WestConnex

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New M5

Environmental Impact Statement

Technical working paper: Air quality



Appendix H

November 2015

WestConnex

Roads and Maritime Services

WestConnex New M5

Air Quality Assessment Report

20 November 2015

Prepared for

Roads and Maritime Services

Prepared by

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Pacific Environment

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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
AWS	automatic weather station
BAM	Beta Attenuation Monitor
BTEX	benzene, toluene, ethylbenzene and xylenes
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
CSA	cross-sectional area
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.

Term	Description
	g/litre).
Emission rate	A quantity which expresses the mass of a pollutant emitted per unit of time (e.g. g/second)
EPHC	Environment Protection Heritage Council
ESP	electrostatic precipitator
EU	European Union
GHG	greenhouse gas
GLC	ground-level concentration
GMR	(NSW) Greater Metropolitan Region
GRAL	Graz Lagrangian Model
GRAMM	Graz Mesoscale Model
GVM	gross vehicle mass
HCV	heavy commercial vehicle (interchangeable with HGV)
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

Term	Description
$PM_{2.5}$	airborne particulate matter with an aerodynamic diameter of less than 2.5 µm
PV	passenger vehicle
RH	relative humidity
Roads and Maritime	(NSW) Roads and Maritime Services
RWR	Residential, workplace and recreational (RWR). This term refers to all discrete receptor locations along the project corridor, and mainly covered residential and commercial land uses.
SCR	Selective catalytic reduction
SEARs	Secretary's Environmental Assessment Requirements
SER	Strategic Environmental Review
SF_6	sulfur hexafluoride
SMPO	Sydney Motorways Project Office
SO_2	sulfur dioxide
SO_X	sulfur oxides
SOA	secondary organic aerosol
SPI	St Peters interchange
TEOM	Tapered Element Oscillating Microbalance
TEOM-FDMS	TEOM with Filter Dynamic Measurement System
THC	total hydrocarbons
TRAQ	Tool for Roadside Air Quality
TSP	total suspended particulate
UFP	ultrafine particles
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
WRTM	WestConnex Road Traffic Model
$\mu g/m^3$	micrograms per cubic metre

Executive summary

The project

NSW Roads and Maritime Services (Roads and Maritime) is seeking approval to construct and operate the New M5 (the project), which would comprise a new, tolled multi-lane road link between the existing M5 East Motorway, east of King Georges Road, and St Peters. The project would also include an interchange at St Peters and connections to the existing road network.

Approval is being sought under Part 5.1 of the Environmental Planning and Assessment Act 1979 (EP&A Act). The project is declared to be State significant infrastructure (SSI) under section 115U(2) of the EP&A Act by reason of the operation of clause 14 and Schedule 3 of the *State Environmental Planning Policy (State and Regional Development) 2011*. Accordingly, the project is subject to assessment under Part 5.1 of the EP&A Act and requires the approval of the Minister for Planning. An environmental impact statement (EIS) is therefore also required. Roads and Maritime is seeking the project to be declared by the Minister for Planning as State significant infrastructure and critical State significant infrastructure under sections 115U(4) and 115V of the EP&A Act.

The project is a component of WestConnex, a 33 kilometre motorway that is intended to link Sydney's west with the airport and the Port Botany precinct. The component projects of the WestConnex program of works are:

- M4 Widening – Pitt Street, Parramatta to Homebush Bay Drive, Homebush (planning approval granted and under construction)
- M4 East – Homebush Bay Drive, Homebush to Parramatta Road and City West Link (Wattle Street) at Haberfield (planning application lodged and subject to planning approval)
- New M5 – (the subject of this EIS)
- King Georges Road Interchange Upgrade (planning approval granted and under construction)
- M4-M5 Link – Haberfield to St Peters (undergoing concept development and subject to planning approval)
- Sydney Gateway (undergoing concept development and subject to planning approval)

Separate planning applications have or will be lodged for each component project. Each project will be assessed separately, but the impact of each project will also be considered in the context of the wider WestConnex program of works.

The key components of the project would include:

- Twin motorway tunnels between the existing M5 East Motorway (between King Georges Road and Bexley Road) and St Peters. The western portals along the M5 East Motorway would be located east of King Georges Road, and the eastern portals at St Peters would be located in the vicinity of the Princes Highway and Canal Road. Each tunnel would be about nine kilometres in length and would be configured as follows:
  - Between the western portals and Arncliffe, the tunnels would be built to be three lanes but marked for two lanes as part of the project. Any change from two lanes to three lanes would be subject to future environmental assessment and approval
  - Between the Arncliffe and St Peters, the tunnels would be built to be five lanes but marked for two lanes as part of the project. Any change from two lanes to any of three, four or five lanes would be subject to future environmental assessment and approval
- The western portals along the M5 East Motorway would be located east of King Georges Road, and the eastern portals at St Peters would be located in the vicinity of the Princes Highway and Canal Road

- Tunnel stubs to allow for a potential future connection to the future M4-M5 Link and a potential future connection to southern Sydney
- Surface road widening works along the M5 East Motorway between east of King Georges Road and the new tunnel portals
- A new road interchange at St Peters, which would initially provide road connections from the main alignment tunnels to Campbell Road and Euston Road, St Peters
- Closure and remediation of the Alexandria Landfill site, to enable the construction and operation of the new St Peters interchange (SPI)
- Two new road bridges across Alexandra Canal which would connect St Peters interchange with Gardeners Road and Bourke Road, Mascot
- Works to enhance and upgrade local roads near the St Peters interchange
- Ancillary infrastructure and operational facilities for electronic tolling, signage (including electronic signage), ventilation structures and systems, fire and life safety systems, and emergency evacuation and smoke extraction infrastructure
- A motorway control centre that would include operation and maintenance facilities
- New service utilities and modifications to existing service utilities
- Temporary construction facilities and temporary works to facilitate the construction of the project
- Infrastructure to introduce tolling on the existing M5 East Motorway
- Surface road upgrade works within the corridor of the M5 South West Motorway and M5 East Motorway
- The ventilation facilities for the project, being:
  - Kingsgrove ventilation facility. This facility provides the outlet for the westbound traffic of the New M5 tunnel (St Peters to Kingsgrove).
  - Arncliffe ventilation facility. This facility provides the outlet for the first section of eastbound traffic of the New M5 tunnel (Kingsgrove to Arncliffe), and the fresh air supply for the second section of the eastbound New M5 tunnel (Arncliffe to St Peters). It will also provide the outlet for the northbound Southern extension tunnel (Kogarah to Arncliffe).
  - St Peters ventilation facility (New M5 outlet). This facility provides the outlet for the second section of the eastbound New M5 tunnel (Arncliffe to St Peters), the future outlet for the eastbound traffic to the M4-M5 Link stub (Arncliffe to St Peters), and the future fresh air supply to the northbound M4-M5 Link (St Peters to Rozelle).

The ventilation facilities for the future M4-M5 Link project and Southern extension have also been considered in this assessment but do not form part of the project.

The purpose of this report

This report has been prepared in response to the Secretary's Environmental Assessment Requirements (SEARs) issued 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, the future M4-M5 Link and the future Southern extension).

  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.

[1] GRAL = Graz Lagrangian model

- 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 (1-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, the total numbers of receptors with exceedances decreased slightly with the project. The exception to this was annual mean $PM_{2.5}$, for which concentrations were (by definition in the assessment) always above the corresponding criterion.
- The spatial changes in air quality as a result of the project were quite complex, reflecting the complex changes in traffic on the network. There were predicted to be substantial reductions in concentrations along the M5 East Motorway, both to the east and west of the M5 East tunnel, as well as along General Holmes Drive and other roads around the airport. Reductions in concentration were also predicted along the section of King Georges Road to the north of the M5 East Motorway, around the northern perimeter of Sydney Park, and on a number of other roads. However, increases in concentration were predicted for King Georges Road to the south of the M5 East Motorway, Stoney Creek Road, Bexley Road to the south of the M5 East Motorway, Harrow Road, Bay Street, Forest Road, and around the southern perimeter of Sydney Park, amongst other roads.
- Where increases in pollutant concentration at receptors were predicted, these were mostly small. Very small proportions of receptors were predicted to have larger increases.

Management of impacts

Construction impacts

Various measures for the management of construction impacts have been identified 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 will 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 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 uphill gradient of four per cent
- Large main line tunnel cross-sectional area (90 square metres)
- 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 will 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, will 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 in 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 compliance with in-tunnel air quality limits cannot be achieved with the proposed ventilation system, the most effective solution will 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.

1 Introduction

NSW Roads and Maritime Services (Roads and Maritime) is seeking approval to construct and operate the New M5 (the project), which would comprise a new, tolled multi-lane road link between the existing M5 East Motorway, east of King Georges Road, and St Peters. The project would also include an interchange at St Peters and connections to the existing road network.

Approval is being sought under Part 5.1 of the Environmental Planning and Assessment Act 1979 (EP&A Act). The project is declared to be State significant infrastructure (SSI) under section 115U(2) of the EP&A Act by reason of the operation of clause 14 and Schedule 3 of the *State Environmental Planning Policy (State and Regional Development) 2011*. Accordingly, the project is subject to assessment under Part 5.1 of the EP&A Act and requires the approval of the Minister for Planning. An environmental impact statement (EIS) is therefore also required.

Roads and Maritime is seeking the project to be declared by the Minister for Planning as State significant infrastructure and critical State significant infrastructure under sections 115U(4) and 115V of the EP&A Act.

On 11 August 2015, the Commonwealth Minister for the Environment determined that the project has the potential to significantly impact on a matter of national environmental significance and is therefore a 'controlled action'. This means that approval of the project will be required from the Commonwealth Minister for the Environment in addition to environmental and planning approvals required under State legislation.

Under the Bilateral Agreement relating to environmental assessment (February 2015) between the Commonwealth Government and the NSW Government, this EIS has been adopted for the purpose of meeting the assessment requirements of both the Commonwealth EPBC Act and the NSW EP&A Act.

This report identifies and assesses the potential air quality associated with construction and operation of the project and supports the EIS for the project.

1.1 Overview of WestConnex

WestConnex is a 33 kilometre motorway that is intended to link Sydney's west with the airport and the Port Botany precinct. The location of WestConnex is shown in Figure 1-1.

The component projects of the WestConnex program of works are:

- M4 Widening – Pitt Street, Parramatta to Homebush Bay Drive, Homebush (planning approval granted on 21 December 2014 and under construction)
- M4 East – Homebush Bay Drive, Homebush to Parramatta Road and City West Link (Wattle Street) at Haberfield (planning application lodged and subject to planning approval)
- New M5 – (the subject of this EIS)
- King Georges Road Interchange Upgrade (planning approval granted on 3 March 2015 and under construction)
- M4-M5 Link – Haberfield to St Peters (undergoing concept development and subject to planning approval)
- Sydney Gateway (is the subject of further investigations by the NSW Government and would be subject to separate planning approval).

Separate planning applications have to will be lodged for each component project. Each project will be assessed separately, but the impact of each project will also be considered in the context of the wider WestConnex program of works.

A proposed Southern extension from Arncliffe to Kogarah is currently being investigated by Transport for NSW, and would connect the New M5 to the southern and bayside suburbs of Sydney, and the proposed F6 motorway.

The WestConnex Delivery Authority (WDA) was established by the NSW Government to manage the delivery of the WestConnex series of projects for Roads and Maritime on behalf of the State. The WDA was a public subsidiary corporation of the Roads and Maritime. Following the achievement of early milestones for the WestConnex program of works, the NSW Government took the opportunity to evolve this early governance model.

On 1 October 2015 the transfer of the project delivery functions of WDA to Sydney Motorway Corporation (SMC) was finalised, forming a single decision-making entity to finance and deliver the WestConnex program of works. SMC is a private corporation, the shareholders of which are the Minister for Roads, Maritime and Freight and the Treasurer, with a majority independent board of nine directors.

Roads and Maritime is the Government client agency for the WestConnex program of works. In that capacity Roads and Maritime will enter into contractual arrangements with SMC subsidiary entities which will design, build, own and operate the motorway on behalf of Roads and Maritime. Roads and Maritime and SMC are working together to manage the planning approval process for the project. However, for the purpose of the planning application for the project, Roads and Maritime is the proponent.

1.2 Overview of the project

The project is shown in Figure 1-2. The key components of the project would include:

- Twin motorway tunnels between the existing M5 East Motorway (between King Georges Road and Bexley Road) and St Peters. The western portals along the M5 East Motorway would be located east of King Georges Road, and the eastern portals at St Peters would be located in the vicinity of the Princes Highway and Canal Road. Each tunnel would be about nine kilometres in length and would be configured as follows:
  - Between the western portals and Arncliffe, the tunnels would be built to be three lanes but marked for two lanes as part of the project. Any change from two lanes to three lanes would be subject to future environmental assessment and approval
  - Between the Arncliffe and St Peters, the tunnels would be built to be five lanes but marked for two lanes as part of the project. Any change from two lanes to any of three, four or five lanes would be subject to future environmental assessment and approval
- The western portals along the M5 East Motorway would be located east of King Georges Road, and the eastern portals at St Peters would be located in the vicinity of the Princes Highway and Canal Road
- Tunnel stubs to allow for a potential future connection to the future M4-M5 Link and a potential future connection to southern Sydney
- Surface road widening works along the M5 East Motorway between east of King Georges Road and the new tunnel portals
- A new road interchange at St Peters, which would initially provide road connections from the main alignment tunnels to Campbell Road and Euston Road, St Peters
- Closure and remediation of the Alexandria Landfill site, to enable the construction and operation of the new St Peters interchange
- Two new road bridges across Alexandra Canal which would connect St Peters interchange with Gardeners Road and Bourke Road, Mascot
- Works to enhance and upgrade local roads near the St Peters interchange



Figure 1-1 Location of WestConnex

- Ancillary infrastructure and operational facilities for electronic tolling, signage (including electronic signage), ventilation structures and systems, fire and life safety systems, and emergency evacuation and smoke extraction infrastructure
- A motorway control centre that would include operation and maintenance facilities
- New service utilities and modifications to existing service utilities
- Temporary construction facilities and temporary works to facilitate the construction of the project
- Infrastructure to introduce tolling on the existing M5 East Motorway
- Surface road upgrade works within the corridor of the M5 East Motorway.

Construction activities associated with the project would generally include:

- Commencement of enabling and temporary works, including construction power, water supply, ancillary site establishment, demolition works, property and utility 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
- Fitout of the road tunnels and support infrastructure, including ventilation and emergency response systems
- Construction and fitout of the motorway control centre and ancillary operations buildings
- Upgrades to surface roads and construction of bridges
- Implementation of environmental management and pollution control facilities for the project.

Subject to the project obtaining environmental planning approval, construction of the project is anticipated to commence around mid-2016 and is expected to take around three years to complete.

The M5 Motorway corridor (the M5 East Motorway and the M5 South West Motorway) is the main passenger, commercial and freight corridor between Port Botany, Sydney Airport and south-west Sydney. Traffic demands on the M5 East Motorway currently exceed the design capacity of the roadway, and as a result, present a significant bottleneck to the M5 Motorway corridor with motorists experiencing heavy congestion and unreliable journey times. The project is needed to provide additional capacity along the M5 Motorway corridor, and would allow for a more robust and reliable transport network.

1.3 Project location

The project would be located within the Canterbury, Hurstville, Rockdale, Marrickville, Sydney and Botany Bay local government areas. The project corridor is located from about five to twenty kilometres to the south and south-west of the central business district of Sydney. The project would traverse the suburbs of Beverly Hills, Kingsgrove, Bexley North, Earlwood, Bardwell Park, Bardwell Valley, Arncliffe, Wolli Creek, Tempe, Sydenham, St Peters, Alexandria and Mascot.

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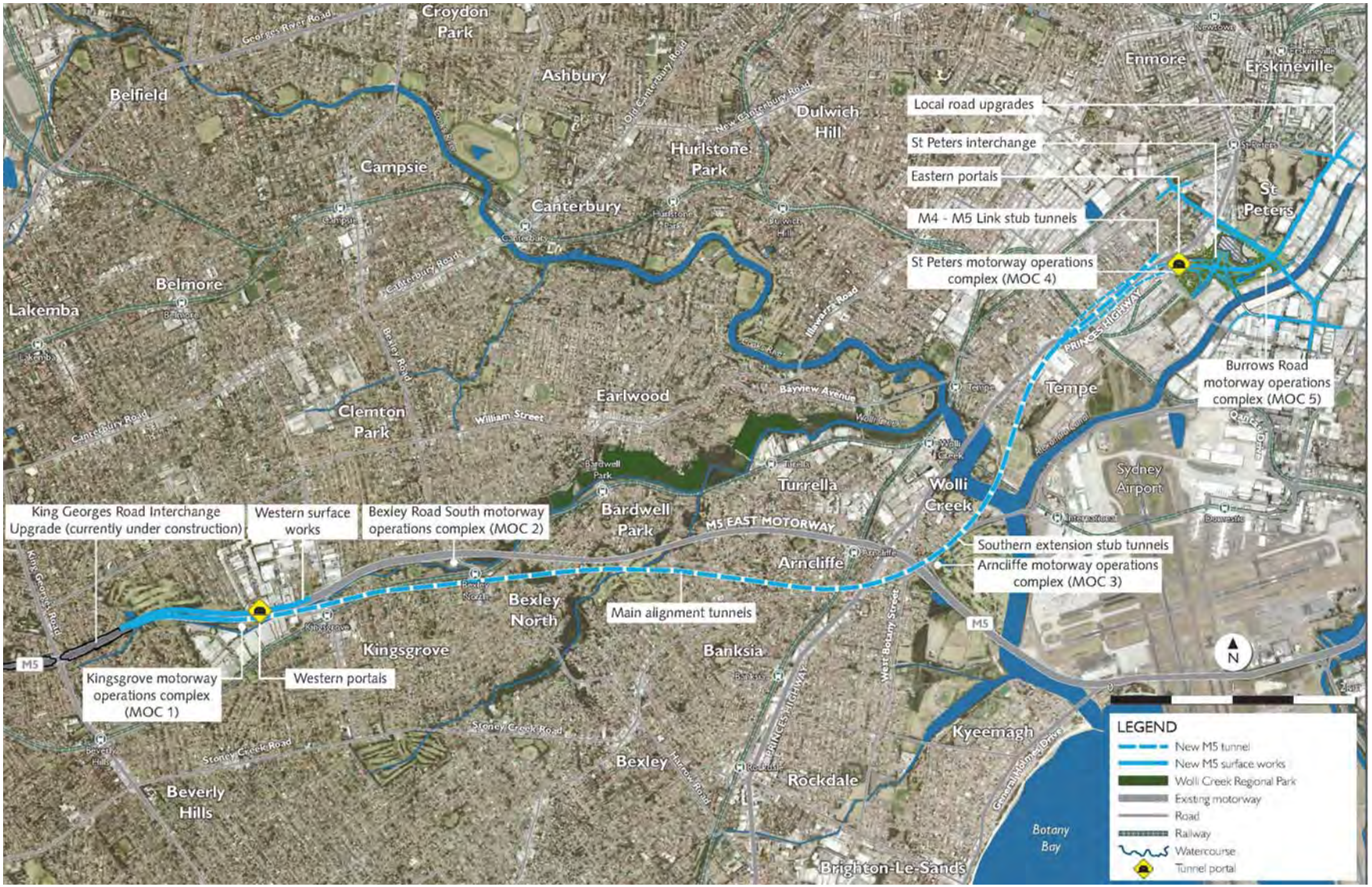


Figure 1-2 Overview of the project

1.4 Secretary's environmental assessment requirements

In preparing this technical report for air quality, the Secretary's environmental assessment requirements (SEARs) issued for the New M5 project (SSI 6788) on 5 March 2015, and reissued on 26 August 2015 have been addressed. 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 (general construction impacts) • Chapter 8 (Alexandria Landfill closure and remediation) • Chapter 9 (operational impacts)
• The identification of all sources of air pollution and assess potential emissions of PM_{10}, $PM_{2.5}$, 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 in the vicinity of St Peters interchange, the alternative surface road network, and in-tunnel air quality.	• Chapter 3 (sources of pollution) • Chapter 9 (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 9 (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 11 (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 (assessment criteria) • Chapter 9 (operational impacts)

[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	
• Consideration of any advice from the Advisory Committee on Tunnel Air Quality on the project particularly in relation to assessment methodology.	• Advice provide by the Advisory Committee for the NorthConnex project was taken into account when developing the assessment methodology.
• 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 11 (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 11 (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.	• Section 8.3.1 (management of odour) • Chapter 11 (management of impacts)
Cumulative assessment of the local and regional air quality due to the operation of the M5 East Motorway ventilation stack, operation of Stage 3 M4 South (Haberfield to St Peters), and surface road operations.	• Chapter 10
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 9 (operational impacts) • Appendix E (emission models) • Appendix J (dispersion model)

In November 2014, the NSW Department of Planning and Environment sought input from government agencies into the preparation of the SEARs for the project. The submissions received by NSW Environment Protection Authority (NSW EPA), Marrickville Council, City of Sydney and City of Botany Bay 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 comments from NSW EPA on the draft SEARs were incorporated in the final version, as provided in Table 1-1.	Not applicable.
Marrickville Council	
Air quality	**Section where addressed in EIS**
• Councils principal concerns are:	
1. Locations and number of exhaust stacks associated with the New M5 and the technology that is to be utilised to ensure adequate air filtration.	Chapter 2 provides a description of the project. Mitigation measures for project operation are described in section 11.2, including a review of the Australian and international experience with filtration systems in tunnel environments.
2. South Marrickville is currently subject to very high numbers of respiratory illnesses (some of the highest in Inner Sydney), likely attributable to the high volumes of traffic and vehicle emissions passing through via routes including the Princes Highway and the Proximity of Sydney Airport. Potential increases must be mitigated and air quality should be actively enhanced via appropriate filtration of exhaust stacks and appropriate distribution of traffic to suitable routes.	Chapter 9 identifies the operational impacts of the project. Mitigation measures for project operation are described in section 11.2.
3. The locations and numbers of exhaust stacks, as well as the technology to be used for filtration to ensure no detrimental effect to local air quality must be clearly outlined. All exhaust stacks must be filtered and monitoring must continue on a regular basis to ensure air quality standards are being adhered to.	Chapter 2 provides a description of the project. Mitigation measures for project operation are described in section 11.2.
4. Impact on St Peters school including noise, air pollution...	Chapter 9 identifies the operational impacts of the project. As a community location, St Peters school is treating in some detail.
City of Sydney	
Air quality	**Section where addressed in EIS**
• An analysis of microclimatic air pollution for each proposed vent location and tunnel entry/exit locations.	Chapter 9 identifies the operational impacts of the project.
• Recommend continuous monitoring stations on all ventilation stack locations and tunnel entry and exit locations plus reporting and mitigation steps to reduce air pollution.	Details of the project-specific ambient air quality monitoring are provided in section 6.7.3 and Appendix F.
• Ventilation stacks should be filtered, as is commonly practiced overseas. Emission sites (stacks and portals) need to be regularly monitored to enable the collection of accurate information on air quality.	Mitigation measures for project operation are described in section 11.2.

Agency letters	
• The location of ventilation stacks and entry/exit portals needs to be carefully considered, and appropriate mitigation measures implemented to help minimise impacts on surrounding environments. It is likely that ventilation stacks will need to be located in some residential areas; it is crucial that they are located to minimise impact on existing residents as far as practicable. Sensitive design should be paramount to limit visual and air quality impacts.	The description of the project is provided in Chapter 2. Chapter 9 identifies the operational impacts of the project. Mitigation measures for project operation are described in section 11.2.
City of Botany Bay	
Air quality	**Section where addressed in EIS**
It is essential that the EIS considers the potential impacts (i.e. noise, air quality & human health, land use, social and economic and amenity) will have on the Mascot Station Precinct during the construction and operation of the Stage 2 of WestConnex.	Chapter 9 identifies the operational impacts of the project.

1.5 Purpose and scope of the report

This 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 New M5 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). 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.

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, 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 Technical Working Paper: Human Health Risk Assessment (EnRisks, 2015)
- Greenhouse gas emissions (assessed in Chapter 22 of the EIS).

1.6 Structure of the report

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 approach. 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 general construction impacts using a semi-quantitative risk-based approach
- Chapter 8 addresses the specific issues of dust and odour associated with the closure of the Alexandria Landfill
- Chapter 9 describes the assessment of operational impacts. It deals with emission modelling, in-tunnel air quality, and dispersion modelling for ambient air quality
- Chapter 10 deals with the cumulative impacts of the project and the M4-M5 Link. The M4 East 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 11 provides a review of air quality mitigation measures, and recommendations on measures to manage any impacts of the project. This 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.

2 The 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

Key components of the project would include:

- Twin motorway tunnels between the existing M5 East Motorway (between King Georges Road and Bexley Road) and St Peters. The western portals along the M5 East Motorway would be located east of King Georges Road, and the eastern portals at St Peters would be located in the vicinity of the Princes Highway and Canal Road. Each tunnel would be about nine kilometres in length and would be configured as follows:
  - Between the western portals and Arncliffe, the tunnels would be line marked for two lanes as part of the project, and built with the provision to be widened to three in the future, subject to additional assessment and approval
  - Between the Arncliffe and St Peters, the tunnels would be built to be five lanes but marked for two lanes as part of the project. Any change from two lanes to any of three, four or five lanes would be subject to future environmental assessment and approval
- The western portals along the M5 East Motorway would be located east of King Georges Road, and the eastern portals at St Peters would be located in the vicinity of the Princes Highway and Canal Road
- Tunnel stubs to allow for a potential future connection to the future M4-M5 Link and a potential future connection to southern Sydney
- Surface road widening works along the M5 East Motorway between east of King Georges Road and the new tunnel portals
- A new road interchange at St Peters, which would initially provide road connections from the main alignment tunnels to Campbell Road and Euston Road, St Peters
- Two new road bridges across Alexandra Canal which would connect St Peters interchange with Gardeners Road and Bourke Road, Mascot
- Closure and remediation of the Alexandria Landfill site, to enable the construction and operation of the new St Peters interchange
- Works to enhance and upgrade local roads near the St Peters interchange
- Ancillary infrastructure and operational facilities for electronic tolling, signage (including electronic signage), ventilation structures and systems, fire and life safety systems, and emergency evacuation and smoke extraction infrastructure
- A motorway control centre that would include operation and maintenance facilities
- New service utilities and modifications to existing service utilities
- Temporary construction facilities and temporary works to facilitate the construction of the project
- Infrastructure to introduce tolling on the existing M5 East Motorway
- Surface road upgrade works within the corridor of the M5 East Motorway.

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

2.3 Construction activities

2.3.1 Overview

Construction activities associated with the project would generally include:

- Commencement of enabling and temporary works, including construction power, water supply, ancillary site establishment, demolition works, property and utility 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
- Fitout of the road tunnels and support infrastructure, including ventilation and emergency response systems
- Construction and fitout of the motorway control centre and ancillary operations buildings
- Upgrades to surface roads and construction of bridges
- Implementation of environmental management and pollution control facilities for the project.

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

2.3.2 Construction footprint

Construction activities required for the project can be grouped into six distinct areas:

- Underground tunnelling and tunnel construction activities
- The western surface works, including:
  - Construction of the M5 East Motorway integration works
  - Construction activities associated with the Kingsgrove North construction compound (C1), the Kingsgrove South construction compound (C2) and the Commercial Road construction compound (C3)
  - Construction of the Kingsgrove motorway operations complex (MOC1).
- The Kingsgrove Road surface works, including the installation of tolling infrastructure on the M5 East Motorway
- The Bexley Road surface works, including:
  - Construction activities associated with the Bexley Road North construction compound (C4), the Bexley Road South construction compound (C5) and the Bexley Road East construction compound (C6)
  - Construction of the Bexley Road South motorway operations complex (MOC2).
- The Arncliffe surface works, including:
  - Construction activities associated with the Arncliffe construction compound (C7)
  - Construction of the Arncliffe motorway operations complex (MOC3).
- The St Peters interchange and local road upgrade surface works, including:
  - Construction of the St Peters interchange
  - Construction activities associated with the Canal Road construction compound (C8), the Campbell Road construction compound (C9), the Landfill Closure construction compound (C10), the Burrows Road construction compound (C11),the Campbell Road bridge construction compound (C12), the Gardeners Road bridge construction compound (C13) and the Sydney Park construction compound (C14)

- Construction of the St Peters motorway operations complex (MOC4) and the Burrows Road motorway operations complex (MOC5)
- Construction of local road upgrade works.

The total area required for construction of the project, including the construction of ancillary facilities, is referred to as the 'construction footprint'. 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.

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.

An overview of the construction footprint is shown in Figure 2-1. The final size and configuration of construction ancillary facilities would be further developed during detailed design.

2.3.3 Landfill closure and remediation

Closure and remediation of the Alexandria Landfill is described in Chapter 5, Chapter 6 and Chapter 17 (Contamination) of the environmental impact statement.

The Alexandria Landfill site was acquired by the NSW Government in December 2014 and the operations of the previous landowner ceased at that time. Activities consistent with the existing planning approvals and environmental protection licences are continuing on site however, the site no longer operates commercially as a landfill.

Works relevant to the air quality assessment are as follows:

- Bulk earthworks to prepare the site for construction of the St Peters interchange

  Earthworks within the St Peters interchange site as part of the closure and remediation of the former Alexandria Landfill would include constructing a raised and vegetated containment mound in the south-western portion of the site.

- Installation of a capping layer. Additional detail regarding the landfill capping system is provided in Chapter 5 and Chapter 6 of the environmental impact statement
- Installation of a cut off wall to minimise inflow from the Botany Sands aquifer
- Upgrade of the leachate management system

  The existing leachate management system across the Alexandria Landfill site would be retained and augmented where required to suit the final landform of the site. This would include the installation of a new leachate collection system and the construction of a new leachate treatment plant. The leachate collection, management and treatment system is summarised in Chapter 5 and detailed in Appendix F (Alexandria Landfill Closure Environmental Plan) of the environmental impact statement.

- Installation of a landfill gas collection and management system

  The gas collection and management system as part of the closure and remediation of the former Alexandria Landfill would comprise a network of radial subsurface drains connecting to a main trunk system, supplemented with vertical gas collection wells where required. Dependant on the volume and composition of the collected gases, the system may either by an active (forced) or passive collection system. Gas would be collected for treatment by either a microbiological system of through the use of a passive flare.

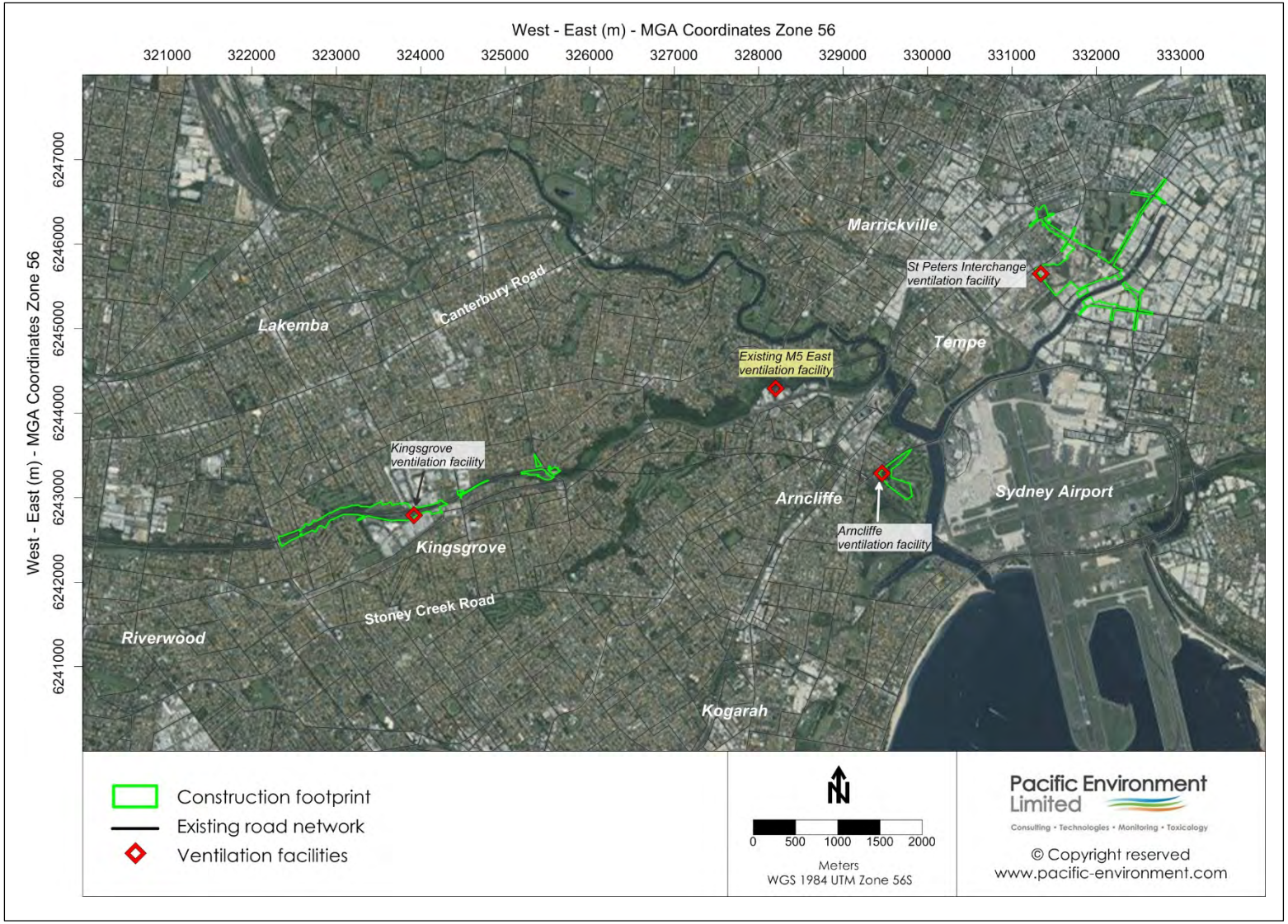


Figure 2-1 Overview of construction footprint and ventilation facilities (excluding M4-M5 Link)

Installation of a groundwater management system. The gas collection and management system as part of the closure and remediation of the former Alexandria Landfill would comprise a network of radial subsurface drains connecting to a main trunk system, supplemented with vertical gas collection wells where required. Dependant on the volume and composition of the collected gases, the system may either by an active (forced) or passive collection system. Gas would be collected for treatment by either a microbiological system of through the use of a passive flare.

2.3.4 Construction program

Subject to environmental planning approval, construction of the New M5 is planned to commence in the mid 2016, with completion of construction in the last quarter of 2019. The total period of construction works is expected to be around three and a half years. The indicative construction program is shown in Table 2-1.

Table 2-1 Indicative construction program

Construction activity	Indicative construction timeframe			
	2016	2017	2018	2019
Establishment of construction compounds				
Landfill closure works				
Construction of western surface works				
Tunnel construction				
Construction of St Peters interchange				
Portal construction				
Construction of local road upgrades				
Construction of permanent operational facilities*				
Mechanical and electrical fit-out				
Establishment of tolling facilities				

*Permanent operational facilities include the motorway operations complexes, ventilation facilities and emergency smoke extractions/ fresh air supply facilities,

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

2.4.1 Overview

The project's ventilation system has been designed to:

- Safeguard the health and amenity of the public and motorists using the main alignment tunnels during normal operation and emergency conditions
- Meet the current in-tunnel, ventilation outlet and ambient air quality criteria relevant to the project
- Achieve applicable air quality criteria for receivers outside the project tunnels
- Operate in an effectively controlled and managed manner
- Meet the requirements of the Australian Government's Civil Aviation Safety Authority
- Minimise the consumption of energy and other resources where doing so would not jeopardise the health and amenity of motorists using the project tunnels or the achievement of applicable air quality criteria.

Details of the design and operation of the project's ventilation system are provided in the following sections.

The tunnel ventilation system would comprise jet fans and ventilation facilities. Equipment to monitor and measure 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. Kingsgrove ventilation facility (Figure 2-2). This facility provides the outlet for the westbound traffic of the New M5 tunnel (St Peters to Kingsgrove).
  - B. Arncliffe ventilation facility (Figure 2-3). This facility provides the outlet for the first section of eastbound traffic of the New M5 tunnel (Kingsgrove to Arncliffe), and the fresh air supply for the second section of the eastbound New M5 tunnel (Arncliffe to St Peters). It will also provide the outlet for the northbound Southern extension tunnel (Kogarah to Arncliffe).
  - C. St Peters ventilation facility (New M5 outlet) (Figure 2-4). This facility provides the outlet for the second section of the eastbound New M5 tunnel (Arncliffe to St Peters), the future outlet for the eastbound traffic to the M4-M5 Link stub (Arncliffe to St Peters), and the future fresh air supply to the northbound M4-M5 Link (St Peters to Rozelle).
- The ventilation facilities for the M4-M5 Link project and Southern extension (2031 cumulative case with project only):
  - D. Southern extension ventilation facility. A proposed future southern extension from Arncliffe to Kogarah is currently being investigated by Transport for NSW, and would connect the New M5 to the southern and bayside suburbs of Sydney, and the proposed F6 motorway. The ventilation facility would provide the outlet for the southbound Southern extension tunnel (St Peters to Kogarah). For the purposes of cumulative assessments for this project, it is assumed that the Southern extension would provide a connection to President Avenue in the south. Depending on the outcome of investigations by Transport for NSW, the project would undergo route and design development. For the purpose of the air quality assessment an approximate location of the facility was used, subject to a separate environmental assessment and approval process.
  - E. St Peters ventilation facility (future M4-M5 Link outlet and supply). This would service the future M4–M5 Link. It would provide the outlet for the mainline and off-ramp to the future southbound M4-M5 Link (Rozelle to St Peters) and future supply to the future southbound M4-M5 Link stub (St Peters to Arncliffe).

The ventilation facility for the future southbound Southern extension tunnel (St Peters to Kogarah) (item D) would not require any construction as part of the project. Construction, fit-out and commissioning would occur as part of the construction of the Southern extension (if approved). Similarly, the future mainline and off-ramp outlet to the future southbound M4-M5 Link (Rozelle to St Peters), and the future supply to the future southbound M4-M5 Link stub (St Peters to Arncliffe) (item E), do not form part of the project.

These ventilation facilities and were included to assess potential cumulative impacts only. The locations of future Southern extension and future M4-M5 Link ventilation facilities, and future fit-out of the future Southern extension parts of item B, are indicative only and subject to assessment and approval.

Further details of the ventilation facilities that were of specific interest to the air quality assessment are provided in Chapter 9.

During maximum traffic flow conditions, a major incident or fire, the fresh air supply facility at Bexley Road emergency smoke extraction facility 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 2-2 Kingsgrove ventilation facility - location



Figure 2-3 Arncliffe ventilation facility – location

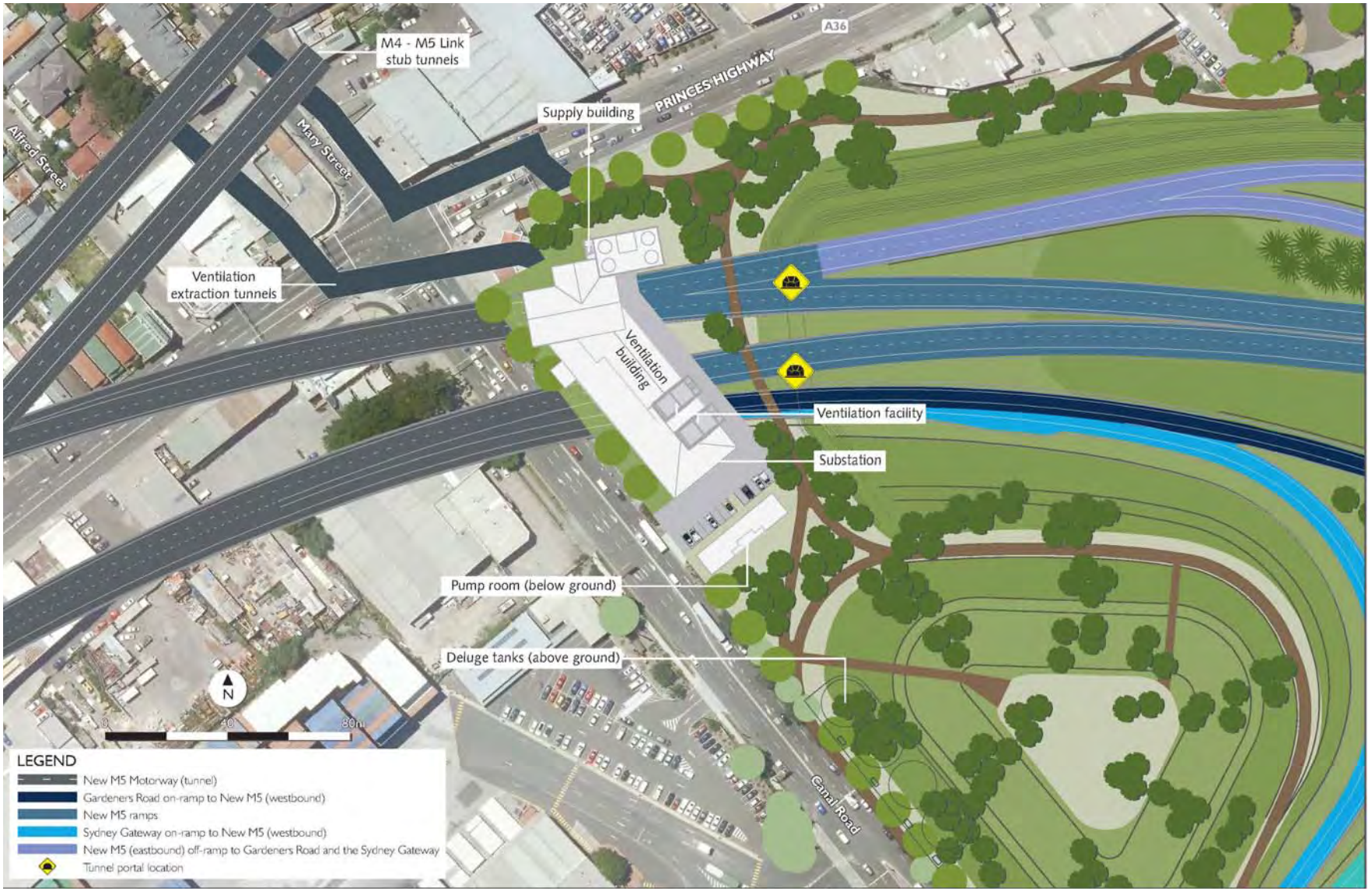


Figure 2-4 St Peters ventilation facility – location

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 and facilities under each of these conditions is detailed in the following sections.

In-tunnel air quality, traffic volumes and average traffic speeds through the project tunnels would be monitored and used to inform decisions about the operation of the project's ventilation system in real time. Operating procedures would be developed and applied to the operation of the ventilation system, including triggers for intervention in the case of elevated concentrations of vehicle emission in the project tunnels, congested traffic conditions or incidents, breakdowns or emergencies. The operating procedures would include:

- Actions to manage the operation of the ventilation system, including increased ventilation rates and potential introduction of additional fresh air into the tunnels
- Actions to manage traffic volumes and average traffic speeds through the project tunnels if required for in-tunnel air quality reasons or during incidents, breakdowns or emergencies within or downstream of the project tunnels
- Incident, breakdown and emergency response actions.

Normal traffic conditions

Under normal traffic conditions (i.e. when traffic flow within the tunnel is at capacity and travelling at the posted speed limit of 80 kilometres per hour), the main alignment tunnels would be longitudinally ventilated. Fresh air would be drawn into the main alignment tunnels from the entry portals and from vehicles travelling through the tunnel, generating a 'piston' effect (the suction created behind a moving vehicle, pulling air through the tunnel) pushing air towards the tunnel exit portals. Under normal traffic conditions, the tunnels would effectively 'self-ventilate', as the piston effect generated from moving vehicles exceeds the fresh air demand, thereby removing the need for mechanical ventilation to move air through the tunnels.

Under these conditions, all air would be discharged from the tunnel via the ventilation outlets at the Kingsgrove motorway operations complex (MOC1), Arncliffe motorway operations complex (MOC3) and the St Peters motorway operations complex (MOC4) with no portal emissions. At the ventilation facility offtake points, tunnel air would be drawn upwards into ventilation facilities with ventilation fans prior to discharge to the atmosphere via an around 30 metre high discharge point at the Kingsgrove ventilation facility, via an around 35 metre high discharge point at the Arncliffe ventilation facility and via an around 20 metre high discharge point at the St Peters ventilation facilities, in line with the Australian Government's Civil Aviation Safety Authority requirements. The air would then be discharged from each ventilation facility to the atmosphere at velocities that would achieve effective dispersion of the tunnel air, while also meeting the Australian Government's Civil Aviation Safety Authority requirements.

Air would be drawn back down from the tunnel exit portals through the ventilation facility. The Arncliffe motorway operations complex (MOC3) would also introduce fresh air into the eastbound tunnel carriageway.

Low speed traffic conditions

Where low speed conditions persist within the tunnels (i.e. when traffic speeds slow towards 40 kilometres per hour or less, typically as a result of a traffic incident), the piston effect associated with traffic movement would be reduced. Traffic management measures (such as speed limitations and lane closures) would be imposed to manage the incident and restore as far as practicable free flowing traffic. Under these conditions, longitudinal ventilation may require mechanical support to move air through the tunnels. Mechanical support would be provided through the use of jet fans, which would operate by moving air in the same direction that the traffic is flowing to provide the minimum fresh air demand required to meet the relevant air quality criteria.

Under these traffic conditions, additional fresh air may also be required to ensure that acceptable air quality is maintained. Additional air may be injected into the main alignment tunnels via the reverse flow operation of axial fans in the emergency smoke extraction facilities at the Bexley Road South motorway operations complex.

During low speed traffic conditions, tunnel air would continue to be discharged from the Kingsgrove, Arncliffe and St Peters ventilation facilities, at the Kingsgrove motorway operations complex (MOC1), Arncliffe motorway operations complex (MOC3) and the St Peters motorway operations complex (MOC4) respectively.

Emergency conditions

The two emergency smoke extraction facilities would maintain air quality in the tunnels in the unlikely event of an emergency. These would be located at the Bexley Road South motorway operations complex (MOC2) and as part of the Arncliffe ventilation facility at the Arncliffe motorway operations complex (MOC3).

In emergency conditions, such as a fire, both carriageways would be closed to traffic and smoke would be extracted from either of the two emergency smoke extraction facilities, or would be ventilated out of the exit portals, depending on the location of the emergency event. Air would be extracted from the tunnel and transferred to the emergency smoke extraction outlet via a combination of shafts and ducts. The smoke would then be discharged from the outlet to the atmosphere. The project's ventilation system has been designed so that if required, jet fans can operate in the reverse direction during an emergency situation.

The operation of the emergency smoke extraction facilities is expected to be infrequent. When emergency smoke extraction is required, the operation of the facilities would only be for a short duration while emergency services and tunnel fire and life safety systems are used to control the emergency situation.

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
- Fire and life safety infrastructure and systems
- Two vehicle cross passages between the two main alignment tunnels around the Bexley Road South and Arncliffe emergency smoke extraction facilities
- Pedestrian cross passages between the two main alignment tunnels at 120 metre intervals
- Tunnel barrier gates preventing access to the tunnels in the event of a tunnel closure as part of the tunnel closure system
- Emergency telephones.
- CCTV throughout the tunnels and approaches
- Vehicle height detection system prior to the tunnel portals
- The inclusion of stop lights, portal closure barriers, moveable median barriers, lane control units and variable message signs
- A breakdown bay 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
- An incident response area of suitable size to station an incident response vehicles at the Burrows Road motorway operations complex (MOC 5), one located at the motorway operations complex and one located at the eastern ventilation facility.

The Kingsgrove motorway operations complex (MOC1) would include a separate emergency response system as a back-up in the unlikely event that the motorway control centre at St Peters is affected by an incident or emergency. This separate emergency response system would include secondary systems with redundant servers and network platforms required to deliver operations management and control system functionality in the event of an incident resulting in the primary systems of the motorway control centre becoming unavailable.

3 Key air quality issues for the New M5 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.

[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 concentrations 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).

Tunnel portal emissions can also be avoided 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 outlets 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 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 New M5 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
  - Potential deterioration in air quality alongside new surface roads
  - Potential deterioration in air quality alongside existing roads which will have an increase in traffic volume
  - Potential deterioration in air quality in the vicinity of tunnel ventilation outlets.
- 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.

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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 from 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.

[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

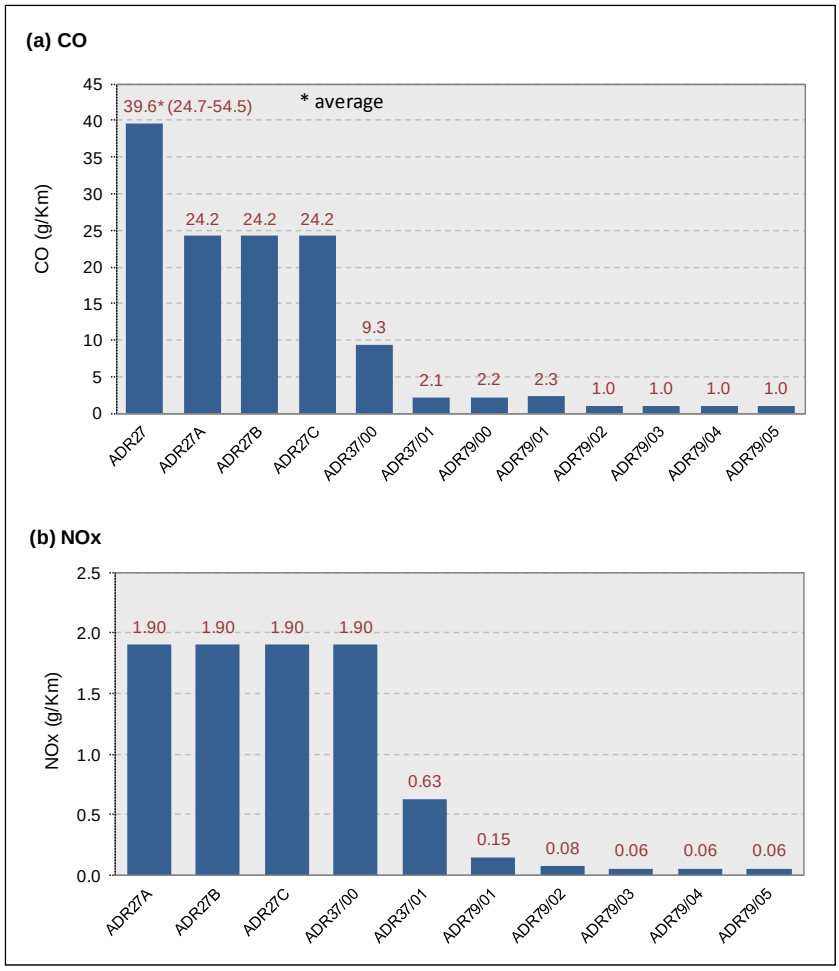


Figure 4-1 **Exhaust emission limits for CO and NO_X applicable to new petrol cars in Australia**

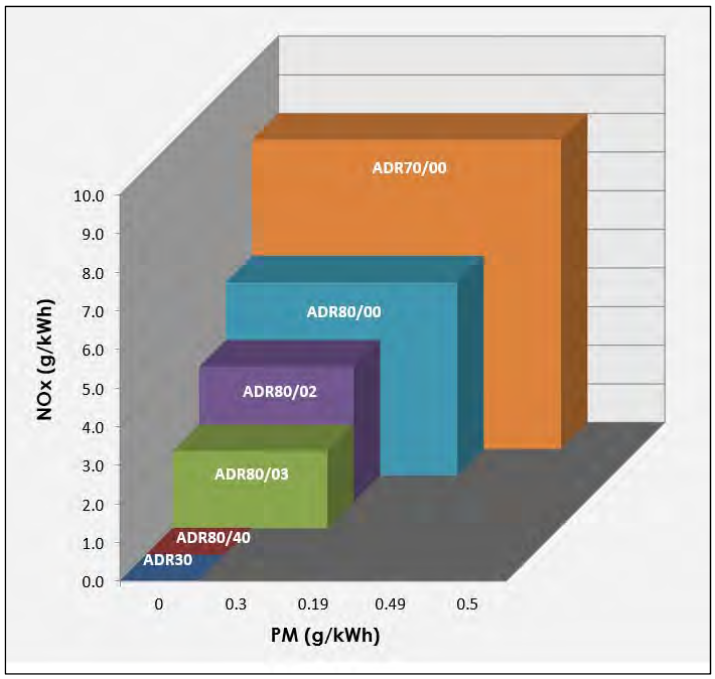


Figure 4-2 **Exhaust emission limits for NO_X and PM applicable to heavy-duty vehicles in Australia**

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 11). 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 Sydney 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).

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.

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

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.

NB: The actual impact assessment criteria that were applicable to the project are summarised in section 5.5.3.

[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.

[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

NSW EPA, which has managed the NEPM variation, has subsequently requested NSW Cabinet approval for the following changes to the PM standards to improve the health protection for the community, given that PM_{10} an $PM_{2.5}$ have no thresholds for health impacts:

- 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 20 µg/m^3
  - An annual average $PM_{2.5}$ target of 7 µg/m^3
  - A 24 hour $PM_{2.5}$ target of 20 µg/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		Calculation	Source
	Concentration	Averaging period		
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 1-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 1-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	24 hours
		0.1 ppm	1 year[(a)]
	Xylenes	0.25 ppm	24 hours
		0.20 ppm	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), and the document which has largely superseded it, the New Zealand Transport Agency's Guide to road tunnels (NZTA, 2013)
- 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 (ACTAQ).

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 New M5 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 8-hour), NO_2 (1-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 representative 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).
- Some studies have 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[17] 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.

[17] GRAL = Graz Lagrangian Model

- 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). An Asbestos Management Plan has been developed for the activities related to the closure of Alexandria Landfill, and the principles detailed in that plan will be applied during construction, particularly during the demolition phase.

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 difficult to reliably 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 general construction impacts using the IAQM procedure is presented in Chapter 7.

The specific issues of dust and odour associated with the closure and remediation of the Alexandria Landfill are addressed in some detail in Chapter 8.

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 5-1.

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

Scenario code	Scenario description
2021-DS	2021 - Do Something (with New M5)
2031-DS	2031 - Do Something (with New M5)
2031-DSC	2031 - Do Something Cumulative (with New M5 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 New M5 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 rationale for the selection of the model is provided in Chapter 9. The GRAL 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 9.

Definition of modelling domains

The modelling domains for the project are shown in Figure 5-1.

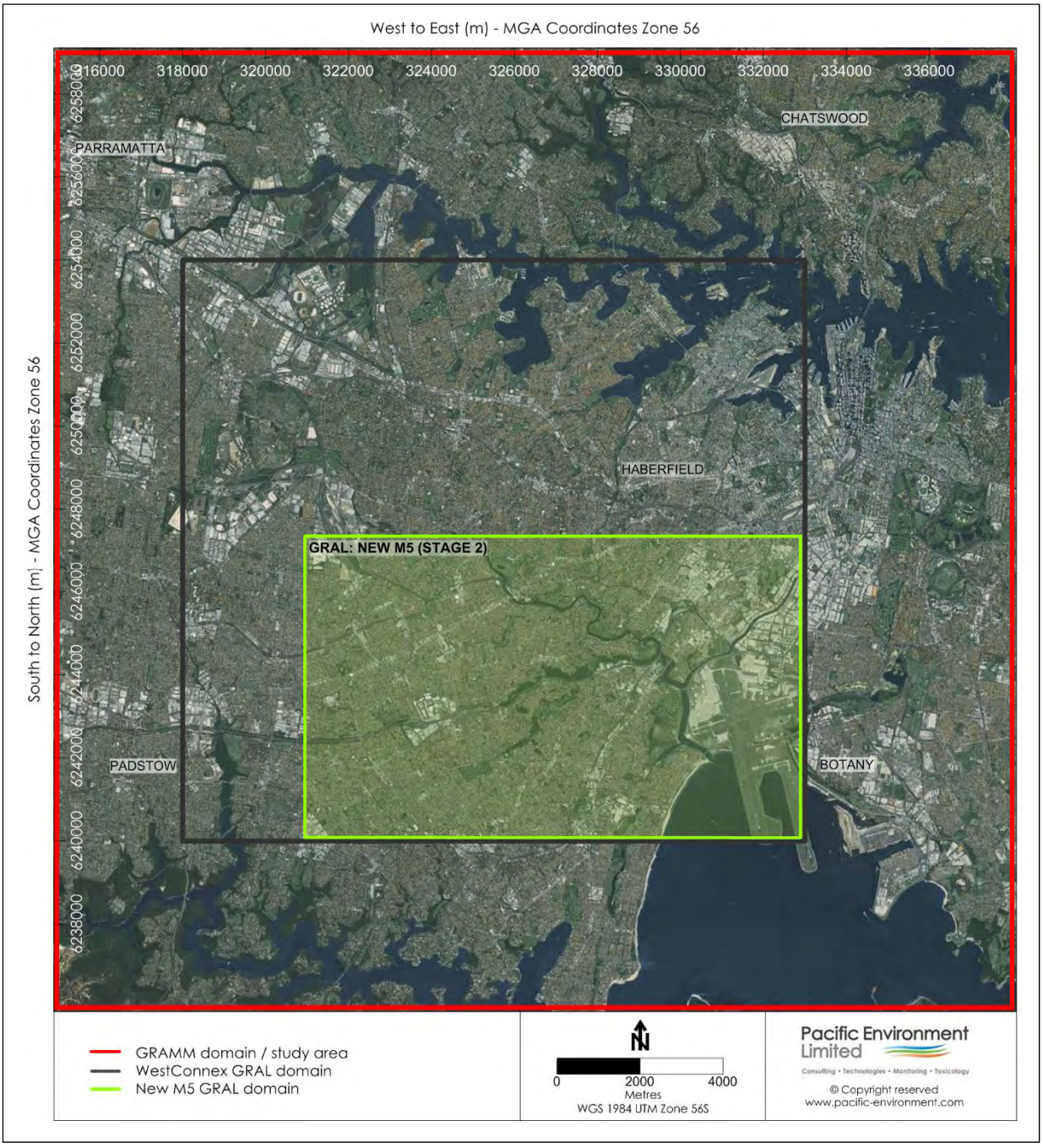


Figure 5-1 Modelling domains for GRAMM and GRAL

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:
  - 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 New M5 project). This improved both the efficiency and consistency of the air quality assessments for the various WestConnex projects.
  - It provided the cumulative impacts of all projects as a matter of course (such as New M5 and future M4-M5 Link ventilation outlets).
  - It maximised the flexibility of the assessment process, and accommodated any future changes in the requirements.
  - It maximised the number of meteorological and air quality monitoring stations that could be included for model evaluation purposes.
- The **New M5 GRAL domain**, shown by the green boundary in the Figure 5-1. This extended 12 kilometres in the x direction and 8 kilometres in the y direction. This was the extent of the domain used in the GRAL dispersion model for the New M5 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.

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. Whilst this is a somewhat artificial construct, as emissions from ventilation outlets do not occur without changes in emissions from the surface road network, it is often the focus of community concerns.

The results have been presented as:

- Pollutant concentrations (and changes) at discrete receptors (in charts and tables).
- Pollutant concentrations (and changes) across the GRAL New M5 modelling domain (as contour plots).
- Pollutant concentrations (and changes) in the vicinity of the project tunnel ventilation outlets (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 New M5)	KGRIU[(a)] and M4 Widening
2021-DS	2021 - Do Something (with New M5)	KGRIU, M4 Widening and New M5
2031-DM	2031 - Do Minimum (no New M5)	KGRIU and M4 Widening
2031-DS	2031 - Do Something (with New M5)	KGRIU, M4 Widening and New M5
2031-DSC	2031 - Do Something Cumulative (with New M5 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) KGRIU = 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 represents the current road network with no new projects or upgrades and 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 'do minimum' case assumes that the King Georges Road Interchange Upgrade and the M4 Widening are complete, but the remainder of the WestConnex projects or the future Southern extension are not built. It is called 'do minimum' rather than 'do nothing' as it assumes that on-going improvements will be made to the broader transport network including some new infrastructure and intersection improvements to improve capacity and cater for traffic growth.
- **2021 'With project' or 'Do Something'**. The New M5 Motorway is complete and open to traffic, including the King Georges Road Interchange Upgrade and the M4 Widening, but without any other WestConnex projects or the future Southern extension.
- **2031 Do Minimum**. A future network including the King Georges Road Interchange Upgrade and the 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 WestConnex projects or the future Southern extension
- **2031 'With project' or 'Do Something'**. The New M5 Motorway complete and open to traffic, including the King Georges Road Interchange Upgrade and the M4 Widening, but without any other WestConnex projects or future Southern extension
- **2031 Full WestConnex program of works and Southern extension**. With all WestConnex projects completed (including the future M4-M5 Link and future Sydney Gateway) and the future Southern extension. In this scenario, the proposed future M4-M5 Link does not provide an access to the CBD north. This excluded contributions from the M4 East ventilation outlets (including the shared outlet with the future 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 deliver acceptable ambient air quality.

The scenarios assessed constant emissions from the ventilation outlets with concentrations at the limits, over a 24-hour period. This represented the theoretical maximum changes in air quality for all potential traffic operations in the tunnel, including unconstrained and worst-case traffic conditions from an emissions perspective, as well as 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 vary 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 future 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 foreseeable operational conditions in the tunnel.

Ambient air quality criteria used in the assessment

Air quality in the New M5 domain was assessed in relation to the most relevant pollutants and criteria from the NSW Approved Methods. The pollutants and criteria are summarised in Table 5-3. The proposed standards and targets for PM_{10} and $PM_{2.5}$ in NSW were also considered but not formally used in the assessment of impacts, and these are shown in italics in the Table.

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 units or deposition units consistent with the standards, and compared with the relevant standards.

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

Pollutant/metric	Concentration[(a)]	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*

Pollutant/metric	Concentration[(a)]	Averaging period	Source
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)

(a) The proposed standards and targets for PM_{10} and $PM_{2.5}$ in NSW were also considered but not formally used in the assessment of impacts, and these are therefore shown in italics.

For air toxics the steps mostly correspond to those above, with some slight differences. 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 screening assessments or the 99.9th percentile of model predictions for more detailed 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[18]. The emissions of SO_2 from road vehicles are therefore now very low, and SO_2 is no longer a major concern in terms of transport-related air quality.

- **Lead (Pb)**. 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. As a result, lead is no longer considered to be an air quality and health concern away from specific industrial activities (such as smelting).

- **TSP**. TSP is rather an old metric that is no longer the focus of health studies. For example, the USEPA replaced its TSP standard with a PM_{10} standard in 1987. For exhaust emissions from road transport it can be assumed that TSP is equivalent to PM_{10} (and also $PM_{2.5}$). Whilst it is possible that a fraction of non-exhaust particles is greater than 10 µm in diameter, this is not well quantified.

- **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).

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

- **Hydrogen fluoride (HF)**. 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 $PM_{2.5}$.

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:

- **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.
- **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).
- **Ventilation outlet concentration**. This is the contribution from tunnel ventilation outlets.
- **Total concentration**. This is the combination of the background, surface road, and ventilation outlet concentrations.
- **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. 1-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.

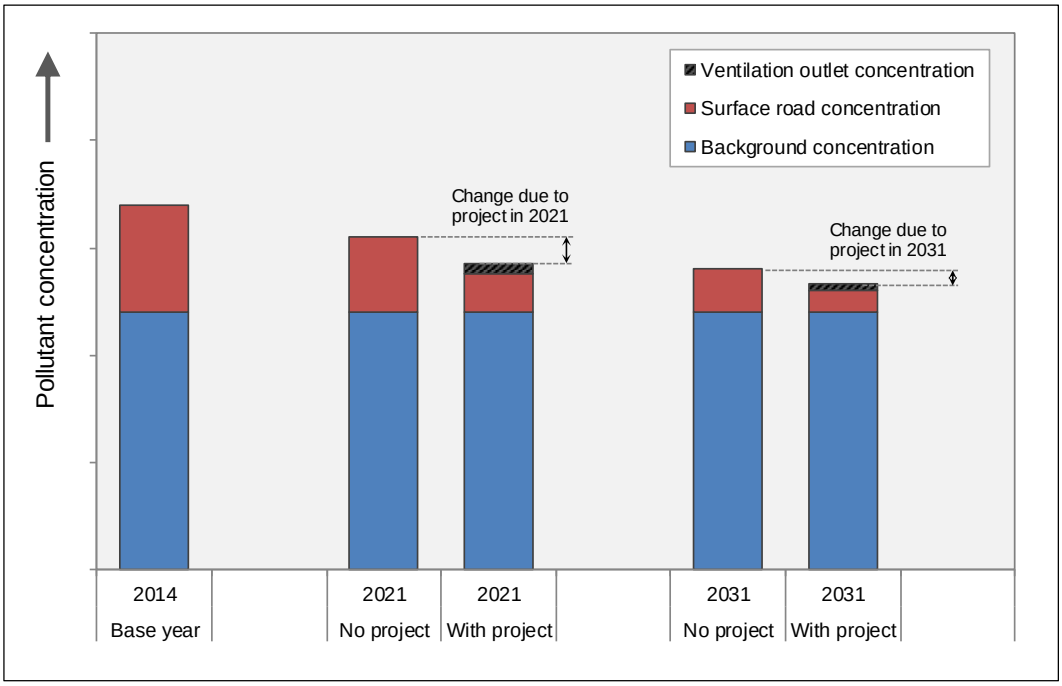


Figure 5-2 Contributions to total pollutant concentrations (example)

Determination of components in New M5 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 New M5 GRAL domain. The concentrations were based on a Cartesian grid of points with an equal spacing of 10 metres in the x and y directions. This resulted in over 960,000 grid locations across the New M5 GRAL domain.

This report also presents distributions of changes in concentration at more than 46,000 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 specified zone within 600 metres either side of the project corridor, and near other significantly affected roadways such as Stoney Creek Road. These included 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 1-hour mean for each hour of the year in each case. The number of such receptors that could be treated in this way was dictated by the limit on the number of time series that could be extracted from GRAL. In total, 35 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 35 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 46,219 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 predicting future impacts accurately. 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 unduly amplify 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 1-hour NO_2 concentration during a given year. Any method which provides a 'typical' or 'average' 1-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 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.

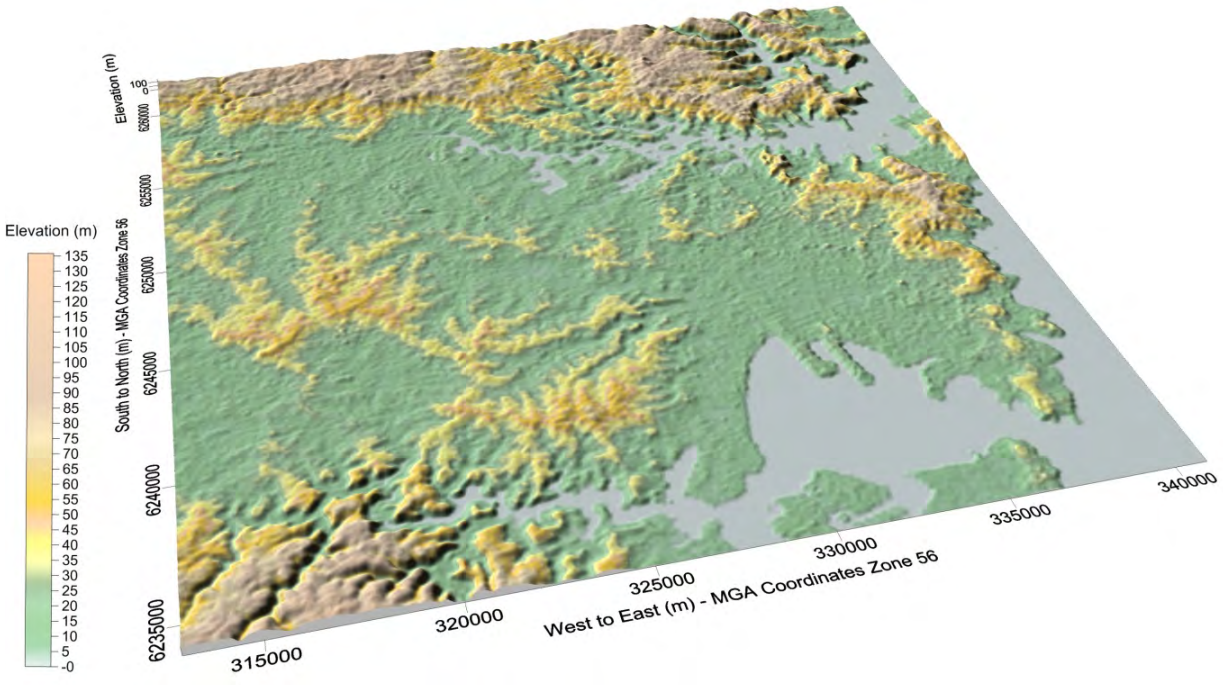


Figure 6-1 Terrain in the WestConnex study area

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 falls from an elevation of around 41 metres Australian Height Datum (AHD) at the western end of the New M5 to an elevation of around 7 metres (AHD) at Kogarah and 10 metres at St Peters, at the eastern end.

Land use within the New M5 GRAL domain consists primarily of urban areas, with pockets of recreational reserves and waterbodies towards the eastern end and around the airport.

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 long-term average temperature and rainfall data for the two closest Bureau of Meteorology (BoM) sites located at Sydney Olympic Park (Site number 066195), and the Canterbury Racecourse (Site number 066194). It is noted that the Sydney Olympic Park station was decommissioned in August 2011. Sixteen years of data were available for this site. 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 16-year average climate summary 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 2011; Latitude: 33.85°S; Longitude: 151.06 °E

Table 6-2 20-year average climate summary 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.

At Sydney Olympic Park February is the wettest month, with an average rainfall of 110 millimetres over an average of eight rain days. At the Canterbury Racecourse site the wettest month is April, with 113 millimetres falling over eight rain days. At Sydney Olympic Park the average annual rainfall is 884 millimetres over an average of 82 rain days per year. The average annual rainfall at Canterbury Racecourse 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. 066194)
    - Fort Denison (Station No. 066022)
    - Sydney Airport AMO (Station No. 066037)
    - Sydney Olympic Park AWS (Station No. 066195)
    - Sydney Olympic Park AWS (Archery Centre) (Station No. 066212)

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 one per cent 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.



Figure 6-2 Meteorological stations in the GRAMM model domain

Having determined the representativeness 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 9.4.4, and an example of a typical wind field is shown in Figure 9-10. Wind speed and direction values were extracted at each of the meteorological stations shown in Figure 6-3, and a 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 9.4.5.

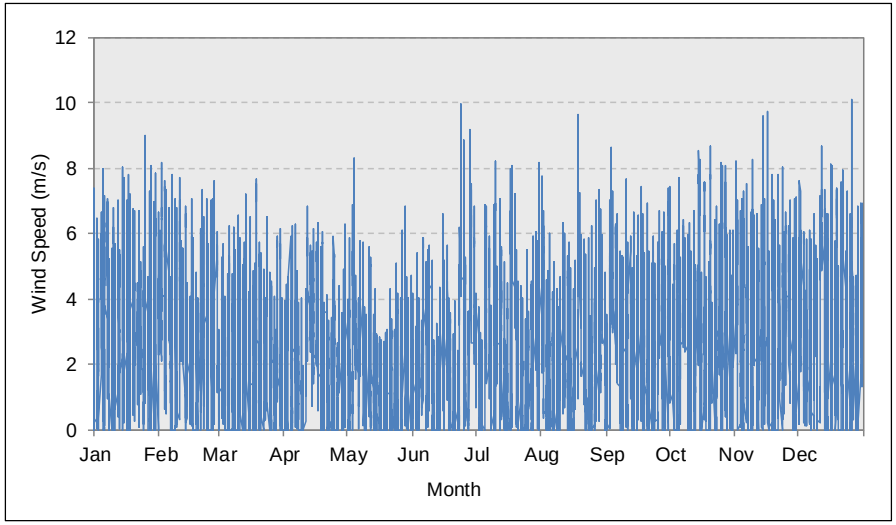


Figure 6-3 Hourly average wind speed at Canterbury Racecourse 2014

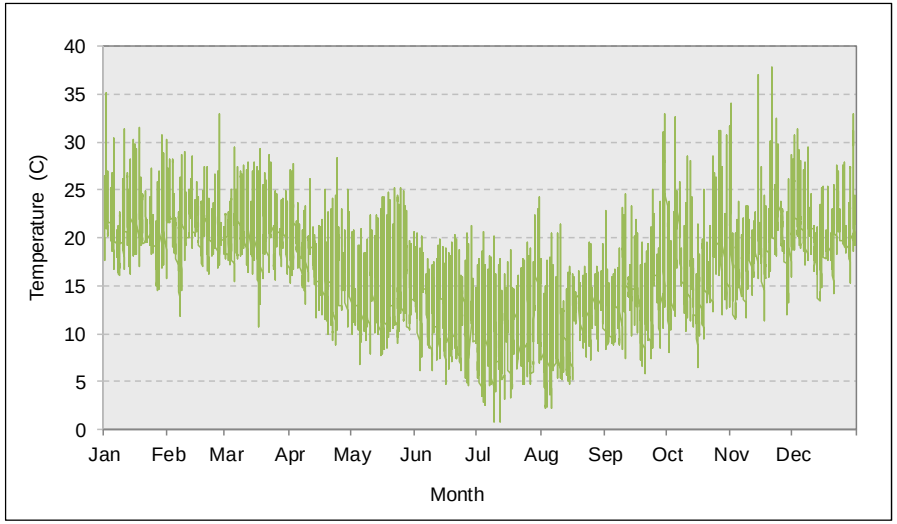


Figure 6-4 Hourly average temperatures at Canterbury Racecourse 2014

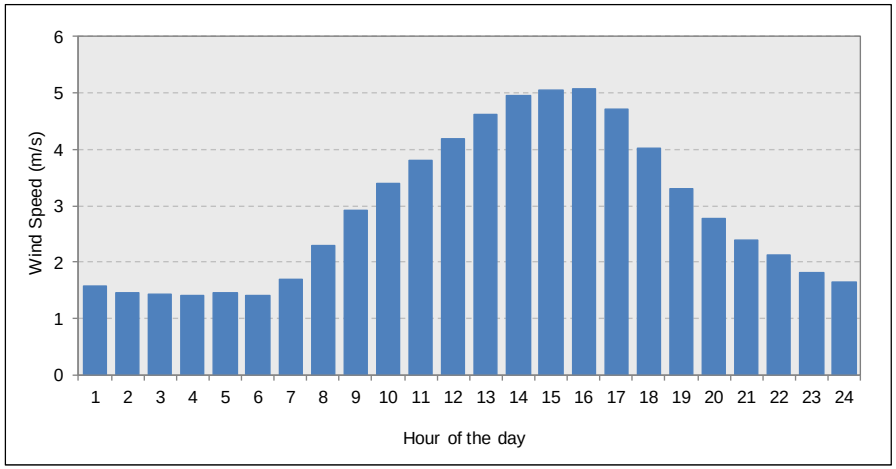


Figure 6-5 Average wind speed by hour of day, Canterbury Racecourse 2014

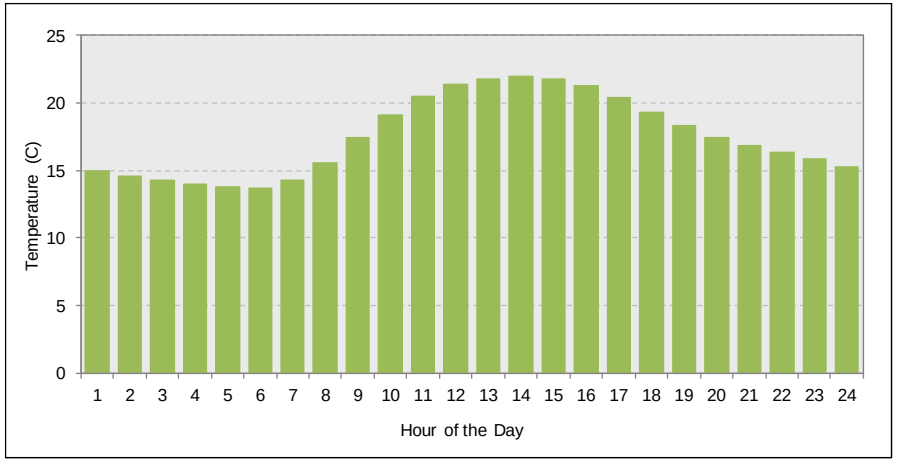


Figure 6-6 Average temperature by hour of day, Canterbury Racecourse 2014

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[19] 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, as well as a detailed breakdown of emissions from road transport, were extracted from the inventory by NSW EPA[20] and are presented here. Emissions were considered for the most recent historical year (2011) and for the future years.

Figure 6-7 shows that road transport was the single largest sectoral contributor to emissions of CO (44 per cent) and NO_X (57 per cent) in Sydney during 2011. 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 is projected to 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 are also expected to decrease, but their smaller contributions to these pollutants mean 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[21]. 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] An emissions inventory defines the amount (in tonnes per year) of pollution that is emitted from each source in a given area.

[20] 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.

[21] 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).

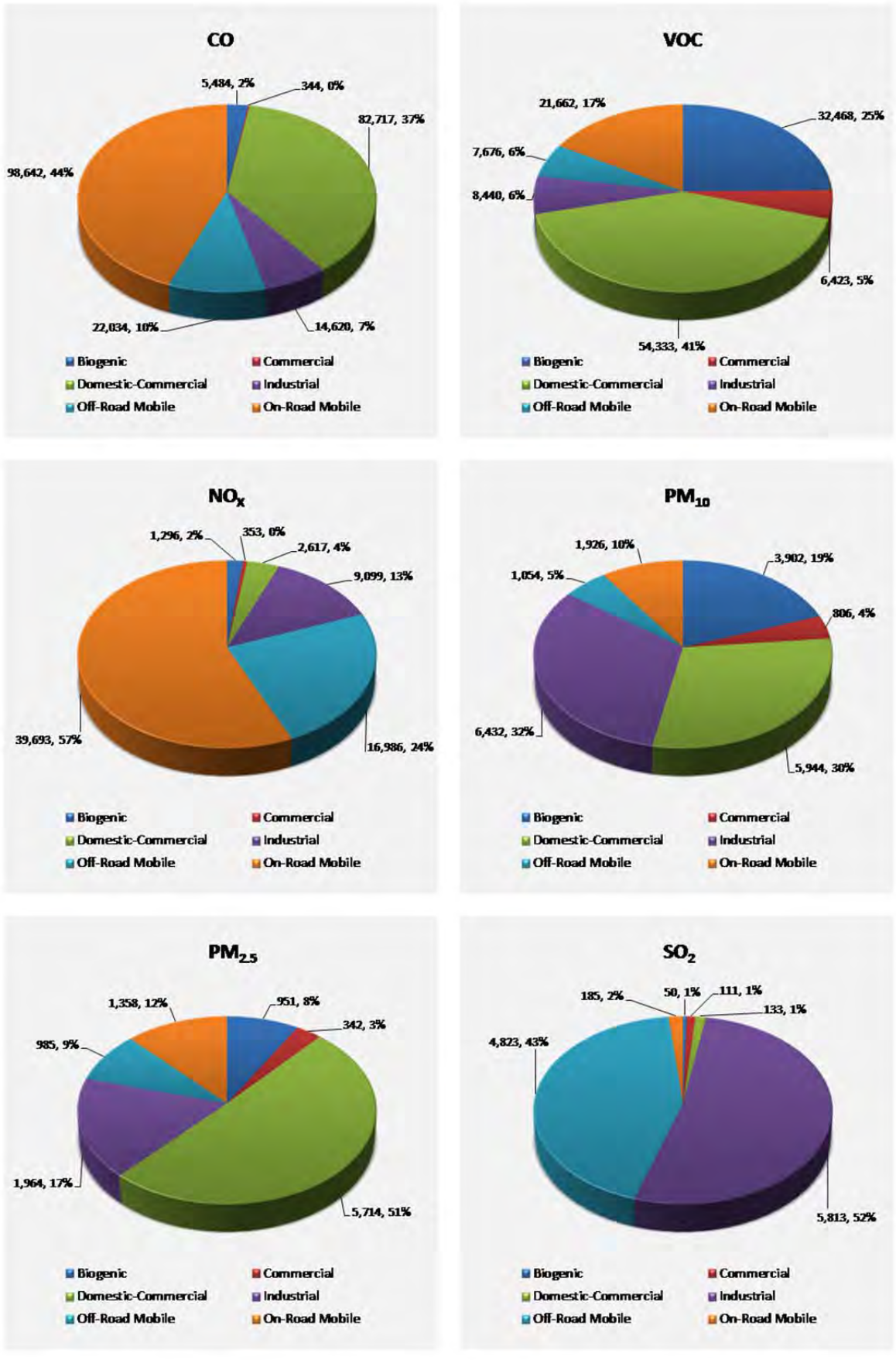


Figure 6-7 Sectoral emissions in Sydney, 2011 (tonnes per year and percentage of total)

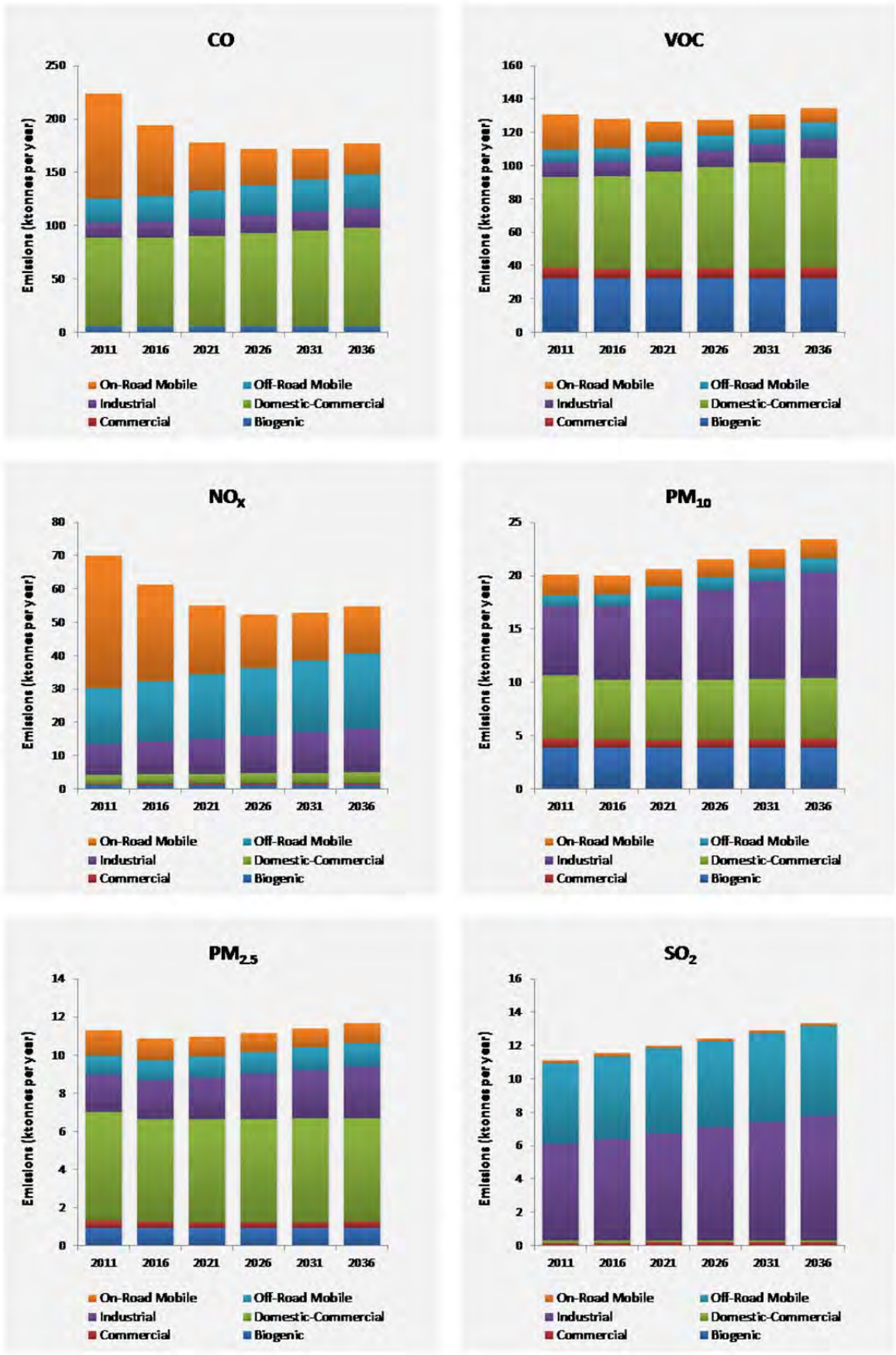


Figure 6-8 Future projections of sectoral emissions – Sydney, 2011-2036

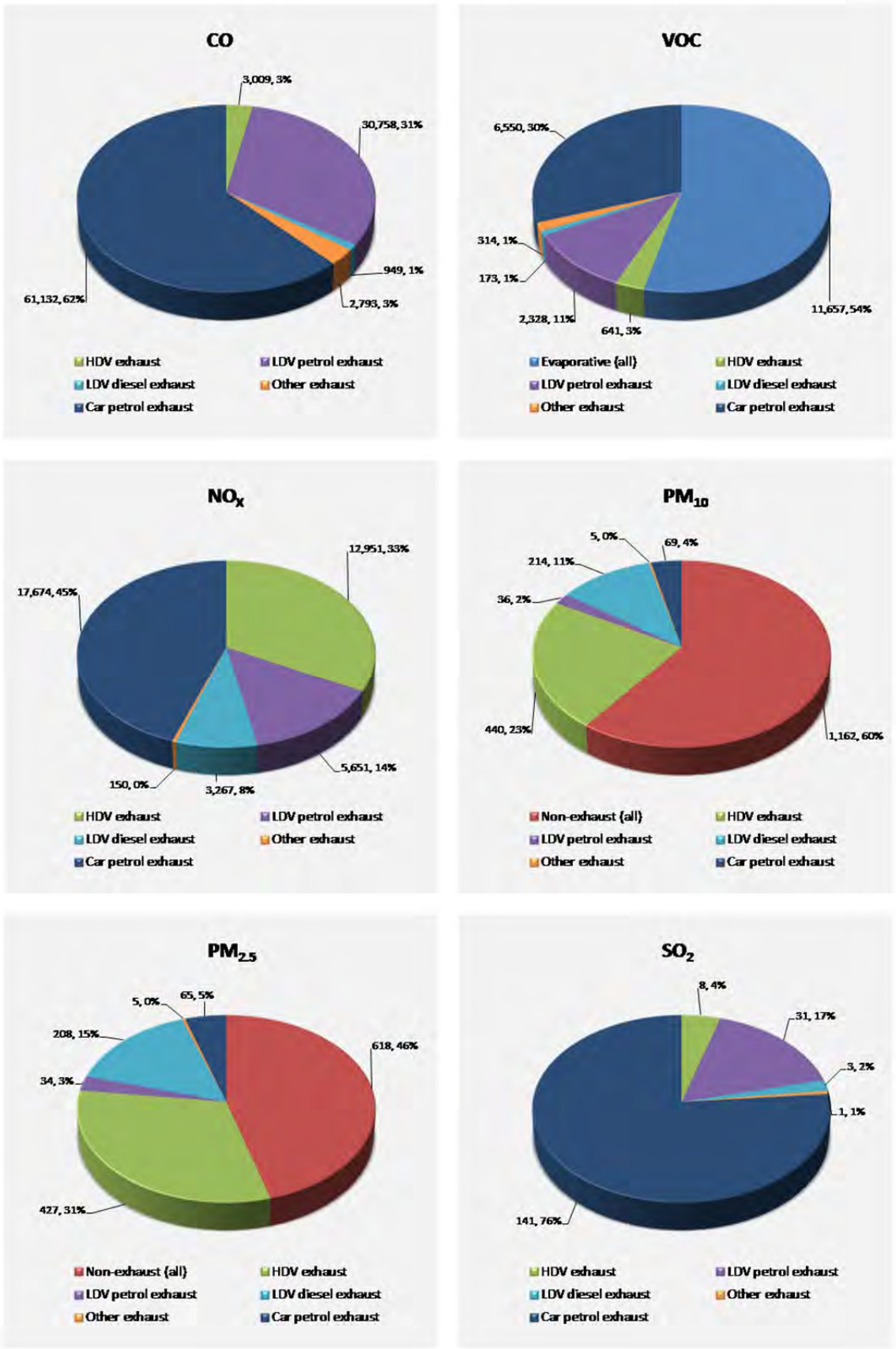


Figure 6-9 **Breakdown of road transport emissions – Sydney, 2011 (tonnes per year and percentage of total)**

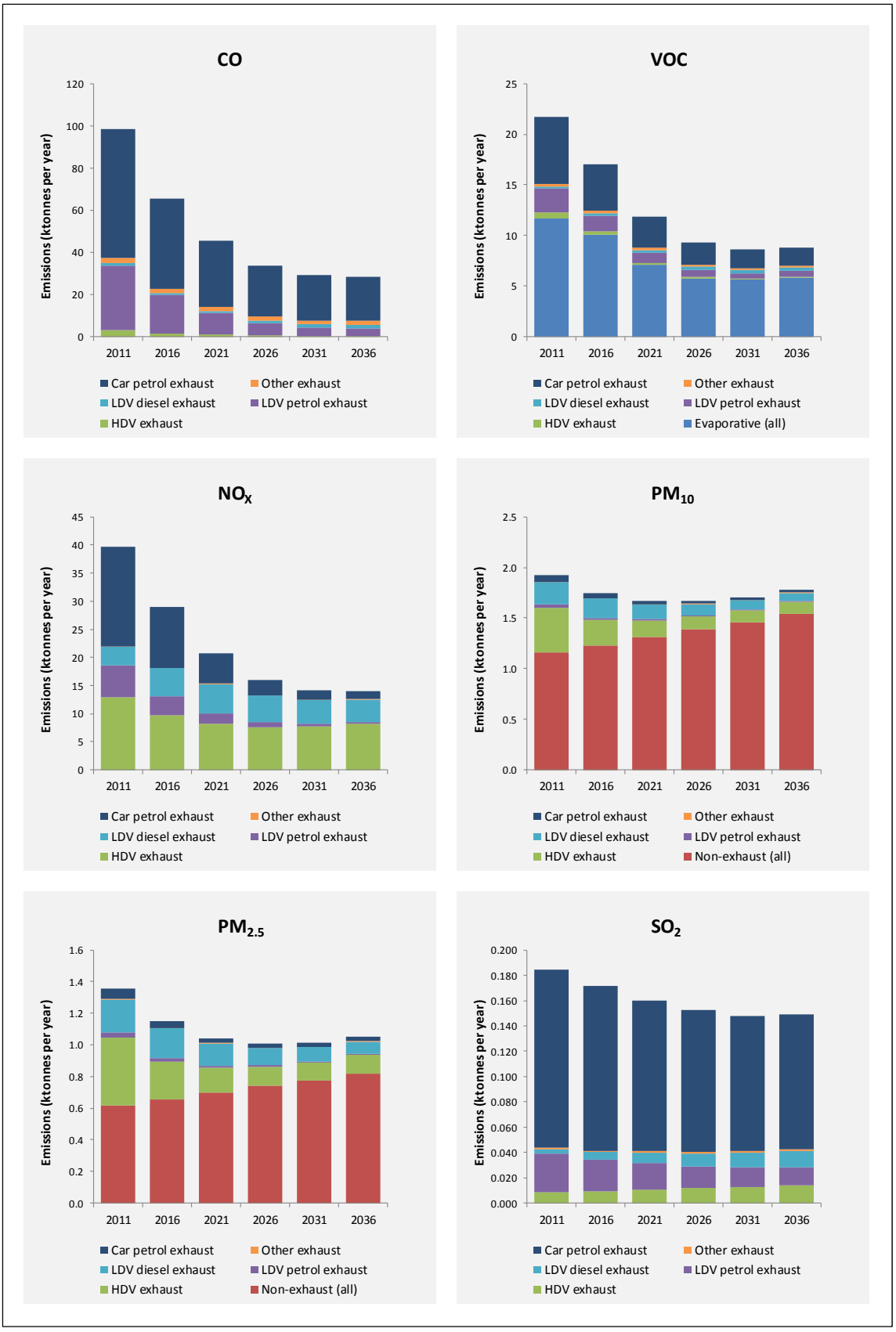


Figure 6-10 Future projections of road transport emissions – Sydney, 2011-2036

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[22,23], 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 CO continue to be below national standards, levels of ozone and particles (PM_{10} and $PM_{2.5}$) still exceed the standards on occasion.

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 1-hour and rolling 8-hour mean CO concentrations
    - All values were well below the air quality criteria of 30 mg/m^3 (1-hour) and 10 mg/m^3 (8-hour).

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

    - Over time 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 1-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 1-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 similar to the highest 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 large between-site variation in recent years suggests that this clustering 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 8 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 1-hour concentrations were very close to or above the advisory reporting standard in the AAQ NEPM of 25 µg/m^3.

6.7.3 Project-specific air quality monitoring

Seven air quality monitoring stations were established by the NSW Government in the New M5 GRAL domain. Pacific Environment was commissioned to operate and maintain the monitoring network, further details of which are provided in Appendix F. The monitoring stations are designed to supplement the existing OEH and Roads and Maritime stations, to establish the representativeness of the data from the OEH and Roads and Maritime 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; three stations are located at urban background sites and four stations are located to characterise population exposure near busy roads.

7 Assessment of general 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.

The closure and remediation of the Alexandria Landfill site is considered separately in Chapter 8.

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 the St Peters interchange, tunnel portals, ventilation facilities, ancillary operations buildings and facilities.

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 activities required for the project can be grouped into six distinct areas:

- Underground tunnelling and tunnel construction
- The western surface works, including:
  - Construction of the M5 East Motorway integration works
  - Construction activities associated with the Kingsgrove North construction compound (C1), the Kingsgrove South construction compound (C2) and the Commercial Road construction compound (C3)
  - Construction of the Kingsgrove motorway operations complex (MOC1).
- The Kingsgrove Road surface works, including the installation of tolling infrastructure on the M5 East Motorway
- The Bexley Road surface works, including:
  - Activities associated with the Bexley Road North construction compound (C4), the Bexley Road South construction compound (C5) and the Bexley Road East construction compound (C6)
  - Construction of the Bexley Road South motorway operations complex (MOC2).
- The Arncliffe surface works, including:
  - Activities associated with the Arncliffe construction compound (C7)
  - Construction of the Arncliffe motorway operations complex (MOC3).

- The St Peters interchange and local road upgrade surface works, including:
  - Construction of the St Peters interchange
  - Construction activities associated with the Canal Road construction compound (C8), the Campbell Road construction compound (C9), the Landfill Closure construction compound (C10), the Burrows Road construction compound (C11),the Campbell Road bridge construction compound (C12), the Gardeners Road bridge construction compound (C13) and the Sydney Park construction compound (C14)
  - Construction of the St Peters motorway operations complex (MOC4) and the Burrows Road motorway operations complex (MOC5)
  - Construction of local road upgrade works.

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. An overview of the construction footprint was shown in Figure 2-1.

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:

- Roadway drainage
- Road pavement
- Road furniture
- Electrical substations
- Low point sumps
- Cross passages, including electrical rooms
- Emergency smoke extraction outlets.

Tunnel excavation and civil finishing works would be followed by fitting out the tunnel with operational infrastructure. This would include power, ventilation, fire safety systems, communications infrastructure, traffic control, tunnel lighting and the operational management control systems and secondary tunnel lighting.

Tunnelling work would 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:

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 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 from construction dust 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 New M5 project, are summarised in the following sections.

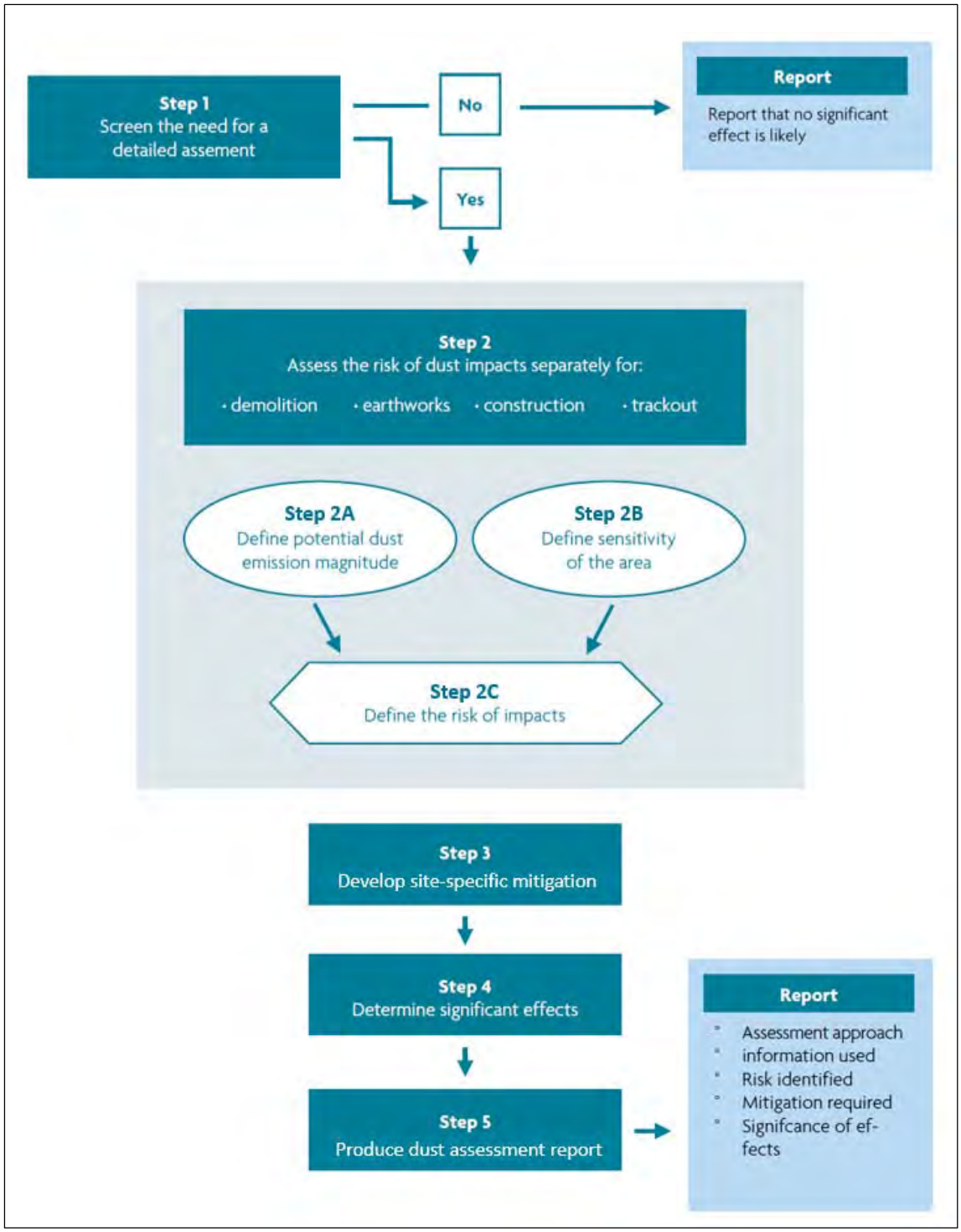


Figure 7-1 Steps in an assessment of construction dust (IAQM, 2014)

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 boundaries of the project construction sites. The area potentially affected by construction dust also contains areas of ecological significance and these were included in the assessment.

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, including 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 categorised as low, medium or high 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 New M5 project are shown in Table 7-2.

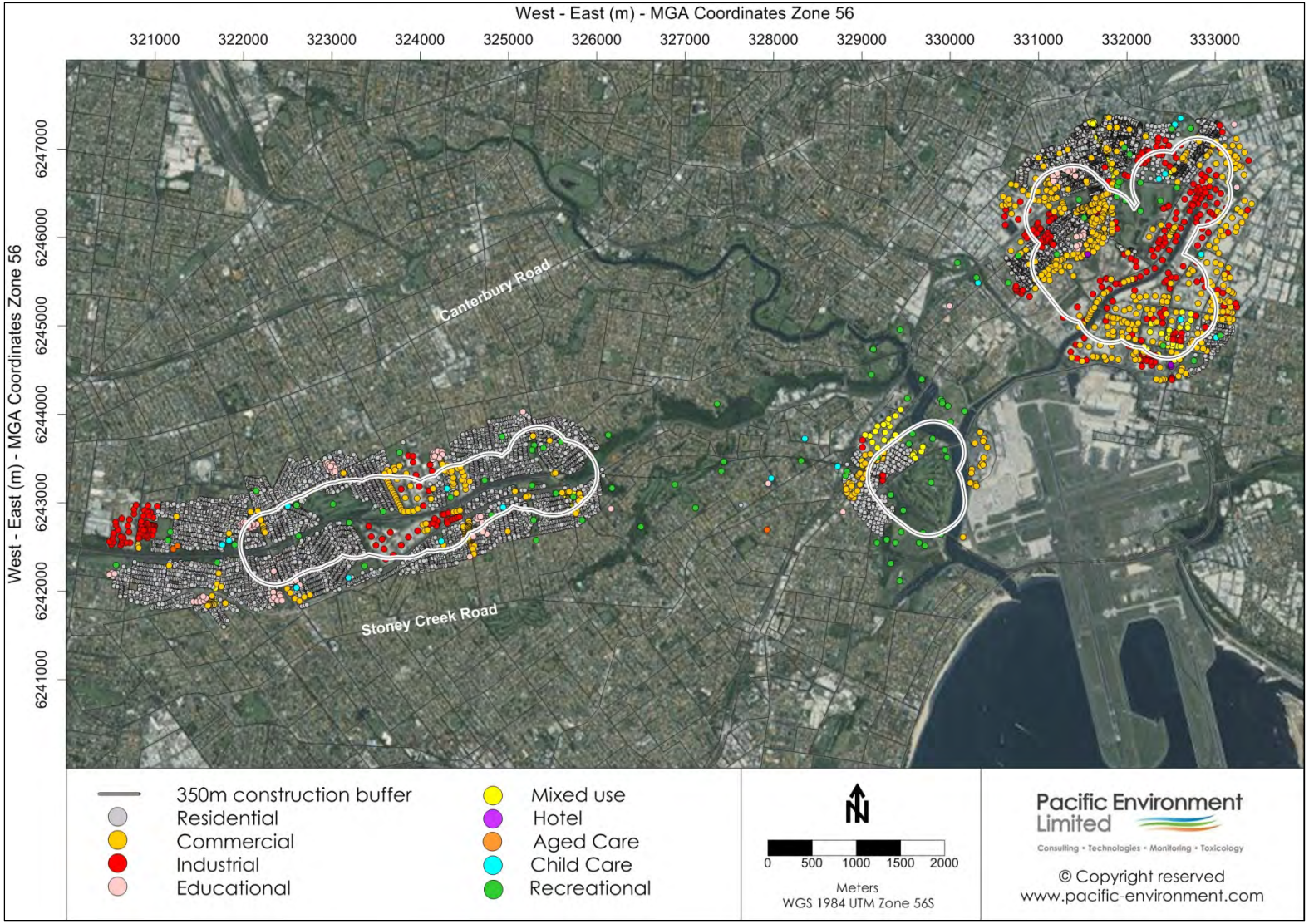


Figure 7-2 Screening assessment – human receptors near the construction of the New M5 project

Table 7-1 Criteria for assessing the potential scale of emissions

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 Results of categorisation of project scale for each type of activity

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

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 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 M5 project we assumed the following numbers of receptors per building:

- Residential property = 1 receptor
- Childcare and Aged care = 30 receptors
- Commercial property = 20 receptors
- Educational = 500 receptors

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

Table 7-4 Results of sensitivity 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	1,816	1,902	3,647	32,101	High
Earthworks	High	1,816	1,902	3,647	32,101	High
Construction	High	1,816	1,902	3,647	32,101	High
Track-out	High	1,816	1,902	-	-	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

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 µgm/^{3} and 40 µgm/^{3} respectively).

Table 7-6 Results of sensitivity to health impacts

Activity	Receptor sensitivity	Annual mean PM_{10} conc ($\mu g/m^3$)(a)	Number of receptors by distance from source (m) <20	20-50	50-100	100-200	200-350	Sensitivity of area
Demolition	High	18-21	1,816	1,902	3,647	8,440	29,661	High
Earthworks	High	18-21	1,816	1,902	3,647	8,440	29,661	High
Construction	High	18-21	1,816	1,902	3,647	8,440	29,661	High
Track-out	High	18-21	1,816	1,902	-	-	-	High

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

Sensitivity of area to ecological impacts

The criteria for determining the sensitivity of an area to ecological impacts caused by construction dust are shown in Table 7-7. Based on the IAQM guidance 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 7-8.

Table 7-7 Criteria for sensitivity of area to ecological impacts

Receptor sensitivity	Distance from source (m) <20	20 – 50
High	High	Medium
Medium	Medium	Low
Low	Low	Low

Table 7-8 Results of sensitivity to ecological impacts

Activity	Receptor sensitivity	Distance from source (m)	Sensitivity of area
Demolition	High	20-50	Medium
Earthworks	High	<20	High
Construction	High	<20	High
Track-out	High	20-50	Medium

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 7-9.

The final results for the Step 2C risk assessment are provided in Table 7-10, combining the scale of the activity and the sensitivity of the area. All activities were determined to be 'high risk' for dust soiling and human health. For ecological receptors, all activities except track-out were determined to be 'high risk'.

Table 7-9 Risk categories

Type of activity	Sensitivity of area (from Step 2B)	Dust emission potential (from Step 2A)		
		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 7-10 Summary of risk assessment for the construction of the project

Type of activity	Step 2A: Potential for dust emissions	Step 2b: Sensitivity of area			Step 2c: Risk of dust impacts		
		Dust soiling	Human health	Ecological	Dust soiling	Human health	Ecological
Demolition	Large	High	High	Medium	High	High	High
Earthworks	Large	High	High	High	High	High	High
Construction	Large	High	High	High	High	High	High
Track-out	Large	High	High	Medium	High	High	Medium

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 11.1.

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 Dust 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 mean 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'.

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.

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8 Alexandria Landfill closure and remediation: dust and odour assessment

8.1 Overview

The site of the Alexandria Landfill at St Peters is currently licensed by NSW EPA as a solid waste landfill, waste storage and recycling facility. Part of the area is planned to form a major component of the St Peters interchange, which will include surface roads, tunnel portals, overpasses and associated infrastructure. The remainder of the site is planned to be redeveloped as public open space comprising a mixture of parkland and pathways.

The site was historically owned by The Austral Brick Company Pty Ltd (Austral) and operated as a quarry and brickworks between 1908 and 1988, after which part of the site was converted into a landfill. The landfill was operated by the City of Sydney Council until 2002, when it was acquired by Dial-A-Dump Industries (DADI). The site is currently licensed by the NSW EPA as a non-putrescible solid waste landfill and waste storage and recycling facility. It is no longer operating as a commercial landfill. Historical waste streams that were relevant in terms of odour included non-putrescible household waste, solid industrial/commercial waste and green waste.

The redevelopment of the site means that it will need to be closed and managed in accordance with the Protection of the Environment Operations (POEO) Act. Assessments were therefore undertaken to estimate the potential impacts of the closure and remediation of the landfill on dust (PM) and odour.

8.2 Dust assessment

8.2.1 Relevant activities

Activities associated with dust generation during closure and remediation of the landfill will include:

- Excavation and exhuming waste to develop the required final landform
- Excavators loading material to trucks
- Hauling cut-and-fill material on unsealed roads
- Dumping material from trucks
- Bulldozers pushing and shaping material
- Grading roads
- Wind erosion from exposed areas

8.2.2 Assessment criteria

The criteria that were applied in the assessment were those stated for airborne PM and deposited dust in the NSW Approved Methods. The criteria for airborne PM are summarised in Table 8-1. Table 8-2 shows the maximum acceptable increase in dust deposition over the existing levels, as well as the maximum total deposition. The criteria for dust deposition are set to provide protection against nuisance impacts (NSW DEC, 2005).

Table 8-1 Assessment criteria for particulate matter (NSW DEC, 2005)

Pollutant	Criterion	Averaging period
TSP	90 µgm^3	Annual
PM_{10}	50 µg/m^3	24 hours
	30 µg/m^3	Annual
$PM_{2.5}$	25 µg/m^3	24 hours
	8 µg/m^3	Annual

Table 8-2 EPA criteria for deposited dust (insoluble solids) (NSW DEC, 2005)

Pollutant	Assessment period	Maximum increase in deposited dust level	Maximum total deposited dust level
Deposited dust	One year	2 g/m^2/month	4 g/m^2/month

8.2.3 Local meteorology

Meteorological data from the BoM Sydney Airport station, approximately 2 kilometres away from the project, were obtained for the assessment. The data for 2014 were used, and the corresponding wind roses are shown in Figure 8-1. On an annual basis wind directions were variable, with the strongest winds from the southern and north-eastern quadrants. Given the coastal nature of both the meteorological and landfill sites, the small percentage of low wind speeds is not surprising.

An important determinant of pollutant dispersion and dilution is the level of turbulence in the lowest 1 km or so of the atmosphere, known as the planetary boundary layer (PBL). Turbulence acts by increasing the cross-sectional area of the plume, and stronger turbulence increases the rate of plume dispersion. Weak turbulence limits dispersion and contributes to high pollutant concentrations downwind of a source.

Turbulence is generated by both thermal and mechanical effects to varying degrees. Thermally driven turbulence occurs when the surface is being heated, in turn transferring heat to the air above by convection. Mechanical turbulence is caused by the frictional effects of wind moving over the Earth's surface, and depends on the roughness of the surface as well as the flow characteristics.

Turbulence in the boundary layer is influenced by the vertical temperature gradient, which is one of several indicators of stability. Atmospheric dispersion models use indicators of atmospheric stability in conjunction with other meteorological data to estimate the dispersion conditions.

Stability can be described across a spectrum ranging from highly unstable through neutral to highly stable. A highly unstable boundary layer is characterised by strong surface heating and relatively light winds, leading to intense convective turbulence and enhanced plume diffusion. At the other extreme, very stable conditions are often associated with strong temperature inversions and light winds, which commonly occur under clear skies at night and in the early morning. Under these conditions plumes can remain relatively undiluted for considerable distances downwind. Neutral conditions are linked to windy and/or cloudy weather, and short periods around sunset and sunrise, when surface rates of heating or cooling are very low.

Current dispersion models (such as AERMOD and CALPUFF) use the Monin-Obukhov Similarity Theory (MOST) to characterise turbulence and other processes in the PBL. One of the measures of the PBL is the Monin-Obukhov length (L), which approximates the height at which turbulence is generated equally by thermal and mechanical effects (Seinfeld and Pandis, 2006). It is a measure of the relative importance of mechanical and thermal forcing on atmospheric turbulence. Because values of L diverge to plus infinity and minus infinity as stability approaches neutral from the stable and unstable sides, respectively, it is often more convenient to use the inverse of L (i.e. 1/L) when describing stability. Table 8-1 shows how the values of 1/L relate to stability.

Figure 8-2 shows the hourly average values of 1/L for the Sydney Airport site. This plot indicates that the PBL is stable overnight and becomes unstable as radiation from the sun heats the surface layer of the atmosphere and drives convection. The changes from positive to negative values of 1/L occur at the shifts between day and night. This indicates that the diurnal patterns of stability are realistic.

Figure 8-3 shows the variations in stability over the year by hour of the day, with reference to the widely-used Pasquill-Gifford classes of stability. The relationship between L and stability class is based on values derived by Golder (1972) and set out in NSW DEC (2005). The reference to stability categories here is only for convenience in describing stability; the model used in the assessment calculated values of L across a continuum. Neutral conditions occur for a large percentage of the time. Atmospheric instability increases during the day and reaches a peak at around 11:00 as solar-driven convective energy peaks. A stable atmosphere is prevalent during the night. These profiles indicate that pollutant dispersion is most effective during the daytime and least effective at night.

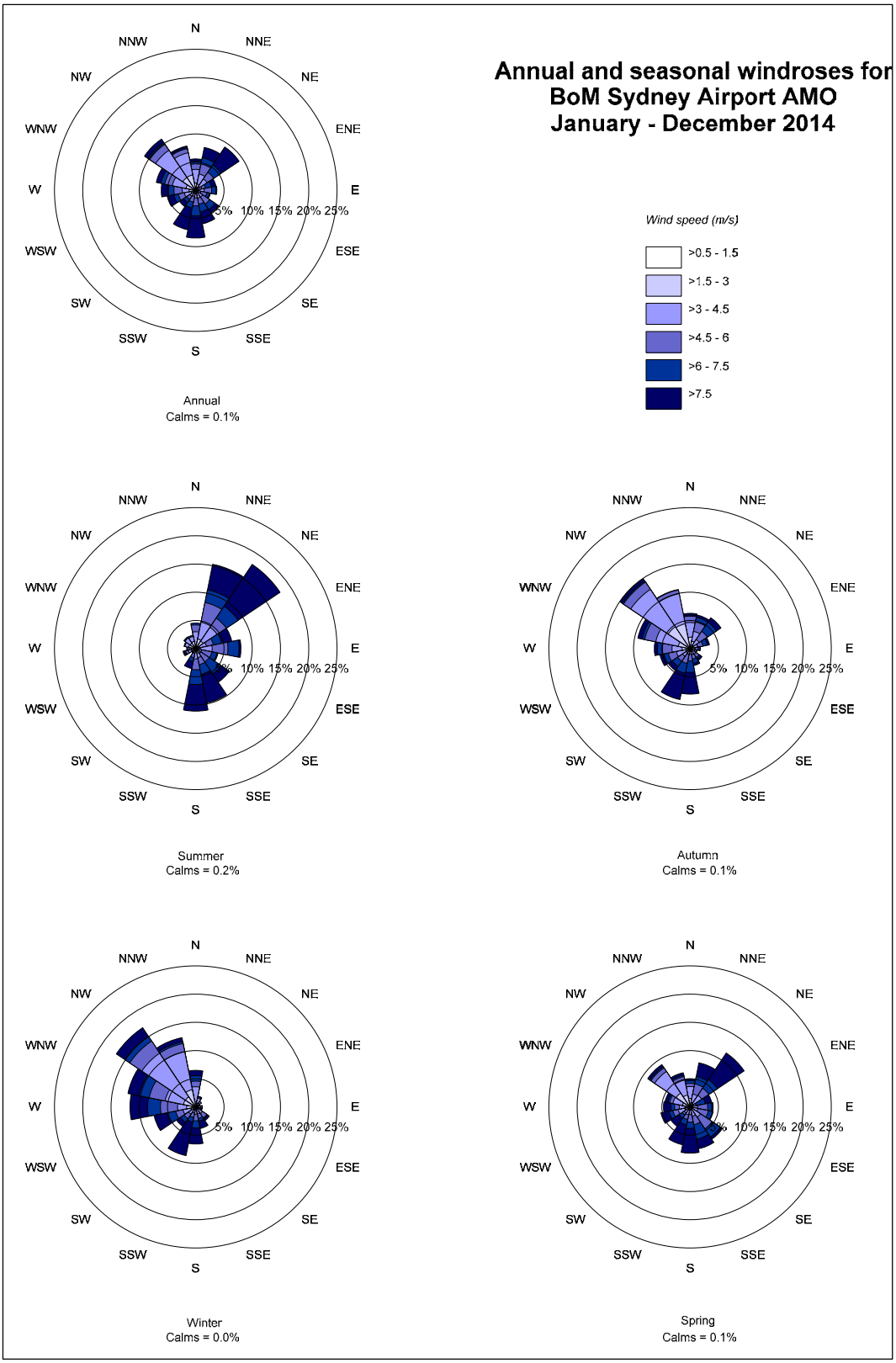


Figure 8-1 Annual and seasonal wind roses for Sydney Airport (2014)

Table 8-3 Inverse of Monin-Obukhov length L with respect to atmospheric stability

1/L	Atmospheric stability
Negative	Unstable
Zero	Neutral
Positive	Stable

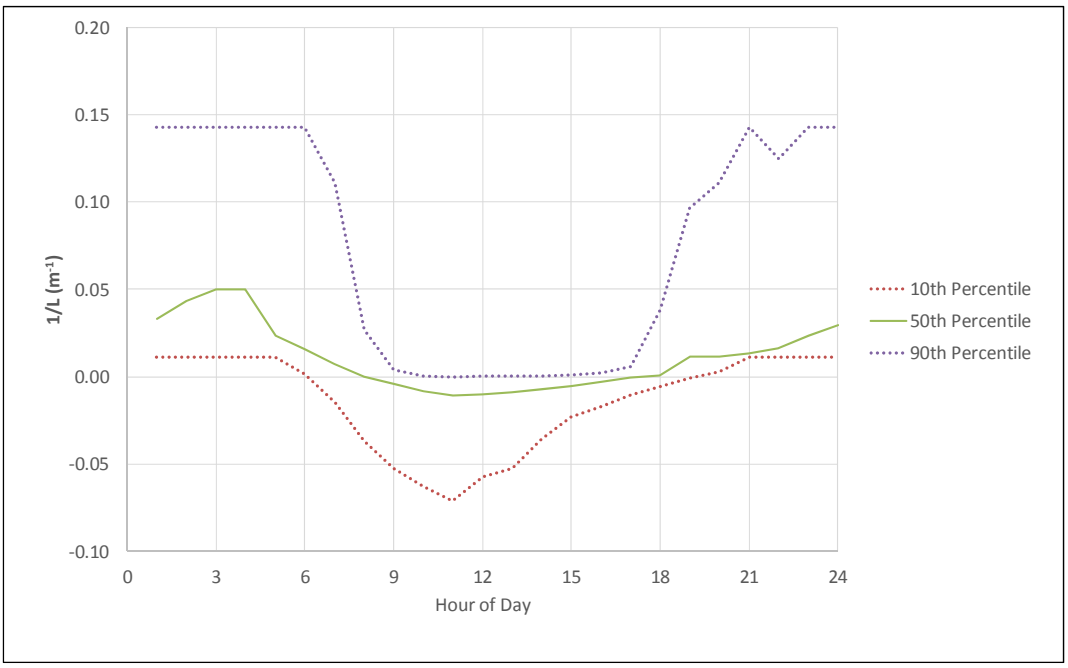


Figure 8-2 Annual statistics of 1/L by hour of day

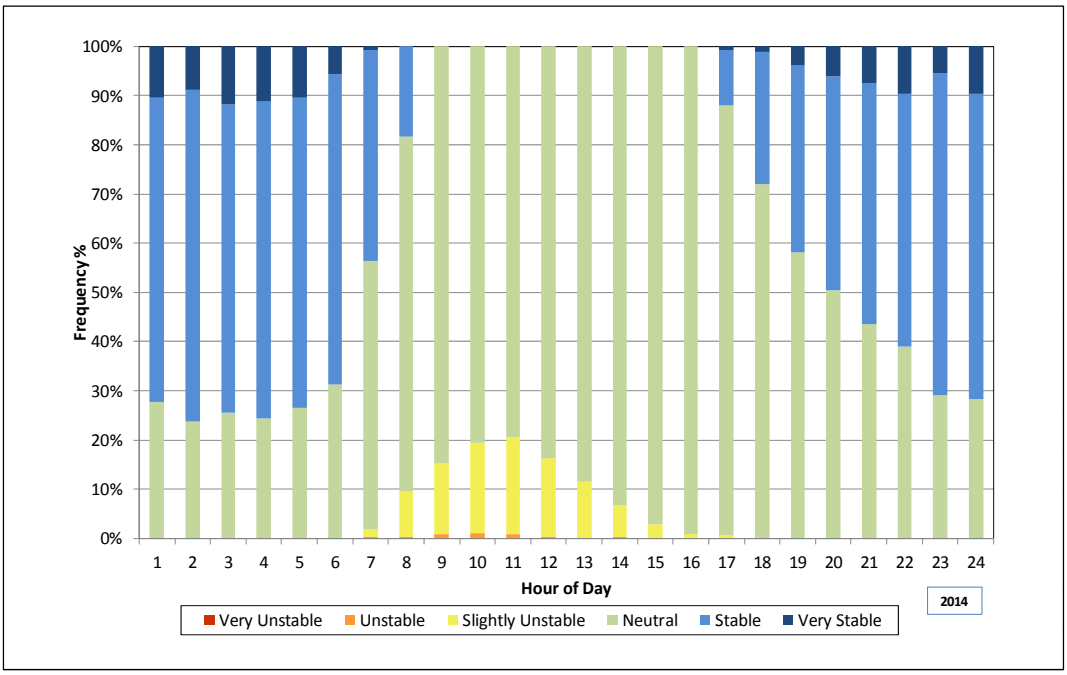


Figure 8-3 Annual distribution of stability type by hour of day

8.2.4 Assessment method

Emission estimation

An emissions inventory for the landfill site in 2014 was developed for TSP, PM_{10} and $PM_{2.5}$. The proposed activities at the site (see section 8.2.1) were analysed, and the PM emissions associated with each activity were estimated for each hour of 2014. Emission factors developed by the USEPA were applied, these being dependent on the level of activity and the wind speed. The emission factors applied are considered to be the most reliable, contemporary methods for determining dust generation rates.

The information used for developing the inventory was based on the descriptions and plans in the Landfill Closure Management Plan for the project design. This information was used to determine the volumes of material excavated and delivered to the site, haul road distances, stockpile areas, truck sizes and other details that are necessary to estimate dust emissions. Dust mitigation measures such as watering of unsealed haul roads and exposed surfaces have been applied to the estimated emissions.

Table 8-4 summarises the quantities of TSP, PM_{10} and $PM_{2.5}$ estimated to be released by each activity. Further information on the calculations is presented for each particle size in Table 8-5, Table 8-6 and Table 8-7.

