WestConnex

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M4 East

Environmental Impact Statement

Appendix H

Volume 2B

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Appendix

WestConnex

Appendix H

Air quality impact assessment

WestConnex

WestConnex Delivery Authority

WestConnex M4 East

Air Quality Assessment Report

4 September 2015

Prepared for

WestConnex Delivery Authority

Prepared by

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Pacific Environment

Document controls

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Glossary of terms and abbreviations

Term	Description
AAQ NEPM	National Environment Protection (Ambient Air Quality) Measure
ABS	Australian Bureau of Statistics
ADR	Australian Design Rule
AHD	Australian Height Datum. The standard reference level used to express the relative height of various features. A height given in metres AHD is essentially the height above sea level. Mean sea level is set as zero elevation.
Airshed	A part of the atmosphere that shares a common flow of air and is exposed to similar influences.
ANSTO	Australian Nuclear Science and Technology Organisation
AQM	air quality management
BAM	Beta Attenuation Monitor
BTS	(NSW) Bureau of Transport Statistics
CBD	central business district
COAG	Council of Australian Governments
CO	carbon monoxide
CO_2	carbon dioxide
CO_2-e	carbon dioxide equivalents
CSIRO	Commonwealth Scientific and Industrial Research Organisation
Defra	(UK) Department for Environment, Food and Rural Affairs
DERM	(Queensland) Department of Environment and Resource Management
DEWHA	Department of Environment, Water, Heritage and the Arts
DGRs	Director-General's Requirements. Requirements and specifications for an environmental impact statement prepared by the Secretary (formerly the Director-General) of the Department of Planning and Environment under section 115Y of the Environmental Planning and Assessment Act 1979.
DP&E	NSW Department of Planning and Environment
DPF	diesel particulate filter
DRIS	Decision Regulation Impact Statement
DSEWPC	(Commonwealth) Department of Sustainability, Environment, Water, Population and Communities
DSITIA	(Queensland) Department of Science, Information Technology, Innovation and the Arts
EC	elemental carbon
EDMS	(NSW) Emissions Data Management System
EIA	Environmental Impact Assessment
EIS	Environmental Impact Statement
Emission factor	A quantity which expresses the mass of a pollutant emitted per unit of activity. For road transport the unit of activity is usually either distance (i.e. g/km) or fuel consumed (i.e. g/litre).
Emission rate	A quantity which expresses the mass of a pollutant emitted per unit of time (e.g. g/second)

Term	Description
EPHC	Environment Protection Heritage Council
ESP	electrostatic precipitator
EU	European Union
GHG	greenhouse gas
GLC	ground-level concentration
GMR	(NSW) Greater Metropolitan Region
GRUB	generally representative upper bound (for community exposure; monitoring sites)
GVM	gross vehicle mass
HDV	heavy-duty vehicle, which includes heavy goods vehicles, buses and coaches
HGV	heavy good vehicle (truck)
HVAS	High volume air samplers
LCV	light commercial vehicle
LDV	light-duty vehicle, which includes cars and light commercial vehicles
NEPC	National Environment Protection Council
NEPM	National Environment Protection Measure
NH_3	ammonia
NHMRC	National Health and Medical Research Council
NIWA	National Institute of Water and Atmospheric Research (New Zealand)
NMVOC	non-methane volatile organic compound
NO	nitric oxide
NO_2	nitrogen dioxide
NO_X	oxides of nitrogen
NPI	National Pollutant Inventory
NSW	New South Wales
NSW EPA	NSW Environment Protection Authority
NSW Health	NSW Department of Health
O_3	ozone
OC	organic carbon
OEH	NSW Office of Environment and Heritage
PAH(s)	polycyclic aromatic hydrocarbon(s)
PIARC	Permanent International Association of Road Congresses
ppb	parts per billion
ppm	parts per million
PM	(airborne) particulate matter
PM_{10}	airborne particulate matter with an aerodynamic diameter of less than 10 µm
$PM_{2.5}$	airborne particulate matter with an aerodynamic diameter of less than 2.5 µm
RH	relative humidity
Roads and Maritime	(NSW) Roads and Maritime Services
SCR	Selective catalytic reduction

Term	Description
SEARs	Secretary's Environmental Assessment Requirements
SER	Strategic Environmental Review
SF_6	sulfur hexafluoride
SMPO	Sydney Motorways Project Office
SO_2	sulfur dioxide
SO_3	sulfur trioxide
SO_X	sulfur oxides
SOA	secondary organic aerosol
TEOM	Tapered Element Oscillating Microbalance
TEOM-FDMS	TEOM with Filter Dynamic Measurement System
TRAQ	Tool for Roadside Air Quality
TSP	total suspended particulate
UK	United Kingdom
UN	United Nations
US	United States
USEPA	United States Environmental Protection Agency
VKT	vehicle-kilometres travelled
VOCs	volatile organic compounds
WDA	WestConnex Delivery Authority
WHO	World Health Organisation
$\mu g/m^3$	micrograms per cubic metre

Executive summary

The project

The NSW Roads and Maritime Services (Roads and Maritime) is seeking approval to upgrade and extend the M4 Motorway from Homebush Bay Drive at Homebush to Parramatta Road and City West Link (Wattle Street) at Haberfield. This includes twin tunnels about 5.5 kilometres long and associated surface works to connect to the existing road network. These proposed works are described as the M4 East project ('the project'). Approval is being sought under Part 5.1 of the *Environmental Planning and Assessment Act 1979* (NSW) (EP&A Act). The project was declared by the Minister for Planning to be State significant infrastructure and critical State significant infrastructure and an environmental impact statement (EIS) is therefore required.

The project is a component of WestConnex, which is a proposal to provide a 33 kilometre motorway linking Sydney's west and south-west with Sydney Airport and the Port Botany precinct.

The individual components of WestConnex are:

- M4 Widening – Pitt Street at Parramatta to Homebush Bay Drive at Homebush (planning approval granted and under construction)
- M4 East (the subject of this report)
- New M5 – King Georges Road at Beverly Hills to St Peters (planning application lodged and subject to planning approval)
- King Georges Road Interchange Upgrade (planning approval granted and work has commenced)
- M4–M5 Link – Haberfield to St Peters, including the Southern Gateway and Southern Extension (undergoing concept development and subject to planning approval).

Separate planning applications will be lodged for each individual component project. Each project will be assessed separately, but the impacts of each project will also be considered in the context of the wider WestConnex.

Key features of the project include the following:

- Two new three-lane tunnels (the mainline tunnels), one eastbound and one westbound, extending from Homebush to Haberfield. Each tunnel would be about 5.5 kilometres long
- A new westbound on-ramp from Parramatta Road to the M4 at Powells Creek, west of George Street at North Strathfield
- An interchange at Concord Road, North Strathfield/ Concord with on-ramps to the eastbound tunnel and off-ramps from the westbound tunnel
- An interchange at Wattle Street (City West Link) at Haberfield with an on-ramp to the westbound tunnel and an off-ramp from the eastbound tunnel. The project also includes on- and off-ramps at this interchange that would provide access to the future M4–M5 Link (which is undergoing concept development and subject to planning approval)
- An interchange at Parramatta Road at Haberfield/Ashfield, with an on-ramp to the westbound tunnel and an off-ramp from the eastbound tunnel
- Installation of tunnel ventilation systems, including ventilation facilities (see below) and other ancillary facilities.

The following ventilation facilities were included in the air quality assessment:

- The ventilation facilities for the project, being:
    A. Eastern ventilation facility (M4 East outlet). This would be located near the Wattle Street (City West Link) and Parramatta Road interchanges at Haberfield. The facility

would provide exhaust from the mainline eastbound tunnel and exhaust from the Wattle Street (City West Link) and Parramatta Road off-ramps

B. Western ventilation facility. This would be located within the existing M4 Motorway reserve near Underwood Road at Homebush. The facility would serve the westbound traffic within the project tunnel.

- The ventilation facilities for the M4-M5 Link project:

C. A City West Link/ Rozelle ventilation facility. This facility would provide the mid-point ventilation outlet for the future M4-M5 Link. An approximate location of the facility was used. It was assumed that the facility would be situated within the Rozelle Goods Yard, subject to a separate environmental assessment and approval

D. Eastern ventilation facility (M4-M5 Link outlet). This would service the future M4–M5 Link. It would provide exhaust from the mainline westbound tunnel and exhaust from the Wattle Street M4-M5 Link off-ramp.

The eastern ventilation facility (M5-M5 Link outlet, item D) would comprise a building only as part of the project. Fit-out and commissioning would occur as part of the construction of the M4-M5 Link (if approved). The City West Link/ Rozelle ventilation facility (item D) does not form part of the project. Both ventilation facilities and were included to assess potential cumulative impacts only. The location of City West Link/ Rozelle ventilation facility was indicative only, and is subject to assessment and approval.

As noted above, the eastern ventilation facility is intended to serve both the M4 East project and the M4-M5 Link project. The ventilation facility would consist of two separate but adjoining buildings with ‘back-to-back’ outlets for the M4 East and the M4-M5 Link projects.

The purpose of this report

This report, which forms an appendix of the EIS for the project, has been prepared in response to the Secretary's Environmental Assessment Requirements (SEARs) issued on 16 June 2015 by the NSW Department of Planning and Environment (DP&E) for the project. The report presents an assessment of the construction and operational activities that have potential to impact on in-tunnel, local and regional air quality.

The report:

- Describes the project
- Identifies key air quality issues for the project
- Summarises the regulation of emissions, air pollution and exposure
- Provides an overview of the air quality assessment methodology
- Describes the existing environment in the general area of Sydney affected by the project, with specific reference to terrain, meteorology, emissions and ambient air quality (outside air)
- Describes the assessment of construction impacts
- Describes the assessment of operational impacts
- Deals with the cumulative impacts of the project and the future M4-M5 Link
- Provides a review of air quality mitigation measures, and recommendations on measures to manage any impacts of the project.

Scenarios

In-tunnel air quality

The scenarios evaluated for in-tunnel air quality reflected the potential modes of operation of the tunnel ventilation system. These scenarios were:

- Expected traffic scenarios. The objective of these scenarios was to demonstrate that the expected operation of the project would result in acceptable in-tunnel air quality. The scenarios reflected the optimum or best operating conditions, where traffic volumes were high and traffic was flowing freely (a speed of 80 kilometres per hour was assumed)
- Capacity (maximum) traffic flow scenarios. These were included to reflect conditions that can generate high in-tunnel pollution levels. Several different speeds were considered, including congestion
- Vehicle breakdown scenario. This included incidents such as vehicle breakdowns or accidents and heavy congestion. It was assessed on the basis that it would represent a worst case in terms of pollution generation.

Ambient air quality

Two types of scenario were considered for ambient air quality:

- Expected traffic scenarios (as described above). The expected traffic scenarios included in the operational ambient air quality assessment were:
    - 2014 - Base Year (existing conditions)
    - 2021 - Do Minimum (no project)
    - 2021 - Do Something (with project)
    - 2031 - Do Minimum (no project)
    - 2031 - Do Something (with project)
    - 2031 - Do Something Cumulative (with project and M4-M5 Link).

  These scenarios took into account future changes over time in the composition and performance of the vehicle fleet, as well as predicted traffic volumes and the distribution of traffic on the network. The objective of these scenarios was to demonstrate that the expected operation of the project would result in acceptable ambient air quality.
- Regulatory worst case scenarios. The objective of the regulatory worst case scenarios was to demonstrate that compliance with the concentration limits for the tunnel ventilation outlets will guarantee acceptable ambient air quality. The scenarios assessed constant ventilation outlet concentrations (at the limits) over a 24-hour period, thus providing a representation of the theoretical maximum changes in air quality and covering all potential operational modes of the traffic in the tunnel, including unconstrained and worst-case traffic conditions from an emissions perspective, and vehicle breakdown situations.

Methods and conclusions

Construction

In the absence of specific direction for projects in NSW, the potential impacts of the construction phase of this project were assessed using guidance published by the UK Institute of Air Quality Management. Professional judgement was required at some stages, and where justification for assumptions could not be fully informed by data a precautionary approach was adopted.

The UK guidance was adapted for use in NSW, taking into account factors such as the assessment criteria for PM_{10} (airborne particulate matter with an aerodynamic diameter of less than 10 μm). The assessment was qualitative in the sense that it assessed the risk that construction works may have on local air quality.

The risk assessment determined that standard management measures would be sufficient to mitigate the effects of construction works on local air quality at the nearest receptors.

Operational impacts – in-tunnel air quality

In-tunnel air quality for the project was modelled using the IDA Tunnel software and Australia-specific emission factors from the Permanent International Association of Road Congresses (PIARC). Traffic volume projections were taken from the WestConnex Road Traffic Model (WRTM) and other sources were used to provide a representative traffic mix for the tunnel.

Consideration was given to peak in-tunnel concentrations of carbon monoxide (CO) and nitrogen dioxide (NO_2), as well as the peak extinction coefficient (for visibility). The work covered expected traffic scenarios, capacity traffic scenarios (at a range of speeds, including congestion) and a vehicle breakdown scenario.

The information presented in the report has confirmed that the tunnel ventilation system will be designed to maintain in-tunnel air quality well within operational limits for all scenarios.

Ambient air quality (expected traffic conditions)

The operational ambient air quality assessment was based upon the use of the GRAL[1] model system. The model system consists of two main modules: a prognostic wind field model (Graz Mesoscale Model - GRAMM) and a dispersion model (GRAL itself). Traffic data were taken from the WRTM, with around 6,000 separate road links being modelled. The traffic data were used in conjunction with emission factors developed by NSW Environment Protection Authority.

The following general conclusions have been drawn from the assessment:

- The predicted concentrations of all criteria pollutants at receptors were usually dominated by the existing background contribution. This applied to short-term criteria as well as annual means. The background concentrations were especially dominant for PM_{10} and $PM_{2.5}$ (airborne particulate matter with an aerodynamic diameter of less than 10 μm and 2.5 μm respectively)
- For some pollutants and metrics (such as annual mean NO_2) there was also a significant contribution from the modelled surface road traffic
- Under expected traffic conditions the contribution of tunnel ventilation outlets to pollutant concentrations was negligible for all receptors
- Any predicted changes in concentration were driven by changes in the traffic volumes on the modelled surface road network, not by the tunnel ventilation outlets
- Exceedances of some air quality criteria (one-hour NO_2, 24-hour PM_{10}, annual $PM_{2.5}$ and 24-hour $PM_{2.5}$) were predicted to occur at a small proportion of receptors both with and without the project. However, because there was a general reduction in the distribution of predicted concentrations along the project corridor, the numbers of receptors with exceedances decreased with the project
- There would be general improvements in air quality along Parramatta Road as a result of the project. This is due to a reduction in traffic volumes along Parramatta Road and the improved dispersion of emissions from diverted traffic through tunnel ventilation outlets.

Management of impacts

Construction impacts

Various measures for the management of construction impacts have been provided in the report. Most of the recommended measures are routinely employed as ‘good practice’ on construction sites. A Construction Air Quality Management Plan will be produced to cover all construction phases of the project. This should contain details of the site-specific mitigation measures to be applied.

Operational impacts

The report has provided a review of the measures that are available for improving tunnel-related air quality, and then describes their potential application in the context of the project. The measures that will be adopted for the project are summarised below.

The project design provisions to reduce pollutant emissions and concentrations within the tunnel will include:

- Minimal gradients. The main alignment tunnels would have a maximum gradient of four per cent
- Large main line tunnel cross-sectional area (90 square metres)

[1] GRAL = Graz Lagrangian model

- Increased height to reduce the risk of incidents involving high vehicles blocking the tunnel.

The project ventilation system has been designed and would be operated so that it will achieve some of the most stringent standards in the world for in-tunnel air quality, and will be effective at maintaining local air quality. The design of the ventilation system will ensure zero portal emissions.

The ventilation system would be automatically controlled using real-time traffic data covering both traffic mix and speed, and feedback from air quality sensors in the tunnel, to ensure in-tunnel conditions are managed effectively in accordance with the agreed criteria. Furthermore, specific ventilation modes will be developed to manage breakdown, congested and emergency situations.

The provision of a tunnel filtration system does not represent a feasible and reasonable mitigation measure and is not being proposed. The reasons for this are as follows:

- The project's in-tunnel air pollutant levels, which are comparable to best practice and accepted elsewhere in Australia and throughout the world, would be achieved without filtration
- Emissions from the ventilation outlets of the project tunnel will have a negligible impact on existing ambient pollutant concentrations
- Of the systems that have been installed, the majority have subsequently been switched off or are currently being operated infrequently
- Incorporating filtration to the ventilation outlets would require a significant increase in the size of the tunnel facilities to accommodate the equipment. It would result in increased project size, community footprint, and capital cost. The energy usage would be substantial and does not represent a sustainable approach.

If in-tunnel air quality levels could not be achieved with the proposed ventilation system, the most effective solution would be the introduction of additional ventilation outlets and additional air supply locations. This is a proven solution and more sustainable and reliable than tunnel filtration systems.

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1 Introduction

1.1 Overview of the project

The NSW Roads and Maritime Services (Roads and Maritime) is seeking approval to upgrade and extend the M4 Motorway from Homebush Bay Drive at Homebush to Parramatta Road and City West Link (Wattle Street) at Haberfield. This includes twin tunnels about 5.5-kilometres long and associated surface works to connect to the existing road network. These proposed works are described as the M4 East project (the project). The local context of the project is shown in Figure 1-1.

Approval is being sought under Part 5.1 of the *Environmental Planning and Assessment Act 1979* (NSW) (EP&A Act). The project was declared by the Minister for Planning to be State significant infrastructure and critical State significant infrastructure, and an environmental impact statement (EIS) is therefore required.

The project is a component of WestConnex, which is a proposal to provide a 33 kilometre motorway linking Sydney's west and south-west with Sydney Airport and the Port Botany precinct. The location of WestConnex is shown in Figure 1-2. The individual components of WestConnex are:

- M4 Widening – Pitt Street at Parramatta to Homebush Bay Drive at Homebush (planning approval granted and under construction)
- M4 East (the subject of this report)
- New M5 – King Georges Road at Beverly Hills to St Peters (planning application lodged and subject to planning approval)
- King Georges Road Interchange Upgrade (planning approval granted and work has commenced)
- M4–M5 Link – Haberfield to St Peters, including the Southern Gateway and Southern Extension (undergoing concept development and subject to planning approval).

Separate planning applications will be lodged for each individual component project. Each project will be assessed separately, but the impacts of each project will also be considered in the context of the wider WestConnex.

The NSW Government has established the WestConnex Delivery Authority (WDA) to deliver WestConnex. WDA has been established as an independent public subsidiary corporation of Roads and Maritime. Its role and functions are set out in Part 4A of the *Transport Administration (General) Regulation 2013* (NSW). WDA is project managing the planning approval process for the project on behalf of Roads and Maritime. However, for the purpose of the planning application for the project, Roads and Maritime is the proponent.

1.2 Project location

The project is generally located in the inner west region of Sydney within the Auburn, Strathfield, Canada Bay, Burwood and Ashfield local government areas (LGAs). The project travels through 10 suburbs: Sydney Olympic Park, Homebush West, Homebush, North Strathfield, Strathfield, Concord, Burwood, Croydon, Ashfield and Haberfield.

The project is generally located within the M4 and Parramatta Road corridor, which links Broadway at the southern end of the Sydney central business district (CBD) and Parramatta in Sydney's west, about 20 kilometres to the west of the Sydney CBD. This corridor also provides the key link between the Sydney CBD and areas further west of Parramatta (such as Penrith and western NSW).

The western end of the project is located at the interchange between Homebush Bay Drive and the M4, about 13 kilometres west of the Sydney CBD. The project at this location would tie in with the M4 Widening project in the vicinity of Homebush Bay Drive.

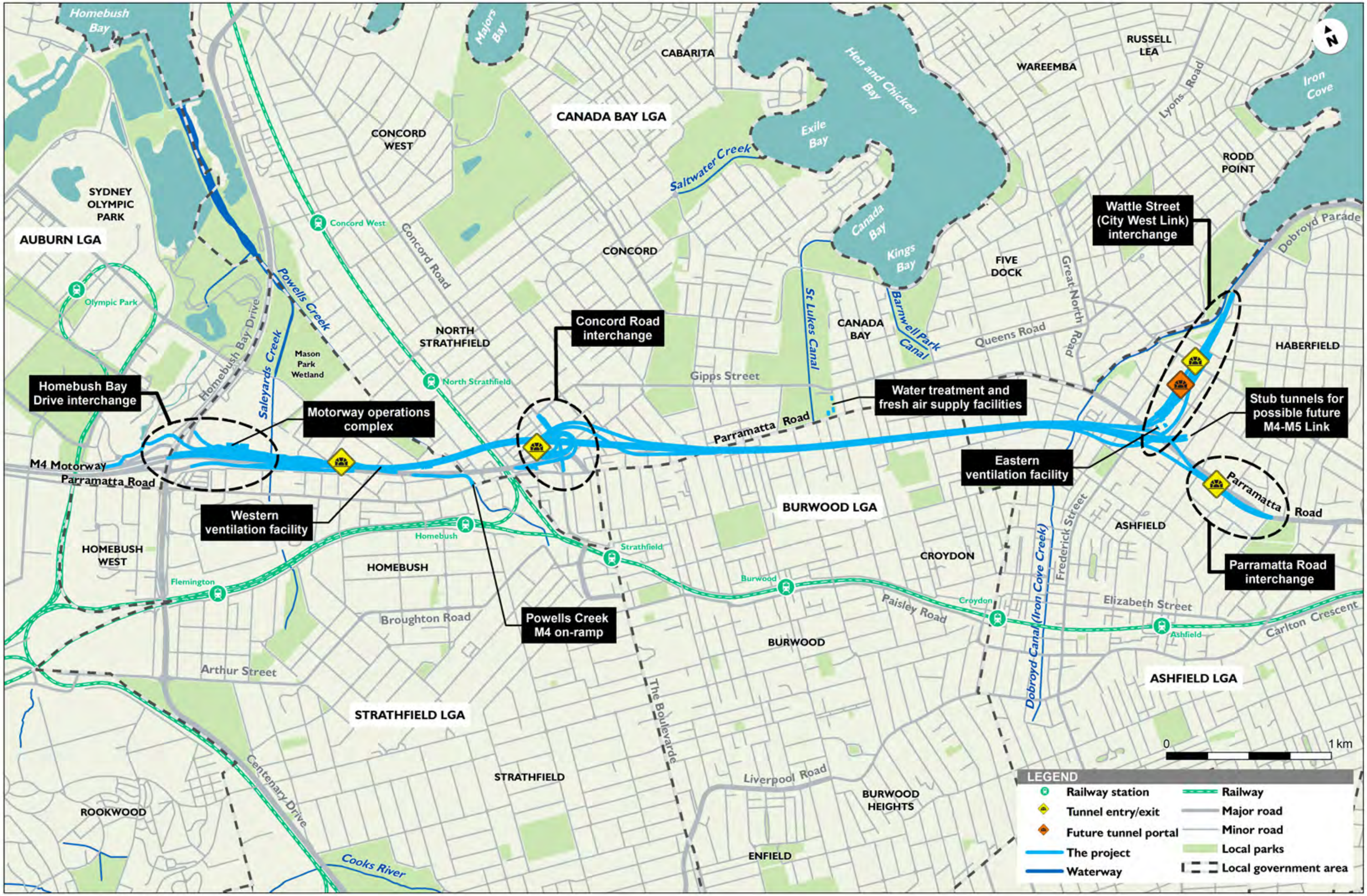

Figure 1.1 Local context of the project

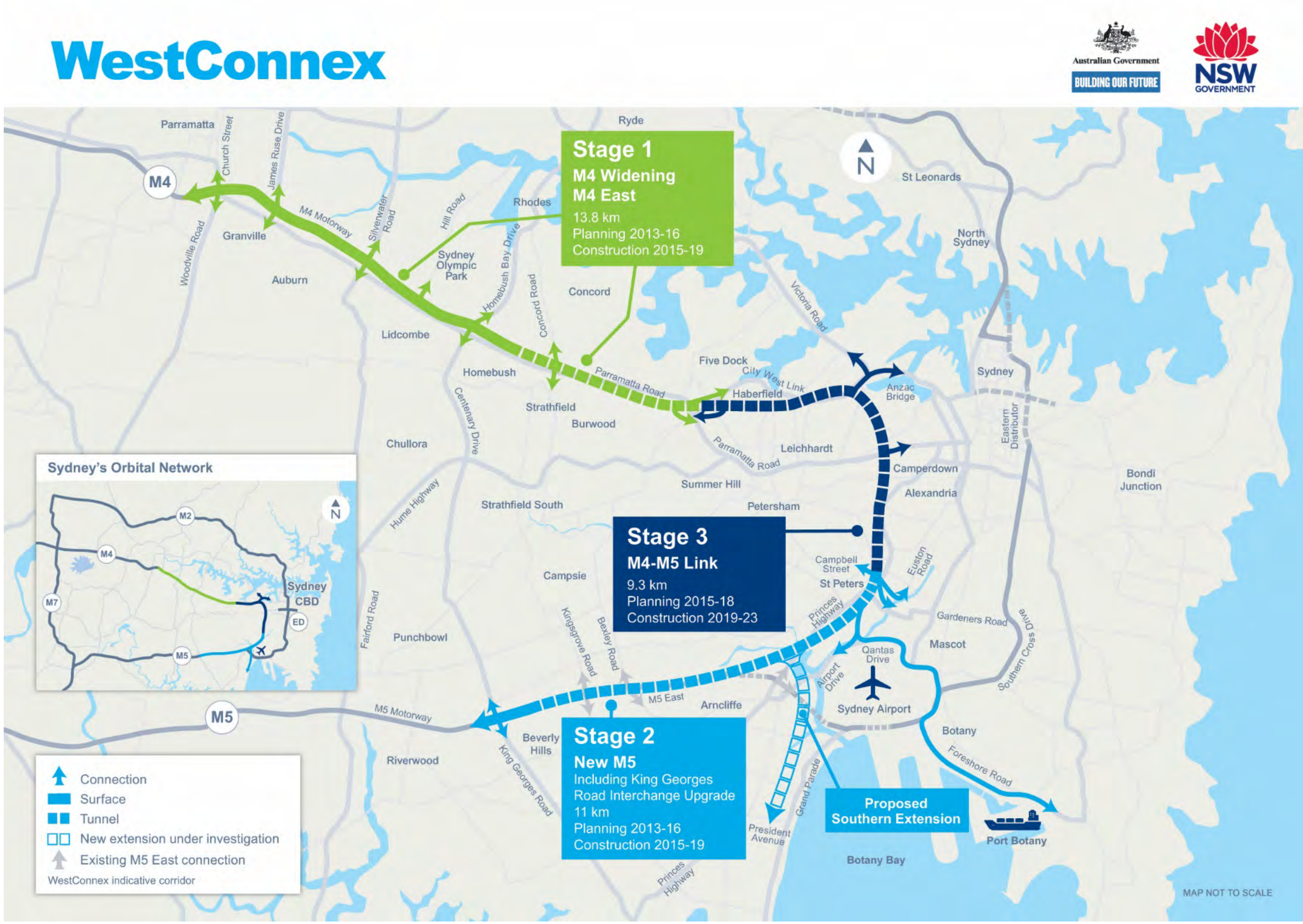

Figure 1-2 **Location of the project**

The tunnel dive structures would start at the centre of the M4, west of the existing pedestrian footbridge over the M4 at Pomeroy Street, and would continue underground to the north of the existing M4 and Parramatta Road, before crossing beneath Parramatta Road at Broughton Street at Burwood. The tunnels would continue underground to the south of Parramatta Road until the intersection of Parramatta Road and Wattle Street at Haberfield. Ramps would connect the tunnels to Parramatta Road and Wattle Street (City West Link) at the eastern end of the project. The tunnels would end in a stub connection to the possible future M4–M5 Link (M4–M5 Link), near Alt Street at Haberfield.

The project would include interchanges between the tunnels and the above ground road network, along with other surface road works, at the following locations:

- M4 and Homebush Bay Drive interchange at Sydney Olympic Park and Homebush (Homebush Bay Drive interchange)
- Powells Creek, near George Street at North Strathfield (Powells Creek M4 on-ramp)
- Queen Street, near Parramatta Road at North Strathfield (Queen Street cycleway westbound on-ramp)
- M4 and Sydney Street, Concord Road and Parramatta Road interchange at North Strathfield (Concord Road interchange)
- Wattle Street (City West Link), between Parramatta Road and Waratah Street at Haberfield (Wattle Street (City West Link) interchange)
- Parramatta Road, between Bland Street and Orpington Street at Ashfield and Haberfield (Parramatta Road interchange).

1.3 Purpose of this report

This report, which forms an appendix of the EIS for the project, has been prepared in response to the Secretary's Environmental Assessment Requirements (SEARs) issued on 16 June 2015 by the NSW Department of Planning and Environment (DP&E) for the project. The report presents an assessment of the construction and operational activities that have potential to impact on in-tunnel, local and regional air quality.

In recent years urban road tunnels in Australia have been subjected to considerable scrutiny, with the following areas of community focus:

- In-tunnel air quality. This report will demonstrate that the proposed ventilation system will achieve some of the most stringent standards in the world for in-tunnel air quality
- Ambient air quality. This report will demonstrate that the proposed ventilation system will be effective at maintaining local air quality
- Portal emissions. No portal emissions are proposed for the M4 East project. This report will demonstrate that the design of the ventilation system will achieve zero portal emissions.

Broad stakeholder and community confidence in the effective management of air quality within and around tunnels is critical to community acceptance of road tunnels, including those forming part of WestConnex, as an effective transport solution (*WestConnex Strategic Environmental Review*, Sydney Motorways Project Office (SMPO), 2013) (Strategic Environmental Review). For example, user- and community-related air pollution issues associated with the Sydney M5 East tunnel led to approval conditions for the M5 East tunnel, including the prohibition of portal emissions, being retained for subsequent tunnels.

Given the importance of WestConnex, it is important to ensure that the context and implications of the project are well understood. Road traffic is a major contributor to air pollution in urban areas such as Sydney. An appreciation of the sources and dispersion pathways of road traffic pollution, including the role of tunnels, is crucial to its control and improvement. This report summarises the existing literature and guidance in a number of different areas, such as road vehicle emissions, air quality standards, and in-tunnel pollution.

The operational air quality assessment for the project has followed a series of logical steps, from understanding the existing conditions, to characterising the changes in traffic, characterising the tunnel ventilation system, quantifying in-tunnel pollution, and estimating impacts on ambient air quality. At each step the best possible use has been made of existing information, and appropriate methods and models have been used. Significant improvements have been made to several methods and models for the explicit purpose of the project assessment, and these developments will be beneficial to future air quality assessments in NSW.

The following impacts of the project were outside the scope of work and have not been addressed in this report:

- Air quality inside buildings
- Air quality inside vehicles
- Health risks associated with air quality (assessed in Chapter 11 of the EIS)
- Greenhouse gas emissions (assessed in Chapter 21 of the EIS).

1.4 Structure of the Report

1.4.1 Description of chapters

The remainder of the report is structured as follows:

- Chapter 2 describes the project, including its construction and the main elements of the proposed ventilation strategy
- Chapter 3 identifies key air quality issues for the project, such as the relevance of motor vehicles and road tunnels to air quality in general, and the experience with Sydney tunnels to date. This Chapter also identifies the air quality assessment requirements for the project
- Chapter 4 summarises the regulation of emissions, air pollution and exposure. It addresses the control of road vehicle emissions and fuel quality, in-tunnel pollution limits, and ambient air quality standards
- Chapter 5 provides an overview of the air quality assessment methodology, outlining key documents, guidelines and policies, summarising previous major road and tunnel project assessments, and introducing specific aspects of the methodology. These aspects include the general approaches that were used for assessing the impacts of project construction and operation, and the scenarios that were evaluated
- Chapter 6 describes the existing environment in the general area of Sydney affected by the project, with specific reference to terrain, meteorology, emissions and ambient air quality
- Chapter 7 describes the assessment of construction impacts using a semi-quantitative risk-based approach
- Chapter 8 describes the assessment of operational impacts. It deals with emission modelling, in-tunnel air quality, and dispersion modelling for ambient air quality
- Chapter 9 deals with the cumulative impacts of the project and the M4-M5 Link. The New M5 ventilation outlets were excluded from the cumulative assessment on the grounds that they would be too far from the project to have a significant impact on air pollutant concentrations
- Chapter 10 provides a review of air quality mitigation measures, and recommendations on measures to manage any impacts of the project. The Chapter deals with both the construction and the operation of the project
- Appendices which address various technical aspects of the air quality assessment. In particular, the report on the ventilation requirements for the project is provided in Appendix L.

1.4.2 Compliance with SEARs

DP&E has issued a list of SEARs that informs the environmental impact assessment. Table 1-1 displays the SEARS that are specific to air quality, and also provides a cross-reference to the relevant section(s) of this report which address these requirements.

Table 1-1 How SEARs have been addressed in this report

SEARs	
Air quality	
Requirement	**Section where requirement is addressed**
An assessment of construction and operational activities that have the potential to impact on in-tunnel, local and regional air quality. The air quality impact assessment must provide an assessment of the risk associated with potential discharges of fugitive[2] and point source[3] emissions on sensitive receivers, and include:	• Chapter 7 (construction) • Chapter 8 (operational impacts)
• The identification of all sources of air pollution and assess potential emissions of PM_{10}, PM2.5, CO, NO_2 and other nitrogen oxides and volatile organic compounds (e.g. BTEX) and consider the impacts from the dispersal of these air pollutants on the ambient air quality along the proposal route, proposed ventilation outlets and portals, surface roads and ramps, the alternative surface road network, and in-tunnel air quality.	• Chapter 3 (sources of pollution) • Chapter 8 (operational impacts)
• Assessment of worst case scenarios for in-tunnel and ambient air quality, including assessment of a range of traffic scenarios, including worst case design maximum traffic flow scenario (variable speed) and worst case breakdown scenario, and discussion of the likely occurrence of each.	• Chapter 8 (operational impacts)
• Details of the proposed tunnel design and mitigation measures to address in-tunnel air quality and the air quality in the vicinity of portals and any mechanical ventilation systems (i.e. ventilation stacks and air inlets) including details of proposed air quality monitoring (including criteria).	• Chapter 10 (management of impacts)
• Demonstrate how the project and ventilation design ensures that concentrations of air emissions meet NSW, national and international best practice for in-tunnel and ambient air quality, and taking into consideration the approved criteria for the NorthConnex project.	• Chapter 5 • Chapter 8 (operational impacts)
• Consideration of any advice from the Advisory Committee on Tunnel Air Quality on the project.	• Advice provide by the Advisory Committee for the NorthConnex project was taken into account when developing the assessment methodology.

[2] The term 'fugitive' is often used to refer to a wide range of emission sources. In the context of this report it has been taken to refer to motor vehicle emissions on surface roads.
[3] It has been assumed for this report that this refers to tunnel ventilation outlets.

SEARs	
• Details of any emergency ventilation systems, such as air intake/exhaust stacks, including protocols for the operation of these systems in emergency situations, potential emission of air pollutants and their dispersal, and safety procedures.	• Section 2.4.3 • Chapter 10 (management of impacts)
• Details of in-tunnel air quality control measures considered, including air filtration. Justification must be provided to support the proposed measures.	• Chapter 10 (management of impacts)
Details of the proposed mitigation measures to prevent the generation and emission of dust (particulate matter and total suspended particulate (TSP)) and air pollutants (including odours) during the construction of the proposal, particularly in relation to ancillary facilities (such as concrete batching plants), the use of mobile plant, stockpiles and the processing and movement of spoil.	• Chapter 10 (management of impacts)
Cumulative assessment of the local and regional air quality due to the operation of the M4-M5 Link and surface road operations.	• Chapter 9
The air quality assessment, including the setting of air quality criteria, must be done in consultation with NSW Health and the Environment Protection Authority and with the consideration of any applicable advice provided by the Advisory Committee on Tunnel Air Quality.	• Section 5.3
Modelling (including dispersion modelling) must be conducted in accordance with the Approved Methods for the Modelling and Assessment of Air Pollutants in NSW (NSW DEC, 2005) or a suitably justified and verified alternative method based on current scientific understanding of atmospheric dispersion. Particular attention must be given to the verification of the method of predicting local air quality or meteorological conditions based on non-local or modelled data.	• Chapter 8 (operational impacts) • Appendix E (emission models) • Appendix J (dispersion model)

In December 2013, the then NSW Department of Planning and Infrastructure sought input from government agencies into the preparation of Director General Requirements (DGRs) (now SEARs) for the project. The submissions received by NSW Environment Protection Authority (NSW EPA), NSW Health, Strathfield Council and Ashfield Council are of relevance to this report. Table 1-2 notes where relevant comments have been addressed in this report.

Table 1-2 Where agency comments have been addressed in this report

Agency letters	
NSW Environment Protection Authority	
Air quality	**Section where addressed in EIS**
• The EA should include a detailed air quality impact assessment, which should:	
1. Assess the risks associated with potential discharges of fugitive and point source emissions for all stages of the proposal. Assessment of risk relates to environmental harm, risk to human health and amenity.	Risks are not quantified in the air quality assessment report. Human health risks are considered in Chapter 10 of the EIS.
2. Justify the level of the assessment undertaken on the basis of risk factors, including but not limited to: a. proposal location b. characteristics of the receiving environment c. type and quantity of pollutants emitted	The assessment considers, in detail, the locations of emission sources, the existing conditions in the receiving environment and the pollutants emitted. These are addressed in multiple sections of the report.
3. Describe the receiving environment in detail. The proposal must be contextualised within the receiving environment (local, regional and inter-regional as appropriate). The description must include but need not be limited to:	The existing environment is described in Chapter 6.
a. meteorology and climate	Chapter 6
b. topography	Chapter 6
c. surrounding land use, receptors	Chapter 6 and Chapter 8
d. ambient air quality	Chapter 6 and Appendix F
4. Include a detailed description of the proposal. All processes that could result in air emissions must be identified and described. Sufficient detail to accurately communicate the characteristics and quantity of all emissions must be provided.	Chapter 2 provides a description of the project. Further information on the sources of air pollution included in the assessment is provided in Chapters 3, 4 and 5.
5. Include a consideration of 'worst case' emission scenarios, and impacts at proposed emission limits and points.	The assessment scenarios are identified in Chapter 5.
6. Emergency and abnormal activities should be addressed, and the mitigation and management options that will be used to prevent, control, abate or minimise potential impacts should be described.	Mitigation measures for project operation are described in section 10.2.
7. Account for cumulative impacts associated with existing emission sources as well as any currently approved developments linked to the receiving environment.	The methodology is summarised in Chapter 5, including the determination of cumulative impacts.
8. Include dispersion modelling where there is a risk of adverse air quality impacts, or where there is sufficient uncertainty to warrant a rigorous numerical impact assessment. Any dispersion modelling must be conducted in accordance with the Approved Methods for the Modelling and Assessment of Air Pollutants in NSW (2005).	No screening-level assessment has been undertaken. A very detailed modelling approach was used to reflect the complex changes in the distribution of traffic emissions across the road network. Modelling has been conducted in accordance with the Approved Methods, where appropriate. The modelling is described in Chapters 5 and 8.
9. Demonstrate the proposal's ability to comply with the relevant regulatory framework, specifically the Protection of the Environment Operations (POEO) Act (1997) and the POEO (Clean Air Regulation (2010).	The *Protection of the Environment Operations (Clean Air) Regulation 2010* specifies in-stack concentration limits for scheduled activities in NSW. As the project is not listed as a plant used for specific

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	purposes (as per Schedule 3 of the Regulation), it is not considered subject to the prescribed limits in Schedule 4. However, it is worth noting that the concentration limits that will be applicable to the ventilation outlets for the project will be much more stringent than those in the Regulation.
10. Provide an assessment of the project in terms of the priorities and targets adopted under the NSW State Plan 2010 and its implementation plan Action for Air.	One of the priority areas in the State Plan is improving the efficiency of the road network during peak times, as measured by travel speeds and volumes on Sydney's road corridors. Whilst WestConnex is not mentioned specifically in the State Plan, one of the outcomes of the project is likely to be increased efficiency and reduced travel times. Action for Air seeks to provide long-term emission reductions, to meet the national air quality standards, and to reduce the population's exposure to air pollution. The main pollutants from the project that are relevant to Action for Air are $PM_{2.5}$ and NO_2. The project addresses the aims of the Action for Air Plan by leading to a net reduction in pollutant concentrations at a large majority of the receptors along the project corridor.
11. Detail emission control techniques/practices that will be employed by the proposal.	Section 10.1 summarises the management of construction impacts, and identifies a range of mitigation measures. Mitigation measures for project operation are described in section 10.2.
12. Consider mobile plant in the assessment of air quality impacts.	Chapter 7. Emissions from mobile plant have not been calculated separately in the construction impact assessment, but are considered as a general factor in the risk-based approach that has been used.
13. Consider a qualitative construction air quality impact assessment when assessing the feasibility of managing spoil underground and/or within sheds on the surface. It is considered that a quantitative construction air quality impact assessment is required if there is substantial handling of spoil on the surface and not inside sheds.	Chapter 7.
14. Air quality modelling scenarios should be canvassed with the Inter-Agency Regulatory Group to obtain in-principle support for the approach; the ventilation strategy is of particular interest.	The methodology and findings of the assessment were presented to government agencies including DP&E, EPA and NSW Health on 26 June and 11 August 2015 respectively.
• Guidance material: 1. Approved Methods for the Modelling and Assessment of Air Pollutants in NSW (2005). 2. POEO (Clean Air) Regulation.	The assessment has been conducted in accordance with the Approved Methods.
NSW Health	
Air quality	**Section where addressed in EIS**
• **General**	

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1. The proponent should provide a comprehensive assessment of the human health risks associated with the tunnel's impact on local and regional air quality during construction and operation.	Human health risk is not addressed in this report. This is considered in Chapter 10 of the EIS.
2. As with our other recent comments for road tunnel projects, consideration should be given to a range of pollutants including $PM_{2.5}$, PM_{10}, TSP, CO, NO_2 and other nitrogen oxides, volatile organic compounds (e.g. BTEX) and ozone. Relevant short- and long-term exposure periods should be considered, depending on the pollutant. Consideration should also be given to the impact of odours.	The pollutants and metrics included in the assessment are defined, with a rationale for inclusion or exclusion, in Section 5. The following have been excluded: a. TSP b. Air toxics for which no air quality impact assessment criteria are given in the Approved Methods. c. ozone Odours are dealt with in section 8.5.10.
3. When assessing the potential health impacts, both incremental changes in exposure from existing background levels and the cumulative impacts of project-specific and existing pollutant levels should be addressed at the location of receptors.	The modelling method and results are described in sections 5 and 8.
4. Exposure should be assessed at the location of the most affected receptors and also for other sensitive receptors such as childcare centres, schools, hospitals and aged care facilities. Consideration should be given to the size of the population exposed to increased concentrations of air pollutants.	With a complex urban project such as WestConnex, it is not possible to know beforehand which will be the most affected receptors. These have been identified through modelling in Chapter 8. Health impacts are considered in Chapter 10 of the EIS.
5. [Suggested wording for SEARs]. Consideration of the additional health risk from air pollutants should be expressed in health terms such as the additional mortality or morbidity estimated to be associated with the increase in pollutant exposure of the affected population following the approach described in Environmental Health Risk Assessment: Guidelines for assessing human health risk from environmental hazards (2012).	Health impacts are considered in Chapter 10 of the EIS.
• **Impacts during operation**	
A detailed description should be provided of the location, configuration and design of all emissions sources including ventilation stack(s) and tunnel portals.	Chapter 2 provides a description of the project.
It is noted that these outlets are not yet identified but as with other road tunnels this is likely to be the issue of most concern and the following points should be considered:	
1. Emissions should be modelled for the range of potential ventilation scenarios involving variable contributions of stack and portal emissions, and for a range of traffic conditions.	Chapter 8 describes the modelling of emissions from the tunnel ventilation outlets, including the model inputs that were used.
2. Modelling should account for the range of expected climatic conditions around proposed ventilation stacks and portals.	Section 6.4 describes the meteorological conditions that were used in the dispersion modelling. The project will be designed to ensure zero portal emissions, and therefore these were not included in the model.

