Civic PM₁₀ Polar Plots – All Data and Night and Day Data

Figure 33 Civic PM₁₀ Polar Plots – Seasonal Data

Figure 34 Florey PM₁₀ Polar Plots – All Data and Night and Day Data

Figure 35 Florey PM₁₀ Polar Plots – Seasonal Data

5.3.3 Nitrogen Dioxide trends

NO₂ is monitored at each AQMS which enables a comparison of trends by hour of day, day of the week and month. These trends are presented in **Figure 36** with the following observed:

- Concentrations peak at a time which correlates with the morning and afternoon traffic peaks hours. Civic recorded significantly higher concentrations than Florey and Monash, which could be due to high volume CBD traffic during peak hours relative to suburbia traffic.
- Average concentrations are highest in the colder months, which is typical due to photochemical reactions being slower during the colder months with NO₂ remaining in the atmosphere for longer periods. Civic recorded significantly higher concentrations than Florey and Monash, which could be due to high volume CBD traffic relative to suburbia traffic.
- Average concentrations appear to be lower on weekends, most notably at Civic, and less so at Florey and Monash. This is likely due to the reduction of commuter traffic on the weekend. Note this is the inverse of the O₃ trend which could be due to their interdependence on photochemical reactions, i.e.: where NO_x concentrations are reduced, higher levels O₃ could remain in the atmosphere which would have otherwise reacted if there was more available NO_x (and VOC), see **Section 5.3.4**.

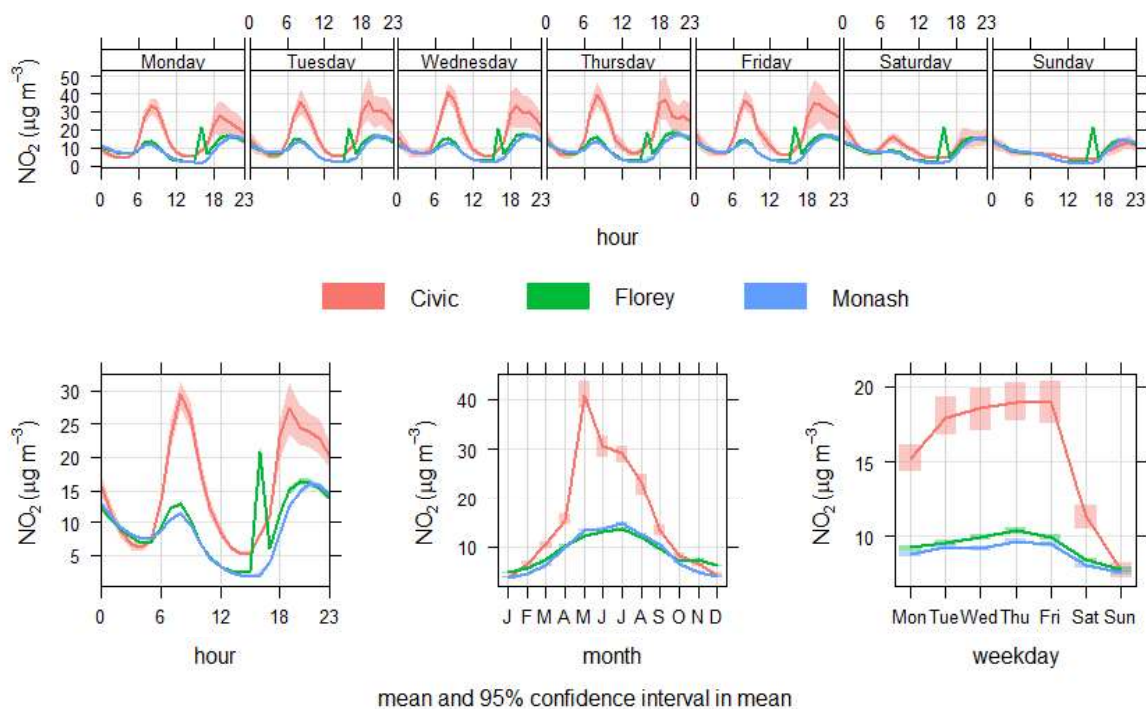
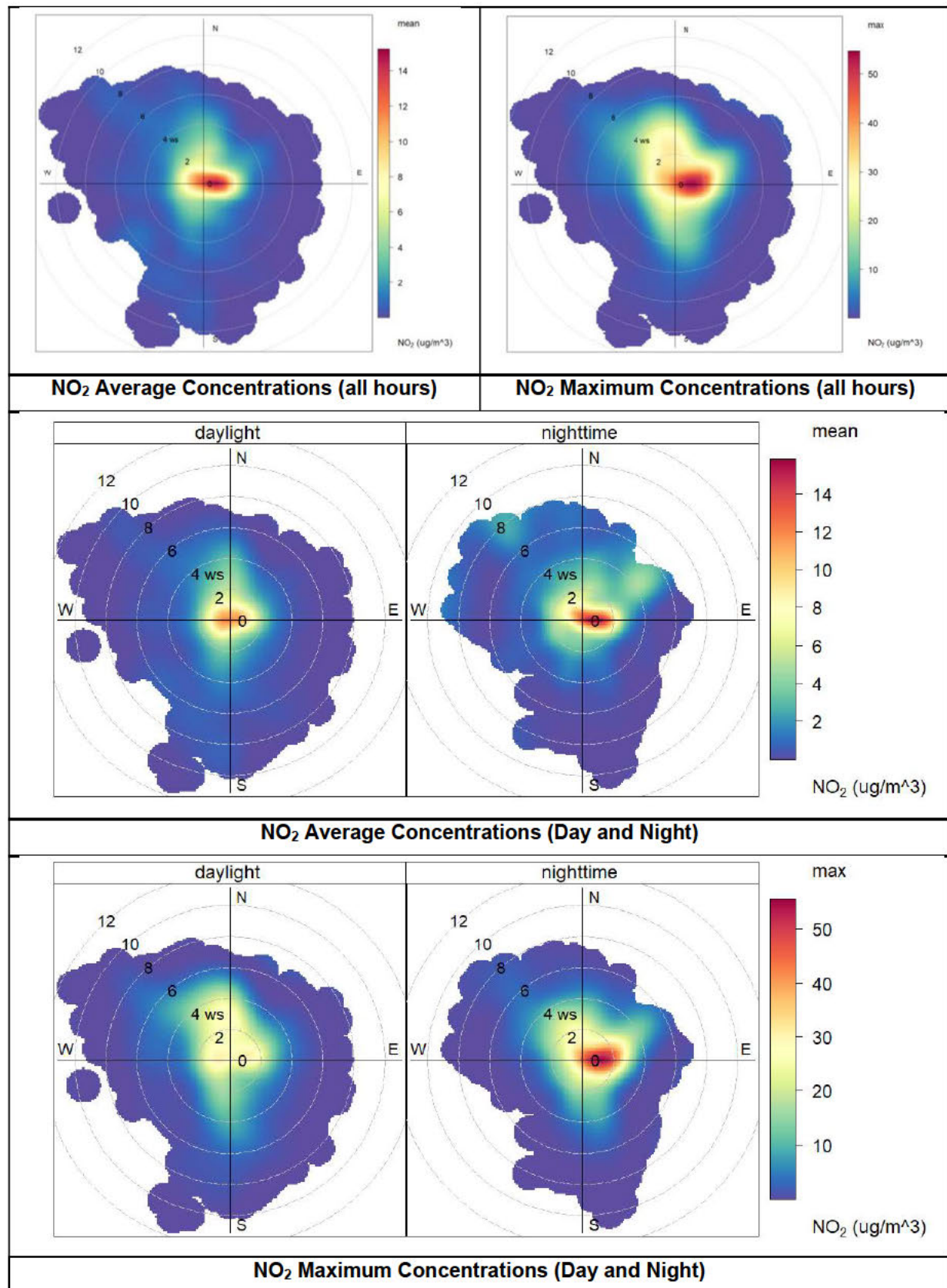
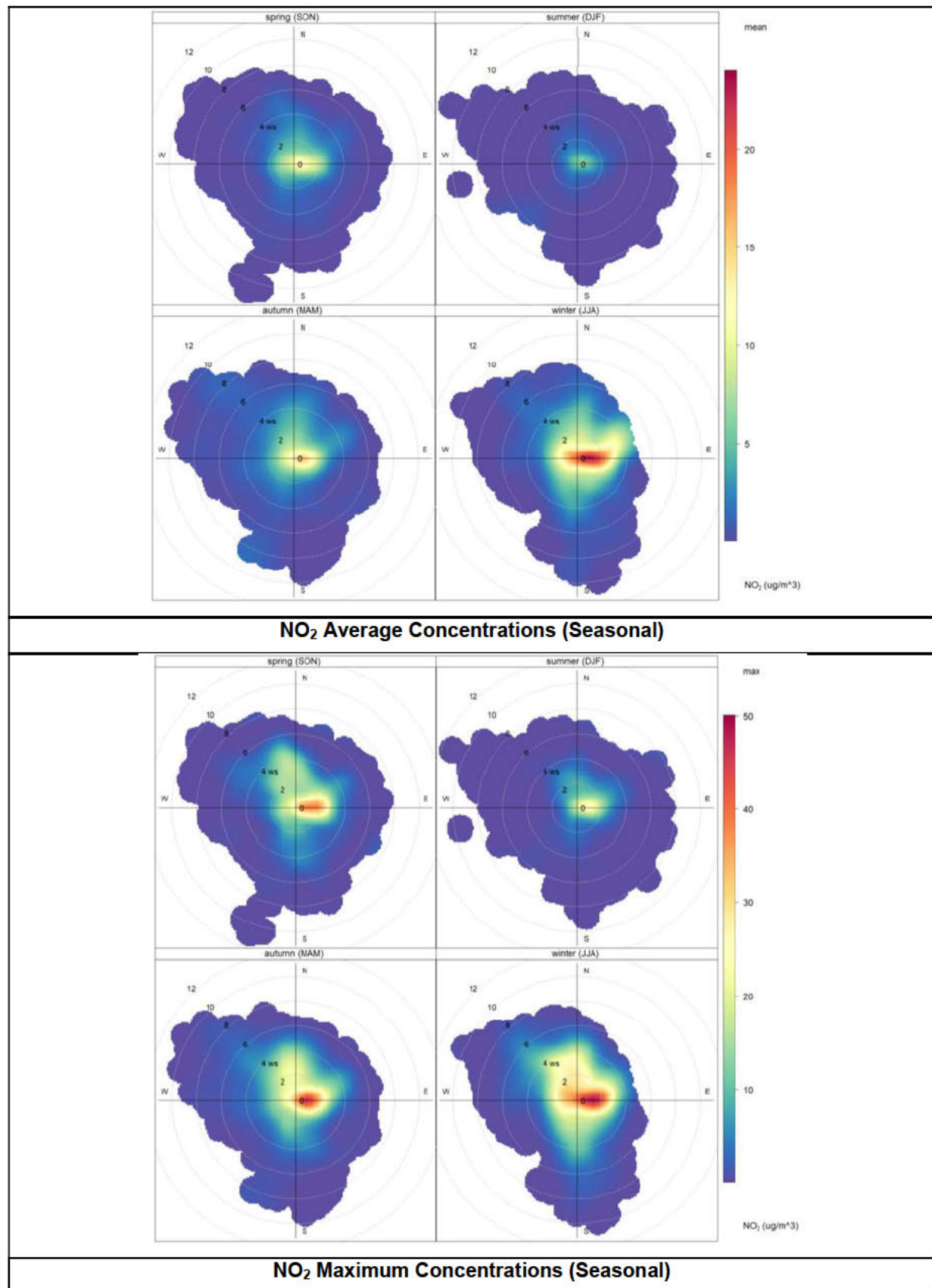
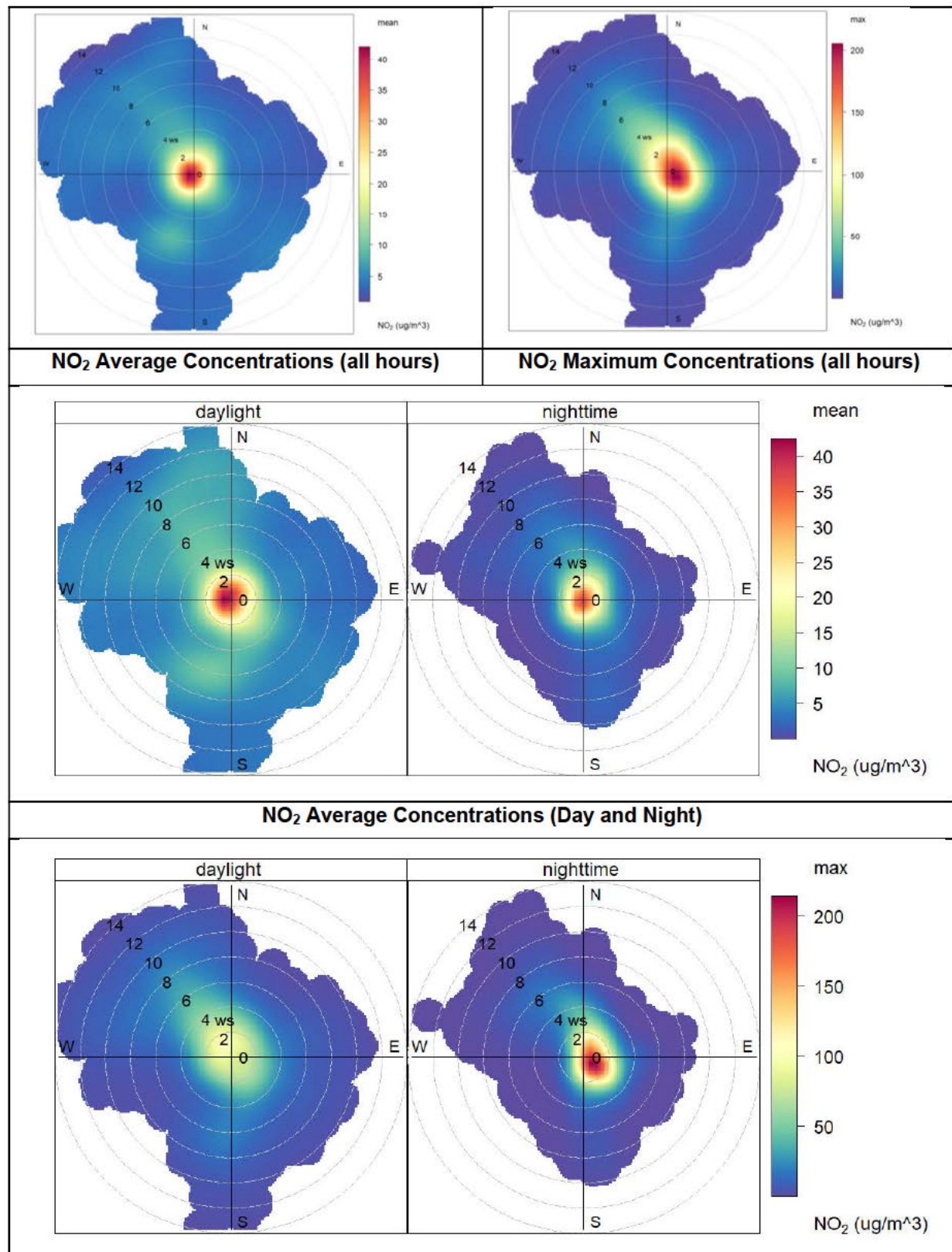


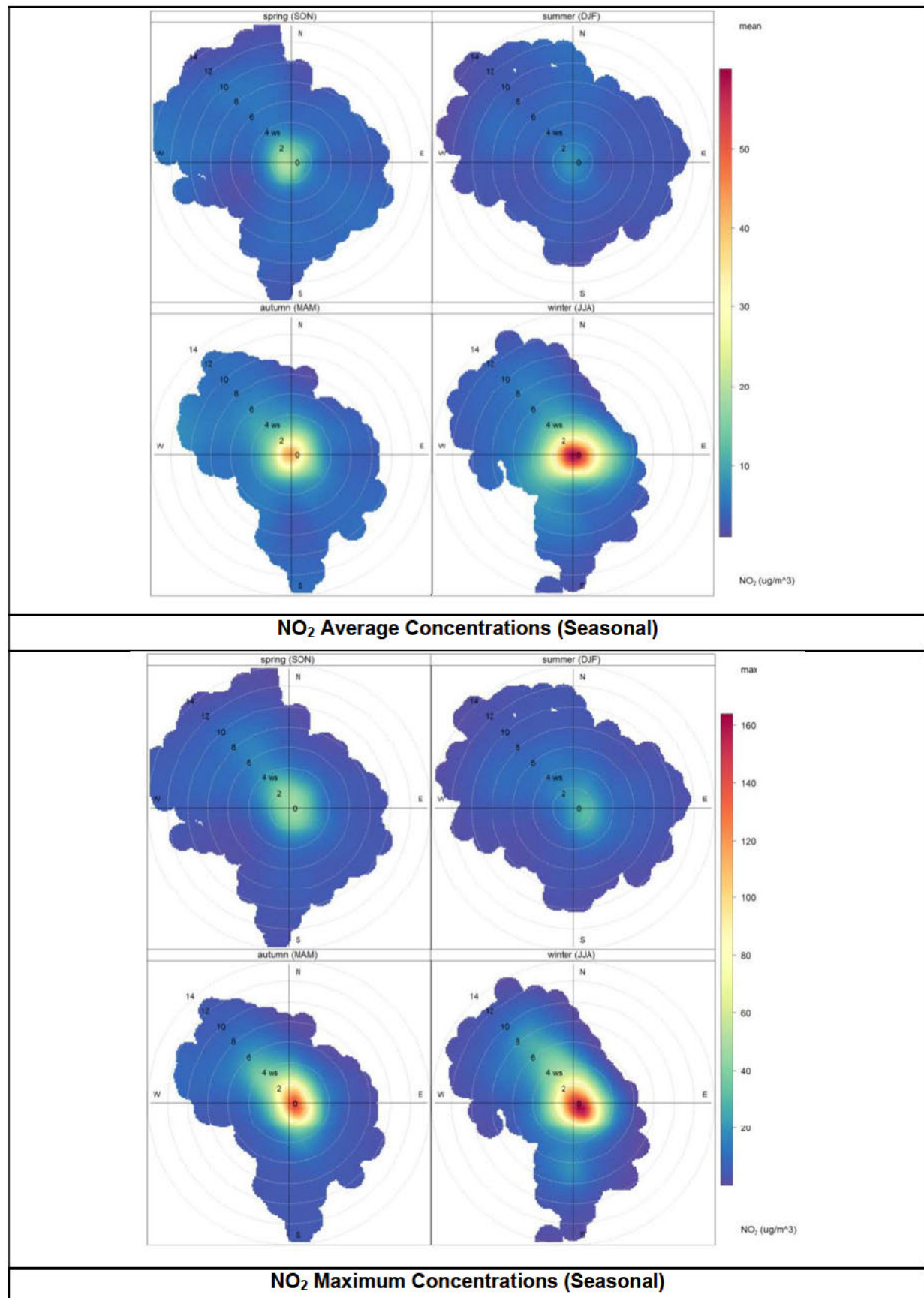
Figure 36 Mean NO₂ variation by hour of day, month and day of the week

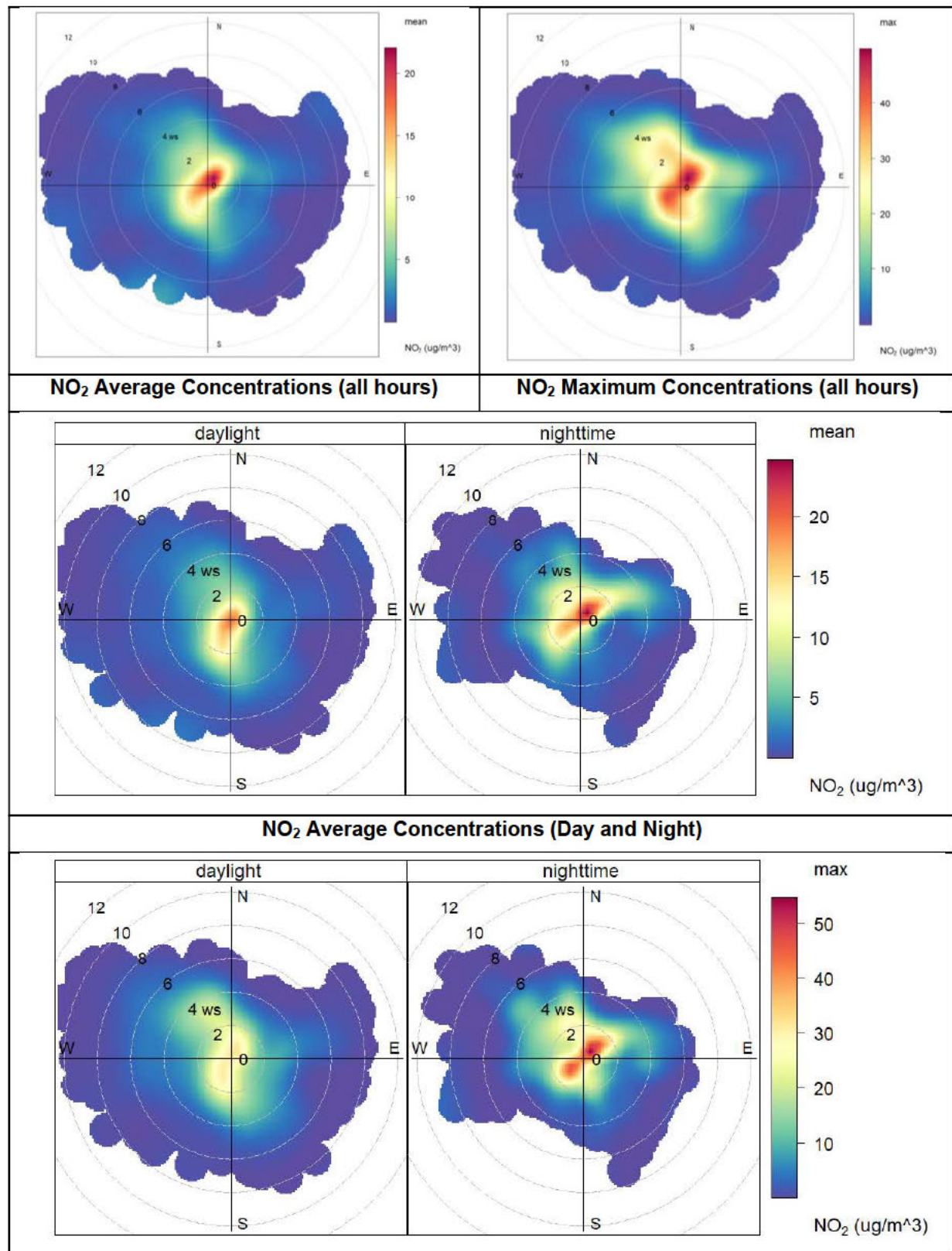
Polar plots for the Monash, Civic and Florey pollution stations for NO₂ are as shown in **Figure 36** to **Figure 42**.

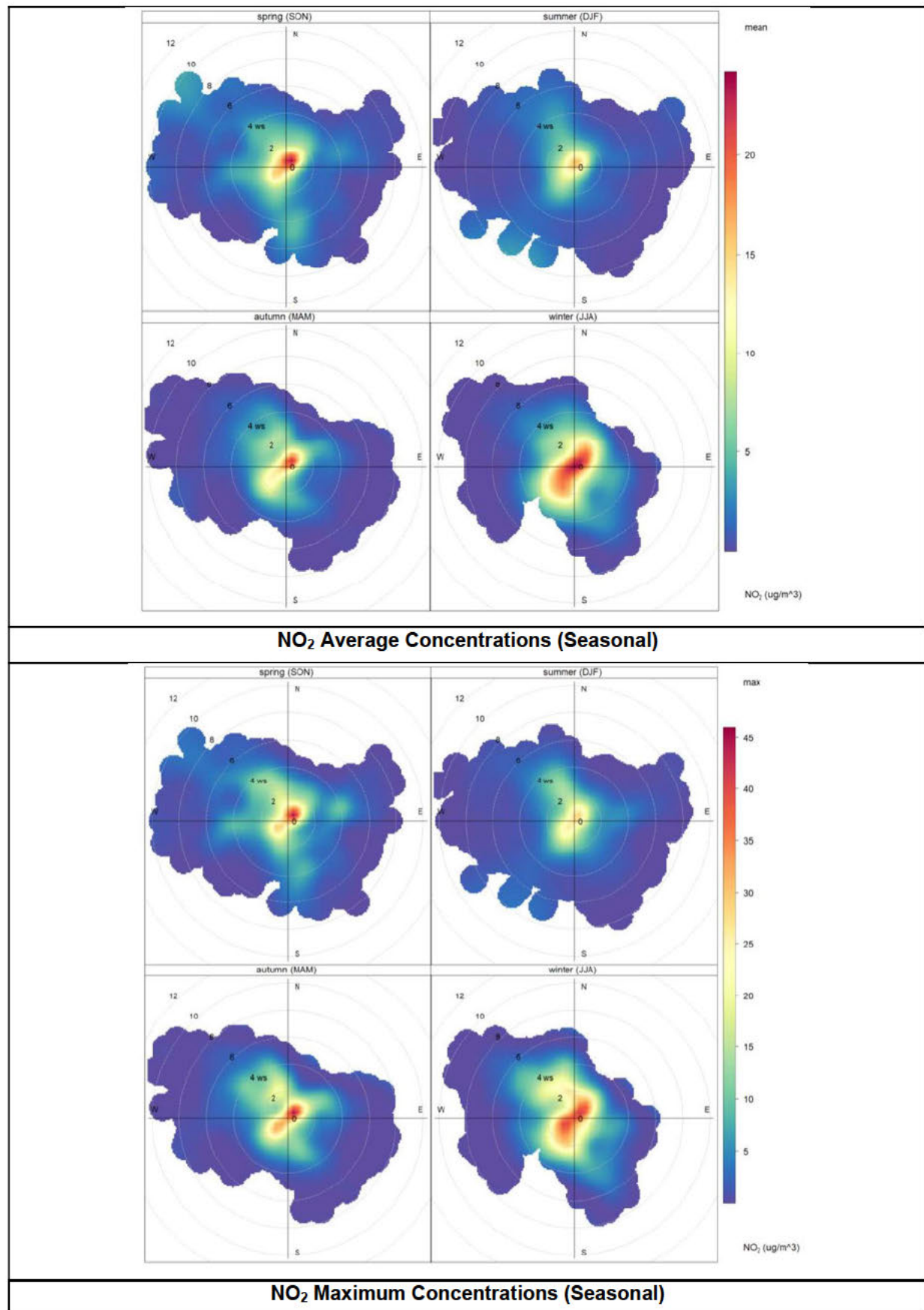
Figure 37 Monash NO₂ Polar Plots – All Data and Night and Day Data

Figure 38 Monash NO₂ Polar Plots – Seasonal Data

Figure 39 Civic NO₂ Polar Plots – All Data and Night and Day Data

Figure 40 Civic NO₂ Polar Plots – Seasonal Data

Figure 41 Florey NO₂ Polar Plots – All Data and Night and Day Data

Figure 42 Florey NO₂ Polar Plots – Seasonal Data

5.3.4 Ozone trends

O₃ is monitored at each AQMS which enables a comparison of trends by hour of day, day of the week and month. These trends are presented in **Figure 43** with the following observed:

- Concentrations are lowest early in the morning and increase throughout the day before peaking in the early afternoon. This diurnal cycle is due to ozone forming due to photochemical reactions with volatile organic compounds (VOC) and nitrogen oxides (NO_x) in the presence of sunlight. Concentrations typically peak in the early afternoon, then reduce throughout the afternoon and into the night as ozone ceases to form in the absence of sunlight and is used in the reaction between ozone and nitrogen oxide (NO) to form nitrogen dioxide (NO₂).
- Average concentrations are higher in the warmer months due to more sunlight hours.
- Average concentrations appear to be slightly higher on weekends, however the magnitude of the trends is not as significant as the hourly or monthly trends.

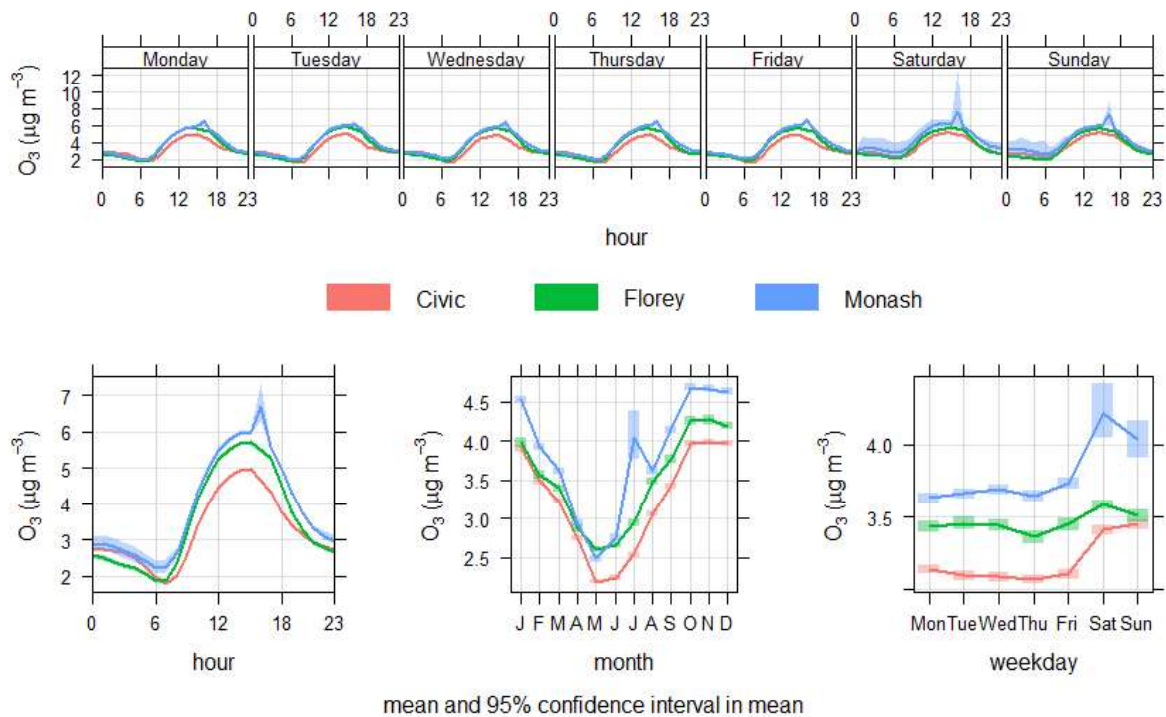


Figure 43 Mean O₃ variation by hour of day, month and day of the week

5.3.5 Carbon monoxide trends

CO is monitored at each AQMS which enables a comparison of trends by hour of day, day of the week and month. These trends are presented in **Figure 44** with the following observed:

- Concentrations are generally highest during the night and lowest during the daytime hours. This diurnal cycle suggests the primary source of the CO is generated throughout the night when dispersion conditions are poor causing the concentrations to increase throughout the night. Florey and Monash experience higher concentrations than Civic during the night before decreasing consistently across the day. Civic however maintains a reasonably steady concentration throughout the day, likely due to baseline CBD traffic volume. As Florey and Monash are located in the suburbs it is likely the nighttime sources are due to heating of residential homes, with CO being a product of wood heaters.
- Average concentrations are highest in the colder months. Monash recorded the highest concentrations, which could be due to wood heater usage and microclimatic effects during the colder months.
- Average concentrations appear to be slightly lower on weekends for Civic only, suggesting the source of CO is more likely to be traffic than heating.