Table 8-4 Estimated TSP, PM_{10} and $PM_{2.5}$ emissions for the landfill closure and remediation (2014)

Activity	Emissions (kg/year)		
	TSP	PM_{10}	$PM_{2.5}$
Dozers pushing waste	2,121	478	223
Excavators removing material and loading haul trucks	2,354	1,113	169
Hauling cut material to main road	38,630	9,548	955
Hauling new material to landfill site	34,093	8,426	843
Emplacing new material at landfill site	2,077	983	149
Dozers shaping new material	2,121	478	223
Wind erosion	4,971	2,486	373
Grading roads	1,536	537	48
Total	**87,903**	**24,048**	**2,981**

Table 8-5 Emissions inventory for TSP

Activity	TSP emission (kg/y)	Intensity	Units	Emission factor	Units	Variable 1	Units	Variable 2	Units	Variable 3	Units	Variable 4	Units	Variable 5	Units	Variable 6	Units	Control measure
Overburden - Dozers pushing overburden	2,121	624	h/y	6.8	kg/h	4	moisture content in %	10	silt content							50	% control	Keeping travel routes moist
Overburden - Excavators loading haul trucks	2,354	1,512,000	t/y	0.00156	kg/t	3.47	average of (wind speed/2.2)^1.3 in m/s	4	moisture content in %									
Overburden - Hauling cut material toemplacement areas	38,630	1,512,000	t/y	0.1022	kg/t	30	payload (tonnes)	30	Average vehicle mass (tonnes)	1.6	km/return trip	1.92	kg/VKT	4.1	% silt content	75	% control	Level 2 watering
Overburden - Hauling new material to landfill site	34,093	1,334,400	t/y	0.1022	kg/t	30	payload (tonnes)	30	Average vehicle mass (tonnes)	1.6	km/return trip	1.92	kg/VKT	4.1	% silt content	75	% control	Level 2 watering
Overburden - Emplacing new material at landfill site	2,077	1,334,400	t/y	0.0015568	kg/t	3.47	average of (wind speed/2.2)^1.3 in m/s	4	moisture content in %									
Overburden - Dozers shaping new material	2,121	624	h/y	6.8	kg/h	4	moisture content in %	10	silt content							50	% control	Keeping travel routes moist
Wind erosion - Landfill site	4,971	11	ha	0.1	kg/ha/h	8,760	h/y									50	% control	Watering
Grading roads	1,536	4,992	km	0.62	kg/km	624	h/y	8	speed of graders in km/h							50	% control	Keeping travel routes moist
TOTAL TSP Emissions (kg/y)	**87,903**																	

Table 8-6 Emissions inventory for PM_{10}

Activity	PM10 emission (kg/y)	Intensity	Units	Emission factor	Units	Variable 1	Units	Variable 2	Units	Variable 3	Units	Variable 4	Units	Variable 5	Units	Variable 6	Units	Control measure
Overburden - Dozers pushing overburden	478	624	h/y	1.5	kg/h	4	moisture content in %	10	silt content							50	% control	Keeping travel routes moist
Overburden - Excavators loading haul trucks	1,113	1,512,000	t/y	0.000736	kg/t	3.47	average of (wind speed/2.2)^1.3 in m/s	4	moisture content in %									
Overburden - Hauling cut material toemplacement areas	9,548	1,512,000	t/y	0.0253	kg/t	30	payload (tonnes)	30	Average vehicle mass (tonnes)	1.6	km/return trip	0.47	kg/VKT	4.1	% silt content	75	% control	Level 2 watering
Overburden - Hauling new material to landfill site	8,426	1,334,400	t/y	0.0253	kg/t	30	payload (tonnes)	30	Average vehicle mass (tonnes)	1.6	km/return trip	0.47	kg/VKT	4.1	% silt content	75	% control	Level 2 watering
Overburden - Emplacing new material at landfill site	983	1,334,400	t/y	0.0007363	kg/t	3.47	average of (wind speed/2.2)^1.3 in m/s	4	moisture content in %									
Overburden - Dozers shaping new material	478	624	h/y	1.5	kg/h	4	moisture content in %	10	silt content							50	% control	Keeping travel routes moist
Wind erosion - Landfill site	2,486	11	ha	0.05	kg/ha/h	8,760	h/y									50	% control	Watering
Grading roads	537	4,992	km	0.215	kg/km	624	h/y	8	speed of graders in km/h							50	% control	Keeping travel routes moist
TOTAL TSP Emissions (kg/y)	**24,048**																	

Table 8-7 Emissions inventory for $PM_{2.5}$

Activity	PM2.5 emission (kg/y)	Intensity	Units	Emission factor	Units	Variable 1	Units	Variable 2	Units	Variable 3	Units	Variable 4	Units	Variable 5	Units	Variable 6	Units	Control measure
Overburden - Dozers pushing overburden	223	624	h/y	0.714	kg/h	4	moisture content in %	10	silt content							50	% control	Keeping travel routes moist
Overburden - Excavators loading haul trucks	169	1,512,000	t/y	0.000112	kg/t	3.47	average of (wind speed/2.2)^1.3 in m/s	4	moisture content in %									
Overburden - Hauling cut material toemplacement areas	955	1,512,000	t/y	0.0025	kg/t	30	payload (tonnes)	30	Average vehicle mass (tonnes)	1.6	km/return trip	0.05	kg/VKT	4.1	% silt content	75	% control	Level 2 watering
Overburden - Hauling new material to landfill site	843	1,334,400	t/y	0.0025	kg/t	30	payload (tonnes)	30	Average vehicle mass (tonnes)	1.6	km/return trip	0.05	kg/VKT	4.1	% silt content	75	% control	Level 2 watering
Overburden - Emplacing new material at landfill site	149	1,334,400	t/y	0.0001115	kg/t	3.47	average of (wind speed/2.2)^1.3 in m/s	4	moisture content in %									
Overburden - Dozers shaping new material	223	624	h/y	0.714	kg/h	4	moisture content in %	10	silt content							50	% control	Keeping travel routes moist
Wind erosion - Landfill site	373	11	ha	0.01	kg/ha/h	8,760	h/y									50	% control	Watering
Grading roads	48	4,992	km	0.0191	kg/km	624	h/y	8	speed of graders in km/h							50	% control	Keeping travel routes moist
TOTAL TSP Emissions (kg/y)	**2,981**																	

Dispersion modelling

Off-site PM concentrations and dust deposition levels due to the landfill closure and remediation activities were predicted using the dispersion model AERMOD. AERMOD is the USEPA's recommended steady-state plume dispersion model for regulatory purposes, and it is widely used in Australia. A significant feature of AERMOD is that Pasquill-Gifford stability classes are replaced with a turbulence-based approach to dispersion that uses the Monin-Obukhov length scale.

The AERMOD system includes AERMET, which is used for the preparation of meteorological input files and AERMAP, which used for the preparation of terrain data.

AERMET derives meteorological variables that are not measured directly, and requires surface and upper air meteorological data as input. The meteorological data from Sydney Airport for 2014 were used as input to AERMET.

Appropriate values for three surface characteristics were required:

- Surface roughness, which is the height at which the mean horizontal wind speed approaches zero, based on a logarithmic profile
- Albedo, which is an indicator of reflectivity of the surface
- Bowen ratio, which is an indicator of surface moisture.

Values of surface roughness, albedo and Bowen ratio were determined based on a review of aerial photography for a radius of 3 kilometres centred on the Project site. Default values for land use were chosen to represent the surrounding area.

Terrain data were sourced from NASA's Shuttle Radar Topography Mission (SRTM) data with a 3 arc second (~90 metre) resolution and processed within AERMAP to create the necessary input files.

The activities at the site were represented by a series of volume sources situated across the site. The locations of these volume sources, as represented in the model, are shown in Figure 8-4.

Background concentrations

The air quality criteria in the Approved Methods relate to the total PM/dust burden in the air, and not just the dust from the landfill closure and remediation. In other words, consideration of background PM/dust levels was also required to allow an assessment of the potential impacts of the landfill closure and remediation against the criteria.

Background concentrations of PM_{10} and $PM_{2.5}$ are discussed in Appendix F. Conservative estimates were made of the PM concentrations and dust deposition in the general vicinity of the landfill. These were:

- 24-hour average PM_{10} 40 $\mu g/m^3$
- 24-hour average $PM_{2.5}$ 19 $\mu g/m^3$
- Annual average PM_{10} 21 $\mu g/m^3$
- Annual average $PM_{2.5}$ 8 $\mu g/m^3$
- Annual average TSP 52 $\mu g/m^3$ (assuming a PM_{10}:TSP ratio of 0.4)
- Annual average deposition 2 g/m^2/month (conservative assumption)

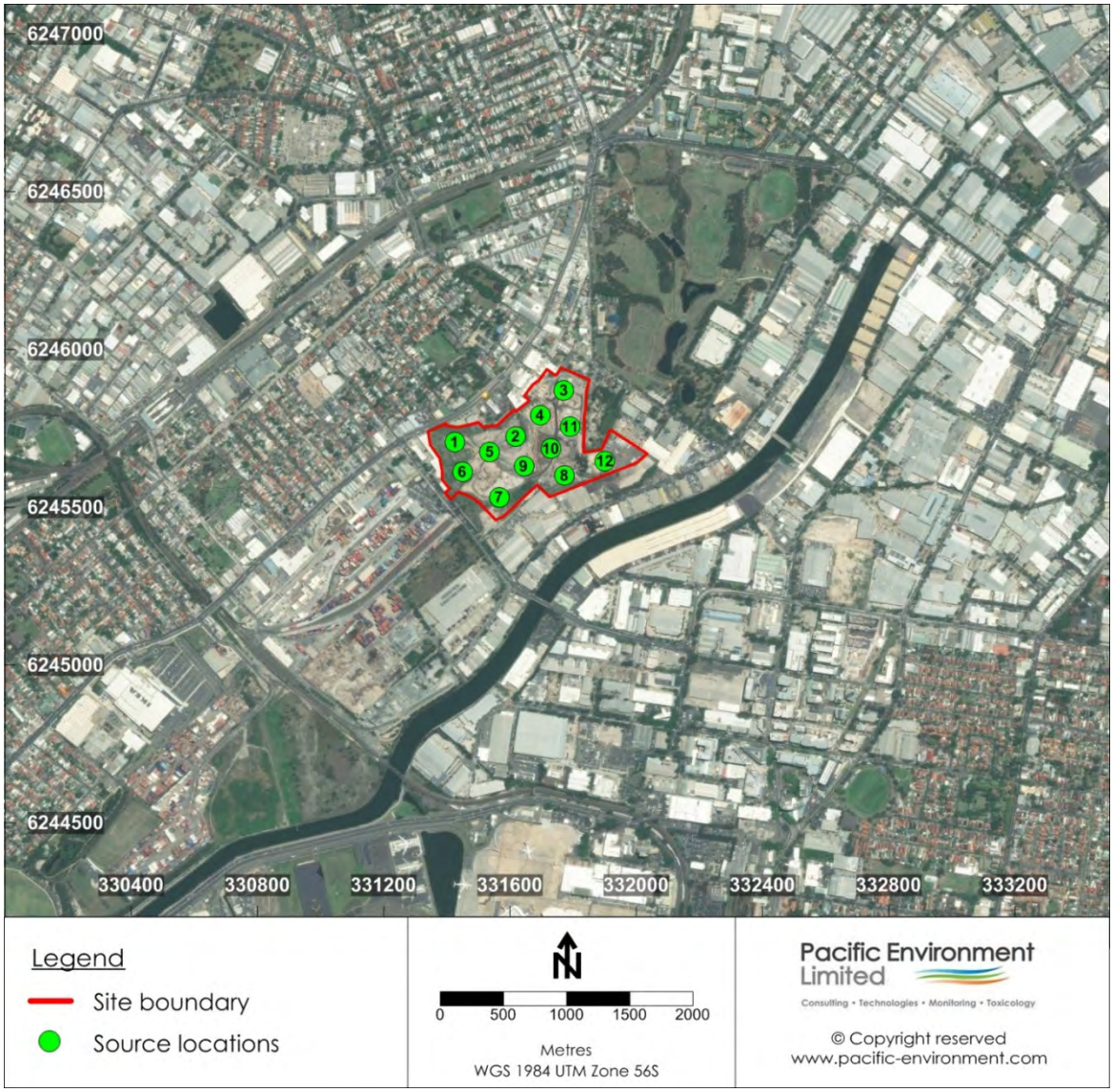


Figure 8-4 Dust source locations as represented in AERMOD

8.2.5 Results

This section presents the results for the PM concentrations and dust deposition rates predicted due to proposed activities as part of the landfill closure and remediation. It should be noted that the model predictions incorporate dust mitigation measures including watering of unsealed haul routes, keeping travel routes moist for bulldozers and graders on-site, and watering of exposed areas that are likely to be prone to wind erosion such as unseeded temporary stockpiles.

Predictions are presented for the closure and remediation works only, so that the predicted contributions from the proposed activities can be seen at the nearest off-site receptors. The results are shown in Figure 8-5 to Figure 8-10. In order to estimate the total impact, which includes the existing background levels, these predictions can be added to the background estimates listed Section 8.2.2.

The predicted levels due to the closure works are low, and even when added to existing concentrations will remain below their relevant air quality criteria. The exceptions to this are annual average $PM_{2.5}$ and 24-hour average PM_{10} at a single receptor.

In the case of annual average $PM_{2.5}$, existing levels are already estimated to be at the criterion of 8 µg/m^3. The estimated contribution from the closure works at the nearest receptors is less than 0.5 µg/m^3 and is based on activities occurring across the entire site continuously 24-hours per day every day of the year. This would clearly not happen in practice.

The other potential exceedance relates to cumulative 24-hour PM_{10} in the industrial area on the southern boundary. Again this is unlikely to be an exceedance in reality. The maximum predicted 24-hour PM_{10} concentration due to operations at the landfill closure site is approximately 10-20 µg/m^3 in that area (Figure 8-6). To exceed the criterion this modelled maximum would need to occur on the same day as the conservative background of 40 µg/m^3. Again, this is conservative as the maximum prediction is based on all activities occurring at the maximum rate on all days of the year.

In terms of predicted off-site dust concentrations due to activities at the landfill closure site, it is unlikely that any further dust mitigation measures would be required, other than those already set out in the Landfill Closure Management Plan.

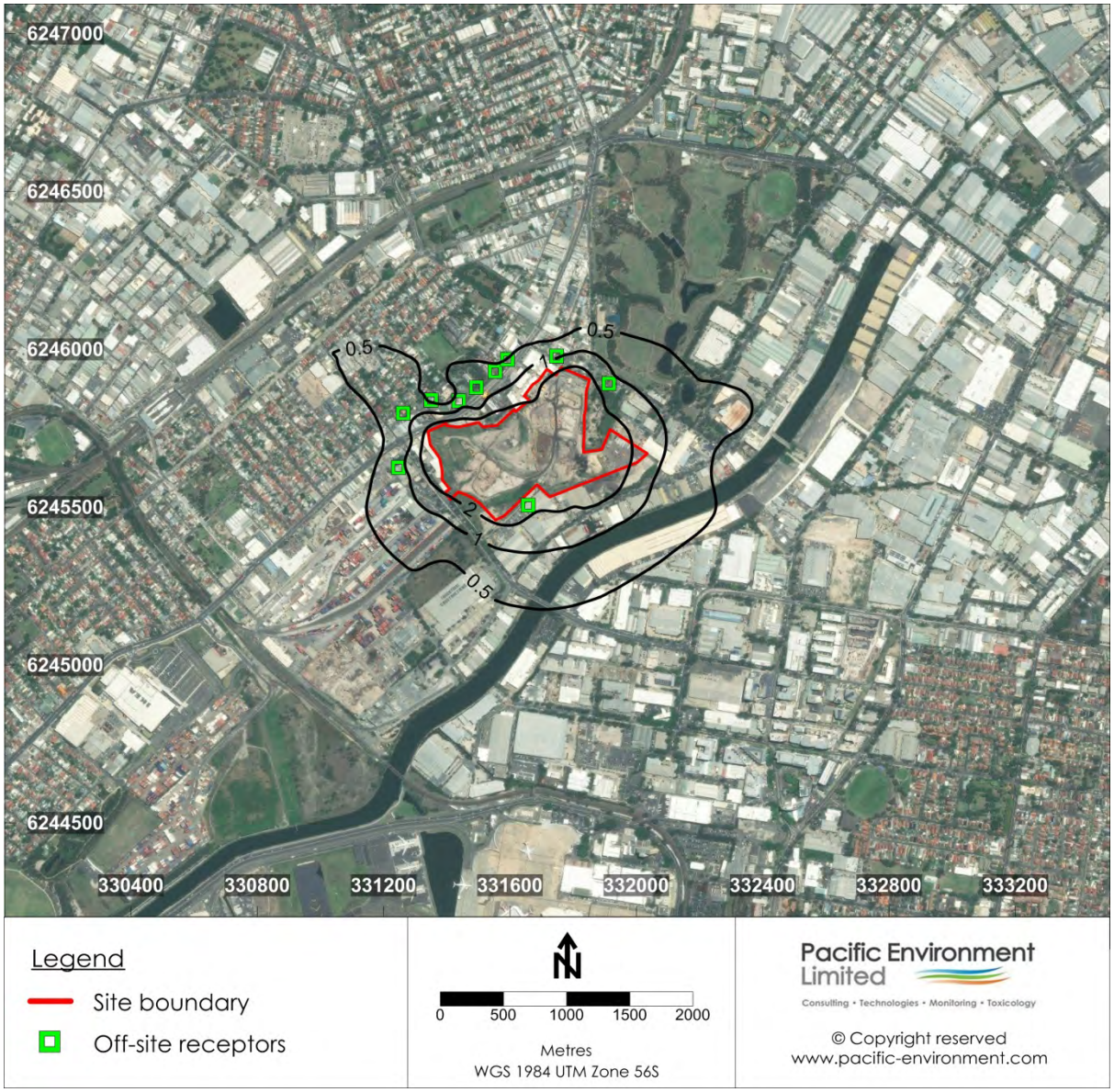


Figure 8-5 **Predicted maximum 24-hour average $PM_{2.5}$ concentration due to landfill closure works (µg/m^3)**

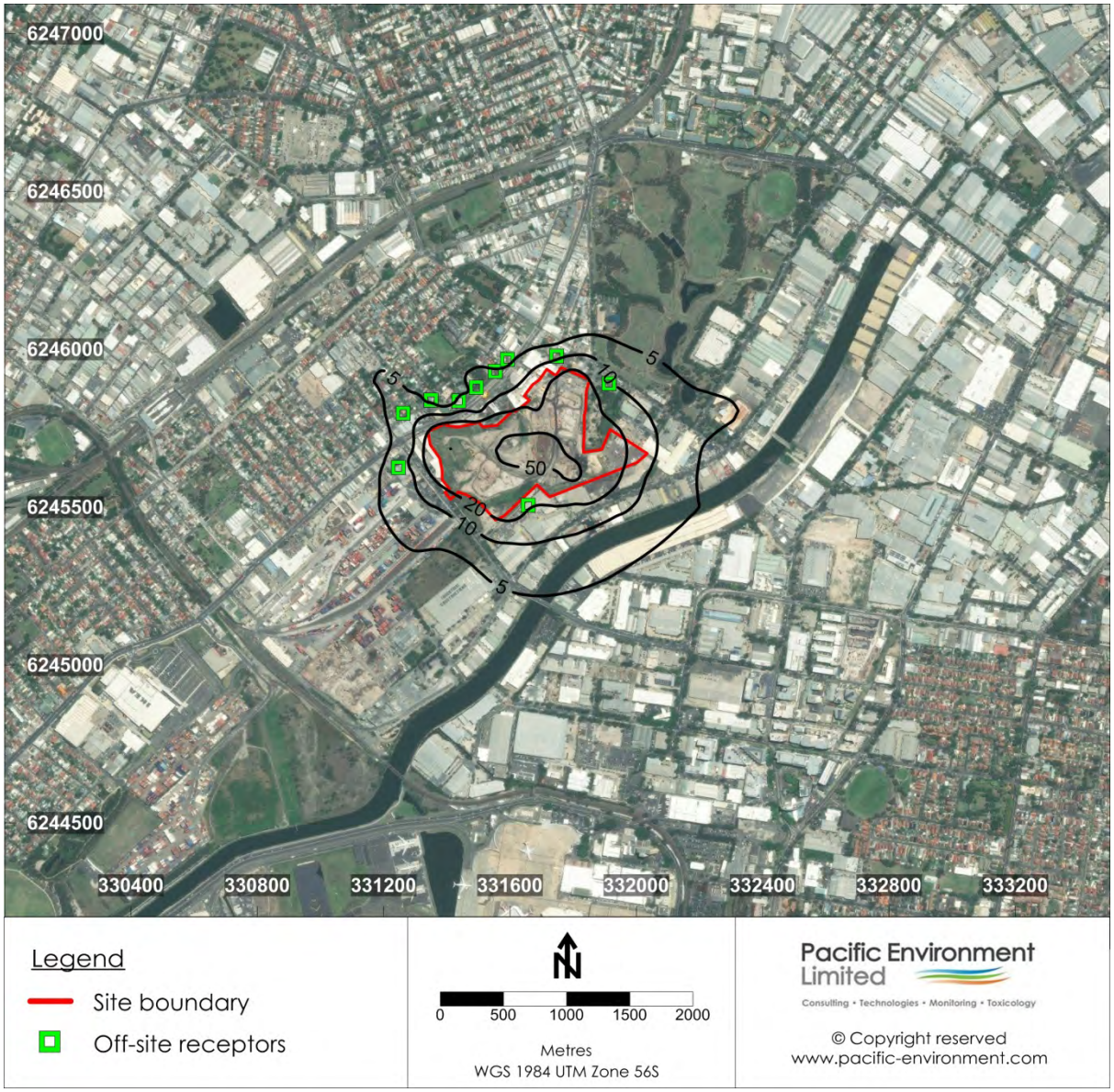


Figure 8-6 **Predicted maximum 24-hour average PM_{10} concentration due to landfill closure works ($\mu g/m^3$)**

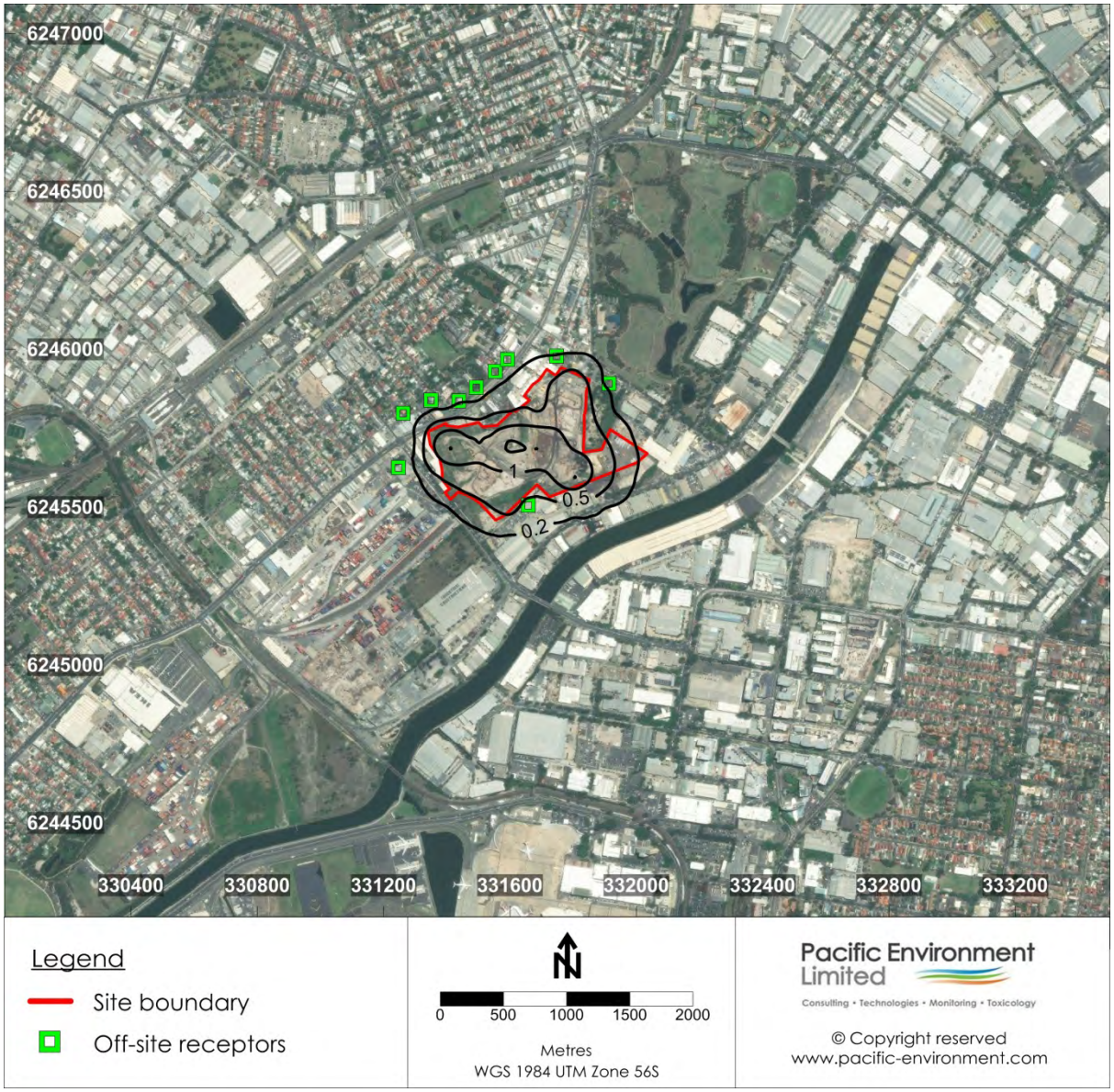


Figure 8-7 Predicted annual average $PM_{2.5}$ concentration due to landfill closure works (µg/m^3)

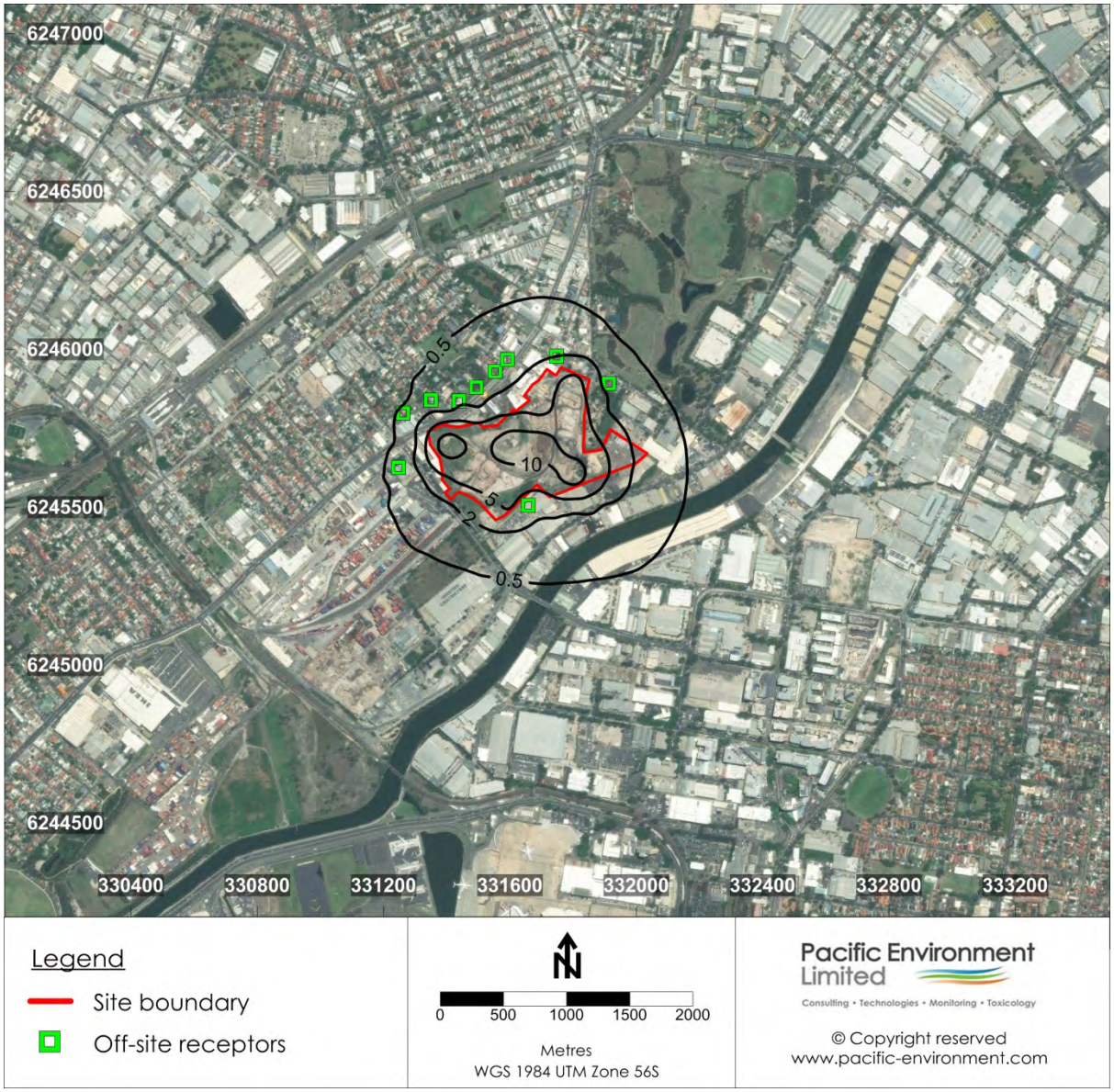


Figure 8-8 Predicted annual average PM_{10} concentration due to landfill closure works (µg/m^3)

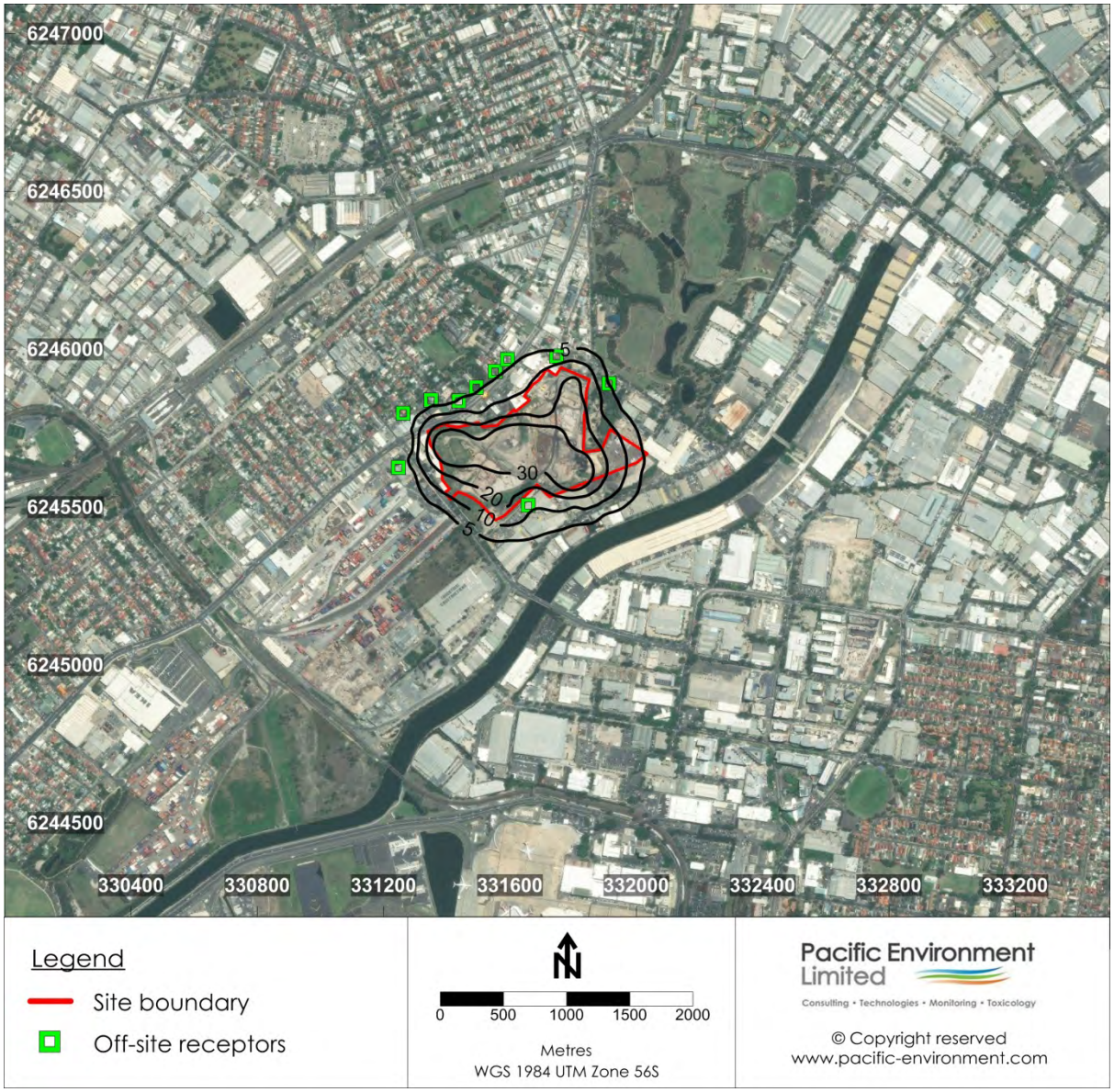


Figure 8-9 Predicted annual average TSP concentration due to landfill closure work (µg/m^3)

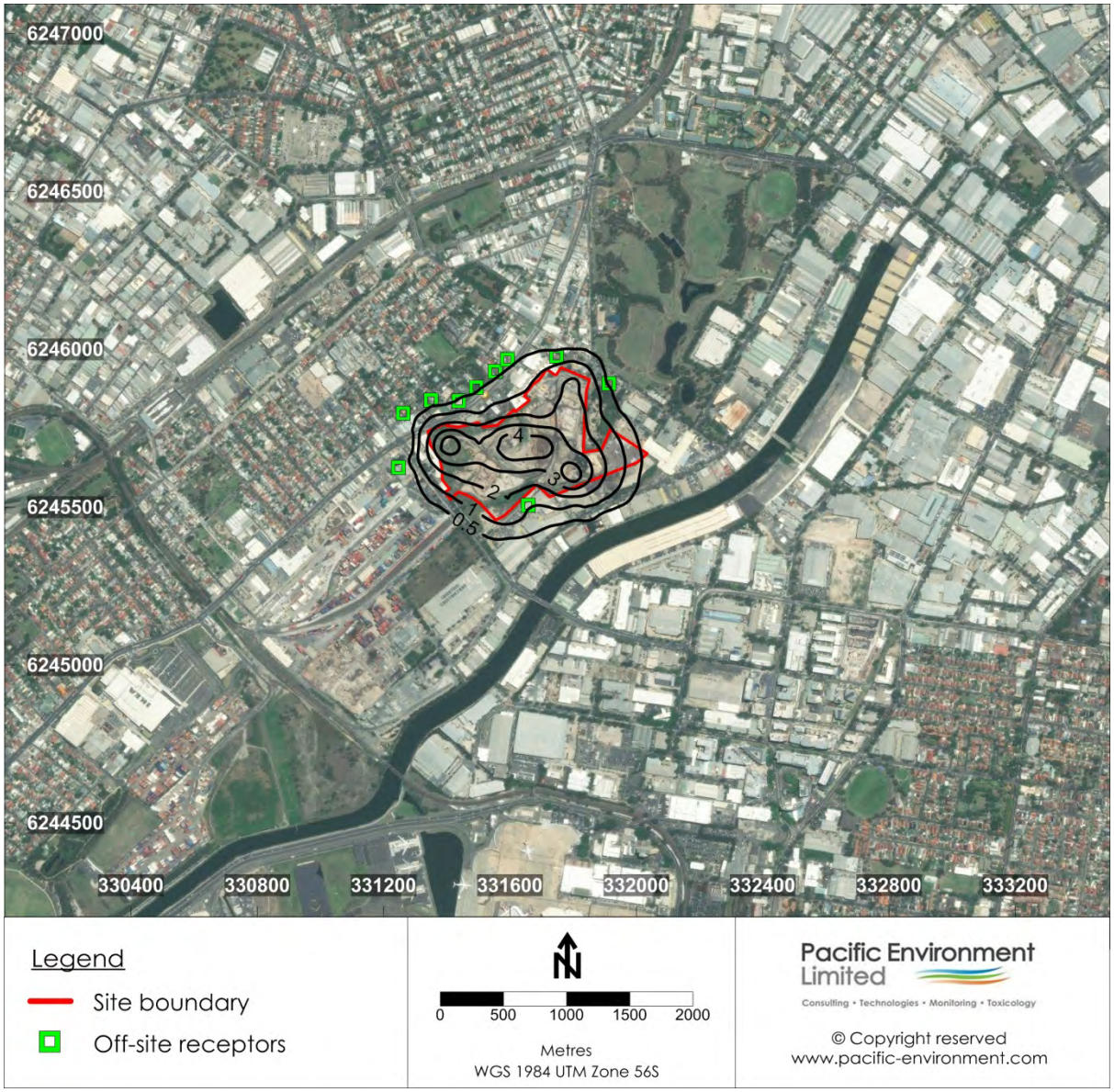


Figure 8-10 Predicted annual average dust deposition due to landfill closure works (g/m^2/month)

8.3 Odour assessment

8.3.1 Relevant activities

The site has operated as a landfill for non-putrescible solid waste, including green waste. Any excavation of that waste and its subsequent exposure to the atmosphere is likely to emit odours.

The collection and treatment of leachate would also be a feature of the landfill site. It is proposed that leachate is collected via a network of sub-surface pipes and then pumped to the leachate treatment plant to be biologically treated to remove ammonia. The ammonia is converted to nitrate by providing aeration to bioreactors. The water is fed to the treated water tank and then discharged to the sewer under a trade waste agreement. Sludge is dewatered and loaded to a dewatered sludge bin for transport off site via trucks. The excess water from the dewatering process is pumped back to the treated water tank.

This process is proposed to be fully enclosed and, as such, is not expected to be a significant source of odour. However, in order to conservatively assess the proposal it has been assumed that the sequencing batch reactor (SBR) tanks and the sludge dewatering area are exposed to the atmosphere.

8.3.2 Assessment criteria

The determination of air quality goals for odour - and their use in the assessment of odour impacts - is recognised as a difficult topic in air pollution science. For example, there is still considerable debate in the scientific community about appropriate odour criteria. However, odour has received considerable attention in recent years, and the procedures for assessing odour impacts using dispersion models have been refined considerably.

NSW EPA has developed odour goals and has specified the way in which these should be applied, using dispersion models to assess the likelihood of nuisance impacts arising from odour emissions. There are two questions that need to be considered:

- What ‘level of exposure’ to odour is considered acceptable to meet current community standards in NSW?
- How can dispersion models be used to determine if predicted ground-level concentrations meet criteria which are based on this acceptable level of exposure?

The term ‘level of exposure’ has been used to reflect the fact that odour impacts are determined by several factors, the most important of which are the so-called FIDOL factors:

- the **F**requency of the exposure
- the **I**ntensity of the odour
- the **D**uration of the odour episodes
- the **O**ffensiveness of the odour
- the **L**ocation of the source

For most odours, when determining offensiveness the context in which an odour is perceived is also relevant. Some odours, for example the smell of sewage, hydrogen sulfide, butyric acid, landfill gas, etc., are likely to be judged offensive regardless of the context in which they occur. Other odours, such as the smell of jet fuel, may be acceptable at an airport but not in a house, and diesel exhaust may be acceptable near a busy road but not in a restaurant.

In summary, whether or not an individual considers an odour to be a nuisance will depend on the FIDOL factors outlined above and, although it is possible to derive formulae for assessing odour annoyance in a community, the response of any individual to an odour is still unpredictable. Odour criteria need to take account of these factors.

The NSW Approved Methods include ground-level concentration criteria for complex mixtures of odorous air pollutants. These have been refined by NSW EPA to take account of the population in the affected area. The difference between odour goals is based on considerations of risk of odour impact rather than differences in odour acceptability between urban and rural areas. For a given odour level there will be a wide range of responses in the population exposed to the odour. In a densely populated area there will therefore be a greater risk that some individuals within the community will find the odour unacceptable than in a sparsely populated area.

Table 8-8 lists the odour criteria to be exceeded not more than 1% of the time for different population sizes. The most stringent of the impact assessment criterion of 2 odour units (OU) at the 99th percentile has been applied to the assessment of the Alexandria Landfill.

Table 8-8 Criteria for the assessment of odour (NSW DEC, 2005)

Population of affected community	Criterion for complex mixtures of odour (OU)
≤ ~2	7
~10	6
~30	5
~125	4
~500	3
Urban (>2000) and/or schools and hospitals	2

It is common practice to use dispersion models to determine compliance with odour criteria. This introduces a complication because Gaussian dispersion models directly predict concentrations over an averaging period of three minutes or greater. The human nose, however, responds to odours over periods of the order of a second or so. During a three-minute period odour levels can fluctuate significantly above and below the mean, depending on the nature of the source.

To determine more rigorously the ratio between a one-second peak concentration and a three-minute (or longer) average concentrations (referred to as the peak-to-mean ratio) that might be predicted by a Gaussian dispersion model, the EPA commissioned a study by Katestone Scientific Pty Ltd (1995, 1998). This study recommended peak-to-mean ratios for a range of variables such as source type, receptor distance, stability class, and stack height (for point sources). The Approved Methods take account of the peak-to-mean factor in the criteria shown in Table 8-8.

It is important to note that the peak-to-mean ratios are based on the Pasquill-Gifford stability classes. Since, as noted earlier, AERMOD uses the Monin-Obukhov length scale to account for atmospheric turbulence, a conservative approach has been taken for area sources and a ratio of 2.5 has been applied.

8.3.3 Assessment method

Emission estimation

In order to represent a disturbed area of excavated non-putrescible waste, a specific odour emission rate of 0.424 OU.m^3/s/m^2 was used. This value was taken from measurements made at the tipping face of a landfill which received both putrescible and non-putrescible solid waste. Given that the Alexandria Landfill was predominantly for non-putrescible waste, the emission rate is considered to be conservative for this assessment.

The value of 0.424 OU.m^3/m^2/s was multiplied by a peak-to-mean ratio of 2.5 to account for nose response time, as discussed above. The resultant emission rate was then multiplied by the estimated area of exposed material. The exposed area was assumed to be emitting odour at the constant rate for the entire one-year modelling period.

For modelling purposes it was assumed that there would be six 7,500 m^2 areas being excavated simultaneously across the site, and that these areas would be emitting at the full rate for every hour of the year.

In addition to the excavated areas, open SBR tanks and a dewatered sludge bin were also assessed. The specific odour emission rate from the leachate contained in the SBR tanks was estimated to be approximately 0.06 $OU.m^3/m^2/s$ (direct measurement made from two separate leachate ponds). This was then multiplied by the exposed area (two tanks with a diameter of 9.75 metres) and again by the peak-to-mean ratio of 2.5. The emission rate for the dewatered sludge bin was approximately 0.17 $OU.m^3/m^2/s$ (representative of dewatered sewage sludge), multiplied by the exposed area of approximately 50 m^2 and the 2.5 peak-to-mean ratio. Emissions for the three main sources are summarised in Table 8-9.

Table 8-9 Odour emission rates for each odour source

Source	Specific odour emission rate ($OU.m^3/m^2/s$)	Total area (m^2)	Peak-to-mean ratio	Total odour emission rate ($OU.m^3/s$)
Excavated waste	0.424	45,000	2.5	47,700
SBR tanks	0.06	600	2.5	90
Dewatered sludge bin	0.17	50	2.5	19

Dispersion modelling

Odour concentrations were predicted using the dispersion model AERMOD, the configuration of which was described in Section 8.2.4. The same local meteorology used for the dust assessment was also used here, as described in Section 8.2.3.

8.3.4 Results

This section provides the predicted odour concentrations due to proposed activities as part of the landfill closure and remediation works. The results, presented in Figure 8-11, show that the predicted 99th percentile odour concentrations at most of the nearest receptors were below 1 OU, the theoretical level of detection. For all but one of the off-site receptors the odour criterion of 2 OU (99th percentile) was not predicted to be exceeded.

There is the chance of some industrial receptors at the southern boundary experiencing levels of up to 7 OU, and therefore some occupants experiencing odour annoyance. However, it should be noted that the modelling has assumed that large areas of the whole site will be exposed continuously which will not be the case. Covers would be applied to exposed areas on a daily basis as part of the Odour Management Plan, which will significantly reduce impacts, particularly close to the site.

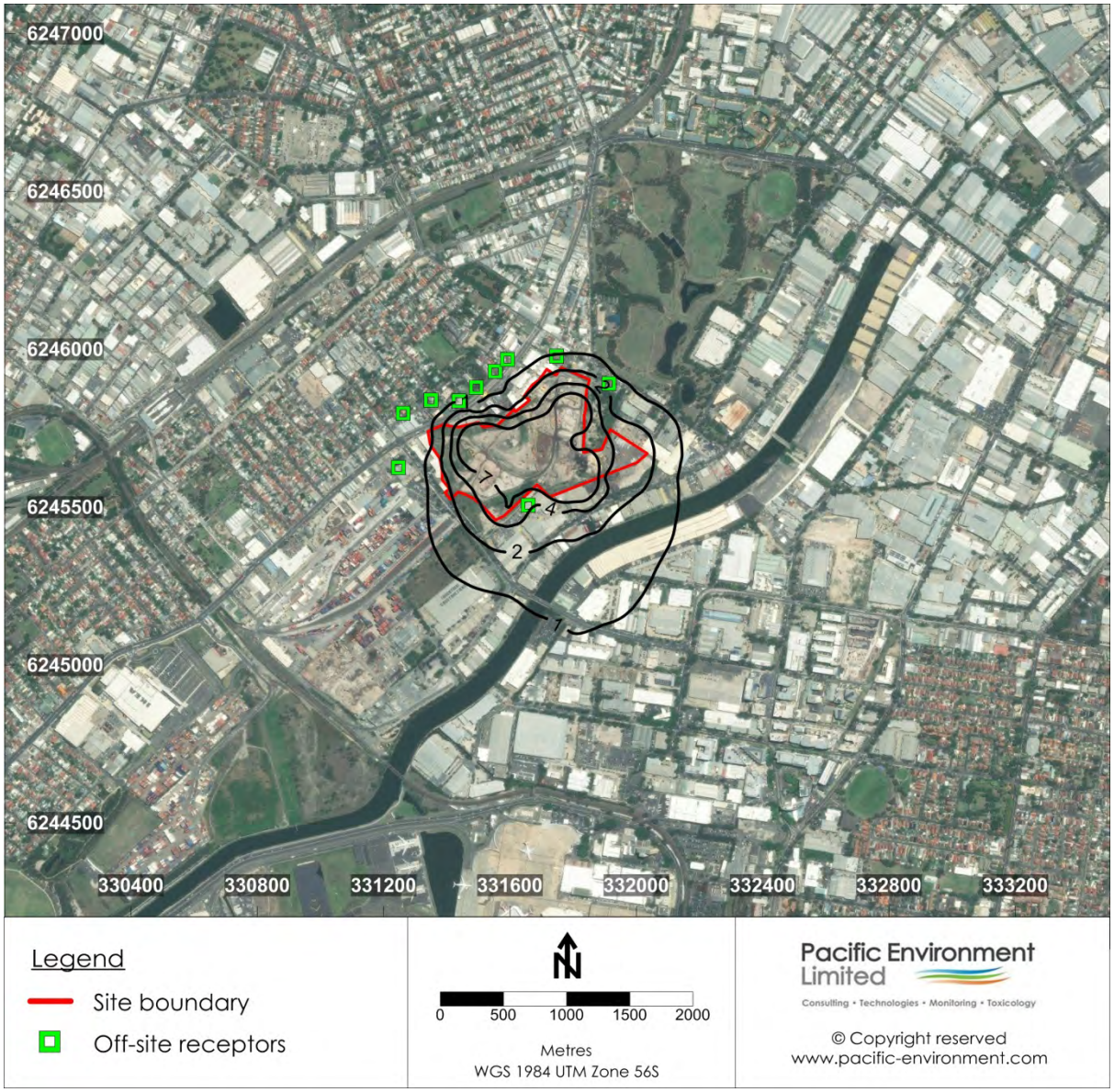


Figure 8-11 **Predicted 99th percentile odour concentration due to landfill closure works – waste excavation and leachate management (OU)**

9 Assessment of operational impacts

9.1 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.

9.2 Emission calculations

9.2.1 Introduction

A spatial emissions inventory was developed for road traffic sources in the WestConnex GRAL domain. The 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.

9.2.2 New M5 tunnel ventilation outlets

Model selection

Emissions from the traffic in the New M5 tunnel were calculated using the emission factors provided in the PIARC guidance Road Tunnels: Vehicle Emissions and Air Demand for Ventilation (PIARC, 2012). 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 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 9.2.3). 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 New M5 tunnel (main line) in 2021 and 2031 are shown in Figure 9-1. 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.

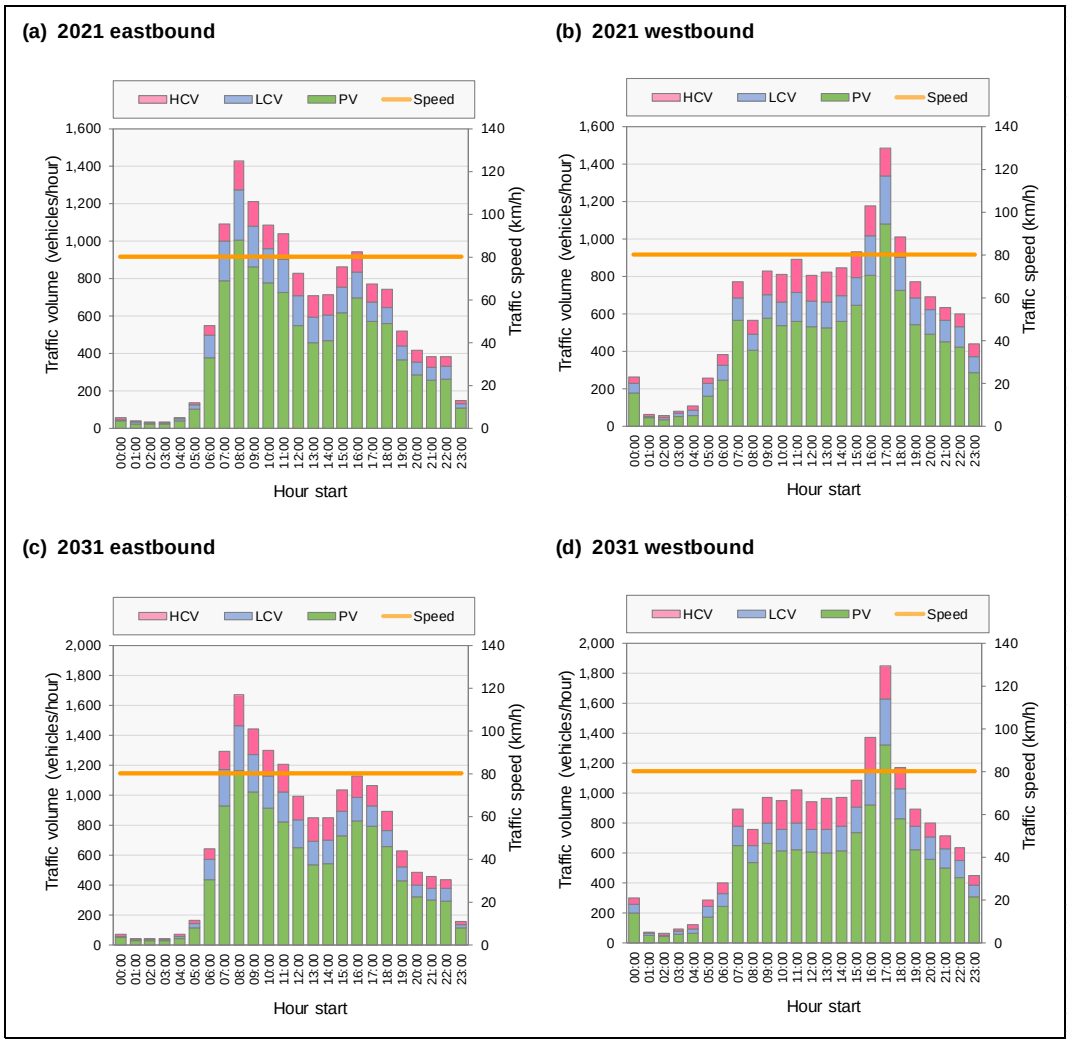


Figure 9-1 Estimated traffic volume, composition and speed in the New M5 tunnel

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 took into account the effects of traffic congestion.

Vehicle breakdown scenario

For the reasons explained in Appendix L, a vehicle breakdown scenario was 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 $PM_{2.5}$ emission rate from the tunnel ventilation work was multiplied by a $PM_{10}/PM_{2.5}$ ratio (1.4) to determine PM_{10}, as in the assessment of the M4 East project (WDA, 2015). The THC emission rates for dispersion modelling were estimated using the THC/NOx ratio from the calculations using the NSW EPA model, again as for the M4 East project. These conversion factors will also be representative of the New M5 project.

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-DSC scenarios are shown in Figure 9-2 and Figure 9-3.

A further step was necessary to model 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 9-17), 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, 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.

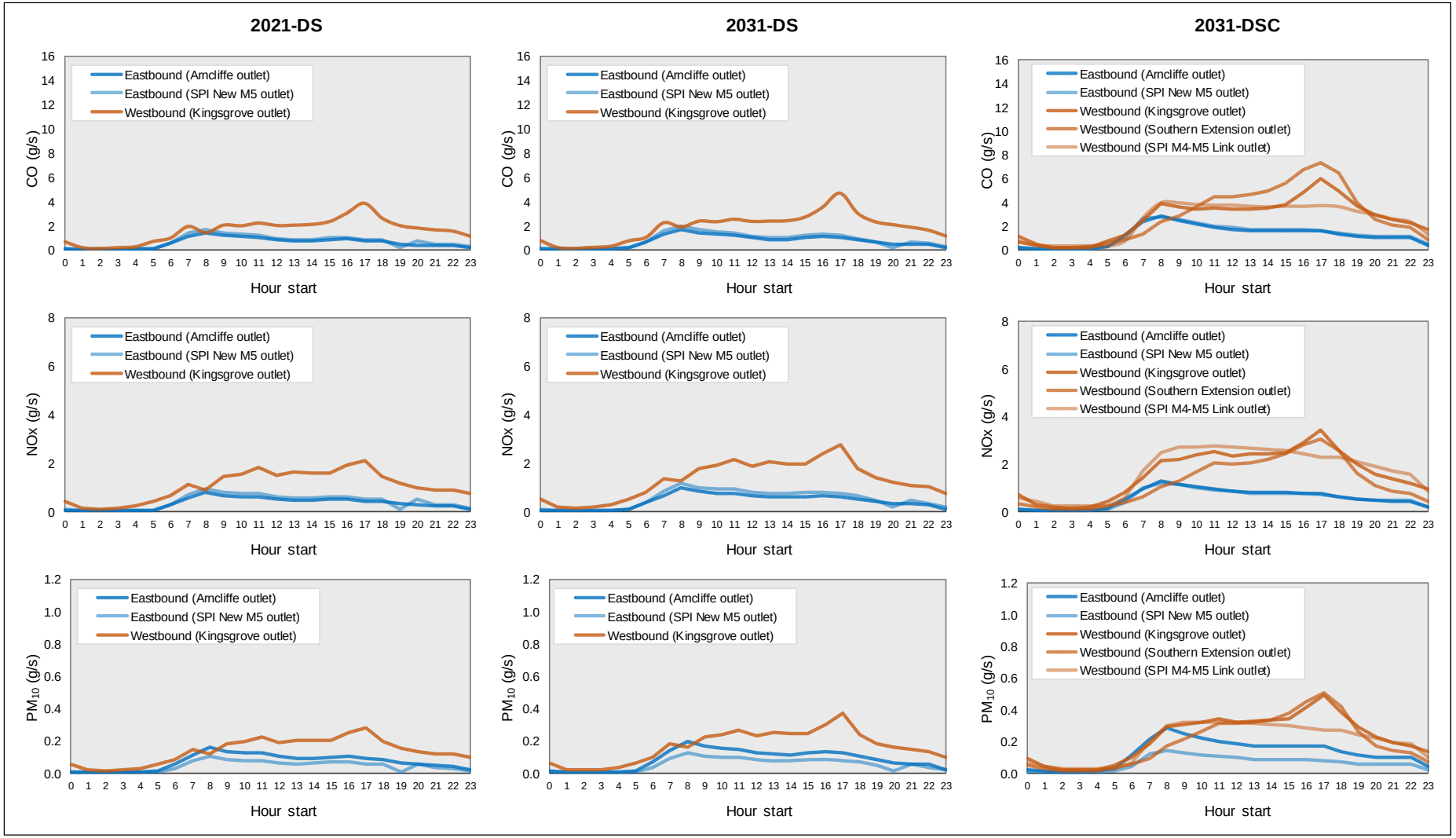


Figure 9-2 Emission rates for project ventilation outlets (CO, NOx and PM_{10})

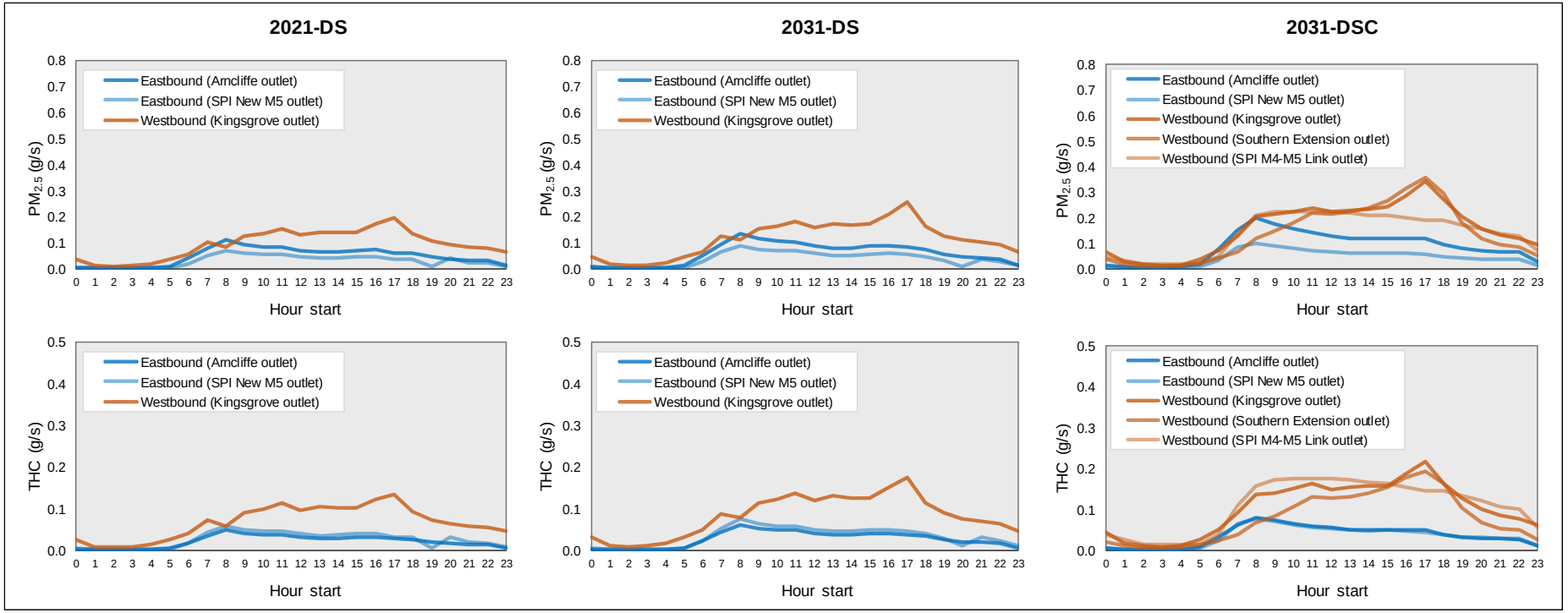


Figure 9-3 Emission rates for project ventilation outlets ($PM_{2.5}$, THC)

9.2.3 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 concentration and air flow measurements 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 9-1. 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 9-1 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

9.2.4 Surface roads

Model selection

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

- 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 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 New M5, but they do need to be considered for roads with a larger proportion of vehicles operating in cold-start mode.
- The full 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 New M5 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 New M5 assessment, because a detailed model was already available from NSW EPA (and reflected the traffic, fuel and fleet conditions in NSW).

[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

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 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).

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 (NSW Roads and Maritime Services, 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 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 9-2).

Table 9-2 Number of road links by scenario

Scenario code	Scenario description	Number of road links included (WestConnex GRAL domain)
2014-BY	2014 - Base Year (existing conditions)	6,178
2021-DM	2021 - Do Minimum (no New M5)	6,187
2021-DS	2021 - Do Something (with New M5)	6,233
2031-DM	2031 - Do Minimum (no New M5)	6,203
2031-DS	2031 - Do Something (with New M5)	6,249
2031-DSC	2031 - Do Something Cumulative (with the full WestConnex and the future Southern extension)	6,387

The dispersion model results were subsequently extracted for the roads in the New M5 GRAL domain. These roads are shown in Figure 9-4. Some of the main roads affected by the project, either directly or indirectly, are also highlighted.

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 9-4 Example of road links included in the New M5 GRAL domain (2021-DS scenario)

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 9-3. 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 9-3 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	
Sub-arterial	All	Arterial
Arterial	All	
Regional arterial	<=70	Commercial arterial
	>70	Commercial highway
Highway	All	Highway / freeway
Motorway	All	
Motorway ramp	All	

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 9-4. The generic road widths were estimated based on samples of roads from Google Earth.

Table 9-4 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 in the WestConnex GRAL domain was estimated using high-resolution terrain data derived from LIDAR surveys. 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. The real-world gradients of selection of traffic model links were also estimated using road length and height information from Google Earth, and the results were found to be in good agreement with the gradients determined from the LIDAR data.

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 9-5. The sub-division was based upon a default traffic mix for each road type in the GMR inventory, as shown in Table 9-6.

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 growth in 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 9-5 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 9-6 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 9-6.
- HCVs from the traffic model were redistributed according to the split for HD-P, RT and AT in Table 9-6.
- Relatively small numbers of buses and motorcycles were added to the traffic model output, again based on the proportions in Table 9-6.

An example of the WRTM output for one link is shown in Figure 9-5, and the transformation of the data for this link into a suitable format for the NSW EPA emission model is shown in Figure 9-6.

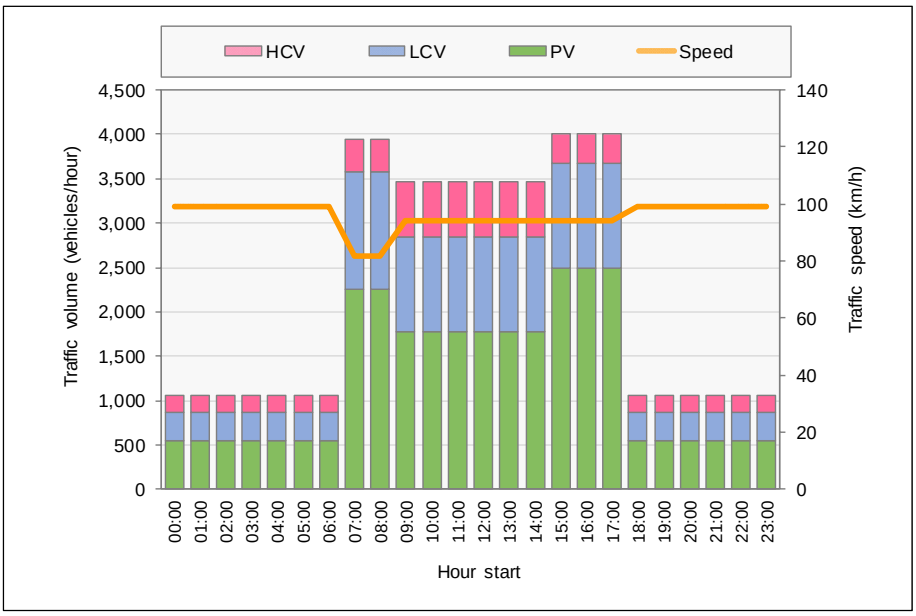


Figure 9-5 Example traffic model output (link 10285-10313, motorway, 2014)

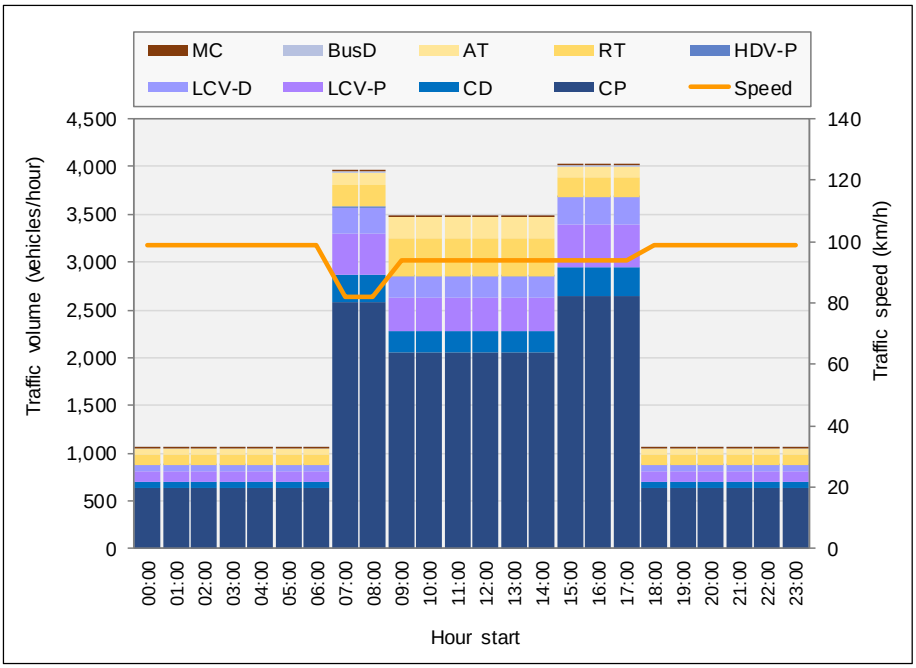


Figure 9-6 Example emission model input (link 10285-10313, highway/freeway, 2014)

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 in the strategic model for the WestConnex GRAL domain. The changes in the total emissions resulting from the project can 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 9-7 and the changes in emissions are shown in Table 9-8. For the pollutants NO_X and PM the net effects of the project on total emissions in 2021 and 2031 were small. In the cumulative case for 2031 there would be an increase in emissions of NO_X and PM of around 1.6 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 9-7 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 New M5)	15.7	9,025	4,068	278	182	934
2021-DS	2021 - Do Something (with New M5)	15.8	9,196	4,056	275	180	940
2031-DM	2031 - Do Minimum (no New M5)	17.6	6,102	2,963	288	179	598
2031-DS	2031 - Do Something (with New M5)	17.7	6,253	2,925	285	176	599
2031-DSC	2031 - Do Something Cumulative (with New M5 and M4-M5 Link)	19.1	6,582	3,010	294	182	585

(a) VKT = vehicle kilometres travelled

Table 9-8 Changes in total emissions in the WestConnex GRAL domain

Scenario comparison	Change in total emissions (%)				
	CO	NOx	PM_{10}	$PM_{2.5}$	THC
Do Minimum (without project) 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%
Do Something (with project) scenarios					
2021-DS vs 2021-DM	+1.9%	-0.3%	-0.9%	-0.8%	+0.7%
2031-DS vs 2031-DM	+2.5%	-1.3%	-1.0%	-1.2%	+0.3%
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 gives an emission threshold for NO_X and VOCs of 90 tonnes/year for new sources, above which projects should proceed to a detailed modelling assessment for ozone. The changes in emissions associated with this project were well below this threshold.

For example, in 2021 there was actually projected to be a decrease in NO_X emissions for the assessed road network of around 12 tonnes per year. This value also equates to a tiny proportion of anthropogenic NO_X 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.

9.2.5 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 NO_X 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. 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 $PM_{2.5}$, which is discussed below, 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 9-7.

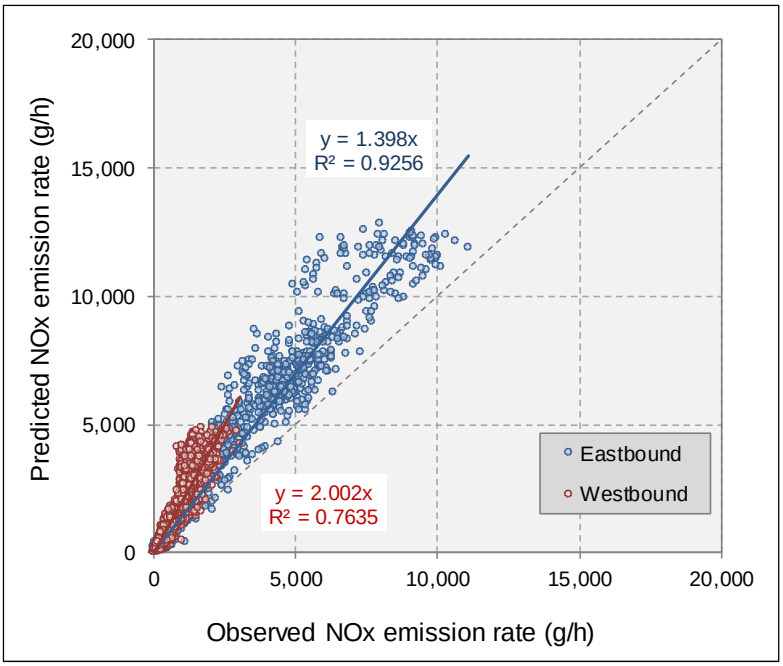


Figure 9-7 **Predicted (simple PIARC model) and observed (Lane Cove tunnel measurements) NO_X emission rates in 2013**

- 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 NO_2. In the case of $PM_{2.5,}$ 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 NO_2 emission factors, are provided in Appendix E.

9.3 In-tunnel air quality

In-tunnel traffic, airflow, pollution levels and temperature for the project and for the future M4-M5 Link were modelled using the IDA Tunnel software[28]. The data used in the tunnel ventilation simulation, and the results of the simulation, are provided in full in Appendix L.

The three pollutants assessed for in-tunnel air quality were NO_2, CO and $PM_{2.5}$ (exhaust only, as visibility). For the operating years of the project, NO_2 will be the pollutant that determines the required airflow and drives the design of ventilation for in-tunnel pollution.

The maximum in-tunnel concentrations of CO and NO_2, as well as the maximum extinction coefficient, were calculated using the methods described in Appendix L. The results for the 2021-DS, 2031-DS and 2031-DSC scenarios are also presented in Figure 9-8. These plots, which show the diurnal change in the maximum in-tunnel value, confirm that the tunnel ventilation system will be designed to maintain in-tunnel air quality well within operational limits.

The maximum in-tunnel concentrations across all time periods for the expected traffic scenarios, the capacity traffic scenarios and the worst case regulatory assessment are presented in Table 9-9. The maximum concentrations for all traffic scenarios, including worst-case conditions, were within the concentrations associated with the regulatory worst case.

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

Scenario		Maximum in-tunnel concentration					
		NO_2 (ppm)		CO (ppm)		$PM_{2.5}$ (mg/m^3)	
		Eastbound	Westbound	Eastbound	Westbound	Eastbound	Westbound
Expected traffic	2021-DS	0.41	0.27	7.99	5.99	0.42	0.38
	2031-DS	0.46	0.32	8.33	6.87	0.5	0.47
	2031-DSC	0.38	0.53	7.15	12.97	0.53	0.8
Capacity traffic	2021-DS	n/a	n/a	n/a	n/a	n/a	n/a
	2031-DS	n/a	n/a	n/a	n/a	n/a	n/a
	2031-DSC	0.52	0.66	9.73	14.84	0.75	0.96
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°C.

[28] http://www.equa.se/en/tunnel/ida-tunnel/road-tunnels

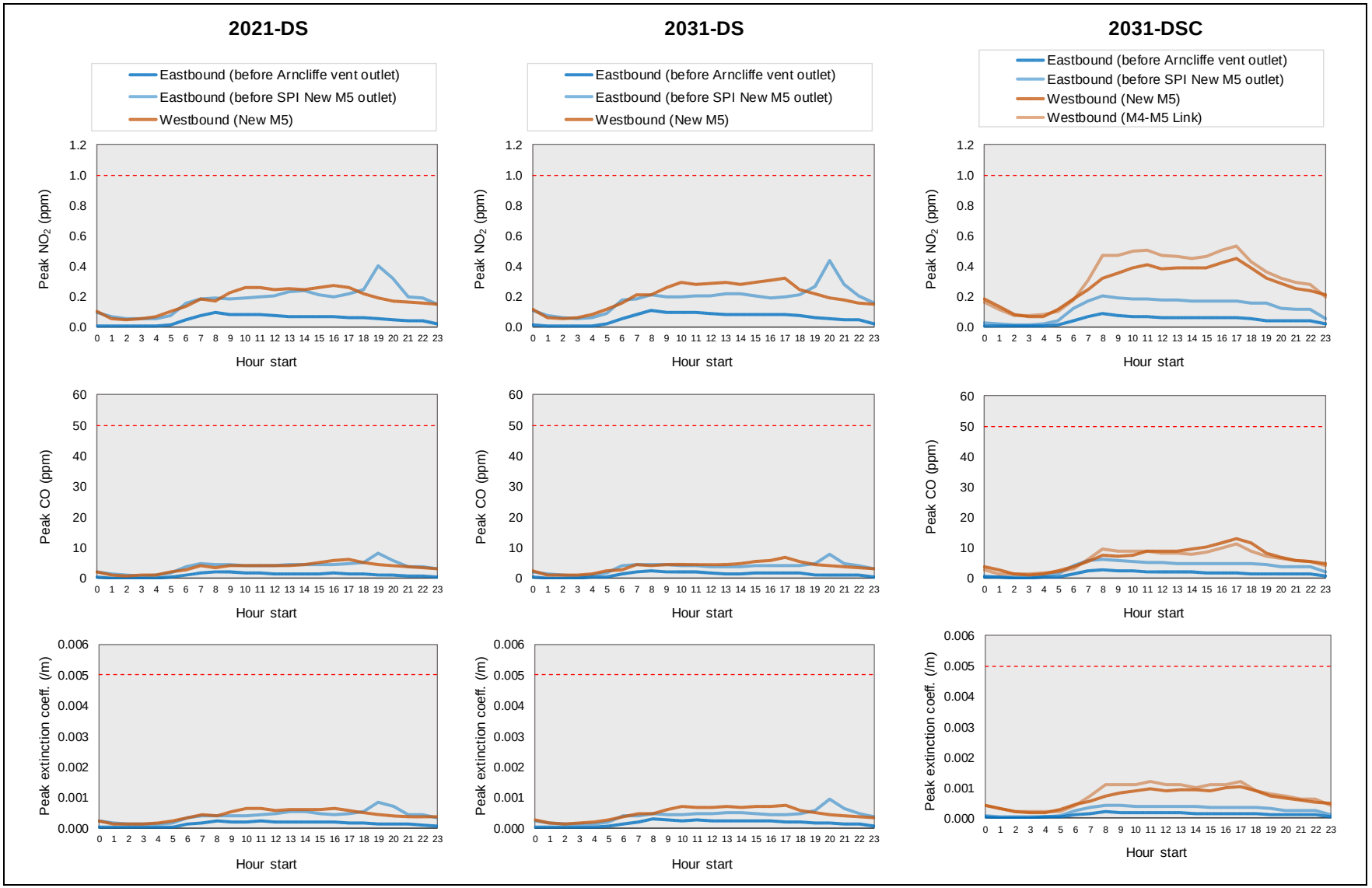


Figure 9-8 Peak in-tunnel NO_2, CO and extinction coefficient (dashed red lines show in-tunnel concentration limits)

9.4 Dispersion modelling

9.4.1 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).

9.4.2 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 a particle model and has the ability to predict concentrations under 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.
- The GRAMM/GRAL system has been validated in numerous studies, as documented by Öttl (2014). These studies have used data sets for:
  - Multiple countries (USA, Norway, Denmark, Germany, Sweden, Austria, Japan, Finland).
  - Multiple source types (power plant stacks, elevated tracers, ground-level tracers, urban roads, street canyons, parking lots, tunnel portals, etc.
  - Different terrain types.
  - Varying meteorological conditions (high/low wind speeds, stable/unstable atmospheric conditions, etc).

The performance of GRAMM/GRAL has been shown to be at least as good as that of other models.

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.

9.4.3 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 9-9. 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.

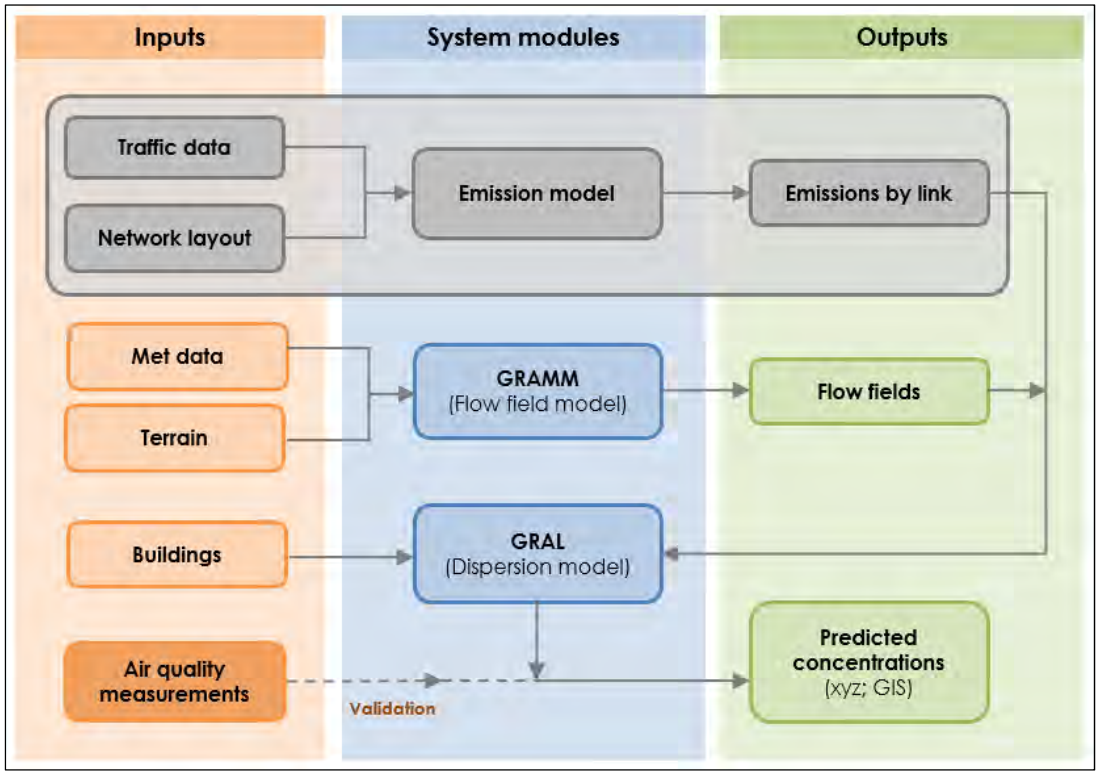


Figure 9-9 Overview of the GRAMM/GRAL modelling system

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 (Öttl 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.

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.

9.4.4 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 9.4.6) as well as the GRAL domain for the New M5 project. Table 9-10 presents the meteorological and topographical parameters that were selected in GRAMM.

Table 9-10 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 metres above ground level 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 9-10 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.

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 predicted 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).

9.4.5 Evaluation of meteorological modelling

As discussed in Section 9.4.4, 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 9-11) and those predicted using the Re-Order function (Figure 9-12) 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 $R^2 = 0.50$

The 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.

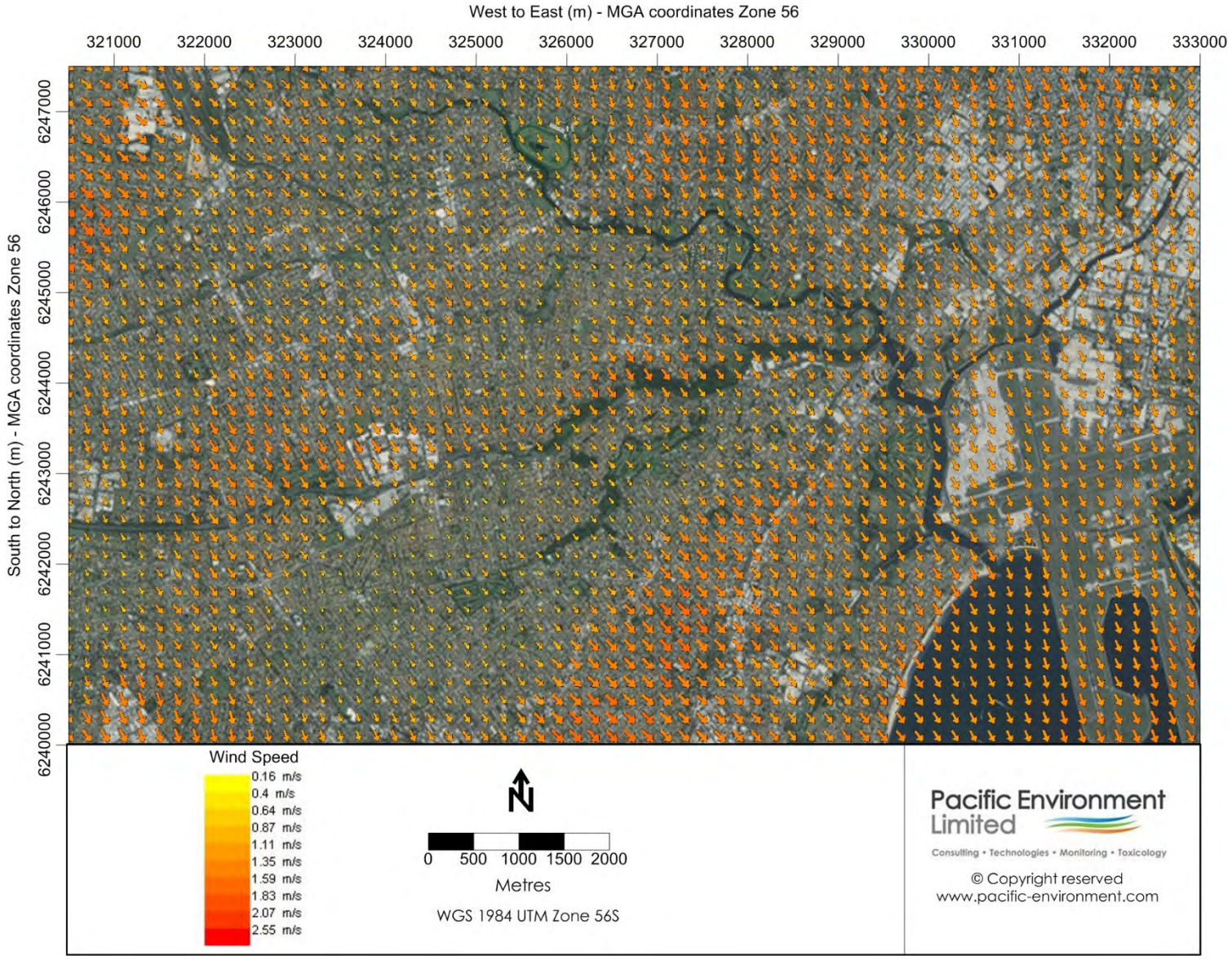


Figure 9-10 Example of a wind field across the New M5 domain

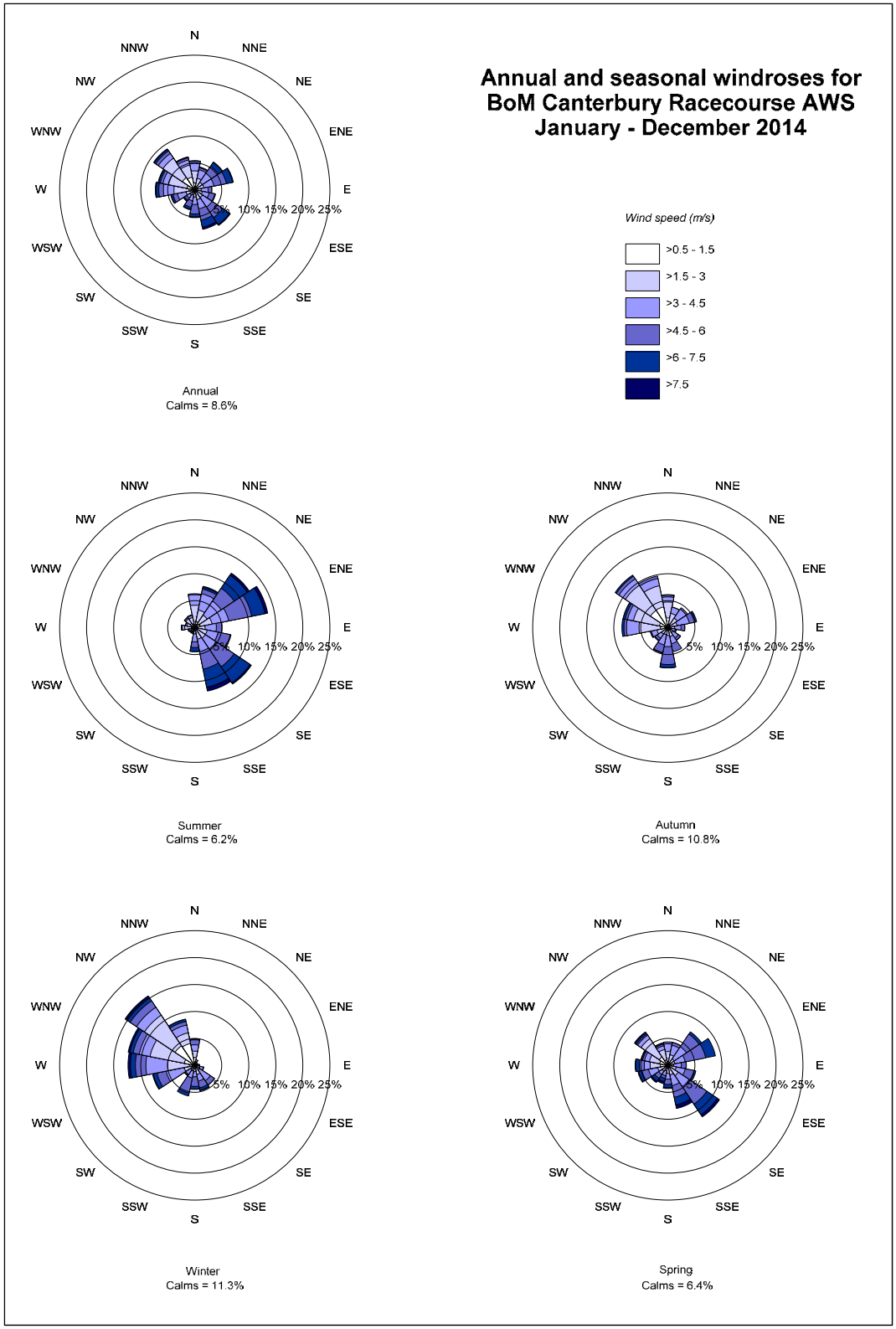


Figure 9-11 Annual and seasonal wind roses for Canterbury Racecourse AWS (2014)

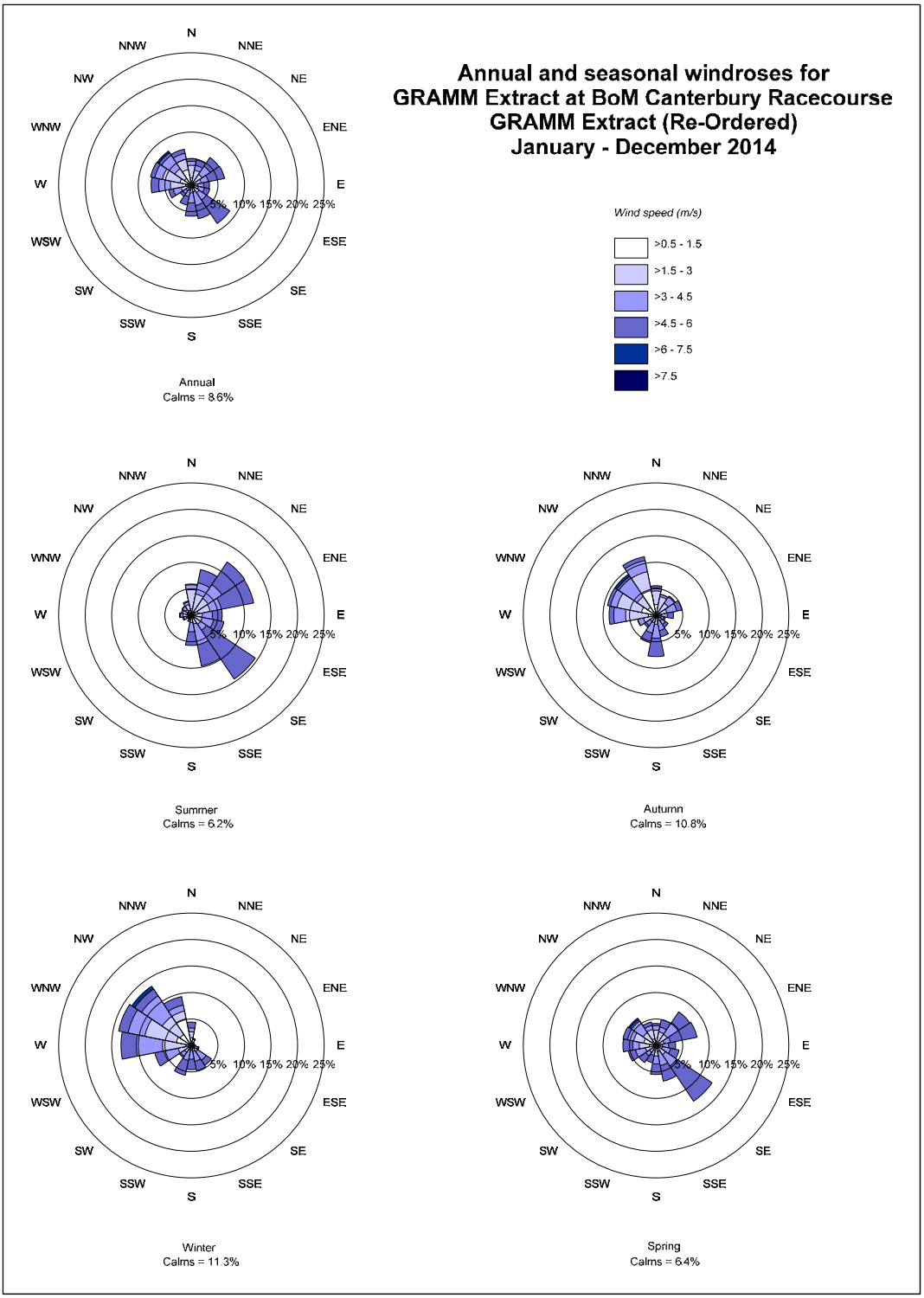


Figure 9-12 Annual and seasonal wind roses for Canterbury Racecourse AWS Re-ordered (2014)

Table 9-11 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 meteorology 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 9-11 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 GRAMM model shows a good agreement at the BoM Canterbury Racecourse site and lesser agreement at other locations, this is to be expected as the 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 New M5 study area. The regression analysis values for these other sites as shown above appear low compared to the Canterbury Racecourse site but are considered fair given that these data were not included in the GRAMM modelling.

Whilst meteorological 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.

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 dimensionless.
- **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 9-12. Overall, it was concluded that GRAMM simulates the meteorology with an acceptable degree of accuracy

Table 9-12 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	-	-

The WestConnex GRAL and New M5 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 New M5 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 10 metres) 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.

9.4.6 GRAL configuration – expected traffic scenarios

GRAL domains and main parameters

Table 9-13 presents the main parameters selected in GRAL for the model runs.

Table 9-13 GRAL configuration

Parameter	Value(s)
General	
Domain in UTM (New M5 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, 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 1-hour mean for each hour of the year in each case. In total, 35 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, 46,219 RWR receptors were included in the assessment (this included the 35 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 9-13 shows the locations of the various discrete receptors. A full list of community receptors is given in Table 9-14, and the numbers of RWR receptors are listed by category in Table 9-15.



Figure 9-13 Modelled discrete receptor locations

Table 9-14 Full list of community receptors

Receptor code	Receptor name	Receptor location	
		x	y
SR01	Active Kids Beverly Hills	321759.34	6242522.13
SR02	Active Kids Narwee	321834.82	6242572.24
SR03	Beverly Hills North Public School	322057.56	6242739.38
SR04	Beverly Hills Girls High School	322434.56	6241894.31
SR05	Barfa Bear Child Care Centre	322502.71	6242962.37
SR06	Regina Coeli Catholic Primary School	322534.93	6242106.78
SR07	Footsteps Early Learning Centre	322598.30	6242038.13
SR08	Footsteps Early Learning Centre OOSH School Care	322634.72	6242067.94
SR09	McCallums Hill Public School	322983.85	6243411.42
SR10	Hurstville City Council Family Day Care Scheme	323188.07	6242153.07
SR11	Kingsgrove North High School	324163.24	6243526.44
SR12	Kingsgrove Early Childhood Health Centre	324237.76	6242567.09
SR13	Kingsgrove World Of Learning	324302.13	6243159.06
SR14	Kingsgrove Day Hospital	324605.26	6242446.62
SR15	Kings Medical Clinic	324617.41	6242385.68
SR16	Kids Oasis Childcare Centre	324938.30	6242947.28
SR17	Clemton Park Public School	325159.24	6244031.99
SR18	The Salvation Army Booth College	326159.87	6242931.27
SR19	Alloa Nursing Home	327926.14	6242694.31
SR20	Athelstane Public School	327937.74	6243217.07
SR21	Kinderoos Childcare Centre	327972.63	6243279.07
SR22	Ladybugs Day Care	328350.84	6243727.16
SR23	Macedonian Community Child Care Centre	328728.78	6243409.25
SR24	Arncliffe Public School	328787.20	6242894.84
SR25	Tempe High School	329994.39	6245223.50
SR26	Tillman Park Child Care Centre	330313.10	6245488.42
SR27	St Pius' Catholic Primary School	331168.07	6246637.69
SR28	Camdenville Public School	331336.13	6246750.02
SR29	Camdenville Public School Preschool	331417.05	6246696.75
SR30	St Peters Public School	331427.41	6246008.99
SR31	Sydney Park Childcare Centre	332359.96	6246661.46
SR32	Sydney Park Childcare Centre	332434.93	6246719.45
SR33	Lady Gowrie Child Centre	332545.11	6247280.29
SR34	Active Kids Mascot	332608.90	6245071.23
SR35	Building Blocks Early Childhood Learning	332838.53	6245806.12

Table 9-15 Summary of RWR receptor types

Receptor type	Number	% of total
Child care / pre-school	25	0.05%
School	129	0.28%
Further education	9	0.02%
Aged care	14	0.03%
Residential	41,579	89.97%
Commercial	2,210	4.78%
Industrial	1,468	3.18%
Hotel	29	0.06%
Park / sport / recreation	136	0.29%
Public services	11	0.02%
Community	13	0.03%
Medical	101	0.22%
Religion	80	0.17%
Construction site	22	0.05%
Other	393	0.85%
Total	**46,219**	**100.00%**

Treatment of elevated receptors

The main emphasis in the assessment was on ground-level concentrations (as specified in the Approved Methods). However, at a number of locations in the GRAL New M5 domain there are multi-storey residential and commercial buildings. The potential impacts of the project at elevated points at these locations could have been different to the impacts at ground level, and therefore these were evaluated separately. In addition, it was considered important to understand how future building developments (e.g. apartment blocks) in the domain might be restricted from an air pollution perspective.

Information on building height was not available for all RWR receptors in the New M5 domain. The heights of those buildings for which this information was available are shown in Figure 9-14, and the distribution of building heights is shown in Figure 9-15.

The distribution in Figure 9-15 also includes a number of locations (around 300) that were not buildings and had a height of less than 1 metre.

Most of the buildings had a height of less than 10 metres. Only a small proportion of buildings had a height of more than 15 metres. However, there were some buildings in the general area of the Arncliffe ventilation outlet that were taller than 30 metres. Based on this assessment, two elevated receptor heights were selected to cover both existing buildings and future developments: 10 metres and 30 metres. For both heights a full modelling run across the GRAL WestConnex domain was conducted across the New M5 domain.

This part of the assessment did not cover all pollutants and averaging period. The focus was on annual average $PM_{2.5}$ concentrations in the 2031-DSC scenario. The GRAL model was used to predict $PM_{2.5}$ concentrations associated with surface roads and tunnel ventilation outlets.



Figure 9-14 Building heights at RWR receptor locations

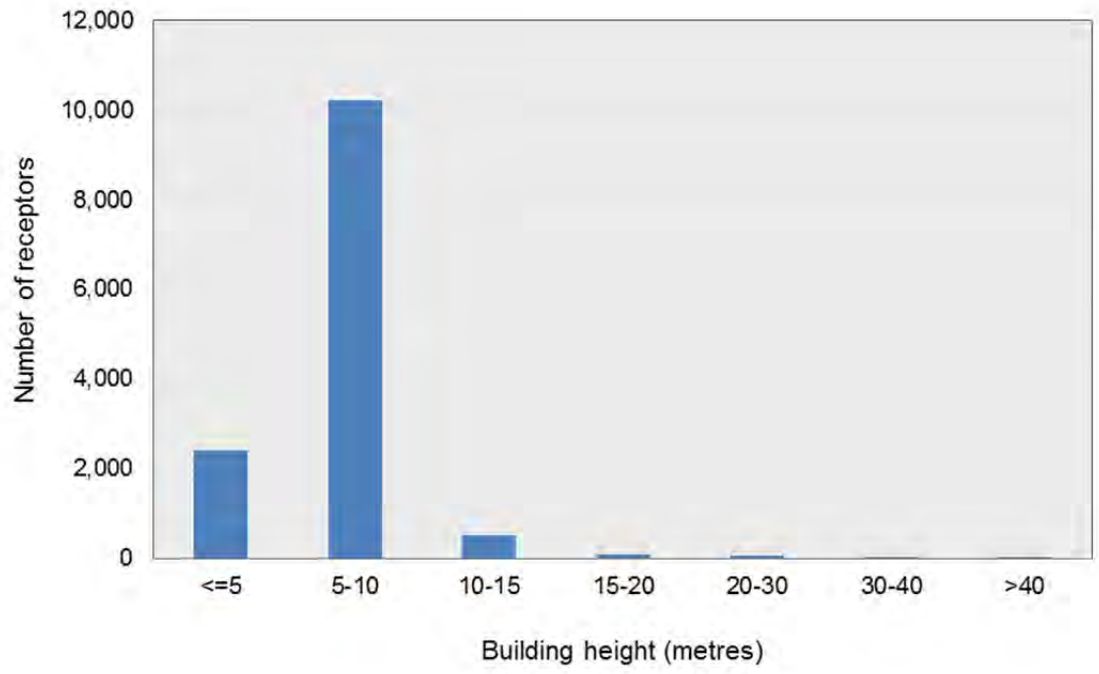


Figure 9-15 Frequency distribution of building heights at RWR receptor locations

The following cases were assessed:

- 2031-DM at a height of 10 metres (surface roads only)
- 2031-DM at a height of 30 metres (surface roads only)
- 2031-DSC at a height of 10 metres (surface roads and ventilation outlets)
- 2031-DSC at a height of 30 metres (surface roads and ventilation outlets)
- Change in annual $PM_{2.5}$ (2031-DSC minus 2031-DM) at a height of 10 metres
- Change in annual $PM_{2.5}$ (2031-DSC minus 2031-DM) at a height of 30 metres

Background concentrations were not taken into account, as these could not be quantified at elevated location. For the same reason, only the changes in the $PM_{2.5}$ concentration are presented in the report.

New M5 ventilation outlets

Locations and heights

The locations and heights of the New M5 (and M4-M5 Link) ventilation outlets included in the assessment are given in Table 9-16.

Emission rates

The project ventilation outlet emission rates are provided in Appendix I.

Table 9-16 Ventilation outlet locations and heights

Tunnel project	Ventilation facility	Traffic direction	Ventilation outlet	Outlet location (MGA)		Ground elevation (m)	Outlet height (m)
				X	Y	Z	
New M5	**A** (Kingsgrove)	WB	KIN-01	323916.00	6242795.00	23	30
	B (Arncliffe)	EB	ARN-01	329446.00	6243283.10	4.0	35
			ARN-02	329453.90	6243289.20	3.5	35
			ARN-03	329450.30	6243276.70	3.7	35
			ARN-04	329458.20	6243283.10	3.2	35
	C (St Peters, New M5)	EB	SPI-01	331340.00	6245650.00	5.3	20
			SPI-02	331346.00	6245655.00	5.2	20
			SPI-03	331334.00	6245656.00	5.1	20
			SPI-04	331340.30	6245661.90	5.4	20
New M5 and M4-M5 Link	**A** (Kingsgrove)	WB	KIN-01	323916.00	6242795.00	23.0	30
	B (Arncliffe)	EB	ARN-01	329446.00	6243283.10	4.0	35
			ARN-02	329453.90	6243289.20	3.5	35
			ARN-03	329450.30	6243276.70	3.7	35
			ARN-04	329458.20	6243283.10	3.2	35
			ARN-05	329454.20	6243300.00	3.4	35
			ARN-06	329450.30	6243305.10	3.7	35
			ARN-07	329458.00	6243311.30	3.1	35
			ARN-08	329461.80	6243306.00	2.8	35
	C (St Peters, New M5)	EB	SPI-01	331340.00	6245650.00	5.3	20
			SPI-02	331346.00	6245655.00	5.2	20
			SPI-03	331334.00	6245656.00	5.1	20
			SPI-04	331340.30	6245661.90	5.4	20
	D (Southern Extension)	WB	SC-01	329025.00	6240855.00	5.0	20
			SC-02	329031.00	6240860.00	5.0	20
			SC-03	329037.00	6240865.00	5.0	20
			SC-04	329026.00	6240865.00	5.0	20
	E (St Peters, M4-M5 Link)	WB	SPI-05	331894.00	6245838.00	11.0	20
			SPI-06	331900.00	6245843.00	11.0	20
			SPI-07	331889.00	6245843.00	11.0	20
			SPI-08	331895.00	6245848.00	11.0	20

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 of 80 kilometres per hour. An example of the diurnal air flow profile is shown as the blue line in Figure 9-16. It was necessary to simplify the ventilation profile for use in GRAL. 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 or close to the envelope of the profile. The simplified profile is shown as the blue columns in the Figure. The air flows that were applied in GRAL are given in Table 9-17.

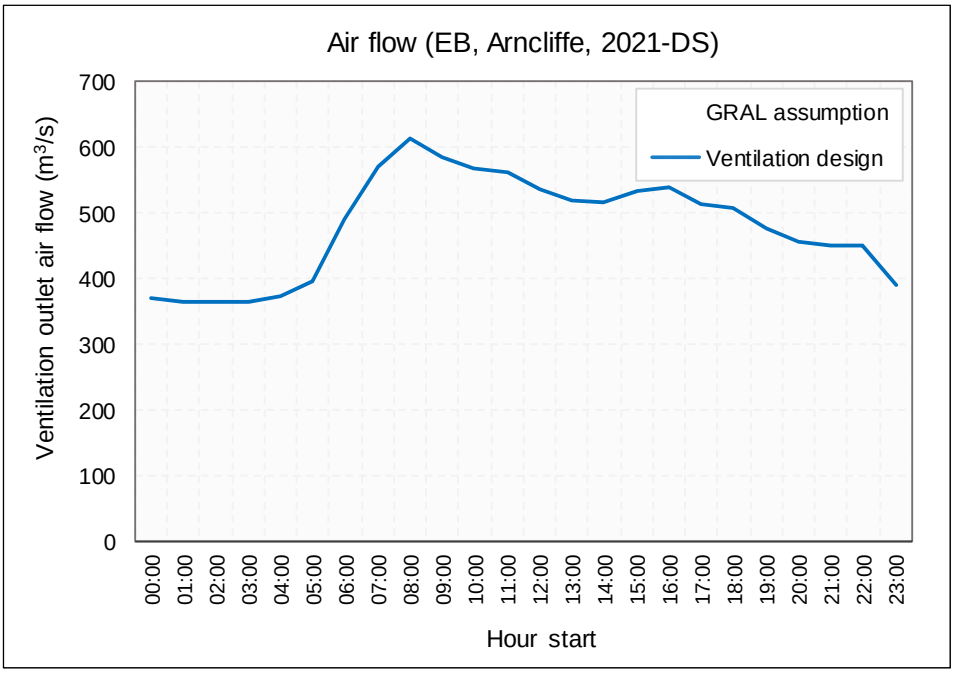


Figure 9-16 Example of ventilation air flow profile used in GRAL

Table 9-17 Ventilation air flows

Tunnel project	Ventilation facility	2021				2031			
		Time period(s) (hour start)	Number of outlets	Total air flow (m^3/s)	Air flow per outlet (m^3/s)	Time period(s) (hour start)	Number of outlets	Total air flow (m^3/s)	Air flow per outlet (m^3/s)
New M5	**A** (Kingsgrove)	Hour 00 Hour 06 to 09 Hour 20 to 23	1	380	380	Hour 00 Hour 06 Hour 21 to 23	1	380	380
		Hour 01 to 05	1	250	250	Hour 01 to 05	1	250	250
		Hour 10 to 19	1	500	500	Hour 07 to 20	1	500	500
	B (Arncliffe)	Hour 00 to 05 Hour 19 to 23	4	380	95	Hour 00 to 05 Hour 22 to 23	4	370	93
		Hour 07 to 09	4	600	150	Hour 06 Hour 12 to 13 Hour 18 to 21	4	480	120
		Hour 06 Hour 10 to 18	4	500	125	Hour 07 to 11 Hour 14 to 17	4	570	143
	C (St Peters, New M5)	Hour 00 to 05 Hour 19 Hour 23	2	130	65	Hour 00 to 06 Hour 19 to 23	2	130	65
		Hour 06 Hour 12 to 18 Hour 20 to 22	2	200	100	Hour 07 Hour 11 to 18	3	280	93
		Hour 07 to 11	4	350	88	Hour 08 to 10	4	390	98
New M5 and M4-M5 Link	**A** (Kingsgrove)	-	-	-	-	Hour 00 to 06	1	300	300
		-	-	-	-	Hour 07 to 23	1	500	500
	B (Arncliffe ventilation facility)	-	-	-	-	Hour 00 to 05	8	630	79
		-	-	-	-	Hour 06 Hour 18 to 23	8	850	106
		-	-	-	-	Hour 07 to 17	8	1000	125
	C (St Peters, New M5)	-	-	-	-	Hour 00 to 06 Hour 18 to 23	4	270	68
		-	-	-	-	Hour 07 to 10	4	450	113
		-	-	-	-	Hour 18 to 23	4	360	90
	D (Southern Extension)	-	-	-	-	Hour 00 to 06	4	280	70
		-	-	-	-	Hour 07 to 23	4	500	125
	E (St Peters, M4-M5 Link)	-	-	-	-	Hour 00 to 06	4	280	70
		-	-	-	-	Hour 07 to 23	4	400	100

Effective outlet diameter and exit velocity

Each ventilation facility would feature multiple variable-speed fans, with the number in use at any given time being determined by the ventilation requirement. The fan configurations of the different ventilation outlets were slightly different (see section 2.4.1).

The Kingsgrove ventilation facility would have an effective outlet diameter and exit velocity that would vary according to the number of fans in use. All other ventilation facilities would have a fixed diameter, and hence a varying exit velocity depending on the air flow. 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 9-18 Effective outlet diameters and exit velocities

Ventilation facility	Air flow per outlet (m^3/s)	Number of fans	CSA per outlet (m^2)	Effective diameter per outlet (m)	Exit velocity (m/s)
New M5, 2021					
A (Kingsgrove)	380	2	60.5	8.8	6.3
	250	2	60.5	8.8	4.1
	500	3	90.8	10.7	5.5
B (Arncliffe)	95	-	15.2	4.4	6.3
	150	-	15.2	4.4	9.9
	125	-	15.2	4.4	8.2
C (St Peters, New M5)	65	-	17.7	4.8	3.7
	100	-	17.7	4.8	5.6
	88	-	17.7	4.8	4.9
New M5, 2031					
A (Kingsgrove)	380	2	60.5	8.8	6.3
	250	2	60.5	8.8	4.1
	500	3	90.8	10.7	5.5
B (Arncliffe)	93	-	15.2	4.4	6.1
	120	-	15.2	4.4	7.9
	143	-	15.2	4.4	9.4
C (St Peters, New M5)	65	-	17.7	4.8	3.7
	93	-	17.7	4.8	5.3
	98	-	17.7	4.8	5.5
New M5 and M4-M5 Link, 2031					
A (Kingsgrove)	300	2	60.5	8.8	5.0
	500	3	90.8	10.7	5.5
B (Arncliffe)	79	-	15.2	4.4	5.2
	106	-	15.2	4.4	7.0
	125	-	15.2	4.4	8.2
C (St Peters, New M5)	68	-	17.7	4.8	3.8
	113	-	17.7	4.8	6.4
	90	-	17.7	4.8	5.1
D (Southern Extension)	70	-	17.7	4.8	4.0
	125	-	17.7	4.8	7.1
E (St Peters, M4-M5 Link)	70	-	17.7	4.8	4.0
	100	-	17.7	4.8	5.6

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 exhaust temperature for the whole year was used. This was an average of the summer and winter data (Figure 9-17).

For sensitivity testing (applicable to all outlets), upper and lower bound temperatures that were 10^{o}C higher and lower than an average of 25^{o}C were applied.

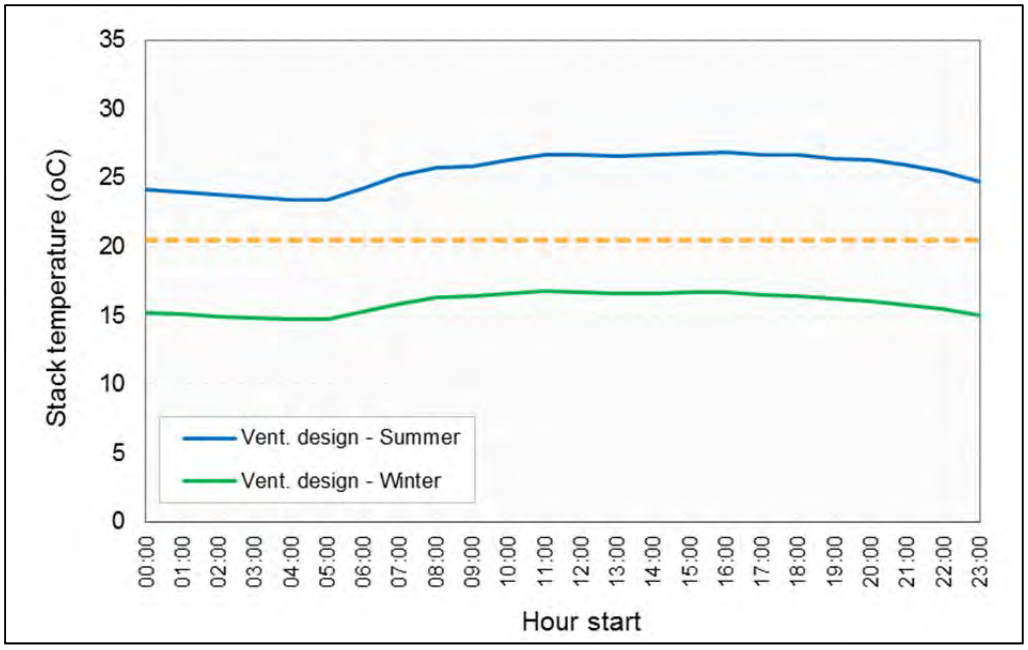


Figure 9-17 Example of outlet temperature used in GRAL (Arncliffe ventilation facility, 2021-DS)

Existing M5 East ventilation outlet

The ventilation outlet for the existing M5 East tunnel was also included as it was within the New M5 GRAL domain.

Location and height

The location and height of the existing M5 East ventilation outlet are given in Table 9-19.

Table 9-19 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 9.2.3.

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) (Table 9-20).

Table 9-20 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^{o}C, reflecting the annual average, was therefore used.

9.4.7 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 9-21. These were converted to mass emission rates (in kg/h) based on assumed ventilation settings. An air flow of 400 m^3/s was assumed for each ventilation facility (subdivided according to the number of outlets where appropriate), with the corresponding number of fans in operation, effective outlet diameters and exit velocities. Work undertaken for the WestConnex M4 East air quality assessment showed that the predicted concentrations were not sensitive to the air flow assumption (WDA, 2015). The assumptions for the ventilation outlets are summarised in Table 9-22.

Table 9-21 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 9-22 Ventilation outlet assumptions for regulatory worst case scenarios

Ventilation facility	Total air flow (m^3/s)	Air flow per outlet (m^3/s)	CSA per outlet (m^2)	Effective outlet diameter (m)	Exit velocity (m/s)	Temp. (^0C)	Emission rate (kg/hour)				
							PM_{10}	$PM_{2.5}$	NO_X	CO	VOC/ THC
A (Kingsgrove)	400	400	60.5[(a)]	8.8	6.6	25	1.584	1.584	28.80	57.6	5.76
B (Arncliffe)	400	100	15.2	4.4	6.6	25	0.396	0.396	0.720	14.4	1.44
C (St Peters, New M5)	400	100	17.7	4.8	5.7	25					
D (Southern extension)	400	100	17.7	4.8	5.7	25					
E (St Peters, M4-M5 Link)	400	100	17.7	4.8	5.7	25					

(a) Assuming two fans in operation.

9.4.8 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 1-hour mean)

For the community receptors, a contemporaneous approach was used, with the 1-hour mean CO concentration from GRAL being added to the corresponding 1-hour background CO concentration for every hour of the year. The maximum total 1-hour concentration was then determined.

For RWR receptors the maximum 1-hour CO concentration from GRAL was added to maximum 1-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 8-hour concentration for the year was then determined.

For RWR receptors the maximum 1-hour CO concentration from GRAL was added to maximum 1-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 9-18).

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

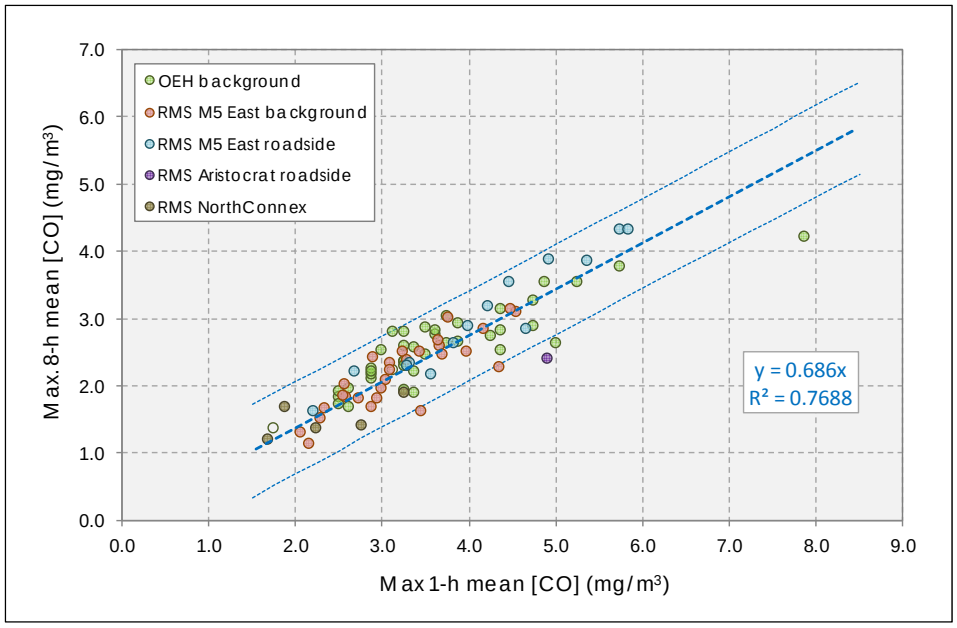


Figure 9-18 **Relationship between maximum rolling 8-hour mean CO and maximum 1-hour mean CO (dotted lines show 95% prediction intervals)**

Nitrogen dioxide (annual mean)

The estimation of NO_2 concentrations near roads is not straightforward. In order to ensure that an appropriate and pragmatic method was selected for the New M5 assessment, a review of the literature and data was undertaken, and analysis of local monitoring data was conducted. Various air quality guidance documents recommend the use of local monitoring data to estimate NO_2 concentrations, where such data are available. Empirical methods for converting NO_X to NO_2 were developed specifically for the New M5 assessment. These methods are documented in Appendix G.

For both the community and RWR receptors, the annual mean NO_X concentration from GRAL was added to a mapped background NO_X concentration. The total annual mean NO_X concentration was then converted to a total annual mean NO_2 concentration using an empirical function.

For both types of receptor the annual mean NO_2 concentration during the modelled year was compared with the corresponding air quality criterion.

Nitrogen dioxide (maximum 1-hour mean)

For community receptors a contemporaneous approach was used. The 1-hour mean NO_X concentration from GRAL was added to the corresponding 1-hour mean background NO_X concentration for every hour of the year. Each total 1-hour mean NO_X concentration was then converted to a maximum 1-hour mean NO_2 concentration using an empirical function. The maximum 1-hour NO_2 concentration for the year was then determined.

For RWR receptors the maximum 1-hour mean NO_X concentration for the year was added to the 98th percentile 1-hour mean background NO_X concentration from the synthetic profile (236 µg/m^3). The total NO_X concentration was then converted to a maximum 1-hour NO_2 concentration. The implications of this simplified approach were investigated by comparing the 'statistical' method using the 98th percentile background NO_X with the contemporaneous method for the 31 community receptors. The results of this comparison are presented in Figure 9-19. There was a reasonably good agreement between the two approaches, with the statistical method resulting in (on average) slightly lower maximum NO_2 concentrations than the contemporaneous method.

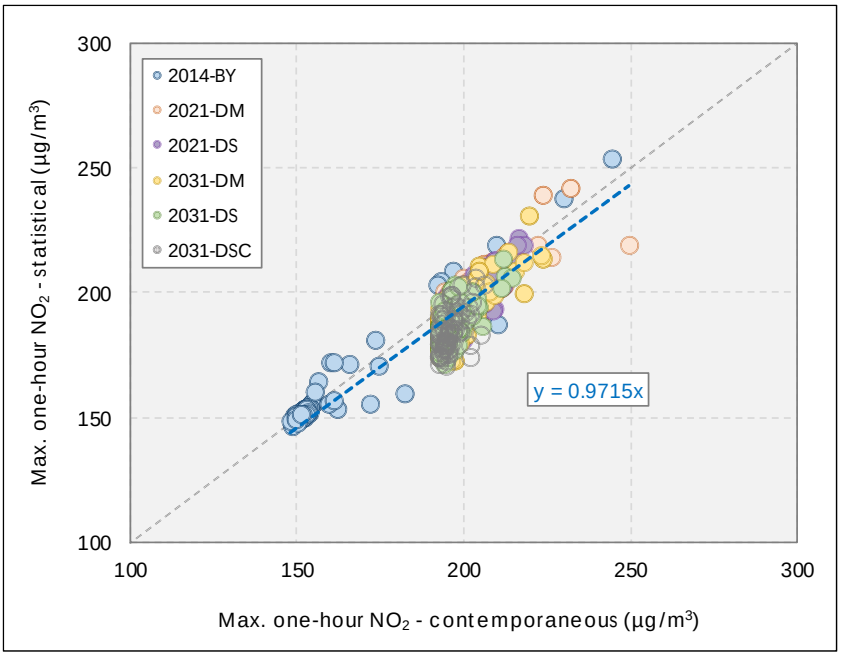


Figure 9-19 Comparison between statistical and contemporaneous approaches for calculating maximum 1-hour NO_2 at community receptors (note that axes do not start at zero)

For both types of receptor the maximum 1-hour NO_2 concentration during the modelled year was compared with the corresponding air quality criterion.

PM_{10} (annual mean)

For both the community and RWR receptors, the annual mean PM_{10} concentration from GRAL was added to a mapped background PM_{10} concentration to give the total annual mean concentration.

For both types of receptor the annual mean PM_{10} concentration during the modelled year was compared with the corresponding air quality criterion.

PM_{10} (maximum 24-hour mean)

For community receptors a contemporaneous approach was used. The 24-hour mean PM_{10} concentration from GRAL was added to the corresponding 24-hour mean background PM_{10} concentration for every day of the year. The maximum 24-hour PM_{10} concentration for the year was then determined.

For RWR receptors the maximum 24-hour mean PM_{10} concentration for the year was added to the 98th percentile 24-hour mean background PM_{10} concentration from the synthetic profile (39.3 µg/m^3). Again, the implications of this simplified approach were investigated by comparing the statistical method using the 98th percentile background PM_{10} with the contemporaneous method for the 31 community receptors (Figure 9-20). Whilst the level of agreement was lower than that for NO_2, the statistical method gave maximum 24-hour PM_{10} concentrations that were, on average close to those determined using the contemporaneous method, and within around ±5 µg/m^3 overall. The statistical method also resulted in proportionally more values above the 24-hour criterion (50 µg/m^3) than the contemporaneous method, which indicates that it is probably overestimating the number of exceedances for the RWR receptors. However, the results of the statistical method are clearly very dependent on the assumption concerning the background concentration, and this highlights the difficulties with the assessment of particulate matter impacts for road transport projects.

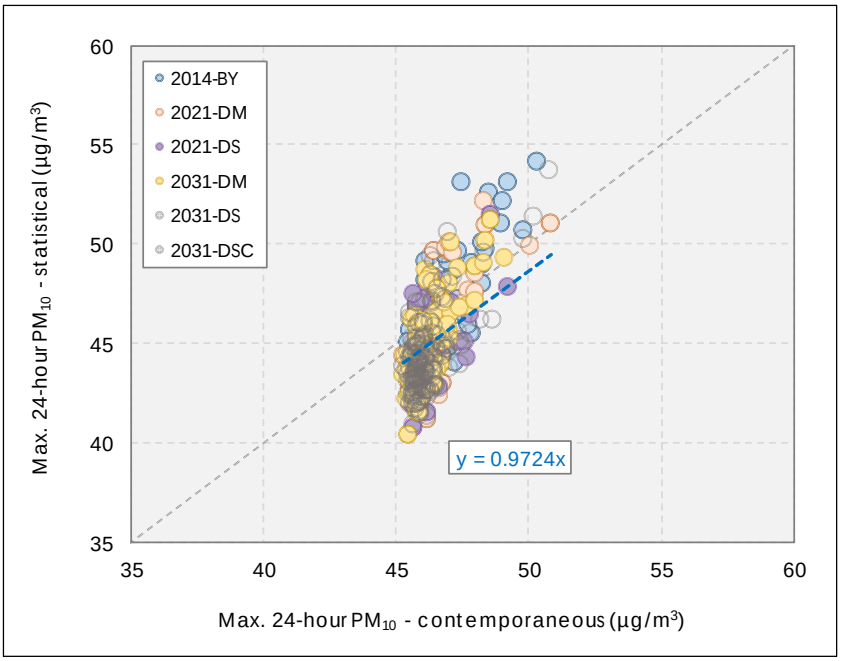


Figure 9-20 Comparison between statistical and contemporaneous approaches for calculating maximum 24-hour PM_{10} at community receptors (note that axes do not start at zero)

For both types of receptor the maximum 24-hour PM_{10} concentration during the modelled year was compared with the corresponding air quality criterion.

$PM_{2.5}$ (annual mean)

For both the community and RWR receptors, the annual mean $PM_{2.5}$ concentration from GRAL was added to a fixed background $PM_{2.5}$ concentration (8 µg/m^3) to give the total annual mean concentration.

For both types of receptor the annual mean $PM_{2.5}$ concentration during the modelled year was compared with the corresponding air quality criterion.

$PM_{2.5}$ (maximum 24-hour mean)

The approaches used for $PM_{2.5}$ were essentially the same as those used for PM_{10}. For the statistical method the 98th percentile 24-hour mean background $PM_{2.5}$ concentration was 18.9 µg/m^3. The comparison between the methods is shown in Figure 9-21. As with PM_{10}, the results of the statistical method are clearly very dependent on the assumption concerning the background concentration.

For both types of receptor the maximum 24-hour $PM_{2.5}$ concentration during the modelled year was compared with the corresponding air quality criterion.

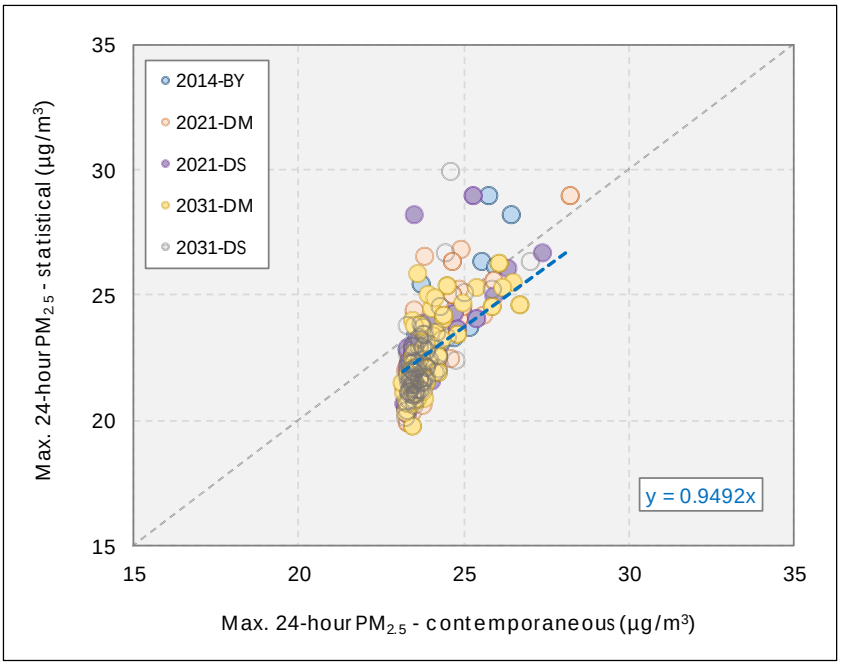


Figure 9-21 **Comparison between statistical and contemporaneous approaches for calculating maximum 24-hour $PM_{2.5}$ at community receptors (note that axes do not start at zero)**

Air toxics

For both the community and RWR receptors, the THC concentrations from GRAL were converted to concentrations for specific air toxics using vehicle exhaust emission speciation profiles. The speciation profiles for the compounds of interest were taken from the GMR emission inventory methodology (NSW EPA, 2012b), and are given in Table 9-23. EPA provides profiles for petrol light-duty vehicles (cars and LCVs) running on petrol with no ethanol (E0) and petrol with 10 per cent ethanol (E10), as well as diesel vehicles (the profiles are the same for light-duty and heavy-duty diesel vehicles).

Table 9-23 **THC speciation profiles by fuel type (NSW EPA, 2012b; Environment Australia, 2003)**

Pollutant/metric	% of THC (where THC=VOC)[a]			
	Petrol light duty		Diesel light duty	Diesel heavy duty
	Petrol (E0)	Petrol (E10)		
Benzene	4.95	4.54	1.07	1.07
PAHs (as b(a)p)	0.03	0.03	0.08	0.08
Formaldehyde	1.46	1.82	9.85	9.85
1,3-butadiene	1.27	1.20	0.40	0.40

(a) NSW EPA assume that THC and VOC are equivalent

(b) Based on a combination of PAH fraction of THC from NSW EPA (2012b) and the b(a)p fraction of PAH from Environment Australia (2003)

The EPA speciation profiles were combined with additional information to determine profiles that were applicable to the GRAL THC predictions. Firstly, for petrol vehicles it was assumed that 60 per cent of the fuel used would be E10; this percentage represents the target for petrol sold in New South Wales under the Biofuels Act 2007. Secondly, the percentages in Table 9-23 were weighted according to THC emissions from the different vehicle categories. In practice, THC emissions for each vehicle type vary according to the year, the road type (fleet mix) and the traffic speed. Given the uncertainties associated with the speciation profiles, for this assessment a single combination of road type and speed was used to represent a 'central estimate' of THC emissions (commercial highway road type,

with a speed of 50 kilometres per hour), although emissions for three years were estimated (2014, 2021 and 2031). The weighted profiles are given in Table 9-24.