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3. Modelling should account for the range of vehicle numbers and relative contributions of heavy/light and diesel vehicles.	Section 8.2 and Appendix E summarise the traffic assumptions for the emission modelling work.
4. Air quality models should be appropriate to the scenario.	The rationale for the dispersion model selection is given in section 8.4.
Consideration should be given to all feasible mitigation measures in addition to stack ventilation, such as filtration of emissions prior to discharge, and a rationale provided for inclusion or exclusion of these measures.	Mitigation measures for project operation are described in section 10.2.
An assessment should be made of in-tunnel air quality and then human health effects of potential exposure scenarios for vehicle occupants (including infants, children and adults) and motorcyclists using the tunnel. Pollutants considered should include CO, $PM_{2.5}$, PM_{10} and NO_2 and exposure levels estimated from the range of traffic flows that may be experienced.	This report addresses in-tunnel air quality, with the full results being presented in Appendix L. The health impacts of in-tunnel exposure are addressed in Chapter 10 of the EIS.
An assessment should be made of the impact of operation of the tunnel on regional air quality.	Section 8.2.3 summarises the total emissions in the study area with and without the project. These changes can be viewed as a proxy for changes in regional air quality (which will be minimal). The changes in emissions associated with the project were well below the thresholds for the assessment of secondary regional pollutants such as ozone.
• **Impacts during construction**	
A detailed description should be provided of potential emissions sources relating to construction including dust from unpaved service locations, dust from transport of spoil and emissions from not-road diesel engines.	The assessment of construction impacts followed a risk-based approach. This is described in Chapter 7.
Consideration should be given to all feasible mitigation measures.	Section 10.1 summarises the management of construction impacts, and identifies a range of mitigation measures.
Strathfield Council	
Air quality and air pollution impact	**Section where addressed in EIS**
A detailed air quality impact statement of the project both covering the construction and operational stage should be prepared for the proposed M4 East and associated tunnelling works.	These requirements are addressed in detail in the report.
Ashfield Council	
Air quality	**Section where addressed in EIS**
Tunnel exhaust systems and filtration systems	
Tunnel exhaust vent discharge will be a key community concern due to potential impact on the health and wellbeing of local residents. The exhaust vents are also likely to be tall, visually prominent structures.	
The EIS must therefore include detailed consideration of the option of using 'vehicle emissions filtering' mechanisms for the tunnel exhaust systems. This must include a detailed proposal produced by an appropriately qualified expert(s), so that an adequate	Mitigation measures for project operation are described in section 10.2, including a review of the Australian and international experience with filtration systems in tunnel

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evaluation can be made of this option. It should also identify 'best practice' options for tunnel filtering in current use for projects of a similar scale to the Stage 1 works.	environments.
Any option for not using a 'vehicle emissions filtering' mechanism must show the position of exhaust vents, the number of properties which will be affected by emissions, and the degree of impact of those emissions on public health. Such an option must also provide evidence based data of appropriate scientific rigour to support no 'vehicle emissions filtering' mechanism for the Stage 1 works.	The provision of a tunnel filtration system does not represent a feasible and reasonable mitigation measure and is not being proposed.
The EIS must include details of the position of the exhaust vents, their heights, and visual treatments and the proposed method of exhausting vehicle emissions.	Chapter 2 provides a description of the project, including, where possible, the design and location of ventilation outlets.

2 Proposed project

2.1 Overview of Chapter

This Chapter describes the following:

- The main features of the project
- The construction of the project
- Specific aspects of the design that are linked to air quality. These essentially relate to the tunnel ventilation strategy.

2.2 Project features

The project would comprise the construction and operation of the following key features:

- Widening, realignment and resurfacing of the M4 between Homebush Bay Drive and Underwood Road at Homebush
- Upgrade of the existing Homebush Bay Drive interchange to connect the western end of the new tunnels to the existing M4 and Homebush Bay Drive, while maintaining all current surface connections
- Two new three-lane tunnels (the mainline tunnels), one eastbound and one westbound, extending from west of Pomeroy Street at Homebush to near Alt Street at Haberfield, where they would terminate until the completion of the M4–M5 Link. Each tunnel would be about 5.5 kilometres long and would have a minimum internal clearance (height) to in-tunnel services of 5.3 metres
- A new westbound on-ramp from Parramatta Road to the M4 at Powells Creek, west of George Street at North Strathfield
- An interchange at Concord Road, North Strathfield/Concord with on-ramps to the eastbound tunnel and off-ramps from the westbound tunnel. Access from the existing M4 to Concord Road would be maintained via Sydney Street. A new on-ramp would be provided from Concord Road southbound to the existing M4 westbound, and the existing on-ramp from Concord Road northbound to the existing M4 westbound would be removed
- Modification of the intersection of the existing M4 and Parramatta Road, to remove the left turn movement from Parramatta Road eastbound to the existing M4 westbound
- An interchange at Wattle Street (City West Link) at Haberfield with an on-ramp to the westbound tunnel and an off-ramp from the eastbound tunnel. The project also includes on- and off-ramps at this interchange that would provide access to the M4–M5 Link. In addition, the westbound lanes of Wattle Street would be realigned
- An interchange at Parramatta Road at Ashfield/Haberfield, with an on-ramp to the westbound tunnel and an off-ramp from the eastbound tunnel. In addition, the westbound lanes of Parramatta Road would be realigned
- Installation of tunnel ventilation systems, including ventilation facilities within the existing M4 road reserve near Underwood Road at Homebush (western ventilation facility) and at the corner of Parramatta Road and Wattle Street at Haberfield (eastern ventilation facility). The eastern ventilation facility would serve both the project and the M4–M5 Link project. Provision has also been made for a fresh air supply facility at Cintra Park at Concord
- Associated surface road work on the arterial and local road network, including reconfiguration of lanes, changes to traffic signalling and phasing, and permanent road closures at a small number of local roads
- Pedestrian and cycle facilities, including permanently re-routing a portion of the existing eastbound cycleway on the northern side of the M4 from west of Homebush Bay Drive to near

Pomeroy Street, and a new westbound cycleway on-ramp connection from Queen Street at North Strathfield to the existing M4

- Tunnel support systems and services such as electricity substations, fire pump rooms and tanks, water treatment facilities, and fire and life safety systems including emergency evacuation infrastructure
- Motorway operations complex on the northern side of the existing M4, east of the Homebush Bay Drive interchange
- Provision of road infrastructure and services to support the future implementation of smart motorway operations (subject to separate planning approval)
- Installation of tolling gantries and traffic control systems along the length of the project
- Provision of new and modified noise walls
- Provision of low noise pavement for new and modified sections of the existing M4
- Temporary construction ancillary facilities and temporary works to facilitate the construction of the project.

An overview of the project at completion is shown in Figure 2-1.

The project does not include work required for reconfiguring Parramatta Road as part of the urban transformation program. The project does not include ongoing motorway maintenance activities during operation. These would be subject to separate assessment and approval as appropriate.

2.3 Construction activities

2.3.1 Overview

Construction activities associated with the project would generally include:

- Enabling and temporary works, including construction power, water supply, ancillary site establishment, demolition works, property adjustments and public transport modifications (if required)
- Construction of the road tunnels, interchanges, intersections and roadside infrastructure
- Haulage of spoil generated during tunnelling and excavation activities
- Fit-out of the road tunnels and support infrastructure, including ventilation and emergency response systems
- Construction and fit-out of the motorway operations complex and other ancillary operations buildings
- Realignment, modification or replacement of surface roads, bridges and underpasses
- Implementation of environmental management and pollution-control facilities for the project.

Construction activities are described in more detail in Chapter 6 of the EIS.

The project assessed in this report does not include surveys, sampling or investigation to inform the design or assessment, such as test drilling, test excavations, geotechnical investigations, or other tests. It also does not include adjustments to, or relocation of, existing utilities infrastructure undertaken prior to commencement of construction. These would be subject to separate assessment and approval as appropriate.

2.3.2 Construction footprint

The total area required for construction of the project, including the construction of ancillary facilities, is referred to as the ‘construction footprint’. The construction footprint would be about 65 hectares in total, comprising about 48 hectares at the surface and about 17 hectares below ground. In addition to below ground works, surface works will be required to support tunnelling activities and to construct surface infrastructure such as interchanges, tunnel portals, ventilation facilities, ancillary operations buildings and facilities, and new cycleway facilities near the Homebush Bay Drive interchange and Queen Street at North Strathfield.

The overall surface construction footprint generally aligns with the operational footprint, with the locations of future operational ancillary facilities being used to support construction work. Some additional areas adjacent to the operational footprint (around the portals and on- and off-ramps, and also at the tunnel mid-point) would also be required during the construction stage only to facilitate construction.

Construction ancillary facilities would be required at 10 locations:

- Homebush Bay Drive civil site (C1)
- Pomeroy Street civil site (C2)
- Underwood Road civil and tunnel site (C3)
- Powells Creek civil site (C4)
- Concord Road civil and tunnel site (C5)
- Cintra Park tunnel site (C6)
- Northcote Street tunnel site (C7)
- Eastern ventilation facility site (C8)
- Wattle Street and Walker Avenue civil site (C9)
- Parramatta Road civil site (C10).

An overview of the construction footprint is shown in Figure 2-2.

The final size and configuration of construction ancillary facilities would be further developed during detailed design.

Figure 2-2 Overview of construction footprint and ventilation facilities

2.3.3 Construction program

Subject to planning approval, construction of the project is planned to start in the second quarter of 2016, with completion planned for the first quarter of 2019. The total period of construction works is expected to be around three years, including nine months of commissioning occurring concurrently with the final stages of construction. The indicative construction program is shown in Table 2-1.

Table 2-1 Indicative construction program overview

Construction activity	Indicative construction timeframe															
	2016				2017				2018				2019			
Construction access excavation (all sites)		■	■	■												
Tunnelling (excavation)			■	■	■	■	■	■								
Tunnel drainage and pavement works						■	■	■	■	■						
Tunnel mechanical and electrical fit out works								■	■	■	■					
Tunnel completion works											■	■	■			
Homebush Bay Drive interchange			■	■	■	■	■	■	■	■						
M4 surface works		■	■	■	■	■	■	■	■	■	■	■				
Western ventilation facility							■	■	■	■	■					
Powells Creek on-ramp		■	■	■	■	■										
Concord Road interchange			■	■	■	■	■	■	■	■	■	■				
Wattle Street interchange		■	■	■	■	■	■	■	■	■	■	■	■			
Parramatta Road interchange		■	■	■	■	■	■	■	■	■	■	■	■			
Eastern ventilation facility		■	■	■	■	■	■	■	■	■	■	■				
Cintra Park fresh air supply facility				■	■	■	■	■	■	■	■	■	■			
Cintra Park water treatment facility										■	■					
Motorway operations complex						■	■	■								
Mechanical and electrical fit out works							■	■	■	■	■	■				
Site rehabilitation and landscaping						■	■	■	■	■	■	■	■			

2.4 Specific aspects of design relating to in-tunnel and ambient air quality

2.4.1 Overview

The tunnel ventilation system is designed to meet the following criteria:

- Ensure that the air quality inside the tunnels is maintained at a level that provides a safe environment for tunnel users during normal, congested and minor incident operations. The design of the ventilation system within the tunnels will cater for the interface to the M4–M5 Link
- Ensure that air is exhausted from the tunnels and is dispersed in a manner that maintains good external air quality
- Provide a safe environment during a major incident or fire that allows all tunnel users to safely evacuate and allows for Fire & Rescue NSW intervention
- Ensure a suitable operational interface between the project and the M4–M5 Link ventilation systems.

The tunnel ventilation system would comprise jet fans and ventilation facilities. Equipment to monitor and measure operational states that affect air quality (both inside and outside the tunnels) and the safety of tunnel users would be incorporated into the project.

During normal operation, the ventilation system would draw fresh air into the tunnels through the tunnel portals and emit air from the tunnels via ventilation facilities.

The following ventilation facilities were included in the air quality assessment:

- The ventilation facilities for the project, being:
    A. Eastern ventilation facility (M4 East outlet). This would be located near the Wattle Street (City West Link) and Parramatta Road interchanges at Haberfield (Figure 2-3). The facility would provide exhaust from the mainline eastbound tunnel and exhaust from the Wattle Street (City West Link) and Parramatta Road off-ramps
    B. Western ventilation facility. This would be located within the existing M4 Motorway reserve near Underwood Road at Homebush (Figure 2-4). The facility would serve the westbound traffic within the project tunnel.
- The ventilation facilities for the M4-M5 Link project (2031 cumulative case with project only):
    E. A City West Link/ Rozelle ventilation facility. This facility would provide the mid-point ventilation outlet for the M4-M5 Link. An approximate location of the facility was used. It was assumed that the facility would be situated within the Rozelle Goods Yard, subject to a separate environmental assessment and approval
    F. Eastern ventilation facility (M4-M5 Link outlet). This would service the future M4–M5 Link. It would provide exhaust from the mainline westbound tunnel and exhaust from the Wattle Street M4–M5 Link off-ramp.

The eastern ventilation facility (M5-M5 Link outlet, item D) would comprise a building only as part of the project. Fit-out and commissioning would occur as part of the construction of the M4-M5 Link (if approved). The City West Link/ Rozelle ventilation facility (item D) does not form part of the project. Both ventilation facilities and were included to assess potential cumulative impacts only. The location of City West Link/ Rozelle ventilation facility was indicative only, and is subject to assessment and approval.

As noted above, the eastern ventilation facility is intended to serve both the M4 East project and the M4-M5 Link project. The ventilation facility would consist of two separate but adjoining buildings with 'back-to-back' outlets for the M4 East and the M4-M5 Link projects, as shown in the plan view of the fan arrangement Figure 2-5.

Figure 2-6 shows the plan view of the fan arrangement of the western ventilation facility. Further details of the ventilation facilities that were of specific interest to the air quality assessment are provided in Chapter 8.

During maximum traffic flow conditions, a major incident or fire, the fresh air supply facility at Cintra Park may be used. During a fire emergency, smoke could be exhausted using the ventilation facilities or from the tunnel portals depending on the location of the fire.

Figure 2-3 **Eastern ventilation facility - location**

Figure 2-4 Western ventilation facility – location

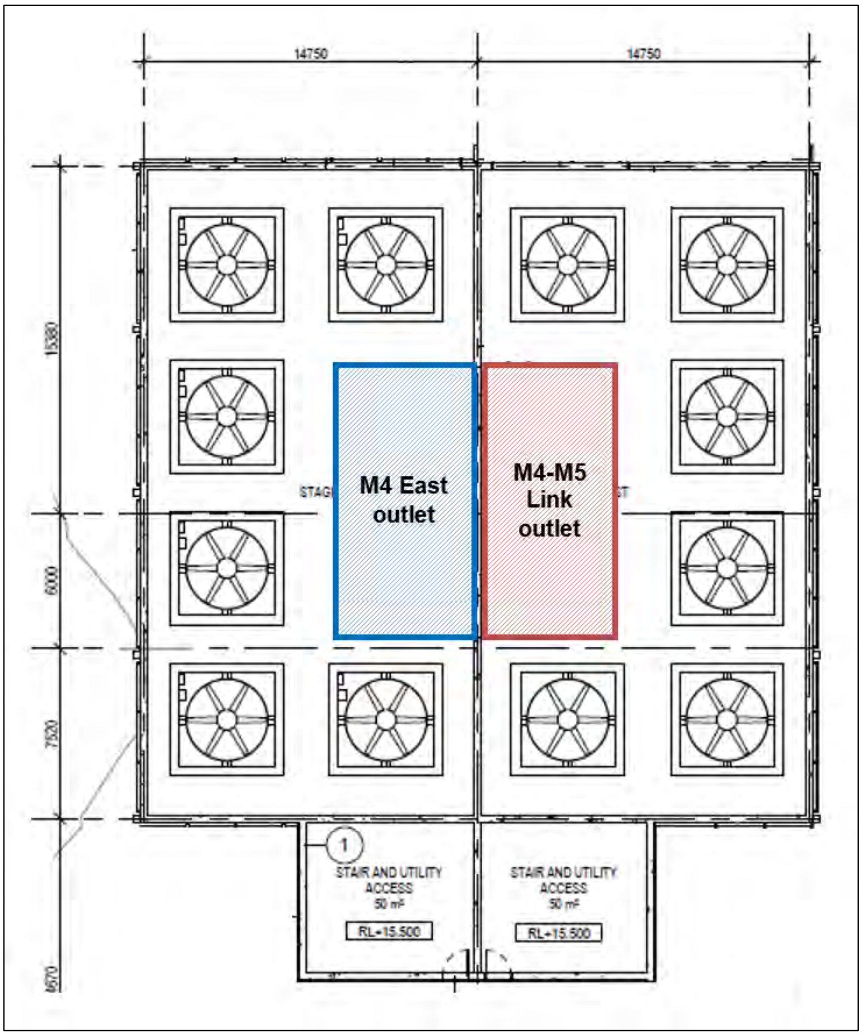

Figure 2-5 Eastern ventilation facility - plan view showing fan layout and outlets

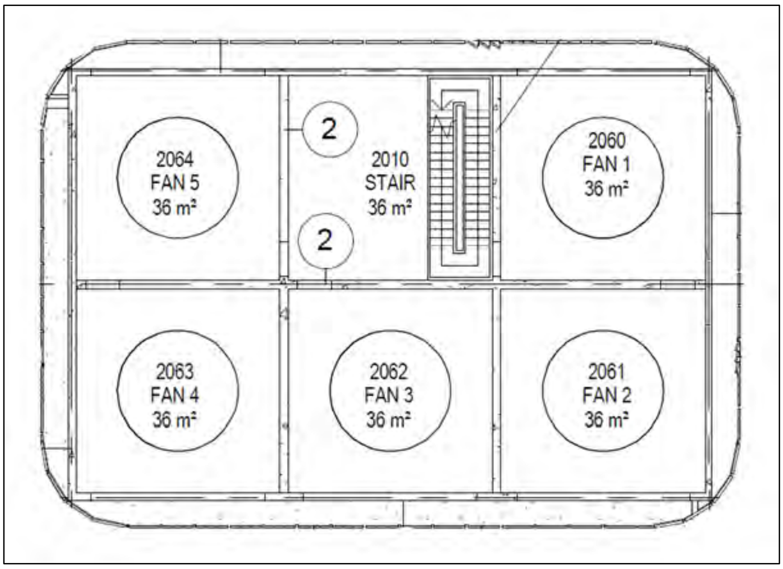

Figure 2-6 Western ventilation facility – plan view showing fan layout

2.4.2 Operating modes

The tunnel ventilation system would operate in the following modes:

- Normal traffic conditions
- Maximum traffic flow conditions which can generate the highest in-tunnel pollution levels
- Major incident conditions including major accident and fire scenarios

Operation of the ventilation system under each of these conditions is detailed in the following Sections.

Normal traffic conditions

Under normal traffic conditions the tunnel ventilation system would use vehicle aerodynamic drag (commonly referred to as the 'piston effect') to draw air in through the entrance portals, and to move the air along the tunnel in sufficient volumes to satisfy the fresh air demand of the traffic.

In-tunnel air containing vehicle emissions would be extracted from the tunnels before it reaches the exit portals. Air would be exhausted through a ventilation off-take inside the tunnels and transferred to the ventilation facility via a shaft. The air would then be discharged from the ventilation outlet to the atmosphere to achieve effective dispersion.

For the tunnel off-ramps, air would be drawn back down the ramp for extraction via the ventilation facility. This would require jet fans to maintain the air flow against the direction of traffic flow. A similar approach would be applied to sections of the mainline tunnels close to the exit portals.

Under low traffic, the vehicle generated piston effect would be lessened. In these situations the airflow would need to be assisted by the jet fans located throughout the tunnels. Under low traffic conditions, emission levels would also be low, consistent with the number of vehicles in the tunnel. Additional fresh air supply is unlikely to be required.

Maximum traffic flow conditions

In the case of an incident (such as a vehicle breakdown or crash) and maximum traffic flow conditions (such as heavy congestion) which can generate the highest in-tunnel pollution levels, the vehicle-generated piston effect would be lessened. In these situations the airflow would need to be assisted by the jet fans located throughout the tunnels.

The ventilation facilities would be operated during maximum traffic flow and minor incident conditions to ensure that acceptable air quality is maintained in the tunnels, and to achieve effective dispersion of tunnel air into the atmosphere. In addition, the fresh air supply facility at Cintra Park may be used.

Major incident conditions

During a major incident or fire, the tunnel ventilation system would be operated to ensure in-tunnel safety. In the case of a fire, the ventilation system would provide air in sufficient quantities to prevent smoke 'back layering' (i.e. flowing back from the fire source) over any vehicles that are stationary behind the incident. Smoke would be exhausted through the ventilation facilities or through the tunnel portals, depending on the location of the fire incident.

2.4.3 Emergency and incident management facilities

The project would be designed to minimise and manage incidents within the tunnel in accordance with the following standards:

- AS4825 – Tunnel fire safety
- US National Fire Protection Association 502 – Standard For Road Tunnels, Bridges, and Other Limited Access Highways, 2014
- Various publications prepared by the Permanent International Association of Road Congress (PIARC) including:
    - Systems and equipment for fire and smoke control in road tunnels, 2006

- Road tunnels: vehicle emissions and air demand for ventilation, 2012
    - Fire and smoke control in road tunnels, 1999
    - Operational strategies for emergency ventilation, 2011

Operational emergency systems and facilities such as emergency shoulders, breakdown bays, and fire suppression and firefighting systems have been included in the design of the project. Emergency incident facilities throughout the tunnel infrastructure would include the following:

- Deluge systems, including water storage tanks and fire pump rooms
- CCTV throughout the tunnels and approaches
- Vehicle height detection system prior to the tunnel portals
- Tunnel barrier gates to prevent access in the event of tunnel closure
- Pedestrian cross passages (for emergency evacuation of vehicle driver and passengers), spaced a maximum of 120 metres apart
- Long egress passages for pedestrians running alongside the on- and off-ramps at the Wattle Street, Parramatta Road and Concord Road interchanges, where it would be impractical to provide a connection to another tunnel
- Intermediate passages for access by Fire & Rescue NSW personnel during emergencies at the Wattle Street, Parramatta Road and Concord Road interchanges, connecting the long egress passages either to the adjacent long egress passages or to the mainline tunnels
- Breakdown bays along both the eastbound and westbound mainline tunnels
- Fire & Rescue NSW emergency cabinets inset into the tunnel walls at 60 metre intervals including fire hose reels, hydrants and fire phones
- Motorist emergency equipment points inset into the tunnel walls at 60 metre intervals including a motorist emergency telephone and a fire extinguisher
- Two incident response areas of suitable size to station an incident response vehicle, one located at the motorway operations complex and one located at the eastern ventilation facility.

3 Key air quality issues for the M4 East project

3.1 Overview of Chapter

This Chapter:

- Summarises the main aspects of traffic-related emissions and air pollution, including the air quality issues that are associated specifically with road tunnels
- Provides up-to-date contextual information on topics such as the main traffic pollutants and their effects, the processes affecting air pollution, and air pollution in and around tunnels
- Identifies the key air quality issues for the project
- Defines the main requirements of the air quality assessment for the project.

3.2 Roads, tunnels and air quality

3.2.1 Significance of road traffic pollution

Road traffic is the main source of several important air pollutants in Australian cities. The pollutants released from motor vehicles have a variety of effects on amenity, health, ecosystems and cultural heritage (see Appendix A). Traffic pollution also has impacts on wider geographical scales[4]. The main focus of concern is currently on the short-term and long-term effects of road transport pollution on human health. For example, these effects account for the majority of the costs to society associated with the impacts of air pollution[5]. The health costs of air pollution in Australia are estimated to be in the order of $11.1 billion to $24.3 billion annually, solely as a result of mortality (Begg *et al.*, 2007; Access Economics, 2008). Road transport is an important contributor; the health costs of emissions from road transport in Australia have been estimated to be $2.7 billion per year (BTRE, 2005).

3.2.2 Pollutants

Many different air pollutants are associated with road vehicles. Those pollutants that are emitted directly into the air are termed ‘primary’ pollutants. In terms of local air quality and health, as well as the quantity emitted, the most important primary pollutants from road vehicles are:

- Carbon monoxide (CO)
- Oxides of nitrogen (NO_X). By convention, NO_X is the sum of nitric oxide (NO) and nitrogen dioxide (NO_2), and is stated as NO_2-equivalents
- Particulate matter (PM). The two metrics that are most commonly used are PM_{10} and $PM_{2.5}$, which are particles with an aerodynamic diameter of less than 10 μm and 2.5 μm respectively.
- Hydrocarbons (HC). The term ‘hydrocarbons’ covers a wide range of compounds which contain carbon and hydrogen. In the context of vehicle emissions, the term ‘volatile organic compounds’ (VOC) is also often used, especially where there is reference to fuel evaporation. The terms VOC and total hydrocarbons (THC) are used interchangeably in this report. Where reference is made to a source document or model, the original term used has been retained

Other pollutants, notably ozone (O_3) and important components of airborne particulate matter, are formed through chemical reactions in the atmosphere. These are termed ‘secondary’ pollutants. Most of the NO_2 in the atmosphere is also secondary in nature.

The characteristics, health effects and environmental effects of the main primary and secondary transport-related pollutants are summarised in Appendix A. The specific pollutants and metrics that were addressed in this assessment are identified in Chapter 5.

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[4] It has become evident that some transport-derived pollutants can travel thousands of kilometres before their impacts occur, contributing to the regional degradation of air quality, to eutrophication, and to acidification. Stable pollutants, including the greenhouse gases carbon dioxide, methane and nitrous oxide can affect the environment on a global scale.

[5] Excluding any climate-related effects of greenhouse gas emissions.

3.2.3 Impact pathways

The links between road traffic, air pollution and health are complex, involving a multi-step impact pathway. The pathway begins with the initial formation of pollutants. The formation processes for traffic-derived pollutants are explained in Appendix B. The processes that lead to emissions of primary pollutants are:

- Combustion, which results in CO, HC, NO_X and PM being emitted from vehicle exhaust
- Evaporation of VOCs from fuel
- Abrasion resulting in PM emissions through tyre wear, brake wear and road surface wear
- Resuspension, which results in particulate matter on the road surface being entrained in the atmosphere.

For a given road section the total mass of a pollutant that is emitted depends upon several factors, including:

- The volume, composition and operation of the traffic
- The road gradient
- The length of the road section.

The emitted pollutants are then dispersed in the ambient air according to the local topography and meteorology, and are transformed into secondary pollutants through chemical reactions. The dispersion and transformation of traffic-derived pollutants are summarised in Appendix B.

The main direct impacts of primary pollutants are near the point of emission; further away concentration decrease rapidly as a result of dispersion and dilution. Because of the time required for their formation, the concentrations of secondary pollutants are not always highest near the emission source. An example of this is the formation of NO_2 from NO emissions.

The resulting effects of road traffic pollution on, for example, the health of a given population are influenced by the concentration to which the population is exposed, the duration of the exposure, and the susceptibility of the population to the relevant pollutants. The situation is complicated by numerous factors, such as multiple pollutants having synergistic effects on health.

The overall exposure of individuals to air pollutants is dependent upon the types of activity in which they are engaged, the locations of those activities, and the pollutant concentrations at those locations. In principle, an understanding of the amount of time spent in different types of environment (such as outdoors in the street, indoors at home, in transit, at the workplace, etc.), and the pollutant concentrations in those environments, allows the calculation of 'integrated' personal exposure (Duan, 1982). However, the calculation of such an integral is often not possible because the pollutant concentrations in the different microenvironments are generally not known. The term 'average exposure' is therefore commonly used, and this is normally taken to mean the pollutant concentration over a specified period (*e.g.* annual mean) at an outdoor location which is broadly representative of where people are likely to spend time. This approach is reflected in the regulation of ambient air quality.

Once the pollutant has crossed a physical boundary within the body, the concept of 'dose' is used (Ott, 1982). The dose is the mass of material absorbed or deposited in the body for an interval of time, and depends on the respiratory activity of the individuals concerned. Responses to doses – the actual health effects - can also vary from person to person, depending on physiological conditions.

3.2.4 Air pollution in and around road tunnels

In-tunnel pollution

The principles of exposure also apply inside road tunnels, where impacts on health are related to the concentration of pollutants in the tunnel and the amount of time spent in the tunnel. The more time spent travelling in a tunnel with elevated pollutant concentrations, the greater the exposure time which, in turn, will increase the risk of effects (NHMRC, 2008; Longley *et al*. 2010). Ensuring that in-tunnel air quality remains within acceptable levels is the key consideration for tunnel ventilation design. Visibility is also an important safety concern for tunnel design. Visibility is reduced by the scattering and absorption of visible light by airborne particles. The amount of scattering or absorption is dependent upon particle size, composition and density (PIARC, 2012).

Portal emissions

In most tunnels around the world emissions are released from the portals, but in Australia several recent urban tunnels have been designed in such a way that portal emissions are avoided. In line with this approach, the project would be designed so that there are no emissions from the tunnel portals (see below).

Ventilation outlet emissions

Ventilation outlets provide an effective means of dispersing the polluted air from a tunnel. Motor vehicle emissions occur at, or close to, ground level, and the worst-case conditions from an air quality perspective are those associated with calm winds and stable atmospheric conditions. Conversely, the ground-level concentrations due to emissions from a tall tunnel ventilation outlet will generally be low under these same conditions, and highest when winds are moderate and mixing is sufficiently intense to force the plume from the outlet to ground-level (PIARC, 2008).

The concentrations of air pollutants at locations of potential population exposure are determined by the emission rates of the pollutants and the effectiveness of the tunnel ventilation system at harnessing the dispersive capacity of the atmosphere (PIARC, 2008). A combination of the design height of the outlet and the amount of fresh air that is mixed with the contaminated air from the tunnel can be used to ensure appropriate dilution before the exhaust plume makes contact with the ground, and good design can ensure compliance with local air quality standards. The tunnel ventilation outlets are located well above ground level to harness the momentum and buoyancy of the plume, providing better dispersion and lower ground-level concentrations. Outlets above the layer directly affected by buildings (this would mean, in general, around two or three times as high as the surrounding buildings) result in even better dispersion (PIARC, 2008).

The release of pollutants from tunnel portals can also be minimised through the extraction of air via ventilation outlets. For much of the tunnel length the air flow caused by the ventilation system can be used to supplement the vehicle aerodynamic drag effect. To achieve zero portal emissions the polluted air in the tunnel must be drawn against the piston effect of the traffic. Given this requirement for pushing air in the opposite direction to the traffic flow, positioning ventilation outlet close to tunnel exit portals has been found to be the most cost-effective and energy-efficient approach, as this minimises the distance over which this ‘reverse flow’ is needed. However, the use of ventilation outlets to avoid portal emissions does have implications:

- An increase in the required throughput of ventilation air, which can significantly increase the design size and capital cost of the ventilation system.
- An increase in the operational cost (and energy use) of the ventilation system, as it must be operated continuously.

The potential air quality impacts of the ventilation outlets themselves are often the focus of community attention in relation to tunnel projects. A consideration of ventilation outlets therefore needs to be included in any detailed air quality assessment (SMPO, 2013). The air quality assessment informs the ventilation outlet design and operating conditions to ensure that good air quality is maintained.

3.3 Sydney tunnels and air quality

NHMRC (2008) described the history of road tunnels in Sydney, and highlighted the importance of accurate modelling at the design stage to ensure that air quality is properly managed.

Since the Eastern Distributor tunnel (1999), the road tunnels constructed in Sydney (including those mentioned above) have all been designed to avoid portal emissions, and the tunnel air is discharged from elevated ventilation outlets.

The M5 East Tunnel is four kilometres long, carries a large volume of traffic (around 110,000 vehicles per day), and is subject to frequent congestion. High levels of in-tunnel pollution and poor visibility were initially reported (NSW Parliament, 2002). NHMRC noted that the emission factors used to design the tunnel ventilation underestimated emissions from the local fleet, and that traffic in the tunnel quickly exceeded the design assumptions. It has also been observed that there was a failure to model the effects of emissions from traffic travelling at low speeds (NSW Department of Planning, 2005). Ambient air quality continues to be monitored at five locations in the vicinity of the ventilation outlet for the M5 East Tunnel. Since opening in December 2001, the tunnel has been operating within the ambient air quality goals set in the approval for the project (SMPO, 2013).

Conversely, for the Cross City Tunnel there was a large overestimation of the traffic volume at opening. This has been attributed to toll avoidance and a reversal of surface road changes designed to feed traffic into the tunnel. Although pollutant concentrations reported inside the Cross City Tunnel are low, the ventilation system was expensive to build and operate (Manins, 2007).

The Lane Cove Tunnel is a 3.6 kilometre structure that connects the M2 Motorway at North Ryde with the Gore Hill Freeway at Artarmon, and is designed to relieve congestion on Epping Road. The tunnel is ventilated by one outlet at each end. Extensive air quality monitoring was conducted in the vicinity of the ventilation outlets and alongside Epping Road. Concentrations of air pollutants decreased alongside Epping Road after the opening of the tunnel, and no exceedances of air pollution standards were attributed to air discharged from the tunnel ventilation outlets (Holmes *et al.,* 2011).

3.4 Advisory Committee on Tunnel Air Quality

Given the community concerns surrounding road tunnels in Sydney, and the scale of WestConnex, the NSW Government established an Advisory Committee on Tunnel Air Quality (ACTAQ). The Committee is chaired by the NSW Chief Scientist and Engineer, and includes representatives from several government departments, including Roads and Maritime, NSW Department of Health (NSW Health), DP&E and NSW EPA. The main role of ACTAQ is to provide the Government with an understanding of the scientific and engineering issues informing tunnel ventilation design and operation based on NSW, national and international experience.

In 2014, ACTAQ released a number of reports on motor vehicle emissions, air quality and tunnels. These reports were consulted as part of the assessment for the project[6].

3.5 WestConnex Strategic Environmental Review

The Strategic Environmental Review for the whole of WestConnex (SMPO, 2013) identified the major potential benefits and challenges associated with the scheme, and considered how the latter could be avoided, managed and/or mitigated during project development and delivery. Issues and strategies were identified in consultation with the key government agencies. The Strategic Environmental Review thus set the scene for subsequent project-specific environmental impact assessments.

Six priority issues were identified as likely to be of community and stakeholder concern, one of which was air quality. A strategic air quality assessment was undertaken to evaluate the potential impacts of WestConnex on regional and local air quality, as well as in-tunnel air quality. The main findings of this assessment were as follows:

- Regional air quality is unlikely to change as a result of WestConnex.
- Transferring vehicles from surface roads into tunnels is likely to improve the air quality along existing surface roads where traffic is reduced. However, local effects on air quality will need to be determined more accurately through detailed assessments.
- The tunnel ventilation systems for WestConnex will be designed and operated to meet stringent in-tunnel criteria and ambient air quality standards. In-tunnel air quality criteria will be developed in consultation with NSW EPA, NSW Health, and DP&E based on a review of current international practice and experience from NSW motorway tunnels.
- Locating ventilation outlets close to the tunnel portals would substantially minimise the costs and energy use for the system.
- Filtration of tunnel emissions is not an efficient or effective mechanism to address in-tunnel, local or regional air quality.

[6] http://www.chiefscientist.nsw.gov.au/reports

- The results of monitoring of earlier tunnel projects and detailed air quality modelling will be used to demonstrate how the proposed approach will protect air quality.
- The number of people using road tunnels would increase substantially with WestConnex. However, the maximum time spent in any tunnel should decrease due to improved traffic flow across the network.

3.6 Community Feedback Report

The M4 East preliminary concept design was displayed to the public between November 2013 and February 2014. The Community Feedback Report (NSW Government, 2014) described the consultation activities during the display period and provided a summary of the comments, concerns and questions raised by stakeholders and the community.

Issues were raised in relation to the potential impacts of the project on current and future air quality, the locations, numbers, design and visual impact of the outlets for the proposed tunnel ventilation system, and potential health impacts. The main issues were as follows:

- The need for air quality studies and monitoring to determine the impacts of the project before, during and after construction.
- The need for the air quality monitoring to address:
    - Ambient air quality near tunnel entry/exit points and ventilation outlets.
    - In-tunnel air quality.
- The need for the publication of air quality data.
- The location and operation of ventilation outlets, and the type of filtration system.
- The management of dust during construction.

The Community Feedback Report also dealt with the health impacts of air pollution. This topic is addressed in Chapter 11 of the EIS.

3.7 Summary of key air quality issues

To summarise the previous sections, the key air quality issues, either real or, just as importantly, perceived, in relation to the project are likely to be as follows:

- Understanding in-tunnel air quality, and the short-term exposure of tunnel users to elevated pollutant concentrations. This relates not only to the exposure of M4 East tunnel users, but also to the cumulative exposure of users of multiple Sydney tunnels.
- Understanding the ambient air quality impacts of tunnel ventilation outlets and changes to the surface road network. This includes potential improvement in air quality alongside existing surface roads which will have a decrease in traffic volume, such as Parramatta Road, as well as potential deterioration in air quality alongside new surface roads, or existing roads which will have an increase in traffic volume.
- Accurate modelling of air quality to inform tunnel ventilation design and management.
- Public understanding of air quality and the magnitude of any project impacts.
- The impacts of the construction of the project.

There was therefore a need for a detailed assessment of the potential impacts of the project on air quality (both adverse and beneficial), and this report presents this assessment. This report also informs the design of the tunnel ventilation system, including the location, design and operation of the outlets for polluted air.

4 Regulation of emissions, air pollution and exposure

4.1 Overview of Chapter

A number of legislative instruments and guidelines apply to air pollution from road transport and in road tunnels. This Chapter:

- Summarises key legislative instruments and guidelines in relation to the project, and covers:
    - National emission standards that apply to new vehicles.
    - Emission regulations, checks and policies that apply to in-service vehicles.
    - Fuel quality regulations.
    - In-tunnel limits on pollutant concentrations for tunnel ventilation design and operational control.
    - Ambient air quality standards and assessment criteria, which define levels of pollutants in the outside air that should not be exceeded during a specific time period to protect public health.
- Compares the regulations in Australia and NSW with those in force elsewhere.

The regulations, guidelines and criteria governing these in Australia and NSW are summarised in the following Sections. More detailed information, including an international context for some of the aspects, is provided in Appendix C.

4.2 Policies and regulations for road vehicle emissions

4.2.1 National emission standards for new vehicles

Under the *Motor Vehicle Standards Act 1989* (Commonwealth), new road vehicles must comply with certain safety and emissions requirements as set out in the Australian Design Rules (ADRs). The specific emission limits which apply to exhaust emissions light-duty and heavy-duty vehicles, and their timetable for adoption in the ADRs, are listed on the Australian Government web site[7], and further information is provided in Appendix C. Some examples, showing the reduction in the allowable emissions with time, are shown in Figure 4-1 and Figure 4-2.

The evaporation of fuel from petrol vehicles constitutes a large fraction of the total on-road mobile VOC emissions in the NSW Greater Metropolitan Region (GMR) (NSW EPA, 2012b). The limits for evaporative emissions in Australia are also given in Appendix C.

The non-exhaust processes that lead to PM emissions from road vehicles are not regulated. Denier van der Gon et al. (2013) concluded that there is an urgent need for a comprehensive research program to improve the understanding, with greater effort being devoted to properly quantifying non-exhaust emissions and assessing their health relevance. The EU Particle Measurement Programme (PMP) is currently evaluating the options for standardising the measurement of non-exhaust particles[8]. Whilst there is a view to develop standardised methodologies, there is currently no plan to regulate non-exhaust PM.

4.2.2 Checks on in-service vehicles

The *National Environment Protection (Diesel Vehicle Emissions) Measure 2001* establishes a range of strategies for state and territory governments to employ to manage emissions from diesel vehicles.

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[7] http://www.infrastructure.gov.au/roads/environment/emission/

[8] Informal Group for the Particle Measurement Programme, Session 35, Brussels, 4-5 Mar 2015; http://www.globalautoregs.com/meetings/709

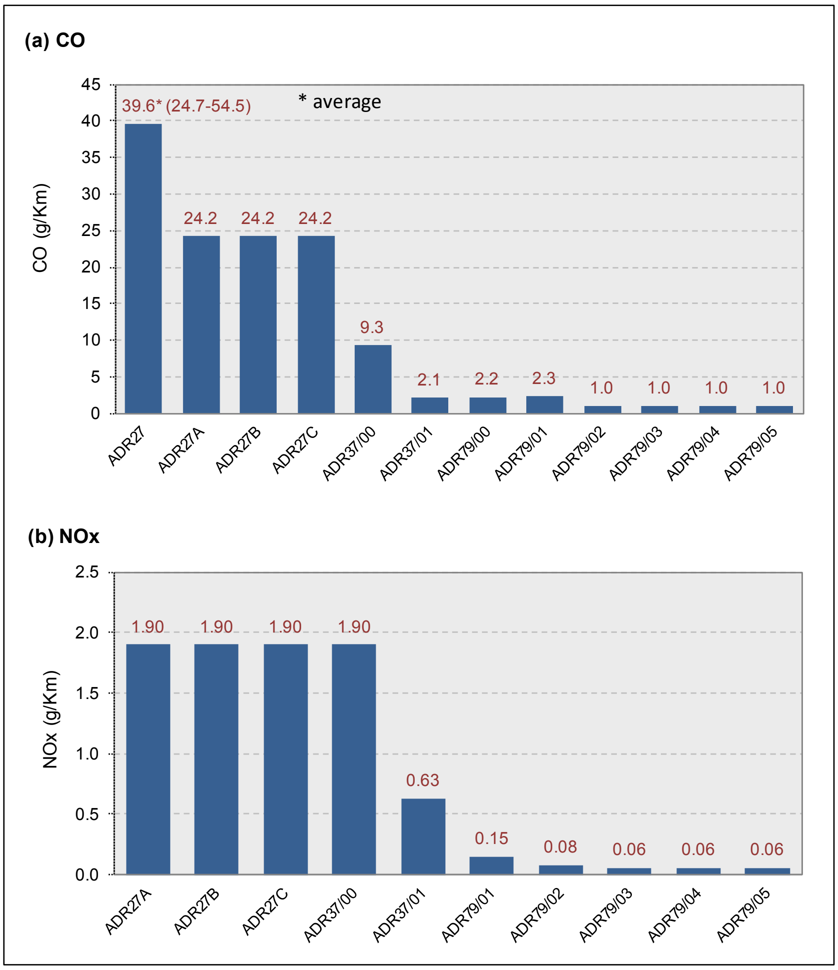

Figure 4-1 Exhaust emission limits for CO and NO_X applicable to new petrol cars in Australia

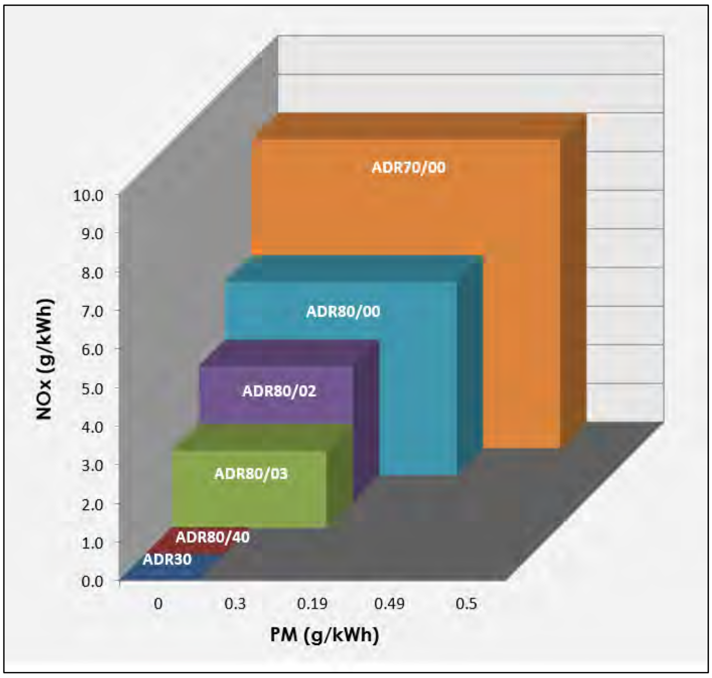

Figure 4-2 Exhaust emission limits for NO_X and PM applicable to heavy-duty vehicles in Australia

In NSW the owners of private vehicles that are more than five years old are required to obtain an 'e-Safety Check' prior to registration renewal, but the only requirements for in-service emissions testing in the NSW regulations[9] are for modified vehicles and LPG conversions.

