75-85 Crown Street and 116 Princess Highway, St Peters

Air quality impact assessment

Prepared for C&M Antoniou Pty Ltd

April 2023

75-85 Crown Street and 116 Princess Highway, St Peters

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C&M Antoniou Pty Ltd

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1 Background

1.1 The development and Council concerns

C&M Antoniou Pty Ltd, by way of Ethos Urban, has submitted a pre-planning proposal for a potential mixed-use development ('the development') at 75-85 Crown Street and 116 Princess Highway, St Peters. Inner West Council (IWC) has undertaken an initial assessment of the application[1], and the document PPP/2021/0009 summarises the key matters. With respect to air quality, PPP/2021/0009 mentions the following potential issues:

- Topic 9: Proximity of the WestConnex (M4-M5 Link) ventilation facility, requiring an air quality impact assessment (AQIA) which considers built form design.
- Topic 13: Demonstration of a quality living environment, given noise and air quality impacts.

The IWC covering letter also mentions the 'impact of WestConnex tunnelling and ventilation, specifically air quality impacts', which suggests that IWC may be expecting the impacts of M4-M5 Link construction to be considered, as well as operational impacts.

In addition, the development includes a proposed height uplift from 6 storeys to 8 storeys, and there was a need to understand whether the proposed uplift would result in higher concentrations of air pollutants than at ground level.

EMM Consulting Pty Ltd (EMM) was commissioned by C&M Antoniou Pty Ltd to conduct the AQIA (this report) for the development in response to the IWC comments. The aim of the report is to understand the effects of the surrounding road infrastructure, as well as background air pollution, on air quality at the development site (including how this varies with height), and hence to understand any resulting constraints.

1.2 Potential air quality impacts

The potential air quality impacts at the site of the development can be framed in terms of the following:

- the impacts of the construction of WestConnex; and
- the impacts of the operation of WestConnex (tunnels and surface roads), as well as other surface roads adjacent to the development.

Both these aspects were considered in detail in the environmental impact statement (EIS) for the M4-M5 Link, as well as the WestConnex M8 project (formerly New M5) which also has tunnel ventilation outlets in the St Peters Interchange (SPI) area.

1.2.1 Construction impacts

The impacts of the construction of WestConnex (eg dust) are being managed using best practice methods, including monitoring. Moreover, any residual impacts at surrounding locations (including the development) would be temporary and would tend to be short-lived. It is therefore not going to be productive to assess these impacts further, and we have considered them to be out of scope.

The impacts of the construction of the development itself have not been considered, again on the assumption that best practice methods for the control of dust will be used.

[1] Formerly for 71-85 Crown Street.

1.2.2 Operational impacts

This report focusses on the assessment of operational impacts.

The impacts of the operation of WestConnex (emissions from tunnel ventilation outlets and surface roads), as well as other surface roads near the development, have already been modelled the in M4-M5 Link EIS for a 'full WestConnex' scenario. However, EMM has conducted a new air quality modelling study for the development for the following reasons:

- detailed results from the EIS specifically for the development site are not publicly available;
- the EIS modelling was restricted to a limited number of heights, and these did not correspond directly to the building levels for the development; and
- the new modelling provided more flexibility in terms of the assessment approach.

The modelling for the AQIA included multiple road transport emission sources and outputs for several heights. The AQIA considered, as far possible, the combined effects of these contributions to long-term (annual) and short-term (1-hour or 24-hour) concentrations of the air pollutants that are most relevant to road transport.

1.2.3 Building design

Air quality impacts are assessed for 'outdoor' locations[2]. The AQIA has therefore not quantified indoor air quality. Similarly, the effects of building design an air quality have not been quantified, although some qualitative advice has been provided.

1.3 Scope of works

The AQIA contains the following elements (operational assessment only):

- a methodology that is broadly consistent with NSW EPA's 'Approved Methods for the Modelling and Assessment of Air Pollutants in New South Wales' (Approved Methods) (NSW EPA 2022);
- characterisation of the existing environment in terms of meteorology, emission sources and air quality (background concentrations);
- identification of specific assessment locations (receptors) at the development site;
- calculation of pollutant emissions (PM_{10}, $PM_{2.5}$ and NO_X) from road sources in the vicinity of the development and for one future year with WestConnex fully operational;
- compilation of a meteorological data file for input into an atmospheric dispersion model;
- use of an atmospheric dispersion model to calculate pollutant concentrations associated with surface road and tunnel ventilation emission sources, and including an assessment of cumulative impacts taking into account background concentrations;
- comparison of model predictions with the impact assessment criteria in the Approved Methods;
- qualitative consideration of the NSW Department of Planning's document 'Development near rail and road corridors and busy roads – interim guideline' (NSW DoP 2008); and
- preparation of an AQIA report (this report).

[2] For example, air quality standards and assessment criteria have been developed for outdoor locations.

It should be noted that AQIAs characterise outdoor air quality, rather than indoor air quality. For example:

- there are no standards for indoor air quality in NSW;
- the Approved Methods document does not refer to indoor air quality;
- the air quality criteria in the Approved Methods are for outdoor environments, and are based on health studies that have used air quality data for outdoor locations;
- the background air quality data used in AQIAs are obtained from outdoor monitoring stations; and
- dispersion models typically make no adjustment for aspects of building design[3] that could affect the ratio between the indoor and outdoor concentrations.

Considering these factors, it is common for AQIAs to focus on 'worst case' outdoor locations, such as the property boundaries or façades that are closest to emission sources.

3 Some comments on this are provided in Section 5.5.

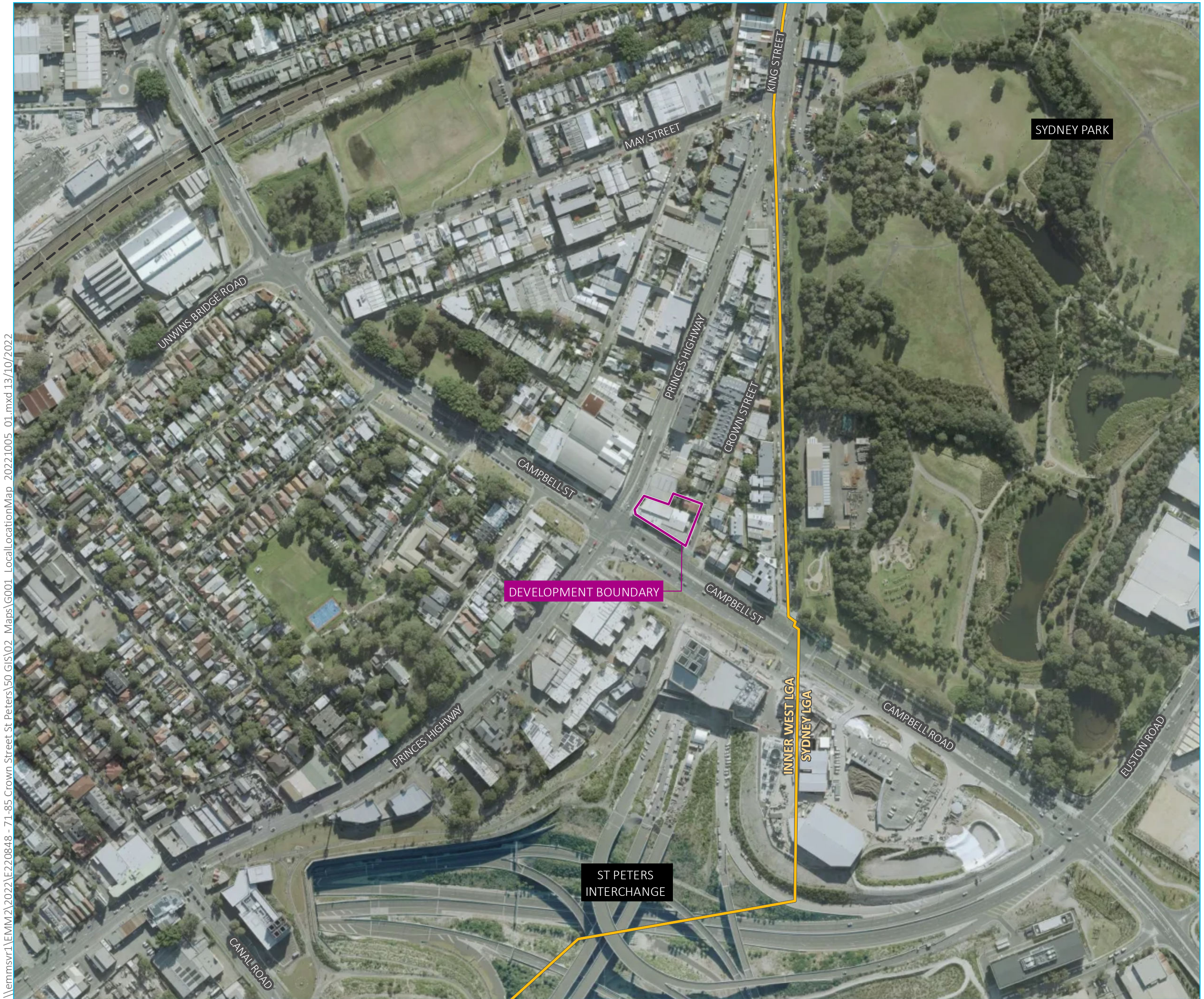
2 The development

2.1 Location and surrounding area

The location of the development site is shown in Figure 2.1. The site is in the suburb of St Peters, and is around 5.5 km to the south-west of the Sydney central business district (CBD).

It is bounded by Princes Highway (A36) to the west, Campbell Street to the south and Crown Street to the east. Princes Highway is a state road that is managed by Transport for NSW (TfNSW). Campbell Street is classified as a regional road, and Crown Street is a local access road.

In recent years the road network around the site has been significantly upgraded as part of the WestConnex project. The upgrades have included the widening of Campbell Street east of the Princes Highway and an upgrade of the intersection of the two roads. A major road interchange –SPI – is also under construction further to the south of the site.



KEY

- Development boundary
- Local government area
- Rail line

Figure 2.1: Location of development

Source: EMM (2022); ABS (2021); DFSI (2020, 2021); ESRI (2022); GA (2011)

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2.2 Current site layout

Figure 2.2 shows the current layout of the site and the assessment locations for the AQIA. The proposed development consists of three independent lots, covering an area of approximately 1,940 m^2. The addresses, lots and current land uses are given in Table 2.1. The site is currently a mix of R1 and B4 land zones.

The site is currently zoned for mixed-use residential. The development includes a proposed height uplift from 6 storeys to 8 storeys. This report aims to determine whether the proposed uplift would result in higher concentrations of air pollutants than at ground level.

Source: EMM (2022); ABS (2021); DFSI (2020, 2021); ESRI (2022); GA (2011)

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Figure 2.2: Site layout

EMM creating opportunities

Table 2.1 Site details (JBS&G Australia 2021)

Address	Lot / DP	Current zoning
75 Crown Street	Lot 24 / DP1249592	General residential (R1)
85 Crown Street	Lot 10 / DP1227918	Mixed use (B4)
116 Princes Highway	Lot 21 / DP1249588	Mixed use (B4)

2.3 Proposed design

The rezoning request is accompanied by an indicative design scheme by Scott Carver Architects which shows:

- demolition of existing structures;
- a mixed-use development with:
  - two basement levels accessed from Crown Street incorporating 81 car parking spaces, end-of-trip (EOT) facilities and plant;
  - a ten-storey building composed of eight residential levels above two commercial floor levels (retail, light industry and office);
  - two (2) double-story units on the ground floor/mezzanine along Crown Street at the furthest distance from Campbell Street;
  - a three-storey plus mezzanine building component facing Crown Street;
  - a four-storey street wall to Princes Highway;
  - a maximum building height of RL 51 to the top of the lift overrun;
  - a gross floor area equal to 9,408 square metres;
  - a total of 87 apartments (16 x studio, 24 x 1 bedroom, 40 x 2 bedroom, 7 x 3 bedroom);
  - common open-space areas at levels 1, 2 and 4 with provision for integrated landscaping and 15% canopy tree cover;
  - a residential lobby to Campbell Street;
  - a loading dock, additional car parking, EOT facilities and waste room at ground floor level;
  - deep soil zones along Campbell and Crown Streets; and
  - integration of public art into the south façade and materiality that references the industrial heritage of the area.

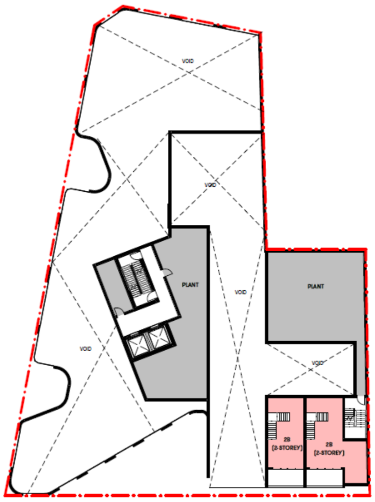
The heights of the building levels are given in Table 2.2. The building would have an overall height of 36 m above ground level (AGL). Plan views of the various levels (excluding those below ground) are shown in Figure 2.3.

Table 2.2 Building levels (above ground only)

Level	Height at top of level AGL (m)	Height RL (m)	Proposed use
Top of roof	36.0	51.0	
Roof (level 9)	33.5	48.5	Plant
Level 8	31.0	45.2	Residential
Level 7	27.7	42.1	Residential
Level 6	24.6	39.0	Residential
Level 5	21.5	35.9	Residential
Level 4	18.4	32.8	Residential
Level 3	15.3	29.7	Residential
Level 2	12.2	26.6	Residential
Level 1	9.1	23.5	Residential/retail
Mezzanine	6.0	20.5	Retail[a]
Ground level	3.0	17.5	Retail[a]

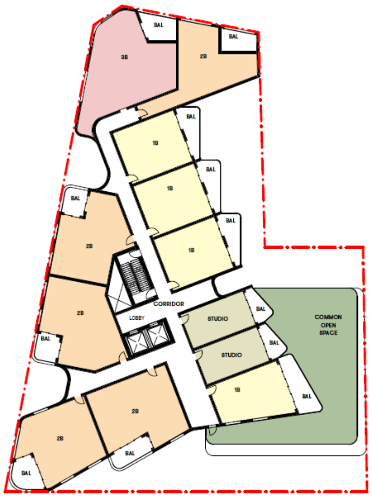
(a) Noting that there would be two double-story units on the ground floor/mezzanine along Crown Street.

Ground floor

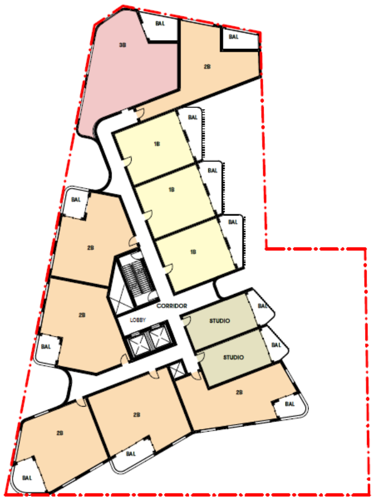


Mezzanine

Level 1

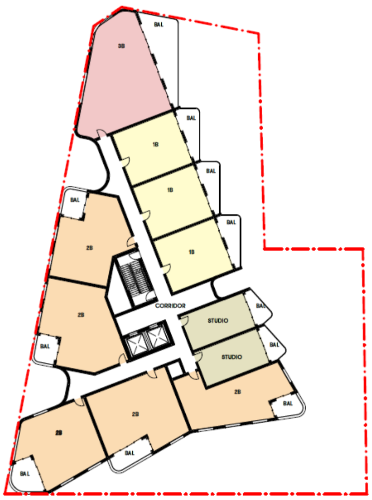


Level 2



Level 3

Level 4



Levels 5-8

Figure 2.3 Level plans (Crown Street is at the bottom of each plan)

3 Assessment methodology

3.1 Overview

The assessment methodology involved the use of an atmospheric dispersion model to estimate the impacts of emissions from road traffic on air quality at the development. The model predictions were combined with measurements of background air quality to determine the total pollutant concentrations (also referred to as 'cumulative impacts') at the development.

The methodology was broadly in accordance with the Approved Methods (NSW EPA 2022), noting that this document is designed primarily for the assessment of industrial facilities. Consideration was also given to the CASANZ[4] Good Practice Guide for the Assessment and Management of Air Pollution from Road Transport Projects (CASANZ 2022).

3.2 Air quality criteria

In relation to AQIAs, the pollutants that are most relevant to road traffic are:

- nitrogen dioxide (NO_2);
- particulate matter with an aerodynamic diameter of less than 10 µm (PM_{10}); and
- particulate matter with an aerodynamic diameter of less than 2.5 µm ($PM_{2.5}$).

These pollutants are important in terms of health, are emitted in substantial quantities from road traffic, have a traffic contribution that can be distinguished from the background, and can have ambient concentrations that are close to (or above) air quality criteria.

Road vehicles emit both nitric oxide (NO) and NO_2. By convention, the sum of NO and NO_2 is referred to as nitrogen oxides (NO_X). Most of the emitted NO_X is in the form of NO, with NO_2 also being formed from NO through complex reactions in the near-road atmosphere. It is therefore convenient to refer to NO_X in modelling to ensure conservation of the total amount of nitrogen oxides.

The particulate matter emitted by vehicles is a complex mixture of solids and liquids, and includes both organic and inorganic components. $PM_{2.5}$ is a subset of PM_{10}. Particles smaller than 2.5 µm, which includes the size range in vehicle exhaust, can penetrate deep into the respiratory system, and it is these particles which are of most concern. Particles between 2.5 µm and 10 µm in diameter are often mechanically generated; in the case of road vehicles the processes are tyre wear, brake wear and road surface wear.

With respect to the assessment of developments in NSW, the air quality criteria are defined in the Approved Methods (NSW EPA 2022). These criteria are identified in Table 3.1. NSW EPA has historically transposed the air quality standards from the National Environment Protection (Ambient Air Quality) Measure (AAQ NEPM)[5] into the Approved Methods. This is currently the case, with the exception of the 2025 goals for $PM_{2.5}$ in the AAQ NEPM. These values are therefore also shown in the table, but NSW EPA does not yet require them to be assessed.

The application of the assessment criteria in Table 3.1 is described in the Approved Methods. Again, the document is chiefly concerned with industrial facilities. Conventionally, the assessment criteria are applied at the nearest existing or likely future 'off-site' sensitive assessment location (referred to as 'receptors' in the Approved Methods).

4 CASANZ is the Clean Air Society of Australia and New Zealand.

5 https://www.legislation.gov.au/Details/F2021C00475

Although it is not stated explicitly, in the case where a new development (such as a residence) is proposed near an existing emission source (such as road traffic), then the appropriate assessment locations will be at the development site.

According to the Approved Methods, the following must be reported for each metric, with units and averaging periods that are consistent with the air quality criteria:

- the incremental impact (ie the predicted impact due to the pollutant source alone); and
- the total impact (ie the incremental impact plus the existing background concentration).

In the case of the short-term criteria (1-hour NO_2, 24-hour PM_{10} and 24-hour $PM_{2.5}$), the total prediction is reported as the 100th percentile (ie the highest) value.

Table 3.1 Impact assessment criteria (NSW EPA 2022)

Pollutant	Averaging period	Impact assessment criterion
NO_2	1 hour	164 µg/m^3
	Annual	31 µg/m^3
PM_{10}	24 hours	50 µg/m^3
	Annual	25 µg/m^3
$PM_{2.5}$	24 hours	25 µg/m^3
		20 µg/m^3 (AAQ NEPM goal by 2025)
	Annual	8 µg/m^3
		7 µg/m^3 (AAQ NEPM goal by 2025)

With respect to the assessment of new developments, and especially new sensitive uses near busy roads, there are several problems with the approach in the Approved Methods. For example:

- The EPA does not regulate surface roads.
- At some locations, the background concentrations can exceed the impact assessment criteria. This is most commonly the case for PM_{10} and $PM_{2.5}$, which are affected by events such as bushfires and dust storms. In such circumstances, there is a requirement in the Approved Methods to demonstrate that no *additional* exceedances of the impact assessment criteria will occur as a result of the proposed activity. However, in the case of new sensitive uses near roads, the development itself is not the source of pollution and, importantly, the developer has no control over emissions.
- Near busy roads, and when the traffic contribution to air pollution is considered, it is more likely that the air quality criteria will be exceeded. In addition, in 2022 the air quality impact assessment criteria for NO_2 were reduced significantly, which means that exceedances of the criteria are now more likely than before.

3.3 Characterisation of existing environment

Meteorological data and background air quality data, based on measurements from local monitoring stations, were required for the assessment. Meteorological data were used as an input to the atmospheric dispersion model, and air quality data were used to define background concentrations. The assessment of air quality requires the selection of a suitable 'representative' year. Given the important influence of meteorology on air pollution, it is important that the representative year is common both.

The following sections describe the data that were considered for use in the AQIA, and the rationale for the selection of the representative year.

3.3.1 Meteorology

Meteorological mechanisms govern the dispersion, transformation and eventual removal of pollutants from the atmosphere. To adequately characterise the dispersion meteorology of an area, information is needed on the prevailing wind regime, ambient temperature and atmospheric stability.