Table 9-24 Weighted THC speciation profiles for 2014, 2021 and 2031

Pollutant/metric	Weighted % of THC for traffic		
	2014	2021	2031
Benzene	4.4	4.3	4.0
PAHs (as b(a)p)	0.03	0.03	0.04
Formaldehyde	2.5	2.5	3.3
1,3-butadiene	1.1	1.1	1.1

Where a refined dispersion modelling technique has been used (as in this case), the criteria in the Approved Methods for individual air toxics relate to incremental impacts (i.e. project only) for an averaging period of one hour and as the 99.9th percentile of model predictions. However, the approach and assessment criteria in the Approved Methods cannot be readily applied to complex road projects in urban areas, as they are based on the assumption that a project represents a new source, and not a modification to an existing source. In the case of the current project the 'impacts' are dependent in part on the emissions from the tunnel ventilation outlets but, more importantly, on how the traffic on the existing road network is affected, and at many receptors the concentrations of air toxics actually decreased as a result of the project. A modified version of the usual approach was therefore used, whereby only the change in the maximum 1-hour concentration of each compound as a result of the project was compared with the corresponding impact assessment criterion in the Approved Methods.

Summary

The approaches used for determining the total concentration of each pollutant for the community and RWR receptors are summarised in Table 9-25.

Table 9-25 Methods for combining modelled (GRAL) contribution and background contribution

Pollutant/ metric	Averaging period	Method	
		Community receptors	RWR receptors
CO	1 hour	1-hour GRAL CO added to contemporaneous 1-hour background CO	Maximum 1-hour GRAL CO added to maximum 1-hour background CO
	8 hours (rolling)	Rolling 8-hour GRAL CO added to contemporaneous rolling 8-hour background CO	Maximum 1-hour GRAL CO added to maximum 1-hour background CO, and converted to maximum rolling 8-hour CO
NO_2	1 hour	1-hour GRAL NO_X added to contemporaneous 1-hour background NO_X, and 1-hour total NO_X converted to maximum total 1-hour NO_2	Maximum 1-hour GRAL NO_X added to 98th percentile 1-hour background NO_X from synthetic profile, then converted to maximum 1-hour NO_2
	1 year	GRAL NO_X added to mapped background NO_X, then converted to NO_2	GRAL NO_X added to mapped background NO_X, then converted to NO_2
PM_{10}	24 hours	24-hour GRAL PM_{10} added to contemporaneous 24-hour background PM_{10}	Maximum 24-hour GRAL PM_{10} added to 98th percentile 24-hour background PM_{10} from synthetic profile
	1 year	GRAL PM_{10} added to mapped background PM_{10}	GRAL PM_{10} added to mapped background PM_{10}
$PM_{2.5}$	24 hours	24-hour GRAL $PM_{2.5}$ added to contemporaneous 24-hour background $PM_{2.5}$	Maximum 24-hour GRAL $PM_{2.5}$ added to 98th percentile 24-hour background $PM_{2.5}$ from synthetic profile
	1 year	GRAL $PM_{2.5}$ added to fixed background $PM_{2.5}$	GRAL $PM_{2.5}$ added to fixed background $PM_{2.5}$ of 8 µg/m^3

9.4.9 Model evaluation

The main approach for evaluating the performance of the GRAL dispersion model for use in the New M5 assessment involved a comparison between predicted and measured concentrations for the full 2014 base year. The method and results of the evaluation are given in Appendix J.

GRAL was configured to provide concentration predictions for CO, NO_X, NO_2 and PM_{10} at each of nine OEH and Roads and Maritime air quality monitoring sites (seven background and two roadside) in the GRAL WestConnex domain. $PM_{2.5}$ was not included as no independent testing of the model performance for $PM_{2.5}$ was possible. The GRAL predictions were for the combined surface road network and the existing M5 East tunnel ventilation outlet. For each monitoring site the GRAL predictions were extracted an hourly time series of concentrations for 2014. These were combined with an estimated background contribution for each monitoring site (as defined in Appendix F). The predicted and measured concentrations were compared using three concentration statistics: annual mean, maximum short-term mean (one hour or 24-hour, depending on the pollutant) and 98th percentile.

The results can be summarised as follows:

- Broadly speaking, there was a good level of agreement between the GRAL predictions and the measurements at both background and roadside sites. An example is shown for annual mean NO_2 in Figure 9-21.
- In almost all cases the model overestimated the concentration. The results suggest that the estimated concentrations ought to be conservative for most of the modelling domain.
- For annual mean and maximum 1-hour NO_2 the model with the empirical NO_X-to-NO_2 conversion methods gave more realistic predictions than the model with ozone limiting method.
- The empirical NO_X-to-NO_2 method for determining the maximum 1-hour concentration is not well suited to the estimation of other NO_2 statistics such as means and percentiles.
- The temporal variation in concentrations at the roadside sites was, on average, well reproduced

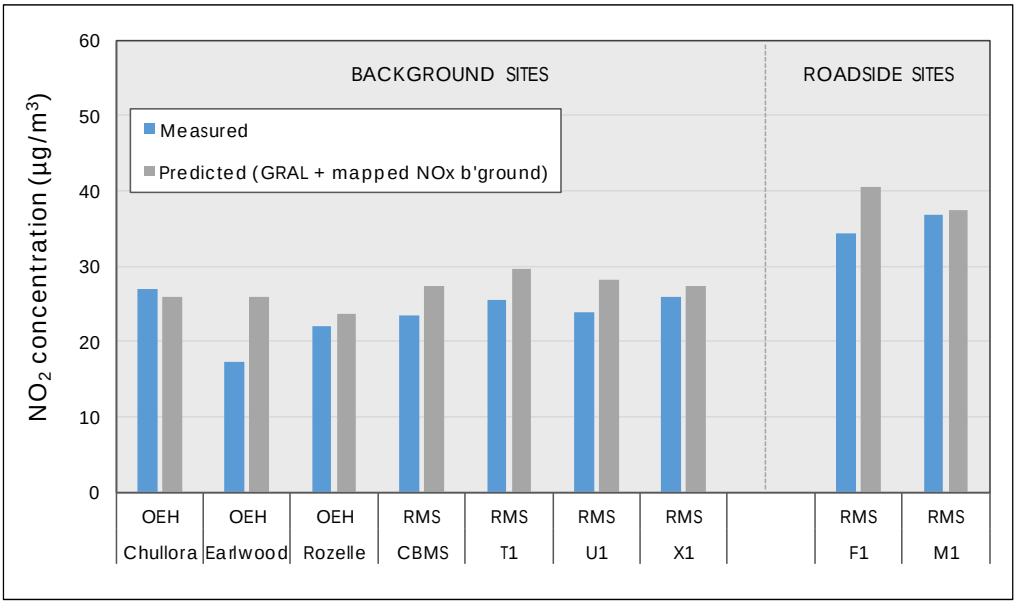


Figure 9-22 Comparison between measured and predicted annual mean NO_2 concentrations

The performance of GRAL was not investigated for the project-specific air quality monitoring stations as data were only available for two months of 2015. However, the air quality assessment for the M4 East project showed that there was generally a good agreement with the monitoring data for that

project. Overall, the results supported the application of the GRAL model in the assessment, along with the empirical conversion methods for NO_2, noting that the results tend to be quite conservative.

9.5 Results for expected traffic scenarios (ground level concentrations)

The ground-level concentration results for the expected traffic scenarios are presented in the following sections of the report.

Each pollutant and metric is treated in turn, and in each case the following has been determined:

- The total ground-level concentration for comparison against NSW impact assessment criteria and international air quality standards.
- The contributions of the different sources (background, surface roads and ventilation outlets) to the ground-level concentration.
- The change in the total ground-level concentration. This was calculated as the difference between the 2021-DS and 2021-DM scenario, and between the 2031-DS and 2031-DM scenario.

The results have been presented as the following, with the emphasis on the 2021-DS scenario:

- Pollutant concentrations at discrete receptors:
    - In bar charts for absolute concentration and changes in concentration for the 35 community receptors.
    - As ranked bar charts for absolute concentration and changes in concentration at the 46,219 RWR receptors.
- Pollutant concentrations across the GRAL New M5 modelling domain (as contour plots). These have only been provided for the most important pollutants: NO_2, PM_{10} and $PM_{2.5}$.
- Pollutant concentrations (and changes in concentration) for the project tunnel ventilation outlets only (as contour plots). These are provided for NO_X, PM_{10} and $PM_{2.5}$.

All results, including tabulated concentrations and contour plots and the results for the 2031-DS and 2031-DSC scenarios, are provided in Appendix K.

9.5.1 Carbon monoxide (maximum 1-hour mean)

Results for community receptors

The maximum 1-hour mean CO concentrations at the 35 community receptors with the project in 2021 and 2031 are shown in Figure 9-23. At all these receptor locations the CO concentration was well below the NSW impact assessment criterion of 30 mg/m^3. The concentrations were also well below the lowest international air quality standard identified in the literature (California, 22 mg/m^3).

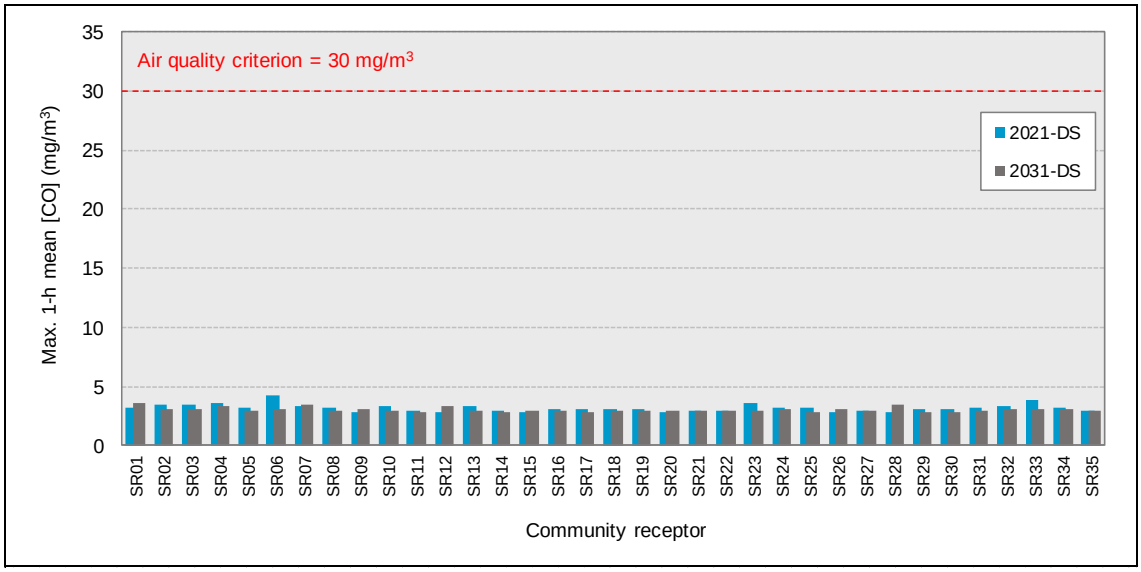


Figure 9-23 Maximum 1-hour mean CO at community receptors (2021-DS and 2031-DS)

Figure 9-24 shows the contributions of the background, surface roads and ventilation outlets to the maximum 1-hour mean CO concentrations in the 2021-DS scenario. In this Figure the hour of the year is not the same for all receptors, hence why the background concentration varies.

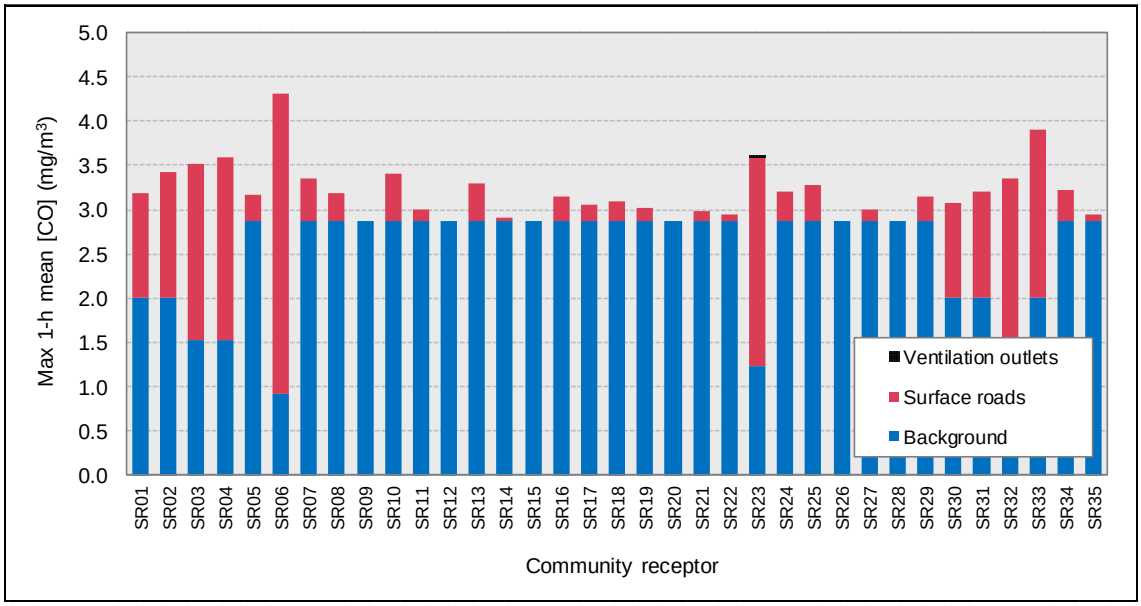


Figure 9-24 Source contributions to maximum 1-hour mean CO at community receptors (2021-DS)

At most of the 31 receptor the maximum concentration was dominated by the background, but at some locations there was a notable surface road contribution (up to 79 per cent of the total). The contribution of tunnel ventilation outlets to the maximum CO concentration was zero for all but one of the receptors (i.e. in most cases the concentration due to outlets was zero during the hour when the maximum total concentration occurred). For each receptor, larger 1-hour contributions from roads and tunnel ventilation outlets may well have occurred during other hours of the year, but would have been superimposed on a lower background.

Figure 9-25 shows the changes in concentration in the Do Something scenarios relative to the Do Minimum scenarios for the community receptors. There was a mixture of increases and decreases in the maximum CO concentration at the receptors (with a change of up to around 0.8 mg/m^3). These changes were small relative to the impact assessment criterion.

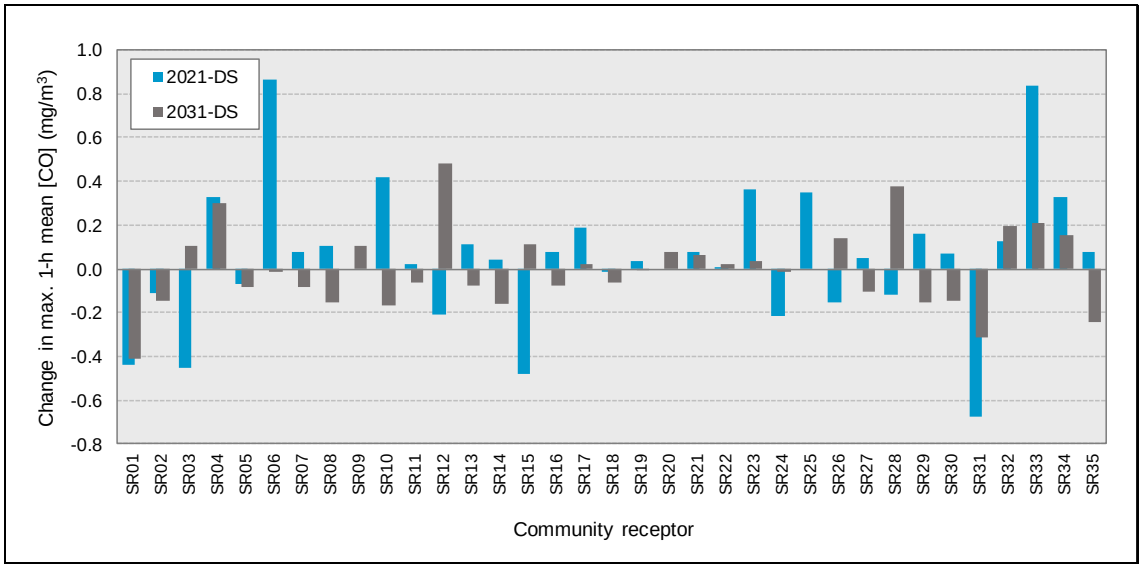


Figure 9-25 Change in maximum 1-hour mean CO at community receptors (2021-DS and 2031-DS)

Results for RWR receptors

The ranked 1-hour CO concentrations at the 46,219 RWR receptors in the 2021-DS scenario are shown in Figure 9-26. The 1-hour CO criterion for NSW was not exceeded at any of the RWR receptors in any scenario. In 2021 and 2031 with the project, the highest 1-hour concentrations were predicted to be 8.7 mg/m^3 and 8.5 mg/m^3 respectively. The largest contribution from ventilation outlets at any receptor was 0.1 mg/m^3.

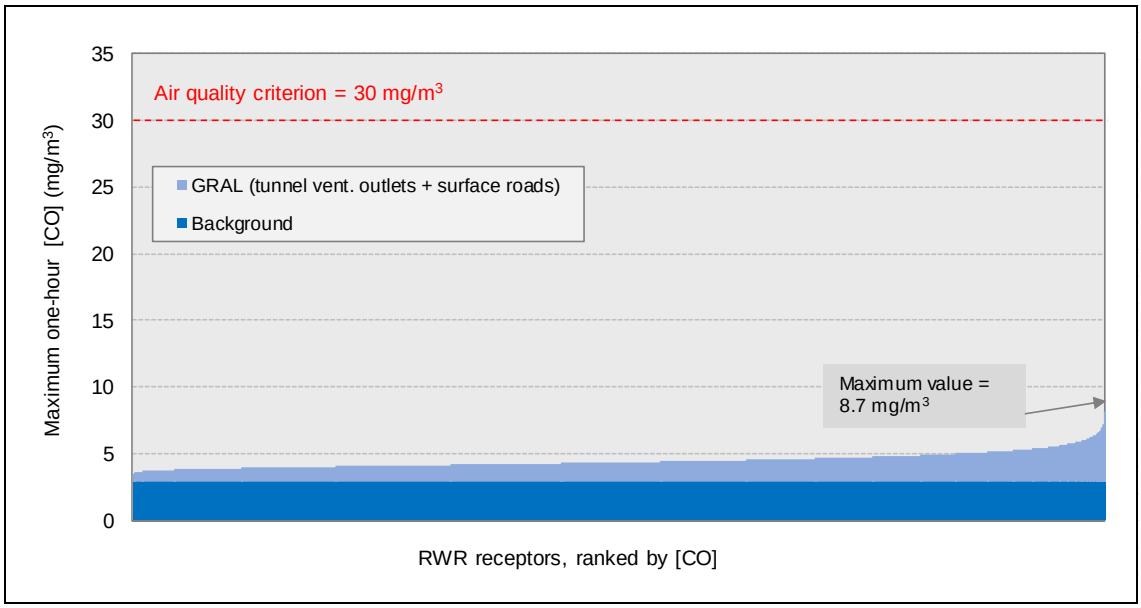


Figure 9-26 Source contributions to maximum 1-hour CO at RWR receptors (2021-DS)

Given that the maximum 1-hour CO concentrations were well below the NSW impact assessment criterion, it was not considered necessary to determine the separate contributions of tunnel ventilation outlets and surface roads.

The changes in the maximum 1-hour CO concentration at the RWR receptors in the 2021-DS scenario (relative to the 2021-DM scenario) are shown, again ranked by change in concentration, in Figure 9-27. There was an increase in concentration at 55 per cent of receptors, and a decrease at 45

per cent, as a result of the project. However, even the largest increase (3.3 mg/m^3 in 2021-DS and 3.5 mg/m^3 in 2031-DS) was small compared with the NSW impact assessment criterion of 30 mg/m^3.

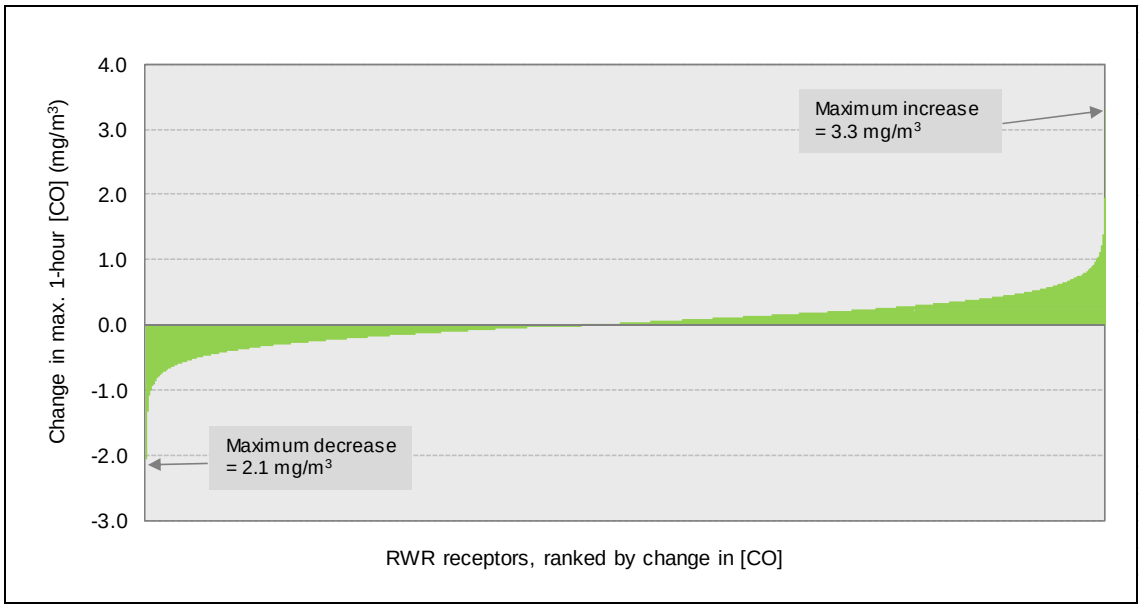


Figure 9-27 Change in maximum 1-hour CO at RWR receptors (2021-DS)

The results for the 2031-DS scenario are given in Appendix K. These closely resembled the results for 2021.

9.5.2 Carbon monoxide (maximum rolling 8-hour mean)

Results for community receptors

Figure 9-28 shows the maximum rolling 8-hour mean CO concentrations at the community receptors with the project in 2021 and 2031. Because no model predictions were available for the period with the highest background concentration, the maximum background value was combined with the maximum model prediction at each receptor. The background was therefore taken to be the same at all locations. As with the 1-hour mean, at all the receptors the concentration was well below the NSW impact assessment criterion, which in this case is 10 mg/m^3. No lower criteria appear to be in force internationally.

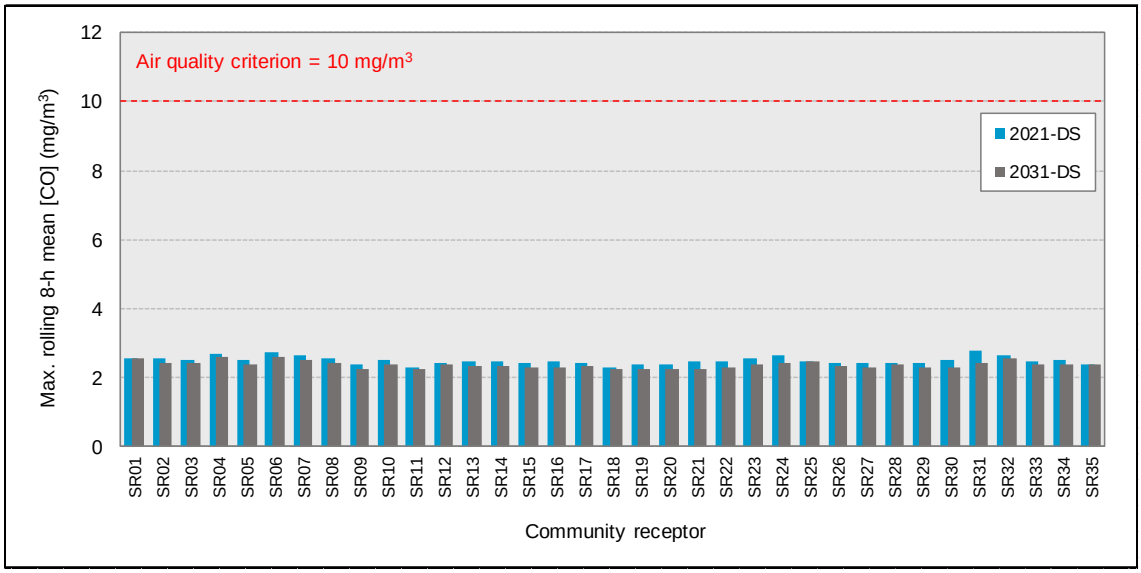


Figure 9-28 Maximum rolling 8-hour mean CO at community receptors (2021-DS and 2031-DS)

The main contributor at these receptors in the 2021-DS scenario was the background concentration (Figure 9-29). The surface road contribution ranged from 8 per cent to 25 per cent, whereas the tunnel ventilation outlet contribution was less than one per cent.

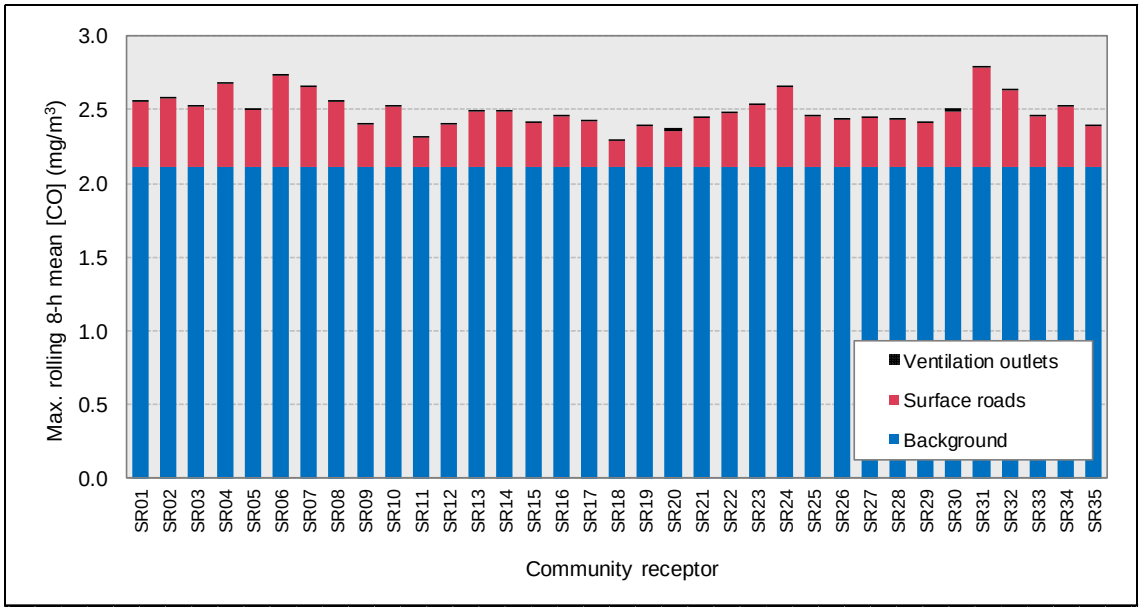


Figure 9-29 Source contributions to maximum rolling 8-hour mean CO at community receptors (2021-DS)

Figure 9-30 shows that the change in the maximum rolling 8-hour CO concentration at all the community receptors was less than 0.4 mg/m^3. The largest increase was around 0.1 mg/m^3.

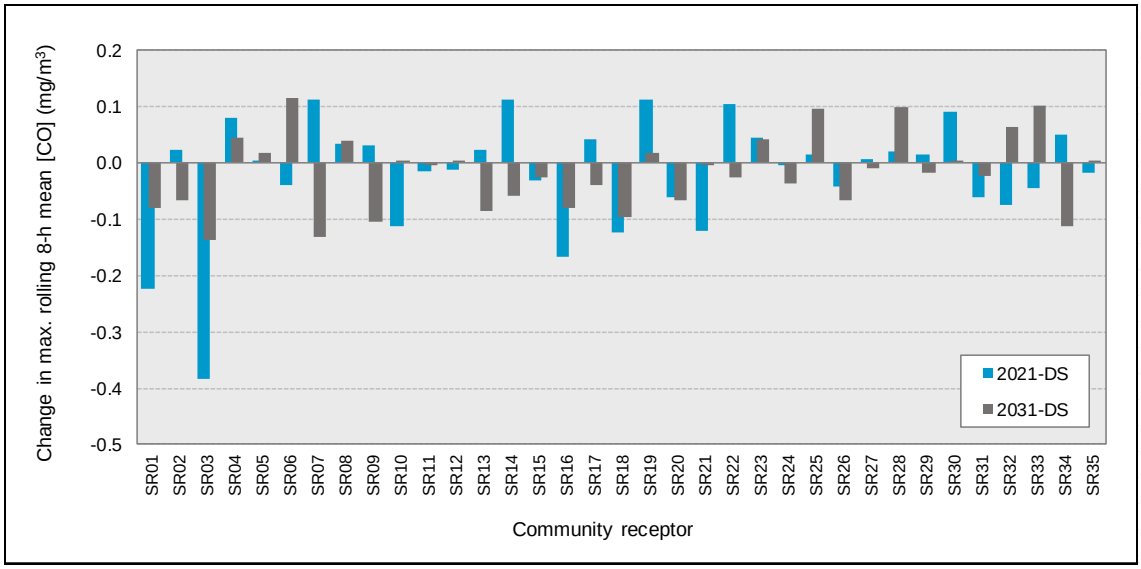


Figure 9-30 Change in maximum rolling 8-hour mean CO at community receptors (2021-DS and 2031-DS)

Results for RWR receptors

Rolling 8-hour mean CO concentrations were not extracted from GRAL. However, these would be broadly similar to those obtained for maximum 1-hour concentrations.

9.5.3 Nitrogen dioxide (annual mean)

Results for community receptors

Figure 9-31 shows the annual mean NO_2 concentrations at the 35 community receptors with the project in 2021 and 2031. At all these receptor locations the concentration was below 35 µg/m^3, and therefore well below the NSW impact assessment criterion of 62 µg/m^3. It should be noted that a lower air quality standard has been adopted elsewhere (e.g. 40 µg/m^3 in the EU). The concentrations at the community receptors were also below this value.

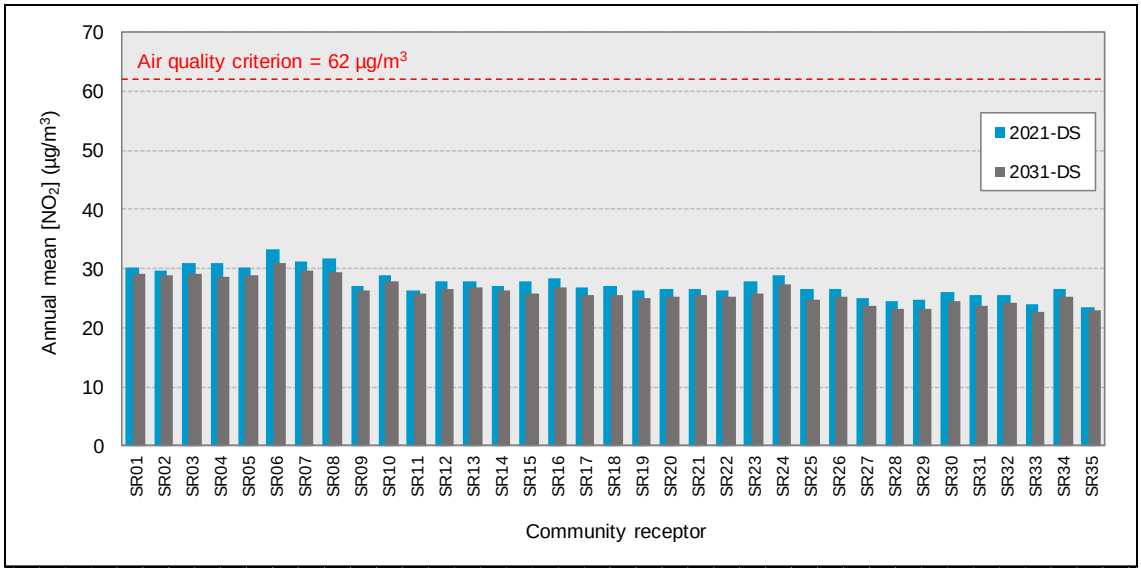


Figure 9-31 Annual mean NO_2 at community receptors (2021-DS and 2031-DS)

Figure 9-32 presents the source contributions to total annual mean NO_2 concentrations in the 2021-DS scenario.

The source contributions were estimated using a 'cumulative' approach involving the following steps:

A. The background NO_X concentration alone was converted to NO_2.

B. The sum of the background and road NO_X concentrations was converted to NO_2.

C. The sum of the background, road and outlet NO_X concentrations was converted to NO_2.

The road and outlet contributions were then obtained as the differences in NO_2, where road NO_2 was determined as NO_2 from Step B minus NO_2 from Step A, and outlet NO_2 was determined from Step C minus Step B. This allowed for the reduced oxidising capacity of the near-road atmosphere at higher total NO_X concentrations.

The results indicate that the background at these receptors is likely to responsible for, on average, around 80 per cent of the predicted annual mean NO_2, with most of the remainder being due to surface roads. Surface roads were responsible for between 12 per cent and 30 per cent of the total in 2021, depending on the receptor. The contribution of tunnel ventilation outlets was less than 1.3 per cent.

Figure 9-33 shows the changes in concentration in the Do Something scenarios relative to the Do Minimum scenarios for the community receptors. There was a small increase in the NO_2 concentration at some receptors (generally <1 µg/m^3), although at some locations there were larger reductions. The largest reduction for these community receptors – around 2.7 µg/m^3 in 2021 – was predicted to occur at receptor SR13 (Kingsgrove World of Learning).

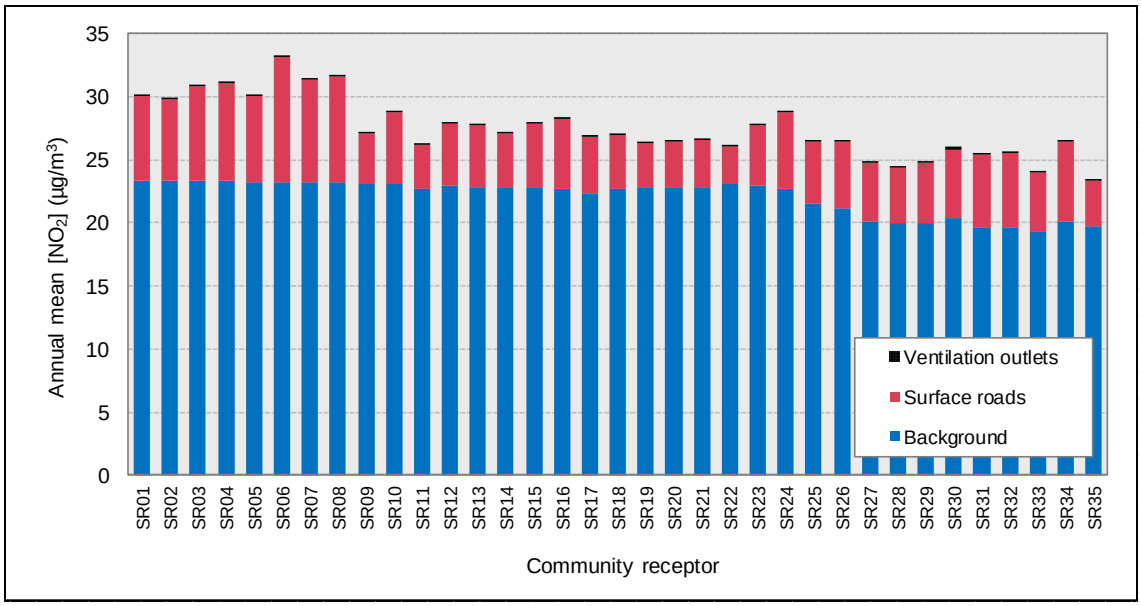


Figure 9-32 Source contributions to annual mean NO_2 at community receptors (2021-DS)

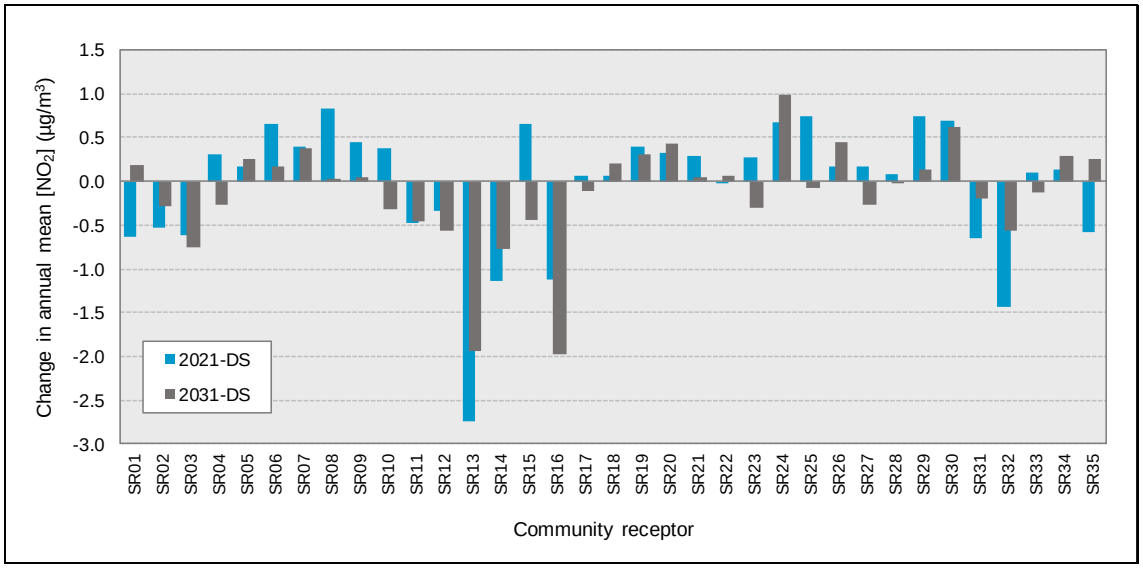


Figure 9-33 Change in annual mean NO_2 at community receptors (2021-DS and 2031-DS)

Results for RWR receptors

The annual mean NO_2 criterion for NSW was not exceeded at any of the 46,219 RWR receptors in any scenario. In 2021 and 2031 the highest concentrations with the project were predicted to be 43.0 µg/m^3 and 39.8 µg/m^3. The maximum annual mean NO_2 concentration in the cumulative case (2031-DSC) was 36.8 µg/m^3.

The annual mean NO_2 concentrations at the RWR receptors in the 2021-DS scenario are shown, with a ranking by total concentration, in Figure 9-34. Concentrations at the vast majority (more than 95 per cent) of receptors were between around 23 µg/m^3 and 32 µg/m^3. As noted above, all concentrations were well below the assessment criterion of 62 µg/m^3, as well as being, in almost all cases, below the EU limit value of 40 µg/m^3. The maximum contribution of tunnel ventilation outlets at any location in the 2021-DS scenario was 0.6 µg/m^3, whereas the surface road contribution ranged between 2.2 µg/m^3 and 19.8 µg/m^3. The corresponding values for the 2031-DS scenario were 0.7 µg/m^3, 1.4 µg/m^3 and 16.6 µg/m^3.

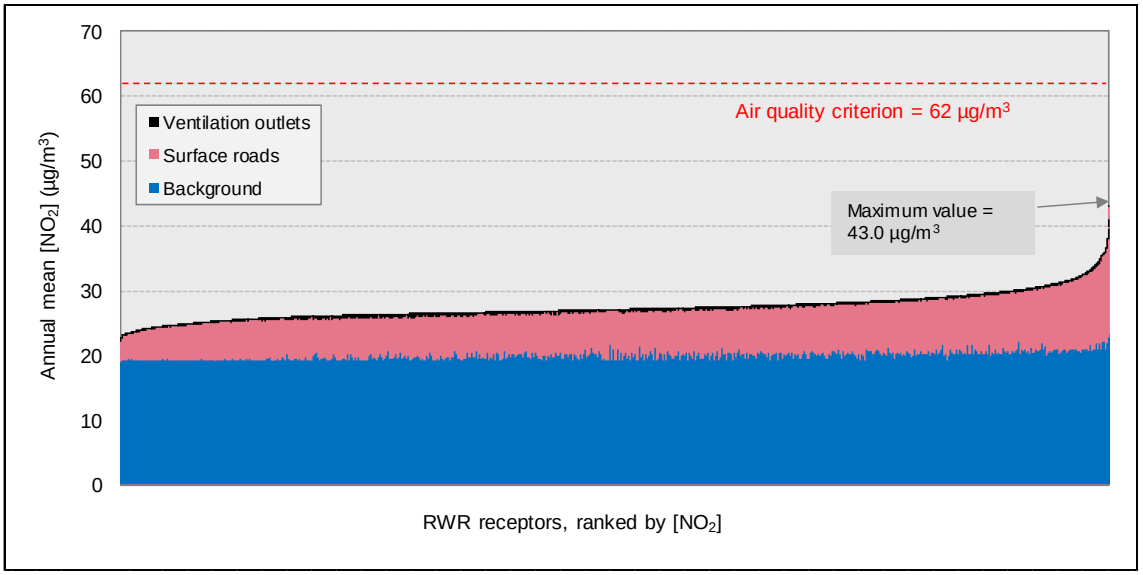


Figure 9-34 Source contributions to annual mean NO_2 at RWR receptors (2021-DS)

The changes in the annual mean NO_2 concentration at the RWR receptors in the 2021-DS scenario (relative to the 2021-DM scenario) are shown, ranked by change in concentration, in Figure 9-35. There was predicted to be an increase in the annual mean NO_2 concentration at 62 per cent of receptors, and a decrease at 38 per cent, in 2021 as a result of the project. Whilst the largest increase was 5.5 µg/m^3, the increase was greater than 2 µg/m^3 for less than one per cent of receptors.

The annual mean NO_2 concentrations, and the changes in the annual mean, in the 2031-DS scenario are given in Appendix K. These closely resemble the results for 2021, with the largest increase in concentration in 2031 being 4.0 µg/m^3.

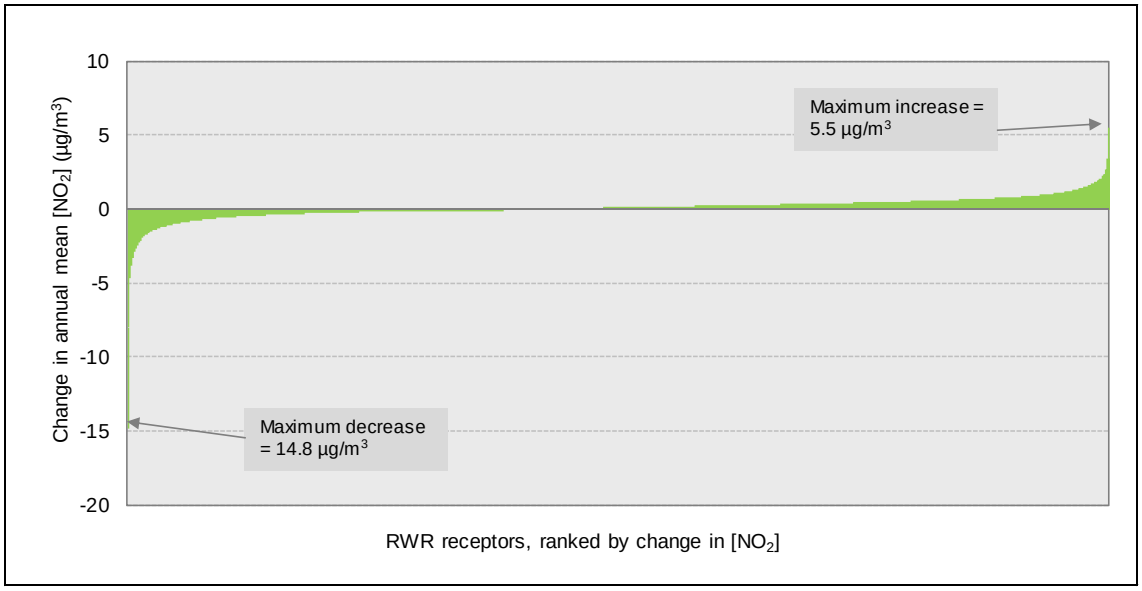


Figure 9-35 Changes in annual mean NO_2 at RWR receptors (2021-DS)

Contour plots for GRAL New M5 domain

Contour plots showing the spatial distribution of annual mean NO_2 concentrations across the New M5 GRAL domain in 2021 are provided for the Do Minimum case (i.e. without the project) in Figure 9-36, and for the Do Something case (i.e. with the project) in Figure 9-37. The maps also show main surface roads and the locations of tunnel ventilation facilities.

It should be noted that some of the roads in the model are presented as being on the surface, whereas in reality they are (minor) tunnels. The main examples of this are the relatively short tunnel on General Holmes drive that passes under the runway, and the Cooks River Tunnel. It was not considered necessary to represent these roads as tunnels given that they were some distance from sensitive receptor locations.

The plots are based on 960,000 data points, spaced at 10 metre intervals across the domain. Many of the points fall along the axes of roads, and are therefore not necessarily representative of population exposure. The plots illustrate the strong links between the spatial distribution of air pollution and the traffic on the road network.

When interpreting the contours for the GRAL New M5 domain, it is helpful to refer to the roads highlighted in Figure 9-4. The highest concentrations are found along the most heavily trafficked roads in the New M5 GRAL domain: the M5 East Motorway, General Holmes Drive, King Georges Road. The M5 East tunnel is also apparent where there is a 'gap' in concentrations along the east-west axis of the M5 East motorway. It is also noticeable that the tunnel ventilation outlets have little impact on annual mean NO_2 concentrations, such as around the existing M5 East ventilation outlet.

The contour plot for the change in concentration with the project in 2021 (Figure 9-38) shows a fairly complex pattern. The green shading represents a decrease in concentration with the project, and the purple shading an increase in concentration. Changes of less than 2 µg/m^3 are not shown.

There are predicted to be substantial reductions in concentration along the M5 East Motorway, both to the east and west of the M5 East tunnel, as well as along General Holmes Drive and other roads around the airport. In 2021 the New M5 is predicted to have a two-way average weekday traffic (AWT) of around 29,500 vehicles per day. By comparison, AWT volumes on the M5 East in 2021 are predicted to decrease from about 116,000 and 101,500 vehicles per day to about 69,000 and 81,000 vehicles per day with the project at the western and eastern end of the M5 East respectively. This equates to a 40 per cent and 20 per cent reduction in daily volumes respectively (AECOM, 2015). Reductions in concentrations are also predicted along the section of King Georges Road to the north of the M5 East Motorway, around the northern perimeter of Sydney Park, and on a number of other roads.

Increases in concentration are predicted for King Georges Road to the south of the M5 East Motorway, Stoney Creek Road, Bexley Road to the south of the M5 East Motorway, Harrow Road, Bay Street, Forest Road, and around the southern perimeter of Sydney Park, amongst other roads. Daily two-way volumes on Stoney Creek Road are predicted to increase by around 35 per cent with the project. This increase reflects the relocation of traffic from the M5 East due to tolling. This relocation would mainly occur in off-peak periods, as the peak hour spare capacity on Stoney Creek Road is limited (AECOM, 2015).

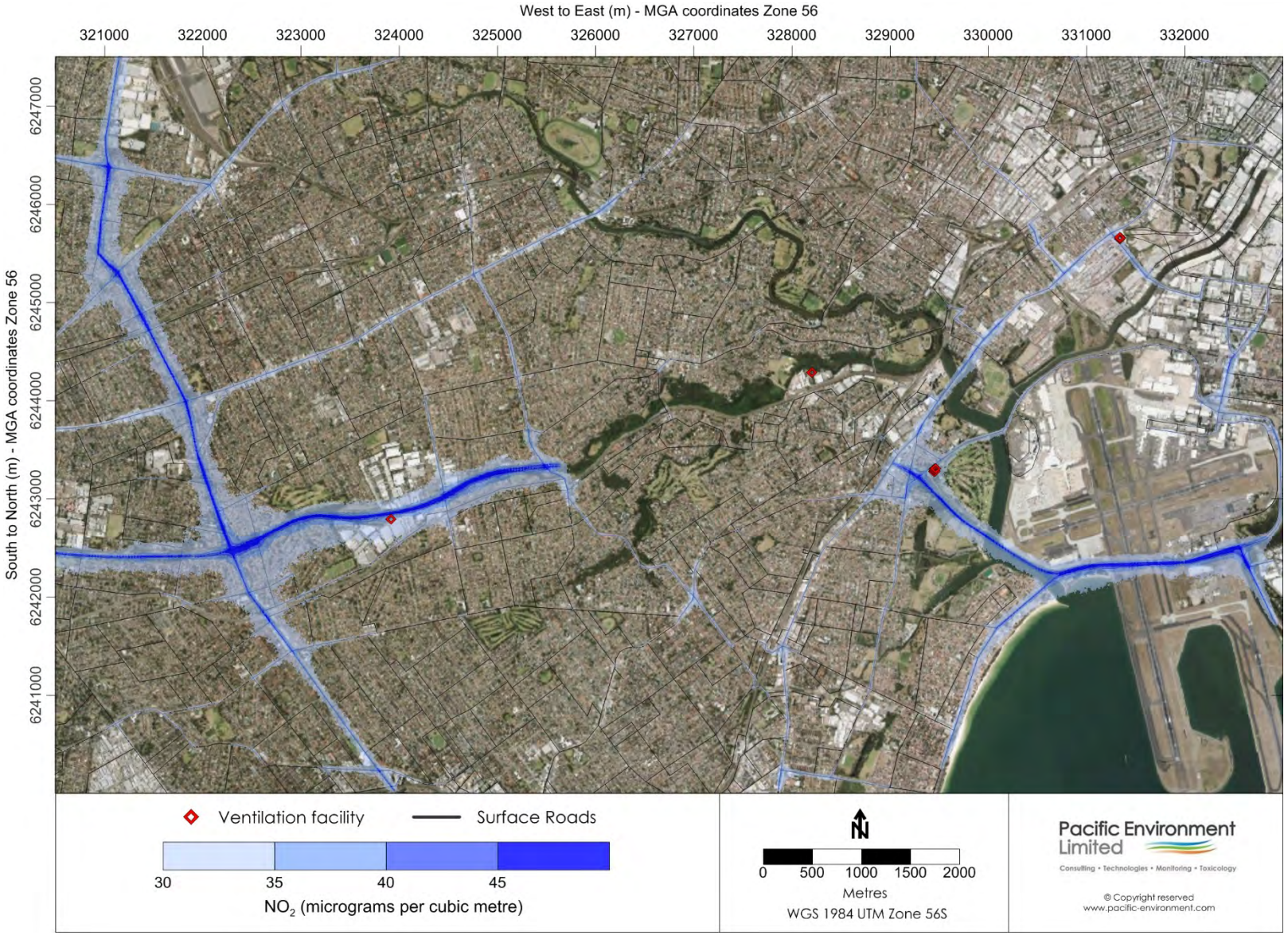


Figure 9-36 Contour plot showing annual mean NO_2 without the project (2021-DM)



Figure 9-37 Contour plot showing annual mean NO_2 with the project (2021-DS)

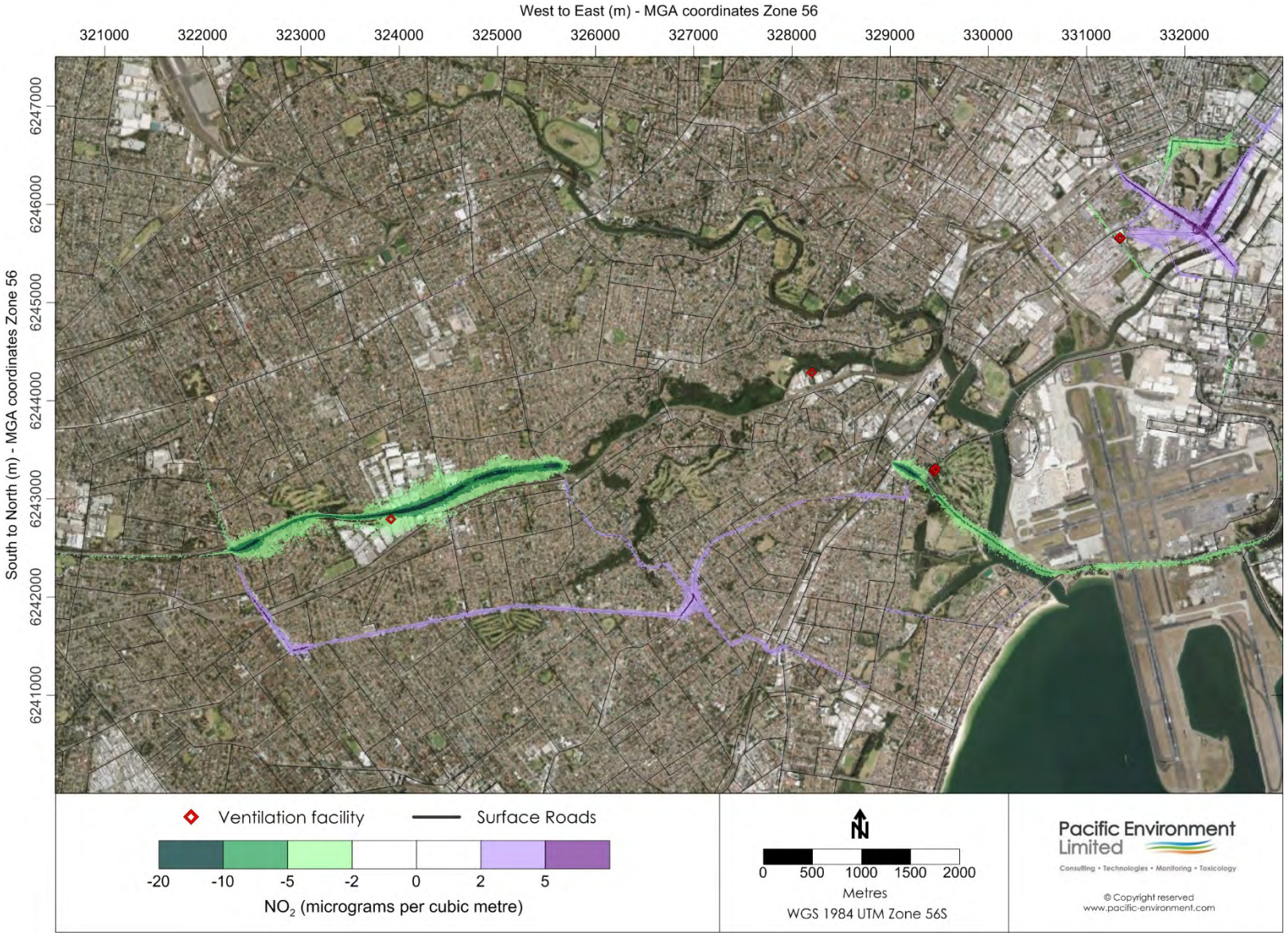


Figure 9-38 Contour plot showing change in annual mean NO_2 with the project (2021-DS)

Contour plots for ventilation outlets only

Contour plots for annual mean NO_X (not NO_2) were also produced for the New M5 ventilation outlets only. These are shown in Figure 9-39 (Kingsgrove outlet), Figure 9-40 (Arncliffe outlet) and Figure 9-41 (SPI New M5 outlet). The contributions from the surface road network and the background are not included in these plots.

The presentation of these contour plots is slightly different to those for the full GRAL New M5 domain. The latter were designed to show changes in air pollution across a wide area. The geographical area covered by each of these ventilation outlet plots (2 kilometres by 2 kilometres grid) was much smaller than the full GRAL New M5 domain. This allowed more local detail, with isopleths and concentration values, to be shown more clearly in the maps.

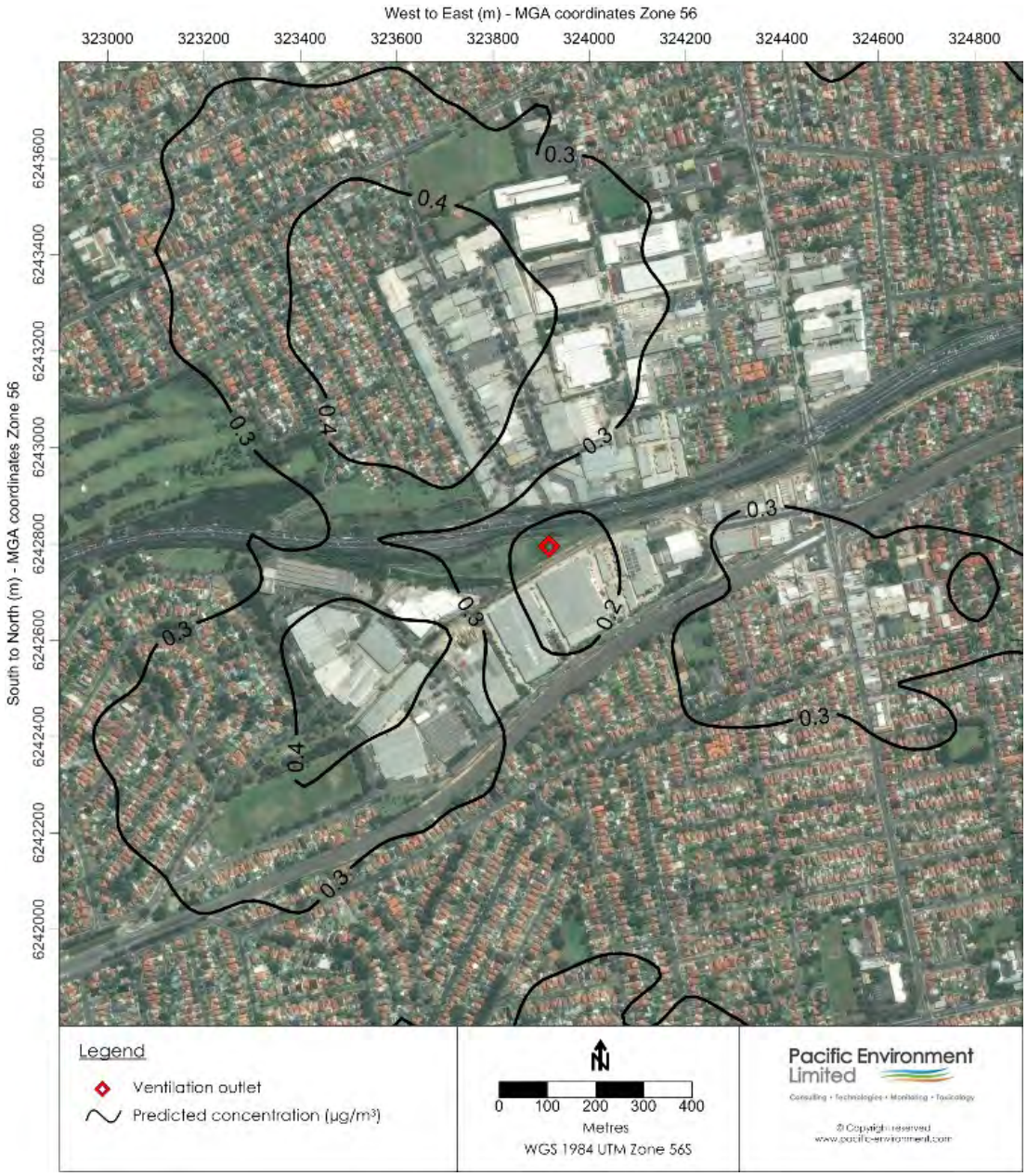


Figure 9-39 Contour plot showing annual mean NO_X for ventilation outlets only (Kingsgrove outlet, 2021-DS)

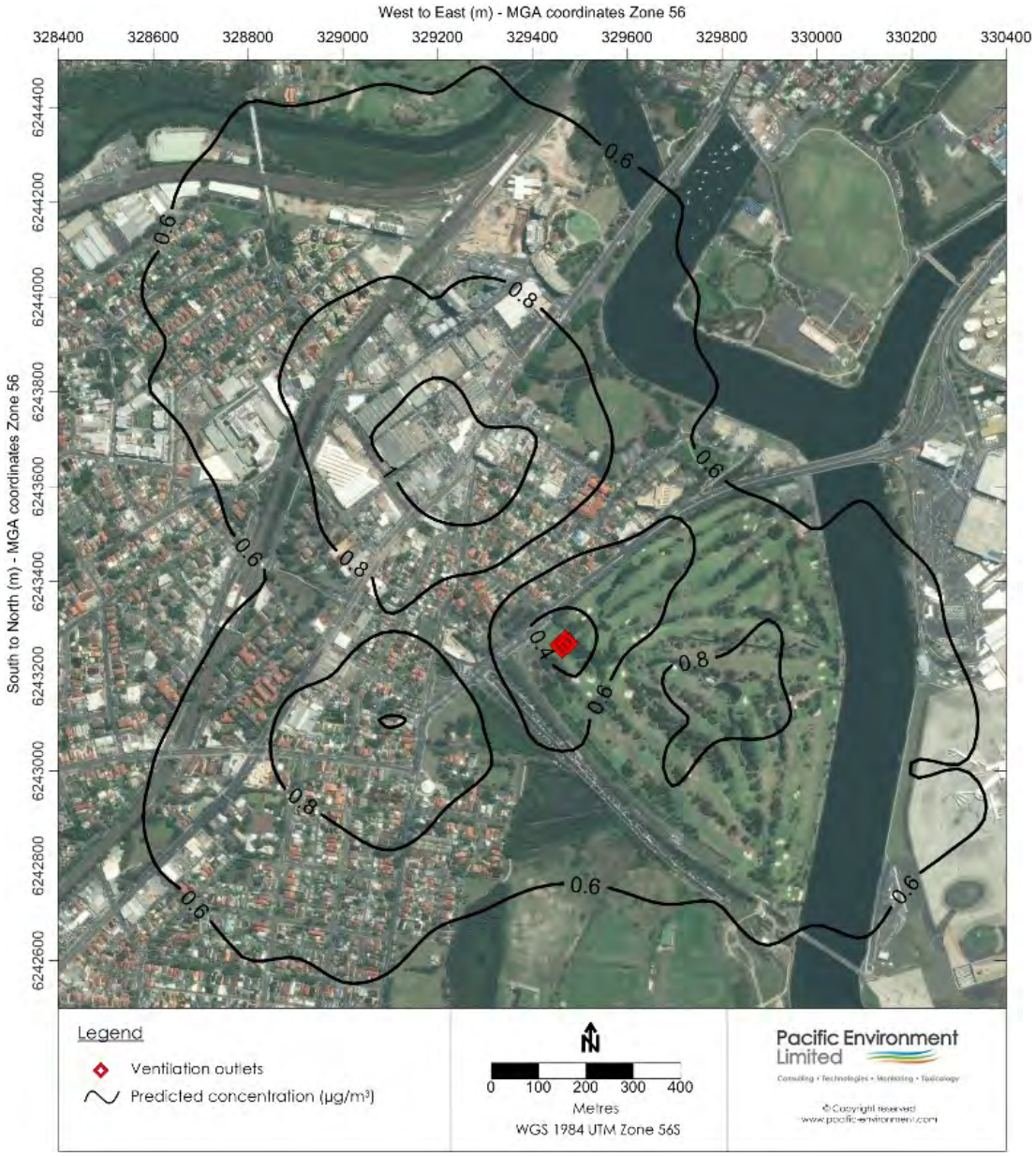


Figure 9-40 Contour plot showing annual mean NO_X for ventilation outlets only (Arncliffe outlet, 2021-DS)

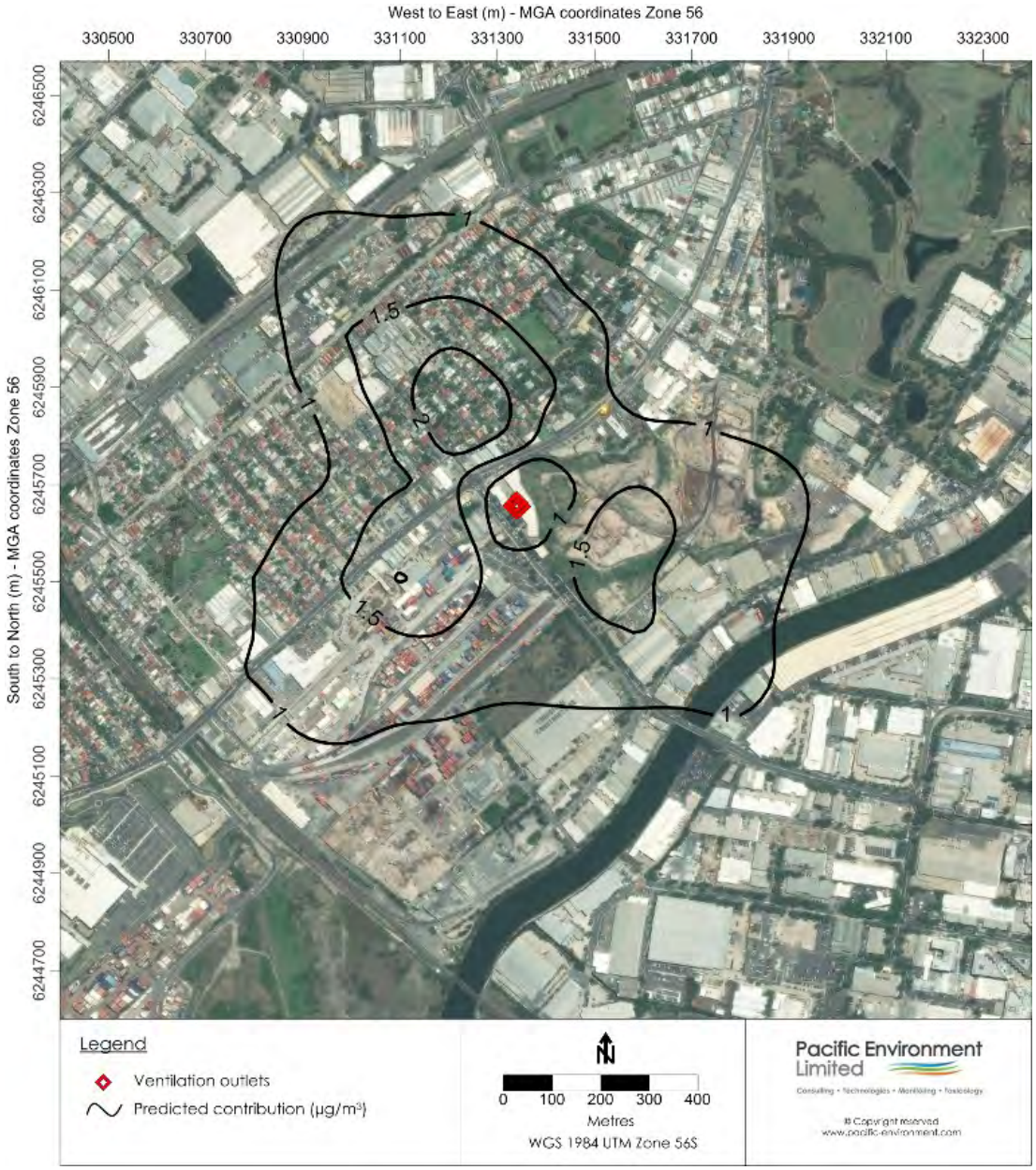


Figure 9-41 Contour plot showing annual mean NO_X for ventilation outlets only (SPI outlet, 2021-DS)

For each ventilation outlet, the range of annual NO_X concentrations across the grid is given in Table 9-26. It should be noted that the values across the grid do not necessarily coincide with receptor location, and the ranges of values at actual receptors would be lower. The ventilation outlet NO_X increments were very low, and their effects were quite localised. The values across the grid in the 2021-DS scenario ranged from 0.2 to 2.2 µg/m^3 (0.2 to 2.5 µg/m^3 in the 2031-DS scenario). The outlet contributions to NO_2 would be even lower, and negligible compared compared with the annual mean criterion of 62 µg/m^3.

Table 9-26 Contribution of project ventilation outlets to annual mean NO_X concentration in 2 km x 2 km grid around outlet

Ventilation outlet	Outlet contribution to annual mean NOx (µg/m^3)		
	2021-DS	2031-DS	2031-DSC
Kingsgrove	0.2 - 0.5	0.2 - 0.6	0.2 - 0.6
Arncliffe	0.4 - 1.0	0.4 - 1.0	0.4 - 0.6
SPI	0.5 - 2.2	0.5 - 2.5	0.5 - 2.5

9.5.4 Nitrogen dioxide (maximum 1-hour mean)

Results for community receptors

The maximum 1-hour mean NO_2 concentrations at the 35 community receptors with the project in 2021 and 2031 are shown in Figure 9-42. At all receptor locations the maximum concentration was below the NSW impact assessment criterion of 246 µg/m^3.

Lower, but not necessarily more stringent, air quality standards are in force in other countries. For example New Zealand has a limit value of 200 µg/m^3, but with 9 allowed exceedances per year. There were no exceedances of the New Zealand standard at any receptors in 2021 or 2031.

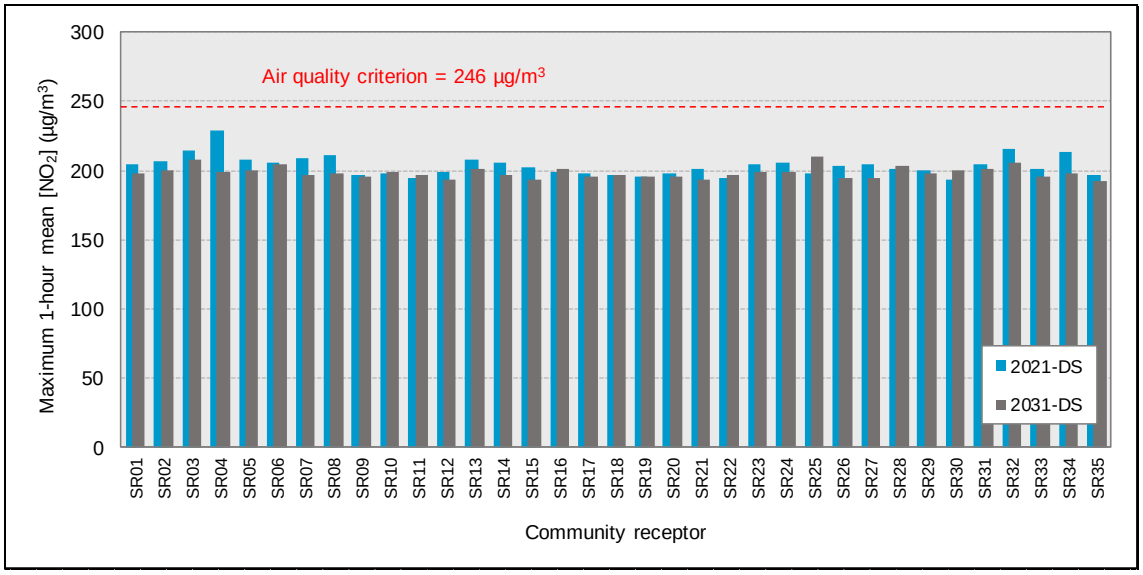


Figure 9-42 Maximum 1-hour NO_2 at community receptors (2021-DS and 2031-DS)

To apportion the contributions of different sources to the maximum NO_2 concentration, it was necessary to identify the hour in which the maximum NOx concentration occurred, and then what the modelled surface road and outlet contributions were during that hour. Once the relevant hours had been identified, the source contributions to maximum 1-hour NO_2 were estimated using the method described earlier for the annual mean. The results are shown in Figure 9-43.

As with the annual mean, the background was the most important source, with generally a small contribution from surface roads. The outlet contribution to the maximum NO_2 concentration was zero or negligible (less than 0.2 per cent) for all receptors. As with 1-hour mean CO, larger 1-hour contributions from roads and outlets may well have occurred during other hours of the year.

The changes in the maximum concentration in the Do Something scenarios relative to the Do Minimum scenarios are shown in Figure 9-44). Again, there was a mixture of small (relative to the criterion) increases and decreases. There were some notable increase in the maximum concentration at a small number of receptors, but these did not result in exceedances of the criterion.

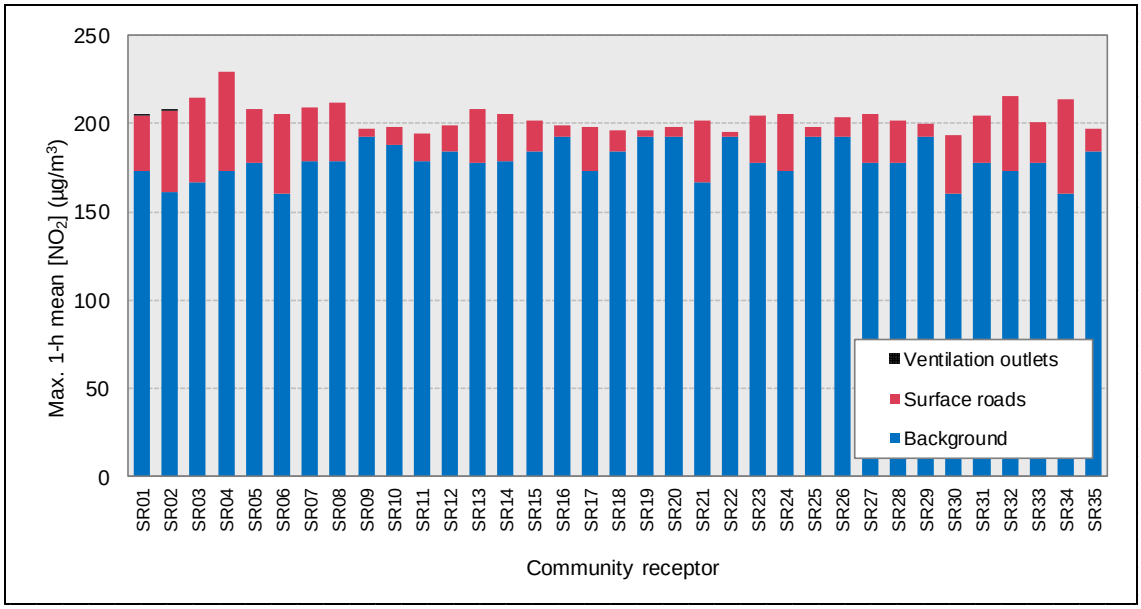


Figure 9-43 Source contributions to maximum 1-hour NO_2 at community receptors (2021-DS)

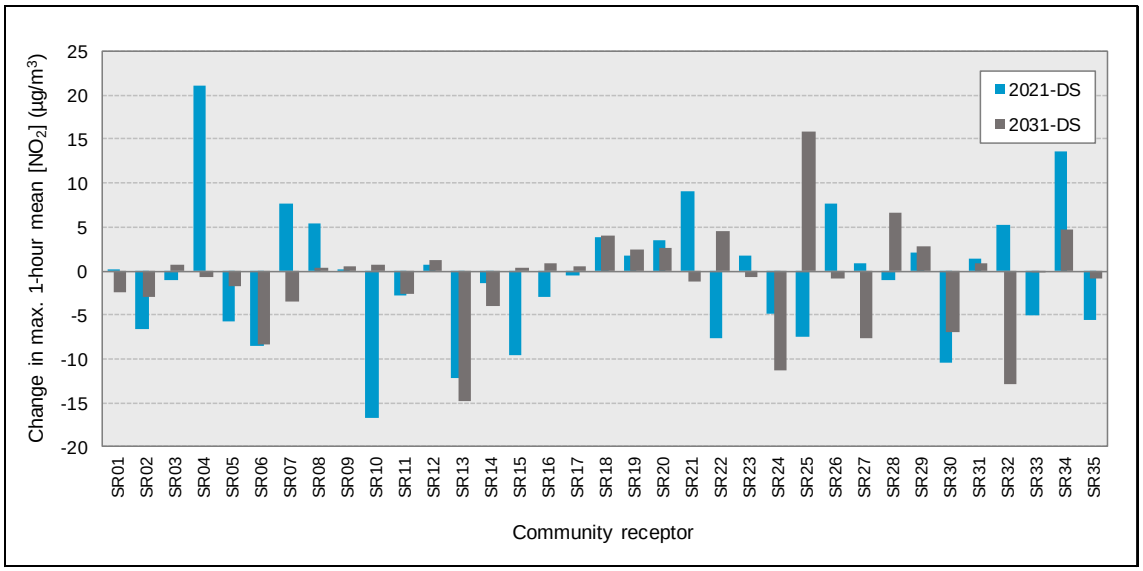


Figure 9-44 Change in maximum 1-hour NO_2 at community receptors (2021-DS and 2031-DS)

Results for RWR receptors

The maximum 1-hour mean NO_2 concentrations at the RWR receptors in the 2021-DS scenario are shown, with a ranking by total concentration, in Figure 9-45. There were some predicted exceedances of the NSW 1-hour NO_2 criterion (246 µg/m^3), both with and without the project. In the 2021-DM scenario the maximum concentration exceeded the criterion at around 1,800 receptors (3.9 per cent of all receptors), but with the introduction of the project in the 2021-DS scenario this decreased to around 1,400 receptors (3.1 per cent). In the 2031-DM scenario (plotted in Appendix K) there were exceedances at 438 receptors (0.9 per cent), decreasing to 244 receptors (0.5 per cent) in the 2031-DS scenario.

The contributions of surface roads and ventilation outlets are not shown separately in Figure 9-45, as these were not additive. However, the maximum contribution of tunnel outlets to NO_X at any receptor was 93 µg/m^3 in 2021-DS (120 µg/m^3 in 2031-DS). This would equate to a very small NO_2 contribution relative to the air quality assessment criterion. Compliance with the New Zealand limit value of 200 µg/m^3 with 9 allowed exceedances per year could not be determined for the RWR receptors, as time series were not available.

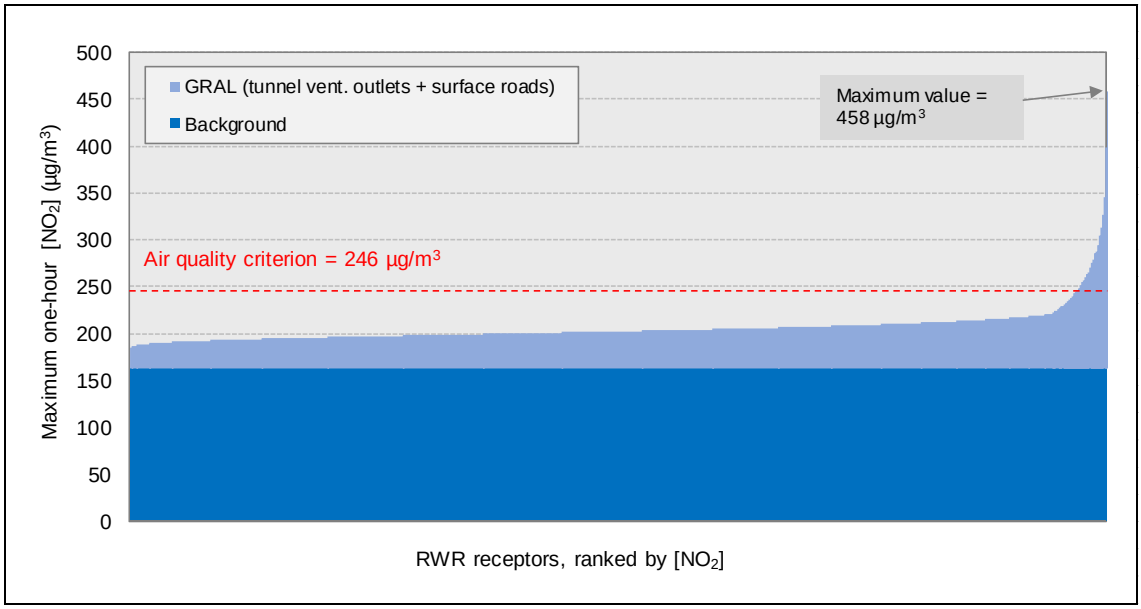


Figure 9-45 Source contributions to maximum 1-hour NO_2 at RWR receptors (2021-DS)

No exceedances of the NSW NO_2 criterion have been measured at ambient air quality monitoring stations in Sydney in recent years, and to some extent the predicted exceedances may be a result of the conservatism in some of the modelling assumptions, and the tendency of the model to overestimate maximum NO_2 concentrations (see Appendix J, Figure J-6). The extent of the overestimation may also be higher in 2031 and 2031 than in 2014 given the assumption of a higher NO_2/NO_X ratio in future years. However, the predictions are for a wider range of site types than those currently used for monitoring in Sydney, and they suggest that exceedances may be happening at non-monitoring locations.

The change in the maximum 1-hour mean NO_2 concentration at the RWR receptors in the 2021-DS scenario (relative to the 2021-DM scenario) are shown, ranked by change in concentration as a result of the project, in Figure 9-46. There was an increase in concentration at 50 per cent of the receptors, and a decrease at 50 per cent. At the majority of receptors the change was relatively small; at more than 95 per cent of receptors the change in concentration was less than 20 µg/m^3.

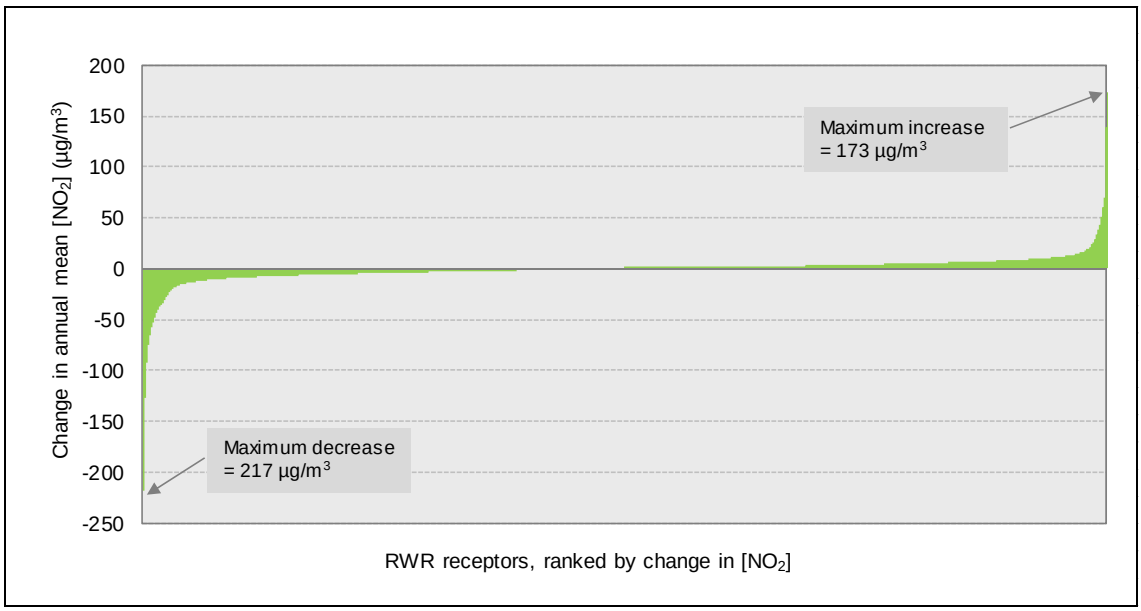


Figure 9-46 Changes in maximum 1-hour NO_2 at RWR receptors (2021-DS)

Contour plots for GRAL New M5 domain

Contour plots of maximum 1-hour NO_2 concentrations in 2021 are provided for the Do Minimum scenario in Figure 9-47, and for the Do Something scenario in Figure 9-48. It is important to note that these maps do not represent a particular time period; each point in the map is a maximum value for any hour of the year. As with annual mean NO_2, the maximum 1-hour concentrations are clearly the highest along the axes of major roads, and in the west of the domain. The contour plot for the change in the maximum one-hour NO_2 concentration with the project in 2021 is given in Figure 9-49.

The equivalent plots for 2031 are presented in Appendix K.

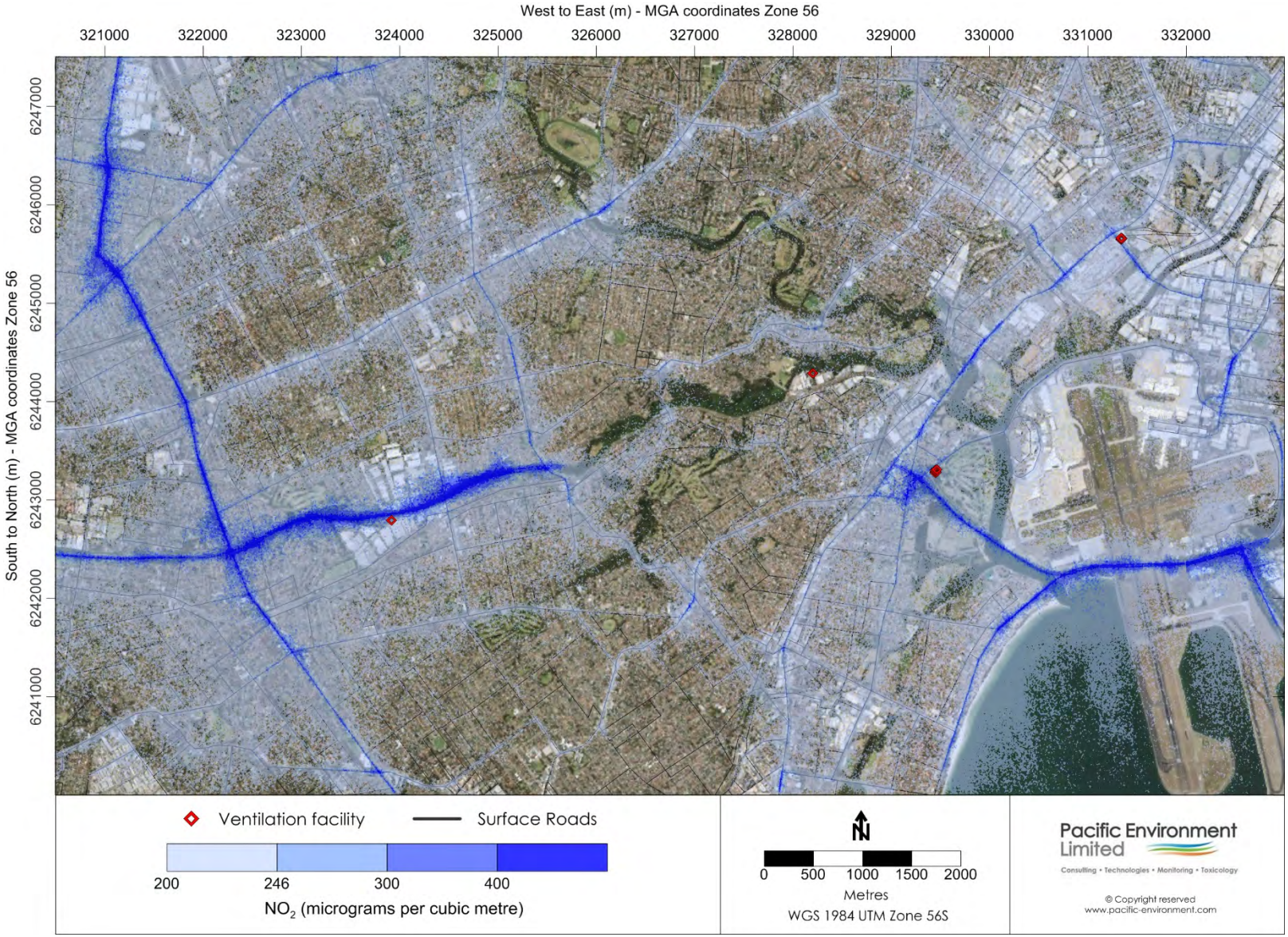


Figure 9-47 Contour plot showing maximum 1-hour NO_2 (2021-DM)

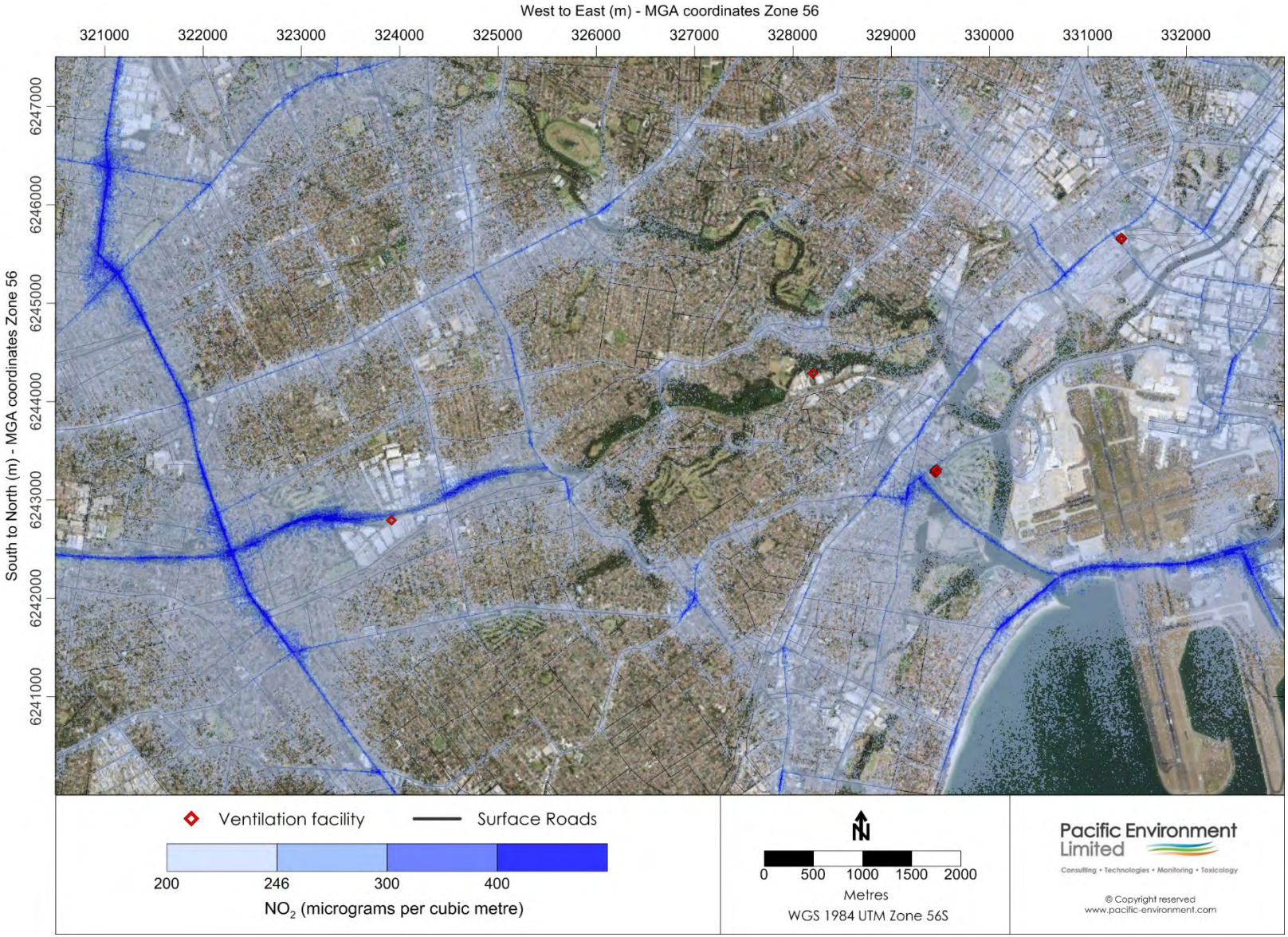


Figure 9-48 Contour plot showing maximum 1-hour NO_2 (2021-DS)



Figure 9-49 Contour plot showing change in maximum 1-hour NO_2 with the project (2021-DS)

Contour plots for ventilation outlets only

A contour plot for the maximum 1-hour NO_X (not NO_2) for the New M5 SPI ventilation outlet only in the 2021-DS scenario is shown in Figure 9-50. The contributions from the surface road network and the background are not included in this plot. The ventilation outlet NO_X increments were low (contributions to NO_2 would be even lower) and their effects were quite localised.

For the Kingsgrove and Arncliffe ventilation outlets the contour plots for maximum 1-hour NO_X are not presented. This is because the range of values was both narrow and low (typically in the range of 10-20 µg/m^3). When combined with the range of meteorological conditions associated with the maximum values for the different locations, this resulted in artefacts in the isopleths. Moreover, these values would equate to low NO_2 increments. The results for the SPI ventilation outlets are given below.

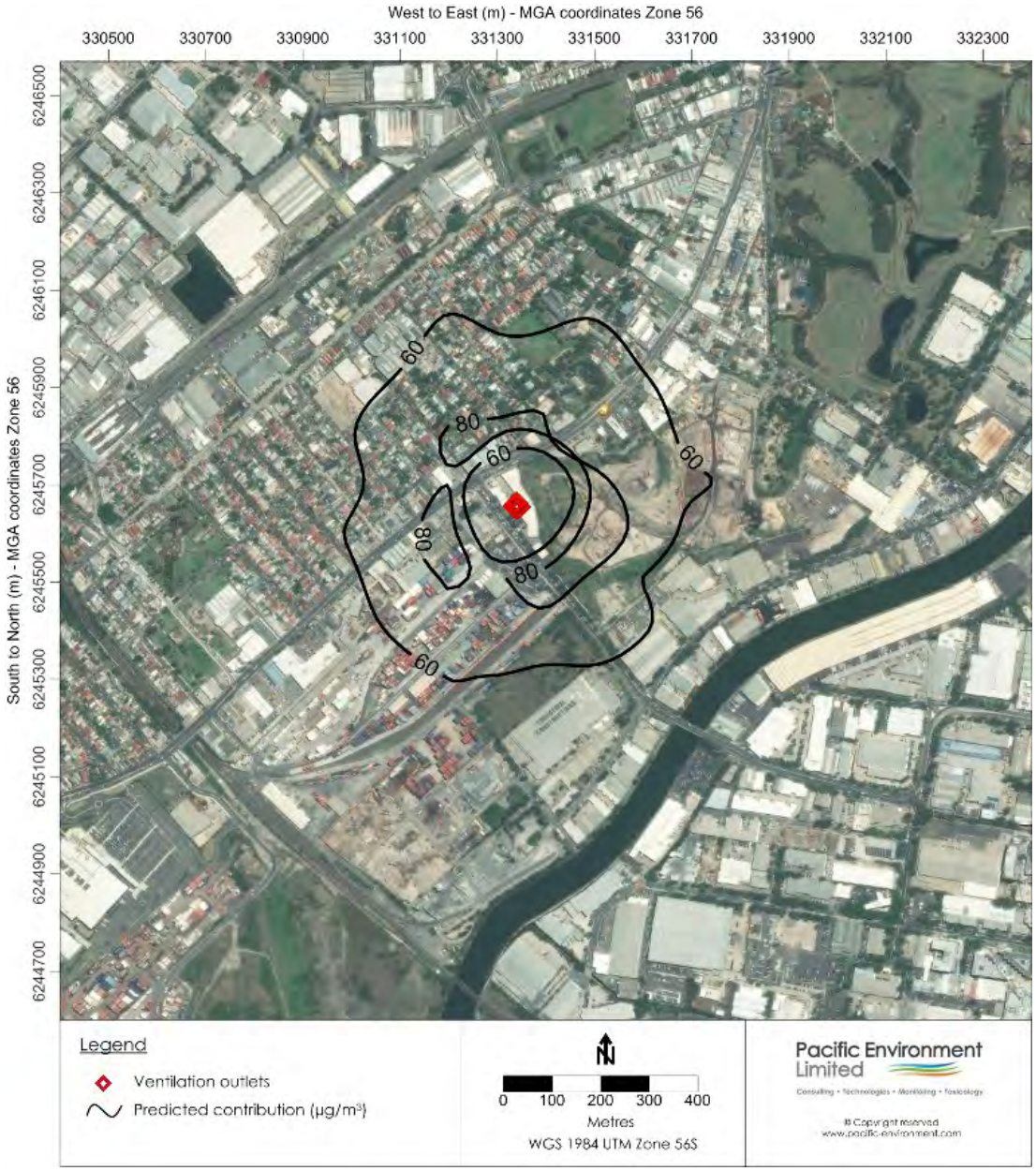


Figure 9-50 Contour plot showing maximum 1-hour NO_X for ventilation outlets only (SPI outlet, 2021-DS)

For each ventilation outlet, the range of maximum 1-hour NO_X concentrations across the grid is given in Table 9-27Table 9-26. The ventilation outlet NO_X increments were again low. The maximum value of 115 µg/m^3 (SPI, 2031-DS) would typically correspond to a value for NO_2 of around 20 µg/m^3, on the basis that NO_X concentrations are already high. This compares with the one-hour criterion for NO_2 of 246 µg/m^3.

Table 9-27 Contribution of project ventilation outlets to maximum 1-hour NO_X concentration in 2 km x 2 km grid around outlet

Ventilation outlet	Outlet contribution to max. 1-hour NOx (µg/m^3)		
	2021-DS	2031-DS	2031-DSC
Kingsgrove	8 - 20	10 - 20	10 - 20
Arncliffe	12 - 35	15 - 45	10 - 20
SPI	20 - 85	20 - 115	10 - 40

9.5.5 PM_{10} (annual mean)

Results for community receptors

The annual mean PM_{10} concentrations at the 35 community receptors with the project in 2021 and 2031 are shown in Figure 9-51. At all the community receptors the concentration was below or equal to 20 µg/m^3, and therefore well below the NSW impact assessment criterion of 30 µg/m^3. PM_{10} concentrations at these receptors – which are near busy roads in Sydney - were only slightly higher than the lowest PM_{10} standards in force in other countries (18 µg/m^3 in Scotland), and mostly lower than the proposed target for NSW of 20 µg/m^3.

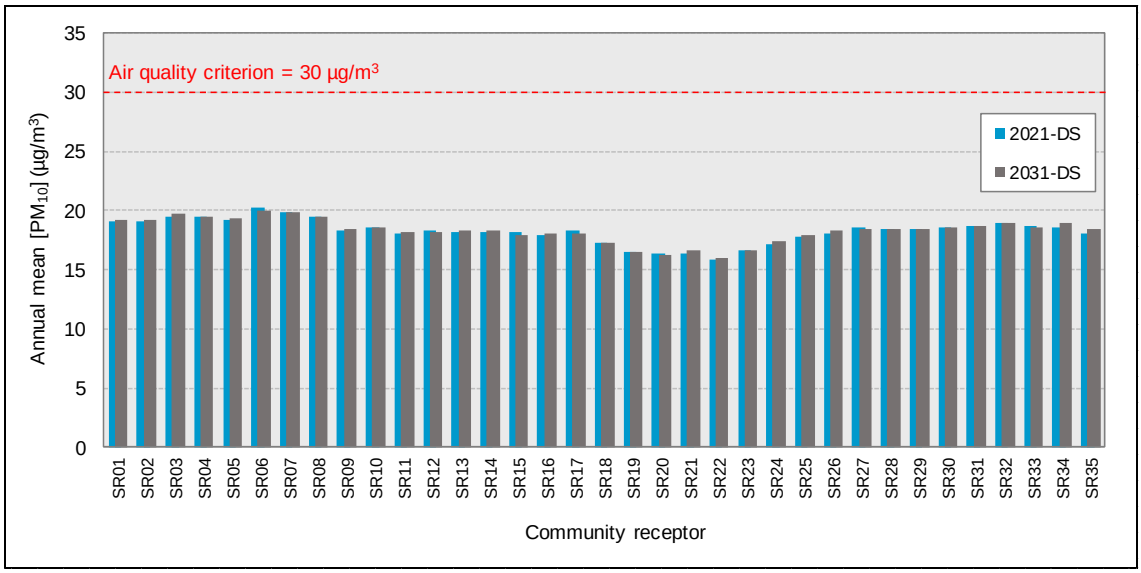


Figure 9-51 Annual mean PM_{10} at community receptors (2021-DS and 2031-DS)

The concentrations in the 2021-DS scenario were again dominated by the background (Figure 9-52), with a small contribution from roads (0.8-3.0 µg/m^3) and a negligible contribution from tunnel ventilation outlets (less than 0.1 µg/m^3).

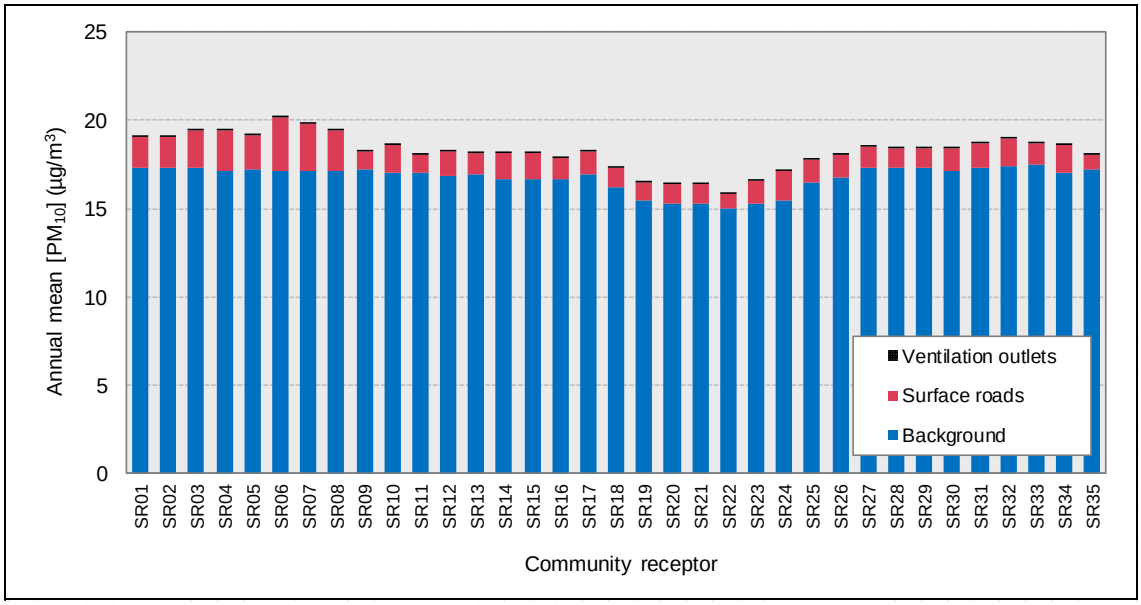


Figure 9-52 Source contributions to annual mean PM_{10} at community receptors (2021-DS)

Figure 9-53 shows the changes in concentration in the Do Something scenarios relative to the Do Minimum scenarios for the community receptors. The largest increase was around 0.5 µg/m^3, and the largest decrease around 0.8 µg/m^3.

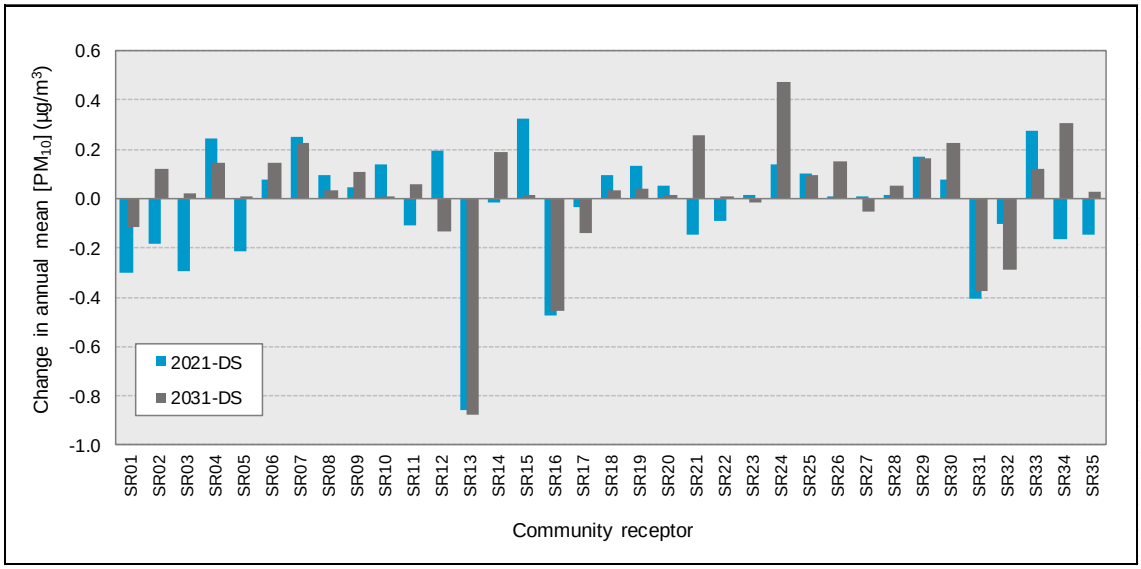


Figure 9-53 Change in annual mean PM_{10} at community receptors (2021-DS and 2031-DS)

Results for RWR receptors

The ranked annual mean PM_{10} concentrations at the RWR receptors in the 2021-DS scenario are shown in Figure 9-54. The concentration at the majority of receptors was below 20 µg/m^3, and concentrations at all receptors were well below the NSW assessment criterion of 30 µg/m^3. The highest predicted concentration at any receptor in this scenario was 24.6 µg/m^3, but as with other pollutants and metrics the highest values were only predicted for a small proportion of receptors. The surface road contribution was between 1.4 µg/m^3 and 7.4 µg/m^3. The largest contribution from tunnel ventilation outlets was 0.11 µg/m^3 in the 2021-DS and 2031-DS scenarios.

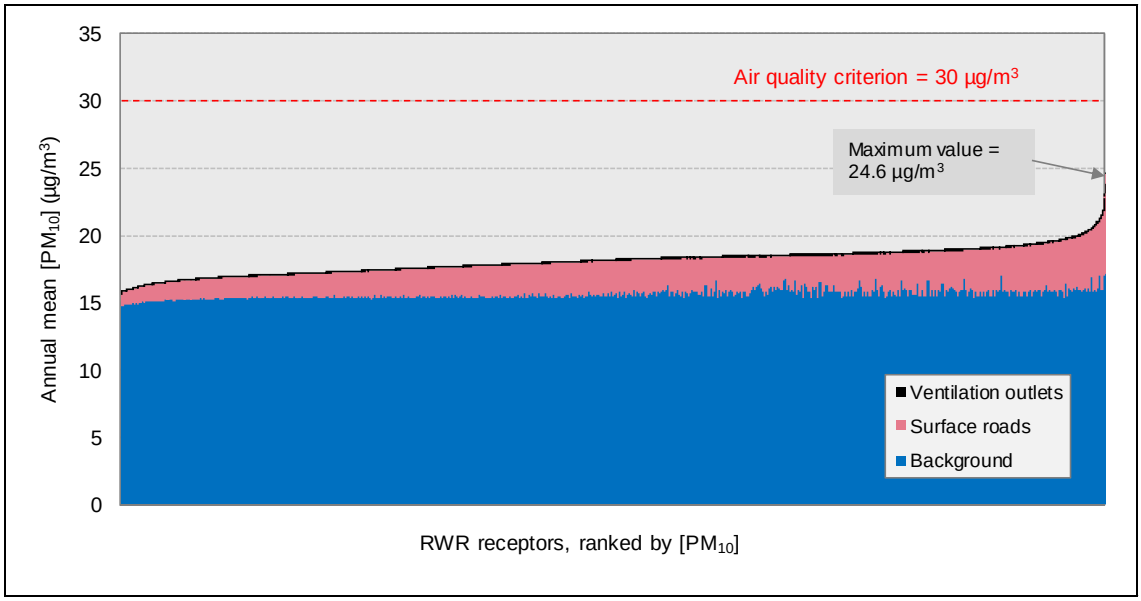


Figure 9-54 Source contributions to annual mean PM_{10} at RWR receptors (2021-DS)

The changes in the annual mean PM_{10} concentration at the RWR receptors in the 2021-DS scenario (relative to the 2021-DM scenario) are shown, ranked by change in concentration, in Figure 9-55. There was an increase in concentration at 64 per cent of the receptors. At the majority of receptors the change was relatively small, and where there was an increase this was greater than 1 µg/m^3 at only 0.1 per cent of receptors.

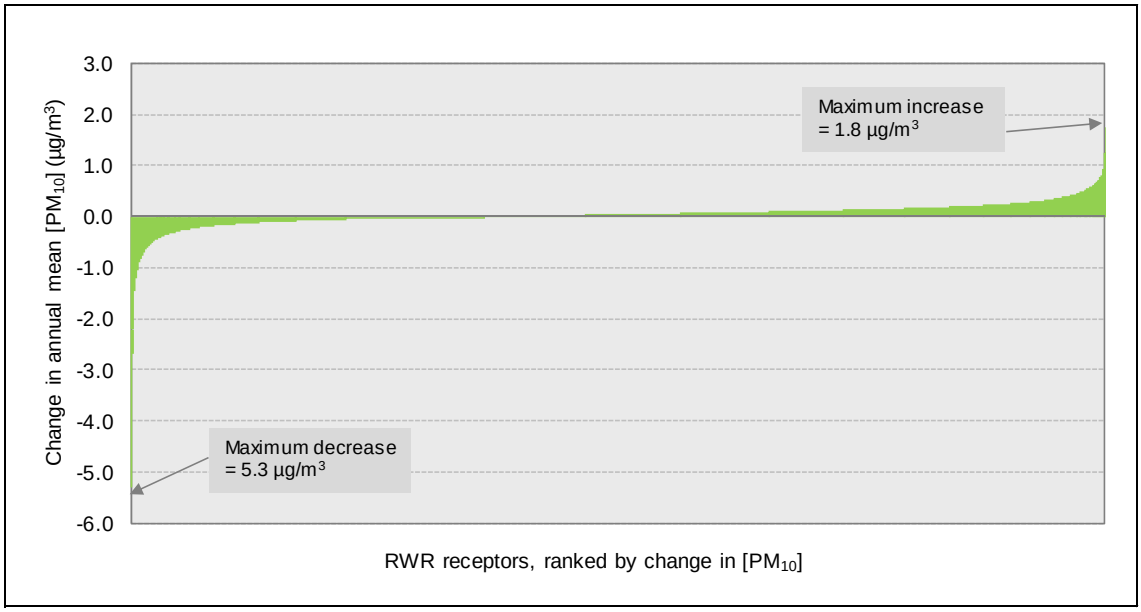


Figure 9-55 Changes in annual mean PM_{10} at RWR receptors (2021-DS)

The corresponding plots for the 2031-DS scenario are given in Appendix K.

Contour plots for GRAL New M5 domain

The contour plots for annual mean PM_{10} in 2021 are given in Figure 9-56, Figure 9-57 and Figure 9-58. As in the case of NO_2, elevated concentrations are evident along the major road corridors. The contour plot for the change in concentration with the project in 2021 (Figure 9-58) also shows complex changes similar to those for NO_2.

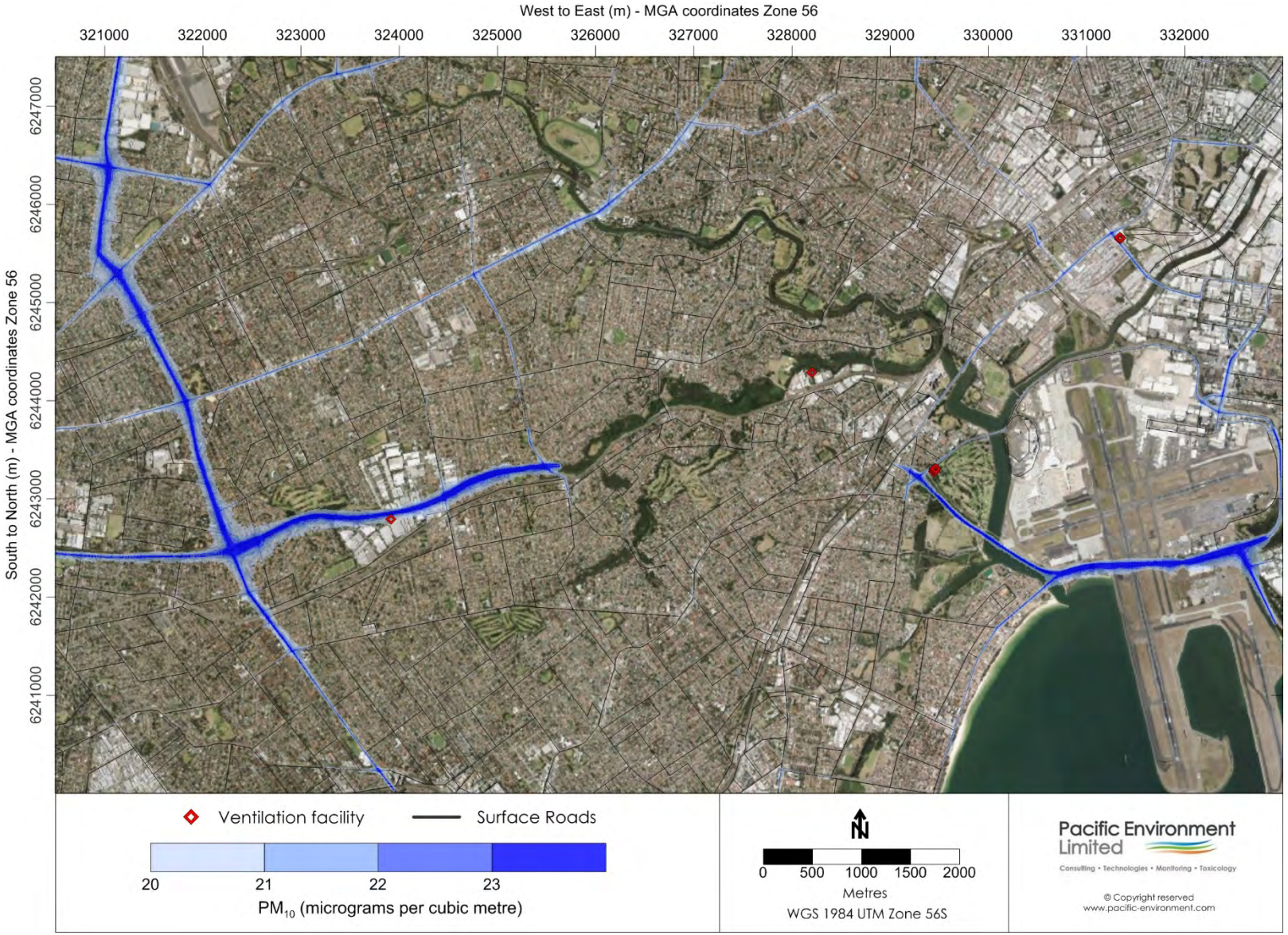


Figure 9-56 Contour plot showing annual mean PM_{10} (2021-DM)

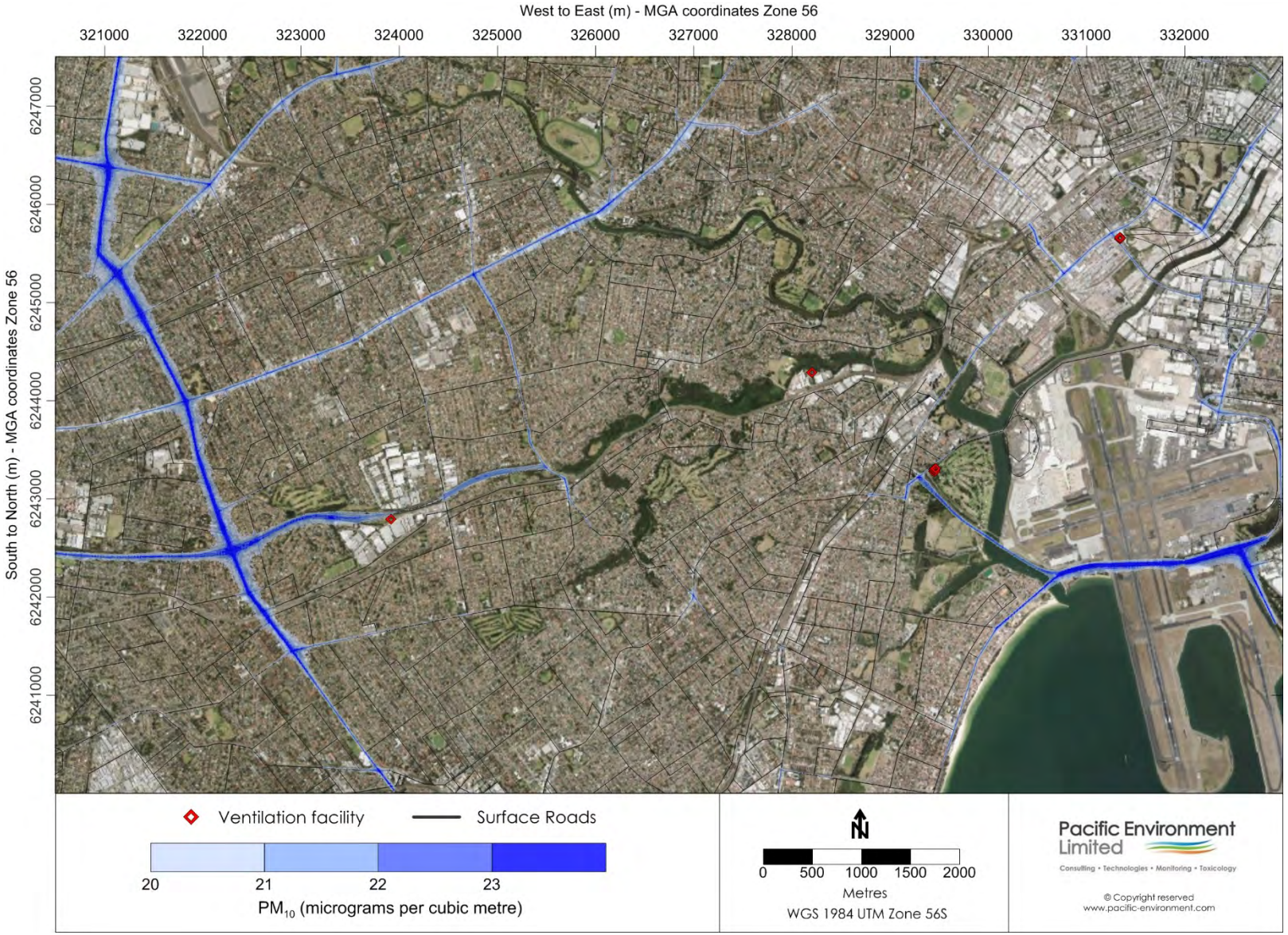


Figure 9-57 Contour plot showing annual mean PM_{10} (2021-DS)



Figure 9-58 Contour plot showing change in annual mean PM_{10} with the project (2021-DS)

Contour plots for ventilation outlets only

The contour plots for annual mean PM_{10} near the New M5 ventilation outlets only are shown in Figure 9-59, Figure 9-60 and Figure 9-61.