The NSW Office of Environment and Heritage (OEH) has, in conjunction with the then NSW Roads and Transport Authority (RTA) (now Roads and Maritime), established a diesel vehicle retrofit program which involves retrofitting engines with pollution-reduction devices, primarily to reduce PM emissions. The program commenced in 2005 and, as of 2011, more than 70 vehicle fleets (covering 520 vehicles) had participated (DSEWPC, 2011).

Specific measures have also been introduced to improve air quality in the M5 East tunnel. An Air Quality Improvement Plan (AQIP) was launched in 2006 in response to community concern about the large numbers of smoky heavy vehicles using the tunnel. The AQIP included the installation of additional jet fans and a smoky vehicle camera/video system in the tunnel. A trial of air filtration technologies was also undertaken (see Chapter 10). A subsequent review of the AQIP led to the implementation of a stronger suite of measures in the 2012 Air Quality Improvement Program (AQIP). These measures included upgrading the smoky vehicle camera system, increasing fines for smoky vehicles detected in the M5 East tunnel and expanding the diesel retrofit program to reduce NO_2 and PM concentrations, both in the M5 East tunnel and across the broader Sydney road network.

4.3 Fuel quality regulations

The *Fuel Quality Standards Act 2000* (Commonwealth) provides a framework for the setting of national automotive fuel quality standards. The first national standards for petrol and diesel were introduced in the *Fuel Standard (Petrol) Determination 2001* and the *Fuel Standard (Automotive Diesel) Determination 2001*. These Standards prohibited the supply of leaded petrol and reduced the level of sulfur in diesel fuel. The regulation of fuel quality continued with the development of standards for LPG, biodiesel and ethanol.

More recent improvements in fuel quality have focused on reducing sulfur content further, as low-sulfur fuel is a prerequisite for modern exhaust after-treatment devices. Australia adopted a Euro 3-equivalent sulfur limit for petrol (150 ppm) in 2005, and a Euro 4-equivalent sulfur limit for diesel (50 ppm) in 2006, to support the introduction of the equivalent vehicle emission standards. From January 2008, a 50 ppm limit was applied to higher octane grades of unleaded petrol to support Euro 4 petrol vehicles. Since January 2009 the sulfur limit in diesel has been further reduced to 10 ppm, primarily to support the introduction of new emissions standards for heavy-duty vehicles; certain vehicle technologies that are employed to meet emission standards are sensitive to sulfur (DIT, 2010).

The Australian Government is currently in the process of reviewing the *Fuel Quality Standards Act 2000*.

4.4 In-tunnel pollution limits

4.4.1 Gaseous pollutants

An understanding of in-tunnel pollutant concentrations is required for three main reasons:

- To design and control ventilation systems. Tunnel builders and operators aim to minimise the significant costs involved in providing active ventilation. As a result, systems are designed, built and operated to provide sufficient ventilation to maintain acceptable air quality in the tunnel, but at reasonable cost (NHMRC, 2008).
- To manage in-tunnel exposure to air pollution.
- To manage external air pollution.

In many tunnels, pollution control is conducted according to guidelines from the World Road Association (PIARC, 2012), and the relevant criteria are presented in Appendix C. The fresh air

[9] The only relevant in-service emission test is the DT80 which is incorporated into the National Vehicle Standards as Rule 147A. However, NSW has not adopted Rule 147A.

requirements for tunnel ventilation design and control purposes in Australia have traditionally been based upon the in-tunnel CO concentration, given that:

- CO emissions have historically been dominated by road transport.
- CO is the only traffic-related pollutant with a short-term (15 minute) WHO health-based guideline.
- CO is relatively resistant to physical or chemical change during the timescales of its atmospheric residence in a road tunnel (NHMRC, 2008).

In the past, most of the CO was emitted by petrol-fuelled vehicles. However, following the introduction and refinement of engine management and exhaust after-treatment systems, CO emissions from such vehicles are now rather low. This has given rise to significant reductions in overall emissions and ambient concentrations. The increased market penetration of diesel vehicles in passenger car fleets (more so in Europe than in Australia) has meant that some countries are now considering the use of NO_2 concentrations for tunnel ventilation design, although this is mainly to ensure compliance with ambient air quality standards outside the tunnel. This shift is further supported by evidence of the increase in primary NO_2 emissions from road vehicles (Carslaw and Beevers, 2004; Carslaw, 2005). However, NHMRC (2008) found very little evidence in the literature of the success or otherwise of implementation of in-tunnel NO_2 limits, other than to note that management of NO_2 is very dependent upon problematic monitoring technology or reliable modelling of in-tunnel NO_2.

4.4.2 Visibility and PM

Another important consideration for tunnel ventilation design is visibility. Consideration of visibility criteria in the design of the tunnel ventilation system is required due to the need for visibility levels that exceed the minimum vehicle stopping distance at the design speed (PIARC, 2012). Visibility is reduced by the scattering and absorption of light by PM suspended in the air. The principle for measuring visibility in a tunnel (using opacity meters) is based on the fact that a light beam decays in intensity as it passes through air. The level of decay can be used to determine the opacity of air. For tunnel ventilation it has become customary to express visibility by the extinction coefficient K.

The amount of light scattering or absorption is dependent upon the particle composition (dark particles, such as soot, are particularly effective), diameter (particles need to be larger than around 0.4 μm), and density. Particles causing a loss of visibility also have an effect on human health, and so monitoring visibility also provides the potential for an alternative assessment of the air quality and health risk within a tunnel. However, such an assessment is limited by the short duration of exposure in tunnels compared with the longer exposure times (24 hours and one year) for which the health effects of ambient particles have been established. Moreover, there is no safe minimum threshold for particles, and so visibility cannot reliably be used as a criterion for health risk (NHMRC, 2008). It is worth adding that the nature of PM emitted by road vehicles is changing with time. Diesel exhaust particles have normally been taken as the reference for visibility. Non-exhaust PM is becoming more important in terms of the mass emitted, but wear particles and resuspended particles have different characteristics to exhaust particles. The evidence suggests that non-exhaust particles are generally larger than exhaust particles, and may have less of an impact on visibility.

4.4.3 Other considerations

In addition to controlling pollution, tunnel ventilation systems must also be capable of responding to emergency incidents involving vehicle fires and smoke release. Demands on smoke control or dilution of chemical releases may mean that the ventilation system has to move larger volumes of air than those required for the dilution of exhaust gases, and this aspect of design must also be considered. The design requirements for smoke control are defined by PIARC (1999, 2007, 2011).

4.4.4 Limit values

The operational in-tunnel limits for CO and NO_2 in several Australian road tunnels are shown in Table 4-1. The maximum allowable concentrations of air pollutants in Sydney tunnels are set by DP&E. In-tunnel air quality is managed using CO as a proxy for all traffic pollutants. The limits are those recommended by the WHO and the National Environmental Protection Council (SMPO, 2013). The 15-minute and 30-minute average CO in-tunnel limits are 87 ppm and 50 ppm respectively. Any exceedances of 200 ppm CO as a three-minute average at any monitor also need to be reported (NHMRC, 2008).

In Sydney, planning approval has recently been granted to the NorthConnex project. It is likely that similar conditions of approval for in-tunnel air quality that were issued for NorthConnex would be issued for the project.

The NorthConnex tunnel ventilation system must be designed and operated so that the average concentrations of CO and NO_2, calculated along the length of the tunnel, do not exceed the concentration limits specified in Table 4-2. A CO limit is also specified for any single point in the tunnel under all conditions (including congested traffic).

A comparison between the limits used in Australian tunnels and those used in tunnels in other countries is provided in Appendix C.

The NorthConnex ventilation system must be designed and operated so that the visibility in the tunnel does not exceed the level specified in Table 4-3.

Table 4-1 Operational limits for CO, NO_2 and visibility in Sydney road tunnels

Tunnel	CO concentration (ppm, rolling average)			NO_2 conc. (ppm)	Visibility (extinction coefficient, m^{-1})
	3-min	15-min	30-min	15-min	
Cross City Tunnel	200	87	50	N/A	0.005-0.012
Lane Cove Tunnel	-	87	50	N/A	0.005-0.012
M5 East Tunnel	200	87	50	N/A	0.005-0.012

Sources: NHMRC (2008), Roads and Maritime (2014), Longley (2014), PIARC (visibility)

Table 4-2 Operational limits for CO and NO_2 in the NorthConnex tunnel

Parameter	Averaging period	Concentration limit (ppm)
In-tunnel average limit along tunnel length		
CO	Rolling 15-minute	87
	Rolling 30-minute	50
NO_2	Rolling 15-minute	0.5
In-tunnel single point exposure limit		
CO	Rolling 3-minute	200

Table 4-3 Operational limit for visibility in the NorthConnex tunnel

Parameter	Averaging period	Average extinction coefficient limit (m^{-1})
In-tunnel average limit along tunnel length		
Visibility	Rolling 15-minute	0.005

4.4.5 Tunnel ventilation outlets

For tunnels in Sydney limits are also imposed on the discharges from the ventilation outlets. In the case of the NorthConnex project the specified limits are shown in Table 4-4.

Table 4-4 Concentration limits for NorthConnex ventilation outlets

Pollutant	Maximum value (mg/m^3)	Averaging period	Reference conditions
Solid particles	1.1	1 hour, or the minimum sampling period specified in the relevant test method, whichever is the greater	Dry, 273 K, 101.3 kPa
NO_2 or NO or both, as NO_2 equivalent)	20	1 hour	Dry, 273 K, 101.3 kPa
NO_2	2.0	1 hour	Dry, 273 K, 101.3 kPa
CO	40	Rolling 1 hour	Dry, 273 K, 101.3 kPa
VOC (as propane)	1.0	Rolling 1 hour	Dry, 273 K, 101.3 kPa

4.5 Tunnel portal emission restrictions

A key operating restriction for tunnels in NSW is the requirement for there to be no emissions of air pollutants from the portals[10]. This requirement is included in the Minister's Conditions of Approval for the M5 East Tunnel, the Cross City Tunnel and the Lane Cove Tunnel. The requirement was initially applied to the M5 East Tunnel as a precautionary measure to protect residents around the tunnel portals, and was retained for the Cross City Tunnel and Lane Cove Tunnel. To avoid portal emissions all the polluted air from a tunnel must be expelled from one or more elevated ventilation outlets along its length. There are some circumstances when portal emissions may be permitted, such as emergency situations, accidents and breakdowns, and during major maintenance periods.

4.6 Ambient air quality standards and criteria

Compliance with ambient air quality standards is a major consideration during road project design and operation. An ambient air quality standard defines a metric relating to the concentration of an air pollutant in the ambient air. Standards are usually designed to protect human health, including sensitive populations such as children, the elderly, and individuals suffering from respiratory disease, but may relate to other adverse effects such as damage to buildings and vegetation. The form of an air quality standard is typically a concentration limit for a given averaging period (e.g. annual mean, 24-hour mean), which may be stated as a 'not-to-be-exceeded' value or with some exceedances permitted. Several different averaging periods may be used for the same pollutant to address long-term and short-term exposure. Each metric is often combined with a goal, such as a requirement for the limit to be achieved by a certain date.

Air pollutants are often divided into 'criteria' pollutants and 'air toxics'. Criteria pollutants tend to be ubiquitous and emitted in relatively large quantities, and their health effects have been studied in some detail. Air toxics are gaseous or particulate organic pollutants that are present in the air in low concentrations, but are defined on the basis that they are, for example, highly toxic, carcinogenic or highly persistent in the environment, so as to be a hazard to humans, plants or animal life.

The health effects of criteria pollutants and some specific air toxics are summarised in Appendix A, and further information on standards and impact assessment criteria is provided below. The actual impact assessment criteria that were applicable to the project are summarised in section 5.5.2.

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[10] This approach is not unique to NSW. For example, each of Brisbane's road tunnels (North South Bypass Tunnel, Airport Link and Northern Link) has been designed to operate and avoid portal emissions (SMPO, 2013).

4.6.1 Criteria pollutants

Ambient Air Quality NEPM

In 1998 Australia adopted a *National Environment Protection (Ambient Air Quality) Measure* (AAQ NEPM)[11], with the goal of ensuring compliance with air quality standards within 10 years of commencement, in order to attain 'ambient air quality that allows for the adequate protection of human health and wellbeing'. The AAQ NEPM established national standards for six criteria pollutants:

- Carbon monoxide (CO)
- Nitrogen dioxide (NO_2)
- Sulfur dioxide (SO_2)
- Lead (Pb)
- Photochemical oxidants as ozone (O_3)
- Particulate matter with an aerodynamic diameter of less than 10 µm (PM_{10}).

The numerical values of the NEPM standards have been incorporated into the NSW Approved Methods, and these are presented later in this section of the report.

The AAQ NEPM was extended[12] in 2003 to include advisory reporting standards for PM with an aerodynamic diameter of less than 2.5 µm ($PM_{2.5}$), and these are shown in Table 4-5.

Table 4-5 Advisory reporting standards for $PM_{2.5}$ in AAQ NEPM

Pollutant or metric	Criterion		Averaging method	Source
	Concentration	Averaging period		
Particulate matter <2.5 µm ($PM_{2.5}$)	25 µg/m^3	24 hours	Calendar day	AAQ NEPM 2003
	8 µg/m^3	1 year	Calendar year	AAQ NEPM 2003

A number of further steps towards improving the regulation of air pollution in Australia have recently been taken. In particular, the National Environment Protection Council published a review of the AAQ NEPM which recommended updating the standards for PM_{10}, $PM_{2.5}$, NO_2, O_3, and SO_2 (NEPC, 2011a), and a methodology for the setting of air quality standards (NEPC, 2011c). The Council of Australian Governments identified air quality as an issue of national priority (COAG, 2012), and agreed to implement a strategic approach to air quality management in the form of a National Plan for Clean Air (NPCA)[13]. The Australian Environment Ministers subsequently agreed to develop a National Clean Air Agreement[14] that will focus on actions to reduce air pollution and improve air quality through cooperative action between industry and government. The Agreement will build on previous initiatives to tackle air pollution in Australia. A meeting of the Australian Environment Ministers was held in Melbourne on 15 July 2015, with one of the topics of discussion being a variation of the AAQ NEPM.

In 2014 NEPC released an Impact Statement and draft variation to the AAQ NEPM in relation to the standards for airborne particles. The Impact Statement evaluated the environmental, social and economic costs and benefits of meeting a range of different standards for airborne particles.

NSW EPA, which has managed the NEPM variation, has subsequently requested NSW Cabinet approval for the following changes to the PM standards:

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[11] National Environment Protection (Ambient Air Quality) Measure (1998). http://www.comlaw.gov.au/Details/C2004H03935/Download

[12] National Environment Protection (Ambient Air Quality) Measure variation (2003), Gazette 2003, no. S190.

[13] On 13 December 2013, COAG revoked the Standing Council on Environment and Water (SCEW), which had been charged with developing the NPCA. Work is currently underway to resolve how SCEW's existing work will be handled in the future.

[14] http://www.environment.gov.au/protection/air-quality/national-clean-air-agreement

- The introduction of an annual mean PM_{10} standard of 25 µg/m^3. There is currently no annual mean standard in the NEPM. However, for the assessment of projects and developments in NSW this could replace the current criterion in the Approved Methods of 30 µg/m^3
- The conversion of the advisory reporting standards for $PM_{2.5}$ in Table 4-5 to formal standards
- The introduction of the following long-term (10 year) targets:
  - An annual average PM_{10} target of 20µg/m^3
  - An annual average $PM_{2.5}$ target of 7µg/m^3
  - A 24 hour $PM_{2.5}$ target of 20µg/m^3.

Following the meeting of the Australian Environment Ministers, a statement was issued[15] in which the Ministers signalled their support for varying the AAQ NEPM to implement these strengthened reporting standards for PM. Ministers agreed in-principle to formalise the $PM_{2.5}$ standards of 8 µg/m^3 (annual) and 25 µg/m^3 (24-hour), with a move to 7 µg/m^3 and 20 µg/m^3 respectively over the longer term. The Ministers also agreed to finalise their consideration of the annual and 24-hour standards for PM_{10} by the end of 2015.

It should be noted that the NEPM is a national monitoring and reporting protocol. The NEPM standards are applicable to urban background monitoring sites which are broadly representative of population exposure. The use of any NEPM air quality criteria in relation to the assessment of projects and developments is outside the scope of the NEPM itself, and is decided by the jurisdictions. The criteria for air quality assessments for projects/developments in NSW are contained in the Approved Methods (see below). However, should the Approved Methods be revised it is possible that they will take into account the new NEPM standards, but they may not necessarily take exactly the same form. Nevertheless, the project will be designed so that any increases in $PM_{2.5}$ concentrations due to emissions from the ventilation outlets are minimal.

NSW Approved Methods

The Australian States and Territories manage emissions and air quality in relation to certain types of source (*e.g.* landfills, quarries, crematoria, and coal mines). The jurisdictions have legislation or guidance which includes design goals, licence conditions or other instruments for protecting local communities from ground-level impacts of pollutants in residential areas outside site boundaries. Where this is the case, the AAQ NEPM standards are often used for air quality assessments.

In NSW, the *Approved Methods for the Modelling and Assessment of Air Pollutants in NSW* (NSW DEC, 2005) (NSW Approved Methods) sets out the statutory methods to be used for assessing air pollution from stationary sources. The NSW Approved Methods are designed mainly for the assessment of industrial point sources, and do not contain specific information on the assessment of, for example, transport schemes and land use changes. Air quality must be assessed in relation to standards[16] and averaging periods for specific pollutants that are taken from several sources, notably the AAQ NEPM.

The metrics, criteria and goals set out for criteria pollutants in the NSW Approved Methods are listed in Table 4-6. The $PM_{2.5}$ advisory standards (Table 4-5) are designed for the evaluation of overall population exposure rather than the impacts of a specific facility, and there is no requirement to evaluate $PM_{2.5}$ in the NSW Approved Methods. However, they are often considered to be applicable in this respect.

[15] http://www.environment.gov.au/about-us/mem

[16] In this Assessment Report the term ‘standard’ is used to refer to the numerical value of the concentration for a given pollutant in legislation. The NSW Approved Methods refer to ‘impact assessment criteria’, and this terminology is also used in the Report.

Table 4-6 Impact assessment criteria for 'criteria pollutants' in NSW Approved Methods (NSW DEC, 2005)

Pollutant or metric	Criterion: Concentration	Criterion: Averaging period	Calculation	Source
Carbon monoxide (CO)	87 ppm or 100 mg/m^3	15 minutes		WHO (2000)
	25 ppm or 30 mg/m^3	1 hour	One hour clock mean	WHO (2000)
	9 ppm or 10 mg/m^3	8 hours	Rolling mean of one-hour clock means	AAQ NEPM 1998
Nitrogen dioxide (NO_2)	120 ppb or 246 μg/m^3	1 hour	One hour clock mean	AAQ NEPM 1998
	30 ppb or 62 μg/m^3	1 year	Calendar year mean	AAQ NEPM 1998
Particulate matter <10 μm (PM_{10})	50 μg/m^3	24 hours[a]	Calendar day mean	AAQ NEPM 1998
	30 μg/m^3	1 year	Calendar year mean	NSW EPA (1998)[b]
Sulfur dioxide (SO_2)	250 ppb or 712 μg/m^3	10 minutes		NHMRC (1996)
	200 ppb or 570 μg/m^3	1 hour	One hour clock mean	AAQ NEPM 1998
	80 ppb or 228 μg/m^3	1 day	Calendar day mean	AAQ NEPM 1998
	20 ppb or 60 μg/m^3	1 year	Calendar year mean	AAQ NEPM 1998
Lead (Pb)	0.5 μg/m^3	1 year	Calendar year mean	AAQ NEPM 1998
Total suspended particulate matter (TSP)	90 μg/m^3	1 year	Calendar year mean	NHMRC (1996)
Photochemical oxidants (as ozone (O_3))	100 ppb or 214 μg/m^3	1 hour	One hour clock mean	AAQ NEPM 1998
	80 ppb or 171 μg/m^3	4 hours	Rolling mean of one-hour clock means	AAQ NEPM 1998
Hydrogen fluoride (HF)[c]	0.50/0.25 μg/m^3	90 days		ANZECC (1990)
	0.84/0.40 μg/m^3	30 days		ANZECC (1990)
	1.70/0.40 μg/m^3	7 days		ANZECC (1990)
	2.90/1.50 μg/m^3	24 hours		ANZECC (1990)

(a) Up to 5 exceedances per year are allowed in the AAQ NEPM, but not in the Approved Methods.

(b) The AAQ NEPM does not specify an annual mean standard for PM_{10}.

(c) The first value is for general land use, which includes all areas other than specialised land use. The second value is for specialised land use, which includes all areas with vegetation that is sensitive to fluoride, such as grape vines and stone fruits.

4.6.2 Air toxics

Air toxics NEPM

In recognition of the potential health problems arising from the exposure to air toxics, the *National Environment Protection (Air Toxics) Measure* (Air Toxics NEPM) identifies 'investigation levels' for five priority pollutants: benzene, formaldehyde, toluene, xylenes and benzo(a)pyrene (as a marker for polycyclic aromatic hydrocarbons). These are not compliance standards but are for use in assessing the significance of the monitored levels of air toxics with respect to protection of human health.

Table 4-7 Investigation levels for air toxics

Source	Substance	Concentration	Averaging period
Air toxics NEPM (investigation levels)	Benzene	0.003 ppm	1 year[(a)]
	Toluene	1.0 ppm 0.1 ppm	24 hours 1 year[(a)]
	Xylenes	0.25 ppm 0.20 ppm	24 hours 1 year[(d)]
	PAHs[(b)] (as b(a)p)[(c)]	0.3 ng/m^3 [(d)]	1 year[(a)]
	Formaldehyde	0.04 ppm	24 hours

(a) Arithmetic mean of concentrations of 24-hour monitoring results
(b) PAH – polycyclic aromatic hydrocarbons
(c) b(a)p – benzo(a)pyrene, the most widely studied PAH and used as an indicator compound
(d) ng/m^3 – nanograms per cubic metre

NSW Approved Methods

The NSW Approved Methods specify air quality impact assessment criteria and odour assessment criteria for many other substances (mostly hydrocarbons), including air toxics, and these are too numerous to reproduce here. The SEARs for the project require an evaluation of BTEX compounds: benzene, toluene, ethylbenzene, and xylenes. The impact assessment criteria in the NSW Approved Methods for priority air toxics and BTEX compounds are given in Table 4-8.

Table 4-8 Impact assessment criteria for air toxics

Source	Substance	Concentration	Averaging period
NSW Approved Methods (impact assessment criteria)	Benzene	0.009 ppm or 0.029 mg/m^3	1 hour
	Toluene[(a)]	0.09 ppm or 0.36 mg/m^3	1 hour
	Ethylbenzene	1.8 ppm or 8 mg/m^3	1 hour
	Xylenes[(a)]	0.04 ppm or 0.19 mg/m^3	1 hour
	PAHs (as b(a)p)	0.0004 mg/m^3	1 hour
	1,3-butadiene	0.018 ppm or 0.04 mg/m^3	1 hour
	Acetaldehyde[(a)]	0.023 ppm or 0.042 mg/m^3	1 hour
	Formaldehyde	0.018 ppm or 0.02 mg/m^3	1 hour

(a) Odour criterion

5 Overview of assessment methodology

5.1 Overview

This Chapter:

- Identifies the key guidelines and policies that are relevant to the air quality assessment for the project
- Reviews recent air quality assessments for major road projects in Australia and New Zealand in order to inform the methodology and to ensure that the assessment was conducted in line with Australian and international best practice
- Describes the general approaches that were used to assess the impacts of the project on air quality, including:
  - Construction
  - Operation – emissions
  - Operation – in-tunnel air quality
  - Operation – ambient air quality
- Defines the scenarios that were assessed
- Explains why certain pollutants and metrics were included in the air quality assessment, and why others were excluded
- Explains the terminology used in the air quality assessment
- Discusses the accuracy and conservatism of the assessment process.

5.2 Key documents, guidelines and policies

The following documents, guidelines and policies were relevant to the air quality assessment:

- The NSW Air Emissions Inventory. This quantifies emissions from all sources of air pollution - domestic, commercial, industrial, off-road mobile and on-road mobile
- The National Environment Protection Measure for Ambient Air Quality (AAQ NEPM). This sets the national health-based air quality standards for six air pollutants
- Approved Methods for the Modelling and Assessment of Air Pollutants in NSW (NSW DEC, 2005)
- Air Quality in and Around Traffic Tunnels by NHMRC (2008)
- Guidance for the Management of Air Quality in Road Tunnels in New Zealand (Longley et al., 2010)
- Guidance from the World Road Association (PIARC), and in particular:
  - Road tunnels: a guide to optimising the air quality impact upon the environment (PIARC, 2008)
  - Road tunnels: vehicle emissions and air demand for ventilation (PIARC, 2012)
- Dispersion modelling guidance, such as the New Zealand Ministry for the Environment's Good Practice Guide for Atmospheric Dispersion Modelling (NZMfE, 2004)
- Guidance on the assessment of dust from demolition and construction (IAQM 2014). This provides guidance on how to assess the sensitivity of receptors and the risk of impact on those receptors due to the various components of the project construction.

5.3 Consultation with government agencies and ACTAQ

The following government agencies and bodies were consulted during the development and production of the methodology and the Air Quality Assessment Report:

- NSW EPA
- NSW Health
- Roads and Maritime
- The Advisory Committee on Tunnel Air Quality.

5.4 Previous road and tunnel project assessments

A number of recent air quality assessments for surface roads and tunnels in Australia and New Zealand were reviewed in order to identify where the methodologies, tools and findings could inform the M4 East assessment. These previous assessments are summarised in Appendix D. The summary includes details of the pollutants considered, the sources of emission factors, the dispersion models used, and the approaches used to assess construction impacts.

The findings can be summarised as follows:

- Assessments have focussed on the following pollutants and metrics: CO (rolling eight-hour), NO_2 (one-hour and annual mean) and PM_{10} (24-hour and annual mean). Some studies also included $PM_{2.5}$ (24-hour and annual mean), VOCs, and specific air toxics such as benzene and PAHs.
- The averaging periods for pollutants are typically based on criteria from the USEPA and the AAQ NEPM, as well as NSW EPA.
- Studies have generally used a ‘do nothing’ scenario as a baseline and have compared the impacts of the proposed project in a specified future year. In some cases, multiple scenarios for the project have been considered (e.g. 10 and 20 years after the project completion). Some studies have modelled different tunnel ventilation options (e.g. one outlet, two outlets, and different locations).
- For baseline scenarios background air quality data have typically been collected from monitoring stations in urban areas. However, in less developed areas, such as northern NSW, project-specific monitoring has been required.
- Several studies have used the international emission factors from PIARC, and weighted these according to the local fleet, rather than using emission factors that are specific to Australian/NZ. Local vehicle emission rates have also been used in some cases (e.g. NSW GMR emissions inventory).
- Studies have generally assumed no future improvements in vehicle technology or fuel, and have modelled emissions based on fleet-average emission factors.
- Traffic data have either been taken from models such as the strategic Sydney traffic model, or based on surveys by local authorities or government agencies (e.g. Roads and Maritime in NSW).
- Air quality impacts have typically been predicted using meteorological processors such as TAPM or CALMET, in combination with dispersion models such as CALPUFF for ventilation outlets and CALINE-based models for surface roads. CALINE is considered to be more accurate than CALPUFF for simulating turbulence close to roads. Others models have also been used, including TRAQ, GRAL and AUSPLUME.
- The number of sensitive receptors assessed has been dependent on the scale of the project. For instance, the NorthConnex project assessed around 7,000 discrete receptors, whereas road upgrades such as the Ballina bypass and Pacific Highway upgrade at Banora Point assessed only tens of receptors.
- The impacts of project construction have generally been assessed qualitatively, and in some cases estimated semi-qualitatively using emissions factors.

5.5 General approach

5.5.1 Construction assessment

The main air pollution and amenity issues at construction sites are:

- Annoyance due to dust deposition (soiling of surfaces) and visible dust plumes
- Elevated PM_{10} concentrations due to dust-generating activities
- Exhaust emissions from diesel-powered construction equipment.

There are other potential impacts from exhaust emissions, such as the release of heavy metals, asbestos fibres or other pollutants during the demolition of certain buildings such as former chemical works, or the removal of contaminated soils. The release of certain fungal spores during the demolition of old buildings can give rise to specific concerns if immune-compromised people are likely to be exposed, for example close to an oncology unit of a hospital. These issues need to be considered on a site by site basis (IAQM, 2014).

Exhaust emissions from on-site plant and site traffic are unlikely to have a significant impact on local air quality, and in the majority of cases they will not need to be quantitatively assessed. Very high levels of soiling can also damage plants and affect the health and diversity of ecosystems.

Dust emissions can occur during the preparation of the land (e.g. demolition and earth moving) and during construction itself, and can vary substantially from day to day depending on the level of activity, the specific operations being undertaken, and the weather conditions. A significant portion of the emissions results from site plant and road vehicles moving over temporary roads and open ground. If mud is allowed to get onto local public roads, dust emissions can occur at some distance from the construction site (IAQM, 2014).

The risk of dust impacts from a demolition/construction site causing loss of amenity and/or health or ecological impacts is related to the following (IAQM, 2014):

- The nature of the activities being undertaken.
- The duration of the activities.
- The size of the site.
- The meteorological conditions (wind speed, direction and rainfall). Adverse impacts are more likely to occur downwind of the site and during drier periods.
- The proximity of receptors to the activities.
- The sensitivity of the receptors to dust.
- The adequacy of the mitigation measures applied to reduce or eliminate dust.

It is very difficult to quantify dust emissions from construction activities. Due to the variability of the weather it is impossible to predict what the weather conditions would be when specific construction activities are undertaken. Any effects of construction on airborne particle concentrations would also generally be temporary and relatively short-lived. Moreover, mitigation should be straightforward, as most of the necessary measures are routinely employed as ‘good practice’ on construction sites. It is therefore usual to provide a qualitative assessment of potential construction dust impacts.

A semi-quantitative approach has been used here, and the impacts of construction have not been specifically modelled. The approach followed the guidance published by the United Kingdom (UK) Institute of Air Quality Management (IAQM, 2014), the aim of which is to identify risks and to recommend appropriate mitigation measures.

The assessment of construction impacts using the IAQM procedure is presented in Chapter 7.

5.5.2 Operational assessment – in-tunnel air quality

Scenarios

The scenarios evaluated for in-tunnel air quality reflected the potential modes of operation of the tunnel ventilation system. These scenarios were:

- Expected traffic. The expected traffic scenarios included in the in-tunnel air quality assessment are summarised in Table 5-2.

Table 5-1 Expected traffic scenarios for the in-tunnel air quality assessment

Scenario code	Scenario description
2021-DS	2021 - Do Something (with M4 East)
2031-DS	2031 - Do Something (with M4 East)
2031-DSC	2031 - Do Something Cumulative (with M4 East and M4-M5 Link projects)

  The objective of these scenarios was to demonstrate that the expected operation of the project would result in acceptable in-tunnel air quality. The scenarios reflected the optimum or best operating conditions, where traffic volumes were high and traffic was flowing freely (a speed of 80 kilometres per hour was assumed). These traffic conditions were not considered to be the worst case or maximum pollution generation cases. The results from the modelling of these scenarios were also used in the health risk assessment for the project.

- Capacity (maximum) traffic flow scenarios. These were included to reflect conditions that can generate high in-tunnel pollution levels. Several different speeds were considered, including congestion.
- Vehicle breakdown scenario. This included incidents such as vehicle breakdowns or accidents and heavy congestion. It was assessed on the basis that it would represent a worst case in terms of pollution generation, especially over the shorter term, and all in-tunnel and ambient air quality limits must be met.

Major incident conditions, including major accident and fire scenarios, were not assessed in terms of air quality. These conditions require significant traffic control measures to be put in place, including tunnel closure. The ventilation system will be operated to provide a safe environment for tunnel occupants (e.g. smoke may be ventilated from the tunnel portals in the case of a fire).

In-tunnel air quality criteria

The ventilation system of the M4 East tunnel has been designed to achieve specified in-tunnel air quality outcomes for traffic volumes up to and including the maximum traffic throughput capacity of the project's main alignment tunnels. These criteria are equivalent to those applied to the NorthConnex project (see section 4.4.4).

Assessment method

The method for assessing in-tunnel air quality is provided in Appendix L.

5.5.3 Operational assessment – ambient air quality

The operational ambient air quality assessment was based upon the use of the GRAL model system. The model system consists of two main modules: a prognostic wind field model (Graz Mesoscale Model - GRAMM) and a dispersion model (GRAL itself). This Section summarises the main elements of the approach, and full details of the methodology are presented in Chapter 8.

Definition of modelling domains

The modelling domains for the project are shown in Figure 5-1. The following terms are used in this report to describe the different geographical areas of the assessment:

- The GRAMM domain (also referred to as the 'study area'), as shown by the red boundary in Figure 5-1. This was used for the modelling of meteorology, and was the largest area included in the assessment. The GRAMM domain covered a substantial part of Sydney, extending 25 kilometres in the east-west (x) direction and 20 kilometres in the north-south (y) direction.
- The WestConnex GRAL domain for dispersion modelling, as shown by the black boundary in Figure 5-1. This extended 15 kilometres in the x direction and 14 kilometres in the y direction. Every dispersion model run was undertaken for the WestConnex GRAL domain, which included all WestConnex projects (a section of the M4 Widening, M4 East, King Georges Road Interchange Upgrade, New M5 and M4-M5 Link). This large size for the WestConnex GRAL domain was defined for a number of reasons:
    - o It facilitated a 'whole of project' modelling approach, whereby the specific information for each WestConnex project could be extracted and presented in more detail for the separate EISs (in this case, for the M4 East project). This improved both the efficiency and consistency of the air quality assessments for the various WestConnex projects.
    - o It provided the cumulative impacts of all projects as a matter of course (such as M4 East and M4-M5 Link combined ventilation outlet).
    - o It maximised the flexibility of the assessment process, and accommodated any future changes in the requirements.
    - o It maximised the number of meteorological and air quality monitoring stations that could be included for model evaluation purposes.
- The M4 East GRAL domain, shown by the blue boundary in the Figure 5-1. This extended 8.5 kilometres in the x direction and 6.2 kilometres in the y direction. This was the extent of the domain used in the GRAL dispersion model for the M4 East project. No separate modelling was undertaken for this domain, rather the model results for this area were extracted from the runs for the WestConnex GRAL domain for presentation in this report.

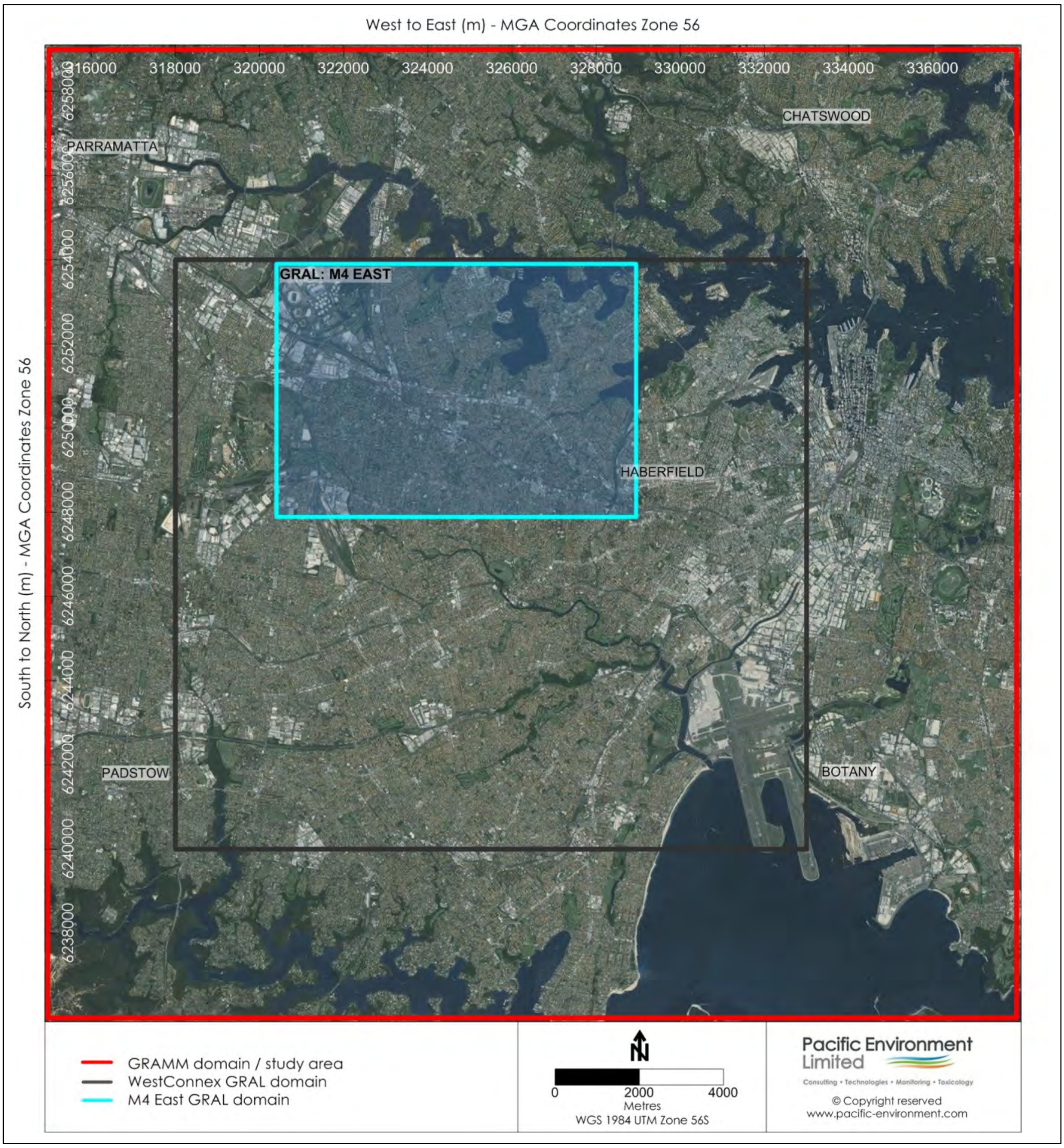

Figure 5-1 Modelling domains for GRAMM and GRAL

Modelling scenarios

Overview

Two types of scenario were considered for ambient air quality:

- Expected traffic scenarios (as outlined in Table 5-2 below))
- Regulatory worst case scenarios (as outlined below in this section).

In each case the following were determined:

- The total pollutant concentration from all contributions (background, surface roads and ventilation outlets)

- The change in the total pollutant concentration. Given the non-threshold nature of some air pollutants (notably PM), it was considered important to assess not only the absolute concentrations relative to the criteria, but also the incremental changes in concentration associated with the project
- The pollutant contribution from ventilation outlets alone.

The results have been presented as:

- Pollutant concentrations at discrete receptors (in charts and tables)
- Pollutant concentrations across the modelling domain (as contour plots).

Expected traffic scenarios

The expected traffic scenarios included in the operational ambient air quality assessment are summarised in Table 5-2. The scenarios took into account future changes over time in the composition and performance of the vehicle fleet, as well as predicted traffic volumes and the distribution of traffic on the network. The objective of these scenarios was to demonstrate that the expected operation of the project would result in acceptable ambient air quality, and they are the main focus of this Air Quality Assessment Report. The results from the modelling of these scenarios were also used in the health risk assessment for the project.

Table 5-2 Expected traffic scenarios for the operational assessment

Scenario code	Scenario description	WestConnex projects included
2014-BY	2014 - Base Year (existing conditions)	No WestConnex projects
2021-DM	2021 - Do Minimum (no M4 East)	KGRIU[(a)] and M4 Widening
2021-DS	2021 - Do Something (with M4 East)	KGRIU, M4 Widening and M4 East
2031-DM	2031 - Do Minimum (no M4 East)	KGRIU and M4 Widening
2031-DS	2031 - Do Something (with M4 East)	KGRIU, M4 Widening and M4 East
2031-DSC	2031 - Do Something Cumulative (with M4 East and M4-M5 Link projects)	KGRIU, M4 Widening, M4 East and other WestConnex stages including New M5, M4-M5 Link, Sydney Gateway and Southern Extension

(a) King Georges Road Interchange Upgrade

These scenarios reflected expected traffic conditions in the corresponding years in terms of volume, composition and speed, as represented in the WestConnex Road Traffic Model (WRTM).

In considering future year land use projections and infrastructure provisions, a suite of scenarios was individually and collectively modelled to understand the level of traffic demand and associated travel patterns. The traffic demand scenarios for the project were represented by the following overarching model years:

- 2012 was adopted as the existing case to match the year of WRTM calibration. This represented the current road network with no new projects or upgrades. For the purpose of the air quality assessment a 2014 base year was used (see below)
- 2021 was adopted as the primary forecasting year for the project
- 2031 was adopted as the case for 10 years after the primary year, and was considered to allow for full ramp-up of traffic demand as travellers respond to the provision of the fully completed WestConnex and the associated tolls.