There are three meteorological stations in the vicinity of the development site. These are:

- the Bureau of Meteorology (BoM) Sydney Airport Automatic Weather Station (AWS), 3.7 km to the south-south-east of the development site;
- the NSW Department of Planning and Environment (DPE) air quality monitoring station at Earlwood, 4.2 km to the west of the development site; and
- the BoM Canterbury Racecourse AWS, 6.1 km to east-north-east of the development site.

The Sydney Airport AWS has a surrounding topography and land use that differs from the situation at the development site. The Sydney Airport AWS is located near the airport runway and is adjacent to Botany Bay. These factors contribute to high average wind speeds at this site. The DPE Earlwood station does not currently comply[6] with the Australian Standard for siting due to trees being located within 20 m. The Canterbury Racecourse AWS is unimpeded by obstacles and is sited on relatively flat terrain. Considering these factors, the Canterbury Racecourse AWS was considered to provide the best representation of the meteorology at the development site. This monitoring station was also used to characterise meteorology in the EIS for the M4-M4 Link project. The meteorological data for modelling were therefore taken from Canterbury Racecourse.

An analysis of the meteorological data from Canterbury Racecourse for the period between 2017 and 2021 is presented in Appendix A. The main findings of the analysis were as follows:

- the data availability for all parameters and all years was relatively high, at close to 90% (noting that recovery is above 90% where hours with zero wind speed and zero wind directions are left in);
- there was a high degree of consistency between years in terms of the most important parameters for pollutant dispersion: wind direction, wind speed and the occurrence of calm winds;
- during the night the winds were light (around 2 m/s), and increasingly from a north-westerly direction until 8.00 am. After 8.00 am the wind speed began to increase, peaking at around 5 m/s in the late afternoon. This increase in wind speed coincided with a shift in wind direction, with winds blowing most frequently from (broadly) the north-east and south-east. Wind speeds began to decrease after around 6.00 pm, with no dominant wind direction by midnight; and
- the proportion of the year when winds were blowing from the WestConnex tunnel ventilation outlets to the development site (ie south-easterly winds) was quite low overall.

3.3.2 Background air quality

Background air quality was characterised using data from the closest DPE monitoring station to the development. This station was at Earlwood, 4.2 km to the west of the development site. It was noted earlier that this site did not comply with the Australian Standard for siting.

6 https://www.environment.nsw.gov.au/topics/air/monitoring-air-quality/sydney/monitoring-stations/earlwood#:~:text=The%20Earlwood%20air%20quality%20monitoring,station%20was%20commissioned%20in%201978.

However, this is likely to be less of a concern for air quality than for meteorology. For example, peak pollutant concentrations are often caused by regional-scale weather events (bushfires etc), and the measurement of these are not likely to be affected by local obstacles such as trees.

Five years of data (2017-2021) from the monitoring station were analysed to inform the selection of an appropriate modelling year and to quantify background concentrations. The analysis of the data is presented in Appendix B.

It is worth noting that two ambient air quality monitoring stations have also been established near the development for the M4-M5 Link project. These monitoring stations are nominally located at Albert Street and Campbell Street. However, the data from these stations were not used for the following reasons:

- the measurements are likely to be affected by road traffic;
- the sites have only been established relatively recently (2021), and therefore a long-term analysis is not possible;
- the measured concentrations will change as the M4-M5 Link project develops (in particular, the measurements will not reflect the traffic conditions for the full WestConnex project in 2033); and
- the data are not readily accessible.

3.3.3 Selection of a representative year

There are no criteria for selecting a representative year for modelling, but it is desirable to use a recent year that reflects 'typical' meteorology and air quality. At present, however, the concept of 'typical' is difficult to interpret, as the data for recent years (especially those for particulate matter) have been strongly affected by drought conditions, extensive bush fires and the La Niña phenomenon[7].

For this assessment, 2018 was selected as the representative year. The reasons for this were as follows:

- there was a high degree of consistency between years in the meteorological data, and any year between 2017 and 2021 would have been suitable for use in the AQIA;
- 2018 was the most recent year before concentrations of PM_{10} and $PM_{2.5}$ were strongly affected by major bushfires (2019 and 2020) and La Niña (2020 and 2021); and
- PM_{10} and $PM_{2.5}$ concentrations in 2018 were reasonably representative of the concentrations in the previous five or six years (ie 2012 to 2017).

3.4 Assessment scenario

The AQIA was conducted for one future-year scenario in which WestConnex would be fully operational. The EIS for the M4-M5 Link considered a range of scenarios for two future years (2023 and 2033) (Pacific Environment 2017a). The scenario that was considered to be most appropriate for this AQIA was '2033 Do Something Cumulative' (2033-DSC), and the 'expected traffic' condition. This scenario was selected for the following reasons:

- it represented conditions well into the future;
- it assumed that all WestConnex projects would be operational;

7 La Niña is the colder counterpart of El Niño, and is part of the broader El Niño–Southern Oscillation (ENSO) climate pattern.

- it included the effects of various other major infrastructure projects (Western Harbour Tunnel, Beaches Link, F6 Extension and Sydney Gateway); and
- for the two tunnel ventilation outlets considered in the AQIA, it had emission rates and outlet concentrations that were generally the highest of all the EIS scenarios[8].

The scenario represented the 24-hour operation of the tunnel ventilation systems under day-to-day conditions of expected traffic demand in 2033. Under normal traffic conditions, fresh air is drawn into a tunnel from the entry portals and pushed towards the tunnel exit portals. As the fresh air is mixed with vehicle exhaust, the in-tunnel concentrations of air pollutants increase along the length of the tunnel. Emissions from the exit portals are prevented by using the fans in the tunnel ventilation system to draw the air back against the flow of traffic near the end of the tunnel, and directing the air through vertical ventilation outlets. The air is discharged to the atmosphere at a velocity that achieves effective dispersion of the polluted tunnel air.

3.5 Characterisation of emission sources

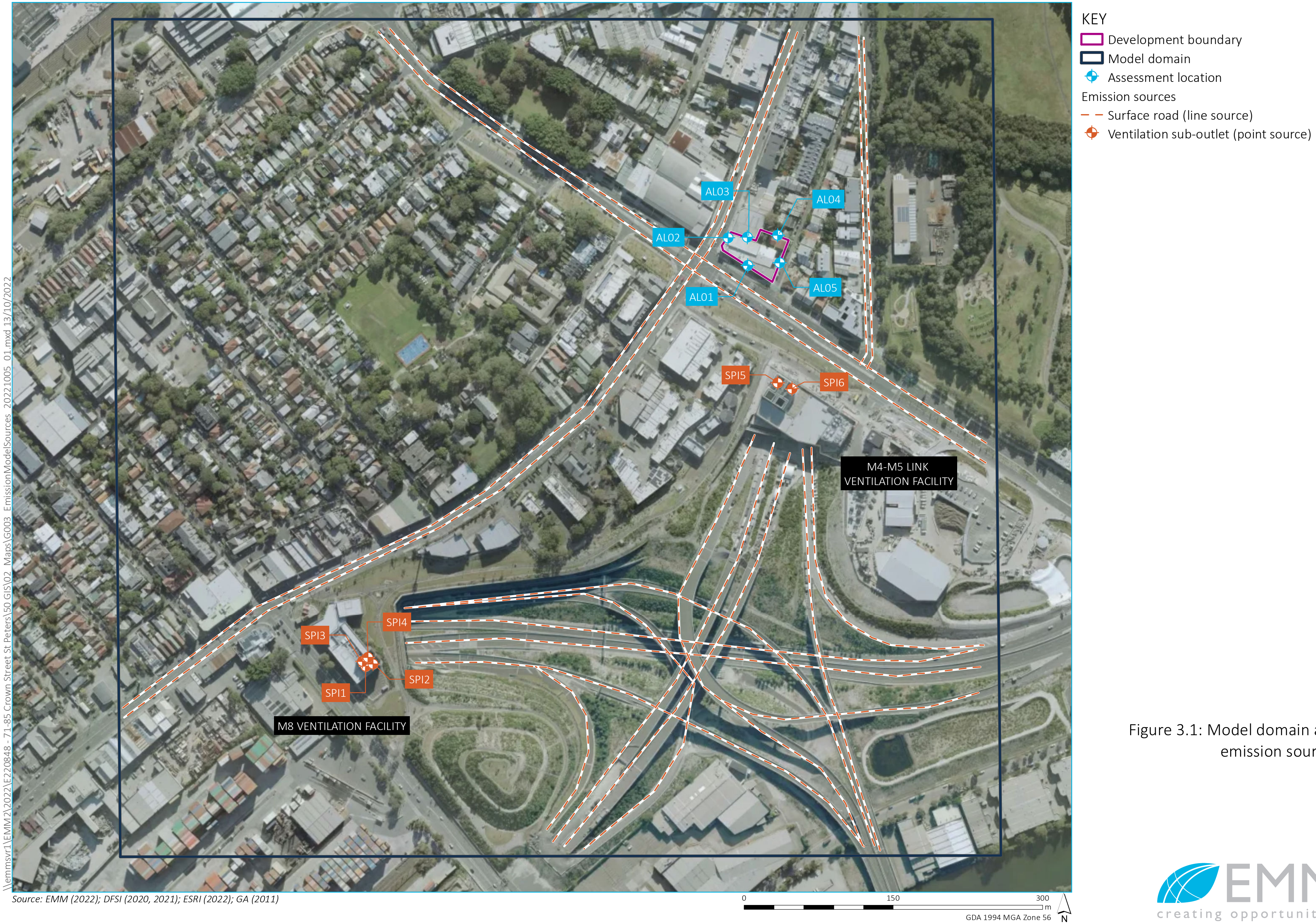
In addition to background air pollution, air quality at the development will be influenced by the following:

- surface roads near the development (notably Princes Highway and Campbell Street);
- surface roads at SPI;
- the ventilation outlet for the WestConnex M4-M5 Link tunnel (approximately 150 m from the site); and
- the ventilation outlet for the WestConnex M8 (formerly New M5) tunnel (approximately 550 m from the site).

When designing the modelling approach for the AQIA, the potential contributions of these sources, and in particular their contributions at different heights above ground level, had to be considered. For example, at ground level at the development, the most important road traffic contributions to air pollution would usually be from the adjacent surface roads. However, the WestConnex tunnel ventilation outlets could have significant short-term contributions at greater elevations, such as when the plumes from the outlets are blown towards the development.

The locations of these emission sources are shown in Figure 3.1 and their characterisation is described in the following sections.

[8] For NOx, the highest emission rates and outlet concentrations were sometimes higher in the 2023 scenarios. However, 2033 was considered to provide a better representation of the situation in the long term.



Source: EMM (2022); DFSI (2020, 2021); ESRI (2022); GA (2011)

Figure 3.1: Model domain and emission sources

EMM creating opportunities

3.5.1 Surface roads

The surface roads included in the AQIA are characterised in Appendix C. The traffic data for these roads in the 2033-DSC scenario were taken from the traffic model outputs for the M4-M5 Link EIS.

Various roads near the development were included in the AQIA. No data were available for Crown Street, as this road was not included in the EIS modelling. However, it is unlikely that the inclusion of Crown Street would have had a significant effect on the outcomes of the AQIA, as the traffic volume will be relatively low.

The surface roads at SPI were all at least 150 m from the development, and their contribution to pollutant concentrations at the development was likely to be small. Nevertheless, these roads were included in the AQIA for completeness, and their characteristics are given in Appendix C.

Emissions from the traffic on the surface roads were calculated using a model developed by NSW EPA, as described by Pacific Environment (2017a). The emission model took into account both exhaust and non-exhaust sources of pollution from road vehicles, the emission characteristics of different vehicle technology, and the evolution of the fleet into the future. Emissions were calculated based on traffic volume, composition, speed and average road gradient. Average road gradient was determined using the road length and the elevation of the start and end points. The resulting emission rates are also provided in Appendix C.

It should be noted that the NSW EPA model did not consider the effects of vehicle powertrain technology other than petrol engines and diesel engines. In other words, it was assumed that there would be zero uptake of hybrids or full electric vehicles. Given that the market penetration of these is likely to increase by 2033, it is expected that the NSW EPA model will overestimate emissions from traffic. This will tend to lead to conservative model predictions in the AQIA.

3.5.2 Tunnel ventilation outlets

i Description

The following tunnel ventilation outlets were included in the assessment:

- WestConnex M8 (formerly New M5) tunnel at SPI (approximately 550 m from the site) [referred to as outlet D in the EIS]. The function of this outlet is to provide the exhaust from the second section of the eastbound M8 tunnel (Arncliffe to St Peters).

- WestConnex M4-M5 Link tunnel at SPI (approximately 150 m from the site) [referred to as outlet K in the EIS]. The function of this outlet is to provide the exhaust from eastbound traffic to the M4-M5 Link (Arncliffe to St Peters). The facility will also provide the ventilation supply to the northbound M4-M5 Link (St Peters to Rozelle).

The locations and heights above ground level of the ventilation outlets are given in Appendix B. For each outlet, four exhaust sub-outlets are provided to improve dispersion of the exhaust air and assist in meeting the Civil Aviation Safety Authority and Sydney Airport's requirements.

The data for these outlets were taken from the EIS for the M4-M5 Link (Pacific Environment 2017a). As noted earlier, the scenario that was considered to be most appropriate for this assessment was '2033 Do Something Cumulative'.

ii Discharge parameters

The discharge parameters of the tunnel ventilation outlets are given in Appendix D. Again, these were taken from the M5-M5 Link EIS (Pacific Environment 2017a). Not all the sub-outlets would be operational at all times of day, and the assumptions concerning their operation were retained from the M4-M5 Link EIS.

3.6 Atmospheric dispersion modelling

3.6.1 Model selection

An appropriate model for the simulation of pollutant dispersion was selected, taking into account the types of emission source in the vicinity of the development and the characteristics of the area. The model used in the assessment was the Graz Lagrangian Model (GRAL)[9] (version 21.09) (Öttl 2021; Öttl & Kuntner 2021). In GRAL, ground-level pollutant concentrations are predicted by simulating the movement of individual 'particles' of a pollutant emitted from an emission source. The trajectory of each of the particles is determined by a mean velocity component and a fluctuating (random) velocity component.

GRAL was selected for this study for a number of reasons. It is suitable for regulatory applications and can utilise a full year of meteorological data. It is also specifically designed for the simultaneous modelling of road transport networks, including line sources (surface roads), point sources (tunnel ventilation outlets) and other sources. In recent years, GRAL has been used to model both large-scale and small-scale infrastructure and developments in Sydney, including all tunnel stages of WestConnex. The use of GRAL therefore provided consistency with the EIS for the M4-M5 Link. The NSW Advisory Committee on Tunnel Air Quality (ACTAQ) has also published a study designed to optimise GRAL in the Australian context (Pacific Environment 2017b).

3.6.2 Model domain

The model domain was defined to include the development site and the relevant emission sources with a suitable spatial buffer (see Figure 3.1). Pollutant concentrations were predicted over a 880 m (x axis) by 840 m (y axis) domain with a 5 m resolution.

3.6.3 Model set-up

i Pollutants

The air quality modelling was conducted for the pollutants NO_X, PM_{10} and $PM_{2.5}$. Concentrations of NO_2 were determined in post-processing using an empirical conversion method.

ii Terrain and land use

Spatially varying terrain and land use data were not included in the modelling, as the terrain and topography surrounding the development is relatively flat and homogenous. The model domain also spans a small area. A surface roughness value of 1.5 m was set in GRAL to represent an urban land use area.

iii Assessment locations

GRAL was used to predict concentrations of PM_{10}, $PM_{2.5}$ and NO_X at five assessment locations (AL01 to AL05) representing each façade of the building (Figure 2.2 and Table 3.2). The assessment locations were replicated at multiple heights above ground in the vertical dimension to represent each level of the building. These are commonly referred to as 'elevated receptors'. The assessment location heights modelled are given in Table 2.2 (ground floor to level 8).

9 GRAL is usually coupled with a meteorological model (Graz Mesoscale Model - GRAMM). For this AQIA, GRAMM was not considered to be necessary given the relatively small geographical scale of the domain and the absence of complex terrain.

Table 3.2 Assessment locations

Assessment location	Description	Coordinates (MGA, m)	
		Easting	Northing
AL01	Site boundary at Campbell Street	331734.3	6246052
AL02	Site boundary at Princes Highway	331713.2	6246078
AL03	Northern site boundary at Lot 21	331733.9	6246080
AL04	Northern site boundary at lot 24	331764.9	6246083
AL05	Site boundary at Crown Street	331767.4	6246052

3.7 Post-processing

Results were obtained for both modelled sources (ie roads plus tunnel ventilation outlets) and modelled sources plus background (ie cumulative).

To estimate cumulative short-term concentrations, a 'contemporaneous' approach was used whereby each predicted short-term concentration (24-hour PM_{10}, 24-hour $PM_{2.5}$ and 1-hour NO_X) was combined with the corresponding background concentration. For annual average cumulative concentrations, a single annual mean background value was added to the predicted annual mean value.

Concentrations of NO_2 were determined in post-processing using an empirical method for converting NO_X to NO_2, as described in Appendix E.

The total cumulative concentrations were compared with the impact assessment criteria from the Approved Methods.

4 Results

4.1 NO_X concentration

4.1.1 Annual mean

The predicted annual mean NO_X concentrations for each assessment location and building level are given in Table 4.1. Although there are no assessment criteria for NO_X, it is useful to consider the results. One reason for this is that they illustrate how the dispersion model is performing without the additional uncertainty that is introduced in the calculation of NO_2. It also allows the different source contributions to be determined.

The NO_X concentrations were generally highest at assessment location AL01 (southern site boundary at Campbell Street) and lowest at assessment location AL04 (northern site boundary at Lot 24).

Table 4.1 Annual mean NO_X concentrations at assessment locations

	NO_X (µg/m^3)				
Building level	**AL01**	**AL02**	**AL03**	**AL04**	**AL05**
Level 8	56.4	53.7	53.8	53.2	56.1
Level 7	57.0	54.3	54.2	53.7	56.5
Level 6	56.9	54.7	54.6	54.1	56.4
Level 5	57.2	54.9	54.6	54.3	56.7
Level 4	57.5	55.6	55.2	54.5	56.5
Level 3	57.6	56.3	56.0	55.2	56.9
Level 2	58.8	57.7	56.8	55.5	57.2
Level 1	60.5	59.8	58.4	56.3	58.1
Mezzanine	63.4	62.8	60.1	56.9	59.3
Ground level	68.6	69.1	63.0	58.8	62.2

At each assessment location the concentration was highest for the ground level and generally decreased with height. The lowest concentrations were usually predicted for the highest levels of building. This pattern reflected the diminishing contribution from surface roads near the development with height. This is further illustrated in Figure 4.1 (note that the concentration scale on the x-axis does not start at zero).

Figure 4.2 shows the various contributions to annual mean NO_X at assessment location AL01 (the location which generally had the highest concentrations of all pollutants). The largest component was the background concentration, which was responsible for around two thirds of the total concentration at ground level, and around 80% of the total at level 8. At ground level, surface roads contributed around 20 µg/m^3, or around 30% of the total NO_X concentration, but at level 8 this had reduced to less than 3 µg/m^3, or around 5% of the total. Conversely, the contribution of the ventilation outlet for the M4-M5 Link increased with height, from 3 µg/m^3 at ground level to 8 µg/m^3 at level 8. The contribution of the ventilation outlet for the M8 was negligible at all levels.