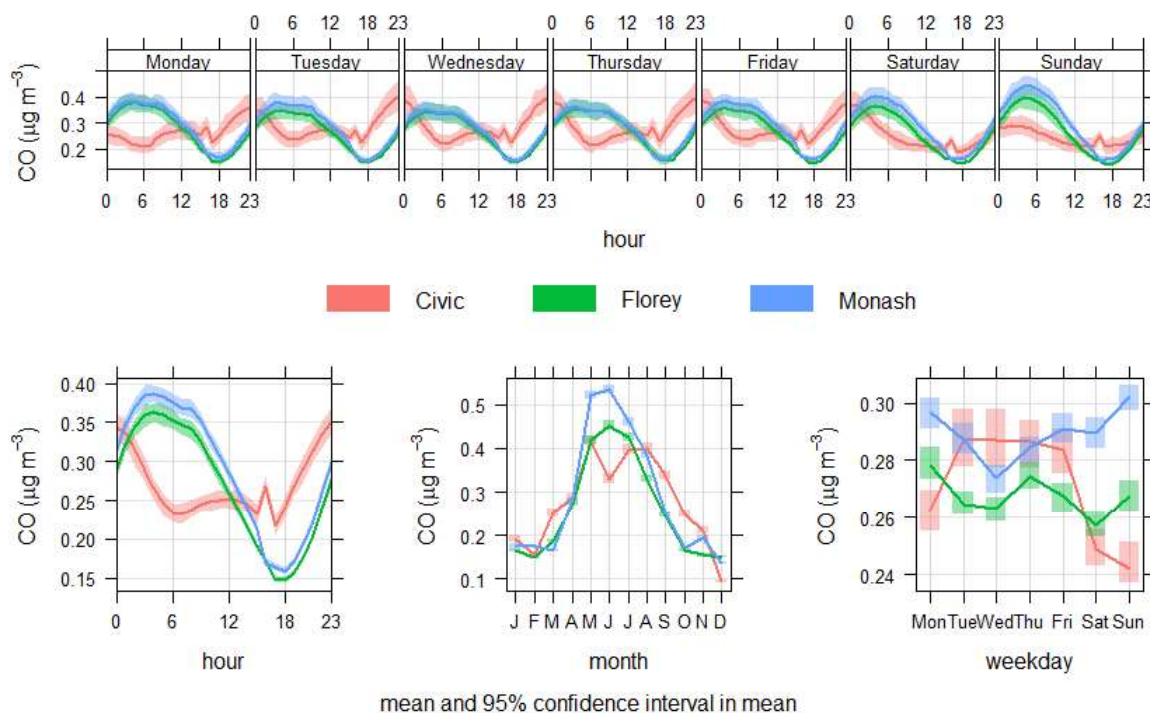


Figure 44 Mean carbon monoxide variation by hour of day, month and day of the week

Polar plots for the Monash, Civic and Florey pollution stations for PM_{10} are as shown in

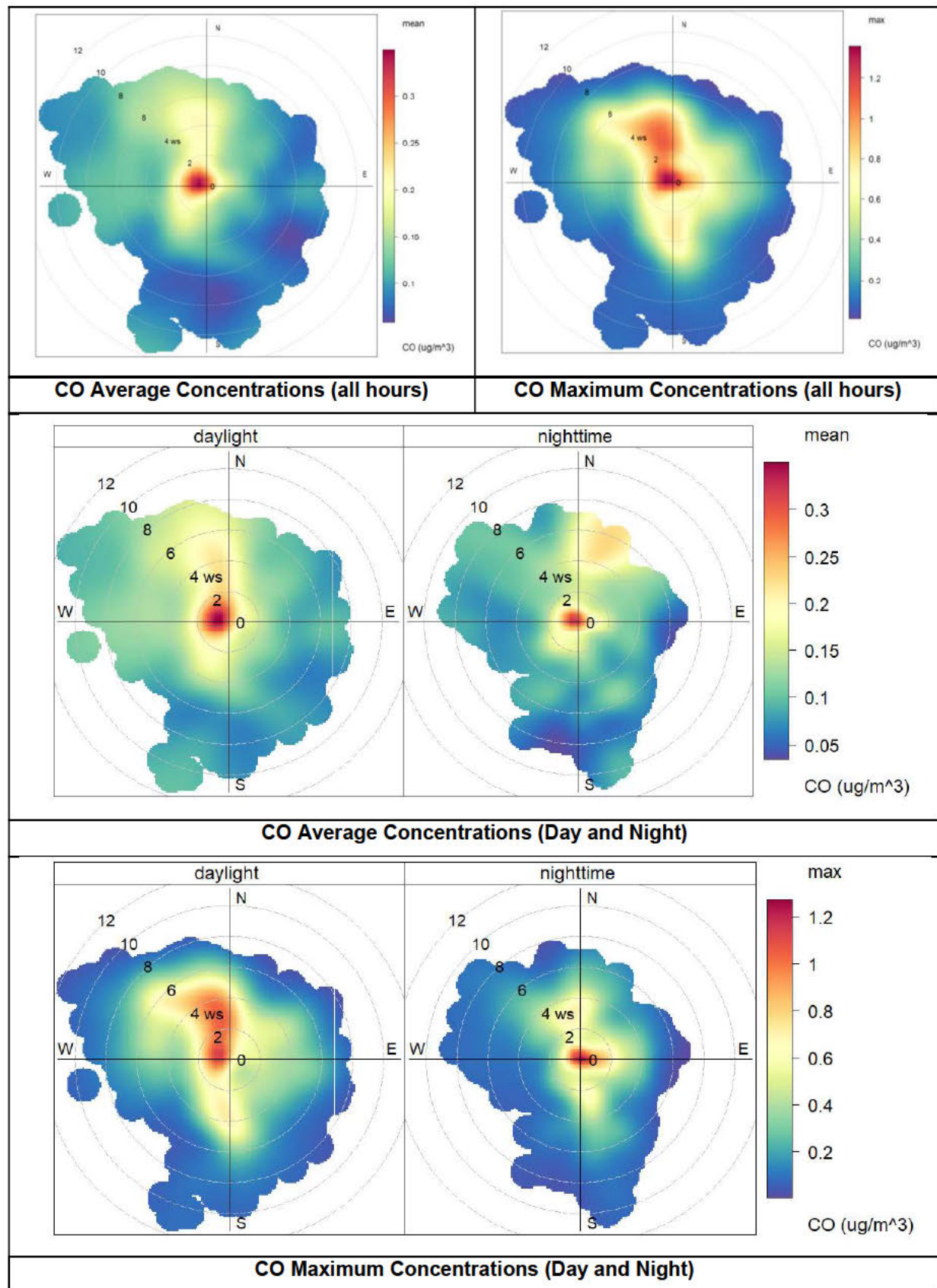


Figure 45 Monash CO Polar Plots – All Data and Night and Day Data

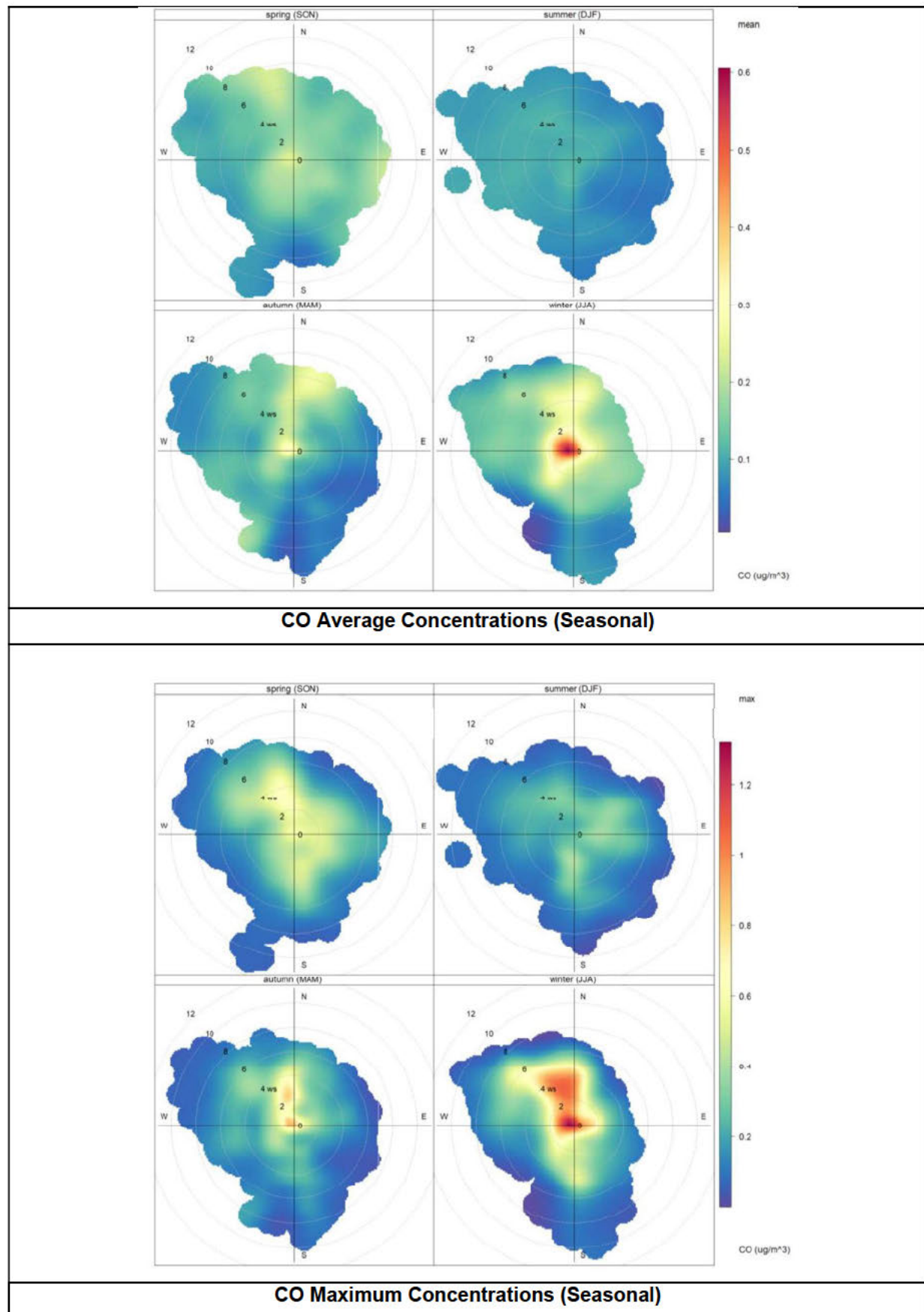


Figure 46 Monash CO Polar Plots – Seasonal Data

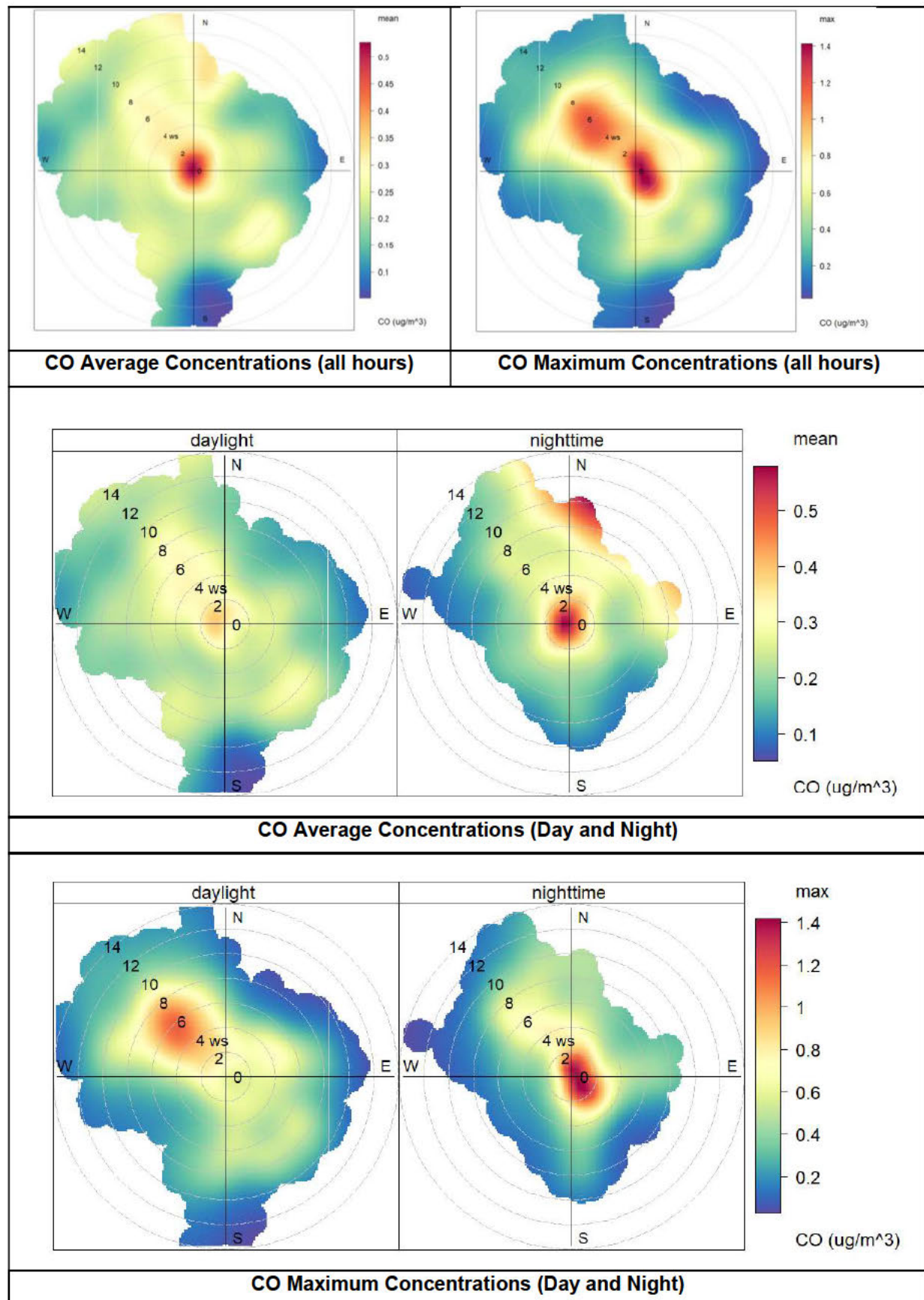


Figure 47 Civic CO Polar Plots – All Data and Night and Day Data

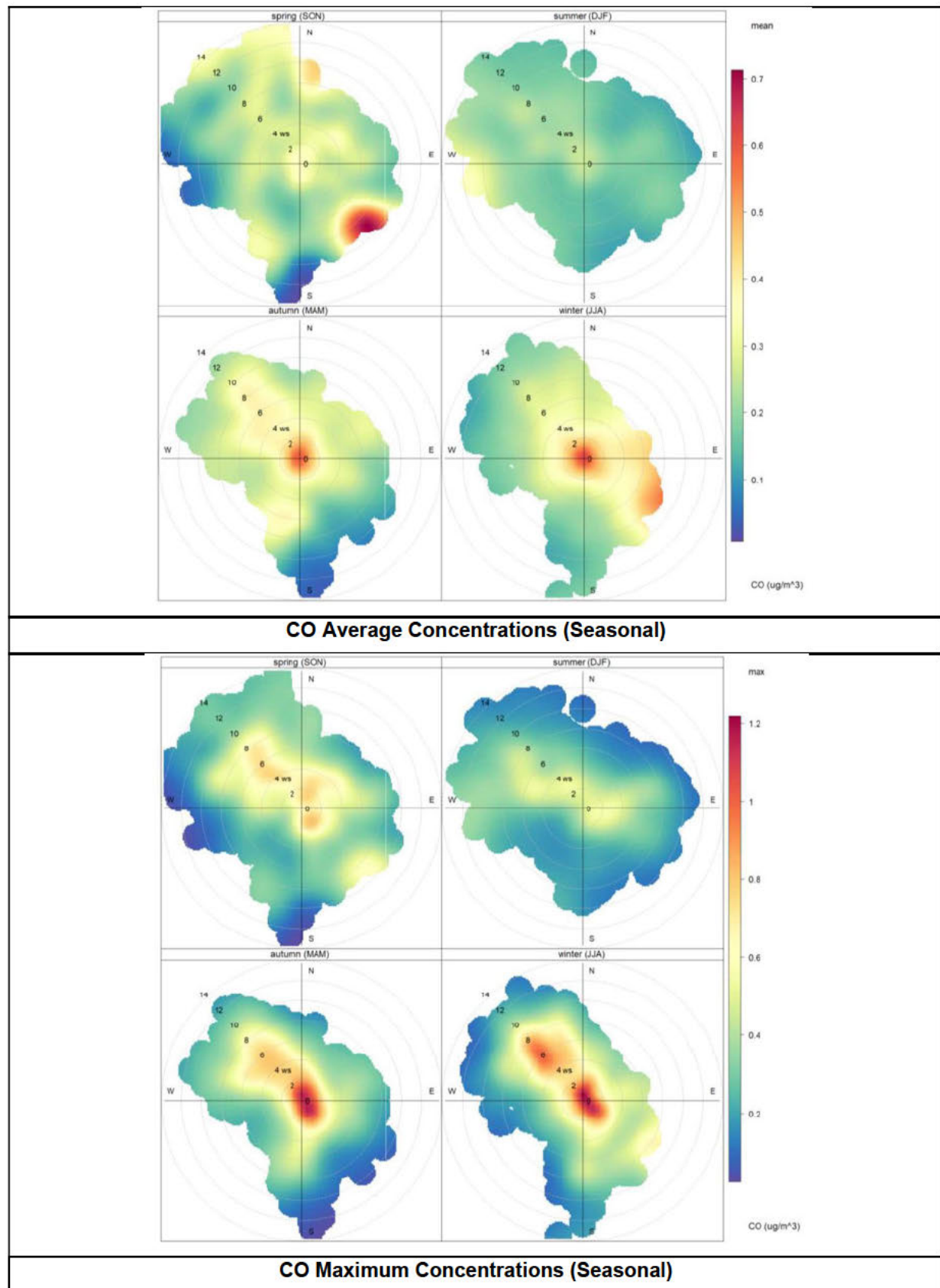


Figure 48 Civic CO Polar Plots – Seasonal Data

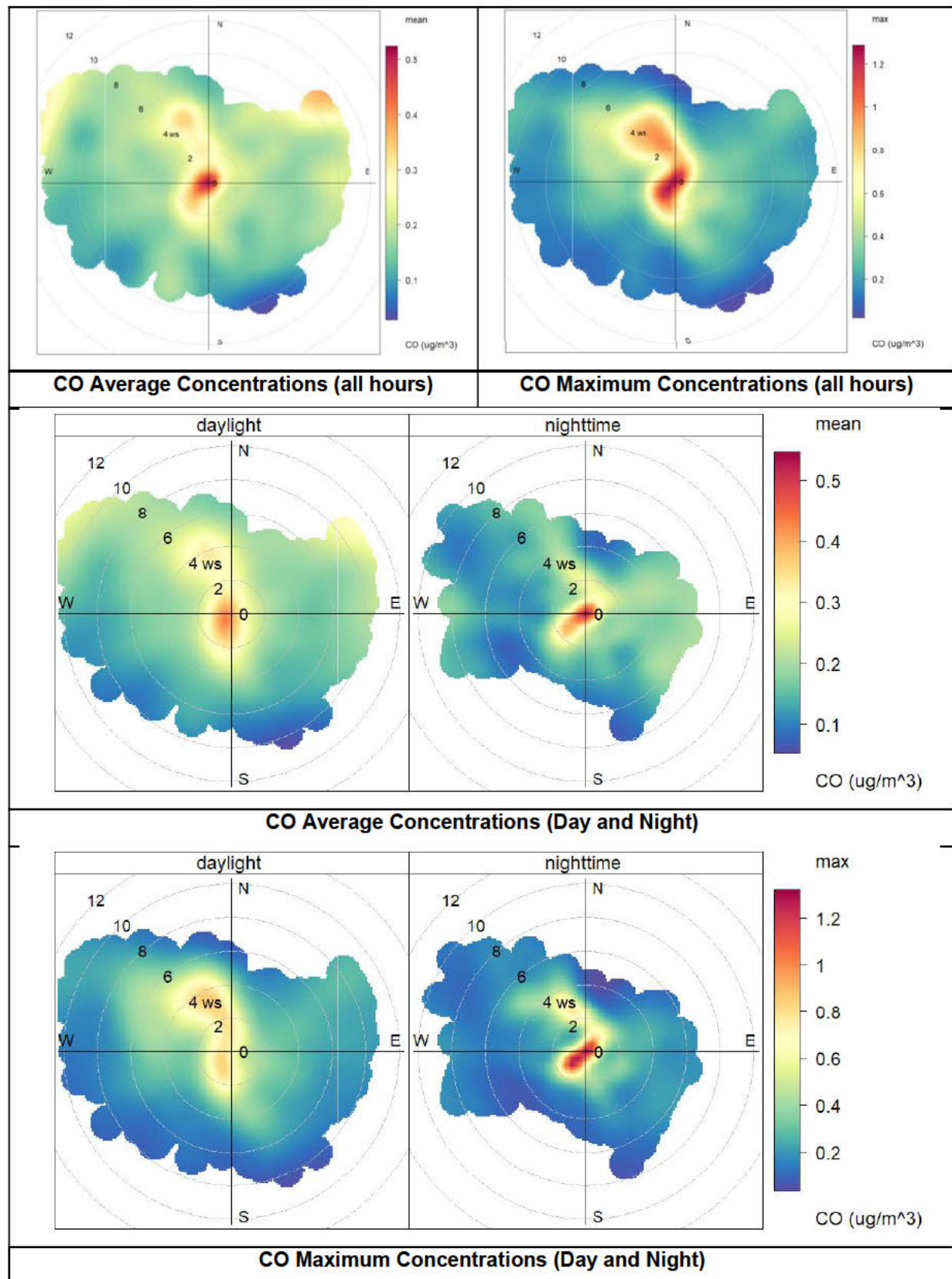


Figure 49 Florey CO Polar Plots – All Data and Night and Day Data

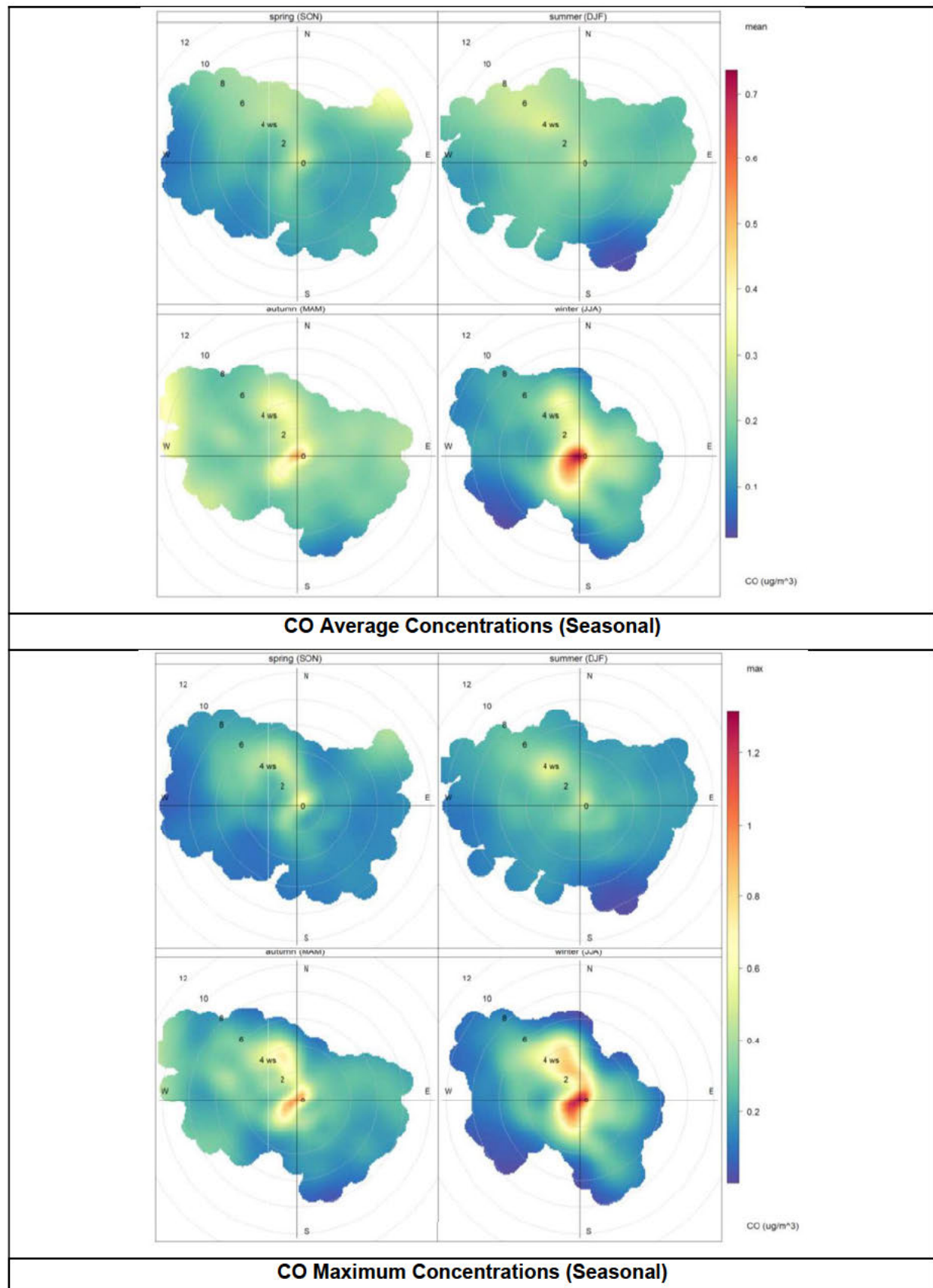


Figure 50 Florey CO Polar Plots – Seasonal Data

5.3.6 Existing Air Pollution Summary

Pollution trends observed through the analysis of the time-series monitoring data from ACT EPA can be summarised as follows:

- A clear diurnal pattern of PM_{2.5} particulate concentrations was observed for the Monash and Florey monitoring stations. PM_{2.5} concentrations peaked at night and fell during the daytime. This pattern was observed for the Civic monitoring station but was not as pronounced.
- There was a clear trend observed for PM_{2.5} particulate concentrations increasing significantly during the colder months. As with the diurnal trends, this was a strong observation for Monash and Florey and much less obvious for the Civic monitoring station.
- Diurnal variation PM₁₀ trends were similar to PM_{2.5} trends but not as pronounced. The Civic PM₁₀ diurnal monitoring results were different in trend to the results from the other stations, showing a generally flat diurnal curve with lower concentrations around 6am and higher concentrations around 10am and 8pm.
- The monthly average PM₁₀ trend is not as pronounced as the PM_{2.5} trend. Monash and Florey have the highest concentrations in the colder months, however Civic has the highest concentrations in the warmer months, which would not be attributable to wood smoke.
- There is also no clear trend for higher PM₁₀ particulate concentrations during the colder months, matching the PM_{2.5} observations. This suggests a source of PM_{2.5} that is different to the sources of PM₁₀. This is in line with domestic wood fired heaters which would be expected to produce a higher proportion of PM_{2.5} during combustion. This would also be exacerbated by more efficient heaters which more efficiently burn the larger particulate which could result in a higher proportion of PM_{2.5} particulates than PM₁₀ particles.
- Nitrogen dioxide concentrations show a very consistent diurnal pattern for Monday to Friday followed by a decreased concentrations for Saturdays and Sundays. This trend was observed for all three stations but was most pronounced at the Civic monitoring location. This trend suggests that the primary source of the pollution is motor vehicles in and around the suburbs of Monash and Florey and particularly at the Civic monitoring location where there would be expected to be a larger number of vehicles using the carpark adjacent to the monitoring station.
- There is a clear diurnal cycle of NO₂ concentration changes during the early morning and late afternoon and an overall increase during the colder months of the year, with concentrations increasing significantly in April and peaking in May (but staying high until around September). This pattern could be due to slower photochemical reactions, including the degradation of NO₂ in the atmosphere in cooler conditions due to lower atmospheric temperatures and less intense sunlight, which can decrease the reaction time for the NO₂ degradation. Additionally, Civic monitored higher concentrations than Monash and Florey suggesting vehicle traffic is the source of most NO₂.

An analysis of the pollution polar plots has been provided below in emission source discussion.

5.3.7 PM_{2.5} estimation with wood heater emission elimination

The sections above have identified that PM_{2.5} concentrations in Monash are elevated at nighttime and early morning during the colder months, which would be due to wood heater emissions overnight. Therefore, it would be expected that if nighttime emissions of wood smoke were eliminated, there would be a reduction in PM_{2.5} concentrations. To estimate the magnitude of the reduction, the monitoring data for Monash had data removed where wood heater emissions are at their highest (identified from monitoring data monthly averages in **Figure 21**), which was May to August for the hours 6pm to 6am, which removed the majority of the peak concentrations due to wood heater emissions. Annual average PM_{2.5} was recalculated on the modified dataset, with a summary of the estimated difference in air quality presented below in **Table 12**, which generally shows an improvement in annual average PM_{2.5} of 1-2 µg/m³ could be expected if nighttime emissions of wood heater smoke were eliminated. If wood heater emissions were eliminated it could reasonably be expected that the ACT would meet the NEPM 2025 goals and go close to meeting the WHO 2021 guidelines.

Note although this is a crude and over simplified estimation which does not consider other factors influencing nighttime dispersion or other background sources of air pollution, it does highlight the potential significance of cold night wood heater emissions.

Table 12 Monash annual average PM_{2.5} – effects of removing wood heater emissions

Year	Actual	Cold night data removed	Difference
2016	7.2	6.1	-1.1
2017	7.7	5.2	-2.5
2018	6.9	5.4	-1.5
2021	6.9	5.3	-1.6
2022	5.1	4.1	-1.0
2023	6.8	5.7	-1.1
Criteria	NEPM 2022	8	
	NEPM 2025	7	
	WHO 2021	5	

Note: 2019 and 2020 data not included due to bushfire effects

5.4 Air Emission Sources

5.4.1 Existing Pollution Sources

The 2023 ACT State of the Environment report (ACT CSE 2023) states that the pollutant of highest concern in the ACT is PM_{2.5}, with the main sources being:

4. Wood heaters, which have the greatest impacts on the ACT's air quality in non-bushfire years. It is estimated that up to 75% of all PM_{2.5} pollution is from wood heaters in the cooler months.
5. Bush fires and planned burns, with impacts being variable depending on the nature of the bush fire season. For example, around 40% of the ACT was burnt in the 2020 bushfires and 70% was burnt in the 2003 fires. The resultant quantities of air pollutants (primarily PM_{2.5}) would be vastly different between these two fire events and other years where bushfires were not as substantial or widespread.
6. Road transport vehicle emissions, which consistently contributes to pollution year-round.

The mortality burden attributable to wood heater smoke particulate matter (PM_{2.5}) in Australia (Nicolas Borchers-Arriagada *et.al.* 2024) paper provides a national wood heater emissions inventory to estimate the contribution of wood heaters to the annual PM_{2.5} contribution throughout Australia. Estimated emissions were derived from state and territory information on wood use in the Australian Energy Update 2020 for the year 2015 and a wood heating emission factor applied based on the distribution of appliance type based on the Air Emission Inventory for the Greater Metropolitan Region in New South Wales 2012.

For the ACT specifically the study estimated that for 2015 the total estimated PM_{2.5} emissions attributed to wood heaters annually was 321,013 kg/year. Dispersion modelling based on the emissions inventory was conducted using the CSIRO Chemical Transport Model (CTM) to estimate the annual average PM₁₀ concentration attributed to woodfired heaters which was estimated at 0.82µg/m³ within the ACT.

It is difficult to quantify the emission of particulates from wood heaters and bush fires without detailed recent source data. Registered facilities, however, who exceed a threshold for air pollutants are required to report their emissions annually as a part of the National Pollutant Inventory (NPI) reporting. A summary of the industries and their contribution to air pollution from the 2023-24 reporting year is provided below which shows the highest contributors of emissions are generally sewerage, construction, waste services and education which shows the ACT lacks significant large sources of industrial pollution.

Table 13 PM_{2.5} NPI sources

Industry	Emissions (kg/pa)
Sewerage and Drainage Services	38,710
Other Construction Material Mining	15,731
Waste Treatment and Disposal Services	12,550
Higher Education	12,447
Other Electricity Generation	7,241
Hospitals (Except Psychiatric Hospitals)	7,147
Laundry and Dry-Cleaning Services	3,058
Scientific Research Services	2,177
Central Government Administration	2,074
Other Petroleum and Coal Product Manufacturing	1,930
Bread Manufacturing (Factory based)	808
Grand Total	103,874

Table 14 PM₁₀ NPI sources

Industry	Emissions (kg/pa)
Higher Education	1,391,900
Other Construction Material Mining	1,062,567
Sewerage and Drainage Services	156,558
Waste Treatment and Disposal Services	56,114
Other Petroleum and Coal Product Manufacturing	45,700
Log Sawmilling	18,522
Laundry and Dry-Cleaning Services	14,538
Other Electricity Generation	14,518
Hospitals (Except Psychiatric Hospitals)	9,352
Scientific Research Services	2,927
Central Government Administration	2,697
Bread Manufacturing (Factory based)	1,664
Air and Space Transport	13
Grand Total	2,777,071

Table 15 Nitrogen Oxides NPI sources

Industry	Emissions (kg/yr)
Other Electricity Generation	1,731,759
Higher Education	1,213,559
Sewerage and Drainage Services	1,121,861
Waste Treatment and Disposal Services	356,247
Other Construction Material Mining	140,209
Log Sawmilling	110,115
Hospitals (Except Psychiatric Hospitals)	98,376
Laundry and Dry-Cleaning Services	73,401
Central Government Administration	58,909
Other Petroleum and Coal Product Manufacturing	53,269
Scientific Research Services	36,874
Bread Manufacturing (Factory based)	26,893
Air and Space Transport	130
Grand Total	5,021,601

5.4.2 Potential Future Sources of Pollutants

As discussed above, there are not many major air pollution sources in the ACT other than domestic wood fires and vehicle emissions. The lack of major industrial emissions means that any change to domestic wood smoke levels or vehicle emissions (for example through electrification, see following section), would have a disproportionate effect on the air pollution levels in the ACT.

The largest potential source of additional pollution in the ACT is through the development of new residential areas. If these areas are allowed to use domestic wood fires for heating, there is the potential for significant increases in air pollution levels.

The ACT State of the Environment Report 2023 (ACT CSE 2023) provides a simplified diagram showing the areas of potential expansion and areas of future urban intensification. The two areas of planned major urban expansion are as follows:

1. The Western Edge Investigation area (WEIA) situated along the western edge of the ACT urban area running from Belconnen in the north to Tuggeranong in the south.
2. Eastern broadacre area (EBA) situated along the eastern edge of the ACT to the east of the existing airport extending south to Tuggeranong.

Reports examining the potential effects of wood smoke on the WEIA have suggested that smoke for the Tuggeranong area would be expected to impact on the WEIA and if that area were allowed to use wood heaters that the smoke generated by the WEIA would also cause problems to the north along the Murrumbidgee River valley in Molonglo and Belconnen.

The EBA has not been examined as closely as the WEIA from an air quality perspective. However, modelling undertaken in **Section 8.0** of this report suggests that existing domestic woodsmoke in the Tuggeranong area and to a lesser extent the Woden Valley would likely impact the EBA area and if the EBA were permitted to use wood heaters, then the woodsmoke problem in this area would likely be exacerbated.

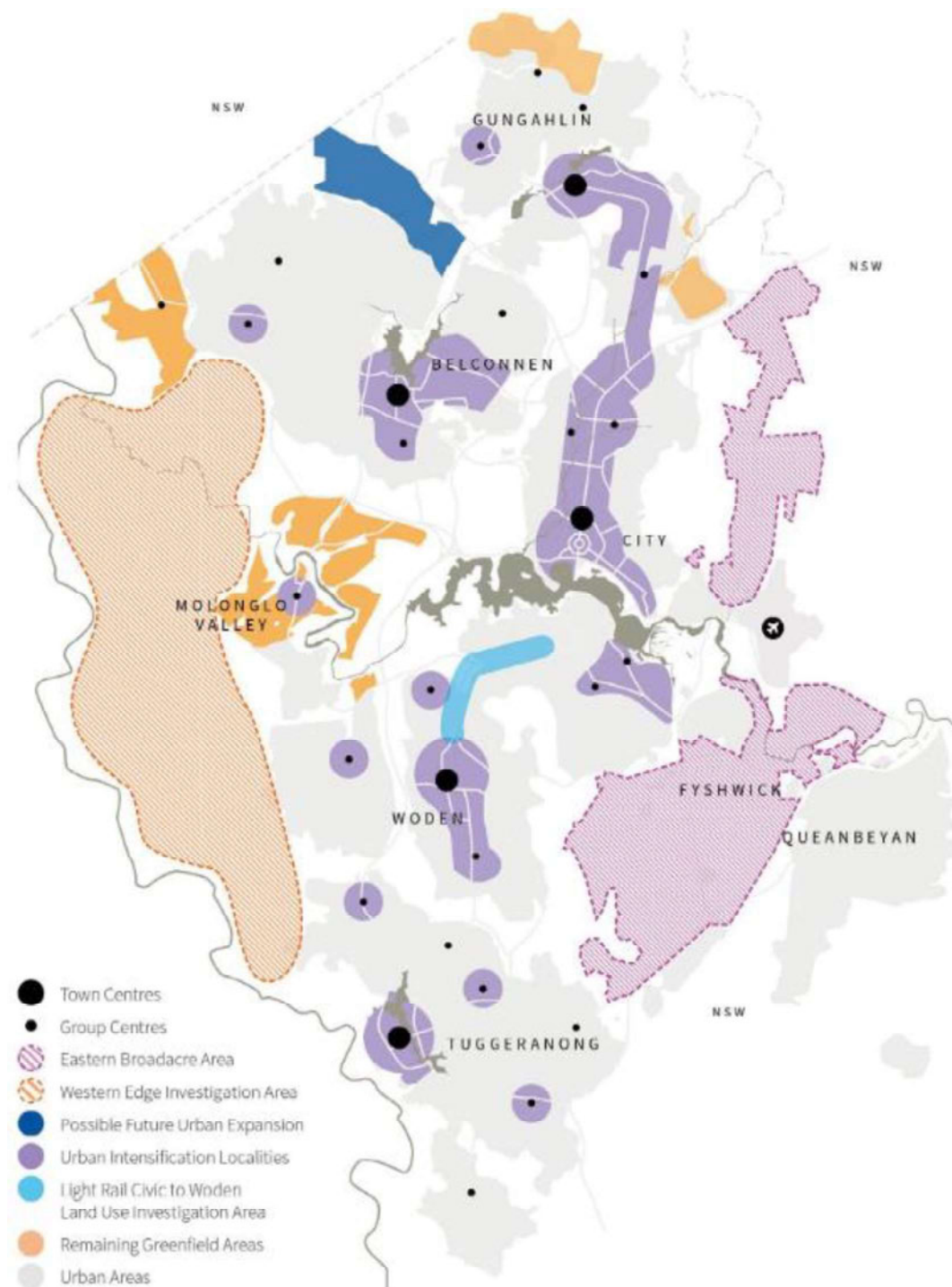


Figure 51 Future development strategic plan. Source: ACT CSE 2023

Urban intensification has several meanings, but from the context of air pollution, if the urban intensification involves the increase in urban densities, then there is the potential for an increased density of wood fire usage. The areas of urban intensification proposed for the ACT occur primarily in Tuggeranong, Woden, Inner North District to Gungahlin and in Belconnen. The Tuggeranong, Woden, Inner North Districts are all areas with existing air pollution concerns both from the perspective of existing air pollution concentrations and microclimatic conditions. Additional wood smoke generated from urban intensification in these areas would make the air pollution levels worse both in the districts themselves, but also in other districts when wood smoke migration occurs (as expected).

5.4.3 Vehicle emissions

As discussed above vehicle emissions are a significant proportion of PM_{2.5} emissions in the ACT. The *ACT Zero Emissions Vehicles Strategy 2022 – 30* (the Strategy) (ACT Government 2022) outlines the ACT's plan to transition from internal combustion engines (ICE) to zero (tailpipe) emission vehicles (ZEVs), noting emissions would still be generated from non-tailpipe sources such as brakes, tyres and road wear. The Strategy states transport contributes to 60% of the ACT's total emissions, with private vehicles accounting for 70% of transport emissions. To reduce emissions the Strategy has targets for 80-90% of new light vehicle sales being ZEVs by 2030 and phasing out ICE vehicles from 2035. The Strategy also commits to implementing pathways and exploring opportunities to replace government commercial and heavy vehicles with ZEVs as the technology becomes available.

If the above targets are achieved, there would be a reduction in transport PM_{2.5} emissions in the ACT year on year until the last ICE vehicles are phased out. This would be a significant reduction of PM_{2.5} being emitted in to the ACT airshed, which would be expected to have a measurable benefit to air quality.

6.0 Microclimate and Pollution Modelling Methodology

6.1 Microclimate and Dispersion Modelling Methodology

The term microclimate refers to a local atmospheric zone where the weather conditions differ from that of the surrounding regional weather conditions. The term is typically applied to a relatively small areas, within a few metres of the Earth's surface and can extend laterally for tens of metres to kilometres.

Microclimates are affected by several factors including:

- Latitude
- Soil type
- The presence of (or proximity to) water bodies such as oceans, lakes and rivers
- The slope or aspect of the area
- Vegetation coverage and
- Land use aspects, such as the presence of buildings and asphalt.

The Graz Mesoscale Model (GRAMM) was employed primarily to simulate the microclimate wind flow characteristics of the ACT urban areas. The GRAMM model was developed in Austria to enable the accurate prediction of wind flows and dispersion characteristics in complex terrain and associated low wind conditions of a region. The GRAMM model has had extensive testing in complex mountainous terrain and is therefore considered suitable for use for the ACT urban microclimatic analysis given the presence of complex mountainous terrain within the modelling domain and its likely influence on local meteorological conditions.

The CALMET model was also employed to analyse additional microclimate influencers of mixing height and vertical temperature profile, which were unable to be extracted from the GRAMM model. The CALMET model was not used for any wind field analysis.

The GRAMM and CALMET models both require a range of data inputs that need to be defined prior to running the model. The data required for a run can be broadly categorised as follows:

- Terrain data.
- Land use data.
- Meteorological data observations.