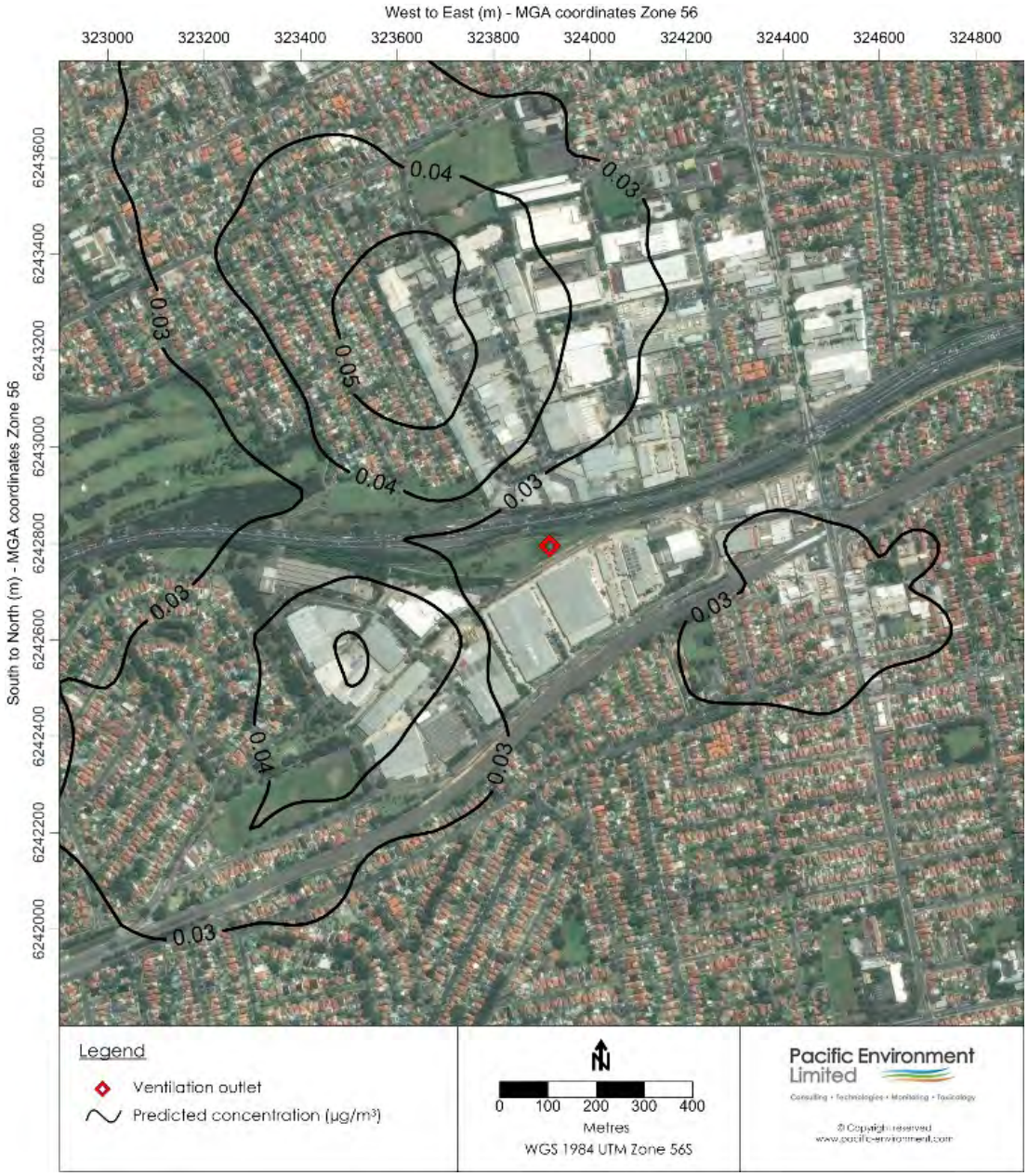


Figure 9-59 Contour plot showing annual mean PM_{10} for ventilation outlets only (Kingsgrove outlet, 2021-DS)

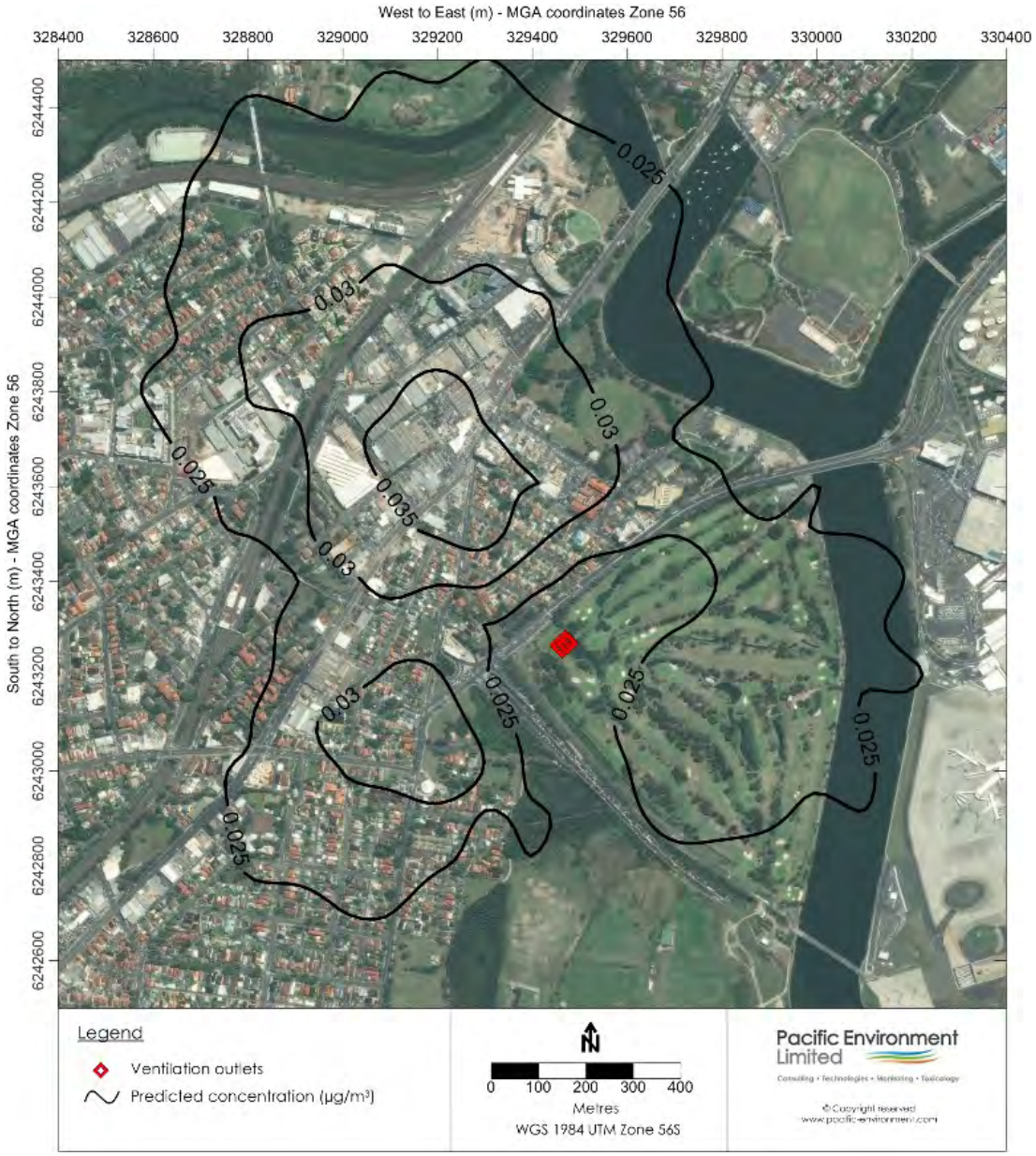


Figure 9-60 Contour plot showing annual mean PM_{10} for ventilation outlets only (Arncliffe outlet, 2021-DS)

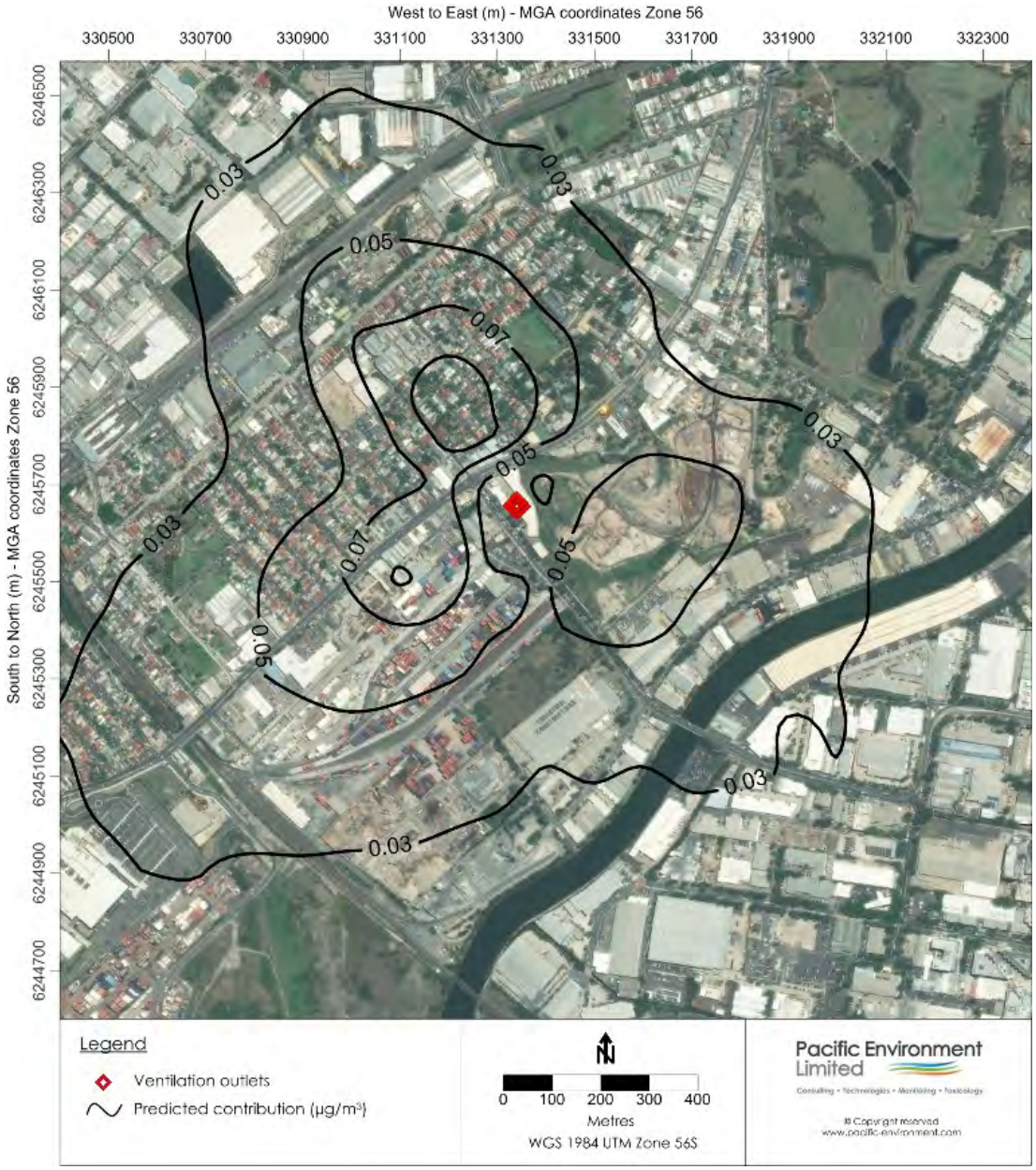


Figure 9-61 Contour plot showing annual mean PM_{10} for ventilation outlets only (SPI outlet, 2021-DS)

For each ventilation outlet, the range of annual mean PM_{10} concentrations across the grid is given in Table 9-28. The maximum value of 0.3 µg/m^3 (SPI, 2031-DSC) is two orders of magnitude lower than the criterion for annual mean PM_{10} of 30 µg/m^3

Table 9-28 Contribution of project ventilation outlets to annual mean PM_{10} concentration in 2 km x 2 km grid around outlet

Ventilation outlet	Outlet contribution to annual mean PM_{10} (µg/m^3)		
	2021-DS	2031-DS	2031-DSC
Kingsgrove	0.02 – 0.05	0.02 – 0.06	0.03 – 0.09
Arncliffe	0.02 – 0.04	0.02 – 0.04	0.05 – 0.10
SPI	0.02 – 0.09	0.01 – 0.09	0.05 – 0.30

9.5.6 PM_{10} (maximum 24-hour mean)

Results for community receptors

The maximum 24-hour mean PM_{10} concentrations at the 35 community receptors with the project in 2021 and 2031 are shown in Figure 9-62. At all receptor locations the maximum concentration was below - but close to - the NSW impact assessment criterion of 50 µg/m^3, which is also the most stringent standard in force internationally. At all by one of the receptors the maximum total 24-hour concentration occurred on one day of the year (10 February), and coincided with the highest 24-hour background concentration in the synthetic PM_{10} profile (44.5 µg/m^3). This provided support for the use of a maximum or high percentile value as the background for the RWR receptors across the New M5 GRAL domain (see section 9.4.8).

The surface road contribution to the maximum 24-hour PM_{10} concentration at each receptor was small (generally <2 µg/m^3), as shown in Figure 9-63. The tunnel ventilation outlet contributions were negligible (mostly less than 0.1 µg/m^3).

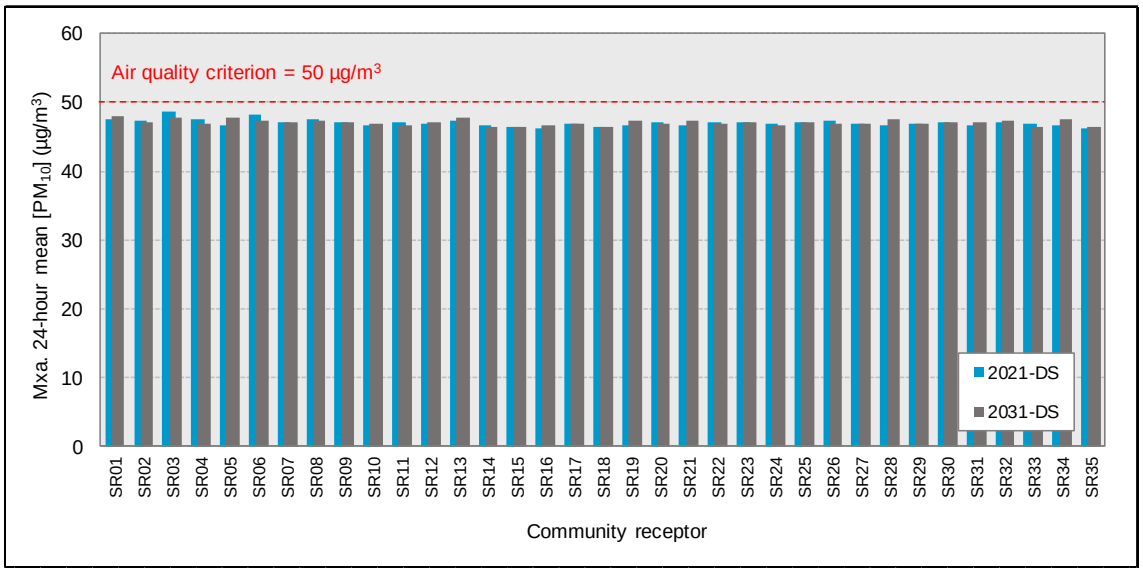


Figure 9-62 Maximum 24-hour PM_{10} at community receptors (2021-DS and 2031-DS)

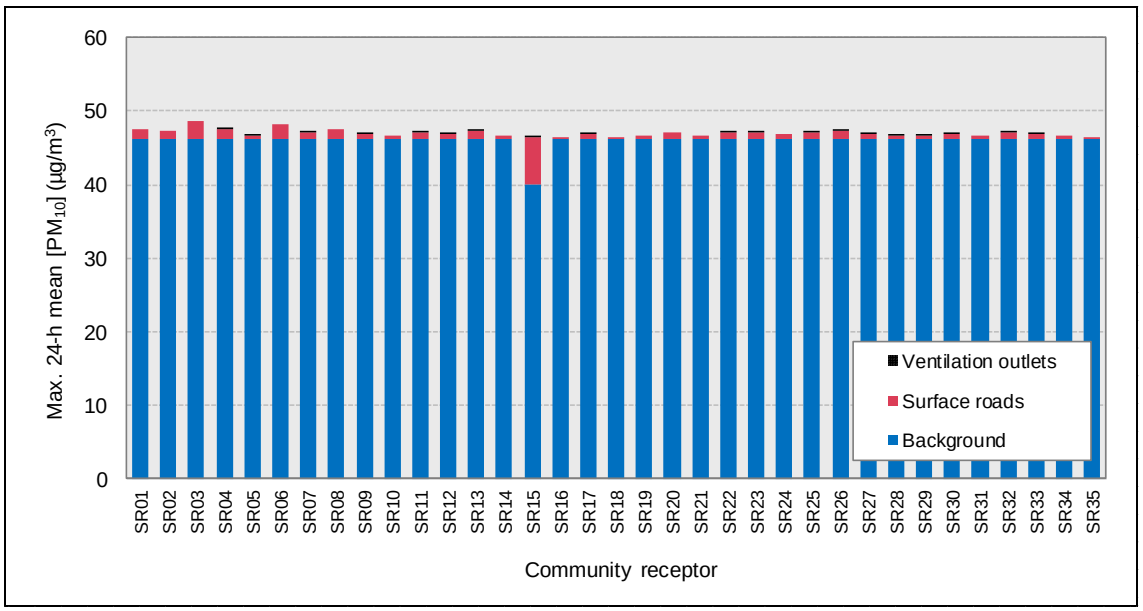


Figure 9-63 Source contributions to maximum 24-hour PM_{10} at community receptors (2021-DS)

Figure 9-64 shows the changes in concentration in the Do Something scenarios relative to the Do Minimum scenarios for the community receptors. The changes were generally small (<1 µg/m^3).

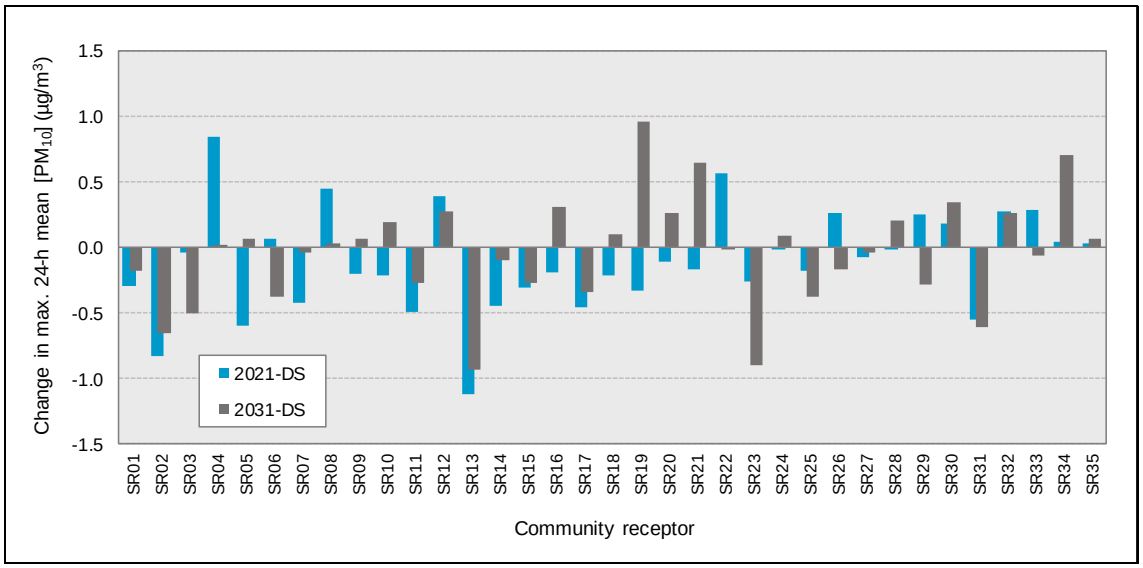


Figure 9-64 Change in maximum 24-hour PM_{10} at community receptors (2021-DS and 2031-DS)

Results for RWR receptors

The ranked maximum 24-hour mean PM_{10} concentrations at the RWR receptors in the 2021-DS scenario are shown in Figure 9-65. The results for the RWR receptors were highly dependent on assumption for the background. The concentration at the majority of receptors was below the NSW impact assessment criterion of 50 µg/m^3. The proportion of receptors with a concentration above the criterion decreased slightly as a result of the project, from 2.6 per cent in the 2021-DM scenario to 2.1 per cent in the 2021-DS scenario. The contributions of surface roads and ventilation outlets were not additive. The maximum contribution of tunnel ventilation outlets at any receptor was 0.5 µg/m^3 in 2021 (1.8 µg/m^3 in 2031).

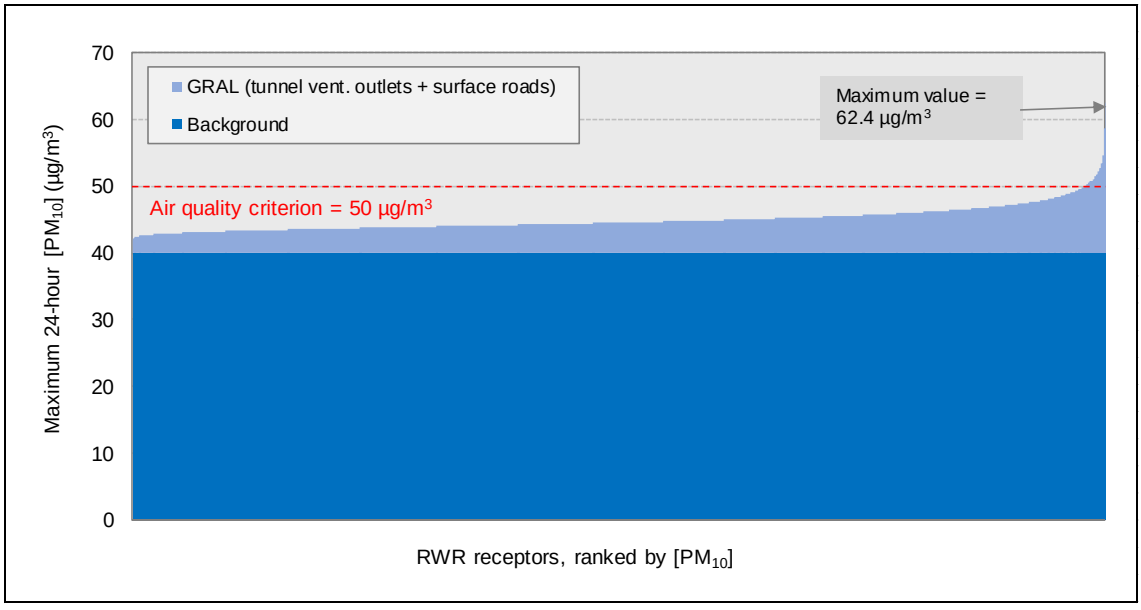


Figure 9-65 Source contributions to maximum 24-hour PM_{10} at RWR receptors (2021-DS)

The changes in the maximum 24-hour mean PM_{10} concentration with the project in 2021 are ranked by change in concentration, in Figure 9-66. There was an increase in concentration at 54 per cent of the receptors. The largest predicted increase in concentration at any receptor as a result of the project in 2021 was 6.8 µg/m^3, and the largest predicted decrease was 18.3 µg/m^3. Where there was an increase this was greater than 2 µg/m^3 at 2.4 per cent of receptors.

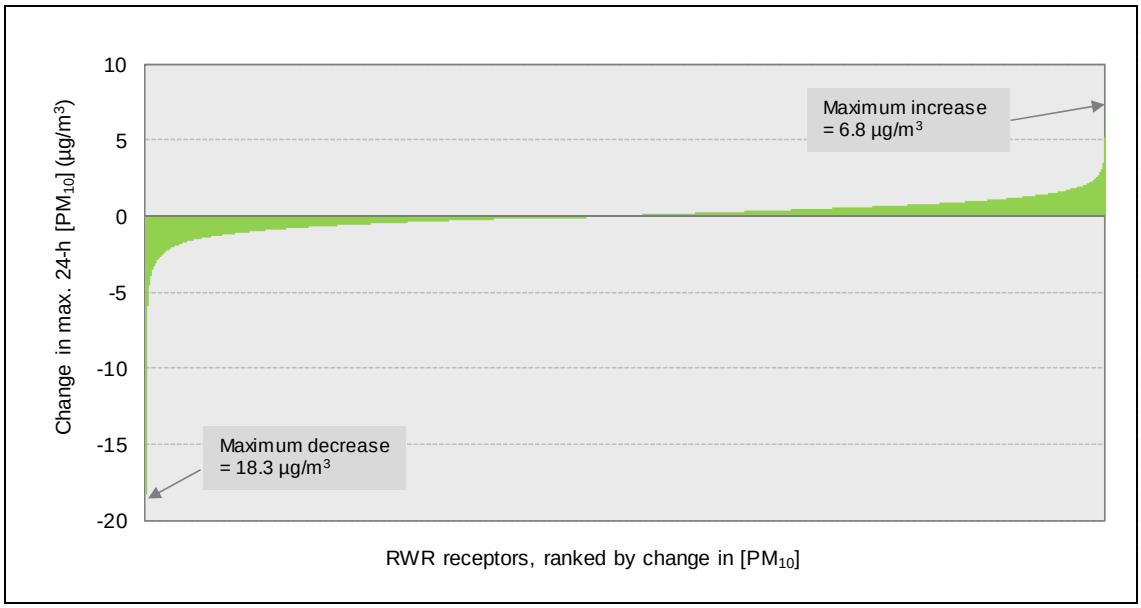


Figure 9-66 Changes in maximum 24-hour PM_{10} at RWR receptors (2021-DS)

Contour plots

The contour plots for maximum 24-hour average PM_{10} in 2021 are given in Figure 9-70, Figure 9-71 and Figure 9-72.

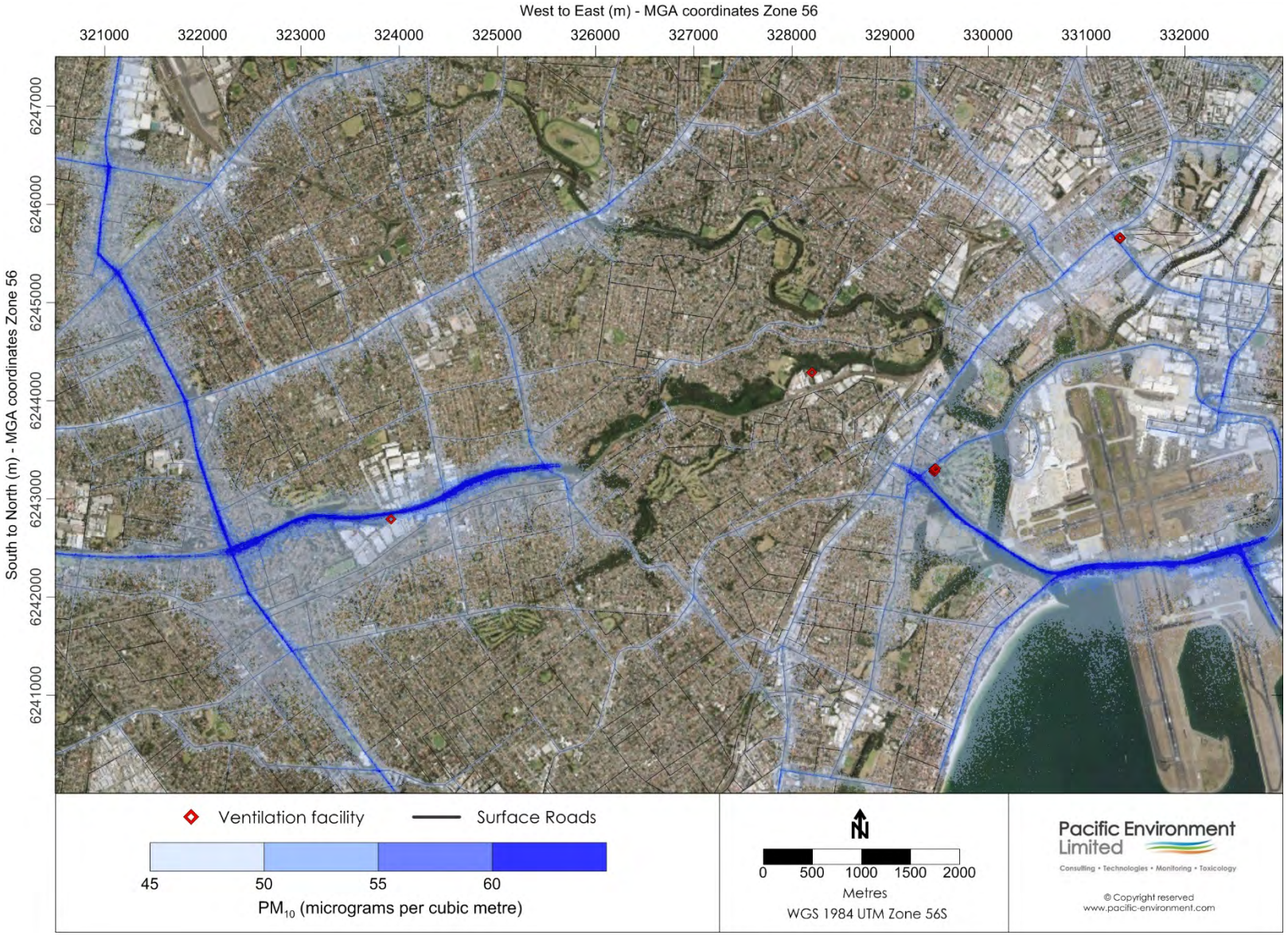


Figure 9-67 Contour plot showing maximum 24-hour average PM_{10} (2021-DM)

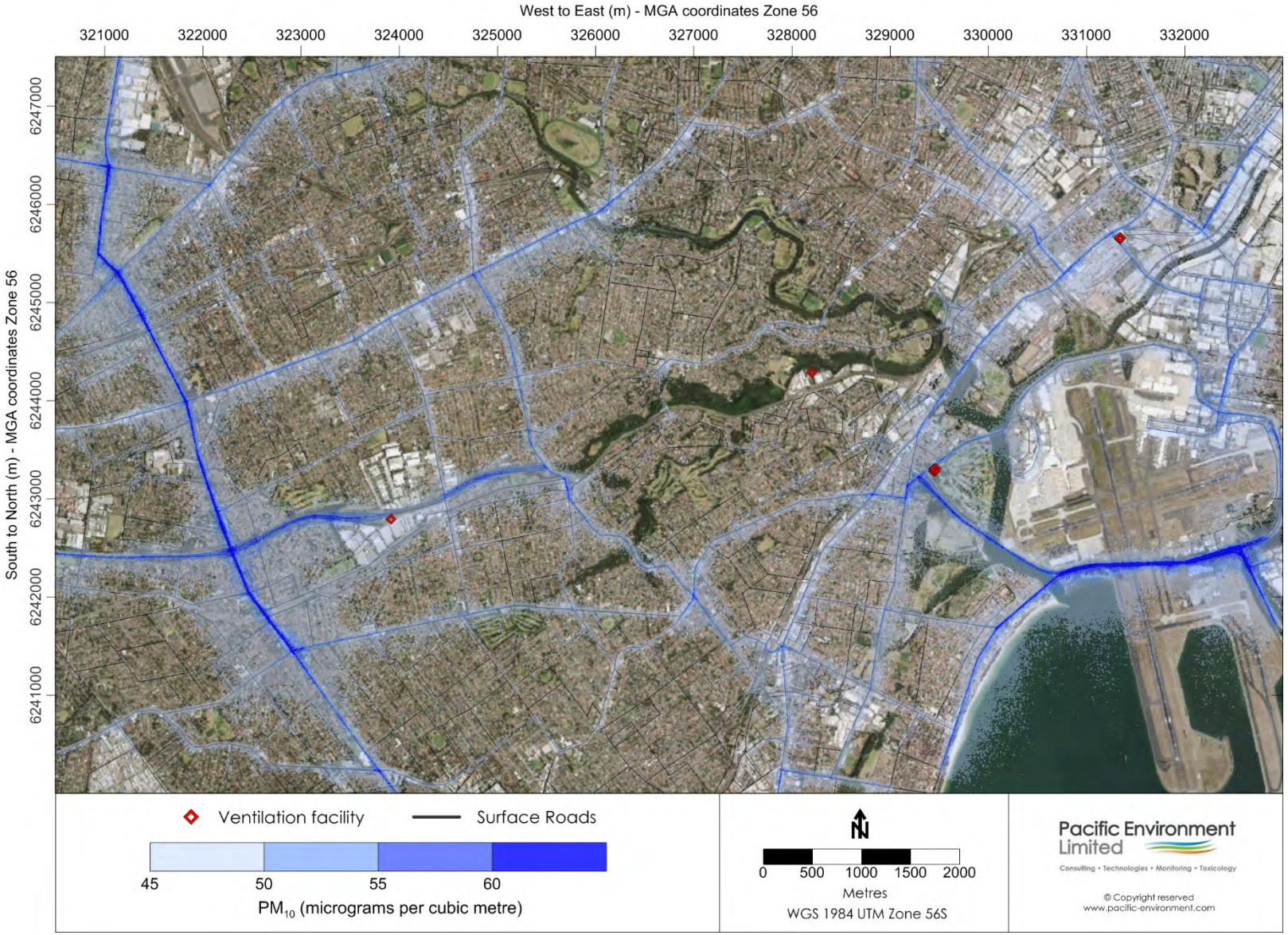


Figure 9-68 Contour plot showing maximum 24-hour average PM_{10} (2021-DS)

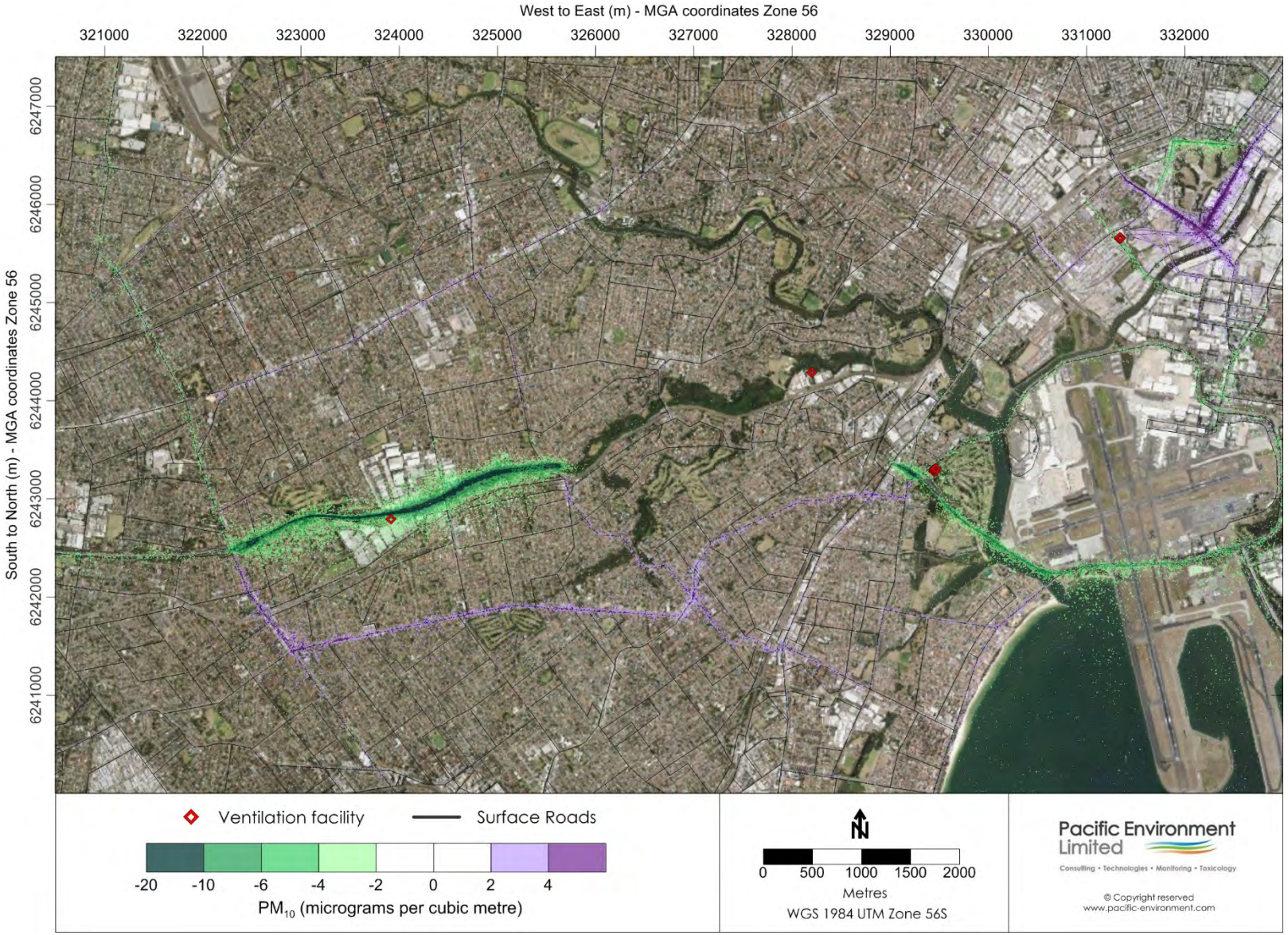


Figure 9-69 Contour plot showing change in maximum 24-hour PM_{10} with the project (2021-DS)

Contour plots for ventilation outlets only

The contour plots for annual mean PM_{10} near the New M5 ventilation outlets only are shown in Figure 9-70, Figure 9-71 and Figure 9-72.



Figure 9-70 Contour plot showing maximum 24-hour PM_{10} for ventilation outlets only (Kingsgrove outlet, 2021-DS)

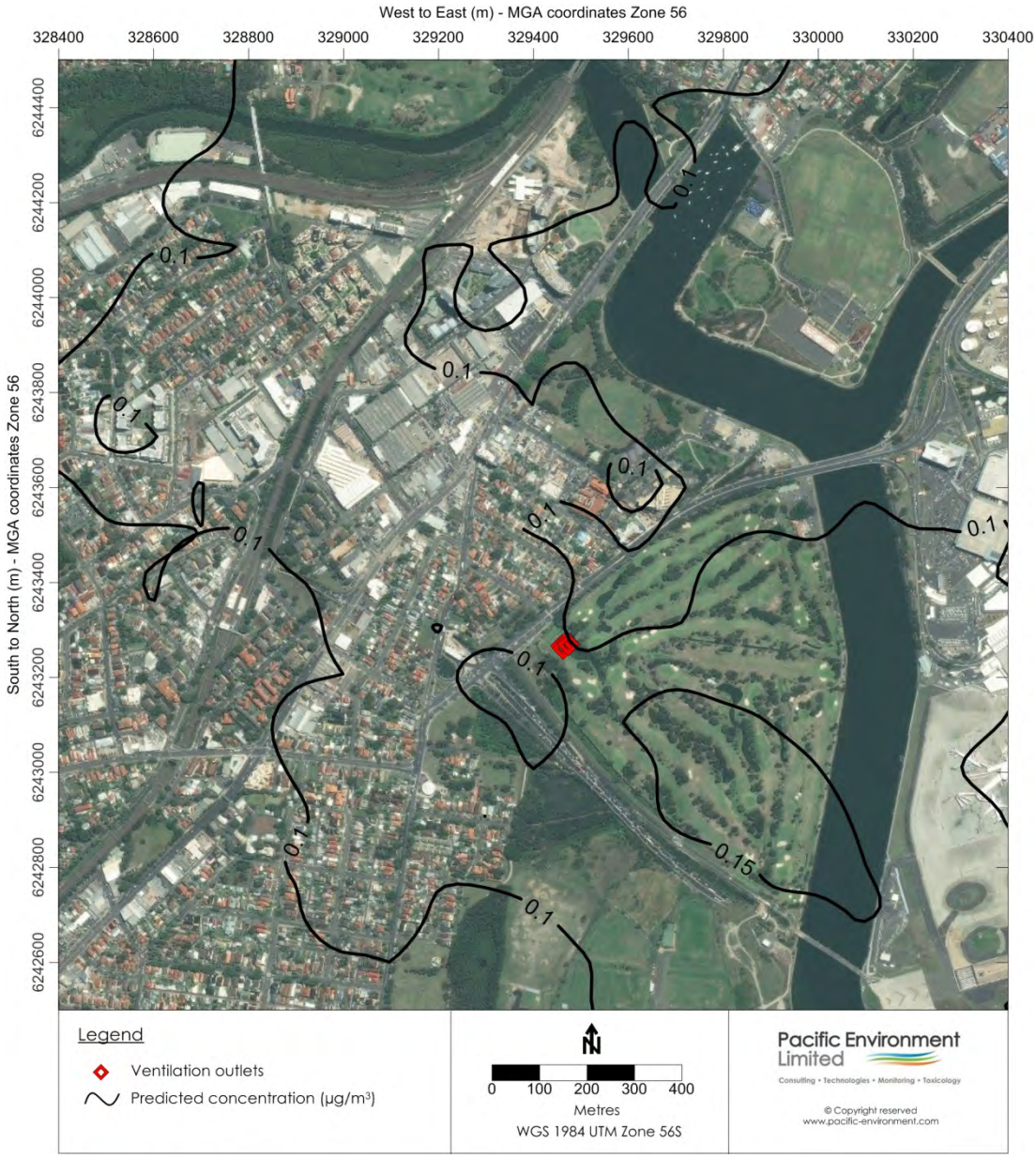


Figure 9-71 Contour plot showing maximum 24-hour PM_{10} for ventilation outlets only (Arncliffe outlet, 2021-DS)

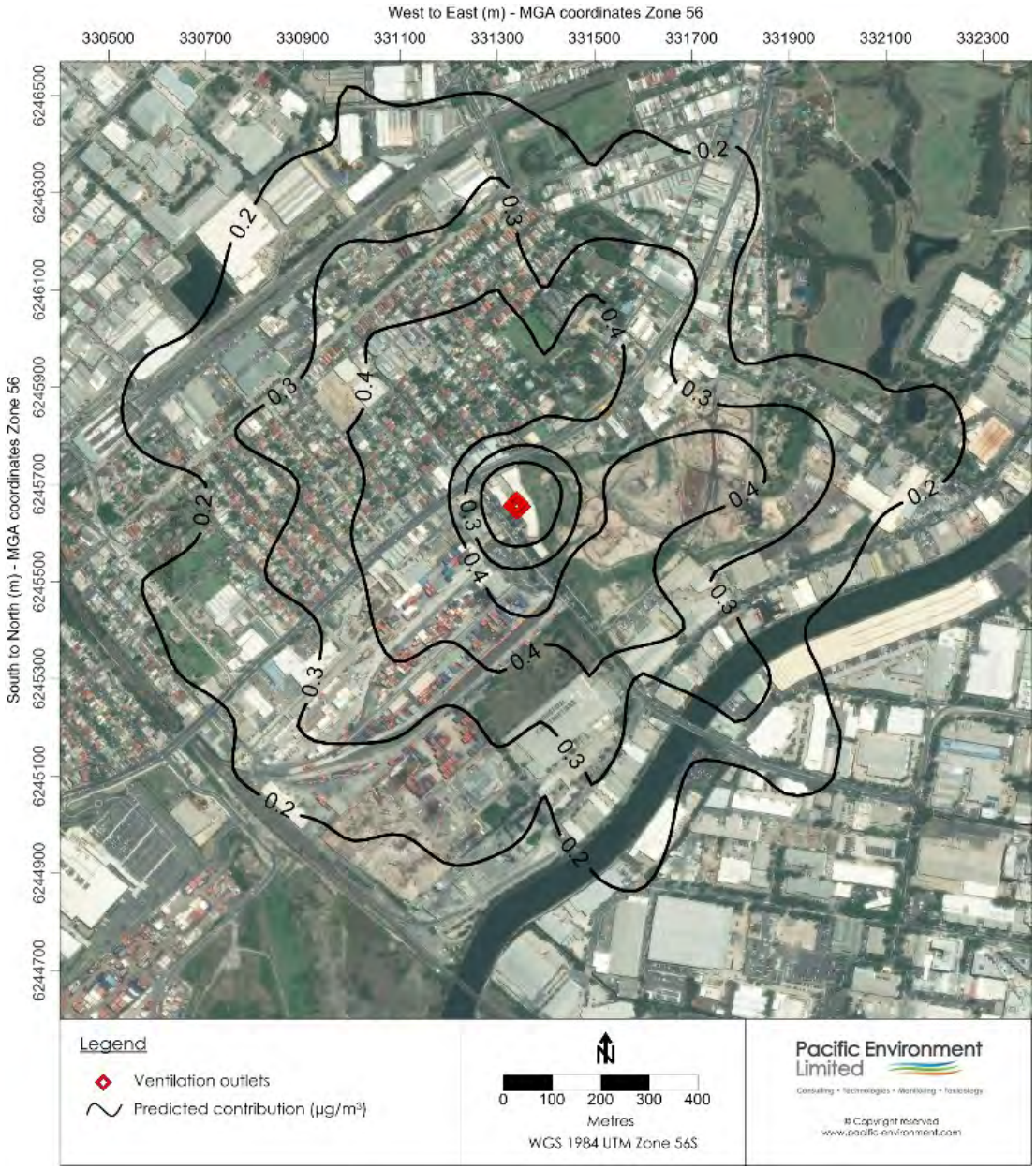


Figure 9-72 **Contour plot showing maximum 24-hour PM_{10} for ventilation outlets only (SPI outlet, 2021-DS)**

For each ventilation outlet, the range of maximum 24-hour PM_{10} concentrations across the grid is given in Table 9-29. The maximum value of 1.5 µg/m^3 (SPI, 2031-DSC) is much lower than the criterion for 24-hour PM_{10} of 50 µg/m^3

Table 9-29 **Contribution of project ventilation outlets to maximum 24-hour PM_{10} concentration in 2 km x 2 km grid around outlet**

Ventilation outlet	Outlet contribution to max. 24-hour PM_{10} (µg/m^3)		
	2021-DS	2031-DS	2031-DSC
Kingsgrove	0.10 – 0.30	0.10 – 0.30	0.10 – 0.40
Arncliffe	0.06 – 0.16	0.06 – 0.17	0.20 – 0.40
SPI	0.10 – 0.40	0.10 – 0.45	0.30 – 1.50

9.5.7 $PM_{2.5}$ (annual mean)

Results for community receptors

The annual mean $PM_{2.5}$ concentrations at the 35 community receptors with the project in 2021 and 2031 are presented in Figure 9-73. The results are based on an assumed background concentration of 8 µg/m^3 (the AAQ NEPM advisory reporting standard), and therefore the Figure shows exceedances at all receptors. Clearly there would also be exceedances of the proposed NSW target of 7 µg/m^3. Internationally, there are no standards lower than 8 µg/m^3 for annual mean $PM_{2.5}$. The next lowest is 12 µg/m^3 (California, Scotland).

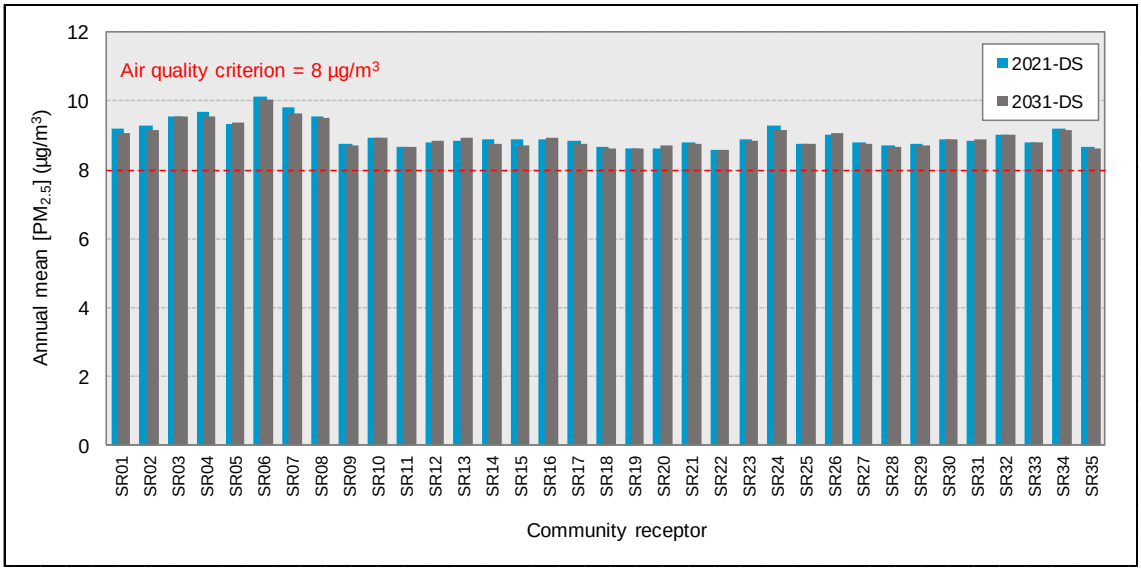


Figure 9-73 Annual mean $PM_{2.5}$ at community receptors (2021-DS and 2031-DS)

Figure 9-74 shows that concentrations were again dominated by the background contribution. The surface road contribution was between 0.6 µg/m^3 and 2.1 µg/m^3. The largest contribution from tunnel ventilation outlets was just 0.06 µg/m^3.

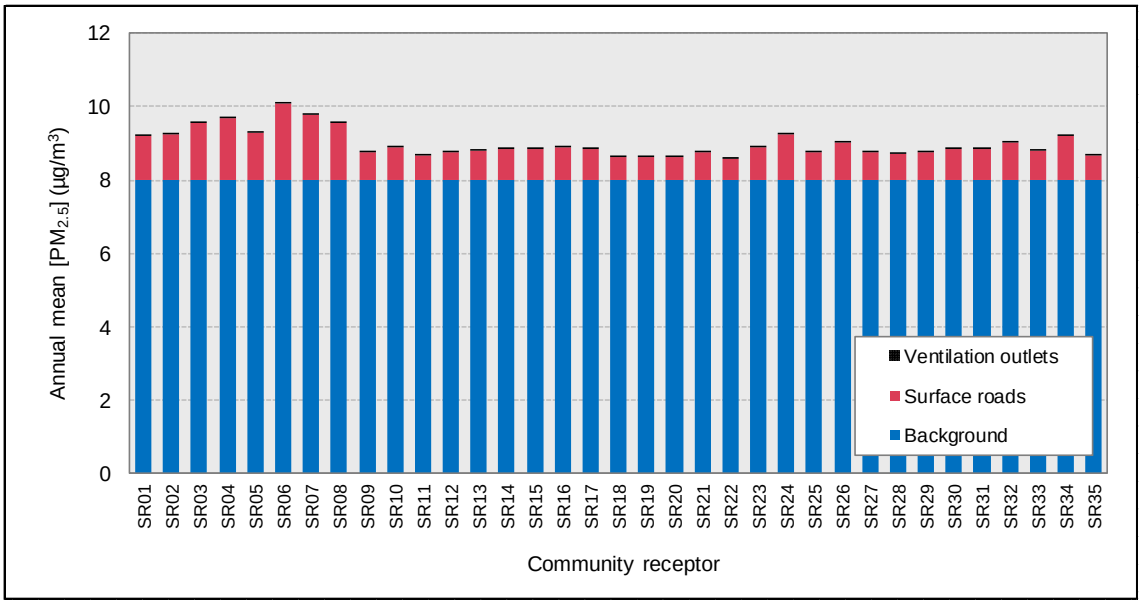


Figure 9-74 Source contributions to annual mean $PM_{2.5}$ at community receptors (2021-DS)

Figure 9-75 shows the changes in $PM_{2.5}$ concentration in the Do Something scenarios relative to the Do Minimum scenarios for the community receptors. The changes in concentration with the project were generally less than ±0.2 µg/m^3. At receptor SR06 (Regina Coeli Catholic Primary School) an increase in concentration of around 0.5 µg/m^3 was predicted in 2021, but the increase in 2031 was much smaller. An increase of just below 0.4 µg/m^3 was predicted in 2031 for receptor SR04 (Beverly Hills Girls High School). These increases represented less than 6% of the air quality criterion for annual mean $PM_{2.5}$.

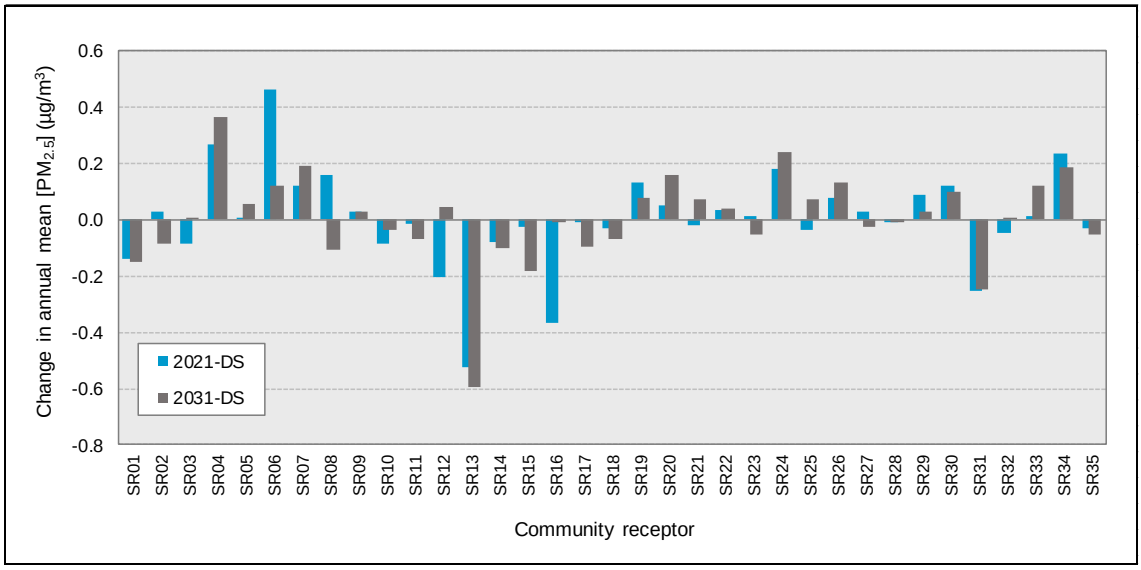


Figure 9-75 Change in annual mean $PM_{2.5}$ at community receptors (2021-DS and 2031-DS)

Results for RWR receptors

The ranked annual mean $PM_{2.5}$ concentrations at the 46,219 RWR receptors in the 2021-DS scenario are shown in Figure 9-76, including the contributions of surface roads and ventilation outlets. As the background concentration was taken to be the same as the NSW criterion of 8 µg/m^3, the concentration at all receptors was above this value. The highest concentration at any receptor in this scenario was 12.7 µg/m^3, but as with other pollutants and metrics the highest values were only predicted for a small proportion of receptors. In 2021 the surface road contribution was between 0.4 µg/m^3 and 4.7 µg/m^3. The largest contribution from tunnel ventilation outlets in both 2021 and 2031 was 0.08 µg/m^3.

The change in the annual mean $PM_{2.5}$ concentration at the RWR receptors in the 2021-DS scenario are ranked in Figure 9-77. The pattern here was similar to that for annual mean PM_{10}. There was an increase in concentration at 63 per cent of the receptors. The largest predicted increase in concentration at any receptor as a result of the project in 2021 was 1.2 µg/m^3, and the largest predicted decrease was 3.5 µg/m^3. Where there was an increase this was greater than 0.5 µg/m^3 at only 0.04 per cent of receptors.

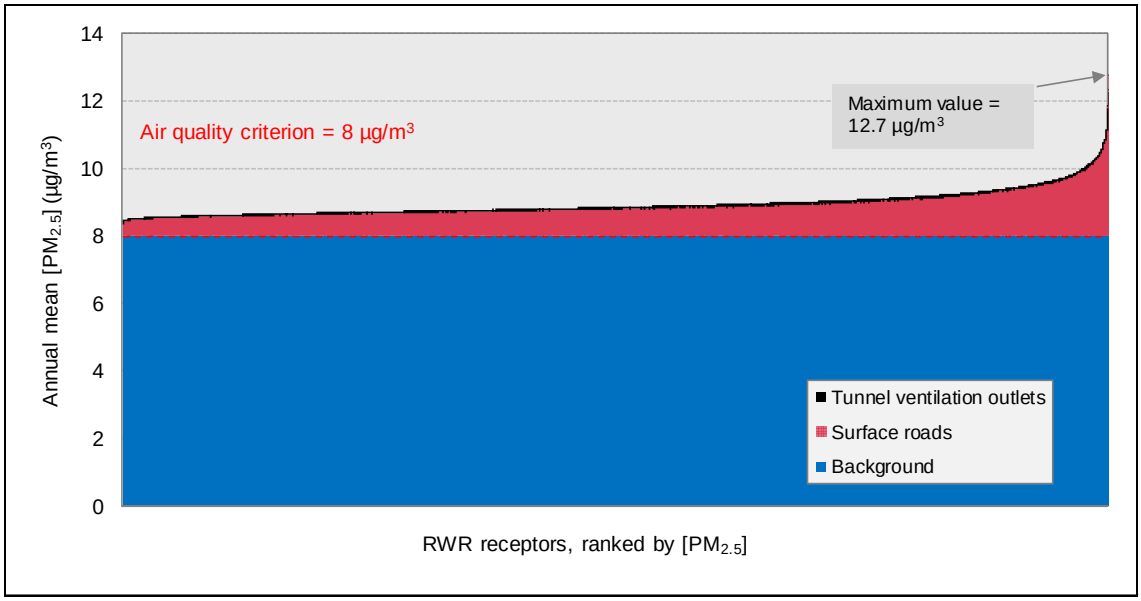


Figure 9-76 Source contributions to annual mean $PM_{2.5}$ at RWR receptors (2021-DS)

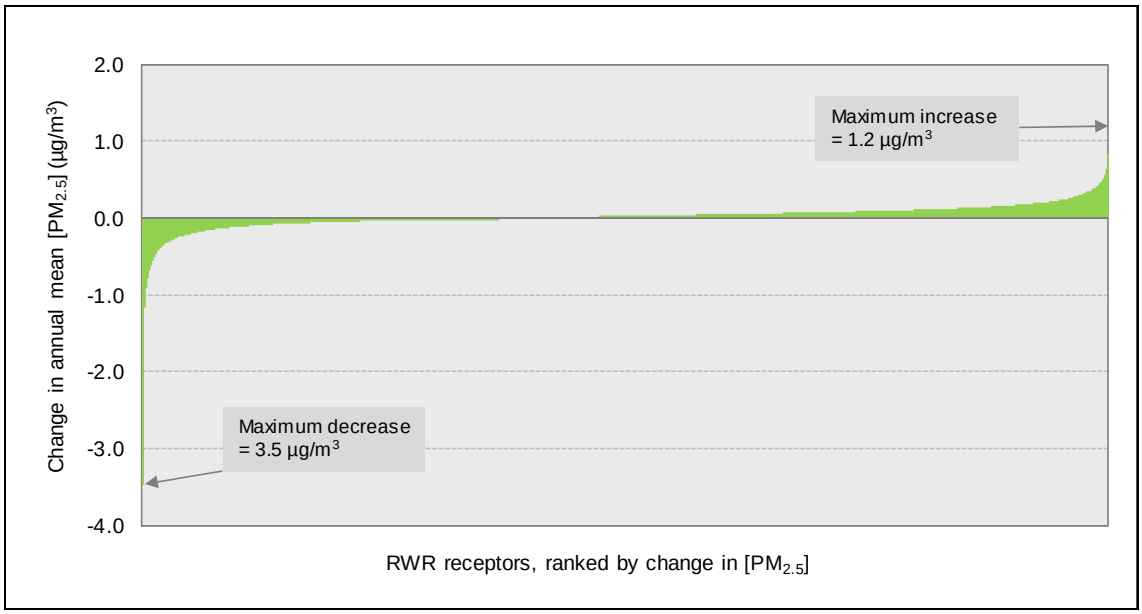


Figure 9-77 Changes in annual mean $PM_{2.5}$ at RWR receptors (2021-DS)

Contour plots – all sources

The contour plots for absolute annual mean $PM_{2.5}$ in 2021 are given in Figure 9-78 (Do Minimum) and Figure 9-79 (Do Something). The contour plot for the change in concentration with the project in 2021 is shown in Figure 9-80.



Figure 9-78 Contour plot showing annual mean $PM_{2.5}$ (2021-DM)

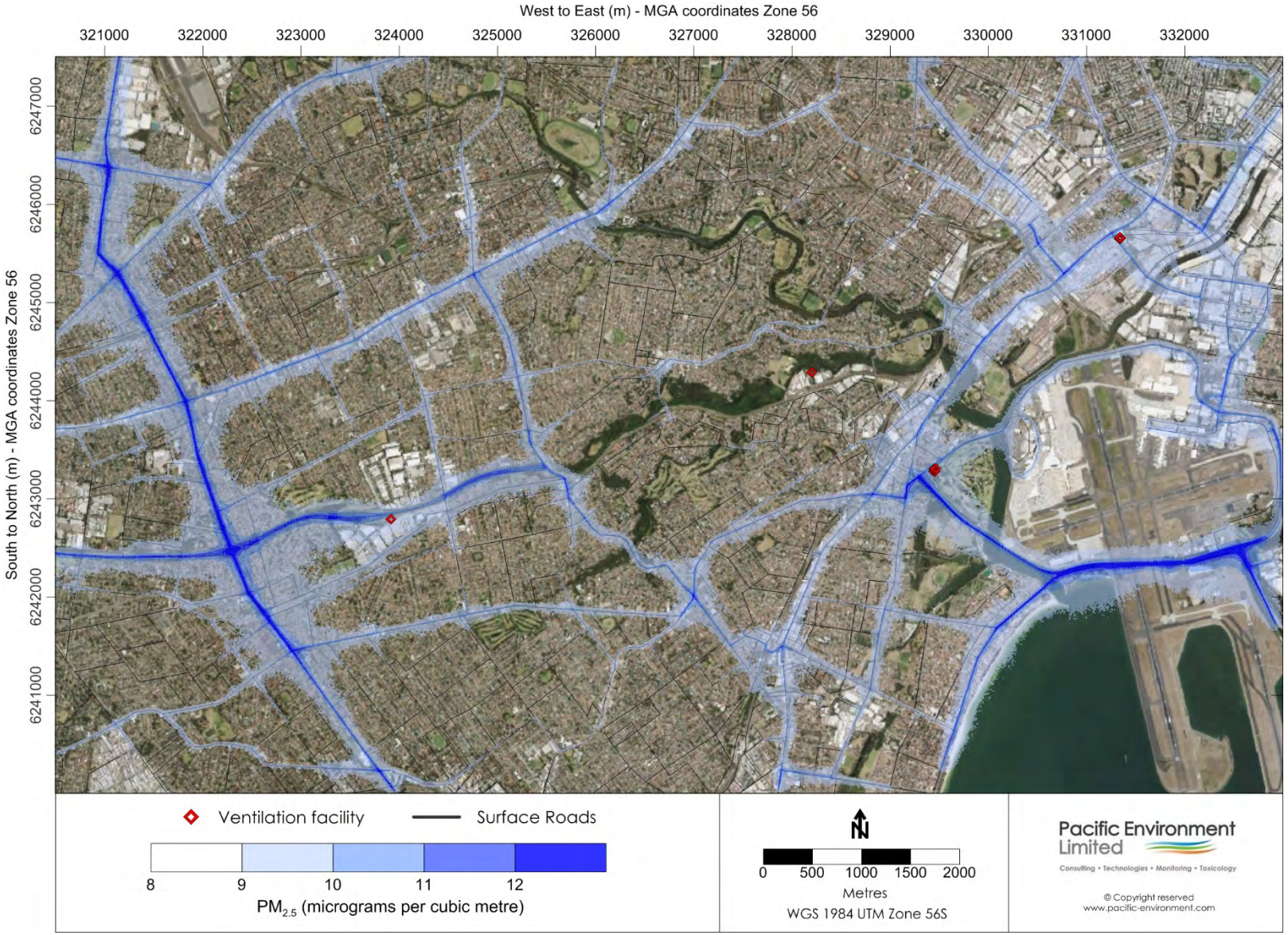


Figure 9-79 Contour plot showing annual mean $PM_{2.5}$ (2021-DS)

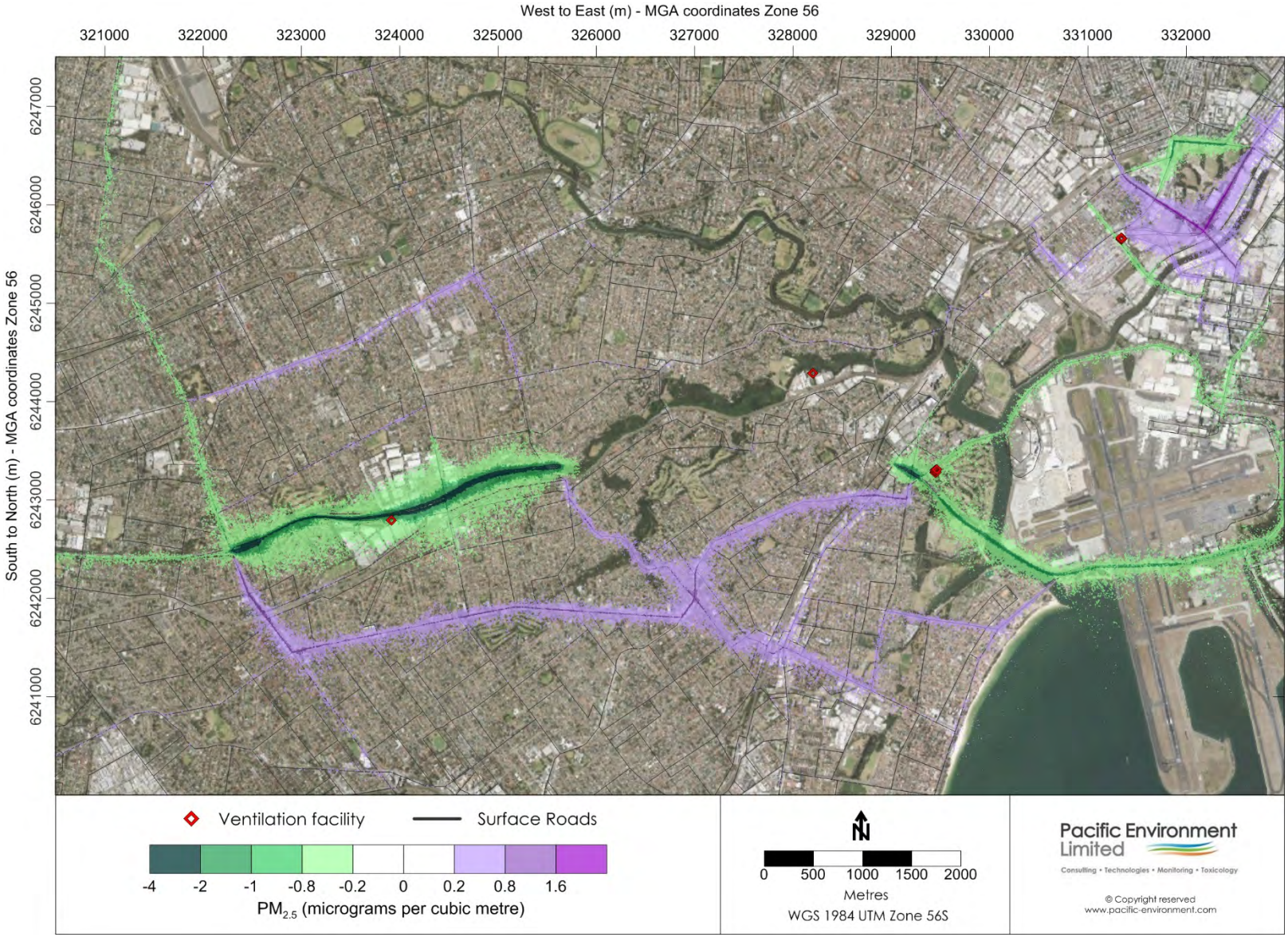


Figure 9-80 Contour plot showing change in annual mean $PM_{2.5}$ with the project (2021-DS)

Contour plots for ventilation outlets only

The contour plots for annual mean $PM_{2.5}$ for the New M5 ventilation outlets only are shown in Figure 9-81, Figure 9-82 and Figure 9-83.

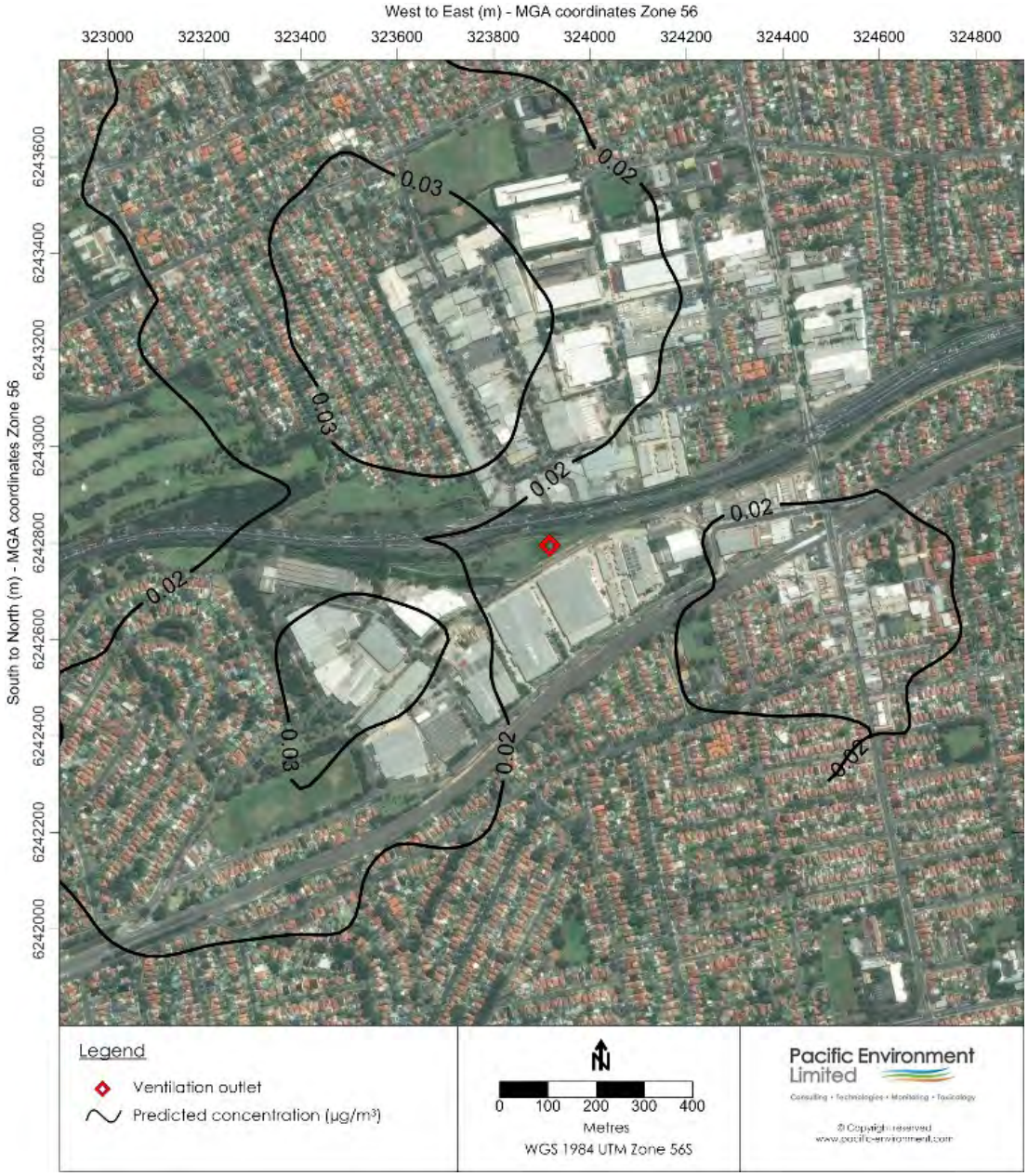


Figure 9-81 Contour plot showing annual mean $PM_{2.5}$ for ventilation outlets only (Kingsgrove outlet, 2021-DS)

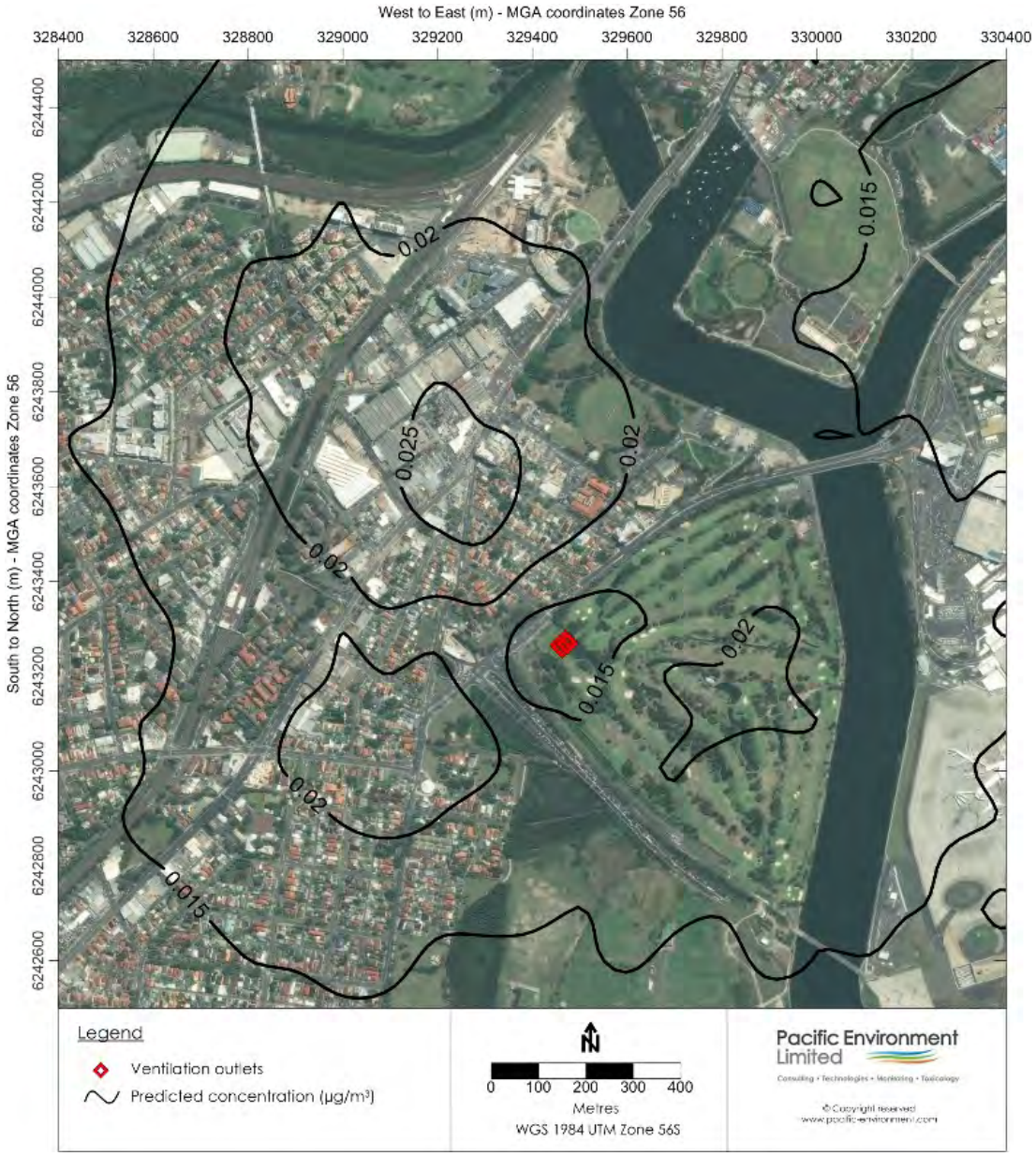


Figure 9-82 Contour plot showing annual mean $PM_{2.5}$ for ventilation outlets only (Arncliffe outlet, 2021-DS)

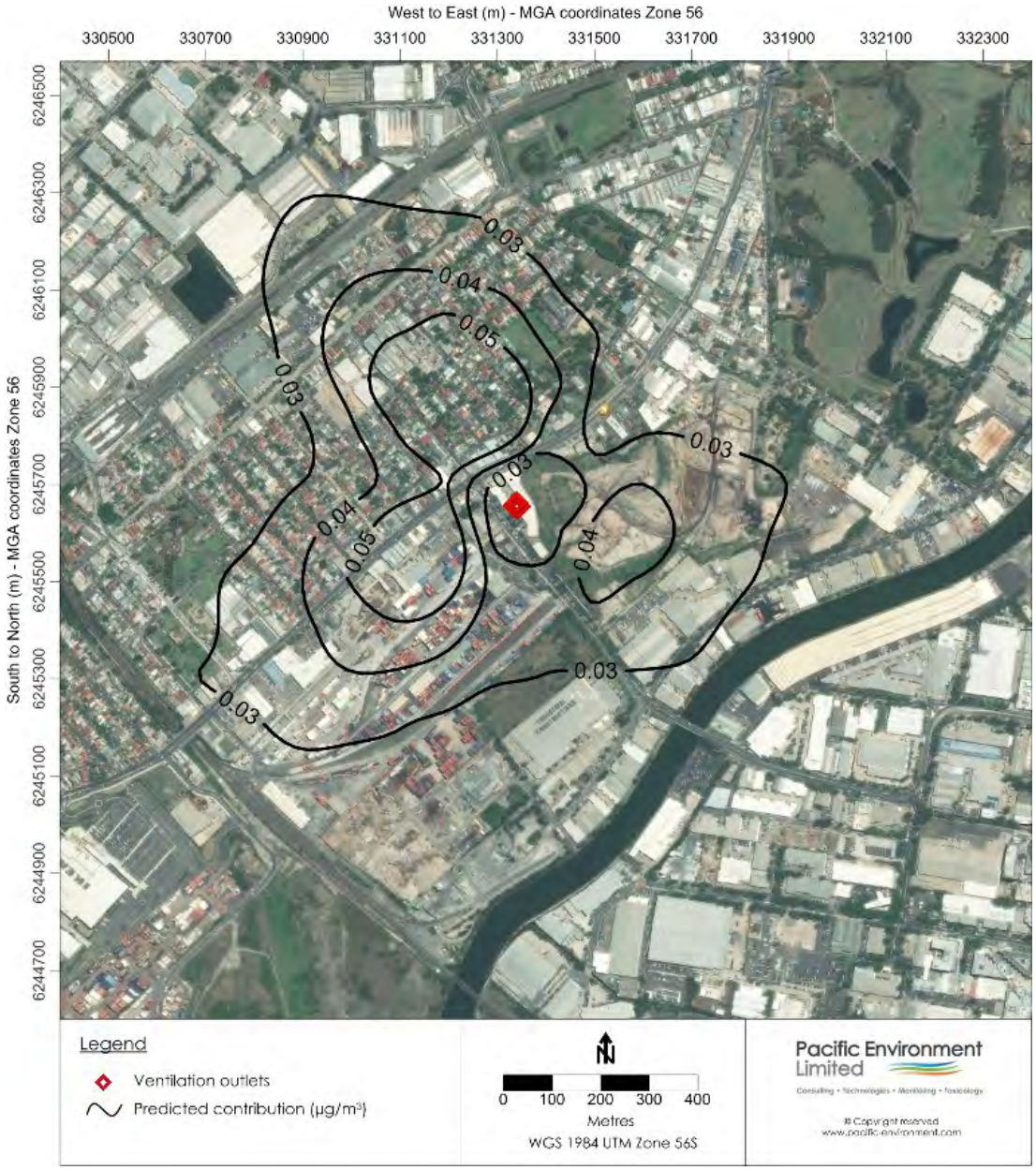


Figure 9-83 Contour plot showing annual mean $PM_{2.5}$ for ventilation outlets only (SPI outlet, 2021-DS)

For each ventilation outlet, the range of annual mean $PM_{2.5}$ concentrations across the grid is given in Table 9-30. The maximum value of 0.2 µg/m^3 (SPI, 2031-DSC) is much lower than the criterion for annual mean $PM_{2.5}$ of 8 µg/m^3

Table 9-30 Contribution of project ventilation outlets to annual mean $PM_{2.5}$ concentration in 2 km x 2 km grid around outlet

Ventilation outlet	Outlet contribution to annual mean $PM_{2.5}$ (µg/m^3)		
	2021-DS	2031-DS	2031-DSC
Kingsgrove	0.01 – 0.04	0.01 – 0.04	0.02 – 0.05
Arncliffe	0.01 – 0.03	0.01 – 0.03	0.04 – 0.07
SPI	0.01 – 0.06	0.01 – 0.06	0.05 – 0.20

9.5.8 $PM_{2.5}$ (maximum 24-hour mean)

Results for community receptors

The maximum 24-hour mean $PM_{2.5}$ concentrations at the community receptors with the project in 2021 and 2031 are shown in Figure 9-84. At most receptor locations the maximum concentration was below - but close to – the NSW impact assessment criterion of 25 µg/m^3. There were predicted exceedances at five of the community receptors with the project in 2021, although at two of these five receptors exceedances were already predicted without the project. It is also noted later in this section that the project resulted in an overall decrease in the overall total number of exceedances across all receptors.

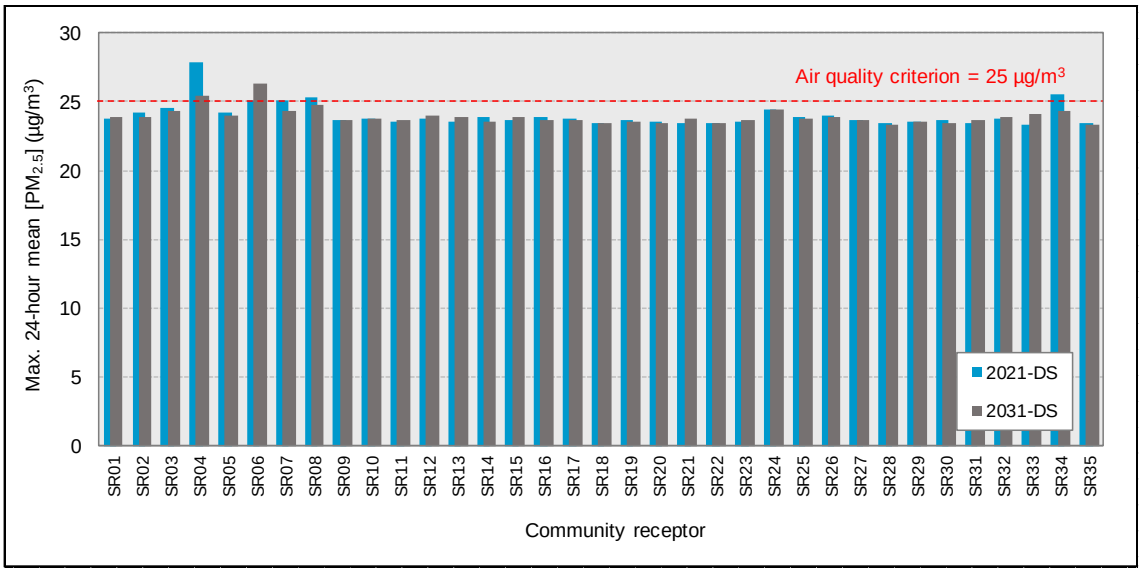


Figure 9-84 Maximum 24-hour mean $PM_{2.5}$ at community receptors (2021-DS and 2031-DS)

Internationally, there are no standards lower than 25 µg/m^3 for 24-hour $PM_{2.5}$. However, a target of 20 µg/m^3 is proposed for NSW, and the results suggest that this will be difficult to achieve in the study area at present.

The road contributions to the maximum 24-hour $PM_{2.5}$ concentration in 2021 were relatively small, except in a few cases, as shown in Figure 9-85. The tunnel ventilation outlet contributions were negligible (≤0.2 µg/m^3).

At all community receptors the maximum total 24-hour concentration occurred on one of three dates, and two of these coincided with the highest 24-hour background concentrations in the synthetic $PM_{2.5}$ profile (21.4 and 23.1 µg/m^3). As with PM_{10}, this provides support for the use of a maximum or high percentile value as the background across the New M5 GRAL domain for the RWR receptors.

Figure 9-86 shows the changes in concentration in the Do Something scenarios relative to the Do Minimum scenarios for the community receptors. The changes were generally small (<0.5 µg/m^3), although there were some changes of up to around 3 µg/m^3 at some receptors.

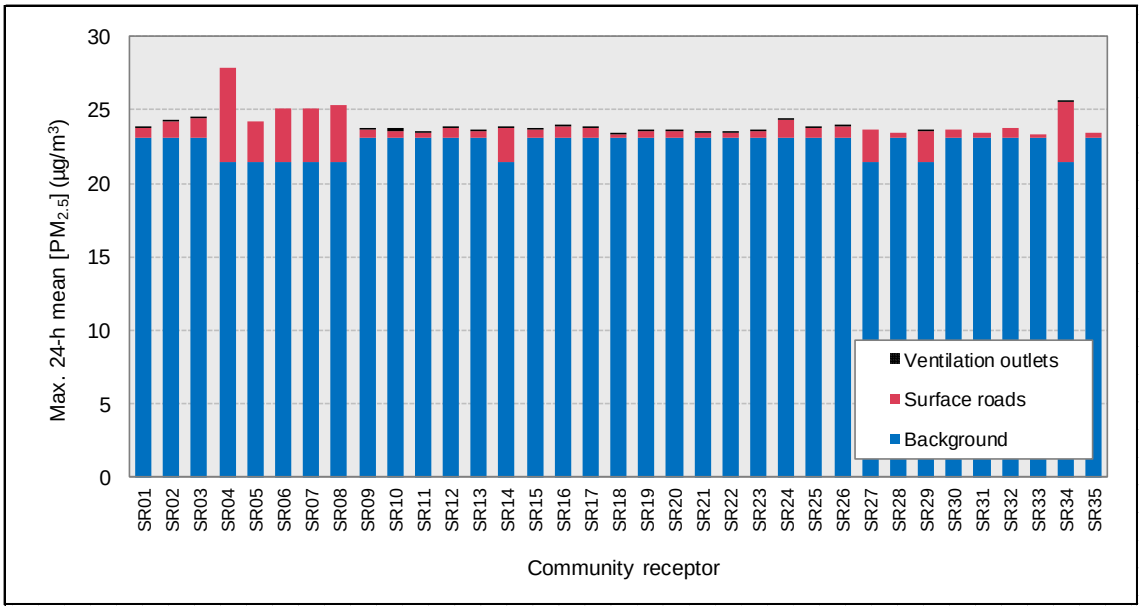


Figure 9-85 Source contributions to maximum 24-hour $PM_{2.5}$ at community receptors (2021-DS)

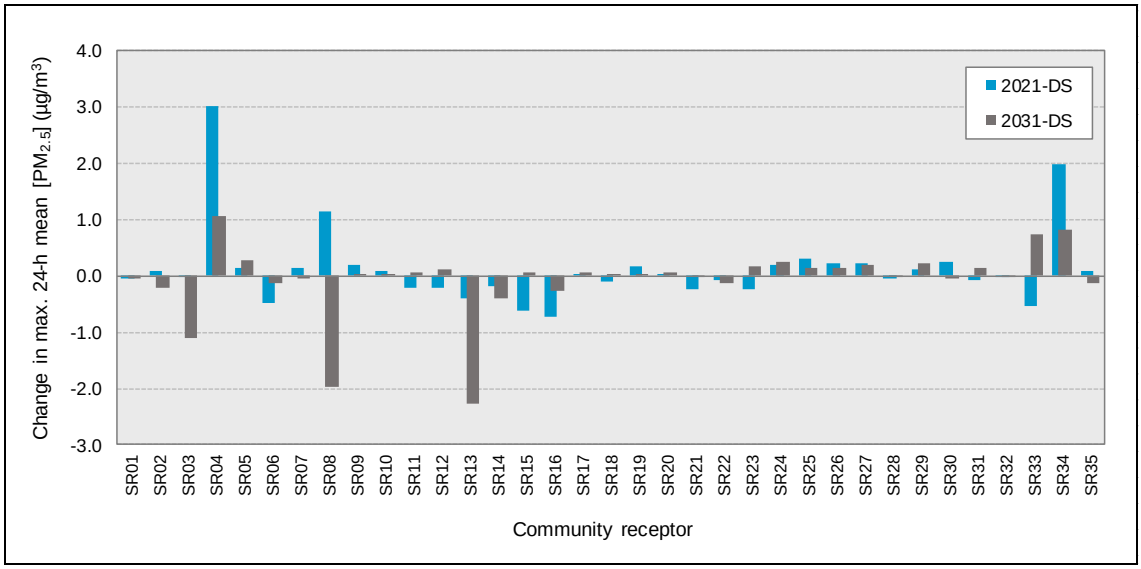


Figure 9-86 Change in maximum 24-hour mean $PM_{2.5}$ at community receptors (2021-DS and 2031-DS)

Results for RWR receptors

The ranked maximum 24-hour mean $PM_{2.5}$ concentrations at the RWR receptors in the 2021-DS scenario are shown in Figure 9-87. The concentration at the majority of receptors was below the NSW impact assessment criterion of 25 µg/m^3. In 2021 the proportion of receptors with a concentration above the criterion decreased from 4.0 per cent in the 2021-DM scenario to 3.2 per cent in the 2021-DS scenario. As with PM_{10}, the contributions of surface roads and ventilation outlets are not shown separately as these were not additive. The maximum contribution of tunnel outlets at any receptor in was 0.39 µg/m^3 in both 2021 and 2031.

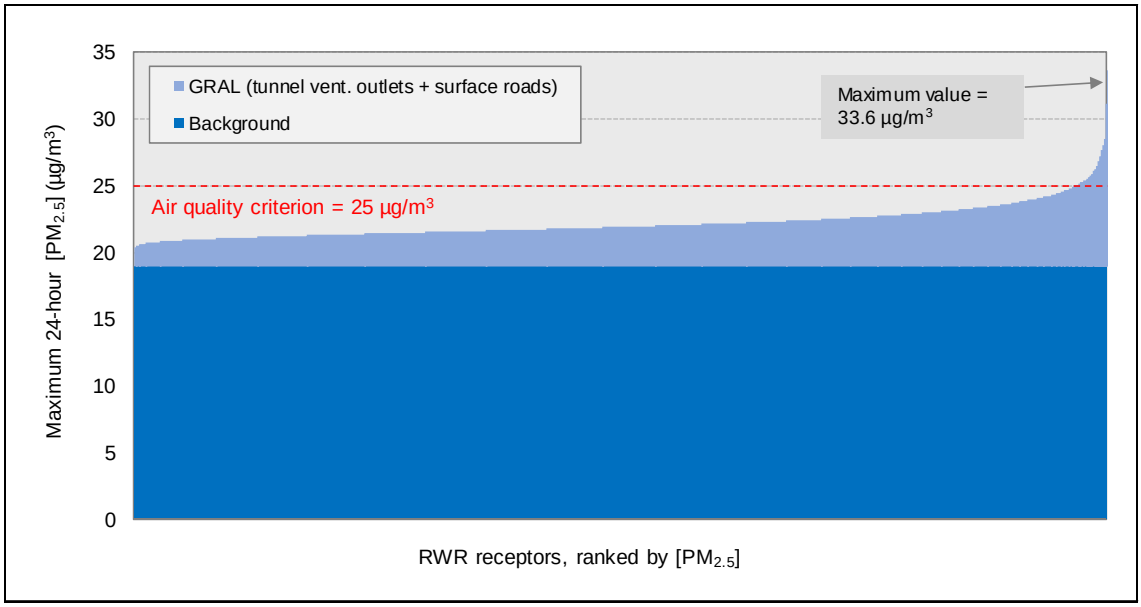


Figure 9-87 Source contributions to maximum 24-hour $PM_{2.5}$ at RWR receptors (2021-DS)

The changes in the maximum 24-hour mean $PM_{2.5}$ concentration at the RWR receptors in the 2021-DS scenario are ranked in Figure 9-88. There was an increase in concentration at 53 per cent of the receptors. The largest predicted increase in concentration at any receptor as a result of the project in 2021 was 4.9 µg/m^3, and the largest predicted decrease was 10.6 µg/m^3. Where there was an increase this was greater than 1 µg/m^3 at 5.3 per cent of receptors.

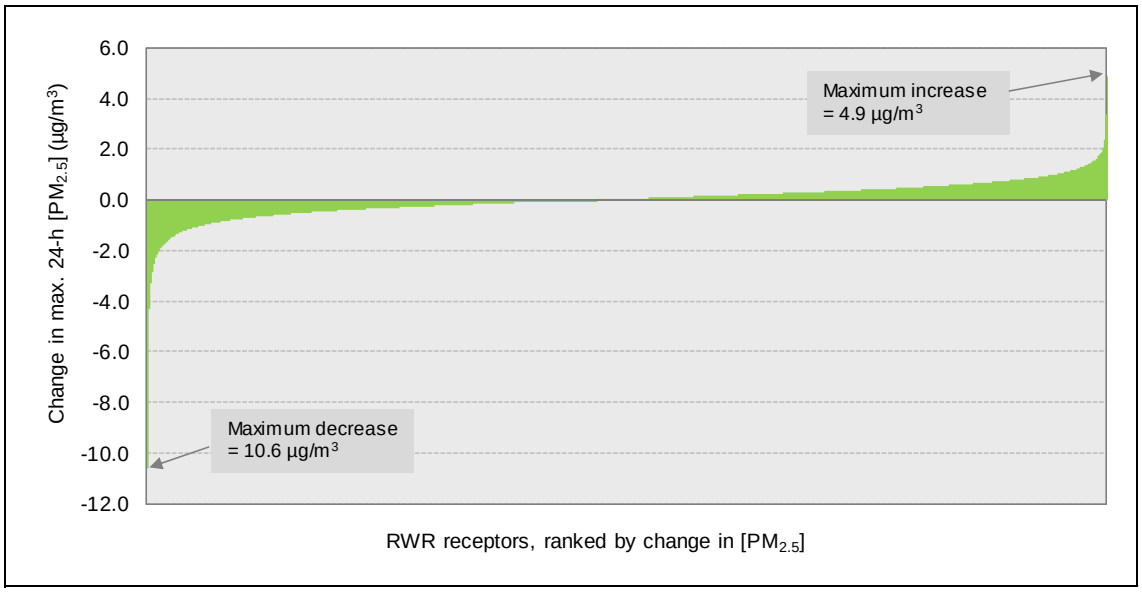


Figure 9-88 Changes in maximum 24-hour $PM_{2.5}$ at RWR receptors (2021-DS)

Contour plots

The contour plots for maximum 24-hour $PM_{2.5}$ in 2021 are given in Figure 9-89 (Do Minimum) and Figure 9-90 (Do Something). The changes with the project in 2021 are shown in Figure 9-91. The equivalent plots for 2031 are presented in Appendix K. Again, elevated concentrations are evident along the major road corridors. The spatial changes are broadly similar to those for annual mean $PM_{2.5}$.



Figure 9-89 Contour plot showing maximum 24-hour average $PM_{2.5}$ (2021-DM)

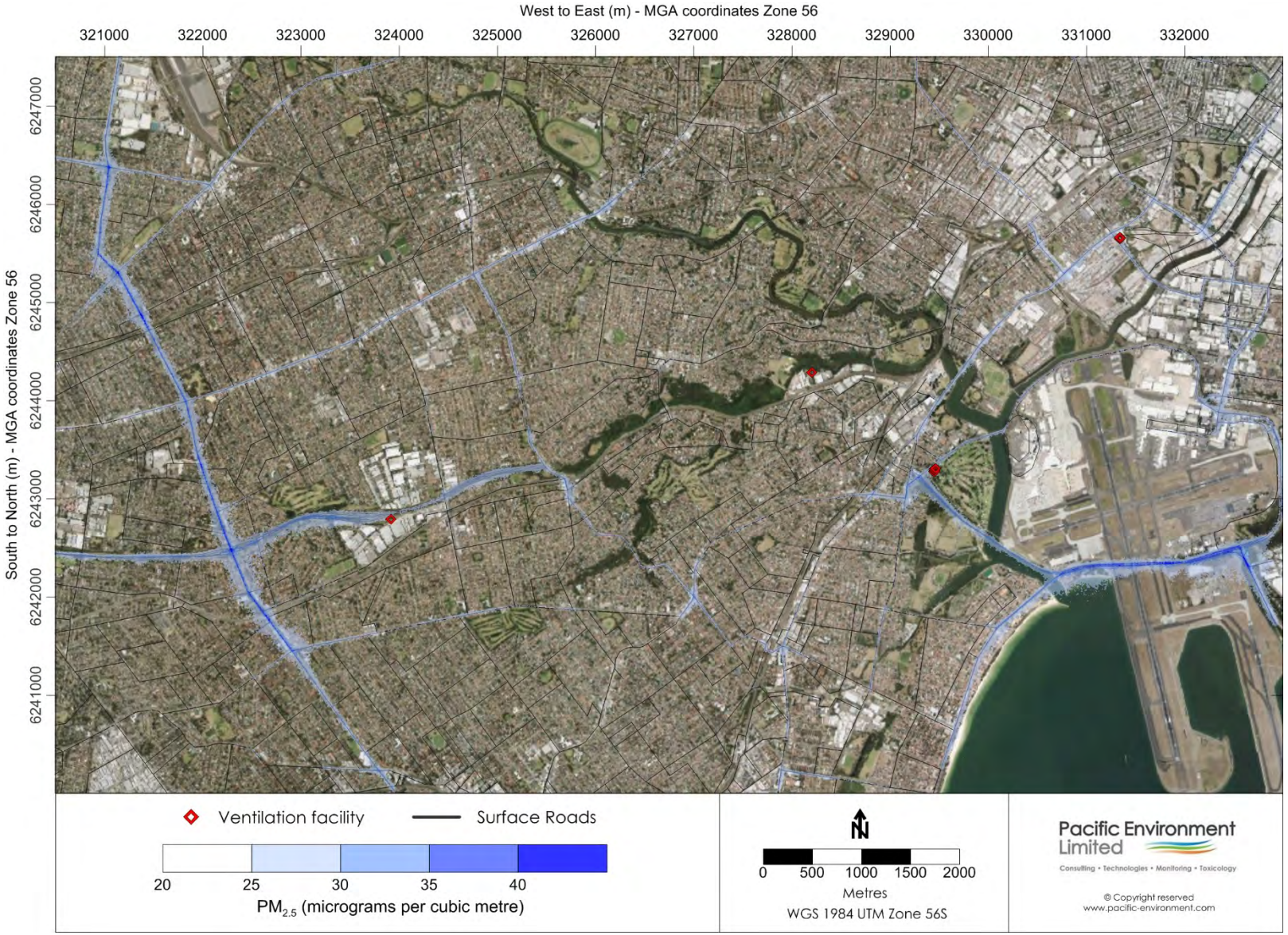


Figure 9-90 Contour plot showing maximum 24-hour average $PM_{2.5}$ (2021-DS)

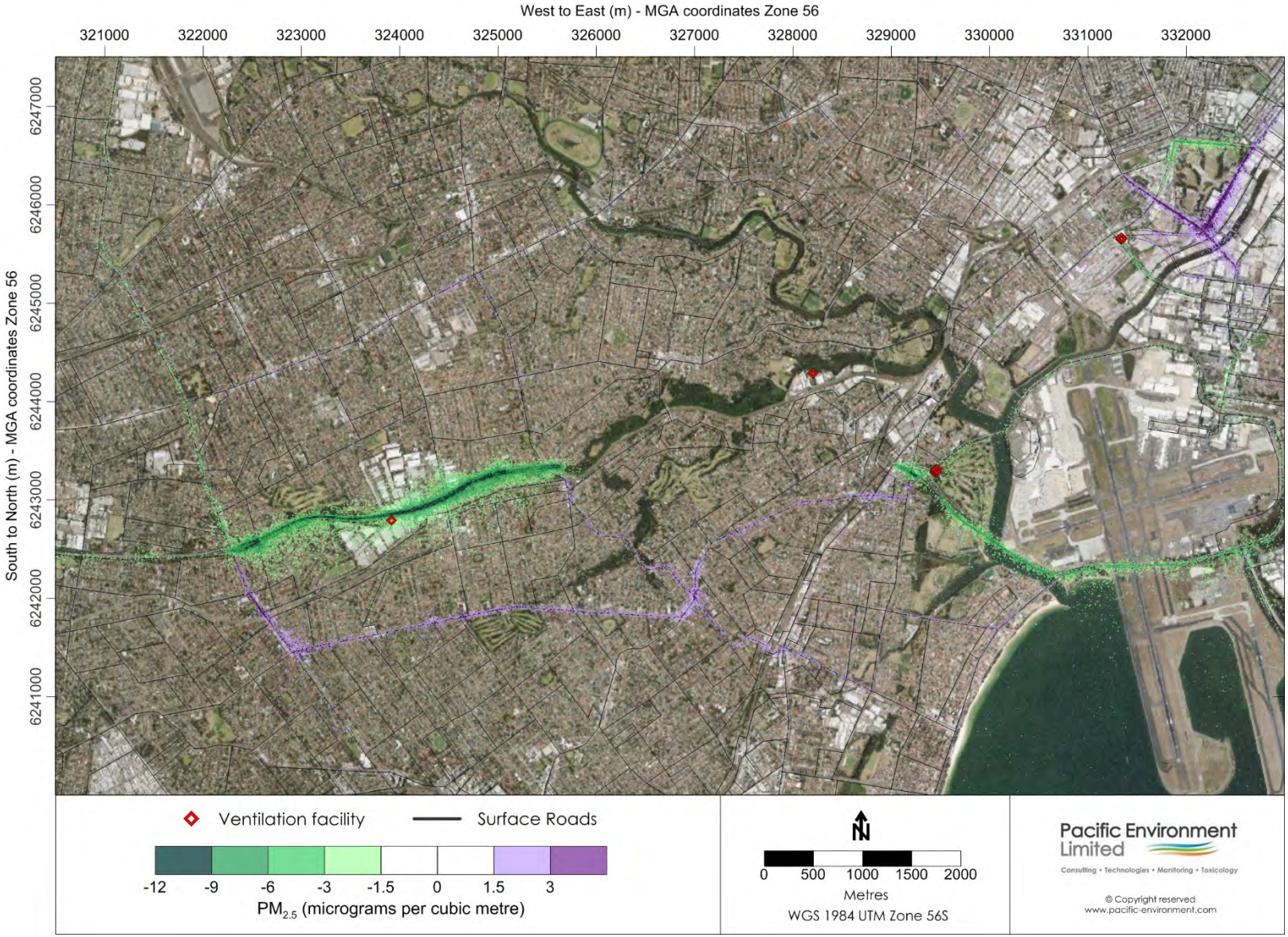


Figure 9-91 Contour plot showing change in maximum 24-hour $PM_{2.5}$ with the project (2021-DS)

Contour plots – ventilation outlets only

Contour plots for maximum 24-hour mean $PM_{2.5}$ and the New M5 ventilation outlets only are shown in Figure 9-92, Figure 9-93 and Figure 9-94.

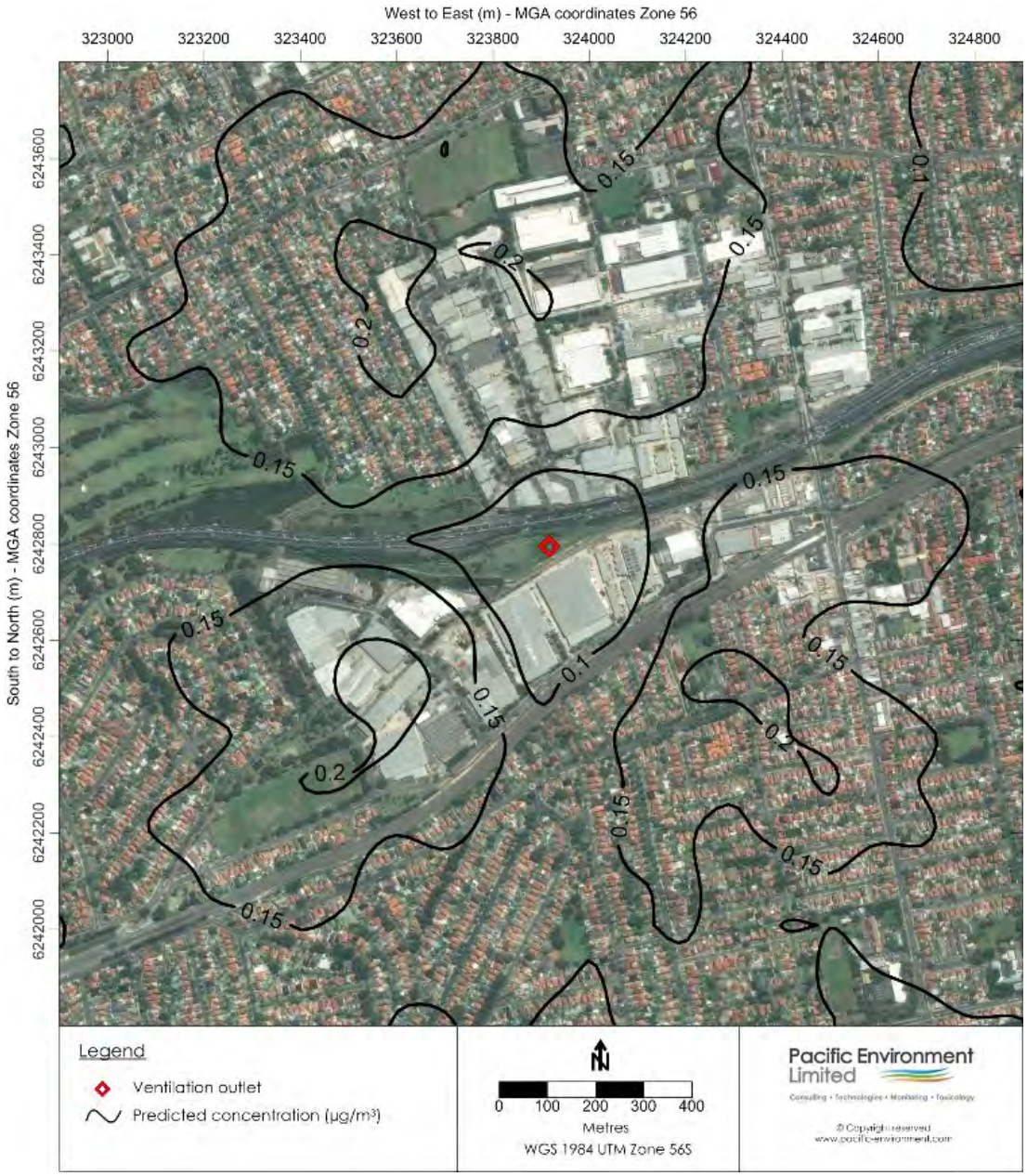


Figure 9-92 Contour plot showing maximum 24-hour mean $PM_{2.5}$ for ventilation outlets only (Kingsgrove outlet, 2021-DS)

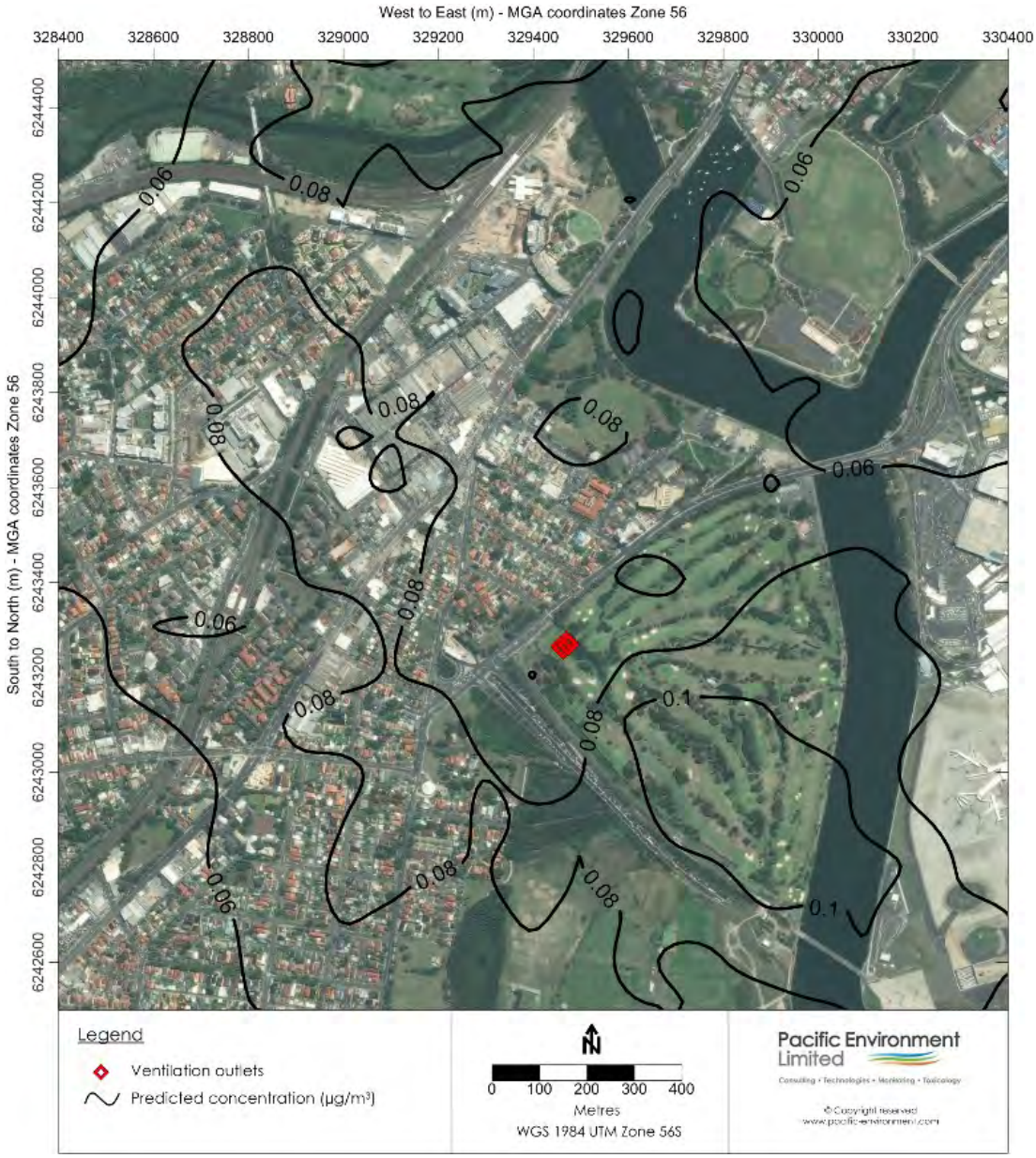


Figure 9-93 Contour plot showing maximum 24-hour mean $PM_{2.5}$ for ventilation outlets only (Arncliffe outlet, 2021-DS)

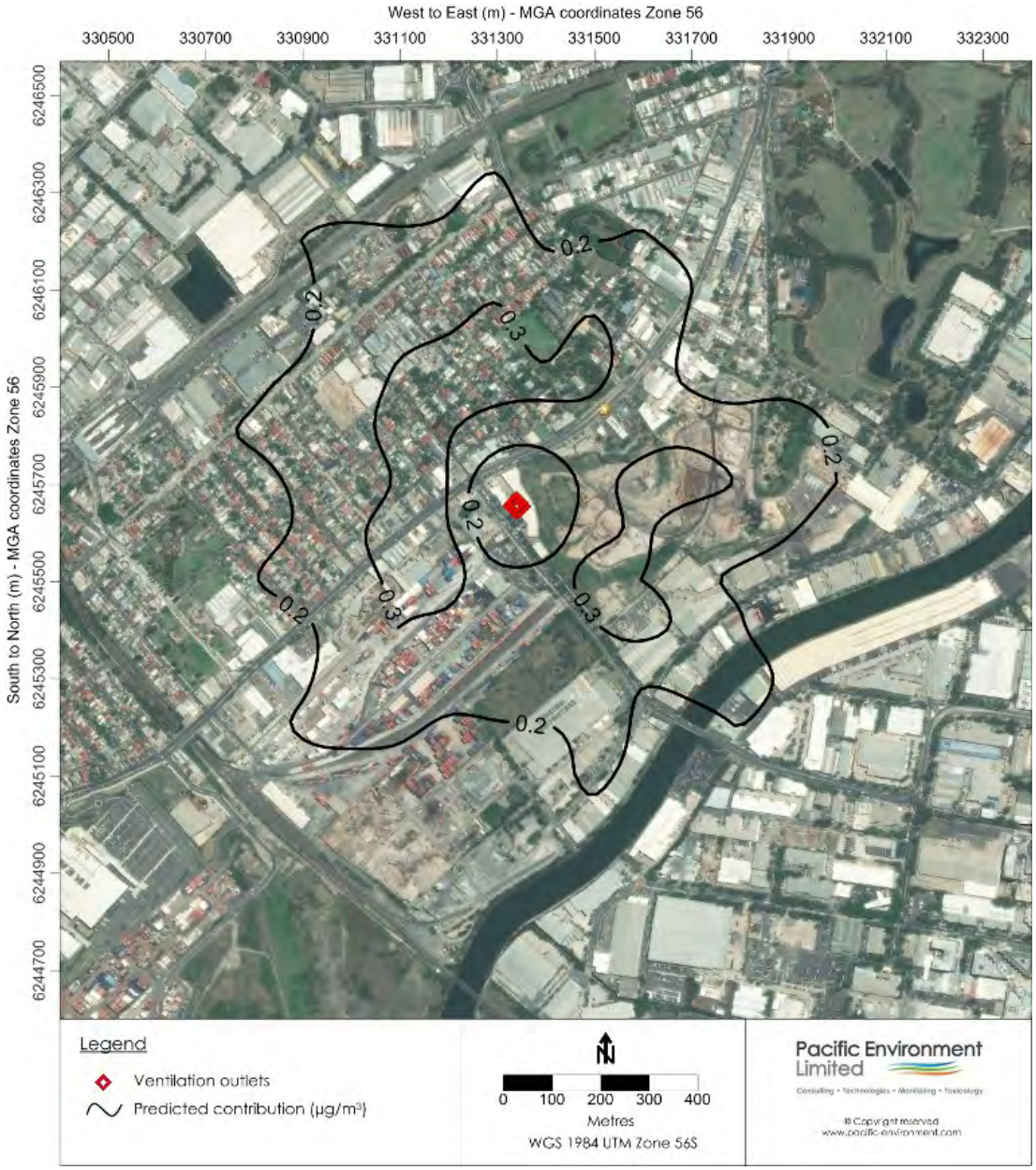


Figure 9-94 **Contour plot showing maximum 24-hour mean $PM_{2.5}$ for ventilation outlets only (SPI outlet, 2021-DS)**

For each ventilation outlet, the range of maximum 24-hour $PM_{2.5}$ concentrations across the grid is given in Table 9-29. The maximum value of 1.0 µg/m^3 (SPI, 2031-DSC) is much lower than the criterion for 24-hour $PM_{2.5}$ of 25 µg/m^3

Table 9-31 **Contribution of project ventilation outlets to maximum 24-hour $PM_{2.5}$ concentration in 2 km x 2 km grid around outlet**

Ventilation outlet	Outlet contribution to max. 24-hour $PM_{2.5}$ (µg/m^3)		
	2021-DS	2031-DS	2031-DSC
Kingsgrove	0.10 – 0.20	0.10 – 0.20	0.15 – 0.30
Arncliffe	0.05 – 0.10	0.03 – 0.10	0.10 – 0.25
SPI	0.05 – 0.30	0.05 – 0.30	0.20 – 1.00

9.5.9 Air toxics

Four air toxics - benzene, PAHs (as BaP), formaldehyde and 1,3-butadiene - were considered in the assessment. These compounds were taken to be representative of the much wider range of air toxics associated with motor vehicles, and they have commonly been assessed for road projects.

The changes in the maximum 1-hour benzene concentration at the community receptors as a result in the project in 2021 and 2031 are show in Figure 9-95, where they are compared with the NSW impact assessment criterion from the Approved Methods. These changes took into account emissions from both surface roads and tunnel ventilation outlets. It can be seen from the Figure that there where there was an increase in the concentration, this was well below the assessment criterion. The changes in the maximum 1-hour BaP, formaldehyde and 1,3-butadiene concentration are presented in Figure 9-96, Figure 9-97, and Figure 9-98 respectively. For each compound, where there was an increase in the concentration, this was well below the NSW impact assessment criterion. The largest increases for the community receptors were also representative of the largest increases for the RWR receptors.

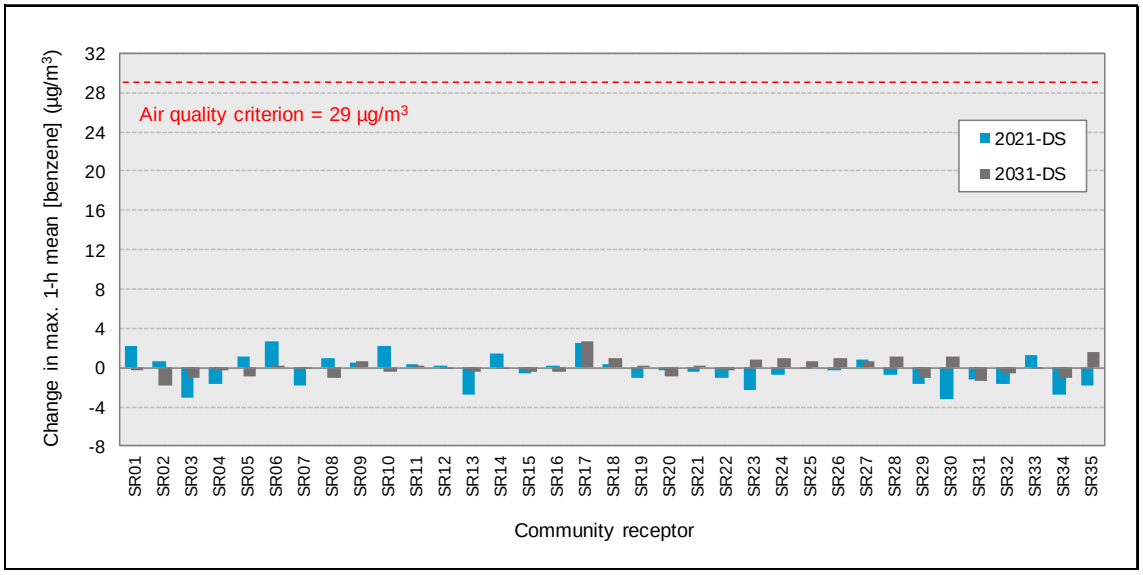


Figure 9-95 Change in maximum 1-hour mean benzene at community receptors (2021-DS and 2031-DS)

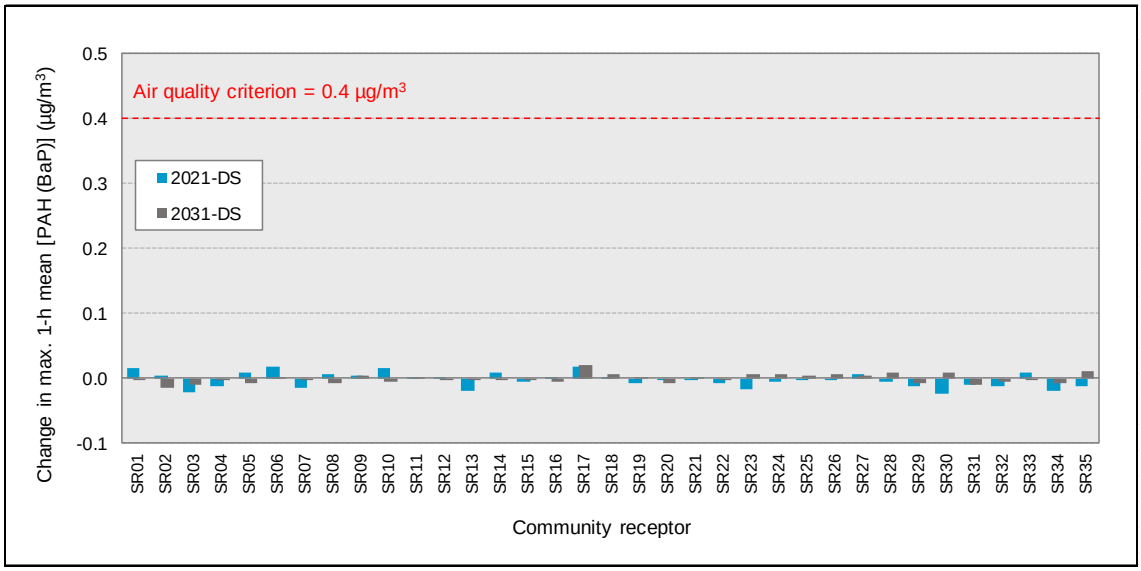


Figure 9-96 Change in maximum 1-hour mean b(a)p at community receptors (2021-DS and 2031-DS)

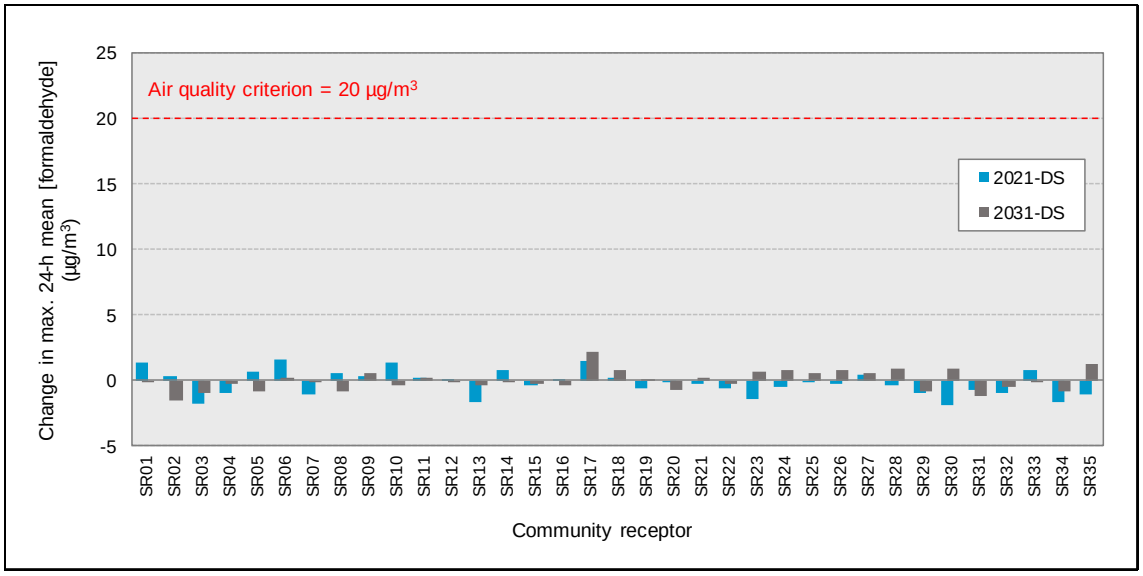


Figure 9-97 **Change in maximum 1-hour mean formaldehyde at community receptors (2021-DS and 2031-DS)**

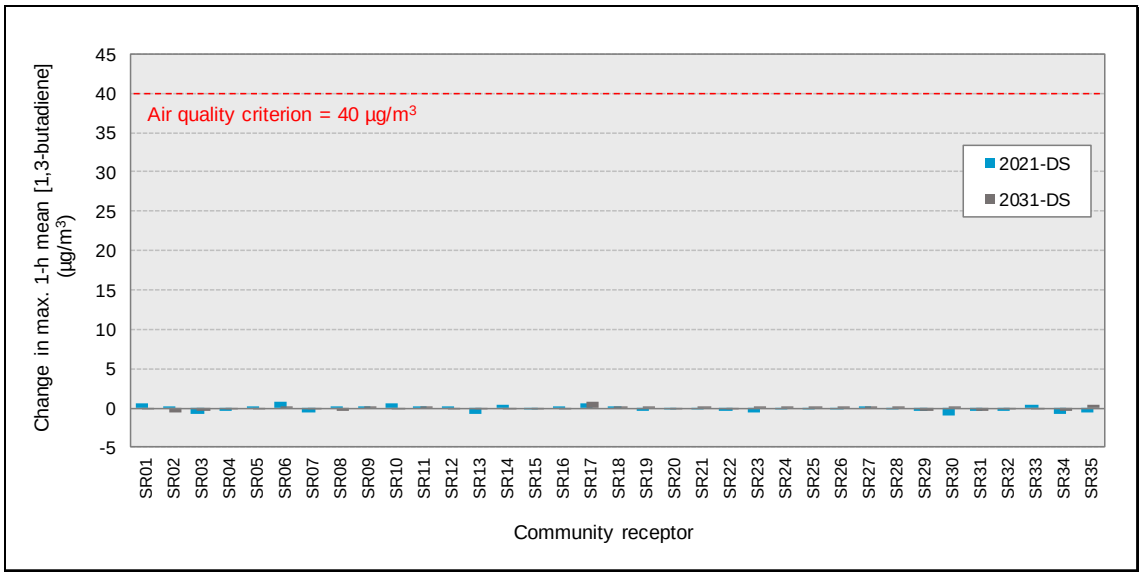


Figure 9-98 **Change in maximum 1-hour mean 1,3-butadiene at community receptors (2021-DS and 2031-DS)**

9.6 Results for expected traffic scenarios (elevated receptors)

Figure 9-99 and Figure 9-100 present contour maps showing the changes in annual mean $PM_{2.5}$ concentrations in the 2031-DSC scenario at heights of 10 metres and 30 metres respectively. These can be compared with the changes in ground-level concentrations for the same scenario (Figure K-140 in Appendix K).

At a height of 30 metres the increases in concentration were larger than at 10 metres, but they were much more localised around the ventilation outlets. This was due to some of the grid points at 30 metres being directly above the ventilation outlets.

No RWR receptors were predicted to experience a change in annual average $PM_{2.5}$ of more than 0.8 $\mu g/m^3$ at a height of 10 metres. The largest increase was 0.8 $\mu g/m^3$. At a height of 30 metres the increase in $PM_{2.5}$ was greater than 0.8 $\mu g/m^3$ at 38 receptors. There were 17 RWR receptors that were predicted to have a change in annual average $PM_{2.5}$ of more than 1.6 $\mu g/m^3$. All these receptor locations were very close to the assumed location of the Southern extension ventilation facility (Figure 9-101).

The implications of these results can be summarised as follows:

- For all existing receptor locations, the changes in concentration at 10 metres are likely to be acceptable. This assumes that the changes in $PM_{2.5}$ concentration for heights between ground level and 10 metres are also acceptable.
- Future developments to height of 10 metres should be possible at all locations in the GRAL New M5 domain.
- For all existing receptor locations, the largest increases in concentration at a height of 30 metres are clustered around the Southern extension outlets. Given that the Southern extension is not formally part of WestConnex, and the precise locations of the outlets are not known at this stage, this does not constitute a problem.
- The contour maps do not seem to impose any significant restrictions on future developments to 30 metres height, except in the immediate vicinity of ventilation outlet.