The main scenarios are expanded upon below.

- 2014 Base Year. This was used to establish existing conditions. The main purpose of including a base year was to enable the dispersion modelling methodology to be verified against real-world air pollution monitoring data. The base year also provided a current baseline which helped to define underlying trends in projected emissions and air quality, and gave a sense of scale to the project impacts (i.e. compared with how emissions and air quality would be predicted to change anyway without the project)
- 2021 Do Minimum. The primary 'do minimum' case assumes that the King Georges Road Interchange Upgrade and the M4 Widening are complete, but the remainder of the WestConnex projects are not built. It is called 'do minimum' rather than 'do nothing' as it assumes that infrastructure schemes currently incomplete but scheduled for opening prior to the assessment year are operational
- 2021 Do Something. As per the primary 'do minimum' with the project complete and open to traffic, but without any other subsequent WestConnex projects
- 2031 Do Minimum. A future network including the WestConnex King Georges Road Interchange Upgrade and M4 Widening and some upgrades to the broader transport network over time to improve capacity and cater for traffic growth but does not include the other subsequent WestConnex projects
- 2031 Do Something. All WestConnex projects complete and also includes the Sydney Gateway and the Southern Extension
- 2031 Do Something Cumulative. An additional 'do something' scenario with the M4 East, New M5 and M4-M5 Link projects in place. This excluded contributions from the New M5 ventilation outlets (including the shared outlet with the M4-M5 Link) given geographical distance. In other words, it was assumed that there would be no 'overlap' in the areas affected by the emissions from the M4 East and New M5 ventilation outlets (approximately six to eight kilometres away).

Regulatory worst case (RWC) scenarios

The objective of these scenarios was to demonstrate that compliance with the concentration limits for the tunnel ventilation outlets will guarantee acceptable ambient air quality.

The scenarios assessed constant ventilation outlet concentrations (at the limits) over a 24-hour period, thus providing a representation of the theoretical maximum changes in air quality and covering all potential operational modes of the traffic in the tunnel, including unconstrained and worst-case traffic conditions from an emissions perspective, and vehicle breakdown situations. The analysis was undertaken to assist regulatory authorities in assessing and determining potential ventilation outlet concentration limits that could be applied to the ventilation outlets through conditions of approval. Assuming that concentration limits are applied to the ventilation outlets, the results of the analysis will demonstrate the air quality performance of the project if it operates continuously at the limits. In reality, ventilation outlet concentrations would over a daily cycle vary due to changing traffic volumes and tunnel fan operation.

The scenarios were:

- RWC-A. This scenario applied to the project only. The same ventilation outlets and assumptions were applicable in 2021 and 2031
- RWC-B. This scenario applied to the project and the M4-M5 Link, taking into account the additional ventilation outlets.

The assumptions underpinning the regulatory worst-case scenarios were very conservative, and resulted in contributions from project ventilation outlets that were much higher than those that could occur under any operational conditions in the tunnel.

Ambient air quality criteria used in the assessment

Air quality in the M4 East domain was assessed in relation to the most relevant pollutants and criteria from the NSW Approved Methods. The proposed standards and targets for PM_{10} and $PM_{2.5}$ in NSW were also considered. The pollutants and criteria are summarised in Table 5-3.

Table 5-3 Air quality criteria applicable to the project assessment

Pollutant/metric	Concentration	Averaging period	Source
Criteria pollutants			
CO	30 mg/m^3	1 hour	NSW DEC (2005)
	10 mg/m^3	8 hours (rolling)	NSW DEC (2005)
NO_2	246 µg/m^3	1 hour	NSW DEC (2005)
	62 µg/m^3	1 year	NSW DEC (2005)
PM_{10}	50 µg/m^3	24 hours	NSW DEC (2005)
	30 µg/m^3	1 year	NSW DEC (2005)
	25 µg/m^3	1 year	NSW proposed standard
	20 µg/m^3	1 year	NSW proposed target
$PM_{2.5}$	25 µg/m^3	24 hours	NEPM Advisory Standard
	20 µg/m^3	24 hours	NSW proposed target
	8 µg/m^3	1 year	NEPM Advisory Standard
	7 µg/m^3	1 year	NSW proposed target
Air toxics			
Benzene	0.029 mg/m^3	1 hour	NSW DEC (2005)
PAHs (as b(a)p)	0.0004 mg/m^3	1 hour	NSW DEC (2005)
Formaldehyde	0.02 mg/m^3	1 hour	NSW DEC (2005)
1,3-butadiene	0.04 mg/m^3	1 hour	NSW DEC (2005)

The application of the assessment criteria is described in the NSW Approved Methods, but the wording is not especially well suited to the assessment of road projects, especially in urban areas where there is an existing and complex spatial distribution of air pollutants.

For criteria pollutants the following steps must be applied:

- The predicted concentrations should be compared with the standards for the nearest existing or likely future ‘off-site’ sensitive receptor
- The incremental impact (predicted impacts due to the pollutant source alone) for each pollutant must be reported in units and averaging periods that are consistent with the air quality standards
- Background concentrations must be included using the procedures specified in Section 5 of the NSW Approved Methods
- The total impact (incremental impact plus background) must be reported as the 100th percentile in concentration or deposition units consistent with the standards and compared with the relevant standards.

For air toxics the steps correspond to those above, but they are slightly different. For example, the criteria for individual pollutants must be applied ‘at and beyond the boundary of the facility’, and incremental impacts must be reported for an averaging period of one hour and as the 100th percentile of model predictions for Level 1 assessments or the 99.9th percentile of model predictions for Level 2 assessments.

Pollutants and metrics excluded from the assessment

The following pollutants/metrics were not considered to be relevant to the ambient air quality assessment of the project (and to road transport projects in general):

- Sulfur dioxide (SO_2). SO_2 is emitted from road vehicles, and results from the oxidation of the sulfur present in fuels during combustion. However, SO_2 emissions are directly proportional to the sulfur content of the fuel, and emissions have decreased considerably as a result of controls on fuel quality. For example, in 1999 the average sulfur content of diesel was 1,300 ppm. In December 2002, a new standard was introduced, reducing the maximum sulfur content of diesel to 500 ppm. Currently, the sulfur level in premium unleaded petrol is 50 ppm, and in diesel it is 10 ppm[17]. The emissions of SO_2 from road vehicles are therefore now very low, and SO_2 is not a major concern in terms of transport-related air quality.
- Lead. In cities, motor vehicles operating on leaded petrol used to be the main source of lead in the atmosphere. However, as a result of the introduction of unleaded petrol in 1985, the progressive reduction of the lead content of leaded petrol, and reductions in emissions of lead from industry, there has been a significant fall in annual average concentrations of lead in ambient air throughout NSW (often to below the minimum detection limit) (NSW DECCW, 2010). Since 2002 the lead content of petrol has been limited to 0.005 g/litre. The result of this is that lead is no longer considered to be an air quality and health concern away from specific industrial activities (such as smelting).
- TSP. For road transport it can (broadly) be assumed that TSP is equivalent to PM_{10}, and therefore the standard for PM_{10} will be the controlling one. Whilst this is definitely the case for exhaust particles, it is possible that a fraction of non-exhaust particles is greater than 10 μm in diameter.
- Ozone (O_3). Because of its secondary and regional nature, ozone cannot practicably be considered in a local air quality assessment. Emissions of ozone precursors (NO_X and VOCs) are distributed unevenly in urban areas and concentrations vary during the day. Complicating this further are the temporal and spatial variations in meteorological processes. Ozone formation is non-linear, so reducing or increasing NO_X or VOC emissions does not necessarily result in an equivalent decrease or increase in the ozone concentration. This non-linearity makes it difficult to develop management scenarios for ozone control (NSW DECCW, 2010). In addition, the changes in emissions associated with the project were well below the thresholds that trigger an ozone assessment (see Chapter 8).
- Hydrogen fluoride. The standards for HF relate to sensitive vegetation rather than human health, and HF is not a pollutant that is relevant to road vehicle operation.

The investigation levels in the Air Toxics NEPM were not included as they are not designed as impact assessment criteria.

It is also worth noting that in recent years a considerable amount of attention has focussed on ‘ultrafine’ particles (UFPs). These are particles with a diameter of less than 0.1 μm. Whilst there is some evidence particles in this size range are associated with adverse health effects, it is not currently practical to incorporate them into an environmental impact assessment. There are several reasons for this, including the rapid transformation of such particles in the atmosphere, the need to treat UFPs in terms of number rather than mass, the lack of robust emission factors, the lack of robust concentration-response functions, the lack of ambient background measurements, and the absence of air quality standards.

In relation to concentration-response functions, the WHO Regional Office for Europe (2013) has stated the following:

> ‘… the richest set of studies provides quantitative information for $PM_{2.5}$. For ultrafine particle numbers, no general risk functions have been published yet, and there are far fewer studies available. Therefore, at this time, a health impact assessment for ultrafine particles is not recommended.’

For the purpose of the project assessment it has therefore been assumed that the effects of UFPs on health are adequately represented by those of $PM_{2.5}$.

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[17] http://www.environment.gov.au/protection/publications/factsheet-sulfur-dioxide-so2

Terminology

The concentration of a given pollutant at a given location has contributions from various different sources. Several different terms have been used to describe these contributions, including the contribution from any project being assessed.

The following terms have been used in this assessment to describe the pollutant concentration at a given location (receptor) and for a given averaging period:

- The background concentration. This is the contribution to the concentration of a pollutant from all sources other than the modelled surface road traffic (major roads only). It includes, for example, contributions from natural sources, industry and domestic activity, as well as minor roads.
- The surface road concentration. This is the contribution from the main surface road network. It includes not only the contribution of the nearest road at the receptor, but the net contribution of the modelled road network at the receptor (excluding minor roads).
- The ventilation outlet concentration. This is the contribution from tunnel ventilation outlets.
- The total concentration. This is the sum of the background, surface road, and ventilation outlet concentrations.
- The change in concentration due to the project. This is the difference between the total concentration with the project and the total concentration without the project, and may be either an increase or a decrease, depending on, amongst other things, how traffic is redistributed on the network as a result of the project.

These terms are relevant to both annual mean and short-term (e.g. one-hour mean or 24-hour mean) ambient air quality criteria.

An example of the different contributions at a receptor for different scenarios is shown in Figure 5-2. The surface road and ventilation outlet concentrations will typically decrease between the base year and the future years as a result of improved emission controls. However, there is the potential for such reductions to be offset by traffic growth. In the example shown, the project has the effect of decreasing total traffic (surface road and ventilation outlet) emissions in the vicinity of the receptor. As the background is assumed to be constant with time (see below), the total concentration with the project in 2021 and 2031 is smaller than the total concentration without the project.

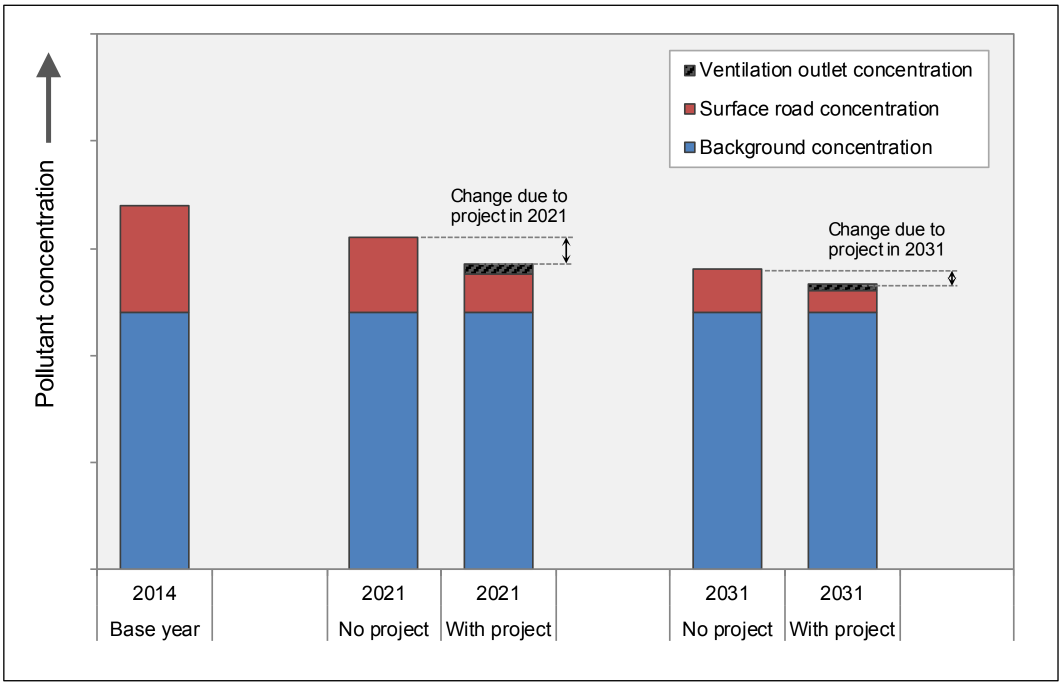

Figure 5-2 Contributions to total pollutant concentrations (example)

Determination of components in M4 East assessment

The different components in Figure 5-2 were determined as follows:

- Background concentrations were based on measurements from air quality monitoring stations at urban background locations in the study area but well away from roads (as defined in Australian Standard AS/NZS 3580.1.1:2007). The approaches used to determine long-term and short-term background concentrations are explained in Appendix F. Background concentrations were assumed to remain unchanged in future years.
- Surface road concentrations and ventilation outlet concentrations were estimated (separately) using a dispersion model (GRAL). The modelling of the road network gave a non-zero concentration at the locations of air quality monitoring stations, which introduced a small element of conservatism into the approach.
- For all pollutants except NO_2, as the background concentration was the same with and without the project, the project increment was equal to the difference between the road concentration (surface roads and ventilation outlets) with and without the project. A different method was required for NO_2 to account for the atmospheric chemistry in the roadside environment (see Appendix G).

Receptors

The Air Quality Assessment Report presents contour maps show concentrations, and changes in concentration, across the entire M4 East GRAL domain. The concentrations are based on a Cartesian grid of points with an equal spacing of 10 metres in the x and y directions. This results in 527,000 grid locations across the M4 East GRAL domain.

This report also presents distributions of changes in concentration at over 10,000 discrete receptor locations along the project corridor where people are likely to be present for some period of the day. Two types of discrete receptor locations were defined for use in the assessment:

- 'Community receptors'. These were taken to be representative of particularly sensitive locations within a zone (600 metres either side) along the project corridor, such as schools, child care centres and hospitals. For these receptors a detailed approach was used to calculate the total concentration of each pollutant. This involved the combination of the contemporaneous road/outlet time series of concentrations from GRAL and the background time series of concentrations, stated as a one-hour mean for each hour of the year in each case. The number of such receptors that could be treated in this was dictated by the limit on the number of time series that could be extracted from GRAL. In total, 31 community receptors were included in the assessment.
- 'Residential, workplace and recreational (RWR) receptors'. These were all discrete receptor locations along the project corridor, and mainly covered residential and commercial land uses. The 31 community receptors were also included. For these receptors a simpler statistical approach was used to combine a concentration statistic for the modelled roads and outlets (e.g. maximum 24-hour mean PM_{10}, annual mean NO_X) with an appropriate background statistic. Around 10,000 RWR receptors were included in the assessment.

The RWR receptors are discrete points in space, classified according to the land use identified at that location. The RWR receptors do not identify the number of residential (or other) properties at the location. The residential land use at an RWR receptor location may range from a single-storey dwelling to a multi-storey, multi-dwelling building. The RWR receptors are therefore not designed for the assessment of changes in total population exposure. The Human Health Risk Assessment Report combines the air quality information with the highest available resolution population data from the Australian Bureau of Statistics to calculate key health indicators that reflect population-weighted change in concentrations across the study area.

It is worth pointing out that whilst not all particularly sensitive receptors along the project corridor were included in the first type, they were included in the second type. This included, for example, aged care facilities and some additional schools. This approach was considered to be appropriate, in that it allowed all relevant receptors to be included in the assessment whilst recognising model limitations.

5.6 Treatment of uncertainty

5.6.1 Accuracy and conservatism

There is generally a desire for a small amount of conservatism in air quality assessments, and conservatism has been built into the studies conducted for many other major infrastructure and development proposals in NSW and elsewhere. The reasons for this include the following:

- Allowing for uncertainty. An assessment on the scale undertaken for the project is a complex, multi-step process which involves various different assumptions, inputs, models, and post-processing procedures. There is an inherent uncertainty in each of the methods used to estimate traffic volume, emissions and concentrations, and there are clearly limits to how accurately any impacts in future years can be predicted. Conservatism is built into some aspects of predictions to ensure that a margin of safety is applied (i.e. to minimise the risk that any potential impacts are underestimated).
- Providing flexibility. It is undesirable for the potential environmental impacts of a project to be defined too narrowly at this stage in the development process. A conservative assessment approach provides flexibility for ongoing design refinements and project implementation within an approved environmental envelope (AECOM, 2014b).

Conversely, it is recognised that excessive conservatism in an assessment risks overstating potential air quality impacts and associated human health risks. This, in turn, may lead to some potentially undesirable outcomes that need to be mitigated and managed, such as the following:

- It may contribute to concerns by the local community and other stakeholders about the impacts of the project.
- It may lead to additional, or more stringent, conditions of approval than necessary, including the mitigation, monitoring and management of air quality.
- Overstatement of vehicle contributions to local air quality may similarly lead to overstating the benefit where vehicle emissions are reduced by the project (AECOM, 2014b).

Air quality assessments therefore need to strike a balance between these potentially conflicting requirements.

The operational air quality assessment for the project has been conducted, as far as possible, with the intention of providing ‘accurate’ or ‘realistic’ estimates of pollutant emissions and concentrations. The general approach has been to use inputs, models and procedures that are as accurate as possible, except where the context dictates that a degree of conservatism is sensible. An example of this is the estimation of the maximum one-hour NO_2 concentration during a given year. Any method which provides a ‘typical’ or ‘average’ one-hour NO_2 concentration will tend to result in an underestimate of the likely maximum concentration, and therefore a more conservative approach is required.

However, the scale of the conservatism can often be quite difficult to define, and this can sometimes result in some assumptions being overly conservative. Skill and experience is required to estimate impacts that err on the side of caution but are not unreasonably exaggerated or otherwise skewed. By demonstrating that a deliberate overestimate of impacts is acceptable, it can be confidently predicted that the actual impacts that are likely to be experienced in reality would also lie within acceptable limits (AECOM, 2014b).

It is worth adding that conservatism in modelling can lead to and potential improvements being overestimated.

5.6.2 Key assumptions

The key assumptions underpinning the assessment of operational impacts have been summarised in Chapter 8. The different elements of the modelling chain for operational impacts (e.g. traffic model outputs, emission model predictions, dispersion model predictions, background concentrations, conversion factors) were assessed in terms of whether they were likely to be broadly accurate or broadly conservative, with quantitative data where possible.

5.6.3 Sensitivity tests

A number of sensitivity tests were also conducted to investigate the effects of varying the key assumptions in the operational assessment. These tests were applied to different stages of the assessment, such as whether the inclusion of buildings in the dispersion model, or the heights of ventilation outlets, would materially affect the outcomes and conclusions of the assessment.

6 Existing environment

6.1 Overview

This Chapter describes the existing environment and conditions in the WestConnex study area. The Chapter:

- Describes the terrain and land use in the study area.
- Describes the meteorology in the study area.
- Considers historical trends in road traffic emissions.
- Establishes the historical and current air quality environment in the study area.
- Establishes meteorological inputs for the operational air quality assessment.
- Determines background concentrations for the operational air quality assessment.

6.2 Terrain and land use

The topography of the land in an area plays an important role in the dispersion of air pollutants. It steers winds, generates turbulence and large scale eddies, and generates drainage flows at night and upslope flows during the day.

Terrain data for Sydney were obtained from the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) website. Figure 6-1 shows the terrain immediately surrounding the WestConnex project, based on 30-metre resolution data.

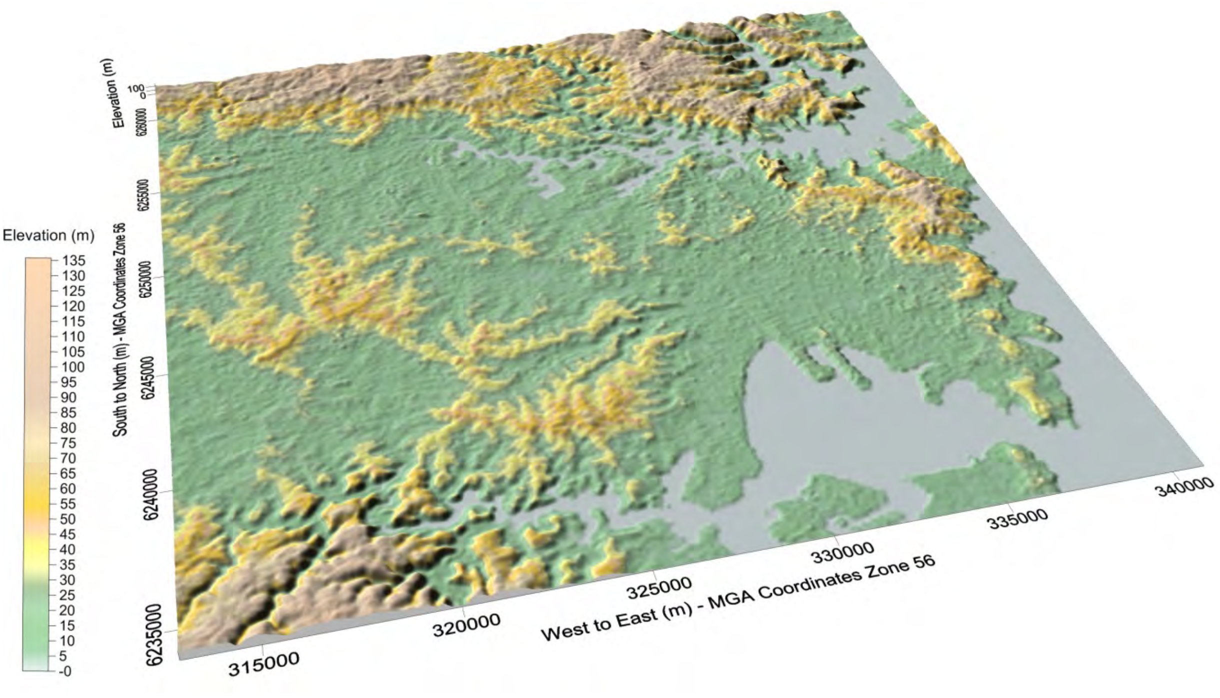

Figure 6-1 Terrain in the WestConnex study area

The terrain within the WestConnex study area is predominantly flat, but increases in elevation to the north of the Five Dock Bay area towards the Hills District and to the south towards the Sutherland Shire and adjoining parkland.

The terrain along the project corridor rises from an elevation of around 15 metres Australian Height Datum (AHD) at the western side of the M4 East to an elevation of around 22 metres (AHD) at the eastern end.

Land use within the M4 East GRAL domain consists primarily of urban areas, with pockets of small recreational reserves and waterbodies around the Five Dock Bay and towards the east coast.

The uniformity of the terrain, and the lack of major obstacles to wind flow, should support good dispersion and air flow throughout the study area.

6.3 Climate

Table 6-1 and Table 6-2 present the 20-year temperature and rainfall data for the two closest Bureau of Meteorology (BoM) sites located at Sydney Olympic Park (Archery Centre) (Site number 066195), and the Canterbury Racecourse (Site number 066194). Monthly averages of maximum and minimum temperatures are presented as well as rainfall data consisting of mean monthly rainfall and the average number of rain days per month.

Table 6-1 Climate averages for Sydney Olympic Park (AWS)

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Mean daily maximum temperature (ºC)												
28.4	28.1	26.6	23.9	20.8	18.3	17.6	19.5	22.5	24.3	25.3	27.4	23.6
Mean daily minimum temperature (ºC)												
19.3	19.4	17.8	14.3	11.2	8.9	7.8	8.7	11.6	13.7	15.8	17.9	13.9
Mean monthly rainfall (mm)												
84.4	109.8	66.0	89.2	88.2	75.8	63.5	56.7	52.7	64.9	76.2	58.0	884.0
Mean rain days per month (number)												
7.6	7.7	7.6	6.9	7.7	6.9	6.3	4.4	5.5	7.1	7.8	6.8	82.3

Source: BOM (2015) Climate averages for Station: 066195; Commenced: 1995 – last record 2015; Latitude: 33.85°S; Longitude: 151.06 °E

Table 6-2 Climate averages for Canterbury Racecourse (AWS)

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Mean daily maximum temperature (ºC)												
27.6	27.2	25.9	23.3	20.5	18.1	17.5	19.0	22.1	23.4	24.6	26.3	23.0
Mean daily minimum temperature (ºC)												
18.3	18.3	16.4	12.7	9.3	7.1	5.8	6.5	9.5	12.0	14.8	16.8	12.3
Mean monthly rainfall (mm)												
76.0	103.6	73.3	113.4	84.9	98.8	57.8	63.3	45.7	62.4	81.4	64.7	927.8
Mean rain days per month (number)												
7.6	7.8	7.5	7.8	7.1	8.9	6.7	5.1	4.7	6.2	8.3	6.8	84.5

Source: BOM (2015) Climate averages for Station: 066194; Commenced: 1995 – last record 2015; Latitude: 33.91°S; Longitude: 151.11 °E

The annual average maximum and minimum temperatures recorded at the Sydney Olympic Park station are 23.6°C and 13.9°C, respectively. At Canterbury Racecourse these are 23.2°C and 12.3°C, respectively. On average, January is the hottest month, with average maximum temperatures of 28.4°C and 27.6°C at Olympic Park and Canterbury, respectively. July is the coldest month at both stations, with average minimum temperatures of 7.8°C and 5.8°C, respectively.

Rainfall data collected at the Sydney Olympic Park station shows that February is the wettest month, with an average rainfall of 110 millimetres over an average of eight rain days. The average annual rainfall is 884 millimetres over an average of 82 rain days per year. Rainfall data from the Canterbury site shows the wettest month on average occurring in April, with 113 millimetres falling over eight rain days. The average annual rainfall is slightly higher at 928 millimetres over an average of 85 rain days per year.

6.4 Meteorology

Several meteorological stations in the study area were considered, and their locations are shown in Figure 6-2. Data relevant to the dispersion modelling such as wind speed, wind direction, temperature and cloud cover were obtained for the following:

- OEH meteorological stations:
    - Chullora
    - Earlwood
    - Rozelle
- BoM meteorological stations:
    - Canterbury Racecourse Automatic Weather Station (AWS) (Station No. 66194)
    - Fort Denison (Station No. 66022)
    - Sydney Airport AMO (Station No. 66037)
    - Sydney Olympic Park AWS (Station No. 66195)
    - Sydney Olympic Park AWS (Archery Centre) (Station No. 66212)

An analysis of the data required as input for GRAMM (further described in Section 8.4.4) was conducted to examine the availability and validity of the data from the above meteorological stations. Data recovery, wind speed, wind direction, temperature and relative humidity information for years 2009 to 2014 were analysed where available for each of the sites listed above. A minimum of five years of data was chosen for analysis in line with the requirements of determining site-representative data as per the Approved Methods. It is noted that the OEH Randwick site is also located within the model domain. However, as it would be less than 500 metres away from the western edge of the domain, it was not considered for inclusion in the model due to potential model boundary effects which could skew the wind fields at this location.

Appendix H provides a summary of the annual data recovery, average wind speed and percentage of calms (wind speeds < 0.5 m/s) for each of the aforementioned meteorological stations for the years 2009 to 2014. The table shows a generally high percentage of data recovery at each site over the last six years. It is noted that the Approved Methods require a meteorological dataset to be at least 90 per cent complete to be deemed acceptable for a Level 2 impact assessment.

There was a high level of consistency in the annual average wind speed and annual percentage of calms across the years within each meteorological station database. Wind speed conditions (and therefore calms) have remained relatively consistent.

Annual and seasonal wind roses for all six years and for all sites were used to analyse the general wind patterns across the study area. These are presented in Appendix H. The wind roses showed very similar wind patterns for all six years at each individual site. The dominant wind patterns are predominantly from the northwest and southeast directions. The seasonal patterns are also very similar between each site. It is noted that the OEH Chullora and Rozelle are in proximity to the M4 East study area. Annual and seasonal wind roses for six years for both sites are shown in Appendix H and show a shift in the dominant wind patterns towards the later years at both sites. The OEH website notes that neither of these sites complies with the current Australian standards for siting due to the obstruction of trees within 20m of both sites. For these reasons, data from these two sites were not deemed reliable and were not chosen for dispersion modelling.

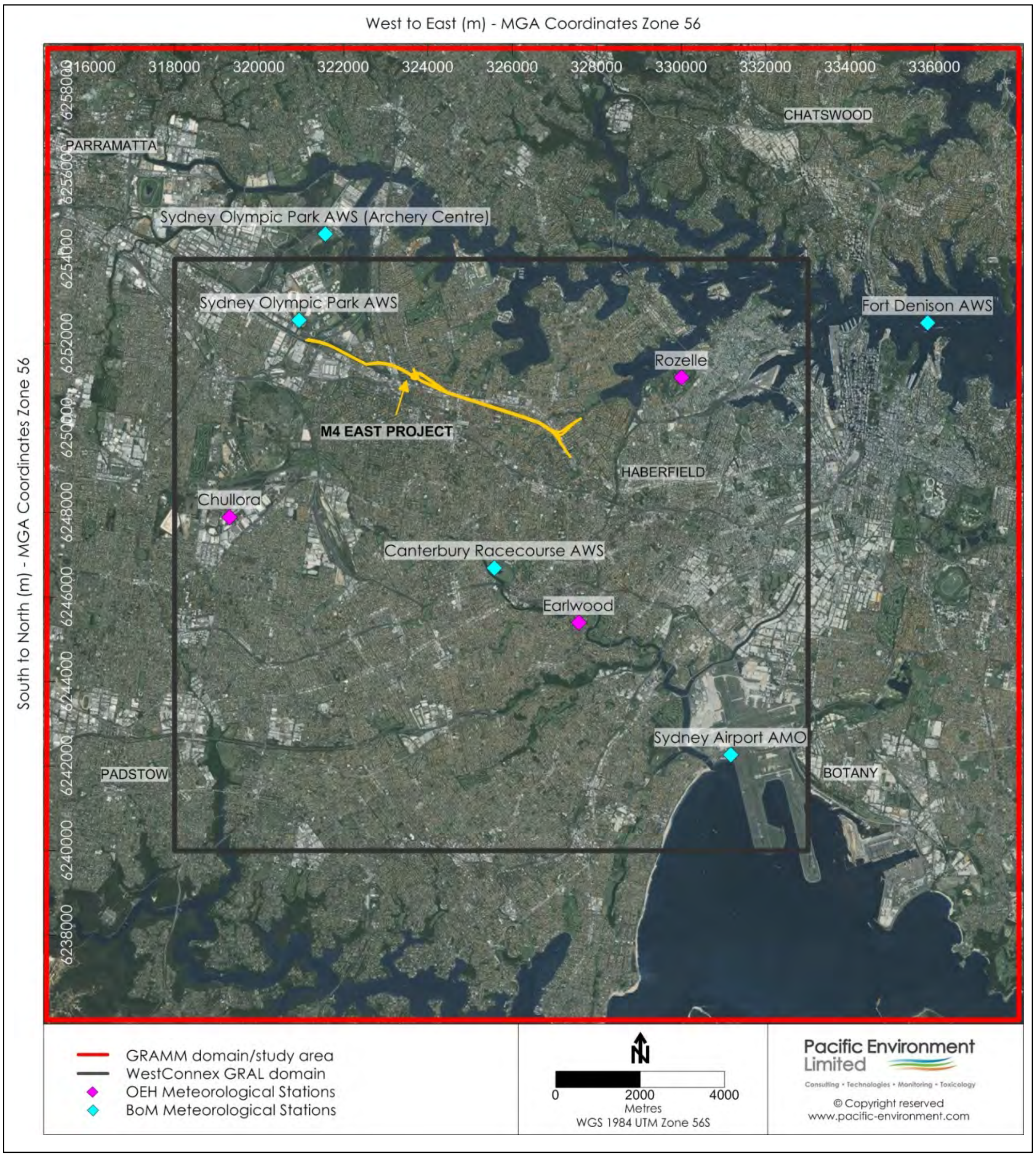

Figure 6-2 Meteorological stations in the GRAMM model domain

Based on the analysis of the available meteorological data within the study area (presented in Appendix H), data from the BoM Canterbury Racecourse AWS meteorological station were chosen as the input to GRAMM for modelling. The site was considered to be representative of the meteorology in the domain.

Analysis of the Canterbury Racecourse data showed that the wind speed and direction patterns for the past six years (2009 to 2014) were consistant from year to year (Appendix H). Annual average wind speeds for each of the six years was also consistent ranging from 3.2 m/s to 3.3 m/s. The annual percentage of calms was also consistent ranging from 8% to 9.4% with the most recent three years only shown 1% difference to each other.

Whilst other sites also showed consistencies in meterolgoical conditions over the six years, the Canterbury Racecourse AWS site is more centrally located with respect to the WestConnex project and was therefore chosen to represent the model domain as it most closely captures the spatial aspects of each of the WestConnex project stages. This also provides consistency when assessing the different stages separately and also together in the cumulative model scenario.

The analysis of six years of data also showed that 2014, the most recent year available, was a representative year. Moreover, the selection of the 2014 meteorological data was consistent with the use of ambient air quality data to define background concentrations for the assessment.

Figure 6-3 to Figure 6-6 show annual and diurnal plots of wind speed and temperature from the Canterbury Racecourse site for 2014. The annual plots show a typical distribution of wind speed and temperature over the course of a year. The diurnal plots also show typical patterns, with higher wind speeds and temperatures during the day and decreases at night and in the early morning.

Having determined the represenatativeness of 2014, these data were then used as input to run the meterorological model (GRAMM) to determine three-dimensional wind fields across the modelling domain. This process is described further in Section 8.4.4, and an example of a typical wind field is shown in Figure 8-13. Wind speed and direction values were extracted at each of the meteorological stations shown in and some statistical analysis was carried out to compare these extracted (predicted) data to the observations at each of those sites. This is discussed further in Section 8.4.5.

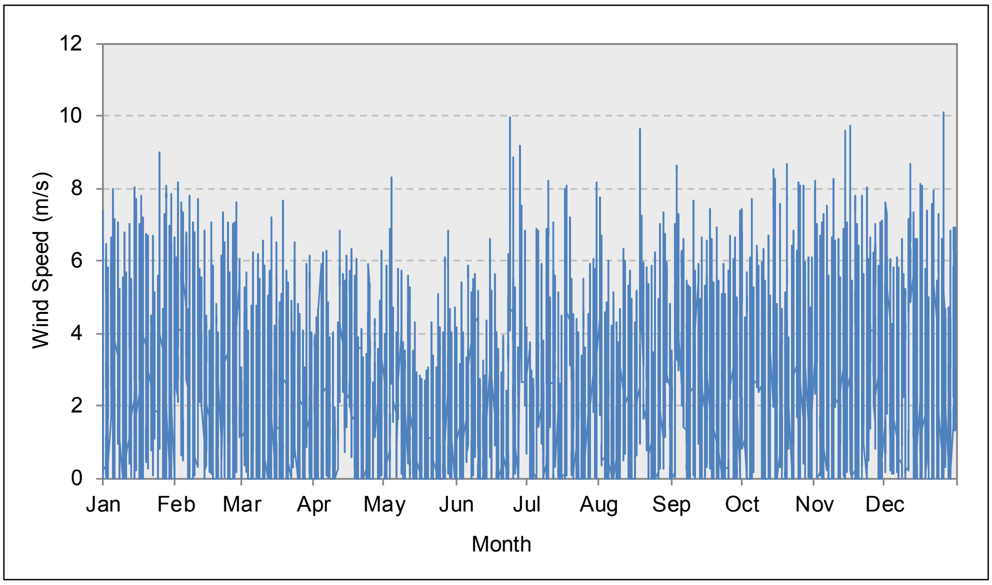

Figure 6-3 Hourly average wind speeds at Canterbury Racecourse – 2014

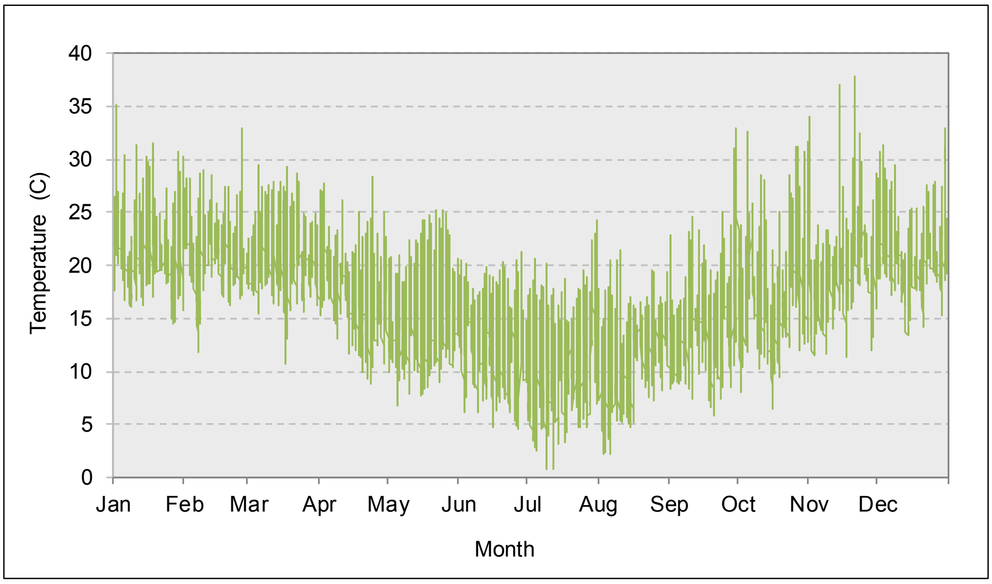

Figure 6-4 Hourly average temperatures at Canterbury Racecourse – 2014

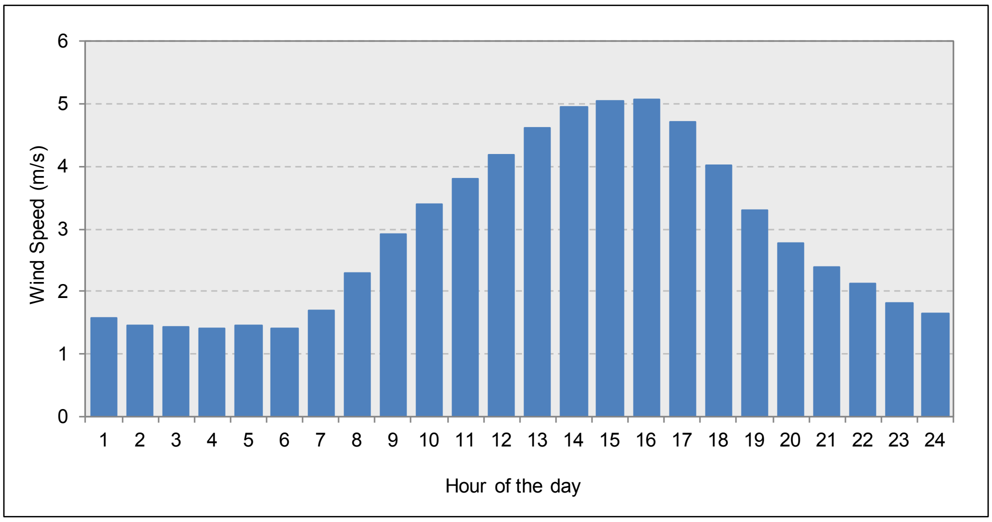

Figure 6-5 Average wind speeds by hour of day at Canterbury Racecourse – 2014

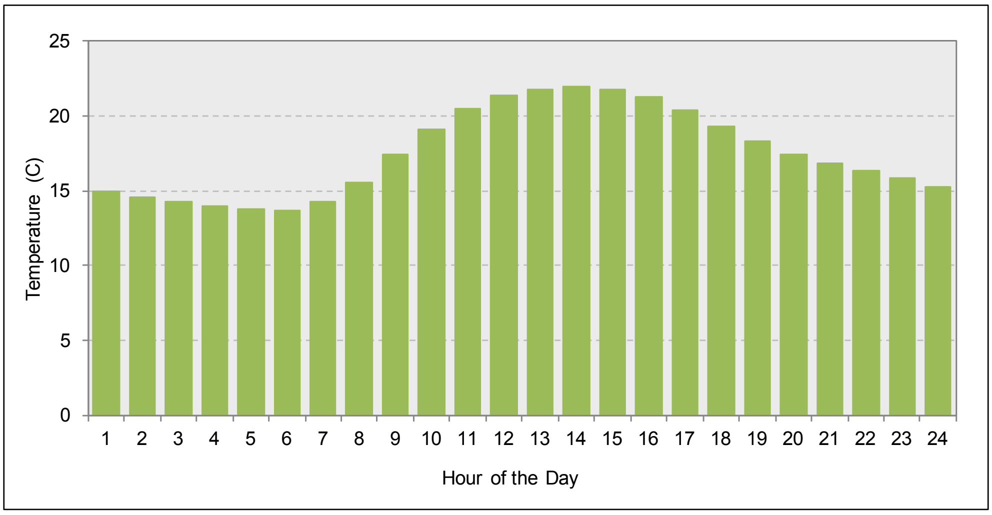

Figure 6-6 Average temperatures by hour of day at Canterbury Racecourse – 2014

6.5 Emissions

Calculations have established that exhaust emissions of some pollutants from road transport have decreased as the vehicle emission legislation has tightened, and are predicted to decrease further in the future (BITRE, 2010). However, over the longer term it is anticipated that emission levels will start to rise again, as increases in annual vehicle activity will start to offset the reductions achieved by the current emission standards and vehicle technologies (DIT, 2012).

The most detailed and comprehensive source of information on current and future emissions in the Sydney area is the emissions inventory[18] that is compiled periodically by NSW EPA. The base year of the latest published inventory is 2008 (NSW EPA, 2012a), and projections are available for 2011, 2016, 2021, 2026, 2031 and 2036. The importance of road transport as a source of pollution in Sydney can be illustrated by reference to sectoral emissions. The data for anthropogenic and biogenic emissions in Sydney, and also for road transport in Sydney, have been extracted from the inventory

[18] An 'emissions inventory defines the amount (in tonnes per year) of each pollutant that is emitted from each source in a given area.

by NSW EPA[19] and are presented here. Emissions were considered for the most recent historical year (2011) and for the future years.

Figure 6-7 shows that in Sydney during 2011 road transport was the single largest sectoral contributor to emissions of CO (44 per cent) and NO_X (57 per cent). It was also responsible for a significant proportion of emissions of VOCs (17 per cent), PM_{10} (10 per cent) and $PM_{2.5}$ (12 per cent). The main contributors to VOCs were domestic-commercial activity and biogenic sources. The most important sources of PM_{10} and $PM_{2.5}$ emissions were the domestic-commercial sector and industry. The contribution to PM from the domestic sector in Sydney was due largely to wood burning for heating in winter. Emissions from natural sources, such as bushfires, dust storms and marine aerosol, also contributed significantly to PM concentrations. Road transport contributed only two per cent of total SO_2 emissions in Sydney, reflecting the desulfurisation of road transport fuels in recent years. SO_2 emissions in Sydney were dominated by the off-road mobile sector and industry.