The inputs have been described in the following sections.

6.1.1 Terrain Data

GRAMM

Terrain data for the assessment was interpolated from 1 second (~30m) Digital Elevations Models (DEMs) to enable the development of the GRAMM modelling domain. Due to the large size of the domain and processing limitations, GRAMM utilised a 250m horizontal grid spacing. Given the size of the ACT urban area and relevant surrounding area and the size of the geographical features that characterise the area, 250m horizontal spacing is a suitable resolution for rendering the topography for the GRAMM domain. The terrain included in the domain is shown below in **Figure 52**. The light green shaded area depicts the urban area of the ACT.

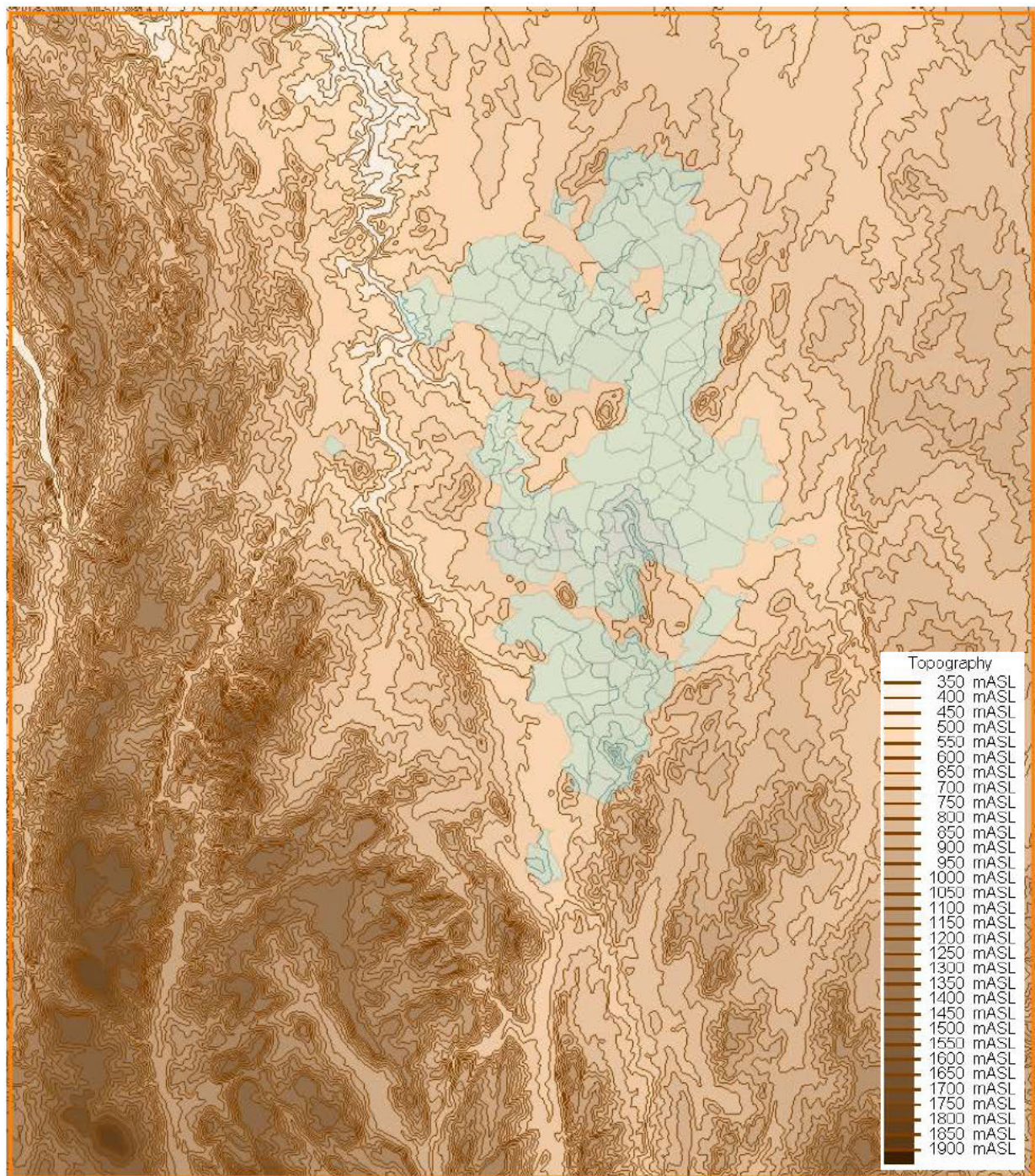


Figure 52 GRAMM Topographical Data

CALMET

Terrain data for the CALMET meteorological grid has been interpolated from the NASA Shuttle Radar Topography Mission Version 3 data set (SRTM1 30 metre resolution). CALMET was run with a 150m horizontal grid spacing, which is suitable for the complex terrain in and around the WEIA and is also consistent with the GRAMM grid spacing.

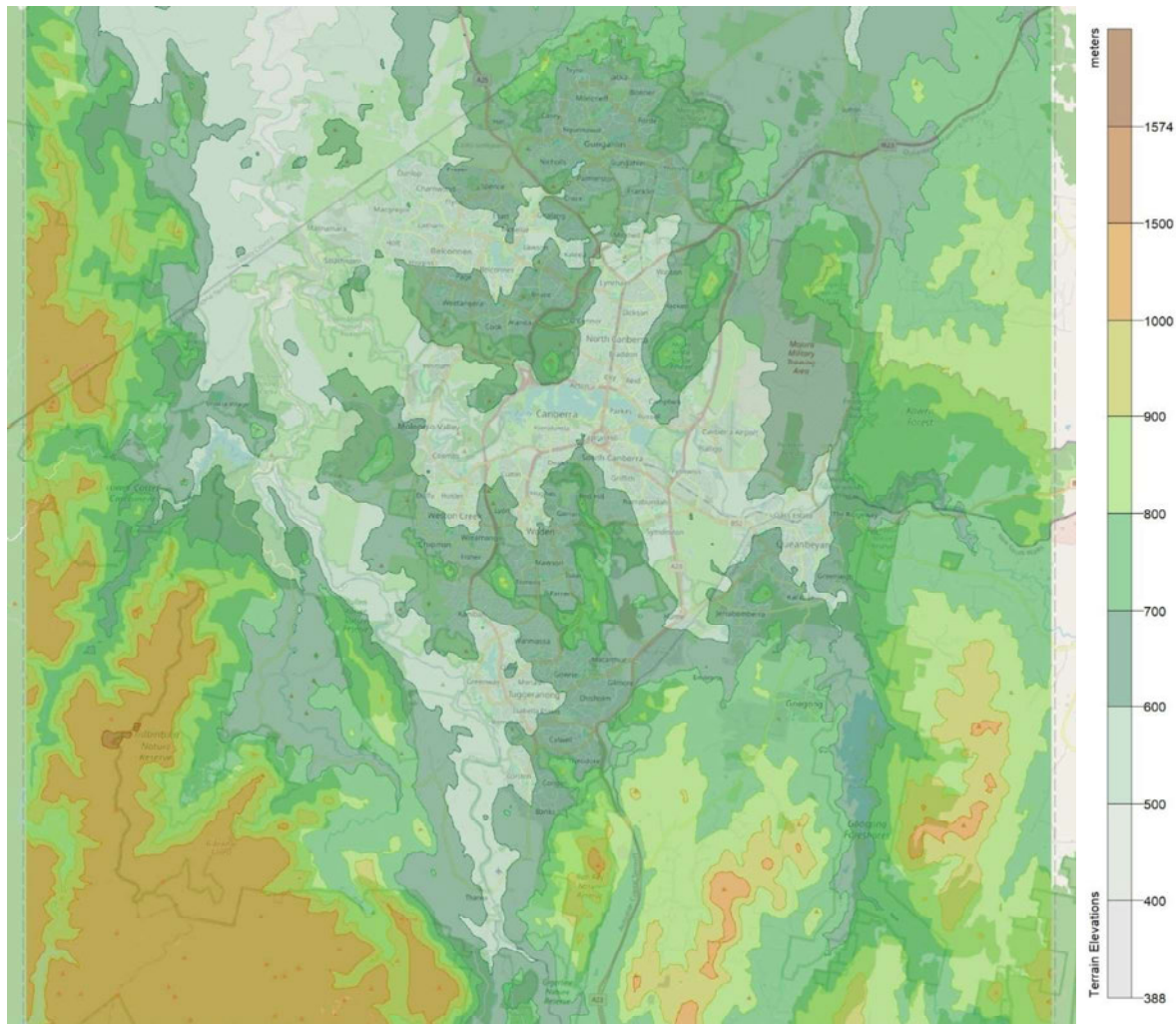


Figure 53 CALMET Topographical Data

6.1.2 Land Use Data

GRAMM

Meteorological modelling requires land use data to be included as an input to the assessment. Land use defines a range of parameters needed by the meteorological models to aid in the prediction of surface air flows within the domain.

The GRAMM model uses the CORINE land use scheme which defines land use according to 44 different categories (as defined in the GRAMM user manual). The spatial distribution of land uses present in the GRAMM ACT domain are presented in Figure 19.

As discussed above, Land use data was extracted from the Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES) “Catchment Scale Land Use of Australia”, December 2018 version. Data was cross checked against recent satellite imagery which showed a good match with the ABARES data.

CALMET

Land use data for the CALMET model has been obtained for the modelling domain from the USGS land use dataset. This dataset differs from the CORINE database but serves a similar purpose. The USGS database has a resolution of 1km which while considered acceptable for the determination of vertical temperature profiles and the broad presence of inversions, it was not considered accurate enough for the analysis of changes to the micro-scale wind flow patterns.

6.1.3 Meteorological Data

Similar meteorological data were used for the GRAMM and CALMET modelling runs. Details of the data used for the GRAMM match to observation algorithm and the CALMET surface observations are provided below.

GRAMM Observational Data

The GRAMM model was configured and run using a two staged approach. In stage one, the GRAMM model was run using synthetic meteorological data, which was developed to provide the model with all possible combinations of wind speed, wind direction and stability class. In the second stage a “match-to-observation” process was performed where actual observation data from automatic weather stations within the GRAMM domain were imported into the model. This imported data then allowed the models algorithm to perform a matching process to best simulate observed weather conditions across the whole study domain. Four observation stations used in this assessment which were sourced from BOM, and Icon Water. The stations used for the modelling were from the following locations:

- LMWQCC (Icon Water)
- Googong (Icon Water)
- Tuggeranong (BOM)
- Canberra Airport (BOM).

These stations provide good spatial coverage of the GRAMM modelling domain and provided a strong dataset of weather conditions to enable the match-to-observation function to best predict weather conditions.

CALMET Observational Data

Some of the CALMET surface observation stations common to those used for GRAMM, along with some other stations not included in the GRAMM model. Monitoring stations used for the CALMET run were as follows:

- Canberra Airport (BOM)
- Tuggeranong (BOM)

In addition to the surface observation data CALMET also requires upper air observation files, which were sourced from The CSIRO's The Air Pollution Model (TAPM) and were extracted at four sites across the urban area of the ACT.

6.1.4 Model Settings

GRAMM and GRAL model parameters used for this assessment are presented in **Table 16** and **Table 17**, respectively. The settings were selected based on guidance provided in Ottl et. al. (2020) and the GRAL and GRAMM manuals for the November 2022 release.

Table 16 GRAMM model settings

Parameter	Value
Version	22.09
Meteorological grid domain	59.25 km x 67.5 km
Horizontal grid resolution	250 m
Reference grid coordinate (SW corner)	656250, 6050000 UTM55S
Vertical thickness of first layer	10 m
Number of vertical layers	15
Vertical stretching factor	1.4
Relative layer height	(Layer 15) 3,874 m
Surface meteorology coordinates	700091, 6090462 (Canberra Airport)

Parameter	Value
	690173, 6078515 (Tuggeranong)
	679692, 6097449 (LMWQCC)
	705388, 6076824 (Googong)
Simulation length	12 Months
Number of wind speed categories	23
Wind speed categories	0, 0.2, 0.4, 0.6, 0.8, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5, 5.0, 5.5, 6.0, 6.5, 7.0, 8.0, 9.0, 10.0, 12.0, 14.0m/s (lower bands)
Number of meteorological conditions	3,564
Maximum time step	10 seconds
Modelling time	3600 seconds

Table 17 GRAL model settings

Parameter	Value
Version	22.09
Flow field grid domain	32.49 km x 44.74 km
Horizontal grid resolution	10 m
Reference grid coordinate (SW corner)	672830; 6065800 UTM55S
Vertical thickness of first layer	2 m
Number of horizontal slices	1 (2 m)
Dispersion time	3600 seconds
Particles per second	300
Surface roughness	0.2
Latitude	-35.3
Modelled height of receptors	2 m
Terrain	Complex terrain – same terrain data as used for GRAMM

6.1.5 Modelled sources

The dispersion model was not intended to specifically model sources to accurately represent the ACT, instead the model would simply demonstrate the expected plume dispersion pathways for different urban areas within the ACT. This was undertaken by assigning a unitary pollution emission rate for each major suburb grouping within ACT, which would allow the identification of pollution dispersion differences due to the effects of land use, topography and meteorology. Each suburb grouping modelled is presented below in **Figure 54**, with emissions from the labelled suburbs post-processed to determine pollutants dispersion. Note these suburbs were selected to represent a mid-point in each of the 2023 Territory Plan's districts.

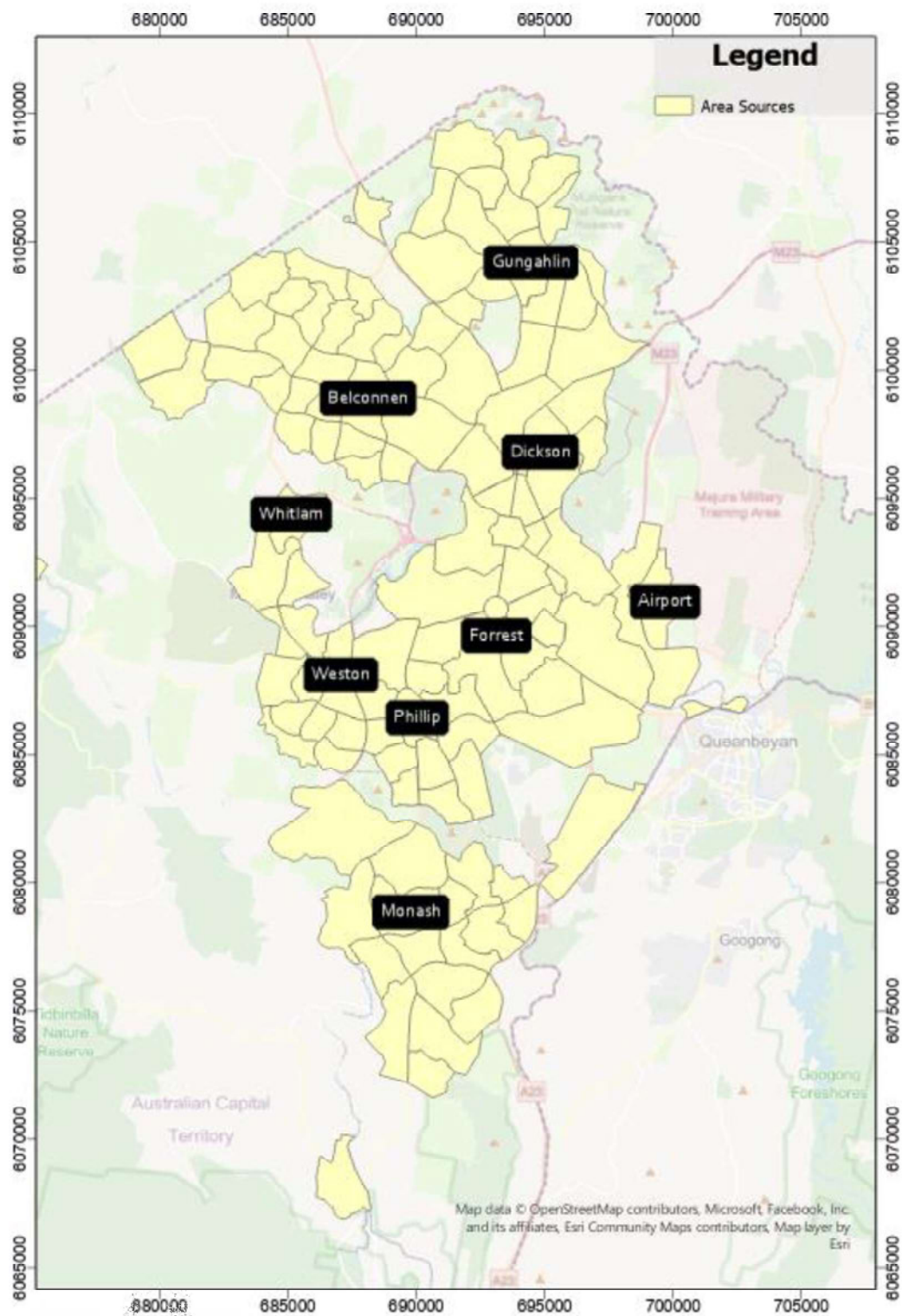


Figure 54 Suburb emission sources modelled

6.2 Climate Change Projections

Climate change projections are discussed in **Section 9.0**. A summary of climate change projections for the ACT region are provide in **Section 9.1** and are based on the NSW and Australian Regional Climate Modelling (NARClIM). Projections originally released in 2014 (NARClIM 1.0) provide climate change projections for two future periods.

- The near future, 2020-2030 or 2030
- The far future 2070 or 2060 to 2070

The most recent projections³ released in 2020 (NARClIM 1.5) include the same future projection scenarios discussed in **Section 9.1**. The following information was also reviewed as part of the assessment based on NARClIM 1.0 and NARClIM 1.5 projections.

- Australian Capital Territory, Climate change snapshot (ACT Government 2014)
- Climate change impacts in the NSW and ACT Alpine Region (NSW Government 2019)
- Projected change in characteristics of near surface temperature inversions for southeast Australia (Fei Ji *et al.*)

Climate change projections discussed in **Section 9.1** were then used to discuss the potential effects of regional climate change on air pollution.

³ NARClIM 2.0 projections are currently in development and are expected to deliver higher resolution climate projections than NARClIM 1.5.

7.0 Microclimate Analysis

7.1 Overview

As discussed in **Section 3.2.1**, the ACT is separated into nine districts. For ease of discussion, the description of the potential domestic wood smoke transportation has been described in terms of these nine districts. A map of the districts is provided below in **Figure 55**.



Figure 55 ACT Urban District Map

The analysis of the microclimatic data has been separated into the following area:

- Wind Speed and Direction
- Temperature
- Mixing Heights
- Atmospheric Stability

Details on these aspects of the microclimate have been examined in the context of their potential effect on the emission of domestic wood smoke within the ACT urban area.

7.2 Wind Speed and Direction

Wind speed and direction have been examined through the examination of wind flow fields. A wind flow field is a representation of wind speed and direction at gridded locations across a modelling domain. The arrows direction indicates the wind direction, while the arrows colour indicates its wind speed. This approach can be used to understand air flow trends across large areas and be used to understand the effects of topography and land use on wind patterns.

Given the large amount of data considered for a typical air quality impact assessment, all wind conditions have not been discussed in this report. Instead, a representative set of wind conditions have been selected to gain a better understanding of the micrometeorological conditions around the ACT urban areas. The wind conditions have been selected on the basis of frequency of occurrence and stability class. For brevity, only the highest wind condition occurrences for each of the 7 stability classes considered by this study have been plotted in this section with the conditions considered shown in **Table 18**.

Wind flow fields for the wind condition with the highest occurrence for each stability class outlined in **Table 18** are shown as **Figure 56** to **Figure 62**.

Table 18 Wind Conditions used for the analysis of meteorology across ACT urban areas.

Flow Field	Wind Speed (m/s)	Wind Direction (Degrees)	Stability Class	Occurrence (%)
1	0.8	170	6	2.43
2	3	150	5	2.07
5	9	330	4	1.05
9	2.5	80	1	0.94
21	1.5	80	2	0.69
26	2	90	7	0.58
29	6	300	3	0.56

An analysis of each of the flow fields listed in **Table 18** is as follows:

7.2.1 Flow Field 1

This flow field represents the wind condition most common in the ACT across the modelled year along with the most common wind field with stability class 6 (moderately stable conditions occurring at night only). This wind condition has a low wind speed from the south with a moderately stable stability class. Wind flow patterns for this condition show winds flowing from the south which reduce in speed as the winds move from elevated terrain to the south of Tuggeranong to the rolling hills around the southern ACT urban area.

Wind patterns of note include:

- Winds from Tuggeranong area splitting to blow either to the north across central ACT urban area or to the northwest to follow the Murrumbidgee River valley (toward the western edge investigation area and Molonglo valley).

- Winds that move from the Tuggeranong area to the north tend to follow the urban areas to the northeast, toward Deakin and Capitol Hill. Winds then flow northward again between the Black Mountain and Mt Ainslie elevated terrain.

Overall, any woodsmoke emitted within the Tuggeranong, Weston Creek or Woden Valley would be expected to potentially transport either to the northwest toward the WEIA and Molonglo Valley or to the north to north east district toward the inner south and inner north districts.

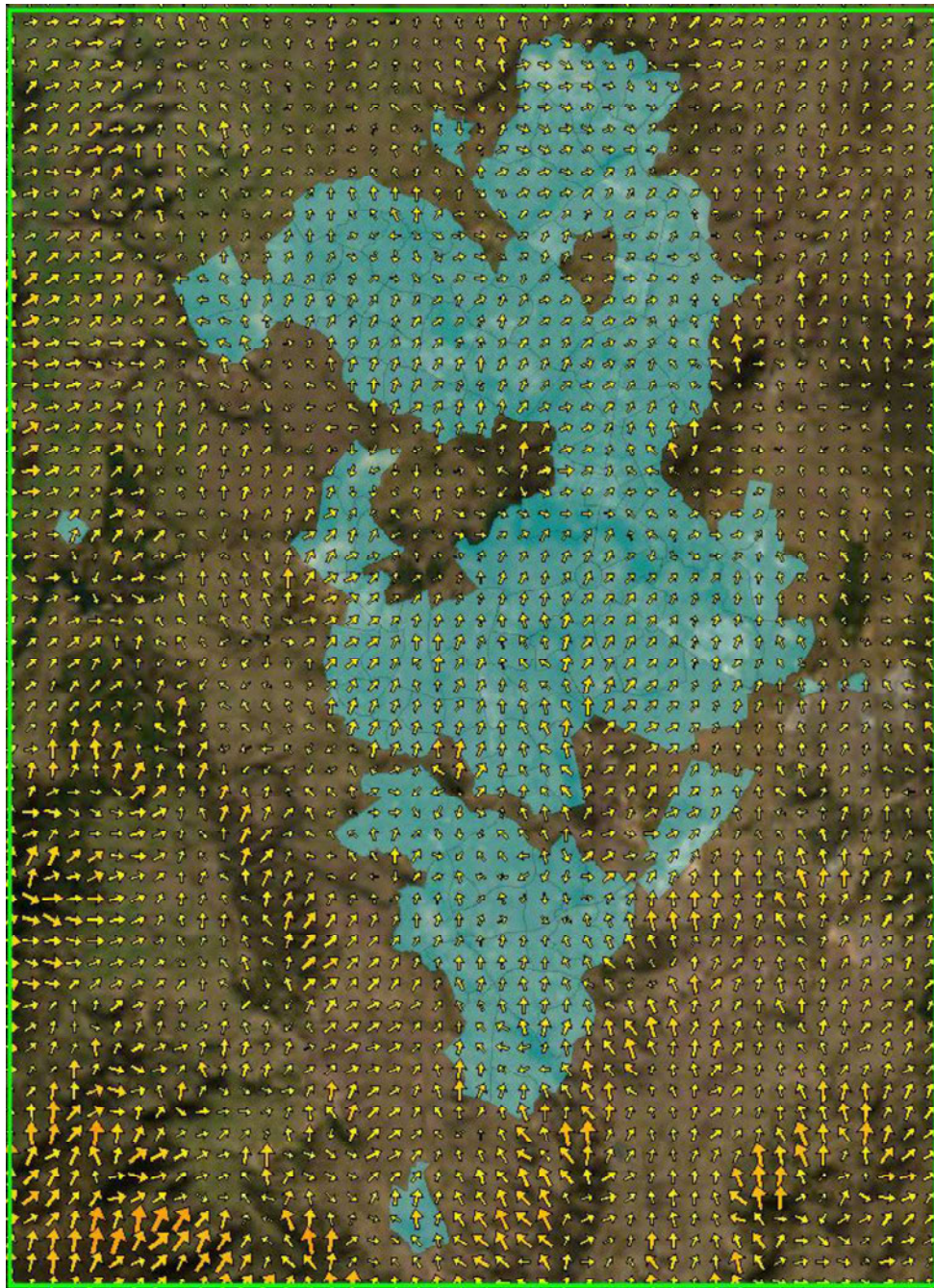


Figure 56 Wind Flow Field 1

7.2.2 Flow Field 2

This flow field represents the wind condition with the most common wind field with stability class 5 (slightly stable conditions occurring at night only). This wind condition has a moderate wind speed from the southeast with a slightly stable stability class. Wind flow patterns for this condition show fairly

consistent winds flowing from the south reducing in speed as the winds move from elevated terrain to the south of Tuggeranong to the rolling hills around the southern ACT urban area. Terrain and land use appear to decrease wind speed across the urban areas and suggest for this wind condition that any smoke emitted from the southern areas of the ACT urban area would be transported to the north.

Wind patterns of note include:

- Wind speeds around the northern area of the Tuggeranong district are low, which would likely result in poor dispersion of air pollution as it is transported to the northern districts. This lower wind speed is replicated across the ACT urban area to the north with lower wind speeds within the urban areas of all northern districts.

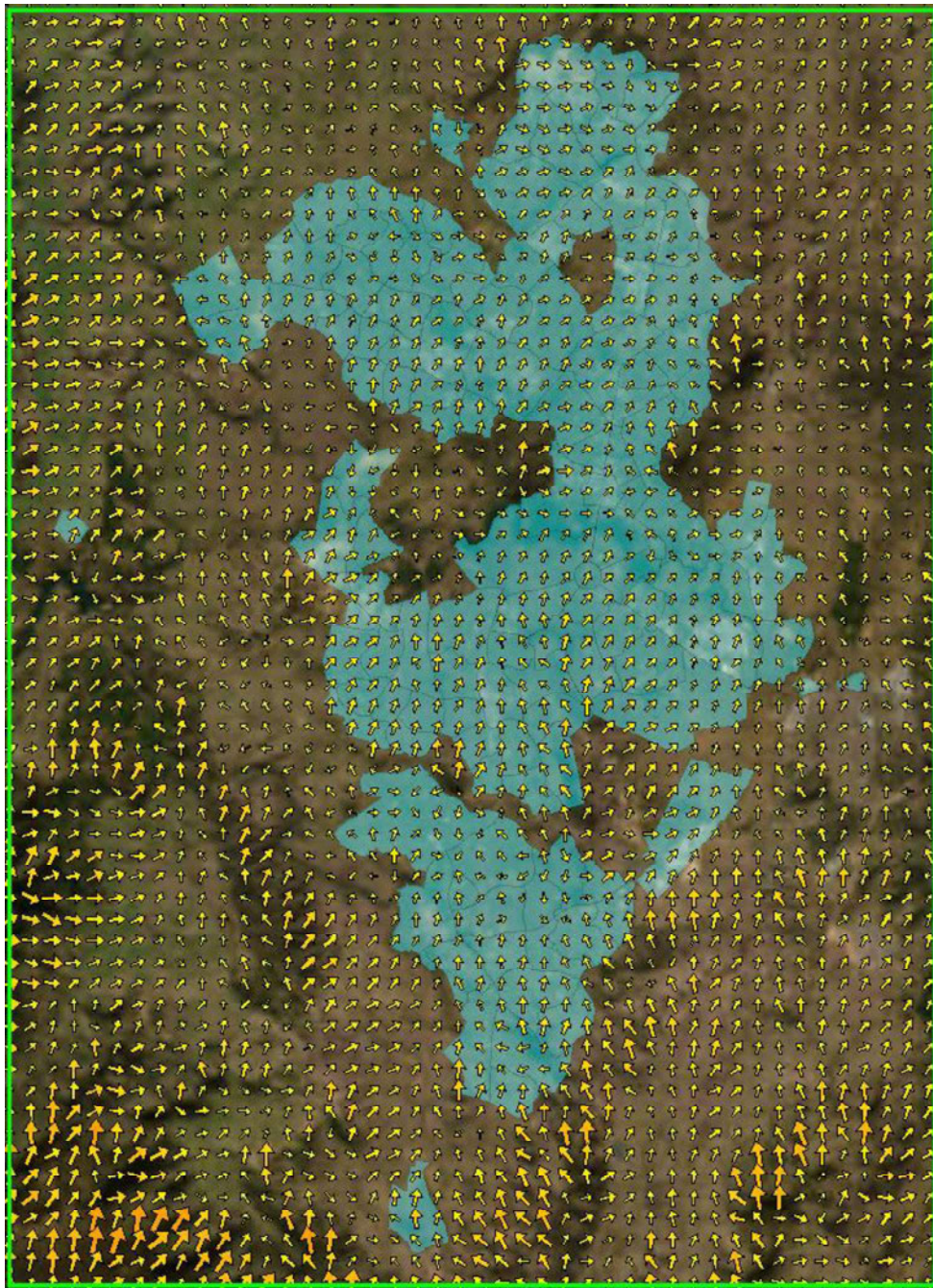


Figure 57 Wind Flow Field 2

7.2.3 Flow Field 5

This flow field represents the wind condition with the most common wind field with stability class 4 (neutral conditions that could occur any time during the day). This wind condition has a high wind speed from the northwest with a neutral stability class. This wind flow field shows that there is no significant interaction between the topography and land use for this wind condition. Given the strength and direction of the winds, even if this occurred during the night-time, effects due to transportation of any wood smoke would likely be minimal due to good dispersion conditions.

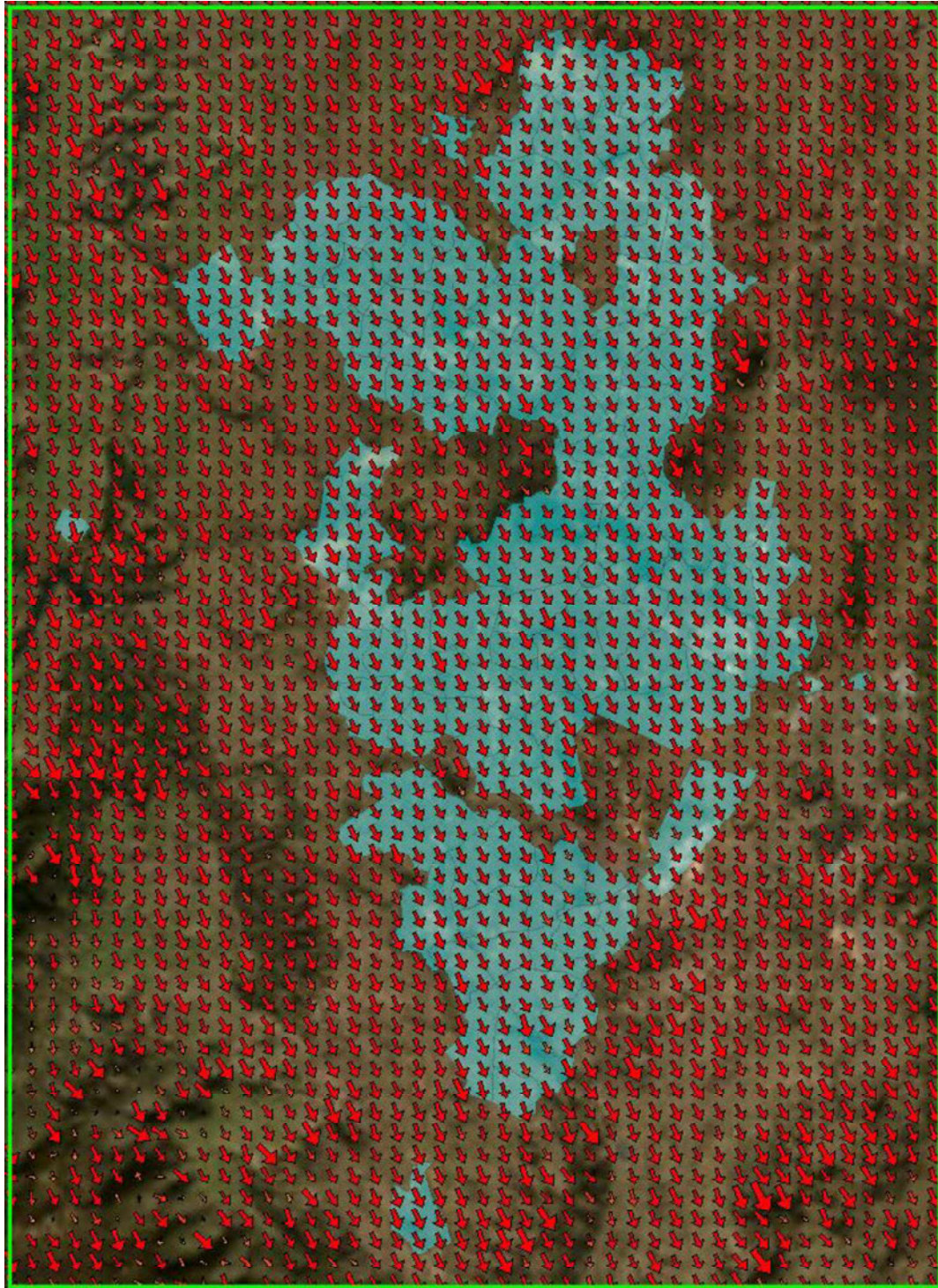


Figure 58 Wind Flow Field 5

7.2.4 Flow Field 9

This flow field represents the wind condition with the most common wind field with stability class 1 (very unstable conditions occurring during daytime only). This wind condition has a moderate wind speed from the east with a neutral stability class. This wind flow shows that there is an interaction between the wind direction and wind speed as air moves across the urban areas of the ACT.

Wind patterns of note include:

- There is an observable wind flow from the from the Tuggeranong area to the northwest along the Murrumbidgee River valley toward Weston Creek District and the WEIA and



Figure 59 Wind Flow Field 9

7.2.5 Flow Field 21

This flow field represents the wind condition with the most common wind field with stability class 2 (unstable conditions occurring during daytime only). This wind condition has a moderate to low wind speed from the east with an unstable stability class.

Wind patterns of note include:

- Wind conditions for this flow field are quite variable, reflecting the instability of the meteorological conditions. Despite this variability, there are still observable patterns, including winds following the Murrumbidgee River valley and air recirculation within the urban areas.
- Wind speeds were generally lower within the urban area than the areas surrounding. Any pollution released within the urban area would be expected to disperse less efficiently in these conditions within the urban area than outside of the urban areas with rural land use conditions.



Figure 60 Wind Flow Field 21

7.2.6 Flow Field 26

This flow field represents the wind condition with the most common wind field with stability class 7 (very stable conditions occurring at night only). This wind condition has a moderate wind speed from the east with a very stable stability class.

Wind patterns of note include:

- Although the base wind direction is from the east, the terrain and land use deflect the winds to a more from the southeast and south, which results in winds blowing across the Tuggeranong area toward the northwest.
- Winds around the Black Mountain and Mt Ainslie elevated terrain show winds channelled in a more northerly direction.
- Wind speeds across the urban areas appear generally lower than the winds outside of the urban areas.



Figure 61 Wind Flow Field 26

7.2.7 Flow Field 29

This flow field represents the wind condition with the most common wind field with stability class 3 (slightly unstable occurring during daytime only). This wind condition has a moderate to high wind speed from the west with a slightly stable stability class. This wind flow field shows that there is only a minor interaction between the topography and land use for this wind condition. Given the strength and direction of the winds, effects due to emission of any wood smoke would likely be minimal due to good dispersion conditions.