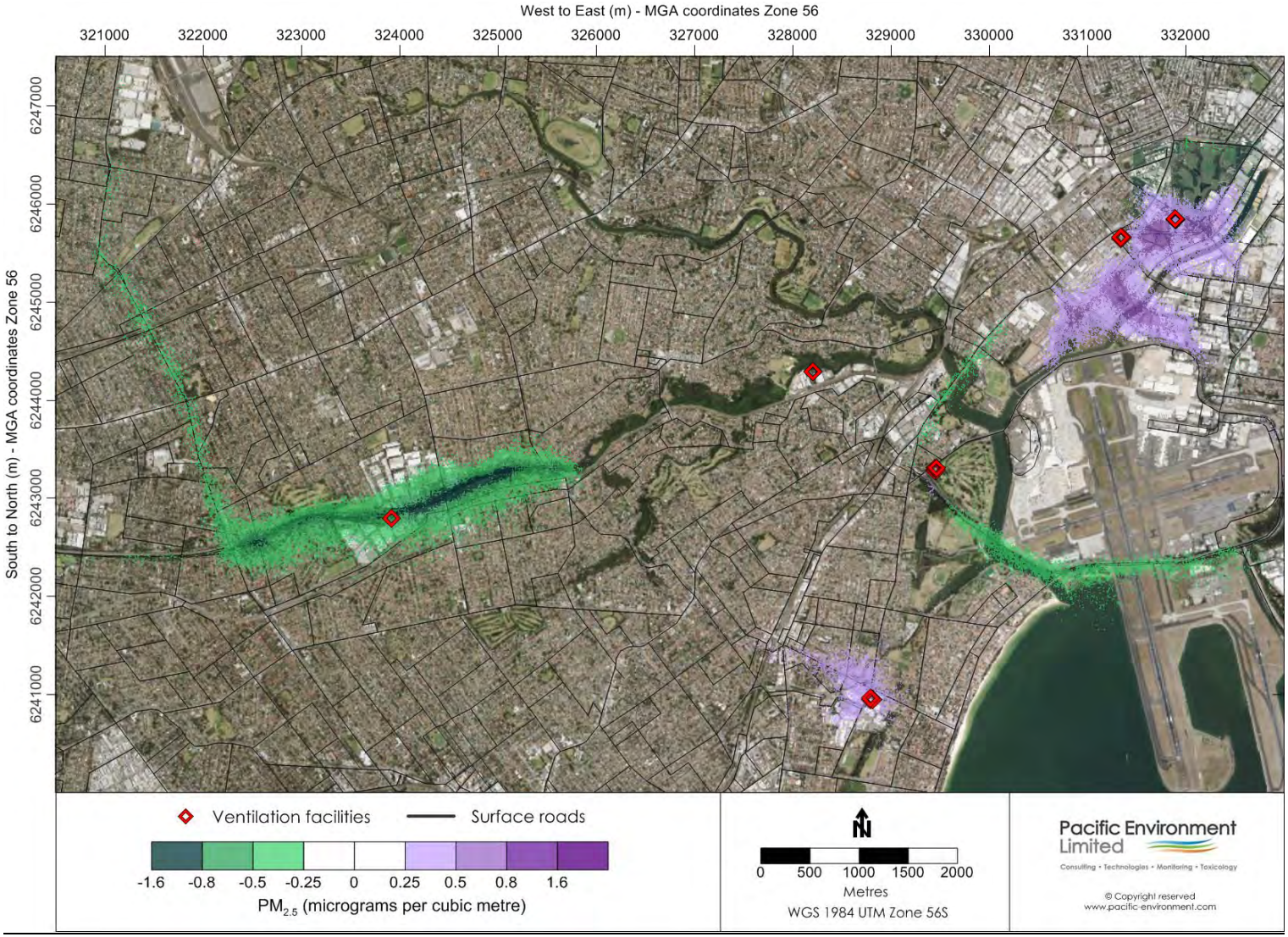


Figure 9-99 **Contour map for change in annual mean $PM_{2.5}$ (2031-DSC minus 2031-DM, 10 m)**

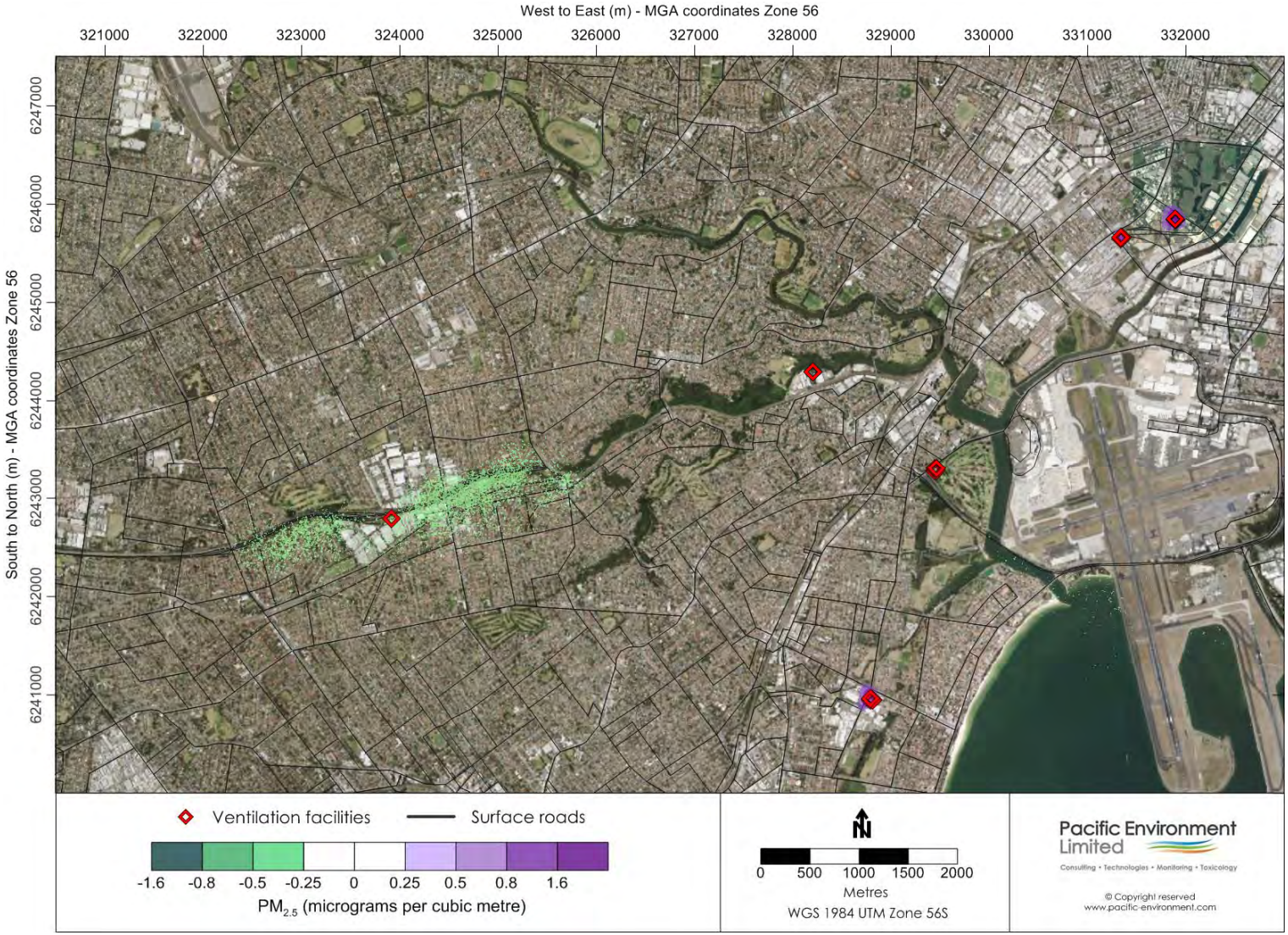


Figure 9-100 **Contour map for change in annual mean $PM_{2.5}$ (2031-DSC minus 2031-DM, 30 m)**

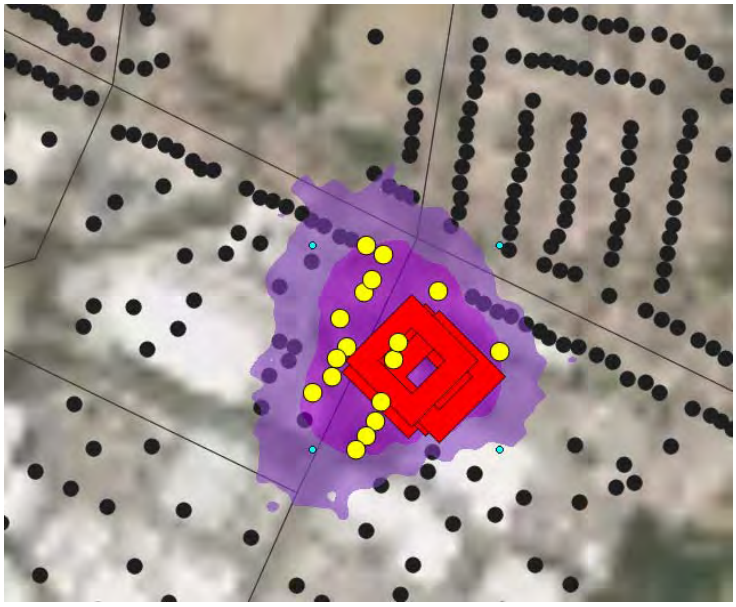


Figure 9-101 RWR receptors in the vicinity of the Southern extension outlets with an increase in annual mean $PM_{2.5}$ of more than 1.6 µg/m3 (shown as as yellow points)

9.6.1 Odour

The issue of odour is mentioned in the SEARs. Odours associated with motor vehicle emissions tend to be very localised and short-lived, and there are not expected to be any significant, predictable or detectable changes in odour as a result of the project.

For each of the RWR receptors the change in the maximum one hour THC concentration as a result of the project was calculated. The largest change in the maximum 1-hour THC concentration across all receptors was then determined, and this was converted to an equivalent change for three of the odorous pollutants identified in the Approved Methods (toluene, xlyenes, and acetaldehyde). These pollutants were taken to be representative of other odorous pollutants from motor vehicles.

The changes in the levels of three odorous pollutants as a result of the project, and the corresponding odour assessment criteria from the Approved Methods, are given in Table 9-32. It can be seen that the change in the maximum 1-hour concentration of each pollutant was an order of magnitude below the corresponding odour assessment criterion in the Approved Methods.

Table 9-32 Comparison of changes in odorous pollutant concentrations with criteria in Approved Methods (RWR receptors)

Scenario	Largest increase in maximum 1-hour THC concentration relative to Do Minimum scenario (µg/m^3)	Largest increase in maximum 1-hour concentration for specific compounds		
		Toluene (µg/m^3)	Xylenes (µg/m^3)	Acetaldehyde (µg/m^3)
2021-DS	243.7	19.8	16.3	3.1
2031-DS	170.8	13.9	11.5	2.6
2031-DSC	111.8	9.1	7.5	1.7
Odour criterion (µg/m^3)		360	190	42

9.7 Results for regulatory worst case scenarios

The results for the regulatory worst case scenarios are given in Table 9-33. The Table shows the maximum contribution of tunnel ventilation outlets at any of the 46,219 RWR receptors in the relevant scenarios. The equivalent maximum values for the expected traffic scenarios are also shown. The values for NO_X have been included to provide context for the NO_2 results, but there are no air quality criteria for NO_X.

Table 9-33 Results of regulatory worst case assessment (RWR receptors)

Pollutant and period	Units	Maximum ventilation outlet contribution at any receptor				
		Regulatory worst case scenario		Expected traffic scenario		
		RWC-A	RWC-B	2021-DS	2031-DS	2031-DSC
CO (one hour)	(mg/m^3)	0.29	0.33	N/A[(a)]	N/A[(a)]	N/A[(a)]
NO_X (annual)	($\mu g/m^3$)	10.61	13.44	2.48	2.98	2.63
NO_X (1 hour)	($\mu g/m^3$)	146.43	173.34	92.51	120.17	43.45
NO_2 (annual)	($\mu g/m^3$)	1.70[(b)]	2.14[(b)]	0.57	0.75	0.61
NO_2 (1 hour)	($\mu g/m^3$)	23.43[(b)]	27.73[(b)]	14.80[(b)]	19.23[(b)]	6.95[(b)]
PM_{10} (annual)	($\mu g/m^3$)	0.58	0.74	0.11	0.11	0.31
PM_{10} (24 hour)	($\mu g/m^3$)	3.67	4.29	0.54	0.53	1.84
$PM_{2.5}$ (annual)[(c)]	($\mu g/m^3$)	0.58	0.74	0.08	0.07	0.22
$PM_{2.5}$ (24 hour) [(c)]	($\mu g/m^3$)	3.67	4.29	0.39	0.39	1.25
THC (one hour)	($\mu g/m^3$)	30.25	31.64	N/A[(a)]	N/A[(a)]	N/A[(a)]

(a) Not determined
(b) Estimated as 16% of NO_X.
(c) The same emission rates were used for PM_{10} and $PM_{2.5}$.

The outlet contribution to the annual mean and maximum 1-hour NO_2 concentrations could not be determined definitively, as these were dependent on total NO_X (and hence the contributions from the background and the surface roads). For both the annual mean and maximum 1-hour NO_2 concentrations it was assumed that the contribution of the ventilation outlets would be most important when the existing NO_X concentration (i.e. the sum of the background and surface road contributions) would be high. Hence, any additional NO_2 from the ventilation outlets would essentially be primary in origin, and a NO_2/NO_X ratio of 0.16 was therefore applied (see Figures G-1 and G-8 in Appendix G).

In the case of the 1-hour NO_2 concentration a different situation could be envisaged. It could be assumed, with some validity, that the NO_2/NO_X ratio is much higher (even unity), but in this case the absolute NO_2 concentration would be relatively low.

The concentrations for the regulatory worst case scenarios were, of course, higher than those for the expected traffic scenarios in all cases, and the following points are noted for the former:

- The maximum contribution to the 1-hour CO concentration was negligible, especially taking into account the fact that predicted CO concentrations for the expected traffic scenarios were well below the NSW impact assessment criterion.
- The maximum contribution to the annual mean NO_2 concentration was not insignificant. For example, the 13.44 $\mu g/m^3$ for the RWC-B scenario was around 22 per cent of the NSW criterion (62 $\mu g/m^3$). However, the predicted total annual NO_2 concentrations at the RWR receptors in the expected traffic scenarios were all at least around 20 $\mu g/m^3$ below the criterion.

- The maximum contribution to the 1-hour mean NO_2 concentration could have been significant. However, the relative contributions from the background, surface roads and ventilation outlets presented earlier in the report suggest that any exceedances of the 1-hour NO_2 criterion are much more likely to be due to a high background and emissions from existing surface roads rather than as a result of emissions from the project ventilation outlets.
- The maximum contribution from the ventilation outlets in the regulatory worst case scenarios would not have had a significant impact on annual mean PM_{10} and $PM_{2.5}$ concentrations.
- The most significant result was that for the 24-hour $PM_{2.5}$ contribution (and similarly the 24-hour PM_{10} contribution).

Whilst the contributions to maximum 1-hour concentrations of NO_2 and 24-hour concentrations of $PM_{2.5}$ could have been significant, the contributions would be theoretical worst cases and there are several reasons why they would not represent a cause for concern in reality. For example:

- The probability of a 'worst case event' occurring that would lead to these concentrations in the ventilation outlets is very low
- Were a worst-case event to occur, the probability of it lasting up to one hour would be very low. It is extremely unlikely that such an event would last for 24 hours
- The probability of a worst-case event coinciding with the worst 24-hour period for dispersion would be very unlikely.
- The probability of a worst-case event coinciding with a high background concentration would also be very low. In the case of NO_2, even if this were to occur the NO_2/NO_X ratio would be low.

In Section 9.3 it was shown that the peak in-tunnel concentrations for all traffic scenarios, including the capacity traffic at different speeds, were well within the in-tunnel concentrations associated with the regulatory worst case scenarios. It therefore follows that the predicted ventilation outlet contributions to ambient concentrations for any in-tunnel traffic scenario would be lower than those shown in Table 9-33.

It can be concluded that emissions from the project ventilation outlets, even in the regulatory worst case scenarios, would be extremely unlikely to result in an adverse impacts on local air quality. WDA will conduct ambient air quality monitoring to demonstrate that emissions from the ventilation outlets will have no detectable impact on local air quality.

9.8 Summary of key assumptions

The assumptions in the air quality impact assessment for the project that were likely to have had the most influence on the outcomes of the assessment are discussed in this Section. This discussion is provided to clarify the level of uncertainty and conservatism in the assessment, and consequently the total conservatism in the predicted air quality impacts of the project.

Table 9-34 Summary of key assumptions and implications for conservatism

Topic and sub-topic		Method and assumptions	Implications for conservatism
1	Background (ambient) air quality		
1.1	General	Background concentrations of air pollutants were derived using the data from OEH and RMS air quality monitoring stations in the study area.	The monitoring sites were considered to accurately reflect background air quality in the study area.
		It was assumed that there would be no contribution from the road network to the concentrations at these sites.	There is likely to be a small contribution from the road network at the monitoring sites. The contribution will vary by pollutant.
		The GRAL model gave non-zero (but generally small) values at the locations of the background monitoring sites.	Total predicted concentrations (GRAL + background) will be generally overestimated across the GRAL domain. The maximum annual mean GRAL predictions at background sites were: - CO 0.03 mg/m^3 - NO_X 29.1 µg/m^3 - PM_{10} 1.6 µg/m^3
		Pollutant concentrations at background monitoring stations in 2014 were assumed to be representative of background concentrations in 2021 and 2031.	The implications of this cannot be quantified. It could be argued that concentrations in the future will decrease as emission controls improve (across all sectors of activity). However, any improvements could also be offset by increases in population and activity.
1.2	CO, rolling 8-hour mean	Hourly monitoring data from several OEH and RMS monitoring stations in 2014 were combined, and the highest monitored concentration in each hour was selected as the background value for that hour.	This resulted in an average concentration that was higher than the average for any individual station, and a distribution of concentrations that was shifted towards higher values than for any individual station.
1.3	NO_X, annual mean	Background annual mean NO_X concentrations were mapped across the GRAL domain.	Notwithstanding the comments under item 1, this approach can be viewed as accurate rather than conservative.
1.4	NO_X, 1-hour mean	Hourly monitoring data several OEH and RMS monitoring stations in 2014 were combined, and the highest monitored concentration in each hour was selected as the background value for that hour.	This resulted in an average concentration that was higher than the average for any individual station, and a distribution of concentrations that was shifted towards higher values than for any individual station.
1.5	PM_{10}, annual mean	Background annual mean PM_{10} concentrations were mapped across the GRAL domain.	Notwithstanding the comments under item 1, this approach can be viewed as accurate rather than conservative.

Topic and sub-topic		Method and assumptions	Implications for conservatism
1.6	PM_{10}, 24-hour mean	24-hour monitoring data from several OEH and RMS monitoring stations in 2014 were combined, and the highest monitored concentration in each hour was selected as the background value for that hour.	This resulted in an average concentration that was higher than the average for any individual station, and a distribution of concentrations that was shifted towards higher values than for any individual station.
1.7	$PM_{2.5}$, annual mean	A single value of 8 µg/m^3 was assumed for the whole GRAL domain.	The measurement of $PM_{2.5}$ is rather uncertain, and therefore it cannot be stated with confidence that this approach is either accurate or conservative.
1.8	$PM_{2.5}$, 24-hour mean	24-hour monitoring data from three OEH monitoring stations in 2014 were combined, and the highest monitored concentration in each hour was selected as the background value for that hour.	This resulted in an average concentration that was higher than the average for any individual station, and a distribution of concentrations that was shifted towards higher values than for any individual station.
2	Traffic forecasts		
2.1	Traffic volumes for New M5 tunnel and surface roads	Traffic volumes were taken from WRTM. The traffic data for a typical weekday were applied to every day of the year in the dispersion model.	This resulted in overestimates of concentrations at weekends.
3	Emission model (surface roads)		
3.1	Model selection	Emissions from vehicles on surface roads were calculated using a model that was adapted from the NSW EPA's inventory model.	The EPA model is not designed to be conservative for surface roads, but the analysis presented in Appendix E indicates that for the conditions in the Lane Cove Tunnel (and probably more widely for tunnels in Sydney during normal operation), the EPA emission factors overestimate real-world emissions (see below).
3.2	CO emission factors	NSW EPA model	LCT analysis indicated an overestimation of real-world emissions in 2013 by a factor of 2.0 to 2.8.
3.3	NO_X emission factors	NSW EPA model	LCT analysis indicated an overestimation of real-world emissions in 2013 by a factor of 2.2 to 3.3.
3.4	PM_{10} emission factors	NSW EPA model, includes both exhaust and non-exhaust sources	LCT analysis indicated an overestimation of real-world emissions in 2013 by a factor of 1.8-3.2.
3.5	$PM_{2.5}$ emission factors	NSW EPA model, includes both exhaust and non-exhaust sources	LCT analysis indicated an overestimation of real-world emissions in 2013 by a factor of 1.7-2.9.
3.6	THC emission factors	NSW EPA model. Exhaust emissions only (no evaporation).	Not included in LCT analysis.

Topic and sub-topic		Method and assumptions	Implications for conservatism
4	Emission model (New M5 tunnel)		
4.1	Model selection	Emissions from vehicles in the New M5 tunnel were calculated using emission factors published by PIARC.	The PIARC emission factors were developed for the purpose of tunnel ventilation design, and as such have been developed to include a design safety margin. The analysis presented in Appendix E indicates that for the conditions in the Lane Cove Tunnel (and probably more widely for tunnels in Sydney during normal operation), the PIARC emission factors overestimate real-world emissions (see below).
4.2	CO emission factors	PIARC model (emission factors provided by PIARC for Australia)	LCT analysis indicated an overestimation of real-world emissions in 2013 by a factor of 1.6 to 1.7.
4.3	NO_X emission factors	PIARC model (emission factors provided by PIARC for Australia)	LCT analysis indicated an overestimation of real-world emissions in 2013 by a factor of 1.4 to 2.0.
4.4	$PM_{2.5}$ emission factors (total)	PIARC model (emission factors provided by PIARC for Australia)	LCT analysis indicated an overestimation of real-world emissions in 2013 by a factor of 2.6 to 4.3.
4.5	$PM_{2.5}$ emission factors (exhaust)	PIARC model (emission factors provided by PIARC for Australia)	LCT analysis indicated an overestimation of real-world emissions in 2013 by a factor of 1.5.
4.6	$PM_{2.5}$ (non-exhaust)	PIARC model	The analysis of the data from the Lane Cove Tunnel showed that the PIARC method yields very conservative estimates of PM emissions for tunnel operation. The PIARC emission estimates based on exhaust PM alone (i.e. with non-exhaust PM excluded) remain conservative (by a factor of around 1.5).
4.7	Other pollutants	Emission factors are only presented by PIARC for CO, NO_X and $PM_{2.5}$. Emissions of other pollutants and metrics (PM_{10}, THC) were determined using ratio methods. The ratios were derived using the EPA model for the same traffic conditions and tunnel configurations as those used in Appendix L.	The conversion method used was not inherently conservative.
4.8	Future year scaling factors	PIARC provides adjustment factors up to the year 2020 to account for expected continuous improvement in engine technologies and emissions. This assessment considered traffic in the years 2021 and 2031. No reduction in emissions was assumed beyond 2020.	The use of 2020 factors for 2031 is expected to result in the overestimation of 2031 emissions and resultant ground level pollutant concentrations due to expected improvements in vehicle emissions over time.

Topic and sub-topic		Method and assumptions	Implications for conservatism
4.9	Portal intake air	Pollutant loads in portal intake air were not considered in the dispersion modelling.	A screening assessment was undertaken for the NorthConnex project. This demonstrated that pollutant loads in portal intake air did not significantly alter the outcomes of the air quality impact assessment (AECOM, 2014b).
5	Dispersion modelling (general)		
5.1	Terrain	Terrain data were taken from Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) website. A 30-metre resolution was used for the modelling of meteorology.	The terrain data were assumed to accurately reflect the study area.
5.2	Meteorology	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.
6	Dispersion modelling (ventilation outlets)		
6.1	Portal emissions	The assessment has been conducted assuming zero emissions from the tunnel portals; that is, all vehicle emissions have been assumed to be vented via the tunnel ventilation outlets near the end of each tunnel.	-
6.	Ventilation outlet heights	The ventilation emission points had been assumed to at the heights as detailed in Table 9-16..	A basic sensitivity analysis has shown that the total predicted concentrations are not likely to be sensitive to ventilation outlet height, based on a sensitivity range of 25 to 35 metres.
	Ventilation outlet exit diameter	The dispersion modelling involved wither time-varying or fixed ventilation outlet diameters, depending on the outlet.	-
	Volumetric flow rates	Volumetric flow rates were initially calculated for each hour of the day based on predicted traffic volumes.	-
	Road gradient	The total tunnel emissions have been calculated based on the sum of each tunnel section's emissions, factoring in the length of each section, the time taken for vehicles in the tunnel to pass through each section, the density of vehicles in the tunnel and the respective gradients.	-
	Outlet temperature	An annual average outlet temperature was used for each ventilation outlet modelled in GRAL.	A basic sensitivity analysis has shown that the total predicted concentrations are not likely to be sensitive to ventilation outlet temperature, based on a sensitivity range of 15 to 35^0C.

Topic and sub-topic		Method and assumptions	Implications for conservatism
8	Post-processing (NO_2) – community receptors		
	NO_X-to-NO_2 conversion, annual mean	A 'best estimate' approach was used, which gave the most likely annual mean NO_2 concentration for a given annual mean NO_X concentration.	The approach used was not inherently conservative.
	NO_X-to-NO_2 conversion, maximum 1-hour mean	A 'detailed' contemporaneous approach was used. This involved the use of a conservative upper bound function which gave the maximum likely 1-hour mean NO_2 concentration for a given 1-hour mean NO_X concentration.	Given the wide range of possible NO_2 concentrations for a given NO_X concentration, this approach was used to conservatively estimate the maximum 1-hour mean NO_2 concentrations. The dispersion modelling evaluation showed, however, that this method was less conservative than the OLM.
9	Post-processing (NO_2) – RWR receptors		
	NO_X-to-NO_2 conversion, annual mean	A 'best estimate' approach was used, which gave the most likely annual mean NO_2 concentration for a given annual mean NO_X concentration.	The approach used was not inherently conservative.
	NO_X-to-NO_2 conversion, maximum 1-hour mean	A 'simple' statistical (non-contemporaneous) approach was applied to determine the maximum 1-hour NO_X concentrations for the much larger number of residential, workplace and recreational' (RWR) receptors. The maximum 1-hour mean NOx value predicted by GRAL was added to the 98th percentile NOx value for the background in the synthetic profile for 2014. The conversion of NO_X to NO_2 was then based on the functions used in the detailed approach.	In general the simple method performed in a similar manner to the detailed method, giving slightly lower maximum NO_2 values.

9.9 Sensitivity tests

Several sensitivity tests were conducted for various model inputs. These included:

- The influence of ventilation outlet temperature.
- The influence of ventilation outlet height.
- The inclusion of buildings near tunnel ventilation outlets.

These tests were based upon a sub-area of the New M5 GRAL domain of approximately 3 km x 3 km around the project's western ventilation outlet. Only the ventilation outlet contribution, and only annual mean $PM_{2.5}$ and maximum 24-hour $PM_{2.5}$, were included in the tests. A sub-set of nine sensitive receptors was evaluated. The predicted concentrations were indicative, as the aim of the sensitivity tests was to compare to assess the proportional sensitivity of the model to specific input parameters.

The following sections present the results of the tests.

9.9.1 Ventilation outlet temperature

The ventilation outlet temperatures for the project assessment were around 25°C. For the temperature sensitivity tests the effects of using outlet temperatures 10°C below and above this value were modelled. In temperature test 1 (TT01) the outlet temperature was set to 15°C, and in temperature test 2 (TT02) the outlet temperature was set to 35°C.

Table 9-35 below presents the results of the temperature sensitivity test. The results show that the predicted concentrations for the ventilation outlet were higher for the lower temperature (by a factor of, on average, around 1.5). However, the predicted concentrations remained well below the advisory reporting standards for $PM_{2.5}$, and made up a very small proportion of the total combined results (for surface roads and ventilation outlets). Even with a significant change in ventilation outlet temperature, the total predicted concentration (roads and ventilation outlets) is unlikely to be impacted significantly. The assumption of a single annual average temperature in GRAL was therefore considered unlikely to represent a large source of uncertainty in the overall predictions.

Table 9-35 Sensitivity test results for temperature (tunnel ventilation outlet only)

ID	Name	TT01 (15°C)		TT02 (35°C)	
		$PM_{2.5}$ (µg/m^3)			
		Max 24h	Annual	Max 24h	Annual
		Advisory Reporting Standard			
		25	*8*	*25*	*8*
SR09	McCallums Hill Public School	0.173	0.016	0.135	0.013
SR10	Hurstville City Council Family Day Care Scheme	0.206	0.026	0.159	0.018
SR11	Kingsgrove North High School	0.234	0.019	0.168	0.013
SR12	Kingsgrove Early Childhood Health Centre	0.269	0.024	0.174	0.012
SR13	Kingsgrove World Of Learning	0.201	0.015	0.130	0.009
SR14	Kingsgrove Day Hospital	0.185	0.018	0.144	0.012
SR15	Kings Medical Clinic	0.189	0.018	0.141	0.011
SR16	Kids Oasis Childcare Centre	0.183	0.016	0.153	0.011
SR17	Clemton Park Public School	0.065	0.004	0.048	0.003

9.9.2 Ventilation outlet height

The height of the western ventilation outlet for the project assessment was 30 metres. In height test 1 (HT01) the height was set to 25 metres and in height Test 2 (HT02) the height was set to 35 metres. These values were approximately five metres below and above the height of the western ventilation facility outlet modelled for the project.

Table 9-36 presents the results of the height sensitivity test. The results were similar to those for the temperature sensitivity tests, with the lower outlet resulting in concentrations that were around 1.3 times greater, on average, than the higher outlet. Again, ventilation outlet height is unlikely to represent a large source of uncertainty in the overall predictions.

Table 9-36 Sensitivity test results for height (tunnel ventilation outlet only)

ID	Name	HT01 (25 metres)		HT02 (35 metres)	
		$PM_{2.5}$ (µg/m^3)			
		Max 24h	Annual Ave	Max 24h	Annual Ave
		Advisory Reporting Standard			
		25	*8*	*25*	*8*
SR09	McCallums Hill Public School	0.166	0.015	0.120	0.012
SR10	Hurstville City Council Family Day Care Scheme	0.202	0.022	0.161	0.019
SR11	Kingsgrove North High School	0.226	0.016	0.172	0.014
SR12	Kingsgrove Early Childhood Health Centre	0.282	0.019	0.168	0.014
SR13	Kingsgrove World Of Learning	0.193	0.013	0.131	0.010
SR14	Kingsgrove Day Hospital	0.188	0.015	0.138	0.013
SR15	Kings Medical Clinic	0.201	0.014	0.143	0.012
SR16	Kids Oasis Childcare Centre	0.164	0.014	0.133	0.012
SR17	Clemton Park Public School	0.058	0.004	0.050	0.003

9.9.3 Buildings

Buildings may be included in dispersion modelling to account for building wake in the vicinity of a ventilation outlet. However, for the project assessment buildings were excluded (the rationale for this was provided earlier in the report). The sensitivity of the inclusion of buildings to predicted concentrations was therefore assessed. The same model domain, resolution and receptor list as for the temperature and height tests were used. The closest commercial buildings to the ventilation outlet were included in test BT01, and in test BT02 they were excluded. The locations and heights of these buildings were estimated from Google Earth.

Table 9-37 presents the results of the buildings sensitivity test. The results show that, when buildings were included, there was an average increase in concentrations associated with the ventilation outlet by a factor of approximately 1.3. Whilst this test was not comprehensive, it indicates that the inclusion or exclusion of buildings is unlikely to represent a large source of uncertainty in the overall predictions. The total predicted concentrations, and the conclusions of the assessment, would not change significantly with the inclusion of buildings.

Table 9-37 Sensitivity test results for buildings (tunnel ventilation outlet only)

ID	Name	BT01		BT02	
		$PM_{2.5}$ (µg/m^3)			
		Max 24h	Annual Ave	Max 24h	Annual Ave
		Advisory Reporting Standard			
		25	*8*	*25*	*8*
SR09	McCallums Hill Public School	0.168	0.017	0.135	0.013
SR10	Hurstville City Council Family Day Care Scheme	0.208	0.026	0.175	0.021
SR11	Kingsgrove North High School	0.224	0.017	0.200	0.015
SR12	Kingsgrove Early Childhood Health Centre	0.293	0.027	0.209	0.016
SR13	Kingsgrove World Of Learning	0.216	0.017	0.146	0.012
SR14	Kingsgrove Day Hospital	0.203	0.019	0.164	0.014
SR15	Kings Medical Clinic	0.198	0.019	0.168	0.013
SR16	Kids Oasis Childcare Centre	0.182	0.016	0.163	0.013
SR17	Clemton Park Public School	0.063	0.004	0.050	0.004

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10 Assessment of cumulative impacts

10.1 Overview

This Chapter of the report addresses the cumulative impacts of the project and the M4-M5 Link. These impacts have already been considered at several points earlier in this report.

The Chapter focuses on cumulative operational impacts. For cumulative construction impacts, the project has already been identified as high risk, and therefore the same conclusions and mitigation measures as those described in Chapter 7 and Chapter 11 would apply.

10.2 In-tunnel air quality

The peak in-tunnel concentrations for the expected traffic cumulative scenario (2031-DSC), were assessed in Appendix L and section 8.3. The results showed that the peak concentrations for all traffic scenarios, including worst-case conditions, were well within the concentrations associated with the regulatory worst case.

10.3 Ambient air quality

10.3.1 Results for expected traffic scenarios (ground-level concentrations)

The results for the expected traffic scenarios and all pollutants are presented in Appendix K.

In the majority of cases the results for the community receptors in the 2031-DSC scenario were very similar to those in the 2031-DS scenario, and an example of this is provided (for annual mean NO_2) in Figure 10-1. The results are therefore not discussed further here.

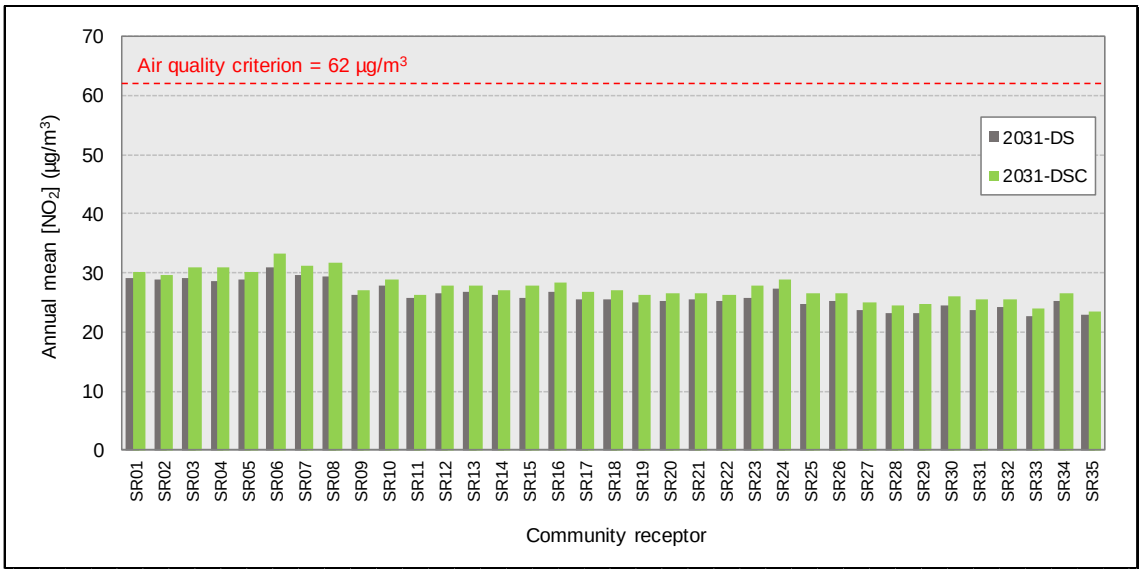


Figure 10-1 Annual mean NO_2 at community receptors (2031-DS and 2031-DSC)

The results for the 2031-DSC scenario at the RWR receptors were also broadly similar to those for the 2031-DS scenario.

Figure 10-2 presents an example of a contour map for the 2031-DSC scenario, in this case showing the changes in annual mean NO_2 concentration.

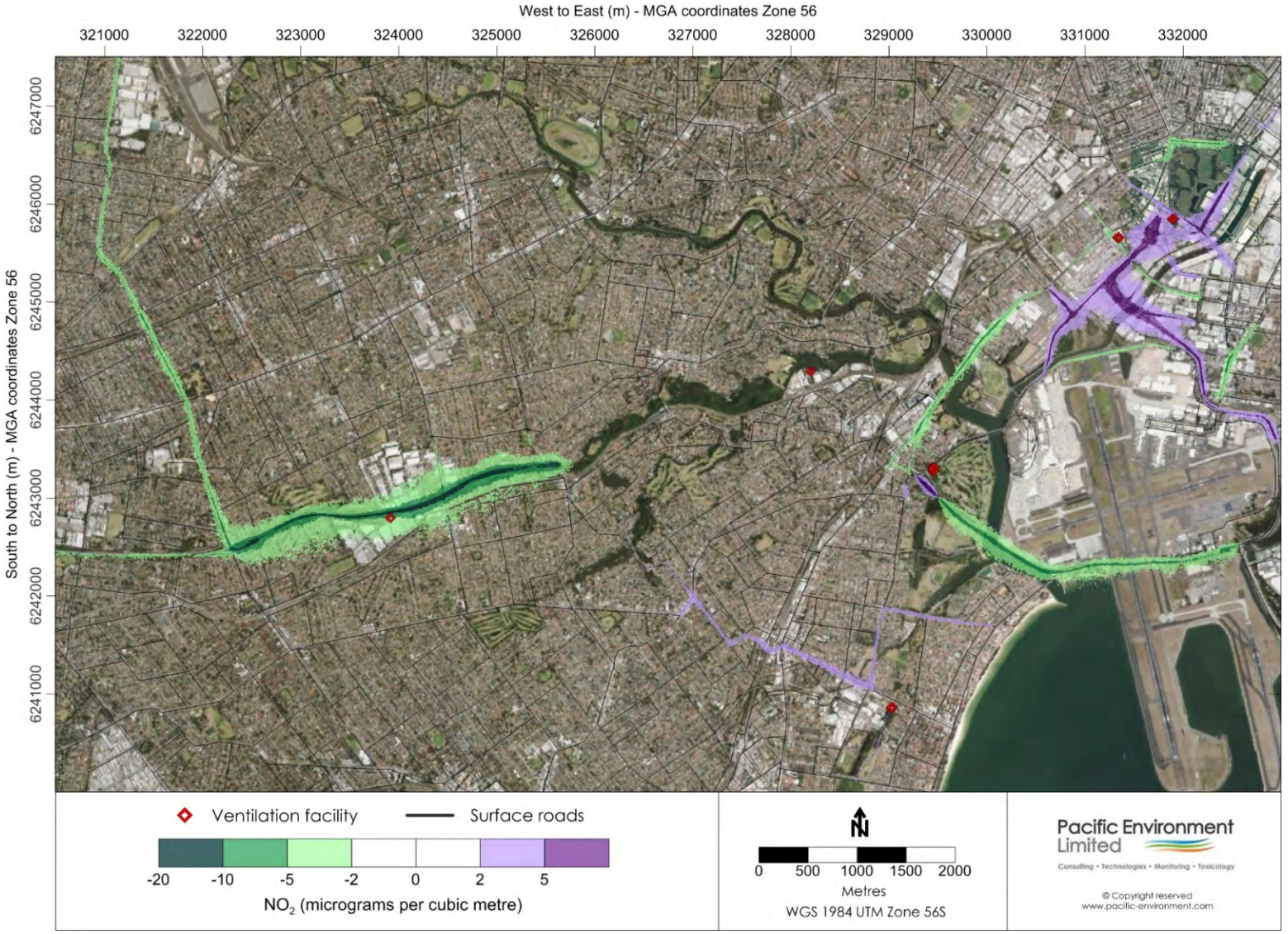


Figure 10-2 Contour map showing change in annual mean NO_2 with the project (2031-DSC)

By 2031, the New M5 is predicted to accommodate a two-way AWT volume of about 34,500 vehicles per day with the project and about 81,500 vehicles per day if the full WestConnex program of works and the future Southern extension, about 134 per cent more. This is due to traffic using the M4-M5 Link and the future Southern extension, with the traffic volume including traffic heading east / west on the New M5 and south west / north-east on the future Southern extension. If the full WestConnex program of works and the future Southern extension is completed, the two-way daily volume on Stoney Creek Road is forecast to reduce and two-way daily traffic on the Princes Highway, north of the M5 East interchange, is forecast to decrease from 79,000 vehicles per day without the project to about 25,000 vehicles per day. This 69 per cent decrease is a substantial reduction along this congested section of the strategic road network (AECOM, 2015).

10.3.2 Results for expected traffic scenarios (elevated receptors)

The results for elevated receptor locations (10 metres and 30 metres) were shown in section 9.6.

10.3.3 Results for regulatory worst case scenarios

The results for the regulatory worst case assessment were presented in section 9.7.

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11 Management of impacts

11.1 Construction impacts

Step 3 of the construction assessment 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 results are shown in Table 11-1 to Table 11-6, and are all highly recommended. 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 New M5 project. This should contain details of the site-specific mitigation measures to be applied. Additional guidance on the control of dust at construction sites in NSW is provided as part of the NSW EPA Local Government Air Quality Toolkit[29]. Detailed guidance is also available from the UK (GLA, 2006) and the United States (Countess Environmental, 2006). For precise requirements, reference should be made to the Baseline Conditions of Approval for the project.

Table 11-1 Mitigation for all sites: communication

	Mitigation measure
1	Develop and implement a stakeholder communications plan that includes community engagement before work commences on site.
2	Display the name and contact details of person(s) accountable for air quality and dust issues at the boundaries of each construction area. This may be the environment manager/engineer or the site manager.
3	Display the head or regional office contact information

Table 11-2 Mitigation for all sites: dust management

	Mitigation measure
4	Develop and implement a Construction Air Quality Management Plan which requires consultation with NSW EPA. Any measures that are required will differ depending on the activities occurring, and so will need to be tailored for each individual site.
Site management	
5	Record all dust and air quality complaints, identify cause(s), take appropriate measures to reduce emissions in a timely manner, and record the measures taken.
6	Make complaints available to the Secretary upon request.
7	Record any exceptional incidents that cause dust and/or air emissions, either on- or offsite, and the action taken to resolve the situation in the log book.
8	Regular communication with other high risk construction sites within 500 metres of the site boundary to ensure plans are co-ordinated and dust and particulate matter emissions are minimised. It is important to understand the interactions of the off-site transport/deliveries which might be using the same strategic road network routes.
Monitoring	
9	Undertake regular on-site and off-site inspection, where receptors are nearby, to monitor dust, record inspection results.
10	Carry out regular site inspections to monitor compliance with the DMP, record inspection results, and make an inspection log available to the local authority when asked.

[29] http://www.epa.nsw.gov.au/air/lgaqt.htm

	Mitigation measure
Preparing and maintaining the site	
11	Plan site layout so that machinery and dust causing activities are located away from receptors, as far as is possible.
12	Ensure where reasonable and feasible appropriate control methods are implemented to minimise dust emissions from the project site.
13	Ensure where reasonable and feasible appropriate control methods are implemented to minimise dust emissions from the project site.
14	Manage the quality of site runoff water.
15	Remove materials that have a potential to produce dust from site as soon as possible, unless being re-used on site. If they are being re-used on-site cover as described below.
16	Stockpiles would be located outside overland flow paths, and where left exposed and undisturbed for longer than 28 days, would be finished and contoured to minimise loss of material in flood or rainfall events. Materials which require stockpiling for longer than 28 days would be stabilised by compaction, covering with anchored fabrics, or seeded with sterile grass where appropriate.
Operating vehicle/machinery and sustainable travel	
17	Ensure all construction vehicles comply with their relevant emission standards.
18	Ensure that, where practicable, engine idling is minimised when vehicles are stationary.
19	Avoid the use of diesel or petrol powered generators and use mains electricity or battery powered equipment where practicable.
20	Impose and signpost a maximum-speed-limit of 20 km/h on surfaced and unsurfaced haul roads and in work areas. Haul roads should be treated with water carts and monitored during earthworks operations, ceasing works if necessary during excessive winds where dust controls are not effective.
21	Produce a Sustainability Plan to manage the sustainable delivery of goods and materials.
22	Promote and encourages sustainable travel (public transport, cycling, walking, and car-sharing).
Construction	
23	Where practicable, only use cutting, grinding or sawing equipment fitted or in conjunction with suitable dust suppression techniques such as water sprays or local extraction (e.g. suitable local exhaust ventilation systems).
24	Ensure an adequate water supply on the site for effective dust/particulate matter suppression/mitigation, using non-potable water where possible and appropriate.
25	Where possible, use enclosed chutes and conveyors and covered skips.
26	Minimise drop heights from conveyors, loading shovels, hoppers and other loading or handling equipment and use fine water sprays on such equipment wherever appropriate.
27	Ensure equipment is readily available on site to clean any dry spillages, and clean up spillages as soon as reasonably practicable after the event using appropriate cleaning methods.
Waste management	
28	No bonfires and burning of waste materials

Table 11-3 Mitigation specific to demolition

	Mitigation measure
29	Soft strip inside buildings before demolition (retaining walls and windows in the rest of the building where possible, to provide a screen against dust).
30	Ensure effective water suppression is used during demolition operations. Hand held sprays are more effective than hoses attached to equipment as the water can be directed to where it is needed. In addition high volume water suppression systems, manually controlled, can produce fine water droplets that effectively bring the dust particles to the ground and may be more useful for covering larger areas.
31	Minimise explosive blasting where possible, using appropriate manual or mechanical alternatives.
32	Bag and remove any biological debris or other hazardous materials such as asbestos, or damp down such material before demolition.

Table 11-4 Mitigation specific to earthworks

	Mitigation measure
33	Re-vegetate earthworks and exposed areas/soil stockpiles to stabilise surfaces as soon as practicable.
34	Use Hessian, mulches or tackifiers where it is not possible to re-vegetate or cover with topsoil, as soon as practicable.
35	Where possible, only remove any covers for exposed areas in small areas during work, and not all at once.

Table 11-5 Mitigation specific to construction

	Mitigation measure
36	Avoid scabbling (roughening of concrete surfaces) if possible.
37	Ensure sand and other aggregates are stored in bunded areas and are not allowed to dry out, unless this is required for a particular process, in which case ensure that appropriate additional control measures are in place.
38	Ensure bulk cement and other fine powder materials are delivered in enclosed tankers and stored in silos with suitable emission control systems to prevent escape of material and overfilling during delivery.
39	For smaller supplies of fine powder materials ensure bags are sealed after use and stored appropriately to prevent dust.

Table 11-6 Mitigation specific to track-out

	Mitigation measure
40	Use water-assisted dust sweeper(s) on the access and local roads, to remove, as necessary, any material tracked out of the site.
41	Avoid dry sweeping of large areas.
42	Ensure vehicles entering and leaving sites are covered to prevent escape of materials during transport.
43	Inspect on-site haul routes for integrity and instigate necessary repairs to the surface as soon as reasonably practicable.
44	Record all inspections of haul routes and any subsequent action in a site log book.
45	Where reasonable and feasible, haul roads will be maintained with water carts and graders, and the condition of the roads will be monitored.
46	Implement site exit controls (e.g. wheel washing system and rumble grids) to dislodge accumulated dust and mud prior to leaving the site where reasonably practicable.
47	Ensure there is an adequate area of hard surfaced road between the wheel wash facility and the site exit, wherever site size and layout permits.
48	Access gates to be located at least 10 metres from receptors where possible.

11.2 Operational impacts

11.2.1 Overview

The SEARs for the New M5 project require details of, and justification for, the air quality management measures that have been considered. This Section of the report firstly reviews 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 have been categorised as follows:

- Tunnel design
- Ventilation design and control
- Air treatment systems
- Emission controls and other measures

11.2.2 Review of approaches

Tunnel design

It is important that the tunnel infrastructure is designed in such a way that the generation of pollutant emissions by the traffic using the tunnel is minimised. The main considerations include avoiding large gradients and congested traffic conditions, including the management of traffic on the roads leading in and out of the tunnel. In addition, the risk of incidents leading to congestion needs to be addressed, including accidents involving oversized vehicles.

Ventilation design and control

There are several reasons why a tunnel needs to be ventilated. The main reasons are:

- Control of the internal environment. It must be safe and comfortable to drive through the tunnel. Vehicle emissions must be sufficiently diluted so as not to be hazardous during normal operation, or when traffic is moving slowly.
- Protection of the external environment. It is unacceptable for polluted air from tunnel portals, or ventilation outlets to present a health or nuisance hazard to the community. Ventilation, and the dispersion of pollutants, is overwhelmingly the most popular method for minimising the impacts of tunnels on ambient air quality. Collecting emissions and venting them via ventilation outlets is a very efficient way of dispersing pollutants. Studies show that the

process of removing surface traffic from heavily trafficked roads and disposing of the same amount of pollution from an elevated location results in substantially lower concentrations at sensitive receptors (PIARC, 2008). Ventilation outlets need to be designed and sited accordingly, and high vertical discharge velocities from outlets may be required to assist dispersion.

- Emergency situations. When a fire occurs in a tunnel it is desirable to be able to control the heat and other combustion products in the tunnel so as to permit safe evacuation of occupants, and to provide the emergency services with a safe route to deal with the fire and to rescue any trapped or injured persons.

A two-fold approach to ventilation design is generally adopted:

- The amount of fresh air required to dilute pollutants to acceptable levels is calculated based on the likely emissions from vehicles in the tunnel, and the ventilation system is designed accordingly. The choice and design of a suitable ventilation system depends upon the following factors:
  - Tunnel length and geometry.
  - Traffic flow and composition.
  - Fresh air requirement under normal and specific traffic conditions.
  - Admissible air pollution levels around tunnel portals.
  - Fire safety considerations.
- Sensors are installed in the tunnel to initiate the operation of the ventilation system in order to maintain the level of pollutants below limit values, or to force the closure of the tunnel should certain limit values be exceeded.

Short tunnels can be adequately and safely ventilated by the piston effect. The external wind may also generate a flow of air within a tunnel due to the static air pressure difference between the portals.

There are three basic concepts for mechanical tunnel ventilation:

- Longitudinal ventilation, whereby air is introduced to, or removed from, the tunnel at a limited number of points. The main movement of air is along the tunnel from the entrance to the exit.
- Transverse ventilation, whereby air may be introduced into a tunnel at various points along its length, and may also be extracted at other points along its length. The main movement of air inside the tunnel is perpendicular to the longitudinal axis of the tunnel.
- Semi-transverse ventilation. Semi-transverse ventilation involves a combination of longitudinal and transverse ventilation. For example, fresh air can be delivered longitudinally through the tunnel portals, and exhaust air is removed uniformly (and transversely) over the length of the tunnel.

Jet fans may also be mounted within the tunnel space, usually at fixed intervals along the tunnel and near to the tunnel ceiling. They function by producing a relatively narrow jet of air moving at a high speed (typically 30 m/s), and rely upon turbulent friction and jet entrainment effects to transfer momentum from the jet into the main body of air in the tunnel.

Ventilation control is achieved by adjusting the number of fans in operation at any one time, with the individual units being operated at full power or not running. A further refinement is available in installations where fan speed is controllable. The required level of ventilation at any particular time tends to be determined in response to visibility levels and the concentrations of airborne pollutants. Normally, the CO concentration or the visibility inside the tunnel in are the only parameters measured for this purpose.

Air treatment systems

There are several air treatment options for mitigating the effects of tunnel operation on both in-tunnel and ambient air quality. Where in-tunnel treatment technologies have been applied to road tunnels, these technologies have focused on the management and treatment of PM. The most common of these is the electrostatic precipitator (ESP), and this is discussed in detail below. Information is provided on the method of operation, the international experience with ESPs in tunnels, and the effectiveness of systems. Other techniques include filtering, denitrification and biofiltration, agglomeration and scrubbing. These are described in less detail.

In Australia, the issue of air treatment frequently arises during the development of new tunnel projects. This issue is generally pursued by local residents or environmental protection associations. All tunnel projects have, however, gravitated towards a decision not to install an air treatment system, and to rely instead on the primary approach of dilution of air pollution (through ventilation systems) (PIARC, 2008; CETU, 2010).

Electrostatic precipitators

Description of method

For a number of years work has progressed on the application of electrostatic precipitators (ESPs) to road tunnel air. In a typical ESP the air flow is initially passed through an ionising chamber containing wires or plates maintained at several thousand volts. These produces a corona that releases electrons into the air-stream. The electrons attach to particles in the air flow, and give them a net negative charge. The particles then pass through a collector chamber or passageway which contains multiple parallel collecting plates. The collecting plates are grounded and attract the charged dust particles.

The cleaning of an ESP is vital to ensure that it remains in proper working order (CETU, 2010). In a conventional 'dry' electrostatic precipitator the collecting plates are periodically shaken to dislodge the collected dust, which then falls into hoppers for collection and disposal. Most electrostatic precipitation systems also involve a regular manual washing and cleaning of the collecting plates to remove collected particles, and to maintain operational efficiency.

Dry ESPs are effective in removing particles between 1 and 10 microns in diameter. Varying efficiency results have been claimed and reported in relation the removal of sub-micron particles. Some ESPs can be retro-fitted to tunnels. Child and Associates (2004) described a relatively low-cost Norwegian system which can be bolted directly to the tunnel roof and fixed to the jet fans. Removal efficiencies of between 66 per cent (PM_1) and 98 per cent (PM_{10}) are claimed.

The ionisation phase prior to the filtration of dust particles produces nitrogen dioxide (NO_2). Specifically, the ionisation produces ozone which reacts with nitrogen monoxide (NO) to form NO_2 (CETU, 2010).

ESPs are generally configured in one of two ways:

- Bypass-type installations. These are typically used to improve visibility in long tunnels, with the air being extracted, filtered and re-injected into the tunnel.
- Extraction-type installation. Where major environmental requirements are involved, ESPs can be installed at the level of the polluted air outlets.

Installations by country

Around the world, there are relatively few road tunnels with installed filtration systems. The international experience with ESPs and filtration systems has been reviewed in a number of documents (e.g. Child & Associates, 2004; Willoughby et al., 2004; NHMRC, 2008; PIARC, 2008; CETU, 2010; AECOM, 2014b). A review of the use of the international electrostatic precipitators by country is provided below. Norway and Japan are two of the world leaders in the construction of road tunnels, and both countries are also involved in the development of ESPs.

Japan

The application of ESPs to remove particles from tunnel air began in Japan, which has about 8,000 road tunnels comprising a total length of 2,500 kilometres. More ESPs have been installed in road tunnels in Japan than in any other country. CETU (2010) listed 46 road tunnels in which ESPs are installed, or was being installed at the time of its report. Most of the Japanese tunnels with particulate matter filtration are less than five kilometres long. ESPs were installed for the first time anywhere in the world in the Tsuruga tunnel (2.1km) in 1979. The development of ESPs has extended the range of longitudinal ventilation. The first long tunnel combining longitudinal ventilation and ESPs was the Kan'etsu tunnel (11km) in 1985.

According to Willoughby et al. (2004), there is no fixed policy in Japan on the installation and use of ESPs, but that tunnels are considered on a case by case basis. CETU state that the ESPs have been installed either to improve in-tunnel visibility, to manage the discharge air pollution from tunnel ventilation outlets or portals, or both. No Japanese road authority gave health concerns as a reason for installation of ESPs. Willoughby et al., (2004) also note that the policy in Japan is to consider ESPs for tunnels longer than 2 km, although ESPs have been installed in shorter tunnels on an experimental basis. Where particulate matter filtration technology is installed to manage in-tunnel visibility (the main reason in Japan), this is typically as a result of a high percentage of diesel powered vehicles and a very high percentage of heavy goods vehicles using the road tunnel (AECOM, 2014b).

For most Japanese road tunnels with ESPs, the ESPs are located in bypass passages (to improve visibility). However, potential environmental impacts have led to the installation of electrostatic precipitators in around ten tunnels. For example, ESPs have been installed at the base of the extraction outlets in the Tennozan (2 km), Kanmon (3.5 km), Asukayama (0.6 km), Midoribashi (3.4 km) and Hanazonobashi tunnels (2.6 km). The Tokyo Bay tunnel (9.6 km) is mainly equipped with ceiling-based ESPs (CETU, 2010). The location the tunnel under Tokyo Bay makes the use of an intermediate ventilation outlet to manage in-tunnel air quality impractical, and a particulate matter filtration system has been installed as an alternative means to manage in-tunnel visibility.

In each case where ESPs have been installed in ventilation outlets, the reason given was that they were installed to limit particulate emissions in response to community concerns, but without support by technical assessment, dispersion modelling or any air quality monitoring at nearby receptors (Willoughby et al., 2004).

Norway

Norway has around 1,000 road tunnels. Norwegian tunnels have specific challenges in terms of visibility. In-tunnel visibility deteriorates significantly in winter when studded tyres are used. These increase abrasion of the road surface and, consequently, the suspension of PM (CETU, 2010). In warmer climates, where studded tyres are not required (such as in Sydney), road abrasion is much less of an issue (AECOM, 2014b).

Only eight of the tunnels in Norway have a PM filtration system installed. Two of these tunnels, the Festning Tunnel and the Bragernes Tunnel, have filtration systems that are designed principally to improve emissions to the environment (CETU, 2010). The Festning Tunnel passes beneath central Oslo. It is 1.8 kilometres long and carries 60,000 vehicles per day. The Laerdal Tunnel, which is the longest road tunnel in the world at 24.5 kilometres, also features a PM treatment system. The tunnel only carries 1,000 vehicles per day, and the principal purpose of the filtration system is to improve visibility within the tunnel, as the tunnel is deep underground with no opportunity to introduce additional fresh air along its length.

According to CETU (2010), the precipitators located upstream of extraction systems in Norwegian tunnels are no longer used for a variety of reasons, in particular the need to replace electrical cables. There are also doubts concerning the benefits of putting the systems back into service given that they have proved less effective than predicted.

Spain

The M-30 Orbital Motorway circles the central districts of Madrid. It is the innermost ring road, with a length is 32.5 kilometres. It has at least three lanes in each direction, supplemented in some parts by two or three lane auxiliary roads. It connects to the main Spanish radial national roads that start in Madrid. From 2005 to 2008, major upgrading works took place, and now a significant portion of the southern part runs underground. The M-30 Orbital Motorway is essentially a number of independent tunnels and surface roads. They are the longest urban motorway tunnels in Europe, with sections of more than six kilometres in length and three to six lanes in each direction (AECOM, 2014b). Overall there are 22 particulate matter filtration systems and four denitrification systems installed by four different manufacturers (CETU, 2010).

France

The Mont Blanc Tunnel was retrofitted with an ESP system around 2010. The tunnel is a two lane bi-directional tunnel 11.6 kilometres long and originally constructed in 1965. It has a relatively small cross sectional area. The objective of the particulate matter filtration system is to contribute to various local initiatives aimed at improving air quality in the Chamonix Valley (CETU, 2010).

Italy

Only one tunnel in Italy - the Le Vigne tunnel in Cesene - has a particulate matter filter system installed. This tunnel is 1.6 kilometres in length and is located in a heavily populated area which is particularly sensitive to air emission from the tunnel portals. The objective of the particulate matter filtration system for this tunnel is to reduce the emission levels from the tunnel portals.

Germany

One tunnel in Germany (under the Elbe in Hamburg) has a small-scale particulate matter filtration systems installed. This has been installed by filtration system manufacturers for trial and development purposes (CETU, 2010).

South Korea and Vietnam

Five tunnels in South Korea and one tunnel in Vietnam (Hai Van Pass tunnel) are equipped with ESPs. The 2010 CETU study identifies that in these two countries, the systems are mainly used to provide adequate in-tunnel visibility where there are constraints on the intake of fresh air into the tunnels (as an alternative means of managing in-tunnel visibility).

Hong Kong

Design and construct contracts have been awarded for the Central Wan Chai Bypass in Hong Kong. It is understood that both denitrification and particulate matter filtration systems are to be installed in this tunnel. This is a 3.7 kilometre twin tunnel with three lanes of traffic in each direction. It is due to open in 2017.

Australia

An in-tunnel air treatment system - including ESP and denitrification technologies – was trialled in the Sydney M5 East tunnel. In its former configuration, prior to the installation of the system, 90 per cent of the exhaust air from the tunnel was discharged via a ventilation outlet, with the remaining 10 per cent being discharged at the portals. Although measurement campaigns have indicated that these discharges do not present any significant impact on external air quality, the filtration system was installed at the tunnel's western portal. The trial was used to manage in-tunnel air being recycled between the westbound and eastbound tunnels, rather than in relation to in-tunnel air being emitted from the ventilation outlet for the tunnels. A structure was built to host air the ESP and NO_2 treatment systems, ventilators, offices and an information centre. A 300-metre ventilation duct was also built. Rather than being discharged by the structure, air is re-injected into the tunnel and then eventually discharged by the existing outlet or the portals. The end-to-end cost of this treatment project has been estimated to be 50 million Australian dollars. The high cost reflects the fact that the tunnel was not originally designed to accommodate such systems (CETU, 2010).

Effectiveness

Japan

The two major manufacturers of ESPs in Japan are Matsushita Electric Co Ltd and Mitsubishi Heavy Industries. Both companies claim efficiency of at least 80 per cent removal of particles for their ESPs (Willoughby et al., 2004). While this is guaranteed by the companies, it is based on laboratory data and the performance has not been measured in an operating tunnel. Research by both companies has targeted improvement of particle collection efficiency and an increase in air speed through the ESPs. The companies report that testing has shown that for air speeds of up to 9 m/s an efficiency of 90 per cent can be achieved. ESPs have been developed and installed (Asukayama tunnel) that can operate at speeds of up to 13 m/s. At this speed, however, the efficiency drops to just over 80 per cent (Willoughby et al., 2004).

As confirmed in the CETU report (2010), ESPs have been installed at the Central Circular Route (Chuo-Kanjo-Shinjuku) in Tokyo since 2007. Data published on the website of the Tokyo Metropolitan Expressway Company claims a minimum 80 per cent PM reduction.

Austria

Child and Associates (2004) report the findings of a study by the Technical University of Graz of an Austrian ESP system in the Plabutsch tunnel. The removal efficiency ranged from more than 99 per cent for particles larger than 10 µm to 67 per cent for particles smaller than 1 µm.

South Korea

For an ESP installed in the Chinbu tunnel in South Korea, Drangsholt (2000) reports an average removal efficiency for particles between 0.3 µm and 10 µm of 83 per cent to 97 per cent.

Australia

The ESP trial in the Sydney M5 East westbound tunnel commenced in March 2010 and lasted 18 months. NSW Roads and Maritime Services (formerly the Roads and Traffic Authority) engaged CSIRO to undertake a six-month monitoring and analysis program of the ESP to review the system's performance.

In a review of the trail, AMOG (2012) concluded the following:

- The PM removal efficiency (for the air passing through the ESP) was around 65 per cent, compared with a target efficiency of 80 per cent. There was a corresponding improvement in in-tunnel visibility. After mixing the filtered air with the tunnel air, the net improvement was reduced to 29 per cent. This was reduced to a much lower overall improvement in visibility at the western end of the tunnel of 6 per cent, which may not have been perceptible to tunnel users.
- The ESP was unable to effectively or, given the cost of the system, cost-effectively, remove PM.
- Around 200 m^3/s of air was drawn through the ESP. It is possible that the ESP was operating at or beyond its air flow velocity limit. The efficiency of the ESP could be improved by significantly reducing the throughput of air or increasing the path length of the system. Both of these options would add to the capital cost of the system, and the space required.
- A major concern was the unreliability of the ESP system, when meant that it could only be used for 84 per cent of the duration of the study.
- The operation of the ESP should cease.

Operational periods

The operating periods of ESPs in tunnels are highly variable. ESPs are not automatically operated continuously, and a number of systems appear to have been rarely (or never) used. Child and Associates (2004) cited the reasons given including low traffic flows, variable efficiency, complexity of operation, and particle levels being well within limit values. In both Norway and Japan the operation of air cleaning technologies is on a needs basis, as the net effect of the technology (coupled with its effectiveness) dictates that the technology is best used when air quality is at its worst and hence the benefit is greatest (Dix, 2006).

The ESPs in Japanese tunnels operate based on actual pollution measurements. In the case of the Kan'etsu tunnel this results in an average operating time of 143 hours per month (20 per cent of the time) at the north portal and 40 hours per month (3 per cent of the time) at the south portal. The Tokyo Bay tunnel only records 12 to 13 hours of operation per year (i.e. approx. 0.15 per cent of the time) (Dix, 2006)

In Norway the need for ESP operation it is usually on a time clock which corresponds with peak hour traffic (Dix, 2006).

According to CETU (2010), the ESPs on the Madrid M-30 network were initially operated for 20 hours per day, but now only operate for a few hours each week.

Material filters

Some dust filtration systems remove airborne particulate matter using physical filters. For example, Matsushita manufacture a system in which sheet filters are attached to filter units, which are incorporated into the dust collector. The dust collector is equipped with an automatic carrying mechanism to transfer the filter units to the regeneration part. When a filter is polluted and clogged with dust and soot, the filter is automatically regenerated by air blow to exfoliate dust and soot. Physical filters may be used in conjunction with ESPs.

According to Willoughby et al. (2004), fabric ('bag') filters are in use in 14 tunnels in Japan, including installation as recently as the Tokyo Bay tunnel. However, as this equipment has been found to only filter about 20 per cent of total PM it is understood that its use is being discontinued. A significant issue is the inability of filter materials to remove the very fine particles that are present in vehicle exhaust.

Denitrification systems

Description of method

Denitrification refers to systems or processes that are designed to remove NO_2, and other oxides of nitrogen, from tunnel air. A number of alternative systems are available. NO_X removal by catalytic and biological processes has been tested in Austria, Germany and Japan in the early 1990s. Due to their weak performance in NO removal efficiency these tests were stopped. Subsequent developments have concentrated on pilot systems for NO_2 removal. No significant progress in robust NO treatment has been reported.

Installations and effectiveness by country

Norway

As of 2004, the operational use of denitrification technology in road tunnels had been limited to the installation of a system supplied by Alstom in the Laerdal tunnel in Norway (Child & Associates, 2004).

However, the performance and efficiency of this installation is difficult to assess, because traffic volumes in the Laerdal tunnel are relatively low. The resulting pollution levels within the tunnel are lower than those required to trigger the use of the electrostatic precipitation and denitrification systems that have been installed. Based on tests in the Festnings tunnel, the Alstom system removes 85-90 per cent of NO_2 and 60-75 per cent of hydrocarbons (Child & Associates, 2004).

Japan

In Japan two types of NO_X-reduction system were developed in 2004. In one of the systems - called 'adsorption' system - NO_2 molecules are removed by the physical adsorption effects of removing agents. In the other system - called 'absorption' - NO_2 molecules are chemically changed to neutral salts by removing agents soaked in alkaline water solutions, and are removed by the absorption of the neutral salts. Both systems have shown NO_2 removal efficiency of 90 per cent. Both technologies are being trialled in the ventilation outlets of the Central Circular Shinjyuka Tunnel. The tunnel is located in crowded city area where it is difficult to comply with the local environmental standards for NO_2 (PIARC, 2008; CETU, 2010).

Germany

FILTRONtec in Germany has also developed a denitrification system. This system has been successfully demonstrated in German road tunnels, although no commercial applications of this technology have taken place (Child & Associates, 2004).

Spain

The M30 project in Madrid has major denitrification systems which are in occasionally in operation (PIARC, 2008).

Australia

The ESP trial in the Sydney M5 East westbound tunnel also included an assessment of a denitrification system consisting of an array of modules containing activated carbon as the filter medium. Around 50 m^3/s of air was drawn through the system.

In a review of the trail, AMOG (2012) concluded the following:

- The system removed 55 per cent of the NO_2 in the processed air, which was much less than expected.
- The system only processed 14 per cent of the air in the westbound tunnel, so could not have a large impact on in-tunnel NO_2 levels. Enlargement of the system to process all tunnel air was considered to be impractical.
- The system is not cost-effective at reducing NO_2, but there may be potential to develop an effective system.

Other technologies

Consideration also needs to be given to the potential use of other novel techniques for reducing in-tunnel pollutant concentrations which are distinctly different from those discussed earlier. A number of these techniques are reviewed below.

Wet electrostatic precipitation

'Wet' ESP differs from dry ESP primarily in the mechanism by which the collecting electrodes are cleaned, and the collected particles removed. In a typical wet ESP, a continuous washing process is used to clean the collecting electrodes, rather than the mechanical shaking process employed in dry ESPs. The wet environment also creates a potential for the removal, or part removal, of soluble pollutant gases, and assists in retaining and removing ultrafine particles. Some conventional electrostatic precipitation systems already involve an automatic wash process to periodically clean the collection plates, and remove the particles that have been collected. The distinction between this approach and the wet system is that the latter involves a continuously wet environment. One of the advantages argued for wet electrostatic precipitation, compared with the conventional process, is that the presence of a continuously wet environment increases the level of efficiency in removing particles smaller than 1 µm and soluble gaseous contaminants. Wet electrostatic precipitation has been used in a number of industrial applications, but does not appear to have been used in road tunnel applications (Child & Associates, 2004).

Bio-filtration

Bio-filtration is general term used to describe processes in which contaminated air is passed over or through some medium containing micro-organisms capable of consuming, converting or otherwise removing some or all of the harmful pollutants present. Child and Associates (2004) describe bio-filtration systems manufactured by Fijita. Polluted air is passed through an aeration layer into one or two soil beds, each 50 centimetres thick. Removal efficiencies are stated as 95 per cent for TSP 91 per cent for NO_2, 88 per cent for NO, 95 per cent for CO and 94 per cent for SO_2. The authors note, however, that the application of bio-filtration processes to emission treatment in road tunnels involves a conflict between the need to move large volumes of air relatively quickly and the need for air to have relatively long exposures or residence times for the biological processes to be effective. Bio-filtration remains an emission treatment option of potential interest, but still an emerging or developing option in respect of road tunnel applications.

Agglomeration

Agglomeration is an electrostatic process whereby opposite electrical charges are applied to very fine airborne particles, causing them to combine or agglomerate into larger particles, which can then be more easily and effectively removed by other processes, or by gravity. Some electrostatic precipitation technologies include the principle of agglomeration in their basic designs. From a road tunnel viewpoint, agglomeration remains an emerging or developing technology, but would appear to have the potential to enhance the effectiveness of other PM removal systems (Child and Associates, 2004).

Scrubbing

Scrubbing describes a range of processes in which contaminated air is passed through a wash liquid, and pollutants are either entrained or dissolved in the liquid. Scrubbing is a well-established treatment technology in a number of industrial process applications, but generally in applications involving more heavily contaminated or polluted air streams than are experienced in road tunnels. Scrubbing has a potential application in the treatment of road tunnel emissions, but at this stage remains an emerging or developing technology in such applications (Child and Associates, 2004).

Photo-catalytic coatings

Considerable efforts have been made by researchers to develop and refine construction materials and coatings which have the potential for reducing levels of air pollution. The de-polluting properties of these materials are normally reliant upon photo-catalysis, whereby a photo-catalytic substance is used to increase the rate of chemical reactions. One of the most commonly used photo-catalysts is the compound titanium dioxide (TiO_2).

The potential of photo-catalytic coatings to reduce air pollution in tunnels is limited on account of the absence of sunlight, although application to portal walls and street furniture may be beneficial (though not necessarily cost-effective). Italy has experimented with photocatalytic denitrification at the relatively short (350 metres) bidirectional Umberto Tunnel in Rome. However, health concerns relating to TiO_2 appear to have limited its use (CETU, 2010).

Emission controls and other measures

Various operational measures are available to manage in-tunnel emissions and ambient air quality. These include the following:

- Traffic management. Traffic management may be employed by tunnel operators to control exposure to vehicle-derived air pollution. Measures might include (PIARC, 2008):
  - Allowing only certain types of vehicle.
  - Regulating time of use.
  - Tolling (including differential tolling by vehicle type, emission standard, time of day, occupancy)
  - Reducing capacity.
  - Lowering the allowed traffic speed.

- Incident detection. Early detection of incidents and queues is essential to enable tunnel operators and the highway authority to put effective traffic management in place. Monitoring via CCTV cameras is normally a vital part of the procedure for minimising congestion within tunnels.
- Preventing abnormal loads.
- Public information and advice. Traffic lights, barriers, variable message signs, radio broadcasts, loudspeakers and other measures can help to provide driver information and hence influence driver behaviour in tunnels.
- Cleaning the tunnel regularly avoiding high concentrations of small particles (PIARC, 2008).

11.2.3 Summary and implications for the New M5 project

Tunnel design

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. By comparison, the M5 East tunnel has a grade of up to eight per cent on the western exit, which causes trucks to slow down and increase emissions.
- Large main line tunnel cross-sectional area (90 square metres). The tunnel will have a large cross-sectional area to reduce the pollutant concentration for a given emission into the tunnel volume, and to permit greater volumetric air throughput.
- Increased height. The height of the New M5 tunnel (5.3 metres) will be significantly greater than that of the M5 East tunnel (4.6 metres). This will reduce the risk of incidents involving high vehicles blocking the tunnel and leading to disruption of traffic.

Ventilation design and control

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.

Air treatment

The effectiveness of the treatment of tunnel emissions has been evaluated as part of the environmental assessment phase of a number of existing Sydney road tunnels, including the M5 East, Cross City Tunnel and Lane Cove Tunnel. It has also been subject of numerous NSW Legislative Council (Upper House) inquiries and independent scientific reviews including by the CSIRO. In general these evaluations have indicated that it is more cost-effective to reduce pollutants at the source, using improved fuel standards and engine technology, which will result in greater benefits to air quality, both in-tunnel and in the ambient air, at the local and regional scales (WDA, 2013).

Electrostatic precipitators

The EIS for NorthConnex included an analysis of the potential costs and benefits of tunnel filtration systems, and argues why such systems are not warranted (AECOM, 2014a,b). These same arguments are also relevant to the New M5 project, and are summarised below.

- New M5 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. As the conventional ventilation system is effective, there would be little benefit in providing an in-tunnel filtration system.
- This Air Quality Assessment Report has demonstrated that the emissions from the ventilation outlets of the New M5 tunnel have a negligible impact on existing ambient pollutant

concentrations. These would meet ambient air quality criteria and would pose a very low risk to human health. In this context, there is no basis to justify installation of filtration systems.

- Of the systems that have been installed, the majority have subsequently been switched off or are currently being operated infrequently (in some cases only a few hours per year in response to unusual or infrequent conditions, and/ or ongoing maintenance requirements). Where the operation of in-tunnel air treatment systems have been discontinued or reduced, the reasons have been that
  - The technology has proved to be less effective than predicted.
  - The forecast traffic volumes have not eventuated.
  - Reductions in vehicle emissions.

  As a result of these reasons, the high ongoing operational costs of the technology have not been justified.

- Most tunnels achieve acceptable air quality criteria without filtration. Less than one per cent of tunnels in the world use filtration to reduce particulate matter or nitrogen dioxide levels to maintain acceptable in-tunnel or external air quality. No tunnels in Australia use filtration to meet

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.

Incorporating filtration to the ventilation outlets would have negligible benefit and 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. Further, the air leaving the outlet is not highly concentrated with pollutants (as demonstrated by the air quality assessment) since it must be of a quality to be acceptable for tunnel users. Any predicted impact on local air quality is very small even without a filtration system.

In summary, the provision of a tunnel filtration system does not represent a feasible and reasonable mitigation measure and is not being proposed.

Denitrification

The technology around tunnel air filtering systems for nitrogen dioxide is relatively new and any benefit has yet to be sufficiently measured.

Emission controls

Smoky vehicle cameras would be installed to automatically detect vehicles with excessive exhaust smoke, with penalties applying to offenders. A similar initiative is in place for the M5 East tunnel and has resulted in a reduction of smoky vehicles using the tunnel.

12 Summary and conclusions

This report presents an assessment of the construction and operational activities that have potential to impact on in-tunnel, local and regional air quality.

The main conclusions of the air quality assessment for the project are summarised below.

12.1 Construction impacts

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 ambient PM_{10} concentrations. 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.

12.2 Operational impacts

12.2.1 In-tunnel air quality

In-tunnel air quality for the project was modelled using the IDA Tunnel software and Australia-specific emission factors from PIARC. Consideration was given to peak in-tunnel concentrations of CO and 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.

12.2.2 Ambient air quality (expected traffic, ground-level concentrations)

General conclusions

The following general conclusions have been drawn from this 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 $PM_{2.5}$.
- 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 (1-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, the total numbers of receptors with exceedances decreased slightly with the project. The exception to this was annual mean $PM_{2.5}$, for which concentrations were (by definition in the assessment) always above the corresponding criterion.

- The spatial changes in air quality as a result of the project were quite complex, reflecting the complex changes in traffic on the network. There were predicted to be substantial reductions in concentrations along the M5 East Motorway, both to the east and west of the M5 East tunnel, as well as along General Holmes Drive and other roads around the airport. Reductions in concentrations were also predicted along the section of King Georges Road to the north of the M5 East Motorway, around the northern perimeter of Sydney Park, and on a number of other roads. However, increases in concentration were predicted for King Georges Road to the south of the M5 East Motorway, Stoney Creek Road, Bexley Road to the south of the M5 East Motorway, Harrow Road, Bay Street, Forest Road, and around the southern perimeter of Sydney Park, amongst other roads.
- Where increases in pollutant concentrations at receptors were predicted, these were mostly small. A very small proportion of receptors were predicted to have larger increases.

Pollutant-specific conclusions (2021-DS and 2031-DS scenarios)

Carbon monoxide (maximum 1-hour mean)

- In all scenarios the predicted maximum 1-hour CO concentration was well below the NSW impact assessment criterion of 30 µg/m^3, as well as the lowest international air quality standard identified in the literature.
- There was an increase in CO at around half of the receptors, although the increase was greater than 1 mg/m^3 for only a very small proportion of them, and even the largest increases were an order of magnitude below the criterion.

Carbon monoxide (maximum rolling 8-hour mean)

- As with the 1-hour mean, at all the receptors the concentration was well below the NSW impact assessment criterion, which in this case is 10 µg/m^3. No lower criteria appear to be in force internationally.
- The tunnel ventilation outlet contribution at the community receptors was less than one per cent in 2021.

Nitrogen dioxide (annual mean)

- The annual mean NO_2 criterion for NSW was not exceeded at any receptor in any scenario. The annual mean NO_2 concentrations at the vast majority of receptors were between around 23 µg/m^3 and 32 µg/m^3. In 2021 and 2031 the highest concentrations with the project were predicted to be 43.0 µg/m^3 and 39.8 µg/m^3, compared with the NSW impact assessment criterion of 62 µg/m^3. The concentrations in 2021 and 2031 were also below international standards.
- The maximum contribution of tunnel ventilation outlets at any location in 2021 was 0.6 µg/m^3, whereas the surface road contribution ranged between 2.2 µg/m^3 and 19.8 µg/m^3. The corresponding values for 2031 were 0.7 µg/m^3, 1.4 µg/m^3 and 16.6 µg/m^3.
- There was predicted to be an increase in annual mean NO_2 at 62 per cent of receptors in 2021, although the increase was greater than 2 µg/m^3 for less than one per cent of receptors.

Nitrogen dioxide (maximum 1-hour mean)

- At all community receptor locations investigated in detail, the maximum on-hour NO_2 concentration was below the NSW impact assessment criterion of 246 µg/m^3. There was also compliance with the most stringent international standards at these receptors.
- As with the annual mean, the background was the most important source, with generally a small contribution from surface roads. The ventilation outlet contribution to the maximum NO_2 concentration was zero or negligible for all these community receptors.
- There were some predicted exceedances of the 1-hour NO_2 criterion at other receptors in the New M5 domain. However, the project resulted in a small decrease in the number of exceedances.

- The maximum contribution of tunnel outlets to NO_X at any receptor was 93 µg/m^3 in 2021-DS (120 µg/m^3 in 2031-DS). This would equate to a very small NO_2 contribution relative to the air quality assessment criterion.

PM_{10} (annual mean)

- The annual mean PM_{10} concentration at the majority of receptors in 2021 was below 20 µg/m^3, and therefore well below the NSW impact assessment criterion of 30 µg/m^3. PM_{10} concentrations were only slightly higher than the lowest PM_{10} standard in the literature (18 µg/m^3 in Scotland), and generally lower than the proposed target for NSW of 20 µg/m^3. The highest predicted concentration at any receptor with the project in 2021 was 24.6 µg/m^3, but as with other pollutants and metrics the highest values were only predicted for a small proportion of receptors.
- The surface road contribution was between 1.4 µg/m^3 and 7.4 µg/m^3. The largest contribution from tunnel ventilation outlets was just 0.11 µg/m^3 in 2021-DS and 2031-DS.
- In 2021 there was an increase in PM_{10} at 64 per cent of the receptors, although the increase was greater than 1 µg/m^3 for only 0.1 per cent five of the receptors. The largest predicted increase in concentration at any receptor as a result of the project in 2021 was 1.8 µg/m^3, and the largest predicted decrease was 5.3 µg/m^3.

PM_{10} (maximum 24-hour mean)

- At all community receptor locations the maximum concentration was below - but close to - the NSW impact assessment criterion of 50 µg/m^3, which is also the most stringent standard in force internationally.
- The surface road contribution to the maximum 24-hour PM_{10} concentration at each community receptor was small (generally <2 µg/m^3). The ventilation outlet contributions were negligible (<0.1 µg/m^3).
- Some exceedances were predicted at a small proportion of other receptors. In 2021 the proportion of receptors with a concentration above the criterion decreased from 2.6 per cent in the Do Minimum scenario to 1.6 per cent with the project. The maximum contribution of tunnel outlets at any receptor was only 0.5 µg/m^3 in 2021 (1.8 µg/m^3 in 2031).
- With the project in 2021, there was an increase in the maximum 24-hour PM_{10} concentration at 54 per cent of all receptors, although the increase was greater than 2 µg/m^3 for only 2.4 per cent of receptors. The largest predicted increase in concentration at any receptor as a result of the project was 6.8 µg/m^3, and the largest predicted decrease was 18.3 µg/m^3.

$PM_{2.5}$ (annual mean)

- The predictions for annual mean $PM_{2.5}$ were based on an assumed background concentration of 8 µg/m^3 (the AAQ NEPM advisory reporting standard), and therefore exceedances were predicted for all receptors. Internationally, there are no standards lower than 8 µg/m^3 for annual mean $PM_{2.5}$. Clearly the predicted exceedances were not a consequence of the project.
- The highest concentration at any receptor in the 2021-DS scenario was 12.7 µg/m^3, but as with other pollutants and metrics the highest values were only predicted for a small proportion of receptors.
- Annual mean $PM_{2.5}$ concentrations were dominated by the background. The surface road contribution was between 0.4 µg/m^3 and 4.7 µg/m^3. The largest contribution from tunnel ventilation outlets in 2021 and 2031 was 0.08 µg/m^3.
- There was an increase in concentration at 63 per cent of receptors, although the increase was greater than 0.5 µg/m^3 for only 0.04 per cent of receptors. The largest predicted increase in concentration at any receptor as a result of the project was 1.2 µg/m^3, and the largest predicted decrease was 3.5 µg/m^3.

$PM_{2.5}$ (maximum 24-hour mean)

- At all community receptor locations the maximum concentration was below - but close to – the NSW impact assessment criterion of 25 µg/m^3. Internationally, there are no standards lower than 25 µg/m^3 for 24-hour $PM_{2.5}$.
- The road contributions to the maximum 24-hour $PM_{2.5}$ concentration were small (generally <2 µg/m^3), except in a few cases. The outlet contributions were negligible (<0.2 µg/m^3).
- The maximum 24-hour mean $PM_{2.5}$ concentrations at the majority of RWR receptors was below the NSW impact assessment criterion of 25 µg/m^3. The proportion of receptors with a concentration above the criterion decreased from 4.0 per cent in the Do Minimum scenario to 3.2 per cent with the project. The maximum contribution of tunnel outlets at any receptor was only 0.39 µg/m^3 in 2021 and 2031.

Air toxics

- Four air toxics - benzene, PAHs (as BaP), formaldehyde and 1,3-butadiene - were considered in the assessment. These compounds were taken to be representative of the much wider range of air toxics associated with motor vehicles, and they have commonly been assessed for road projects.
- The changes in the maximum 1-hour concentrations were compared with the relevant NSW impact assessment criteria. For each compound, where there was an increase in the concentration, this was well below the NSW impact assessment criterion.

Pollutant-specific conclusions (2031-DSC scenario)

In the majority of cases the results for the community and RWR receptors in the 2031-DSC scenario were very similar to those in the 2031-DS scenario.

12.2.3 Ambient air quality (expected traffic, elevated receptors)

At a height of 30 metres the increases in concentration were larger than at 10 metres, but they were much more localised around the ventilation outlets. This was due to some of the grid points at 30 metres being directly above the ventilation outlets.

No RWR receptors were predicted to experience a change in annual average $PM_{2.5}$ of more than 0.8 µg/m^3 at a height of 10 metres. The largest increase was 0.8 µg/m^3. At a height of 30 metres the increase in $PM_{2.5}$ was greater than 0.8 µg/m^3 at 38 receptors. There were 17 RWR receptors that were predicted to have a change in annual average $PM_{2.5}$ of more than 1.6 µg/m^3. All these receptor locations were very close to the assumed location of the Southern extension ventilation facility

The implications of these results can be summarised as follows:

- For all existing receptor locations, the changes in concentration at 10 metres are likely to be acceptable. This assumes that the changes in $PM_{2.5}$ concentration for heights between ground level and 10 metres are also acceptable.
- Future developments to height of 10 metres should be possible at all locations in the GRAL New M5 domain.
- For all existing receptor locations, the largest increases in concentration at a height of 30 metres are clustered around the Southern extension outlets. Given that the Southern extension is not formally part of WestConnex, and the precise locations of the outlets are not known at this stage, this does not constitute a problem.
- The contour maps do not seem to impose any significant restrictions on future developments to 30 metres height, except in the immediate vicinity of ventilation outlet.

12.2.4 Ambient air quality (regulatory worst case)

The regulatory worst case scenario was assessed for the tunnel ventilation outlets only. The findings were as follows:

- The maximum contribution to the maximum 1-hour CO concentration was negligible.
- The maximum contribution to the annual mean NO_2 concentration was not insignificant. However, total concentrations would have remained well below the criterion.
- The maximum contribution to the 1-hour mean NO_2 concentration could have been significant. However, the relative contributions from the background, surface roads and ventilation outlets presented earlier in the report suggest that any exceedances of the 1-hour NO_2 criterion are much more likely to be due to a high background and emissions from existing surface roads rather than as a result of emissions from the project ventilation outlets.
- The maximum contribution from the ventilation outlets in the regulatory worst case scenarios would not have had a significant impact on annual mean PM_{10} and $PM_{2.5}$ concentrations.
- The most significant result was that for the 24-hour $PM_{2.5}$ contribution (and similarly the 24-hour PM_{10} contribution).

Whilst the contributions to maximum 1-hour concentrations of NO_2 and 24-hour concentrations of $PM_{2.5}$ could be significant they would not represent a cause for concern in reality.

The peak in-tunnel concentrations for all traffic scenarios, including the capacity traffic at different speeds, were well within the in-tunnel concentrations associated with the regulatory worst case scenarios. It therefore follows that the predicted ventilation outlet contributions to ambient concentrations for any in-tunnel traffic scenario would be lower than those for the regulatory worst case.

It can be concluded that emissions from the project ventilation outlets, even in the regulatory worst case scenarios, would be extremely unlikely to result in an adverse impacts on local air quality. WDA will conduct ambient air quality monitoring to demonstrate that emissions from the ventilation outlets will have no detectable impact on local air quality.

12.3 Management of impacts

12.3.1 Construction impacts

A range of measures for the management of construction impacts has 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 New M5 project. This should contain details of the site-specific mitigation measures to be applied.

12.3.2 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.

Tunnel design

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 4 per cent.
- Large main line tunnel cross-sectional area (90 m^2).
- Increased height to reduce the risk of incidents involving high vehicles blocking the tunnel.

Ventilation design and control

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.

Air treatment

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:

- New M5 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 New M5 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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Appendix A - Traffic pollutants and their effects

A.1 Overview

This Appendix summarises the health and non-health effects of the traffic-related pollutants that were included in the assessment.

Road vehicles emit a complex mixture of pollutants. These are generated though combustion processes (CO, NO_X, PM and many different hydrocarbon compounds), evaporation processes (VOCs) and abrasion processes (PM from tyre wear, brake wear, etc.). The resuspension of material on the road surface also contributes to ambient PM concentrations, but this is not always considered in models because of its site-specific nature and a lack of suitable emission factors.

Various studies have linked road traffic emissions to health outcomes, and this Appendix has considered reviews of these studies by the following organisations:

- The World Health Organization (WHO).
- The United States Environmental Protection Agency (USEPA).
- The Committee on the Medical Effects of Air Pollutants (COMEAP) in the UK.
- The Health Effects Institute (HEI).

In the following sections a traditional approach is used to explain the health effects of traffic pollutants, whereby each pollutant is treated separately. The traffic pollutants causing most concern at present are NO_2 and PM. For example, $PM_{2.5}$ from vehicle exhaust is increasingly cited as a key health-related metric. It has been noted by WHO that there is an elevated health risk associated with living close to roads, but also that this is unlikely to be explained by $PM_{2.5}$ alone (WHO Regional Office for Europe, 2013).

A.2 Carbon monoxide

A.2.1 Health effects

Carbon monoxide (CO) is a colourless, odourless gas. It can be harmful to humans because, when inhaled, it is taken up by haemoglobin in the blood (forming carboxyhaemoglobin) in preference to oxygen, thus reducing the capacity of the blood to transport oxygen. The affinity of CO for haemoglobin is more than 200 times greater than that of oxygen.

At low concentrations the symptoms of CO intoxication include lethargy in healthy adults, and chest pain in people with heart disease. At higher concentrations CO leads to impaired vision and coordination, headaches, dizziness, confusion and nausea. CO is fatal at very high concentrations[1]. Symptoms are not generally reported until the carboxyhaemoglobin level in the blood exceeds 10%. This is approximately the equilibrium value achieved with an ambient concentration of 70 mg/m^3 for a person engaged in light activity. There is evidence that there is a risk for individuals with cardiovascular disease at lower carboxyhaemoglobin levels. A carboxyhaemoglobin level in the blood of 40-50% usually leads to death. However, in most Australian towns and cities the levels of CO in ambient air are well below those that are hazardous to human health. Only in larger cities do CO levels have the potential to have harmful effects[2].

A.2.2 Other effects

CO plays a role in the formation of ground-level ozone. It also has an indirect radiative forcing effect on climate by elevating concentrations of methane and tropospheric ozone through chemical reactions with other atmospheric constituents (e.g. the hydroxyl radical, OH) that would otherwise destroy them.

[1] http://www.epa.gov/iaq/co.html#Health_Effects

[2] http://www.environment.gov.au/protection/publications/factsheet-carbon-monoxide-co

A.3 Nitrogen dioxide

A.3.1 Health effects

Nitrogen dioxide (NO_2) is one of the most important road traffic pollutants. It is an irritant and oxidant which has been linked to a range of adverse health effects including deterioration in lung function, respiratory symptoms, asthma prevalence and incidence, cancer incidence, and birth outcomes (e.g. birth weight). The most consistent associations, however, have been found with respiratory outcomes (COMEAP, 2009).

For short-term exposure, the extensive review by the WHO Regional Office Europe (2013) noted that many studies have documented associations between variations in NO_2 concentration and respiratory symptoms, hospital admissions and mortality, even after adjustment for PM and other pollutants for some health outcomes.

For long-term exposure, there is likely to be a causal relationship between NO_2 and respiratory effects, although NO_2 may act as a marker for other traffic pollutants. The evidence for cardiovascular effects and total mortality is suggestive, but not sufficient to infer a causal relationship (WHO Regional Office for Europe, 2013; USEPA, 2015).

A recent review by NSW Health (2015) concluded that there are some limited data to support the setting of a health-based NO_2 limit for road tunnels. At concentrations below 0.2 ppm no health effects have been observed in chamber studies. At concentrations between 0.2 ppm and 0.5 ppm for 20-30 minutes, some health effects have been observed in susceptible groups. For example, Svartengren et al. (2000) found that exposure to air pollution in road tunnels may significantly enhance asthmatic reactions to subsequently inhaled allergens. NSW Health noted that, for exposures at concentrations above 0.5 ppm for 20-30 minutes, health effects were observed in healthy people. It was concluded that the evidence suggests that sensitive populations may experience adverse health effects if exposed for 20-30 minutes to tunnel air with an NO_2 concentration of 0.5 ppm.

A.3.2 Other effects

Emissions of nitrogen oxides (NO_x) are implicated in regional phenomena such as acidification, eutrophication and loss of biodiversity, as well as the formation of secondary PM in the atmosphere. NO_2 also absorbs visible solar radiation and contributes to impaired atmospheric visibility. It is an important regulator of the oxidising capacity of the troposphere (the lowest layer of the atmosphere), in that it controls the build-up and fate of radicals[3]. It also plays a critical role in determining ozone concentrations in the troposphere.

A.4 Particulate matter

A.4.1 Health effects

The pollutant generally accepted as having the greatest public health impact is particulate matter (Harrison, 2010). The biological effects of inhaled particles are determined by their physical and chemical properties, by their sites of deposition, and by their mechanisms of action. The extent to which particles can penetrate the respiratory tract, and their potential for causing health effects, is directly related to their size (Harrison et al., 2010). Notably, particles with a diameter of less than 2.5 µm ($PM_{2.5}$) can penetrate deep into the human respiratory system, and it is these which are of most concern.

In recent years evidence has accumulated indicating that airborne particles have a range of adverse effects on health. These effects – which are diverse in scope, severity and duration - include:

- Premature mortality.
- Aggravation of cardiovascular disease such as atherosclerosis.
- Aggravation of existing respiratory disease such as asthma.

[3] Radicals (or 'free radicals') are atomic or molecular species with unpaired electrons. These unpaired electrons are usually highly reactive, so radicals are likely to take part in chemical reactions.

- Changes to lung tissue, structure and function.
- Cancer[4]. Importantly, the International Agency for Research on Cancer has recently classified outdoor air pollution as carcinogenic to humans, with a specific emphasis on PM and diesel engine exhaust (IARC, 2012; 2013).
- Reproductive and developmental effects.
- Changes in the function of the nervous system.

There is evidence that short-term and long-term exposure to $PM_{2.5}$ causes illness and death from cardiovascular conditions, and is likely to cause respiratory conditions (USEPA 2009; WHO Regional Office for Europe, 2013). The effects observed in relation to $PM_{2.5}$ from a large study conducted in Australia and New Zealand (EPHC, 2010) are consistent with the effects reported in the international literature.

There is extensive evidence that short-term exposure to particles with a diameter of less than 10 µm (PM_{10}) is associated with health effects, and that these effects are independent of the effects of $PM_{2.5}$ (USEPA, 2009; WHO Regional Office for Europe, 2013). There is substantially less evidence that long-term exposure to PM_{10} has health effects that are independent of those caused by long-term exposure to $PM_{2.5}$. As with $PM_{2.5}$, the effects observed in the Australian and New Zealand NEPC multi-city study (EPHC, 2010) in relation to PM_{10} exposure are consistent with those observed internationally.

Studies have also investigated the relationship between specific PM components (for example, black carbon, secondary organic aerosol (SOA) and secondary inorganic aerosol (SIA)) and health effects (WHO Regional Office for Europe, 2013). In the future, the use of these metrics may provide a better indication of exposure to PM from particular sources, such as vehicle exhaust, and may improve the understanding of the associated health risks.

No safe threshold has been identified for the human health effects of particles (NSW DECCW, 2010); for $PM_{2.5}$ there is substantial evidence of health associations down to very low levels. In Canada, Crouse *et al.* (2012) investigated the long-term exposure to ambient $PM_{2.5}$ and observed associations with cardiovascular mortality at concentrations as low as only a few micrograms per cubic meter. This last study is particularly relevant, because it investigated the effects of $PM_{2.5}$ at the levels commonly experienced in Australia.

A.4.2 Other effects

Particulate matter has the capacity to influence climate locally, regionally and globally. Black carbon from combustion sources has much the same effect as a greenhouse gas, although the mechanisms are different. White particles such as ammonium sulfate are reflective and have a net cooling effect by reflecting incoming solar radiation back to space. Water-soluble particles can act as cloud condensation nuclei, thus affecting the reflectivity of clouds and leading to a reduction in land surface warming (Harrison, 2010).

Airborne particles also reduce atmospheric visibility by the scattering and absorption of visible light. Visibility is an important safety concern for tunnel design. The amount of scattering or absorption is dependent upon particle size, composition and density. Vehicle exhaust contains a large number of very small particles (0.01 to 0.20 µm diameter) (see Appendix B), and particles in this size range are very effective at light extinction (PIARC, 2012).

A.5 Air toxics

Road vehicles produce a wide range of organic compounds through combustion and evaporation. These compounds are involved in the formation of photochemical smog, which is associated with irritation of the eyes and respiratory tract, amongst other things. Many of the organic compounds emitted by road vehicles also have impacts on health and the environment in their own right.

It is uncommon for air quality assessments to address a large number of organic pollutants. It is more

[4] Particles may contain carcinogenic substances such as polycyclic aromatic hydrocarbons (PAHs) or heavy metals.

usual for a small number of the most important components to be assessed, with inferences being made in relation to others. The compounds included in the assessment were benzene, benzo(a)pyrene (as a marker for polycyclic aromatic hydrocarbons), formaldehyde, and 1,3-butadiene. With respect to road traffic these pollutants are generally less of a concern than in the past, as improvements in fuel quality, through higher fuel standards, in recent years have reduced the amounts being emitted from vehicles.

A.5.1 Benzene

Benzene is a constituent of automotive petrol, but since 2006 the benzene content in Australia has been limited to 1% by volume (compared with 5% previously). This reduction had an immediate and sustained impact on ambient benzene levels.

Short-term inhalation exposure to benzene can cause drowsiness, dizziness, headaches, as well as eye, skin, and respiratory tract irritation, and, at high levels, unconsciousness. Long-term inhalation exposure has caused blood disorders including reduced numbers of red blood cells and anaemia. Reproductive effects have been reported for women. Increased incidence of leukaemia has been observed in humans occupationally exposed to benzene. The USEPA has classified benzene as known human carcinogen[5].

A.5.2 Polycyclic aromatic hydrocarbons

The term polycyclic aromatic hydrocarbons (PAH) covers a large group of organic compounds with two or more fused aromatic rings. Around 500 PAHs and related compounds have been detected in the air (WHO, 2000). PAHs are formed by incomplete combustion of fuels, including transport fuels, and can be present in both the gas and (more commonly) particle phases. The USEPA has designated 32 PAH compounds as priority pollutants. A short list of compounds is often targeted for measurement in environmental samples. Of these, the most measurements have been made for benzo(a)pyrene, and this compound is used as a marker for PAHs in the Air Toxics NEPM.

PAHs are a concern because they are persistent in the environment for long periods of time. There is little information on the health effects of exposure to individual PAHs at specific concentrations. Short-term exposure to mixtures of PAHs is known to cause skin irritation and inflammation. Anthracene, benzo(a)pyrene and naphthalene are direct skin irritants, while anthracene and benzo(a)pyrene are reported to cause an allergic skin response. The health effects of long-term exposure to PAHs may include cataracts, kidney and liver damage and jaundice. Naphthalene, a specific PAH, can cause the breakdown of red blood cells if inhaled or ingested in large amounts. Long-term studies of workers exposed to mixtures of PAHs and other workplace chemicals have shown an increased risk of skin, lung, bladder and gastrointestinal cancers (USEPA, 2008; SA Health, 2009).

A.5.3 Formaldehyde

Formaldehyde is a colourless gas with a pungent odour. Major sources include power plants, manufacturing facilities, incinerators, and automobile exhaust. Short-term and long-term inhalation of formaldehyde can result in respiratory symptoms, and eye, nose, and throat irritation. Limited human studies have reported an association between formaldehyde exposure and lung and nasopharyngeal cancer. The USEPA considers formaldehyde to be a probable human carcinogen[6].

A.5.4 1,3-butadiene

Motor vehicle exhaust is a source of 1,3-butadiene. Although it breaks down quickly in the atmosphere, it is usually found in ambient air at low levels in urban and suburban areas. Short-term exposure to 1,3-butadiene by inhalation results in irritation of the eyes, nasal passages, throat, and lungs. Epidemiological studies have reported a possible association between 1,3-butadiene exposure and cardiovascular diseases. The USEPA has classified 1,3-butadiene as carcinogenic to humans by inhalation[7].

[5] http://www.epa.gov/ttn/atw/hlthef/benzene.html

[6] http://www.epa.gov/ttn/atw/hlthef/formalde.html

[7] http://www.epa.gov/ttnatw01/hlthef/butadien.html

Appendix B - Pollutant formation, dispersion and transformation

B.1 Overview

This Appendix summarises the processes that are involved in the formation of traffic pollutants, and their subsequent dispersion and transformation in the atmosphere. It is not designed to be comprehensive, but to provide additional contextual information for the pollutants included in the assessment.

B.2 Formation of primary pollutants

B.2.1 Combustion

Most road vehicles are powered by internal combustion engines in which energy is derived from the burning of fuel in air. The main products of combustion are CO_2 and water vapour. However, several different processes lead to other compounds being present in vehicle exhaust in lower concentrations. The formation these compounds during combustion is summarised in the following sections.

B.2.1.1 Carbon monoxide

Not all of the fuel is completely consumed during combustion. Incomplete combustion usually results from insufficient oxygen in the combustion mixture, and this leads to the production of carbon monoxide (CO). Historically, the main source of CO in urban areas has been petrol vehicles. However, emissions of CO from petrol vehicles have reduced substantially in recent years as a result of the emission legislation effectively mandating the fitting of a three-way catalyst (TWC)[1]. Diesel engines produce relatively little CO as they burn the fuel with excess air in the combustion chamber, even at high engine loads.

B.2.1.2 Hydrocarbons

During combustion the flame is 'quenched' by the cylinder walls, leaving behind unburnt and partially burnt fuel that is expelled with the exhaust. The unburnt and partially burnt fuel contains many different organic compounds, referred to collectively as total hydrocarbons (THC). As with CO, hydrocarbon emissions from petrol vehicles have greatly decreased as a result of TWCs, and hydrocarbon emissions from diesel engines are low for the reason mentioned above for CO.

B.2.1.3 Oxides of nitrogen

At the high temperatures and pressures in the combustion chamber some of the nitrogen in the air is oxidised, forming mainly nitric oxide (NO) with some nitrogen dioxide (NO_2). NO formation is also enhanced by oxygen-rich fuelling conditions, and proceeds via two main mechanisms. The main NO mechanism is known as the 'thermal' (or Zel'dovich) cycle, and this is responsible for more than 90 per cent of emissions (Heywood, 1988; Vestreng *et al.*, 2009). NO_2 is predominantly a secondary pollutant, being produced by the oxidation of NO in atmospheric photochemical reactions (see Section B.3.3.1). Any NO_2 that is emitted directly from vehicles is referred to as 'primary NO_2'.

NO_X emissions from petrol vehicles have also decreased as a consequence of TWCs. However, analyses in Europe have shown that, despite the reductions in vehicle emissions that are calculated in inventories, NO_2 concentrations at many roadside monitoring sites are not decreasing. Further analyses have indicated that a significant proportion of ambient NO_2 must be emitted directly from vehicle exhaust, and that the direct road traffic contribution to ambient NO_2 has increased in recent

[1] Concentrations of pollutants in the exhaust gas depend on the air/fuel mixture. For lean mixtures (*i.e.* where there is an excess of air in the combustion chamber) the exhaust gases contain little CO or HC, but high concentrations of NO_X. Rich mixtures (*i.e.* where there is an excess of fuel) produce high concentrations of CO and HC, with little NO_X. A TWC results in the simultaneous conversion of CO to CO_2, HC to water, and NO_X to nitrogen. The emission rates of these pollutants are typically an order of magnitude lower than those for non-catalyst petrol cars. A closed-loop air-fuel ratio controller is required to maintain stoichiometric conditions for the TWC to work effectively. Precise control is especially important for efficient NO_X reduction, as the NO_X conversion drops dramatically for lean mixtures.

Appendix C - Review of legislation and criteria relating to emissions and air quality

C.1 Overview

This Appendix provides supplementary information, including an international context, on key legislative instruments and guidelines in relation to the project.

C.2 National emission standards for new vehicles

C.2.1 Exhaust emissions

For emission testing purposes, the legislation distinguishes between the following:

- Light-duty vehicles. These have a gross vehicle mass (GVM) of less than 3,500 kilograms, and are subdivided into:
    - Light-duty passenger vehicles, including cars, sports utility vehicles (SUVs), four-wheel drive (4WD) vehicles and 'people movers'.
    - Light-duty commercial vehicles, including vans and utility vehicles used for commercial purposes.

  The legislation also distinguishes between petrol and diesel vehicles.
- Heavy-duty vehicles, with a GVM of more than 3,500 kilograms.

Exhaust emissions are inherently variable, and so the best way to ensure that an emission test is reproducible is to perform it under standardised laboratory conditions. Light-duty vehicles are tested using a power-absorbing chassis dynamometer. The emissions from heavy-duty vehicles are regulated by engine dynamometer testing, reflecting that the same engine model could be used in many different vehicles.

The Australian Design Rules (ADRs) set limits on the exhaust emissions of CO, HC, NO_X and PM. Some of the pollutants in vehicle exhaust are not regulated, including specific 'air toxics' and the greenhouse gases CO_2, CH_4 and N_2O. The specific emission limits which apply to light-duty and heavy-duty vehicles, and their timetable for adoption in the ADRs, are listed on the Australian Government website[1]. Although the test procedures have changed with time, the exhaust emission limits have tightened significantly in recent years. There has been a greater alignment with the international vehicle emissions standards set by the UNECE[2], although the Australian standards have delayed introduction dates (DIT, 2010).

Australia is currently implementing the Euro 5[3] emission standards for new light-duty vehicle models (cars and light commercial vehicles). New vehicle models have been required to comply with these standards since November 2013. The Euro 6 standards will commence for new models from July 2017 (Australian Government, 2010). Existing model vehicles must meet the Euro 6 standards from 1 July 2018. With full implementation of Euro 6, the World Harmonized Light-duty Vehicle Test Cycle (WLTC) will replace the current test cycle (Mock et al., 2014).

In the case of heavy-duty vehicles the Euro V standards are currently being implemented in Australia, and the Euro VI standards are currently under discussion. Whilst the Euro VI standards will reduce the limit on NO_X emissions by 77 per cent relative to Euro V, and by 89 per cent relative to Euro IV, advanced test protocols that improve real-world conformity to NO_X limits should result in reductions that are closer to 95 per cent (Muncrief, 2015).

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

[2] United Nations Economic Commission for Europe.

[3] In accordance with the European legislation, a slightly different notation is used in this Report to refer to the emission standards for LDVs, HDVs and two-wheel vehicles. For LDVs and two-wheel vehicles, Arabic numerals are used (e.g. Euro 1, Euro 2…etc.), whereas for HDVs Roman numerals are used (e.g. Euro I, Euro II…etc.).

The ADRs do not mandate the use of particular technology. However, it was necessary for vehicle manufacturers to fit catalytic converters to light-duty petrol vehicles in order to meet the emission limits introduced by ADR37/00. For light-duty diesel vehicles, particulate traps will generally be required for compliance with the very low PM emission limits at the Euro 5 stage. For Euro 6/VI the required NO_X reductions will be achieved with combustion improvements (high-pressure fuel injection and advanced air/fuel management), exhaust gas recirculation, closed-loop SCR systems and lean NO_x trap (LNT) technology. To support the introduction of new technologies there is usually a need for improved fuel quality (e.g. reduced fuel sulfur content). Fuel regulations therefore tend to be updated to support new emission standards.

The European Commission is introducing a mandatory test procedure for 'real driving emissions' (RDE), to be applied during the type approval of light-duty vehicles. These are measured on the road by a portable emission measurement system (PEMS), rather than in the laboratory. The RDE initiative complements the introduction of the WLTC and procedures. The new RDE procedure will require exhaust emission control systems to perform under a broad range of different operating conditions.

Several shortcomings of the regulations have been identified in the EU. For heavy-duty vehicles the Euro V standards have not achieved the anticipated reductions in NO_X emissions (Ligterink et al., 2009). Whilst the Euro 5 standards have resulted in dramatic reductions in PM emissions from light-duty diesels, real-world NO_X emissions from Euro V trucks and buses have continued to far exceed certification limits (Carslaw et al., 2011).

C.2.2 Evaporative emissions

The test procedure for evaporative emissions involves placing a vehicle inside a gas-tight measuring chamber equipped with sensors to monitor the temperature and VOC concentrations, and following a prescribed operational procedure. The chamber is known as a SHED (Sealed Housing for Evaporative Determination). The limits for evaporative emissions are specified in the ADRs.

C.3 In-tunnel limits

Guidelines for the calculation of the fresh air requirements of tunnel ventilation systems are presented by PIARC (2012). Three types of value are defined:

- Design values: These determine the required capacity of the tunnel ventilation system. The ventilation capacity for normal tunnel operation is defined by the air demand required to dilute vehicle emissions to maintain allowable in-tunnel air quality.
- Set points: These are used for the incremental operation of the tunnel ventilation system. For example, tunnel sensors trigger mechanical ventilation in stages before the measured concentration of a gas reaches its sensor limit level (Highways Agency et al., 1999). Set points are generally lower than design values, and are selected so that the design conditions are not exceeded, taking into account the time lag between the traffic conditions and the ventilation system.
- Threshold values: These ensure safe operation of the tunnel, and must not be exceeded. If a threshold value is attained, immediate action is required, such as tunnel closure.

It is prudent for design modelling to include predictions for a range of traffic speeds, and to establish worst-case conditions. However, PIARC notes that the application of overly stringent design values can result in over-sizing of the ventilation system, and thresholds or set points that are too low can cause excessive operational energy use and cost. Nevertheless, the PIARC document states that the emission factors it provides for designing tunnel ventilation tend to be conservative, including a safety margin.

Table C-1 provides a summary of the PIARC in-tunnel CO and visibility limits for ventilation design, tunnel operation, and tunnel closure. The 100 ppm value for CO corresponds to a WHO recommendation for short-term (15-minute) exposure, and is widely used for ventilation design. Exposure at this concentration should not persist for more than 15 minutes, although the length of most tunnels is such that the exposure duration is much less than 15 minutes. In such cases, a higher level of CO may be allowed in the tunnel. The limits for visibility are designed for the purpose of safe driving rather than the protection of health.

The limit values for in-tunnel CO and visibility in a number of countries are shown in Table C-2. The national limits for CO in each country are broadly similar to the values recommended by PIARC.

Table C-1 CO and visibility limit values (PIARC, 2012)

Traffic situation	CO conc. (ppm)	Visibility	
		Extinction coefficient (/m)	Transmission *s* (beam length: 100 m)
Free-flowing peak traffic 50-100 km/h	70	0.005	60
Daily congested traffic, stopped on all lanes	70	0.007	50
Exceptional congested traffic, stopped on all lanes	100	0.009	40
Planned maintenance work in a tunnel under traffic[(a)]	20	0.003	75
Threshold for closing the tunnel[(b)]	200	0.012	30

(a) National workplace guidelines should be considered.

(b) To be used for tunnel operation only, and not for ventilation design.

Table C-2 In-tunnel CO and visibility limits for ventilation design and tunnel closure

Country	Condition for ventilation design	Limit values for ventilation design		Limit values for tunnel closure	
		CO (ppm)	Visibility (/m)	CO (ppm)	Visibility (/m)
Austria	Regular congestion	100	0.007	150[(a)]	0.012[(a)]
				100[(b)]	-
France	Free-flow and congested	50	0.005	-	-
Germany	Regular congestion	70	0.005	200	0.012
	Occasional congestion	100	0.007	-	-
Hong Kong	5-min average	100	-	-	-
Japan	60 km/h	50-100	<0.009	150	0.012
	80 km/h	50-100	<0.007		
Norway[(c)]	Mid-tunnel	75	-	100[(d)]	-
Switzerland	Any	70	0.005	200[(e)]	0.012[(e)]
UK[(f)]	Tunnel <500 m	10	PIARC	-	-
	Tunnel 500 m to 1,000 m	50	PIARC	-	-
	Tunnel 1,000 m to 2,500 m	35	PIARC	-	-
USA	Fluid peak traffic, 60 km/h	100	<0.009	150	0.012
	Fluid peak traffic, 80-100 km/h	100	<0.007		
	Congested traffic	100	<0.009		

(a) If exceeded for more than 1 minute.

(b) If exceeded for more than 10 minutes.

(c) In Norway, NO/NO_2 and particulate matter are also used for design and control purposes.

(d) If exceeded at tunnel mid-point for more than 15 minutes.

(e) If exceeded for more than 3 minutes.

(f) Limit values for tunnels longer than 2,500 m are derived from first principles.

Sources: Norwegian Public Roads Administration (2004), ASTRA (2003), CETU (2010), MEPC (1993), RABT (2003), RVS (2004)

PIARC has not released definitive recommendations for NO_2 in tunnels, and there are scientific and technical challenges in managing compliance with NO_2 limits. Based on the findings of health studies

PIARC has proposed an in-tunnel limit for NO_2 of 1 ppm as the design value, defined as an average value along the length of the tunnel (PIARC, 2012).

It is noted by PIARC that many countries do not apply a NO_2 limit specifically for tunnels, but occupational short-term exposure limits apply. These are typically higher than the 1 ppm proposed by PIARC. Some countries have introduced NO_2 as the target pollutant for in-tunnel air quality monitoring, with the threshold value normally following national and/or WHO recommendations. Depending on the situation, either NO_2 or NO_x inside the tunnel, or NO_2 outside the tunnel, can be taken as the design parameter for ventilation sizing.

Examples of in-tunnel NO_2 values for ventilation control from several countries are summarised in Table C-3. It is noted in PIARC (2012) that the WHO limits aim at improving air quality in general, and are not intended to be applied to peak exposures. Nevertheless, different values have been adopted for different time frames, and it appears that some of these are quite stringent. In the UK, consideration was given to lowering the NO_2 limit to 1 ppm, but tunnel operators stated that it would not be feasible to comply with this limit (Tarada, 2007). PIARC adds that passage through a tunnel typically only lasts for a few minutes, and therefore stringent NO_2 thresholds should only be considered where it might be warranted by traffic conditions and/or ambient conditions.

The CO, NO_2 and PM concentrations in the ambient fresh air used for dilution are normally relatively low, but should be checked for tunnels in urban areas, where ambient CO concentrations are typically between 1 ppm and 5 ppm. A typical ambient peak NO_2 concentration would be 200 $\mu g/m^3$. The situation can be modified, however, when air from the portal of one bore enters the portal of the adjacent bore as 'fresh air', although simple structural design features (*e.g.* anti-recirculation walls) can minimise or even eliminate such effects (PIARC, 2012).

For longitudinally ventilated tunnels in which traffic demands are high, or may change suddenly, PIARC recommends a minimum air flow speed of 1.0-1.5 m/s.

Table C-3 International in-tunnel NO_2 limits

Country	NO_2 (ppm)	Notes	Source
PIARC	1.0	Averaged over tunnel length	PIARC (2012)
Belgium	0.2	1 hour	WHO (2006)
	0.5	<20 minutes	PIARC (2012)
France	0.4	15 minutes, average for length of tunnel	CETU (2010)
Hong Kong	1.0	5 minutes, ventilation control	Hong Kong EPD (1995)
Norway[(a)]	0.75	15 minutes, tunnel mid-point	Norwegian Public Roads Administration (2004)
Sweden[(b)]	0.2	1 hour	WHO (2006)
UK[(c)]	4	Tunnel <500 m	Highways Agency *et al.* (1999)
	3	Tunnel 500 m to 1,000 m	
	1.5	Tunnel 1,000 m to 2,500 m	

(a) Resulting in tunnel closure.
(b) PIARC states that Sweden is in the process of abandoning the WHO threshold.
(c) Design and control. Limit values for tunnels longer than 2,500 m are derived from first principles.

C.4 Ambient air quality standards and goals

For the criteria pollutants included in the assessment, the impact assessment criteria in the NSW Approved Methods are compared with the WHO guidelines and the standards in other countries/organisations in Table C-4. For CO the NSW standards are numerically lower than, or equivalent to, those in most other countries and organisations. The NSW standards for NO_2 are higher than in the other countries and organisations except for the United States. In the case of PM_{10}, the NSW standard for the 24-hour mean is lower than or equivalent to the standards in force

elsewhere, whereas the annual mean standard is in the middle of the range of values for other locations. The $PM_{2.5}$ standards are lower than, or equivalent to, those used elsewhere. However, such comparisons do not necessarily mean that the Australian standards are more or less stringent than those elsewhere. For example, to a large degree the lower standards in Australia for PM are made possible by relatively low natural background concentrations and the absence of significant anthropogenic transboundary pollution (which is a major issue in Europe, for example). Moreover, there are differences in implementation; there is no legal requirement for compliance with the standards and goals in Australia, whereas there is in some other countries and regions.

Table C-4 Comparison of international health-related ambient air quality standards[a]

Country/Region/ Organisation	CO			NO_2			PM_{10}		$PM_{2.5}$	
	15 min. (mg/m^3)	1 hour (mg/m^3)	8 hours (mg/m^3)	1 hour ($\mu g/m^3$)	1 day ($\mu g/m^3$)	1 year ($\mu g/m^3$)	24-hours ($\mu g/m^3$)	1 year ($\mu g/m^3$)	24-hours ($\mu g/m^3$)	1 year ($\mu g/m^3$)
NSW Approved Methods	100(0)	30(0)	10(0)	246(0)	-	62	50(0)	30	25(0)[b]	8[b]
WHO	100(0)	30(0)	10(0)	200	-	40	50[c]	20	25[c]	10
Canada	-	-	-	-	-	-	120[d,e]	-[d]	28/27[f]	10/8.8[f]
European Union	-	-	10(0)	200(18)	-	40	50(35)	40	-	25[g]
Japan	-	-	22(0)	-	75-115	-	-	-	-	-
New Zealand	-	30[h]	10(1)	200(9)	100[h]	-	50(1)	20[h]	25[h]	-
UK	-	-	10(0)[i]	200(18)	-	40	50(35)	40	-	25
UK (Scotland)	-	-	10(0)[j]	200(18)	-	40	50(7)	18	-	12
United States (USEPA)	-	39(1)	10(1)	190[k]	-	100	150(1)	-	35[l,m]	12[l]
United States (California)	-	22(0)	10(0)	344(0)	-	57	50	20	-	12

(a) Numbers in brackets shows allowed exceedances per year for short-term standards. Non-health standards (e.g. for vegetation) have been excluded.
(b) Advisory reporting standard.
(c) Stated as 99th percentile.
(d) Although there is no national standard, some provinces have standards.
(e) As a goal.
(f) By 2015/2020.
(g) The 25 $\mu g/m^3$ value is initially a target, but will become a limit in 2015. There is also an indicative 'Stage 2' limit of 20 $\mu g/m^3$ for 2020.
(h) By 2020.
(i) Maximum daily running 8-hour mean.
(j) Running 8-hour mean.
(k) 98th percentile, averaged over 3 years.
(l) Averaged over three years.
(m) Stated as 98th percentile.

years (Jenkin, 2004; Carslaw and Beevers, 2004; Carslaw, 2005; Hueglin *et al.*, 2006; Grice *et al.*, 2009). Two contributing factors have been cited:

- Diesel vehicles emit more NO_x than petrol vehicles, and with a larger proportion of NO_2 in NO_x (termed *f*-NO_2). The market share of diesel vehicles has increased in many European countries in recent years.
- The average value of *f*-NO_2 in diesel exhaust is increasing. This appears to be linked to the growth in the use of specific after-treatment technologies in modern diesel vehicles which involve *in situ* generation of NO_2, such as catalytically regenerative particle filters (Carslaw, 2005).

Furthermore, it seems likely that real-world NO_x emissions from road vehicles are not decreasing as rapidly as models are predicting (Rexeis and Hausberger, 2009). Whilst this does not, in itself, affect actual NO_2 concentrations, it does suggest that NO_x controls have not been sufficiently stringent, or that vehicles are not performing as expected. The consequence of this is that there is now a great deal of interest in the tighter regulation of NO_x and NO_2 emissions from diesel vehicles and the effects of different after-treatment devices.

Historically a fairly low value for *f*-NO_2 (5-10 per cent) has been used in air quality and in-tunnel assessments in NSW. However, primary NO_2 emissions from vehicles in Sydney are not well documented. A recent update of the evidence was provided by Boulter and Bennett (2015). Several different data sets and analytical techniques were presented, including emission modelling, the analysis of ambient air quality measurements, and the analysis of emissions from tunnel ventilation outlets. The work focussed on highway traffic conditions, as these were considered to be the most relevant to tunnels in Sydney. The findings suggested that there has been a gradual increase in *f*-NO_2 in recent years, from less than 10 per cent before 2008 to around 15 per cent in 2014.

Time series (2003-2041) of NO_X and NO_2 emission factors for highway traffic in the NSW EPA inventory model, weighted for the default traffic mix in each year, and the associated values of *f*-NO_2, are shown in Figure B-1. The *f*-NO_2 values for different vehicle types and emission legislation were taken from Pastramas *et al.* (2014). Emission factors are also presented for situations with and without the adoption of the Euro VI regulation. Whilst the NO_X emission factors are predicted to decrease with time, there is a sharp increase in *f*-NO_2 after 2008, with a levelling off at around 12-15 per cent (no Euro VI case) between 2020 and 2030. The main reason for the increase in *f*-NO_2 is the increased market penetration of diesel cars into the Sydney vehicle fleet. There is insufficient information on the types and distributions of exhaust after-treatment devices fitted to vehicles in Sydney, and so it is not possible to determine the extent to which this is a contributing factor.

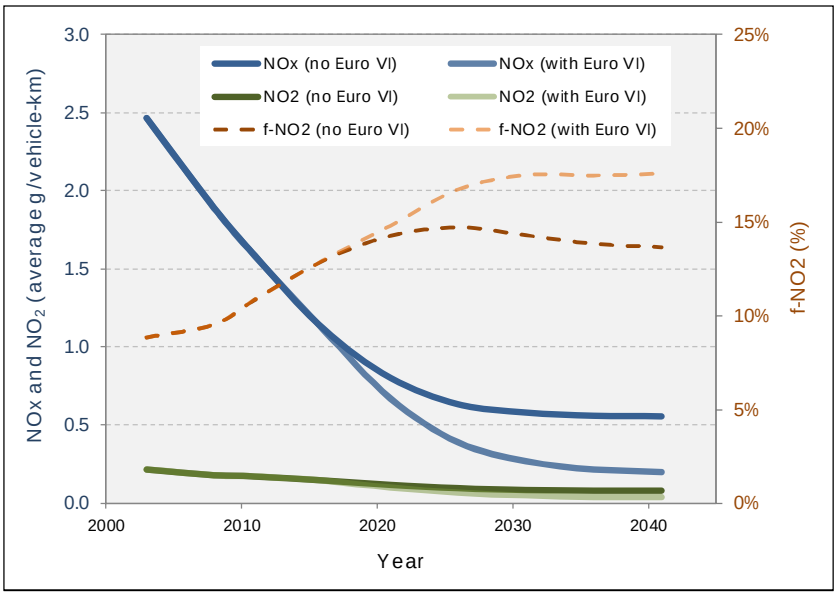


Figure B-1 **Emission factors for NO_x, NO_2 and f-NO_2 from the GMR emissions inventory model for highways/freeways (80 km/h), weighted for default traffic mix.**

B.2.1.4 Particulate matter

Incomplete combustion also results in the production of particulate matter (PM). Diesel vehicles therefore represent the main (exhaust) source of PM from road transport, although recent studies indicate that gasoline-powered vehicles with direct fuel injection also contribute to PM emissions (PIARC, 2012).

Particles in diesel exhaust cover a range of sizes, and the shape of the size distribution depends on whether the weighting is by number or mass, as shown in Figure B-2. There are three distinct size modes: the nucleation mode (sometimes referred to as 'nuclei' or 'nanoparticles'), the accumulation mode, and the coarse mode. The nucleation mode has traditionally been defined as particles with a diameter of less than 50 nanometres (nm), but other size-cut offs have been used. Accumulation mode particles range in size from around 50 nm to around 1 µm, with particles smaller than 0.1 µm being referred to as ultrafine particles. The coarse mode consists of particles larger than around 1 µm.

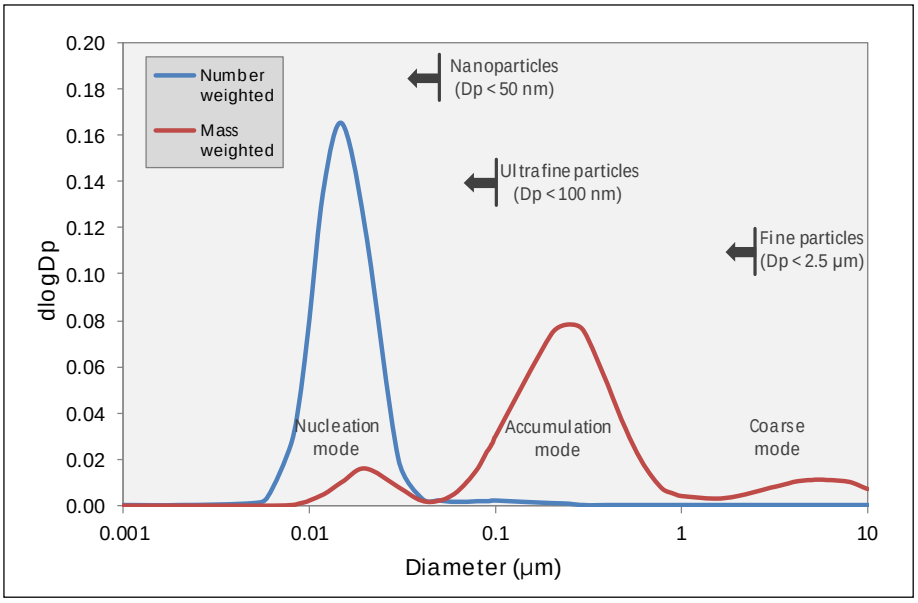


Figure B-2 Typical particle size distributions in vehicle exhaust; the y-axis is a normalised log scale (adapted from Kittelson, 1998)

The processes of particle formation during diesel combustion have been described in detail (*e.g.* Heywood, 1988). Carbonaceous spherules (soot) are initially created in the cylinder. A phase of particle growth then follows, involving the adsorption of gas-phase components, as well as coagulation and agglomeration. Almost all the particle mass found in the exhaust prior to dilution is present as these carbonaceous agglomerates. Most nucleation mode particles are thought to originate from the condensation of volatile material (hydrocarbons, hydrated sulphuric acid and salts) in the exhaust gas during dilution, rather than during combustion itself, and their formation is a function of measurement parameters such as temperature, dilution ratio, residence time, and humidity (Kittelson, 1998; Abdul-Khalek *et al.*, 1999; Mathis, 2002), as well as fuel sulphur content (Maricq *et al.*, 1999; Ntziachristos *et al.*, 2000). Particles in the coarse mode are formed by re-entrainment of material previously deposited on engine cylinder and exhaust system surfaces.

The usual means of complying with the stringent PM mass emission limits for modern diesel vehicles is through the use of a diesel particulate filter (DPF) which physically captures particles in the exhaust stream. However, DPFs can have limited effectiveness in controlling non-solid PM components, and some increases in particle number have also been reported due to hydrocarbon and sulphate nucleation occurring downstream of after-treatment devices.

B.2.2 Evaporation

Volatile organic compounds (VOCs) are emitted from the fuel systems of petrol vehicles as a result of evaporation. The compounds which are emitted are mainly of light hydrocarbons (C_4-C_6) (CONCAWE, 1987). Evaporative emissions from diesel-fuelled vehicles are considered to be negligible due to the low volatility of diesel fuel.