The projections of sectoral emissions in Figure 6-8 show that the road transport contribution to emissions CO, VOCs and NO_X will decrease substantially between 2011 and 2036 due to improvements in emission-control technology. For PM_{10}, $PM_{2.5}$ and SO_2 the road transport contributions will also decrease, but their smaller contributions means that these decreases will have only a minor impact on total emissions.

The breakdown of emissions in 2011 from the road transport sector by process and vehicle type is presented in Figure 6-9. Petrol passenger vehicles (mainly cars) accounted for a large proportion of the vehicle kilometres travelled (VKT) in Sydney[20]. Exhaust emissions from these vehicles were responsible for 62 per cent of CO from road transport in Sydney in 2011, 45 per cent of NOx, and 76 per cent of SO_2. They were a minor source of PM_{10} (4 per cent) and $PM_{2.5}$ (9 per cent). Non-exhaust processes were the largest source of road transport PM_{10} (60 per cent) and $PM_{2.5}$ (46 per cent). This is a larger proportion than in, say, most European countries, as there are relatively few diesel cars in Australia. It is also a cause for concern, as there are currently no controls for non-exhaust particles (and no legislation), and emissions will increase in line with projected traffic growth. Heavy-duty diesel vehicles are disproportionate contributors of NOx and PM emissions due to their inherent combustion characteristics, high operating mass (and hence high fuel usage) and level of emission control technology (NSW EPA, 2012b). Evaporation is the main source of VOCs.

The projections of road transport emissions are broken down by process and vehicle group in Figure 6-10. There are projected to be substantial reductions in emissions of CO, VOCs, and NO_X between 2011 and 2036. There will be smaller changes in emissions of PM_{10} and $PM_{2.5}$ on account of the growing contribution of non-exhaust particles. SO_2 emissions are proportional to fuel sulfur content, and this is assumed to remain constant in the inventory.

The inventory also provides emissions of specific organic compounds, based on speciation profiles of petrol and diesel fuels.

[19] The data were provided for the project Economic Analysis to Inform the National Plan for Clean Air (Particles), undertaken by Pacific Environment on behalf of the NEPC Service Corporation.

[20] Diesel passenger vehicles have represented only a very small proportion of the total passenger vehicle fleet. However, the improved performance of light-duty diesel vehicles over the last 10 years, together with superior fuel economy, has boosted sales and the market share is increasing (NSW EPA, 2012b).

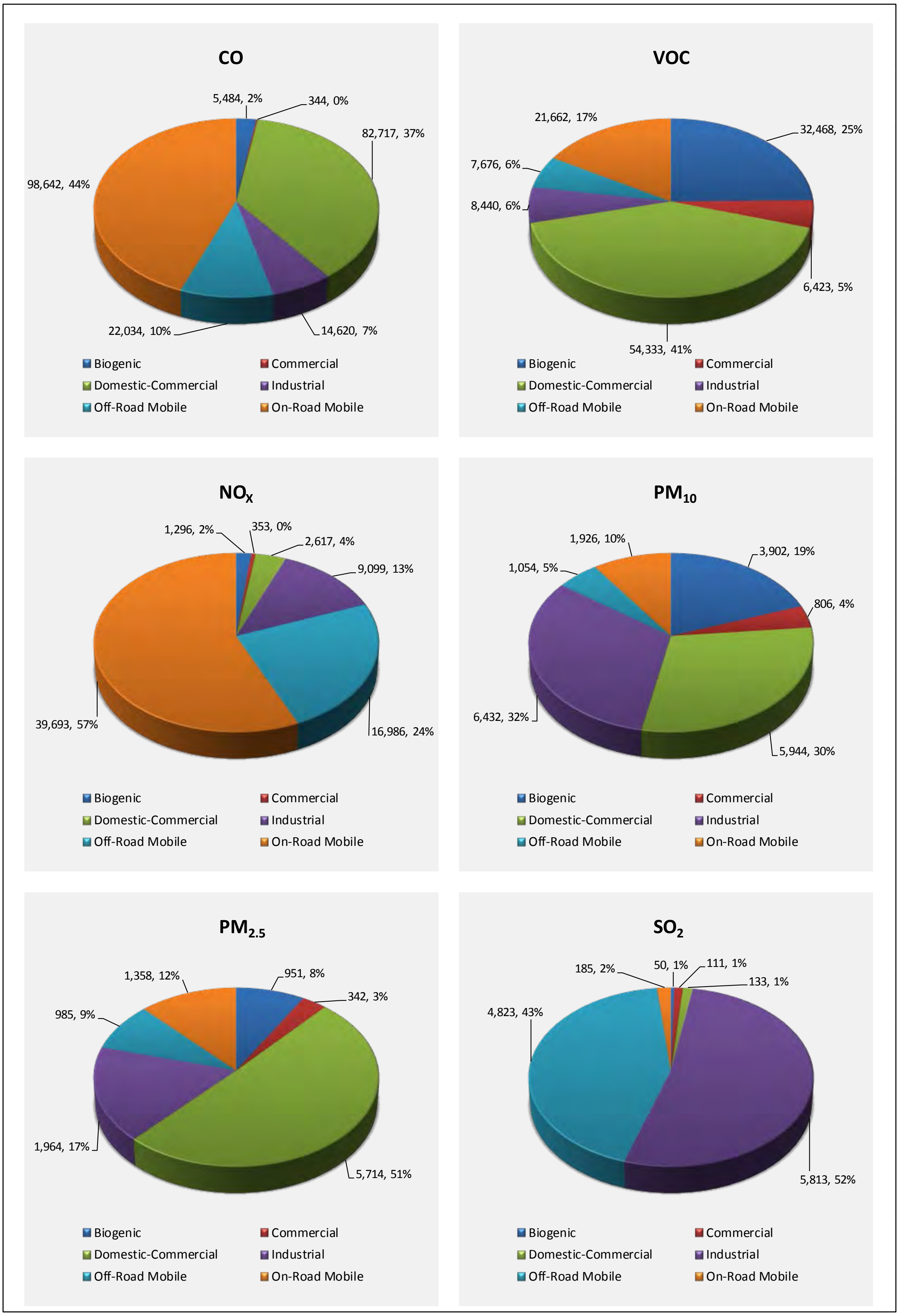

Figure 6-7 Sectoral emissions in Sydney, 2011 (values in tonnes per year and percentage of total)

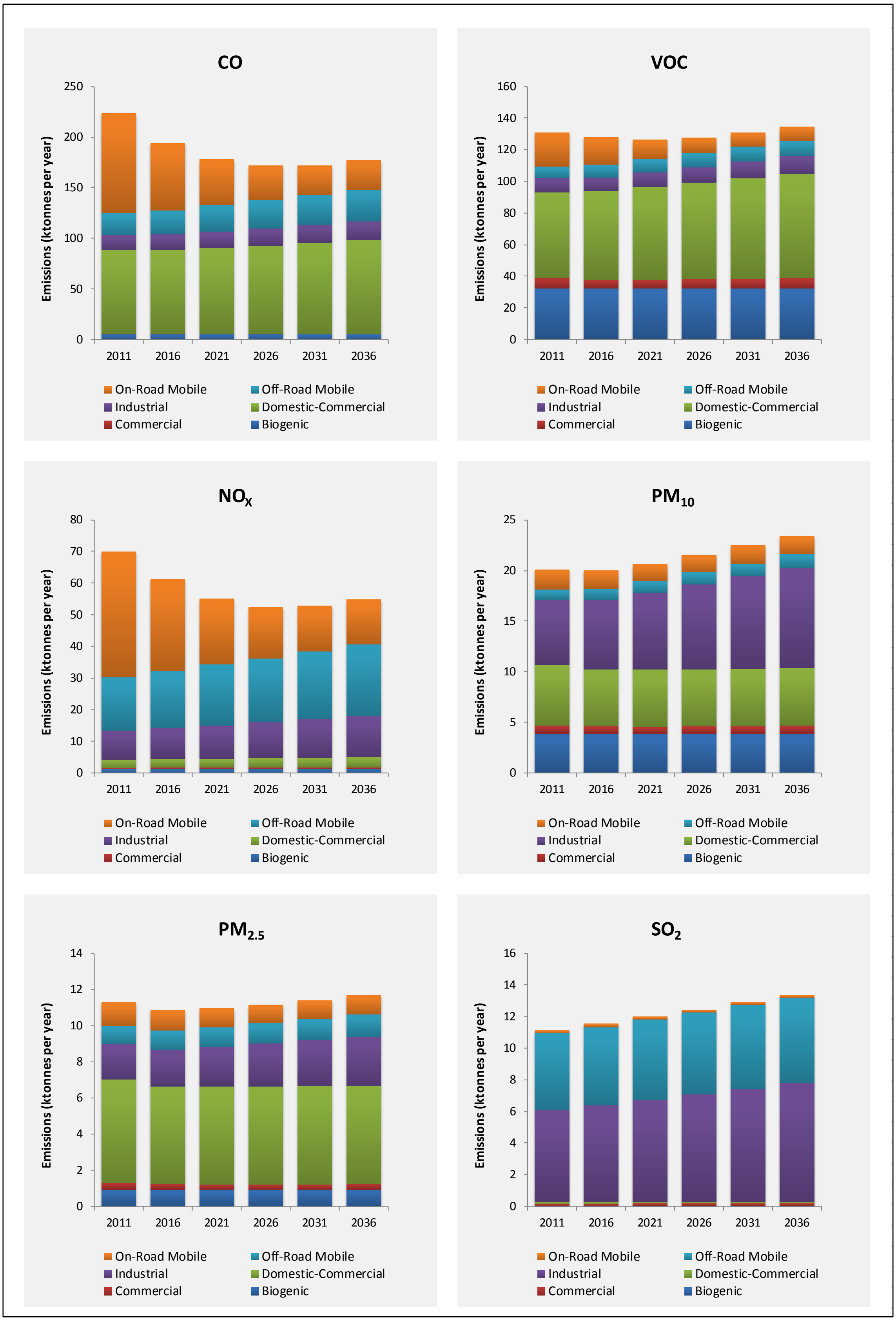

Figure 6-8 Projections of sectoral emissions – Sydney, 2011-2036

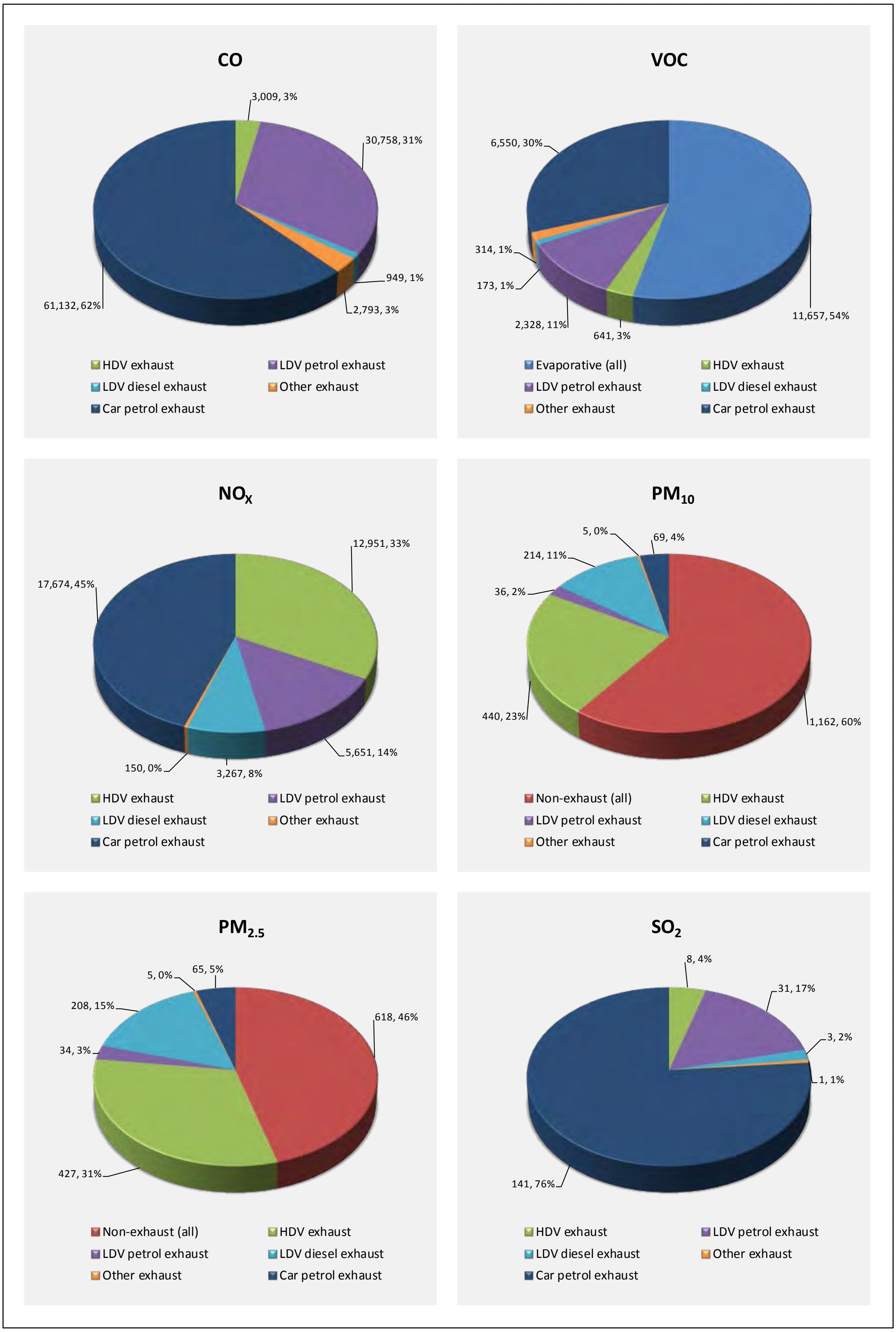

Figure 6-9 Breakdown of road transport emissions – Sydney, 2011 (values in tonnes per year and percentage of total)

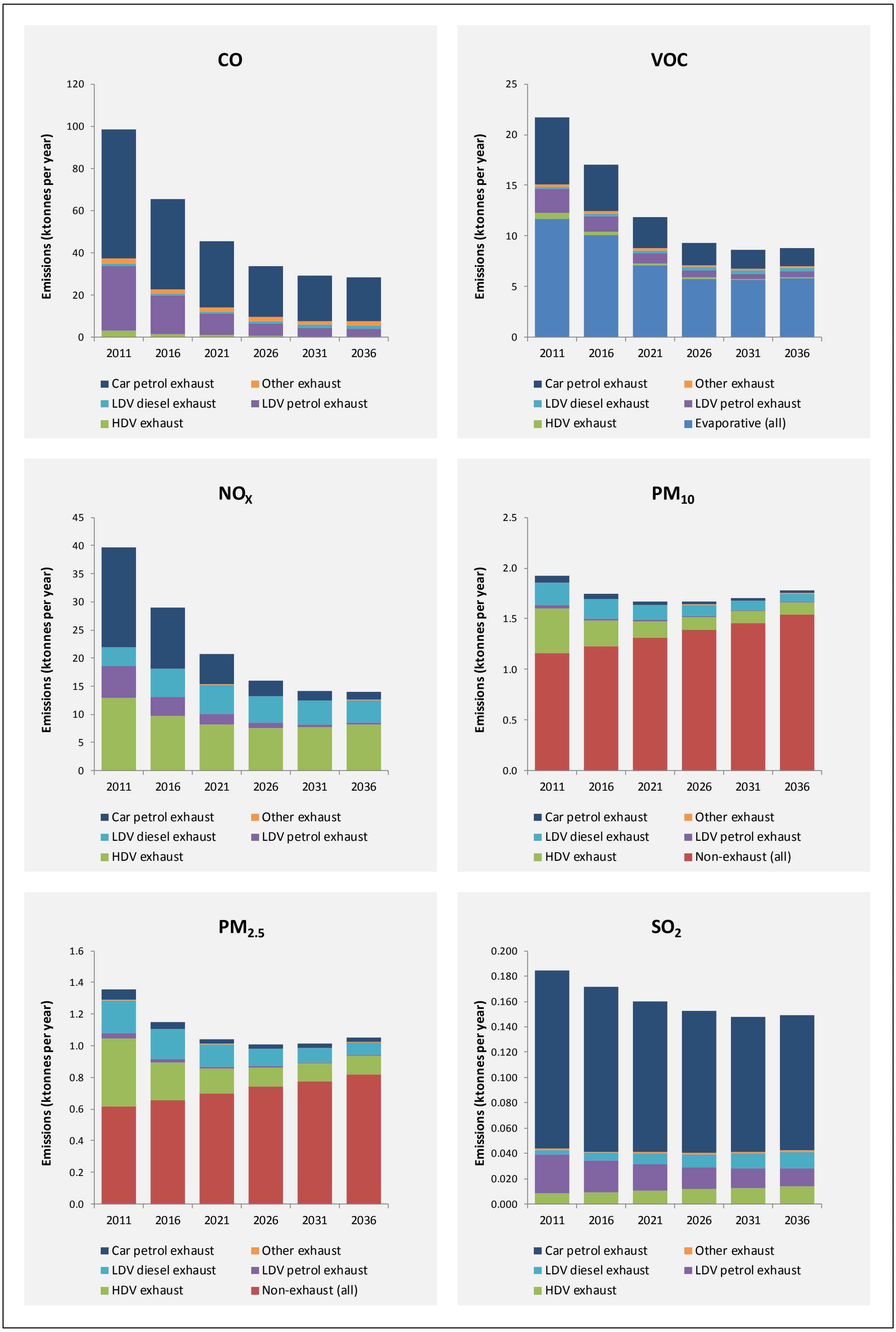

Figure 6-10 Projections of road transport emissions – Sydney, 2011-2036

6.6 In-tunnel air quality

Air quality is monitored continuously in all Sydney's major road tunnels. Monitors are installed along the length of each tunnel. These typically measure CO and visibility, and are specially designed for use in road tunnels where access for routine essential maintenance is restricted by the need to minimise traffic disruption. The instruments typically only have a coarse resolution. More precise instrumentation has been installed in the ventilation outlets of some tunnels, with measurements including PM_{10}, $PM_{2.5}$, NO_X and NO_2. Some of the data are available on the web sites of the tunnel operators[21,22], and measurements from some of the tunnels have been used to support the air quality assessment for the project.

6.7 Ambient air quality

In order to understand the likely and potential impacts of the project on air quality, a good understanding of the existing air quality in Sydney was essential. The following sections provide a brief overview of air quality in Sydney and a summary of an extensive analysis of the data from monitoring stations in the study area.

6.7.1 General characteristics of air quality on Sydney

Air quality in the Sydney region has improved over the last few decades. The improvements have been attributed to initiatives to reduce emissions from industry, motor vehicles, businesses and residences.

Historically, elevated levels of CO were generally only encountered near busy roads, but concentrations have fallen as a result of improvements in motor vehicle technology. Since the introduction of unleaded petrol and catalytic converters in 1985, peak CO concentrations in central Sydney have plummeted, and the last exceedance of the air quality standard for CO in NSW was recorded in 1998 (NSW DECCW, 2009; 2010).

While levels of NO_2, SO_2 and carbon CO continue to be below national standards, levels of ozone and particles (PM_{10} and $PM_{2.5}$) can exceed the standards from time to time.

Ozone and PM levels are affected by:

- The annual variability in the weather.
- Natural events such as bushfires and dust storms, as well as hazard-reduction burns.
- The location and intensity of local emission sources, such as wood heaters, transport and industry (NSW OEH, 2015).

6.7.2 Data from existing monitoring sites in the study area

A detailed analysis of historical trends (2004-2014) and the current state of Sydney's air quality is provided in Appendix F. The analysis was based upon data from multiple long-term monitoring stations operated by OEH and Roads and Maritime, as well as from monitoring stations that were established more recently and specifically for the project. The data from the long-term monitoring sites were also used to define appropriate background concentrations of pollutants for the project assessment.

The data for specific air quality metrics during the period 2004-2014 can be summarised as follows:

- Maximum one-hour and rolling eight-hour mean CO concentrations
    - o All maximum values were well below the air quality criteria of 30 mg/m^3 (one-hour) and 10 mg/m^3 (eight-hour).

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[21] http://www.lanecovemotorways.com.au/downloads.htm

[22] http://www.crosscity.com.au/AirQuality.htm

- There was a general downward trend in concentration, but it was not statistically significant at any site.

- Annual mean NO_2 concentration
  - Concentrations at all sites were well below the NSW air quality criterion of 62 µg/m^3. Values at the OEH sites exhibited a systematic, and generally significant, downward trend. However, in recent years the concentrations at some sites appear to have stabilised. At the Roads and Maritime background sites there was no significant downward trend.
  - The average NO_2 concentrations at the roadside sites were 34-37 µg/m^3, and therefore around 10-15 µg/m^3 higher than those at the background sites. Even so, the NO_2 concentrations at roadside were also well below the assessment criterion.
- Maximum one-hour NO_2 concentration
  - Although variable, maximum NO_2 concentrations have been quite stable with time, and the values at all sites continue to be below the NSW criterion of 246 µg/m^3.
  - The maximum one-hour mean NO_2 concentrations at the Roads and Maritime roadside sites in 2014 were 115 and 122 µg/m^3 respectively. These values are on a par with the higher maximum values for the background sites.
- Annual mean PM_{10} concentration
  - Concentrations at the OEH sites showed a downward trend between 2004 and 2014, but this was only statistically significant at two sites. In recent years the annual mean concentration at the OEH sites has been between 17 µg/m^3 and 20 µg/m^3, except at Lindfield where the concentration is substantially lower (around 14 µg/m^3). The concentration at the Roads and Maritime background sites appears to have stabilised at around 15 µg/m^3. These values can be compared with air quality criterion of 30 µg/m^3.
- Maximum 24-hour PM_{10} concentration
  - Maximum 24-hour PM_{10} concentrations exhibited a slight downward trend, but there was a large amount of variation from year to year. In 2014 the concentrations at the various sites were clustered around 40 µg/m^3, but the historical patterns suggest that this would be unlikely to continue into the future.
- Annual mean $PM_{2.5}$ concentration
  - $PM_{2.5}$ is only measured at three OEH sites in the study area. Concentrations at the two OEH sites close to WestConnex – Chullora and Earlwood - showed a broadly similar pattern, with a systematic reduction between 2004 and 2012 being followed by a substantial increase between 2012 and 2014. The main reason for the increase was a change in the measurement method. The increases meant that background $PM_{2.5}$ concentrations in the study area during 2014 were already very close to or above the advisory reporting standard in the AAQ NEPM of eight µg/m^3.
- Maximum 24-hour $PM_{2.5}$ concentration
  - There has been no systematic trend in the maximum 24-hour $PM_{2.5}$ concentration. As with the annual mean $PM_{2.5}$ concentration, the maximum one-hour concentrations are very close to or above the advisory reporting standard in the AAQ NEPM of 25 µg/m^3.

6.7.3 Project-specific monitoring

WDA has established five monitoring stations in the M4 East GRAL domain to support the development and assessment of the project. WDA commissioned Pacific Environment to operate and maintain the monitoring network, further details of which are provided in Appendix F. The monitoring stations were designed to supplement the existing OEH and Roads and Maritime stations, establish the representativeness of the data from these sites, and to provide long-term air quality data in the vicinity of the project. The locations of the monitoring stations were determined with consideration being given to of a number of criteria; one station is located at an urban background site and four stations are located to characterise population exposure near busy roads.

Although the time period covered by the project-specific monitoring sites was too short for them to be included in the characterisation of background air quality, the data from the urban background site for the project was used to examine the representativeness of the OEH and Roads and Maritime sites for this purpose (Appendix F). In addition, the project-specific monitoring data were used to evaluate the performance of the GRAL model in the vicinity of the project (Appendix J).

7 Assessment of construction impacts

7.1 Overview

This Chapter deals with the potential impacts of the construction phase of the project. The guidance published by the UK Institute of Air Quality Management (IAQM, 2014) was applied for the construction assessment. Professional judgement was required at some stages, and where justification for assumptions could not be fully informed by data a precautionary approach was adopted.

The IAQM guidance is designed primarily for use in the UK, although it may be applied elsewhere. Here, the guidance has been adapted for use in NSW, taking into account factors such as the assessment criteria for ambient PM_{10} concentrations.

7.2 Construction footprint

The majority of the construction footprint of the project is located underground. However, surface works would be required to support tunnelling activities and to construct surface infrastructure such as interchanges, tunnel portals, ventilation facilities, ancillary operations buildings and facilities, and the eastbound cycleway near the Homebush Bay Drive interchange.

The overall surface construction footprint generally aligns with the operational footprint, with the locations of future operational ancillary facilities being used to support construction work. Some additional areas adjacent to the operational footprint (around the portals and on- and off-ramps, and also at the tunnel mid-point) would also be required during the construction stage only to facilitate construction access. Construction ancillary facilities would be located at the following 10 locations:

- Homebush Bay Drive civil site (C1)
- Pomeroy Street civil site (C2)
- Underwood Road tunnel and civil site (C3)
- Powells Creek civil site (C4)
- Concord Road civil and tunnel site (C5)
- Cintra Park tunnel site (C6)
- Northcote Street tunnel site (C7)
- Eastern ventilation facility site (C8)
- Wattle Street and Walker Avenue civil site (C9)
- Parramatta Road civil site (C10).

Despite this, additional land utilised only during the construction period would be required at:

- Pomeroy Street (Bill Boyce Reserve)
- Underwood Road
- Cintra Park
- Parramatta Road near Northcote Street
- Parramatta Road near Walker Avenue and the eastern ventilation facility
- Wattle Street (Reg Coady Reserve).

In order to facilitate access to construction areas, additional areas adjacent to the operational footprint would be required around the portals and on and off-ramps. The total area required to facilitate construction of the project is referred to as the construction footprint. The construction footprint would be around 46 hectares in total. An overview of the construction footprint was shown in Figure 2-2.

7.3 Construction activities for the project

7.3.1 Tunnelling

The majority of tunnelling activities would be carried out underground and are therefore not considered in the construction footprint, or this risk assessment. However, each of the tunnelling launch and support sites would require support services for the tunnelling activity including power supply, ventilation, water supply, construction water treatment plants, workforce facilities and spoil handling and removal.

On completion of the tunnelling works, a variety of civil finishing works would occur, including:

- Stormwater and groundwater drainage systems
- Pavement construction
- Electrical and communication conduits
- Deluge and hydrant fire mains
- Road furniture installation
- Cross passages and long egress passages
- Substations
- Low point sump
- Ventilation facilities
- Architectural panels
- Painting.

Tunnelling work where practical will continue 24-hours per day, seven days per week until completion.

7.3.2 Surface earthworks and structures

Surface earthworks would be required for the following above ground locations:

- Cycleway on the northern side of the existing M4, starting east of Homebush Bay Drive
- Widening of the existing M4 west of Homebush Bay Drive
- Dive structures and cut and cover tunnel sections at the four interchange locations
- Realignment of Wattle Street
- Realignment of Parramatta Road
- Ancillary facilities such as the motorway operations complex and ventilation facilities.

Earthworks would be completed using conventional methods of road construction. The general earthworks construction method would include:

- Vegetation clearance and topsoil stripping. Mulched vegetation and topsoil would be stockpiled for later re-use in site rehabilitation and landscaping works
- Areas of new cut and fill to design levels, and widening of existing cuts and embankments. This may include the construction of retaining walls and reinforced soil walls
- Installation of road drainage infrastructure.

The project will also require three new bridges to be constructed and three existing bridges to be modified or replaced.

The construction of new bridges would generally involve:

- Construction of the substructure, likely to be from cast in-situ concrete in the following sequence:
    - Piling works, such as bored piles
    - Pile cap construction including localised excavation around the piles
    - Pier or column construction
- Headstock construction
- Construction of the superstructure, likely to be through the placement of pre-cast concrete segments.

The project has been designed with the aim of minimising the need for land acquisition and property demolition as far as practical. However, the project would require the demolition of a number of properties located within the construction footprint. Generally, demolition works would be undertaken early in the construction program to ensure site readiness and to allow main construction activities to commence.

7.4 Assessment procedure

The IAQM assessment procedure for assessing risk is shown in Figure 7-1. Professional judgement is required in some steps, and where justification cannot be given a precautionary approach should be adopted.

Activities on construction sites can be divided into four types to reflect their different potential impacts, and the potential for dust emissions is assessed for each activity that is likely to take place. These activities are:

- Demolition. Demolition is any activity that involves the removal of existing structures. This may also be referred to as de-construction, specifically when a building is to be removed a small part at a time.
- Earthworks. This covers the processes of soil stripping, ground levelling, excavation and landscaping. Earthworks will primarily involve excavating material, haulage, tipping and stockpiling.
- Construction. Construction is any activity that involves the provision of new structures, modification or refurbishment. A structure will include a residential dwelling, office building, retail outlet, road, etc.
- Track-out. This involves the transport of dust and dirt by HDVs from the construction/demolition site onto the public road network, where it may be deposited and then re-suspended by vehicles using the network.

The assessment methodology considers three separate dust impacts:

- Annoyance due to dust soiling.
- The risk of health effects due to an increase in exposure to PM_{10}.
- Harm to ecological receptors

The assessment is used to define appropriate mitigation measures to ensure that there will be no significant effect.

The assessment steps, as they were applied to the M4 East project, are summarised in the following Sections.

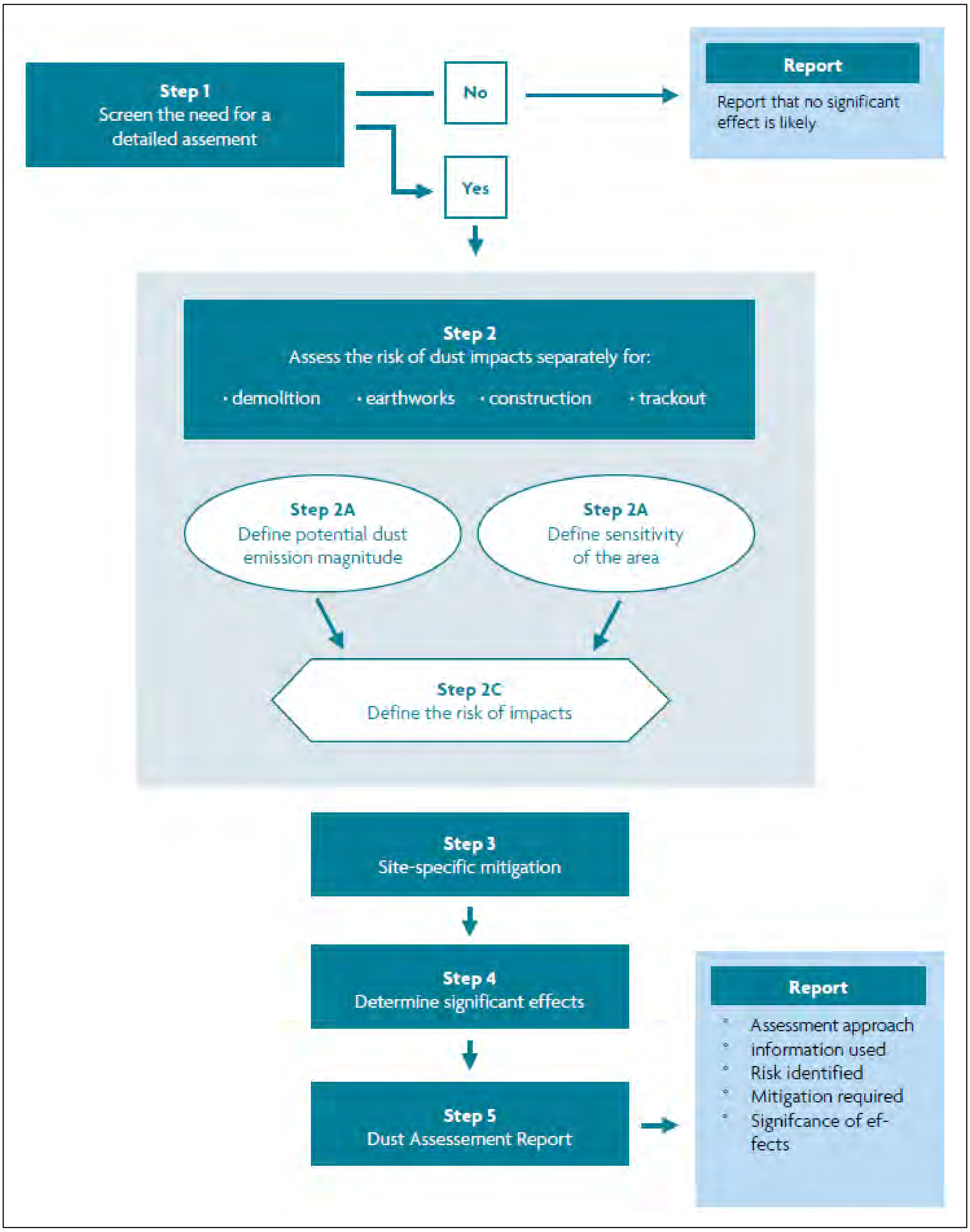

Figure 7-1 Steps in an assessment of construction dust (IAQM, 2014)

7.5 Step 1: Screening

Step 1 is a screening assessment. A construction dust assessment will normally be required where:

- There are human receptors within 350 metres of the boundary of the site and/or within 50 metres of the route(s) used by construction vehicles on the public highway, up to 500 metres from the site entrance(s).
- There are ecological receptors within 50 metres of the boundary of the site and/or within 50 metres of the route(s) used by construction vehicles on the public highway, up to 500 metres from the site entrance(s).

A 'human receptor', refers to any location where a person or property may experience the adverse effects of airborne dust or dust soiling, or exposure to PM_{10} over a time period relevant to air quality standards and goals. In terms of annoyance effects, this will most commonly relate to dwellings, but may also refer to other premises such as buildings housing cultural heritage collections (e.g. museums and galleries), vehicle showrooms, food manufacturers, electronics manufacturers, amenity areas and horticultural operations (e.g. salad or soft-fruit production). An 'ecological receptor' refers to any sensitive habitat affected by dust soiling. This includes the direct impacts on vegetation or aquatic ecosystems of dust deposition, and the indirect impacts on fauna (e.g. on foraging habitats) (IAQM, 2014).

In this screening stage the individual areas of proposed construction works were examined in combination. It can be seen from Figure 7-2 that there are multiple off-site human receptors within 350 metres of the boundary of the project site. The area potentially affected by construction dust does not contain any areas of ecological significance[23]. The construction assessment therefore proceeded to Step 2 for soiling and human health impacts only and the ecological impacts were not assessed.

7.6 Step 2: Risk assessment

In Step 2 the risk of dust arising in sufficient quantities to cause annoyance and/or health effects was determined separately for each scenario and each of the four activities (demolition, earthworks, construction, and track-out). Risk categories were assigned to the site based on two factors:

- The scale and nature of the works, which determines the magnitude of potential dust emissions. This is assessed in Step 2A.
- The sensitivity of the area. The proximity of sensitive receptors (i.e. the potential for effects). This is assessed in Step 2B.

These factors are combined in Step 2C to give the risk of dust impacts. Risks are described in terms of there being a low, medium or high risk of dust impacts for each of the four separate potential activities. Where there is risk of an impact, then site-specific mitigation will be required in proportion to the level of risk.

7.6.1 Step 2A: Potential for dust emissions

The criteria for assessing the potential scale of emissions based on the scale and nature of the works are shown in Table 7-1. Based on these criteria, the appropriate categories for the M4 East project are shown in Table 7-2.

[23] DPI (2000). Mapping the estuarine habitats of NSW. Department of Primary Industries. http://www.dpi.nsw.gov.au/research/areas/aquatic-ecosystems/estuarine-habitats-maps

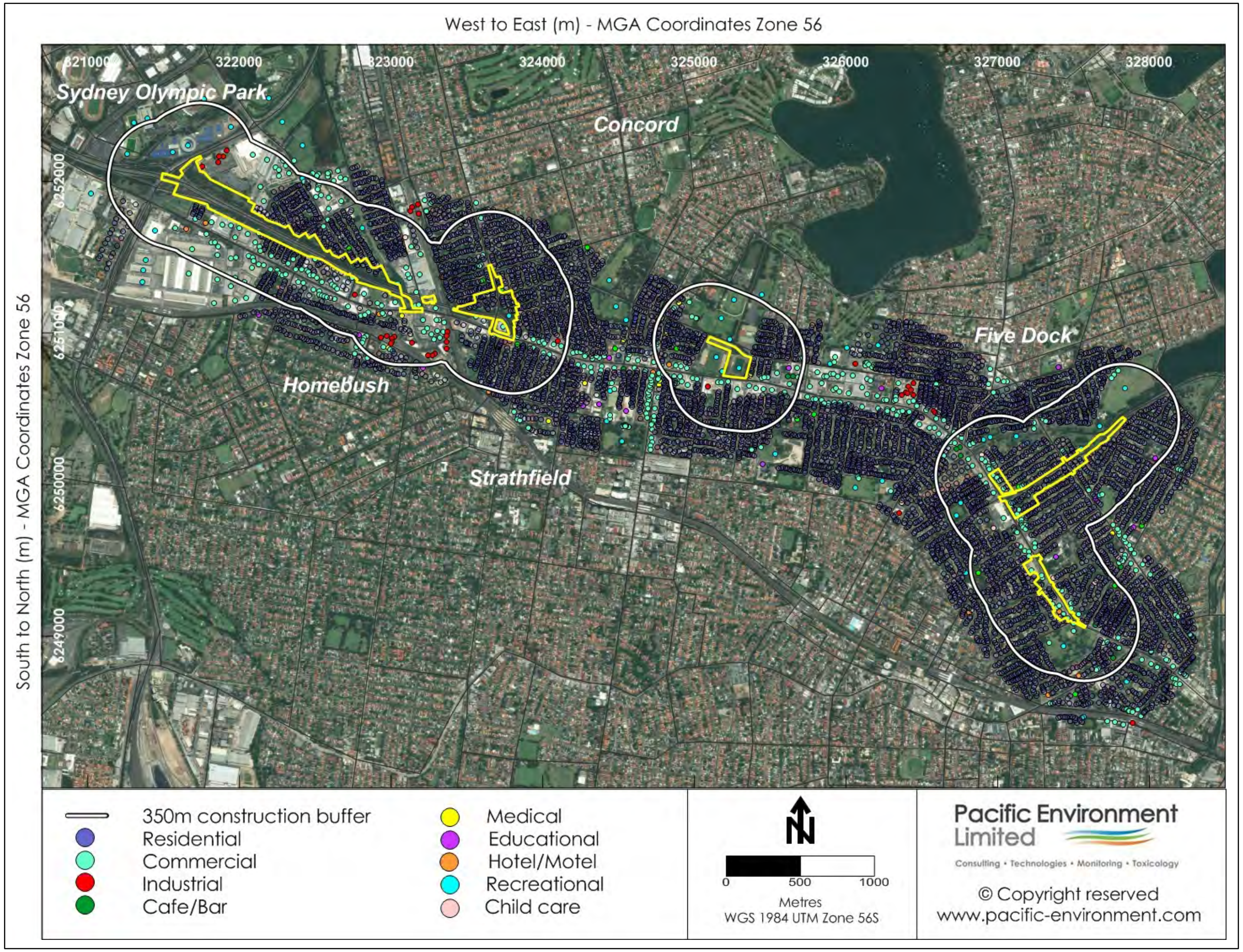

Figure 7-2 Screening assessment – human receptors near the M4 East project

Table 7-1 Main scenarios for operational assessment

Type of activity	Site category		
	Large	Medium	Small
Demolition	Building volume >50,000 m^3, potentially dusty construction material (e.g. concrete), on-site crushing and screening, demolition activities >20 m above ground level.	Building volume 20,000–50,000m^3, potentially dusty construction material, demolition activities 10-20 m above ground level.	Building volume <20,000 m^3, construction material with low potential for dust release (e.g. metal cladding, timber), demolition activities <10 m above ground and during wetter months.
Earthworks	Site area >10,000 m^2, potentially dusty soil type (e.g. clay, which will be prone to suspension when dry due to small particle size), >10 heavy earth-moving vehicles active at any one time, formation of bunds>8 m in height, total material moved >100,000 tonnes.	Site area 2,500-10,000 m^2, moderately dusty soil type (e.g. silt), 5-10 heavy earth moving vehicles active at any one time, formation of bunds 4-8 m in height, total material moved 20,000-100,000 tonnes.	Site area <2,500 m^2, soil type with large grain size (e.g. sand), <5 heavy earth moving vehicles active at any one time, formation of bunds <4 m in height, total material moved <20,000 tonnes, earthworks during wetter months.
Construction	Total building volume >100,000 m^3, piling, on site concrete batching; sandblasting	Building volume 25,000-100,000 m^3, potentially dusty construction material (e.g. concrete), piling, on site concrete batching.	Total building volume <25,000 m^3, construction material with low potential for dust release (e.g. metal cladding or timber).
Track-out	>50 HDV (>3.5t) OUTWARD movements in any one day, potentially dusty surface material (e.g. high clay content), unpaved road length >100 m.	10-50 HDV (>3.5t) OUTWARD movements in any one day, moderately dusty surface material (e.g. high clay content), unpaved road length 50–100 m.	<10 HDV (>3.5t) OUTWARD movements in any one day, surface material with low potential for dust release, unpaved road length <50 m.

Table 7-2 Main scenarios for operational assessment

Type of activity	Site category
Demolition	Large
Earthworks	Large
Construction	Large
Track-out	Large

7.6.2 Step 2B: Sensitivity of area

The sensitivity of the area takes into account the specific sensitivities of local receptors, the proximity and number of the receptors, and the local background PM_{10} concentration. Dust soiling and health impacts are treated separately.

Sensitivity of area to dust soiling effects on people and property

The criteria for determining the sensitivity of an area to dust soiling effects are shown in Table 7-3. Based on the IAQM guidance the receptor sensitivity was assumed to be ‘high’.

Table 7-3 Criteria for sensitivity of area to dust soiling effects (IAQM, 2014)

Receptor sensitivity	Number of receptors	Distance from source (m)			
		<20	<50	<100	<350
High	>100	High	High	Medium	Low
	10-100	High	Medium	Low	Low
	1-10	Medium	Low	Low	Low
Medium	>1	Medium	Low	Low	Low
Low	>1	Low	Low	Low	Low

The number of receptors in each distance band was estimated from an aerial photograph of the site. The exact counting of the number of 'human receptors' is not required by the IAQM guidance. Instead it is recommended that judgement is used to determine the approximate number of receptors within each distance band. For receptors which are not dwellings professional judgement should be used to determine the number of human receptors. In the case of the M4 East project we assumed the following numbers of receptors per building:

- Residential property = 1 receptor
- Café/restaurant = 10 receptors
- Commercial property = 20 receptors
- Hotel = 50 receptors

The numbers of receptors for each scenario and activity, and the resulting outcomes are shown in Table 7-4.