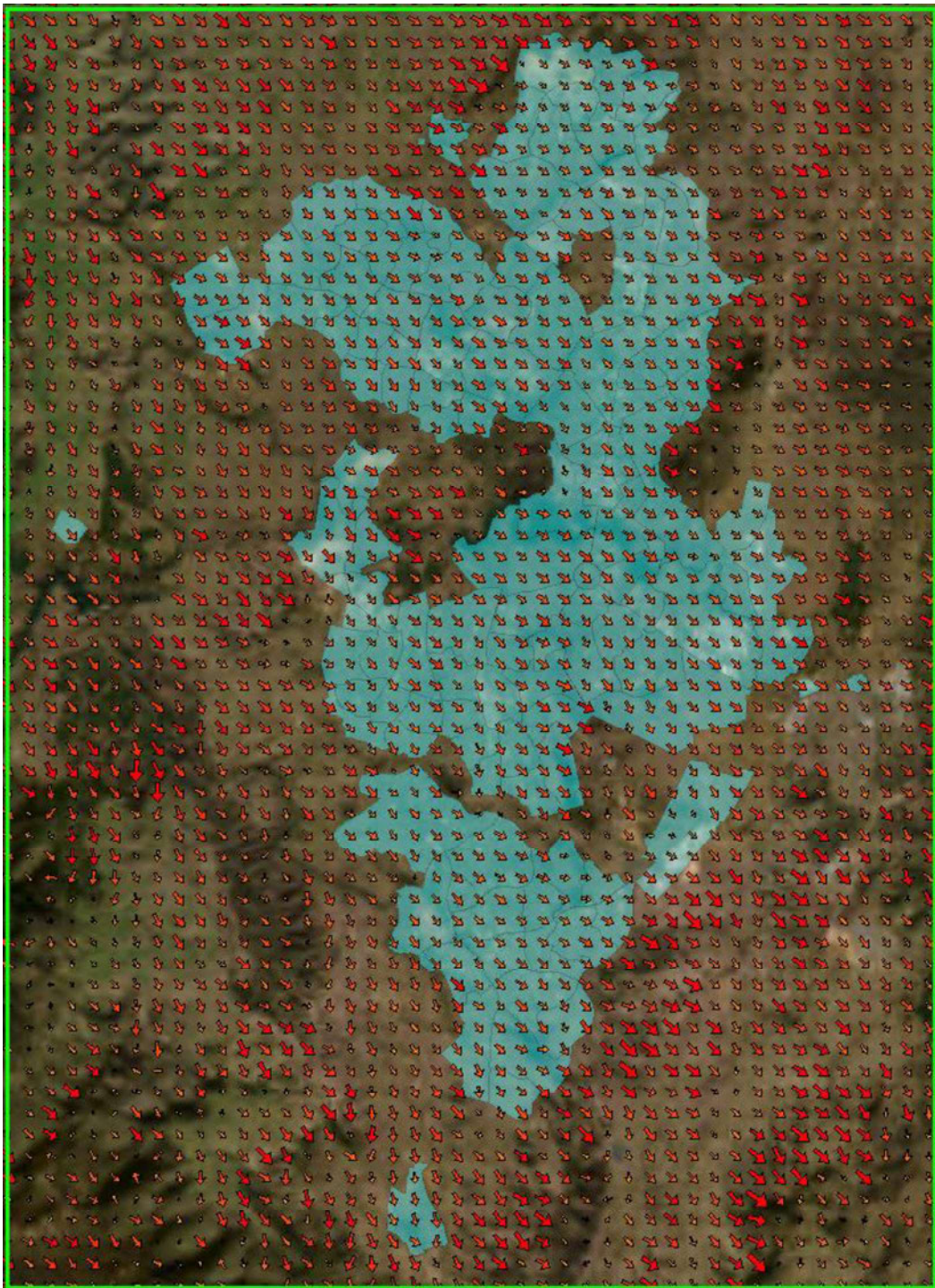


Figure 62 Wind Flow Field 29

7.2.8 Overall Observations

Observations from the analysis above is as follows:

- The urban areas of ACT have an effect on the wind speed and direction of the microclimate. Wind speeds are generally lower than areas outside of the urban land use areas. With the change in speed, the urban areas also appear to change the direction of the air flow across the urban areas.
- Under light wind speeds from the south (predominant wind condition during nighttime), air flow appears to either direct air from the Tuggeranong district either to the northwest toward the WEIA or Weston Creek areas or to the north to north-northeast toward Woden Valley, Inner South and Inner North and City districts.
- There are wind flows observed where winds under low winds speeds are directed along the Murrumbidgee River valley toward the north. These conditions may be affected by katabatic drift as cool air in winter falls down the valleys from the Tuggeranong and Woden Valley areas to the north or west toward the Inner south or WEIA areas. This katabatic air movement is observed during very low wind speed conditions and would be expected to result in the transport of woodsmoke laden air under poor dispersion conditions (katabatic drift does not have significant vertical mixing occurring with the movement of air).
- The northern suburbs around Belconnen and Gungahlin do not appear to affect the wind flow as much as the southern suburbs and have wind conditions broadly similar to the conditions in the larger district. There is some evidence of katabatic drift to the western edge of Belconnen closer to the Murrumbidgee River valley, but is less noticeable than for the southern districts around Tuggeranong.

7.3 Temperature

As shown in **Section 4.1** and **Figure 7**, temperatures across the ACT do not vary significantly. This analysis focuses on the surface temperatures only and does not take into account the changes in temperature with an increase in altitude. Meteorological modelling undertaken for the micrometeorological analysis included an analysis of vertical temperature profiles.

Vertical temperature profiles are crucial for understanding temperature inversions, which significantly impact weather, air quality, and atmospheric stability. These profiles provide detailed information on how temperature changes with altitude, allowing meteorologists to identify inversion layers where temperature increases with height instead of the usual decrease. Recognizing these inversions is essential because they can trap pollutants near the ground, leading to poor air quality and health issues. Additionally, inversions can affect weather patterns, influencing cloud formation, precipitation, and wind patterns. Understanding vertical temperature profiles helps in predicting and mitigating the effects of these inversions on the environment and public health.

As discussed in **Section 4.1.5**, conditions that may result in temperature inversions are common in the ACT (Class F and G stability classes). To further examine the potential for inversions and investigate their strength, data was extracted from the CALMET data at several locations. The analysis focused on:

1. Evidence of inversions during the 2018 meteorology year used for the analysis; and
2. Strength of the inversions across the year to understand the relative effect of the inversion and how they may affect pollution from domestic wood fires.

Vertical temperature profiles were obtained for Tuggeranong and Belconnen (two locations with high residential land use and known elevated PM_{2.5} concentrations). Temperature profiles have been prepared for the following periods (for both locations):

- Summer Class 6 / 4 / 2 Stability Vertical Profile (January 1)
- Winter Class 6 Stability Vertical Profile (July 1)

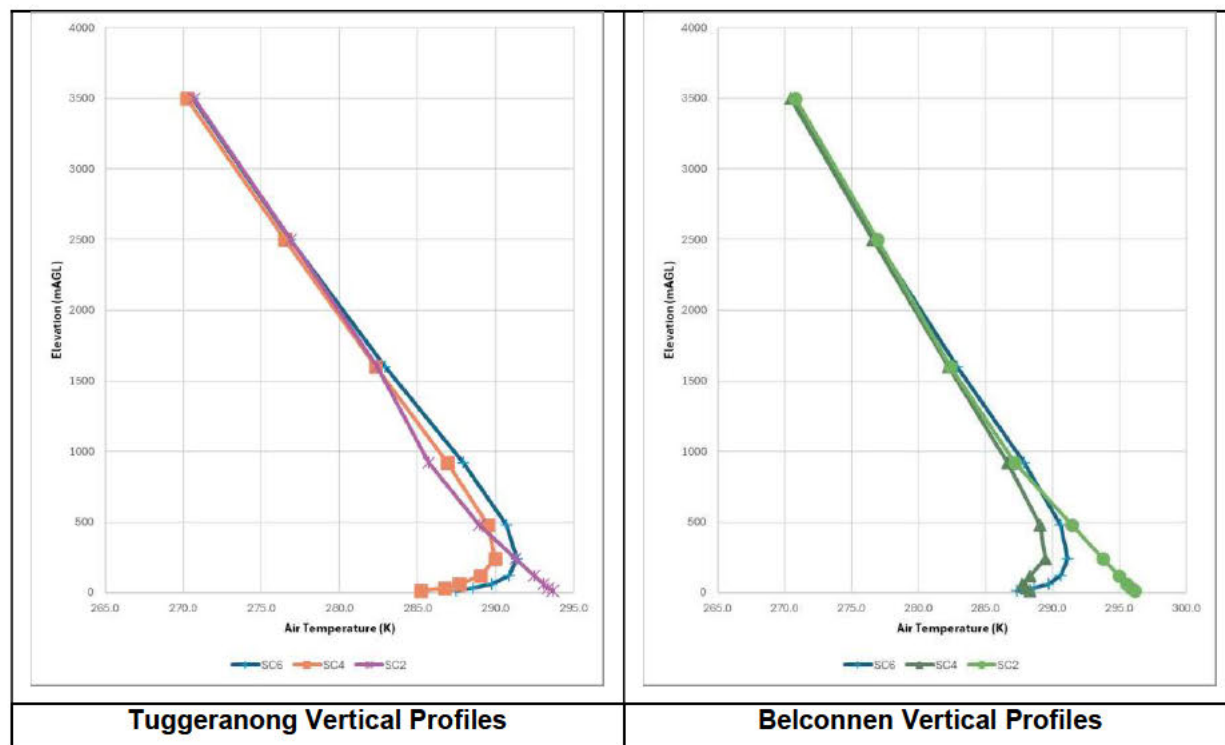


Figure 63 Vertical Profiles (1 January 2018)

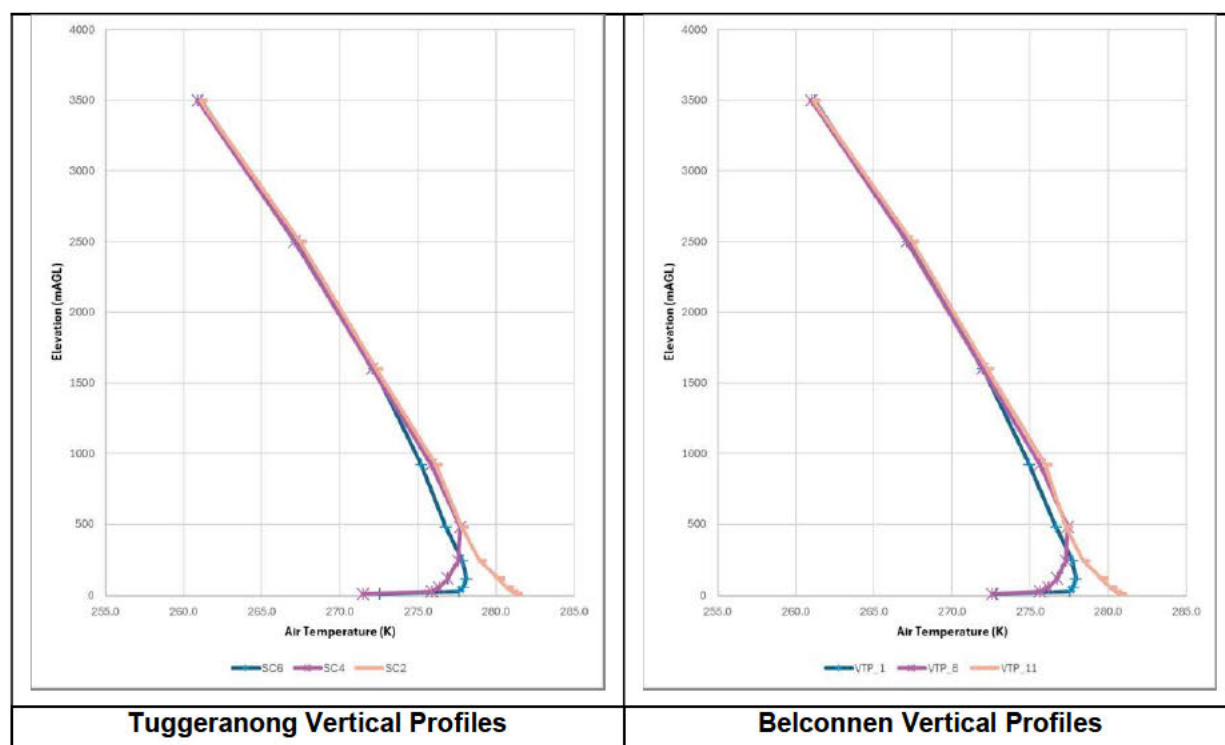


Figure 64 Vertical Profiles (1 July 2018)

Vertical profiles show that there are inversions present in both summer and winter. The inversion conditions in summer show weaker inversions with higher inversion elevations as compared with July inversion which are very strong and at low elevations. The implications of this are that in summer months, inversions are weaker and break up faster and trap less pollution underneath the inversion. In addition, pollution levels from sources like wood fired heaters are much lower, meaning the implications of an inversion forming are much less severe. Winter conditions show very strong inversion conditions

with low elevations for the inversions. With woodsmoke emissions common in winter, the inversion conditions would result in trapping of emissions under a low inversion increasing the pollution concentrations in the mixing layer. This matches the observations made in relation to existing pollution concentrations.

As suggested above by the temperature profiles, the strength of the inversions vary across the year. An analysis of the inversion strength was undertaken by examining the temperature difference between the surface condition and the maximum vertical profile temperature. If there is no inversion the difference is negative and shows normal vertical temperature decrease with elevation. If the temperature is positive, there is the potential for an inversion forming.

Data in **Figure 65** below shows the average inversion strength for January to December 2018. This clearly shows a peak in inversion strength around May to July, with lowest inversion strength occurring between October and December. The implications of this finding are that as inversion conditions formed in cooler months corresponding with wood smoke emissions in the ACT, the inversion conditions would be expected to significantly exacerbate the air pollution during these periods of time.

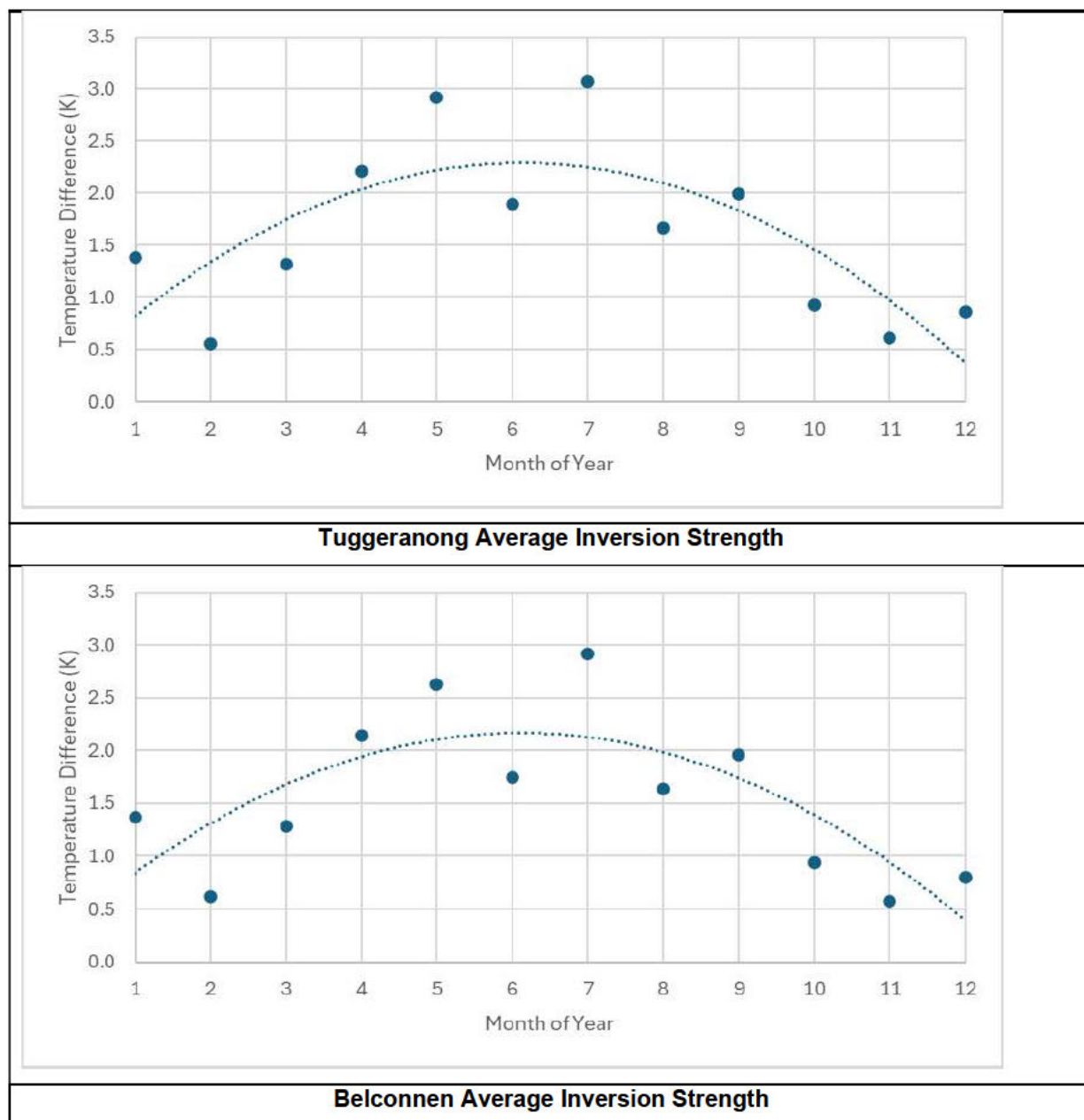


Figure 65 Vertical Profiles Strength 2018 – Tuggeranong and Belconnen

7.4 Mixing Height

Mixing height was not able to be extracted from the GRAMM model, therefore the CALMET model was used to determine mixing height in the WEIA under certain meteorological conditions.

Mixing height refers to the depth of the atmospheric surface layer beneath an elevated temperature inversion. The mixing height defines the height above the earth's surface where the mixing of air occurs. High mixing heights are associated with the greatest pollutant dispersion. Low mixing heights mean there is less air for pollutants to be dispersed within, leading to greater pollutant concentrations at ground level.

Mixing heights were analysed at several locations across the ACT urban area, with an annual comparison of the mixing height per hour of day and an analysis of mixing heights between summer and winter months.

Diurnal variation is seen in mixing heights (refer **Figure 66**), with the maximum heights seen in the afternoon and minimum mixing heights occurring during the early morning. Average mixing heights in the ACT urban area are typical for the region, with a maximum of around 1600 m and a minimum of around 150 m. Again, this is suggestive of higher pollutant concentrations at ground level if pollutants are present in the airshed.

Summer and winter mixing heights are quite different with peak summer mixing heights observed around 2200m and a peak winter mixing height of 1200m. This large difference in mixing heights would be expected to result in higher concentrations of pollution in winter and the increased occurrence of inversions trapping an emitted pollution.

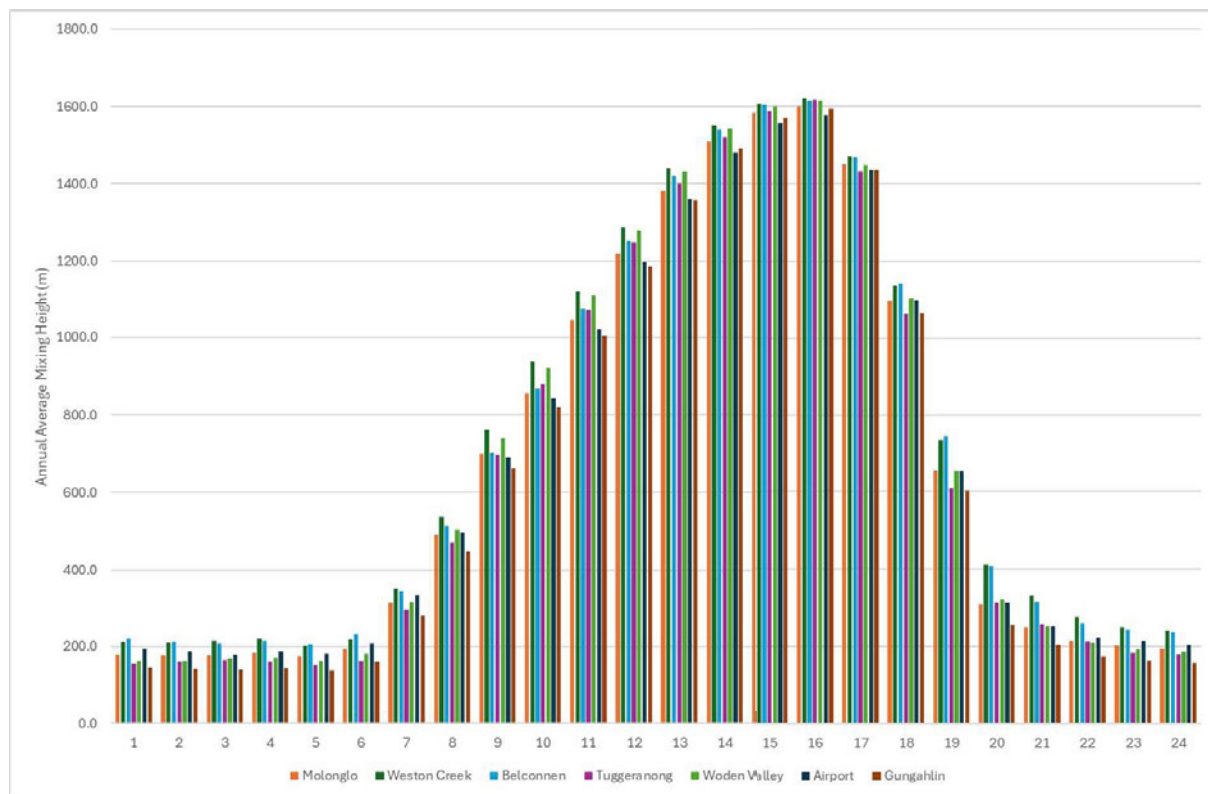


Figure 66 Annual Average Mixing Heights

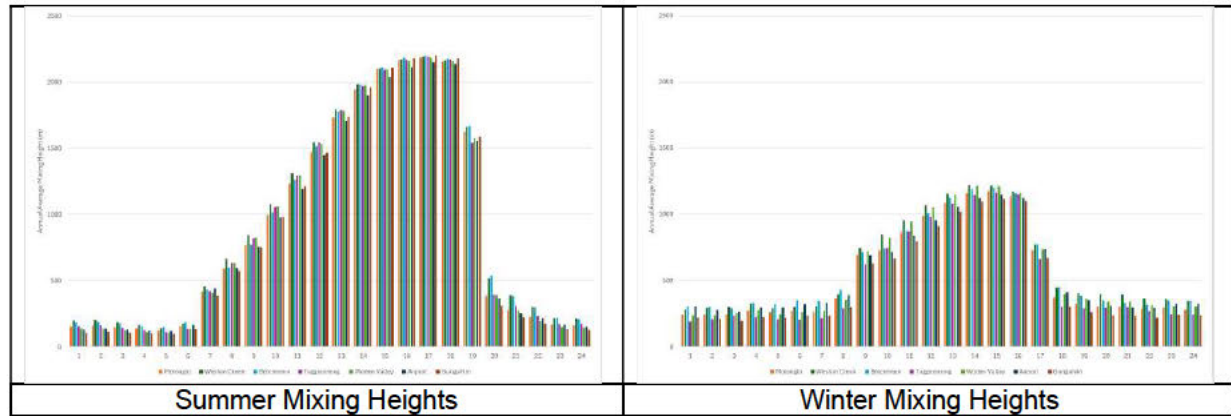


Figure 67 Summer and Winter Average Mixing Heights

8.0 Pollutant Transport and Air Dispersal Patterns

The GRAL dispersion model was used to examine whether any “hot spots” for pollutant accumulation occurred when using arbitrary emissions data from all suburbs equally. The purpose of this coarse scale modelling was to identify where pollutants may accumulate or persist in higher concentrations due to micro-climate effects and terrain influences.

The investigation was not pollutant specific however is relevant to all non-buoyant pollutants, which includes the pollutants of interest to this report.

The investigation was limited to:

1. Emissions from all suburbs to determine pollution dispersion trends due to micro-climate and terrain effects within the ACT urban areas.
2. Emissions from within hotspots, i.e.: Monash and Florey basins, to determine the direction of pollution dispersion.

Pollution analysis was undertaken through the analysis of several suburbs within different areas of the ACT urban environment. The areas examined included:

- Belconnen (Belconnen district)
- Airport (East Canberra district)
- Gungahlin (Gungahlin district)
- Dickson (Inner North and City district)
- Forrest (Inner South district)
- Whitlam (Molonglo Valley district)
- Monash (Tuggeranong District district)
- Weston (Weston Creek district)
- Phillip (Woden Valley district)

Each suburb was modelled assuming a constant emission rate across the suburb, mimicking emissions from domestic wood fires. Pollution concentration contours assuming wood smoke emissions from a single discrete suburb within each of Canberra’s nine districts between the months of April and August (months that the analysis in **Section 5.0** suggest are the periods when worst case pollution levels occur) is provided below.

Analysis of the concentration’s contours show the following:

The overall findings of the analysis of the dispersion conditions are as follows:

- Air pollution emitted from southern districts have the potential to migrate in several directions, but predominantly toward the north through the Woden Valley and Inner South / North corridor and northwest along the edges of the Murrumbidgee River valley toward Weston Creek and the Molonglo Valley.
- Air pollution emitted in the norther districts of Belconnen and Gungahlin tends to stay close to those districts and does not migrate south toward the Molonglo or inner north or south districts.
- In terms of reducing the effects of air pollution from domestic wood fires, the areas of primary focus should be the Tuggeranong, Woden Valley, Weston Creek and Molonglo Valley districts. The secondary areas of focus would be the inner south and inner north districts.

8.1 Modelled sources

As introduced in **Section 6.1.5** the dispersion model was set up to model emissions from all suburbs equally, which would not occur in reality, with the purpose of this coarse scale modelling to identify differences in pollutant transport characteristics and where pollutants may accumulate or persist in higher concentrations due to micro-climate effects and terrain influences.

The investigation was not pollutant specific however is relevant to all non-buoyant pollutants, which includes the pollutants of interest to this report.

8.2 Dispersion patterns

Dispersion patterns were analysed for the months of April to August, where ambient temperatures are lowest and the atmosphere has more frequent periods of stability and pollutant concentrations monitored were typically highest, outside of bushfire periods. The dispersion patterns were processed for the maximum concentrations, which represent the worst 1-hour period as opposed to an average of the April to August months. The maximum was used to best highlight microclimatic effects as these are generally of short-term due to daily diurnal or seasonal climatic patterns. The dispersion patterns for each district from the Territory Plan 2023 are presented in the following sections, overlaid on a topographical map to aid in the identification of the effects of terrain.

8.2.1 Belconnen District

Belconnen is a central suburb of the district Belconnen, which was used as a general source of emissions in the dispersion model to assess dispersion characteristics for the district. Emissions from Belconnen (as shown in **Figure 68**) showed that plume tended to stay within the Belconnen district. The plume extended toward the southwest (toward the Murrumbidgee River valley), and toward the south and east, but the majority stayed close to the source of the emissions.

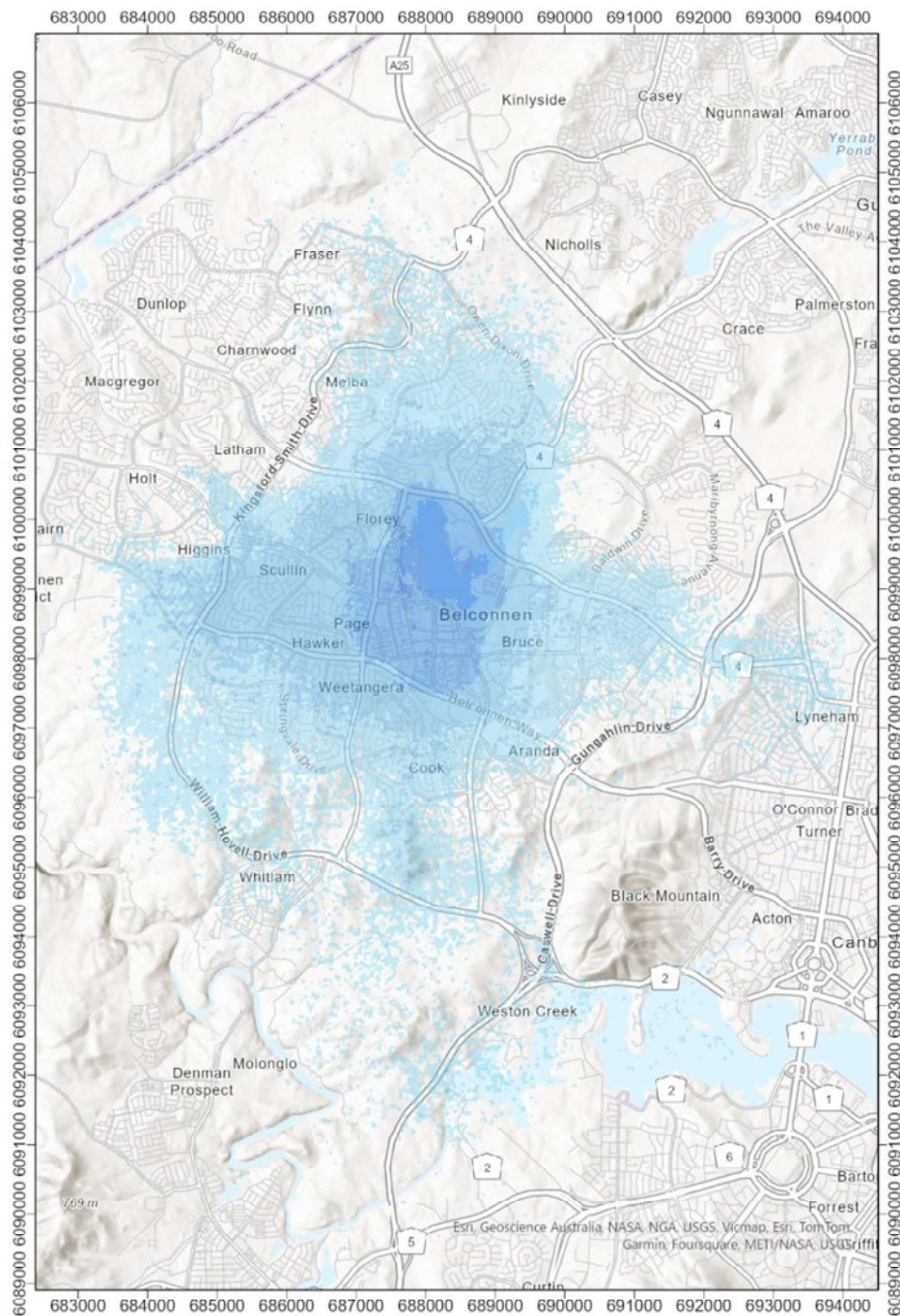


Figure 68 Belconnen dispersion patterns

8.2.2 East Canberra District (Airport)

The Canberra Airport within the district East Canberra was used as a general source of emissions in the dispersion model to assess dispersion characteristics for the district. Emissions from the airport (as shown in **Figure 69**) would be expected to extend toward the north, west and east, with plumes extending toward Inner South districts. The Mt Ainslie range prevents significant movement of pollution from East Canberra toward Gungahlin.

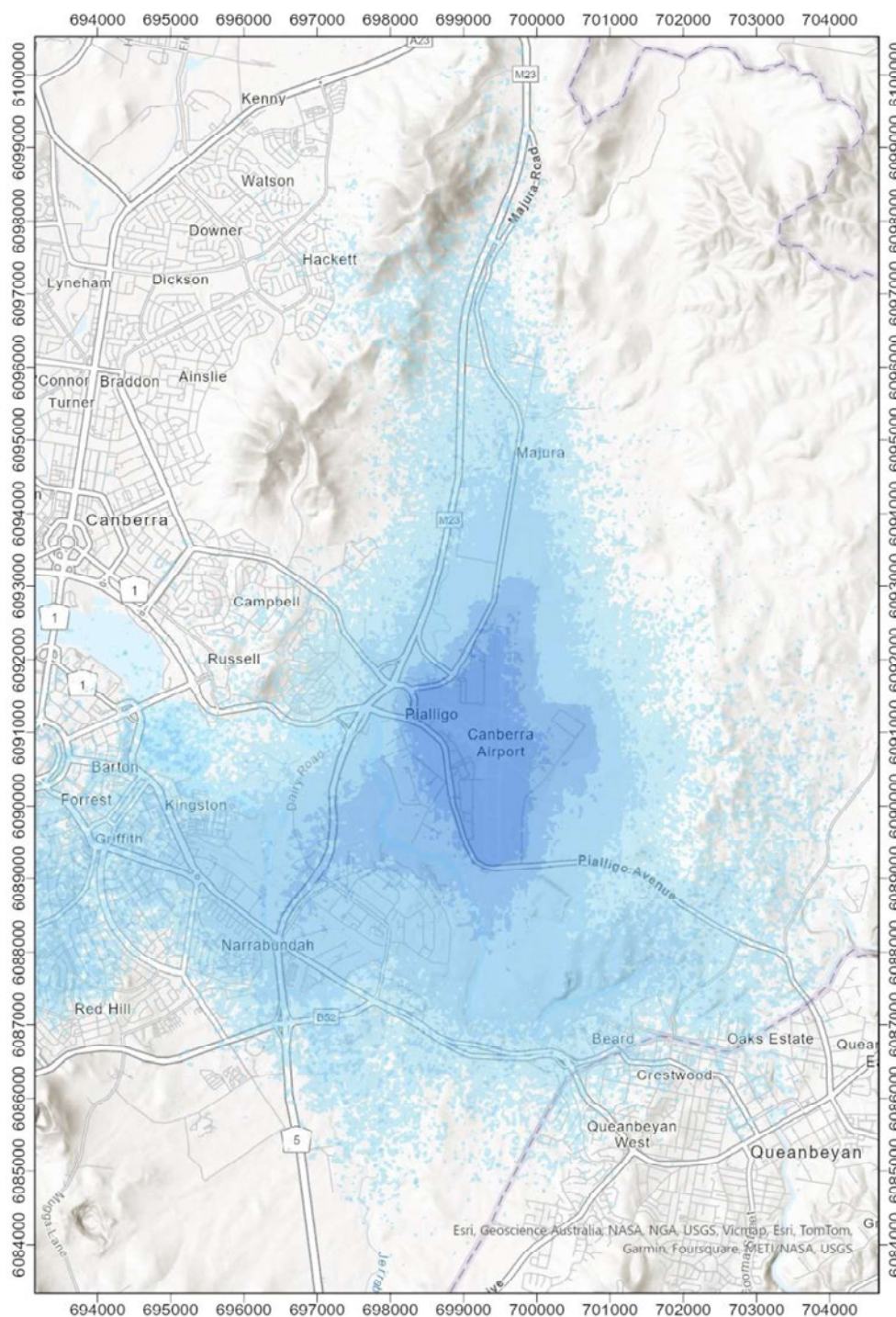


Figure 69 Canberra airport dispersion patterns

8.2.3 Gungahlin District

The suburb Gungahlin of the district Gungahlin was used as a general source of emissions in the dispersion model to assess dispersion characteristics for the district. Emissions from Gungahlin (as shown in **Figure 70**) showed that plume tended to stay within the Gungahlin district. The plume did extend toward the southwest (toward the Belconnen district and Murrumbidgee River valley), but the majority stayed close to the source of the emissions.

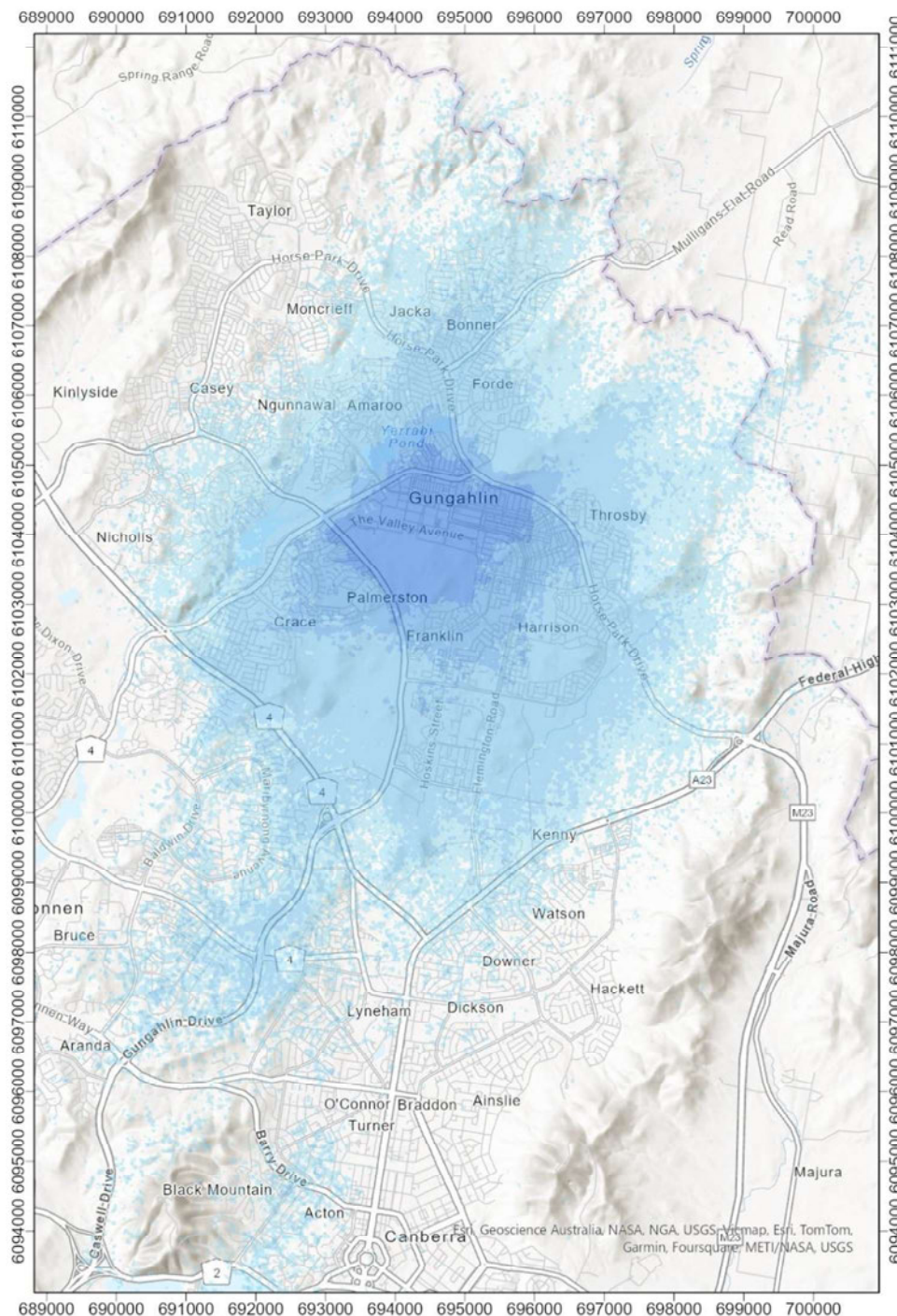


Figure 70 Gungahlin dispersion patterns

8.2.4 Inner North District (Dickson)

The suburb Dickson within the district Inner North was used as a general source of emissions in the dispersion model to assess dispersion characteristics for the district. Emissions within Dickson (as shown in **Figure 71**) are heavily affected by the influence of the elevated terrain of the Black Mountain Reserve and the Mt Ainslie Nature reserve. Pollution emitted within this district extends to the north and south toward Gungahlin and Inner South districts.