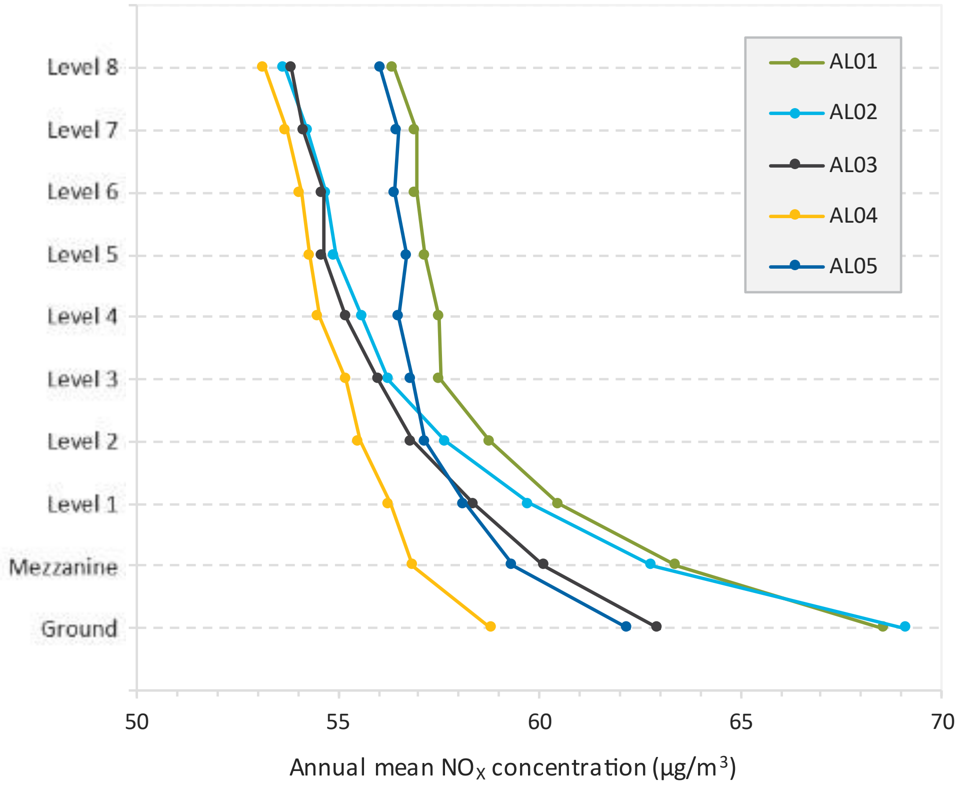


Figure 4.1 Annual mean NO_X concentrations for all assessment locations and heights

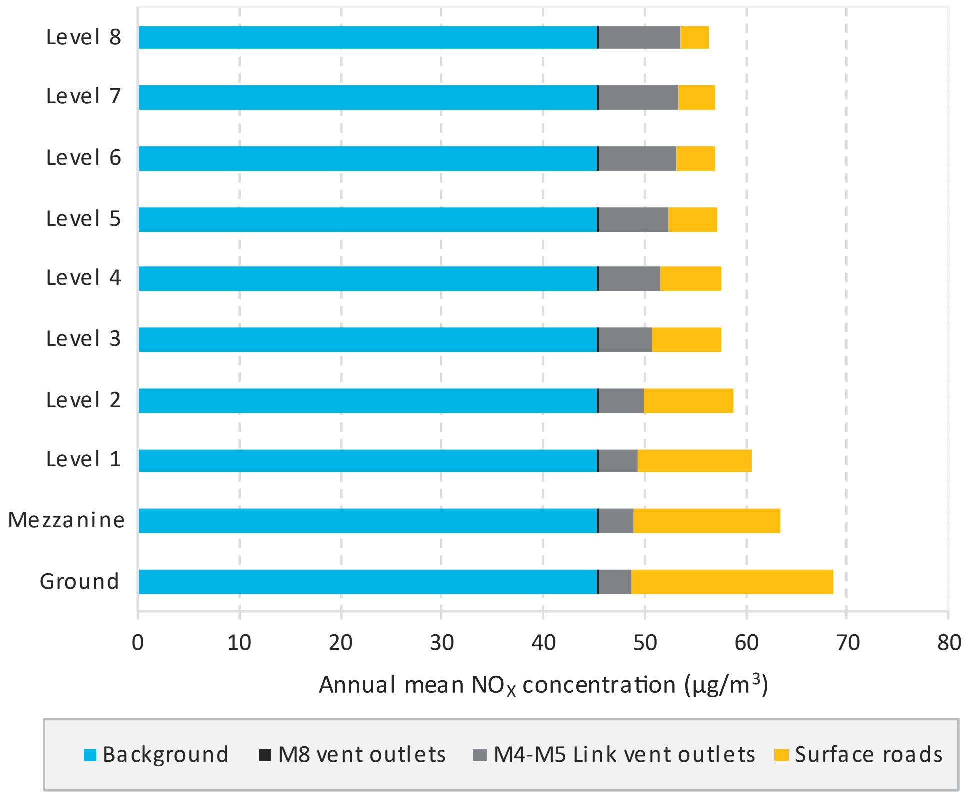


Figure 4.2 Contributions to annual mean NO_X at assessment location AL01

4.1.2 1-hour

The predicted maximum 1-hour NO_X concentrations in 2018 for each assessment location and building level are given in Table 4.2. There are no assessment criteria for 1-hour NO_X. As with annual mean NO_X, the maximum 1-hour NO_X concentrations were generally highest at AL01 and lowest at AL04, and the concentration was highest for the ground level and lowest for the highest levels. Above level 5 the maximum 1-hour NO_X concentration approached the background value of around 460 µg/m^3.

Table 4.2 Maximum 1-hour NO_X concentrations at assessment locations

	NO_X (µg/m^3)				
Building level	**AL01**	**AL02**	**AL03**	**AL04**	**AL05**
Level 8	464.3	460.0	464.4	464.9	462.8
Level 7	466.0	462.9	461.4	460.0	463.4
Level 6	468.0	468.7	460.7	464.1	467.2
Level 5	464.5	470.7	460.6	466.3	462.0
Level 4	471.8	473.9	469.8	464.0	468.2
Level 3	488.0	472.7	479.7	467.1	471.7
Level 2	516.2	489.5	500.7	492.9	489.1
Level 1	535.2	536.8	509.0	507.4	519.8
Mezzanine	544.3	542.8	556.3	509.0	553.8
Ground level	683.1	671.7	623.8	544.6	568.5

Figure 4.3 shows the various contributions to the maximum total 1-hour NO_X concentration at assessment location AL01. It should be noted that the values in the table occurred in different hours of the year, hence the variation in the background contribution. It can be seen that, during these hours, the contributions from both tunnel ventilation outlets were zero. On the other hand, the contribution from surface roads was substantial for the lower building levels, but was small above level 4.

The maximum contributions for each source (for any hour of the year) were also considered (Table 4.3). It is worth noting that these did not coincide with the maximum total concentration. The values have been calculated across all assessment locations, and are not additive. They generally show that:

- after the background, the largest contribution was from surface roads;
- the contribution from the M8 outlet was small and did not change significantly with height; and
- the contribution from the M4-M5 ventilation outlet was larger than that from the M8 outlet, and increased with height, but was smaller than the surface road contribution.

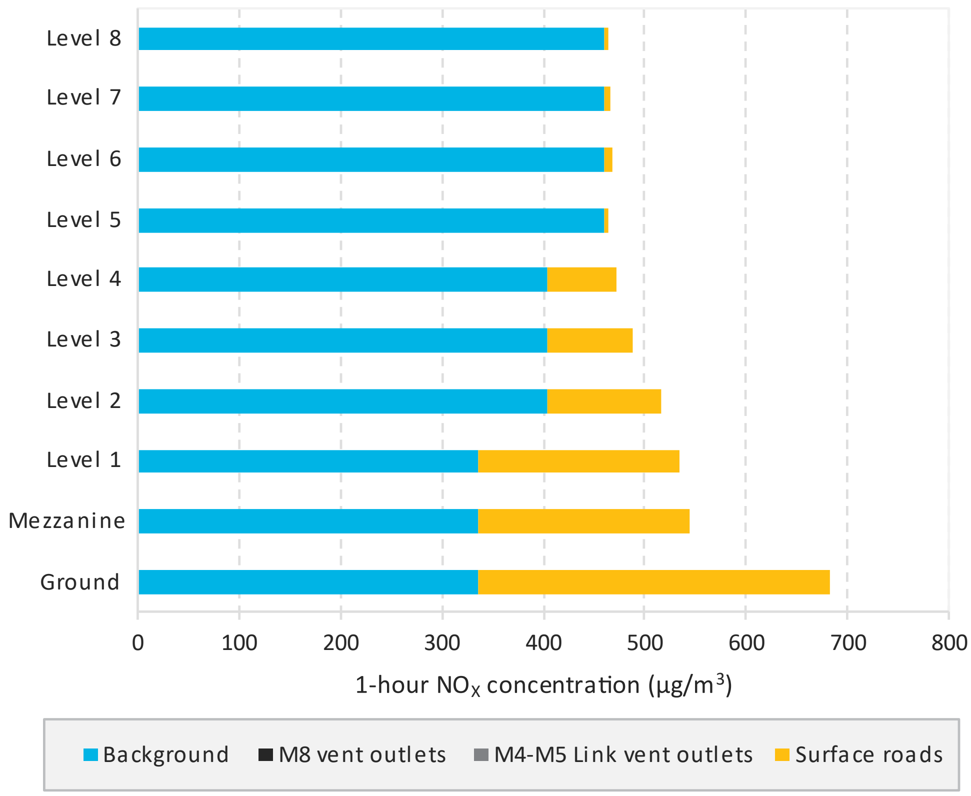


Figure 4.3 Contributions to maximum 1-hour NO_X at assessment location AL01

Table 4.3 Maximum 1-hour NO_X concentration by source (across all assessment locations)

Building level	NO_X (µg/m³)[(a)]			
	Background	M8 ventilation outlet	M4-M5 Link ventilation outlet	Surface roads
Level 8	459.7	6.3	76.0	97.0
Level 7	459.7	5.9	63.7	104.8
Level 6	459.7	6.0	62.6	115.5
Level 5	459.7	5.5	53.6	137.6
Level 4	459.7	5.0	43.5	138.6
Level 3	459.7	7.2	40.6	154.3
Level 2	459.7	4.5	32.5	167.6
Level 1	459.7	5.0	30.2	237.0
Mezzanine	459.7	5.6	27.0	266.8
Ground level	459.7	6.0	28.5	406.4

(a) Note that values are not additive.

4.2 NO_2 concentration

4.2.1 Annual mean

The predicted annual mean NO_2 concentrations for each assessment location and building level are given in Table 4.4. As with NO_X, the highest concentration were generally found at AL01, and the lowest at AL04. Again, at each assessment location the concentration was highest for the ground level and lowest for the highest levels.

Table 4.4 Annual mean NO_2 concentrations at assessment locations

	NO_2 (µg/m³)				
Building level	**AL01**	**AL02**	**AL03**	**AL04**	**AL05**
Level 8	24.5	23.8	23.8	23.7	24.4
Level 7	24.7	24.0	23.9	23.8	24.6
Level 6	24.7	24.1	24.1	23.9	24.5
Level 5	24.7	24.1	24.1	24.0	24.6
Level 4	24.8	24.3	24.2	24.0	24.6
Level 3	24.8	24.5	24.4	24.2	24.6
Level 2	25.2	24.9	24.6	24.3	24.7
Level 1	25.6	25.4	25.0	24.5	25.0
Mezzanine	26.3	26.2	25.5	24.7	25.3
Ground level	27.6	27.8	26.2	25.2	26.0

For all assessment locations and building levels, the annual mean NO_2 concentration was below the NSW air quality criterion of 31 µg/m³.

For assessment location AL01, the annual mean NO_2 concentrations at the different building levels are compared with the NSW air quality criterion in Figure 4.4.

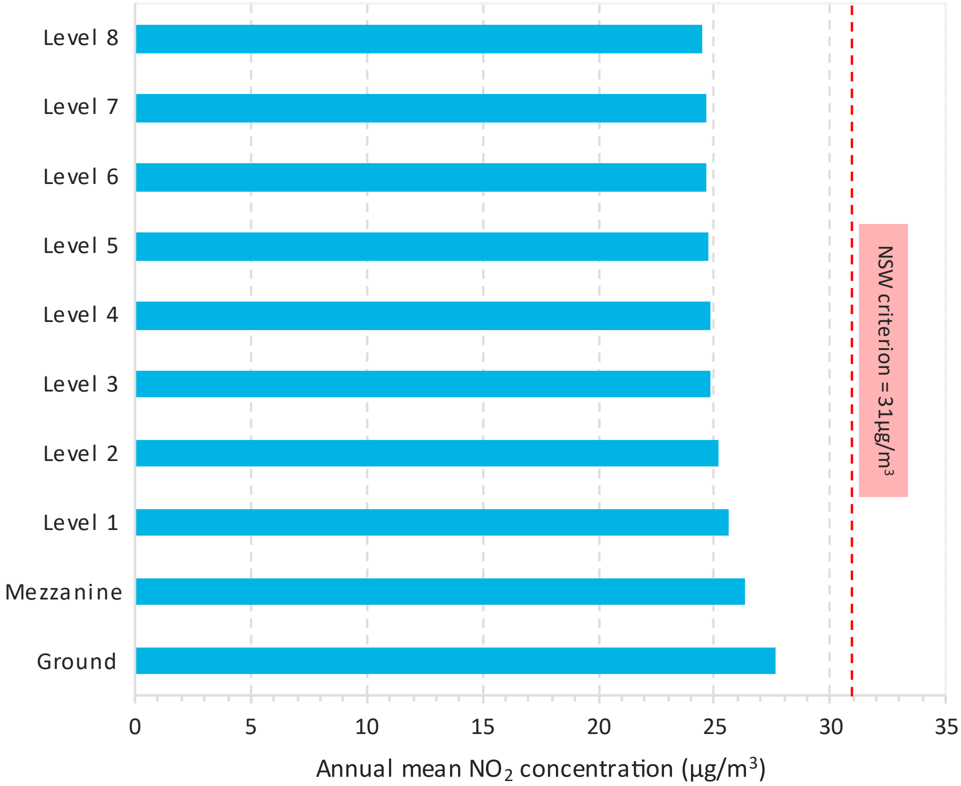


Figure 4.4 Annual mean NO_2 at assessment location AL01

4.2.2 1-hour

The predicted maximum 1-hour NO_2 concentrations in 2018 for each assessment location and building level are given in Table 4.5. The results were very similar in all cases, at around 140 µg/m^3. For reference, the maximum 1-hour NO_2 concentration in the background profile was around 103 µg/m^3.

For all assessment locations and building levels, the maximum 1-hour NO_2 concentration was below the NSW air quality criterion of 164 µg/m^3.

It can be seen that, although the maximum NO_X concentrations were highest near ground level, for NO_2 the maximum concentrations were lowest, although the variation across building heights was small. This is possibly an artefact of the empirical conversion method (see Appendix E). Maximum 1-hour NO_2 concentrations are difficult to predict reliably, and the values in Table 4.5 should be taken to be indicative. Nevertheless, we expect that they provide a reasonable estimate.

Table 4.5 Maximum 1-hour NO_2 concentrations at assessment locations

	NO_2 (µg/m³)				
Building level	**AL01**	**AL02**	**AL03**	**AL04**	**AL05**
Level 8	144.1	144.2	144.1	144.1	144.1
Level 7	144.1	144.1	144.1	144.2	144.1
Level 6	144.0	144.0	144.1	144.1	144.1
Level 5	144.1	144.0	144.1	144.1	144.1
Level 4	144.0	143.9	144.0	144.1	144.0
Level 3	143.7	144.0	143.8	144.1	144.0
Level 2	143.1	143.7	143.4	143.6	143.7
Level 1	142.6	142.5	143.2	143.3	143.0
Mezzanine	142.3	142.3	141.9	143.2	142.0
Ground level	137.5	138.0	139.7	142.3	141.6

For assessment location AL01, the maximum 1-hour NO_2 concentrations at the different building levels are compared with the NSW air quality criterion in Figure 4.5.

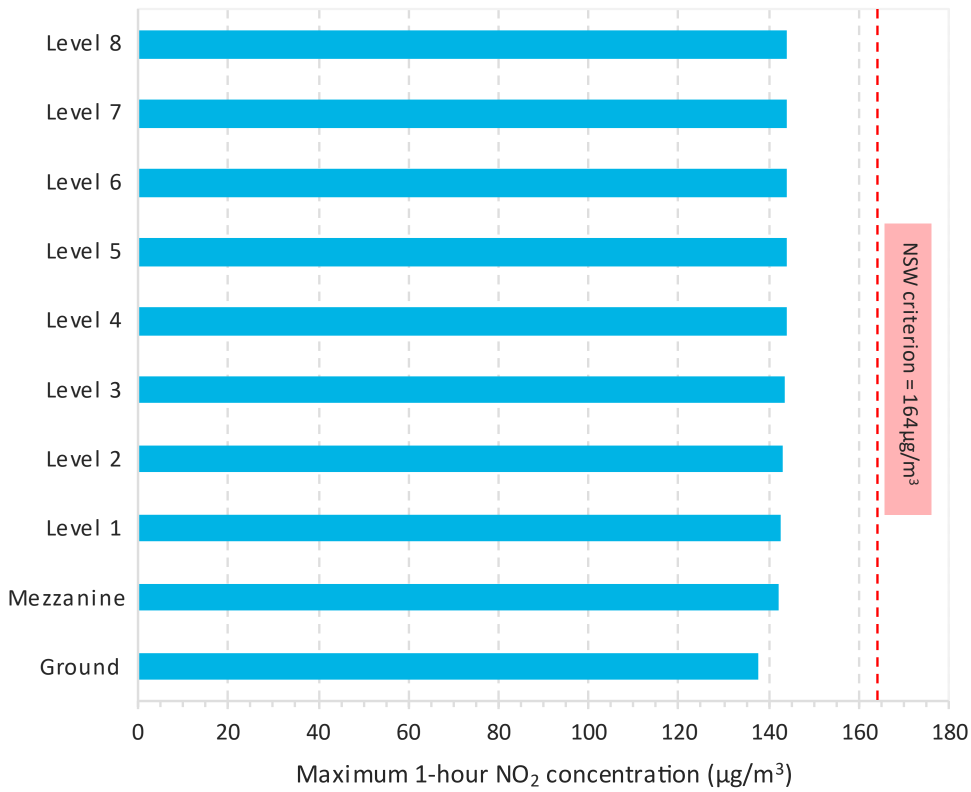


Figure 4.5 Maximum 1-hour NO_2 at assessment location AL01

4.3 PM_{10} concentration

4.3.1 Annual mean

The predicted annual mean PM_{10} concentrations for each assessment location and building level are given in Table 4.6. As with NO_X, concentrations were generally highest at AL01 and lowest at AL04, and concentrations were highest for the ground level and lowest for the higher levels. However, the contribution of road traffic to PM_{10} was much less pronounced than for NO_X.

Table 4.6 Annual mean PM_{10} concentrations at assessment locations

	PM_{10} (µg/m^3)				
Building level	**AL01**	**AL02**	**AL03**	**AL04**	**AL05**
Level 8	21.4	21.0	21.0	20.9	21.4
Level 7	21.5	21.0	21.0	21.0	21.4
Level 6	21.4	21.0	21.0	21.0	21.4
Level 5	21.4	21.1	21.1	21.0	21.4
Level 4	21.4	21.1	21.1	21.0	21.3
Level 3	21.4	21.1	21.1	21.1	21.3
Level 2	21.4	21.2	21.2	21.0	21.3
Level 1	21.6	21.4	21.3	21.1	21.4
Mezzanine	21.9	21.7	21.5	21.2	21.5
Ground level	22.6	22.4	21.8	21.4	21.8

For all assessment locations and building levels, the annual mean PM_{10} concentration was below the NSW air quality criterion of 25 µg/m^3.

Figure 4.6 shows the various contributions to annual mean PM_{10} at AL01. The largest component was the background, which was responsible for 88% of the total concentration at ground level, and 92% of the total at level 8. At ground level, surface roads contributed 2.2 µg/m^3, or around 10% of the total, but at level 8 this had reduced to 0.3 µg/m^3, or 1% of the total. The contribution of the ventilation outlet for the M4-M5 Link increased from 0.5 µg/m^3 at ground level to 1.4 µg/m^3 at level 8. The contribution of the ventilation outlet for the M8 was again negligible.

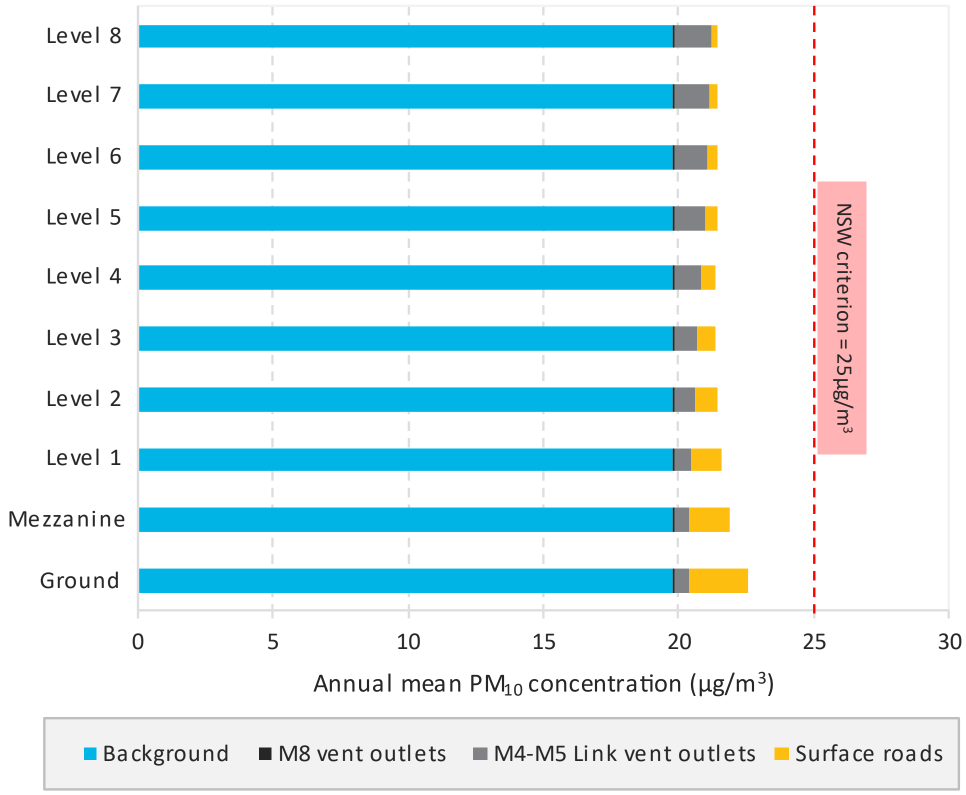


Figure 4.6 Contributions to annual mean PM_{10} at assessment location AL01

4.3.2 24-hour

The maximum 24-hour concentration of PM_{10} in the background profile was above the corresponding criterion of 50 µg/m³. In fact, there were five exceedance days for PM_{10} in 2018. In such cases, the Approved Methods refers to *additional* exceedances of the criterion. Consequently, the sixth highest 24-hour predictions for PM_{10} during the year are given in Table 4.7.