Table 7-4 Criteria for sensitivity of area to dust soiling effects

Receptor sensitivity	Receptor sensitivity	Number of receptors by distance from source (m)				Sensitivity of area
		<20	20-50	50-100	100-350	
Demolition	High	991	1,713	1,999	11,448	High
Earthworks	High	991	1,713	1,999	11,448	High
Construction	High	991	1,713	1,999	11,448	High
Track-out	High	991	1,713	-	-	High

Sensitivity of area to human health impacts

The criteria for determining the sensitivity of an area to human health impacts caused by construction dust are shown in Table 7-5. Based on the IAQM guidance[24] the receptor sensitivity was assumed to be 'high'. The numbers of receptors for each scenario and activity, and the resulting outcomes are shown in Table 7-6.

[24] The sensitivity of people to the health effects of PM_{10} is based on exposure to elevated concentrations over a 24-hour period. High sensitivity receptors relate to locations where members of the public are exposed over a time period relevant to the air quality objective for PM_{10} (in the case of the 24-hour objectives, a relevant location would be one where individuals may be exposed for eight hours or more in a day). Indicative examples include residential properties. Hospitals, schools and residential care homes should also be considered as having equal sensitivity to residential areas for the purposes of this assessment.

Table 7-5 Criteria for sensitivity of area to health impacts (IAQM, 2014)

Receptor sensitivity	Annual mean PM_{10} conc. ($\mu g/m^3$) (a)	Number of receptors	Distance from source (m)				
			<20	<50	<100	<200	<350
High	>24	>100	High	High	High	Medium	Low
		10-100	High	High	Medium	Low	Low
		1-10	High	Medium	Low	Low	Low
	21-24	>100	High	High	Medium	Low	Low
		10-100	High	Medium	Low	Low	Low
		1-10	High	Medium	Low	Low	Low
	18-21	>100	High	Medium	Low	Low	Low
		10-100	High	Medium	Low	Low	Low
		1-10	Medium	Low	Low	Low	Low
	<18	>100	Medium	Low	Low	Low	Low
		10-100	Low	Low	Low	Low	Low
		1-10	Low	Low	Low	Low	Low
Medium	-	>10	High	Medium	Low	Low	Low
		1-10	Medium	Low	Low	Low	Low
Low	-	>1	Low	Low	Low	Low	Low

(a) Scaled to Sydney according to the ratio of NSW and UK annual mean standards (30 $\mu gm/^3$ and 40 $\mu gm/^3$ respectively).

Table 7-6 Criteria for sensitivity of area to dust soiling effects

Activity	Receptor sensitivity	Annual mean PM_{10} conc ($\mu g/m^3$)(a)	Number of receptors by distance from source (m)					Sensitivity of area
			<20	20-50	50-100	100-200	200-350	
Demolition	High	18-21	991	1,713	1,999	2,954	8,494	High
Earthworks	High	18-21	991	1,713	1,999	2,954	8,494	High
Construction	High	18-21	991	1,713	1,999	2,954	8,494	High
Track-out	High	18-21	991	1,713	-	-	-	High

(a) Appendix F shows a suitable and conservative level for this to be 18-21 $\mu g/m^3$

7.6.3 Step 2C: Risk of dust impacts

The dust emission potential determined in Step 2A is combined with the sensitivity of the area determined in Step 2B to give the risk of impacts with no mitigation applied. The criteria are shown in Table 7-7.

The final results for the Step 2 risk assessment are provided in Table 7-8. All activities were determined to be 'high risk' for dust soiling and human health.

Table 7-7 Criteria for sensitivity of area to health impacts (IAQM, 2014)

Type of activity	Sensitivity of area	Dust emission potential		
		Large	Medium	Small
Demolition	High	High Risk	Medium Risk	Medium Risk
	Medium	High Risk	Medium Risk	Low Risk
	Low	Medium Risk	Low Risk	Negligible
Earthworks	High	High Risk	Medium Risk	Low Risk
	Medium	Medium Risk	Medium Risk	Low Risk
	Low	Low Risk	Low Risk	Negligible
Construction	High	High Risk	Medium Risk	Low Risk
	Medium	Medium Risk	Medium Risk	Low Risk
	Low	Low Risk	Low Risk	Negligible
Track-out	High	High Risk	Medium Risk	Low Risk
	Medium	Medium Risk	Low Risk	Negligible
	Low	Low Risk	Low Risk	Negligible

Table 7-8 Summary of risk assessment for construction

Type of activity	Step 2A: Potential for dust emissions	Dust soiling	Human health	Ecological	Dust soiling	Human health	Ecological
Demolition	Large	High	High	N/A	High	High	N/A
Earthworks	Large	High	High	N/A	High	High	N/A
Construction	Large	High	High	N/A	High	High	N/A
Track-out	Large	High	High	N/A	High	High	N/A

7.7 Step 3: Mitigation

Step 3 involved determining mitigation measures for each of the four potential activities in Step 2. This was based on the risk of dust impacts identified in Step 2C. For each activity, the highest risk category was used. The suggested mitigation measures are discussed in Section 10.1.

7.8 Step 4: Significance of risks

Once the risk of dust impacts has been determined in Step 2C and the appropriate dust mitigation measures identified in Step 3, the final step is to determine whether there are residual significant effects arising from the construction phase of a proposed development. For almost all construction activity, the aim should be to prevent significant effects on receptors through the use of effective mitigation. Experience shows that this is normally possible. Hence the residual effect will normally be 'not significant' (IAQM, 2014).

However, even with a rigorous Construction Air Quality Management Plan in place, it is not possible to guarantee that the dust mitigation measures will be effective all the time. There is the risk that nearby residences, commercial buildings, hotel, cafés and schools in the immediate vicinity of the construction zone, might experience some occasional dust soiling impacts. This does not imply that impacts are likely, or that if they did occur, that they would be frequent or persistent. Overall construction dust is unlikely to represent a serious ongoing problem. Any effects would be temporary and relatively short-lived, and would only arise during dry weather with the wind blowing towards a receptor, at a time when dust is being generated and mitigation measures are not being fully effective. The likely scale of this would not normally be considered sufficient to change the conclusion that with mitigation the effects will be ‘not significant’.

In the western and central areas of the project, the nearest sensitive receptors are located along Parramatta Road north and south of the designated construction area. At the eastern end of the project as Parramatta Road turns towards the southeast, receptors are towards the east and west of Parramatta Road as well as along Wattle Street to the northeast.

A review of the annual and seasonal wind roses (Appendix H) indicates that winds that could be capable of transporting emissions towards receptors. In view of the transitional nature of the prevailing winds with respect to the receptors this could occur at any time of year.

There are unlikely to be any construction projects of this magnitude occurring concurrently with this project in the immediate vicinity. As such, cumulative impacts due to construction are unlikely.

8 Assessment of operational impacts

8.1 Overview

This Chapter describes in detail the methods used to assess the operational impacts of the project on emissions and air quality, and presents the results of the assessment. The assessment took into account the emissions from motor vehicles on both surface roads and tunnel roads.

The Chapter describes the following:

- **Emissions**, including:
  - The emission models that were used and the reasons for their selection.
  - Model inputs.
  - Emission model evaluation.
  - Results.
- **In-tunnel air quality**, including the approach used and the results.
- **Ambient air quality**, including:
  - The meteorological and dispersion models that were used and the reasons for their selection.
  - Model set-up.
  - Post-processing of dispersion model outputs.
  - Meteorological and dispersion model evaluation.
  - Results.
- **Key assumptions** in the assessment, including a discussion of the level of conservatism associated with these assumptions where possible.
- **Sensitivity tests** that were conducted.

8.2 Emissions

8.2.1 Introduction

A spatial emissions inventory was developed for road traffic sources in the WestConnex GRAL domain. This following components were treated separately:

- Emissions from the proposed ventilation outlets of the project tunnel. These were calculated using the emission factors provided by PIARC (2012) – Australian Appendix.
- Emissions from the traffic on the surface road network, including any new roads associated with the project. These were calculated on a link-by-link basis using an emission model developed by NSW EPA (2012b).
- Emissions from the ventilation outlet of the M5 East tunnel (the only existing tunnel in the WestConnex GRAL domain). These were calculated using historical measurements in the ventilation outlet.

The assessment was conducted assuming no emissions from the project tunnel portals; that is, all emissions from the traffic in the tunnel were assumed to be released to the atmosphere via the eastern and western ventilation facilities.

The stages in the calculation of the emissions inventory are described below. More detailed descriptions of the models used, including evaluations, are provided in Appendix E.

8.2.2 M4 East tunnel ventilation outlets

Model selection

Emissions from the traffic in the M4 East tunnel were calculated using the emission factors provided in the PIARC guidance Road Tunnels: Vehicle Emissions and Air Demand for Ventilation (PIARC, 2012). PIARC recommends that its guidance is used for calculating the ventilation requirements for road tunnels. The guidance has been widely used internationally for the sizing of tunnel ventilation systems, and the 2012 guidance updates and replaces earlier guidance (e.g. PIARC, 2004). The approach establishes the ventilation capacity for normal operation, which is defined as the minimum amount of fresh air required to dilute vehicle emissions to maintain in-tunnel air quality and visibility within specified limits (see Section 4.4.4).

Appendix 3, Section 3.1 of the PIARC guidance includes aggregated emission rates for Australian vehicles. These Australia-specific emission rates have recently been used for tunnel ventilation calculations in NSW (see Appendix D), and they were also used for the current project. The three pollutants assessed for tunnel ventilation purposes were NO_2, CO and $PM_{2.5}$.

Input data

Expected traffic scenarios

Total expected traffic volumes in the tunnel were taken initially from the WRTM (see section 8.2.3). The traffic composition in the WRTM fleet was adjusted to match the PIARC vehicle definitions. Data from several sources were used to determine a realistic traffic mix for the tunnel traffic. The estimated traffic volume, composition and speed in the M4 East tunnel (main line) in 2021 and 2031 are shown in Figure 8-1. A traffic speed of 80 kilometres per hour (i.e. free-flowing traffic) was used for all time periods. The division of the traffic at tunnel on-ramps and off-ramps was also taken into account.

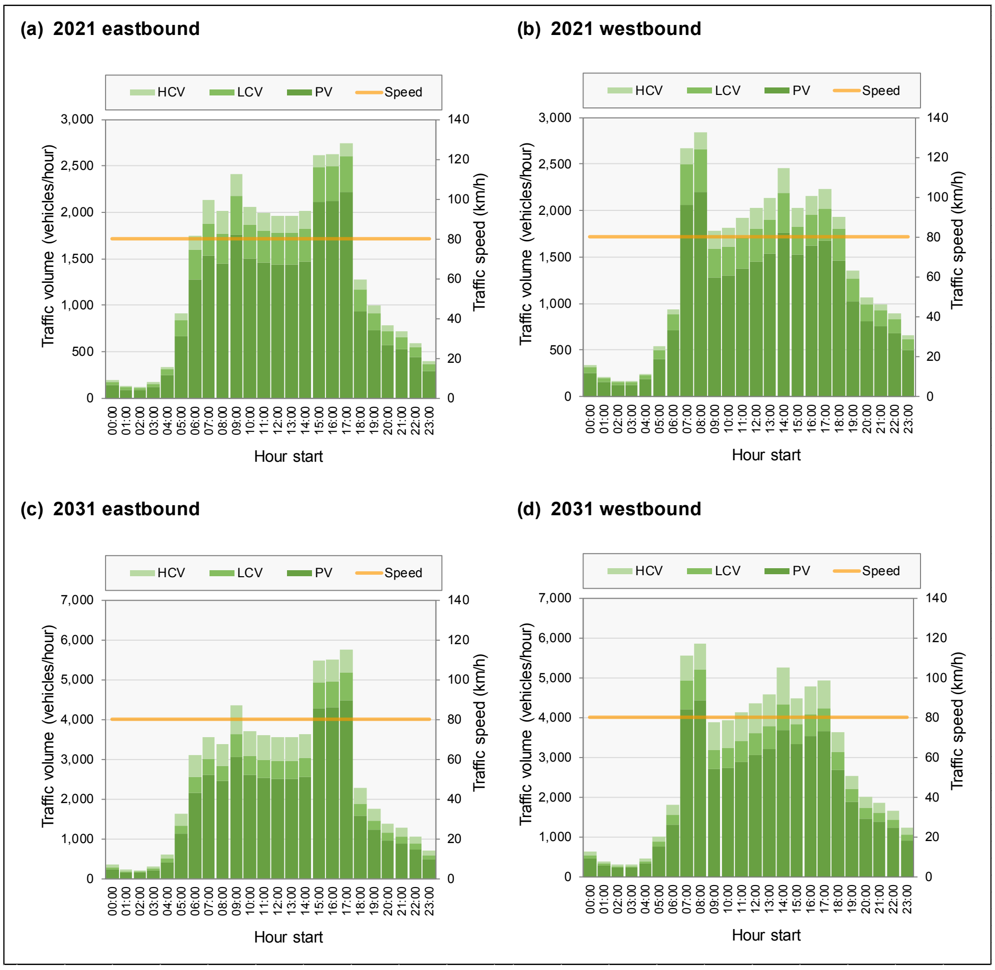

Figure 8-1 Estimated traffic volume, composition and speed in the M4 East tunnel

Capacity traffic scenarios

Capacity traffic volumes were generated as described in Appendix L. The traffic volumes at capacity were then modelled for a range of speeds (20, 40, 60 and 80 kilometres per hour). The lower speeds taken into account the effects of traffic congestion.

Vehicle breakdown scenario

For the reasons explained in Appendix L, a vehicle breakdown scenario is likely to result in lower emissions than the capacity traffic scenarios.

Other considerations

Some modifications were required to the emission rates of these pollutants for the purpose of dispersion modelling. These modifications involved the following:

- Converting the NO_2 emission rates to the NO_X emission rates required for dispersion modelling.
- Estimating emissions of pollutants and metrics not included in the in-tunnel assessment (PM_{10} and THC).

To convert the NO_2 emission rates to the NO_X emission rates required for dispersion modelling, the NO_2/NO_X ratio used was 13 per cent. This value was representative of the ratio used for the tunnel ventilation work.

The emission modelling for the M4 East tunnel was duplicated using the NSW EPA emissions model (and the European Environment Agency's Guidebook method for non-exhaust PM) in conjunction with the same traffic data and tunnel geometry used for the in-tunnel air quality assessment. These calculations were used to determine PM_{10} and THC emission rates. The $PM_{2.5}$ emission rate from the tunnel ventilation work was multiplied by a $PM_{10}/PM_{2.5}$ ratio (1.4) to determine PM_{10}. The THC emission rates for dispersion modelling were estimated using the THC/NOx ratio from the calculations using the NSW EPA model.

The diurnal profiles of outlet emission rates for each scenario and ventilation outlet are given in Appendix I. The diurnal profiles for the emission rates of CO, NO_X, PM_{10}, $PM_{2.5}$ and THC in the 2021-DS, 2031-DS and 2031-DS scenarios are shown in Figure 8-2 and Figure 8-3.

A further step was necessary for the modelling of ventilation outlet emissions in GRAL. In the model, emissions from point sources are characterised as a single annual average value, stated in kg/h. This average value therefore had to be calculated for the separate time periods modelled for each outlet (see Table 8-17), and 'modulation factors' (ratios, relative to the average) were used in GRAL to replicate the variation in emissions within each time period. The average emission factors for each time period are also shown in the tables in Appendix I. No seasonal variation was built into the emission rates.

The pollutant concentrations in the tunnel outlets that are consistent with the assumptions in GRAL are also provided in Appendix I.

Results

Expected traffic scenarios

The ventilation outlet emission rates for the expected traffic scenario are provided in Appendix I.

Capacity traffic scenarios

The emission rates for the capacity traffic scenarios are given in Appendix L. However, dispersion modelling was not conducted for these scenarios for the reasons given in section 8.3.

Breakdown scenarios

The vehicle breakdown scenario is discussed in Appendix L. Again, dispersion modelling was not conducted for this scenario.

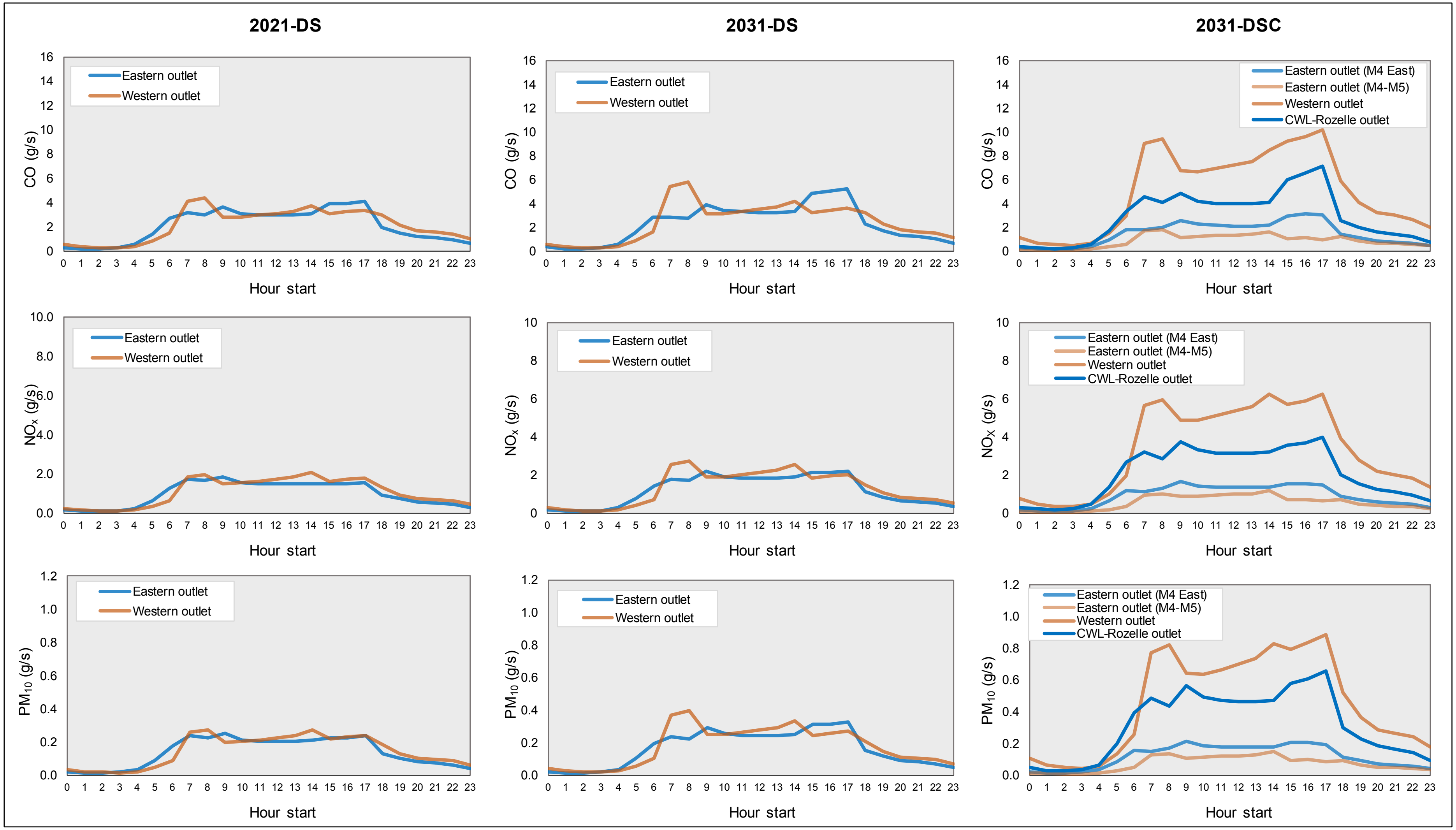

Figure 8-2 **Emission rates for project ventilation outlets (CO, NOx and PM_{10})**

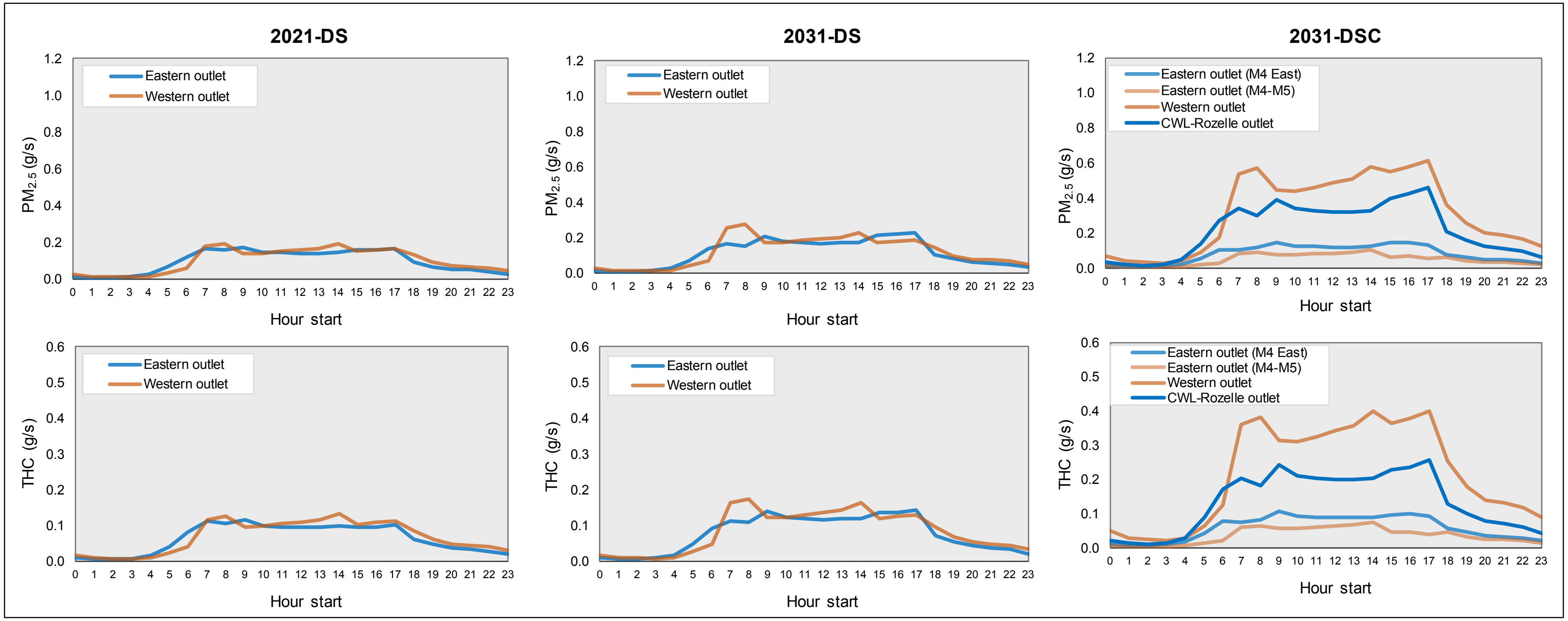

Figure 8-3 Emission rates for project ventilation outlets ($PM_{2.5}$, THC)

8.2.3 Surface roads

Model selection

The following emission model characteristics were considered to be desirable for the surface road calculations:

- Good availability and accessibility (e.g. readily able to accommodate future updates).
- A high level of detail and robustness (i.e. based on sound principles, taking into account all processes generating emissions and the most important factors determining emission rates, and including all relevant pollutants).
- A good level of maintenance (i.e. being up-to-date).
- A good representation of the vehicles and fuels used in Sydney.
- A good representation of driving conditions in Sydney.
- The inclusion of emission projections for future years.

When estimating emissions from road transport it is important to distinguish between different types of vehicle, between vehicles using different types of fuel, and between vehicles conforming to different emission regulations. One of the most important factors is how vehicle operation (e.g. speed and acceleration are represented. Road gradient is also an important factor.

Various emission modelling approaches have been developed for the road transport sector. Most emission models are empirical in nature, being based on data from laboratory or real-world tests. A large number of emission models have been developed for surface roads.

The PIARC emission rates used for the tunnel ventilation work cover driving situations which are typical for road tunnels rather than surface roads (PIARC, 2012). PIARC states that the use of emission rates for surface roads should only be considered as an option where no local or national emissions data are available, and this was not the case for the project.

The most appropriate emission model for surface roads was considered to be the one developed by NSW EPA for the emissions inventory covering the Greater Metropolitan Region (GMR) (NSW EPA, 2012b). The main reasons for this choice were as follows:

- The model has been developed to a high standard; it is one of the most sophisticated models that has been developed for calculating emissions from road vehicles in NSW.
- The model includes pollutants that are not included in the PIARC model (e.g. PM_{10} and THC).
- The model has been specifically designed for use in the NSW GMR, and takes into account:
    - The operation of vehicles on surface roads.
    - The characteristics of vehicle fleets in the GMR.
- Many of the emission factors have been derived using an extensive database of Australian measurements. They allow for the deterioration in emissions performance with mileage, the effects of tampering or failures in emission-control systems, and the use of ethanol in petrol.
- The model includes emission factors for specific road types.
- Emission projections for several future years are available, taking into account the technological changes in the vehicle fleet.
- The model is up to date. The NSW GMR inventory was overhauled in 2012, with significant refinements to the road transport methodology.
- The model includes cold-start emissions. These are not likely to be relevant to motorway tunnels such as the M4 East, but they do need to be considered for roads with a larger proportion of vehicles operating in cold-start mode.
- The full emission inventory model is described in the report by NSW EPA (2012b). In 2012, a simplified version of the inventory model was developed by NSW EPA for use in the Roads and

Maritime air quality screening model TRAQ[25]. In January 2015 the EPA provided Pacific Environment with revised algorithms, and these were implemented in the methodology for this assessment, along with a number of other refinements including emission factors for primary NO_2.

The following models were also considered, but were not included for the reasons provided:

- National Pollutant Inventory (NPI) model. The NPI is compiled and maintained by the Australian Government. Manuals are provided on the NPI web site[26] to enable emissions from each sector of activity to be calculated. For road vehicles, Environment Australia (2000) provides the emissions estimation techniques for the relevant NPI substances, as well as guidance on the spatial allocation of emissions. The NPI manual for road vehicles is now well out of date, and could not therefore be recommended for use in the M4 East assessment. It has not been considered further in this Report. It is worth noting, however, that a new motor vehicle emission inventory for the NPI has recently been developed using the COPERT Australia software (see below) (Smit, 2014).
- COPERT Australia. This is a commercial model for calculating emissions from traffic on surface roads (Smit and Ntziachristos, 2012; 2013)[27]. The model has been developed to a high standard. It follows a similar structure to that of the COPERT 4 model that is widely used in Europe. COPERT Australia covers all the main vehicle classes and driving conditions in Australia, and is based upon a database of emission tests that is similar to that used in the NSW inventory model. However, the model was not evaluated in detail as part of the M4 East assessment, because a detailed model was already available from NSW EPA (and reflected the traffic, fuel and fleet conditions in NSW).

Input data

WestConnex Road Traffic Model

The accurate characterisation of traffic activity (such as number of vehicles, trip distances and modes of operation) and the fleet composition is vital to the estimation of emissions. Although models and emission factors are continually improving, activity data remains one of the main sources of uncertainty in the calculation of emissions

Data on traffic volume, composition and speed for surface roads in the WestConnex GRAL model domain were taken from the WestConnex Road Traffic Model (WRTM) which covered an extensive area south of Sydney Harbour. The traffic model provided outputs on a link-by-link basis for the different scenarios and for all major roads affected by the scheme. The WestConnex network coverage is shown in Figure 8-4.

The WRTM was developed to forecast traffic patronage and assess the most likely range of future traffic patronage across the WestConnex network. It is a regional strategic model for demand analysis and future forecasting. A number of different versions of the WRTM were developed. WRTM Version 2.1, with induced traffic demand, was used for the purpose of this report. WRTM Version 2.1 assumes the NSW Department of Planning and Environment’s 2014 land use projections.

The demand for road trips between zones (trip matrices) for the range of forecast years modelled are derived from the Transport for NSW’s Bureau of Transport Studies (BTS) multi modal Strategic Travel Model (STM) using the latest (2014) land use projections. The zone-to-zone (origin/destination) trip matrices were distributed and assigned to the modelled road network using a model that included least cost travel equations and input values of travel time from surveys.

The WRTM patronage forecasting model developed for this project comprises two separate elements, the Base Demand Model and the Toll Choice Assignment Model (to incorporate toll choice behaviour).

[25] Tool for Roadside Air Quality (TRAQ).
[26] http://www.npi.gov.au/reporting/industry-reporting-materials/emission-estimation-technique-manuals
[27] http://www.emisia.com/copertaustralia/General.html

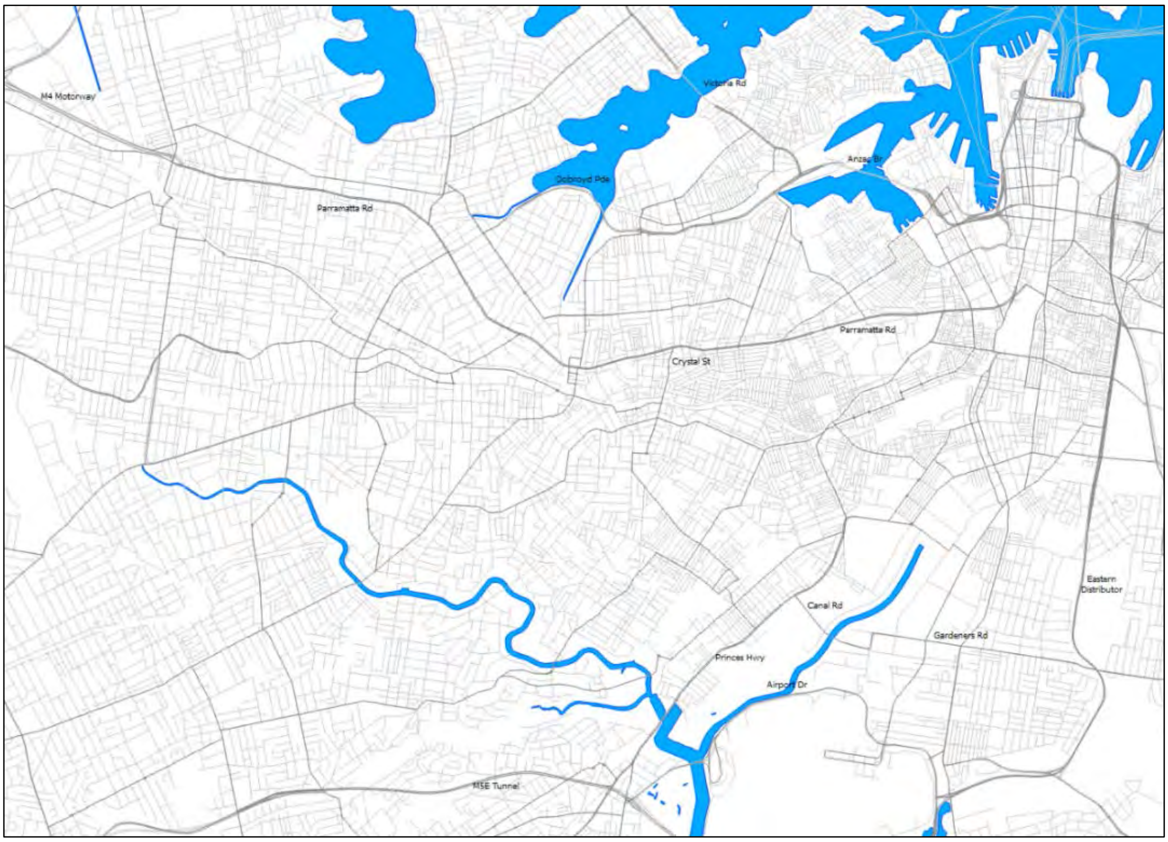

Figure 8-4 **Coverage of WestConnex Road Traffic Model**

The Base Demand Model provides the forecast capability to address changes in land use, trip distribution and mode choice and produces vehicle traffic demands for peak and off-peak periods. This model was calibrated against travel time survey data and screen-line traffic counts undertaken in 2012 and early 2013.

A separate Toll Choice Assignment Model was developed to test the impacts of tolls on the network. This model is designed to forecast the traffic choosing to use tolled and non-tolled routes for the representative peak and inter-peak periods of the day. It was developed to model the range of driver behaviour and was adjusted to match the observed patronage on existing tolled roads.

Induced traffic (mode shifts and new traffic generated from WestConnex) was calculated using an elasticity approach independent of the WRTM.

Traffic forecast modelling is highly complex. Reasonable variations in input parameters, data and assumptions result in variations in forecast traffic demand. Forecast traffic from models should therefore be considered as a range as opposed to absolute numbers. The WRTM within its inputs and assumptions has been constructed to produce the best estimate of the future traffic demands given the constraints of time and data availability.

The following sections describe the outputs from the traffic model and how these were adapted for use in GRAL.

Time periods

The WRTM represented an average weekday during a school term. There was no seasonal variation in the outputs (Roads and Maritime, 2015).

The model included the following time periods:

- The morning ('AM') peak period (07:00-09:00).
- The inter-peak ('IP') period (09:00-13:00).
- The afternoon ('PM') peak period (13:00-18:00).
- The night-time ('EV') period (18:00-07:00).

The WRTM represented an average one-hour within each of these periods.

Network description

For surface roads the dispersion modelling was undertaken for the main roads in the WestConnex GRAL domain, as defined in the WRTM. The road network in the domain was defined in terms of the start node and end node of each link in the WRTM, with each direction of travel being treated separately. The road network included between 6,187 and 6,387 individual links, depending on the scenario (Table 8-1). The dispersion model results were subsequently extracted for the roads in the M4 East GRAL domain (Figure 8-5).

Table 8-1 Number of road links by scenario

Scenario code	Scenario description	Number of road links included
2014-BY	2014 - Base Year (existing conditions)	6,178
2021-DM	2021 - Do Minimum (no M4 East)	6,187
2021-DS	2021 - Do Something (with M4 East)	6,233
2031-DM	2031 - Do Minimum (no M4 East)	6,203
2031-DS	2031 - Do Something (with M4 East)	6,249
2031-DSC	2031 - Do Something Cumulative (with M4 East and M4-M5 Link)	6,387

The WRTM output included both surface roads and tunnels (including ramps), and therefore the latter were removed from the traffic files before being entered into GRAL. Several of the links in the WRTM represented tunnels and tunnel on/off ramps. As they were not for surface roads, these links were removed from the traffic model output file prior to it being used in GRAL. In some cases part of the link represented a surface road, and part of it represented a tunnel road. Where this was the case the link was split into two sections based on the tunnel portal location, and the tunnel sections were removed from the traffic model file.

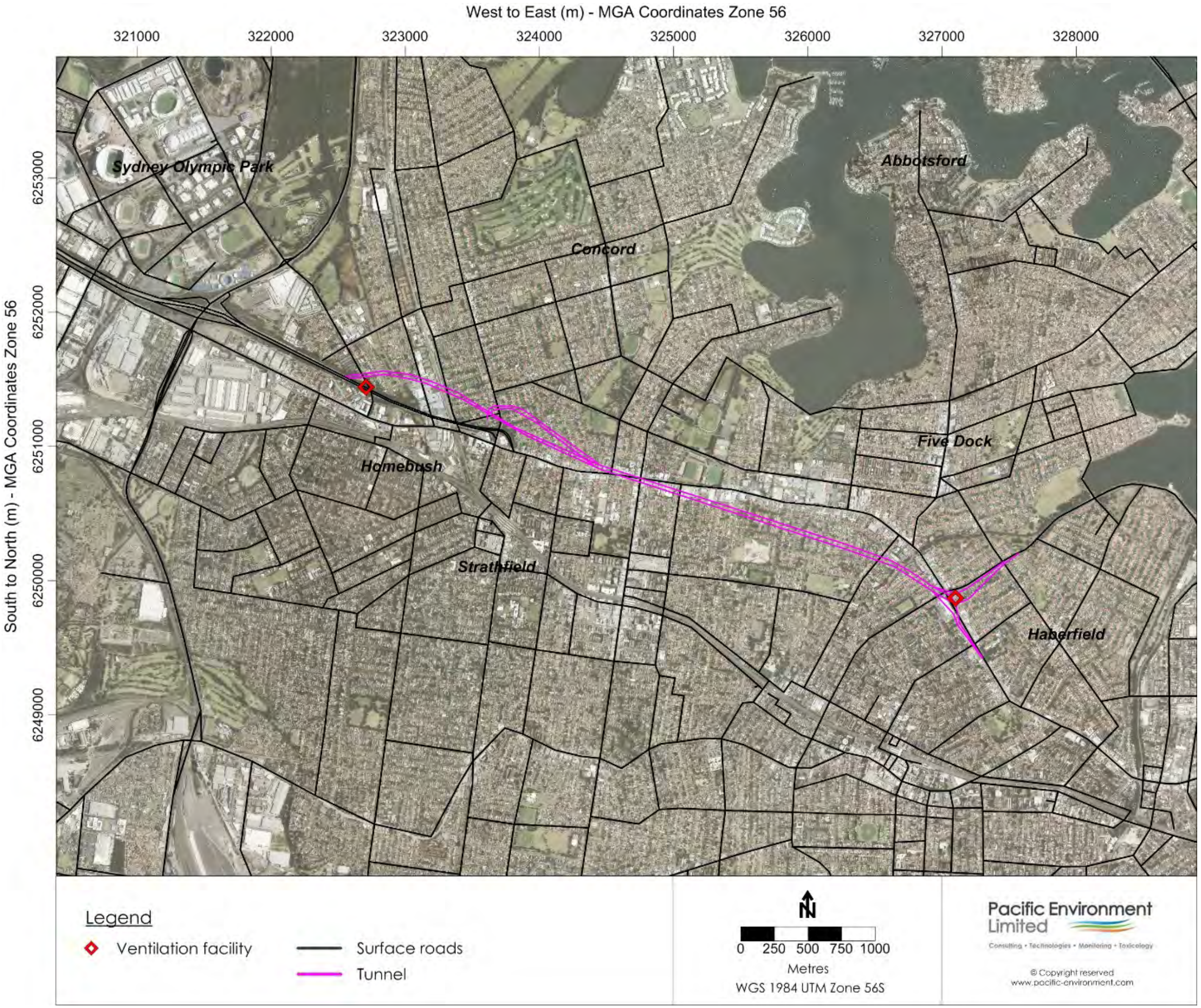

Figure 8-5 **Example of road links included in the M4 East GRAL domain (2021-DS scenario)**

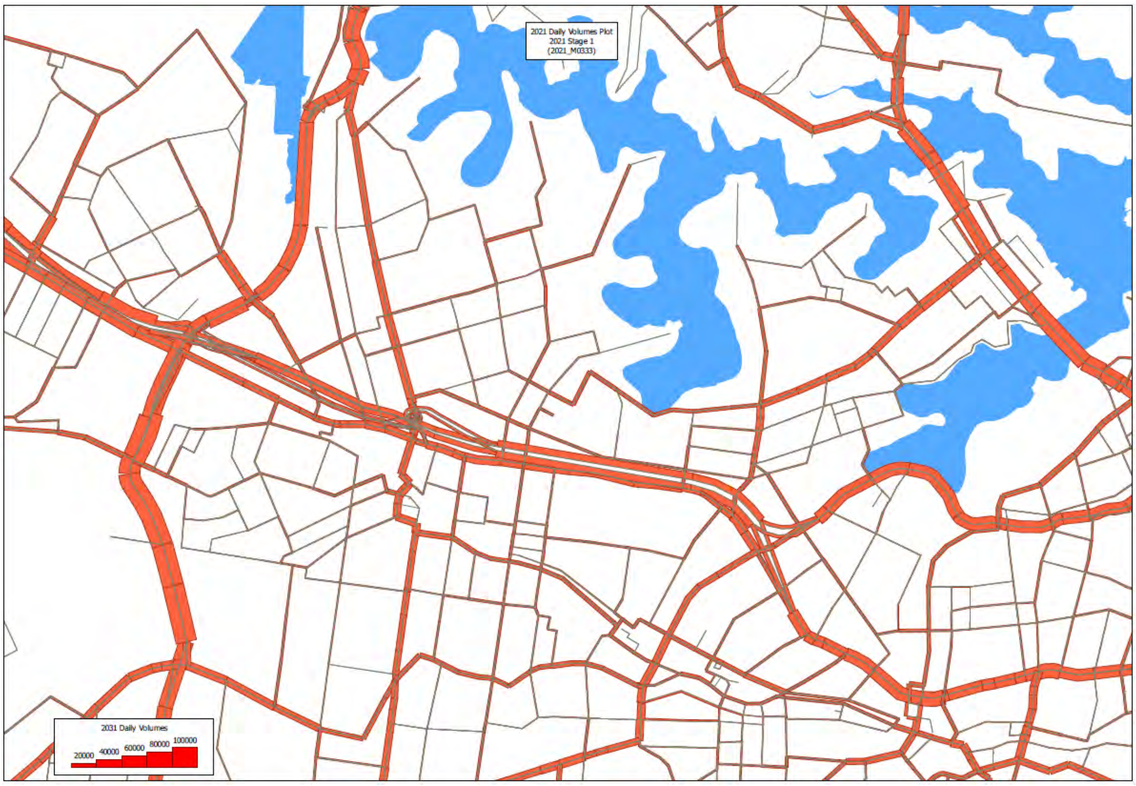

Figure 8-6 **Modelled daily traffic volumes with the project (2021-DS)**

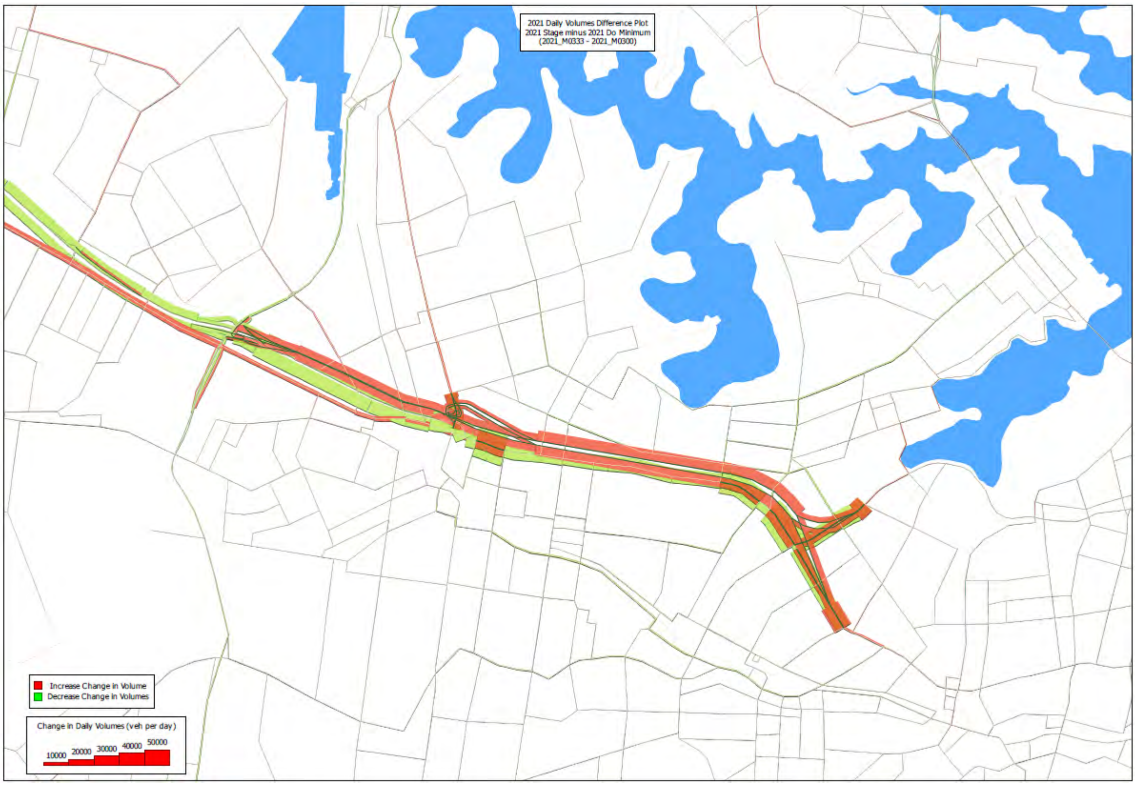

Figure 8-7 **Modelled change in daily traffic volume with the project (2021)**

Road classification

In the WRTM each road link was defined in terms of its functional class. For the purpose of calculating emissions, the functional class was converted into a NSW EPA road type, as shown in Table 8-2. The characteristics of different road types are described in Table E-1 of Appendix E. Regional arterial roads in the WRTM were treated as either commercial arterials or commercial highways in the NSW EPA emission model, depending on whether the free-flow traffic speed (taken as the evening period speed) was less than or higher than 70 kilometres per hour.