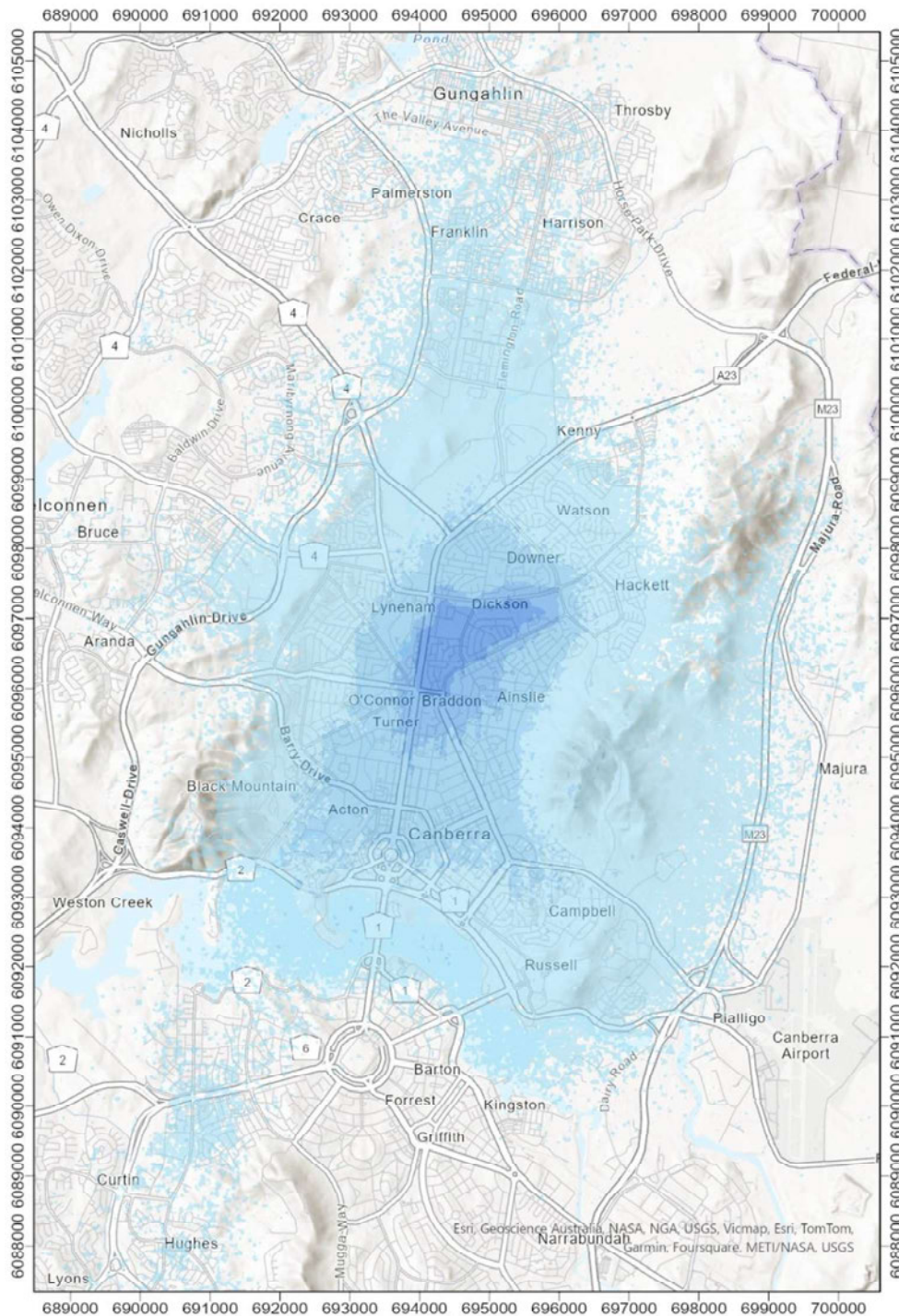


Figure 71 Dickson dispersion patterns

8.2.5 Inner South District (Forrest)

The suburb Forrest within the district Inner South was used as a general source of emissions in the dispersion model to assess dispersion characteristics for the district. Emissions from Forrest (as shown in **Figure 72**) showed pollution plumes extending in three distinct directions. Pollution contours extended out to the southwest toward Woden Valley and beyond to Tuggeranong, to the north toward Inner North district and southeast toward east Canberra. Pollution contours extended a significant distance to the north between the elevated terrain of the Black Mountain Reserve and the Mt Ainslie Nature reserve.

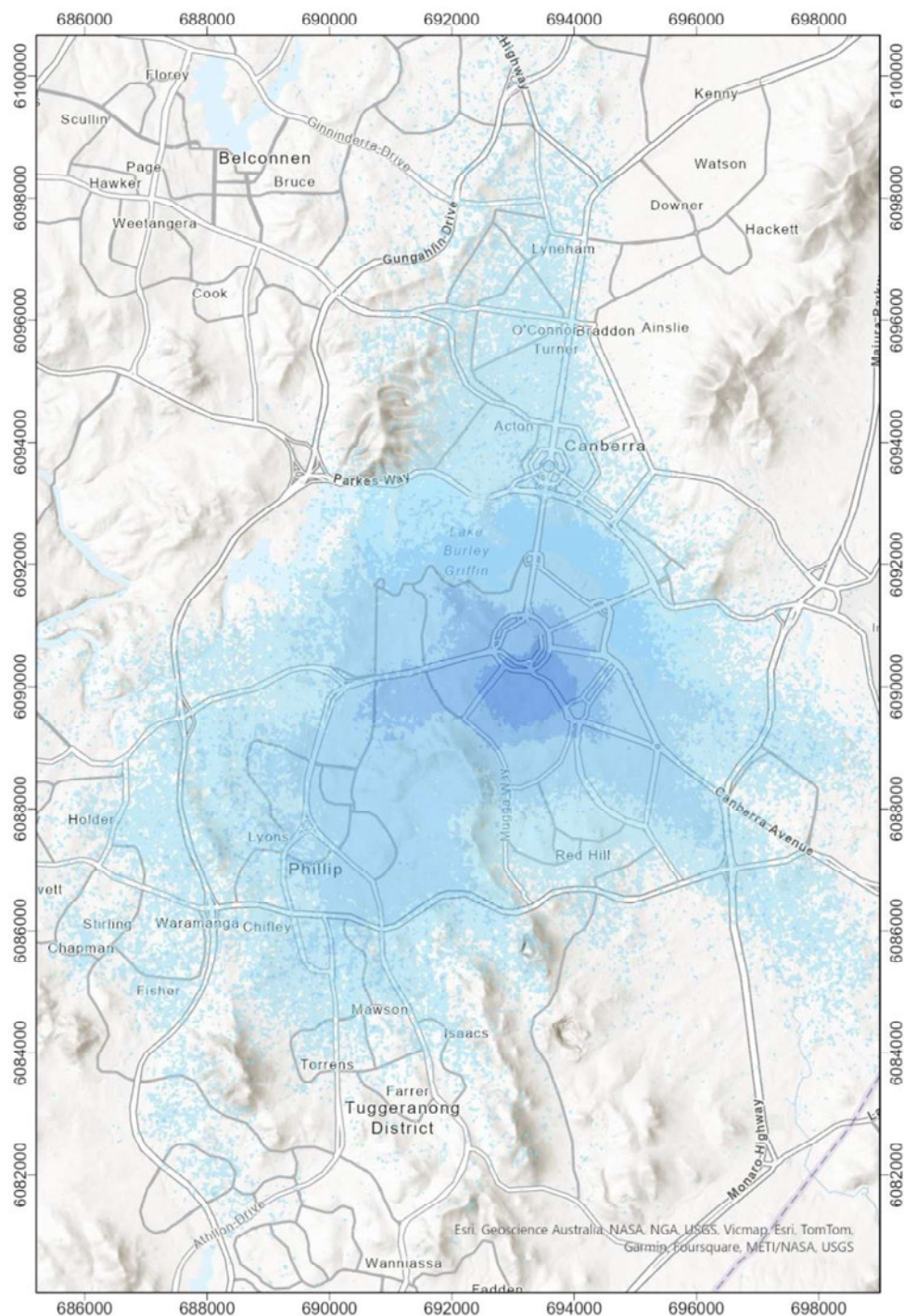


Figure 72 Forrest dispersion patterns

8.2.6 Molonglo Valley District (Whitlam)

The suburb Whitlam within the district Molonglo Valley was used as a general source of emissions in the dispersion model to assess dispersion characteristics for the district. Emissions from Whitlam (as shown in **Figure 73**) within the Molonglo Valley showed pollution extending to the northwest, west, east and south. Plumes extended along the elevated terrain along the Murrumbidgee River toward Belconnen, along the Molonglo river valley to the west, toward Inner South district to the east and toward Weston Valley and Tuggeranong to the south.

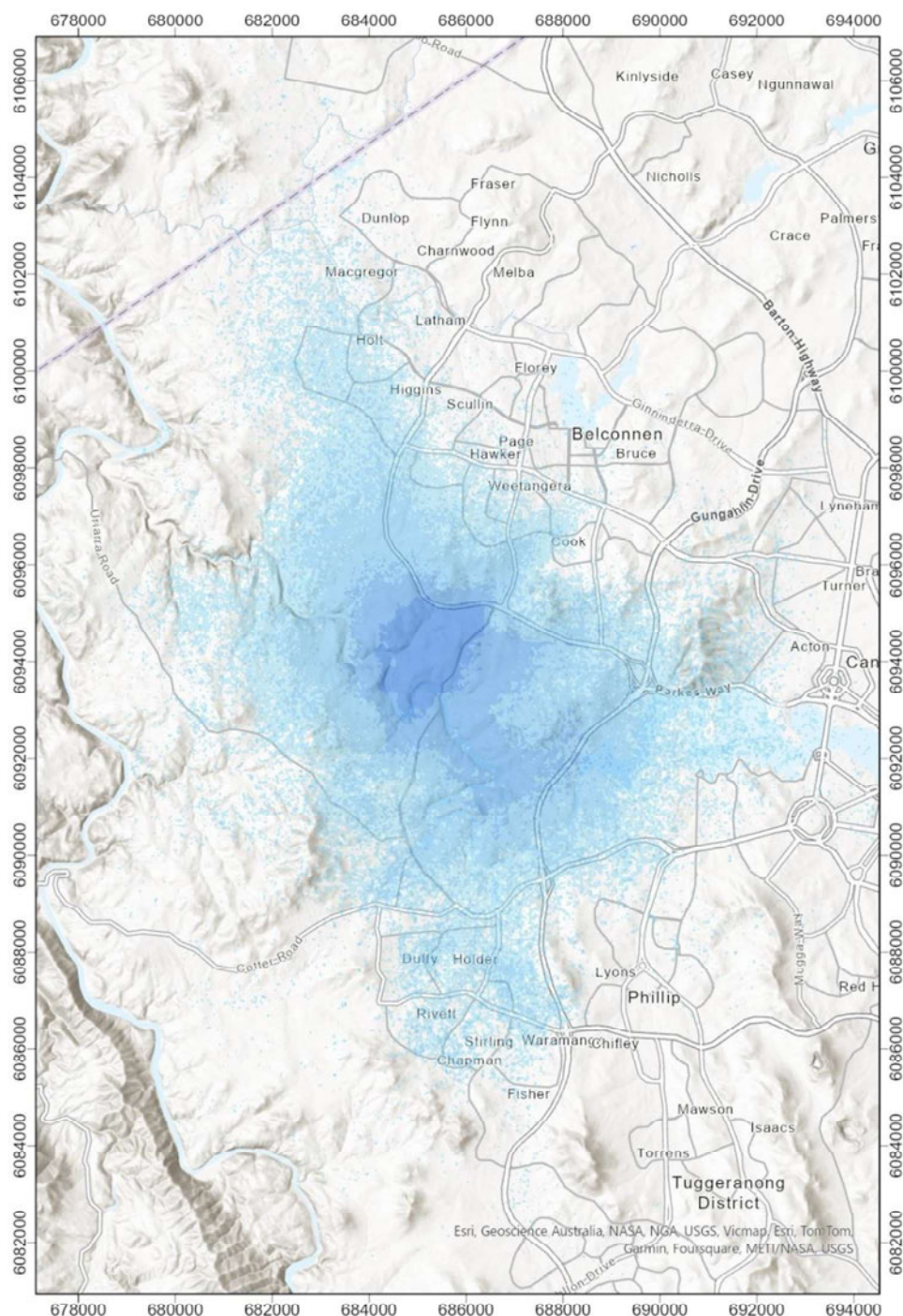


Figure 73 Whitlam dispersion patterns

8.2.7 Tuggeranong District (Monash)

Emissions from Monash (as shown in **Figure 74**) show pollution moving in four distinct directions. Pollution contours extended out to the west following the Murrumbidgee River valley, to the north toward Woden Valley and Inner South Districts, east toward East Canberra and south, within complex terrain to the south of the Tuggeranong district around the suburbs of Gordon to Banks. This pollution shape matches the Microclimatic analysis undertaken in **Section 0**. Although only a broad scale modelling investigation has been undertaken, any pollution emitted in the Tuggeranong district would migrate outside of the district in multiple directions, contributing to air pollution outside of the district.

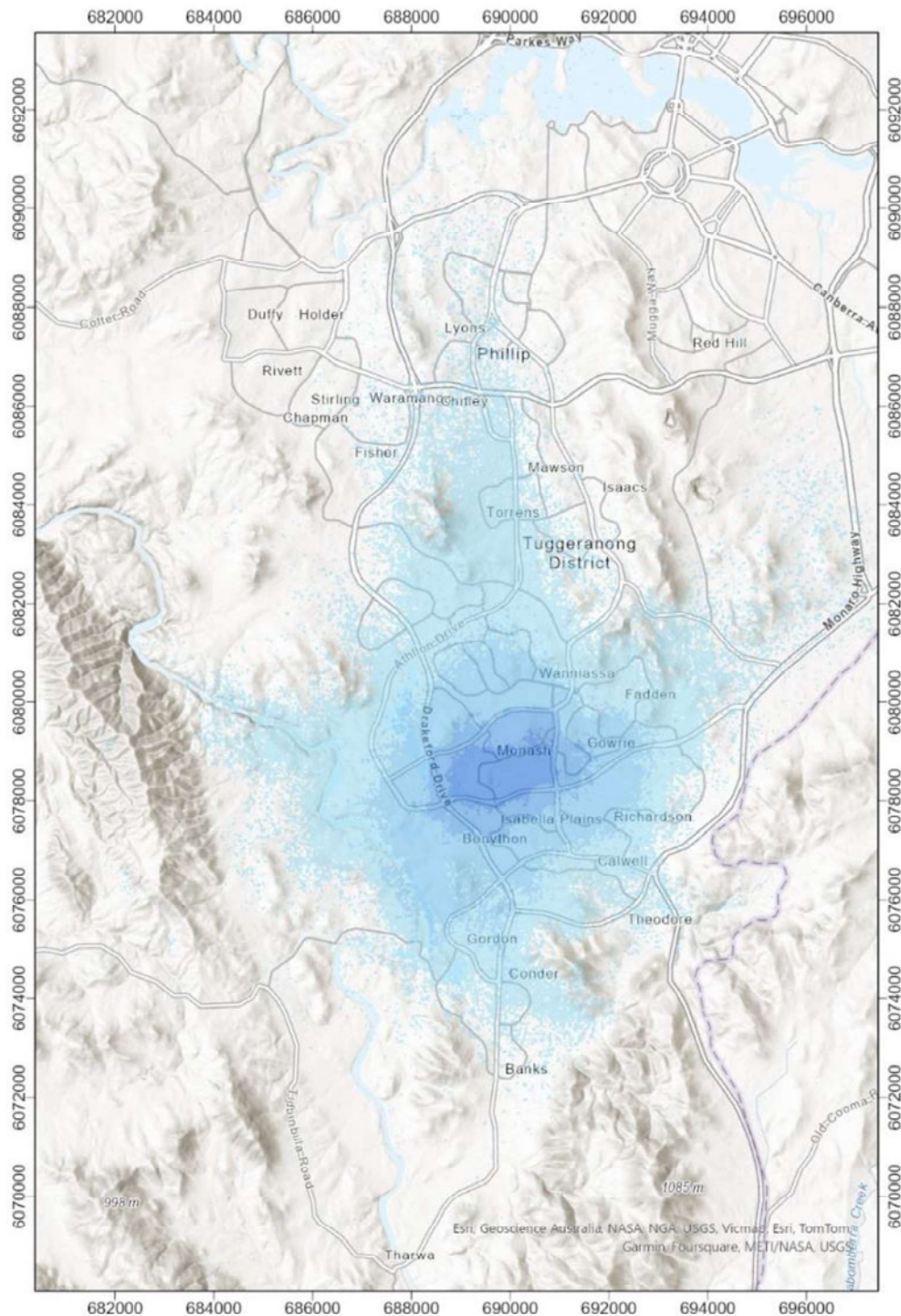


Figure 74 Monash dispersion patterns

8.2.8 Weston District

The suburb Weston within the district Weston was used as a general source of emissions in the dispersion model to assess dispersion characteristics for the district. Emissions from Weston (as shown in **Figure 75**) showed pollution plumes extended in four distinct directions. Pollution contours extended out to the west across the proposed WEIA, to the north toward the Molonglo Valley, east toward Inner South district and south toward Tuggeranong.

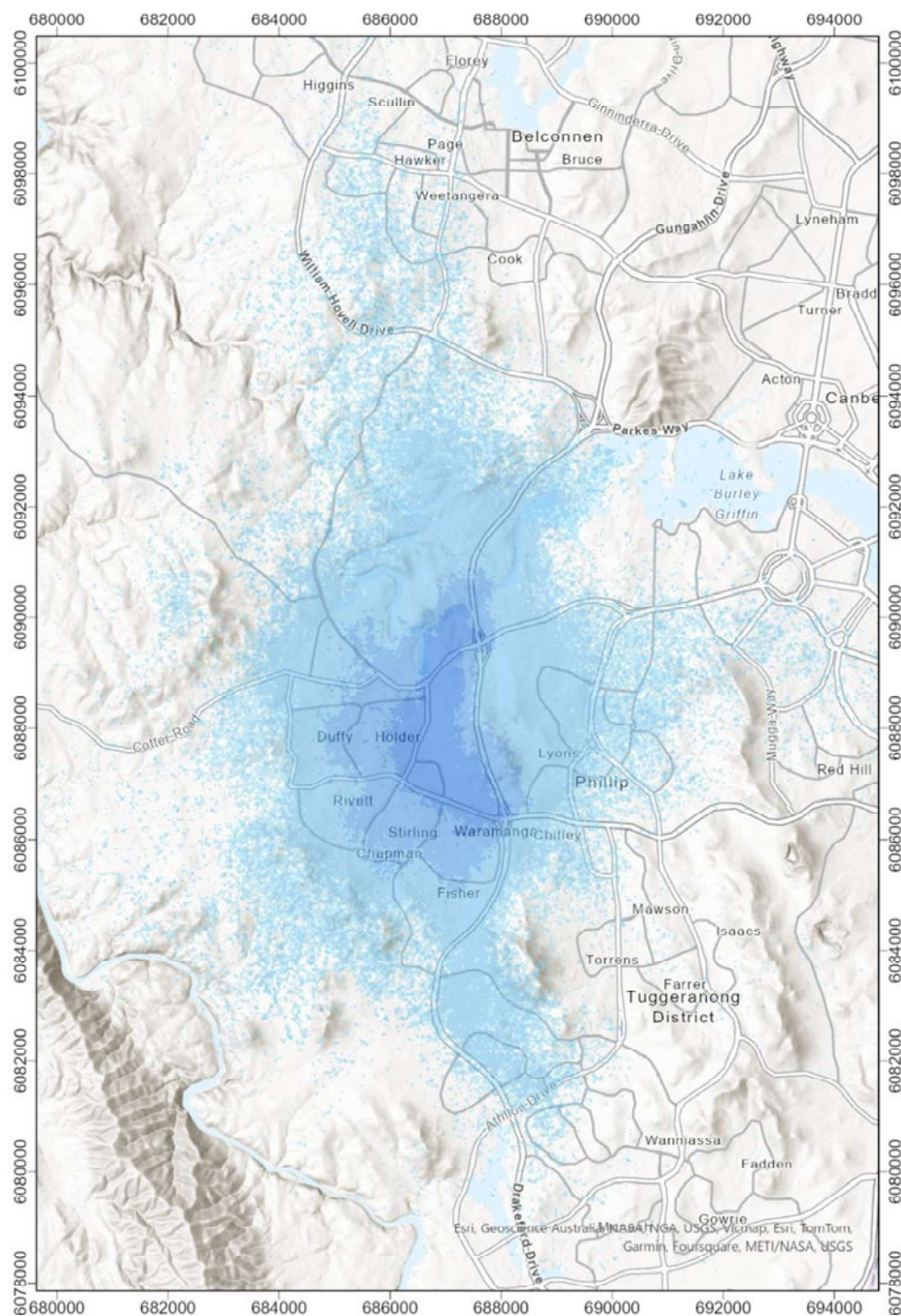


Figure 75 Weston dispersion patterns

8.2.9 Woden District (Phillip)

The suburb Phillip within the district Woden was used as a general source of emissions in the dispersion model to assess dispersion characteristics for the district. Emissions from Phillip (as shown in **Figure 76**) showed pollution largely stayed within the Woden Valley and Weston Creek Districts, with the exception of plumes extending to the north and south of the district. Pollution emitted in the Woden district would be expected to largely remain within the Woden Valley with some of the pollution migrating north or South, contributing to air pollution outside of the district in Tuggeranong or Inner South districts.

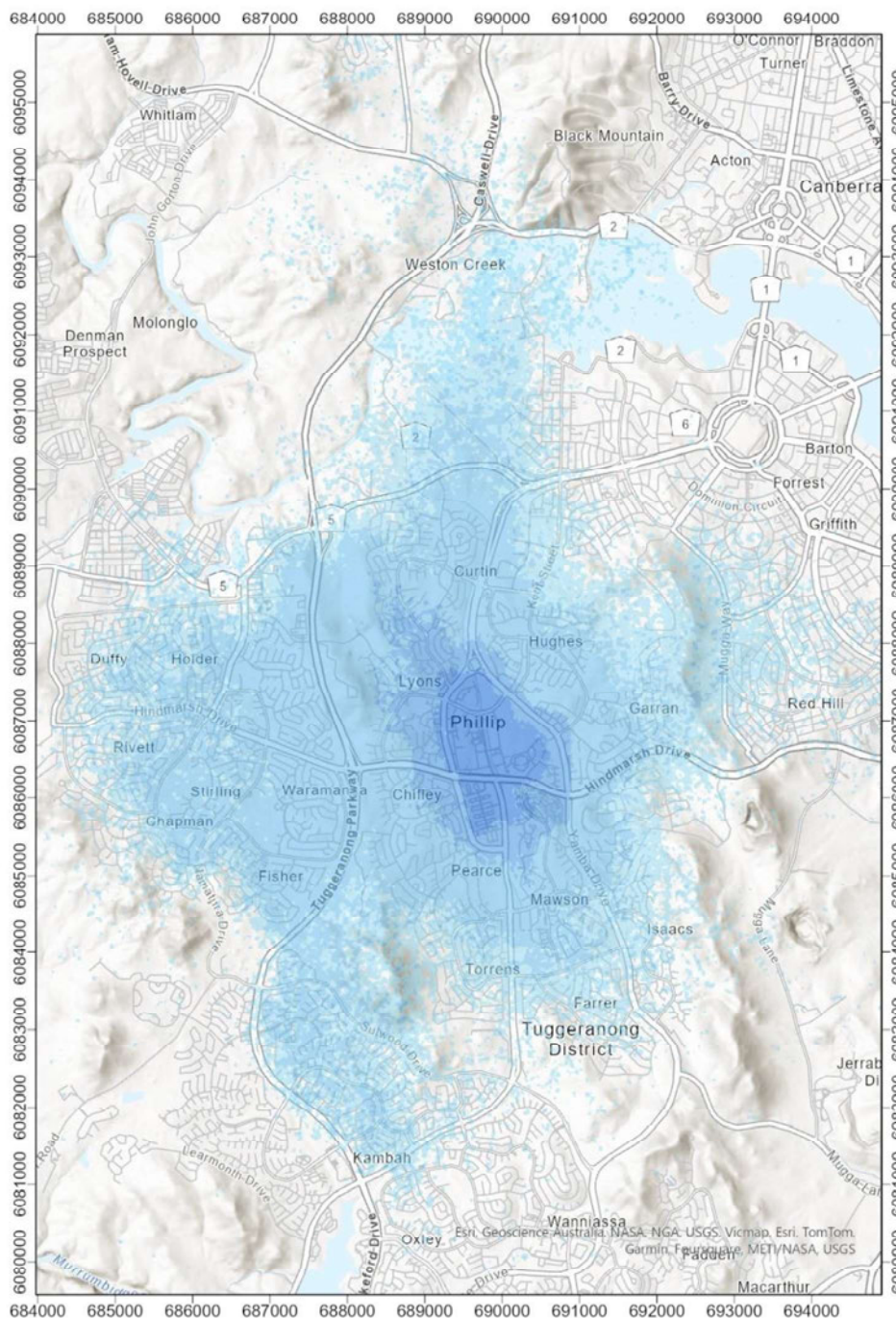


Figure 76 Phillip dispersion patterns

9.0 Climate Change

9.1 Climate Change Predictions

Climate change projections for the ACT region based on NARCIIM 1.5 near future and far future projections are summarised in **Table 19**. Additional information is also provided in the following subsections which also references the older, yet still relevant to this assessment, NARCIIM 1.0.

Table 19 NARCIIM 1.5 ACT near and far future climate projections

Variable	Trend	Near future (2030 or 2020-2039)	Far Future (2070 or 2060-2079)
Change in average temperature (°C)	increase	+0.66 annual change mean Mean temperatures are projected to rise by 0.7°C by 2030. The increases are occurring across the region with the greatest increases during summer. All models show there are no declines in mean temperatures across the ACT.	+2.04 annual change mean Mean temperatures are projected to rise by 2°C by 2070. The increases are occurring across the region with the greatest increases during summer. All models show there are no declines in maximum temperatures across the ACT.
Change in number of hot days a year (max temp > 35°C)	increase	+1.8 annual change Hot days are projected to increase across the region by an average of 2 days per year by 2030. The greatest increases are seen around Canberra which is projected to experience 1-5 more hot days per year.	+6.2 annual change Hot days are projected to increase across the region by an average of 6 days per year by 2070. The greatest increases are seen around Canberra which is projected to experience 10-20 more hot days per year.
Change in number of cold nights (min temp < 2°C)	decrease	-13.1 annual change Cold nights are projected to decrease across the region by an average of 13 fewer nights per year by 2030. The ACT is projected to experience this across the region. Changes in cold nights can have significant impacts on native ecosystems and agricultural crops reliant on cold winters.	-42.5 annual change Cold nights are projected to decrease across the region by an average of 43 fewer nights per year by 2070. The ACT is projected to experience this across the region. Changes in cold nights can have significant impacts on native ecosystems and agricultural crops reliant on cold winters.
Change in rainfall (%)	variable	-2.8% annual change There will be little change in annual rainfall across the ACT by 2030. Rainfall will increase in autumn but there will be less rain in winter and spring.	-0.4% annual change Annual rainfall varies across the ACT by 2070. The greatest increases are seen around Canberra during summer and autumn. Decreases occur across the region during spring and most of the region during winter.
High fire danger days, Changes in number of days a year FFDI ⁴ > 50	increase	+0.1 annual change Fire weather is classified as severe when the FFDI is above 50. Severe fire weather is projected to increase in summer and spring across the region by 2030. Declines during autumn are likely due to increases in rainfall. There is	+0.3 annual change Fire weather is classified as severe when the FFDI is above 50. Severe fire weather is projected to increase in summer and spring across the region by 2070. Declines during autumn are likely due to increases in rainfall. There is no change during winter. These

⁴ Forest Fire Danger Index (FFDI) is used in NSW to quantify fire weather. The FFDI combines observations of temperature, humidity and windspeed

		no change during winter. These increases are being seen during the peak prescribed burning season (spring) and peak fire risk season (summer).	increases are being seen during the peak prescribed burning season (spring) and peak fire risk season (summer).
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9.1.1 Temperatures

Minimum and maximum temperature projections for the ACT region have been summarised based on the Climate Change Impacts in the NSW and ACT Alpine Region report (NSW Government 2018). The report utilises near and far future projections from NARCIIM 1.0 to provide estimated annual and seasonal changes to wind speed for 2020 to 2039 and for 2060 to 2079. Projections are as follows:

- Near future projections for 2020 to 2039 estimate:
 - Maximum temperature increases of 0.7°C
 - Minimum temperature increases of 0.6°C
- For far future projections between 2060 to 2070 estimate:
 - Maximum temperature increases of 2.0°C
 - Minimum temperature increases of 2.0°C

The projections above are generally uniform across the entire ACT, however NARCIIM provides projections to approximately a grid size of 10km. **Figure 77** below shows that the Minimum temperature in the far future scenario are projected to increase the most in the alpine region to the south-west of the ACT.

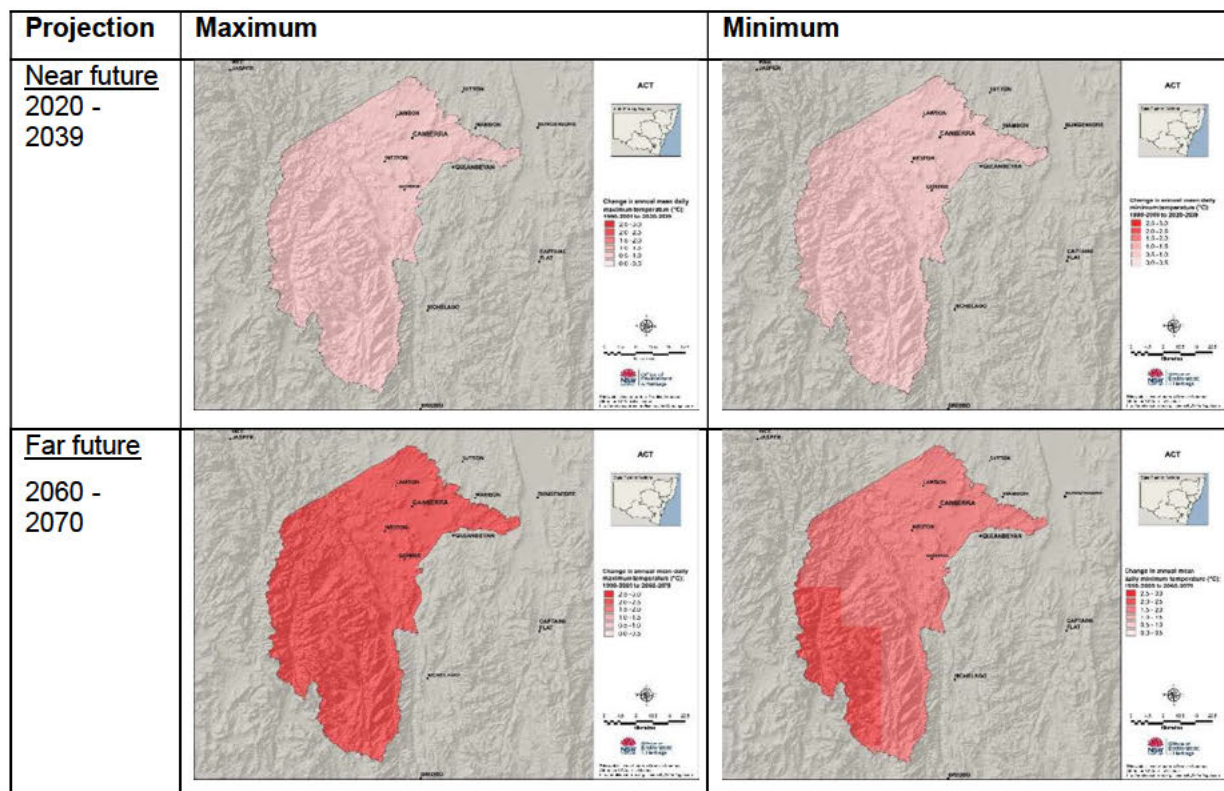


Figure 77 NARCIIM temperature projections

Implications of the above changes in temperature are that the ACT will experience a higher number of “hot” days where temperatures exceed 35°C. As shown in **Figure 78** the areas in the north of the ACT, such as urban Canberra would be more affected by hot days than in the southern alpine areas of the ACT.

Conversely, the number of cold nights (with temperatures less than 2°C) are projected to decrease with significantly less cold nights forecast in the near and far future (decrease of about 5-10 less cold days in the near future and over 40 less cold nights in the far future, refer Figure 78). The southern alpine areas are projected to have the largest decrease in cold nights.

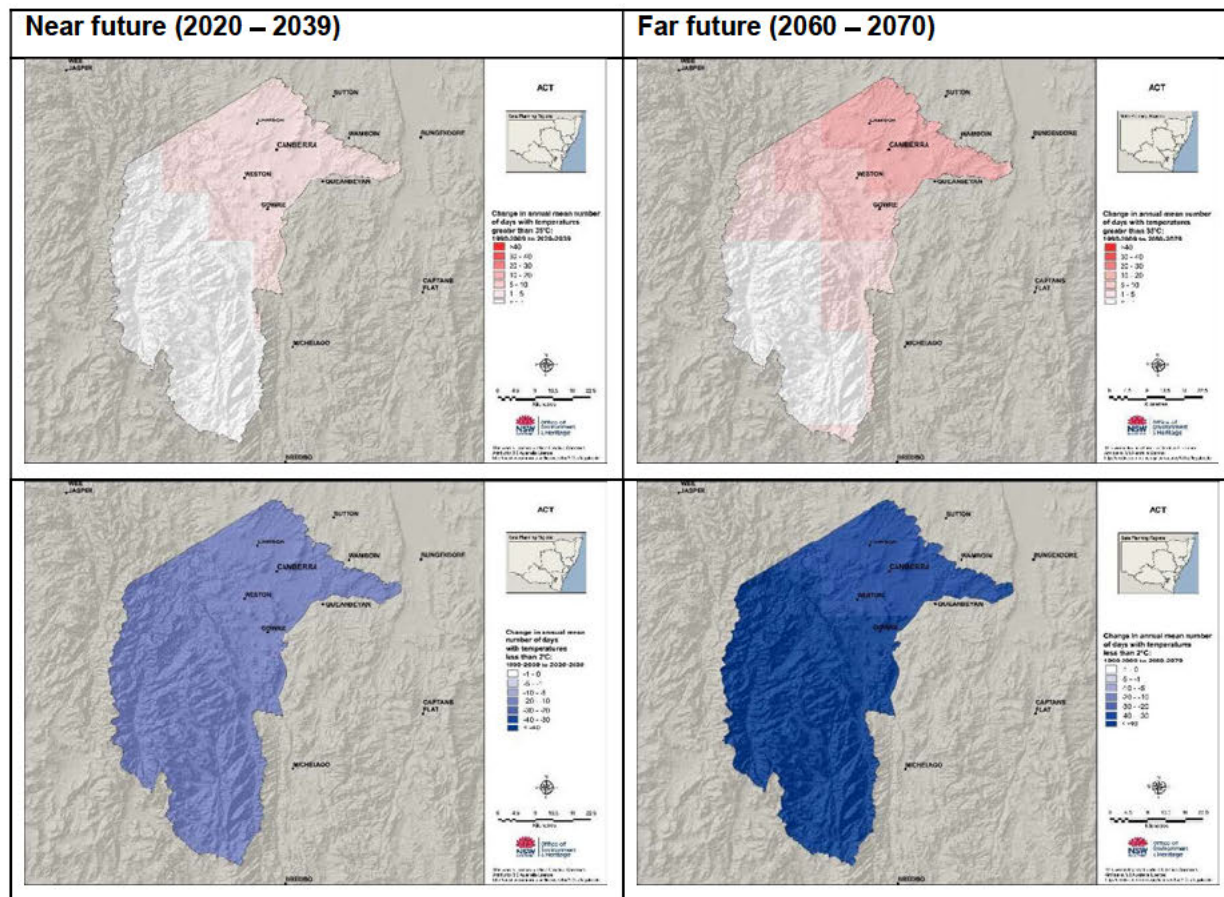


Figure 78 NARCIIM hot days and cold nights projections

As temperature heavily influences micrometeorological conditions (as discussed above in Section 4.1.2), any change would be expected to impact on the meteorology and by inference pollution dispersion. Hotter temperatures increase convective mixing in the atmosphere. During the summer months, it is expected that the hotter conditions would result in meteorology that results in better overall pollution dispersion conditions.