Table 4.7 Sixth highest 24-hour PM_{10} concentrations at assessment locations

	PM_{10} (µg/m³)				
Building level	**AL01**	**AL02**	**AL03**	**AL04**	**AL05**
Level 8	41.1	40.9	41.1	41.0	41.2
Level 7	41.3	41.0	41.0	41.1	41.4
Level 6	41.3	41.1	41.1	41.3	41.5
Level 5	41.4	41.2	41.4	41.3	41.5
Level 4	41.4	41.4	41.5	41.4	41.9
Level 3	41.7	41.6	41.7	41.6	42.1
Level 2	42.0	41.8	42.0	41.9	42.2
Level 1	42.6	42.5	42.1	42.0	42.6
Mezzanine	43.4	43.2	42.8	42.3	42.9
Ground level	44.7	44.6	43.3	42.9	43.5

For all assessment locations and building levels, the sixth highest 24-hour PM_{10} concentration was below the NSW air quality criterion of 50 µg/m^3. In other words, no additional exceedances were predicted.

Figure 4.7 shows the various contributions to the sixth highest 24-hour PM_{10} concentration at AL01. The background was clearly the largest component of the total (90% at ground level, and 98% at level 8). The sixth highest 24-hour PM_{10} concentration in the background, and the highest value below the criterion, was 40.3 µg/m^3, which occurred on 29 May. However, the sixth highest total concentration coincided, in all cases, with the seventh highest background value of 40.1 µg/m^3, which occurred on 18 July. At ground level, surface roads contributed 4.3 µg/m^3, or around 10% of the total. The contributions of the two ventilation outlets were negligible.

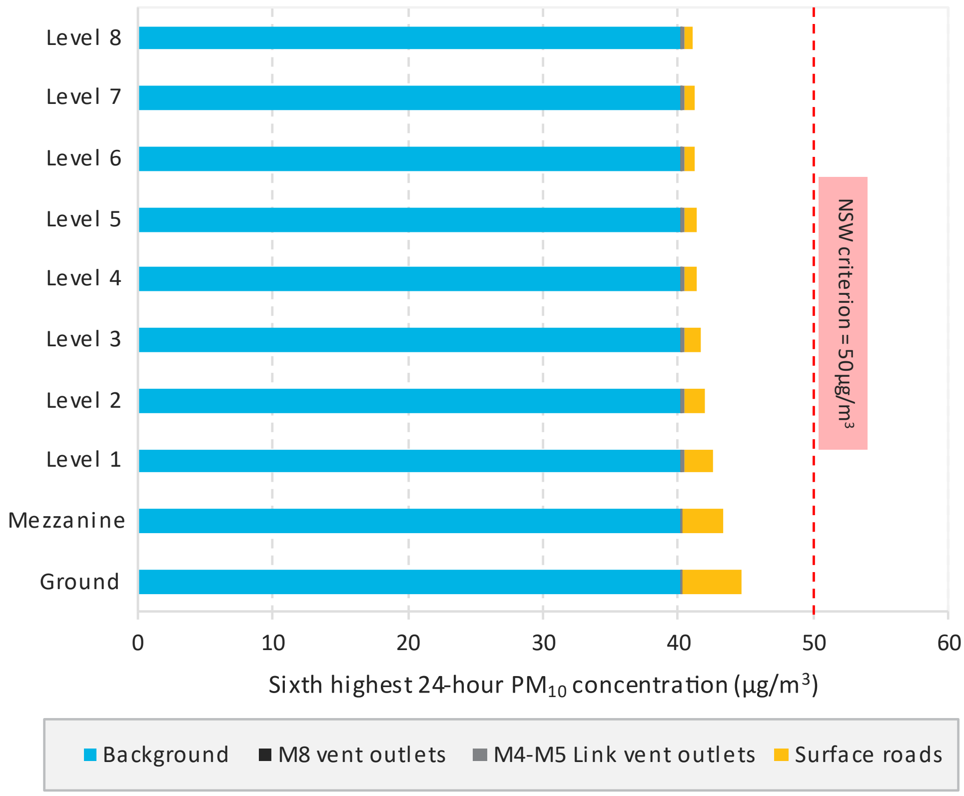


Figure 4.7 Contributions to sixth highest 24-hour PM_{10} at assessment location AL01

4.4 $PM_{2.5}$ concentration

4.4.1 Annual mean

The predicted annual mean $PM_{2.5}$ concentrations are given in Table 4.8. The general patterns in concentration were similar to those predicted for NO_X and PM_{10}.

For all assessment locations and building levels, the annual mean $PM_{2.5}$ concentration exceeded the NSW air quality criterion of 8 µg/m^3 and the AAQ NEPM goal for 2025 of 7 µg/m^3.

Table 4.8 Annual mean $PM_{2.5}$ concentrations at assessment locations

Building level	$PM_{2.5}$ (µg/m³)				
	AL01	AL02	AL03	AL04	AL05
Level 8	8.9	8.6	8.6	8.6	8.9
Level 7	8.9	8.6	8.6	8.6	8.9
Level 6	8.9	8.6	8.7	8.6	8.9
Level 5	8.9	8.7	8.7	8.6	8.8
Level 4	8.9	8.7	8.7	8.6	8.8
Level 3	8.9	8.7	8.7	8.6	8.8
Level 2	8.9	8.8	8.7	8.7	8.8
Level 1	9.0	8.9	8.8	8.7	8.8
Mezzanine	9.2	9.1	8.9	8.7	8.9
Ground level	9.6	9.4	9.1	8.8	9.0

Figure 4.8 shows the contributions to annual mean $PM_{2.5}$ at AL01. Once again, the largest component was the background. In this case, the background concentration of 7.8 µg/m³ was already very close to the NSW air quality criterion of 8 µg/m³, and above the AAQ NEPM goal for 2025 of 7 µg/m³. At ground level, surface roads contributed 1.4 µg/m³, and at level 8 this had reduced to 0.2 µg/m³. The contribution of the ventilation outlet for the M4-M5 Link increased from 0.4 µg/m³ at ground level to 0.9 µg/m³ at level 8. The contribution of the ventilation outlet for the M8 was again negligible.

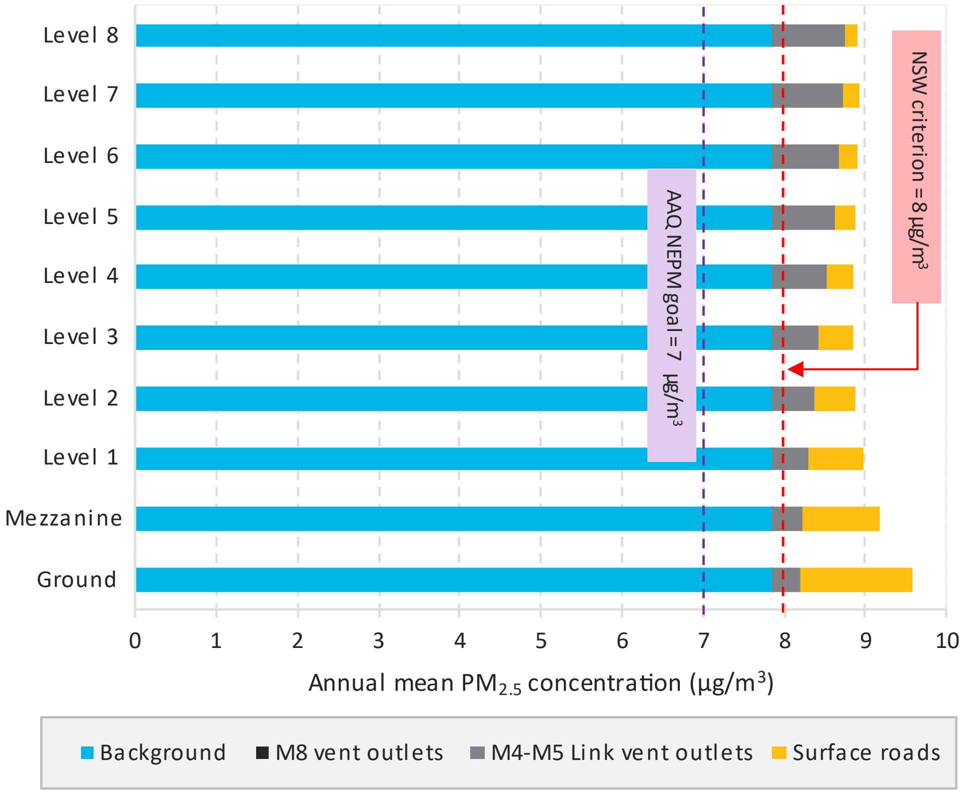


Figure 4.8 Contributions to annual mean $PM_{2.5}$ at assessment location AL01

4.4.2 24-hour

The 24-hour concentration of $PM_{2.5}$ in the background profile was above the corresponding criterion of 25 µg/m^3 on one day in 2018. Therefore, the second highest 24-hour predictions for $PM_{2.5}$ during the year are given in Table 4.9.

> The second highest 24-hour $PM_{2.5}$ concentration only exceeded the NSW air quality criterion of 25 µg/m^3 at the ground level of assessment location AL01.

Table 4.9 Second highest 24-hour $PM_{2.5}$ concentrations at assessment locations

	$PM_{2.5}$ (µg/m^3)				
Building level	**AL01**	**AL02**	**AL03**	**AL04**	**AL05**
Level 8	23.8	23.7	23.7	23.7	23.8
Level 7	23.8	23.7	23.7	23.7	23.8
Level 6	23.8	23.7	23.7	23.7	23.8
Level 5	23.9	23.8	23.8	23.7	23.8
Level 4	23.9	23.8	23.8	23.8	23.8
Level 3	24.0	23.9	23.8	23.8	23.9
Level 2	24.1	23.9	23.9	23.8	24.0
Level 1	24.3	24.0	24.0	23.9	24.1
Mezzanine	24.6	24.2	24.2	24.1	24.2
Ground level	25.3	25.0	24.4	24.2	24.4

Figure 4.9 shows the contributions to the second highest 24-hour $PM_{2.5}$ concentration at AL01. As before, the background was the largest component. Depending on the assessment location and height, the second highest concentration occurred on either 2 August or 8 May, when the background concentrations were 23.5 µg/m^3 and 22.7 µg/m^3, respectively. At ground level, surface roads contributed 2.6 µg/m^3, or around 10% of the total. The contributions of the two ventilation outlets were negligible.

A corresponding assessment was also conducted for the AAQ NEPM goal for 2025 of 20 µg/m^3. In this case, there were 5 days on which the background concentration was above 20 µg/m^3.

> The sixth highest 24-hour $PM_{2.5}$ concentration exceeded the AAQ NEPM goal for 2025 of 20 µg/m^3 at all assessment locations and most levels. The only exceptions were AL02 above level 3, and AL03 above level 4.

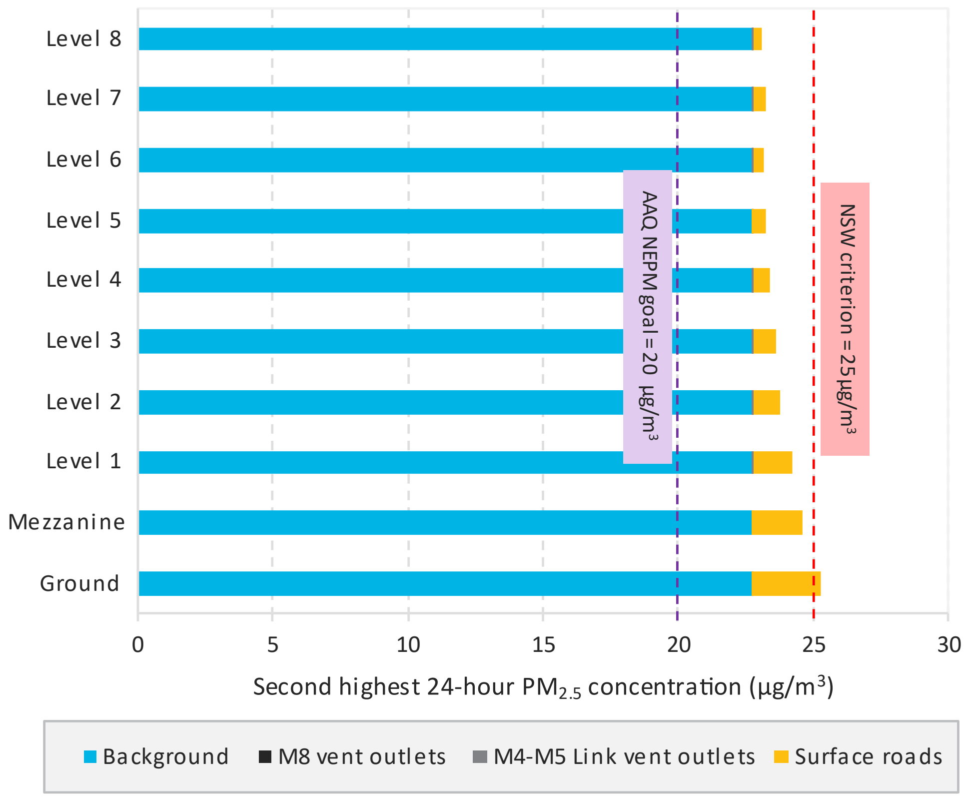


Figure 4.9 Contributions to second highest 24-hour $PM_{2.5}$ at assessment location AL01

5 Summary and discussion

5.1 Background

EMM has conducted an AQIA for a potential mixed-use development at 75-85 Crown Street, St Peters. The AQIA responded to key air quality matters raised by IWC, notably:

- proximity of the WestConnex (M4-M5 Link) ventilation facility, requiring an air quality impact assessment (AQIA) which considers built form design; and
- demonstration of a quality living environment, given noise and air quality impacts.

In addition, the development includes a proposed height uplift from 6 storeys to 8 storeys, and there was a need to understand whether the proposed uplift would result in any further detrimental impact on upper floor units from an air quality perspective.

This AQIA focussed on the assessment of operational air quality impacts from road traffic. The aim was to understand the effects of the surrounding road infrastructure, as well as background air pollution, on air quality at the development site (including how this varies with height), and hence any resulting constraints.

5.2 Assessment methodology

The AQIA methodology was broadly in accordance with the Approved Methods (NSW EPA 2022).

The AQIA involved the use of an atmospheric dispersion model (GRAL) to estimate the impacts of emissions from road traffic on air quality at the development. The modelling was conducted for the calendar year 2018, and included emissions from surface roads near the development (notably Princes Highway and Campbell Street), surface roads at SPI, and the ventilation outlets for the WestConnex M8 and M4-M5 Link tunnels. Measured background concentrations were taken from the DPE monitoring station at Earlwood. The AQIA considered the combined effects of these contributions to long-term and short-term concentrations of NO_2, PM_{10} and $PM_{2.5}$.

Concentrations were predicted for each level of the potential development. The model predictions were compared with the air quality criteria in the Approved Methods, as well as the goals for 2025 ($PM_{2.5}$ only) in the AAQ NEPM. Allowances were made for cases where the background measurements already included exceedances of the criteria.

5.3 Results and interpretation

The main findings of the AQIA are summarised below.

5.3.1 Variation in pollutant concentration with height

One of the aims of this report was to determine whether the proposed uplift would result in higher concentrations of air pollutants than at ground level.

At each assessment location the total concentration of each pollutant (NO_X, NO_2, PM_{10}, $PM_{2.5}$) was highest at ground level and generally decreased with height. The lowest concentrations were usually predicted for the highest levels of building. This pattern reflected the diminishing contribution from surface roads near the development with height.

5.3.2 Source contributions

One of the main drivers for this AQIA has been the concern, expressed by IWC, that the development is close to the WestConnex M4-M5 Link ventilation outlet. Therefore, the contributions of different sources to pollutant concentrations at the development site were considered.

The findings were, in general:

- the largest component of the total concentration was the background;
- at ground level, the second largest component was surface roads, but their contribution decreased with height;
- the third largest component (where relevant) was the M4-M5 Link outlet, which increased with height; and
- the contribution of the M8 outlet was negligible.

Therefore, whilst the M4-M5 Link outlet contributed to the concentrations at the development, the AQIA has shown that it is not the main contributor. This is not surprising given that the proportion of the year when winds are blowing from the tunnel ventilation outlets to the development site (ie south-easterly winds) is quite low. More important – especially closer to ground level where the concentrations are highest – are the existing background and the surface road contribution. In this respect, the upgrade to Campbell Street as part of WestConnex, and the associated increase in traffic volume, is a significant factor.

5.3.3 Compliance with criteria

The following points summarise the predicted concentrations at the development in relation to the NSW air quality assessment criteria:

- for all assessment locations and building levels, the annual mean NO_2 concentration was below the NSW air quality criterion of 31 µg/m^3;
- for all assessment locations and building levels, the maximum 1-hour NO_2 concentration was below the NSW air quality criterion of 164 µg/m^3;
- for all assessment locations and building levels, the annual mean PM_{10} concentration was below the NSW air quality criterion of 25 µg/m^3;
- for all assessment locations and building levels, the sixth highest 24-hour PM_{10} concentration was below the NSW air quality criterion of 50 µg/m^3, and hence there were no additional exceedances;
- for all assessment locations and building levels, the annual mean $PM_{2.5}$ concentration exceeded the NSW air quality criterion of 8 µg/m^3 and the AAQ NEPM goal for 2025 of 7 µg/m^3;
- the second highest 24-hour $PM_{2.5}$ concentration only exceeded the NSW air quality criterion of 25 µg/m^3 at the ground level of assessment location AL01; and
- the sixth highest 24-hour $PM_{2.5}$ concentration exceeded the AAQ NEPM goal for 2025 of 20 µg/m^3 at all assessment locations and at most levels, with the only exceptions being AL02 above level 3, and AL03 above level 4.

The limiting pollutant for the development site is therefore $PM_{2.5}$. The most established air quality metric for characterising the risk of air pollution to health is annual mean $PM_{2.5}$. For all building levels, the air quality criterion for annual mean $PM_{2.5}$ (8 µg/m^3) was predicted to be exceeded across the development site.

This was primarily due to the background concentration (7.8 µg/m^3) already being very close to the criterion. This is a common situation in the Sydney metropolitan area. For example, the background concentrations at DPE monitoring stations in the metropolitan area 2018 ranged from 6.8 µg/m^3 in Bargo to 10.1 µg/m^3 in Liverpool, and therefore predicted exceedances near busy roads are often inevitable. An absolute criterion for annual mean $PM_{2.5}$ is therefore impractical as a generalised assessment metric, and this situation will be exacerbated if NSW EPA adopts the NEPM goal of 7 µg/m^3. There are also no formally defined metrics (such as an incremental change) to determine acceptability in cases where the existing background levels are already above (or very close to) the criterion, as in this case.

Given the above, the future occupants of the potential development should be aware of the risks[10] associated with their level of exposure to $PM_{2.5}$, given the proximity to busy roads. The risk of adverse health impacts at any location is not, and cannot be, zero. The risk also increases as the concentration increases. However, this should also be placed into context. Hypothetically, a person spending a year next to the heavily trafficked Campbell Street would have a considerably lower long-term exposure to $PM_{2.5}$ than a person spending a year in a park in Liverpool. Options for reducing risk should always be considered. For example, the building design should, as far as possible, be guided by best practice with respect to air quality, as discussed in Section 5.5.

For 24-hour $PM_{2.5}$, the second highest predicted concentration only exceeded the criterion of 25 µg/m^3 at the ground level of AL01. The practical implication of this is that sensitive uses (eg residences, childcare centres, aged care centres) should be avoided at this location. To provide a margin of safety, we recommend that such uses are actually avoided below level 1 of the building. It is likely that the AAQ NEPM goal for 2025 of 20 µg/m^3 will be exceeded on most levels of the building. However, NSW EPA has not yet adopted this value for AQIAs.

5.4 Assumptions and limitations

The NSW EPA model assumed that there would be zero update of hybrids or full electric vehicles by 2033. This, in itself, will tend to lead to conservative model predictions in the AQIA.

A limitation of the AQIA is the assessment of 1-hour NO_2 concentrations using the empirical method, which may have resulted in some artefacts in the predictions. However, we consider that the possible underestimation of NO_2 concentrations for a small number of hours in the year is less important (in terms of health outcomes) than accurate prediction of long-term concentrations.

5.5 Building design

The issue of building design has not been addressed quantitatively in this report. AQIAs are usually conducted for 'outdoor' assessment locations[11], and these are simply positions in space. Therefore, the effects of building design on indoor air quality are not considered.

The building design should, as far as possible, be guided by best practice with respect to air quality. NSW DoP (2008) provides qualitative advice on how air pollution impacts can be reduced.