There are several different mechanisms of evaporation. 'Diurnal losses' result from the thermal expansion and emission of vapour, mainly in the fuel tank, in response to changes in ambient temperature during the day. 'Hot-soak losses' occur when a warm engine is turned off and heat is dissipated into the fuel system. Whilst a vehicle is being driven the engine provides a continuous input of heat into the fuel system, resulting in 'running losses'.

Evaporative emissions are dependent upon four major factors: the vehicle design, the ambient temperature, the volatility of the petrol and the driving conditions. Emissions are decreasing as a result of new cars being equipped with sealed fuel injection systems and activated carbon canisters in fuel tank vents (Krasenbrink *et al*., 2005).

B.2.3 Abrasion and resuspension

As well as being present in vehicle exhaust, PM is generated by various abrasion processes including tyre wear and brake wear.

Tyre wear is a complex process. The amount, size, and chemical composition of the emitted PM is influenced by various factors including tyre characteristics, the type of road surface, vehicle characteristics and vehicle operation. Tyres contain a vast array of organic compounds and several important inorganic constituents. Although some research has been carried out to characterise wear particles, the understanding remains incomplete (Thorpe and Harrison, 2008).

Brake wear particles are composed of metals (iron, copper, lead, etc.), organic material, and silicon compounds which are used as binders in brake pads, but again composition varies greatly (Thorpe and Harrison, 2008). Test track and wind tunnel measurements have revealed that typically 50 per cent of the brake wear debris escapes the vehicle and enters the atmosphere, although the actual proportion depends on the severity of the braking and the design of the vehicle (Sanders *et al*., 2003). It appears that most airborne brake wear particles are quite coarse, although a substantial proportion has a diameter of less than 2.5 μm (Garg *et al*., 2000; Abu-Allaban *et al*., 2003; Iijimia *et al*., 2007).

Another source - the resuspension of material previously deposited on the road surface - occurs as a result of tyre shear, vehicle-generated turbulence, and the action of the wind. Studies in the United States have indicated that resuspension is responsible for between 30 per cent and 70 per cent of total PM_{10} in urban areas (Zimmer *et al*., 1992; Gaffney *et al*., 1995; Kleeman and Cass, 1999). Large contributions of resuspension have also been observed in some European studies (notably in Scandinavia), although the conditions in these studies (e.g. climate, use of studied tyres in winter) are not necessarily representative of those in Sydney.

It is possible that non-exhaust PM is less important for tunnels than for surface roads, as under normal operating conditions in many road tunnels there is probably less braking than on surface roads (e.g. fewer intersections), and less cornering (i.e. tyre wear). This is likely to result in less material being deposited on roads in tunnels than on roads in the external environment, resulting in a smaller contribution from resuspension. However, these effects are not well quantified at present.

B.2.4 Construction dust and odour

Dust emissions occur as a result of construction activities, and these can lead to elevated PM_{10} concentrations and nuisance. A potential source of PM (both airborne and on the road surface), especially during the project construction phase, is fugitive dust from uncovered loads. However, the Protection of the Environment Operations (Waste) Regulation 2014 requires waste transported by a vehicle to be covered during its transportation. Exhaust emissions from diesel-powered construction equipment can also be significant.

Where construction activities involve, for example, the excavation of waste and its subsequent exposure to the atmosphere, this is likely to result in odour emissions which also need to be managed.

Construction-related air quality issues need to be considered and managed on a site-by-site basis.

B.3 Pollutant dispersion and transformation

B.3.1 Spatial distribution of pollution in an urban area

Once pollutants have been released into the atmosphere they are subject to various physical dispersion processes. These processes, in combination with a varying density of emission sources and chemical transformations (see Section B.3.3), result in a very uneven distribution of pollution across an urban area.

Figure B-3 shows a simplified representation of pollutant concentrations in and around an urban area with a high density of population and activity in the centre and a lower density in the surrounding districts. The regional background pollution originates from a range of sources, extends over a wide area, and is relatively constant outside the urban area. Within the urban area there is an additional 'urban background' component which is influenced by area-wide emission sources such as domestic and commercial heating, as well as general contributions from transport and industry. Alongside heavily-trafficked roads there is likely to be a significant local contribution to the concentration. This local traffic contribution is more pronounced for some pollutants (notably NO_X) than others (such as PM).

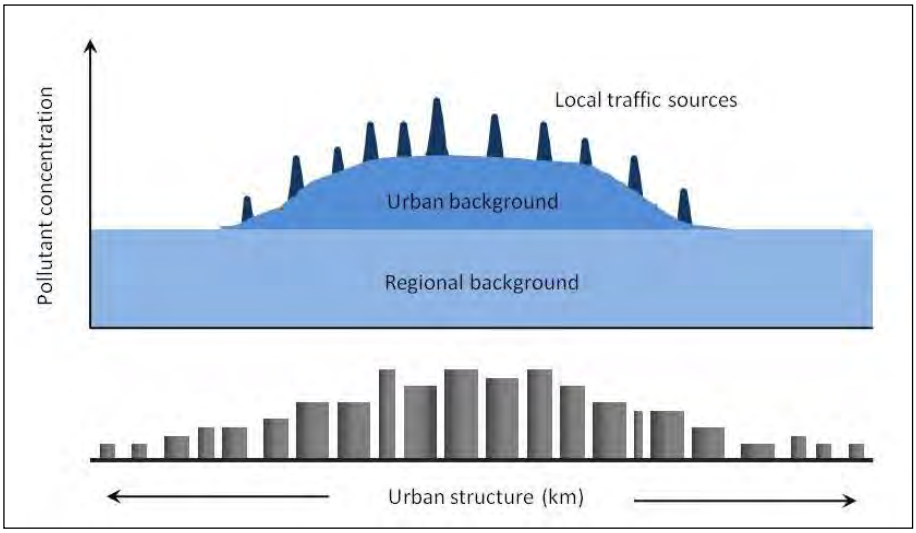


Figure B-3 Simplified representation of urban structure and pollution levels (adapted from Keuken *et al*., 2005)

The general dispersion and transformation of pollutants is influenced to a large extent by the local meteorology. For example, the temperature inversions and low wind speeds associated with stable high-pressure systems can restrict dispersion and lead to high concentrations. High temperatures in summer promote the formation of ozone and other photochemical pollutants, and extreme weather events are often associated with peak levels of pollution. The frequency and severity of pollution events in Sydney are strongly influenced by the regional terrain and the presence of the sea, which affect the circulation of air (DSEWPC, 2011).

Dispersion is also influenced by the local topography and by the presence of local obstacles such as buildings. Buildings generate turbulence and can create complicated air flow patterns including areas of accelerated flow and wakes. The influence of buildings on the plume from a tunnel ventilation outlet is known as building downwash. This can occur when the aerodynamic turbulence induced by nearby buildings causes a pollutant emitted from the elevated outlet to be rapidly mixed to the ground. This will depend on a number of factors such as the height and speed at which the plume is released, as

well as the height of the nearest buildings and their distance from the stack. Whether or not a plume is directly influenced by building downwash will also depend on the speed of the ambient air at the time the plume is released. In other words, if wind speeds are low, the effect the building has on the plume may be negligible. These are important considerations for the design of tunnel ventilation outlets.

In the vicinity of roads, vehicle-induced turbulence needs to be taken into account. Alongside roads the turbulence caused by the moving vehicles is likely to be more significant than that caused by buildings.

B.3.2 Concentration gradients near roads

Traffic pollutants undergo rapid changes in the near-road environment, and concentration gradients in the vicinity of roads have been examined in various studies. Some examples of the results for different pollutants and periods of the day are shown in Figure B-4. The Figure is based on the findings of Gordon *et al.* (2012), who used a mobile laboratory to measure the concentration gradients of ultrafine particles (UFP), black carbon (BC), CO_2, NO, and NO_2 at varying distances from a major highway in Toronto, Canada.

For primary pollutants such as NO and BC, concentrations decay exponentially with increasing distance from the road. Reviews have shown that these typically decrease to background levels between around 100 and 500 metres from roads (e.g. Karner *et al*., 2010; Zhou and Levy, 2007).

Many primary pollutants react together, and with pollutants from other sources, to form secondary pollutants. For these the situation is more complex; because of the time required for their formation, the concentrations of secondary pollutants are not always highest near the emission source.

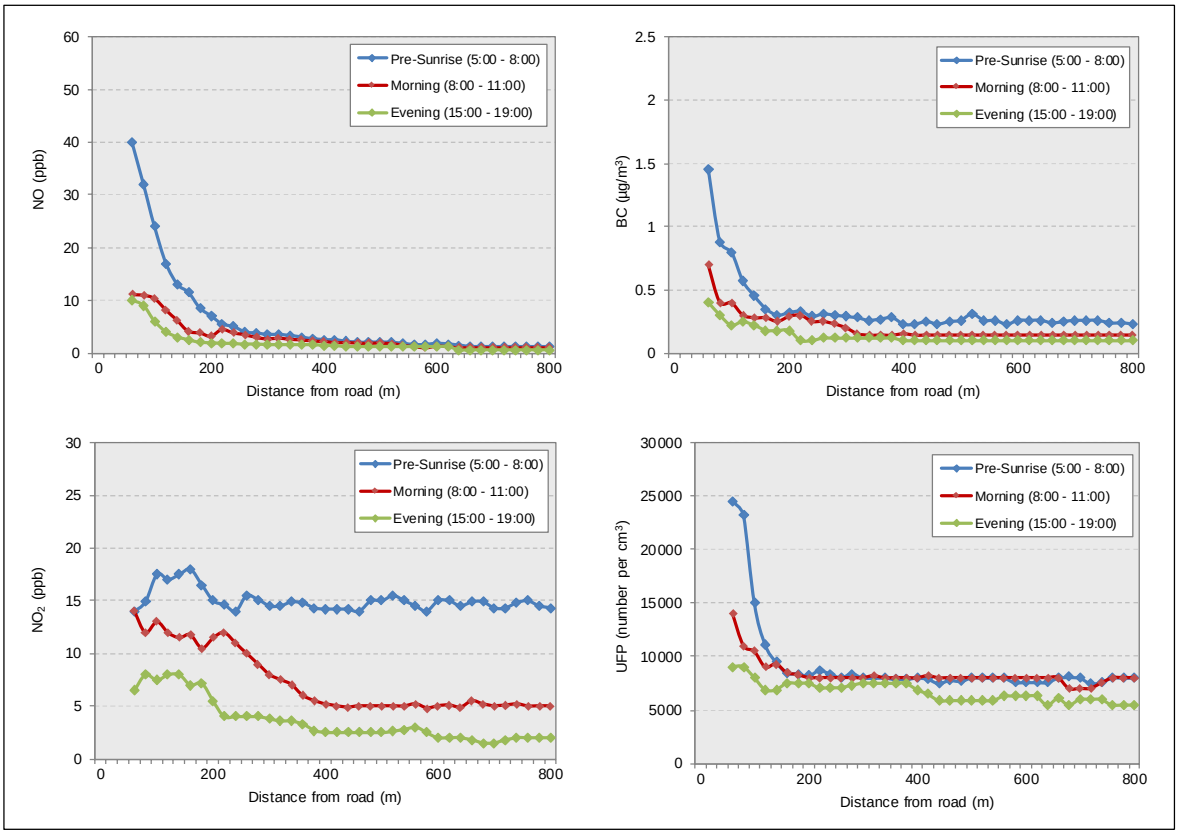


Figure B-4 Median concentrations of pollutants in the vicinity of a major highway (adapted from Gordon et al., 2012)

B.3.3 Pollutant transformation

B.3.3.1 Nitrogen dioxide

Some of the most important reactions for near-road air quality are those that lead to the formation and destruction of NO_2. Under the majority of atmospheric conditions, the main mechanism for NO_2 formation in the atmosphere is through rapid reaction of NO with ozone (O_3):

Equation B1

$NO + O_3 \rightarrow NO_2 + O_2$

Where this is the only important reaction (e.g. at night-time), NO is transformed into NO_2 until either all the NO has been converted to NO_2 or until all the ozone has been used up. At polluted locations comparatively close to sources of NO_x (such as roads) NO is in large excess and it is the availability of O_3 which limits the quantity of NO_2 that can be produced by this reaction. The timescale for consumption of O_3 depends on the concentration of NO. Under normal ambient daytime conditions the reverse process also occurs – the destruction of NO_2 by photolysis to form NO and ozone, as shown in Equation B2 and Equation B3:

Equation B2

NO_2 + sunlight $\rightarrow$ NO + O

Equation B3

$O + O_2 (+M) \rightarrow O_3 (+M)$

where **M** is a third body, most commonly nitrogen.

Dilution process decreases the NO_2 concentration with distance from the road, whereas chemical reactions tend to favour NO_2 production. As a result, the decay rate of NO_2 is lower than that of NO in near-road environments (see Figure B-4). However, the NO_2/NO_X ratio increases with increasing distance from the roadway until it reaches the background level.

It is worth noting that inside a road tunnel there is usually a high concentration of NO from vehicle exhaust, and any available oxidant - principally ozone - is removed relatively quickly. Once the ozone is removed, NO_2 formation via Equation B1 will stop (Barrefors, 1996). As there is little natural sunlight inside a road tunnel, the destruction of NO_2 via Equation B2 is also limited. Consequently, much of the NO_2 in tunnel air is likely to be primary in origin.

B.3.3.2 Particulate matter

The fate of freshly emitted particles in the atmosphere depends upon their size. Nucleation mode particles have a short lifetime in the atmosphere since they readily transform into larger particles and deposit efficiently to surfaces. Accumulation mode particles are too large to be subject to rapid diffusion and too small to settle from the air rapidly under gravity. Their further growth is inhibited because they do not coagulate quickly and there are diffusion barriers to their growth by condensation. Particles in the accumulation mode can therefore have a long atmospheric lifetime (typically 7–30 days). For coarse particles range gravitational settling velocities become appreciable and therefore atmospheric lifetimes are shorter than for accumulation mode particles.

A substantial fraction of the fine PM mass, especially at background locations, is secondary in nature. Secondary particles are formed by atmospheric reactions involving both inorganic and organic gaseous precursors, several of which are emitted by road vehicles.

The formation of secondary inorganic aerosol is comparatively well understood, although some mechanistic details still remain to be determined (USEPA, 2009). This aerosol is composed mainly of ammonium sulfate ($(NH_4)_2SO_4$) and ammonium nitrate (NH_4NO_3), with some sodium nitrate. These compounds originate from the conversion of sulfur oxides (SO_X) and nitrogen oxides (NO_X) in the atmosphere to sulfuric and nitric acids, which are then neutralised by atmospheric ammonium (NH_4^+). The precursor to atmospheric ammonium is ammonia (NH_3). SO_X and NO_X typically arise from

combustion sources. NH_3 emissions are dominated by agricultural sources, such as the decomposition of urea and uric acid in livestock waste (AQEG, 2005).

Secondary organic aerosol is linked to the formation and transformation of low-volatility organic compounds in the atmosphere. The formation of these compounds is governed by a complex series of reactions involving a large number of organic species (Kroll and Seinfeld, 2008). As a result of this complexity a great deal of uncertainty exists around the process of formation (USEPA, 2009).

The formation of secondary particles happens slowly; the overall oxidation rates of SO_2 and NO_2 are around 1 per cent per hour and 5 per cent per hour respectively. The slowness of these processes - and the fact that the resulting particles are small and therefore have a relatively long atmospheric lifetime - means that secondary particles are usually observed many kilometres downwind of the source of the precursors.

Particles are removed from the atmosphere by both dry deposition and wet deposition processes. Dry deposition is caused by gravitational sedimentation, interception/impaction, diffusion or turbulence, although other processes can occur. In wet deposition, atmospheric water (raindrops, snow, *etc.*) scavenges airborne particles, with subsequent deposition on the earth's surface.

Appendix D - Examples of previous ambient air quality assessments

D.1 Road tunnel assessments

Table D-1 NorthConnex, Sydney

Project (type of assessment)	NorthConnex (EIS)
Project description	A proposed nine-kilometre toll tunnel linking the M1 Pacific Motorway at Wahroonga to the Hills M2 Motorway at West Pennant Hills. During operation, the ventilation system would draw fresh air into the tunnels and emit air from within the tunnels via two ventilation facilities. One of the ventilation facilities would be located near the northern tunnel portal and one would be located near the southern tunnel portal.
Pollutants/metrics modelled	PM_{10}, $PM_{2.5}$, TSP, NO_x, CO, PAHs and VOCs
Approach	- Assessment scenarios. - The dispersion models. - Meteorological data. - Terrain and land use data. - Sensitive receivers. - Model input parameters. - Emissions assumptions (estimation and rates). - Ventilation outlet parameters. - Cumulative assessment.
Scenarios	Three principal air quality scenarios were evaluated: - Comparison of air quality with and without the project. - Assessment of air quality at the expected opening of the project (2019), and after ten years of operation (2029). - Assessment of air quality in the event of a breakdown in one of the tunnels.
Traffic data	Strategic Sydney traffic model
Background air quality	For PM_{10}, $PM_{2.5}$ and NO_2, the ambient concentrations were determined by taking the maximum of the concentrations predicted by CAL3QHCR (with the project) and those measured by the OEH at its Lindfield and Prospect monitoring stations. For CO the maximum concentration recorded at the OEH monitoring station at Prospect was used.
Emission factors	PIARC.
Met/dispersion model(s)	MM5/CALMET/CALPUFF (ventilation stacks) and CAL3QHCR (surface roads). Meteorological grid domain: 60 kilometres x 62.5 kilometres Meteorological grid resolution: 250 metre resolution. Five surface met stations.
Receptors	A total of 6,919 discrete receptors were assessed. Of these, 3,332 were located along the project corridor.
Model validation	Not specified.
Construction assessment	Potential construction air quality impacts associated with the project were assessed qualitatively by describing the nature of proposed works, plant and equipment, potential emissions sources and levels.
Reference	AECOM (2014a,b)

Table D-2 East-West Link, Eastern Section, Melbourne

Project (type of assessment)	East West Link: Eastern Section, Melbourne. (project cancelled)
Project description	Six-lane tunnel from the Eastern Freeway in Clifton Hill to CityLink in Parkville.
Pollutants/metrics modelled	Peak and mean CO Peak and mean NO_2 Peak and mean PM_{10} Peak and mean $PM_{2.5}$ AQ criteria from Victoria's State Environment Protection Policy (Air Quality Management 2001) (SEPP (Air Quality Management)).

Approach	Regional impacts were downscaled to the local level to identify potential hot-spots within a few hundred metres (major intersection level) and to quantify the changes from 'no-build' to 'build' scenarios. Compared model predictions to design criteria for the predicted ground-level concentration at portal locations and elevated/depressed road sections. Consideration was given to the possibility of turning down/off the forced ventilation during low-usage overnight conditions to achieve minimal portal emission impact (this was subsequently adopted as an operational practice). For tunnel vent emissions, a point source assessment was undertaken to establish performance requirements. Risk assessment matrix included.
Scenarios	2021 without project 2021 with project 2031 with project
Traffic data	Traffic model AM peak, PM peak, mid-day, off-peak
Background air quality	Hourly varying values for NO_2 and PM_{10} (TEOM) were taken from two EPA Victoria monitoring sites. The data for 2008 were used to match the concentrations with the meteorological data. Background values for other pollutants were taken from other recent road projects in Victoria.
Emission factors	PIARC
Met/dispersion model(s)	AUSPLUME 6.0 and AUSROADS 1.0
Receptors	Hoddle Street Overpass: roadside receptors. A series of discrete receptors was placed across transects from the Eastern Freeway for the location of maximum ground-level concentrations for NO_2 to a distance of 250 metres away. The dominating line source was CityLink, at a height of around 10 metres above ground level, and as such receptors were placed at this height to obtain worst-case results. Gridded receptors were modelled with ±1.0 km domain and 20 m resolution Total number of receptors was not given.
Model validation	Not specified.
Construction assessment	Environmental management plan created for construction, but only qualitatively assessed.
Notes	Strategic transport modelling (VLC 2013) was undertaken for the purpose of estimating the amounts and types of vehicles that could potentially use East West Link – Eastern Section roads. Assessed future scenarios with and without the Project.
Reference	GHD (2013)

Table D-3 Waterview Connection, Auckland

Project (type of assessment)	Western Ring Route: Waterview Connection, Auckland, New Zealand
Project description	Two tunnels between Great North Road Interchange and the Alan Wood Reserve. Separate tunnels for northbound and southbound traffic. Longitudinal ventilation.
Pollutants/metrics modelled	Max 8-hour mean CO Max 1-hour mean CO Max 1-hour mean NO_x Max 1-hour mean NO_2 Max 24-hour mean PM_{10} Annual mean PM_{10} Max 24-hour mean $PM_{2.5}$ Annual mean benzene Criteria from National Environmental Standards (AQNES), New Zealand Air Quality Guidelines (NZAAQG) and Auckland Regional Air Quality Targets (ARAQT).
Approach	Only portal emissions modelled.
Scenarios	Base year of 2006 2016 With Project 2016 Do Nothing 2026 With Project

	2026 Do Nothing
Traffic data	EMME/3 traffic model
Background air quality	The baseline scenario was the cumulative air quality for the 2006 base year. PM_{10}: hourly 2007 data from the mean of 1-hour average concentrations from 5 sites. $PM_{2.5}$ hourly 2007 data from the mean of 1-hr average concentrations from 3 sites. CO: hourly 2007 data from the mean of 1-hr average concentrations from 6 sites. Benzene: Baseline derived from passive monitoring conducted for the Project.
Emission factors	Detailed emissions factors have been derived from VEPM. Portal emission rates varied with respect to traffic volume and ambient wind speed.
Met/dispersion model(s)	GRAL (tunnel portals), VEPM, CALMET, CALPUFF, AUSROADS (surface roads)
Model validation	The 2006 base year scenario was used for validation of the dispersion model. Data on meteorology and measured background concentrations were taken from 2007, although the traffic volumes used in the model were based on 2006 census data.
Receptors	Sensitive receptors within 2km of either tunnel ventilation stack or within 300 m of a major surface road. 25 schools 38 early-learning centres 11 healthcare centres 10 residential 6 sports fields 8 receptors with “Existing SH20 Designation”
Construction assessment	Compliant with the raft NZTA Standard Producing Air Quality Assessments for State Highway Projects and the NZ Ministry for Environment’s Good Practice Guide for Assessing and Managing the Environmental Effects of Dust Emissions”
Reference	BECA (2010)

Table D-4 Lane Cove Tunnel, Sydney

Project (type of assessment)	Lane Cove Tunnel, Sydney
Project description	Tunnel consists of twin tubes ventilated by two ventilation outlets.
Pollutants/metrics modelled	Max 8-hour mean CO Max 1-hour mean CO Max 1-hour mean NO_2 Annual men NO_2 Max 24-hour mean PM_{10} Annual mean PM_{10} 1-hour mean HC Annual mean HC Criteria: EPA/AAQ NEPM.
Approach	Validation of the ambient air quality assessment undertaken for the tunnel ventilation system as assessed in the Environmental Assessment for the Revised Ventilation Design for the Lane Cove Tunnel Project, utilising actual monitoring data. Two modelling scenarios: using estimated emissions from the EIS and using measured stack emissions data.
Scenarios	Emissions data from in-stack monitoring. Modelling included normal and congested conditions.
Traffic data	Traffic volume data for the period of October 2007 to September 2008.
Background air quality	Background air quality monitoring was undertaken at Epping Road, Mowbray Road and Military Road for the Proposal. In addition, the OEH air quality monitoring site at Lindfield was used.
Emission factors	PIARC (2006 taken to be worst case scenario)
Met/dispersion model(s)	TAPM/CALMET/CALPUFF
Receptors	Concentrations at receptors at both ground and elevated levels.
Model validation	Predicted results using stack monitoring data were compared with the predicted results using emission estimations from the EIS.
Construction assessment	Emissions from construction were estimated using SPCC and USEPA emission

	factors. No dispersion modelling was undertaken.
Reference	PAEHolmes (2010)

Table D-5 Northern Link, Brisbane

Project (type of assessment)	Northern Link (Legacy Way), Brisbane (EIS)
Project description	The Project involved the construction and operation of an underground toll road (tunnel) between the Western Freeway, in Toowong, and the Inner City Bypass (ICB), at Kelvin Grove. Longitudinal tunnel, two ventilation outlets.
Pollutants/metrics modelled	Max 8-hour mean CO Max 1-hour mean NO_2 Annual mean NO_2 Max 24-hour mean PM_{10} Annual mean PM_{10}
Scenarios	See below.
Traffic data	- Annualised Average Daily Traffic (AADT) for years 2007 (existing), 2014, 2016, 2021 and 2026. - Scenarios with and without project. - Modelled 2007 (existing), 2014, 2016, 2021 and 2026 AADT for selected surface roads and in tunnel sections. - Indicative flow profiles for light and heavy vehicles by hour of day for each section of tunnel and for surface roads.
Background air quality	The background data were constructed from air quality monitoring data, specifically, those collected from the Bowen Hills and Rocklea sites.
Emission factors	National Pollutant Inventory (2000)
Met/dispersion model(s)	CALMET/ CALPUFF, CAL3QHCR
Receptors	Exact receptor locations not specified.
Model validation	Not specified
Construction assessment	Qualitative assessment of potential impacts of specific activities and mitigation measures.
Reference	Holmes Air Sciences (2008)

Table D-6 Airport Link, Brisbane

Project (type of assessment)	Airport Link, Brisbane (EIS)
Project description	Twin-bore, 6 km road tunnel from Bowen Hills to Wooloowin in Brisbane. Longitudinal ventilation, three elevated outlets near each end as well as an intermediate outlet at Kedron.
Pollutants/metrics modelled	Max 8-hour mean CO Max 1-hour mean NO_2 Annual mean NO_2 Max 24-hour mean PM_{10} Annual mean PM_{10} Criteria: EPA/AAQNEPM
Approach	Emissions estimated for each ventilation outlet and all surface roads.
Emission factors	PIARC, modified to account for age, vehicle mix, speed etc. No potential future improvements in vehicle technology or fuel standards included. SEQ inventory EFs compared with PIARC EFs.
Background air quality	2004 was chosen for both the background meteorological and ambient air quality monitoring records. The monitoring sites are summarised as follows: - Eagle Farm, operated by the EPA but now decommissioned, included measurements of NOx, O_3, SO_2 and PM_{10}. - Bowen Hills, operated by Simtars but now decommissioned, included measurements of CO, NOx, PM_{10} and $PM_{2.5}$. - Kedron, currently monitoring and operated by Simtars. Measurements include CO, NOx, PM_{10} and $PM_{2.5}$.
Met/dispersion model(s)	CALMET/ CALPUFF; CAL3QHCR for near-road impacts.

Receptors	Not specified.
Model validation	Not specified.
Construction assessment	Not considered, as modelled for the feasibility assessment.
Reference	Holmes Air Sciences (2006)

Table D-7 Vic Park Tunnel, Auckland

Project (type of assessment)	Vic Park Tunnel, Auckland
Project description	Realignment of State Highway 1 between Harbour Bridge and Wellington St, including tunnel and widening of existing carriageway.
Pollutants/metrics modelled	Max 8-hour mean CO Max 1-hour mean CO Max 1-hour mean NO_2 Max 24-hour mean NO_2 Max 24-hour mean PM_{10} Annual mean PM_{10} Annual mean benzene Criteria from NZ National Environmental Standards (NES) for Air Quality.
Approach	Modelled both the surface roads and the proposed tunnel portal.
Scenarios	In total four scenarios were modelled: - 2010 without the VPT project - 2010 with the VPT project - 2021 without the VPT project - 2021 with the VPT project
Traffic data	Traffic models developed by BECA.
Background air quality	Takapuna. The monitoring station is located approximately 8-kilometres from the site and about 25 m from a major intersection. It is important to note that the concentrations measured at both these sites are already influenced by traffic emissions.
Emission factors	New Zealand Transport Emission Rate model (NZTER). Assumed that tunnel was a motorway, with EFs being derived for free, interrupted and congested flow conditions.
Met/dispersion model(s)	CALINE 4/CAL3QHCR applied to both surface roads and tunnel portals
Receptors	10 ground-level receptors, 15 elevated receptors at heights up to 14 m.
Model validation	In the modelling validation study, the total NOx concentrations were modelled and the NO_2 concentrations were calculated based on the NSW accepted practice which assumes that NO_2 concentrations are 10% of NOx by weight at the kerbside, 15% by weight at 10 m and 20% by weight at 30 m and beyond.
Construction assessment	Construction impacts were not assessed in the study.
Notes	Breakdown of vehicles by fuel type based on NZ Motor Vehicle Registration Statistics, Land Transport Safety Authority (LTSA), 2004. Fleet composition assumed to be constant for future scenarios.
Reference	Holmes Air Sciences (2006)

Table D-8 M5 East Tunnel, Sydney

Project (type of assessment)	M5 East Tunnel, Sydney (partial portal emissions and trial of tunnel filtration technology). The filtration trial proceeded without partial portal emissions.
Project description	Potential impacts of regular partial portal emissions from the tunnel to manage in-tunnel haze. Four-kilometre long twin tunnels from Bexley to Arncliffe, with a recirculating ventilation system with a single ventilation outlet located at Turrella (approximately 800 m from the tunnel).
Pollutants/metrics modelled	Max 8-hour mean CO Max 1-hour mean CO Max 15-min mean CO Max 30-min mean CO Max 1-hour mean NO_2 Annual mean NO_2 Max 24-hour mean PM_{10} Annual mean PM_{10}

	24-hour mean PM2.5 Annual mean $PM_{2.5}$ VOCs/PAH
Approach	Model the dispersion of emissions from the M5 East tunnel portals by computational fluid dynamics (CFD), and a health risk assessment.
Scenarios	Varying air volumes emitted from the portals.
Traffic data	Modelled emissions based on fleet average emission data (NPI 2000).
Background air quality	Background concentration for the criteria pollutants, PM_{10}, CO and NO_2, were derived from the ambient monitoring stations located adjacent to the Bexley Road (F1) and Marsh Street (M1) portals for each 5-minute period throughout the whole of the calendar year 2005.
Emission factors	Pollutant concentrations in the air discharged during portal emissions determined using measurements from sensors within the tunnel and other reported emission factors.
Met/dispersion model(s)	CFD (FLUENT) Varying portal outflow rates were modelled, with the maximum outflow rate being continuous from 5 am and 7 pm for conservatism.
Receptors	At Bexley Rd, a closely-spaced (30m spacing) rectangular shaped modelling receptor grid was employed covering all relevant residences within the range of 0 to 150 m of the portal. At the Marsh St portal, to ensure that the whole of the residential area was modelled a selection of individual residences covering all residences within 200 m of the portal were modelled.
Model validation	State-of-the-art CFD modelling software, FLUENT Version 6.2d, with current ISO 9001 certification and guaranteed model validity was used.
Construction assessment	Construction impacts not quantitatively assessed, although an environmental management plan was created to include construction activities (only relevant to the construction of the filtration plant).
Reference	Synergetics (2006)

Table D-9 Cross City Tunnel, Sydney

Project (type of assessment)	Cross City Tunnel, Sydney
Project description	Twin two-lane road tunnels for traffic travelling east–west across Central Sydney between Darling Harbour and Kings Cross.
Pollutants/metrics modelled	Max 8-hour mean CO Max 1-hour mean CO Max 1-hour mean NO_2 Max 24-hour mean PM_{10} Annual mean benzene Criteria: EPA/AAQ NEPM.
Approach	Modelled 3 ventilation options: - 2 ventilation outlets (one near the exit portal of each tunnel) - 2 ventilation outlets (one near the exit portal of each tunnel with a cross-over vent stack near the eastern portals). - 1 stack (at western end with recirculation at the eastern end). Adopted option was a single outlet at the western end with an additional ventilation tunnel from the eastern end of the project.
Scenarios	With construction Without tunnel construction and minor road improvements
Traffic data	Traffic volume data collected in 1998, and 2006, and projected for 2016. Details of traffic model given in “Technical Paper No. 8”
Background air quality	Details given in "Technical Paper No. 16 Air Quality"
Emission factors	Details not given in report, but in "Technical Paper No. 16 Air Quality"
Met/dispersion model(s)	AUSPLUME
Receptors	Elevated receptors: Darling Walk (15 metres), IMAX Theatre (30 metres), Park Royal Hotel (40 metres) Millennium Towers (60 metres), Darling Park Stage 3 (70 metres), Darling Park Stage 2 (145 metres)

	37 Street receptors around Sydney CBD.
Model validation	Details not given.
Construction assessment	Described on an area by area basis in precincts: Darling Harbour, Central, Hyde Park.
Notes	All emissions assumed to vent through a ventilation outlet. A single outlet option was adopted.
Reference	PPK (2000)

D.2 Surface road assessments

Table D-10 WestConnex M4 Widening

Project (type of assessment)	WestConnex M4 Widening
Project description	- M4 Widening including: - Construction of a new two lane viaduct for westbound traffic, on the southern side of the existing viaduct structure between Church Street, Parramatta and Wentworth Street, Granville. - Reconfiguration of the traffic lanes on the existing viaduct structure to four lanes eastbound and two lanes westbound. - Construction of a new bridge/viaduct over Duck River at Auburn.
Pollutants/metrics modelled	Max 8-hour mean CO Max 1-hour mean CO Max 1-hour mean NO_2 Annual mean NO_2 Max 24-hour mean PM_{10} Annual mean PM_{10} 24-hour mean $PM_{2.5}$ Annual mean $PM_{2.5}$ VOCs/PAH
Approach	To determine whether there is any significant change in the existing levels of emissions from the road, and where the change occurs and the relative scale of the change.
Scenarios	Four scenarios were assessed: - Base 'do minimum' (2017) - without the M4 Widening project. - M4 Widening (2017) - project opening year. - Future 'do minimum' (2027) - 10 years after the Base 'do minimum', but not including the M4 Widening or the WestConnex schemes. - Full WestConnex (2027) – development of the full WestConnex Scheme represented by adding all stages of the scheme to the Future 'do minimum' case.
Traffic data	Source of traffic volumes not specified.
Background air quality	The background monitoring data includes data for NO_2, CO (Rozelle and Chullora) and PM_{10}.
Emission factors	TRAQ (derived from method in NSW GMR emissions inventory).
Met/dispersion model(s)	TRAQ (CALINE 4)
Receptors	7 Receptors along a transect of the proposed widening. At these receptors, air quality was assessed at 20m, 50m and 100m from the nearest lane of the motorway
Model validation	Not specified
Construction assessment	Assessed quantitatively using USEPA AP42 Emissions Factors
Notes	None.
Reference	Todoroski Air Sciences (2014)

Table D-11 Pacific Highway, Ballina Bypass

Project (type of assessment)	Pacific Highway Ballina Bypass (EIS).
Project description	Upgrade between Hexham and the QLD border by constructing a four lane duel carriageway bypass of Ballina.
Pollutants/metrics modelled	Max 1-hour mean CO Max 1-hour mean NO_x Max 1-hour mean HC

	Max 1-hour mean PM_{10} Max 1-hour mean lead Criteria: NEPM, NHMRC
Approach	Model the impacts of the potential bypass construction and compare this to existing air quality.
Scenarios	Bypass construction in 2016. No bypass construction (existing air quality)
Traffic data	EMME/2 transport model using 1994 as a base year and the future scenario in 2016
Background air quality	CO was monitored over a two week period from 21/7/1997 at a location 50 m away from the Pacific Highway and 200m east of Teven Road.
Emission factors	Not stated in main report.
Met/dispersion model(s)	CALINE 4
Receptors	8 receptors along the proposed bypass and three receptors in Ballina.
Model validation	Not specified.
Construction assessment	Construction emissions estimated using SPCC and USEPA EFs.
Notes	Emission rates for morning and afternoon peak hours for 2 scenarios.
Reference	Connell Wagner (1998)

Table D-12 Pacific Highway Upgrade, Banora Point

Project (type of assessment)	Pacific Highway Upgrade, Banora Point
Project description	Freeway-standard link between the Chinderah bypass and the Tweed Heads bypass, bypassing an existing section of the Pacific Highway.
Pollutants/metrics modelled	Max 8-hour mean CO Max 1-hour mean CO Max 1-hour mean NO_2 Annual mean NO_2 Max 24-hour mean PM_{10} Annual mean PM_{10} Criteria: NEPM, DECC.
Approach	PIARC (2004), adjusted to reflect the NSW vehicle fleet and grades, speed, and %HDV.
Scenarios	• A base case (2010, no upgrade). • With the proposed upgrade in 2010. • With the proposed upgrade 2020.
Traffic data	Traffic flow data was calculated based on predicted annual average traffic flow data for the three scenarios. Hourly traffic volumes were calculated using a generic profile from traffic count data collected on the Pacific Highway north of Terranora Road in February 2007. For modelling purposes, the route (proposed upgrade and existing highway) was split into southern, mid and northern sections. Traffic on the on and off-ramps and on the existing Pacific Highway was also modelled as part of the proposed upgrade 2010 and 2020 scenarios.
Background air quality	No air quality monitoring data available for the study area. However, monitoring data collected by the Department of Environment and Climate Change at Newcastle swimming pool in Wallsend and at the Newcastle sportsground (on Dumaresq Street) is considered indicative of air quality in a coastal town like Banora Point.
Emission factors	Dust emission rates from US EPA (1995) *AP-42 Compilation of Air Pollutant Emission Factors* and the NSW Mineral Council (2000) Particulate Matter and *Mining Interim Report.* Vehicle emissions rates, using vehicle emission data from PIARC (2004).
Met/dispersion model(s)	CAL3QHCR
Receptors	Receptor locations were chosen to represent the residential areas closest to the proposed upgrade and positioned at ground level, at fixed distances of 0, 10, 20, 30 and 50 metres from the road in the following locations : Receptor Location 1: northbound carriageway close to the southern off-ramp. Receptor Location 2: northbound carriageway of the Old Pacific Highway, just north of Terranora Road.

	Receptor Location 3: north and southbound carriageways close to Short Street. Receptor Location 4: north and southbound carriageways close to Minjungbal Drive.
Model validation	Not specified
Construction assessment	Qualitative construction scenario.
Reference	Holmes Air Sciences (2008)

Table D-13 Pacific Highway Upgrade, Bulahdelah

Project (type of assessment)	Pacific Highway Upgrade, Bulahdelah
Project description	Around 8.5 km of dual carriageway.
Pollutants/metrics modelled	Max 8-hour mean CO Max 1-hour mean CO Max 1-hour mean NO_2 Max 24-hour mean PM_{10} Annual mean PM_{10} Annual mean benzene Criteria: NEPM, WHO, DEC, NHMRC.
Approach	Metropolitan Air Quality Study (1997) provided by DEC.
Scenarios	Only one scenario for proposed road works considered
Traffic data	Traffic flow data for 2008 and 2018
Background air quality	No monitoring undertaken specifically for this project, but there are data available from the DEC monitoring network and earlier data from north of Bulahdelah. The station closest to the route is near the Pacific Highway at Beresfield near Newcastle
Emission factors	Metropolitan Air Quality Study (MAQS) (Carnovale et al, 1997) and rates provided by the DEC.
Met/dispersion model(s)	CALINE 4 with BREEZE ROADS package used to assess impacts.
Receptors	Receptors were placed at fixed distances of 0 m, 10 m, 30 m and 50 m from sections of the roads closest to residences and other sensitive areas including Bulahdelah Central School and St. Joseph's Primary School.
Model validation	Williams et al. (1994)
Construction assessment	Construction qualitatively assessed.
Reference	Holmes Air Sciences (2004)

Table D-14 M2 Upgrade

Project (type of assessment)	M2 Upgrade
Project description	Widening sections of the motorway and additional access/egress points.
Pollutants/metrics modelled	Max 1-hour mean NO_2 Max 8-hour mean CO Max 24-hour mean PM_{10} Max 24-hour mean $PM_{2.5}$ Criteria: DECCW.
Approach	A cumulative impact assessment has been undertaken to determine the combined effect of the project with other proposed activities within the region.
Scenarios	2021 no M2 upgrade 2021 with M2 upgrade
Traffic data	The Transurban Sydney Strategic Traffic Model (TUSTM)
Background air quality	CSIRO Lindfield Laboratories at West Lindfield, approximately 1.5 kilometres southeast of the intersection of Lane Cove Road and the M2 Motorway. For PM10 and PM2.5, data from other locations in Sydney has been assessed (Liverpool and Lucas Heights, and Magdala Park in North Ryde).
Emission factors	Provided by DECCW for light and heavy vehicles assume no improvement in vehicle exhaust standards to the assessment year of 2021.

Met/dispersion model(s)	TAPM, CAL3QHCR
Receptors	65 receptors including residential, commercial, institutional and recreational receptors locations along the length of the M2 Motorway.
Model validation	Not specified.
Construction assessment	Construction qualitatively assessed.
Notes	Air quality within the tunnel and associated with emission from the tunnel openings has been assessed. Modelled a 'do nothing' and 'upgrade' scenario.
Reference	Heggies (2009)

Table D-15 M80 Upgrade

Project (type of assessment)	M80 Upgrade Project. VIC
Project description	Widening the existing M80 freeway
Pollutants/metrics modelled	* NO_2 * PM_{10} Criteria from EPA's State Environment Protection Policy – Air Quality Management Intervention Levels.
Approach	VicRoads Screening Tool detailed in the "Technical Guidelines for Assessing the Air Quality Impacts of Road Developments" was used for the assessment of the impacts of the M80 Upgrade Project.
Scenarios	Modelled existing traffic volumes (2008) and estimated traffic volumes in 2021
Traffic data	Traffic volumes supplied by VicRoads
Background air quality	Measured NO_2 and PM_{10} concentrations at Footscray and Alphington for the years 2002 to 2007.
Emission factors	VicRoads Screening Tool detailed in the "Technical Guidelines for Assessing the Air Quality Impacts of Road Developments" was used for the assessment.
Met/dispersion model(s)	VicRoads Screening Tool
Receptors	17 residences located < 100 m to the M80
Model validation	Not specified.
Construction assessment	Not specified.
Reference	Bassett Consulting Engineers (2009)

Table D-16 Pacific Highway Upgrade, Tintenbar to Ewingsdale

Project (type of assessment)	The Project involves the construction and operation of approximately 17 km of dual carriageway including twin 430 m long tunnels, commencing from the northern section of the Ballina Bypass, through to Ewingsdale Road
Project description	Upgrade of the Pacific Highway from Tintenbar to Ewingsdale.
Pollutants/metrics modelled	Max 1-hour mean CO Max 1-hour mean NO_2 Max 1-hour mean PM_{10} Criteria: DECC, NEPM, EPA.
Approach	Use of a dispersion model that simulates worst-case meteorology.
Scenarios	With Project 2012 Without project 2012 With Project 2022
Traffic data	Traffic data supplied by Arup for 2012 and 2022; traffic counts south of Ivy Lane, south of Bangalow and north of Bangalow Road; Light and heavy vehicle traffic volumes by hour of day
Background air quality	Monitoring data have been collected by the RTA at the Pacific Highway near Coffs Harbour.
Emission factors	PIARC. Assessment is based on emission rates assuming that the roadway is flat. No potential

	future improvements in vehicle technology or fuel standards have been included in the PIARC emission estimates which will result in some overestimation of emission rates for future years. Assumed reductions in the proportion of older vehicles in the fleet has simulated some improvement to vehicle emissions in future years.
Met/dispersion model(s)	CALINE 4
Receptors	A total of 18 receptors, whereby at 3 locations, air quality was assessed at kerb, and 10, 20, 30, 50, and 100 m away from road.
Model validation	Not specified
Construction assessment	Construction qualitatively assessed.
Notes	Pollutant emissions have been estimated for each tunnel ventilation outlet and for all surface roads.
Reference	Holmes Air Sciences (2008)

Table D-17 Foxground and Berry Bypass, NSW

Project (type of assessment)	Foxground and Berry Bypass. NSW
Project description	Upgrade of 11.6 km of the Princes Highway between Toolijooa Road north of Foxground and Schofields Lane south of Berry, to achieve a four lane divided highway (two lanes in each direction) with median separation. The project includes bypasses of Foxground and Berry.
Pollutants/metrics modelled	Max 1-hour CO Max 8-hour CO Max 1-hour NO_2 Annual average NO_2 Max 24-hour average PM_{10} Annual average PM_{10} AQ criteria from WHO, NEPC and EPA.
Scenarios	For 2017, and 2037: Do Nothing Do Minimum
Traffic data	- Average speed by road type sourced from the Traffic and Transport Assessment Technical Paper (AECOM,2012) - Average Annual Daily Traffic (AADT) and VKT, for light and heavy vehicles, were sourced from the Traffic and Transport Assessment Technical Paper (AECOM, 2012). - Rate of fuel consumption calculated for each road type within the traffic impact footprint using the basic fuel-speed formula (Equation 1 in Austroads Guide to Project Evaluation Part 4: Project Evaluation Data part 6).
Background air quality	1997-2005 data: Croom Road in Albion Park, 2005-2007 data: Terry Reserve in Albion Park South
Emission factors	Vehicle emissions data from PIARC were adjusted to reflect NSW fleet. No future improvements in vehicle technology or fuel standards have been included in the emission estimates.
Met/dispersion model(s)	CAL3QHCR
Receptors	69 receptors
Model validation	Williams et. al. (1994)
Construction assessment	Construction semi-qualitatively assessed (emissions estimated but not modelling).
Reference	PAEHolmes (2012)

Table D-18 Pacific Highway Upgrade, Woolgoolga to Ballina

Project (type of assessment)	Pacific Highway Upgrade, Woolgoolga to Ballina. NSW
Project description	The Woolgoolga to Ballina upgrade would involve upgrading ~155 km of highway. Starting from the southern end, the project would 'tie in' to the northern extent of the Sapphire to Woolgoolga upgrade (about five kilometres north of Woolgoolga), which is currently being constructed. At its northern end, the project would tie in to the southern

	extent of the recently opened Ballina bypass.
Pollutants/metrics modelled	Max 1-hour CO Max 8-hour CO Max 1-hour NO_2 Annual average NO_2 Max 24-hour average PM_{10} Annual average PM_{10}
Approach	Assessment of greenhouse gas emissions as part of the Transport Authorities Greenhouse Group, 2011.
Scenarios	2016, and 2026 with and without the project.
Traffic data	Average daily traffic on the Pacific Highway at the time of monitoring was around 19,700 vehicles (RTA, 2004).
Background air quality	Roads and Maritime monitored air quality at a site adjacent to the Pacific Highway at Korora between Korora Public School and the Korora Rural Fire Brigade, north of Coffs Harbour.
Emission factors	Emissions associated with traffic from the project have been calculated using the Road and Maritime Services Tool for Roadside Air Quality (TRAQ).
Met/dispersion model(s)	TRAQ
Receptors	11 sections of the Pacific Highway.
Model validation	Not specified
Construction assessment	Construction qualitatively assessed.
Notes	Various scenarios were considered, in terms of the project's intended year of opening (2016), 10 years after opening, and with and without the project.
Reference	NSW Roads and Maritime Services (2012)

Appendix E - Description and evaluation of emission models

E.1 Overview

A spatial emissions inventory was developed for road traffic sources in the WestConnex GRAL domain. The modelling of emissions was required for the following components:

- Emissions from the proposed ventilation outlets of the project tunnel. These were calculated using the emission factors provided by PIARC (2012).
- 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).

Descriptions of these two models used, and evaluations of their performance, are provided in the following sections.

E.2 Model descriptions

E.2.1 PIARC model

E.2.1.1 Hot exhaust emissions

The guidance by PIARC (2012) provides hot exhaust emission rates (in grams per hour) for CO, NO_X and opacity. The emission rates were derived from the Handbook of Emission Factors (HBEFA) which is used in Germany, Austria, Switzerland and other European countries (INFRAS, 2010). The underlying emission data were obtained from tests on European vehicles conforming to European standards, and were filtered by PIARC to better represent in-tunnel driving behaviour. Appendix 3, Section 3.1 of the PIARC guidance presents aggregated emission rates for Australian vehicles. These are defined for a base year of 2010 and for the following vehicle types:

- Petrol cars.
- Diesel cars.
- Light commercial vehicles. These are referred to as 'LDVs' by PIARC.
- Diesel HGVs. These are referred to as 'trucks' by PIARC.

For each vehicle type the emission rates are presented as discrete values for different speeds (0 kilometres per hour to 130 kilometres per hour, in intervals of 10 kilometres per hour) and different road gradients (-6 per cent to +6 per cent, in intervals of 2 per cent). No guidance is provided on how to determine emission rates for intermediate speeds and gradients.

Opacity values are provided for both exhaust and non-exhaust particles, and these can be converted to $PM_{2.5}$. It is assumed by PIARC that $PM_{2.5}$ concentrations are directly proportional to opacity, with:

Equation E1

$$\mathbf{K = 0.0047 \times C_{PM2.5}}$$

Where:

K is the opacity (m^{-1})

$\mathbf{C_{PM2.5}}$ is the $PM_{2.5}$ concentration (mg/m^3)

Similarly, the opacity units for emission rates in the PIARC guidance (in m^2/h) are converted into $PM_{2.5}$ emission rates (in g/h) using a factor of 4.7 (i.e. 1 g/h = 4.7 m^2/h).

The influence of fleet renewal, and the introduction of vehicles conforming to more stringent emission standards, is taken into account using scaling factors for future years. These are presented for 2015 and 2020, relative to 2010. No scaling factors are provided for other years. The PIARC model also involves the use of altitude scaling factors, although these are set to unity below an altitude of 1,000 m, and no factors are provided for Australia as no major urban areas are at altitude.

E.2.1.2 Cold-start emissions

PIARC does not provide emission factors for cold-start emissions.

E.2.1.3 Primary NO_2 emissions

It is noted by PIARC that in previous years 90-95 per cent of the NO_X in vehicle exhaust was emitted as NO, but the implementation of diesel after-treatment systems such as oxidation catalysts, diesel particulate filters (DPFs) and selective catalytic reduction (SCR) systems have tended to increase the primary NO_2 fraction (termed *f*-NO_2). PIARC adds that in many European road tunnels NO_2 can be around 20-30 per cent of NO_X. Only on roads with very few cars with diesel engines will the NO_2 contribution be below 10 per cent. However, PIARC does not provide specific guidance on the fraction of NO_2 that should be used in Australia, or indeed elsewhere.

E.2.1.4 Non-exhaust PM emissions

PIARC notes that the quantification of non-exhaust PM emissions is highly uncertain. Whilst emissions due to abrasion processes correlate with traffic volume and speed, the quantity of resuspended particles is strongly related to the cleanness of the tunnel and whether the traffic is one-way or two-way. In the PIARC guidance it is assumed that the emission rates for non-exhaust $PM_{2.5}$ are dependent only upon the broad type of vehicle (LDV/HDV), and are constant per vehicle-km. There is an additional complexity in that non-exhaust particles are mainly larger than 1 µm in diameter, and do not strongly affect light extinction. However, it is assumed in the guidance that Equation E1 applies to non-exhaust particles as well as to exhaust particles (PIARC, 2012).

E.2.2 NSW EPA model

E.2.2.1 Hot running exhaust emissions

The NSW EPA method for calculating hot running emissions involves the use of matrices of base composite emission factors for the following cases:

- Five pollutants (CO, NO_X, PM_{10}, $PM_{2.5}$, THC)[1].
- Nine vehicle types: petrol passenger vehicles, diesel passenger vehicles, light-duty commercial petrol vehicles (<=3,500 kg), light-duty commercial diesel vehicles (<=3,500 kg), heavy-duty commercial petrol vehicles (>3,500 kg), rigid trucks (3.5-25 t, diesel), articulated trucks (> 25 t, diesel), heavy public transport buses (diesel only), and motorcycles. The composite emission factor for each vehicle type took into account VKT by age and the emission factors for specific emission standards.
- Five road types (residential, arterial, commercial arterial, commercial highway, highway/ freeway), to allow for differences in traffic composition and driving patterns.
- Nine model years (2003, 2008, 2011, 2016, 2021, 2026, 2031, 2036 and 2041). The year defines the composition of the fleet for each type of vehicle, allowing for technological changes. The base year for the inventory is 2008, and therefore the data for years after 2008 are projections.

The road types used in the NSW GMR emissions inventory have been mapped to RTA functional classes by EPA (Table E-1). Further information on the mapping of these categories is provided in the inventory report (NSW EPA, 2012b).

Each base composite emission factor is defined for a VKT-weighted average speed (the base speed) associated with the corresponding road type. Dimensionless correction factors – in the form of 6^{th}-order polynomial functions – are then applied to the base emission factors to take into account the

[1] It is assumed that $PM_{2.5}$ is equivalent to PM_{10}, which is appropriate for exhaust emissions.

actual speed on a road. According to EPA, the speed correction factors are valid up to 110 kilometres per hour for light-duty vehicles, and up to 100 kilometres per hour for heavy-duty vehicles.

Emission factors have also been provided by EPA for heavy-duty vehicles with and without the implementation of the Euro VI regulation.

Table E-1 Road types used in NSW EPA emissions inventory model

NSW GMR inventory road type	RTA functional class	Definition/description
Local/residential	Local road	Secondary road with prime purpose of access to property. Low congestion and low level of heavy vehicles. Generally one lane each way, undivided with speed limit up to 50 kilometres per hour. Regular intersections, mostly unsignalised, and low intersection delays.
Arterial	Sub-arterial and arterial	Connection from local roads to arterials. May provide support role to arterial roads for movement of traffic during peak periods. Distribute traffic within residential, commercial and industrial areas. Speed limit 50-70 kilometres per hour, 1-2 lanes. Regular intersections, mostly uncontrolled. Lower intersection delays than residential roads, but significant congestion impact at high volume: capacity ratio (V/C).
Commercial arterial	Arterial	Major road for purpose of regional and inter-regional traffic movement. Provides connection between motorways and sub-arterials/collectors. May be subject to high congestion in peak periods. Speed limit 60-80 kilometres per hour, typically dual carriageway. Regular intersections, many signalised, characterised by stop-start flow, moderate to high intersection delays and queuing with higher V/C.
Commercial highway	Arterial	Major road for purpose of regional and inter-regional traffic movement. Provides connection between motorways and sub-arterials/collectors. May be subject to moderate congestion in peak periods. Speed limit 70-90 kilometres per hour, predominantly dual carriageway. Fewer intersections than commercial arterial, with smoother flow but subject to some congestion at high V/C.
Highway/freeway	Motorway	High volume road with primary purpose of inter-regional traffic movement with strict access control (i.e. no direct property access). Speed limit 80-110 kilometres per hour, predominantly 2+ lanes and divided carriageway. Relatively free-flowing when not congested, slowing with congestion approaching V/C limit but minimal stopping.

The emission factor for a given traffic speed is calculated as follows:

Equation E2

$$\mathbf{EF_{HotSpd}} = \mathbf{EF_{HotBasSpd}} \times \frac{\mathbf{SCF_{Spd}}}{\mathbf{SCF_{BasSpd}}}$$

Where:

$\mathbf{EF_{HotSpd}}$ is the composite emission factor (in g/km) for the defined speed

$\mathbf{EF_{HotBasSpd}}$ is the composite emission factor (in g/km) for the base speed

$\mathbf{SCF_{Spd}}$ is the speed-correction factor for the defined speed

$\mathbf{SCF_{BasSpd}}$ is the speed-correction factor for the base speed

Each speed-correction factor is a 6th order polynomial: **SCF = $aV^6 + bV^5 + \ldots + fV + g$**, where **a** to **g** are constants and V is the speed in kilometres per hour.

Some examples of the resulting emission factors are shown in the Figures below. Figure E-1 shows how NO_X emissions (per vehicle-km) from petrol cars vary as a function of average speed[2] on different road types. The data show that some types of road, notably arterial roads, are associated with higher emissions for a given average speed than others. Figure E-2 shows how emissions (again, per vehicle-km) of different pollutants from petrol cars will decrease in the future as emission-control technology improves. PM emissions from petrol vehicles are projected to be dominated by non-exhaust particles. Because these are unregulated the reduction in emissions in the future will be lower than for the other pollutants.

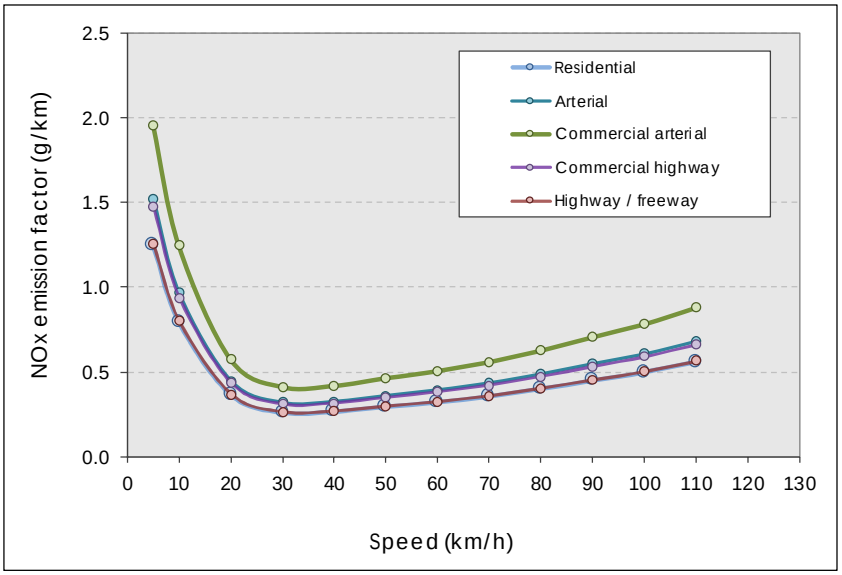


Figure E-1 NO_X emission factors for petrol cars in 2014

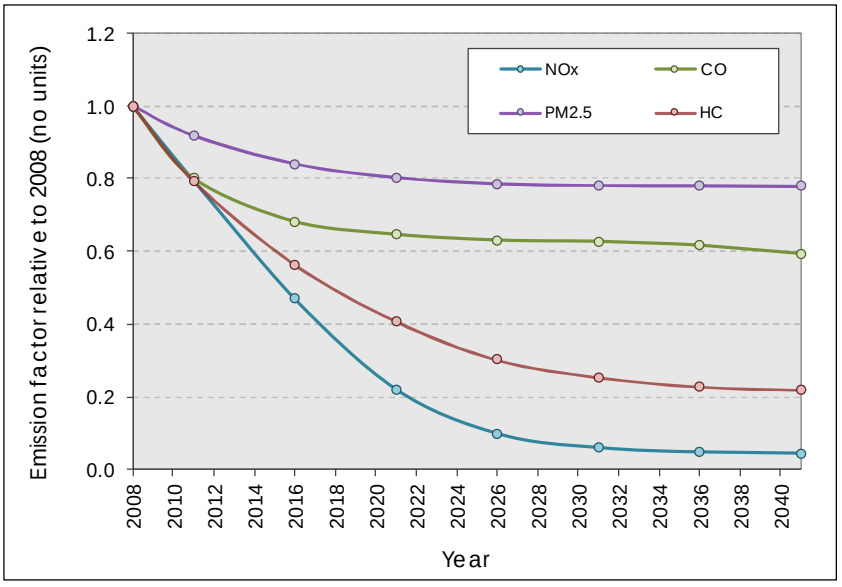


Figure E-2 Emission factors for petrol cars at 80 kilometres per hour, normalised to 2008

[2] 'Average speed' should not be confused with 'constant speed'. The former is calculated for a driving cycle which includes periods of acceleration, deceleration, cruise, and idle, as encountered in real-world traffic.

E.2.2.2 Gradient factors

Correction factors were applied to allow for the effects of road gradient on hot running emissions. NSW EPA did not develop gradient correction factors for the GMR inventory, but these were determined separately by Sinclair Knight Merz (SKM) for use in the TRAQ[3] model.

The gradient factors for TRAQ were taken from the (now superseded) version of the PIARC tunnel ventilation guidance of 2004, and therefore revised factors were determined using the emission rates in the PIARC guidance from 2012. For each gradient and speed, the gradient correction factor was determined by dividing the corresponding PIARC emission rate by the emission rate for zero gradient.

The gradient correction is introduced as follows:

Equation E3

$$\mathbf{EF_{HotGradCor} = EF_{HotSpd} \times G}$$

Where:

$EF_{HotGradCor}$ is the composite emission factor (in g/km), corrected for road gradient

G is the road gradient correction factor. Different values of **G** are used for each pollutant, vehicle type and speed.

No gradient corrections were applied to THC (any vehicles) or to PM emissions from petrol vehicles.

E.2.2.3 Cold-start emissions

The method for calculating cold-start emissions involved the application of adjustments to the base hot emission factors to represent the extra emissions which occur during 'cold running'. The adjustments took into account the distance driven from the start of a trip, the parking duration and the ambient temperature. Cold-start emissions were only calculated for light-duty vehicles. No cold-start adjustment was made for PM. The amount of cold running was dependent on the road type, and no cold running was assumed for highways.

Cold-start emissions are therefore calculated as follows:

Equation E4

$$\mathbf{EF_{Cold} = EF_{HotBasSpd} \times (CS-1)}$$

Where:

EF_{Cold} is the cold-start emission factor (in g/km)

CS is a cold start adjustment factor (>1). Different values of **CS** are used for each pollutant, vehicle type, road type and year.

E.2.2.4 Primary NO_2 emissions

No primary NO_2 emission factors were available for Australian vehicles. Primary NO_2 emissions were therefore determined by NSW EPA using the *f*-NO_2 values for the various vehicle types and emission standards that have recently been developed for the EMEP/EEA Air Pollutant Emission Inventory Guidebook and the COPERT 4 model (Pastramas et al., 2014).

E.2.2.5 Non-exhaust PM emissions

The method for non-exhaust PM_{10} and $PM_{2.5}$ emissions was drawn from the EMEP/EEA Air Pollutant Emission Inventory Guidebook (EEA, 2013), and included tyre wear, brake wear and road surface wear. Emission factors (in g/km) were provided for each vehicle type, road type and year. Information

[3] TRAQ is an air quality screening model for roads that has been developed by Roads and Maritime.

was required for parameters such as vehicle load and number of axles, and the assumptions used for vehicles in the NSW GMR are described in NSW EPA (2012b).

E.2.2.6 Evaporative emissions

Evaporative emissions of VOCs are not included in the EPA model described here, although they are included in the more detailed full inventory model. The calculation of evaporative emissions is relatively complex, as it requires an understanding of temperature profiles, fuel vapour pressure, fuel composition, and operational patterns. Moreover, it is difficult to link evaporative emissions to traffic activity on specific road links, as running losses are only one component (for example, evaporative emissions also occur when vehicles are stationary). For these reasons evaporative emissions have been excluded from the model and the M4 East assessment. Ambient concentrations of VOCs are also very low, and the inclusion of evaporative emissions would be unlikely to result in adverse impacts on air quality.

E.2.3 Fleet data

In order to combine the emission factors in the models with traffic data, information was also required on the following:

- The fuel split (petrol/diesel) for cars (Figure E-3). This was assumed to be the same for all road types.
- The fuel split (petrol/diesel) for LCVs (Figure E-4). This was also assumed to be the same for all road types.
- The sub-division of HDVs into rigid HGVs, articulated HGVs and buses (Figure E-5).

These splits were provided for NSW EPA for the road types included in the EPA model, and as used in the GMR inventory. The values were based on VKT data from the Bureau of Transport Statistics Household Travel Survey, Strategic Travel Model, and Freight Movement Model (NSW EPA, 2012b and references therein).

An examination of vehicle registration (sales) data in NSW has recently been conducted by NSW EPA (Jones, 2015). Whilst there are some differences[4] between the geographical coverage and the definitions of vehicle groups, the EPA analysis has highlighted some discrepancies between the actual vehicle sales figures and the inventory projections.

Figure E-6 shows the diesel proportions for cars ('PC' = cars and people-movers) and SUVs.

NSW EPA note the following in relation to these data:

- The actual growth in diesel car sales has been lower than projected in the inventory. For example, the actual NSW-wide diesel proportion of sales in 2014 was 8 per cent, compared with a projection for 2014 in the inventory of 19 per cent. These data are shown by the blue lines.
- The proportions of new four-wheel-drive (4WD) vehicles that are diesel in the sales data are in good agreement with the inventory projections. These data are shown by the red lines.
- The proportion of passenger vehicles (PV = cars + people-movers + SUV) that are SUVs is underestimated in the inventory projections for 2014 at 29 per cent, compared with 37 per cent in the sales data. These data are shown by the green lines.

Figure E-7 shows the total passenger vehicle (PV) fleet (cars + people-movers + SUV) and light commercial vehicles (LCV).

4 The vehicle registration data to the end of 2014 were NSW-wide, whereas the inventory projection were for the GMR only. There may be some bias due to the different geographical areas (e.g. there may be more diesel vehicles and more SUV/4WD in regional areas). In addition, for LCVs the inventory defines these as GVM <=3500kg in line with the ADR's (i.e. primarily utes and vans), while the RMS rego data lists light trucks as those commercial vehicles with GVM <=4500 kg; thus there may be a bias again to diesel in the RMS as those vehicles 3.5t – 4.5t will be almost exclusively diesel.

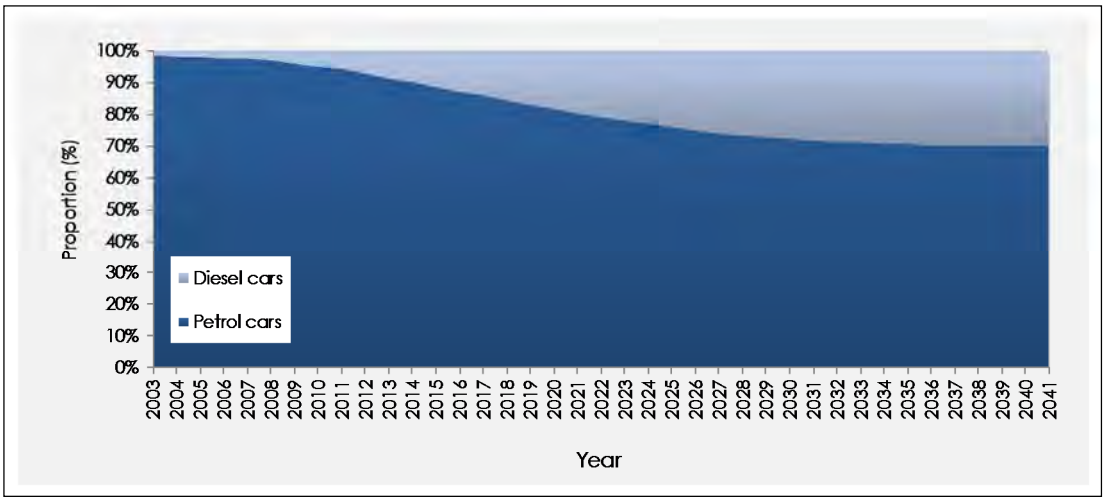


Figure E-3 Fuel split for cars

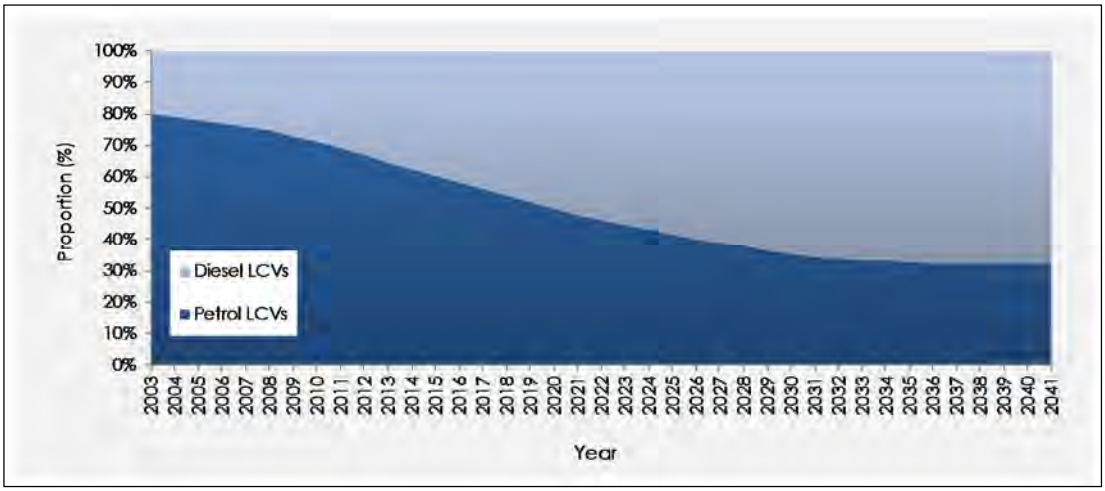


Figure E-4 Fuel split for LCVs

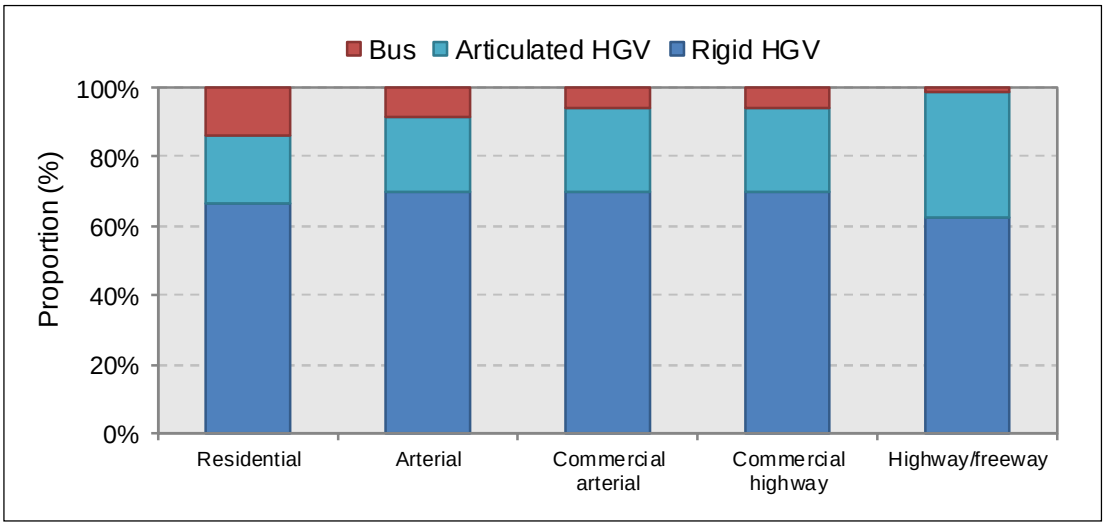


Figure E-5 Vehicle type split for HDVs (year = 2021)

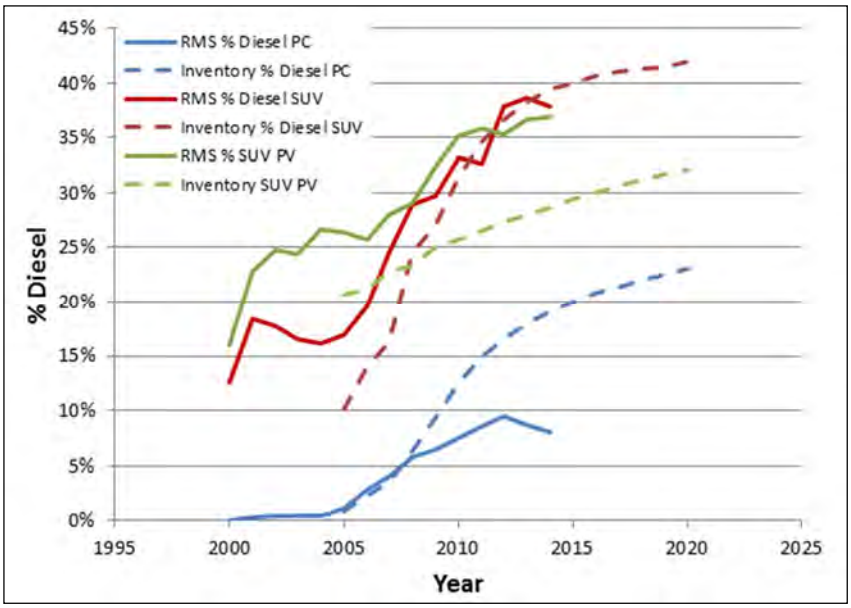


Figure E-6 Diesel proportions for cars and SUVs

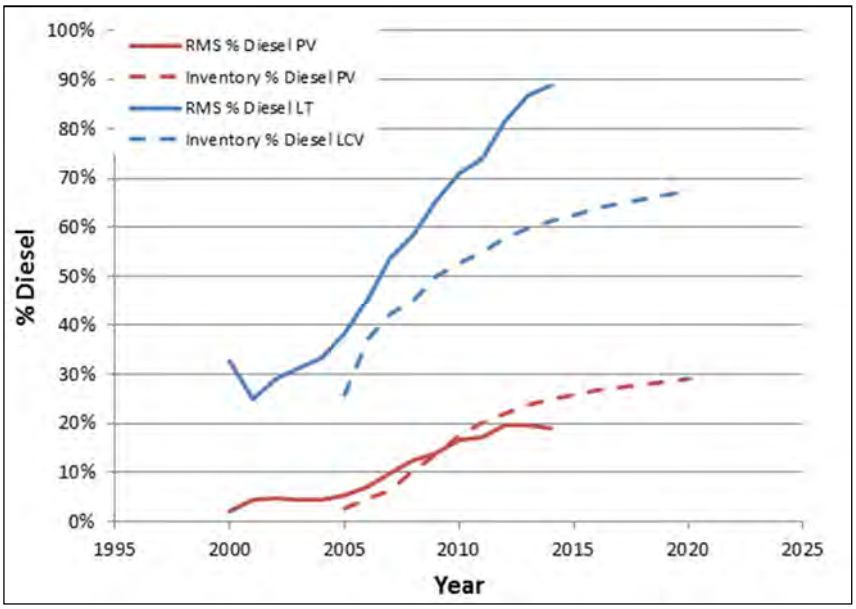


Figure E-7 Diesel proportions for all passenger vehicles and light commercial vehicles

In relation to these data, NSW EPA note the following:

- The proportion of total new passenger vehicles (cars, people-movers and 4WD/SUV) that are diesel is higher in the inventory projection for 2014 (25 per cent) than in the sales data (19 per cent).
- In contrast to cars, the actual diesel proportion of LCVs in 2014 (89 per cent) was substantially higher than the projection (61 per cent).

It was beyond the scope of this work to include these discrepancies in the M4 East assessment. NSW EPA is currently updating the emissions inventory, and the fleet information will be revised as part of this process.

E.2.4 Model summary

The algorithms in the PIARC and EPA models were converted into spreadsheet tools which could be readily used for air quality assessments of road projects, including the processing of data from the WestConnex traffic models. The content of each tool is summarised in Table E-2.

Table E-2 Summary of models

Parameter		Model	
		PIARC	EPA
Years		2010-2021[a]	2008-2041
Emission processes	Hot exhaust	✓	✓
	Cold-start	×	✓
	Evaporative	×	×
	Non-exhaust	✓	✓[b]
Pollutants included	CO	✓	✓
	NO_X	✓	✓
	NO_2	×	✓
	PM_{10}	×	✓
	$PM_{2.5}$	✓	✓
	THC/VOC	×	✓
	CO_2 (exhaust)	×	✓
	$CO_{2\text{-}e}$	×	✓
Vehicle categories	Petrol car	✓	✓
	Diesel car	✓	✓
	Petrol LCV	Combined	✓
	Diesel LCV		✓
	Petrol HGV	×	✓
	Rigid HGV	✓[c][d]	✓[e]
	Articulated HGV	✓[d]	✓[e]
	Bus	✓[c][d]	✓[e]
	Motorcycle	×	✓
Effects on emissions	Road type	×	✓
	Average speed	✓	✓
	Road gradient	✓	✓[f]
Fuel splits for each year	Cars: petrol/diesel	✓	✓
	LCVs: petrol/diesel	✓	✓
Limitation of HGV speed to 100 km/h		✓	✓
Interpolation of emission factors for actual speed and road gradient		✓	✓
Calculations for any time period		✓	✓
Unlimited road links		✓	✓
Output units	Avg. g/vehicle-km	✓	✓
	g/h from traffic	✓	✓
	g/km/h from traffic	✓	✓

a) For the purpose of model evaluation, the data for 2021 were obtained by extrapolation of the PIARC year scaling factors for 2010-2020. It was considered inappropriate to extrapolate further into the future.
b) Based on full implementation of the method for non-exhaust PM in EEA (2013).
c) Rigid trucks and buses combined.
d) Based on simple scaling factors for an 'average' HDV.
e) Results available with and without ADR80/04 (Euro VI) for HDVs.
f) Using gradient scaling factors from PIARC (2012).

E.3 Model evaluation

E.3.1 Model comparison

E.3.1.1 Emission rates for zero per cent gradient

The PIARC and EPA emission rates were initially compared for a road gradient of 0 per cent. The emission rates for CO, NO_X[5] and $PM_{2.5}$ (both exhaust and non-exhaust) are shown in Figure E-8 to Figure E-15. For ease of comparison, the following assumptions were made in the calculation of these emission rates:

- The emission rates for LCVs were calculated using the PIARC and EPA models and were based on the fuel split for Australia in PIARC (2012) (i.e. 50 per cent petrol and 50 per cent diesel).
- The emission rates for HGVs calculated using the EPA model were based on the split between rigid and articulated vehicles for Australia in PIARC (2012) (i.e. 83 per cent rigid and 17 per cent articulated).
- For HGVs, separate emission rates were calculated using the EPA model for scenarios with and without the implementation of the Euro VI legislation. This only affected NO_X and exhaust $PM_{2.5}$.

It is worth repeating that:

- The PIARC method does not provide emission rates for 2031 and have therefore been assumed to the same as 2021.
- For cars and LCVs the valid speed range in the EPA approach is 5 to 110 kilometres per hour.
- The speed of HGVs has been restricted to 100 kilometres per hour in all models.

It is clear from these figures that the prediction of one model relative to the other depends on the pollutant, vehicle type, traffic situation and year being investigated. However, a more general overview of the behaviour of the different models can be obtained from the weighted results for a 'typical' highway tunnel traffic mix, as shown in Figure E-9, Figure E-11 and Figure E-15. For each pollutant the weighted emission rates were calculated based on a peak-hour traffic mix of 62 per cent petrol car, 7 per cent diesel car, 18 per cent petrol LCV, 10 per cent diesel LCV and 3 per cent HGV. These figures show the following:

- CO: In 2014 and 2021 the CO emission rates of the two models were similar at low speeds. For speeds between around 20 and 60 kilometres per hour the PIARC model tended to give higher emission rates than the EPA model. The EPA model gave significantly higher emission rates than the PIARC model at high speeds. In 2031 the EPA model gave lower emissions than the PIARC model at speeds below 70 km/h, but higher emissions at speeds above 70 km/h.
- NO_X: The PIARC and EPA models gave broadly similar NO_X emission rates for speeds below 40 kilometres per hour in all years. For 2014 and 2021 the EPA models gave the highest results for speeds above 40 kilometres per hour. For 2031 the models gave quite similar results.
- $PM_{2.5}$: For all years the PIARC model gave systematically higher total $PM_{2.5}$ emission rates than the EPA model. This was due to the conservative assumptions concerning non-exhaust PM in the PIARC model, although exhaust emissions in the PIARC model were also higher than those in the EPA model.

[5] NO_2 is not included in the PIARC model.

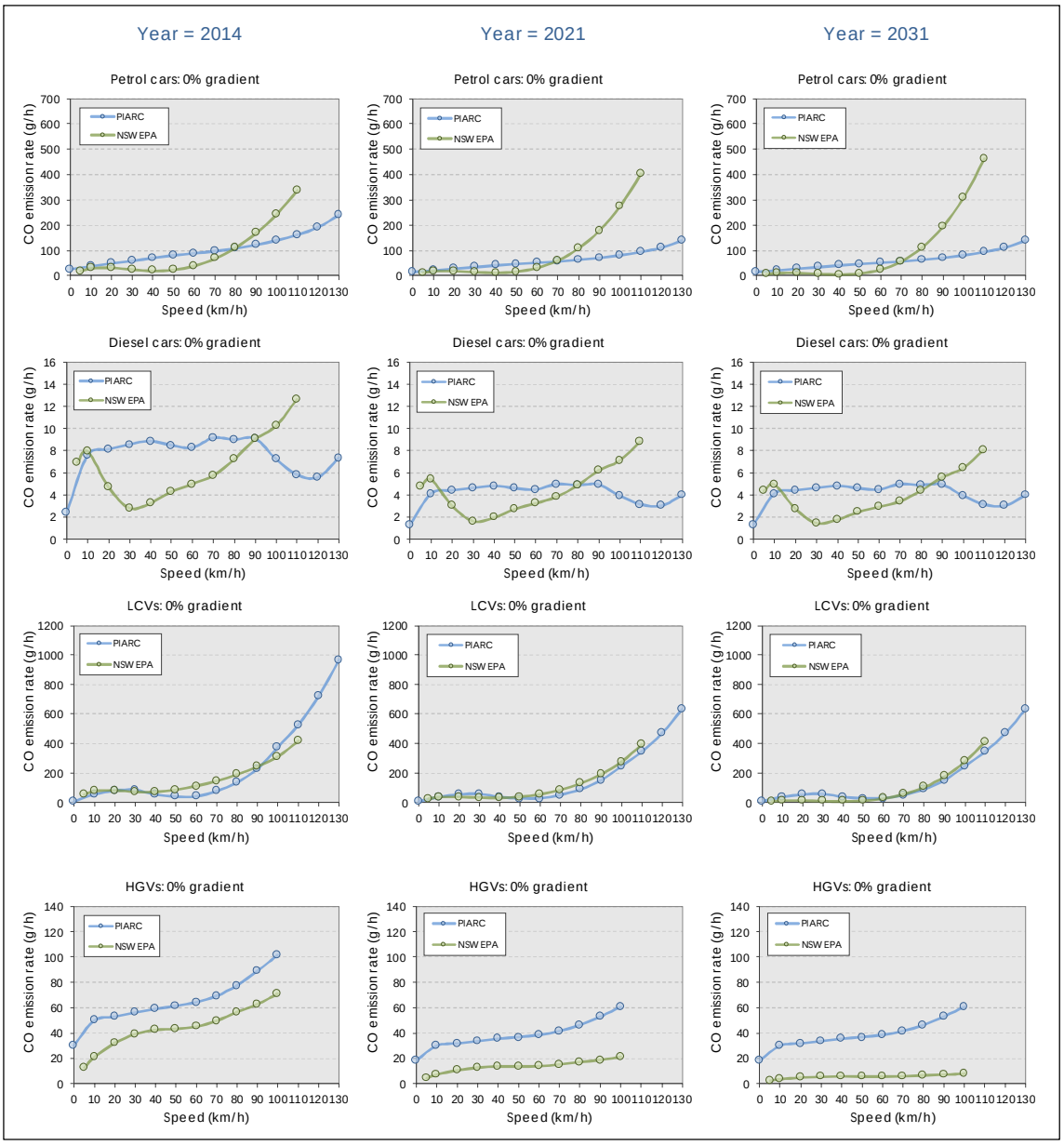


Figure E-8 **CO emission rates at zero per cent gradient for 2014, 2021 and 2031**

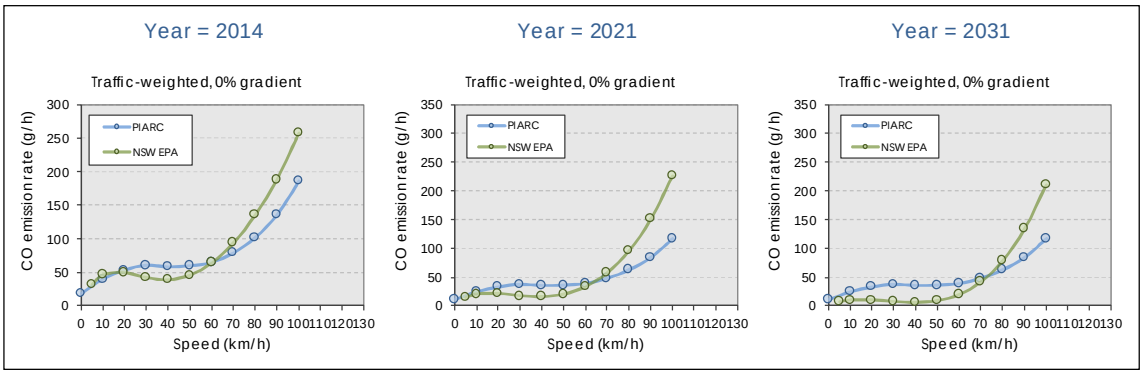


Figure E-9 **Traffic-weighted CO emission rates at zero per cent gradient and highway traffic mix for 2014, 2021 and 2031**

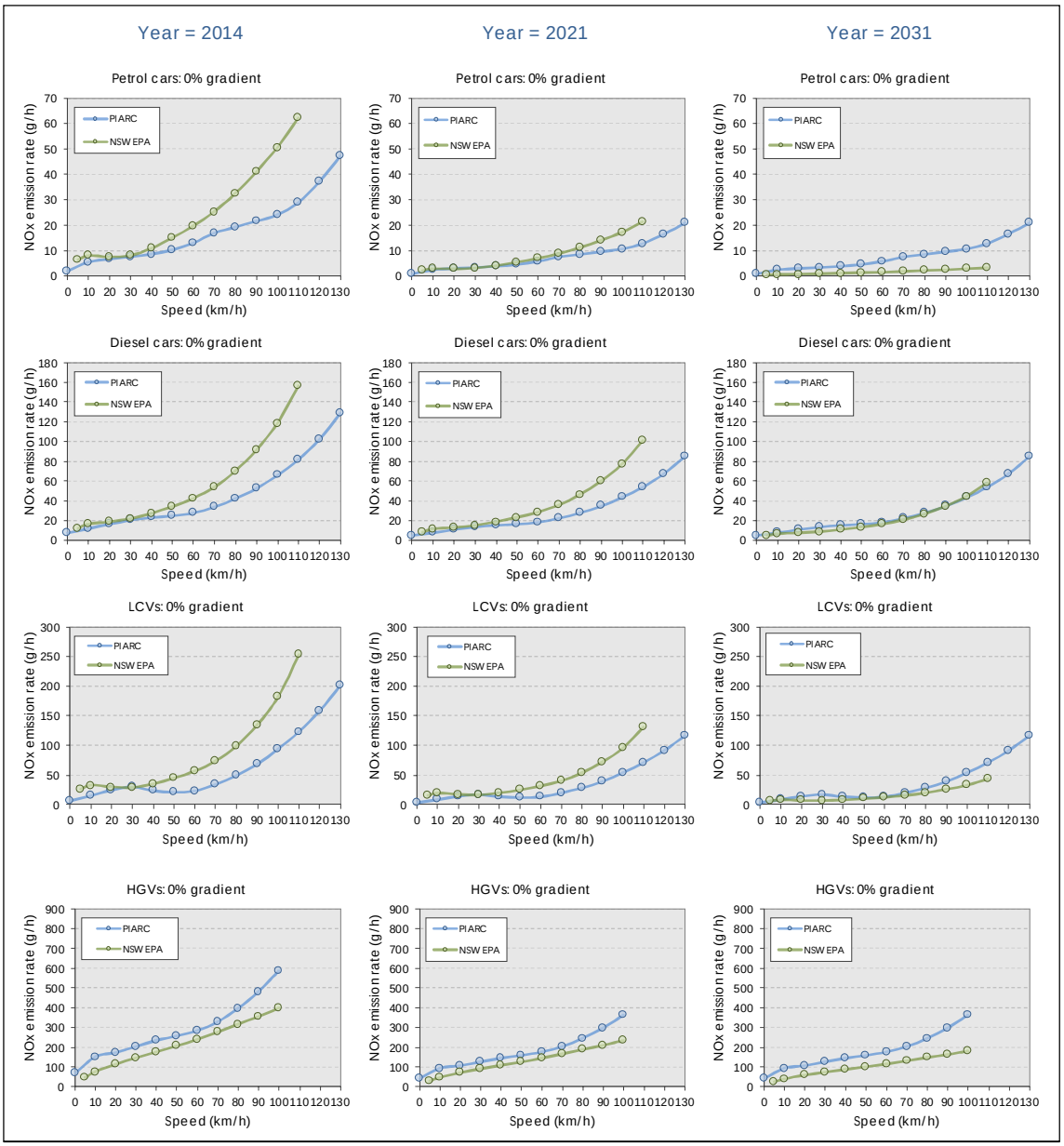


Figure E-10 **NO_x emission rates at zero per cent gradient for 2014, 2021 and 2031**

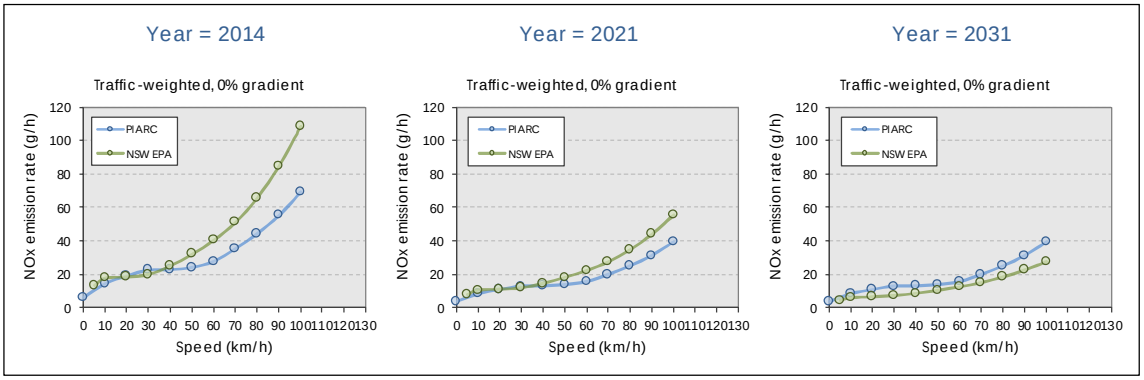


Figure E-11 **Traffic-weighted NO_X emission rates at zero per cent gradient for and highway traffic mix 2014, 2021 and 2031**

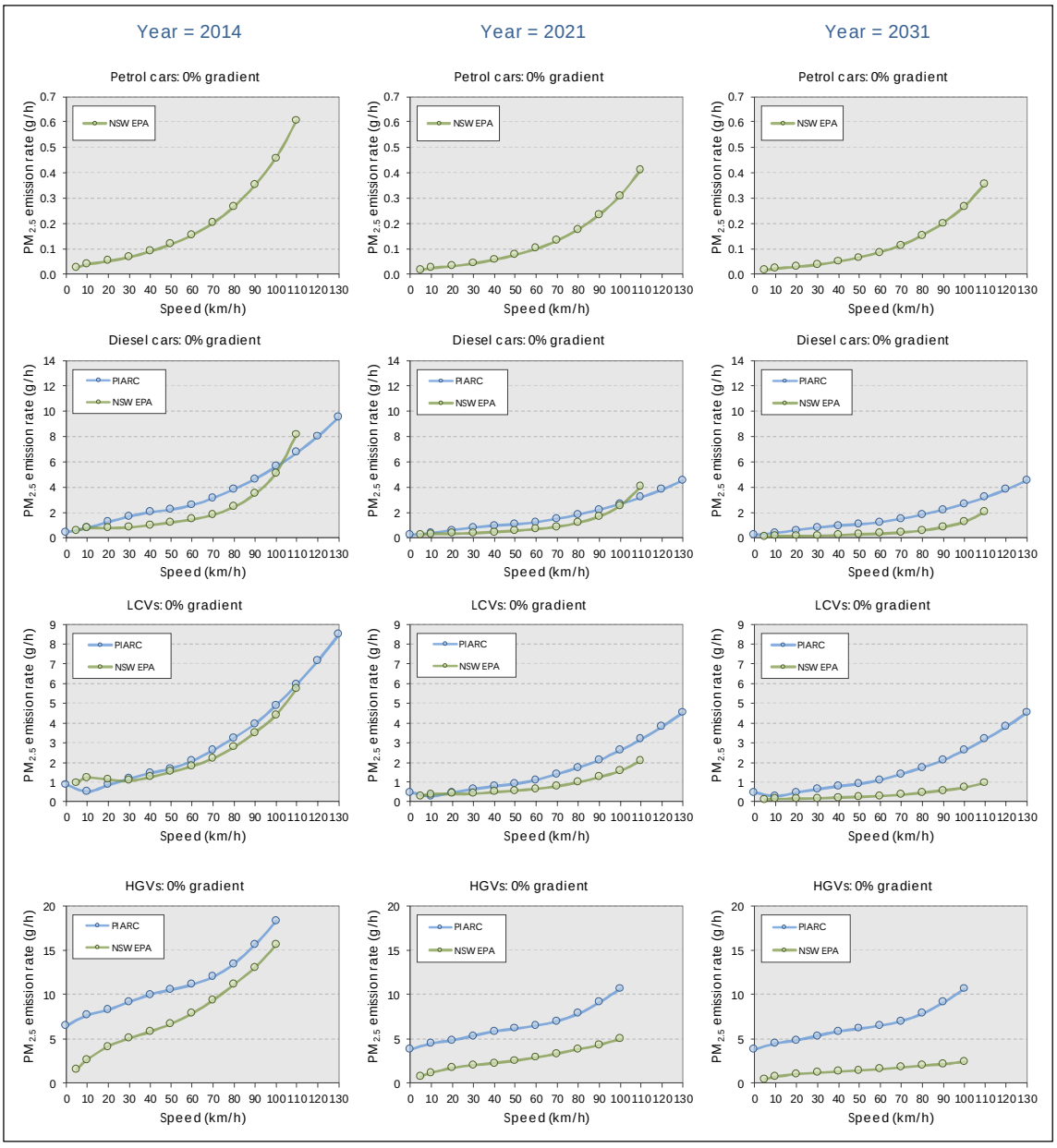


Figure E-12 Exhaust $PM_{2.5}$ emission rates at zero per cent gradient for 2014, 2021 and 2031

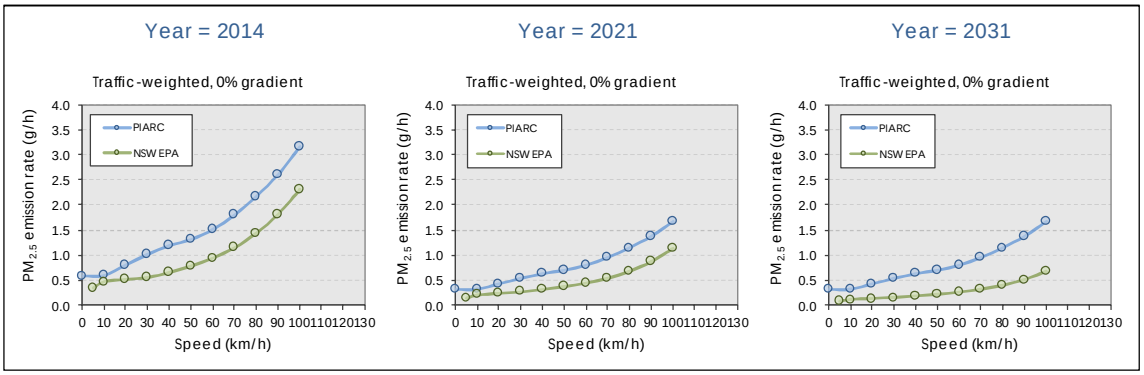


Figure E-13 Traffic-weighted exhaust $PM_{2.5}$ emission rates at zero per cent gradient and highway traffic mix for 2014, 2021 and 2031

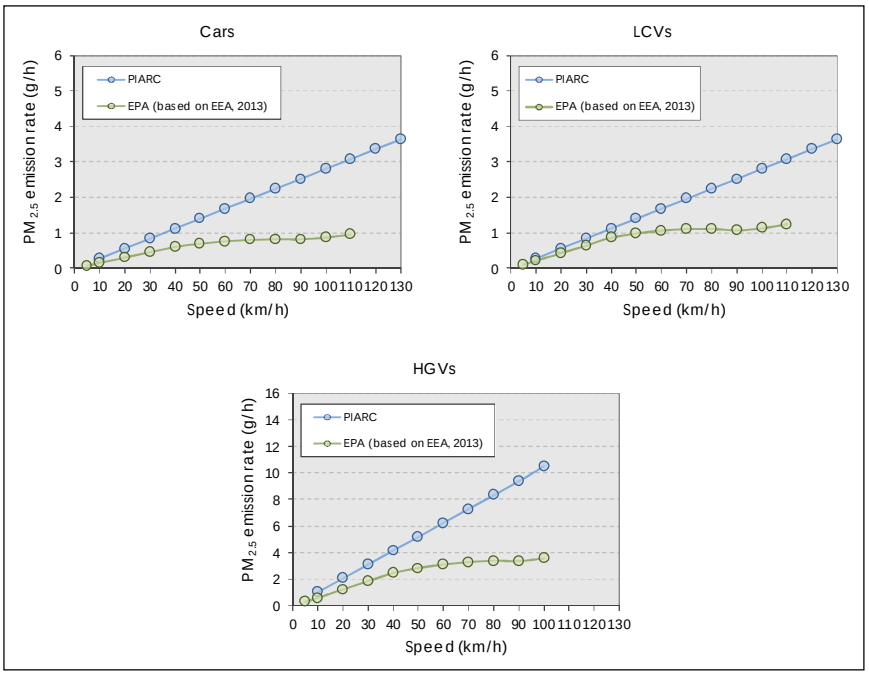


Figure E-14 Non-exhaust $PM_{2.5}$ emission rates at zero per cent gradient for 2014, 2021 and 2031

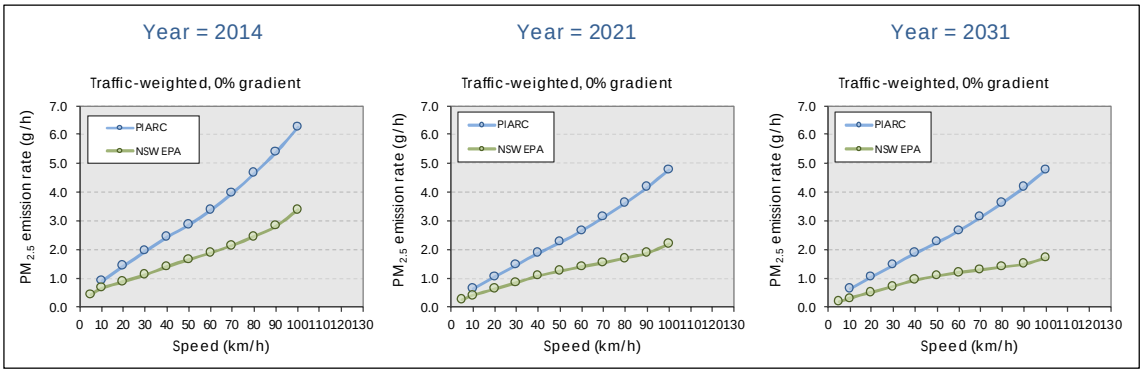


Figure E-15 Traffic-weighted total $PM_{2.5}$ emission rates at zero per cent gradient for highway traffic mix 2014, 2021 and 2031

E.3.2 Model validation

E.3.2.1 Performance of PIARC model

The accuracy of the PIARC model at representing vehicle emissions (CO, NO_X and $PM_{2.5}$) in the Lane Cove Tunnel was recently investigated by Boulter and Manansala (2014). The ventilation conditions in the tunnel result in all vehicle emissions being released from the ventilation outlets. No pollution is released from the tunnel portals. This makes it possible to compare the predicted mass emission rate (in g/h) for the traffic in each direction of the tunnel with the observed emission rate in the corresponding ventilation outlet. The same data (from October and November 2013) were used in the M4 East assessment to re-evaluate the accuracy of the PIARC model, as some changes to the implementation of the models by Pacific Environment had been made. The pollutants NO_2 and PM_{10} were also included in this part of the work, where possible.

The predicted and observed emission rates in the Lane Cove Tunnel were compared using a linear regression approach. In Figure E-16 separate results are shown for each pollutant and each direction in the tunnel; the eastbound tunnel is predominantly uphill, and the westbound tunnel is predominantly downhill. In each graph the dashed red line represents a 1:1 ratio between the predicted and observed emission rates, and the solid lines show the linear regression fits to the data, forced through the origin[6]. The $PM_{2.5}$ predictions are shown with and without the non-exhaust component. The average quotients of the predicted and observed values are given in Table E-3.

Some general patterns were apparent in the results for the PIARC model:

- There was generally a strong correlation between the predicted and observed emission rates for CO, NO_x and $PM_{2.5}$, with R^2 between 0.76 and 0.93. The strong correlations were due in large part to the narrow range of operational conditions (*i.e.* traffic composition, speed) in the Lane Cove Tunnel. In fact, the modelled emission rates were more or less directly proportional to the traffic volume. The variability in the regression plots was therefore linked to the variability of the measurements in the ventilation outlets with traffic volume.
- Different regression slopes were obtained for the eastbound and westbound directions. The eastbound tunnel has a net uphill slope which would increase engine load and emissions, whereas in the downhill westbound tunnel engines would tend to be under lower load, with some newer vehicles possibly having very low fuelling. Such effects may not be adequately reflected in the gradient adjustments in the models.
- On average, the PIARC model **overestimated** pollutant emissions in the tunnel. This is likely to be due in part to the following:
    - The inherent over-prediction built into the PIARC gradient factors, as well as other conservative assumptions.
    - The tunnel environment itself affecting emissions. The piston effect and any forced ventilation in the direction of the traffic flow may combine to produce an effective tail wind that reduces aerodynamic drag on the vehicles in the tunnel (John et al., 1999; Corsmeier et al., 2005).
- The model overestimated $PM_{2.5}$ emissions by a wider margin (a factor of between 2.6 and 4.3) than CO and NO_X. When exhaust emissions of $PM_{2.5}$ are relatively low (i.e. in the westbound tunnel), the overestimation of total $PM_{2.5}$ emissions as a ratio is much greater than when exhaust emissions are relatively high (i.e. in the eastbound tunnel). This confirms that that **the emission rates for non-exhaust $PM_{2.5}$ in the PIARC model are very conservative**. It can be seen from Figure E-16 that the $PM_{2.5}$ predictions of the PIARC model are still generally conservative (by a factor of around 1.5) even when the non-exhaust component is excluded.

The differences between the predicted and observed emission rates are influenced not only by errors in the emission factors in the model, but also the assumptions concerning the fleet composition and age distribution. Moreover, there are inherent errors in the outlet concentration and air flow measurements.

[6] As the outlet emission rates were adjusted for the background contribution, and there were no other in-tunnel emission sources, it was considered acceptable to run the regression model with the constant constrained to zero.

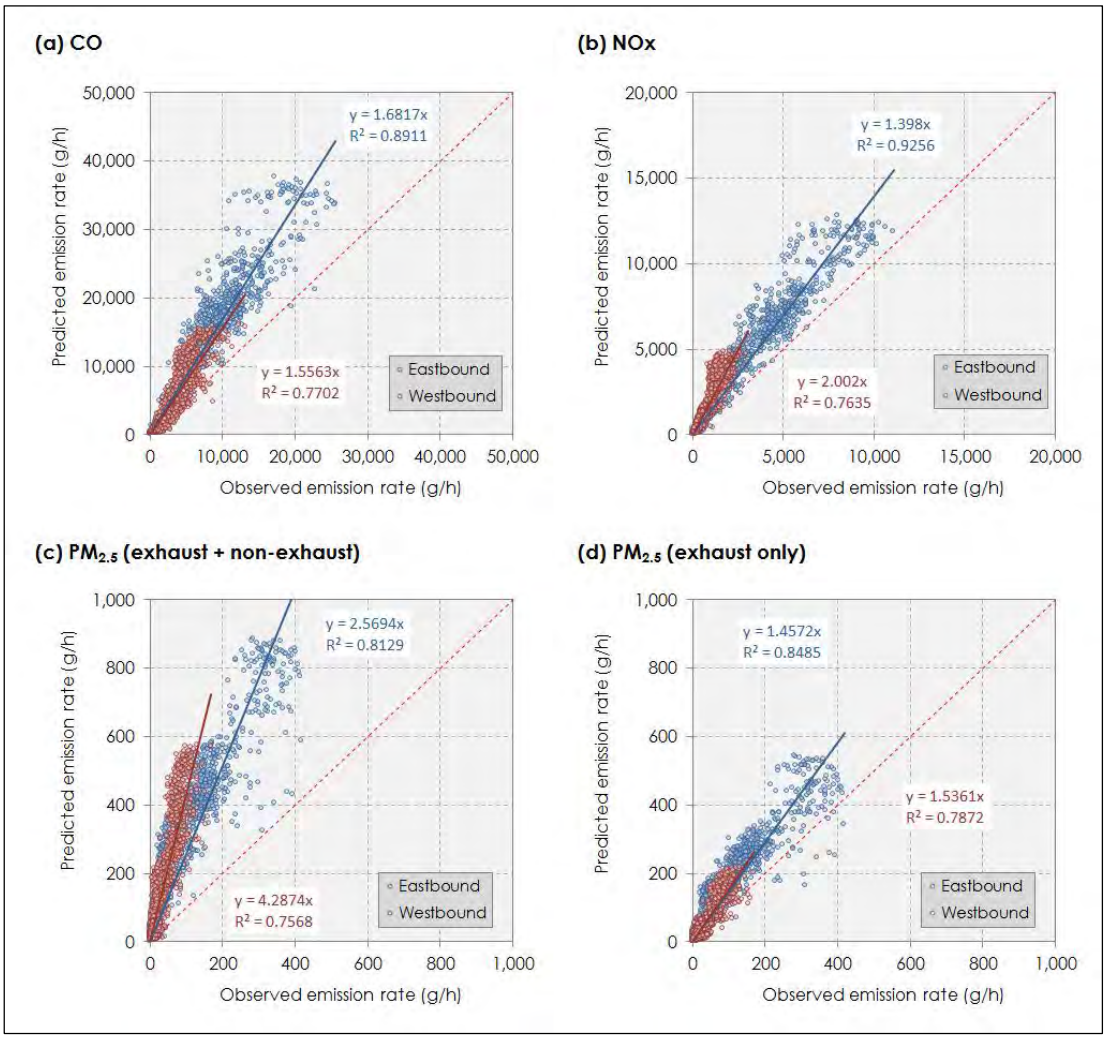


Figure E-16 Predicted vs observed emission rates – PIARC model

Table E-3 Summary of predicted vs observed emission rates

Methodology	Predicted emission rate / observed emission rate				
	CO	NO_X	NO_2	PM_{10}	$PM_{2.5}$
Eastbound					
PIARC	1.68	1.40	Not calculated	Not calculated	2.57
Westbound					
PIARC	1.56	2.00	Not calculated	Not calculated	4.29

E.3.2.2 Performance of NSW EPA model

A corresponding analysis was undertaken for the EPA model. The regression plots are shown in Figure E-17. The average quotients of the predicted and observed values are given in Table E-4.

The performance of the EPA model was similar to that of the PIARC model, with similar correlation coefficients. The EPA model gave a larger overestimation of emissions than the PIARC model for CO, NO_X and NO_2, and a smaller overestimation for $PM_{2.5}$.

Interestingly, in the westbound tunnel the NO_2 data had more scatter than the NO_X data, and a low correlation coefficient was obtained. This is in part due to the relatively low emissions in the westbound tunnel and is possibly also a consequence of the measurement technique

(chemiluminescence), which does not generally respond well to NO_2 concentrations which fluctuate rapidly on short timescales. The NO_X measurements are less affected by this problem, and ought to be more reliable.

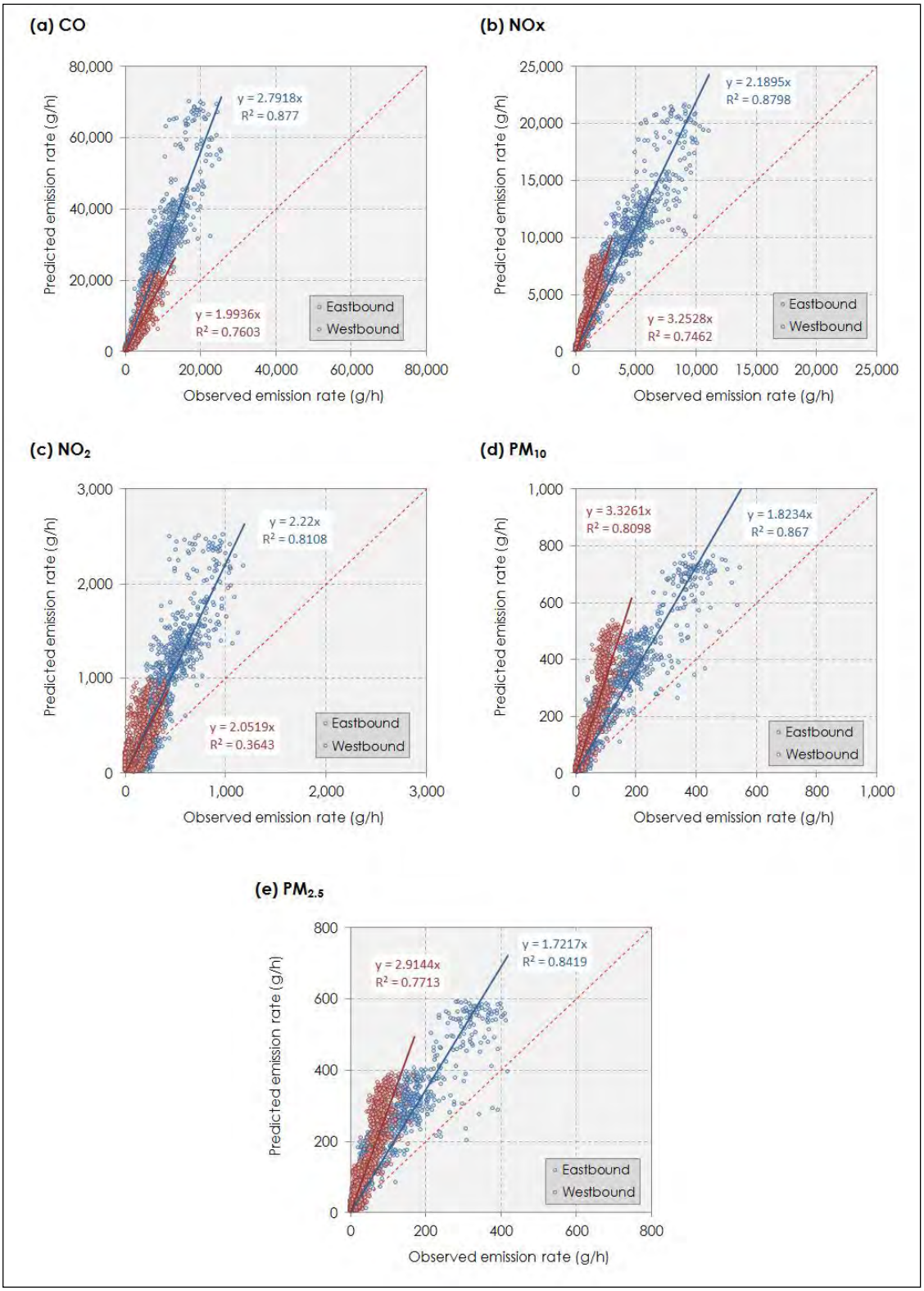


Figure E-17 Predicted vs observed emission rates – EPA model (with PIARC gradient scaling factors)

Table E-4 Summary of predicted vs observed emission rates

Methodology	Predicted emission rate / observed emission rate				
	CO	NO_X	NO_2	PM_{10}	$PM_{2.5}$
Eastbound					
NSW EPA	2.79	2.19	2.22	1.82	1.72
Westbound					
NSW EPA	1.99	3.25	2.06	3.32	2.91

E.3.2.3 Emission factors by vehicle type

A multiple linear regression (MLR) approach was used to determine mean emission factors (in g/km) for LDVs and HDVs based on the adjusted outlet emission rates (CO, NO_X, PM_{10} and $PM_{2.5}$). Multiple linear regression can be used to test how well a dependent variable can be predicted on the basis of multiple independent variables. The inputs to the MLR were the hourly mean emission factor for the traffic (dependent variable) and the corresponding numbers of LDVs and HDVs in the tunnel each hour (independent variables). A similar MLR method has been used in various studies to derive emission factors (e.g. Imhof et al., 2005; Colberg et al., 2005). The following regression model was applied to derive the emission factors:

Equation E5

$$\mathbf{EF_{total} = (N_{LDV} \times EF_{LDV}) + (N_{HDV} \times EF_{HDV}) + c}$$

where:

EF_{total} = the hourly mean emission factor for all traffic in the tunnel, as determined from the tunnel ventilation outlet measurements (g/km/h)

N_{LDV} = the number of LDVs in the tunnel per hour (vehicles/hour)

N_{HDV} = the number of HDVs in the tunnel per hour (vehicles/hour)

EF_{LDV} = the emission factor per LDV in the tunnel (g/vehicle.km)

EF_{HDV} = the emission factor per HDV in the tunnel (g/vehicle.km)

c = a constant (intercept on y-axis)

The hourly mean emission factor for all traffic in the tunnel was obtained by dividing the emission rate by the length of the main line tunnel (3.61 km), with the on- and off-ramps being ignored. The emissions on the ramps were negligible (less than around 2 per cent) compared with the emissions on the main lines.

As the outlet emission rates had already been adjusted to allow for the background contribution, and as there were no other in-tunnel emission sources it was considered acceptable to run the regression model with the constant constrained to zero.

The overall mean observed and predicted emission factors for LDVs, HDVs and all traffic (weighted for traffic volume) are shown in Table E-5, and the predicted/observed ratios are given in Table E-6.

Table E-5 Emission factors by vehicle type and direction

Direction	Pollutant	LDV (g/vehicle.km)			HDV (g/vehicle.km)			All traffic (g/vehicle.km)[a]		
		Observed	PIARC	NSW EPA	Observed	PIARC	NSW EPA	Observed	PIARC	NSWEPA
Eastbound	CO	1.47	2.75	4.61	3.66	0.79	1.09	1.62	2.71	4.48
	NO_X	0.29	0.57	1.18	8.42	8.82	6.93	0.61	0.89	1.39
	NO_2	0.06	N/A	0.14	0.37	N/A	0.85	0.08	N/A	0.16
	PM_{10}	0.01	N/A	0.04	0.36	N/A	0.31	0.03	N/A	0.05
	$PM_{2.5}$	0.01	0.05	0.03	0.32	0.35	0.27	0.02	0.06	0.04
Westbound	CO	0.72[b]	1.21	1.53	-[c]	0.48	0.48	0.78	1.18	1.49
	NO_X	0.13	0.27	0.51	1.07	2.81	2.78	0.18	0.37	0.60
	NO_2	0.03	N/A	0.06	0.03	N/A	0.34	0.03	N/A	0.07
	PM_{10}	0.01	N/A	0.03	0.08	N/A	0.21	0.01	N/A	0.04
	$PM_{2.5}$	0.01	0.04	0.02	0.07	0.13	0.17	0.01	0.04	0.03

(a) Weighted for traffic volume.
(b) Based on regression for LDV only (see point (c) below).
(c) Multiple regression analysis did not result in a valid emission rate.

Table E-6 Predicted/observed emission factors by vehicle type and direction

Direction	Pollutant	LDV (predicted/observed)		HDV (predicted/observed)		All traffic (predicted/observed)[a]	
		PIARC	NSW EPA	PIARC	NSW EPA	PIARC	NSW EPA
Eastbound	CO	1.9	3.1	0.2	0.3	1.7	2.8
	NO_X	1.9	4.0	1.0	0.8	1.5	2.3
	NO_2	N/A	2.4	N/A	2.3	N/A	2.1
	PM_{10}	N/A	3.0	N/A	0.9	N/A	1.9
	$PM_{2.5}$	5.2	3.2	1.1	0.8	3.0	1.9
Westbound	CO	N/A	N/A	N/A	N/A	1.5	1.9
	NO_X	2.0	3.8	2.6	2.6	2.0	3.2
	NO_2	N/A	2.2	N/A	11.6	N/A	2.2
	PM_{10}	N/A	3.9	N/A	2.7	N/A	3.3
	$PM_{2.5}$	5.8	3.3	2.0	2.6	4.4	2.9

(a) Weighted for traffic volume.

It has already been observed that both the PIARC and EPA models overestimated emissions in the Lane Cove Tunnel. It was noted by Boulter and Manansala (2014) that this is due in large part to the use of conservative gradient scaling factors. These additional results show that:

- For LDVs the predicted emissions were higher than the observed emissions in both the eastbound and westbound tunnels, except for NO_2 in the westbound tunnel for which the values predicted using the PIARC model and the observed values were the same.
- For HDVs, emissions of CO, NO_X, PM_{10} and $PM_{2.5}$ in the eastbound tunnel were underestimated by the models, whereas emissions of NO_2 were overestimated. In the westbound tunnel the predicted emissions were either equal to or higher than the observed emissions.

E.3.2.4 Primary NO_2 emissions

Inside a road tunnel most of the NO_2 in the air is primary in origin; it is emitted directly from vehicle exhaust pipes rather than being formed in the tunnel atmosphere. Whilst it is possible that certain reactions could lead to the formation of NO_2 in longer tunnels, the NO_2/NO_X proportion in the air from the ventilation outlets of most tunnels ought to provide a reliable indication of the overall average NO_2/NO_X proportion in vehicle exhaust (Boulter et al., 2007). The measurements from the Lane Cove Tunnel ventilation outlets provided useful information on primary NO_2 emissions from the vehicles in the tunnel, and the observed values of *f*-NO_2 calculated from the MLR analysis are given in Table E-7. The corresponding values for the NSW EPA model are also shown.

The average measured values of *f*-NO_2 for all vehicles were 13 per cent in the eastbound tunnel and 17 per cent in the westbound tunnel. The models were broadly in agreement with the measurements on average, giving a value of around 12 per cent (the same method for calculating NO_2 was used in both models). However, the models did not reproduce the observed difference in *f*-NO_2 between LDVs and HDVs. For the former, *f*-NO_2 was underestimated, whereas for the latter it was overestimated.

Table E-7 Primary NO_2 values

Vehicle type	Model	Eastbound			Westbound		
		NO_X (g/vkm)	NO_2 (g/vkm)	*f*-NO_2	NO_X (g/vkm)	NO_2 (g/vkm)	*f*-NO_2
LDV	Observed	0.29	0.06	**19%**	0.13	0.03	**19%**
	NSW EPA	1.18	0.14	**12%**	0.51	0.06	**11%**
HDV	Observed	8.42	0.37	**4%**	1.07	0.03	**3%**
	NSW EPA	6.93	0.85	**12%**	2.78	0.34	**12%**
All Vehicles[(a)]	Observed	0.61	0.08	**13%**	0.18	0.03	**17%**
	NSW EPA	1.39	0.16	**12%**	0.60	0.07	**11%**

(a) Weighted for traffic volume.

As noted in Appendix B, a recent update of the evidence for vehicles on the road in Sydney was provided by Boulter and Bennett (2015). Although a range of different data sets and methods were used, the level of agreement in both the *f*-NO_2 values and the trend was found to be good. The evidence suggested that there has been a gradual increase in *f*-NO_2 in recent years for highways, from less than 10 per cent before 2008 to around 15 per cent in 2014. It was also concluded that the approach of incorporating the European values for *f*-NO_2 in models for Sydney produced a satisfactory agreement with measurements.

Appendix F - Existing air quality and background concentrations

F.1 Introduction

When predicting the impact of any new or modified source of air pollution, it is necessary to take into account the way in which the emissions from the source will interact with existing pollutant levels. Defining these existing levels and the interactions can be challenging, especially in a large urban area such as Sydney where there is a complex mix of sources. Pollutant concentrations can fluctuate a great deal on short time scales, and substantial concentration gradients can occur in the vicinity of sources such as busy roads. Meteorological conditions and local topography are also very important; cold nights and clear skies can create temperature inversions which trap air pollution near ground level, and local topography can increase the frequency and strength of these inversions. In the case of particulate matter, dust storms, natural bush fires and planned burning activities are often associated with the highest concentrations (SEC, 2011).

This Appendix provides the results of a thorough analysis of the air quality monitoring data that were available for the study area. The analysis was based on measurements conducted during the 11-year period between 2004 and 2014, the principal aim being to **establish background pollutant concentrations** for use in the New M5 assessment, taking into account the factors identified above. The analysis dealt with temporal and spatial patterns in the data, and contributed to the general understanding of air quality in Sydney.

This approach was in accordance with the NSW Approved Methods, which states:

> 'Including background concentrations in the assessment enables the total impact of the proposal to be assessed. The background concentrations of air pollutants are ideally obtained from ambient monitoring data collected at [or as close as possible to] the proposed site.' (NSW DEC, 2005)

Background concentrations were determined for the following pollutants and metrics, as these are especially relevant to road transport:

- CO – one-hour mean
- CO – rolling 8-hour mean
- NO_X – annual mean
- NO_X – one-hour mean
- PM_{10} – annual mean
- PM_{10} – 24-hour mean
- $PM_{2.5}$ – annual mean
- $PM_{2.5}$ – 24-hour mean

Background concentrations of NO_2 and O_3 were also determined. These were used to test the NO_X-to-NO_2 conversion methods developed in Appendix G.

For air toxics the NSW Approved Methods do not require the consideration of background concentrations. However, some data have been presented to demonstrate that prevailing concentrations in Sydney are very low.

The approach that was used was similar to that developed to support the EIS for the WestConnex M4 East project (WDA, 2015), with adaptations to better suit the conditions for the New M5.

F.2 Monitoring sites

The siting and classification of air quality monitoring stations is governed, as far as practicable, by the requirements of Australian Standard AS/NZS 3580.1.1:2007 - Methods for sampling and analysis of ambient air - Guide to siting air monitoring equipment. The Standard recognises that air quality is monitored for different purposes, and for convenience it classifies monitoring sites as follows based on functional requirements:

- Peak sites. These are located where the highest concentrations and exposures are expected to occur (such as near busy roads or industrial sources).

- Neighbourhood sites. These are located in areas which have a broadly uniform land use (e.g. residential or commercial zones), and can be used to characterise general trends in air quality.
- Background sites. These sites are located in urban or rural areas to provide information on air quality away from specific sources of pollutants such as major roads or industry.

The Standard also recognises that, in practice, a given site may serve more than one function.

Considerations when siting a monitoring station include the possibility of restricted airflow caused by vicinity to buildings, trees, walls, *etc.*, and chemical interference due to, for example, local industrial emissions.

Air pollutants and meteorological parameters – such as temperature, wind speed and wind direction – are usually measured on an automatic and continuous basis, and such monitoring is conducted at several locations across Sydney. To support the New M5 assessment, data were obtained for the monitoring sites and periods listed in Table F-1. The locations of these sites are shown in Figure F-1.

Until relatively recently, almost all of the air quality monitoring in Sydney has focussed on background locations within urban agglomerations but away from specific sources such as major roads. The monitoring sites in Sydney that are operated by NSW OEH are located in such environments, and have provided a long and vital record of regional air quality. The closest active OEH monitoring sites to the New M5 project were those at Chullora, Earlwood, Randwick and Rozelle. These sites were between around three and six kilometres from the project (above surface components). The OEH sites at Lindfield, Liverpool and Prospect were further away (between around 15 and 30 kilometres from the project), but were still considered important in terms of characterising air quality in the wider Sydney region.

RMS has established several long-term monitoring stations in response to community concerns relating to the ventilation outlet of the M5 East tunnel, and to monitor operational compliance of the tunnel with ambient air quality standards. Four of the RMS sites (CBMS, T1, U1, X1) were in the vicinity of the ventilation outlet. Sites U1 and X1 were located on a ridge to the north of the outlet, in the region of the predicted maximum impact. However, the impacts of the outlet at the monitoring sites are very small in practice, and these could effectively be considered as urban background sites. Two RMS sites (F1 and M1) were much closer to busy roads near the M5 East tunnel portals.

Consideration was also given to shorter-term data from other RMS air quality monitoring stations. Several monitoring sites were established for the NorthConnex project (AECOM, 2014a), with data being available from December 2013 to January 2015. Data were also available from an additional RMS roadside site ('Aristocrat'), located near the junction of Epping Road and Longueville Road. The Aristocrat site was only operational between 2008 and 2009, but given the low number of roadside monitoring sites in Sydney the data were valuable to the analysis.

WestConnex Delivery Authority (WDA) has established five new monitoring stations in the M4 East area (WDA, 2015) and seven new monitoring stations in the New M5 area to support the development and assessment of the respective projects. WDA commissioned Pacific Environment to operate and maintain the monitoring network. The New M5 network includes three monitoring stations at urban background sites and four stations that are located to characterise air quality near busy roads.

NB: The New M5 monitoring stations became operational in July 2015. However, the time period covered by the project-specific monitoring sites was too short for them to be included in the air quality assessment. Nevertheless, the locations and descriptions of the project-specific monitoring sites have been included here for completeness.

For the purpose of the analysis the air quality monitoring data were separated according to site type. Given the main purpose of the work described in this Chapter (i.e. to determine background concentrations for the project assessment), the emphasis was placed on the background monitoring sites. However, the air quality data from the monitoring sites near roads have been used for the development of empirical NO_X-to-NO_2 conversion methods (Appendix G) and/or dispersion model evaluation (see Appendix J). For convenience, all the monitoring sites which have been considered or used in the assessment are summarised in this single location.