Inversion conditions as a result of the changing night-time temperatures are discussed below.

9.1.2 Temperature Inversions

Predicted changes to the frequency, strength and length of temperature inversions in the ACT have been based on the journal article *Projected Change in characteristics of near surface temperature inversions for southeast Australia* (Fei Ji *et al* 2018). The study utilised simulated temperature profiles derived from NARCIIM 1.0 to investigate changes to near surface temperature inversions. Results of the investigation for the ACT are as follows:

- The frequency of occurrence of near surface temperature inversions is expected to increase by up to 10%.
- The strength of a temperature inversion refers to the difference between the surface temperature and the temperature at the top of the inversion layer. The greater the temperature difference the higher the strength of the temperature inversion. The strength of the temperature inversions in urban areas within the ACT are projected to increase between 20 and 30% by 2060 to 2070.
- The duration of temperature inversions is expected to decrease between 0-10% by 2060 to 2070.

9.1.3 Rainfall

Rainfall projections for the ACT region have been summarised based on the ACT Climate Change Snapshot report (OEH 2014). The report utilises near and far future projections from NARClIM 1.0 to provide estimated annual and seasonal changes to rainfall for 2020 to 2039 and for 2060 to 2079.

Generally, rainfall is projected to decrease in spring and increase in autumn. **Figure 79** shows the seasonal projections, clearly showing a reduction in spring, with the far future projection having a larger reduction than the near future. Overall winter is also projected to experience drying where autumn and spring are generally projected to experience increased rainfall, aside from the near future summer projection for the western area of the ACT.

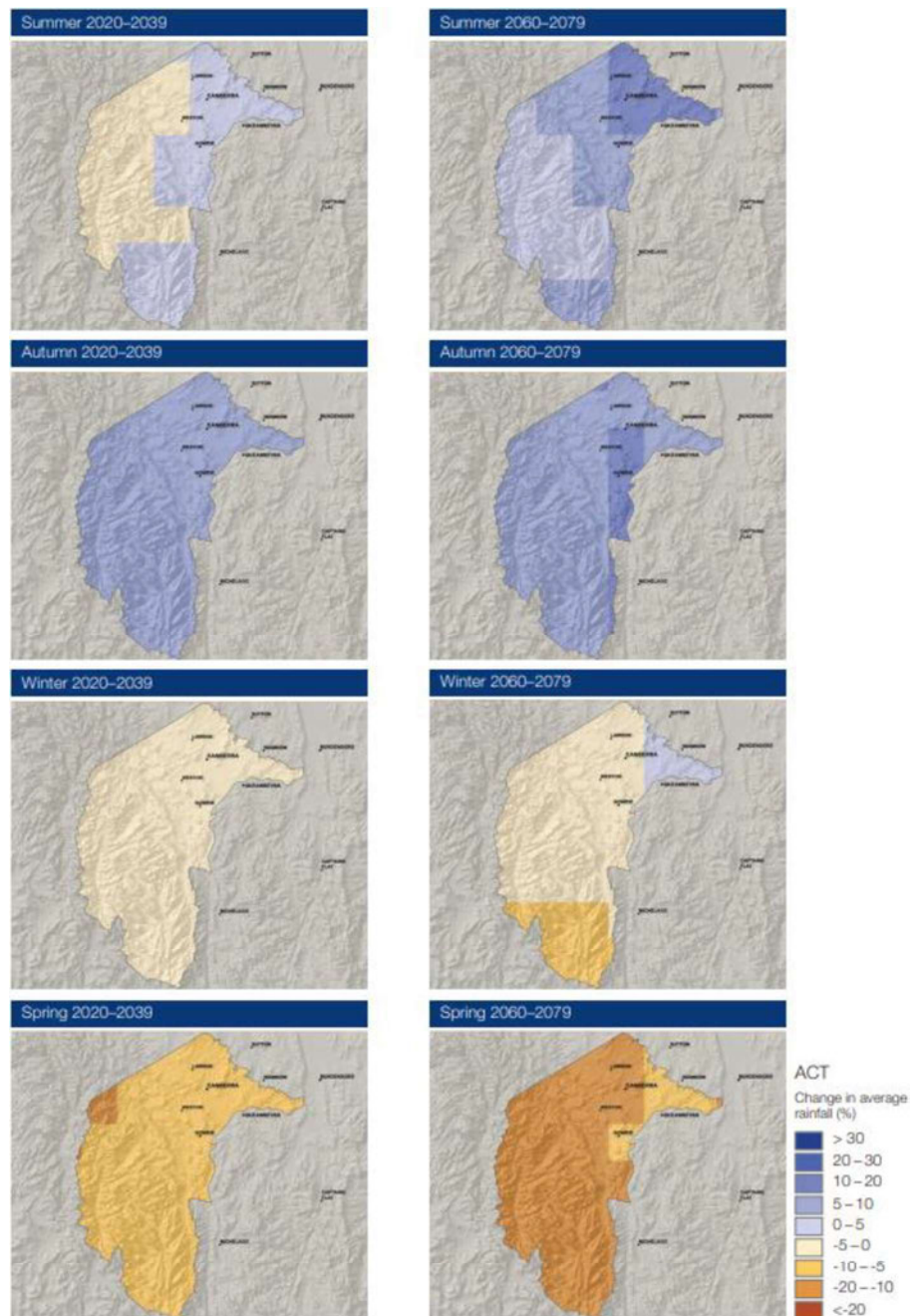


Figure 79 Seasonal rainfall projections

9.1.4 High fire danger days

High fire danger days, using the forest fire danger index (FFDI), projections for the ACT region have been summarised based on the ACT Climate Change Snapshot report (OEH 2014). The report utilises near and far future projections from NARCClim 1.0 to provide estimated annual and seasonal changes to rainfall for 2020 to 2039 and for 2060 to 2079. A FFDI value of 50 or higher represents a risk of “severe” fire weather. **Figure 80** shows that increased fire danger is projected on an annual basis for both the near future and far future projections, with the far future having the highest values. The figure also shows that fire danger is mostly associated with summer and spring, with autumn and winter projected to have only a small change.

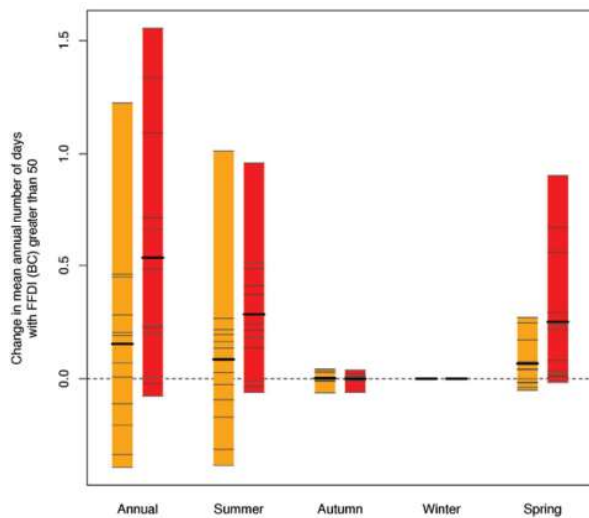


Figure 80 Projected changes in average annual number of days with a severe FFDI, annually and by season (2030 yellow; 2070 red)

As fire danger is projected to increase for summer and spring, these seasons would be of highest impact to the ACT. The projections vary across the ACT due to the difference in input factors to the FFDI. These spatial differences for summer and spring are presented below in **Figure 81**.

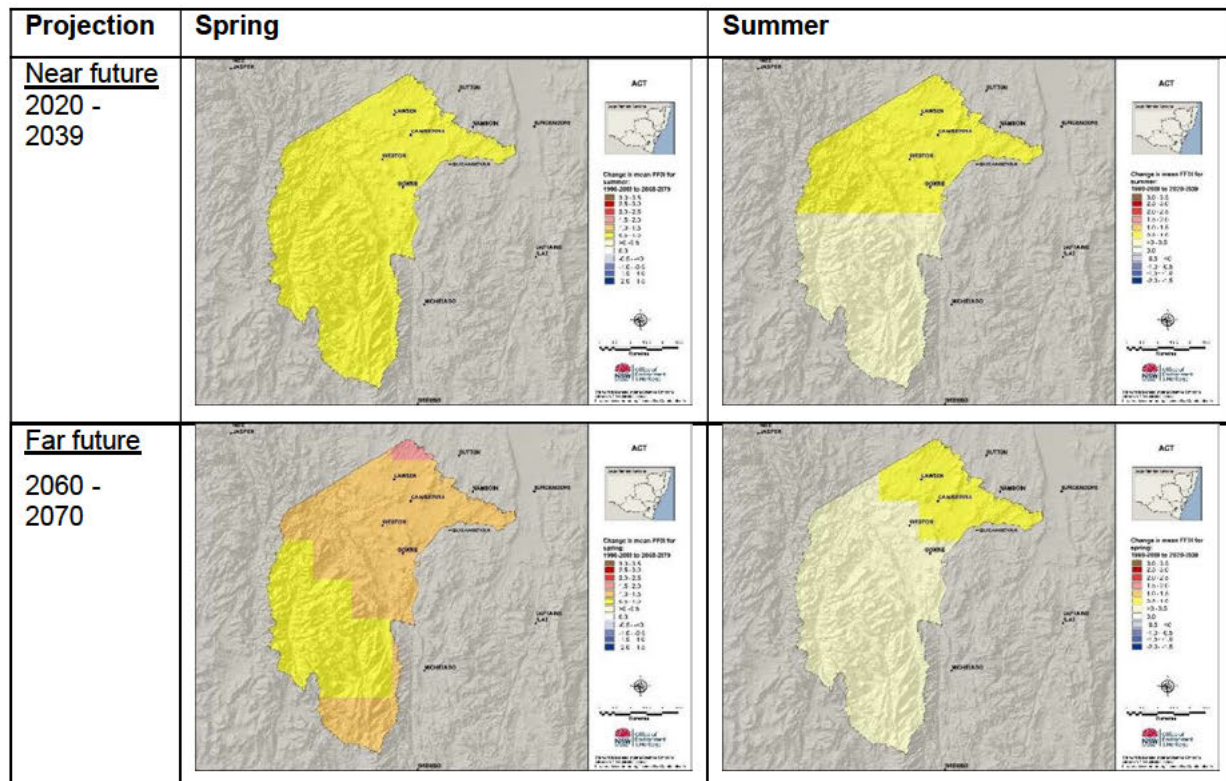


Figure 81 NARClIM FFDI projections

9.1.5 Wind speed

Mean and maximum wind speed projections for the ACT region have been summarised based on the Climate Change Impacts in the NSW and ACT Alpine Region report (NSW Government 2018). The report utilises near and far future projections from NARClIM 1.0 to provide estimated annual and seasonal changes to wind speed for 2020 to 2039 and for 2060 to 2079. Projections are as follows:

- Near future projections for 2020 to 2039 estimate:
 - For average wind speed:
 - A mean annual wind speed decrease of less than 2% for most urban areas, some areas may experience a decrease of 2-4% including in the northern Gungahlin District.
 - Mean wind speeds for summer and winter are expected to increase by up to 2%.
 - Mean wind speeds for spring and autumn decrease during spring and autumn by 4-6%.
 - For maximum daily wind speed:
 - A decrease in the maximum wind speed of less than 2%
 - Seasonal estimates are consistent with annual projections with exception to spring decreases between 2-6% estimated for urban areas.
- For far future projections between 2060 to 2070 estimate:
 - For average wind speed:
 - A mean annual wind speed decrease of 4-6% for most urban areas.
 - Seasonally average wind speeds are expected to decrease across all seasons ranging from up to 2% in winter and up to 8-10% decrease in spring.
 - For maximum daily wind speed:
 - A decrease in the maximum wind speed of less than 2%

- Seasonal estimates maximum daily windspeeds are consistent with annual projections for summer and autumn, projected to increase by 2-4% for northern districts and up to 2% for southern districts and decrease by 2-4% across urban areas in spring.

9.2 Influences on Pollutant Transport and Air Dispersal

9.2.1 Wind Speed

Arguably atmospheric dispersion and pollutant transport is primarily driven by wind speed and wind direction. Higher wind speeds generally result in more rapid dispersal of air pollutants; resulting in more favourable air pollutant ground level concentrations at closer distances to a given source when compared to low wind speed conditions.

Mean annual average wind speeds are generally projected to decrease by less than 2% within urban areas by 2020-2039 and by 4-6% by 2060-2070. A less than 2 percent increase is unlikely to have a material impact in pollutant dispersal in the short term; however further decreases in wind speed projected out into the far future may have a notable impact in pollutant dispersal.

Meteorological analysis on wind conditions reported in **Section 7.0** show that the most common wind condition in the study area is a low wind speed (0.8 m/s) under stable wind conditions occurring 24.3% of the time. Under these meteorological conditions air pollutants would be expected to disperse slowly and further long term decreases in wind speed may exacerbate unfavourable conditions.

Furthermore, districts with lower annual average lower wind speeds are already susceptible to more unfavourable wind conditions and may be slightly more susceptible to poor air dispersal conditions in the long term. Particularly during the spring when wind speeds are expected to decrease in urban areas by up to 8-10%.

Projections for the maximum daily wind speeds are expected to decrease annually by less than 2% over the near and long term. This has the potential to reduce the favourable air dispersal conditions; however, given the small change this is not expected to have a material difference on air pollutant concentration.

9.2.2 Temperature Inversions

Temperature inversions, particularly near surface temperature inversions can exacerbate air pollutant concentrations by restricting convective movements, resulting in elevated ground level pollutant concentrations. As such changes to the frequency strength and duration of temperature inversions can affect urban air quality.

The frequency of occurrence of near surface temperature is expected to increase by up to 10% within the ACT by 2060-2070 and the strength of the temperature inversions in urban areas within the ACT are projected to increase between 20 and 30%. Both the increase in frequency and substantial increase in temperature inversion strength of near surface temperature inversions suggests that future inversion conditions may amplify poor air quality events.

This is particularly important during the winter months when there is a higher prevalence for temperature inversions (refer to **Section 7.3**) that also coincides with peak use of woodfire heaters; trapping fine particulates close to the surface.

The districts of Tuggeranong, Weston Creek, Woden Valley and Molonglo Valley are also likely to be more susceptible air quality impacts from an increase in frequency and strength of near surface temperature inversion. This risk has been identified based on existing microclimatic conditions and topography effects that induce a higher prevalence of temperature inversions identified in **Section 7.3**.

9.2.3 Rainfall

Generally, changes to both annual and seasonal rainfall influence air quality in two ways. Directly wet deposition is an important mechanism for reducing air pollution, particularly particulate matter, where rain is responsible for removing particulates from the atmosphere. Indirectly rain also influences soil moisture content which affects the potential for wind generated dust from exposed surfaces.

Predicted changes to rainfall in both the near and far future as discussed in **Section 9.1** was found to vary seasonally. By 2030 annual average rainfall is expected to be similar, however higher rainfall is

expected in autumn, and less during spring and winter. By 2070, rainfall is expected to increase during both increase in summer and autumn and decrease during spring and winter.

Predicted seasonal fluctuations suggest there is a potential for increased wet deposition and higher soil moisture contents during summer and autumn which may potentially result in marginally lower ambient particulate concentrations. The reverse may be expected during winter and spring where there is less opportunity for particulates to be washed out of the atmosphere due to lower rain events; and lower soil moisture contents potentially giving rise to marginal increased risk in windblown dust from exposed surfaces.

10.0 Air Quality and Urban Development

10.1 Sources of Air Pollution from Urban Development

As discussed above, there are a range of air pollution sources within the ACT. While wood smoke and vehicle emissions dominate the overall inventory of air pollution sources, there are a range of other sources that can be considered. The following section discusses different urban development characteristics for the different ACT urban area districts and highlights potential air pollution sources that may occur in those districts.

10.1.1 Belconnen District

Table 20 provides a summary of identified air pollution sources from future urban development based on key development requirements identified within the in the Belconnen District Strategy discussed in **Section 3.2.3.1**. Already the most populated of the ACT districts Belconnen is expected to undergo significant urban regeneration and greenfield development to meet projected population growth in this area with an additional 21,200 dwellings required within the Belconnen District by 2050. Transport infrastructure works would also be required to meet increasing demands.

Table 20 Summary of air pollution sources from urban development within the Belconnen District

Source Type	Discussion
Urban renewal	- Significant redevelopment of brownfield sites and urban renewal required to meet projected housing demand. - Replacement of low density housing with medium density housing in existing suburbs around centres and key transit routes; may result in poorer air dispersal conditions including formation of urban canyons. - Potential construction dust risks associated with development. Infill areas and redevelopment sites; likely pose a higher dust risk due to proximity and density of surrounding sensitive receptors.
Greenfield Development	- Potential for land use conflicts with surrounding development. - Potential construction dust risks associated with development.
Transport infrastructure	- Potential increase and/or changes in regional distribution of vehicle emissions associated with infrastructure projects, including: - additional rapid transport connections between Belconnen and Molonglo Valley - transport growth areas in Ginninderry and Kippax - freight network and access around Kippax - Upgrades to priority travel routes - Potential beneficial impacts associated reduction in road vehicle emissions from transport modal shift associated with long term strategic initiative to investigation and deliver the light rail network to Belconnen town centre. - Potential construction dust risks associated with development of transport infrastructure projects.
Bushfire events	Potential air quality risks associated with development of greenfield sites where new development interfaces bushland areas (urban-bushland interface).

10.1.2 East Canberra District

Table 21 provides a summary of identified air pollution sources from future urban development based on key development requirements identified within the in the East Canberra District Strategy discussed in **Section 3.2.3.2**. This district is not anticipated to undergo significant urban regeneration or greenfield

development. Future development would focus on enhancing employment opportunities, while maintaining a modest development footprint to protect environmentally sensitive areas.

Table 21 Summary of air pollution sources from urban development within the East Canberra District

Source Type	Discussion
Urban renewal	District is not anticipated to undergo significant urban regeneration.
Greenfield Development	District is not anticipated to undergo significant greenfield development.
Transport infrastructure	- Transport infrastructure identified to facilitate the districts important role in freight, logistics and facilitation of economic activity across the ACT. - Potential increase and/or changes in regional distribution of vehicle emissions associated with infrastructure projects to support cross-border infrastructure and road connectivity and identification and protection of major road and rail corridors. - Potential beneficial impacts associated reduction in road vehicle emissions from transport modal shift associated with long term strategic initiative to expand the light rail network. - Potential construction dust risks associated with development of transport infrastructure projects.
Bushfire events	District has a high proportion of existing urban bushland interfaces; where there is a higher perceived air quality risks; associated with bushfires.

10.1.3 Gungahlin District

Table 22 provides a summary of identified air pollution sources from future urban development based on key development requirements identified within the in the Gungahlin District Strategy discussed in **Section 3.2.3.3**. The district forms the ACTs

The Gungahlin District is the ACT's major greenfield growth area and houses a light industrial estate in the suburb of Mitchell. Land releases in greenfield development areas as well as urban regeneration in established areas will be required to meet the estimated additional 17,900 dwellings required by 2050.

Table 22 Summary of air pollution sources from urban development within the Gungahlin District

Source Type	Discussion
Urban renewal	- Significant urban renewal required in existing suburbs to meet projected housing demand. - Replacement of low density housing with medium density housing in existing suburbs around centres and key transit routes; may result in poorer air dispersal conditions including formation of urban canyons. - Potential construction dust risks associated with development. Infill areas and redevelopment sites; likely pose a higher dust risk due to proximity and density of surrounding sensitive receptors.
Greenfield Development	- Significant greenfield development including five ongoing greenfield areas and Indicative Land Release Program sites at Casey, Taylor, Jacka, Kenny and the Gungahlin town centre. - Potential for land use conflicts with surrounding development. - Potential construction dust risks associated with development.
Transport infrastructure	- Potential increase and/or changes in regional distribution of vehicle emissions associated with infrastructure projects, including: - Ongoing capacity for freight and heavy vehicles on key roads into Mitchell to support its industrial and urban services

Source Type	Discussion
	function including the potential for extension of Morisset Drive to the Federal Highway - Progressive upgrades to priority active travel routes including along the Barton Highway, Flemington Road and within Franklin and Gungahlin town centre - Potential rapid transport services to the northern suburbs of the Gungahlin district connection the town centre to group centres in Casy, Moncrief and Amaroo. • Potential beneficial impacts associated reduction in road vehicle emissions from transport modal shift associated with expected increased patronage to light rail network in future years. • Potential construction dust risks associated with development of transport infrastructure projects.
Bushfire events	• Potential air quality risks associated with development of greenfield sites where new development interfaces bushland areas (urban-bushland interface). • Northern extent of district is predicted to have the greatest increase in FFDI (+1.5-2.0) during the spring when burn offs are typically scheduled; higher than any other district.

10.1.4 Inner North District

Table 23 provides a summary of identified air pollution sources from future urban development based on key development requirements identified within the in the Inner North District Strategy discussed in Section 3.2.3.1. The Inner North District is expected to undergo significant urban regeneration, and redevelopment of brownfield sites to meet projecting population growth in this area with an additional 24,200 dwellings required within the district by 2050. Transport infrastructure works would also be required to meet increasing demands.

Table 23 Summary of air pollution sources from urban development within the Inner North District

Source Type	Discussion
Urban renewal	• Significant redevelopment of brownfield sites and urban renewal required to meet projected housing demand. • Replacement of low density housing with medium density housing in existing suburbs around centres and key transit routes; may result in poorer air dispersal conditions including formation of urban canyons. • Potential construction dust risks associated with development. Infill areas and redevelopment sites; likely pose a higher dust risk due to proximity and density of surrounding sensitive receptors.
Greenfield development	• District is not anticipated to undergo significant greenfield development with exception to land release program sites at Watson.
Transport infrastructure	• Potential increase in vehicle emissions in city centre as transport infrastructure demands increases with population growth. • Potential beneficial impacts associated reduction in road vehicle emissions from transport modal shift associated with: - Delivery of Stage 2a of the Canberra Light Rail from Alinga Street to Commonwealth Park. Longer term benefits may also include further extension of the light rail network to Woden and potential links between Belconnen, Russel and Canberra Airport. - Long term City Centre planning as multimodal transport hub and increased public transport network facilities.

Source Type	Discussion
	Potential construction dust risks associated with development of transport infrastructure projects.
Bushfire events	- District has a high proportion of existing urban bushland interfaces; where there is a higher perceived air quality risks; associated with bushfires, such as the suburbs of Watson, Hackett, Ainslie and Acton. - Potential air quality risks associated with development of greenfield sites where new development at Watson interfaces bushland areas (urban-bushland interface).

10.1.5 Inner South District

Table 24 provides a summary of identified air pollution sources from future urban development based on key development requirements identified within the in the Inner South District Strategy discussed in **Section 3.2.3.1**. A modest estimated additional 7,000 dwellings required within the Inner South District to meet 2050 population growth projections; and demands met by, land releases, brownfield redevelopment and increased housing density within existing suburbs.

Table 24 Summary of air pollution sources from urban development within the Inner South District

Source Type	Discussion
Urban renewal	- Moderate redevelopment of brownfield sites and urban renewal required to meet projected housing demand. - Replacement of low density housing with medium density housing in existing suburbs around centres and key transit routes; may result in poorer air dispersal conditions including formation of urban canyons. - Potential construction dust risks associated with development. Infill areas and redevelopment sites; likely pose a higher dust risk due to proximity and density of surrounding sensitive receptors
Greenfield development	District is not anticipated to undergo significant greenfield development
Transport infrastructure	- Potential increase and/or changes in regional distribution of vehicle emissions associated with infrastructure projects, including: - Planning for Canberra Railway Station as a key element of the strategic investigation corridor from Parliamentary zone to Fyshwick - Supporting development control plans around Kingston and Fyshwick support and maintain capacity for freight traffic in the district. - Potential beneficial impacts associated reduction in road vehicle emissions from transport modal shift associated with: - Delivery of Stage 2b from the City Centre to Woden - Long term planning initiatives including improved public transport connections and upgrades to cycling network - Potential construction dust risks associated with development of transport infrastructure projects.
Bushfire events	District has existing urban bushland interfaces where there is a higher perceived air quality risks; associated with bushfires. This includes south of Deakin and Red Hill and to the east of Fyshwick.

10.1.6 Molonglo District

Table 25 provides a summary of identified air pollution sources from future urban development based on key development requirements identified within the in the Molonglo District Strategy discussed in Section 3.2.3.6. An additional estimated additional 24,000 dwellings required within the Molonglo Valley to meet 2050 population growth projections. Expected development under existing plans on greenfield sites are expected to meet this housing demands. No urban regeneration areas have been identified under the Molonglo Valley District Strategy.

Table 25 Summary of air pollution sources from urban development within the Molonglo District

Source Type	Discussion
Urban renewal	District is not anticipated to undergo significant urban renewal.
Greenfield development	- Significant greenfield development including the new suburb of Whitlam and other future residential suburbs marked for future development. - Potential for land use conflicts with surrounding development. - Potential construction dust risks associated with development.
Transport infrastructure	- Potential increase and/or changes in regional distribution of vehicle emissions associated with current and future infrastructure projects, including: - Construction of the remaining stage of the John Gorton Drive strategic investigation corridor, including a bridge over the Molonglo River - Construction of two major road connections into the district including the east-west east-west arterial linking Denman Prospect and the Molonglo group centre in the west to the Tuggeranong Parkway in the east. - Priority connections within the district and priority connections to adjacent districts. - Additional rapid transport connections between Belconnen and Molonglo Valley - Potential construction dust risks associated with development of transport infrastructure projects.
Bushfire events	- District has a high proportion of existing urban bushland interfaces; where there is a higher perceived air quality risks; associated with bushfires. - Potential air quality risks associated with development of greenfield sites interface bushland areas (urban-bushland interface).

10.1.7 Tuggeranong District

Table 26 provides a summary of identified air pollution sources from future urban development based on key development requirements identified within the in the Tuggeranong District Strategy discussed in Section 3.2.3.7. Modest population growth is forecasted for the Tuggeranong District with an estimated 1,100 dwellings required within the district to meet 2050 population growth projections. Additional transport infrastructure would be required within the district to support city growth by 2050.

Table 26 Summary of air pollution sources from urban development within the Tuggeranong District

Source Type	Discussion
Urban renewal	- Modest redevelopment of brownfield sites and urban renewal required to meet projected housing demand. - Potential traffic generating development with proposed upgrades to Tuggeranong Town Centre and Wanniassa group centre.

Source Type	Discussion
	Potential construction dust risks associated with development. Infill areas and redevelopment sites; likely pose a higher dust risk due to proximity and density of surrounding sensitive receptors.
Greenfield development	District is not anticipated to undergo significant greenfield development
Transport infrastructure	- Potential increase and/or changes in regional distribution of vehicle emissions associated with infrastructure projects, including: - Upgrades to priority travel routes - Cross boarder infrastructure and road connectivity investigations to accommodate housing growth in South Jerrabomberra - Duplication of Athllon Drive and upgrades to the Monaro Highway between Hume and Isabella Drive. - Potential beneficial impacts associated reduction in road vehicle emissions from transport modal shift associated with long term strategic initiative to expand the light rail network. - Potential construction dust risks associated with development of transport infrastructure projects.
Bushfire events	District has a high proportion of existing urban bushland interfaces; where there is a higher perceived air quality risks; associated with bushfires.

10.1.8 Weston District

Table 27 provides a summary of identified air pollution sources from future urban development based on key development requirements identified within the in the Weston District Strategy discussed in **Section 3.2.3.8**. The district is not expected to see substantial levels of new development, with only modest population growth forecast for the region. Potential opportunities investigated within the district will likely focus on employment opportunities and longer term transport initiatives.

Table 27 Summary of air pollution sources from urban development within the Weston District

Source Type	Discussion
Urban renewal	District is not anticipated to undergo significant urban regeneration.
Greenfield Development	District is not anticipated to undergo significant greenfield development.
Transport infrastructure	- Potential increase and/or changes in regional distribution of vehicle emissions associated with infrastructure projects, including: - Upgrades to Streeton Drive intersections. - Longer term strategic objectives to investigate rapid transit connections from Weston Creek to Woden and Molonglo Valley. - Potential construction dust risks associated with development of transport infrastructure projects.
Bushfire events	The southern portion of the district has a high proportion of existing urban bushland interfaces; where there is a higher perceived air quality risks; associated with bushfires.

10.1.9 Woden District

Table 28 provides a summary of identified air pollution sources from future urban development based on key development requirements identified within the in the Woden District Strategy discussed in Section 3.2.3.9.

The Woden District Strategy (ACT Government 2023i) outlines the future development for the district. Future development opportunities are expected to stem from the proposed extension of the light rail network from the City Centre to Woden. Modest population growth is forecasted for the Woden District with an estimated 3,400 dwellings required within the district to meet 2050 population growth projections; increases in higher density dwelling types are marked for this district.

Table 28 Summary of air pollution sources from urban development within the Woden District

Source Type	Discussion
Urban renewal	• Modest redevelopment of brownfield sites and urban renewal required to meet projected housing demand. High density redevelopment anticipated around Woden City Centre and the former Curtain Horse Paddocks. • Replacement of low density housing with medium density housing in existing suburbs around centres and key transit routes; may result in poorer air dispersal conditions including formation of urban canyons. • Potential construction dust risks associated with development. Infill areas and redevelopment sites; likely pose a higher dust risk due to proximity and density of surrounding sensitive receptors.
Greenfield Development	• District is not anticipated to undergo significant greenfield development.
Transport infrastructure	• Potential increase and/or changes in regional distribution of vehicle emissions associated with infrastructure projects, including: - Future planning of Athlon Drive identified as a multimodal transport and urban corridor - Implement upgrades to priority travel routes - Identification of strategies to improve road corridors including Melrose Drive and Hindmarsh Drive - Longer term investigations into future rapid transit connections from Weston Creek to Woden and Molonglo Valley • Potential beneficial impacts associated reduction in road vehicle emissions from transport modal shift associated delivery of Stage 2b of the Canberra Light Rail from Commonwealth Park to Woden.. • Potential construction dust risks associated with development of transport infrastructure projects.
Bushfire events	• The western portion of the district has a high proportion of existing urban bushland interfaces; where there is a higher perceived air quality risks; associated with bushfires.

10.2 Influence of Climate Change on Future Urban Development

The climate change influences most applicable to influencing future urban development would be due to changes in temperature and the number of high fire danger days. As detailed in **Section 9.1.1**, daily average, minimum and maximum temperatures are projected to increase in the near future and far future across the entire ACT. Likewise, high fire danger days are also projected to increase during summer and spring. Increased temperatures increase the demand for cooling, and increased fire danger can influence the way urban development is planned and constructed. Heat and fires can influence urban planning with more time planned to be spent indoors in air conditioning and therefore have more facilities more angled towards indoor experiences, such as indoor sports as opposed to outdoor sports.

Maximum and minimum temperature increases for both near and far future projections are uniform across the entire ACT (refer Figure 77), and therefore the effects to urban development are expected to be common for all urban areas. Minimum temperatures are projected to increase more in the south-western alpine region of the ACT, however the impacts to urban development are negligible as that area is not urbanised. Heat can influence urban planning with more time planned to be spent indoors in air conditioning and therefore have more facilities designed for indoor experiences, such as indoor sports as opposed to outdoor sports.

Temperature inversions are projected to increase in frequency and strength, however decrease in duration. As inversions setup atmospheric conditions where air pollution can not effectively disperse, it is likely an increase in temperature inversion frequency and strength may result in a reduction in air quality during the cooler months, compounding the issues which are already experienced in the ACT, namely wood smoke accumulation in the Tuggeranong district during cool nights. To adapt to the projected increase in temperature inversions, a reduction in emissions would be the best way to improve air quality. As domestic wood heaters are considered a major source of emissions during cool periods, government policy to further restrict or ban domestic wood heaters would likely be the most effective way to control emissions.

Fire danger days are projected to increase the most in spring and summer, with the highest increases to the north of the ACT, where urban areas are already existing and set to increase in population, refer **Figure 81**. Adapting to increased fire danger days would likely influence urban development by implementing measures to reduce vulnerability to fire and increase fire resilience. Such measures, as suggested by Gonzalez-Mathiesen and March, 2014, could include urban planning policy which includes :

- Consideration the landscape's likelihood to experience bush fire impacts, such as proximity to vegetation and fire transport routes. For example, an area located downwind or uphill of a vegetated area could be an increased fire risk zone.
- Implementation of separation distances which consider topography and vegetation.
- Policy for management of vegetation and other fuel sources.
- Policy for management of urban density and structure design (building standards) in areas identified as being fire prone.
- Consideration of the availability and capacity of emergency services such as fire and ambulance. Procedures for emergency services may need to differ in areas identified as being fire prone.
- Water resilience planning to ensure water availability for fire fighting in areas identified as being fire prone.

Similar to increased temperature, increased risk of fire can influence urban planning with more time planned to be spent indoors in air conditioning and therefore have more facilities more angled towards indoor experiences.

11.0 Summary of Findings

Overall, the findings of the study were as follows:

- Existing air pollution levels:
 - A clear diurnal pattern of PM_{2.5} particulate concentrations was observed for the Monash and Florey monitoring stations. PM_{2.5} concentrations peaked at night and fell during the daytime. This pattern was observed for the Civic monitoring station but was not as pronounced.
 - There is a clear trend observe for PM_{2.5} particulate concentrations increasing significantly during the colder months. As with the diurnal trends, this was a strong observation for Monash and Florey and much less obvious for the Civic monitoring station.
 - PM₁₀ trends were not as pronounced as those observed for PM_{2.5}. Diurnal variation was similar to the trend observed for PM_{2.5} but was less pronounced.
 - The Civic PM₁₀ diurnal monitoring results were different in trend to the results from the other stations, showing a generally flat diurnal curve with lower concentrations around 6am and higher concentrations around 10am and 8pm.
 - There is also no clear trend for higher PM₁₀ particulate concentrations during the colder months, matching the PM_{2.5} observations. This suggests a source of PM_{2.5} that is different to the sources of PM₁₀. This is in line with domestic wood fired heaters which would be expected to produce a higher proportion of PM_{2.5} during combustion. This would also be exacerbated by more efficient heaters which more efficiently burn the larger particulate which could result in a higher proportion of PM_{2.5} particulates than PM₁₀ particles.
 - Nitrogen dioxide concentrations show a very consistent diurnal pattern for Monday to Friday followed by a decreased concentrations for Saturdays and Sundays. This trend was observed for all three stations but was most pronounced at the Civic monitoring location. This trend suggests that the primary source of the pollution is motor vehicles in and around the suburbs of Monash and Florey and particularly at the Civic monitoring location where there would be expected to be a larger number of vehicles using the carpark adjacent to the monitoring station.
 - There is a clear increase in NO₂ concentrations during the colder months of the year, with concentrations increasing significantly in April and peaking in May (but staying high until around September). There are several possible reasons for this ranging from higher heating loads during cooler conditions leading to higher NO₂ concentrations (this could be a signal of higher domestic wood heater usage in winter) to poorer combustion vehicle performance in winter resulting in higher NO₂ emissions. Photochemical reactions in the atmosphere are also slower in cooler conditions due to atmospheric temperatures and less intense sunlight, which can decrease the reaction time for the NO₂ degradation.
 - The different criteria values used for the analysis showed that the criteria used had a significant effect on the compliance levels. The use of the 2022 NEPM criteria resulted in significantly less short-term exceedances than the 2025 NEPM criteria (for PM_{2.5} only). Despite the additional exceedances, the recent annual average concentrations complied with the 2025 NEPM criteria. The WHO criteria resulted in a significantly higher number of short term and annual average exceedances. These criteria are quite low and should only be considered as part of a thorough review of the benefits and cost of implementing these criteria.
- Micrometeorology findings included the following:
 - The urban areas of ACT have an effect on the wind speed and direction of the microclimate. Wind speeds are generally lower than areas outside of the urban land use areas. With the change in speed, the urban areas also appear to change the direction of the air flow across the urban areas
 - Under light wind speeds from the south (predominant wind condition during nighttime), air flow appears to either direct air from the Tuggeranong district either to the northwest toward the

WEIA or Weston Creek areas or to the north to north-northeast toward Woden Valley, Inner South and Inner North and City districts.