Several best practice measures to reduce exposure have been incorporated into the design of the development, such as:

- minimising the formation of urban canyons by having buildings of different heights mixed with open areas;
- orientating buildings so that outdoor living areas and other sensitive uses are shielded from traffic emissions;

10 This should be based on advice from a health expert.

11 For example, air quality standards and assessment criteria have been developed for outdoor locations.

- placing less sensitive rooms – such as garages, laundries, bathrooms and corridors – on the side of the building closest to the traffic to act as a buffer;
- placing residences furthest from, and commercial and retail spaces closest to, surface traffic (see below); and
- minimising the number of doors and windows that can be opened, especially on walls adjacent to the road, which is incorporated into the design through the placement of wintergardens on the southern elevation.

A buffer between residences and surface traffic would be incorporated into the design through the placement of commercial uses on most of the ground floor. Figure 5.1 shows the approximate area of exceedance (red shading) of the 24-hour $PM_{2.5}$ criterion, and the proposed locations of residences (pink areas), at ground level. It can be seen that the two ground floor/mezzanine double-story units along Crown Street satisfy the 24-hour $PM_{2.5}$ criterion.

Figure 5.1 Area of exceedance of 24-hour $PM_{2.5}$ criterion at ground level

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Appendix A
Analysis of meteorological data

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A.1 Monitoring station

The characteristics of the BoM monitoring station at Canterbury Racecourse are summarised in Table A.1. The monitoring station has been operational since 1995, and data for the five-year period between 2017 and 2021 were analysed for the AQIA.

Table A.1 Meteorological monitoring station

Item	Description
Station name	Canterbury Racecourse AWS
BoM site number	066194
Location	Latitude: -33.91; Longitude: 151.11
Elevation (m, AHD)	3
Distance from development site (km)	6.1
Start of operation	1995
Monitoring period included in assessment	2017 to 2021
Parameters measured	Temperature, relative humidity, pressure, wind speed, wind direction, sigma theta, rainfall, cloud height, visibility.

A.2 Data summary

Hourly meteorological data from Canterbury Racecourse were provided by BoM. The data were based on hourly averages of 1-minute raw values.

An overview of the meteorological data for Canterbury Racecourse between 2017 and 2021 is presented in Figure A.1. The plots in the left panel show the time series of 24-hour mean values of sigma theta[12], relative humidity, temperature, wind direction and wind speed, with the grey bars indicating the presence of data and the red bars the missing data. For each parameter, some overall summary statistics are also given, including the number (and percentage) of missing points, the minimum, the maximum, the mean, the median and the 95th percentile. The percentage data capture in each year is shown in green font. The panel on the right shows the frequency distribution of each parameter.

The data availability for all parameters and all years was relatively high, at close to 90% when the wind speed and wind direction values in a given hour were both zero.

12 Standard deviation of wind direction.

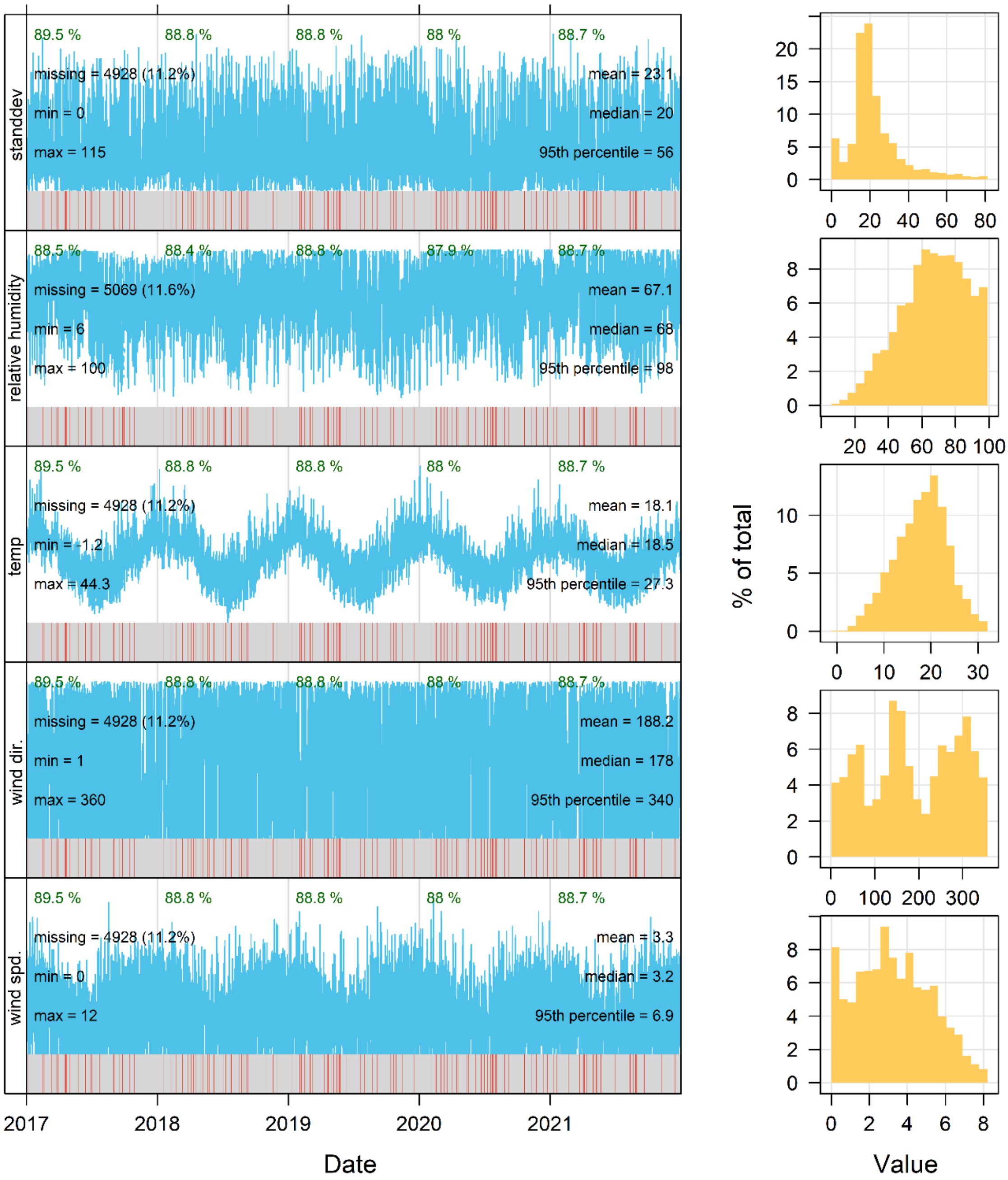

Figure A.1 Meteorological data summary (Canterbury Racecourse, 2017-2021)

A.2.1 Between-year comparison

Inter-annual diurnal profiles for wind speed, wind direction, temperature and relative humidity are shown in Figure A.2 to Figure A.5. For each data series, the box is bounded on the top by the third quartile, and on the bottom by the first quartile. The median is represented by a horizontal line through the box. The whiskers (vertical lines) extend from the ends of the box to the minimum and maximum values. The profiles were generally very similar from year to year.

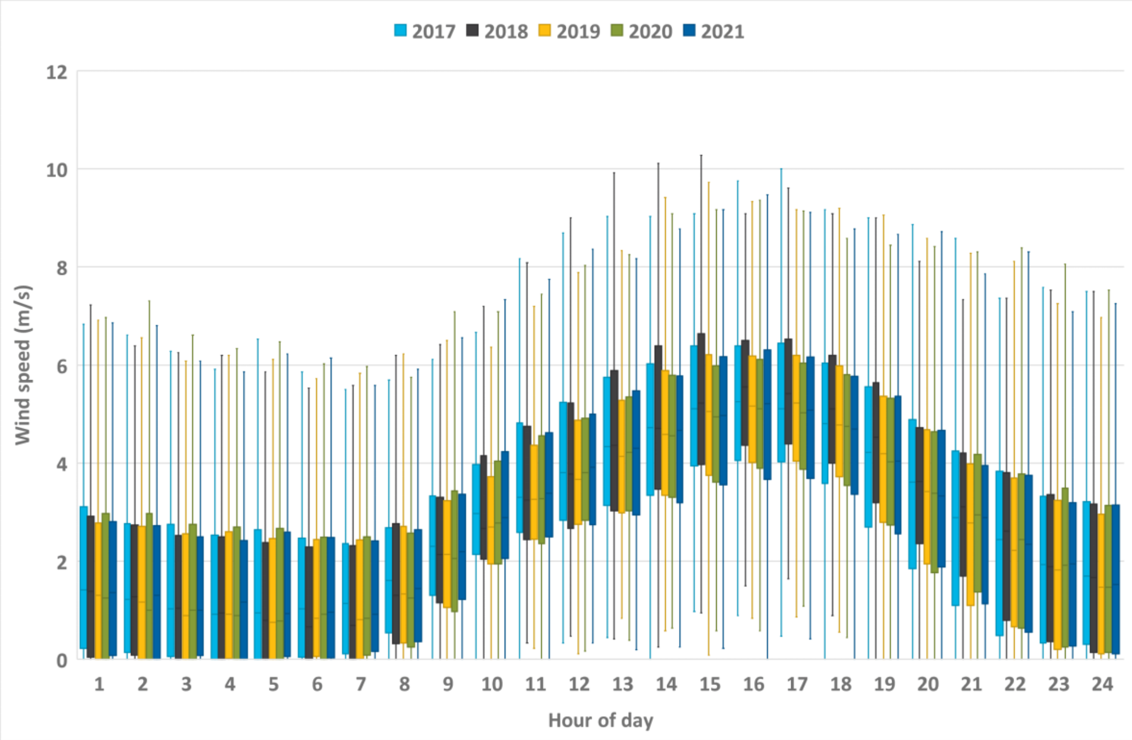

Figure A.2 Inter-annual variability in diurnal wind speed (Canterbury Racecourse, 2017-2021)

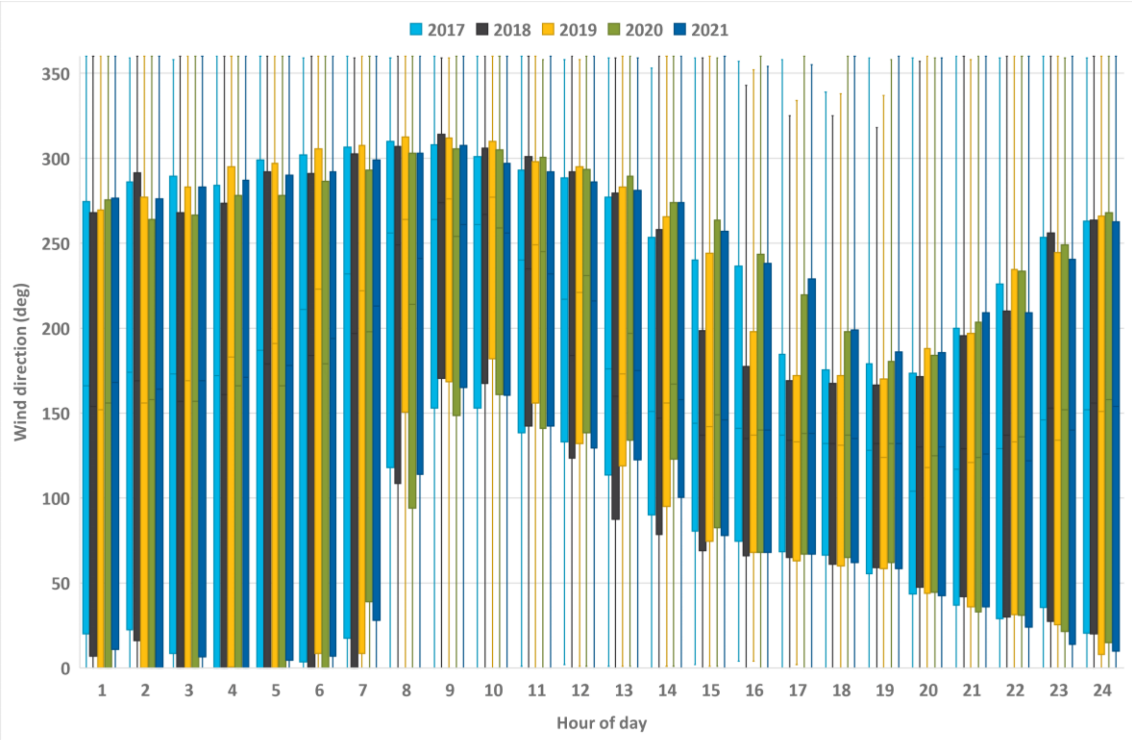

Figure A.3 Inter-annual variability in diurnal wind direction (Canterbury Racecourse, 2017-2021)

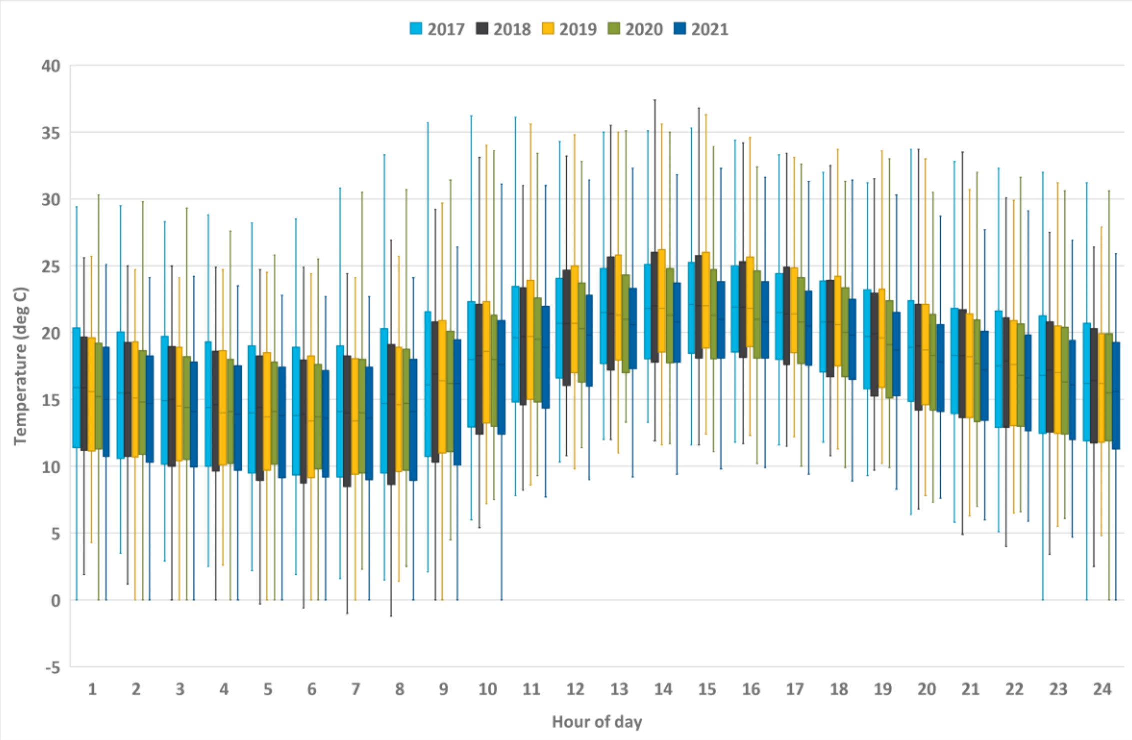

Figure A.4 Inter-annual variability in diurnal temperature (Canterbury Racecourse, 2017-2021)

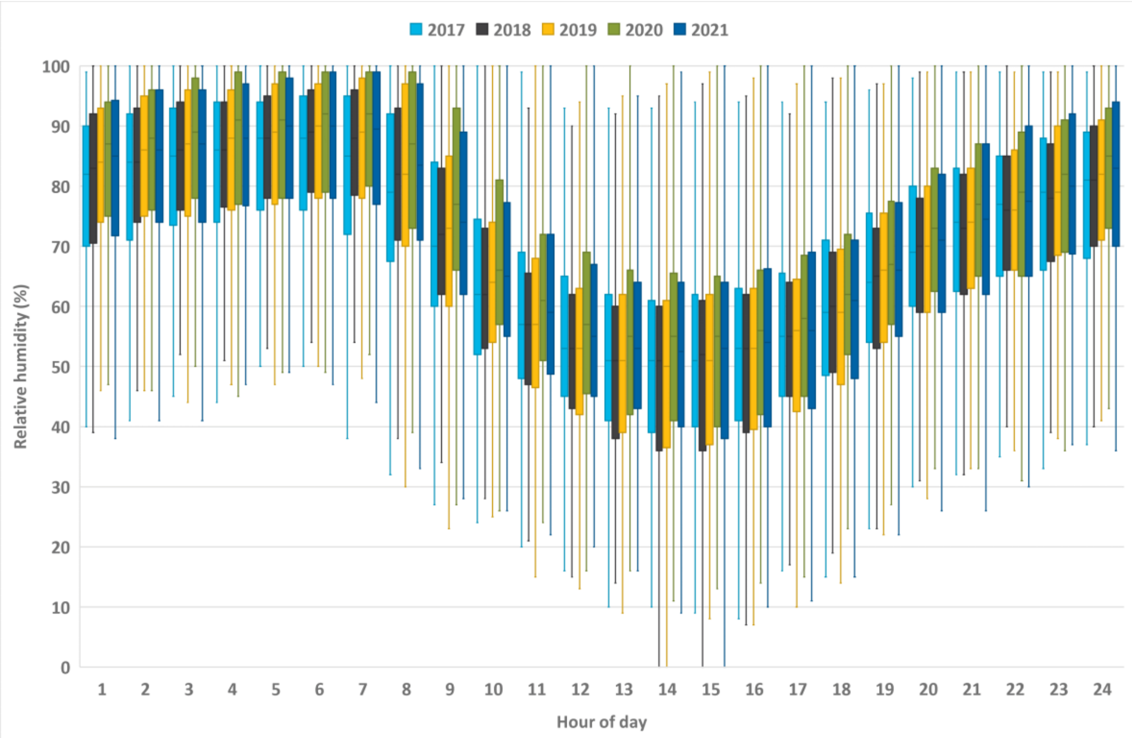

Figure A.5 Inter-annual variability in diurnal relative humidity (Canterbury Racecourse, 2017-2021)

A.2.2 Wind speed and direction

Annual wind roses for Canterbury Racecourse – created from the wind speed and wind direction data – are presented in Figure A.6. There was a high degree of consistency in wind direction, average wind speed, and percentage occurrence of calm winds (defined as wind speeds <= 0.5 m/s) across the five-year period. On an annual basis, the prevailing winds are broadly from the west, north-west, north-east and south-west. The annual mean wind speed was around 3.3 m/s to 3.4 m/s, and the annual frequency of calm conditions was around 7% to 8%.

Seasonal wind roses are shown in Figure A.7. The wind patterns in spring and summer were similar, with dominant north-easterly and south-easterly winds. Through autumn and winter, winds from the western quadrants increased in frequency, becoming dominant in winter. The mean wind speed ranged from 2.8 m/s in winter to 3.9 m/s in summer. The seasonal average percentage of calm conditions ranged from 4.7% in summer to 10.4% in winter.

Wind roses for each hour of the day (averaged across all years) are shown in Figure A.8. From midnight to 8.00 am (hours 00 to 07), the winds were light (typically around 2 m/s), and increasingly from a north-westerly direction. After 8.00 am the wind speed began to increase, peaking at around 5 m/s in the late afternoon. This increase in wind speed coincided with a shift in wind direction, with winds blowing most frequently from (broadly) the north-east and south-east. Wind speeds began to decrease after around 6.00 pm, with no dominant wind direction by midnight.

It is useful to note that the proportion of the year when winds were blowing from the WestConnex tunnel ventilation outlets to the development site (ie south-easterly winds) was quite low overall.