Table 8-2 Assignment of WRTM road types to NSW EPA road types

Road type in WRTM	Evening period speed (km/h)	NSW EPA road type
Minor	All	Residential
Collector	All	Residential
Sub-arterial	All	Arterial
Arterial	All	Arterial
Regional arterial	<=70	Commercial arterial
Regional arterial	>70	Commercial highway
Highway	All	Highway / freeway
Motorway	All	Highway / freeway
Motorway ramp	All	Highway / freeway

Road width

The width of each road was not required for the emission modelling, but it was required as an input for the GRAL dispersion model to define the initial plume dispersion conditions. It was not feasible to determine the precise width of every road link in modelled road network, and therefore a generic value was assumed for each road type (for one direction), as shown in Table 8-3. The generic road widths were estimated based on samples of roads from Google Earth.

Table 8-3 Assumed road width by road type

Road type	Estimated road width (m)
Minor	5
Collector	5
Sub-Arterial	6
Arterial	7
Regional arterial	9
Highway	8
Motorway	7
Motorway ramp	7

Road gradient

The average gradient of each road link was estimated using high-resolution (five metre) terrain data Terrain data for the WestConnex GRAL domain were obtained from the ASTER website, as before. For each node point in the traffic model output the elevation above sea level was determined. The average gradient of each link ($\Delta z/\Delta x$) was then estimated based on the difference in the height (Δz) of the start node and the end node and the approximate length of the link (Δx) from the traffic model. The upper and lower limits of gradient for use in the emissions model were +8 per cent and -8 per cent respectively.

Traffic volume, speed and mix (including fuel split)

The traffic volume and speed for each road link and each time period were taken from WRTM.

The WRTM defines vehicles according to the following classes:

- Private vehicles (PVs). These were mainly cars.
- Light commercial vehicles (LCVs). These included cars, utility vehicles, vans and light rigid trucks that are registered for business or commercial use.
- Heavy commercial vehicles (HCVs). These included all rigid and articulated trucks.

Buses, coaches and motorcycles were not explicitly modelled in WRTM.

The division of these classes into emission-relevant vehicle categories was based on the WRTM output and default traffic mix by year and road type from the NSW EPA emission inventory.

The volumes for cars, LCVs and HCVs from the strategic model were sub-divided into the nine vehicle types that are defined in the EPA model to reflect differences in emissions behaviour. These vehicle types are summarised in Table 8-4. The sub-division was based upon a default traffic mix for each road type in the GMR inventory, as shown in Table 8-5.

The default traffic mix for each road type took into account the projected fuel split (i.e. petrol/diesel). In recent years the refinement of light-duty diesel engines and their superior fuel economy relative to petrol engines has led to increased sales and a larger market share. As a consequence, there are projected increases in the proportions of diesel cars and diesel LCVs in the future. The petrol/diesel splits for cars and LCVs in the inventory are determined based on sales (registration) statistics, 'attrition' functions, and VKT.

Table 8-4 Vehicle types in the NSW EPA emissions model

Code	Vehicle type	Vehicles included
CP	Petrol car[a]	Petrol car, 4WD[e], SUV[f] and people-mover, LPG[g] car/4WD
CD	Diesel car[a]	Diesel car, 4WD, SUV and people-mover
LCV-P	Petrol LCV[b]	Petrol light commercial vehicle < 3.5 tonnes GVM[h]
LCV-D	Diesel LCV	Diesel light commercial vehicle < 3.5 tonnes GVM
HDV-P	Petrol HDV[c]	Petrol heavy commercial vehicle < 3.5 tonnes GVM
RT	Diesel rigid HGV[d]	Diesel commercial vehicle 3.5 t < GVM < 25 t
AT	Diesel articulated HGV	Diesel commercial vehicle > 25 tonnes GVM
BusD	Diesel bus	Diesel bus > 3.5 tonnes GVM
MC	Motorcycle	Powered two-wheel vehicle

(a) Referred to as 'passenger vehicle' in the inventory
(b) LCV = light commercial vehicle
(c) HDV = heavy-duty vehicle
(d) HGV = heavy goods vehicle
(e) 4WD = four-wheel drive
(f) SUV = sports-utility vehicle
(g) LPG = liquefied petroleum gas
(h) GVM = gross vehicle mass

Table 8-5 Default traffic mix by road type

Road type	Year	Proportion of traffic (%)								
		CP	CD	LCV-P	LCV-D	HDV-P	RT	AT	BusD	MC
Residential	2014	72.1	8.0	9.5	5.7	0.1	2.6	0.8	0.6	0.5
	2021	63.7	15.7	7.4	8.1	0.1	3.0	0.9	0.6	0.5
	2031	56.7	22.4	5.3	10.2	0.1	3.3	1.0	0.6	0.5
Arterial	2014	69.3	7.7	10.7	6.5	0.1	3.6	1.1	0.5	0.5
	2021	60.9	15.0	8.4	9.2	0.1	4.1	1.3	0.5	0.5
	2031	54.3	21.4	6.0	11.5	0.1	4.4	1.3	0.5	0.5
Commercial arterial	2014	67.0	7.5	11.4	6.9	0.1	4.6	1.6	0.4	0.5
	2021	58.8	14.5	8.9	9.8	0.1	5.2	1.8	0.4	0.5
	2031	52.2	20.6	6.4	12.3	0.1	5.5	1.9	0.4	0.5
Commercial highway	2014	67.0	7.5	11.4	6.9	0.1	4.6	1.6	0.4	0.5
	2021	58.8	14.5	8.9	9.8	0.1	5.2	1.8	0.4	0.5
	2031	52.2	20.6	6.4	12.3	0.1	5.5	1.9	0.4	0.5
Highway/ freeway	2014	60.1	6.7	10.4	6.2	0.3	9.8	5.8	0.2	0.4
	2021	51.6	12.7	8.0	8.8	0.2	11.4	6.6	0.3	0.4
	2031	45.1	17.8	5.7	11.0	0.3	12.4	7.0	0.3	0.4

There are, almost always, discrepancies between the outputs of traffic models and the input requirements for emission models, and therefore some assumptions were required. In the case of WRTM the most notable of these were as follows:

- The proportions of LCVs in the traffic model outputs were very high compared with typical proportions on the road in relation to how such vehicles are defined in emission models. For example, it is likely that many of the vehicles defined as LCVs in the traffic model were, from an emissions perspective, cars, and some of them would have been more like rigid heavy-duty vehicles. The approach taken was therefore to combine PVs and LCVs from the traffic model, and redistribute these according to the relevant split (road type, year) between CP, CD, LVC-P and LCV-D from Table 8-5.
- HCVs from the traffic model were redistributed according to the split for HD-P, RT and AT in Table 8-5.
- Relatively small numbers of buses and motorcycles were added to the traffic model output, again based on the proportions in Table 8-5.

An example of the WRTM output for one link is shown in Figure 8-8, and the transformation of the data for this link into a suitable format for the NSW EPA emission model is shown in Figure 8-9.

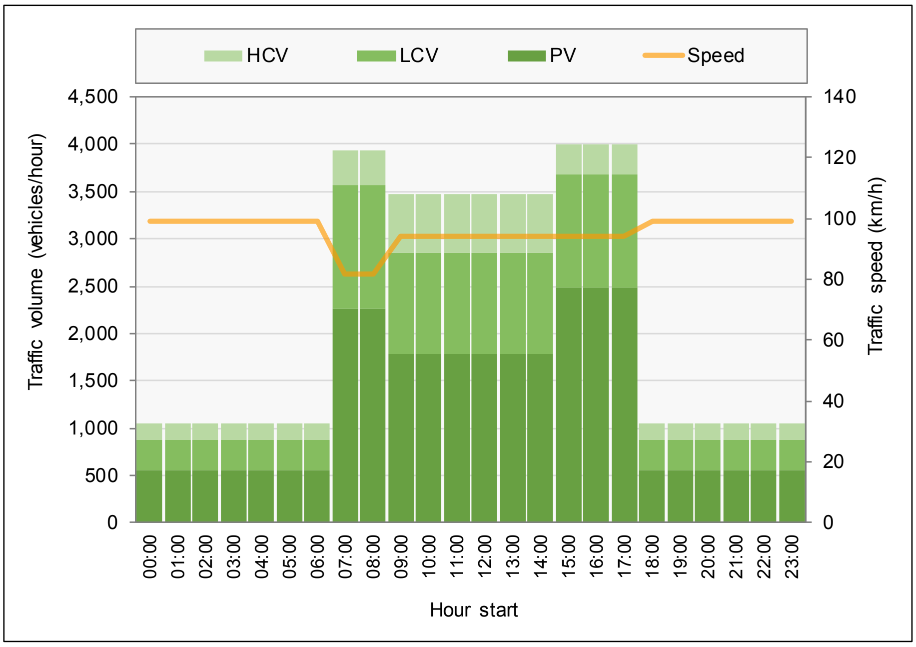

Figure 8-8 Example traffic model output (link 10285-10313, motorway, 2014)

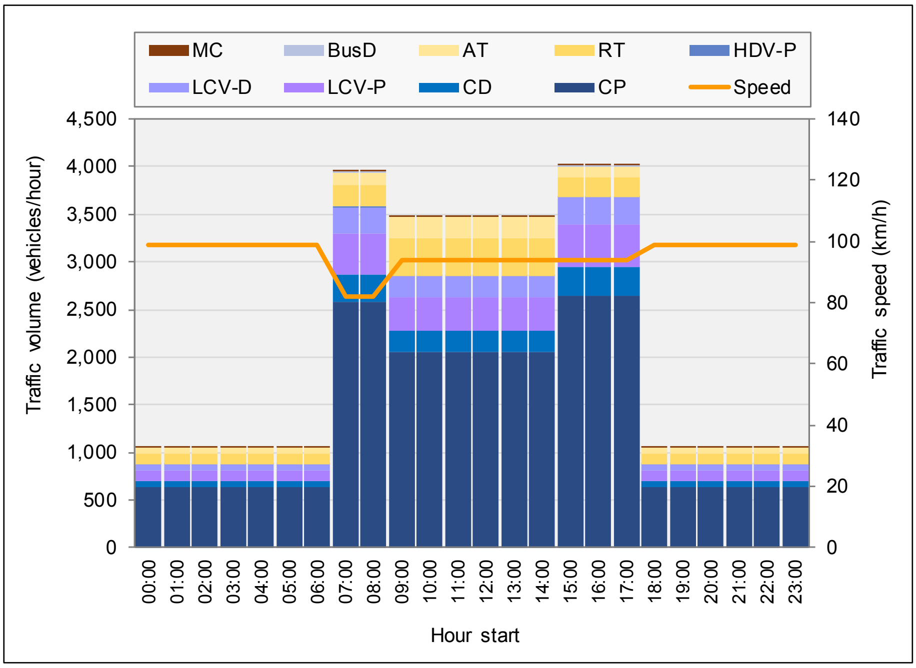

Figure 8-9 Example emission model input (link 10285-10313, highway/freeway, 2014)

Results

Expected traffic scenarios

As emissions were determined for more than 6,000 road links, multiple pollutants and multiple scenarios, it is not practical to present the data in this report. Instead, total emissions have been calculated for all roads included in the strategic model for the WestConnex GRAL domain. The changes in the total emissions resulting from the project can also be viewed as a proxy for its regional air quality impacts.

The emissions in the WestConnex GRAL domain, in tonnes per year, are shown in Table 8-6 and the changes in emissions are shown in Table 8-7. For the pollutants (NO_X and PM) the net effects of the project on total emissions in 2021 and 2031 were very small (less than one fifth of one per cent). In the cumulative case for 2031 there would be an increase in emissions of NO_X and PM of around 1.5 to two per cent. The effects of the project on emissions were much smaller than the projected reductions in emissions with time. For example, between 2014 and 2031, NO_X emissions (without the project) were projected to decrease by 55 per cent.

Table 8-6 Total emissions in the WestConnex GRAL domain

Scenario code	Scenario description	Total VKT[(a)] per day (million vehicle-km)	Total emissions (tonnes/year)				
			CO	NOx	PM_{10}	$PM_{2.5}$	THC
2014-BY	2014 - Base Year (existing conditions)	14.5	15,240	6,581	322	234	1,542
2021-DM	2021 - Do Minimum (no M4 East)	15.7	9,025	4,068	278	182	934
2021-DS	2021 - Do Something (with M4 East)	15.8	9,039	4,076	278	182	926
2031-DM	2031 - Do Minimum (no M4 East)	17.6	6,102	2,963	288	179	598
2031-DS	2031 - Do Something (with M4 East)	17.7	6,139	2,968	288	179	593
2031-DSC	2031 - Do Something Cumulative (with M4 East and M4-M5 Link)	19.1	6,585	3,011	294	182	585

(a) VKT = vehicle kilometres travelled

Table 8-7 Changes in total emissions in the WestConnex model domain

Scenario comparison	Change in total emissions (%)				
	CO	NOx	PM_{10}	$PM_{2.5}$	THC
Do Minimum scenarios					
2021-DM vs 2014-BY	-40.8%	-38.2%	-13.7%	-22.4%	-39.4%
2031-DM vs 2014-BY	-60.0%	-55.0%	-10.4%	-23.6%	-61.2%
Project scenarios					
2021-DS vs 2021-DM	0.2%	0.2%	0.0%	0.0%	-0.8%
2031-DS vs 2031-DM	0.6%	0.2%	0.0%	0.0%	-0.8%
2031-DSC vs 2031-DM	7.9%	1.6%	2.0%	1.9%	-2.2%

Regional air quality can also be framed in terms of a change in the capacity for ozone production. NSW EPA has recently developed a Tiered Procedure for Estimating Ground Level Ozone Impacts from Stationary Sources (ENVIRON, 2011). Whilst this does not relate specifically to road projects, it does given an emission threshold for NO_X and VOCs of 90 tonnes/year for new sources for proceeding to a detailed modelling assessment for ozone. The changes in emissions associated with the project were well below this threshold.

For example, the increase in NOx emissions for the assessed road network in 2021 was estimated to be eight tonnes per year. This value also equates to a tiny proportion of anthropogenic NOx emissions in the Sydney airshed in 2016 (around 53,700 tonnes). It was therefore concluded that the regional impacts of the project would be negligible, and undetectable in ambient air quality measurements at background locations.

Regulatory worst case scenarios

No emission modelling was required for the regulatory worst case scenarios, as the emissions from the ventilation outlets were simply determined by the outlet concentration limits.

8.2.4 Existing M5 East tunnel ventilation outlet

Emissions of NO_X, CO, PM_{10} and $PM_{2.5}$ from the existing M5 East tunnel were calculated using hourly in-stack concentrations and air flow data for 2014 supplied by Roads and Maritime. Emission scaling factors for the future years (2021 and 2031) were developed using the NSW EPA emission model and typical tunnel traffic. The emission rates are summarised in Table 8-8. As with the project ventilation outlets, two separate source groups were defined to reflect different air flow regimes, and hourly 'modulation factors' (ratios, relative to the average) were used in GRAL to replicate the variation in emissions within each time period. Seasonal variation in emissions was represented using monthly modulation factors.

Table 8-8 Emission rates: existing M5 East outlet

Year	Period (hour start)	Emission rate (kg/h)			
		NO_X	CO	PM_{10}	$PM_{2.5}$
2014	Hours 00-05 and 22-23	6.31	32.89	0.14	0.07
	Hours 06-21	20.39	74.21	0.84	0.63
2021	Hours 00-05 and 22-23	3.52	22.13	0.10	0.04
	Hours 06-21	11.65	40.48	0.67	0.45
2031	Hours 00-05 and 22-23	2.41	18.08	0.10	0.04
	Hours 06-21	7.95	27.01	0.63	0.40

8.2.5 Emission model evaluation

Whilst the derivation of the emission rates has not been published, PIARC states that there is a built-in margin of safety. Notably, the emission rates for CO and PM are inherently conservative. This conservatism in the PIARC method is designed to minimise the possibility that tunnel ventilation systems will be underspecified. The emission rates for non-exhaust PM are considered to be especially conservative. In the case of NOx the emission rates have been shown to be more representative of real-world emissions (Hinterhofer et al., 2014). However, the actual level of conservatism built into the PIARC approach is not documented by PIARC. It was also therefore considered important to quantify this level of conservatism for traffic conditions in Sydney tunnels, and this work is described in Appendix E.

The PIARC and NSW EPA models were evaluated in two ways:

- By direct comparison of the emission rates, both for individual vehicle types and weighted for traffic composition. The emission rates were compared in detail for a zero per cent road gradient, and in a more aggregated manner for other gradients. As noted above, this work also illustrated a comparison between the simple and detailed PIARC models.
- Through validation against real-world air pollution measurements in the Lane Cove Tunnel. This work improved the understanding of the overall level of conservatism built into the PIARC model for in-tunnel emissions, and also provided an indication of the performance of the NSW EPA model for a tunnel environment, bearing in mind that the NSW EPA model is designed for application to surface roads.

The findings of the model evaluation are given in Appendix E, and are summarised below.

Model comparison

The different models could not be clearly ranked in terms of their predicted emission levels, as this was dependent on the pollutant, vehicle type and traffic situation being investigated. However, the weighted results for the typical highway traffic mix and zero per cent gradient showed the following:

- In future years the NSW EPA models gave the highest CO emission rates at speeds above around 60 kilometres per hour, but the lowest CO emission rates at lower speeds.
- The PIARC and NSW EPA models gave broadly similar NO_X emission rates for speeds below 50 kilometres per hour in all years. For 2014 and 2021 the NSW EPA models gave the highest results for speeds above 50 kilometres per hour. For 2031 all models gave quite similar results.
- For all years, the PIARC models gave systematically higher total $PM_{2.5}$ emission rates than the NSW EPA models. This was due to the conservative assumptions concerning non-exhaust PM in the PIARC models.
- Although there were some differences between the results from the simple and detailed PIARC models, for conditions that are relevant to Sydney tunnels, and the most critical pollutant (NO_X), the model predictions for the traffic as a whole were similar.

With the exception of $PM_{2.5}$, the results from the different models were broadly comparable for other road gradients, and there were no extreme effects of road gradient. For uphill gradients the NSW EPA models tended to give higher emission rates of CO, NO_X and NO_2 than the PIARC models.

Model evaluation based on Lane Cove Tunnel data

The main findings of the model validation exercise were as follows:

- There was generally a strong correlation between the predicted and observed emission rates for CO, NOx and $PM_{2.5}$. An example of this is provided in Figure 8-10.

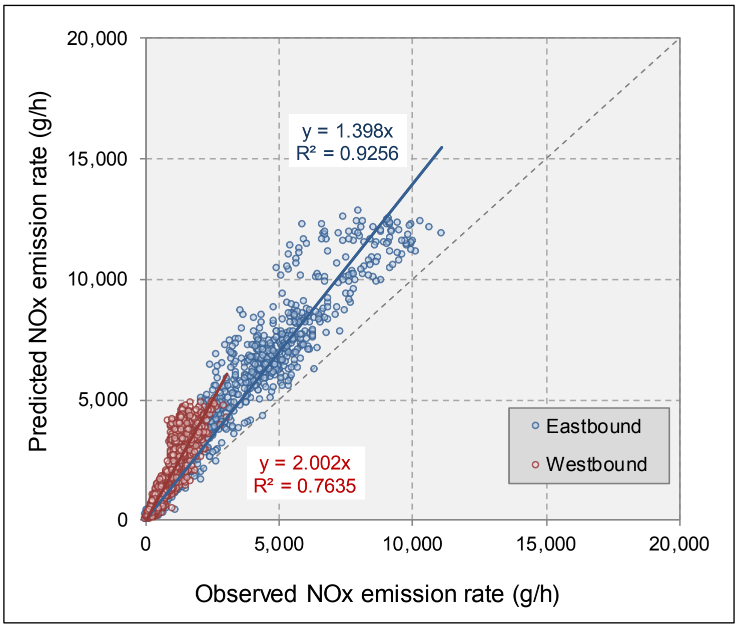

Figure 8-10 Predicted (simple PIARC model) and observed (Lane Cove tunnel measurements) NO_X emission rates in 2013

- On average, both the simple and detailed PIARC models overestimated pollutant emissions in the tunnel, with the exception of NO_2 in the westbound tunnel. This is may be due in part to the following:
  - An inherent over-prediction in the PIARC gradient factors.

- The tunnel environment itself affecting emissions through reduced aerodynamic drag on the vehicles in the tunnel.

- The detailed PIARC model gave a smaller overestimation of emissions than the simple PIARC model, with the exception of CO in the eastbound tunnel.
- The detailed PIARC model overestimated CO emissions by a factor of 1.4 to 2.4, NO_X emissions by a factor of 1.3. In the eastbound tunnel NO_2 was overestimated by a factor of 1.4, but in the westbound tunnel NO_2 was slightly underestimated.
- The detailed PIARC model overestimated $PM_{2.5}$ emissions by a wider margin: by a factor of between 1.7 and 3.5. When exhaust emissions of $PM_{2.5}$ are relatively low (westbound tunnel), the overestimation of total $PM_{2.5}$ emissions is much greater than when exhaust emissions are relatively high (eastbound tunnel). This confirms that that the emission rates for non-exhaust $PM_{2.5}$ in the PIARC models are very conservative.

The NSW EPA model gave a larger overestimation of emissions than the PIARC models for CO, NOx and NO2. In the case of PM2.5, the NSW EPA and PIARC models overestimated emissions to a similar extent.

Additional analyses of the emission model predictions by vehicle type, and calculations of primary NO2 emission factors, are provided in Appendix E.

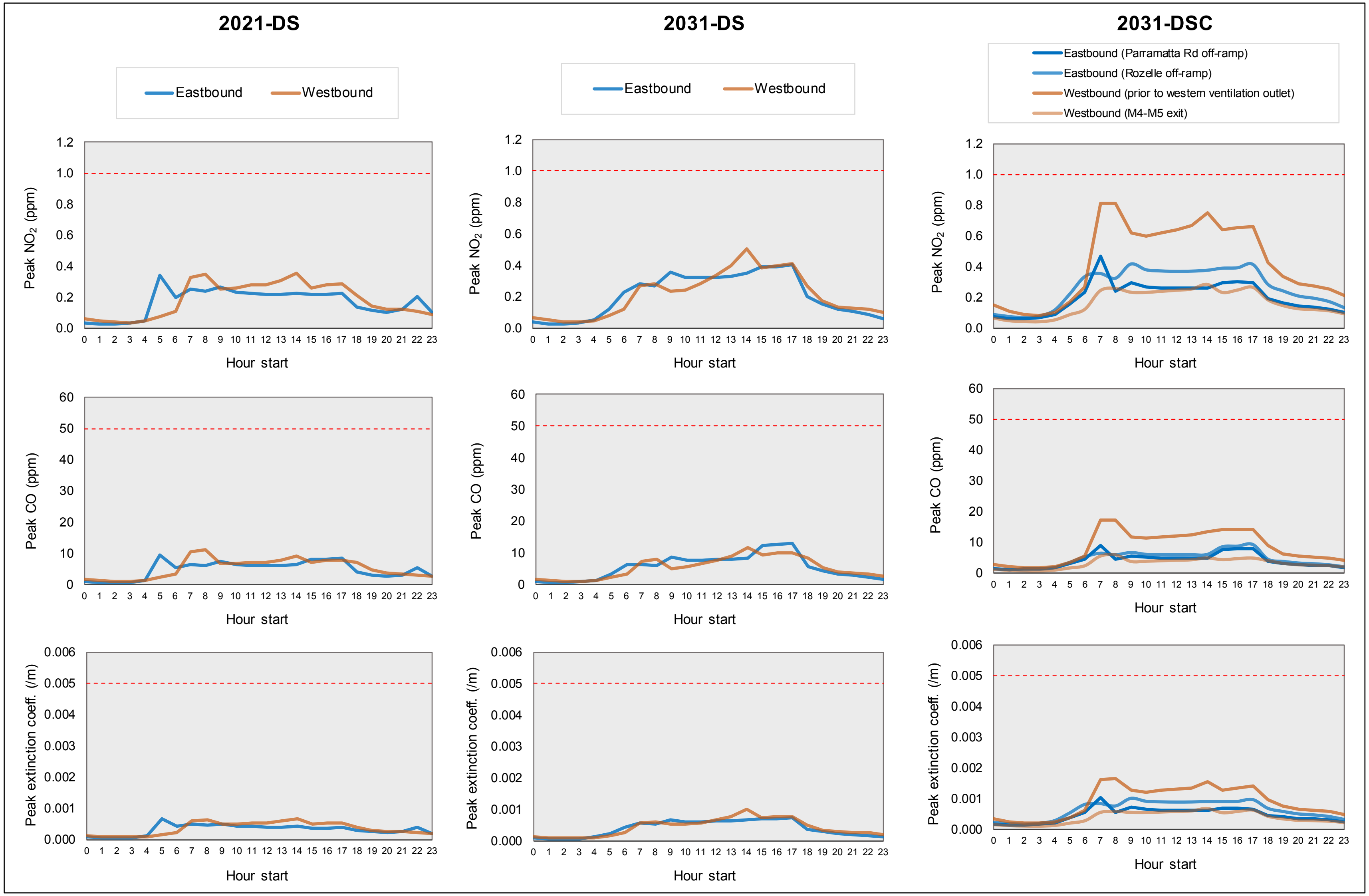

Figure 8-11 **Peak in-tunnel NO_2, CO and extinction coefficient (dashed red lines show in-tunnel concentration limits)**

Table 8-9 Maximum in-tunnel concentrations for all scenarios

Scenario		NO_2 (ppm)		CO (ppm)		$PM_{2.5}$ (mg/m^3)	
		Maximum in-tunnel concentration					
		Eastbound	Westbound	Eastbound	Westbound	Eastbound	Westbound
Expected traffic	2021-DS	0.45	0.35	12	11	0.44	0.38
	2031-DS	0.40	0.51	13	12	0.41	0.52
	2031-DSC	0.47	0.81	9.1	17	0.62	0.96
Capacity traffic	2021-DS	0.62	0.88	12	16	0.79	1.05
	2031-DS	0.62	0.88	12	16	0.79	1.05
	2031-DSC	0.62	0.88	12	16	0.79	1.05
Regulatory worst case[(a)]		1.07	1.07	35.0	35.0	1.1	1.1

(a) CO and NO_2 volume concentrations estimated for a temperature of 25^{o}C.

8.3 Dispersion modelling

8.3.1 Overview

The atmosphere is a complex physical system, and the movement of air in a given location is dependent on a number of variables, including temperature, topography and land use, as well as larger-scale synoptic processes. Dispersion modelling is a method of simulating the movement of air pollutants in the atmosphere using mathematical equations. This requires an understanding of the complex interactions and chemical reactions involved, available input data, processing time and data storage limitations. The model configuration particularly affects model predictions during certain meteorological conditions and source emission types. For example, the prediction of pollutant dispersion under low wind speed conditions (typically defined as those less than 1 m/s) or for low-level, non-buoyant sources, is problematic for most dispersion models. To accommodate these effects, the model is configured to provide conservative estimates of pollutant concentrations at particular locations. While the models, when used appropriately and with high quality input data, can provide very good indications of the scale of pollutant concentrations and the likely locations of the maximum concentrations occurring, their outputs should not be considered to be representative of exact pollutant concentrations at any given location or point in time (AECOM, 2014b).

8.3.2 Model selection

The GRAL system (version 14.11) was selected for the dispersion modelling for this study. GRAL was chosen for the following reasons:

- GRAL is suitable for regulatory applications and can utilise a full year of meteorological data.
- GRAL is very accessible.
- GRAL is a particle model and has the ability to predict low-wind-speed conditions (<1 m/s) better than most Gaussian models (e.g. CALINE).
- GRAL is specifically designed for the simultaneous modelling of road transport networks, including line sources (surface roads), point sources (tunnel ventilation outlets) and other sources.
- GRAL can take into account vehicle wake effects.
- GRAL can characterise pollution dispersion in complex local terrain and topography, including the presence of buildings in urban areas.
- GRAL has been validated in a wide range of studies featuring complex and flat terrain and with varying meteorological conditions (high/low wind speeds, stable/unstable atmospheric conditions etc.

Whilst the GRAL system has not been used extensively in Australia, it was used in the assessment of the Waterview Connection tunnels near Auckland, New Zealand (BECA, 2010). The model set up for this project has been tailored to suit the needs of both the study at hand and the regulatory requirements in NSW in relation to air quality.

8.3.3 Model overview

The model system consists of two main modules: a prognostic wind field model (Graz Mesoscale Model - GRAMM) and a dispersion model (GRAL itself). An overview of the GRAMM/GRAL modelling system is presented in Figure 8-12. Whilst the system has in-built algorithms for calculating emission rates (the grey area of the Figure), these were replaced by the project-specific emission rates.

GRAMM is the meteorological driver for the GRAL system. Its main features include the use of prognostic wind fields, a terrain-following grid, and the computation of surface energy balance. The prognostic wind field model provides a good representation of dynamic effects due to obstacle-influenced air flows, and is capable of accommodating complex topography with high horizontal resolution (Oettl et al., 2003). A grid resolution of less than 10 metres is possible in GRAMM, although larger grid cells tend to be required for larger areas to maintain acceptable processing times.

GRAL is a Lagrangian model, whereby ground-level pollutant concentrations are predicted by simulating the movement of individual ‘particles’ of a pollutant emitted from an emission source in a three-dimensional wind field. The trajectory of each of the particles is determined by a mean velocity component and a fluctuating (random) velocity component.

GRAL stores concentration fields for user-defined source groups. Up to 99 source groups can be defined (e.g. traffic, domestic heating, industry), and each source group can have specific monthly and hourly emission variations. In this way annual mean, maximum daily mean, or maximum concentrations for defined periods can be computed. Usually about 500-600 different meteorological situations are sufficient to characterise the dispersion conditions in an area during all 8,760 hours of the year.

Other general parameters required by the program include surface roughness length, dispersion time, number of traced particles (influences the statistical accuracy of results), counting grids (variable in all three directions), as well as size of the investigated area.

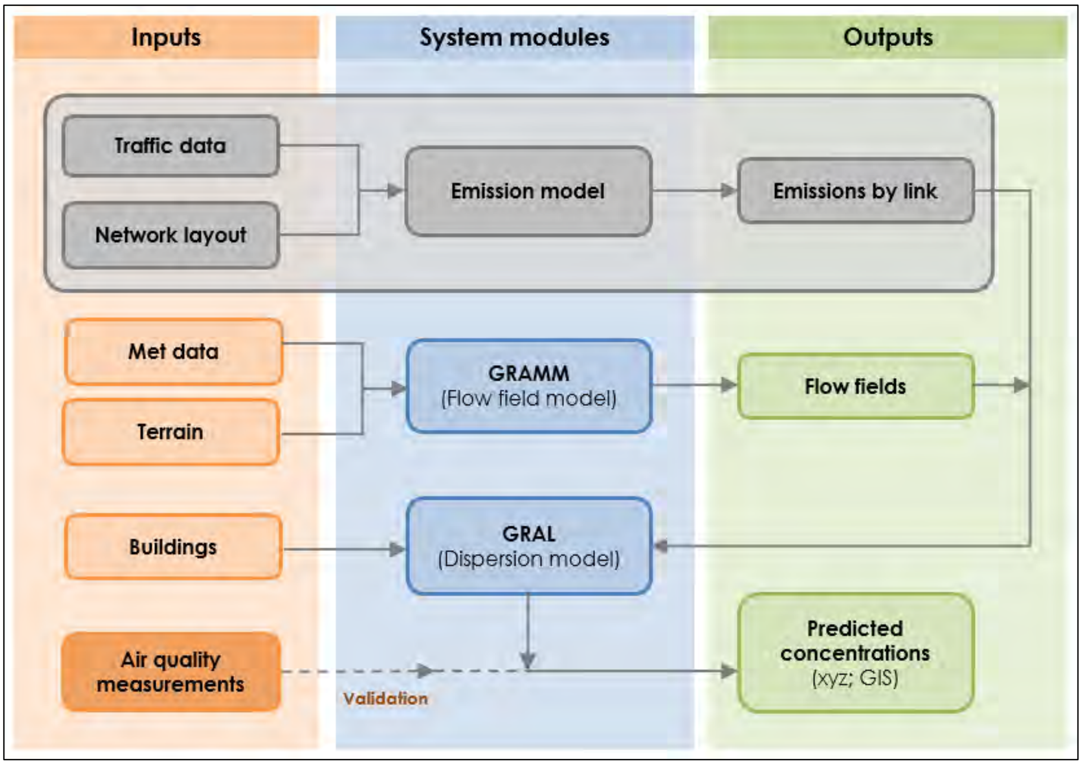

Figure 8-12 Overview of the GRAMM/GRAL modelling system

Because the simulation of an hourly time series of a whole year would be very time consuming, GRAL computes steady-state concentration fields for classified meteorological conditions (using 3-7 stability classes, 36 wind direction classes, and several wind speed classes). The steady-state concentration field for each classified meteorological situation is stored as a separate file. Based on these results, the concentration fields for the annual mean value, maximum daily mean value and maximum value are calculated using a post-processing routine. Diurnal and seasonal variations for each source group can be defined in GRAL using 'emission modulation factors'. The final result is a time series of concentration that is dependent on the classified meteorological situations and the seasonal and diurnal emission modulation factors.

8.3.4 GRAMM configuration

GRAMM domain and set-up

The GRAMM domain was defined so that it covered the full extent of the WestConnex project with a sufficient buffer zone to minimise boundary effects in GRAL. The GRAMM domain, which was shown in Figure 5-1, was 23 kilometres along the east-west axis and 23 kilometres along the north-south axis. The Figure also shows the GRAL model boundary for the WestConnex project (further described in Section 8.4.6) as well as the GRAL domain for the M4 East project.

Table 8-10 presents the meteorological and topographical parameters that were selected in GRAMM.

Table 8-10 GRAMM set-up parameters

Parameter	Input/value
Meteorology	
Meteorological station	BoM Canterbury Racecourse AWS (Station 66194)
Period of meteorology	1 January 2014 – 31 December 2014
Meteorological parameters	Wind speed (m/s), Wind direction (^{o}), stability class (1-7)
Number of wind speed classes	10
Wind speed classes (m/s)	0-0.5, 0.5-1.5, 1.5-2.5, 2.5-3.5, 3.5-4.5, 4.5-5.5, 5.5-6.5, 6.5-7.5, 7.5-9 >9
Number of wind speed sectors	36
Sector size (degrees)	10
Anemometer height above ground (m)	10
Concentration grids and general GRAMM input	
GRAMM domain in UTM (m)	N = 6259000, S = 6236000, E = 315000, W = 338000
Horizontal grid resolution (m)[a]	200
Vertical thickness of first layer (m)[b]	10
Number of vertical layers	15
Vertical stretching factor[c]	1.2
Relative top level height (m)[d]	730
Maximum time step (s)[e]	10
Modelling time (s)	3,600
Relaxation velocity[f]	0.1
Relaxation scalars[f]	0.1

(a) Defines the horizontal grid size of the concentration grid.
(b) Defines the cell height of the lowest layer of the flow field. Typical values are 1-2 m.
(c) Defines how quickly cell heights increase with height above ground. For example, a factor of 1.1 means a cell is 10% higher than the one below it.
(d) Defined as the relative height from the lowest level in the domain.
(e) Defines the amount of time taken to ensure that calculations are done efficiently but stably.
(f) These are chosen to ensure the numerical stability of GRAMM simulations.

Terrain

Terrain data were processed within the GEOM (Geographical/Geometrical grid processor) component of GRAMM. As described in Section 6.2, the terrain data for the GRAMM domain were obtained from the ASTER website, and converted into a text file for use in GRAMM. The terrain data used in GRAMM had a resolution of 30 metres. The terrain within the study area is predominantly flat, but increases in elevation to the north of the Five Dock Bay area towards the Hills District and to the south towards the Sutherland Shire and adjoining parkland. Whilst this may not be classed as 'complex terrain' a terrain file has been included for robustness.

Land Use

Various land use types can be specified in GRAMM, including 'urban', 'agricultural', 'body of water', 'forest', etc. Specific land use files were not used in the modelling as the GRAL GUI (Graphical User Interface) currently only supports the import of CORINE (Coordination of Information on the Environment) land cover parameters which are only available for countries in Europe.

As discussed in Section 6.2, the land use in the study area primarily consists of urban areas with pockets of small recreational reserves and waterbodies. To account for this type of land use the surface roughness length parameter was set to 0.5 to capture the roughness effects of an urban setting. GRAMM uses roughness lengths, albedo, temperature conductivity, soil moisture content (an average value generated by default), soil heat capacity and emissivity in its calculations. Future work using GRAL could include the investigation of a conversion scheme for Australian land use information as well as sensitivity testing.

Reference meteorological data

GRAMM features a method for computing wind fields in complex terrain. The flow field computations are based on classified 'meteorological situations' (wind direction, wind speed, dispersion classes and frequency) that are derived from local wind observations and stability classes. The meteorological requirements for the model are comparatively low, involving an assessment of atmospheric stability status (classified as stable, neutral, or unstable), wind speed, and wind direction. As GRAMM uses input data from a single meteorological station, it is important to select a site that is both reliable and representative of meteorology within the domain.

As discussed in Section 6.4, meteorological data from the BoM Canterbury Racecourse AWS site for 2014 were selected for use in GRAMM. An analysis of six years of data from this site was completed, and from this it was determined that the site was representative of meteorological conditions in the study area. Due to this, and its location in the middle of the study area, it was deemed appropriate for modelling. An evaluation of the predicted meteorological parameters using these data determined that GRAMM simulates the meteorology within an acceptable degree of accuracy (Appendix H). The stability class (classes 1-7) required for GRAMM was calculated using the temperature at 10 m and cloud content data from the BoM Sydney Airport AMO meteorological station. Cloud content data are not measured at the BoM Canterbury Racecourse AWS site.

Figure 8-13 provides an example of a wind field situation across the study area. In total, 1,087 different wind fields were produced to represent the different conditions in each hour of the meteorological file. The wind fields are based upon the wind speeds and wind directions at the BoM Canterbury Racecourse AWS site. In this particular example, winds are from a northwest direction, with higher wind speeds over elevated terrain to the northeast. The terrain of the study area was not especially complex (i.e. relatively flat), and this is reflected in the broadly similar wind conditions across the area. The wind field shows how the dispersion of a pollutant that is emitted from any point in the domain will be affected.

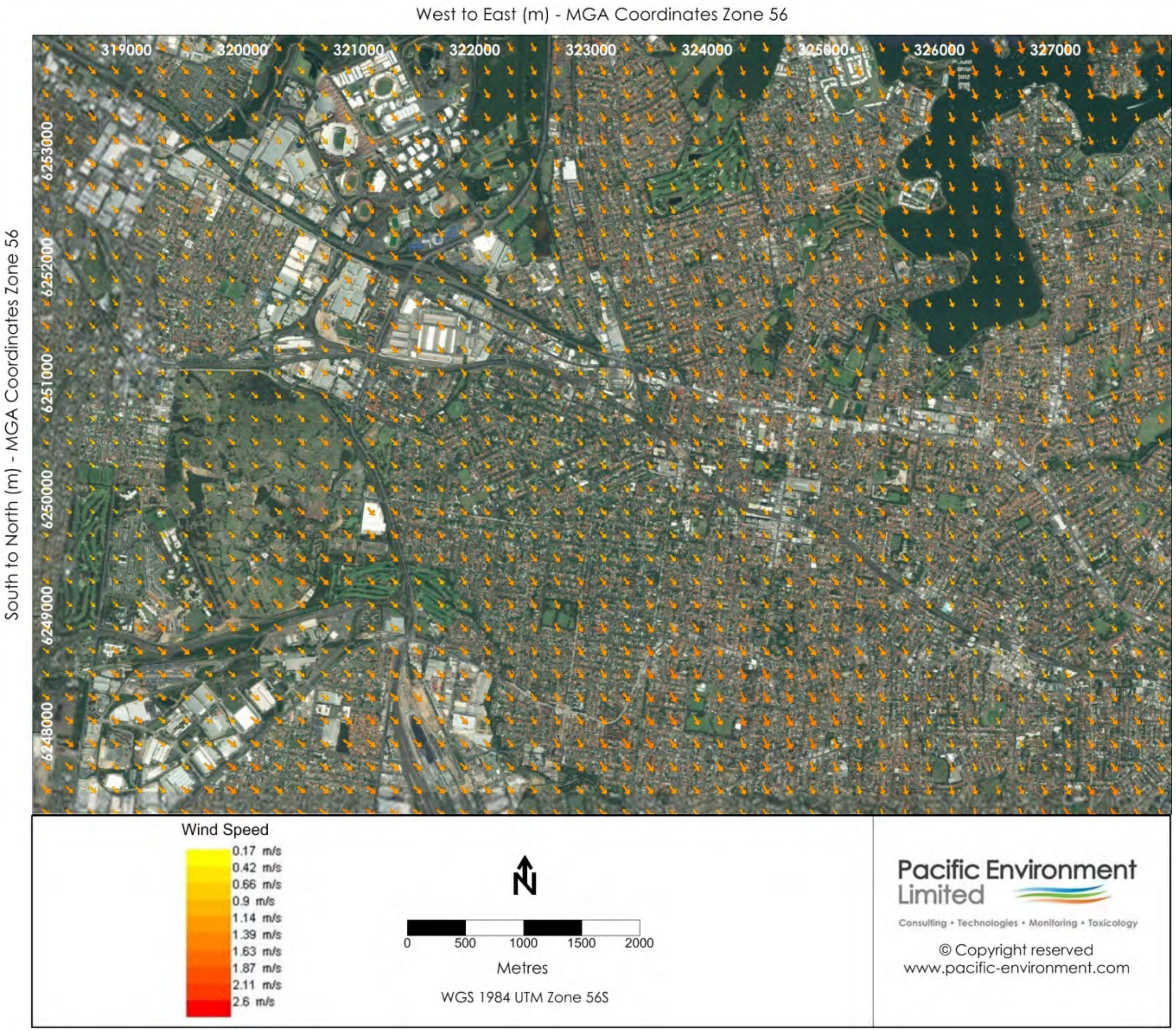

Figure 8-13 Example of a wind field across the study area

GRAMM Re-order function

The GRAMM ‘Re-Order’ function was used to refine the order of the predicted wind fields to provide a better match to the observations the BoM Canterbury Racecourse site. GRAMM simulates flow fields based on a time series of wind speed, direction and stability class at a specific point usually located within the GRAMM domain (in this case, the BoM Canterbury Racecourse site). GRAMM then breaks up the time series into many frequency bins of different ‘dispersion situations’ based on the measured meteorological data. At the end of the GRAMM simulation, a wind field is stored corresponding to each dispersion situation (in this case, 1,087 situations), which by default are ordered by frequency of occurrence.