- There are wind flows observed where winds under low winds speeds are directed along the Murrumbidgee River valley toward the north. These conditions may be affected by katabatic drift as cool air in winter falls down the valleys from the Tuggeranong and Woden Valley areas to the north or west toward the Inner south or WEIA areas. This katabatic air movement is observed during very low wind speed conditions and would be expected to result in the transport of woodsmoke laden air under poor dispersion conditions (katabatic drift does not have significant vertical mixing occurring with the movement of air).
- The northern suburbs around Belconnen and Gungahlin do not appear to affect the wind flow as much as the southern suburbs and have wind conditions broadly similar to the conditions in the larger district. There is some evidence of katabatic drift to the western edge of Belconnen closer to the Murrumbidgee River valley, but is less noticeable than for the southern districts around Tuggeranong.
- Pollution Transportation (dispersion modelling)
 - When considered from a high level, as an overall picture, the air pollution transport for the ACT urban areas showed a clear south to north transportation pattern. Pollution generated at Tuggeranong tended to move norther or northwest leading through either the Woden Weston Creek districts toward the Inner south district or to the northwest toward the WEIA.
 - Pollution moving through the inner south district was funnelled between the Black Mountain and Mt Ainslie elevated terrain channelling pollution into the inner north district. Pollution then migrated further north toward Gungahlin.
 - Pollution moving through the WEIA and being generated within the Molonglo Valley appeared to move along the Murrumbidgee River valley toward Belconnen. The pollution didn't appear to move into the older established areas of Belconnen but rather was transported around the western edge of the district (where new development is currently occurring).
- Climate change influences can be summarised as follows:
 - NARClIM projects for the ACT include an increase in temperature of between 0.66 to 2.0°C over the near to far term projections. This would result in an increase of between 1.8 to 6.2 additional days above 35°C and a decrease in cold days (days less than 2°C) of between 13.1 to 42.5 days.
 - Rainfall is projected to decrease by 2.8% to 0.4% over the year over the near to far term projections.
 - The climate change is expected to result in better day-time convective mixing but conversely, an increase in potential inversion conditions due to the combination of warmer upper air coupled with cooler air conditions close to the ground within the ACT urban areas. This finding seems counterintuitive and should be tested over time for accuracy.
 - NARClIM projects for the ACT an increase in high fire danger days. While high fire days have the potential to result in significant increases in short term air pollution levels, they are unlikely to influence the emission of pollution from domestic wood fires which occur in winter when fire days are much less likely to occur.

12.0 Recommendations

12.1 Future urban planning

Every development project will, to some degree, affect the local air quality. This impact is determined by several factors such as the nature, location, and design of the development. Consideration of air quality issues at the planning stage can ensure a strategic approach to air quality and potentially minimise local air quality impacts.

When considering how to reduce air pollution, there are several considerations that need to be included. The following sections outline air pollution strategies that can be adopted to decrease air pollution levels in urban areas. These strategies focus on existing urban areas, urban development areas and undeveloped urban areas

Strategies that can be adopted for existing urban areas to decrease air pollution levels are as follows:

- **Public Transportation Enhancement:** Improve and expand public transit systems to reduce reliance on private vehicles. Encourage the use of bicycles and walking through better infrastructure and safety measures.
- **Emission Control Policies:** Implement stricter emission standards for vehicles and industries. Introduce low-emission zones where only vehicles meeting specific emission criteria are allowed.
- **Develop Green Spaces and Urban Forests:** Increase the number of parks and green belts to act as air filters and improve air quality. Promote rooftop gardens and green walls to enhance urban greenery.
- **Renewable Energy Adoption:** Encourage the use of renewable energy sources such as solar and wind. Provide incentives for installing solar panels on residential and commercial buildings.
- **Industrial Emission Regulation:** Implement regulations to control industrial emissions. Encourage industries to adopt cleaner technologies and practices.
- **Public Awareness Campaigns:** Conduct campaigns to educate the public on reducing pollution, such as carpooling and reducing energy consumption.

Strategies that can be implemented in Urban Development Areas include:

- **Sustainable Urban Planning:** Design cities to minimize commuting distances and promote mixed-use development. Incorporate green building standards and energy-efficient infrastructure from the start.
- **Integrated Public Transport Systems:** Plan and develop integrated and accessible public transport networks. Include bike lanes and pedestrian-friendly pathways.
- **Green Infrastructure:** Plan for ample green spaces and tree planting in new developments. Use permeable materials for sidewalks and roads to reduce heat and improve air quality.
- **Clean Energy Infrastructure:** Ensure that new developments have allowances for infrastructure for renewable energy sources. Promote the use of electric vehicles by installing charging stations.
- **Waste Management Systems:** Implement efficient waste management systems to reduce landfill emissions. Encourage recycling and composting to minimize waste.

Strategies that can be implemented in Undeveloped Urban Areas include:

- **Preservation of Natural Areas:** Protect existing natural areas to serve as pollution buffers. Designate conservation areas and prevent deforestation.
- **Strategic Urban Planning:** Plan for low-density, eco-friendly development to minimize environmental impact. Use zoning laws to control the type and extent of development.
- **Sustainable Agriculture Practices:** Encourage sustainable agricultural practices to reduce pollution from farming activities. Implement buffer zones between agricultural areas and urban developments.

- **Pollution Monitoring and Regulation:** Establish monitoring stations to track air quality. Implement regulations to prevent pollution from new developments.
- **Ecological Restoration:** Restore degraded areas to improve air quality and biodiversity. Use native plants for reforestation and land rehabilitation projects.

Strategies that can be applied across all development areas include:

- **Air Quality Monitoring:** Regularly monitor air quality to identify pollution sources and trends. Use the data to inform and adjust policies and measures. Based on the analysis of existing monitoring data, the following is recommended:
 1. Install an additional monitoring station within the Weston Creek / Woden Valley / Inner south district to understand the pollution levels in the inner west area of the ACT urban area.
 2. Install an additional monitoring station within the WEIA. This is needed to understand the potential air pollution in this area. Given the residential growth potential of this area, an understanding of the existing pollution would be beneficial in justification for wood smoke bans.
 3. Investigate the potential for relocating the Civic monitoring station. As it is not Australian standard compliant and is located within an urban canyon in a heavily used carpark
 4. Install meteorological sensors at all existing and new pollution monitoring stations. This allows a measure of directionality to be added to the monitoring data.
- **Legislation and Enforcement:** Enact and enforce laws that limit emissions from various sources. Ensure compliance through regular inspections and penalties for violations.
- **Community Engagement:** Involve local communities in decision-making processes regarding air quality. Promote community-led initiatives for pollution reduction.
- **Technology and Innovation:** Invest in research and development of new technologies to reduce emissions. Promote the use of smart technologies for monitoring and managing air quality.

While the above strategies are all relevant to land development within the ACT, there are specific measures that would be expected to disproportionately benefit air quality in the ACT. These areas have been discussed in **Section 12.1.1 to 12.1.3**.

12.1.1 Woodfire heater restrictions

Of the air pollution sources in the ACT, the wood smoke emissions represent the component of air pollution that can be readily implemented to significantly decrease air pollution. Options for decreasing woodsmoke include:

- Extension of wood fired heater installation bans to undeveloped urban areas, greenfield sites and redevelopment sites. Given that there is a clear understanding of the negative effects of woodsmoke in the ACT, it is considered critical that new development areas implement bans on domestic wood heaters early in the district planning stages, similar to those implemented to Dunlop, East O'Malley the Molonglo Valley (excluding Wright).
- It is difficult to implement bans on existing wood heaters in urban areas that have them, as the wood heaters were installed as per the policy at the time and there are financial implications on the community for such a ban. However, there are a range of options available for consideration for existing urban areas, such as:
 - **Restrictions on wood heaters:** There are several restriction options for areas where wood heaters are prevalent, which could be adopted and over time would reduce the prevalence of wood heaters in older areas of the ACT. Options that could be considered include:
 - Banning of the installation of second-hand wood heaters.
 - Banning of the installation of new or replacement wood heaters.
 - Legislate the requirement to remove wood heaters when a residence is sold.

- **Education and Awareness programs:** There are existing ACT community awareness programs such as 'Burn Better, the Wood Heater Removal Program, and the prohibition of wood heater installation in select suburbs and regulation of firewood merchants.

With the ever growing public awareness around the effect of air pollution on health, these community programs could be reworked to further raise awareness in the community about the health and environmental impacts of wood smoke. This can be achieved through community workshops, preferably during periods where wood smoke impacts are noticeably high to encourage higher community engagement, and through the provision of easy-to-understand information on proper wood-burning techniques to minimize smoke production and the health effects of the woodsmoke on different sectors in the community i.e. those with asthma or cardiovascular disease are often badly affected by woodsmoke even if living in houses that are not generating that smoke. Educate residents on the benefits of using seasoned (dry) wood and proper storage.

- **Regulatory measures:** Over time, burn bans and restrictions on the use of wood heaters should be implemented. These may include:
 - Temporary or permanent bans on wood burning during certain weather conditions (e.g. inversions, high pollution days).
 - Enforcing of "no-burn" days when air quality is forecasted to be poor.
 - Implementation and enforcement of tighter emissions standards for existing wood-burning appliances.
 - Require the use of EPA-certified wood stoves and heaters.
- **Provide grants and incentives:** Grants have historically been used in the ACT (eg: wood heater replacement program). As above with the community education programs, these measures could be reviewed and potentially implemented with more effective incentives provided to either improve energy efficiency of existing houses through the retrofitting of ceiling and underfloor insulation or towards the cost of energy efficient heaters that do not use wood as a fuel. In addition, there is the option to offer rebates or tax credits for the purchase or installation of certified wood stoves or alternative heating systems.
- **Provide alternatives to wood burning:** Encourage the use of electric heating and cooking instead of wood or gas.
- **Air Quality Monitoring:** Install air quality monitoring stations to more closely track wood smoke levels and identify pollution hotspots and areas of pollution migration. This data can then be used to inform policy decisions and enforce regulations as discussed above. When installing pollution monitoring equipment, it is also vital to install meteorological data collection equipment as meteorology is crucial to the transport or accumulation of pollution across the ACT. Better understanding of meteorology would aid in the planning of regulatory actions.
- **Inspection and Compliance Programs:** With the implementation of regulatory action, it is vital to ensure that there is a regulatory enforcement process in place to ensure regulatory requirements are implemented. While this would need to be carefully timed and implemented, violators of the regulatory restrictions would need to be punished to deter non-compliance.
- Urban development areas are those areas with the ACT where urban intensification is expected to occur. While not as simple to implement as a ban on undeveloped urban areas, when areas are being redeveloped, a mix of the requirements listed above should be considered. Where possible the solutions should focus on the Avoid / Minimise / Mitigate approach, with the solutions focused as follows:
 - **Extend wood heater ban:** This would require the implementation of a ban on the installation of new wood heaters in areas zoned for urban intensification. Only new development within these zones would be subject to the ban. This would need to be carefully planned through the assessment of air quality impacts against NEPM standards or goals if wood heaters were allowed to be used. Note there may be limitations on what can be banned under existing legislation e.g. if the use of wood fires is included in the zoning development codes or precinct codes.

- All of the measures listed for existing developments are relevant to urban development areas.

12.1.2 Planning and development near busy roads.

The district strategies identify that; particularly for more established districts, such as Belconnen, Inner North, Inner South, Woden urban regeneration; including a shift towards higher density development would be required to meet future housing needs. The transition from lower to high density urban development may result in poorer air dispersal conditions including formation of urban canyons, particularly around busy roads. Planning and design considerations to minimise exposure to vehicle emissions, are presented in **Table 29**.

Table 29 Planning and Design Considerations for Development near Busy Roads

Consideration	Comment
Building Siting, Heights, and Orientation	• Incorporating an appropriate separation distance between sensitive uses and busy roads using broad scale site planning principles such as building siting and orientation. The location of living areas, outdoor space and bedrooms and other sensitive uses (such as childcare centres, hospitals and senior living) should be as far away as practicable from the major source of air pollution. • Building heights adjacent to busy roads should be varied and interspersed with open areas to minimise the formation of urban canyons. • Where possible step back the upper stories of roadside buildings to increase dispersion of air pollutants and minimise cannoning effects of tall buildings close to the road. • Where possible maximise the setback distance from busy roads to facilitate dispersal of air pollutants.
Childcare Centres	• Where new schools and childcare centres are being considered, the design should ensure that there is sufficient separation from busy roads to avoid adverse air quality impacts; particularly in the case of long day-care centres where young children and babies are subject to emissions from morning and afternoon peak traffic. Measures to avoid, reduce or mitigate against air quality impacts at any childcare centres include: - Where possible avoid siting childcare centres on busy roads. - Courtyards or play areas should be protected from adverse air quality impacts by buildings. - Where siting childcare centres on busy roads is unavoidable the layout should be considered to minimise air quality impacts such as orienting non-sensitive services like storage, bathrooms, and car parking in areas subject to air pollution.
Hospitals	• Hospitals should be located to ensure that vulnerable patients or the elderly are not placed in an area subject to adverse air quality impacts. • Should a hospital be naturally ventilated with windows that open to balcony /outdoor areas, the site layout should ensure that the areas used by patients are suitable separated from busy roads or incorporate design features that mitigate air quality impacts to acceptable levels.
Landscaping	• Using vegetative screens, barriers or earth mounds where appropriate to assist in maintaining ambient air amenity. • Landscaping has the added benefit of improving aesthetics and minimising visual intrusion from an adjacent roadway. • Make allowances for vegetated buffer zones along roads where possible, using both low scale planting and large shade trees. • In high density urban areas consider allowances for green roofs on multistorey buildings which may result in potential air quality benefits.
Ventilation	• For ventilation of indoor areas, adjacent to Captain Cook Drive mechanical ventilation air inlet ports should be sited to maximise the distance from the road to reduce inflows of air pollutants.

Consideration	Comment
	The location of open-able windows should be considered in the design of the development located adjacent to the roadway emission sources.
Senior Housing	- Senior housing should be located to ensure that vulnerable patients or the elderly are not placed in an area subject to adverse air quality impacts. - Should senior housing front a main road; layouts should be considered to minimise air quality impacts such as orienting non-sensitive services like storage, bathrooms and carparking in areas subject to air pollution.
Zoning	Where possible propose less sensitive land use for development that will front main road such as open space or for commercial or retail use. Here buildings may act as a barrier that shields and protects highly sensitive areas from high-emission zones.

12.1.3 Green Infrastructure

The strategic placement of green infrastructure (GI) such as open areas and vegetated areas as part of street scaping is an important consideration for urban development areas; particularly in areas identified for urban renewal identified for medium to high density development. Placement of GI can be considered to manage roadside pollutant concentrations at the local scale. However, introduction of GI can either promote or disrupt the dispersion of air pollution by either exerting additional mechanical turbulence or decreasing turbulent kinetic energy. Within urban canyons trees have the potential to reduce wind speeds and reduce air exchange between the air above rooftops and within the canyon leading to the accumulation of pollutants inside the street canyon. For street canyons, the aspect ratio is critical to the appropriate GI form.

Table 30 provides recommendations for suitable green infrastructure without negatively impacting the dispersal of vehicle emissions based on the street aspect ratio; and associated urban canyon classification. Shallow canyons provide more opportunities for a wide array of GI, while GI in deep street canyons should be restricted so poor dispersal conditions are not further exacerbated.

Table 30 Determination of Appropriate Green Infrastructure for Street Canyons Based on Aspect Ratio

Classification	Aspect Ratio	GI Recommendation
Deep Street Canyon	$H/W \geq 2$	Green walls only
Mid-Depth Street Canyon	$H/W 0.5-2$	- Green walls - Low-level vegetation (shrubs and low hedges)
Shallow Street Canyon	$H/W \geq 0.5$	- Green walls - Low-level vegetation (shrubs and low hedges) - Small and open-crowned trees on the windward side of the canyon spaced broadly apart.
Source: Barwise & Kumar 2020		

12.2 Future Studies

Additional studies or future project work recommended to better understand air pollution in the ACT is as follows:

- Development of an ACT-wide meteorology and pollution model to aid in the understand the effects of existing air pollution and pollution transport within the urban areas of the ACT. This should be developed as a live model capable of providing forecast meteorology and pollution levels based on historical understanding of smoke emissions i.e. emission rates based on meteorology.
- Undertake a study to obtain a clear understanding of the numbers of wood heaters and wood stoves in use in the ACT. Currently it is unclear how many are in use in the ACT urban areas making policy decisions harder to implement.
- Additional pollution monitoring stations and meteorological monitoring sensors should be put in place. A new pollution and meteorology station is recommended for WEIA, Woden Valley, Molonglo Valley and Gungahlin areas. Meteorology sensors are recommended for all existing and new stations. Sensors are recommended to measure the following (at a minimum):
 - Wind Speed and direction (including sigma theta)
 - Humidity
 - Rainfall
 - Solar radiation
 - Temperature (at 2 and 10m)
 - Atmospheric pressure
 - PM₁₀ and PM_{2.5}

The location of these stations should be confirmed using meteorological and pollution modelling to ensure their siting is ideal for the urban area.

Note the recommended monitoring stations are not required to be NEPM stations as the key data of importance to the ACT airshed is particulates and meteorology. The stations should be sited as close as practical to AS3580.14:2014 Methods for sampling and analysis of ambient air Meteorological monitoring for ambient air quality monitoring applications to ensure the best possible data.

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- ACT Government (2023f) *Part Six Molonglo Valley District Strategy, District Strategies 2023, Volume Two Distinct Strategies*, ACT Government Canberra
- ACT Government (2023g) *Part Seven Tuggeranong District Strategy, District Strategies 2023, Volume Two Distinct Strategies*, ACT Government Canberra
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Appendix A

District Strategies

Appendix A District Strategies

The ACT Planning Strategy 2018 (the Planning Strategy) informs policy development and investment in Canberra and its districts. The strategy provides a vision for a more compact and efficient city and a strategic direction that the future urban growth will be supported by delivering up to 70% of new homes within Canberra's existing urban footprint.

There are nine districts within Canberra and each one has their own strategy. The strategies help direct forecasted growth towards 2038 and beyond 2050 to areas of Canberra that are best suited for it. They also outline what future services, transport and infrastructure is needed in those areas.

An overview of change areas and key sites for each District Strategy are described below. Change areas and key sites are loosely categorised based on current knowledge of individual sites and their immediate surrounding areas and are defined as follows:

- **Category 1** – Change areas where detailed planning can proceed, consultation needs to occur, and change could happen within 0-5 years.
- **Category 2** – Change areas where detailed planning can proceed, consultation needs to occur, and change could happen within 0-10 years.
- **Category 3** – Change areas where detailed planning can be considered, consultation needs to occur, and change could happen within 0–15 years.

In addition to change areas and key sites a summary of potential urban regeneration areas and supporting transport infrastructure requirements.

Belconnen District Strategy

The Belconnen District is in Canberra's northwest and is the most heavily populated of Canberra's nine districts. The Belconnen District Strategy (ACT Government 2023a) outlines the future development for the district. Future development would focus on infill areas, primarily in and around the Belconnen town centre and other central hubs within the district, Lawson North and in greenfield development as part of the Ginninderry in the west of the district.

The plan includes several change areas and key sites identified for development within the next 15 years as summarised in **Table 31**. The Belconnen District Strategy Plan is also shown in **Figure 82**.

Table 31 Identified Change Areas and Key Sites in the Belconnen District Strategy 2023

Category	Change Area	Key Sites
1	• Ongoing greenfield development in West Belconnen (Ginninderry) and in Lawson south and a Commonwealth Government project at Lawson north. • Proposes Territory Plan amendment at the Belconnen town centre and approved Territory Plan variation at Kippax group centre.	• Site 1 - Belconnen town centre (west) including Westfield Belconnen shopping centre and surrounds identified for greater urban intensification. • Site 5 - Block 71 Section 51 Holt located as part of the former Kippax playing fields and created to enable expansion of the group centre. • Site 6 – Lawson North which contains the former Belconnen Naval transmission station, identified for residential development and cultural or natural conservation purposes. • Site 8 – West Belconnen including the remaining greenfield areas from Macgregor west to the ACT border, identified for future residential development, open space, community, and retail facilities.
2	• ACT Government projects fronting Lake Ginninderra adjoining the town centre. • Commonwealth Government project at CSIRO Ginninderra.	• Site 2 - Belconnen town centre (east) located between Benjamin Way and the lake shore, including the Emu Bank identified for further development including community and retail facilities and public space. • Site 7 – CSIRO Ginninderra the former CSIRO Ginninderra Experiment Station, which is

Category	Change Area	Key Sites
		approximately 701 hectares and is identified for urban development
3	- Ongoing implementation of University of Canberra Masterplan - A Commonwealth Government project at the Australian Institute of Sport - Two ACT Government sites at Lake Ginninderra (East and West).	- Site 3 - Lake Ginninderra (west), located on the lake shore between the lake and Joynton Smith Drive, marked for new development including new streets, and urban blocks with mixed-use buildings and public domain. - Site 4 - Lake Ginninderra (east), located on the eastern shore of Lake Ginninderra between the lake and Ginninderra Drive marked for development of open space, facilities, and amenities.

An additional estimated additional 21,200 dwellings required within the Belconnen District to meet 2050 population growth projections. Land releases and redevelopment of brownfield sites will not be enough to meet housing needs with a projected shortfall of 14,000 to 15,000 dwellings by 2050 when expected development under existing plans and key sites and change areas identified above are accounted for. Housing density in existing suburbs would need to increase through urban regeneration areas. This includes replacement of low density housing with medium density housing in existing suburbs around centres and key transit routes including town housing, dual occupancies, duplexes, triplexes, and terrace housing.

Additional transport infrastructure would be required within the district to support increased population growth by 2050. This would include:

- Medium term strategic initiatives in the next ten years including:
 - Planning for additional rapid transport connections between Belconnen and Molonglo Valley
 - Investigate and invest in structural transport growth areas in Ginninderry and Kippax
 - Improve freight network and access around Kippax
 - Progressively implement upgrades to priority travel routes between:
 - Southern Cross Drive and Belconnen Way linking Kippax and Belconnen town centre
 - Lake Ginninderra Circuit path and connecting paths to the town centre and Southern Cross Drive via Florey
- Long term strategic initiative within the next 20 years to investigation and deliver the light rail network to Belconnen town centre including connecting the City Centre and Canberra Airport
- Longer term strategic initiative in over 20 years' time to investigate additional transport connections between west Belconnen and main employment centres in the east.

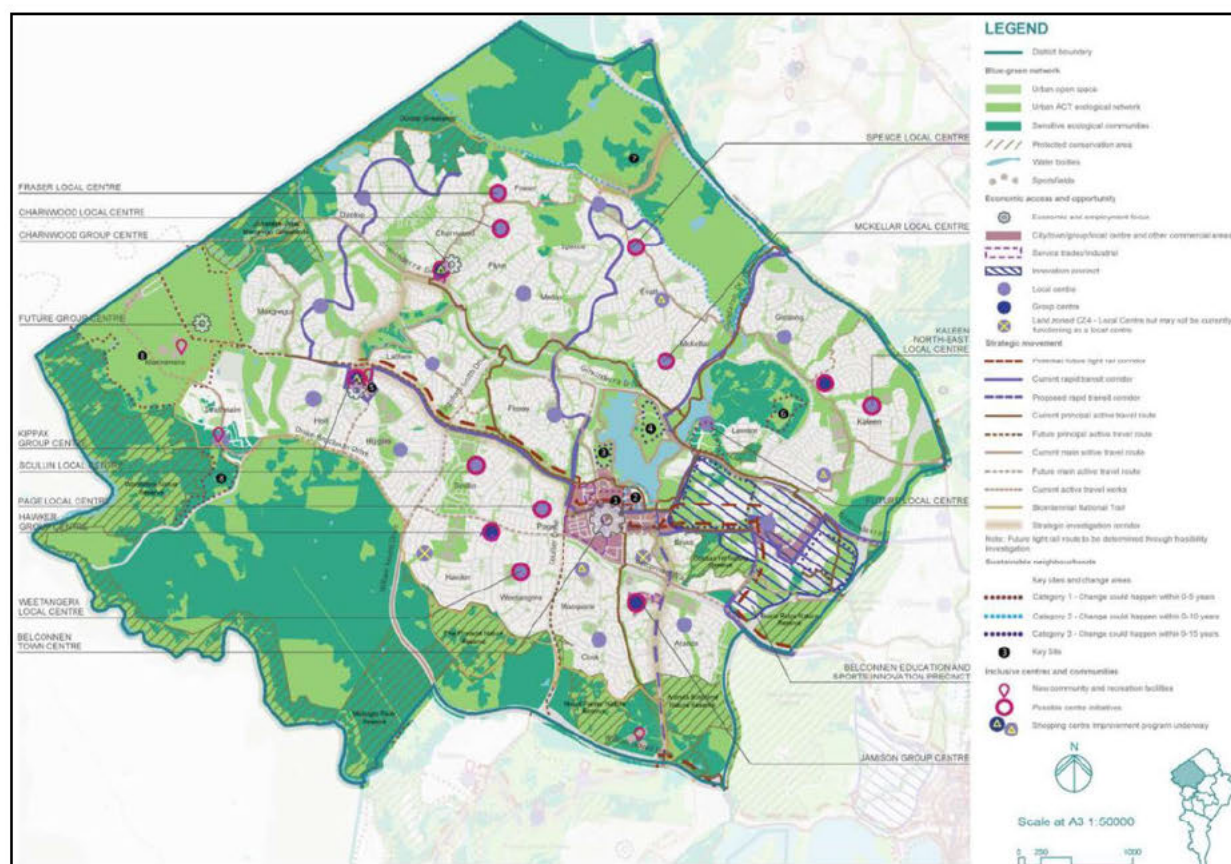


Figure 82 Belconnen District Strategy Plan

Source: Part One Belconnen District Strategy 2023

East Canberra District Strategy

The East Canberra District contains the aviation, freight and business hub of Canberra Airport and is a key employment district while also containing environmentally sensitive areas and threatened flora, fauna and ecological communities. The East Canberra District Strategy (ACT Government 2023b) outlines the future development for the district. Future development would focus on enhancing employment opportunities, while maintaining a modest development footprint to protect environmentally sensitive areas.

The plan includes several change areas and key sites identified for development within the next 15 years as summarised in Table 32. The East Canberra District Strategy Plan is also shown in Figure 83.

Table 32 Identified Change Areas and Key Sites in the East Canberra District Strategy 2023

Category	Change Area	Key Sites
1	- Oaks Estate subject to a Territory Plan variation - Site at Symonston listed in the Indicative Land Release Program	There are no Category 1 key sites.
2	Five locations identified for potential for future change subject to the outcomes of the Eastern Broadacre studies and the Strategic Assessment of environmental values	There are no Category 2 key sites.
3	Site at Symonston identified for further investigation	There are no Category 3 key sites.

East Canberra District does not have any areas that will be investigated for potential urban regeneration.

The district is important for freight, logistics and facilitation of economic activity across the ACT and its gateway role to key industrial areas. Additional transport infrastructure would be required within the district to improve connectivity by 2050. This would include:

- Short term strategic initiatives within the next five years including:
 - Identification and protection of major road and rail corridors
 - Support cross-border infrastructure and road connectivity to accommodate anticipated employment and housing growth East Canberra District does not have any areas that will be investigated for potential urban regeneration.
- Medium term strategic initiatives in the next ten years including:
 - Planning for expansion of the light rail network
 - Investigate improvement to public transport access to East Canberra, from Inner South Hume and Tuggeranong District.
- Longer term strategic initiative in over 20 years' time to investigate potential for high speed rail connection through the district.

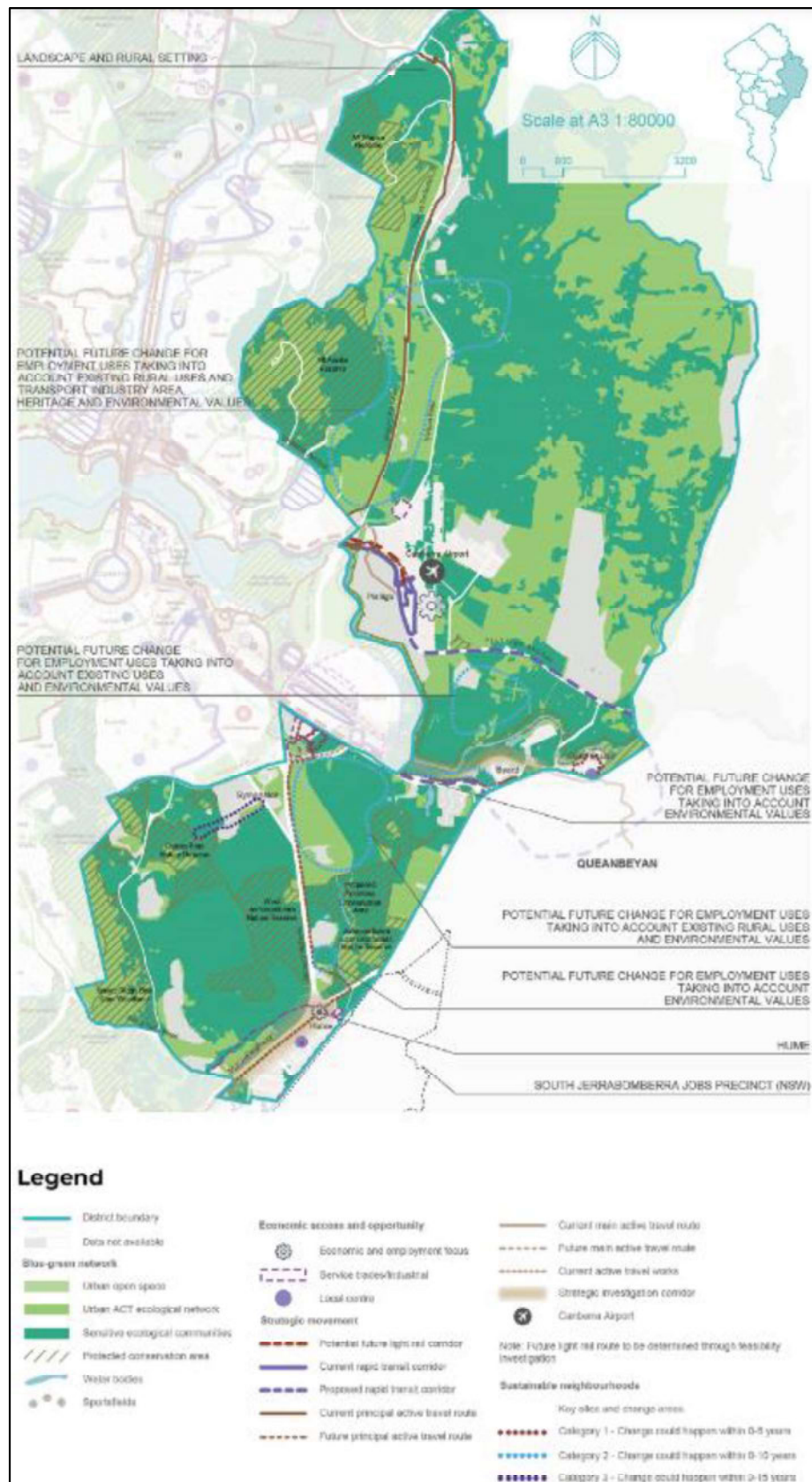


Figure 83 East Canberra District Strategy Plan

Source: Part Two East Canberra District Strategy 2023

Gungahlin District Strategy

The Gungahlin District is in Canberra's northern most district and the ACT's major greenfield growth area over the past thirty years, including new suburbs Taylor and Jacka in the north and the soon to be established suburb of Kenny in the southeast. As one of the newer districts, Gungahlin has more compact forms of development and street layouts, though this differs between suburbs depending on when they were established. The district also houses a light industrial estate in the suburb of Mitchell. The operation of Stage 1 of the Canberra light rail network from Gungahlin town centre to the City Centre has stimulated housing growth and development along the corridor.

The Gungahlin District Strategy (ACT Government 2023c) outlines the future development for the district. The plan includes several change areas and key sites identified for development within the next 15 years as summarised in **Table 33**. The Gungahlin District Strategy Plan is also shown in **Figure 84**.

Table 33 Identified Change Areas and Key Sites in the Gungahlin District Strategy 2023

Category	Change Area	Key Sites
1	Five ongoing greenfield areas and Indicative Land Release Program sites at Casey, Taylor, Jacka, Kenny and the Gungahlin town centre	No Category 1 key sites identified.
2	Two rural blocks identified for future planning and investigations are required.	- Site 3 – Rural Block 800 Gungahlin marked for improved access and conservation of sites cultural and ecological values. - Site 4 – Rural Block 348 Gungahlin, conservation and enhancement of heritage and environmental values associated with Gungahlin Homestead and Landscape.
3	Two rural blocks identified for future development associated with the adjoining exhibition park in Canberra complex	- Site 1 – Rural Block 466 Gungahlin directly associated with Exhibition Park in Canberra (EPIC) currently used as parking, future development to be co-ordinate with future use of EPIC. - Site 2 – Rural Block 765 Gungahlin associated with EPIC currently used as parking, future development to be co-ordinate with future use of EPIC.

An additional estimated additional 17,900 dwellings required within the Gungahlin District to meet 2050 population growth projections. Land releases will not be enough to meet housing needs with a projected shortfall of 2,000 to 2,500 dwellings by 2050 when expected development under existing plans are accounted for. Housing density in existing suburbs would need to increase through urban regeneration areas. This includes replacement of low density housing with medium density housing in existing suburbs around centres and key transit routes including town housing, dual occupancies, duplexes, triplexes, and terrace housing.

The establishment of light rail from the town centre to the City Centre has been the most significant public transport project within Gungahlin District and patronage is expected to increase over the coming years. Ongoing capacity for freight and heavy vehicles on key roads into Mitchell to support its industrial and urban services function is expected to be maintained including the potential for extension of Morisset Drive to the Federal Highway to reduce road pressures and heavy vehicle traffic on Flemington Road. Other strategic transport initiatives identified for the district include:

- A short term initiative within the next five years to investigate progressive upgrades to priority active travel routes including along the Barton Highway adjacent to Palmerston and Crace, along Flemington Road and within Franklin and Gungahlin town centre.
- A medium term initiative within the next ten years to investigate new rapid transport services to the northern suburbs of the Gungahlin district connection the town centre to group centres in Casey, Moncrief and Amaroo.

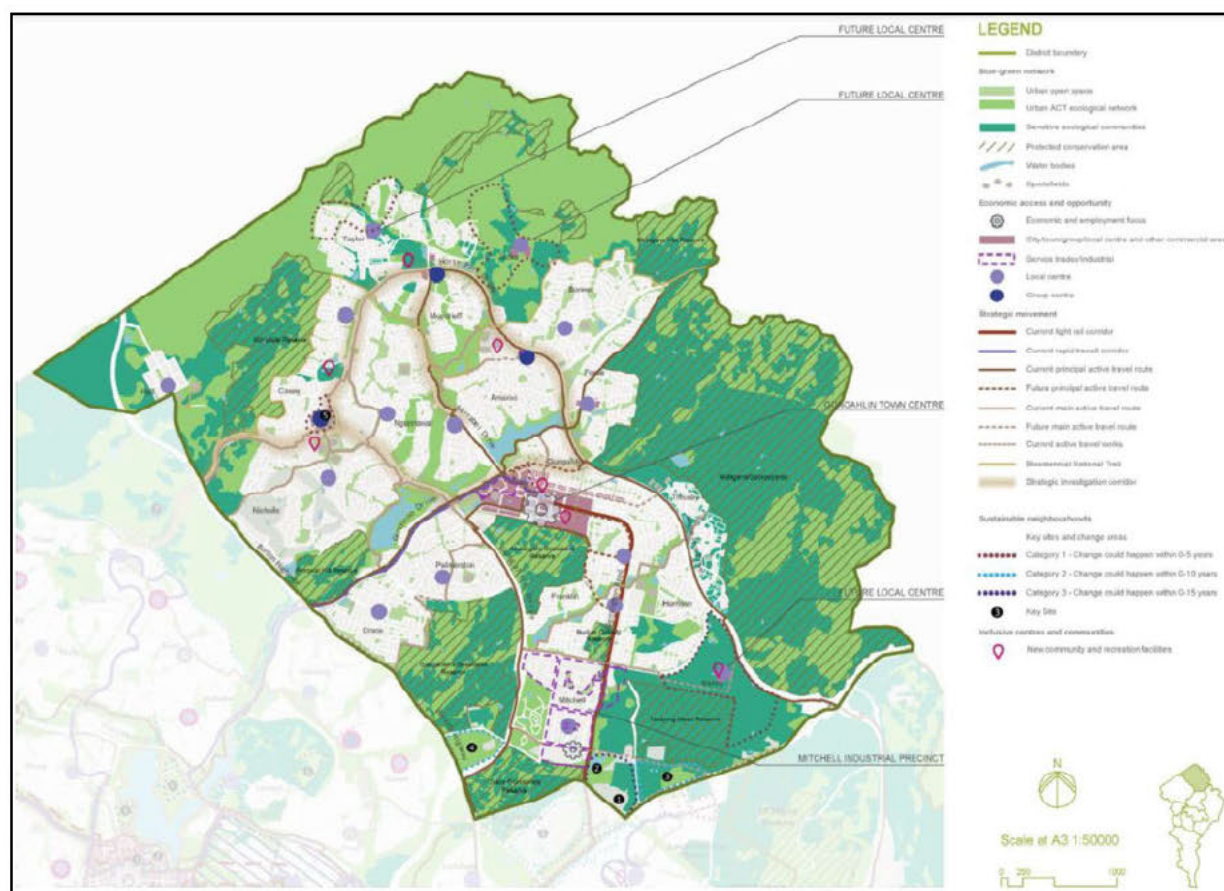


Figure 84 Gungahlin District Strategy Plan

Source: Part Three Gungahlin District Strategy 2023

Inner North and City District Strategy

The Inner North and City District is centrally located immediately north of Lake Burley Griffin. There is a central spine along Northbourne Avenue from the lake through to the Federal Highway and the ACT border with NSW to the north. The district is highly urbanised and includes the City Centre and several established suburbs. The Inner North District Strategy (ACT Government 2023d) outlines the future development for the district. The district has seen significant population growth and development in recent years catalysed in part by the light rail corridor linking the Gungahlin District to the City Centre.