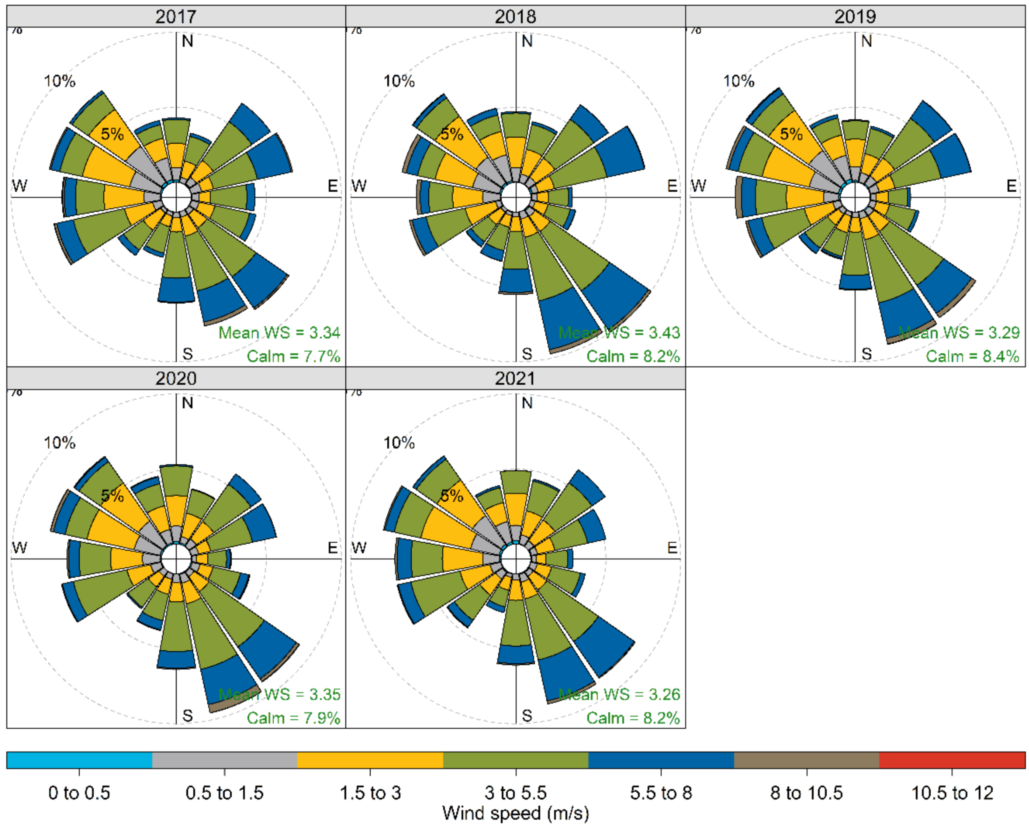

Figure A.6 Annual wind roses (Canterbury Racecourse, 2017-2021)

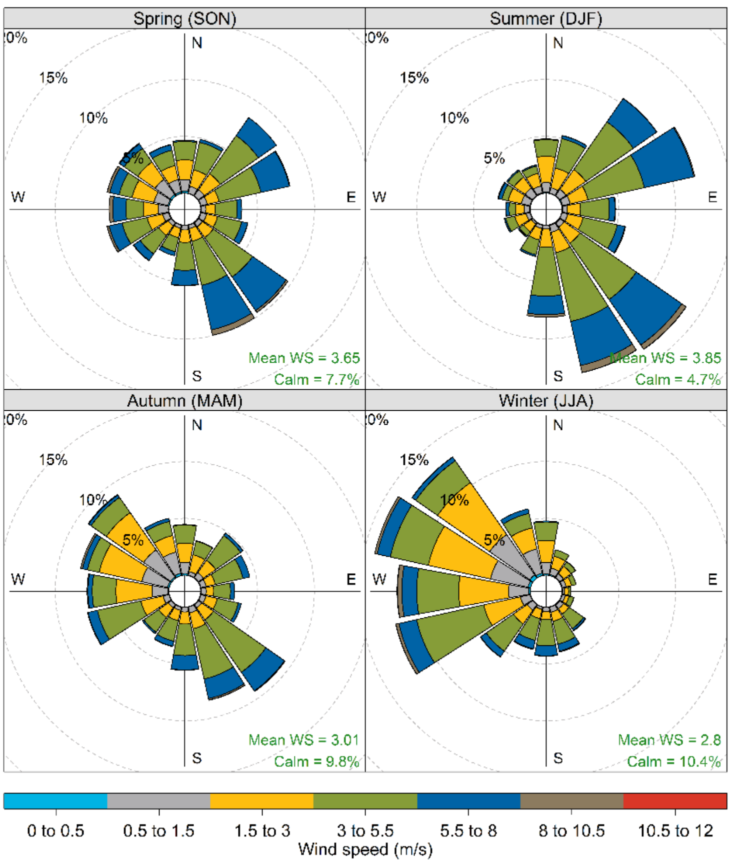

Figure A.7 Seasonal wind roses (Canterbury Racecourse, 2017-2021)

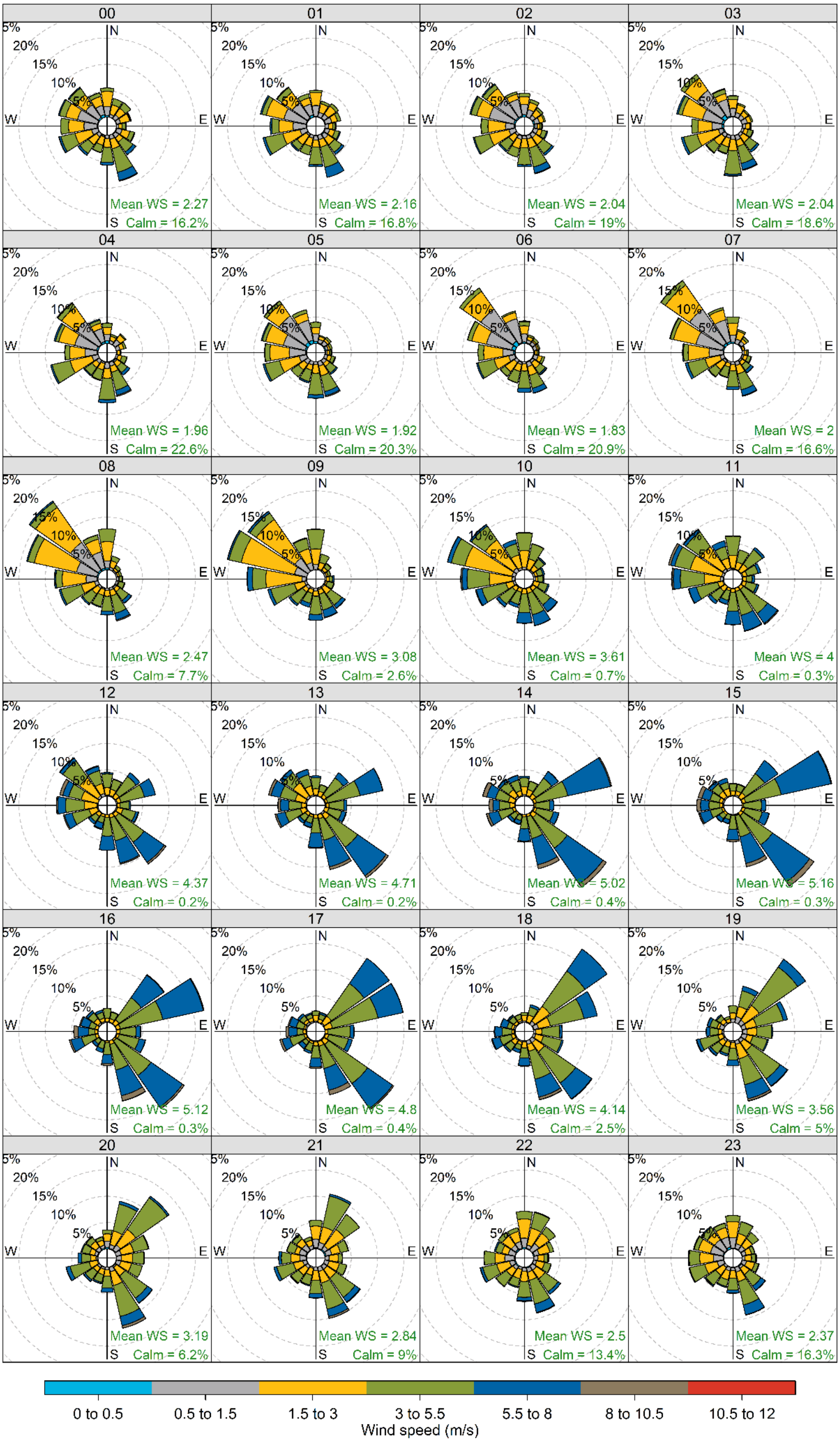

Figure A.8 **Hourly wind roses (Canterbury Racecourse, 2017-2021)**

A.3 Meteorological data processing

The representative year for the GRAL modelling was taken to be 2018. The meteorological data from Canterbury Racecourse in 2018 were processed into a suitable format for the modelling.

It is noted that 10.9% of the data included hours when the wind speed and wind direction were zero for the same hour. Given the 0 m/s wind speeds in these hours, these data were considered calms. If these hours were left in the GRAL modelling in this format, there would be an incorrect number of northerly winds (ie hours with '0' wind direction). If the data were removed, 10.9% of calms would be excluded incorrectly. Therefore, the data were included in the modelling but with the 0 m/s wind speed and directions filled in using interpolation.

There were only 22 hours in the 2018 dataset that were missing wind speed and direction. These hours were filled using interpolation. A complete year of meteorological data was therefore used in the modelling.

Appendix B

Analysis of ambient air quality monitoring data

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B.1 NO_2 analysis

The air quality criteria for NO_2 relate to 1-hour average and annual average concentrations.

Figure B.1 shows the time series in the daily maximum 1-hour average NO_2 concentration at the DPE Earlwood monitoring station. The time series shows a systematic pattern during each year, with peak concentrations being highest in winter and lowest in summer. There were no exceedances of the 1-hour air quality criterion (164 µg/m^3) during the five-year period.

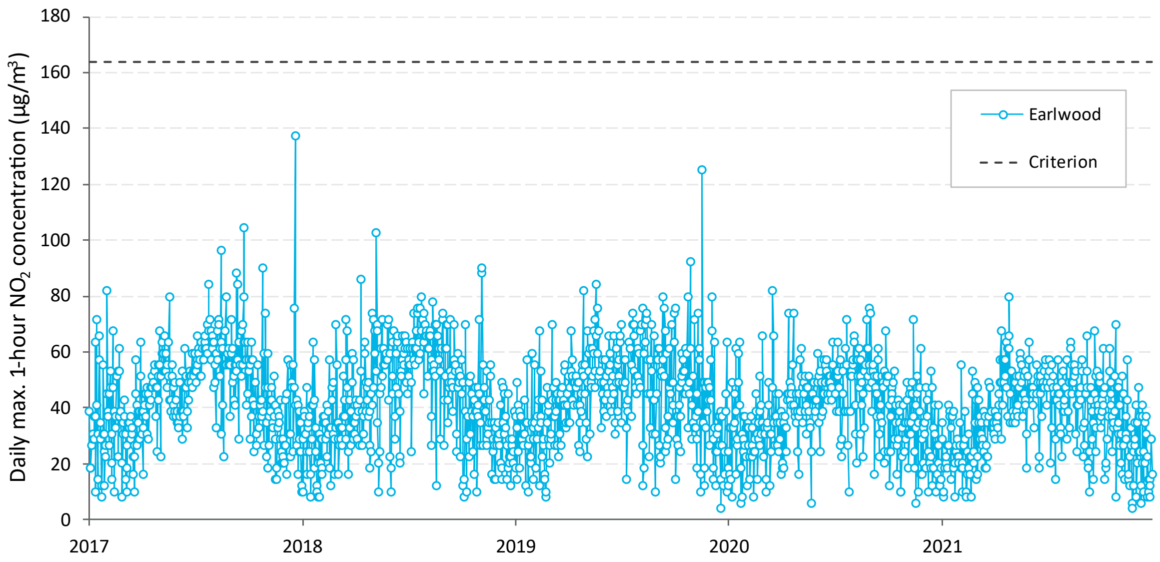

Figure B.1 Daily maximum 1-hour average NO_2 concentrations at DPE Earlwood monitoring station

Figure B.2 shows the time series in annual average NO_2 concentrations at Earlwood, in this case over a longer period (from 2000 to 2021). Concentrations have decreased over time, from around 30 µg/m^3 in 2000 to around 18 µg/m^3 in 2021. The annual average air quality criterion for NO_2 (31 µg/m^3) was not exceeded during this period.

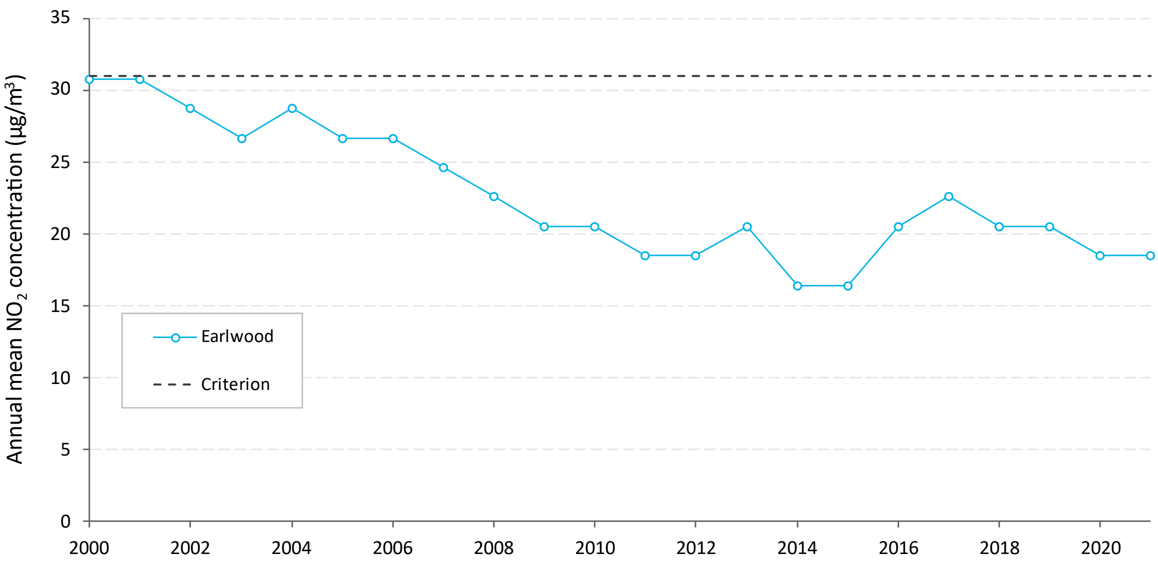

Figure B.2 Annual average NO_2 concentrations at DPE Earlwood monitoring station

Summary statistics for NO_2 for 2017-2021 are shown in Table B.1. The data availability in all years was greater than 92%.

Table B.1 Statistics for NO_2 concentrations at the DPE Earlwood monitoring station

Year	Data availability (%)	Annual average (µg/m³)[(a)]	Maximum 1-hour average (µg/m³)[(b)]	98th percentile 1-hour average (µg/m³)	Highest 1-hour average below criterion (µg/m³)	Number of exceedance hours per year[(b)]
2017	94.5%	22.6	137.5	61.6	137.5	0
2018	93.6%	20.5	102.6	61.6	102.6	0
2019	92.0%	20.5	125.2	59.5	125.2	0
2020	92.5%	18.5	82.1	51.3	82.1	0
2021	92.2%	18.5	80.0	51.3	80.0	0

(a) Annual average criterion = 31 µg/m³.

(b) 1-hour criterion = 164 µg/m³.

B.2 PM_{10} analysis

The air quality assessment criteria for PM_{10} relate to 24-hour average and annual average concentrations.

The time series in the 24-hour PM_{10} concentrations at the DPE Earlwood monitoring station between 2017 and 2021 is shown in Figure B.3, along with the corresponding criterion of 50 µg/m³. The plot illustrates the day-to-day variability in PM_{10} concentrations. Exceedances of criterion were mainly constrained to those years with several, or prolonged, extreme natural events. For example, the figure shows the impact of the 'Black Summer' bushfires of late 2019 and early 2020. Although not shown here, PM_{10} also has a diurnal and seasonal variation. For example, PM_{10} concentrations tend to be elevated during in summer as a result of several factors, including lower rainfall leading to dry conditions, stronger winds generating dust, bush fires and dust storms.

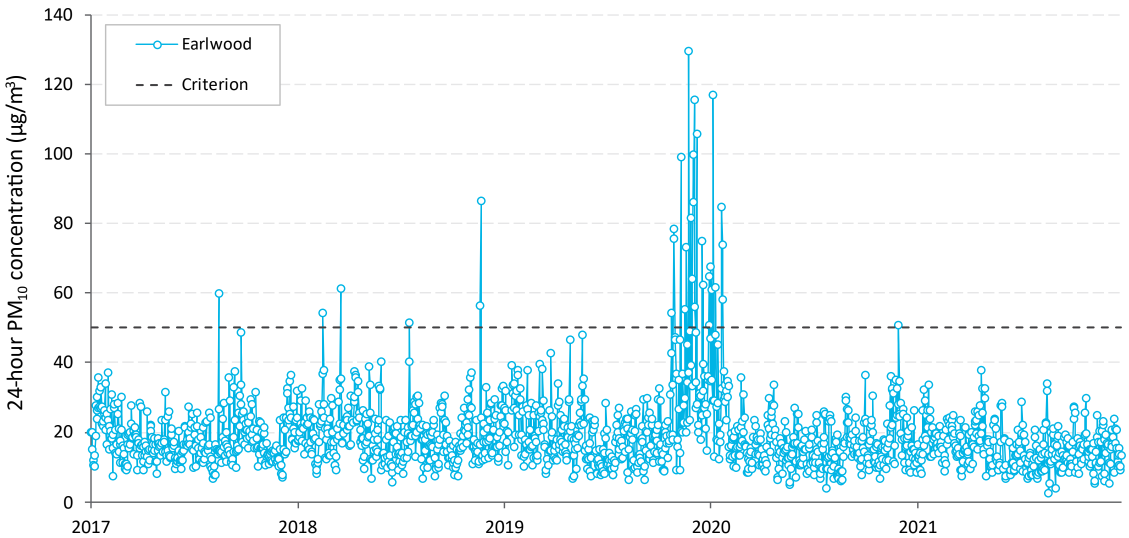

Figure B.3 24-hour average PM_{10} concentrations at DPE Earlwood monitoring station

Figure B.4 shows the long-term time series in annual average. There has been an underlying downward trend in concentrations. However, there are marked peaks in the data which are strongly influenced by the dust storm of September 2009 and the Black Summer bushfires. The La Niña phenomenon resulted in low concentrations in 2020 and 2021.

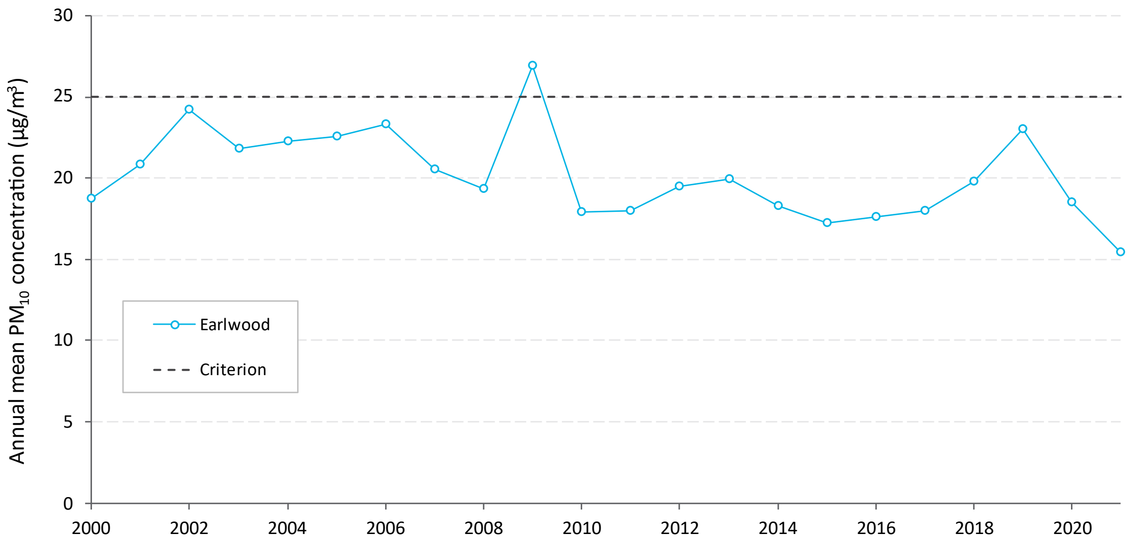

Figure B.4 Annual average PM_{10} concentrations at DPE Earlwood monitoring station

Summary statistics for PM_{10}, including numbers of exceedances of the 24-hour criterion, are provided in Table B.2. The effects of the 2019-2020 bushfires are again clear in the data, with much higher maximum concentrations and more exceedances than in other years.

Table B.2 Statistics for PM_{10} concentrations at the DPE Earlwood monitoring station

Year	Data availability (%)	Annual average (µg/m³)(a)	Maximum 24-hour average (µg/m³)(b)	98th percentile 24-hour average (µg/m³)	Highest 24-hour average below criterion (µg/m³)	Number of exceedance days per year(b)
2017	99.1%	18.0	59.8	34.5	48.4	1
2018	98.7%	19.8	86.50	38.7	40.3	5
2019	98.5%	23.0	129.4	77.8	49.0	17
2020	99.3%	18.5	116.7	50.6	47.9	9
2021	98.3%	15.4	37.6	29.8	37.6	0

(a) Annual average criterion = 25 µg/m³.

(b) 24-hour criterion = 50 µg/m³.

B.3 $PM_{2.5}$ analysis

The air quality assessment criteria for $PM_{2.5}$ also relate to 24-hour average and annual average concentrations.

The time series in the 24-hour $PM_{2.5}$ concentrations at Earlwood between 2017 and 2021 is shown in Figure B.5, along with the corresponding criterion of 25 µg/m³. As with PM_{10}, the most prominent feature is the cluster of high concentrations during the Black Summer bushfires.