Table F-1 Automatic, continuous monitoring sites considered in the assessment

Organisation	Project	Site name	Location	Site type	Easting	Northing	Period covered
OEH	N/A	Chullora	Southern Sydney TAFE - Worth Street	Urban background	319248	6247889	2004-2014
		Earlwood	Beaman Park	Urban background	327568	6245394	2004-2014
		Lindfield	Bradfield Road	Urban background	328711	6260391	2004-2014
		Liverpool	Rose Street	Urban background	306440	6243322	2004-2014
		Prospect	William Lawson Park	Urban background	306745	6258646	2004-2014
		Randwick	Randwick Barracks	Urban background	337511	6243844	2004-2014
		Rozelle	Rozelle Hospital	Urban background	330033	6251201	2004-2014
RMS	M5 East tunnel	M5E: CBMS	Gipps Street, Bardwell Valley	Urban background[(a)]	327706	6243494	2008-2013
		M5E: T1	Thompson Street, Turrella	Urban background[(a)]	328821	6244176	2008-2013
		M5E: U1	Jackson Place, Undercliffe	Urban background[(a)]	328254	6244455	2008-2013
		M5E: X1	Wavell Parade, Earlwood	Urban background[(a)]	328091	6244425	2008-2013
		M5E: F1	Flat Rock Rd, Kingsgrove (M5 East Freeway)	Peak (roadside)[(b)]	325204	6243336	2008-2013
		M5E: M1	M5 East tunnel portal	Peak (roadside)[(b)]	329258	6243280	2008-2013
	NorthConnex	NC-01	Headen Sports Park	Urban background	322016	6266783	Dec 2013 to Jan 2015
		NC-02	Rainbow Farm Reserve	Urban background	318890	6262905	Dec 2013 to Jan 2015
		NC-03	James Park	Urban background	325161	6269429	Dec 2013 to Jan 2015
		NC-04	Observatory Park	Peak (roadside)	320644	6264948	Dec 2013 to Jan 2015
		NC-05	Brickpit Park	Peak (roadside)	318896	6262651	Dec 2013 to Jan 2015
	Lane Cove Tunnel	Aristocrat	Longueville Road / Epping Road	Peak (roadside)	330662	6257119	Oct 2008 to Nov 2009
WDA	WestConnex M4 East	M4E: 01	Wattle Street, Haberfield	Peak (roadside)	327558	6250221	Aug 2014 onwards
		M4E: 02	Edward Street, Concord	Peak (near-road)[(c)]	323765	6251147	Sep 2014 onwards
		M4E: 03	Bill Boyce Reserve, Homebush	Peak (near-road)[(c)]	322467	6251603	Sep 2014 onwards
		M4E: 04	Concord Oval, Concord	Peak (roadside)	325022	6250748	Nov 2014 onwards
		M4E: 05	St Lukes Park, Concord	Urban background	325190	6251155	Nov 2014 onwards
	WestConnex New M5	New M5: 01	St Peters Public School, Church St, St Peters	Urban Background	331334	6246008	Aug 2015 onwards
		New M5: 02	Princes Highway, St Peters	Peak (roadside)	331660	6246057	Jul 2015 onwards
		New M5: 03	West Botany St, Arncliffe	Peak (roadside)	329182	6243270	Jul 2015 onwards
		New M5: 04	Bestic St, Rockdale	Urban Background	329175	6241749	Jul 2015 onwards
		New M5: 05	Bexley Rd, Kingsgrove	Peak (roadside)	325364	6243468	Jul 2015 onwards
		New M5: 06	Beverley Hills Park, Beverley Hills	Urban Background	323298	6242293	Jul 2015 onwards
		New M5: 07	Canal Rd, St Peters	Peak (roadside / industrial)	331513	6245415	Jul 2015 onwards

(a) These sites were established to characterise air quality in the vicinity of the M5 East tunnel ventilation outlets, but are effectively at urban background locations.

(b) These sites were established to characterise air quality in the vicinity of the M5 East tunnel portals.

(c) Due to practical constraints at this location, the monitoring site is some distance from the closest major road (M4 motorway). Nevertheless, the monitoring station should adequately characterise exposure to air pollution at nearby properties.

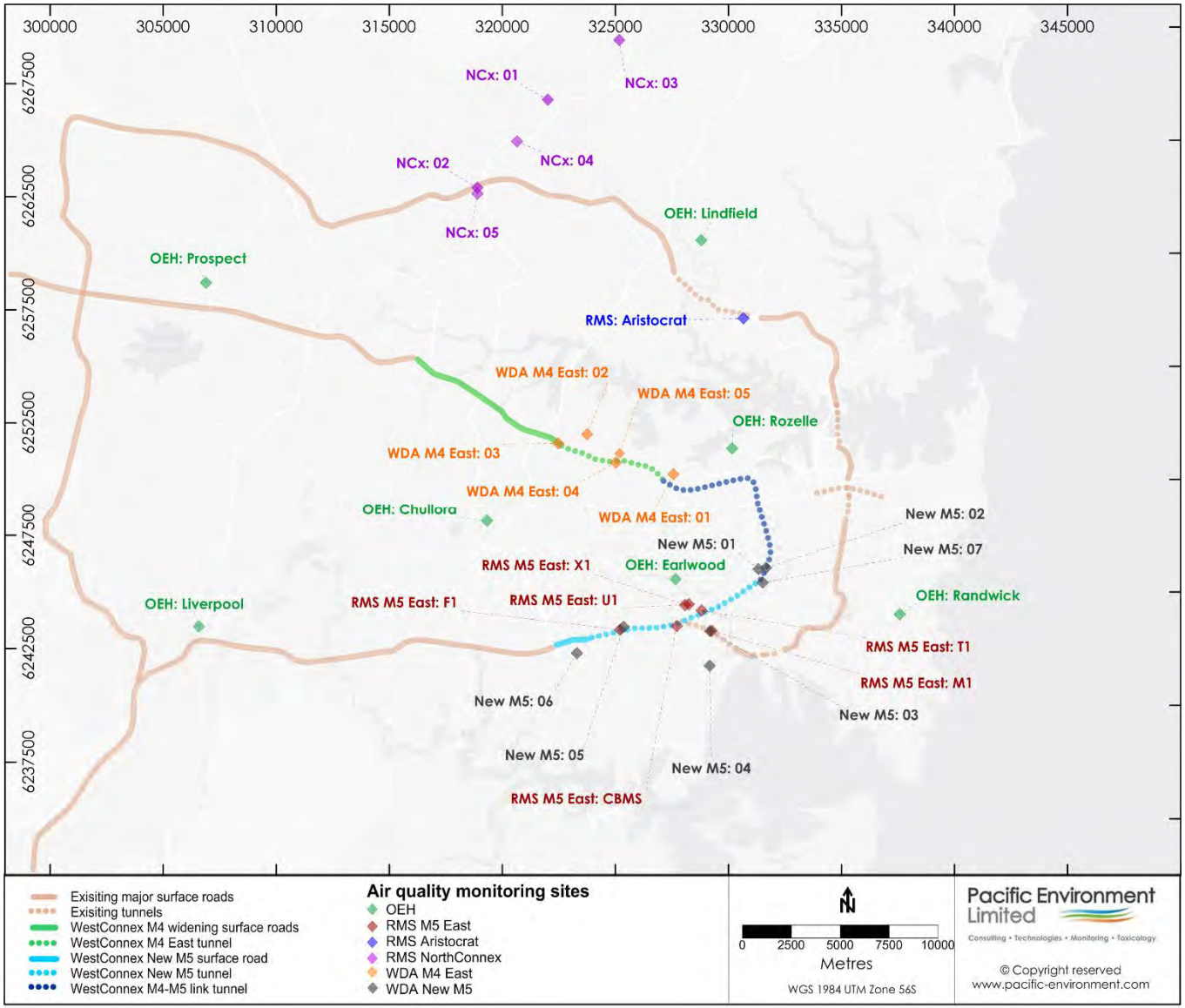


Figure F-1 Locations of air quality monitoring sites in relation to WestConnex

F.3 Measured parameters and methods

The parameters measured at each site are given in Table F-2. The coverage of pollutants was variable. CO was measured at most sites, and NO, NO_2 and NO_X were measured at all sites. Ozone was measured at the OEH, WDA and RMS NorthConnex sites, but not at the RMS M5E and Aristocrat sites. PM_{10} was measured at all sites but one[1], but $PM_{2.5}$ was measured at fewer sites, and there was only a longer-term record of $PM_{2.5}$ at three OEH sites. There were no multi-year data for hydrocarbons.

Table F-2 Parameters by monitoring station (roadside sites are shown by shading)

Monitoring station		Pollutants					Meteorological parameters			
		CO	NO, NO_2, NO_X	O_3	PM_{10}	$PM_{2.5}$	WS, WD[(a)]	Temp.	Humidity	Solar radiation
OEH	Chullora	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Earlwood	-	✓	✓	✓	✓	✓	✓	✓	-
	Lindfield	-	✓	✓	✓	-	✓	✓	✓	-
	Liverpool	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Prospect	✓	✓	✓	✓	-	✓	✓	✓	✓
	Randwick	-	✓	✓	✓	-	✓	✓	✓	-
	Rozelle	✓	✓	✓	✓	-	✓	✓	✓	✓
RMS	M5E: CBMS	✓	✓	-	✓	-	✓	✓	✓	✓
	M5E: T1	✓	✓	-	✓	-	✓	✓	✓	✓
	M5E: U1	✓	✓	-	✓	-	✓	✓	✓	✓
	M5E: X1	✓	✓	-	✓	-	✓	✓	✓	✓
	M5E: F1	✓	✓	-	✓	-	✓	✓	✓	✓
	M5E: M1	✓	✓	-	✓	-	✓	✓	✓	✓
	NC-01	✓	✓	✓	✓	✓	✓	✓	✓	✓
	NC-02	✓	✓	✓	✓	✓	✓	✓	✓	✓
	NC-03	✓	✓	✓	✓	✓	✓	✓	✓	✓
	NC-04	✓	✓	✓	✓	✓	✓	✓	✓	✓
	NC-05	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Aristocrat	✓	✓	-	-	-	✓	✓	✓	✓
WDA	M4E: 01	✓	✓	✓	✓	✓	✓	✓	✓	✓
	M4E: 02	✓	✓	✓	✓	✓	✓	✓	✓	✓
	M4E: 03	✓	✓	✓	✓	✓	✓	✓	✓	✓
	M4E: 04	✓	✓	✓	✓	✓	✓	✓	✓	✓
	M4E: 05	✓	✓	✓	✓	✓	✓	✓	✓	✓
	New M5: 01	✓	✓	✓	✓	✓	✓	✓	✓	✓
	New M5: 02	✓	✓	✓	✓	✓	✓	✓	✓	✓
	New M5: 03	✓	✓	✓	✓	✓	✓	✓	✓	✓
	New M5: 04	✓	✓	✓	✓	✓	✓	✓	✓	✓
	New M5: 05	✓	✓	✓	✓	✓	✓	✓	✓	✓
	New M5: 06	✓	✓	✓	✓	✓	✓	✓	✓	✓
	New M5: 07	✓	✓	✓	✓	✓	✓	✓	✓	✓

(a) WS = wind speed; WD = wind direction

[1] PM_{10} was actually monitored at the Aristocrat site, but the record was relatively short and incomplete.

The pollutant measurements at each site were conducted in accordance with the relevant Australian Standards[2]. The methods used were, in general terms:

- CO - Gas filter correlation infrared (GFC-IR).
- $NO/NO_2/NO_X$ - chemiluminescence detection (CLD).
- O_3 - Non-dispersive ultra-violet (NDUV) spectroscopy.
- $PM_{10}/PM_{2.5}$ - Tapered-element oscillating microbalance (TEOM) and/or beta-attenuation monitor (BAM).

In the case of PM it is well documented that the values obtained are sensitive to the measurement method used. The data used in this analysis were collected using different instruments, and this clearly introduces some uncertainty in the results. For example, for $PM_{2.5}$ TEOM monitors were used for all OEH sites up to early 2012. A combination of TEOM and BAMs were used during 2012 when a decision was made to replace the continuous TEOM $PM_{2.5}$ monitors with the USEPA equivalent-method BAM. However, for traceability all data were used as received.

F.4 Data processing and analysis

The monitoring data were used in the form provided, with the following exceptions:

- For gases, any volumetric concentrations (*e.g.* ppm or ppb) were converted to mass units (*e.g.* mg/m^3 or $\mu g/m^3$). For consistency, an ambient pressure of 1 atmosphere and a temperature of 0^oC were assumed throughout for the conversions. In the Approved Methods, for some pollutants a conversion temperature of 25^oC is used, which gives slightly lower mass concentrations. The use of 0^oC is therefore slightly conservative.
- For PM_{10} and $PM_{2.5}$, the data on days with bush fires and/or dust storms were removed, as the inclusion of the high concentrations on some of these days would have resulted in an inaccurate picture of underlying trends. The affected days were identified by OEH.

All data were handled using a consistent time base of one-hour. The data were then further averaged, where appropriate, according to the time periods in the Approved Methods. Values were only deemed to be valid where there was a sufficient amount of data; a period was taken to have sufficient data where the data capture rate was greater than 75 per cent[3].

F.5 Long-term trends at background sites

In this part of the analysis the long-term trends in air pollution at background monitoring sites in Sydney were investigated. Only the OEH and Roads and Maritime monitoring sites with a multi-year record were considered, and the following aspects were examined:

- Trends in annual mean concentration.
- Trends in monthly mean concentration, to identify any seasonal patterns.
- Trends in other relevant short-term criteria specified in the Approved Methods.
- Exceedances of the air quality criteria in the Approved Methods.

[2] Full details of the methods and procedures used at the WDA monitoring sites are presented in monthly monitoring reports for the M4 East network, and these are available on request from WDA.

[3] Clause 18 (5) of the AAQ NEPM specifies that the annual report for a pollutant must include the percentage of data available in the reporting period. An average concentration can be valid only if it is based on at least 75 per cent of the expected samples in the averaging period. The 75 per cent data availability criterion is specified as an absolute minimum requirement for data completeness (PRC, 2001).

F.5.1 Carbon monoxide

F.5.1.1 Annual mean concentration

In NSW there is no air quality criterion for the annual mean CO concentration, but the trends and patterns are still of interest. The annual mean CO concentrations at the OEH and RMS monitoring sites are shown in Figure F-2, and the corresponding statistics are provided in Table F-3. The Mann–Kendall nonparametric test was used to determine the statistical significance of trends at the 95 per cent confidence level.

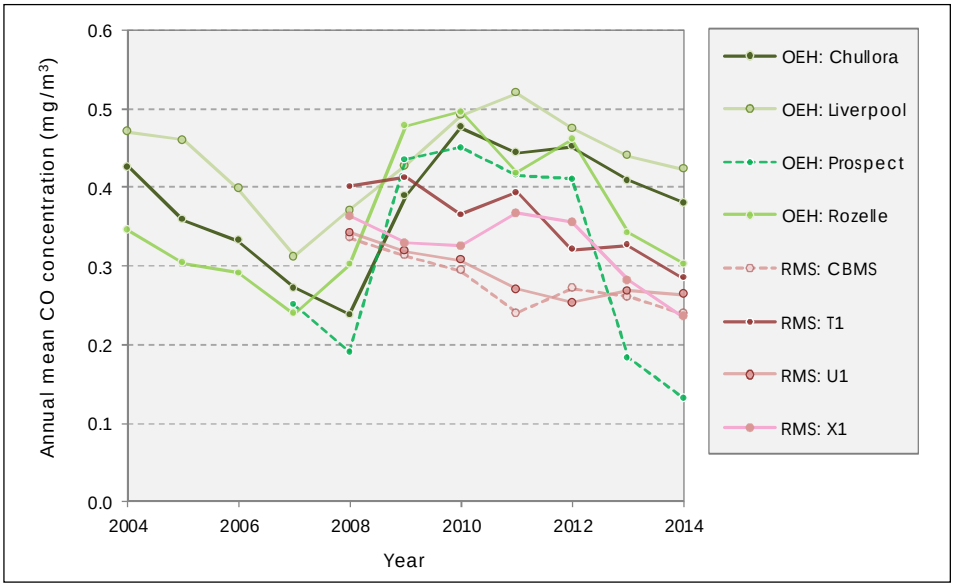


Figure F-2 Trend in annual mean CO concentration

Table F-3 Annual mean CO concentration at OEH and RMS background sites

Year	Annual mean concentration (mg/m^3)[(a)]										
	OEH Chullora	OEH Earlwood	OEH Lindfield	OEH Liverpool	OEH Prospect	OEH Randwick	OEH Rozelle	RMS CBMS	RMS T1	RMS U1	RMS X1
2004	0.43	-	-	0.47	-	-	0.34	-	-	-	-
2005	0.36	-	-	0.46	-	-	0.30	-	-	-	-
2006	0.33	-	-	0.40	-	-	0.29	-	-	-	-
2007	0.27	-	-	0.31	0.25	-	0.24	-	-	-	-
2008	0.24	-	-	0.37	0.19	-	0.30	0.34	0.40	0.34	0.36
2009	0.39	-	-	0.43	0.44	-	0.48	0.31	0.41	0.32	0.33
2010	0.48	-	-	0.49	0.45	-	0.50	0.29	0.37	0.31	0.33
2011	0.44	-	-	0.52	0.42	-	0.42	0.24	0.39	0.27	0.37
2012	0.45	-	-	0.48	0.41	-	0.46	0.27	0.32	0.25	0.36
2013	0.41	-	-	0.44	0.18	-	0.34	0.26	0.33	0.27	0.28
2014	0.38	-	-	0.42	0.13	-	0.30	0.24	0.28	0.26	0.24
Long-term mean	**0.38**	-	-	**0.44**	**0.31**	-	**0.36**	**0.28**	**0.36**	**0.29**	**0.32**
Significance[(c)]	◄►	-	-	◄►	◄►	-	◄►	◄►	◄►	◄►	◄►

(a) Only years with >75 per cent complete data shown
(b) Average of year from October 2008 to September 2009.
(c) ▼ = significantly decreasing, ▲ = significantly increasing, ◄► = no trend

At the OEH sites the annual mean concentration decreased between 2004 and the start of 2008, but then began to increase again during 2008, and continued to do so until around 2010. CO concentrations then decreased again between 2010 and 2014. There was a net overall decrease of

around 10 per cent between 2004 and 2014. A different pattern was apparent in the data from the RMS sites, where there was a more systematic downward trend in concentrations between 2008 and 2013. However, the Mann-Kendall test showed that there was no significant trend in annual mean CO concentration at any of the sites.

The long-term mean concentrations at the RMS sites were within the range of values observed at the OEH sites (around 0.3-0.4 mg/m^3). Whilst CO was not measured at Earlwood, the concentration profiles at the other OEH monitoring stations closest to WestConnex – Chullora and Rozelle were similar, and the long-term average concentrations were almost the same (0.38 and 0.36 mg/m^3 respectively).

By comparison, the long-term mean CO concentrations at the RMS roadside sites (F1 and M1) were 0.54 and 0.45 mg/m^3 respectively.

F.5.1.2 Monthly mean concentration

Monthly mean concentrations provide additional data on seasonal patterns in air pollution. An example of the seasonal variation in CO concentrations at a monitoring site – in this case OEH's Chullora site - is given in Figure F-3. The Figure was produced using the 'smooth trend' function in the Openair[4] software, and the shading around the trend line gives the 95 per cent confidence intervals.

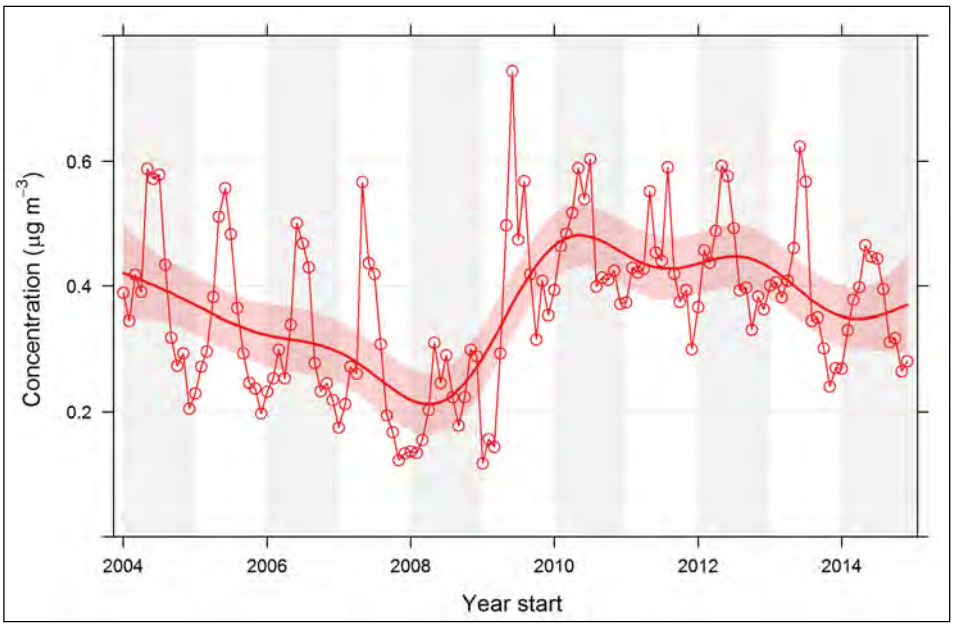


Figure F-3 Monthly mean CO concentration at OEH Chullora monitoring site

There is a strong seasonal influence on CO concentrations, with the values being much higher in winter than in summer. This is commonly observed for CO, and is due to a combination of winter-time factors such as an increase in combustion for heating purposes, elevated 'cold start' emissions from road vehicles, and more frequent and persistent temperature inversions in the atmosphere reducing the effectiveness of dispersion. It was desirable to ensure that such seasonal effects were represented in the assumed background concentrations for the New M5 project.

F.5.1.3 Maximum one-hour mean concentration

The trends in the maximum one-hour mean CO concentration by year are shown in Figure F-4 and Table F-4. All maximum values were well below the air quality criterion of 30 mg/m^3. The patterns at all background sites were broadly similar, with a general downward trend. The trend was statistically significant at two of the OEH sites.

[4] http://www.openair-project.org/Default.aspx

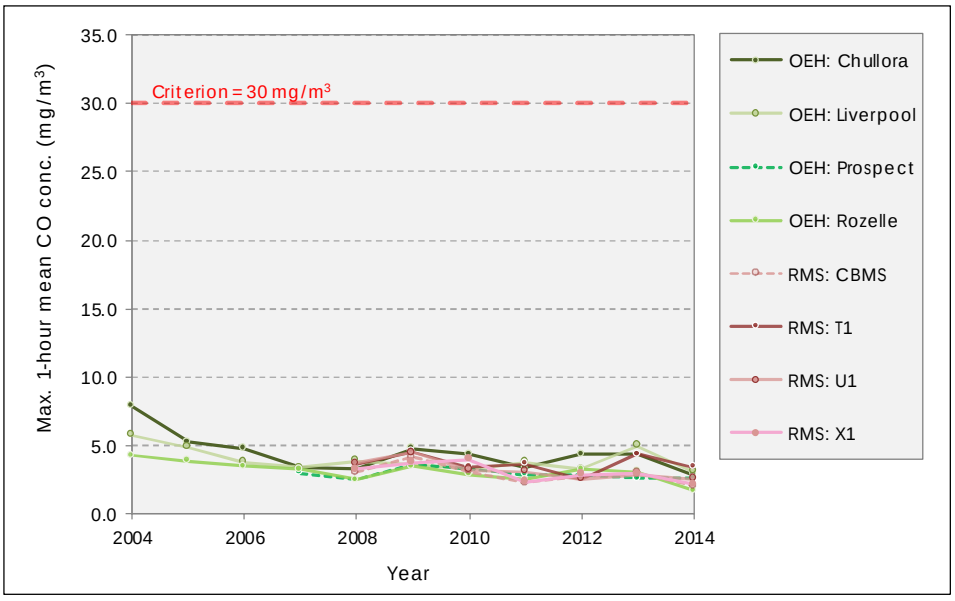


Figure F-4 **Trend in maximum one-hour mean CO concentration**

Table F-4 **Maximum one-hour mean CO concentration at OEH and RMS background sites**

Year	Annual mean concentration (mg/m^3)[(a)]										
	OEH Chullora	OEH Earlwood	OEH Lindfield	OEH Liverpool	OEH Prospect	OEH Randwick	OEH Rozelle	RMS CBMS	RMS T1	RMS U1	RMS X1
2004	7.87	-	-	5.75	-	-	4.25	-	-	-	-
2005	5.25	-	-	4.87	-	-	3.87	-	-	-	-
2006	4.75	-	-	3.75	-	-	3.50	-	-	-	-
2007	3.37	-	-	3.37	3.00	-	3.25	-	-	-	-
2008	3.25	-	-	3.87	2.50	-	2.50	3.03	3.66	3.69	3.30
2009	4.75	-	-	3.62	3.62	-	3.50	4.18	4.55	4.47	3.77
2010	4.37	-	-	3.25	3.25	-	2.87	3.10	3.43	3.24	3.98
2011	3.37	-	-	3.75	2.87	-	2.50	2.29	3.65	3.09	2.33
2012	4.37	-	-	3.25	2.87	-	3.25	2.73	2.57	2.58	2.87
2013	4.37	-	-	5.00	2.62	-	3.12	3.00	4.36	2.89	2.95
2014	2.87	-	-	3.12	2.62	-	1.75	2.06	3.45	2.56	2.15
Long-term mean	4.42	-	-	3.96	2.92	-	3.12	2.91	3.67	3.22	3.05
Significance[(c)]	▼	-	-	◄►	◄►	-	▼	◄►	◄►	◄►	◄►

(a) Only years with >75 per cent complete data shown
(b) Average of year from October 2008 to September 2009.
(c) ▼ = significantly decreasing, ▲ = significantly increasing, ◄► = no trend

F.5.1.4 Maximum rolling 8-hour mean concentration

The trends in the maximum rolling 8-hour mean CO concentration by year are shown in Figure F-5 and Table F-5. All maximum values were well below the air quality criterion of 10 mg/m^3; the long-term averages were between around 2 and 3 mg/m^3. By comparison, the long-term mean values at the RMS roadside sites (F1 and M1) were 3.5 and 2.5 mg/m^3 respectively. The patterns at all background sites were broadly similar; there was a general downward trend, but it was not statistically significant at any site. Whilst there was some spatial variation in CO, it was not systematic, and the between-site variation was small compared with the criterion.

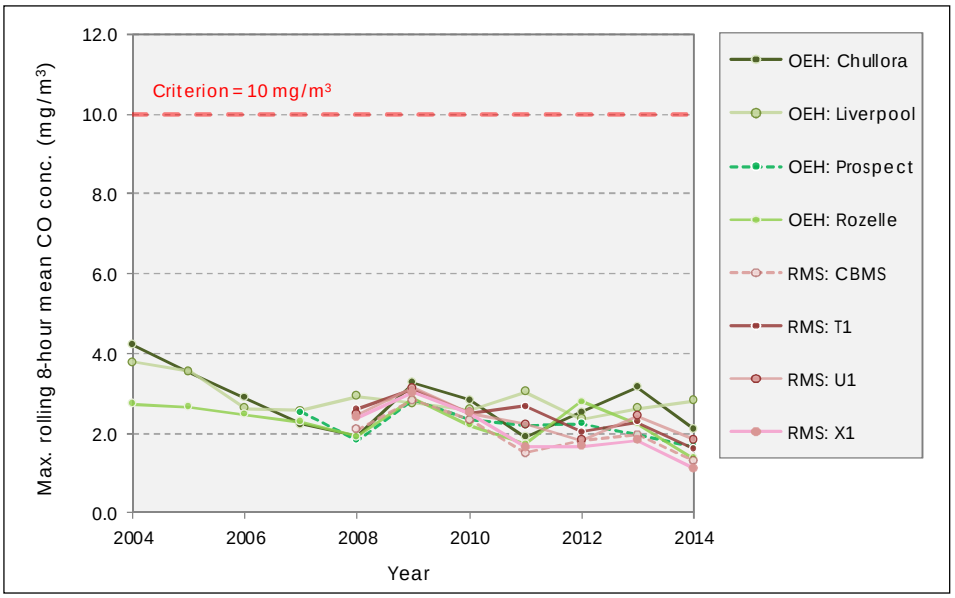


Figure F-5 **Trend in maximum rolling 8-hour mean CO concentration**

Table F-5 **Maximum rolling 8-hour mean CO concentration at OEH and RMS background sites**

Year	Annual mean concentration (mg/m^3)[a]										
	OEH Chullora	OEH Earlwood	OEH Lindfield	OEH Liverpool	OEH Prospect	OEH Randwick	OEH Rozelle	RMS CBMS	RMS T1	RMS U1	RMS X1
2004	4.22	-	-	3.78	-	-	2.73	-	-	-	-
2005	3.53	-	-	3.54	-	-	2.66	-	-	-	-
2006	2.89	-	-	2.62	-	-	2.46	-	-	-	-
2007	2.22	-	-	2.57	2.52	-	2.28	-	-	-	-
2008	1.93	-	-	2.93	1.82	-	1.91	2.08	2.60	2.46	2.38
2009	3.27	-	-	2.75	2.83	-	2.87	2.84	3.10	3.14	3.01
2010	2.82	-	-	2.59	2.35	-	2.21	2.33	2.51	2.50	2.51
2011	1.89	-	-	3.03	2.18	-	1.73	1.51	2.67	2.23	1.66
2012	2.53	-	-	2.36	2.25	-	2.79	1.81	2.02	1.83	1.68
2013	3.14	-	-	2.62	1.96	-	2.23	1.97	2.27	2.43	1.82
2014	2.11	-	-	2.80	1.68	-	1.37	1.31	1.61	1.84	1.13
Long-term mean	**2.78**	-	-	**2.87**	**2.20**	-	**2.30**	**1.98**	**2.40**	**2.35**	**2.03**
Significance[c]	◄►	-	-	◄►	◄►	-	◄►	◄►	◄►	◄►	◄►

(d) Only years with >75 per cent complete data shown
(e) Average of year from October 2008 to September 2009.
(f) ▼ = significantly decreasing, ▲ = significantly increasing, ◄► = no trend

F.5.1.5 Exceedances of air quality criteria

Between 2004 and 2014, there were no exceedances of the rolling 8-hour mean criterion for CO of 10 mg/m^3, or the one-hour criterion of 30 mg/m^3, at any of the background sites included in the analysis.

F.6 Nitrogen oxides

F.6.1.1 Annual mean concentration

The annual mean NO_X concentrations at the monitoring sites are shown in Figure F-6, and the corresponding statistics are provided in Table F-6. There are no air quality criteria for NO_X in NSW, but it is important to understand NO_X in order to characterise NO_2 (see Appendix G).

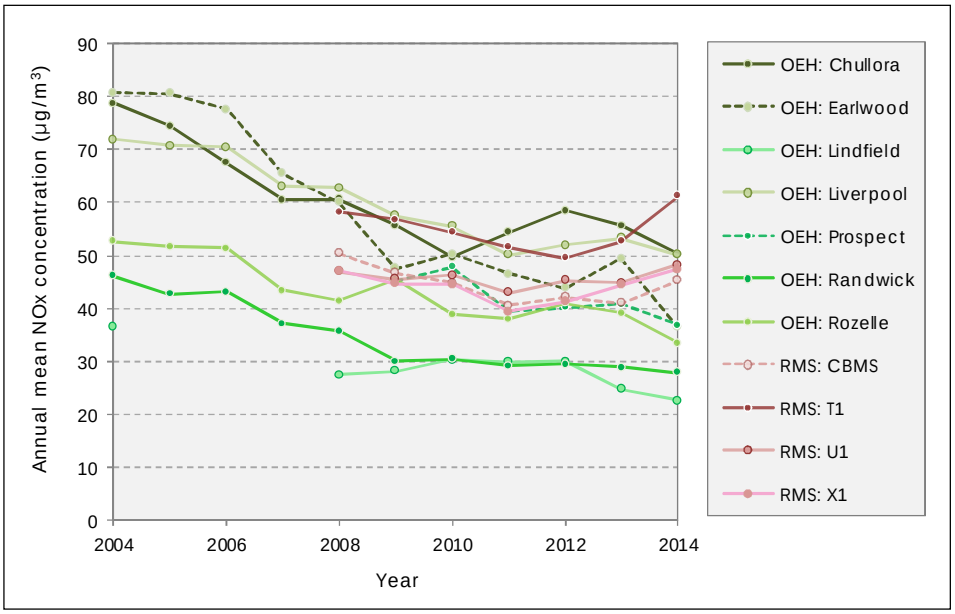


Figure F-6 Trend in annual mean NO_X concentration

Table F-6 Annual mean NO_X concentration at OEH and RMS background sites

Year	Annual mean concentration (µg/m^3)[(a)]										
	OEH Chullora	OEH Earlwood	OEH Lindfield	OEH Liverpool	OEH Prospect	OEH Randwick	OEH Rozelle	RMS CBMS	RMS T1	RMS U1	RMS X1
2004	78.7	80.6	36.6	71.8	-	46.0	52.7	-	-	-	-
2005	74.4	80.5	-	70.7	-	42.7	51.7	-	-	-	-
2006	67.5	77.5	-	70.5	-	43.2	51.3	-	-	-	-
2007	60.4	65.5	-	63.0	-	37.2	43.4	-	-	-	-
2008	60.7	60.0	27.5	62.7	-	35.8	41.5	50.3	58.2	47.0	47.1
2009	55.7	47.5	28.2	57.5	45.1	30.1	45.4	46.7	56.7	45.5	44.6
2010	49.7	50.2	30.4	55.4	47.7	30.4	38.9	44.8	54.3	46.2	44.6
2011	54.3	46.5	29.9	50.0	39.5	29.2	38.0	40.5	51.5	42.9	39.4
2012	58.5	43.8	30.0	52.0	40.1	29.4	40.9	42.2	49.6	45.3	41.3
2013	55.6	49.4	24.8	53.3	40.8	28.9	39.1	41.0	52.7	44.8	44.4
2014	50.2	36.5	22.6	50.1	36.9	27.9	33.5	45.2	61.1	48.2	47.3
Long-term mean	**60.5**	**58.0**	**28.7**	**59.7**	**41.7**	**34.6**	**43.3**	**44.4**	**54.9**	**45.7**	**44.1**
Significance[(c)]	▼	▼	◄►	▼	◄►	▼	▼	◄►	◄►	◄►	◄►

(a) Only years with >75 per cent complete data shown
(b) Average of year from October 2008 to September 2009.
(c) ▼ = significantly decreasing, ▲ = significantly increasing, ◄► = no trend

There was a general tendency for annual mean NO_X concentrations to decrease between 2004 and 2014. At the OEH sites concentrations typically decreased by around 35 per cent overall between 2004 and 2014, although there was a 55 per cent reduction at the Earlwood site. For those OEH sites with a complete record between 2004 and 2014 the Mann-Kendall test showed that the downward trend in concentrations was statistically significant. At the RMS sites, on the other hand, there was no significant trend in concentrations. There is also a suggestion of a levelling-off of concentrations in recent years, although there are different patterns at the various sites.

There were some quite systematic spatial variations in the annual mean NO_X concentration. For example, at the OEH Chullora, Earlwood and Liverpool sites the long-term mean concentration was around 60 µg/m^3, compared with around 42-43 µg/m^3 at Prospect and Rozelle, 35 µg/m^3 at Randwick and 29 µg/m^3 at Lindfield. Concentrations at the RMS T1 site were comparable with those at the OEH sites having relatively high values, with concentrations at the RMS sites CBMS, U1 and X1 being slightly lower. This spatial variation was taken into account in the derivation of background NO_X concentrations for the New M5 project.

Although not shown here, the long-term mean NO_X concentrations at the RMS roadside sites (F1 and M1) were substantially higher than those at the background sites, and very similar at 106 and 107 µg/m^3 respectively. This illustrates the ongoing contribution of NO_X emissions from road transport.

F.6.1.2 Monthly mean concentration

Figure F-7 provides an example of the monthly mean NO_X concentrations, in this case showing the significant downward trend at the Earlwood site. The reduction in concentrations with time can clearly be seen. As with CO there is a strong seasonal influence on NO_X concentrations, with the values being much higher in winter than in summer. This is again likely to be due to an increase in emissions from combustion sources and more frequent temperature inversions in winter. Another contributing factor may be the reaction of NO_2 with the hydroxyl radical (OH) acting as a sink for NO_X. Concentrations of OH are highest in the summer. As before, it was desirable to ensure that such seasonal variations were represented in the assumed background concentrations for the New M5 project.

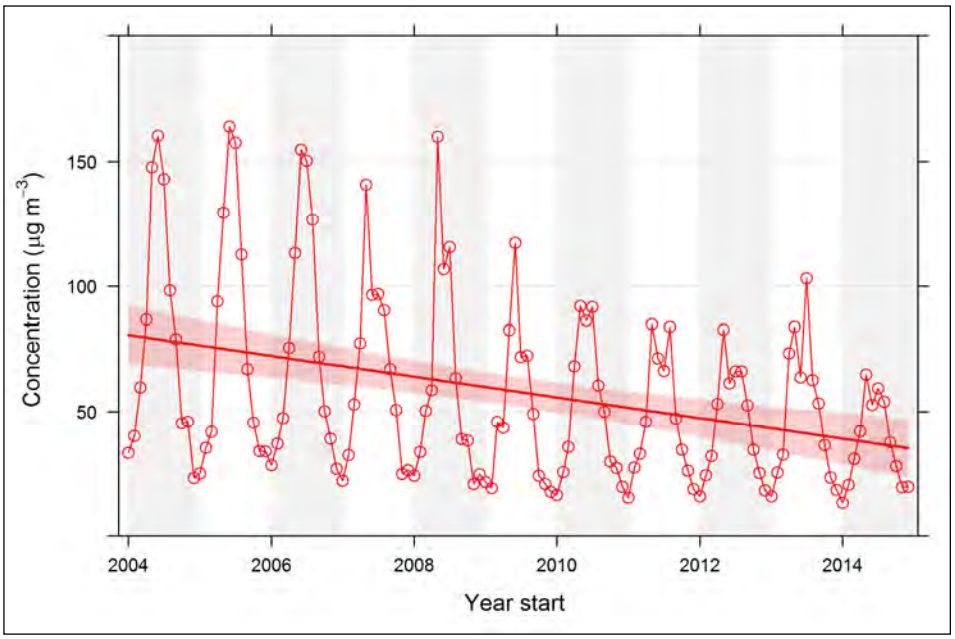


Figure F-7 Monthly mean NOx concentration at OEH Earlwood monitoring site

F.6.1.3 Maximum one-hour mean concentration

The long-term trends in the maximum one-hour mean NO_X concentration are shown in Figure F-8**.** Again, there are no air quality criteria for NO_X, and these are largely of interest in relation to the one-hour criterion for NO_2. As with the annual mean concentration, there has been a general downward trend in peak concentrations.

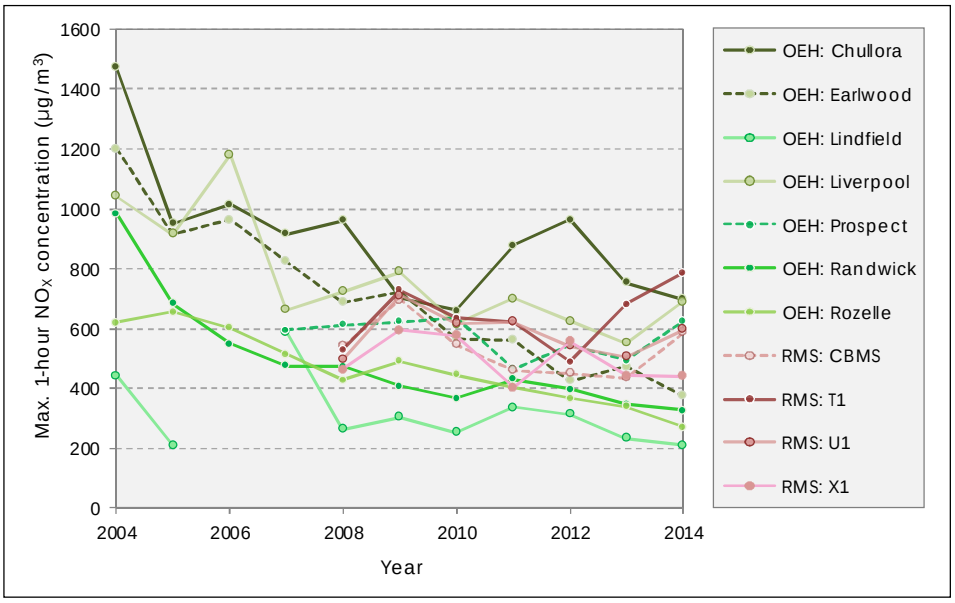


Figure F-8 Trend in maximum one-hour mean NO_X concentration

For comparison, the maximum one-hour mean NO_X concentrations at the RMS roadside sites (F1 and M1) in 2014 were 750 and 650 µg/m^3 respectively. These values are close to the upper end of the range of values for the background sites, but actually lower than the value for RMS site T1. It may be the case that under certain meteorological conditions the background sites are affected by NO_X emissions from busy roads well away from the sites.

F.6.2 Nitrogen dioxide

F.6.2.1 Annual mean concentration

The long-term trends in annual mean NO_2 concentrations are shown in Figure F-9, and the corresponding statistics are provided in Table F-7. The concentrations at all sites were well below the NSW air quality assessment criterion of 62 µg/m^3.

The NO_2 concentrations at the OEH sites exhibited a systematic downward trend - with a reduction of between around 20 per cent and 40 per cent depending on the site - and one that was statistically significant at four of the sites. However, in recent years the concentrations at some sites appear to have stabilised. At the RMS background sites there was no significant downward trend.

As with NO_X, there was some spatial variation in NO_2 concentrations, but the pattern across the monitoring sites was not quite the same. Nevertheless, concentrations were again generally highest at the Chullora site and lowest at Lindfield and Randwick.

The long-term average NO_2 concentrations at the RMS roadside sites (F1 and M1) were 34 and 37 µg/m^3 respectively, 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.

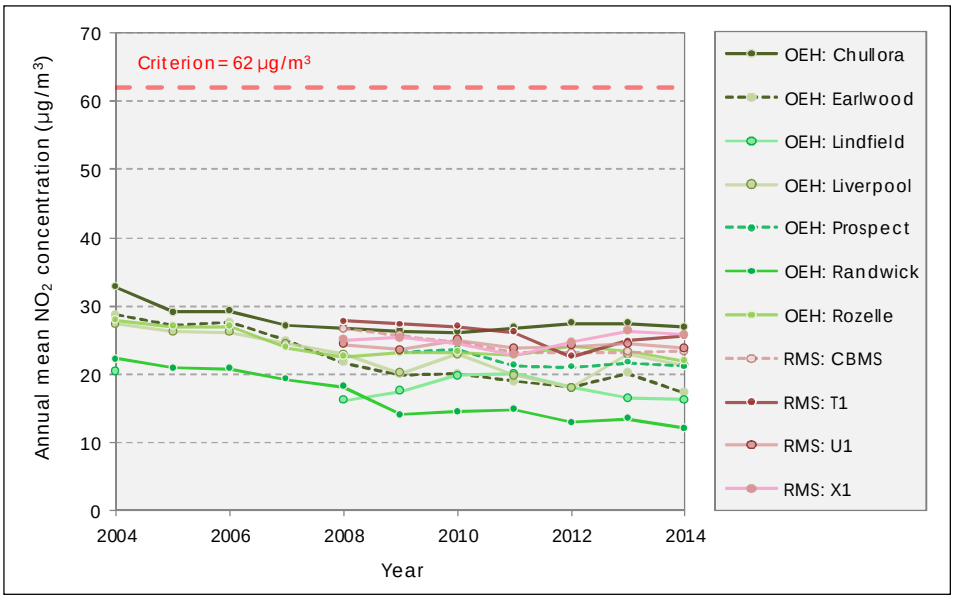


Figure F-9 Trend in annual mean NO_2 concentration

Table F-7 Annual mean NO_2 concentration at OEH and RMS background sites

Year	Annual mean concentration (µg/m³)[a]										
	OEH Chullora	OEH Earlwood	OEH Lindfield	OEH Liverpool	OEH Prospect	OEH Randwick	OEH Rozelle	RMS CBMS	RMS T1	RMS U1	RMS X1
2004	32.8	28.7	20.4	27.4	-	22.2	27.9	-	-	-	-
2005	29.1	27.1	-	26.2	-	20.9	27.0	-	-	-	-
2006	29.2	27.6	-	26.1	-	20.8	27.0	-	-	-	-
2007	27.1	24.9	-	24.5	-	19.2	23.9	-	-	-	-
2008	26.7	21.7	16.1	22.9	-	18.1	22.6	26.7	27.7	24.3	25.0
2009	26.3	19.9	17.4	20.1	23.1	14.1	23.1	25.7	27.4	23.5	25.4
2010	26.2	20.1	19.8	22.9	23.7	14.6	23.2	24.8	27.1	25.1	24.5
2011	26.8	18.9	20.0	19.9	21.3	14.8	22.9	23.1	26.1	23.8	22.8
2012	27.4	18.1	18.0	18.1	21.1	13.0	24.0	23.1	22.5	24.2	24.7
2013	27.5	20.2	16.5	22.9	21.7	13.5	23.4	23.2	25.0	24.5	26.3
2014	26.9	17.3	16.3	21.3	21.1	12.1	21.9	23.4	25.5	23.8	25.8
Long-term mean	**27.8**	**22.2**	**18.1**	**22.9**	**22.0**	**16.7**	**24.3**	**24.3**	**25.9**	**24.2**	**24.9**
Significance[c]	◄►	▼	◄►	▼	◄►	▼	▼	◄►	◄►	◄►	◄►

(a) Only years with >75 per cent complete data shown
(b) Average of year from October 2008 to September 2009.
(c) ▼ = significantly decreasing, ▲ = significantly increasing, ◄► = no trend

F.6.2.2 Monthly mean concentration

The seasonal variation in NO_X was mirrored by that for NO_2. This is illustrated in the data for Earlwood in Figure F-10. This Figure also shows more clearly that NO_2 concentrations at this site have stabilised in recent years.

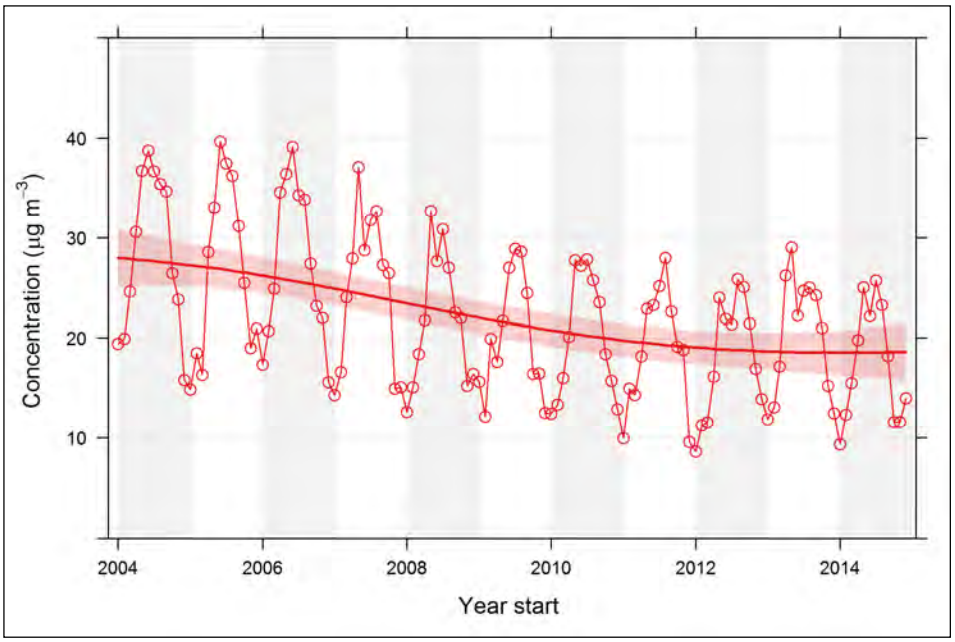


Figure F-10 Monthly mean NO_2 concentration at OEH Earlwood monitoring site

F.6.2.3 Maximum one-hour mean concentration

The trends in the maximum one-hour mean NO_2 concentration by year are given in Figure F-11. The within-site variation for this metric is similar to the between site variation, but when viewed overall the values have been quite stable with time (varying around 100 µg/m^3), and are all below the NSW air quality assessment criterion of 246 µg/m^3. The maximum one-hour mean NO_2 concentrations at the RMS roadside sites (F1 and M1) in 2014 were 115 and 122 µg/m^3 respectively. As with NO_X, these values are on a par with the higher values for the background sites.

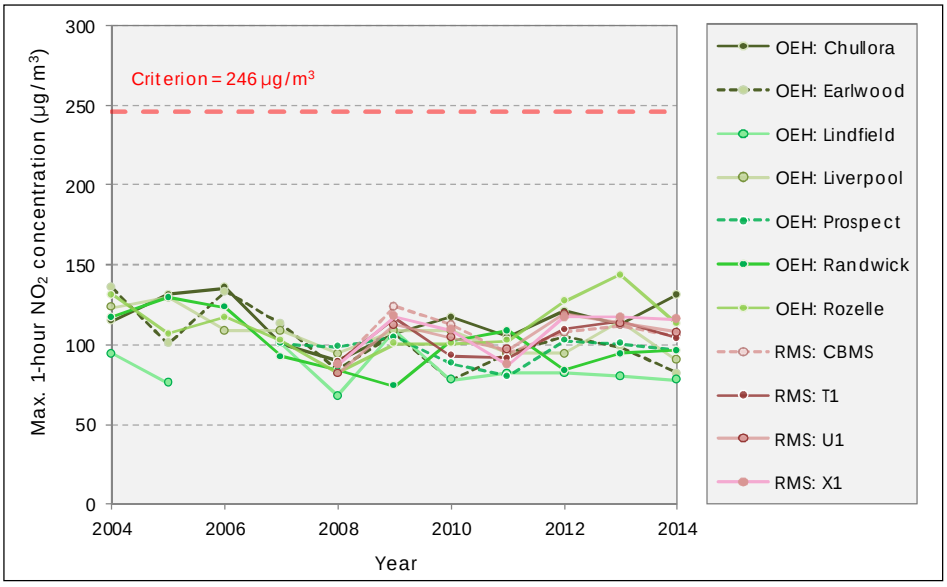


Figure F-11 Trend in maximum one-hour mean NO_2 concentration

F.6.2.4 Exceedances of air quality criteria

There were no exceedances of the annual mean criterion for NO_2 of 62 µg/m^3 (Table F-7). In fact, annual mean concentrations were well below the criterion at all sites and in all years. There were also no exceedances of the one-hour mean criterion for NO_2 (246 µg/m^3).

F.6.3 Ozone

F.6.3.1 Annual mean concentration

Annual mean ozone concentrations at the OEH sites - presented in Figure F-12 and Table F-8 - were relatively stable between 2004 and 2014, being typically around 30-35 µg/m^3. The main exception was the Randwick site, where the typical annual mean concentration was substantially higher, at closer to 40 µg/m^3. This is likely to be due to the coastal nature of Randwick, with easterly winds having low concentrations of ozone-scavenging species, notably NO_X (see Figure F-6).

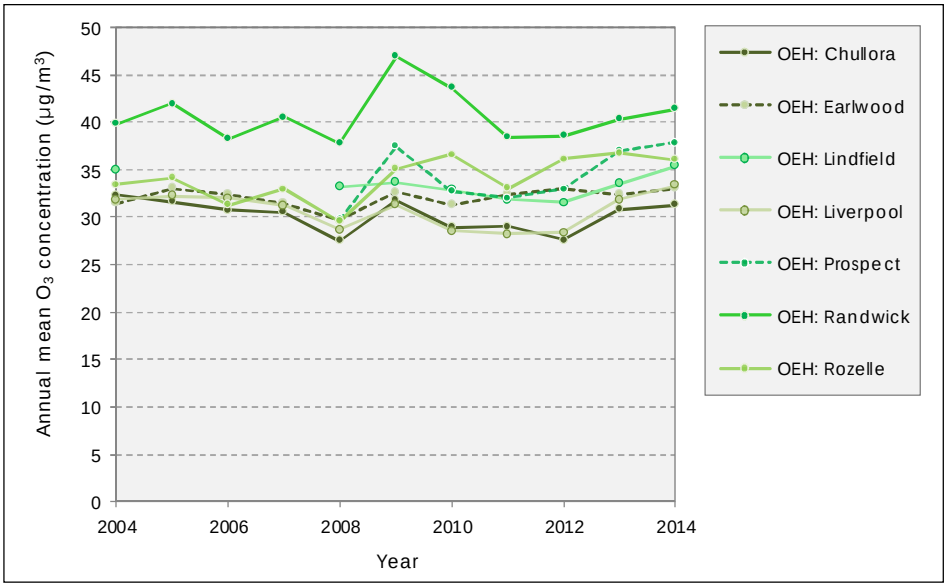


Figure F-12 Trend in annual mean O_3 concentration

Table F-8 Annual mean O_3 concentration at OEH background sites

Year	Annual mean concentration (µg/m^3) [(a)]						
	Chullora	Earlwood	Lindfield	Liverpool	Prospect	Randwick	Rozelle
2004	32.3	31.5	35.0	31.8	-	39.8	33.5
2005	31.6	33.0	-	32.2	-	42.0	34.2
2006	30.7	32.4	-	32.0	-	38.3	31.3
2007	30.5	31.4	-	31.2	-	40.5	32.9
2008	27.5	29.7	33.2	28.7	29.8	37.8	29.6
2009	31.8	32.7	33.7	31.3	37.5	46.9	35.1
2010	28.9	31.3	32.9	28.6	32.8	43.6	36.6
2011	29.0	32.4	31.9	28.2	32.0	38.4	33.0
2012	27.5	33.0	31.5	28.4	33.0	38.6	36.1
2013	30.8	32.4	33.5	31.8	37.0	40.3	36.8
2014	31.3	33.0	35.4	33.4	37.9	41.4	36.0
Long-term mean	**30.2**	**32.1**	**33.4**	**30.7**	**34.3**	**40.7**	**34.1**
Significance[(b)]	◄►	◄►	◄►	◄►	▲	◄►	▲

(a) Only years with >75 per cent complete data shown

(b) ▼ = significantly decreasing, ▲ = significantly increasing, ◄► = no trend

F.6.3.2 Monthly mean concentration

As with NO_X and NO_2, ozone concentrations vary according to the season. They are highest in the late spring and early summer – when photochemical activity is high - and lowest in the autumn and winter. An example profile - for the Earlwood site – shown in Figure F-13.

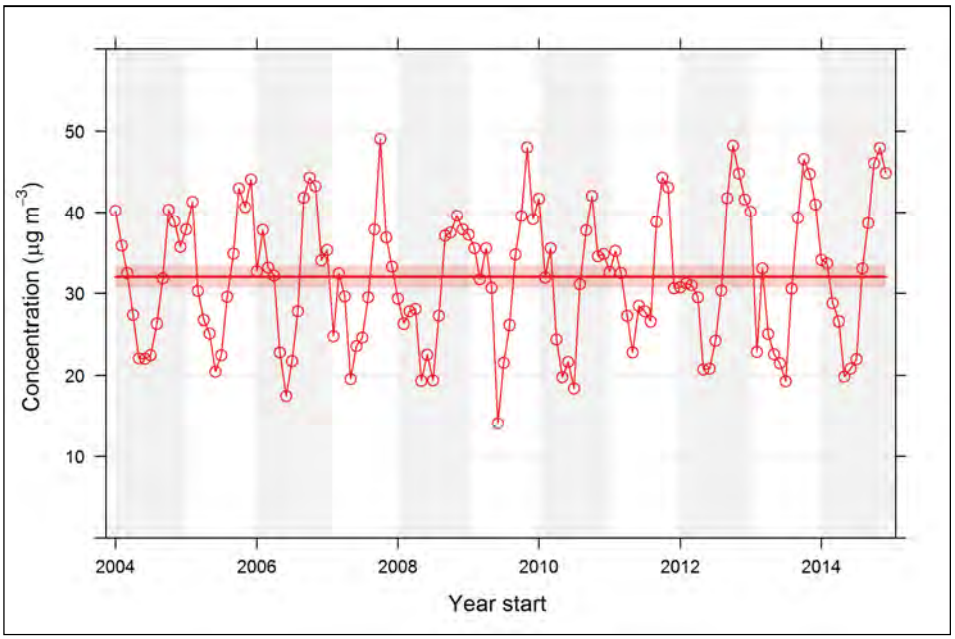


Figure F-13 Monthly mean O_3 concentration at OEH Earlwood monitoring site

F.6.3.3 Exceedances of air quality criteria

Table F-9 and Table F-10 show that there were exceedances of the rolling 4-hour mean and 1-hour mean standards for ozone at several monitoring sites.

Table F-9 Exceedances of rolling 4-hour mean O_3 standard

Year	Number of exceedances of rolling 4-hour standard per year (171 µg/m^3)						
	Chullora	Earlwood	Lindfield	Liverpool	Prospect	Randwick	Rozelle
2004	**7**	**1**	**5**	**11**	-	**2**	**2**
2005	**1**	0	-	**6**	-	0	0
2006	**10**	**4**	-	**17**	-	0	**2**
2007	0	0	-	**7**	-	**2**	0
2008	0	0	0	**1**	**2**	0	0
2009	**6**	**7**	**3**	**10**	**18**	0	0
2010	0	0	0	**1**	**7**	0	0
2011	**4**	**3**	**1**	**5**	**13**	0	0
2012	0	0	0	0	0	0	0
2013	**3**	**3**	0	**6**	**6**	0	0
2014	0	0	0	**3**	**5**	0	0

Table F-10 Exceedances of 1-hour O_3 standard

Year	Number of exceedances of 1-hour standard per year (214 µg/m^3)						
	Chullora	Earlwood	Lindfield	Liverpool	Prospect	Randwick	Rozelle
2004	**2**	0	**1**	**5**	-	**2**	0
2005	0	0	-	**3**	-	0	0
2006	**3**	**2**	-	**11**	-	0	0
2007	0	0	-	**3**	-	0	0
2008	0	0	0	0	**1**	0	0
2009	**3**	**3**	**1**	**3**	**4**	0	0
2010	0	0	0	0	**3**	0	0
2011	**1**	0	0	**1**	**5**	0	0
2012	0	0	0	0	0	0	0
2013	**1**	**1**	0	**5**	**2**	0	0
2014	0	0	0	**1**	**2**	0	0

F.6.4 PM_{10}

F.6.4.1 Annual mean concentration

Annual mean PM_{10} concentrations at the OEH and RMS sites are given in Figure F-14 and Table F-11. Concentrations at the OEH sites showed a net decrease between 2004 and 2014, by as much as 20 per cent in the case of the Chullora site. Only the Chullora and Earlwood sites had a statistically significant downward trend in concentrations.

In recent years the annual mean PM_{10} 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 RMS sites in recent years appears to have stabilised at around 15 µg/m^3. These values can be compared with air quality criterion of 30 µg/m^3.

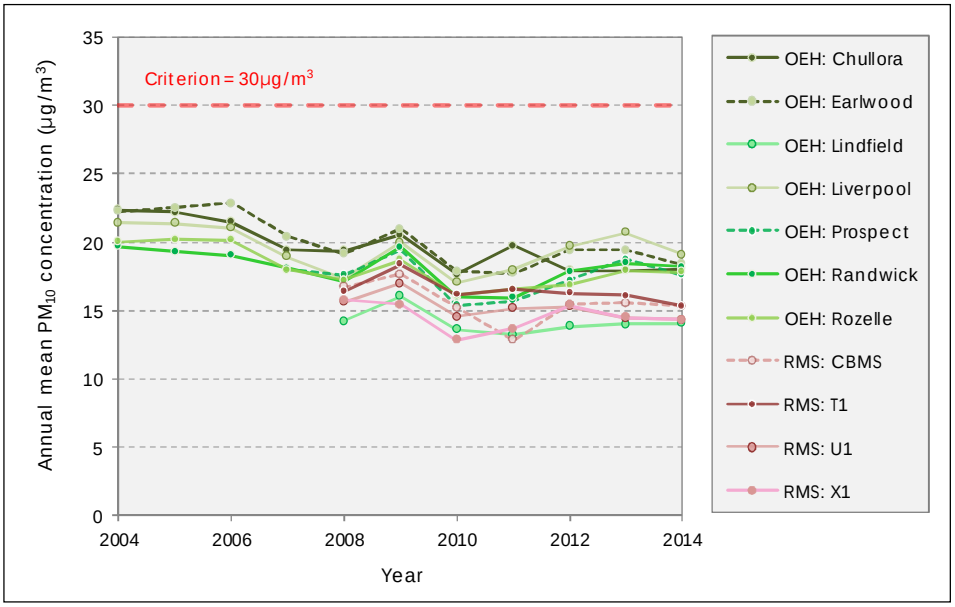


Figure F-14 Trend in annual mean PM_{10} concentration

Table F-11 Annual mean PM_{10} concentration at OEH and RMS background sites

Year	Annual mean concentration (µg/m^3)[(a)]										
	OEH Chullora	OEH Earlwood	OEH Lindfield	OEH Liverpool	OEH Prospect	OEH Randwick	OEH Rozelle	RMS CBMS	RMS T1	RMS U1	RMS X1
2004	22.3	22.2	-	21.4	-	19.7	20.0	-	-	-	-
2005	22.2	22.5	-	21.3	-	19.3	20.2	-	-	-	-
2006	21.5	22.9	-	21.0	-	19.0	20.2	-	-	-	-
2007	19.4	20.4	-	18.9	18.0	18.1	18.0	-	-	-	-
2008	19.4	19.1	14.2	17.4	17.6	17.2	17.2	16.7	16.4	15.6	15.8
2009	20.5	20.9	16.1	20.0	19.5	19.6	18.7	17.7	18.3	17.0	15.5
2010	17.7	17.9	13.6	17.0	15.4	16.0	16.1	15.2	16.2	14.6	12.8
2011	19.8	17.7	13.2	18.0	15.7	15.9	16.6	12.8	16.6	15.2	13.7
2012	17.9	19.4	13.8	19.7	17.2	17.9	16.9	15.5	16.2	15.3	15.4
2013	17.9	19.4	14.0	20.7	18.8	18.5	17.9	15.7	16.1	14.4	14.5
2014	18.1	18.3	14.1	19.1	17.6	18.2	17.8	15.3	15.3	14.4	14.4
Long-term mean	**19.7**	**20.1**	**14.1**	**19.5**	**17.5**	**18.1**	**18.1**	**15.7**	**16.7**	**15.2**	**14.6**
Significance[(b)]	▼	▼	◄►	◄►	◄►	◄►	◄►	◄►	◄►	◄►	◄►

(a) Only years with >75 per cent complete data shown

(b) ▼ = significantly decreasing, ▲ = significantly increasing, ◄► = no trend

F.6.4.2 Monthly mean concentration

The monthly mean concentrations at the Chullora site are shown in Figure F-15**.** For PM_{10} there is a weaker seasonal effect than for the gaseous pollutants, with concentrations tending to be higher in summer and lower in winter. The Figure also shows more clearly how mean concentrations are tending to stabilise at around 20 µg/m^3.

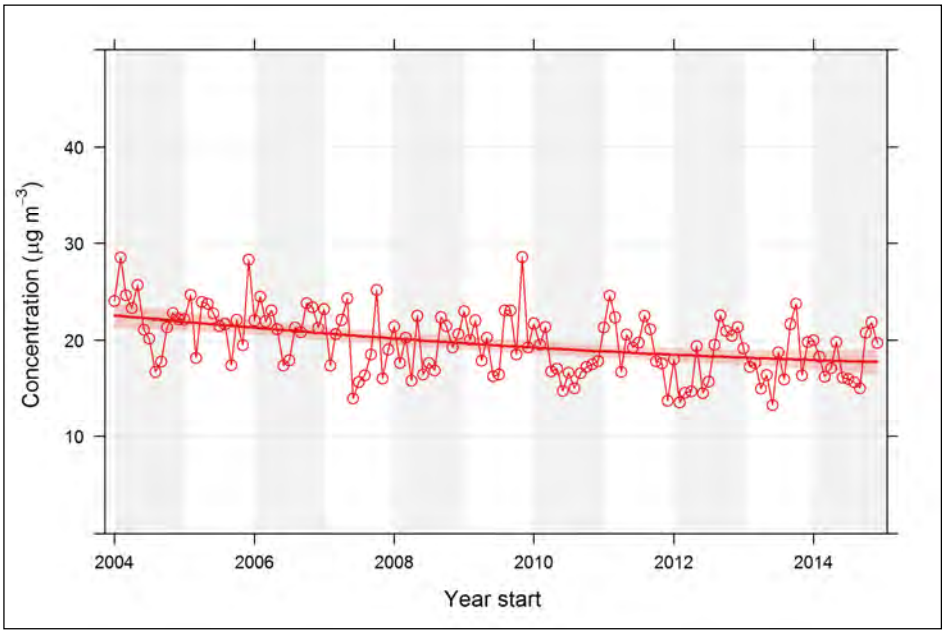


Figure F-15 Monthly mean PM_{10} concentration at OEH Chullora monitoring site

F.6.4.3 24-hour mean concentration

The maximum 24-hour mean PM_{10} concentrations are shown in Figure F-16. These appear to exhibit a slight downward trend overall, but there is a large amount of variation from year to year at most

sites. 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.

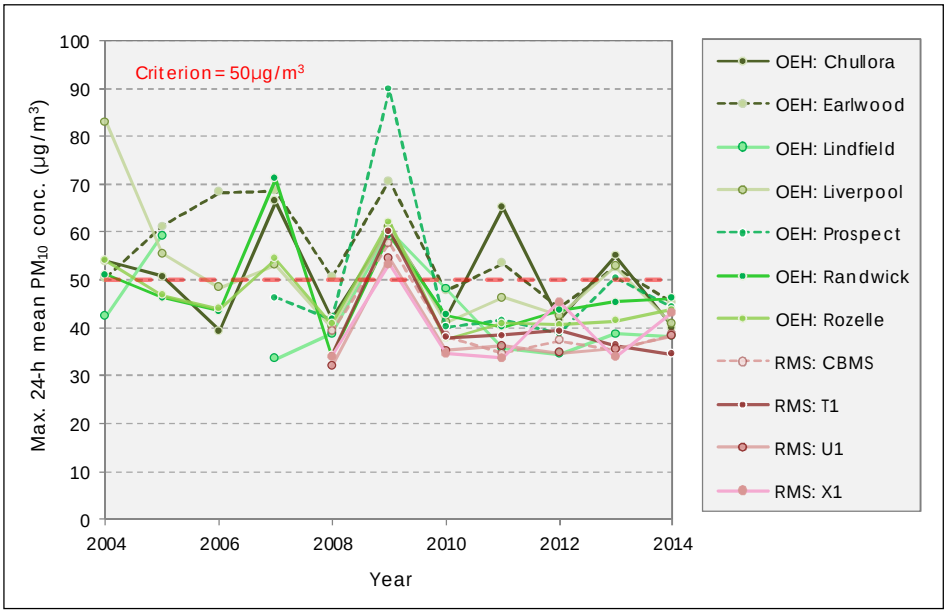


Figure F-16 Trend in maximum 24-hour mean PM_{10} concentration

F.6.4.4 Exceedances of air quality criteria

There were no exceedances of the annual mean criterion for PM_{10} of 30 µg/m^3, but Table F-12 shows that there were exceedances of the 24-hour criterion of 50 µg/m^3, notably in the warm, dry year of 2009 (days with bush fires and dust storms were excluded from this analysis).

Table F-12 Exceedances of 24-hour PM_{10} standard

Year	Number of exceedances of 24-hour standard per year (50 µg/m^3)						
	Chullora	Earlwood	Lindfield	Liverpool	Prospect	Randwick	Rozelle
2004	**3**	**1**	0	1	-	**1**	**1**
2005	**1**	**2**	**1**	**2**	-	0	0
2006	0	**5**	-	0	-	0	0
2007	**2**	**3**	0	**1**	0	**1**	**1**
2008	0	**1**	0	0	0	0	0
2009	**2**	**4**	**1**	**3**	**3**	**2**	**2**
2010	0	0	0	0	0	0	0
2011	**8**	**1**	0	0	0	0	0
2012	0	0	0	0	0	0	0
2013	**1**	**2**	0	**1**	**1**	0	0
2014	0	0	0	0	0	0	0

F.6.5 $PM_{2.5}$

F.6.5.1 Annual mean concentration

An extensive time series of $PM_{2.5}$ measurements was only available for three monitoring sites in the wider study area (Figure F-17 and Table F-13). 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. Here, it is important to recognise the following:

- As noted earlier, during 2012 OEH made a decision to replace its continuous TEOM $PM_{2.5}$ monitors with USEPA-equivalent BAMs. This is the main reason for the increase in the measured concentrations between 2012 and 2014. It is well documented that there are considerable uncertainties in the measurement of $PM_{2.5}$ (AQEG, 2012).
- 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 8 $\mu g/m^3$.

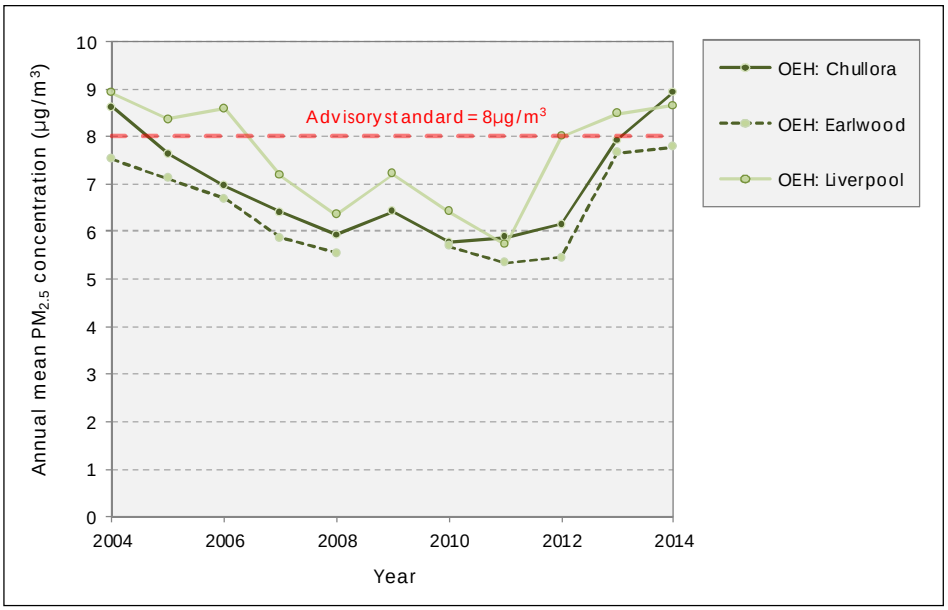


Figure F-17 Long-term trends in annual mean $PM_{2.5}$ concentration

Table F-13 Annual mean $PM_{2.5}$ concentration at OEH background sites

Year	Annual mean concentration ($\mu g/m^3$) [(a)]						
	Chullora	Earlwood	Lindfield	Liverpool	Prospect	Randwick	Rozelle
20-04	8.6	7.5	-	8.9	-	-	-
2005	7.6	7.1	-	8.4	-	-	-
2006	7.0	6.7	-	8.6	-	-	-
2007	6.4	5.9	-	7.2	-	-	-
2008	5.9	5.5	-	6.4	-	-	-
2009	6.4	-	-	7.2	-	-	-
2010	5.8	5.7	-	6.4	-	-	-
2011	5.9	5.3	-	5.7	-	-	-
2012	6.1	5.5	-	8.0	-	-	-
2013	7.9	7.7	-	8.5	-	-	-
2014	8.9	7.8	-	8.7	-	-	-
Long-term mean	**7.0**	**6.5**	**-**	**7.6**	**-**	**-**	**-**
Significance[(b)]	◄►	◄►	-	◄►	-	-	-

(a) Only years with >75 per cent complete data shown

(b) ▼ = significantly decreasing, ▲ = significantly increasing, ◄► = no trend

F.6.5.2 Monthly mean concentration

The monthly mean $PM_{2.5}$ concentrations at the Chullora site are shown in Figure F-19. There are some differences between seasons, but they are not systematic.

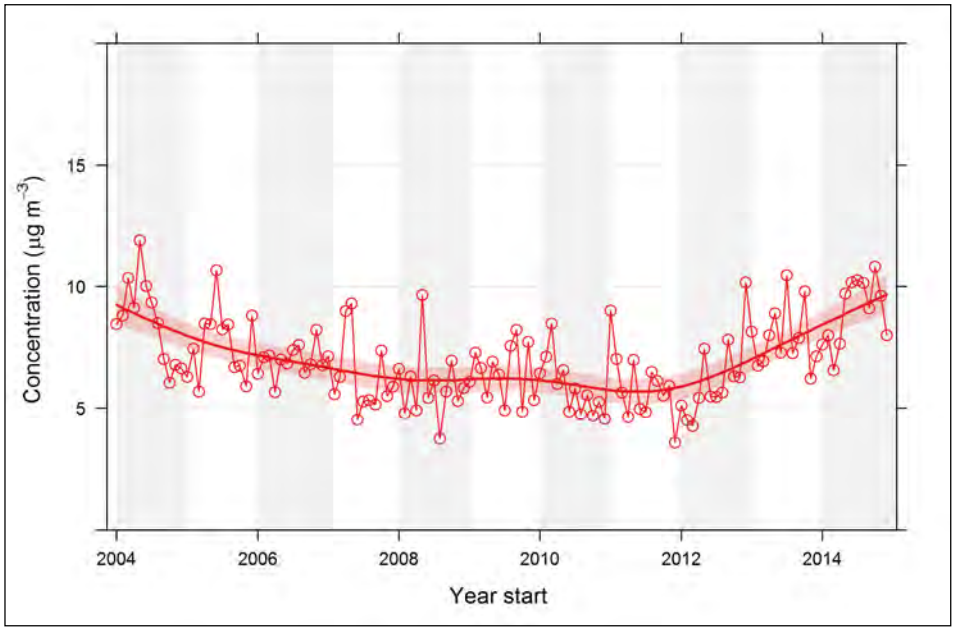


Figure F-18 Monthly mean $PM_{2.5}$ concentration at OEH Chullora monitoring site

F.6.5.3 24-hour mean concentration

The maximum 24-hour mean $PM_{2.5}$ concentrations at the three long-term $PM_{2.5}$ monitoring sites are shown in Figure F-19. There has been no systematic trend in the maximum value, although there appears to have been a general increase between 2006 and 2014. As with the annual mean $PM_{2.5}$ concentrations, the maximum one-hour concentrations are very close to or above the advisory reporting standard in the AAQ NEPM of 25 µg/m^3.

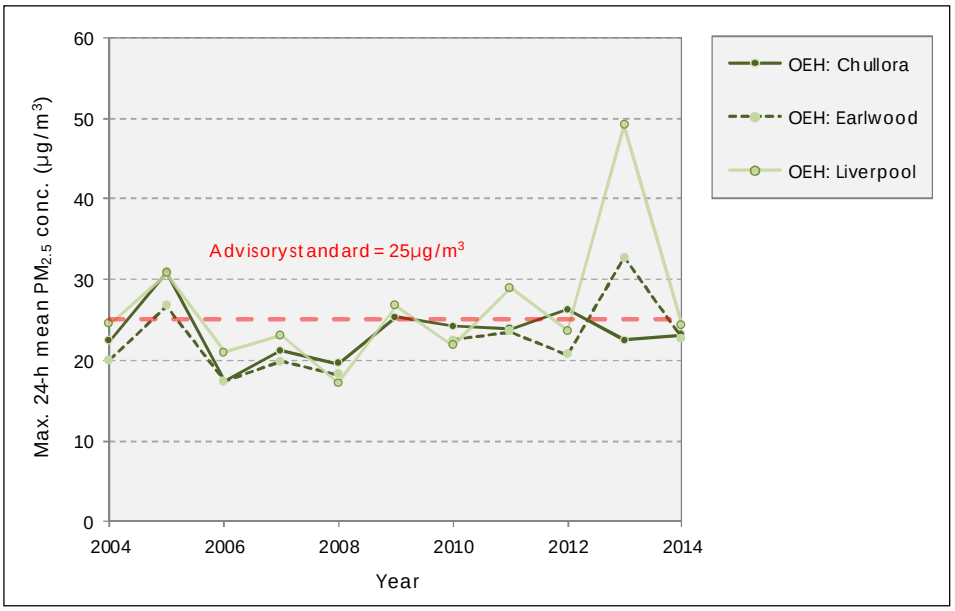


Figure F-19 Trend in maximum 24-hour mean $PM_{2.5}$ concentration

F.6.5.4 Exceedances of air quality criteria

As noted earlier, there there have been some exceedances of the NEPM advisory reporting standard for annual mean $PM_{2.5}$ of 8 µg/m^3, and these seem to be more likely in the future given the change in monitoring method. Table F-14 summarises the exceedances of the 24-hour criterion of 25 µg/m^3.

Table F-14 Exceedances of advisory 24-hour $PM_{2.5}$ standard

Year	Number of exceedances of advisory 24-hour standard per year (25 µg/m^3)						
	Chullora	Earlwood	Lindfield	Liverpool	Prospect	Randwick	Rozelle
2004	0	0	-	0	-	-	-
2005	**3**	**2**	-	**2**	-	-	-
2006	0	0	-	0	-	-	-
2007	0	0	-	0	-	-	-
2008	0	0	-	0	-	-	-
2009	**1**	0	-	**1**	-	-	-
2010	0	0	-	0	-	-	-
2011	0	0	-	**1**	-	-	-
2012	**1**	0	-	0	-	-	-
2013	0	**2**	-	**4**	-	-	-
2014	0	0	-	0	0	-	-

F.6.6 Air toxics

Fewer data were available to characterise the concentrations of air toxics in Sydney. The main sources of data were the following:

- An Ambient Air Quality Research Project that was conducted between 1996 and 2001 (NSW EPA, 2002). The project investigated concentrations of 81 air toxics, including dioxins, VOCs, PAHs and heavy metals. More than 1,400 samples were collected at 25 sites. Three air toxics – benzene, 1,3-butadiene and benzo(α)pyrene – were identified as requiring ongoing assessment to ensure they remain at acceptable levels in the future.
- An additional round of data collection between October 2008 and October 2009. The five NEPM air toxics and additional VOCs were monitored at two sites in Sydney:
    - Turrella: formaldehyde, acetaldehyde, 19 PAHs including benzo(a)pyrene, and 41 VOCs including benzene, toluene and xylenes.
    - Rozelle: formaldehyde, acetaldehyde, 41 VOCs including benzene, toluene and xylenes.

  This study collected 24-hour concentrations of formaldehyde, acetaldehyde, and 34 organic compounds every sixth day, and 19 PAHs at one location on the same days. Sixty-one samples were collected at each location during the sampling period.

The findings of the studies were summarised by NSW DECCW (2010), and some results for selected pollutants are given in Table F-15. In the 1996-2001 monitoring campaign the concentrations of most compounds were very low. Some 23 compounds were not, or rarely, detected. Annual average concentrations of benzene were below the Air Toxics NEPM investigation level (0.003 ppm or 3 ppb) at all sites. The maximum annual concentrations of toluene and xylenes were less than 5 per cent of the investigation levels, and maximum 24-hour concentrations were less than 2 per cent and 4 per cent of the investigation levels respectively. The 2008-09 monitoring campaign also found low concentrations of all compounds, with many observations below detection limits. Concentrations of the five pollutants in the Air Toxics NEPM were low compared to the respective investigation levels.

The concentrations of the pollutants in Table F-15 generally halved between the two campaigns. Improved engine technology and a greater proportion of the vehicle fleet being fitted with catalysts reduced emissions from road vehicles. Benzene concentrations showed a larger decrease as a result

of a reduction in the maximum allowed benzene concentration in automotive fuels (NSW DECCW, 2010).

Table F-15 Average concentrations of selected organic pollutants

Pollutant	Concentration (ppb)				
	1996-2001			2008-2009	
	Sydney CBD	Rozelle	St Marys	Turrella	Rozelle
Benzene	2.3	1.1	0.4	0.4	0.3
Toluene	4.2	2.2	0.8	1.8	0.9
Xylene (m + p)	2.2	1.0	0.4	0.7	0.5
Xylene (o)	0.8	0.4	0.1	0.3	0.2
1,3-butadiene	0.4	0.2	0.1	<0.1	<0.1

Source: (NSW DECCW, 2010)

In the 2008-2009 campaign the highest benzo(a)pyrene concentration was 0.4 ng/m^3, and the average for the year was 0.12 ng/m^3. Concentrations of formaldehyde were low: the highest concentration was only 11 per cent of the investigation level (NSW DECCW, 2010).

The results clearly showed levels of air toxics were below the monitoring investigation levels, and well below levels observed in overseas cities. There were no occasions on which any of the air toxics monitored exceeded the monitoring investigation levels at any location. The results for benzo(a)pyrene, with levels of approximately 65 per cent of the NEPM monitoring investigation level, were the most significant (NEPC, 2011b).

F.7 Bivariate polar plots

F.7.1 Overview

Polar plots for each of the OEH monitoring sites were created using the *Openair* software. Whilst these plots were not used directly in the determination of the background concentrations for the New M5 project, they did assist in the understanding of differences between pollutant concentrations at the different sites.

Some examples of polar plots are shown in Figure F-20. These indicate how concentrations vary by wind speed and wind direction, with statistical smoothing techniques giving a continuous surface. The monitoring station is located at the centre of each plot. The axes show the directions from which the wind is coming, and the distance from the origin indicates the wind speed; the further from the centre that concentrations appear, the higher the wind speeds when they were measured. Calm conditions appear close to the centre. The examples are for a secondary pollutant – ozone – which tends to be distributed quite evenly in space, and hence there are few strong features in the plot. The Figure does show, however, that ozone formation is greatest in the summer months.

The polar plot is a useful diagnostic tool for understanding potential sources of air pollutants at a given site. For many situations an increasing wind speed generally results in lower concentrations due to increased dilution through advection and increased turbulence. Ground-level, non-buoyant sources - such as road traffic – therefore tend to have highest concentrations under low wind speed conditions, but various processes can lead to other concentration-wind speed dependencies. For example, buoyant plumes from tall outlets can be brought down to ground level, resulting in high concentrations under high wind speed conditions. Wind-blown dust (*e.g.* from exposed areas of soil) also increases with increasing wind speed, and particle suspension can be important close to coastal areas where higher wind speeds generate more sea spray (Carslaw, 2015).

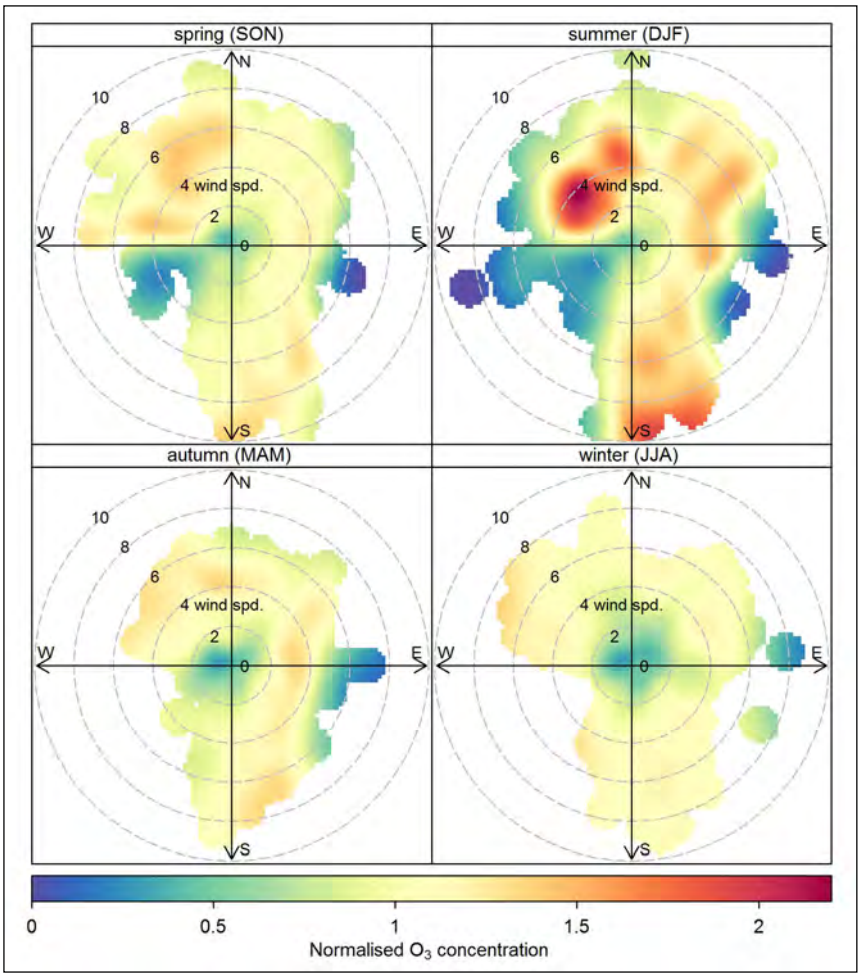


Figure F-20 Polar plots of normalised ozone concentration by season at Rozelle

Some typical features of polar plots include the following:

- A maximum concentration, or a 'smeared' peak, at low wind speed, which is indicative of a local, ground-level source such as road traffic. As the wind speed increases concentrations due to a road source will tend to decrease due to the increased dilution of the plume.
- Highly resolved features at high wind speeds, but possibly low concentrations, which indicate more distant sources.
- Relationships between pollutants which provide information on the emission characteristics of different sources. For example, a site with high 'smeared' NO_X concentrations at low wind speeds, is likely to be a nearby road.

The Openair polar plots for the OEH sites have been interpreted below. Each plot is based upon all the available data for the period 2004-2014, and the concentrations have been normalised to permit easier comparison. The interpretation is qualitative, and to some degree speculative.

F.7.2 Chullora

The polar plots for the Chullora site are shown in Figure F-21. The plots for CO, NO_X and NO_2 show strong similarities, with the highest concentrations occurring for low wind speeds and a tendency for elevated concentrations along a broad north-south wind direction axis. There also appears to be a source of these pollutants to the east. The similarities between these plots indicate a common combustion source - probably the local road network.

The plots for O_3 and NO_X show the well-established inverse relationship between these pollutants. This is also apparent in the data from the other OEH monitoring sites, and is not commented upon further.

The patterns for CO and NO_X do not show up strongly in the PM_{10} and $PM_{2.5}$ plots. This is likely to be due to contributions from several other sources of PM. PM_{10} concentrations appear to be influenced by a source to the west of the monitoring site under high wind speeds. This may be wind-blown dust from open land to the west of the site. $PM_{2.5}$, on the other hand, is more evenly distributed (probably reflecting the secondary PM contribution), although there is a strong source to the south-east under high wind conditions.

There were no strong seasonal influences in the polar plots for the Chullora site.

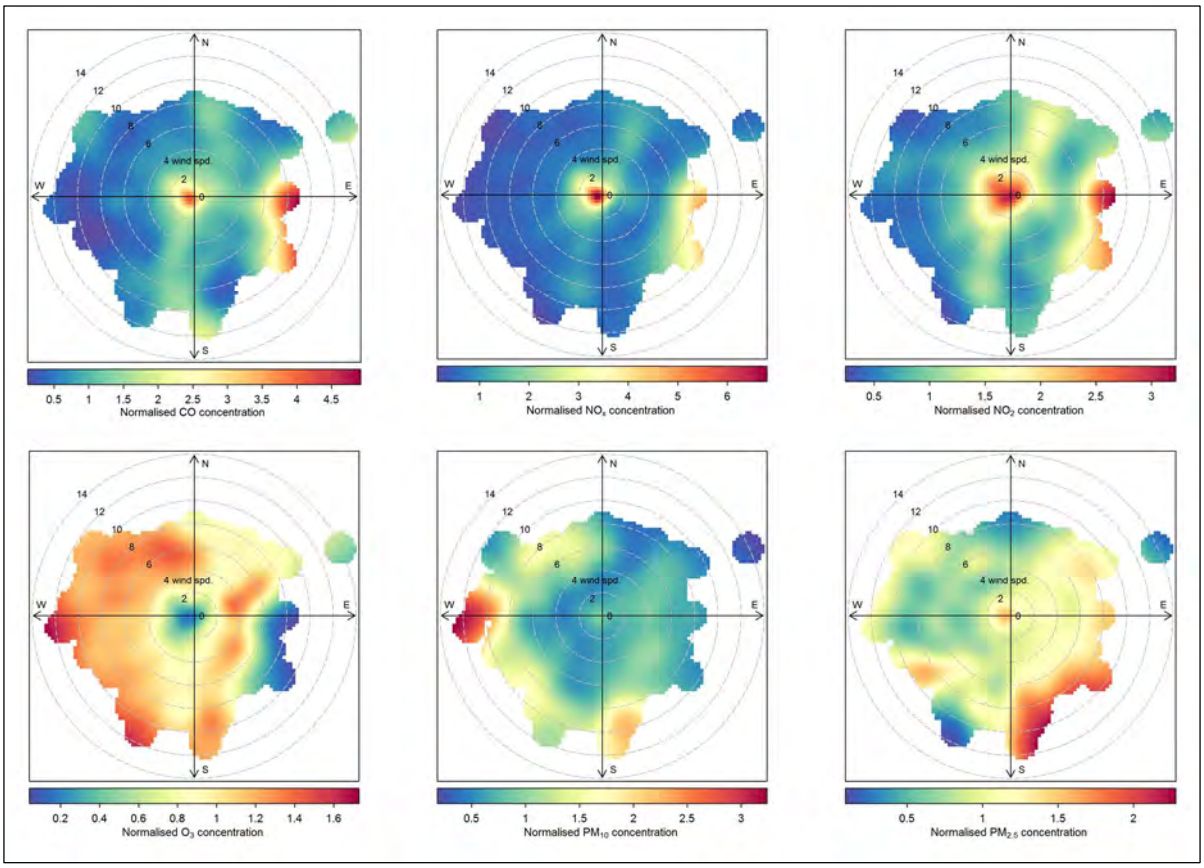


Figure F-21 Polar plots – Chullora, normalised

F.7.3 Earlwood

The polar plots for the Earlwood site are shown in Figure F-22. These plots have relatively simple patterns. NO_X and NO_2 concentrations are highest when the winds are strong and from an easterly direction. The seasonal data showed that this influence was especially strong during winter, hinting strongly that this is an effect of combustion for heating purposes.

PM_{10} concentrations are highest when the winds are strong and from a westerly direction (especially in winter and spring). $PM_{2.5}$ concentrations, while more evenly distributed than PM_{10}, are high when the winds are strong from a southerly direction (especially in summer). The reasons for these patterns were not clear, but different sources and effects are evidently influencing PM_{10} and $PM_{2.5}$.

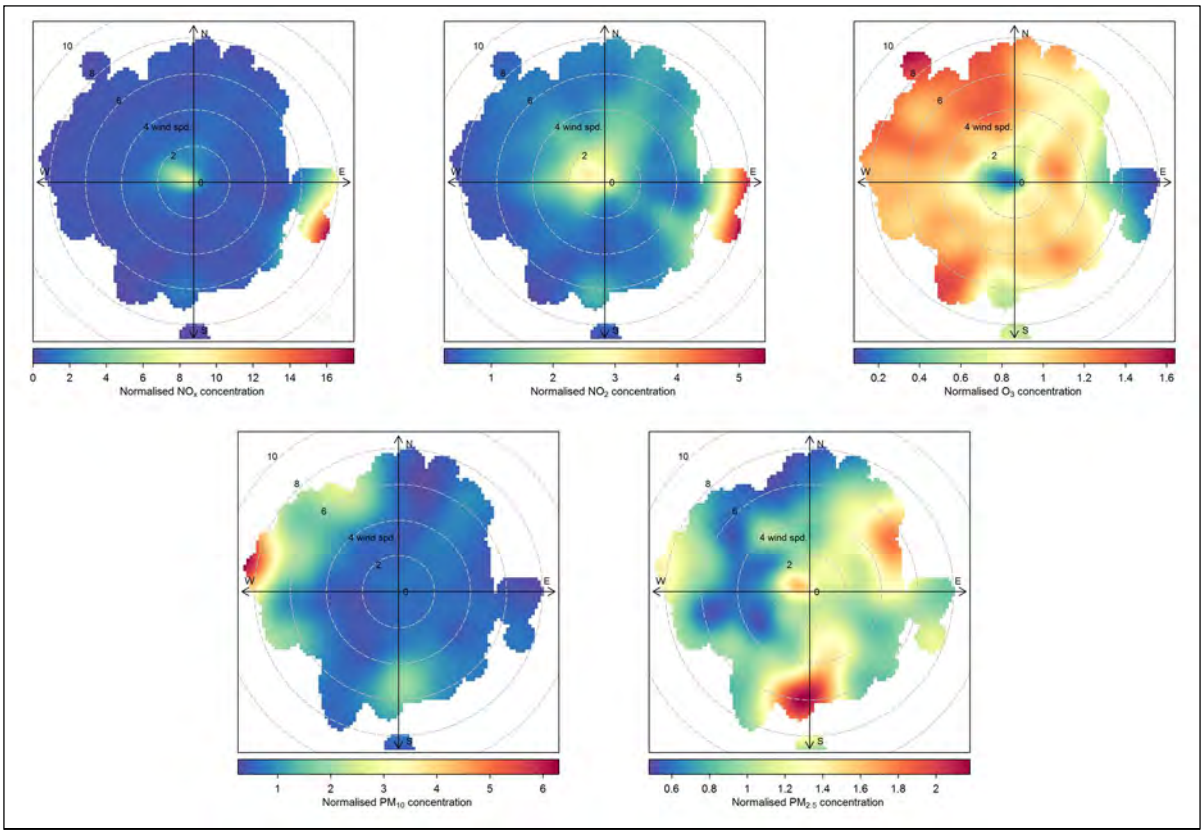


Figure F-22 Polar plots – Earlwood, normalised

F.7.4 Lindfield

In Figure F-23, The smeared NO_X and NO_2 concentrations at the plot origin indicate the presence of a local ground-level source, as well as a broad source further afield to the north. This probably reflects the population distribution around the monitoring sire. There is also an influence further way and to the west, which may be the M2 Motorway and Lane Cove Road.

PM_{10} concentrations are high when there is a strong westerly wind. This may be due to wind-blown dust from the open land immediately to the west of the monitoring site.

There are no strong seasonal effects at the Lindfield site, apart from higher concentrations from the west under high wind speed conditions in spring, and higher concentrations from the south under high wind speed conditions in the summer. It is not clear what is responsible for these effects.

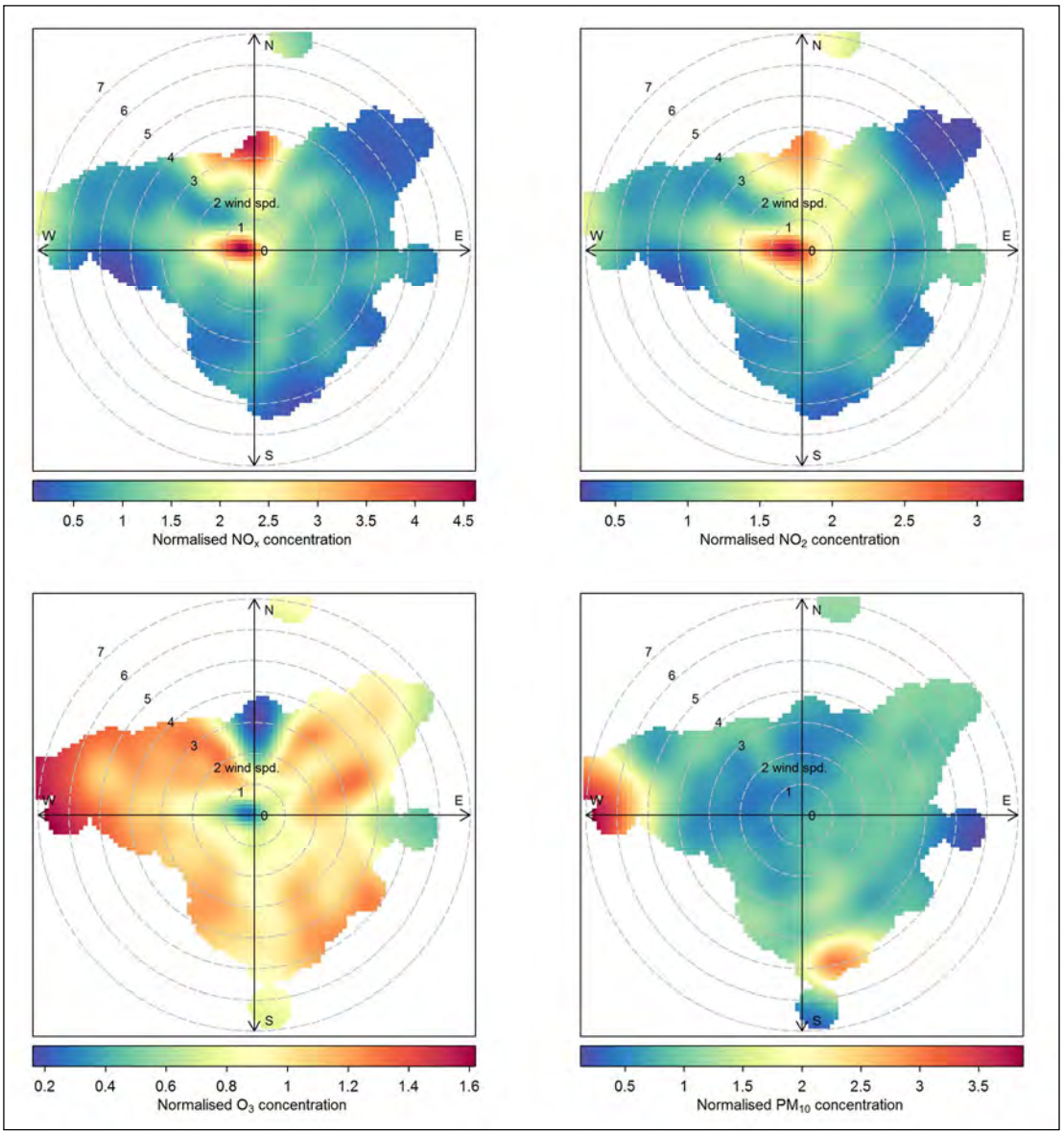


Figure F-23 Polar plots – Lindfield, normalised

F.7.5 Liverpool

At the Liverpool monitoring site the concentrations of CO, NO_X, NO_2 and $PM_{2.5}$ for low wind speeds are not particularly high (Figure F-24). There is, however, a distinct influence form a north-westerly direction, indicating a common combustion source. This may involve a contribution from Hoxton Park Road. However the effect is most prominent in winter, and this is more indicative of combustion for heating purposes, probably from the commercial centre of Liverpool. The M5 Motorway, around 500 metres south of the monitoring site, does not appear to have a significant influence on the measured concentrations.

PM_{10} concentrations are influenced by a source to the north-north-west of the monitoring site, but only under strong wind conditions and during the winter months. Again, this coincides with open land to the north-west of the site, and could be a result of wind-blown dust.

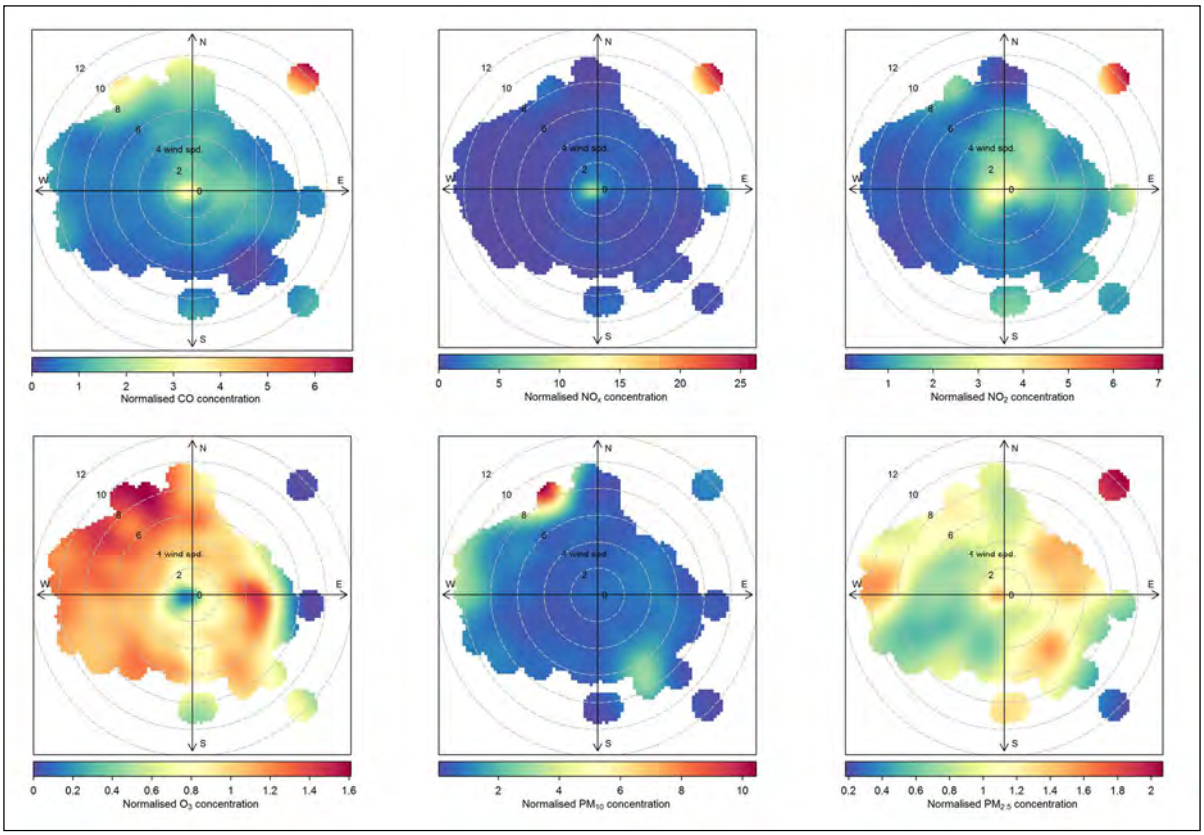


Figure F-24 Polar plots – Liverpool, normalised

F.7.6 Prospect

Concentrations of CO, NO_X and NO_2 at the Prospect site (Figure F-25) are highest when wind speeds are low, and the high concentration are almost centred on the monitoring station. There are, however, sources of NO_X to the east and south-east under high wind speeds. This may be associated with the transport of NO_X from major roads in the area, although these are some distance away (Prospect Highway, 500 metres to the east; Great Western Highway, 800 metres to the south; M4 Motorway, 1.2 kilometres to the south). There is no strong seasonal influence on NO_X at the site, suggesting that it is not related to combustion for heating purposes.

PM_{10} seems to be strongly influenced – under high winds - by sources which are spread out quite widely to the west of the monitoring site. As at the other sites, this may be due to wind-blown dust from the open land, gravel and sand areas adjacent to the site.

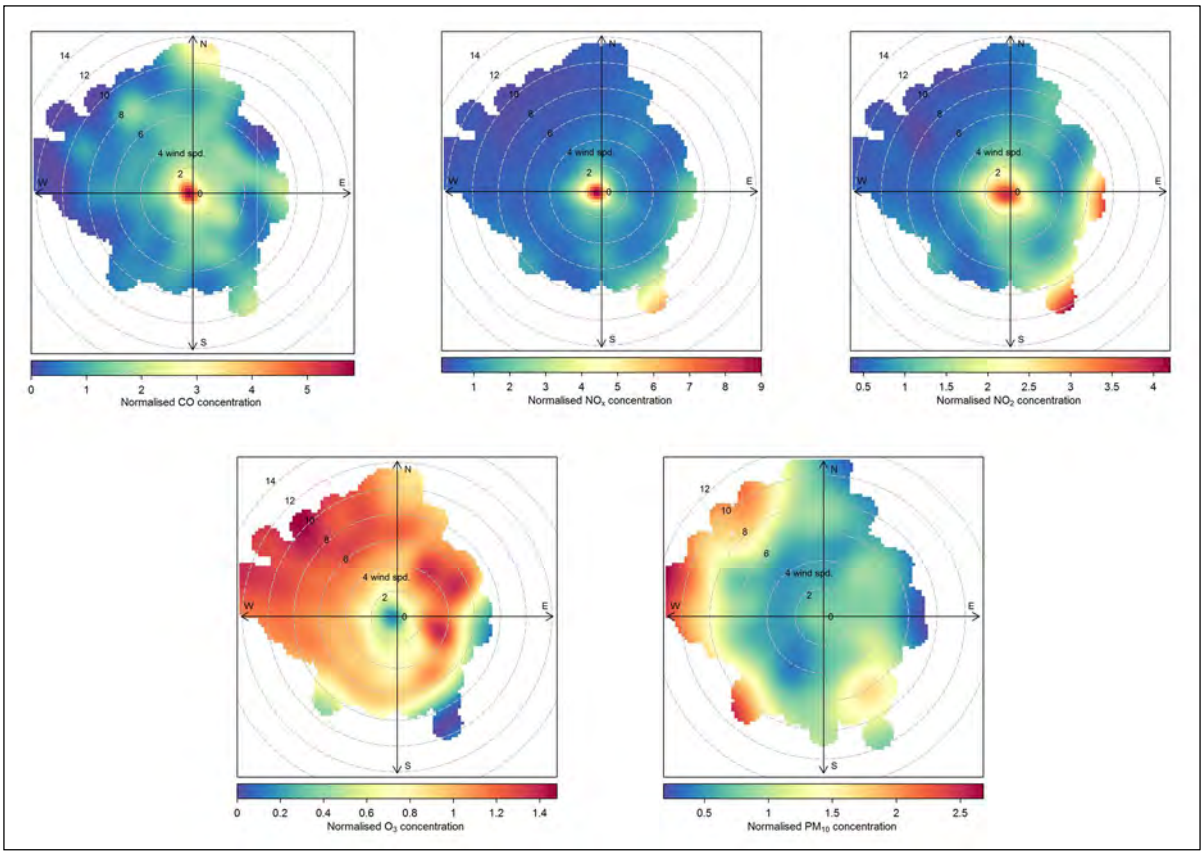


Figure F-25 Polar plots – Prospect, normalised

F.7.7 Randwick

At the Randwick site, NO_X and NO_2 concentrations are highest when the wind speed is low and the wind is coming from the west, with dispersion under stronger winds. There is no seasonal effect in the polar plot for NO_X. This indicates the presence of a road near to the monitoring site, which could be Anzac Parade and/or Avoca Street. Sydney Airport, around 5 kilometres to the west of the monitoring site, may also be affecting NO_X concentrations in this area.

The PM_{10} plot for Randwick shows that the highest concentrations occur when the wind speed is high and is blowing from three distinct directions. Given that these directions coincide with open land and land under development, this seems to be a confirmation that high PM_{10} concentrations are associated with wind-blown dust from local sources.

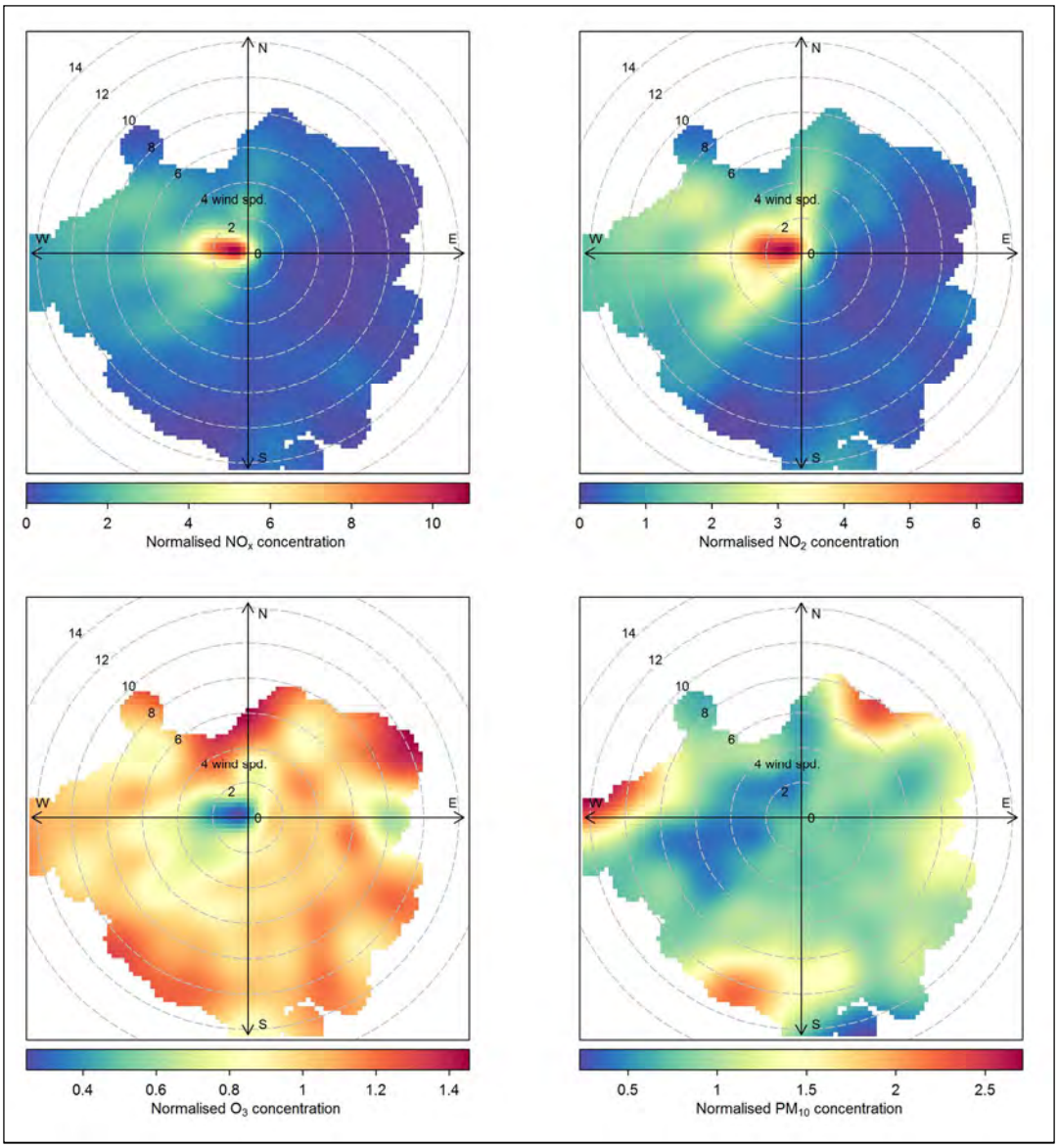


Figure F-26 Polar plots – Randwick, normalised

F.7.8 Rozelle

The polar plot for CO at the Rozelle site indicates that there are multiple combustion sources affecting the site. These are likely to be associated with the University of Sydney campus immediately to the south-west, and roads within 500 metres (Victoria Road to the north-east, and Darling Street to the south-west).

The highest NO_X/NO_2 concentrations occur when winds are along an east-west axis, which suggests contributions from the University campus and residential areas. The peak associated with easterly winds may also be linked to Victoria Road.

The highest PM_{10} concentrations at the monitoring site are associated with strong southerly winds, especially in summer. As at the other OEH monitoring sites, this seems to be due to wind-blown dust from open land to the south of the Rozelle site.

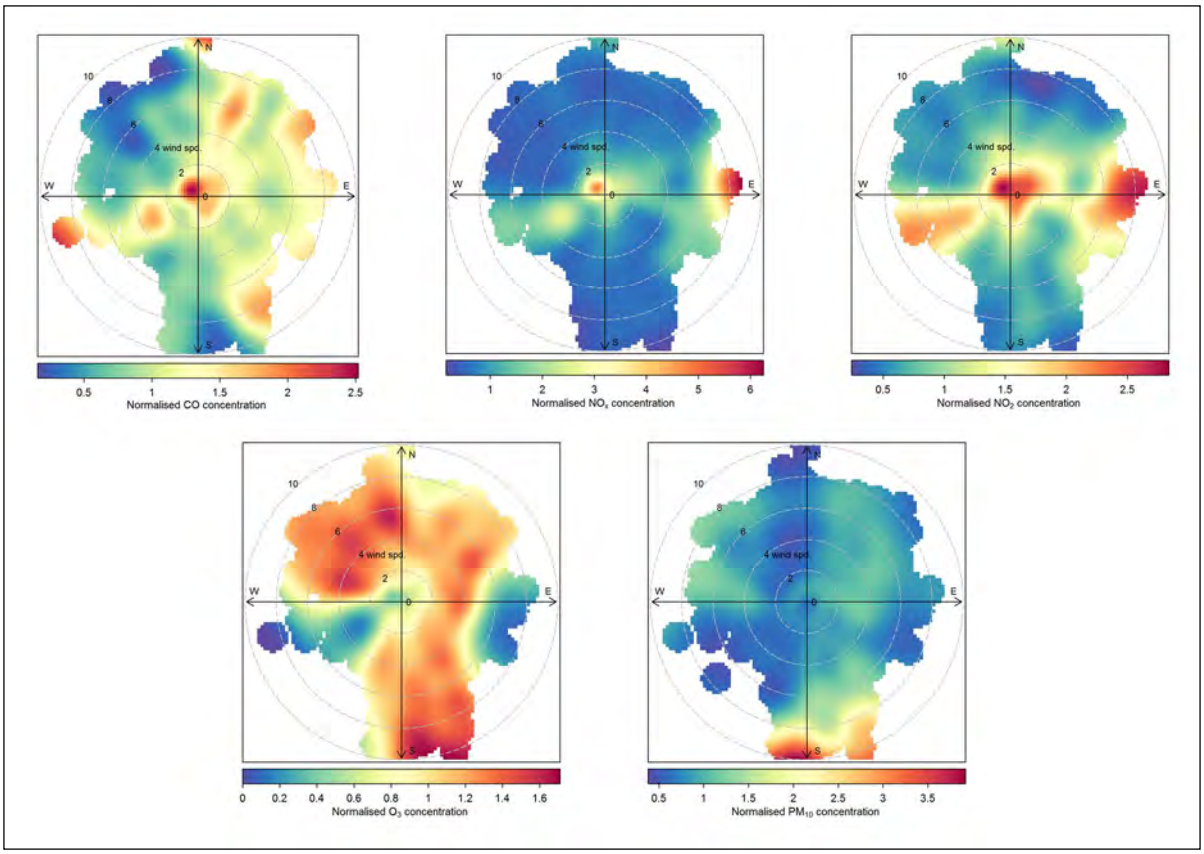


Figure F-27 Polar plots – Rozelle, normalised

F.8 Results for project-specific background monitoring site

There was quite an extensive history of air quality monitoring by RMS in the vicinity of the M5 East tunnel (and also the New M5 project). Project-specific monitoring for the New M5, which addressed some of the gaps in the RMS monitoring in terms of pollutants and locations, began in July 2015 (see Table F-1). Given the relatively short time period between the commencement of the project-specific monitoring for the New M5 and the production of this air quality assessment report, it was not considered to be helpful to include the project-specific monitoring data in the report.

F.9 Assumed Background concentrations

F.9.1 General approaches in New M5 assessment

Various approaches have been used in previous air quality assessments to define long-term (annual mean) and short-term (*e.g.* 1-hour, 24-hour) background concentrations. The selection of a suitable method is strongly dependent on the quantity and quality of available data. The general approaches used in the New M5 assessment are introduced below. The specific approaches for the various pollutants and metrics are then described in the subsequent sections. Background concentrations were developed using the data from the OEH sites at Chullora, Earlwood, Randwick and Rozelle sites, as well as the RMS M5 East background sites.

F.9.1.1 Annual mean concentrations

In the case of annual mean concentrations (such as those for PM_{10} and $PM_{2.5}$) it is relatively straightforward to define background values. For smaller projects it has often been sufficient to use a single background value, and to assume that this is representative of the whole study area. However, for a project such as WestConnex, which covers a large geographical area and features different types of land use, it was considered important to allow for spatial variation in annual mean concentrations where possible. Maps of background annual mean concentrations of some pollutants

were therefore developed for the WestConnex study area. When developing these maps the data from any non-background sites were excluded.

F.9.1.2 Short-term concentrations

It is more difficult to accurately predict short-term concentration peaks, as these vary considerably in magnitude, in time of occurrence, and in location. In some previous assessments a single value has been used for short-term concentrations, such as the maximum measured 24-hour mean PM_{10} concentration. This is the 'Level 1' method in the NSW Approved Methods. However, such an approach is very conservative, and results in unrealistically high cumulative concentrations; it is very unlikely that the maximum background values will coincide in space and time with the maximum predicted values. This approach was therefore not used for the New M5 project.

The approach used for community receptors in the New M5 assessment was broadly consistent with the 'Level 2' method in the Approved methods. This requires that existing background concentrations of a pollutant in the vicinity of a proposal should be included in the assessment as follows (NSW DEC, 2005):

- At least one year's worth of continuous ambient pollutant measurements should be obtained for a suitable background site. The background data should be contemporaneous with the meteorological data used in the dispersion modelling.
- At each receptor, each individual dispersion model prediction is added to the corresponding measured background concentration (*e.g.* the first hourly average dispersion model prediction is added to the first hourly average background concentration) to obtain total hourly predictions.
- At each receptor, the maximum concentration for the relevant averaging period is determined.

The unstated assumption is that one of the paired project-background concentration combinations will result in a realistic estimate of the maximum concentration that could be expected.

For the New M5 project this approach was applied to the short-term concentration metrics for CO (rolling 8-hour mean), NO_X (1-hour mean), PM_{10} (24-hour mean) and $PM_{2.5}$ (24-hour mean). NO_X was used in place of NO_2 for the reasons given in Appendix G. It would not have been practical to define both the spatial and temporal variation in short-term background concentrations in detail. As the temporal variation is generally more pronounced than the spatial variation, this was considered to be more important. For each short-term air quality metric a synthetic time series of background concentrations was therefore determined.

F.9.2 Carbon monoxide: one-hour mean

Figure F-28 shows examples of one-hour mean CO concentration profiles at the OEH Chullora and Rozelle sites, and the RMS CBMS, T1, U1 and X1 sites, during June of 2014. Peak concentrations generally occurred simultaneously at the three sites, indicating a regional background influence.

Given that there was a slight downward trend in the maximum one-hour mean CO values, the concentrations in 2014 were considered to be appropriate for use in the New M5 assessment, with the likelihood that the 2014 values would be slightly conservative in future years. Because of the seasonal variation in CO concentrations, a background profile of the one-hour mean CO concentration during 2014 was determined. To maintain a margin of safety a synthetic profile was constructed, with each value for a time period being the maximum of those at the OEH and RMS sites. This profile is shown in Figure F-29.

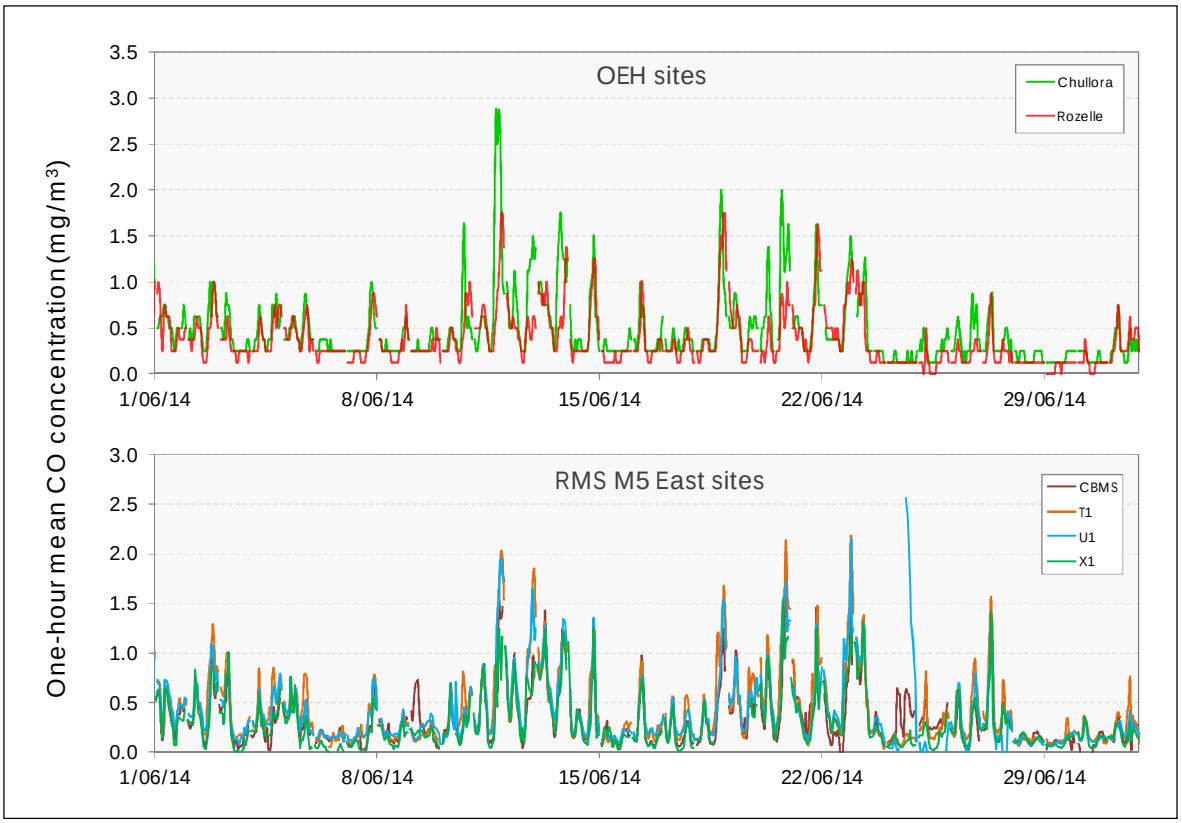


Figure F-28 **One-hour mean CO concentration at OEH and RMS M5 East sites (example for June 2014)**

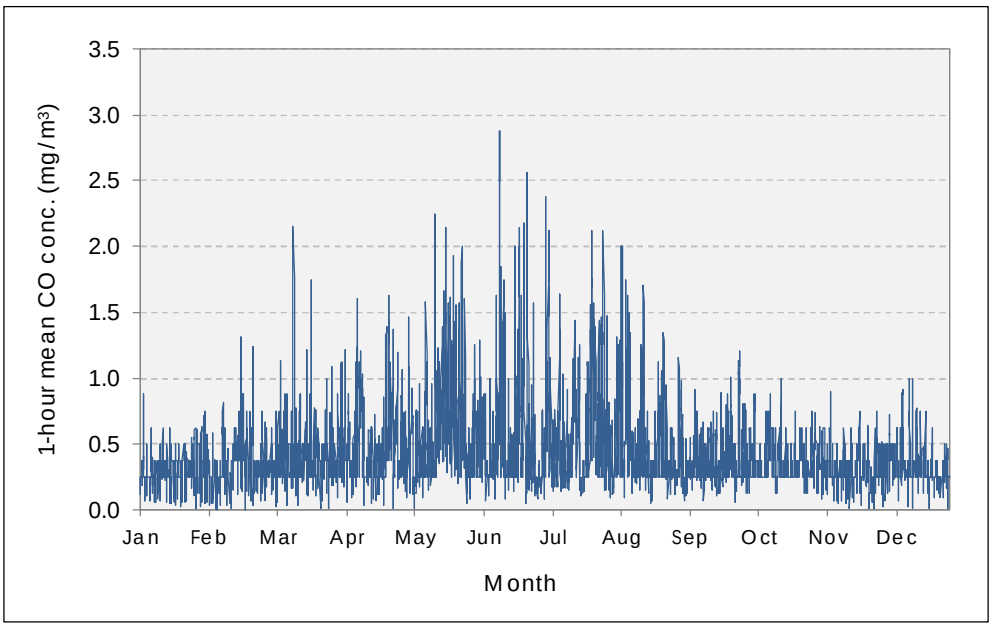


Figure F-29 **Synthetic background concentration profile for one-hour mean CO**

F.9.3 Carbon monoxide: rolling 8-hour mean

The rationale for the rolling 8-hour mean CO concentration was similar to that for the one-hour mean. A synthetic profile was constructed for 2014, with each value for a time period being the maximum of those at the OEH and RMS sites. This profile is shown in Figure F-30.