The Re-Order function searches within these generated flow fields and fits (‘re-orders’) these to better match the observed data at the location of the meteorological measurement. For example, flow field number 500 may best fit dispersion situation number 1 and so on. In this example, flow field number 500 is renamed to be wind field number 1 which corresponds to the highest frequency situation. This procedure is then repeated for all dispersion situations.

The Re-Order function is applied as it is understood that in meteorological modelling, the initial model results may not be realised in full detail, especially in complex terrain. Therefore, the Re-Order function is applied as a type of ‘nudging’ mechanism to ensure that prediction meteorological conditions are representative of the observed meteorology. It is noted that the Re-Order function only re-orders those wind fields with similar stability classes (e.g. a flow field with stable conditions is only matched to other flow fields with stable conditions).

8.3.5 Evaluation of meteorological modelling

As discussed in Section 8.4.4, the re-order function was used to refine the simulated GRAMM wind fields. Wind speed and direction data were then extracted from the re-ordered data at each of the meteorological monitoring stations and some comparisons made.

One-hour data for wind speed and wind direction are evaluated visually as time series, frequency distributions and wind roses. The observed seasonal variations in wind patterns (Figure 8-14) and those predicted using the Re-Order function (Figure 8-15) compare very well.

Further analytical examination is presented using linear regression and percentile plots. The visual and analytical examination is presented in Appendix H. Predicted annual average wind speeds are quite similar to the observed values at the two closest sites to the project, Canterbury Racecourse and Sydney Olympic Park. The percentage of calms also correlate quite well at these two sites.

The main differences between observations and predictions are for the Sydney Airport site, where wind speeds are observed to be higher and show significantly less calm conditions, than the predicted values. This may be due to the coastal nature of this site where wind speeds are typically higher due to the relatively uninterrupted nature of on-shore winds. The surface roughness length parameter for GRAMM was set to 0.5 to capture the roughness effects of an urban setting (see Section 6.2). This will then be less representative of the coastal Sydney Airport site and may lead to reduced predicted wind speeds. Regardless, lower predicted wind speeds may result in more conservative predicted concentrations, in particular for surface road sources which are the dominant contributor to ground-level concentrations, but also for ventilation outlets.

Regression analysis of wind speed (see Appendix H) showed a very good agreement between predicted and observed values at the Canterbury Racecourse site, but less so at the other sites. In summary, the R^2 values are listed as follows:

- Canterbury Racecourse wind speed $R^2 = 0.92$
- Sydney Airport wind speed $R^2 = 0.49$
- Sydney Olympic Park wind speed $R^2 = 0.60$
- Rozelle wind speed $R^2 = 0.45$
- Chullora wind speed $R^2 = 0.50$

Percentile plots shown in Appendix H demonstrate a slight under-prediction of high wind speeds at Canterbury Racecourse. There is also an under prediction at Sydney Olympic Park at the highest wind speeds, and a slight over prediction in the lower to mid range. Percentile plots at these two sites are much closer to unity than for sites further away from the project.

Table 8-11 provides a comparison of the annual average wind speeds, standard deviation of wind speed and percentage of calms between the observed and predicted meterology at five meterological stations. The table again shows that the agreement between the BoM Canterbury Racecourse obsvered and predicted meterology is good whilst results are less close at the other locations. As noted above, the results for the BoM Sydney Airport site may be different largely due to the location of the airport and roughness length selected at this exact location. As discussed in Section 6.4, observed wind data at Rozelle and Chullora in the more recent years has shown a significant shift in winds than in previous years. This may be a factor in the regresssion analsyis results shown here for these locations.

Table 8-11 Summary statistics – observed and predicted (2014)

Site	Observed			Predicted		
	Annual average wind speed (m/s)	Standard deviation wind speed (m/s)	% Calms	Annual average wind speed (m/s)	Standard deviation wind speed (m/s)	% Calms
BoM Canterbury Racecourse	3.2	2.0	8.4	3.0	1.7	8.6
BoM Sydney Airport	5.8	2.6	<1.0	3.1	1.6	8.6
BoM Sydney Olympic Park	2.8	1.6	7.5	3.1	1.7	8.6
EPA Rozelle	1.8	1.4	14.6	3.1	1.7	8.6
EPA Chullora	1.9	1.1	4.8	3.1	1.6	8.1

It should be noted that whilst the model shows a good agreement at the BoM Canterbury Racecourse site and lesser agreement at other locations, this is to be expected as the GRAMM model (like many other meteorological models) uses data from one location to represent the study area. This is not uncommon in studies with relatively small model domains and predominantly uniform land-use and terrain features such as that in the M4 East study area. The regression analysis values for these other sites as shown above appear low compared to the Canterbury Racecourse site but are consdiered fair considering that these data were not included in the GRAMM modelling.

Whilst meteorlogical conditions are an important aspect of any disperion modelling excersise, it may not always be the most important aspect in determining predicted concentrations in near-source environments such as this. Section 8 of the report provides a validation of the GRAL predictions as compared with measured data. The analysis shows a good agreement between predictions and measurements and shows that the model is slightly over predicting at all locations which is as expected and required in an assessment of this nature. This shows that although GRAMM may not be predicting meteorology with 100% accuracy at all locations across the domain, the GRAL model (for which GRAMM is an input), is predicting results at an appropriate level of accuracy at varying locations in the study area.

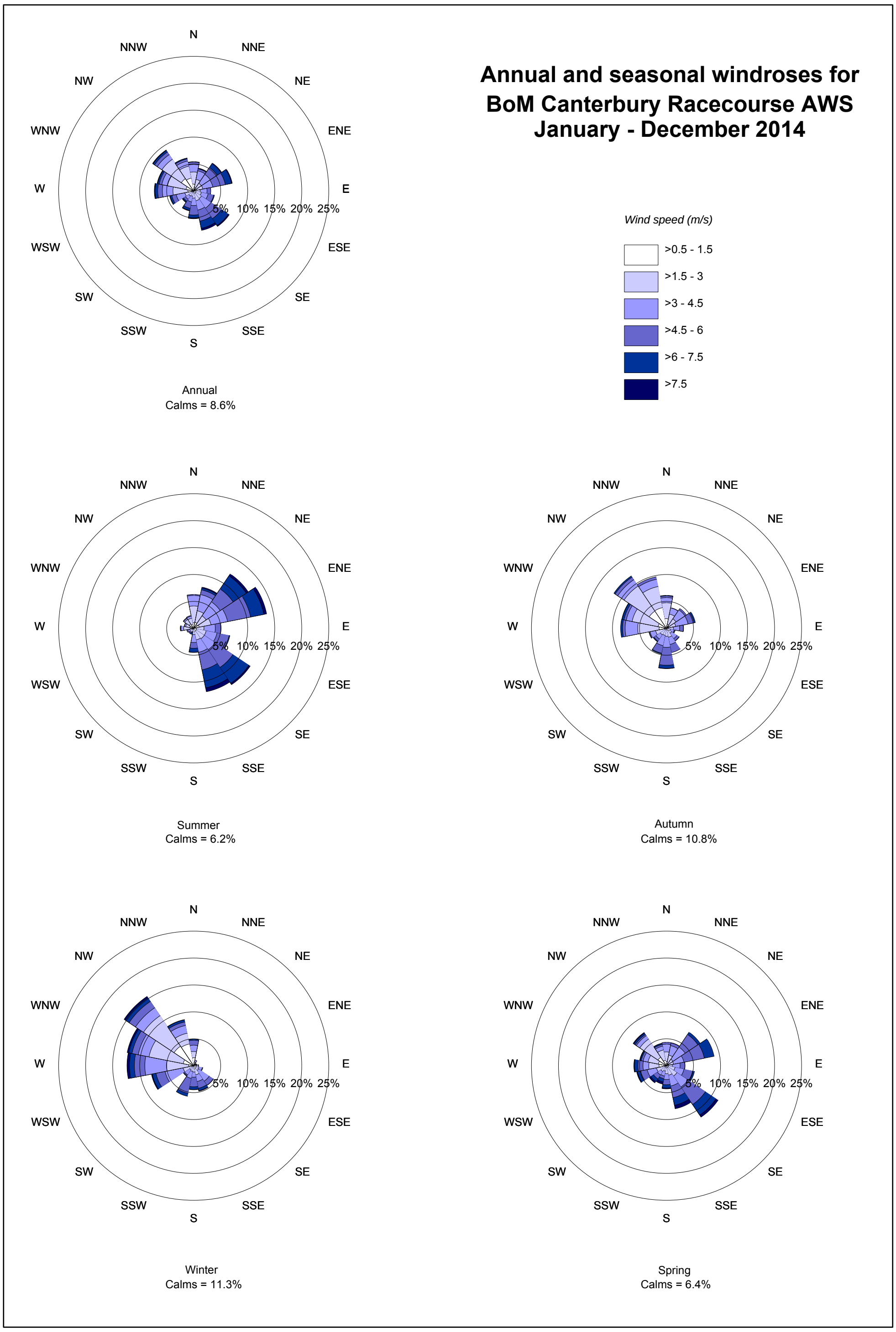

Figure 8-14 Annual and seasonal wind roses for Canterbury Racecourse AWS (2014)

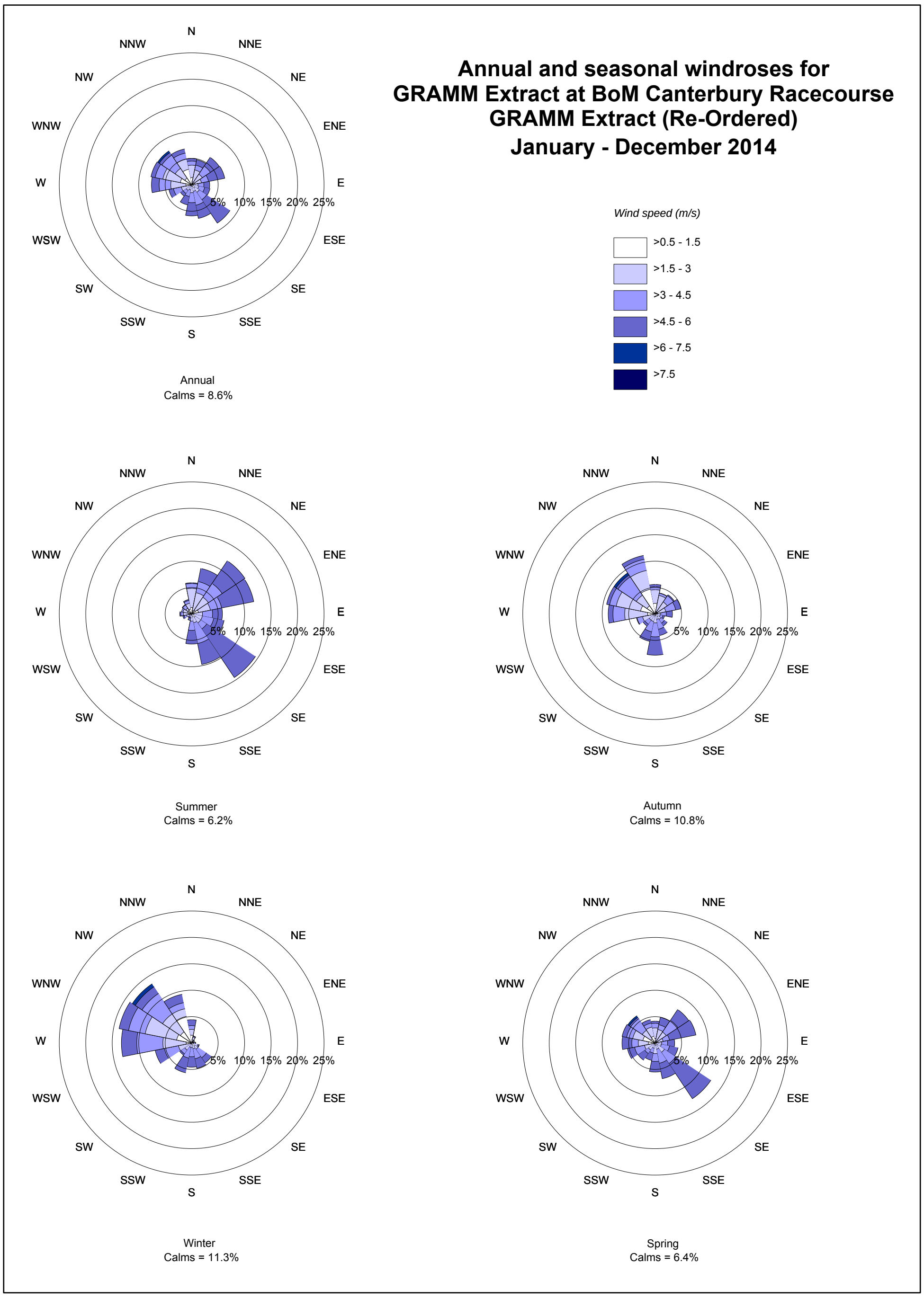

Figure 8-15 Annual and seasonal wind roses for Canterbury Racecourse AWS Re-ordered (2014)

Statistical evaluation

Several statistical metrics were used to evaluate the performance of GRAMM. The metrics were taken from the BOOT Statistical Model Evaluation Software Package (Chang and Hanna, 2005), and model performance was assessed against benchmarks from Emery et al. (2001). These metrics are described in more detail with statistical equations in Appendix H.

The metrics used were as follows:

- Index of agreement. This measures how well the predictions and measurements are matched in terms of how they deviate from the mean.
- Mean gross error. This measures how much of the prediction error is so large that it cannot be due to errors that are normally expected in measurements.
- Mean bias. This is the average of the errors in a group of predicted values.
- Fractional bias. This is similar to Mean Bias but is 'non-dimensional', meaning values.
- Skill v. This compares the amount of scatter in the modelled and measured data.
- Skill r. This compares overall error in the predictions to scatter in the measured values. If this value is <1 then it shows the model is predicting well.

The results for the BoM Canterbury Racecourse data for 2014 are presented in Table 8-12. Overall, it was concluded that GRAMM simulates the meteorology with an acceptable degree of accuracy

Table 8-12 Statistical evaluation of GRAMM performance

Statistical measure	Wind speed			Wind direction	
	Ideal value	Benchmark	Result	Benchmark	Result
IOA	1	≥ 0.6	0.92	-	-
Mean gross error	0	≤ 2 m/s	1.22	≤ 30º	4.8
Mean bias	0	≤ ± 0.5 m/s	0.32	≤ 10º	3.8
Fractional bias	0	≤ ± 0.67	0.32	-	-
Skill v	-	1	0.65	-	-
Skill r	-	< 1	0.80	-	-

8.3.6 GRAL configuration – expected traffic scenarios

GRAL domains and main parameters

Table 8-13 presents the main parameters selected in GRAL for the model runs.

The WestConnex GRAL and M4 East GRAL domains were described in Section 5.5.3. GRAL was configured to provide predictions for a Cartesian grid of points with an equal spacing of 10 metres in both the x and y directions. For the WestConnex GRAL domain the total number of points in the grid was around 2.1 million. For this assessment the results are only presented for the smaller M4 East GRAL domain (527,000 points).

Typically, GRAMM simulations are performed with a coarse resolution relative to that of the GRAL resolution (in this case a GRAMM resolution of 200 metres compared with the GRAL resolution of 10m) to capture meteorological conditions over a larger study area. For the Project, the terrain was resolved even further by selecting the original terrain file (with a much higher resolution of 30 metres) to be included in the GRAL model.

Table 8-13 GRAL configuration

Parameter	Value(s)
General	
Domain in UTM (M4 East GRAL)	N = 6254000, S = 6247800, E = 320400, W = 328900
Domain in UTM (WestConnex GRAL)	N = 6254000, S = 6240000, E = 318000, W = 333000
Dispersion time (s)	3600
Number of particles per second[(a)]	400 for roads and outlets
Surface roughness[(b)]	0.5
Latitude (˚)[(c)]	-33
Buildings	None
Concentration grid	
Vertical thickness of concentration layers (m)	1
Horizontal grid resolution (m)	10
Number of horizontal slices	1
Height above ground level (m)[(d)]	3 (effectively ground level)

(a) Defines the total number of particles released in each dispersion situation.

(b) Defines the roughness length in the whole model domain. The roughness length alters the shape of the velocity profile near the surface.

(c) Average latitude of the model domain.

(d) Defines the height above ground for each concentration grid. In specific reference to the GRAL model, a height of 3m represents concentrations effectively at 'ground level'. In the GRAL model, 0m is the direct boundary layer which contains boundary conditions not appropriate for accurate concentration predictions.

Representation of buildings

The size of the GRAL domain and the fine grid resolution meant that building data could not be practically included in the modelling. Due to the complex nature of GRAL's prognostic building calculations, the ideal model set-up to account for the effects of buildings would be a maximum domain size of around two kilometres by two kilometres, with a maximum horizontal grid resolution of five metres. To include buildings in the project set-up, and utilising GRAL's prognostic building calculation approach, would have resulted in extremely long model run times (in the order of weeks per scenario). Moreover, the post-processing of the results at a five metre resolution across a modelling domain of 15 kilometres by 14 kilometres would have been impractical.

It is worth noting however, that there are only a small number of tall buildings in proximity to the proposed ventilation outlets, and therefore the effects of building downwash (see Appendix B) would probably have been rather limited.

Receptors

Receptors are defined by NSW EPA as anywhere someone works or resides, or may work or reside, including residential areas, hospitals, hotels, shopping centres, playgrounds, recreational centres, etc. Due to its location in a highly built-up area of Western Sydney, the project modelling domain contains a large number of sensitive receptors. Many of these sensitive receptors are located immediately adjacent to the existing major road network.

As noted earlier in the report, two types of discrete receptor were defined for use in the assessment:

- 'Community receptors'. These were particularly sensitive locations such as schools, child care centres and hospitals. For these receptors a detailed approach was used to calculate the total concentration of each pollutant. This involved the combination of the contemporaneous road/outlet time series of concentrations from GRAL and the background time series of concentrations, stated as a one-hour mean for each hour of the year in each case. In total, 31 community receptors were included in the project assessment.

- RWR receptors. These were all other discrete receptor locations, and mainly covered residential and commercial land uses. For these receptors a simpler statistical approach was used to combine a concentration statistic for the modelled roads and outlets (e.g. maximum 24-hour mean PM_{10}, annual mean NO_X) with an appropriate background statistic. In total, 10,362 RWR receptors were included in the assessment (this included the 31 community receptors).

The RWR receptors are discrete points in space, classified according to the land use identified at that location. The RWR receptors do not identify the number of residential (or other) properties at the location. The residential land use at an RWR receptor location may range from a single-storey dwelling to a multi-storey, multi-dwelling building. The RWR receptors are therefore not designed for the assessment of changes in total population exposure. The Human Health Risk Assessment (Chapter 11 of the EIS) combines the air quality information with the highest resolution population data from the Australian Bureau of Statistics to calculate key health indicators that reflect varying population density across the study area.

The main reason for the distinction was to permit a more detailed analysis for community receptors. The number of such receptors that could be included was dictated by the limit on the number of time series for individual receptors that could be extracted from GRAL. Due to the computational requirements of GRAL, it was not possible to include a large number of time series for community receptors.

Figure 8-16 shows the locations of the various discrete receptors. A full list of community receptors is given in Table 8-14, and the numbers of RWR receptors are listed by category in Table 8-15.

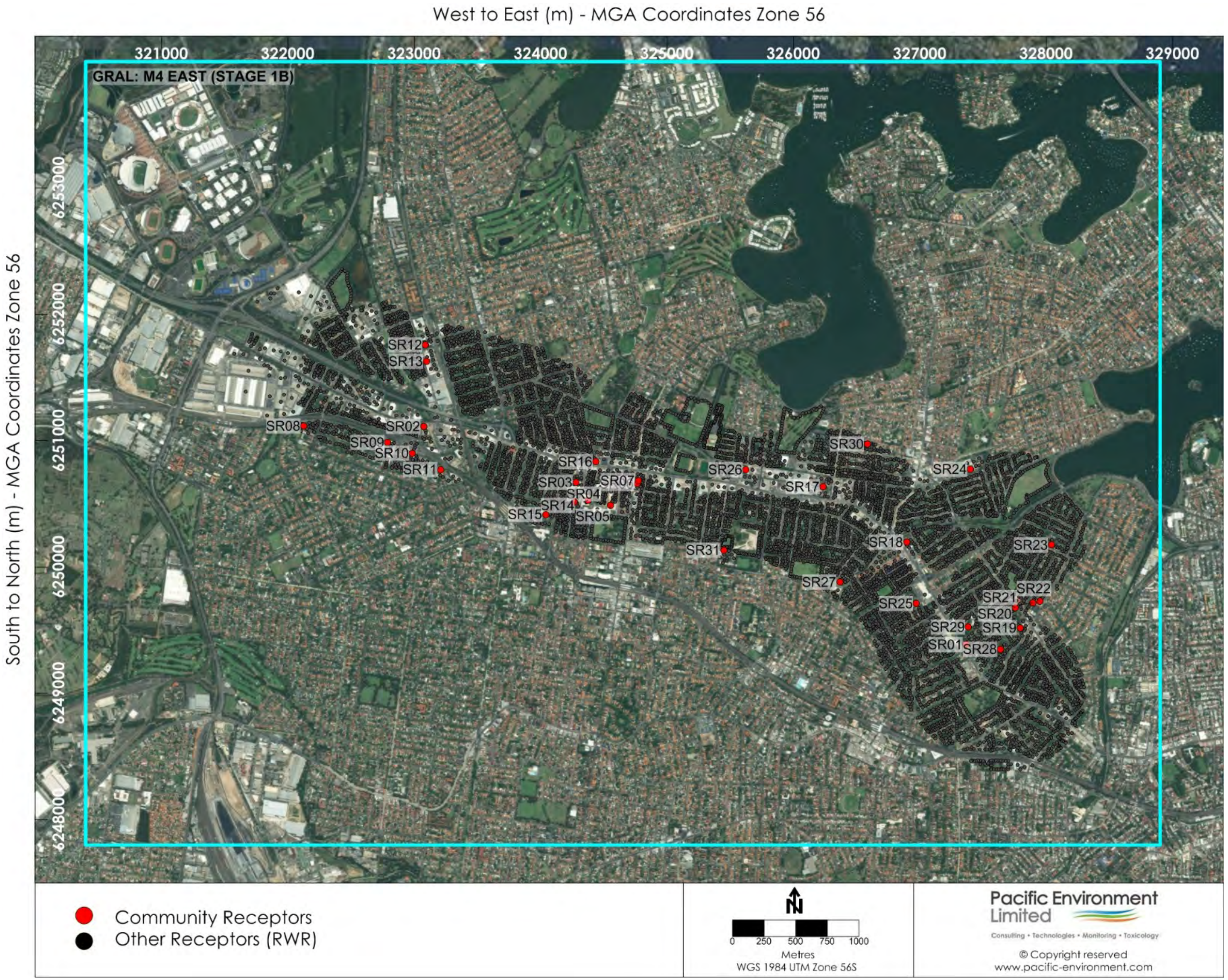

Figure 8-16 **Modelled discrete receptor locations**

Table 8-14 Full list of community receptors

Receptor code	Receptor name	Receptor location	
		x	y
SR01	Peek-A-Boo Early Learning	327364	6249386
SR02	Aiya Medical Centre	323074	6251114
SR03	St John of God Burwood Hospital	324279	6250670
SR04	MLC School Sydney	324373	6250528
SR05	Southern Cross Catholic Vocational College	324552	6250486
SR06	Burwood ENT Surgery	324764	6250661
SR07	Burwood Chest Clinic	324772	6250684
SR08	Homebush Boys High School	322126	6251117
SR09	Homebush Public School	322791	6250986
SR10	Homebush Medical Centre	322985	6250902
SR11	Pre-University New College	323209	6250772
SR12	McDonald College	323089	6251759
SR13	Light House Child Care	323095	6251629
SR14	MLC School Sydney	324268	6250516
SR15	Strathfield Private Hospital	324039	6250416
SR16	St Mary's Catholic Primary School	324437	6250834
SR17	Rosebank College	326234	6250636
SR18	Little VIPs	326895	6250197
SR19	Ella Community Child Care Centre	327793	6249519
SR20	Ramsay Street Medical Centre	327755	6249680
SR21	St. John of Arc Catholic School	327895	6249716
SR22	Saint Joan of Arc's Catholic Church Haberfield	327948	6249729
SR23	Dobroyd Point Public School	328040	6250175
SR24	Domremy College	327401	6250774
SR25	The Infants Home	326973	6249712
SR26	Lucas Gardens School	325624	6250771
SR27	Educare Playschool	326366	6249880
SR28	Goodstart Early Learning	327638	6249350
SR29	Haberfield Public School	327384	6249525
SR30	Happy Little Campers	326584	6250974
SR31	Burwood Girls High School	325448	6250134

Table 8-15 Summary of RWR receptor types

Receptor type	Number
Residential	7,251
Garage	1,493
Commercial	456
Industrial	38
Educational establishment	97
Child care centre	9
Medical centre / hospital	16
Place of worship	17
Hotel	9
Café/bar	9
Outdoor 'active'	549
Outdoor 'passive'	210
Total	**10,154**

M4 East ventilation outlets

Locations and heights

The locations and heights of the WestConnex ventilation outlets included in the assessment are given in Table 8-16.

Table 8-16 Ventilation outlet locations and heights

Tunnel project	Ventilation outlet	Traffic direction	Outlet location (MGA)		Ground elevation (m)	Outlet height (m)
			X	Y	Z	
M4 East	**A** (Eastern ventilation facility, M4 East outlet)	EB	327101	6249870	15.3	25.0
	B (Western ventilation facility)	WB	322708	6251442	7.5	30.5
M4 East and M4-M5 Link	**A** (Eastern ventilation facility, M4 East outlet)	EB	327101	6249870	15.3	25.0
	C (Eastern ventilation facility, City West Link/Rozelle)	EB	330523	6250293	5.1	25.0
	B (Western ventilation facility)	WB	322708	6251442	7.5	30.5
	D (Eastern ventilation facility, M4-M5 Link outlet)	WB	327107	6249871	15.3	25.0

The ventilation outlet for the existing M5 East tunnel was also included as it was within the WestConnex GRAL domain. However, it was located well outside (around four kilometres to the south) of the M4 East GRAL domain, and had a negligible effect on concentrations in the project assessment.

Emission rates

The ventilation outlet emission rates are provided in Appendix I.

Volumetric flow rates

The project would be serviced by ventilation systems, the operating parameters of which would vary depending on traffic volume. The volume of air to be extracted from the tunnels, and hence the number and output of the fans, would therefore vary by time of day. This would result, in turn, in hourly-varying outlet exit velocities, effective outlet diameters, and emission rates. A number of assumptions were required to accommodate these factors in GRAL.

The volumetric air flow (in m^3/s) for each of the tunnel ventilation outlets is provided in Appendix L. The required air flow was provided for each hour of the day based on the projected traffic data for normal operation and a traffic speed 80 kilometres per hour. An example of the diurnal air flow profile is shown as the green line in Figure 8-17. It was necessary to simplify the ventilation profile for use in GRAL in order to reduce the model run times to a manageable level. Each profile was therefore simplified to three phases (nominally ‘high’, ‘medium’ and ‘low’). To maintain a degree of conservatism in the dispersion modelling the simplified air flows were, as far as possible, set to values that were within the envelope of the profile. The simplified profile is shown as the green columns in the Figure. The air flows applied in GRAL are given in Table 8-16.

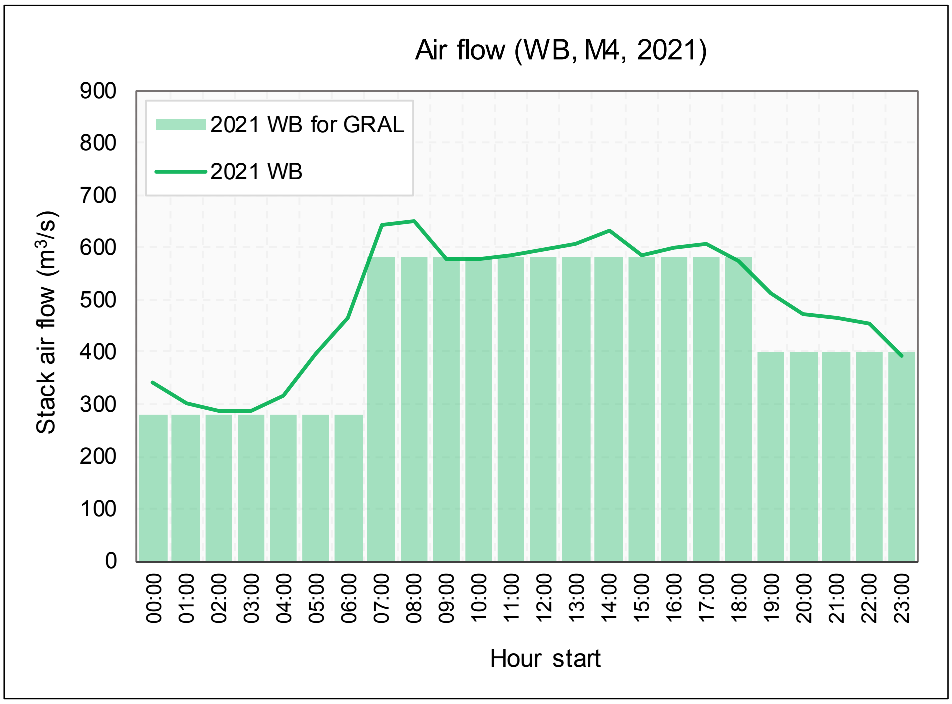

Figure 8-17 Example of ventilation air flow profile used in GRAL

Table 8-17 Ventilation air flows

Tunnel project	Ventilation outlet	2021		2031	
		Time period (hour start)	Air flow (m^3/s)	Time period (hour start)	Air flow (m^3/s)
M4 East	**A** (Eastern ventilation facility, M4 East outlet)	00:00-05:00	280	00:00-05:00	280
		06:00-17:00	680	06:00-17:00	760
		18:00-23:00	400	18:00-23:00	420
	B (Western ventilation facility)	00:00-06:00	280	00:00-06:00	300
		07:00-18:00	580	07:00-18:00	580
		19:00-23:00	400	19:00-23:00	400
M4 East and M4-M5 Link	**A** (Eastern ventilation facility, M4 East outlet)	-	-	00:00-05:00	240
		-	-	06:00-18:00	350
		-	-	19:00-23:00	280
	C (Eastern ventilation facility, City West Link/Rozelle)	-	-	00:00-05:00	350
		-	-	06:00-17:00	750
		-	-	18:00-23:00	500
	B (Western ventilation facility)	-	-	00:00-06:00	350
		-	-	07:00-18:00	720
		-	-	19:00-23:00	500
	D (Eastern ventilation facility, M4-M5 Link outlet)	-	-	00:00-06:00	175
		-	-	07:00-14:00	320
		-	-	15:00-23:00	250

Effective outlet diameter and exit velocity

Each ventilation facility would feature multiple variable-speed fans, the number of which in use at any given time would be determined by the ventilation requirement. The fan configurations of the different ventilation outlets were slightly different (see Figure 2-5 and Figure 2-6). The eastern ventilation facility and City West Link/ Rozelle outlet would have a fixed diameter, and hence a varying exit velocity depending on the air flow. The western ventilation outlet would have an effective outlet diameter and exit velocity that would vary according to the number of fans in use.

Given that actual operational conditions were not known, the number of fans in use was based on the volumetric air flow. It was assumed that:

- Each fan would have a rating of 200 m^3/s, but would never be used at its maximum capacity.
- At least two fans would be in use at all times.
- So, for example, an air flow of less than 200 m^3/s would require two fans, an air flow of 400 m^3/s would require three fans, and an air flow of 750 m^3/s would require 4 fans.

The time-varying outlet diameters were represented in GRAL using different source groups in combination with modulation factors to switch source groups on and off by time period, as required.

Table 8-18 Effective outlet diameters and exit velocities

Ventilation outlet	Air flow (m^3/s)	Number of fans	Combined outlet CSA (m^2)	Effective outlet diameter (m)	Exit velocity (m/s)
M4 East, 2021					
A (Eastern ventilation facility, M4 East outlet)	280	2	72	9.6	3.9
	400	3	72	9.6	5.6
	680	4	72	9.6	9.4
B (Western ventilation facility)	280	2	72	9.6	3.9
	400	3	108	11.7	3.7
	580	3	108	11.7	5.4
M4 East, 2031					
A (Eastern ventilation facility, M4 East outlet)	280	2	72	9.6	3.9
	420	3	72	9.6	5.8
	760	4	72	9.6	10.6
B (Western ventilation facility)	300	2	72	9.6	4.2
	400	3	108	11.7	3.7
	580	3	108	11.7	5.4
M4 East and M4-M5 Link, 2031					
A (Eastern ventilation facility, M4 East outlet)	240	2	72	9.6	3.3
	280	2	72	9.6	3.9
	350	2	72	9.6	4.9
C (City West Link/Rozelle)	350	2	72	9.6	4.9
	500	3	72	9.6	6.9
	750	4	72	9.6	10.4
B (Western ventilation facility)	350	2	72	9.6	4.9
	500	3	108	11.7	4.6
	720	4	144	13.5	5.0
D (Eastern ventilation facility, M4-M5 Link	175	2	72	9.6	2.4
	250	2	72	9.6	3.5
	320	2	72	9.6	4.4

Outlet temperature

The temperature of emissions from ventilation outlets is an important determinant of the dispersion of pollutants. Plumes with higher temperatures have higher buoyancy, which generally means that the plume is carried higher into the atmosphere, resulting in improved dispersion. The temperature of the plume is influenced by the number of vehicles moving through the tunnels, as some of the heat from the vehicle exhaust emissions would be carried through to the ventilation outlets.

Diurnal temperature profiles are provided for each ventilation outlet in Appendix L. Separate profiles were provided for summer and winter. For simplicity in GRAL, a single temperature for the whole year was used. This was an average of the summer and winter data (Figure 8-18). Upper and lower bound temperatures (10^{o}C higher and lower than the average) were also defined for sensitivity testing.

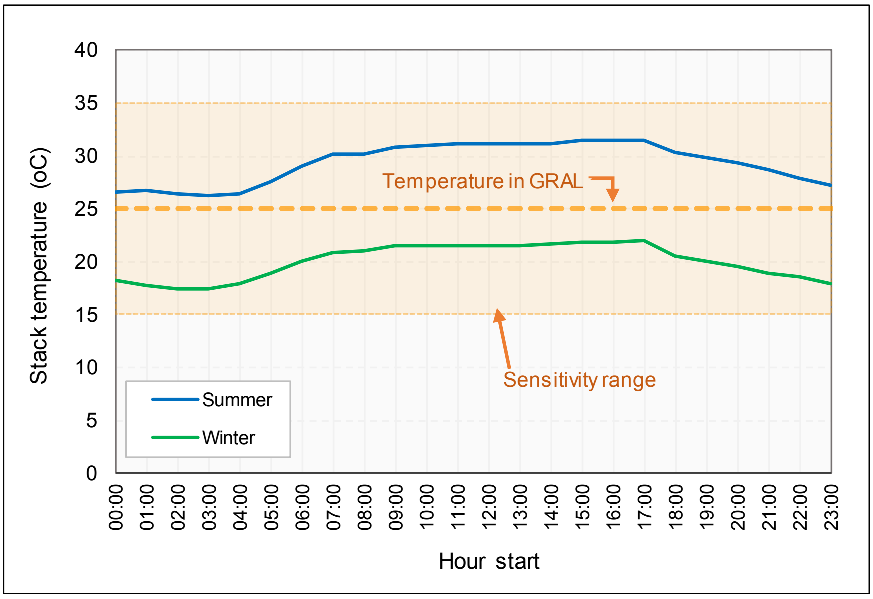

Figure 8-18 Example of outlet temperature used in GRAL (eastern ventilation facility, 2021-DS)

Existing M5 East ventilation outlet

Location and height

The location and height of the existing M5 East ventilation outlet are given in Table 8-19.

Table 8-19 M5 East ventilation outlet location and height

Tunnel ventilation outlet	Outlet location (MGA)		Outlet height (m)
	x	y	
M5 East	328204.2	6244290.1	35

Emission rates

The ventilation outlet emission rates were provided in Section 8.2.4.

Volumetric flow rates and exit velocity

The volumetric air flows for the M5 East outlet were determined from measurements during 2014, and a simplified diurnal profile was developed for GRAL following the approach described earlier for the project. The air flows were converted to exit velocities using a cross-sectional area for the outlet of 42.3 m^2 (effective circular diameter of 7.3 m), and are summarised in

Table 8-20 M5 East ventilation outlet exit velocity

Period (hour start)	Exit velocity (m/s)
Hours 00-05 and 22-23	10
Hours 06-21	20

Outlet temperature

The temperature of the air in the M5 East outlet did not vary greatly during the day or from month to month. A constant temperature of 30°C, reflecting the annual average, was therefore used.

8.3.7 GRAL configuration – regulatory worst case scenarios

As noted earlier, the objective of these scenarios was to demonstrate that compliance with the concentration limits for the tunnel ventilation outlets will guarantee acceptable ambient air quality.

The regulatory worst case assessment involved a separate modelling exercise for the tunnel ventilation outlets only. The concentration limits for the tunnel ventilation outlets, taken from the NorthConnex conditions of approval, are shown in Table 8-21. These were converted to mass emission rates (in kg/h) based on assumed ventilation settings. A 'medium' level air flow of 400 m^3/s was assumed for each outlet, with the corresponding number of fans in operation, effective outlet diameters and exit velocities. Sensitivity tests were also conducted using alternative 'high' (800 m^3/s) and 'low' (200 m^3/s) air flows with corresponding outlet conditions and emission rates, but these gave ambient concentrations that were very similar to those for the medium air flow case and have therefore not been reported here. The assumptions for the ventilation outlets are summarised in Table 8-22.

Table 8-21 Concentration limits for ventilation outlets

Pollutant	Limit concentration (mg/m^3)
PM_{10}	1.1[(a)]
$PM_{2.5}$	1.1
NO_X	20.0
NO_2	2.0
CO	40.0
VOC/THC	4.0

(a) Stated as 'solid particles' in the conditions of approval.

Table 8-22 Ventilation outlet assumptions for regulatory worst case scenarios

Ventilation outlet	Air flow (m^3/s)	Number of fans	Combined outlet CSA (m^2)	Effective outlet diameter (m)	Exit velocity (m/s)	Temp. (^{0}C)	Emission rate (kg/hour)				
							PM_{10}	$PM_{2.5}$	NO_X	CO	VOC/ THC
A (Eastern ventilation facility, M4 East outlet)	400	3	72	9.6	5.6	25	1.58	1.58	28.8	57.6	5.76
B (Western ventilation facility)	400	3	108	11.7	3.7	25					
A (Eastern ventilation facility, M4 East outlet)	400	3	72	9.6	5.8	25					
C (City West Link/Rozelle)	400	3	72	9.6	6.9	25					
D (Eastern ventilation facility, M4-M5 Link	400	3	72	9.6	11.1	25					

8.3.8 Calculation of total concentrations and comparison with air quality criteria

Total concentrations were required to enable comparisons with the applicable air quality criteria. This required a variety of different methods because of the range of metrics in the criteria and also the nature of the information that could be extracted from GRAL for the two types of receptor.

Carbon monoxide (maximum one-hour mean)

For the community receptors, a contemporaneous approach was used, with the one-hour mean CO concentration from GRAL being added to the corresponding one-hour background CO concentration for every hour of the year. The maximum total one-hour concentration was then determined.

For RWR receptors the maximum one-hour CO concentration from GRAL was added to maximum one-hour background concentration.

For both types of receptor the maximum total CO concentration during the modelled year was compared with the corresponding air quality criterion.

Carbon monoxide (maximum rolling 8-hour mean)

For the community receptors, a contemporaneous approach was used, with the rolling 8-hour mean CO concentration from GRAL being added to the corresponding rolling 8-hour background CO concentration for every hour of the year. The maximum total rolling eight-hour concentration for the year was then determined.

For RWR receptors the maximum one-hour CO concentration from GRAL was added to maximum one-hour background concentration. The result was then converted to a maximum rolling 8-hour CO concentration using a relationship based on the data from the air quality monitoring stations in Sydney (see Figure 8-19).

For both types of receptor the maximum total CO concentration during the modelled year was compared with the corresponding air quality criterion.

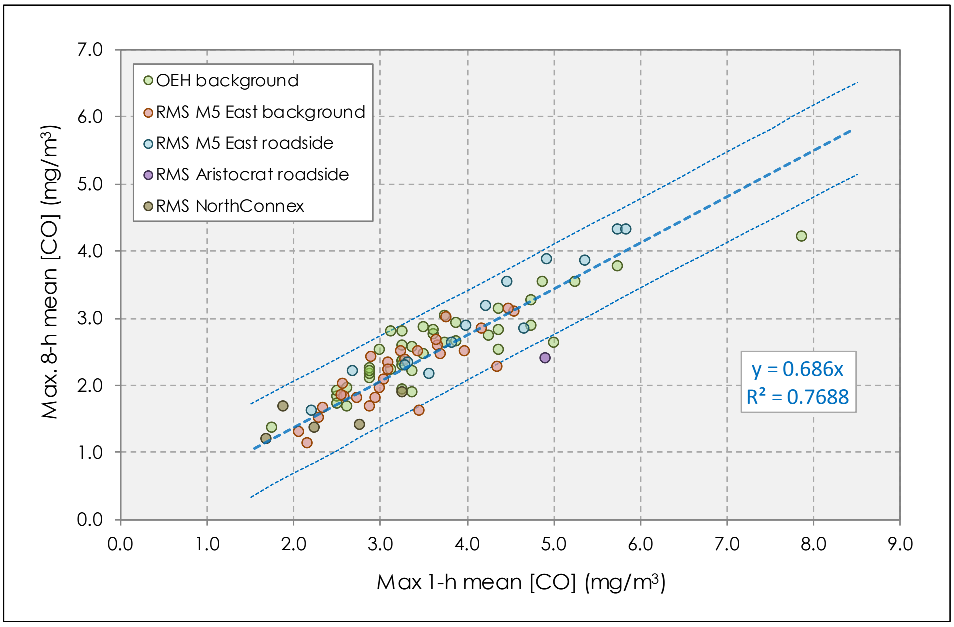

Figure 8-19 **Relationship between maximum rolling 8-hour mean CO and maximum one-hour mean CO (dotted lines show 95% prediction intervals)**