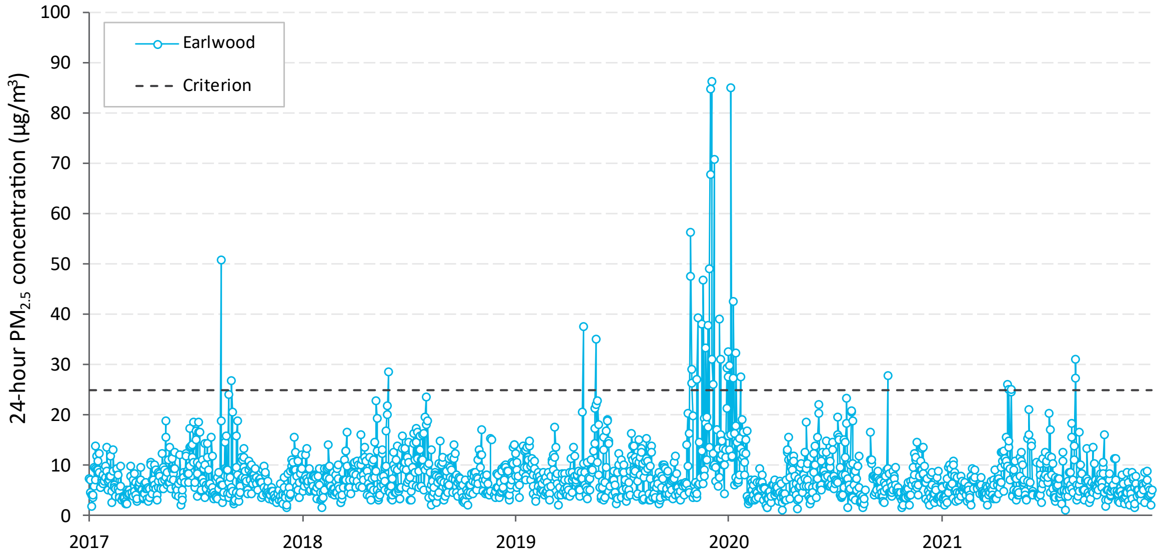

Figure B.5 **24-hour average $PM_{2.5}$ concentrations at DPE Earlwood monitoring station**

Long-term annual average $PM_{2.5}$ concentrations are shown in Figure B.6. There was a general increase in annual average concentrations from 2012 onwards. This was due to a change in the monitoring method; it is well documented that $PM_{2.5}$ measurements are sensitive to the measurement method used. During 2012, DPE made a decision to replace its tapered-element oscillating microbalances (TEOMs) with beta-attenuation monitors (BAMs), which tend to give higher readings. The annual average criterion of 8 µg/m³ was exceeded in 2019.

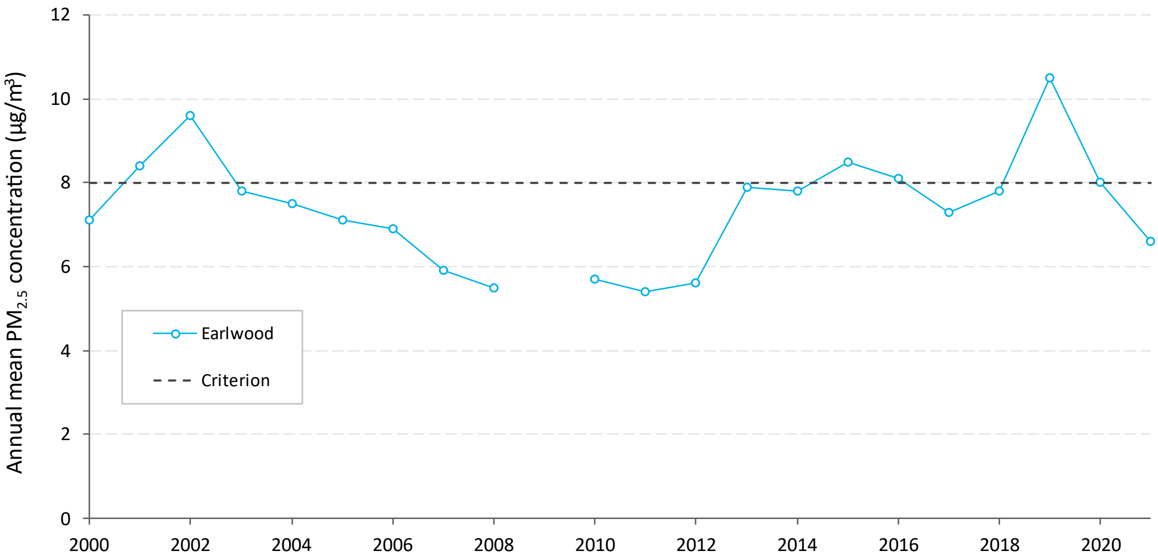

Figure B.6 **Annual average $PM_{2.5}$ concentrations at DPE Earlwood monitoring station**

Summary statistics for $PM_{2.5}$ for 2017-2021 are shown in Table B.3, including the number of exceedances of the 24-hour criterion.

Table B.3 Statistics for $PM_{2.5}$ concentrations at the DPE Earlwood monitoring station

Year	Data availability (%)	Annual average (µg/m³)(a)	Maximum 24-hour average (µg/m³)(b)	98th percentile 24-hour average (µg/m³)	Highest 24-hour average below criterion (µg/m³)	Number of exceedance days per year(b)
2017	98.2%	7.3	50.9	18.6	23.9	2
2018	96.5%	7.8	28.5	18.7	23.5	1
2019	95.8%	10.5	86.2	46.8	22.7	22
2020	97.0%	8.0	85.1	27.4	23.2	9
2021	97.5%	6.6	31.0	20.1	24.9	3

(a) Annual average criterion = 8 µg/m³.

(b) 24-hour criterion = 25 µg/m³.

B.4 Background concentration profiles

The representative year for the modelling was taken to be 2018. Background concentration profiles for NO_X (1-hour), NO_2 (1-hour), PM_{10} (24-hour) and $PM_{2.5}$ (24-hour) were derived from the 2018 data from Earlwood. Gap-filling techniques, involving either interpolation or duplication of data from a previous day, were used to complete the datasets. Any resulting negative values in the background profiles were set to zero. Summary statistics for the 2018 background concentrations, based on the complete profiles, are provided in Table B.4.

Table B.4 Summary statistics for background concentrations (2018)

Pollutant	Averaging period	Statistic	Units	Value
NO_X	Annual	Mean	µg/m³	45.4
	1-hour	Maximum	µg/m³	459.7
NO_2	Annual	Mean	µg/m³	21.2
	1-hour	Maximum	µg/m³	102.6
PM_{10}	Annual	Mean	µg/m³	19.8
	24-hour	Maximum	µg/m³	86.5
		98th percentile	µg/m³	38.6
		Days over 50 µg/m³	-	5
		Highest value <50 µg/m³	µg/m³	40.3
$PM_{2.5}$	Annual	Mean	µg/m³	7.8
	24-hour	Maximum	µg/m³	28.5
		98th percentile	µg/m³	18.5
		Days over 25 µg/m³	-	1
		Highest value <25 µg/m³	µg/m³	23.5

As noted previously, but both annual mean and maximum 1-hour NO_2 concentrations were below the respective impact assessment criteria (31 µg/m³ and 164 µg/m³). The maximum 24-hour concentrations of both PM_{10} and $PM_{2.5}$ were above the corresponding criteria (50 µg/m³ and 25 µg/m³).

There were five exceedance days for PM_{10}, and one exceedance day for $PM_{2.5}$. The sixth highest 24-hour PM_{10} concentration, and the highest value below the criterion, was 40.3 µg/m^3. The second highest 24-hour $PM_{2.5}$ concentration, and the highest value below the criterion, was 23.5 µg/m^3.

It should be noted that the background profiles are based on measurements that involve the sampling of air at a height of between two and three metres above ground level. This is broadly consistent with human breathing height, and with the requirement to assess ground-level concentrations in the Approved Methods. However, when assessing concentrations at elevated locations (as in the case of the multi-storey development that is the subject of this report), the corresponding background concentrations cannot be known accurately. For the purpose of this report, it has been assumed that the air in the vicinity of the development is well mixed, and that the background concentrations above are representative for all the heights investigated.

Appendix C
Surface road parameters

creating opportunities

Table C.1 Surface roads near development (2033-DSC scenario)

Road type	Direction	Period	Volume	Car (%)	LCV (%)	HGV (%)	Bus (%)	MC (%)	Speed (km/h)
Princes Highway (north of Campbell Street)									
Arterial	NB	AM	922	61.9	20.3	16.8	0.5	0.5	28.0
		IP	2,381	71.1	21.8	6.1	0.5	0.5	28.0
		PM	1,385	65.1	17.7	16.2	0.5	0.5	28.0
		EV	1,503	66.5	31.3	1.2	0.5	0.5	29.0
		Total	**6,191**						
	SB	AM	1,223	72.9	25.1	1.0	0.5	0.5	20.0
		IP	4,558	70.4	26.8	1.8	0.5	0.5	19.0
		PM	2,887	75.5	22.0	1.4	0.5	0.5	11.0
		EV	1,826	71.3	26.2	1.4	0.5	0.5	21.0
		Total	**10,494**						
Princes Highway (south of Campbell Street)									
Arterial	NB	AM	4,665	74.2	24.4	0.5	0.5	0.5	7.0
		IP	5,007	72.0	23.7	3.4	0.5	0.5	22.0
		PM	2,640	73.1	21.0	4.9	0.5	0.5	21.0
		EV	6,846	71.9	25.9	1.2	0.5	0.5	21.0
		Total	**19,159**						
	SB	AM	2,610	75.8	22.3	1.0	0.5	0.5	24.0
		IP	10,865	70.2	27.6	1.2	0.5	0.5	23.0
		PM	6,286	80.0	17.7	1.3	0.5	0.5	23.0
		EV	8,277	72.7	25.0	1.3	0.5	0.5	24.0
		Total	**28,037**						
Princes Highway (near St Peters Anglican Church)									
Arterial	NB	AM	4,665	74.2	24.4	0.5	0.5	0.5	7.0
		IP	5,007	72.0	23.7	3.4	0.5	0.5	22.0
		PM	2,640	73.1	21.0	4.9	0.5	0.5	21.0
		EV	6,846	71.9	25.9	1.2	0.5	0.5	20.0
		Total	**19,159**						
	SB	AM	2,610	75.8	22.3	1.0	0.5	0.5	50.0
		IP	10,865	70.2	27.6	1.2	0.5	0.5	48.0
		PM	6,286	80.0	17.7	1.3	0.5	0.5	50.0
		EV	8,277	72.7	25.0	1.3	0.5	0.5	50.0
		Total	**28,037**						
Princes Highway (north of Canal Road)									
Arterial	NB	AM	4,654	73.4	24.3	1.3	0.5	0.5	9.0
		IP	7,350	71.6	25.1	2.3	0.5	0.5	6.0
		PM	3,018	73.6	21.2	4.2	0.5	0.5	18.0
		EV	6,905	73.6	24.1	1.4	0.5	0.5	37.0
		Total	**21,926**						
	SB	AM	2,829	75.1	22.4	1.4	0.5	0.5	23.0
		IP	10,697	72.0	25.9	1.1	0.5	0.5	23.0
		PM	6,308	80.1	17.5	1.4	0.5	0.5	22.0
		EV	9,628	72.1	25.6	1.2	0.5	0.5	23.0
		Total	**29,463**						

Table C.1 Surface roads near development (2033-DSC scenario)

Road type	Direction	Period	Volume	Car (%)	LCV (%)	HGV (%)	Bus (%)	MC (%)	Speed (km/h)
Princes Highway (south of Canal Road)									
Arterial	NB	AM	5,961	74.4	22.7	1.9	0.5	0.5	22.0
		IP	9,750	71.0	24.1	3.9	0.5	0.5	24.0
		PM	2,787	77.1	19.1	2.8	0.5	0.5	25.0
		EV	8,107	73.7	23.2	2.1	0.5	0.5	25.0
		Total	**26,604**						
	SB	AM	1,877	78.0	18.1	2.9	0.5	0.5	51.0
		IP	9,998	71.5	25.2	2.3	0.5	0.5	51.0
		PM	5,928	78.4	18.0	2.6	0.5	0.5	50.0
		EV	9,265	73.2	24.9	0.9	0.5	0.5	51.0
		Total	**27,068**						
Campbell Street (west of Princes Highway)									
Arterial	EB	AM	1,733	67.2	24.6	7.2	0.5	0.5	15.0
		IP	4,307	58.9	28.7	11.3	0.5	0.5	13.0
		PM	2,649	57.8	33.0	8.2	0.5	0.5	12.0
		EV	4,590	62.2	26.6	10.2	0.5	0.5	21.0
		Total	**13,280**						
	WB	AM	1,293	68.7	27.1	3.2	0.5	0.5	16.0
		IP	3,504	60.0	29.4	9.6	0.5	0.5	16.0
		PM	2,081	70.5	28.5	0.0	0.5	0.5	14.0
		EV	3,927	65.2	25.5	8.3	0.5	0.5	21.0
		Total	**10,805**						
Campbell Street (east of Princes Highway)									
Arterial	EB	AM	5,599	71.6	24.8	2.6	0.5	0.5	45.0
		IP	6,582	63.1	27.0	8.9	0.5	0.5	50.0
		PM	4,031	60.5	31.8	6.7	0.5	0.5	49.0
		EV	9,361	68.3	25.1	5.6	0.5	0.5	50.0
		Total	**25,573**						
	WB	AM	2,805	68.9	22.8	7.3	0.5	0.5	35.0
		IP	9,462	65.9	28.3	4.8	0.5	0.5	34.0
		PM	5,607	74.8	20.8	3.4	0.5	0.5	34.0
		EV	9,801	70.3	24.7	4.0	0.5	0.5	35.0
		Total	**27,675**						
Campbell Road (between Barwon Park Road and Euston Road)									
Arterial	EB	AM	6,026	71.6	25.1	2.4	0.5	0.5	37.0
		IP	7,876	62.4	29.1	7.5	0.5	0.5	38.0
		PM	4,798	60.5	32.6	5.8	0.5	0.5	38.0
		EV	10,576	67.0	26.4	5.6	0.5	0.5	38.0
		Total	**29,276**						
	WB	AM	3,710	70.2	23.2	5.6	0.5	0.5	50.0
		IP	11,381	63.7	29.1	6.2	0.5	0.5	49.0
		PM	6,962	73.2	23.1	2.7	0.5	0.5	49.0
		EV	11,526	69.1	25.9	4.0	0.5	0.5	50.0
		Total	**33,579**						

Table C.1 Surface roads near development (2033-DSC scenario)

Road type	Direction	Period	Volume	Car (%)	LCV (%)	HGV (%)	Bus (%)	MC (%)	Speed (km/h)
Barwon Park Road (north of Campbell Street)									
Residential	NB	AM	429	70.6	28.4	0.0	0.5	0.5	19.0
		IP	1,295	58.5	40.1	0.5	0.5	0.5	19.0
		PM	767	60.8	37.0	1.2	0.5	0.5	11.0
		EV	1,214	57.2	36.5	5.4	0.5	0.5	23.0
		Total	**3,705**						
	SB	AM	905	74.4	24.6	0.0	0.5	0.5	22.0
		IP	1,920	52.7	33.4	12.9	0.5	0.5	24.0
		PM	1,356	66.6	32.4	0.0	0.5	0.5	22.0
		EV	1,725	62.1	32.4	4.5	0.5	0.5	26.0
		Total	**5,906**						

Table C.2 Surface roads at SPI (2033-DSC scenario)

Road type	Period	Volume	Car (%)	LCV (%)	HGV (%)	Bus (%)	MC (%)	Speed (km/h)
Link ID: 26461-80087								
Highway/freeway	AM	540	50.1	37.2	11.7	0.4	0.6	60.0
	IP	758	29.2	38.8	31.0	0.4	0.6	60.0
	PM	2,194	56.6	39.2	3.3	0.4	0.6	60.0
	EV	962	36.2	45.9	17.0	0.4	0.6	60.0
	Total	**4,453**						
Link ID: 26461-83321								
Highway/freeway	AM	1,018	54.5	29.0	15.5	0.4	0.6	79.0
	IP	1,581	47.4	27.7	23.8	0.4	0.6	80.0
	PM	2,092	60.6	27.3	11.0	0.4	0.6	79.0
	EV	1,582	49.4	36.4	13.1	0.4	0.6	80.0
	Total	**6,273**						
Link ID: 78308-83321								
Highway / freeway	AM	795	46.8	39.4	12.8	0.4	0.6	80.0
	IP	1,972	44.0	37.3	17.7	0.4	0.6	80.0
	PM	1,931	47.6	36.2	15.1	0.4	0.6	79.0
	EV	1,961	41.8	43.6	13.6	0.4	0.6	80.0
	Total	**6,658**						
Link ID: 78308-83327								
Highway/freeway	AM	872	53.9	40.2	4.9	0.4	0.6	80.0
	IP	6,012	43.0	47.7	8.3	0.4	0.6	80.0
	PM	7,217	53.9	42.4	2.7	0.4	0.6	79.0
	EV	4,621	42.7	52.5	3.9	0.4	0.6	80.0
	Total	**18,722**						
Link ID: 80087-83327								
Highway/freeway	AM	812	58.7	31.2	9.1	0.4	0.6	60.0
	IP	1,817	42.0	41.3	15.7	0.4	0.6	60.0
	PM	4,374	54.2	41.9	2.9	0.4	0.6	15.0
	EV	1,687	36.2	49.6	13.2	0.4	0.6	60.0
	Total	**8,690**						
Link ID: 80088-26460								
Highway/freeway	AM	2,098	49.2	44.7	5.1	0.4	0.6	58.0
	IP	1,109	33.2	40.5	25.3	0.4	0.6	60.0
	PM	1,108	45.3	39.3	14.4	0.4	0.6	60.0
	EV	575	35.1	53.9	9.9	0.4	0.6	60.0
	Total	**4,890**						
Link ID: 80088-85150								
Highway/freeway	AM	2,481	48.0	47.0	4.0	0.4	0.6	56.0
	IP	880	41.0	54.8	3.2	0.4	0.6	60.0
	PM	241	55.5	42.7	0.8	0.4	0.6	60.0
	EV	497	40.4	58.2	0.4	0.4	0.6	60.0
	Total	**4,099**						

Table C.2 Surface roads at SPI (2033-DSC scenario)

Road type	Period	Volume	Car (%)	LCV (%)	HGV (%)	Bus (%)	MC (%)	Speed (km/h)
Link ID: 83313-80087								
Highway/freeway	AM	273	75.2	19.1	4.8	0.4	0.6	60.0
	IP	1,059	51.3	43.1	4.6	0.4	0.6	60.0
	PM	2,182	51.8	44.7	2.5	0.4	0.6	59.0
	EV	723	36.1	54.8	8.2	0.4	0.6	60.0
	Total	**4,236**						
Link ID: 83313-85788								
Highway/freeway	AM	5,873	70.0	13.6	15.4	0.4	0.6	79.0
	IP	11,451	51.2	21.3	26.5	0.4	0.6	80.0
	PM	7,984	74.6	9.8	14.6	0.4	0.6	80.0
	EV	7,076	46.9	21.4	30.8	0.4	0.6	80.0
	Total	**32,383**						
Link ID: 83321-85788								
Highway/freeway	AM	1,812	51.2	33.6	14.3	0.4	0.6	80.0
	IP	3,552	45.5	33.0	20.4	0.4	0.6	80.0
	PM	4,023	54.4	31.6	13.0	0.4	0.6	80.0
	EV	3,542	45.2	40.4	13.4	0.4	0.6	80.0
	Total	**12,930**						
Link ID: 84036-78309								
Highway/freeway	AM	2,498	53.5	43.0	2.6	0.4	0.6	80.0
	IP	5,987	43.8	51.4	3.8	0.4	0.6	80.0
	PM	2,168	54.1	41.1	3.8	0.4	0.6	80.0
	EV	4,116	41.2	52.4	5.4	0.4	0.6	80.0
	Total	**14,768**						
Link ID: 85789-26460								
Highway/freeway	AM	2,124	54.6	31.3	13.1	0.4	0.6	73.0
	IP	3,446	50.2	34.3	14.5	0.4	0.6	79.0
	PM	1,370	57.4	29.9	11.8	0.4	0.6	79.0
	EV	1,388	49.4	38.0	11.6	0.4	0.6	80.0
	Total	**8,328**						
Link ID: 85789-78309								
Highway/freeway	AM	679	48.0	40.2	10.8	0.4	0.6	80.0
	IP	2,141	40.4	42.6	16.0	0.4	0.6	80.0
	PM	1,852	52.2	38.8	8.0	0.4	0.6	79.0
	EV	1,292	38.2	42.3	18.6	0.4	0.6	80.0
	Total	**5,964**						
Link ID: 85789-85150								
Highway/freeway	AM	7,241	77.7	11.8	9.6	0.4	0.6	79.0
	IP	11,542	53.8	18.4	26.9	0.4	0.6	80.0
	PM	6,137	67.0	15.5	16.5	0.4	0.6	80.0
	EV	7,926	48.5	19.8	30.7	0.4	0.6	80.0
	Total	**32,846**						