The plan includes several change areas and key sites identified for development within the next 15 years as summarised in **Table 34**. The Belconnen District Strategy Plan is also shown in **Figure 85**.

Table 34 Identified Change Areas and Key Sites in the Inner North District Strategy 2023

Category	Change Area	Key Sites
1	- Four proposals for Territory Plan amendments along Northbourne Avenue and a site at Watson. - Indicative Land Release Program Sites at Watson - Two sites subject of the National Capital Plan including Acton Waterfront and the University of New South Wales Reid Campus	There are no Category 1 key sites
2	Proposal for Territory Plan amendments at Thoroughbred Park.	Site 1 – Thoroughbred Park racecourse and surrounds, future development aimed at promoting active fronts to Federal Highway, Flemington Road

Category	Change Area	Key Sites
	Three ongoing ACT Government planning projects relating to Ainslie Avenue, the City and Gateway Urban Design Framework	and light rail as well as enhancement of community centre and promotion of higher density housing close to rail stops.
3	- Future planning and investigations for the Exhibition Park in Canberra site - Territory Plan amendment proposal for Ainslie Football Club	There are no Category 3 key sites

An additional estimated additional 24,000 dwellings required within the Inner North District to meet 2050 population growth projections. Land releases and redevelopment of brownfield sites will not be enough to meet housing needs with a projected shortfall of 6,000 to 7,000 dwellings by 2050 when expected development under existing plans and key sites and change areas identified above are accounted for. Housing density in existing suburbs would need to increase through urban regeneration areas. This includes replacement of low density housing with medium density housing in existing suburbs around centres and key transit routes including town housing, dual occupancies, duplexes, triplexes, and terrace housing.

Additional transport infrastructure would be required within the district to support increased population growth by 2050. This would include:

- Short term strategic initiative within the next five years to deliver Stage 2a of the Canberra Light Rail from Alinga Street to Commonwealth Park.
- Medium term strategic initiative in the next ten years to continue investigations and planning for future light rail corridors including a potential link between Belconnen, Russel and Canberra Airport.
- Long term strategic initiatives within the next 20 years to:
 - Undertake detailed planning for the City Centre and its future as a multimodal transport hub
 - Investigate options for increasing the capacity of the public transport network to relieve demand pressures including Northbourne Avenue Corridor linkages.

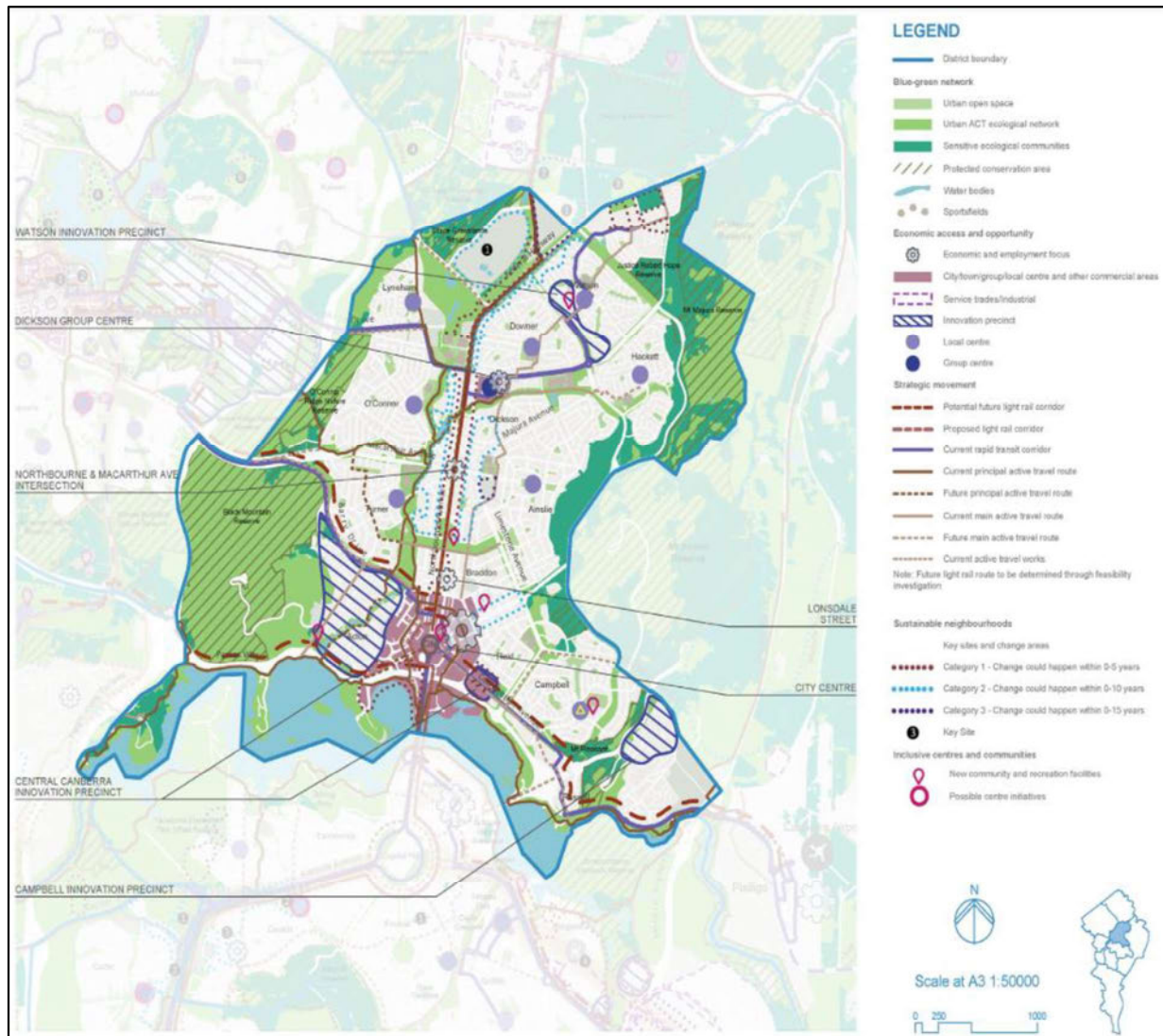


Figure 85 Inner North District Strategy Plan

Source: Part Four Inner North District Strategy 2023

Inner South District Strategy

The Inner South District is one of ACT's most established districts, extending from the Fyshwick industrial precinct in the east to Yarralumla and Deakin in the west. The Inner South District Strategy (ACT Government 2023e) outlines the future development for the district. The construction and operation of the proposed Stage 2b Canberra Light Rail Project extending from Commonwealth Avenue to Woden is expected to bring a positive transformation of the district.

The plan includes several change areas and key sites identified for development within the next 15 years as summarised in **Table 35**. The Inner South District Strategy Plan is also shown in **Figure 86**.

Table 35 Identified Change Areas and Key Sites in the Inner South District Strategy 2023

Category	Change Area	Key Sites
1	- Two sites for Territory Plan amendments at Deakin and Fyshwick - Yarralumla estate development plan - A site in Fyshwick on the indicative Land Release Program - East Lake Place Plan	Site 4 – East Lake urban renewal precinct marked for mixed development including community facilities and affordable housing as well as promotion of public transport corridor
2	ACT government projects associated with the proposed light rail corridor from the City Centre to Woden and at Fyshwick East	Site 1 – Section 19 Forest, marked for improved access and landscaping. Site 2 – Deakin Local Centre, marked for enhancement of community and retail facilities and promotion of connectivity between the local centre and future light rail corridor. Site 3 – West Deakin, enhancement of the area as an employment hub and promotion of connectivity between the Deakin local centre and future light rail corridor.
3	- An ACT Government project along the heavy rail corridor in Fyshwick - National Capital Authority project under the National Capital Plan at the former CSIRO Forestry site at Yarralumla	There are no Category 3 key sites

An additional estimated additional 7,000 dwellings required within the Inner South District to meet 2050 population growth projections. Land releases and redevelopment of brownfield sites will not be enough to meet housing needs with a projected shortfall of 3,500 to 4,000 dwellings by 2050 when expected development under existing plans and key sites and change areas identified above are accounted for. Housing density in existing suburbs would need to increase through urban regeneration areas. This includes replacement of low density housing with medium density housing in existing suburbs around centres and key transit routes including town housing, dual occupancies, duplexes, triplexes, and terrace housing.

In addition to current investigations and future delivery into the Canberra Light Rail from City Centre to Woden additional transport infrastructure would be required within the district to support increased population growth by 2050. This would include:

- Short term strategic initiatives within the next 5 years include:
 - Planning for Canberra Railway Station as a key element of the strategic investigation corridor from Parliamentary zone to Fyshwick
 - Ensure future development control plans around Kingston and Fyshwick support and maintain capacity for freight traffic in the district.
- Medium term strategic initiatives in the next ten years including:
 - Improve public transport connections.
 - Progressively deliver upgrades and additions to cycling network.

- Lake Ginninderra Circuit path and connecting paths to the town centre and Southern Cross Drive via Florey
- Long term strategic initiative within the next 20 years to investigate the long term potential for enhance public transport connections to Fyshwick.

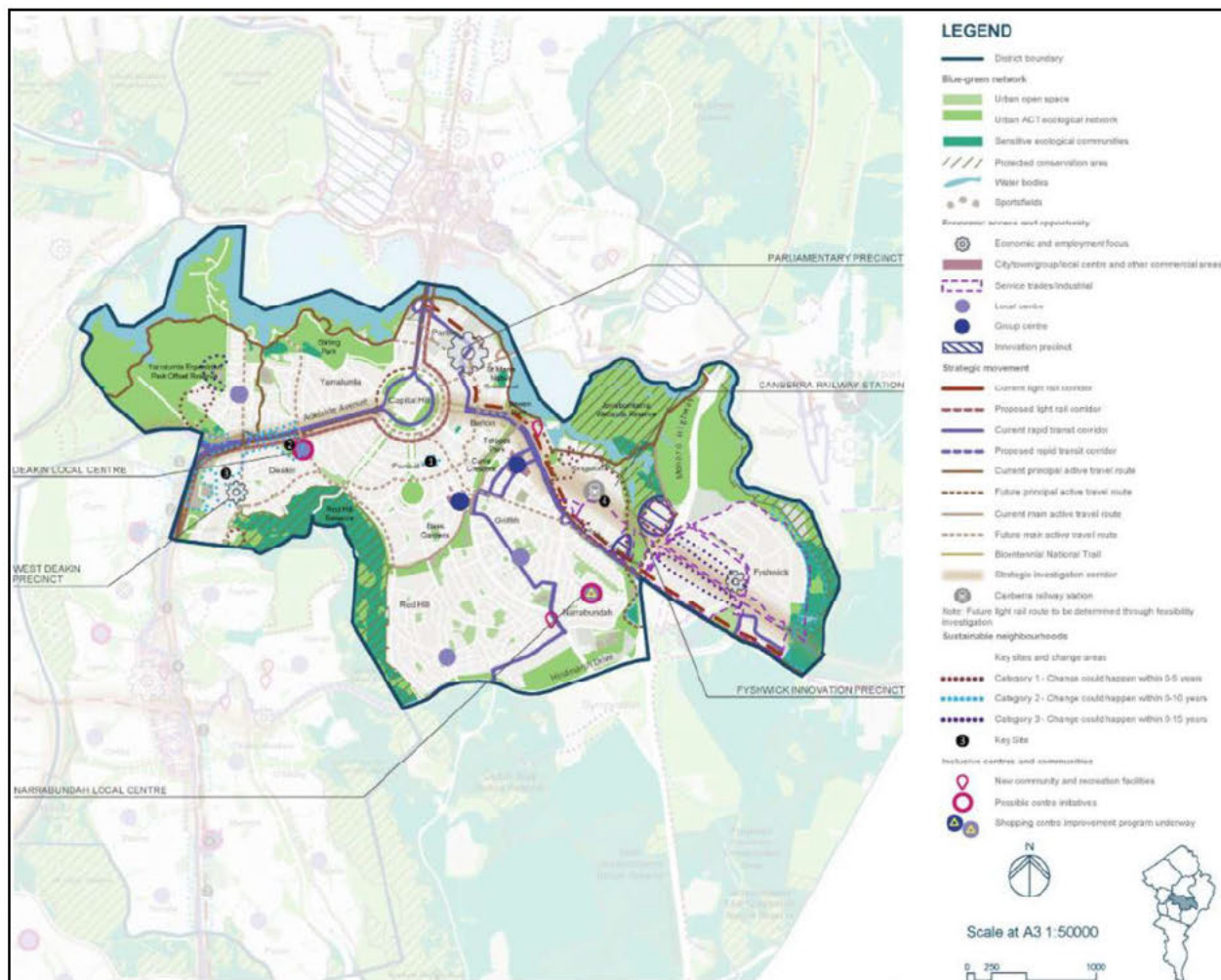


Figure 86 Inner South District Strategy Plan

Source: Part Five Inner South District Strategy 2023

Molonglo Valley District Strategy

The Molonglo Valley District is located less than 10km from the City Centre between the districts of Belconnen and Weston Creek; and is the newest of nine districts and the main greenfield development area within the ACT. It includes the new suburb of Whitlam and other future residential suburbs marked for future development. The suburb of Molonglo will also include the district's main commercial hub. The Molonglo District Strategy (ACT Government 2023f) outlines the future development for the district which will cater for a large proportion of the overall demand for low density detached dwellings in the ACT as well as future medium density residential dwellings including townhouses and apartments.

The plan includes several change areas and key sites identified for development within the next 15 years as summarised in Table 36. The Molonglo Valley District Strategy Plan is also shown in Figure 87.

Table 36 Identified Change Areas and Key Sites in the Molonglo Valley District Strategy 2023

Category	Change Area	Key Sites
1	- Ongoing planning and estate development - planning in the greenfield area as well as sites on the Indicative Land Release Program.	There are no Category 1 key sites
2	Ongoing greenfield planning for areas north of the Molonglo River	There are no Category 2 key sites
3	There are no Category 3 change areas	There are no Category 3 key sites

An additional estimated additional 24,000 dwellings required within the Molonglo Valley to meet 2050 population growth projections. Expected development under existing plans on greenfield sites are expected to meet this housing demands. No urban regeneration areas have been identified under the Molonglo Valley District Strategy.

Current road projects in the road network include construction of the remaining stage of the John Gorton Drive strategic investigation corridor, including a bridge over the Molonglo River. There are also two major road connections into the district including the east-west east–west arterial linking Denman Prospect and the Molonglo group centre in the west to the Tuggeranong Parkway in the east.

Additional transport infrastructure would be required within the district to support increased population growth by 2050 and provide adequate transport infrastructure to new land release areas and connections to other districts. This would include:

- Short term strategic initiatives within the next five years to implement priority upgrades to Molonglo Valley, including connections within the district and priority connections to adjacent districts.
- Medium term strategic initiative within the next ten years to plan for additional rapid transport connections between Belconnen and Molonglo Valley.
- Longer term strategic initiative in over 20 years' time to further enhance and plan for potential enhancements and additions to the rapid transport network to Molonglo Valley.

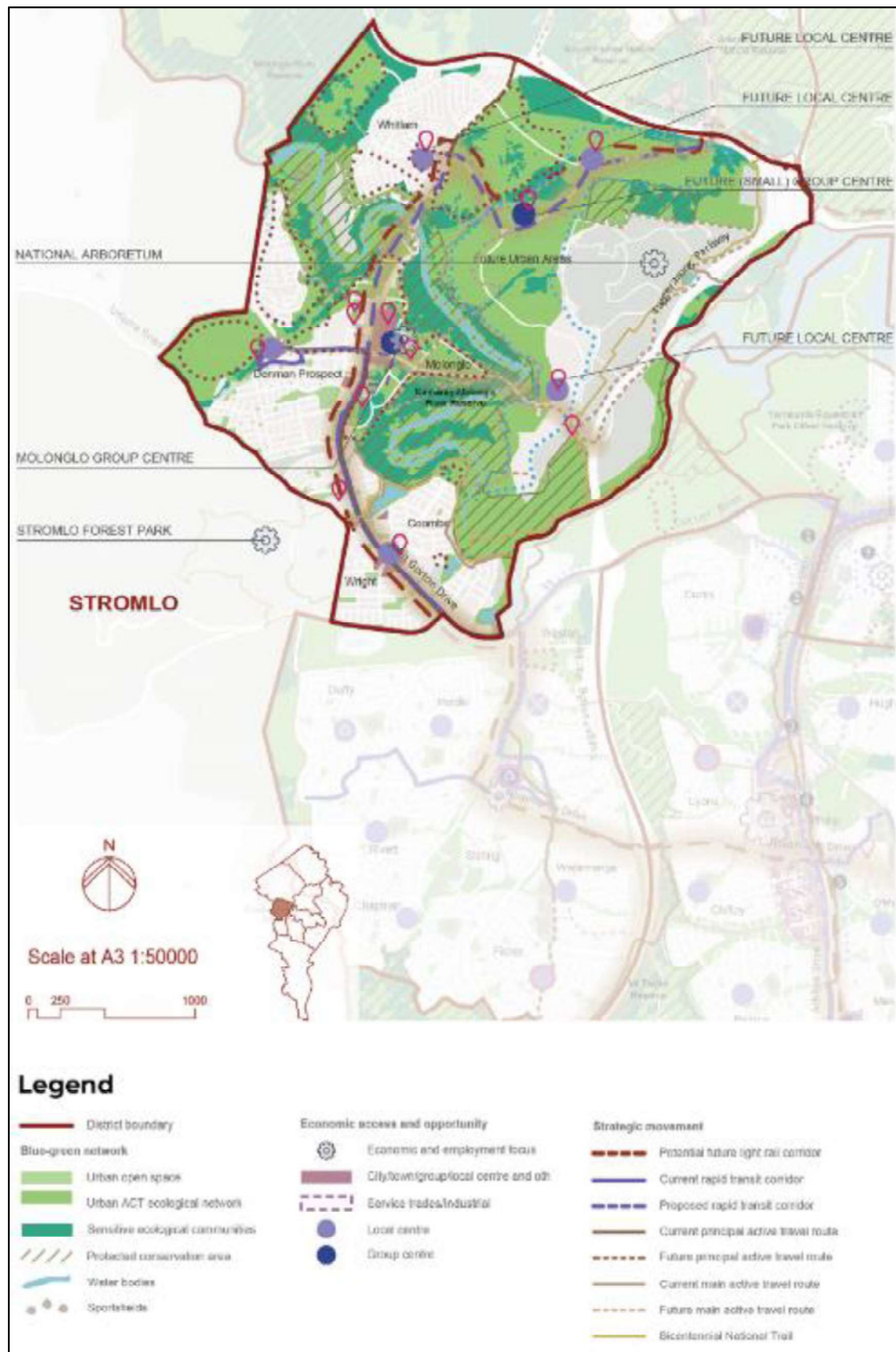


Figure 87 Molonglo Valley District Strategy Plan

Source: Part Six Molonglo Valley District Strategy 2023

Tuggeranong District Strategy

The Tuggeranong District Strategy is the ACT's southernmost and second largest district. The Tuggeranong town centre is the main employment hub the district also has many local and group centres servicing low density residential suburbs. The Tuggeranong District Strategy (ACT Government 2023g) outlines the future development for the district which is expecting moderate population growth.

The plan includes several change areas and key sites identified for development within the next 15 years as summarised in **Table 37**. The Tuggeranong District Strategy Plan is also shown in **Figure 88**.

Table 37 Identified Change Areas and Key Sites in the Tuggeranong District Strategy 2023

Category	Change Area	Key Sites
1	One project related to the new ice sports facility near the town centre	There are no Category 1 key sites
2	- One site related to the Indicative Land Release Program at - ACT Government projects associated with group centres and the town centre.	- Site 1 – Tuggeranong Town Centre, Upgrade of the centre, local area improvements. Identified as rapid transit/light rail corridor intermodal link. - Site 2 – Wanniasa group centre, redevelopment including mixed use blocks and identified for rapid transport, light rail corridor as multimodal link.
3	There are no Category 3 change areas	There are no Category 3 key sites

Modest population growth is forecasted for the Tuggeranong District with an estimated 1,100 dwellings required within the district to meet 2050 population growth projections. Future housing opportunities including expected development under existing plans, identified change areas and key sites and potential urban regeneration areas can provide a housing surplus within the district.

Additional transport infrastructure would be required within the district to support city growth by 2050. This would include:

- Short term strategic objectives within the next five years to:
 - Progressively implement upgrades to priority travel routes
 - Investigate cross boarder infrastructure and road connectivity to accommodate housing growth in South Jerrabomberra
 - Continue with duplication of Athllon Drive and upgrades to the Monaro Highway between Hume and Isabella Drive.
- Long term strategic initiative within the next twenty years to further investigate and deliver the light rail network to Tuggeranong town centre.

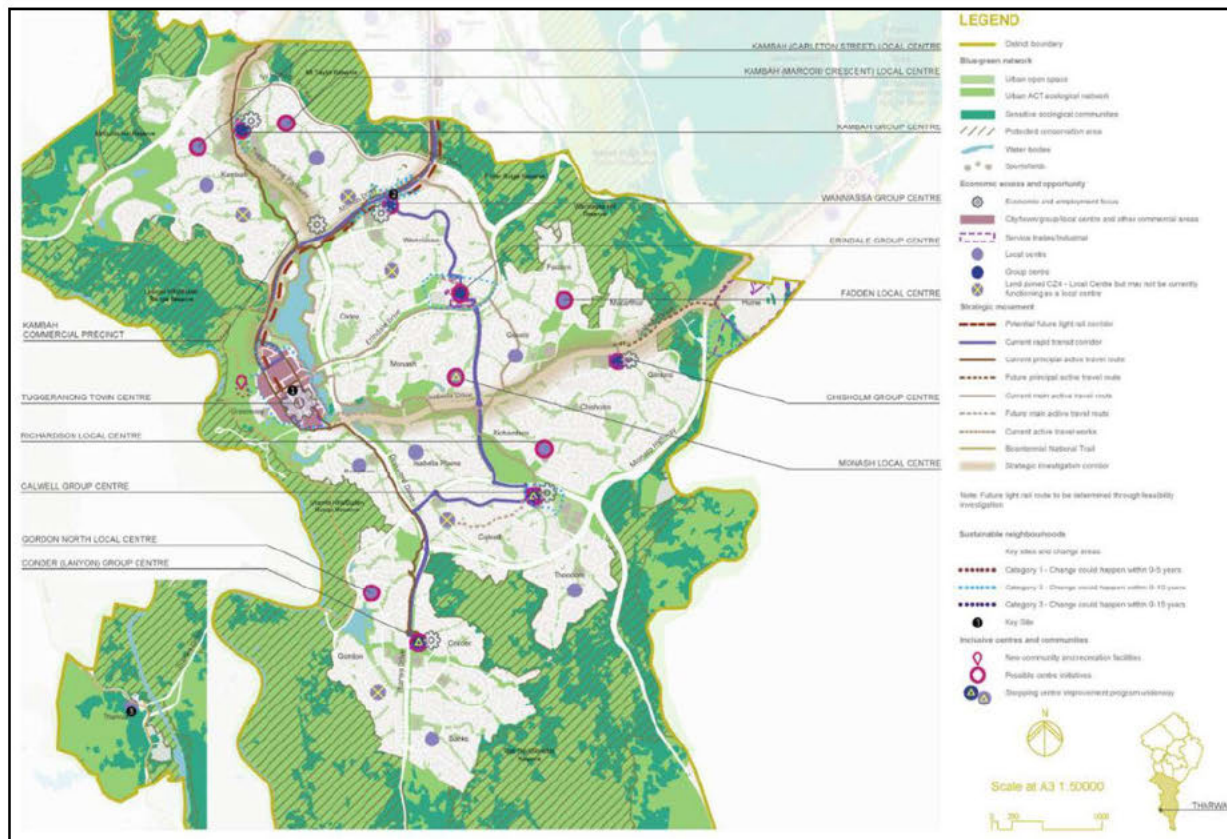


Figure 88 Tuggeranong District Strategy Plan

Source: Part Seven Tuggeranong District Strategy 2023

Weston Creek District Strategy

The Weston Creek District located south of the Weston Creek District is the smallest of ACT's district. It has a largely suburban character and is not expected to see substantial levels of new development, with only modest population growth forecast for the region. Potential opportunities investigated within the district are likely to focus on employment opportunities and longer term transport initiatives.

The Weston Creek District Strategy (ACT Government 2023h) outlines the future development for the district. The plan includes several change areas and key sites identified for development within the next 15 years as summarised in **Table 38**. The Weston Creek District Strategy Plan is also shown in **Figure 89**.

Table 38 Identified Change Areas and Key Sites in the Weston Creek District Strategy 2023

Category	Change Area	Key Sites
1	Two sites subject to development proposals, one of which is being progressed under the National Capital Plan.	There are no Category 1 key sites.
2	Two sites relating to the Indicative Land Release Program.	There are no Category 2 key sites.
3	There are no Category 3 change areas	There are no Category 3 key sites.

Modest population growth is forecasted for the Weston Creek District with only an estimated 300 dwellings required within the district to meet 2050 population growth projections. Future housing opportunities including expected development under existing plans and potential urban regeneration areas can provide a housing surplus within the district.

Additional transport infrastructure would be required within the district to support city growth by 2050. This would include:

- Short term strategic objective within the next five years to deliver upgrades to Streeton Drive intersections.
- A Longer term strategic objective over 20 years or more is to investigate corridors for future rapid transit connections from Weston Creek to Woden and Molonglo Valley.

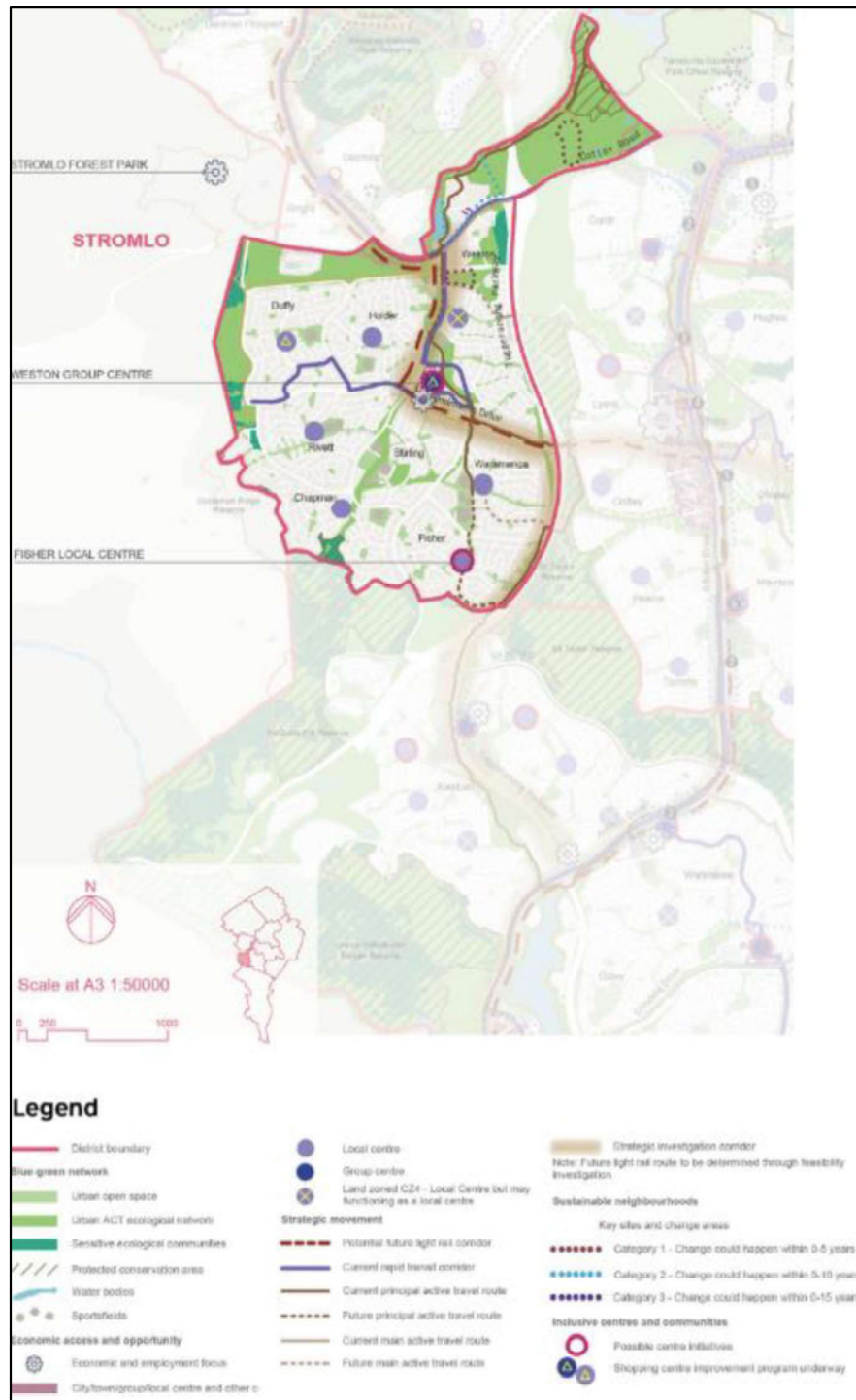


Figure 89 Weston Creek District Strategy Plan

Source: Part Eight Weston Creek District Strategy 2023

Woden District Strategy

The Woden district is located towards the southern end of the ACT, just north of the Tuggeranong District. The district itself houses a relatively small population. Woden town centre is the central employment hub for the district, it also poses a key transport hub for Canberra's South side.

The Woden District Strategy (ACT Government 2023i) outlines the future development for the district. Future development opportunities are expected to stem from the proposed extension of the light rail network from the City Centre to Woden; with population growth and increases in higher density dwelling types marked for this district.

The plan includes several change areas and key sites identified for development within the next 15 years as summarised in **Table 39**. The Woden District Strategy Plan is also shown in **Figure 90**.

Table 39 Identified Change Areas and Key Sites in the Woden District Strategy 2023

Category	Change Area	Key Sites
1	Territory plan amendment at the Federal Golf Course and the new CIT Woden Campus project at the Woden town centre	There are no Category 1 key sites.
2	Planning for growth and change along the future light rail corridor from the City Centre to Woden and along the Athllon Drive corridor	- Site 1 – North Curtain partial redevelopment of the former Curtain Horse Paddocks along Yarra Glen to accommodate townhouses and multi-unit dwellings. - Site 2 – Curtain edge north and south, aimed at promoting future light rail connectivity and permitting dwellings such as townhouses with a 3-storey limit - Site 3 – Woden North marked as future light rail corridor. - Site 4 – Woden Town Centre, marked for future light rail corridor and urban renewal - Site 5 – Phillip and Athllon Drive, marked for rapid transit and potential future light rail corridor, street upgrades and further development as an employment hub. - Site 6 – Mawson and Farrer North, improve the centre and contribute to the potential future light rail infrastructure including stabling facilities. - Site 7 – Mawson and Ferra South, redevelopment as high amenity urban edge, marked for rapid transit and potential future light rail corridor, and street upgrades
3	There are no Category 3 change areas	There are no Category 3 key sites.

Modest population growth is forecasted for the Woden District with only an estimated 3,400 dwellings required within the district to meet 2050 population growth projections. Future housing opportunities including expected development under existing plans and potential urban regeneration areas can provide a housing surplus within the district.

Additional transport infrastructure would be required within the district to support city growth by 2050 and address areas of the network already facing congestion. This would include:

- Short term strategic objectives within the next five years to:
 - Future planning of Athllon Drive identified as a multimodal transport and urban corridor.
 - Implement upgrades to priority travel routes.
- Medium term strategic objectives within the next 10 years to:
 - Deliver Stage2b of the light rail Project from the City Centre to Woden

- Identify strategies to improve road corridors including Melrose Drive and Hindmarsh Drive
- A Longer-term strategic objective over 20 years or more is to investigate corridors for future rapid transit connections from Weston Creek to Woden and Molonglo Valley.

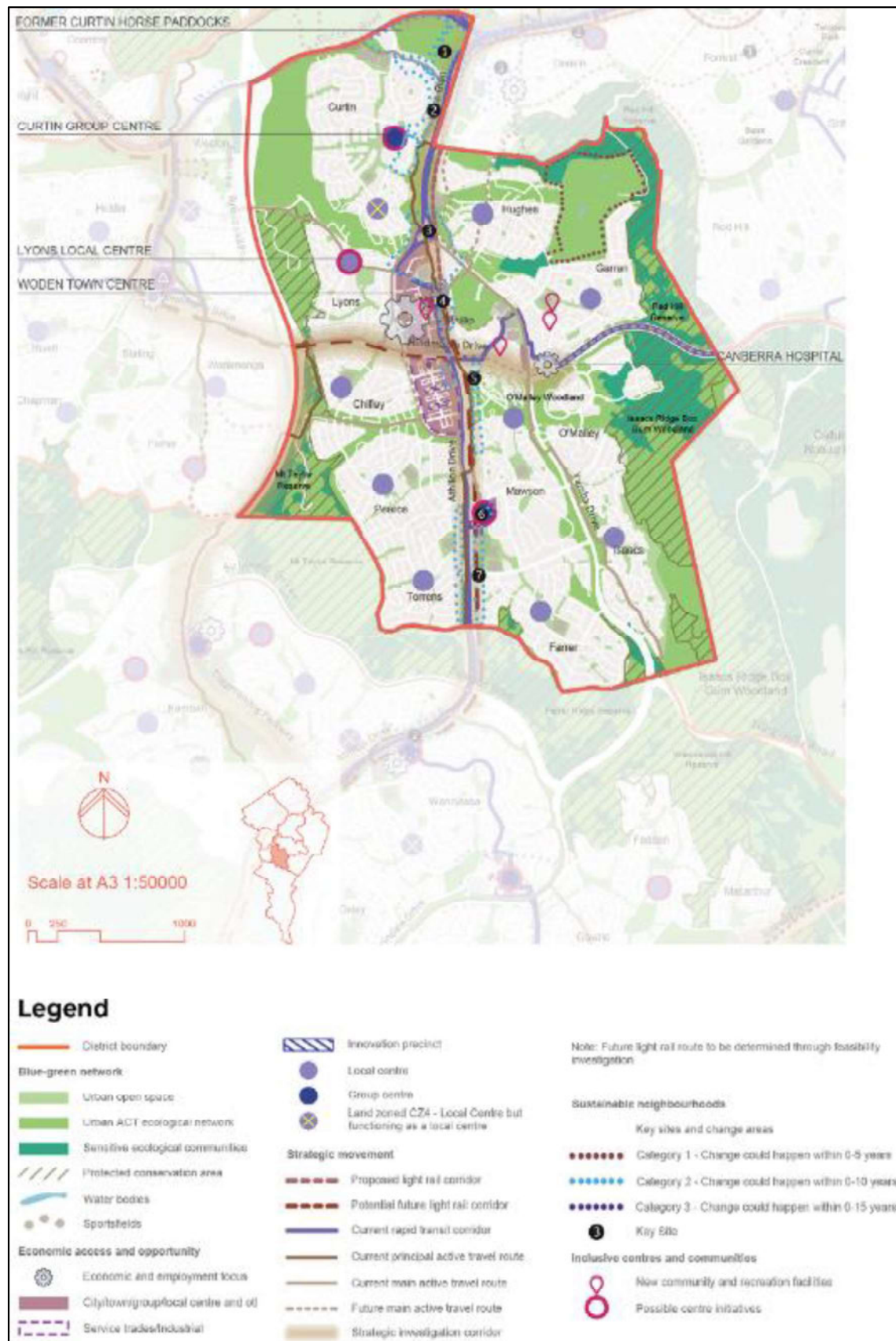


Figure 90 Woden District Strategy Plan

Source: Part Nine Woden District Strategy 2023