Table C.3 NO_X emission rates for surface roads

Road	Direction	Link ID	Emission rate (kg/km/h)			
			AM	IP	PM	EV
Princes Highway (north of Campbell Street)	NB	12183-12129	0.341	0.178	0.331	0.038
	SB	12129-12183	0.198	0.281	0.545	0.045
Princes Highway (south of Campbell Street)	NB	12191-12183	1.718	0.269	0.325	0.151
	SB	12183-12191	0.470	0.726	0.765	0.242
Princes Highway (near St Peters Anglican Church)	NB	22974-12191	2.183	0.399	0.469	0.242
	SB	12191-22974	0.221	0.325	0.356	0.112
Princes Highway (north of Canal Road)	NB	12184-22974	2.191	1.429	0.685	0.213
	SB	22974-12184	0.305	0.384	0.457	0.160
Princes Highway (south of Canal Road)	NB	19904-12184	0.895	0.536	0.264	0.171
	SB	12184-19904	0.306	0.553	0.624	0.213
Campbell Street (west of Princes Highway)	EB	12128-12183	0.861	0.931	1.134	0.330
	WB	12183-12128	0.272	0.353	0.274	0.132
Campbell Street (east of Princes Highway)	EB	12183-14011	0.460	0.235	0.269	0.132
	WB	14011-12183	0.763	0.784	0.800	0.345
Campbell Road (between Barwon Park Rd and Euston Rd)	EB	14011-12181	0.435	0.248	0.280	0.139
	WB	12181-14011	1.009	1.114	1.071	0.454
Barwon Park Road (north of Campbell Street)	NB	12129-14011	0.061	0.072	0.157	0.036
	SB	14011-12129	0.152	0.232	0.166	0.059
SPI		26461-80087	0.037	0.029	0.073	0.012
SPI		26461-83321	0.431	0.303	0.476	0.097
SPI		78308-83321	0.212	0.210	0.370	0.085
SPI		78308-83327	0.184	0.540	0.870	0.153
SPI		80087-83327	0.469	0.492	1.747	0.204
SPI		80088-26460	0.376	0.157	0.214	0.022
SPI		80088-85150	0.435	0.053	0.021	0.011
SPI		83313-80087	0.008	0.011	0.044	0.004
SPI		83313-85788	2.219	2.229	1.919	0.715
SPI		83321-85788	0.716	0.589	0.990	0.213
SPI		84036-78309	0.398	0.369	0.248	0.130
SPI		85789-26460	0.279	0.157	0.110	0.026
SPI		85789-78309	0.073	0.094	0.118	0.028
SPI		85789-85150	0.819	0.853	0.644	0.300

Table C.4 PM$_{10}$ emission rates for surface roads

Road	Direction	Link ID	Emission rate (kg/km/h)			
			AM	IP	PM	EV
Princes Highway (north of Campbell Street)	NB	12183-12129	0.028	0.018	0.027	0.005
	SB	12129-12183	0.024	0.031	0.042	0.006
Princes Highway (south of Campbell Street)	NB	12191-12183	0.106	0.035	0.038	0.021
	SB	12183-12191	0.051	0.074	0.082	0.026
Princes Highway (near St Peters Anglican Church)	NB	22974-12191	0.112	0.037	0.040	0.022
	SB	12191-22974	0.043	0.063	0.068	0.021
Princes Highway (north of Canal Road)	NB	12184-22974	0.113	0.066	0.047	0.021
	SB	22974-12184	0.053	0.068	0.078	0.028
Princes Highway (south of Canal Road)	NB	19904-12184	0.118	0.068	0.037	0.024
	SB	12184-19904	0.034	0.061	0.071	0.025
Campbell Street (west of Princes Highway)	EB	12128-12183	0.048	0.047	0.055	0.020
	WB	12183-12128	0.028	0.031	0.028	0.015
Campbell Street (east of Princes Highway)	EB	12183-14011	0.102	0.045	0.054	0.027
	WB	14011-12183	0.068	0.073	0.080	0.033
Campbell Road (between Barwon Park Rd and Euston Rd)	EB	14011-12181	0.113	0.058	0.068	0.034
	WB	12181-14011	0.080	0.086	0.091	0.037
Barwon Park Road (north of Campbell Street)	NB	12129-14011	0.008	0.009	0.012	0.004
	SB	14011-12129	0.018	0.019	0.018	0.006
SPI		26461-80087	0.011	0.007	0.024	0.003
SPI		26461-83321	0.021	0.013	0.026	0.005
SPI		78308-83321	0.015	0.014	0.025	0.006
SPI		78308-83327	0.013	0.035	0.070	0.011
SPI		80087-83327	0.020	0.018	0.077	0.007
SPI		80088-26460	0.040	0.011	0.018	0.002
SPI		80088-85150	0.048	0.005	0.003	0.001
SPI		83313-80087	0.004	0.006	0.023	0.002
SPI		83313-85788	0.117	0.097	0.102	0.030
SPI		83321-85788	0.036	0.027	0.052	0.011
SPI		84036-78309	0.035	0.030	0.021	0.010
SPI		85789-26460	0.039	0.020	0.015	0.004
SPI		85789-78309	0.011	0.013	0.019	0.004
SPI		85789-85150	0.110	0.085	0.073	0.029

Table C.5 $PM_{2.5}$ emission rates for surface roads

Road	Direction	Link ID	Emission rate (kg/km/h)			
			AM	IP	PM	EV
Princes Highway (north of Campbell Street)	NB	12183-12129	0.018	0.011	0.017	0.003
	SB	12129-12183	0.015	0.019	0.027	0.003
Princes Highway (south of Campbell Street)	NB	12191-12183	0.071	0.021	0.023	0.012
	SB	12183-12191	0.031	0.046	0.050	0.016
Princes Highway (near St Peters Anglican Church)	NB	22974-12191	0.076	0.023	0.025	0.014
	SB	12191-22974	0.025	0.037	0.040	0.013
Princes Highway (north of Canal Road)	NB	12184-22974	0.077	0.046	0.030	0.013
	SB	22974-12184	0.031	0.040	0.045	0.016
Princes Highway (south of Canal Road)	NB	19904-12184	0.071	0.041	0.022	0.015
	SB	12184-19904	0.020	0.037	0.043	0.015
Campbell Street (west of Princes Highway)	EB	12128-12183	0.032	0.033	0.038	0.013
	WB	12183-12128	0.017	0.020	0.017	0.009
Campbell Street (east of Princes Highway)	EB	12183-14011	0.059	0.026	0.031	0.016
	WB	14011-12183	0.043	0.045	0.049	0.021
Campbell Road (between Barwon Park Rd and Euston Rd)	EB	14011-12181	0.064	0.033	0.039	0.019
	WB	12181-14011	0.050	0.055	0.057	0.023
Barwon Park Road (north of Campbell Street)	NB	12129-14011	0.005	0.006	0.008	0.003
	SB	14011-12129	0.011	0.012	0.011	0.004
SPI		26461-80087	0.006	0.004	0.014	0.002
SPI		26461-83321	0.014	0.009	0.017	0.003
SPI		78308-83321	0.010	0.009	0.017	0.004
SPI		78308-83327	0.009	0.023	0.046	0.007
SPI		80087-83327	0.014	0.013	0.052	0.005
SPI		80088-26460	0.025	0.007	0.011	0.001
SPI		80088-85150	0.029	0.003	0.002	0.001
SPI		83313-80087	0.002	0.003	0.013	0.001
SPI		83313-85788	0.079	0.066	0.069	0.020
SPI		83321-85788	0.025	0.018	0.035	0.007
SPI		84036-78309	0.023	0.020	0.014	0.007
SPI		85789-26460	0.024	0.013	0.009	0.002
SPI		85789-78309	0.007	0.008	0.012	0.002
SPI		85789-85150	0.069	0.054	0.046	0.018

Appendix D
Ventilation outlet parameters

Table D.1 Ventilation outlet locations and heights

Outlet	Sub-outlets	X	Y	Outlet height above ground level (m)
M8 at SPI (outlet D in the EIS)	SPI-1	331340	6245650	20.0
	SPI-2	331346	6245655	
	SPI-3	331334	6245656	
	SPI-4	331340	6245662	
M4-M5 Link at SPI (outlet K in the EIS)	SPI-5	331765	6245940	22.0
	SPI-6	331775	6245933	
	SPI-7	331775	6245925	
	SPI-8	331765	6245918	

Table D.2 Discharge parameters for M5-M5 Link tunnel (SPI outlet)

Hour	GRAL source group	No. of outlets	Air flow per outlet (m^3/s)	Effective diameter per outlet (m)	Exit velocity (m/s)	Outlet temp. (°C)	NO_X (g/s)	PM_{10} (g/s)	$PM_{2.5}$ (g/s)
0	K-1	2	135	9	2.1	28.3	0.379	0.061	0.040
1							0.203	0.034	0.023
2							0.159	0.027	0.018
3							0.164	0.028	0.018
4							0.303	0.049	0.032
5	K-2	2	225	9	3.5		0.837	0.130	0.085
6	K-3	2	310	9	4.8		1.790	0.340	0.222
7							2.476	0.468	0.306
8							2.525	0.442	0.289
9							2.681	0.444	0.290
10							2.745	0.446	0.292
11							2.819	0.452	0.295
12							2.847	0.453	0.296
13							2.810	0.450	0.294
14							2.503	0.417	0.273
15							2.291	0.404	0.264
16							2.171	0.413	0.270
17							1.923	0.339	0.221
18							1.759	0.284	0.186
19							1.668	0.266	0.174
20							1.644	0.260	0.170
21							1.625	0.257	0.168
22	K-2	2	225	9	3.5		1.109	0.174	0.114
23							0.549	0.087	0.057

Table D.3 Discharge parameters for M8 tunnel (SPI outlet)

Hour	GRAL source group	No. of outlets	Air flow per outlet (m^3/s)	Effective diameter per outlet (m)	Exit velocity (m/s)	Outlet temp. (°C)	NO_X (g/s)	PM_{10} (g/s)	$PM_{2.5}$ (g/s)
0	D-1	2	80	5.6	3.2	21.2	0.043	0.007	0.005
1							0.027	0.004	0.003
2							0.024	0.004	0.002
3							0.024	0.004	0.002
4							0.029	0.005	0.003
5							0.068	0.012	0.008
6	D-2	3	100	5.6	4.0		0.303	0.053	0.034
7	D-3	3	127	5.6	5.1		0.635	0.120	0.078
8							0.512	0.087	0.057
9							0.453	0.074	0.048
10							0.427	0.068	0.044
11							0.411	0.064	0.042
12	D-2	3	100	5.6	4.0		0.394	0.061	0.040
13							0.382	0.059	0.038
14							0.372	0.057	0.037
15							0.360	0.055	0.036
16							0.348	0.053	0.035
17							0.264	0.044	0.029
18							0.229	0.039	0.026
19							0.206	0.036	0.023
20							0.191	0.033	0.022
21							0.180	0.031	0.020
22	D-1	2	80	5.6	3.2		0.065	0.012	0.008
23							0.042	0.007	0.005

Appendix E

NO_X to NO_2 conversion method

EMM creating opportunities

E.1 Overview

The estimation of NO_2 concentrations is not straightforward. One reason for this is that conversion of NO to NO_2 occurs in the atmosphere following release from the source, and is dependent on the local atmospheric conditions, including the amount of ozone available. The reactions involved also occur on a similar timescale to the dispersion.

Various guidance documents recommend the use of local monitoring data, where available, to estimate NO_2 from modelled NO_X. Both NO_X and NO_2 have been measured for several years at a range of monitoring stations across NSW. A substantial amount of data from these stations was used to develop empirical NO_X-to-NO_2 conversion functions for several road tunnel projects in Sydney, with separate approaches for annual mean and 1-hour mean NO_2. The empirical approach was also adopted for this AQIA, and the methods that were used are described below.

E.2 Annual mean concentrations

Figure E.1 shows the relationship between the annual mean concentrations of NO_X and NO_2 at monitoring stations in NSW between 1994 and 2019. The data for background stations and road stations are shown separately. In the low-NO_X range of the graph there is an excess of ozone and therefore NO_2 formation is limited by the availability of NO. In the high-NO_X range there is an excess of NO, and therefore NO_2 formation is limited by the availability of ozone. The Figure also shows that there is not a large amount of scatter in the data, and for this reason a 'central-estimate' approach for estimating NO_2 from NO_X was considered to be appropriate.

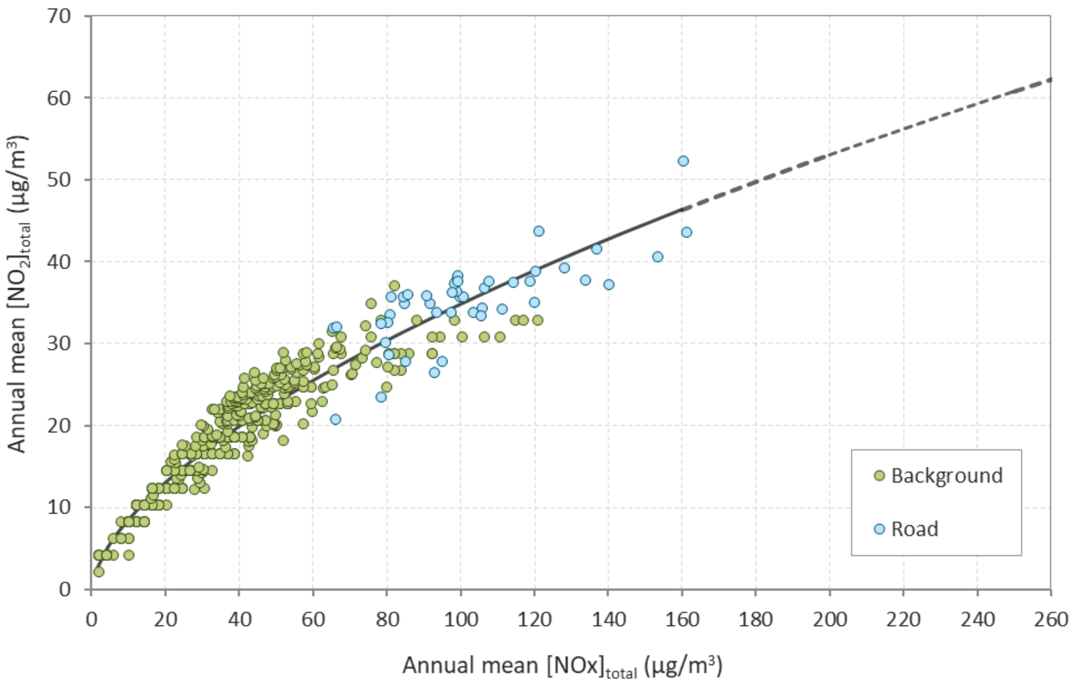

Figure E.1 Relationship between annual mean NO_X and NO_2

The solid line represents a regression model fit to the data (ie the central-estimate situation) which will give the most likely annual NO_2 concentration for a given annual NO_X concentration. The function giving the best fit was selected from a large number of alternatives using curve-fitting software, and is described by the following equation:

$$[NO_2] = 2.0959567 \times [NO_X]^{0.61}$$

At very low NO_X concentrations (<=7 µg/m^3) the relationship is constrained to a NO_2:NO_X ratio of 1.

For NO_X concentrations greater than 160 µg/m^3 it has been assumed that the equation can be extrapolated (the dashed line). Given the absence of high annual mean NO_X concentrations, the extrapolation to concentrations above the measurement range is uncertain.

NB: The use of the function will lead to exceedances of the annual mean criterion for NO_2 in NSW of 31 µg/m^3 where the annual mean NO_X concentration exceeds 82.8 µg/m^3.

E.3 One-hour mean concentrations

For the maximum 1-hour mean NO_2 concentrations the situation is more complicated. One-hour mean NO_X and NO_2 concentrations are much more variable than annual mean concentrations. Patterns in the hourly data can be most easily visualised by plotting the 1-hour mean NO_2/NO_X ratio against the 1-hour mean NO_X concentration, as shown for the various monitoring stations in Figure E.2. The blue line is discussed below.

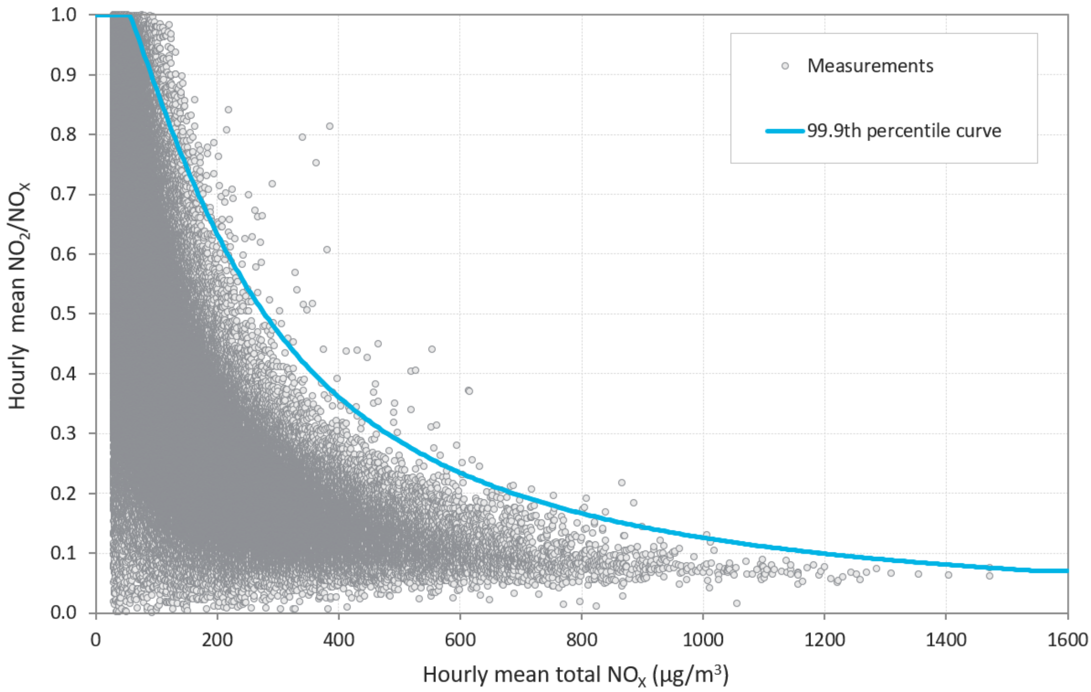

Figure E.2 Relationship between 1-hour mean NO_2/NO_X and total NO_X

This plot shows the following:

- For low NO_x concentrations there is a wide range of possible NO_2/NO_x ratios, whereas for higher NO_X concentrations the range is much more constrained.
- A distinct outer envelope can be fitted to the data which includes all (or very nearly all) the measurement points, and this envelope has a strong inverse relationship with the NO_X concentration. In the envelope the NO_2/NO_X ratio is highest (1.0) at low NO_X concentrations, representing complete, or near-complete, conversion of NO to NO_2. At the high end of the NO_X concentration range the ratio is much lower and levels out at a value of slightly less than 0.1.

Although the range and variability of the data varied by station type, the general patterns in the data were quite consistent. It was therefore considered appropriate to combine the datasets. In particular, the outer envelope of the NO_X:NO_2 ratio was very consistent, and so it was also considered appropriate to define one (conservative) approach to reflect this envelope.

Several steps were taken to simplify the dataset. The data contained many low values of NO_X, and these were not considered particularly important in terms of estimating peak NO_2 concentrations. All NO_X concentrations less than 30 µg/m^3 were therefore removed, as were any negative concentrations of NO_X and NO_2. All values of the NO_2/NO_X ratio greater than 1.0 were also removed.

The method then involved the following steps:

- the data were allocated to multiple NO_X bins, at an interval of 20 µg/m^3;
- for each NO_X bin the 99.9th percentile NO_2/NO_X ratio was calculated; and
- a curve was fitted to the 99.9th percentile points.

The resulting data and the 99.9th percentile curve are shown in Figure E.2.

The 99.9th percentile curve was used in the assessment, and approximated a conservative upper bound estimate of the NO_2/NO_X ratio across a wide range of 1-hour NO_X concentrations.

The curve is described by the following equations:

For NO_X values less than or equal to 55 µg/m^3:

$$\frac{[NO_2]}{[NOx]} = 1.00$$

For NO_X values between 55 µg/m^3 and 1,555 µg/m^3:

$$\frac{[NO_2]}{[NOx]} = \frac{a}{(1 + (\frac{[NOx]}{b})^c)}$$

Where

a = 1.12592521

b = 237.948879

c = 1.44533388

For NO_X values greater than 1,555 µg/m^3 a cut-off for the NO_2/NO_X ratio of 0.07 has been assumed:

$$\frac{[NO_2]}{[NOx]} = 0.07$$

Given the use of the 99.9th percentile values, for any given NO_X concentration, at least in the low-mid range, the corresponding NO_2 concentration would only be underestimated around one time in a thousand. Of course, there are very few data points at the highest NO_X concentrations, and therefore any underestimation (or overestimation) cannot be easily demonstrated.

It is also worth noting that exceedances of the criterion cannot be predicted using the 99.9th percentile curve across a wide range of NO_X concentrations; a total NO_X concentration of more than around 2,300 µg/m^3 is required to give an exceedance.

The method is applied to the maximum 1-hour total NO_X concentration at a given assessment location. It should also be noted that the maximum predicted NO_X concentration will not occur during the same hour of the year at all locations in the model domain.

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