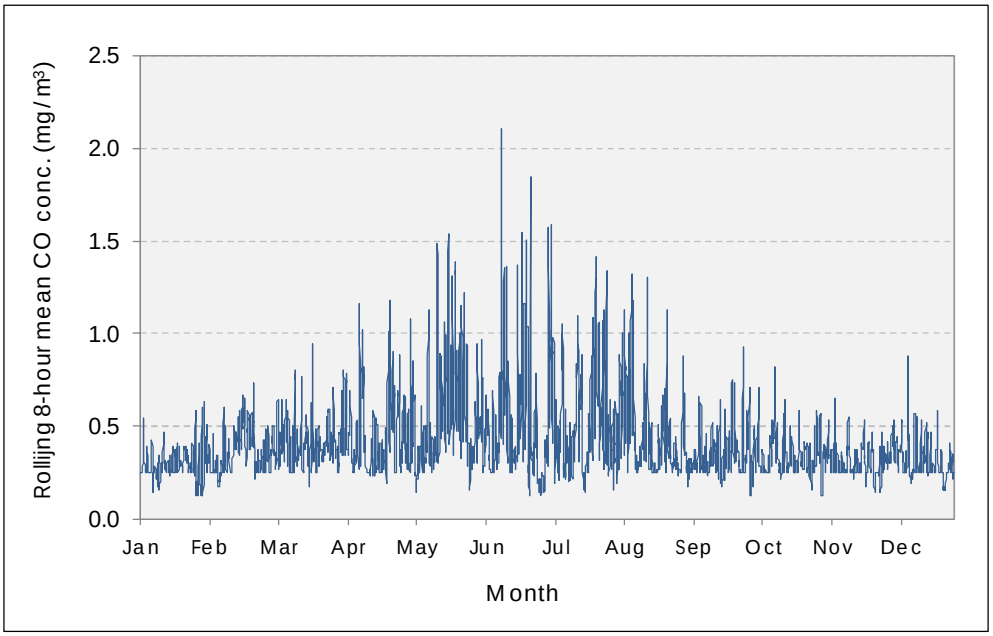


Figure F-30 Synthetic background concentration profile for rolling 8-hour mean CO

F.9.4 NO_X: annual mean

Annual mean concentrations of NO_X at the OEH sites have shown a downward trend in recent years, wheras those at the RMS sites decreased between 2008 and 2011 but have increased in recent years (Figure F-6). On balance, it was considered that the concentrations in 2014 would represent typical (but probably slightly conservative) background concentration going forward into the future. It was also noted earlier that there was quite a systematic spatial pattern in NO_X concentrations.

To allow for this spatial variation, the data from the OEH and RMS background monitoring sites were used to determine a background map for annual mean NO_X across Sydney in 2014, as shown in Figure F-31.

The background map was created in the Golden Software Surfer package using a geostatistical Kriging method, whereby gridded values are interpolated based on the statistical relationship of the surrounding measured values. The RMS site T1 was excluded from the dataset as NO_X concentrations at this location have exhibited a marked upward trend in recent years. The background map shows that there is a general NO_X concentration gradient from the south-west of Sydney to the north-west.

The NO_x map for the full WestConnex modelling (GRAL) domain is shown in more detail in Figure F-32. To determine background NO_X concentrations for discrete receptor locations within the modelling domain that did not coincide with grid nodes, the 'grid residual' function in Surfer was used. This function calculates the difference between the grid value and a specified data value at any X-Y location. By setting the data value for a given X-Y point to zero, it can be used to return the **estimated** concentration for the point.

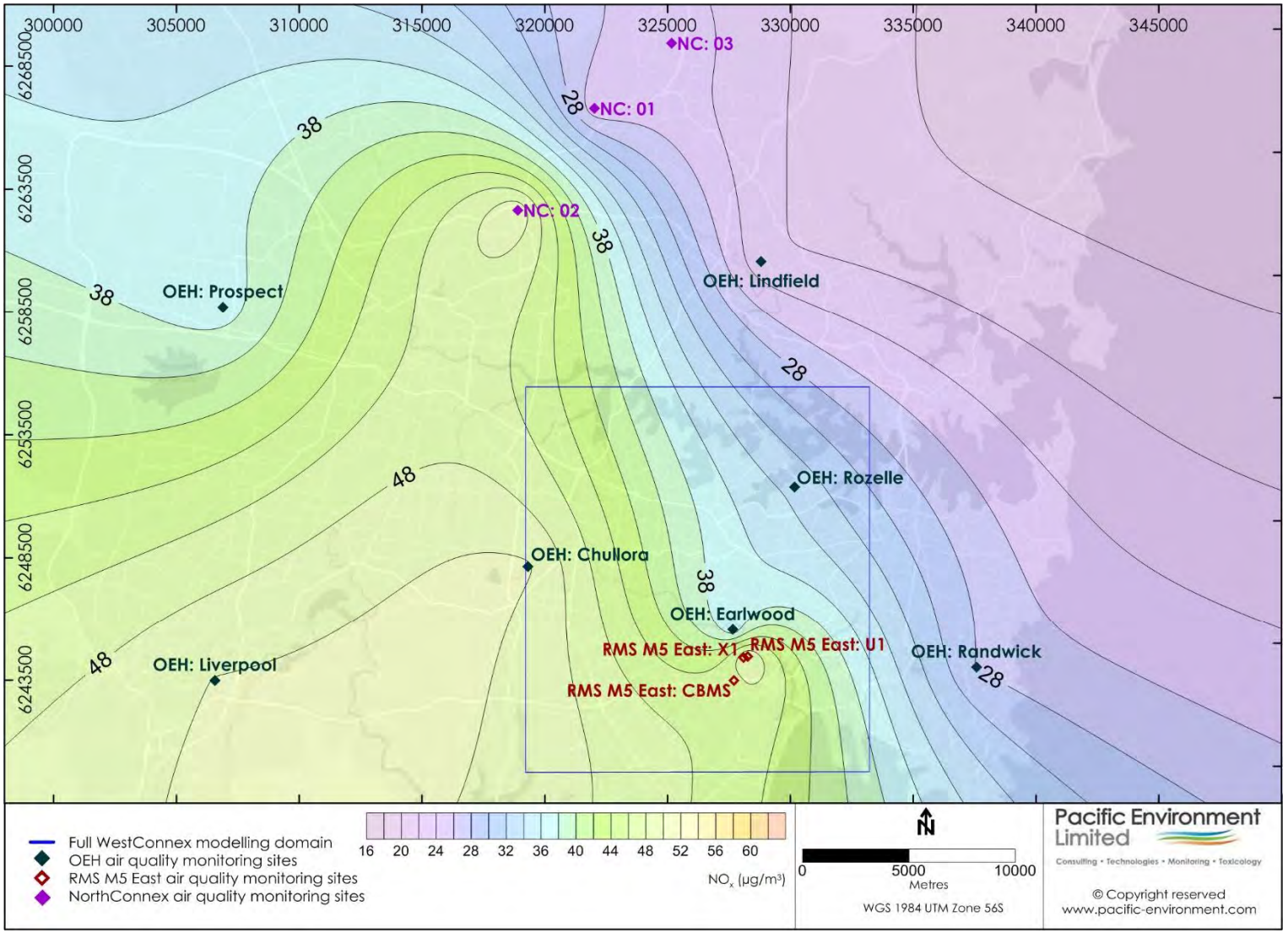


Figure F-31 Background map for annual mean NO_X concentration across Sydney in 2014

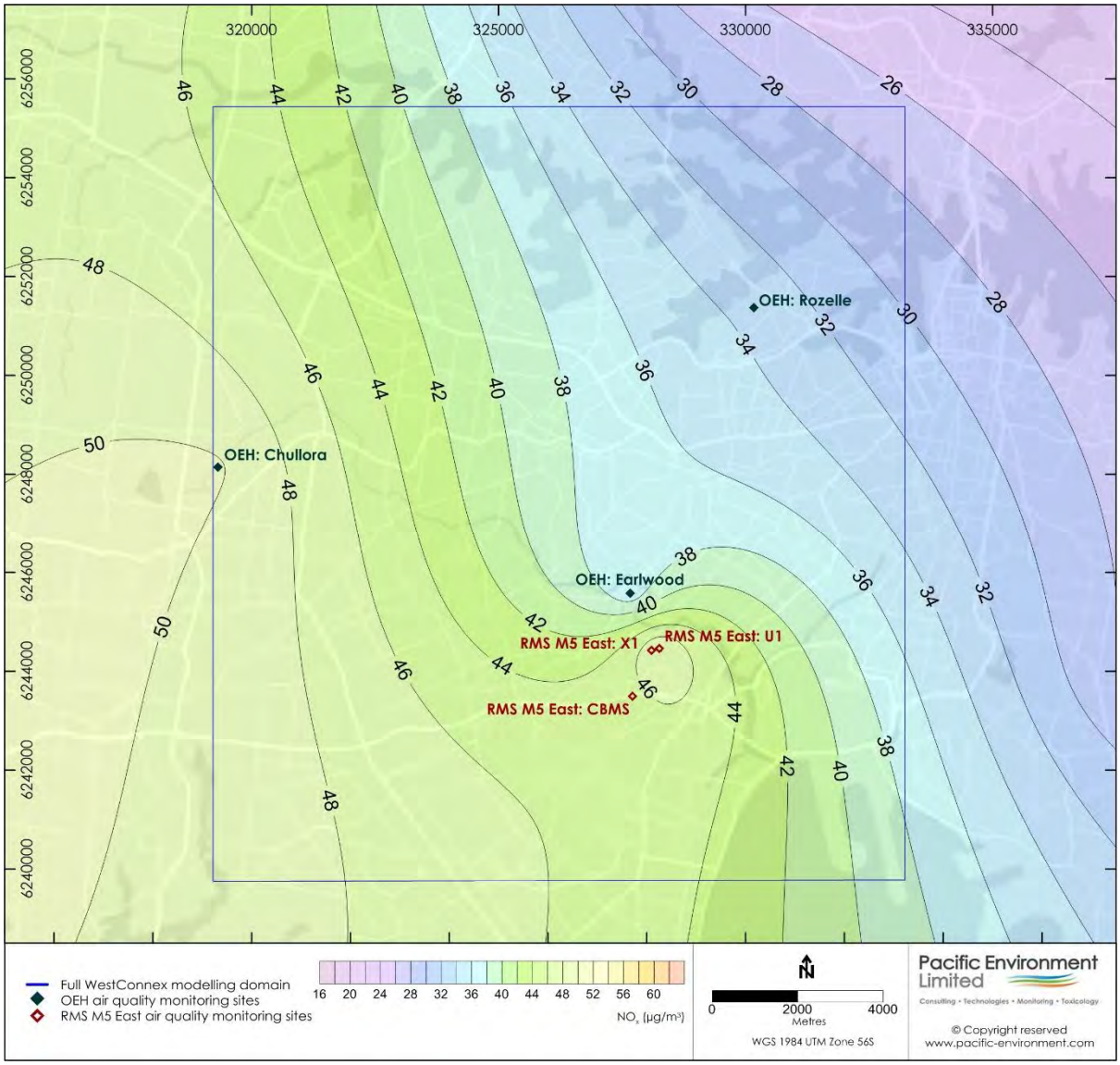


Figure F-32 Background map for annual mean NO_X concentration in 2014 (detail for WestConnex GRAL modelling domain)

F.9.5 NO_X: one-hour mean

The approach for one-hour mean NO_X was similar to that used for CO, with a synthetic concentration profile for 2014 being determined to allow for seasonal and spatial variation. Figure F-33 shows examples of one-hour concentration profiles at the OEH Chullora, Earlwood and Rozelle sites, and the RMS CBMS, U1 and X1 sites, during June of 2014. Peak concentrations regularly occurred simultaneously at the three sites, indicating a regional influence.

In order to introduce margin of safety the maximum concentration across the seven sites in each one-hour time step was used to define a synthetic background concentration profile for New M5 project in future years. Some minor filling of gaps was required. Most of the gaps were for single one-hour periods during the night (associated with instrument calibration), and these were filled by linear interpolation. The final synthetic background concentration profile for 2014 is shown in Figure F-34.

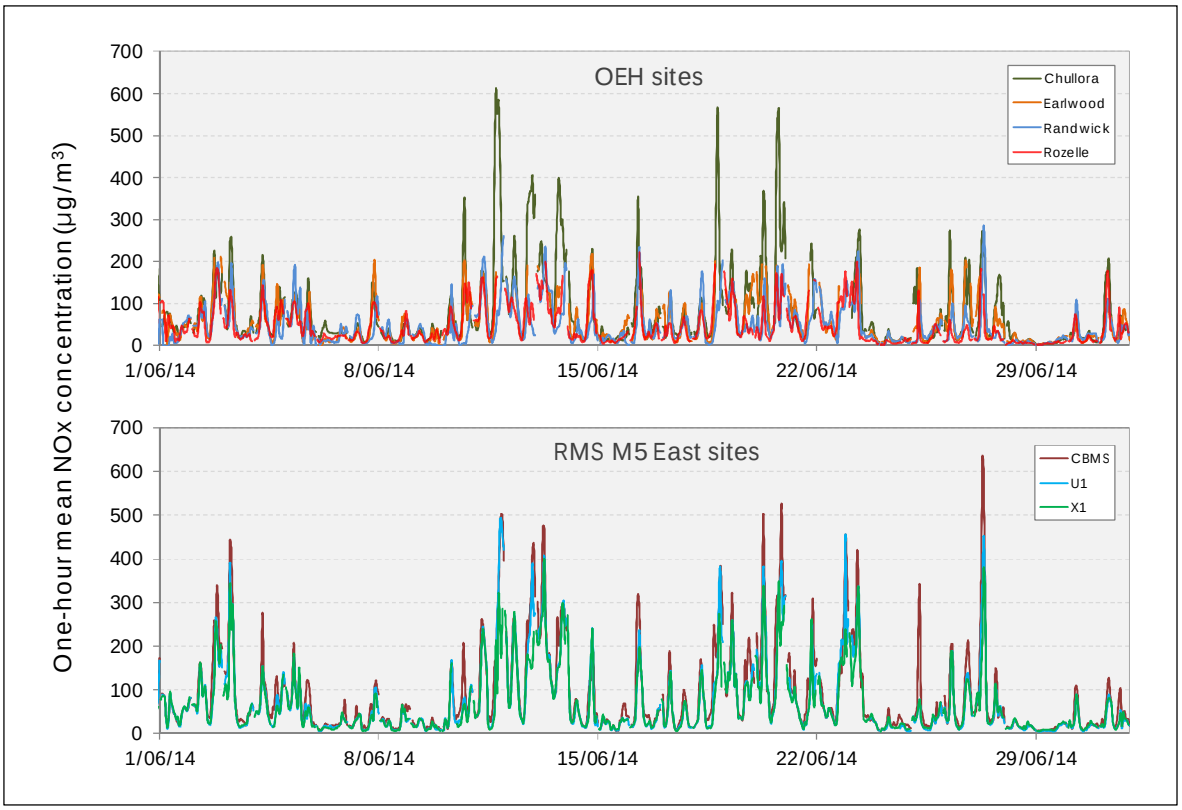


Figure F-33 **One-hour mean NO_X concentration at OEH and RMS M5 East sites (example for June 2014)**

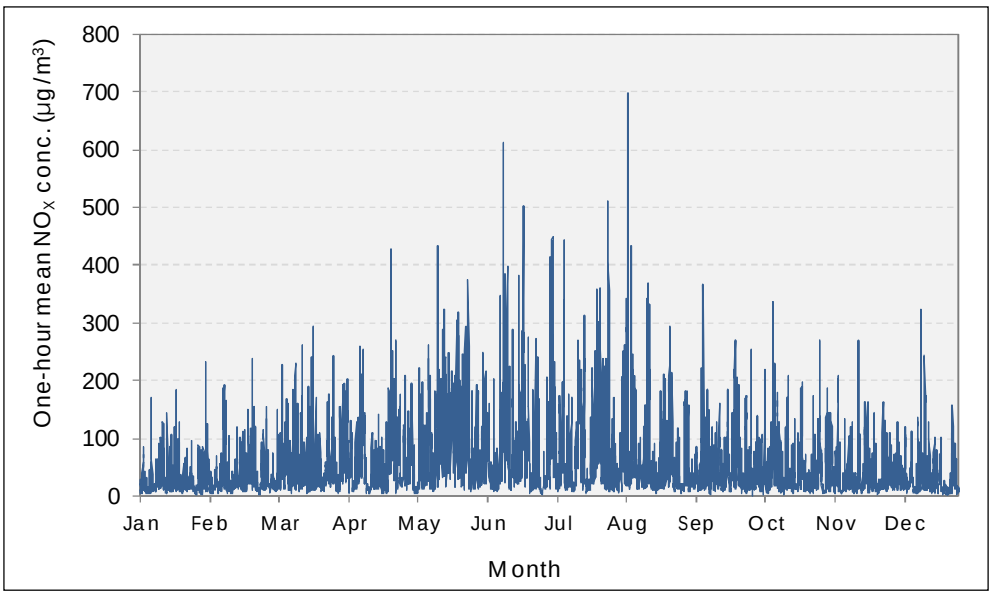


Figure F-34 **Synthetic background concentration profile for one-hour mean NO_X in 2014**

F.9.6 NO_2 and O_3

Synthetic background concentration profiles for 2014 were developed for one-hour mean NO_2 and O_3 concentrations using the available data from the OEH and RMS sites. These were only used to test the empirical NO_X-to-NO_2 conversion methods that were developed for the assessment (Appendix G), and not for the assessment itself. The synthetic concentration profile for NO_2 is shown in Figure F-35, and that for O_3 is shown in Figure F-36.

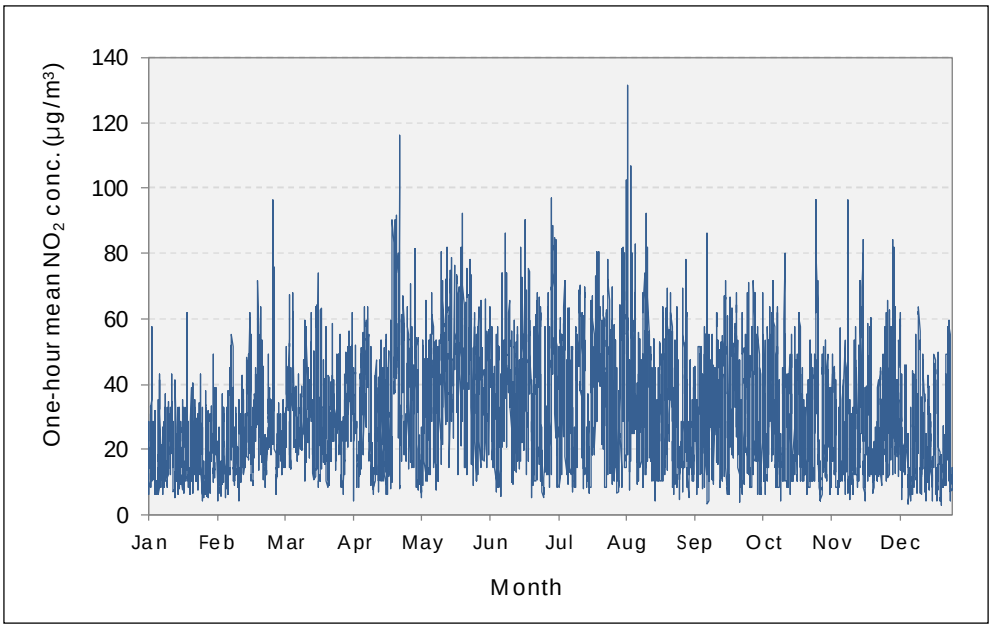


Figure F-35 Synthetic background concentration profile for one-hour mean NO_2

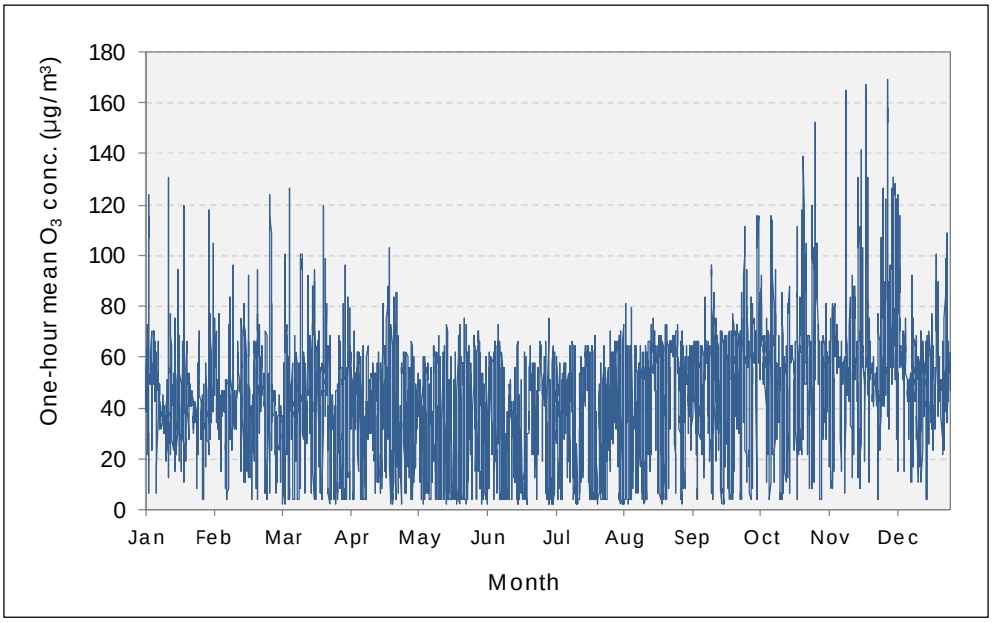


Figure F-36 Synthetic background concentration profile for one-hour mean O_3

F.9.7 PM_{10}: annual mean

The mapping approach for annual mean PM_{10} was the same as that used for annual mean NO_X. The background PM_{10} map for Sydney in 2014 is shown in Figure F-37, and the map for the WestConnex GRAL domain is provided in Figure F-38.

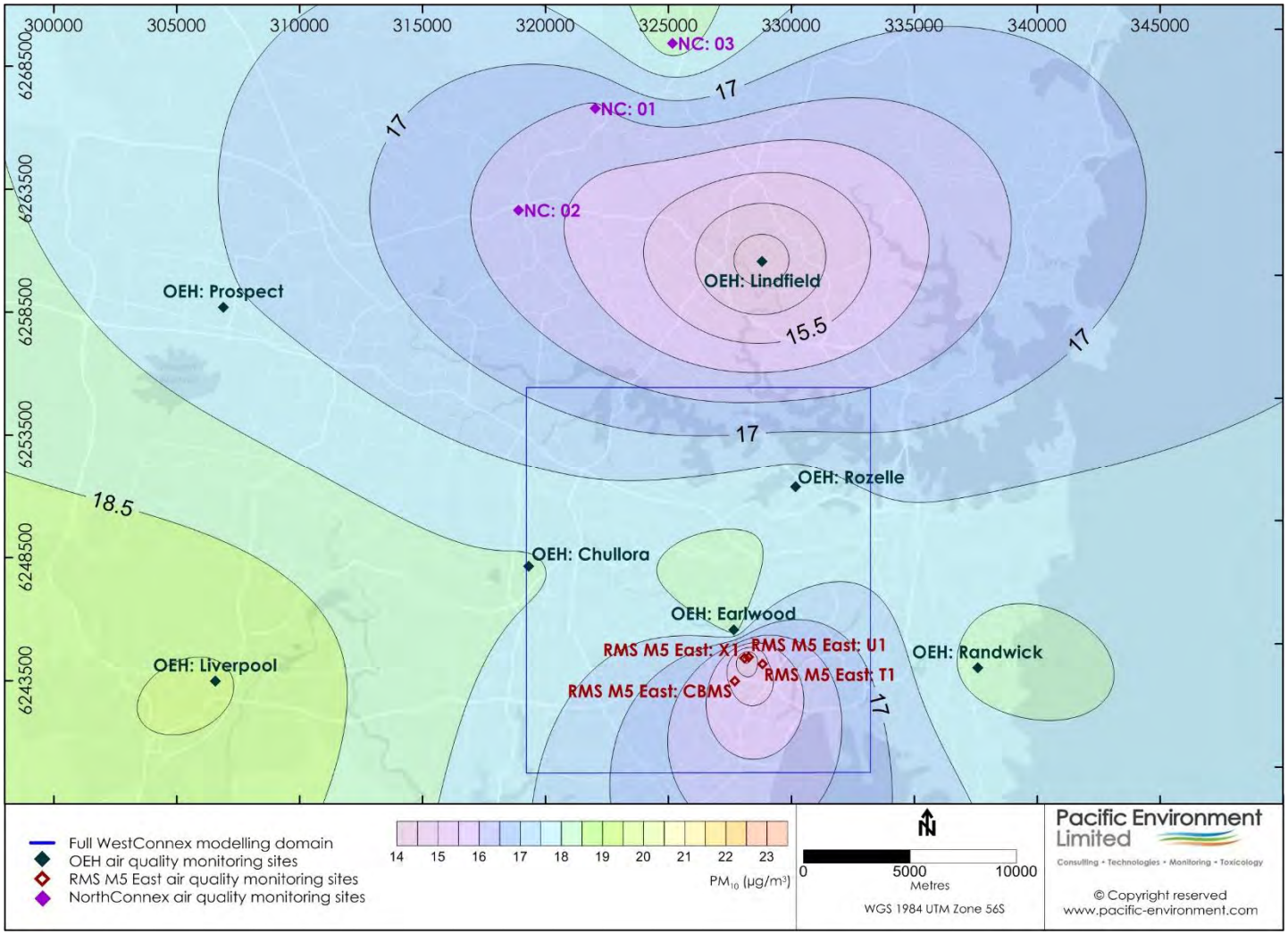


Figure F-37 Background map for annual mean PM_{10} concentration across Sydney in 2014

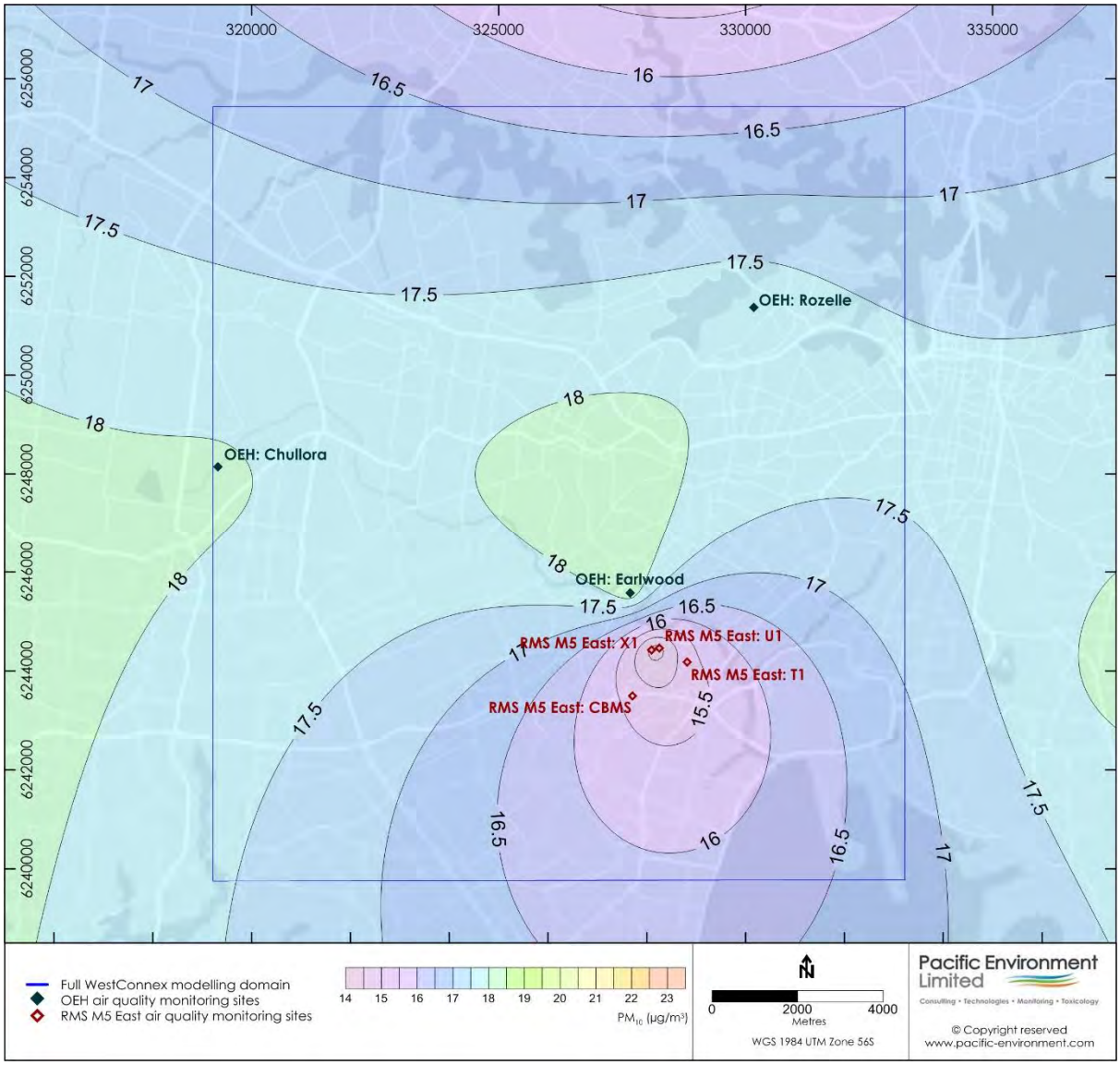


Figure F-38 Background map for annual mean PM_{10} concentration in 2014 (detail for WestConnex GRAL modelling domain)

F.9.8 PM_{10}: 24-hour mean

Figure F-39 shows the concentration profiles for 24-hour mean PM_{10} during 2014 at four OEH and four RMS sites. The strong similarities between the peaks and troughs in the profiles at the three sites show that the sites are characterising the same (*i.e*. regional) patterns in PM_{10}, although the absolute values vary slightly.

A synthetic 24-hour mean PM_{10} concentration profile for 2014 was also determined. This was based on the maximum concentration across the eight sites during each 24-hour time step. The final concentration profile is shown in Figure F-40.

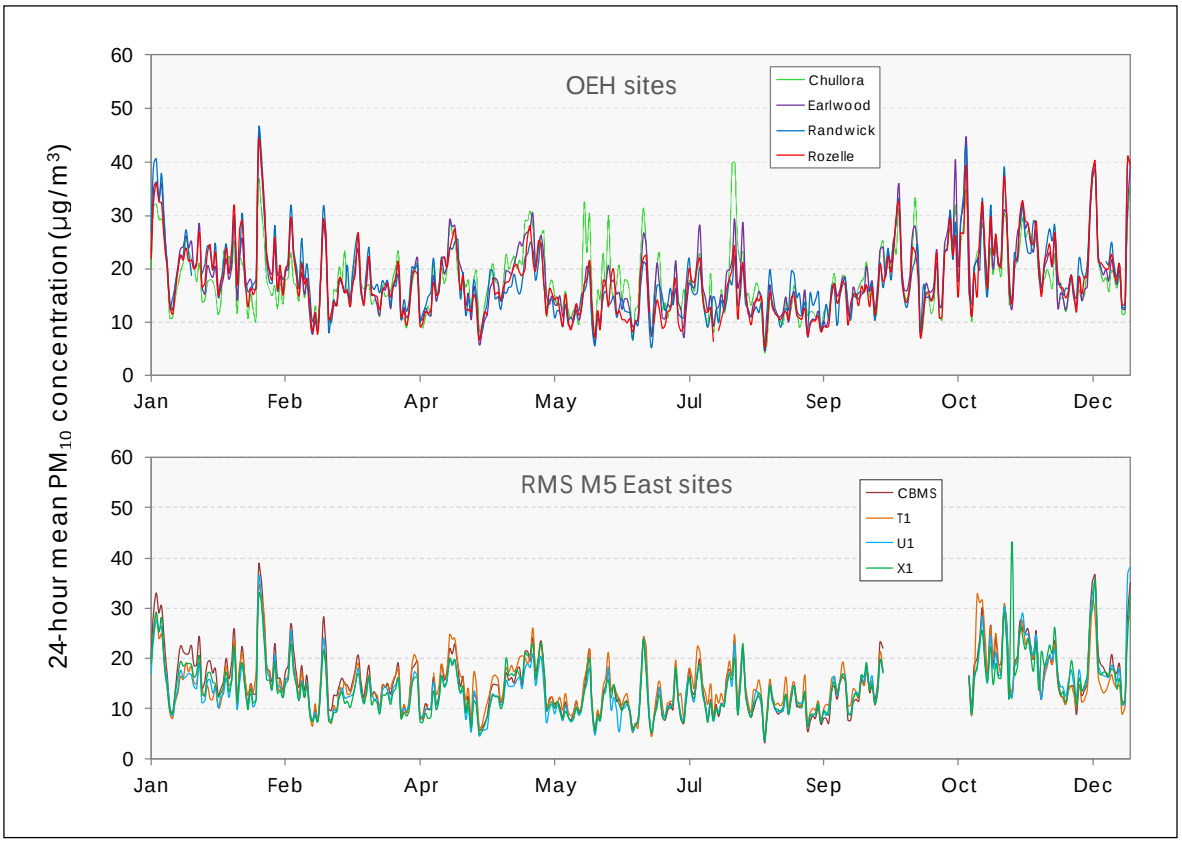


Figure F-39 24-hour mean PM_{10} concentration at OEH and RMS sites during 2014

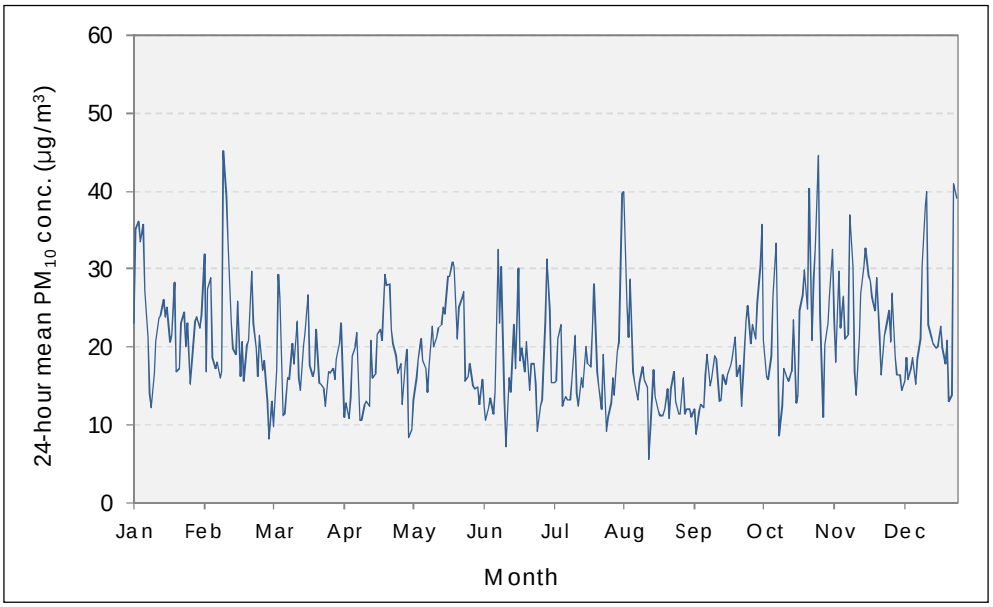


Figure F-40 Synthetic background concentration profile for 24-hour mean PM_{10}

F.9.9 $PM_{2.5}$: annual mean

The observations in Section F.6.5.1 render any assessment of the impacts of the New M5 project against the annual mean standard somewhat meaningless. For the purpose of the assessment a nominal $PM_{2.5}$ concentration of 8 $\mu g/m^3$ has been assumed, and any incremental changes due to the project have been assessed in relation to this concentration.

F.9.10 $PM_{2.5}$: 24-hour mean

The approach for $PM_{2.5}$ also involved the development of a synthetic concentration profile for 2014, although in this case it was just based on the data for Chullora and Earlwood sites. The concerntrations from the two sites are shown in Figure F-41, and the synthetic profile in Figure F-42.

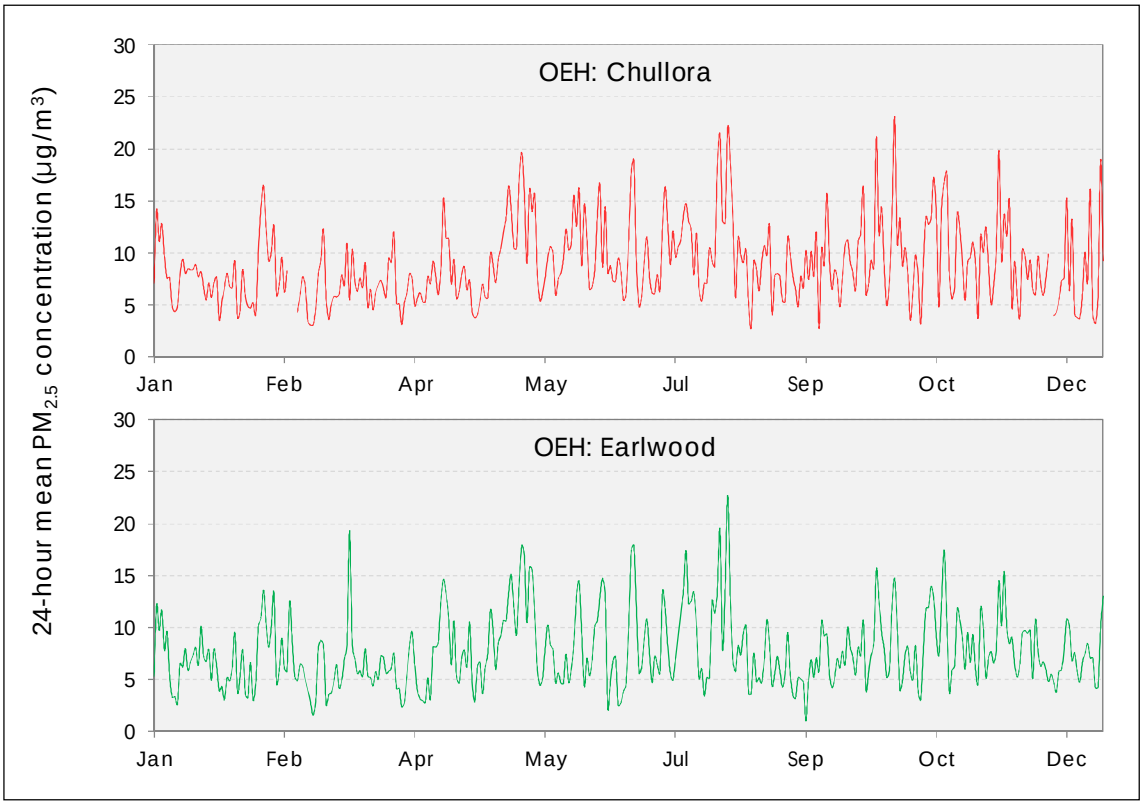


Figure F-41 24-hour mean $PM_{2.5}$ concentration at Chullora and Earlwood during 2014

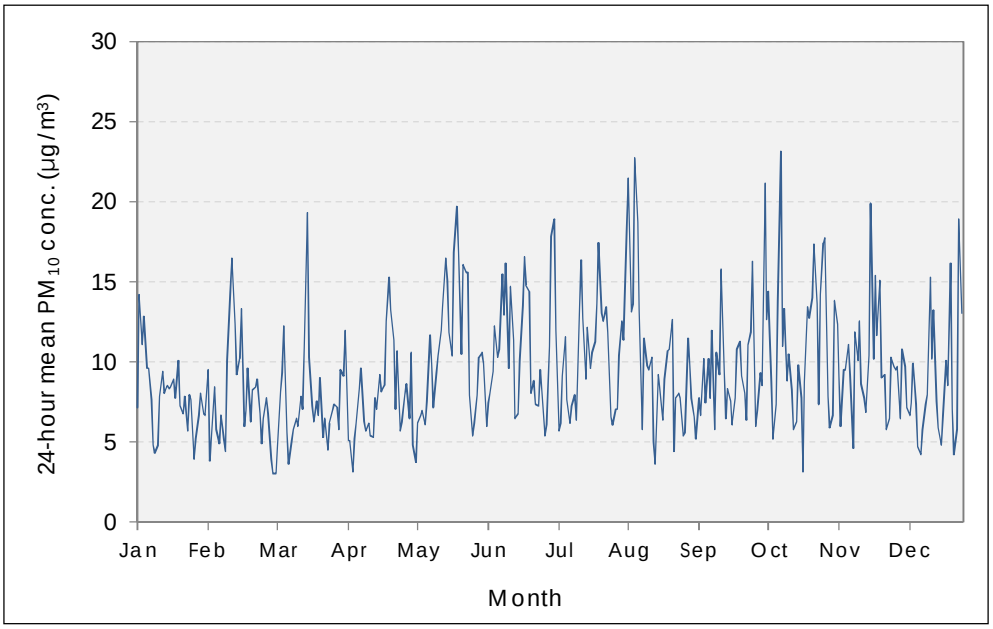


Figure F-42 Synthetic background concentration profile for 24-hour mean $PM_{2.5}$

F.9.11 Summary

The characteristics of the assumed background concentrations, and the forms of the concentrations, are provided in Table F-16. Because of their nature the synthetic profiles had slightly higher annual mean concentrations than the sites used to develop the maps. However, the synthetic profiles were only designed for the evaluation of short-term criteria.

Table F-16 Characteristics of assumed background concentrations

Pollutant/ metric	Averaging period	Form	Units	Statistical descriptors		
				Mean	Max	98th %ile
CO	1 hour	Synthetic profile	mg/m^3	0.43	2.87	1.33
	8 hours (rolling)	Synthetic profile	mg/m^3	0.42	2.11	1.08
NO_X	Annual	Map	µg/m^3	Spatially varying	-	-
	1 hour	Synthetic profile	µg/m^3	65.1	697.8	294.1
PM_{10}	Annual	Map	µg/m^3	Spatially varying	-	-
	24 hours	Synthetic profile	µg/m^3	20.5	46.1	40.0
$PM_{2.5}$	Annual	Single value	µg/m^3	8.0	-	-
	24 hours	Synthetic profile	µg/m^3	9.4	23.1	18.9

Appendix G - NO_X-to-NO_2 conversion

G.1 Overview

Some atmospheric pollutants have slow chemical reaction rates, and for air quality modelling on an urban scale they can essentially be treated as inert (Denby, 2011). This is not the case for NO_2 since it is rapidly formed through the atmospheric reaction of NO with O_3, and is destroyed by sunlight during the day (see Appendix B). This is one reason why air pollution models are generally configured to predict NO_x concentrations, with the spread of NO_X being simulated as though it were a non-reactive gas (NZMfE, 2008). However, as air quality criteria address NO_2 rather than NO_X it is necessary to estimate NO_2 concentrations from the modelled NO_X concentrations. Many different approaches to this conversion have been developed over the years, and this Appendix describes the approach used for the New M5 assessment.

The estimation of NO_2 concentrations near roads is not straightforward. It requires an understanding of the complexity of NO_2 formation and destruction, and here there are a number of challenges. These include:

- How to account for the amount of primary NO_2 emitted in vehicle exhaust. This is dependent on the composition of the traffic, and is changing as the vehicle fleet evolves.
- How to account for the amount of conversion of NO to NO_2 in the atmosphere following release from the source, as this is dependent on the local atmospheric conditions, including the amount of ozone available.
- How to determine cumulative NO_2 concentrations, or in other words how to combine the road traffic contribution and the background (non-road) contribution.
- How to provide a realistic estimate of the change (whether this be an increment or decrement) in the NO_2 concentration that results from a road project.

The challenges are also greater for the 1-hour air quality criterion than for the annual mean criterion. For example, the maximum predicted NO_X concentration will not occur during the same hour of the year at all locations in the model domain.

In order to ensure that an appropriate and pragmatic method was selected for the New M5 assessment, a review of the literature and data was undertaken. This Appendix presents the findings of the review and contains the following:

- A brief summary of the available guidance relating to the estimation of NO_2 concentrations.
- A review of the methods that are commonly used for estimating NO_2 concentrations. These either involve the use of empirical data or the modelling of atmospheric chemistry. In practice empirical approaches tend to be applied, as local knowledge on the inputs required for modelling chemistry is often incomplete.
- An analysis of the NO_X and NO_2 data from ambient air quality monitoring stations in Sydney, including the monitoring stations that were established specifically for the New M5 project. This analysis was used to estimate NO_X-to-NO_2 conversion methods for the specific purpose of the New M5 assessment, and more widely for complex road projects in Sydney.

G.2 Guidance on NO_2 estimation

G.2.1 New South Wales

Guidance on the conversion of modelled NO_X to NO_2 is provided in the Approved Methods for the Modelling and Assessment of Air Pollutants in New South Wales (NSW DEC, 2005). Three methods are described for calculating the oxidation of NO to NO_2, from Method 1, the most simple, to Method 3, the most complex.

G.2.2 North America

The USEPA's Guideline on Air Quality Models (GAQM) provides recommendations on the use of air quality models to determine compliance with National Ambient Air Quality Standards (NAAQS). The Guideline is published as Appendix W of 40 CFR Part 51. In this case, three 'Tiers' of assessment are provided, with Tier1 being the simplest and Tier 3 the most complex. Additional guidance on the assessment of 1-hour NO_2 concentrations has recently been provided in the following:

- Applicability of Appendix W Modeling Guidance for the 1-hour NO_2 National Ambient Air Quality Standard, June 28, 2010[1].
- Additional Clarification Regarding Application of Appendix W Modeling Guidance for the 1-hour NO_2 National Ambient Air Quality Standard, March 1, 2011[2].

Other recent guidelines include:

- Modeling Compliance of the Federal 1-Hour NO_2 NAAQS (CAPCOA, 2011).
- Air Quality Model Guideline (Alberta Government, 2013).

[1] http://www.epa.gov/scram001/guidance/clarification/ClarificationMemo_AppendixW_Hourly-NO2-NAAQS_FINAL_06-28-2010.pdf
[2] http://www.epa.gov/region7/air/nsr/nsrmemos/appwno2_2.pdf

- Guidelines for Air Quality Dispersion Modelling in British Columbia (BCMoE, 2008).

G.2.3 New Zealand

The following documents provide guidance on the estimation of NO_2 for air quality assessments in New Zealand:

- Good Practice Guide for Atmospheric Dispersion Modelling (NZMfE, 2004).
- Good Practice Guide for Assessing Discharges to Air from Industry (NZMfE, 2008), which updates the 2004 document.

G.2.4 United Kingdom

Guidance documents from the UK include:

- Review of background air-quality data and methods to combine these with process contributions (Environment Agency, 2006).
- Review of methods for NO to NO_2 conversion in plumes at short ranges (Environment Agency, 2007). This report focusses on the regulation of large industrial point sources.
- Local Air Quality Management Technical Guidance LAQM.TG(09) (Defra, 2009). This document is designed to support UK local authorities in carrying out their duties with respect to air quality management. A number of tools have been developed to support the guidance, including background maps of air pollutants, with year adjustment factors and a calculator that can be used to derive NO_2 from NO_X which is predicted when modelling emissions from roads.

G.3 Estimation methods

G.3.1 General approaches

In some assessments the road traffic and background concentrations to NO_2 at any given receptor have simply been added together to give the cumulative concentration, i.e.:

Equation G1

$$[NO_2]_{total} = [NO_2]_{road} + [NO_2]_{background}$$

where:

$[NO_2]_{total}$ is the total estimated NO_2 concentration at the receptor

$[NO_2]_{road}$ is the modelled NO_2 concentration at the receptor due to a road (or roads) in the modelling domain

$[NO_2]_{background}$ is the existing background NO_2 concentration at the receptor due to emissions from all sources other than roads

As the background is often assumed to be fixed, in this formulation the NO_2 increment or decrement associated with a project is simply the change in the value of $[NO_2]_{road}$ for model runs with and without the project. This has to be determined in some way from the road NO_X increment. However, there is a flaw in this approach. Whilst the road and background contributions to NO_X are additive, this is not the case for NO_2. The potential for oxidising NO to NO_2 is dependent on the amount of ozone that is available, which in turn is dependent on the NO concentration. The higher the existing background NO concentration, the less ozone that is available and the smaller the possibility of oxidising the NO from road vehicles to NO_2.

For any given model prediction/scenario it is therefore more appropriate to determine the total NO_2 concentration from the total NO_X concentration. This can be expressed as follows:

Equation G2

$$[NO_X]_{total} = [NO_X]_{road} + [NO_X]_{background}$$

Equation G3

$$[NO_2]_{total} = f([NO_X]_{total})$$

Where $f([NO_X]_{total})$ is the method used to convert total NO_X to total NO_2.

The NO_2 increment or decrement associated with the project is then calculated as follows:

Equation G4

$$[NO_2]_{project} = [NO_2]_{total\ (with\ project)} - [NO_2]_{total\ (without\ project)}$$

G.3.2 Specific methods

Several methods are available for characterising the transformation of NO to NO_2. These include:

- Total conversion method:
    - Assuming that all NO_X from the emission source being modelled is present as NO_2 (i.e. there is always total conversion of NO to NO_2. This is 'Method 1' in the NSW Approved Methods and the USEPA's 'Tier 1' approach).
- NO_2/NO_X ratio methods, including:
    - Assuming a constant NO_2/NO_X ratio. This is the USEPA's 'Tier 2' approach, which is referred to as the 'ambient ratio method' (ARM).
    - Assuming a variable NO_2/NO_X ratio to all for influences such as the season and distance from source.

  NO_X to NO_2 conversion methods that use ambient ratios are usually based on empirical data. Empirical relationships fall within the 'Method 3' in the NSW EPA Approved Methods.
- Reactant-limited methods, whereby the instantaneous conversion of NO is constrained only by the amount of oxidant(s) available. Such methods include:
    - The 'ozone limiting method (OLM)', in which NO to NO_2 conversion is limited by the amount of ozone available (known as 'ozone titration'). This is 'Method 2' in the NSW Approved Methods, and is a USEPA Tier 3 approach.
    - The plume volume molar ratio method (PVMRM), which is also based on ozone titration. This is a USEPA 'Tier 3' approach. It is not mentioned in the NSW Approved Methods.
- Reactive plume methods. These use complex or simplified atmospheric photochemical reaction schemes which derive NO_2 concentrations from first principles. Such approaches have been incorporated into some of the latest generation of air pollution models.

The different methods presented in the literature are summarised in the following Sections.

G.3.3 Total conversion of NO to NO_2

G.3.3.1 Description

The most basic – and most conservative – method for estimating the NO_2 concentration at a receptor is based on the assumption that all emitted NO is oxidised to NO_2, or in other words all modelled NO_X from roads is present as NO_2:

Equation G5

$$[NO_2]_{road} = [NO_X]_{road}$$

Equation G6

$$[NO_2]_{total} = [NO_2]_{road} + [NO_2]_{background}$$

This approach is often used as a screening step; if compliance with air quality standards is obtained using this approach, then it can be assumed that there will be negligible risk of exceedances in reality and more detailed calculations for NO_2 are not required. If, on the other hand, the estimated NO_2 concentrations are close to or higher than the air quality standards then more detailed, less conservative methods should be applied.

G.3.3.2 Application in NSW Approved Methods

For annual mean concentrations the modelled NO_x concentration is converted to NO_2 (assuming 100% conversion of NO), and the result is then simply added to the background NO_2 concentration.

For 1-hour means, the cumulative concentration can be determined in one of two ways:

- Level 1 (maximum): The maximum modelled 1-hour mean NO_2 concentration is added to the maximum background 1-hour mean NO_2 concentration.
- Level 2 (contemporaneous): Using contemporaneous assessment of model predictions and ambient concentrations. The cumulative NO_2 concentration is determined by adding the modelled 1-hour mean NO_2 concentration with the contemporaneous background 1-hour mean NO_2 concentration.

G.3.3.3 Limitations and performance

This method represents a worst-case situation. It does not allow for the availability of ozone or NO_2 destruction through photolysis, and will overestimate NO_2 concentrations. The overestimation will be largest at high NO_X concentrations where NO_2 formation is ozone-limited. This is explored further in Section G5. The total conversion method is therefore of limited use where an accurate estimate of NO_2 is required.

G.3.4 NO_2/NO_X ratio methods

G.3.4.1 Description

Constant ratio

In the USEPA's ARM, the predicted NO_X concentration for a receptor is multiplied by an empirically derived NO_2/NO_X ratio to determine the NO_2 concentration at the receptor. The NO_2/NO_X ratio is based upon average NO_2 and NO_X concentrations in ambient air at a representative site. For example, in the USEPA 'Tier 2' approach the modelled annual mean NO_X concentrations is multiplied by a default NO_2/NO_X ratio of 0.75. For 1-hour concentrations a NO_2/NO_X ratio of 0.80 is used.

Variable ratio

ARM2

A new empirical method, known as ARM2, has recently been developed by the American Petroleum Institute in response to the frequent observation that hourly NO_2 concentrations estimated using the existing USEPA three-tier approach are much higher than observed concentrations. ARM2 is based on an empirical fit to the 98th percentiles of the binned 1-hour NO_2/NO_X and NO_X values collected from different monitoring stations between 2001 and 2010 (RTP, 2013; Podrez, 2015). The USEPA has approved the use of ARM2 for regulatory 1-hour NO_2 assessments under certain circumstances.

Janssen method

The NSW Approved Methods refer to the approach of Janssen et al. (1988). This involves the use of an empirical equation for estimating the oxidation rate of NO in power plant plumes. The equation is dependent on distance downwind from the source and the parameters A and α, and has the following form:

Equation G7

$$[NO_2]/[NO_X] = A\,(1 - \exp(-\alpha x))$$

where:

x = the distance from the source

A and **α** are classified according to the O_3 concentration, wind speed and season (Janssen et al. (1988) provide values for **A** and **α**).

Given that this method requires the distance from the source to be quantified, the method is not suitable for complex road networks.

Defra method

An empirical approach to calculating NO_2 from NO_X concentrations at roadside sites was developed by Defra in the UK in 2002 and then updated in 2007[3]. In 2009 Defra published a revised approach for predicting NO_2 from NO_X concentrations at roadside sites, which takes account of the difference between fresh emissions of NO_x, the background NO_x, the concentration of O_3, and the different proportions of primary NO_2 emissions in different years. The approach has been incorporated into a simple spreadsheet which is available from the Defra web site.

[3] http://laqm1.defra.gov.uk/review/tools/monitoring/calculator.php

G.3.4.2 Limitations and performance

The ARM2 method has some advantages over other USEPA Tier 3 methods. For example, it does not require ambient ozone data. The performance of the ARM2 method is comparable to that of the OLM and the PVMRM. However, all three methods over-predict NO_2/NO_X ratios (RTP, 2013).

According to NZMfE (2004) the Janssen approach is based upon the rate of diffusion of O_3 into the emission plume rather than the rates of reaction. It is therefore probably only applicable to the particular power station studied, and is of questionable application to other sources. Although the Approved Methods describe the application of the Janssen method to determine annual mean and 1-hour mean concentrations, its lack of applicability to road networks means that it has not been explored in detail in this Appendix. There is little information on how the NO_2/NO_X ratio changes with distance from the road; monitoring data are usually only available for roadside and/or background locations.

Given that it has been developed to represent vehicle fleets and near road atmospheres in the UK, it is unlikely that the Defra calculator is suitable for use in Sydney, although this ought to be investigated further. However, this was beyond the scope of the New M5 assessment.

G.3.5 Reactant-limited methods

G.3.5.1 Description

Ozone limiting method

The USEPA's ozone limiting method (OLM) is one of several reactant-limited approaches. It uses a simple approach to the reaction chemistry of NO and O_3 in order to estimate NO_2 concentrations. It is assumed that all the available O_3 in the atmosphere will react with the NO from the source until either all the O_3 is consumed or all the NO is used up (Cole and Summerhays, 1979; Tikvart, 1996). A slightly different approach to the OLM has been developed for use in New Zealand (NZMfE, 2008).

Plume volume molar ratio method

The plume volume molar ratio method (PVMRM) extends the basic chemistry of the OLM. The PVMRM determines the conversion rate for NO_x to NO_2 based on a calculation of the number of NO_x moles emitted into the plume, and the number of O_3 moles contained within the volume of the plume between the source and receptor. The ratio between the two molar quantities is multiplied by the NO_X concentration to calculate the NO_2 concentration.

Both the OLM and PVMRM require two key model inputs, namely NO_2/NO_X emissions ratio at source and background ozone concentrations.

G.3.5.2 Implementation in NSW Approved Methods

The USEPA version of the OLM (adapted here for road projects) is represented by the equation (NSW DEC, 2005):

Equation G8

$$[NO_2]_{total} = \{0.1 \times [NO_X]_{road}\} + MIN\ \{(0.9) \times [NO_X]_{road}\ \text{or}\ (46/48) \times [O_3]_{background}\} + [NO_2]_{background}$$

where:

$[NO_2]_{total}$ = predicted concentration of NO_2 in µg/m^3

$[NO_X]_{road}$ = dispersion model prediction of NO_X from roads in µg/m^3

MIN = minimum of the two quantities within the braces

$[O_3]_{background}$ = background ambient O_3 concentration in µg/m^3

(46/48) = molecular weight of NO_2 divided by the molecular weight of O_3 in µg/m^3

$[NO_2]_{background}$ = background ambient NO_2 concentration in µg/m^3

The method involves an initial comparison of the estimated maximum NO_X concentration and the ambient O_3 concentration to determine the limiting factor to NO_2 formation:

- If the O_3 concentration is greater than the maximum NO_X concentration, then total NO_X to NO_2 conversion is assumed.

- If the maximum NO_X concentration is greater than the ozone concentration, the formation of NO_2 is limited by the ambient ozone concentration.

The OLM – in the above form – is based on the assumption that 10% of the initial NO_x emissions are NO_2. The emitted NO reacts with ambient ozone to form additional NO_2. If the ozone concentration is greater than 90% of the predicted NO_x concentration, all the NO_X is assumed to be converted to NO_2. Otherwise, NO_2 concentrations are calculated on the assumption of total conversion of the ozone. The predicted NO_2 concentration is then added to the background NO_2 concentration.

The following approaches are presented in the Approved methods for the 'maximum' and 'contemporaneous' calculations:

- Level 1 (maximum): The maximum 1-hour and annual average background concentrations of NO_2 and O_3 ($[NO_2]_{background}$, $[O_3]_{background}$) are used in Equation G8.
- Level 2 (contemporaneous): Continuous 1-hour average background concentrations of NO_2 and O_3 are obtained for the same period as the dispersion modelling predictions (usually one year). The value of $[NO_2]_{total}$ is then calculated for every hour of the dispersion model simulation by substituting the hourly values of $[NO_X]_{road}$, $[NO_2]_{background}$ and $[O_3]_{background}$ into Equation G8.

As before, the Level 1 approach is used as a screening step. The OLM is usually applied using the Level 2 approach, and this has the advantage of yielding various statistics for NO_2, including:

- The annual mean concentration (based on the 1-hour predictions for a year).
- The maximum concentration.
- Percentile concentration values.
- The frequency with which the 1-hour NO_2 criterion is exceeded.

In the NSW submission to the EIS for the NorthConnex project in Sydney, it is stated that that an average value for the NO_2/NO_X ratio of 16%[4] would be more appropriate than 10%. The OLM equation should therefore be adjusted as follows (AECOM, 2014b):

Equation G9

$$[NO_2]_{total} = \{0.16 \times [NO_X]_{road}\} + MIN\ \{(0.84) \times [NO_X]_{road}\ \text{or}\ (46/48) \times [O_3]_{background}\} + [NO_2]_{background}$$

The effect of the adjustment is to increase the amount of NO_2 emitted directly, potentially increasing the NO_2 concentrations that are predicted under low ambient O_3 concentrations.

G.3.5.3 Limitations and performance

Several limitations of the OLM have been noted:

- The approach is known to be conservative:
    - The method assumes that the atmospheric conversion of NO to NO_2 occurs instantaneously. In reality, the reaction requires time. This assumption therefore leads to an overestimate of NO_2 concentrations close to the source (NZMfE, 2004).
    - The method assumes that all ozone is available to the emission source being evaluated. The OLM will be too conservative when, for example, a new source is to be located in close proximity to existing sources. The new source will be competing with the existing sources for the available ozone, and the rate of conversion of NO to NO_2 will not be as great as if the new source was in an isolated location (NZMfE, 2004).
    - Ozone is assumed to be uniformly and continuously mixed across the cross section of the plume. The OLM does not account for the molar ratio of NO to ozone in the plume (reactions occur in proportion to the moles of each gas rather than in proportion to the concentrations assumed by the OLM), nor does it account for the gradual entrainment and mixing of ambient ozone in the plume.
    - Situations in which the OLM has been demonstrated to substantially overestimate NO_2 concentrations include during daylight hours when the photochemical equilibrium reverses the oxidation of NO by O_3, and during stable, night-time conditions when both NO_2 and O_3 are removed by reaction with vegetation and other surfaces (NZMfE, 2004).

[4] This is the upper bound of the estimated ratio used for the in-tunnel modelling in Appendix L for primary NO_2. The in-tunnel modelling considers the ratio variations for different traffic speeds and different tunnel grades.

- The OLM model requires a record of 1-hour average background concentrations over a year. Apart from the expense of obtaining such information at a single location, there are significant problems in locating the monitoring site relative to existing emission sources and a proposed new emission source because of the perceived difficulty of accounting for scavenging of O_3 by NO (NZMfE, 2004).
- The USEPA states that the OLM should only be used on a 'plume-by-plume' basis. This is a severe limitation in relation to road projects.

Some of these limitations also apply to the PVMRM. Because of the different methods used, there are cases where PVMRM will perform better than OLM, and vice versa. The PVMRM better simulates the NO to NO_2 conversion chemistry during plume expansion, and works well for isolated elevated point sources. However, OLM may be the better choice for low level releases and area sources. For low level releases the modelled plume may extend below ground level, but the PVMRM will still use the full volume of the plume to estimate the NO_x-to-NO_2 conversion. This may lead to overly conservative NO_2 concentrations.

G.3.6 Reactive plume models

Various photochemical reaction schemes are applied in regional-scale and urban-scale air pollution models. One of the most commonly used is the Generic Reaction Scheme (Azzi *et al.*, 1992). More detailed photochemical models and schemes have been developed in recent years, including the EMEP scheme (Simpson *et al*., 2003), the Carbon Bond-IV mechanism (Gery *et al*., 1989), and the CB05 photochemical mechanism (Yarwood *et al*., 2005).

However, the use of such models is uncommon for regulatory local air quality assessments. A major drawback of these methods is that the near-source chemical reactions may not be well described. Many of the atmospheric chemistry schemes developed for regional and global models include reactions on timescales that are much longer than the residence times of pollutants in urban areas, and as such introduce an additional complexity and computational time that is unnecessary (Denby, 2011). As noted by the Environment Agency (2007), care is required to select a chemical mechanism, and advanced photochemical modelling requires a comprehensive set of emissions data for a wide range of compounds (notably hydrocarbons), as well as the appropriate meteorological data. These are major constraints on any regulatory work.

G.4 Development of empirical conversion methods for Sydney

G.4.1 Overview

Various air quality guidance documents recommend the use of local monitoring data to estimate NO_2 concentrations, where such data are available. Empirical methods for converting NO_X to NO_2 were therefore developed specifically for the New M5 assessment.

The analysis involved the fitting of functions to the monitoring data. Functions have been fitted to data of this type for many years, notably in the form of the 'Derwent-Middleton' equation (Derwent and Middleton, 1996), and this continues to be the case (e.g. Podrez, 2015).

The methods were based upon the analysis of substantial amounts of air quality monitoring data from locations in Sydney, and are also applicable more widely to other complex road projects in the airshed. One reason for this analysis was to quantify and address the conservatism in some of the other methods in use, whereby exceedances of NO_2 air quality standards can be predicted for a given NO_X concentration, even where the monitoring data show that this situation is not the reality.

NO_X and NO_2 have been measured for several years at a range of locations across Sydney, as described in Appendix F. Based on the analysis of the data, separate approaches were developed for annual mean and 1-hour mean NO_2 concentrations. These approaches were as follows:

- For annual mean NO_2 concentrations:
    - A best estimate approach, which gave the most likely annual mean NO_2 concentration for a given annual mean NO_X concentration. This method was used in the air quality assessment.
    - A reasonable worst case estimate which gave the maximum possible annual mean NO_2 concentration for a given annual mean NO_X concentration. This method was developed for sensitivity testing.
- For the maximum 1-hour mean NO_2 concentrations the situation was more complicated. Ideally, for every receptor the average NO_2 concentration in each hour of the year should be determined using a contemporaneous approach which combines the hourly background and road NO_X contributions, and then converts the total NO_X to total NO_2. However, this approach is impractical where many receptors are being investigated, and indeed the number of receptors for which a full time series of predictions can be obtained is often limited in the dispersion model (as is the case with GRAL), or is computationally very intensive. Two approaches for calculating maximum 1-hour NO_2 concentrations were therefore used:

- A ‘detailed’ contemporaneous approach that was only applied to the community receptors (e.g. schools, hospitals, day care centres). This also involved the use of a conservative upper bound function which gave the maximum likely 1-hour mean NO_2 concentration for a given 1-hour mean NO_X concentration. Given the wide range of possible NO_2 concentrations for a given NO_X concentration, this approach was used to conservatively estimate the maximum 1-hour mean NO_2 concentrations.
- A ‘simple’ statistical (non-contemporaneous) approach which was applied to determine the maximum 1-hour NO_X concentrations for the much larger number of residential, workplace and recreational’ (RWR) receptors. The conversion of NO_X to NO_2 was then based on the functions used in the detailed approach.

The two methods for estimating the maximum 1-hour mean NO_2 concentration were also compared for the sensitive receptors.

G.4.2 Methods used in the project assessment

G.4.2.1 Annual mean concentrations

Figure G-1 shows the relationship between the annual mean concentrations of NO_X and NO_2 at the monitoring stations in Sydney across all years. As the values shown are measurements, they equate to $\mathbf{[NO_X]_{total}}$ and $\mathbf{[NO_2]_{total}}$. In the low-NO_X range of the graph there is an excess of ozone and therefore NO_2 formation is limited by the availability of NO. In the high-NO_X range there is an excess of NO, and therefore NO_2 formation is limited by the availability of ozone.

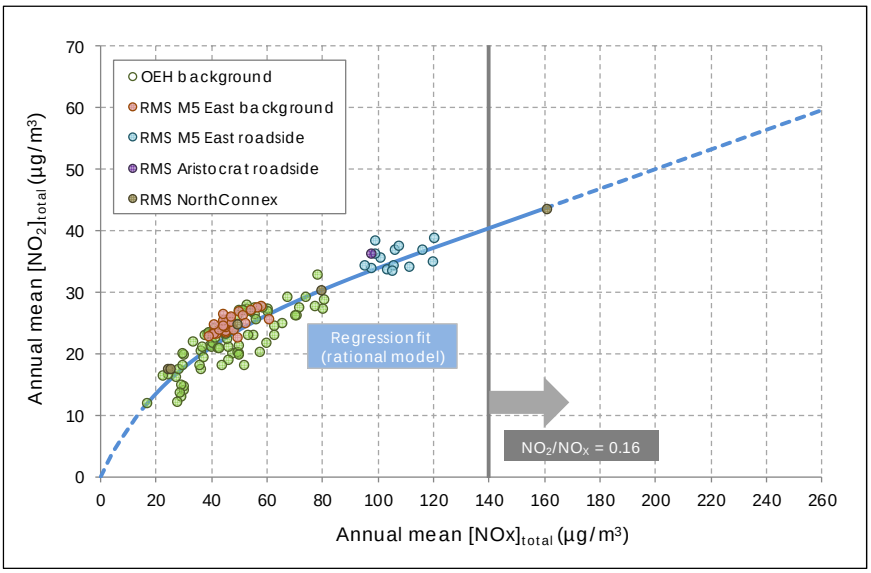


Figure G-1 Annual mean NO_X and NO_2 concentrations at monitoring sites in Sydney

The solid blue in Figure G-1 represents a regression model fit to the data (i.e. the best estimate situation) which will give the likely NO_2 concentration for a given NO_X concentration. The function giving the best fit – the rational model – was selected from a large number of alternatives using curve-fitting software. This function, which was used in the New M5 assessment, is described by the following equations:

For $\mathbf{[NO_X]_{total}}$ values less than or equal to 140 µg/m^3:

Equation G10

$$[NO_2]_{total} = \frac{a + b[NOx]_{total}}{1 + c[NOx]_{total} + d([NOx]_{total})^2}$$

Where:

a = -7.6313×10^{-4}
b = 9.9470×10^{-1}
c = 2.3750×10^{-2}
d = -4.5287×10^{-5}

For $\mathbf{[NO_X]_{total}}$ greater than 140 µg/m^3 it has been assumed that the available ozone has been consumed and so NO_2 is linearly proportional to NO_X with a NO_2/NO_X ratio of 0.16, representing the current f-NO_2 value for vehicle exhaust quoted by NSW EPA in its response to the EIS for the NorthConnex project (AECOM, 2014b):

Equation G11

$$\mathbf{[NO_2]_{total} = 40.513 + (0.16 \times ([NO_X]_{total} - 140))}$$

The work presented by Boulter and Bennett (2015) suggests that an annual average value for f-NO_2 of 0.16 is an overestimate for the 2014 vehicle fleet, but is likely to be more representative for future years.

The dashed blue line represents the extrapolation of the function to values below and above the range of measurements. Given the absence of high annual mean NO_X concentrations, the extrapolation to concentrations above the measurement range is rather uncertain, but on the basis of the primary NO_2 assumption it is likely to be rather conservative.

Given that the total NO_X concentration was used to determine the total NO_2 concentration, in order to determine the change in NO_2 associated with the project the background NO_2 concentration was subtracted. That is:

Equation G13

$$\mathbf{[NO_2]_{project} = [NO_2]_{total} - [NO_2]_{background}}$$

Where both $\mathbf{[NO_2]_{total}}$ and $\mathbf{[NO_2]_{background}}$ were determined using Equations G10 and G11.

For a given project contribution to NO_X at a receptor, the higher the background NO_X the lower the project NO_2 increment will tend to be, as less ozone will generally be available for converting the NO from the project to NO_2.

The use of the function could theoretically lead to exceedances of the annual mean criterion for NO_2 in NSW of 62 µg/m^3. However, a very high annual mean NO_X concentration - more than 260 µg/m^3 - would be required. This is much higher than the measurements in Sydney have yielded to date.

G.4.2.2 One-hour mean concentrations

Detailed contemporaneous approach

One-hour mean NO_X and NO_2 concentrations are much more variable than annual mean concentrations. Patterns in the hourly data can be most easily visualised by plotting the 1-hour mean NO_2/NO_X ratio against the 1-hour mean NO_X concentration, as shown for the various monitoring sites – including the New M5 sites - in Figure G-2 to Figure G-7.

In each dataset it is clear that for low NO_x concentrations there is a wide range of possible NO_2/NO_x ratios, whereas for higher NO_X concentrations the range is much more constrained. A distinct outer envelope can be fitted to the data which includes all (or very nearly all) the measurement points, and this envelope has a strong inverse relationship with the NO_X concentration. In the envelope the NO_2/NOx ratio is highest (1.0) at low NO_X concentrations, representing complete, or near-complete, conversion of NO to NO_2. At the high end of the NO_X concentration range the ratio is much lower and levels out at a value of around 0.1. The highest NO_X concentrations occur mostly during the winter months when temperature inversions prevent the effective dispersion of pollution.

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

The derivation of a conversion method from these data for the New M5 assessment was adapted from that recommended by BCMoE (2008)[5]. This method involved the following steps:

- The range of NO_X concentrations for which the NO_2/NO_X ratio is equal to 1.0 is estimated.
- The NO_X concentration for which NO_2/NO_X is equal to 0.1 is estimated.

[5] BCMoE (2008) recommends that the ozone limiting method should only be applied if adequate monitoring data are not available to establish representative NO/NO_2 ratios.

- An exponential equation of the following form is fitted to the upper envelope of the scatter:

  $NO_2/NO_X = a \times [NOx]^b$

  where **a** and **b** are selected through an iterative process to produce a curve that fits the upper bound of the envelope of the scatter.

  The equation is defined so that the NO_2/ NO_x ratio never exceeds unity or falls below 0.1.

- The equation is checked to ensure that NO_2 does not decrease with an increase in NO_X.

The data from all Sydney monitoring sites between 2004 and 2014 (and in the case of the WestConnex M4 East sites, April 2015) – a total of more than 900,000 data points – are shown in Figure G-8, and the steps described above have been applied. Around 16% of the data points were for roadside monitoring sites.

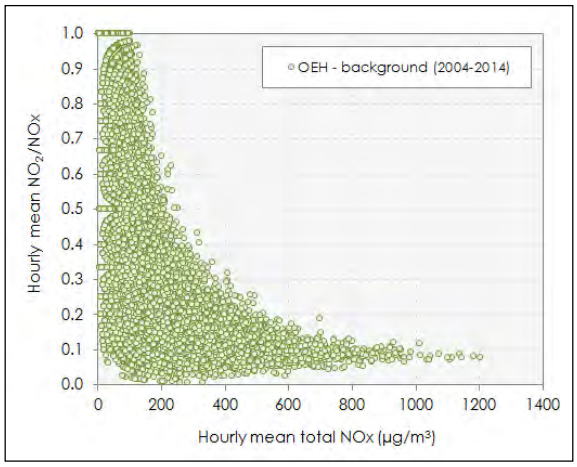


Figure G-2 **Hourly mean NO_2/NO_X and NO_X at OEH background sites**

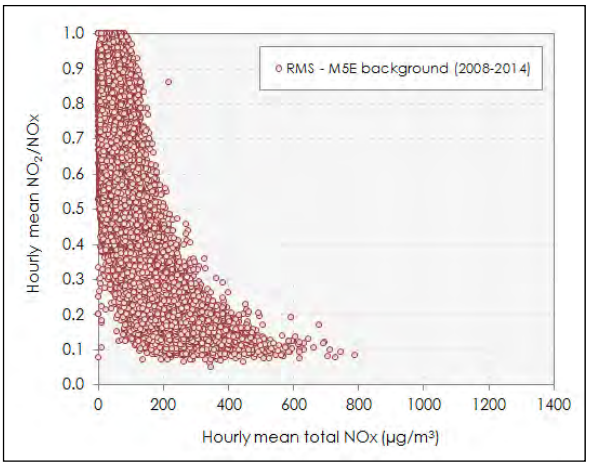


Figure G-3 **Hourly mean NO_2/NO_X and NO_X at RMS M5 East background sites**

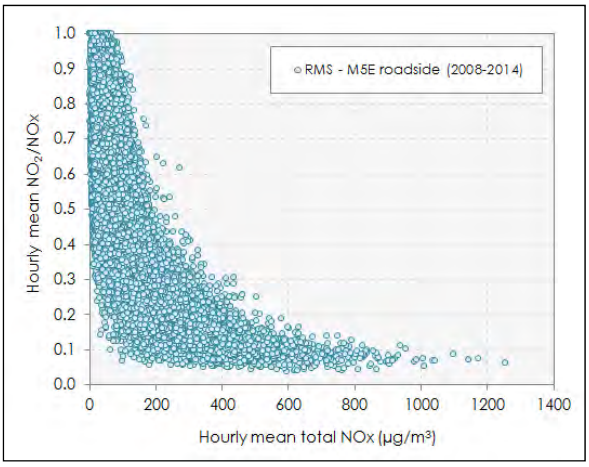


Figure G-4 **Hourly mean NO_2/NO_X and NO_X at RMS M5 East roadside sites**

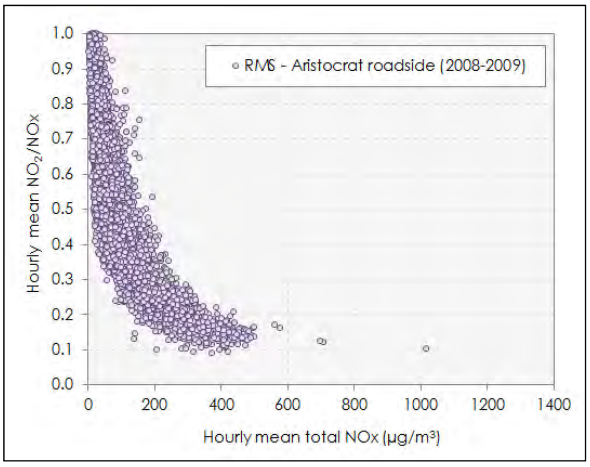


Figure G-5 **Hourly mean NO_2/NO_X and NO_X at RMS Aristocrat (roadside) site**

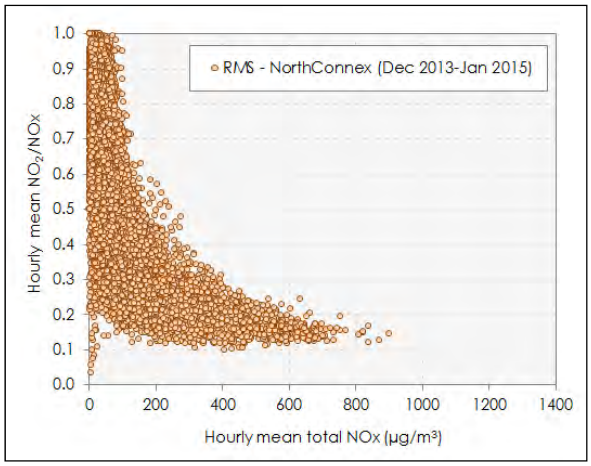


Figure G-6 **Hourly mean NO_2/NO_X and NO_X at RMS NorthConnex sites**

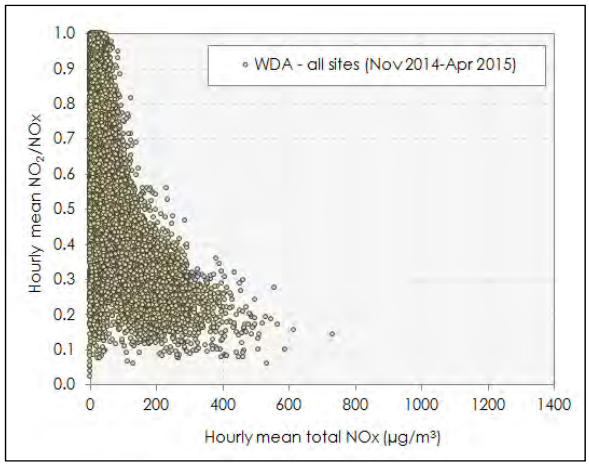


Figure G-7 **Hourly mean NO_2/NO_X and NO_X at WDA M4 East sites**

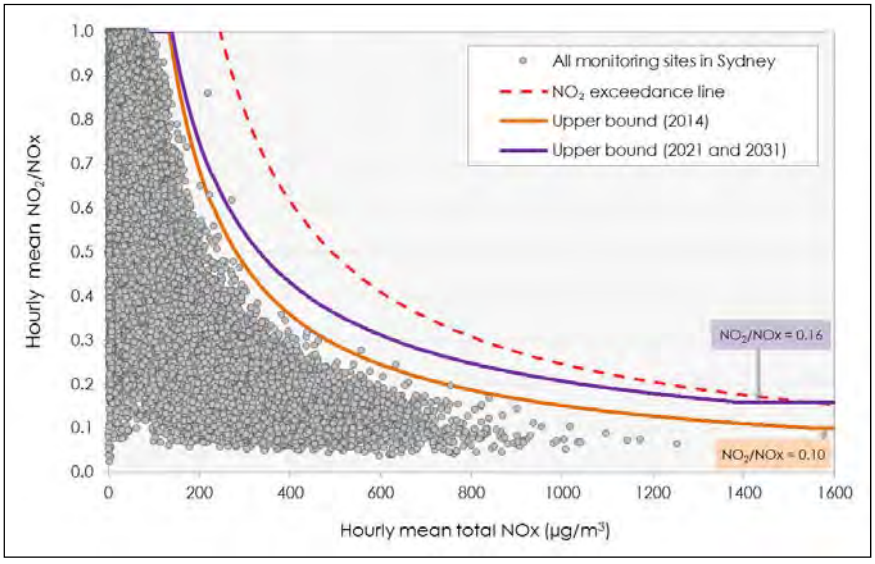


Figure G-8 **Hourly mean NO_X and NO_2/NO_X ratio for monitoring sites at various locations in Sydney**

The solid orange line in Figure G-8 represents the outer envelope of all data points, and approximates to a conservative upper bound estimate for 2014, or in other words the maximum NO_2/NO_X ratio for a given NO_X concentration in 2014. This is described by the following equations:

For $[NO_X]_{total}$ values less than or equal to 130 µg/m^3:

Equation G14

$$\frac{[NO_2]_{total}}{[NOx]_{total}} = 1.0$$

For $[NO_X]_{total}$ values greater than 130 µg/m^3 and less than or equal to 1,555 µg/m^3:

Equation G15

$$\frac{[NO_2]_{total}}{[NOx]_{total}} = a \times [NOx]_{total}^{b}$$

where:

a = 100
b = -0.94

For $[NO_X]_{total}$ values greater than 1,555 µg/m^3 a cut-off for the NO_2/NO_X ratio of 0.10 has been assumed. That is:

Equation G16

$$\frac{[NO_2]_{total}}{[NOx]_{total}} = 0.1$$

The dashed red line in Figure G-8 shows the NO_2/NO_X ratio that would be required for an exceedance of the NO_2 criterion of 246 µg/m^3 at each NO_X concentration. It is clear from Figure G-8 that an exceedance of the 1-hour criterion for NO_2 cannot be predicted using the upper bound curve for 2014 across a wide range of NO_X concentrations.

However, as noted earlier, for future years it is possible that the upper bound estimate for 2014 will not be appropriate, given that primary NO_2 emissions could increase. An exploratory analysis by Pacific Environment indicated that, on average for highway traffic in Sydney, *f*-NO_2 could increase to 0.16 by 2031 (Boulter and Bennett, 2015). Whilst the increase in *f*-NO_2 would be combined with lower overall NO_x emissions, in could be expected that for high ambient NO_X concentrations the ambient NO_2/NO_X ratio could exceed 0.1. Here, it has been assumed that a minimum value for the NO_2/NO_X ratio of 0.16 would be appropriate for the 2021 and 2031 scenarios, and a corresponding function (the purple line) is shown in Figure G-8.

This function, which is essentially arbitrary, is described by the following equations:

For $\mathbf{[NO_X]_{total}}$ values less than or equal to 140 µg/m^3, Equation G14 applies.

For $\mathbf{[NO_X]_{total}}$ values greater than 140 µg/m^3 and less than or equal to 1,375 µg/m^3, Equation 15 applies with the following coefficients:

a = 52

b = -0.80

For $\mathbf{[NO_X]_{total}}$ values greater than 1,375 µg/m^3 a cut-off for the NO_2/NO_X ratio of 0.16 has been assumed. That is:

Equation G17

$$\frac{[NO_2]_{total}}{[NOx]_{total}} = 0.16$$

This conservative upper bound estimate for 2021 and 2031 is shown as a purple line in Figure G-8.

Even this assumption would only result in an exceedance of the NO_2 criterion at very high NO_X concentrations (above around 1,500 µg/m^3). If a more conservative estimate for the minimum ambient NO_2/NO_X ratio of 0.20 were to be assumed, the total NO_X concentration required for NO_2 exceedance in Figure G-8 would be around 1,200 µg/m^3.

Given that the background concentrations developed for the New M5 assessment were also slightly conservative (see Appendix G), this will be a conservative estimate of NO_2 using this approach.

Simple statistical approach

The simple approach involved the following steps for a given receptor:

Step 1: The maximum 1-hour mean NO_x value predicted by GRAL was added to the 98th percentile NO_x value for the background (in the synthetic profile for 2014 this was 236 µg/m^3). This step will tend to result in an overestimation of the maximum total NO_X concentration, as the probability of the two values coinciding in time is low. The 98th percentile was used in preference to the maximum as it is much less variable.

Step 2: The maximum total NO_X concentration from Step 1 was converted to a maximum total NO_2 concentration using the relevant function for the year from Figure G-8. The validity if this approach was examined through comparison with the contemporaneous approach (see Section G.5.2.2).

G.4.2.3 Limitations and performance

The limitations of empirical methods for NO_X-to-NO_2 conversion include the following:

- They do not make any allowance for future changes, such as a potential increase in primary NO_2 emissions or changes in ozone concentrations. Here, this has been addressed through the use of a more conservative function for converting NO_X to NO_2 than the ambient measurements to date would suggest.
- In general the methods do not differentiate between receptor locations at different distances from emission sources.
- They are only useful for the general locations where they were developed. The methods will not provide the correct dynamic response to changes in emissions, boundary conditions or meteorology unless these influences are implicitly included in their formulation (Denby, 2011).

However, despite, or as a result of, their empirical nature such models can give quite satisfactory results, especially for annual mean concentrations as there is a clear dependence of NO_2 on NO_X concentrations (Denby, 2011).

G.5 Comparison of methods

In a further analysis, the functions for calculating NO_2 from NO_X based on the monitoring data from Sydney were compared with some alternative approaches. The results of these comparisons for both annual mean and 1-hour mean NO_2 concentration are given below.

G.5.1 Annual mean NO_2 concentrations

The following methods for calculating annual mean NO_2 concentrations were compared:

- The best estimate approach based on the Sydney monitoring data (see Section G.4.2.1).
- The complete conversion method (see Section G.3.3).
- The USEPA constant ambient ratio method (ARM), with a NO_2/NO_X ratio of 0.75 (see Section G.3.4.1).
- The ozone limiting method (OLM), with an *f*-NO_2 value of 0.16 (see Section G.3.5.1).

In order to compare the different methods for annual mean NO_2 it was necessary to assume background concentrations of NO_X, NO_2 and, in the case of the OLM, O_3. The synthetic profiles for the WestConnex modelling domain (and associated annual mean concentrations) described in Appendix F were used for this purpose.

In the case of the OLM, the conversion method was applied to the contemporaneous hourly background data and project increment data for one year. An example dataset from another road project was used to provide the NO_X project increments. This project had an hourly time series for more than 500 receptor points. However, many of the receptors had similar concentrations and therefore a much smaller sample was extracted. The sample included a wide range of NO_X concentrations. The results of the comparison are shown in Figure G-9.

The total conversion method gave the highest NO_2 concentrations, and for the conditions defined here it resulted in an exceedance of the NO_2 criterion of 62 µg/m^3 when the total NO_X concentration was around 90 µg/m^3. The ARM and the OLM gave quite similar results, and also resulted in exceedances of the NO_2 criterion when the total NO_X concentration was around 100-120 µg/m^3. All three of these methods gave much higher NO_2 concentrations than the envelope and regression functions based on the Sydney monitoring data.

It is also worth repeating that work in the United States has shown that the performance of the ARM2, PVMRM, and OLM methods is very similar (RTP, 2013).

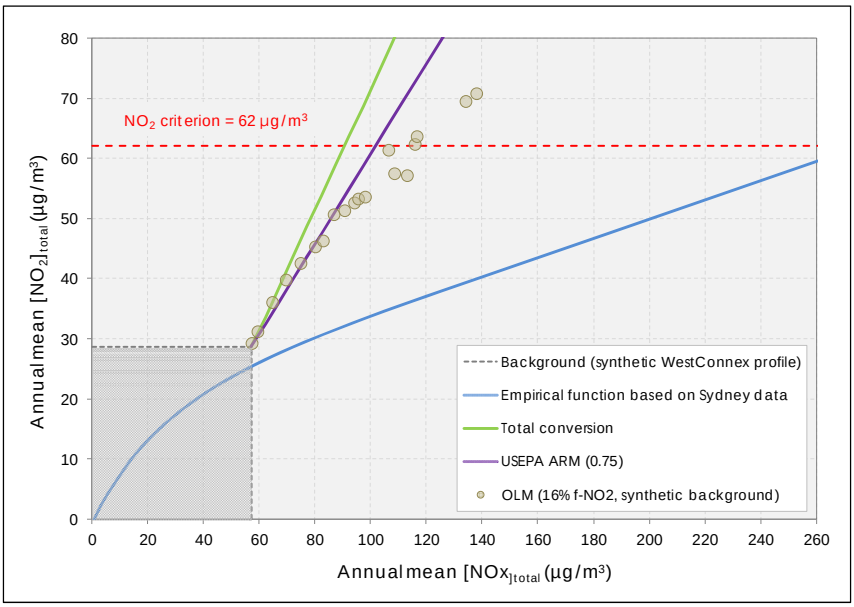


Figure G-9 Comparison of methods for calculating annual mean NO_2 concentration

Although the concentrations in the synthetic background profiles were quite conservative, the results show that that the annual mean NO_2 concentrations predicted using the total conversion, ARM and OLM methods are unrealistically high, and would tend to result in an improbable number of exceedance of the NO_2 criterion. These methods were therefore considered to be unsuitable for the New M5 assessment.

G.5.2 One-hour mean NO_2 concentrations

G.5.2.1 Detailed contemporaneous method

In the case of 1-hour mean NO_2 concentrations, only the OLM was compared with the empirical contemporaneous method. Again, the synthetic background profiles for the WestConnex modelling domain were used, and an *f*-NO_2 value of 0.16 was assumed.

For the road contribution to NO_x, the same example dataset as that mentioned above for annual mean concentrations was used. The hourly results for ten receptors from the dataset, with representative NO_X concentrations across the range, are shown in Figure G-10. It can be seen that the OLM predicted NO_2/NO_X ratios for many 1-hour periods that were higher than those predicted by the conservative upper bound function. The OLM gave a small number of exceedances of the NO_2 criterion of 246 µg/m^3. This work shows that the OLM will yield overly conservative maximum NO_2 concentrations for road projects in Sydney.

G.5.2.2 Simple statistical method

Some limited testing of the performance of the simple statistical method was also possible based on a comparison with the more detailed contemporaneous method for the community receptors. The results of this comparison are provided in Chapter 9. In general the simple method performed in a similar manner to the detailed method, giving slightly lower maximum NO_2 values.

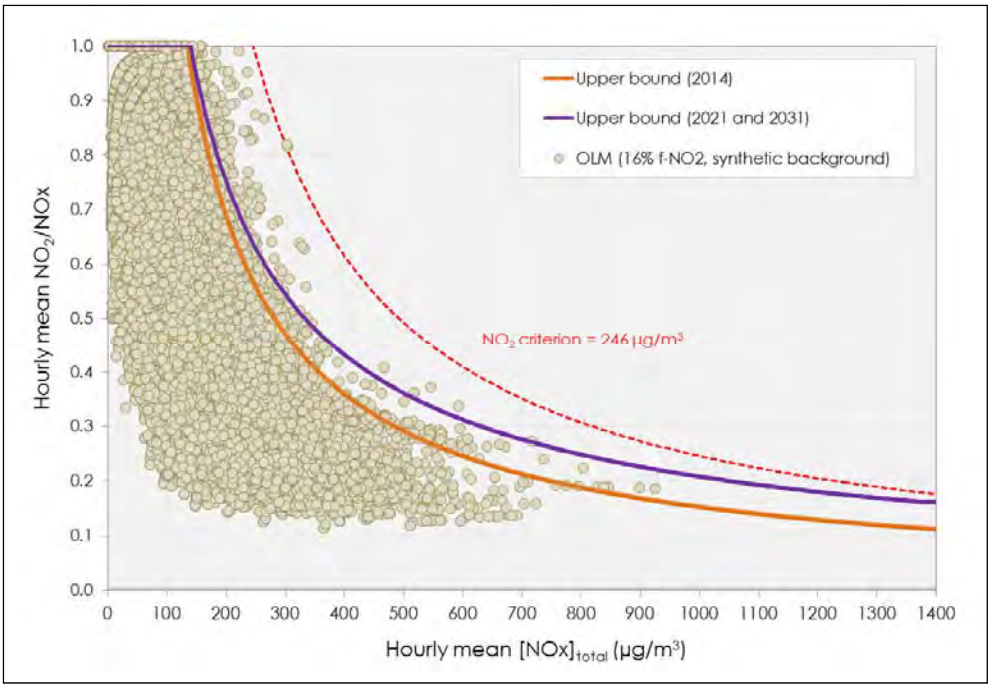


Figure G-10 Comparison of OLM and empirical methods for calculating 1-hour mean NO_2 concentration

Appendix H - Meteorological data analysis and model evaluation

H.1 Meteorological data analysis

Table H-1 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 meteorological stations between the years 2009 and 2014. The table shows a generally high percentage of data recovery at each site. 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. Therefore, any dataset in a year with less than 90 per cent data recovery was disregarded for modelling purposes but was included in the data analysis.

Table H-1 Summary of data recovery, average wind speed and percentage calms

Site and parameter	2009	2010	2011	2012	2013	2014
OEH Chullora						
Data recovery (%)	100	100	100	100	97	100
Average wind speed (m/s)	2.3	2.2	2.1	1.9	1.9	1.8
Annual calms (%)	7.6	7.0	7.4	10.4	11.5	11.6
OEH Earlwood						
Data recovery (%)	100	100	97	100	99	100
Average wind speed (m/s)	1.6	1.6	1.4	1.4	1.4	1.3
Annual calms (%)	18.1	16.8	17.5	22.0	23.1	22.0
OEH Rozelle						
Data recovery (%)	69	94	100	100	98	99
Average wind speed (m/s)	1.8	1.8	1.8	1.7	1.8	1.7
Annual calms (%)	21.7	23.1	21.3	24.9	23.1	22.1
BoM Canterbury Racecourse AWS						
Data recovery (%)	61	88	91	89	89	90
Average wind speed (m/s)	3.3	3.2	3.3	3.3	3.3	3.3
Annual calms (%)	9.4	8.4	8.0	8.7	8.8	8.6
BoM Fort Denison AWS						
Data recovery (%)	97	96	100	100	98	100
Average wind speed (m/s)	4.3	4.4	4.4	4.4	4.4	4.3
Annual calms (%)	1.6	0.8	0.5	0.2	0.4	0.3
BoM Sydney Airport AMO						
Data recovery (%)	67	66	100	100	100	100
Average wind speed (m/s)	5.7	5.7	5.7	5.6	5.7	5.5
Annual calms (%)	0.3	0.2	0.2	0.3	0.1	0.1
BoM Sydney Olympic Park AWS						
Data recovery (%)	55	N/A	N/A	N/A	N/A	N/A
Average wind speed (m/s)	2.0	N/A	N/A	N/A	N/A	N/A
Annual calms (%)	14.7	N/A	N/A	N/A	N/A	N/A
BoM Sydney Olympic Park AWS (Archery Centre)						
Data recovery (%)	N/A	N/A	31	90	89	90
Average wind speed (m/s)	N/A	N/A	2.9	2.7	2.7	2.6
Annual calms (%)	N/A	N/A	8.8	11.1	11.4	10.2

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. The annual average wind speeds at the BoM Fort Denison and BoM Sydney Airport AMO sites were higher than those at the other sites. This can be explained by the generally exposed nature of these sites and their proximity to bodies of water.

Annual and seasonal wind roses for all six years and for all sites were created to analyse the general wind patterns across the WestConnex study area. The wind roses showed very similar patterns for all six years at each individual site. Figure H-1 to Figure H-14 show the annual and seasonal wind roses for the OEH and BoM meteorological stations listed in Table H-1. It is noted that no wind roses are shown for the BoM Sydney Olympic Park AWS station as this site was decommissioned in 2009. The BoM Sydney Olympic Park Archery Centre site was commissioned in 2011. The wind roses show similarities in the dominant wind patterns; winds were predominantly from the north-west and south-east directions. The seasonal patterns were also very similar between sites. The BoM Fort Denison site is located in the harbour and is therefore the wind flow may be strongly influenced by local conditions.

It is noted that the OEH Rozelle and Chullora are located in proximity to the New M5 project area. Figure H-1 and Figure H-2 present the annual and seasonal wind roses for the OEH Chullora site for 2009 to 2014. The wind roses for 2009 to 2011 show mostly similar wind patterns with a fair distribution of winds from all angles annual but with some west south-westerly dominance. The wind roses for 2012 to 2014 however, show a significant change in wind pattern both annually and by season with very dominant northeast/southwest winds not seen in earlier years. The winter wind roses in particular show a shift in the dominant winds from mostly westerlies in 2009 to 2011 to south-westerlies in 2012 to 2014.

Figure H-5 and Figure H-6 present the annual and seasonal wind roses for the OEH Rozelle site for 2009 to 2014. The wind roses for 2009, 2010 and 2014 show similar wind patterns with dominant winds from the northwest, northeast and south to varying degrees in all seasons. The wind roses for 2011, 2012 and 2013 however, show an anti-clockwise shift in this pattern changing the domain winds to the west-northwest, north-northeast and south-southeast. It is not clear what has caused this shift in wind patterns at the OEH Chullora and Rozelle meteorological stations. However, it is noted that according to the OEH website (http://www.environment.nsw.gov.au/AQMS/sitesyd.htm), both of these sites do not currently comply with Australian Standard AS/NZS 3580.1.1:2007[1], as the clear sky angle is < 120˚ due to trees within 20 metres of both monitoring sites. For these reasons, these stations were not chosen for use in the GRAMM model.

Based on the analysis of the available meteorological data within the study area, data from the BoM Canterbury Racecourse AWS meteorological station were chosen as the input to GRAMM for modelling. The site was also located closest to the centre of the GRAMM domain for WestConnex, and was considered to be representative of the general wind patterns in the domain. As 2014 was the most recent year of available meteorological data, it was the preferred year for modelling. The analysis showed that the 2014 data were representative of conditions in previous years. 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.

Additional analysis of the data from the BoM Canterbury Racecourse AWS was undertaken, and Figure H-7 and Figure H-8 present the annual and seasonal wind roses for this site for 2009-2011 and 2012-2014, respectively. Figure H-15 also shows 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 of wind speed and temperature also show typical patterns, with higher wind speeds and temperatures during the day, decreasing at night and in the early morning.

Having determined the representativeness of the 2014 data sets over the previous six years, the next step was to evaluate the performance of the meteorological model (GRAMM) using these data. The various methodologies used to carry out this analysis are described in Section H.2.

[1] AS/NZS 3580.1.1:2007 - Methods for sampling and analysis of ambient air - Guide to siting air monitoring equipment

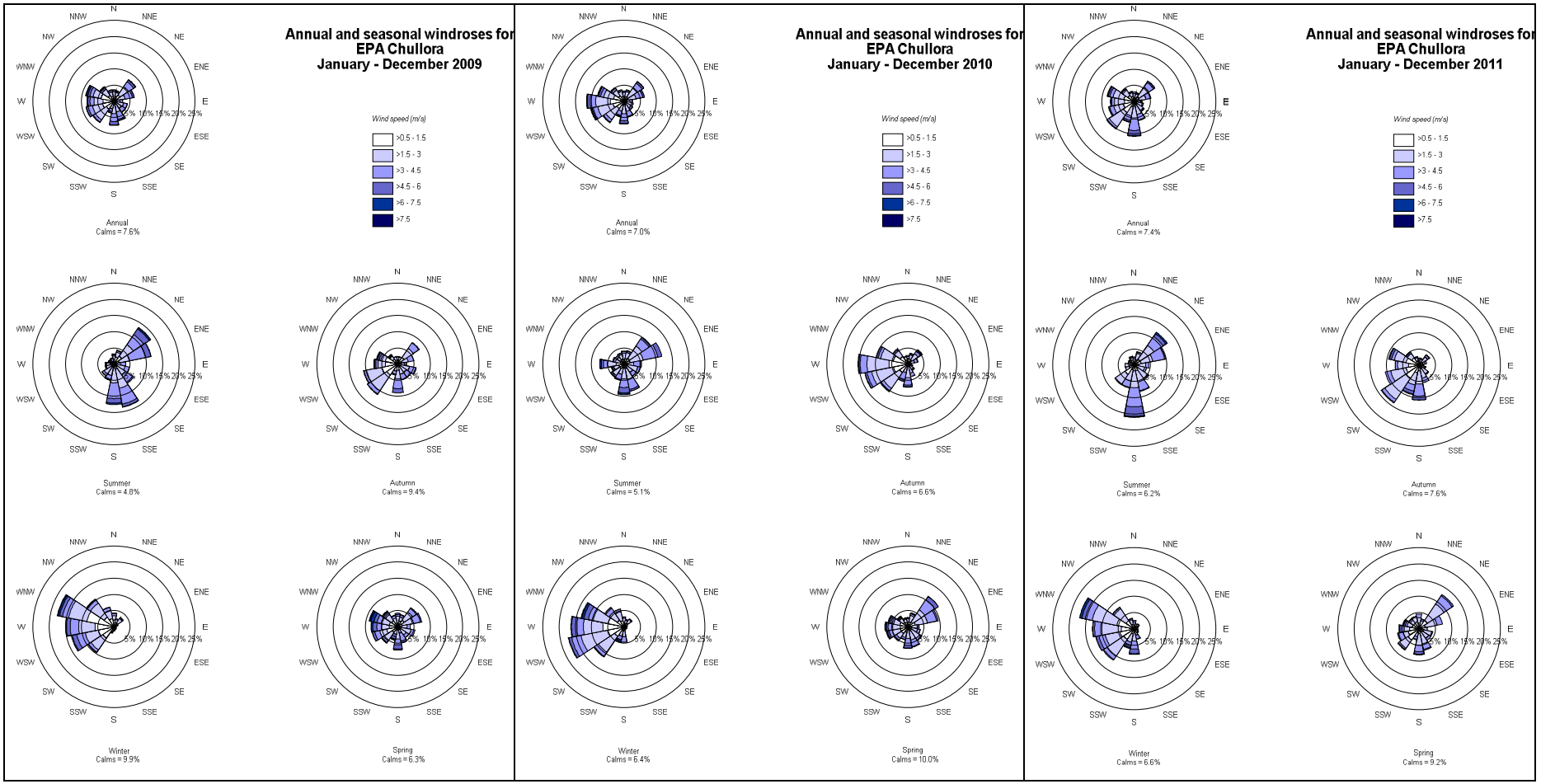


Figure H-1 Annual and seasonal wind roses for OEH meteorological station Chullora (2009-2011)

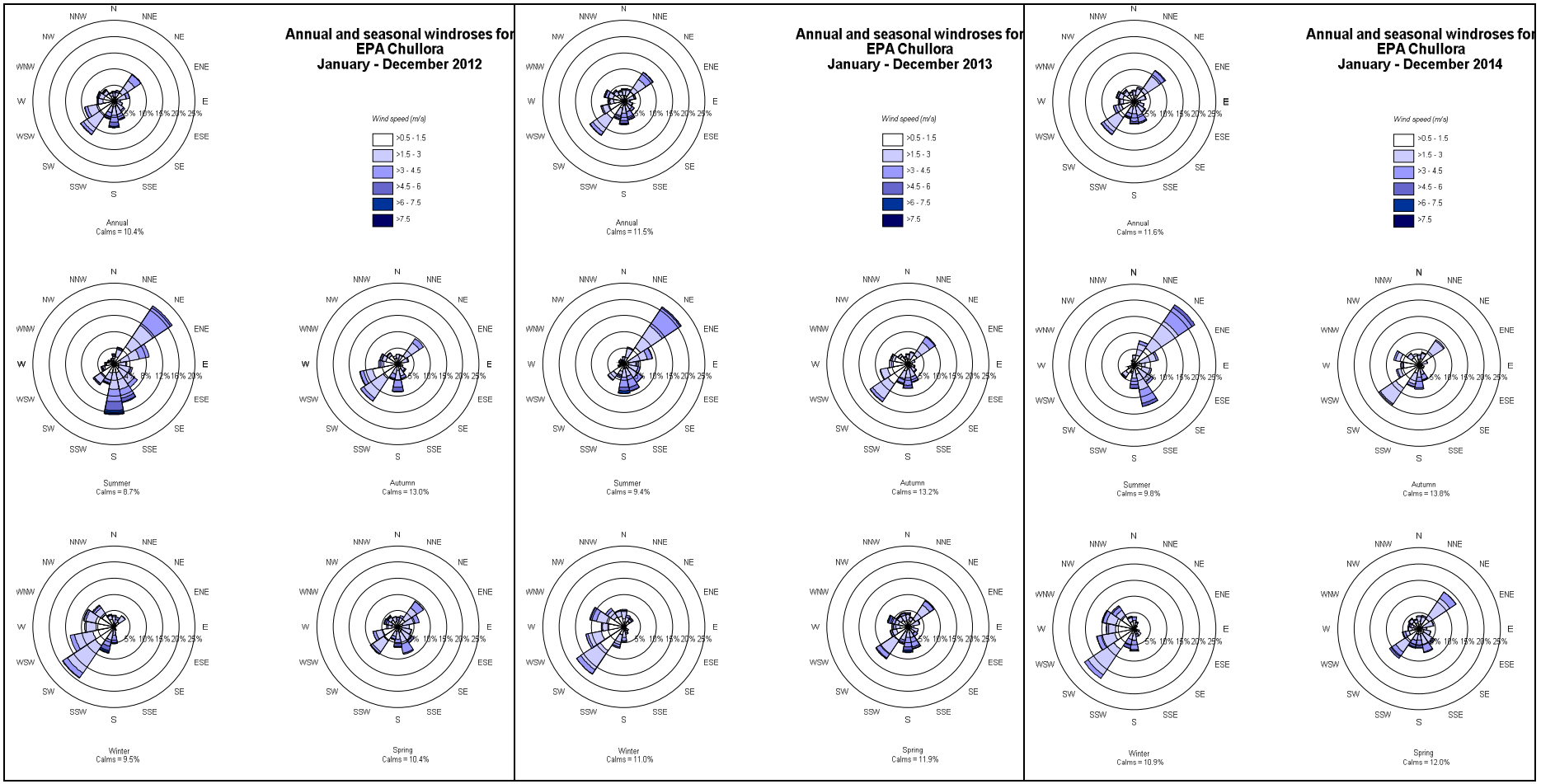


Figure H-2 Annual and seasonal wind roses for OEH meteorological station Chullora (2012-2014)

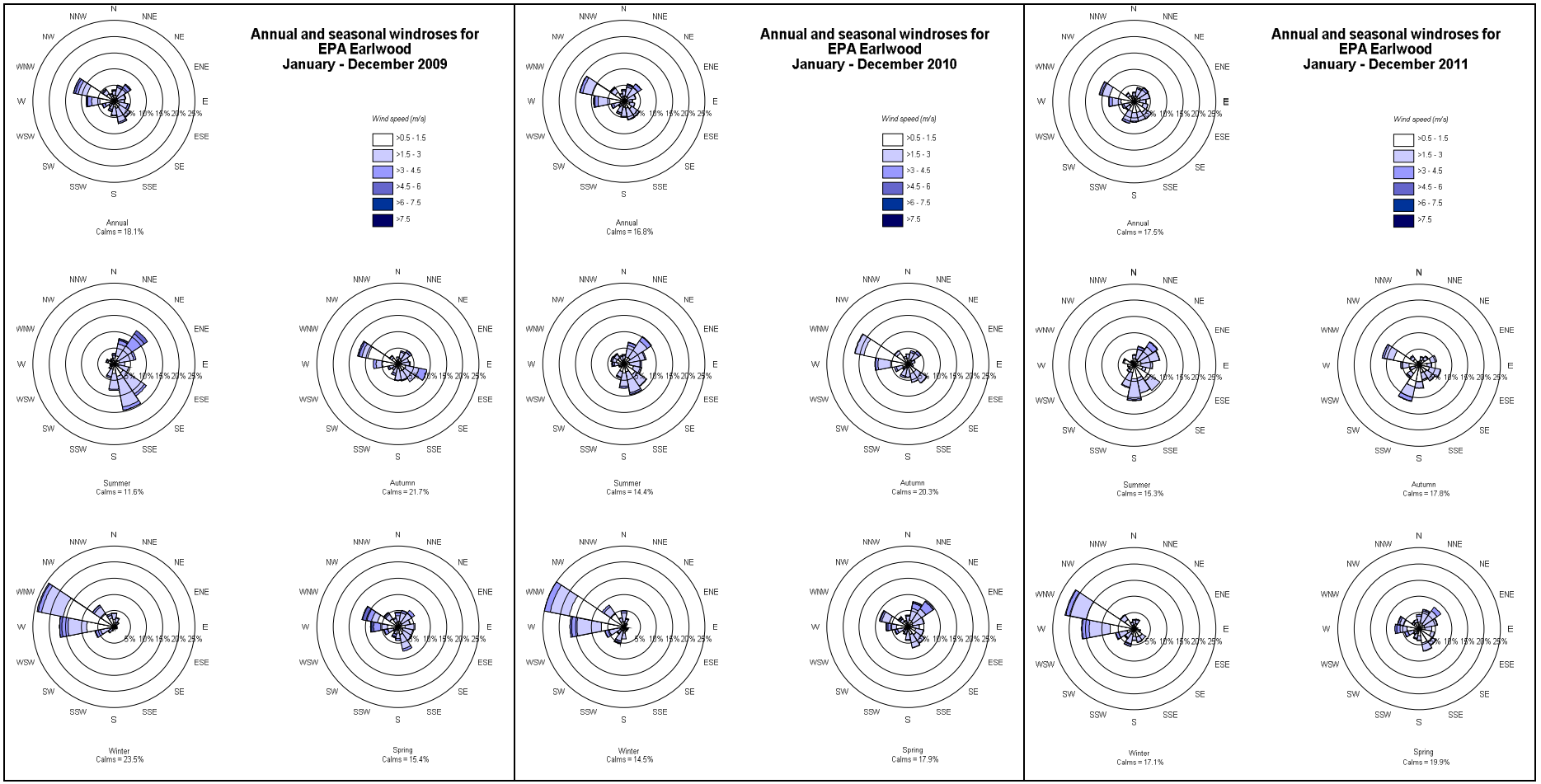


Figure H-3 Annual and seasonal wind roses for OEH meteorological station Earlwood (2009-2011)

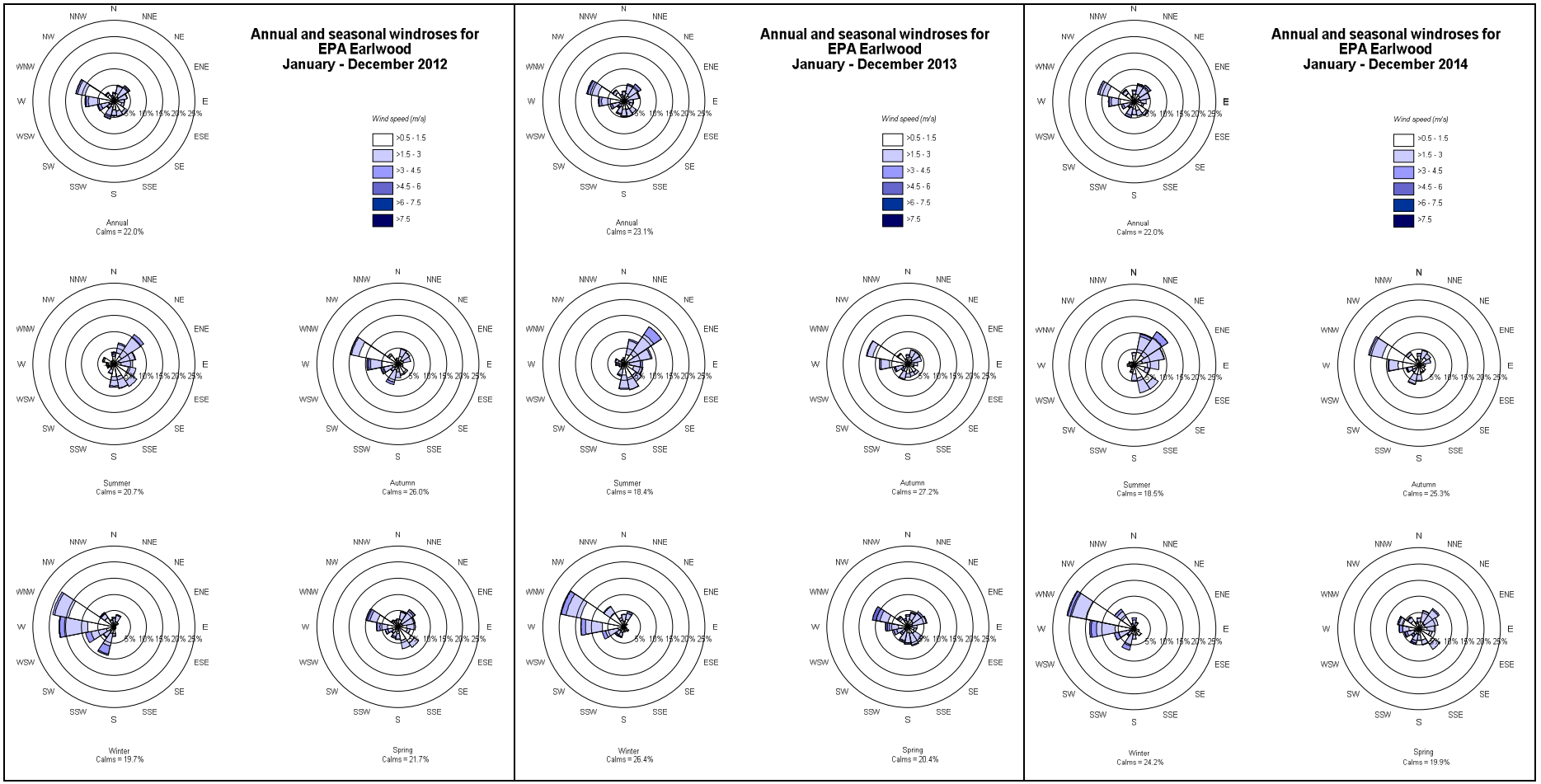


Figure H-4 Annual and seasonal wind roses for OEH meteorological station Earlwood (2012-2014)

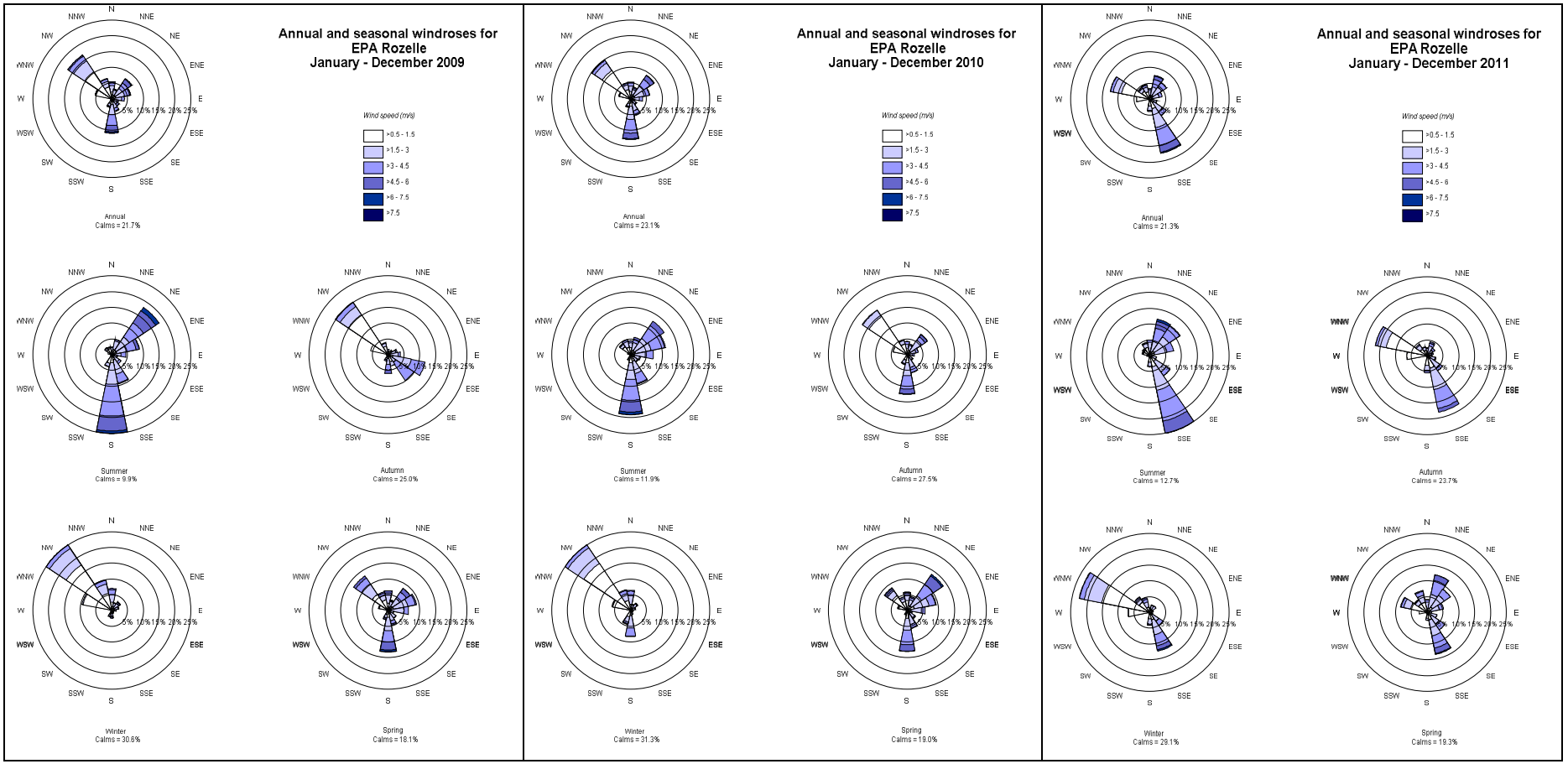


Figure H-5 Annual and seasonal wind roses for OEH meteorological station Rozelle (2009-2011)

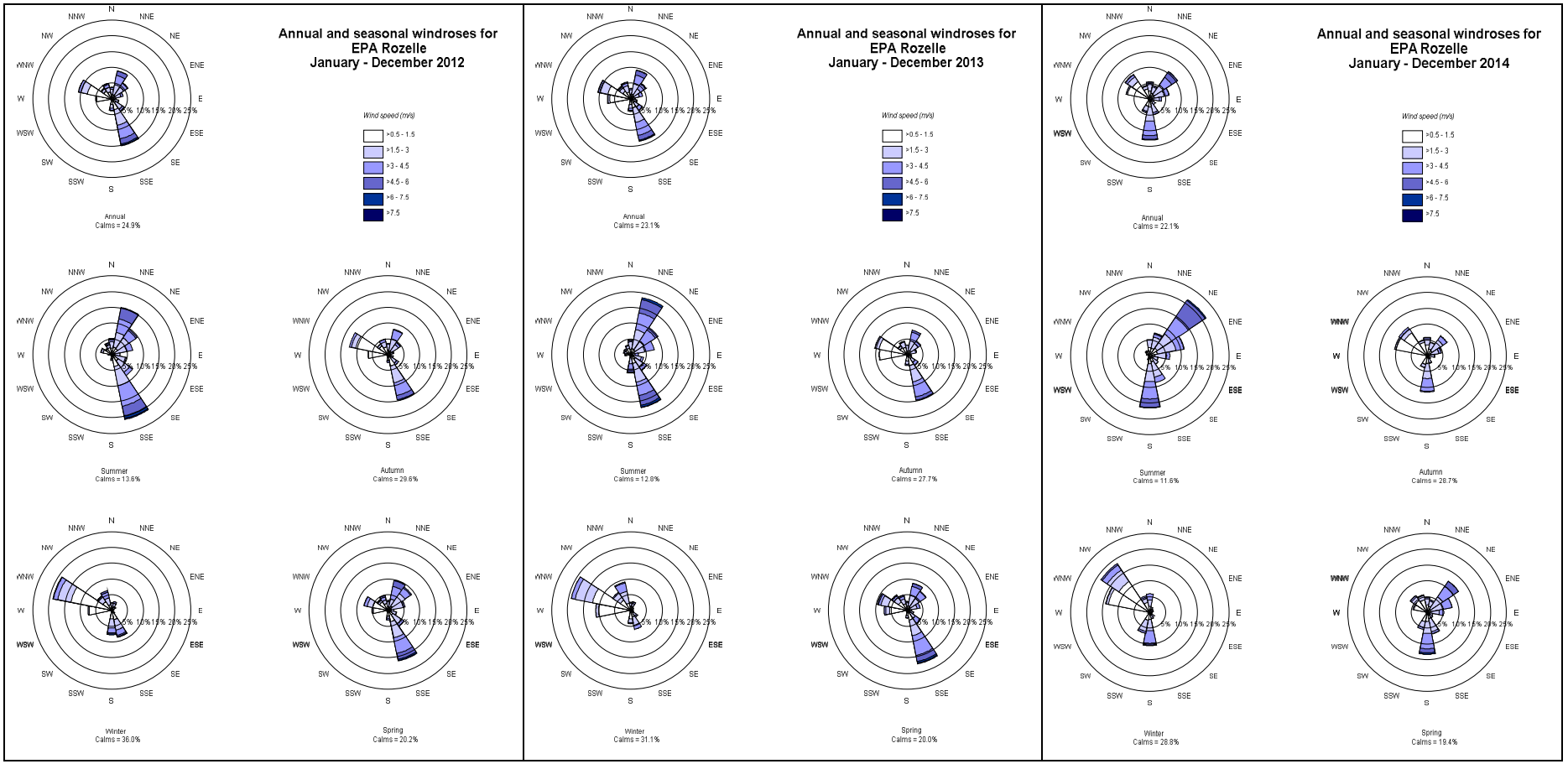


Figure H-6 Annual and seasonal wind roses for OEH meteorological station Rozelle (2012-2014)

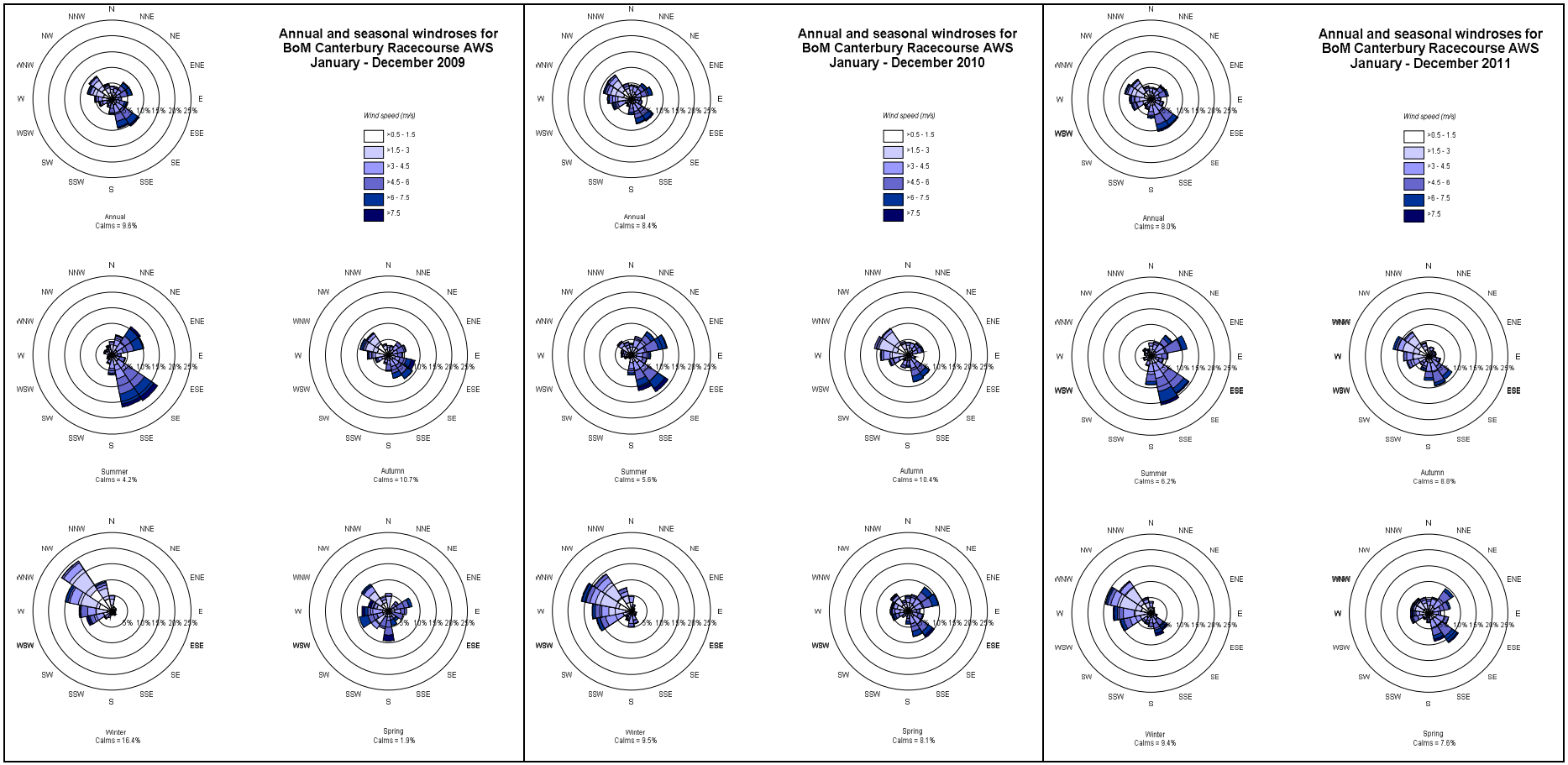


Figure H-7 Annual and seasonal wind roses for BoM Canterbury Racecourse AWS (2009 – 2011)

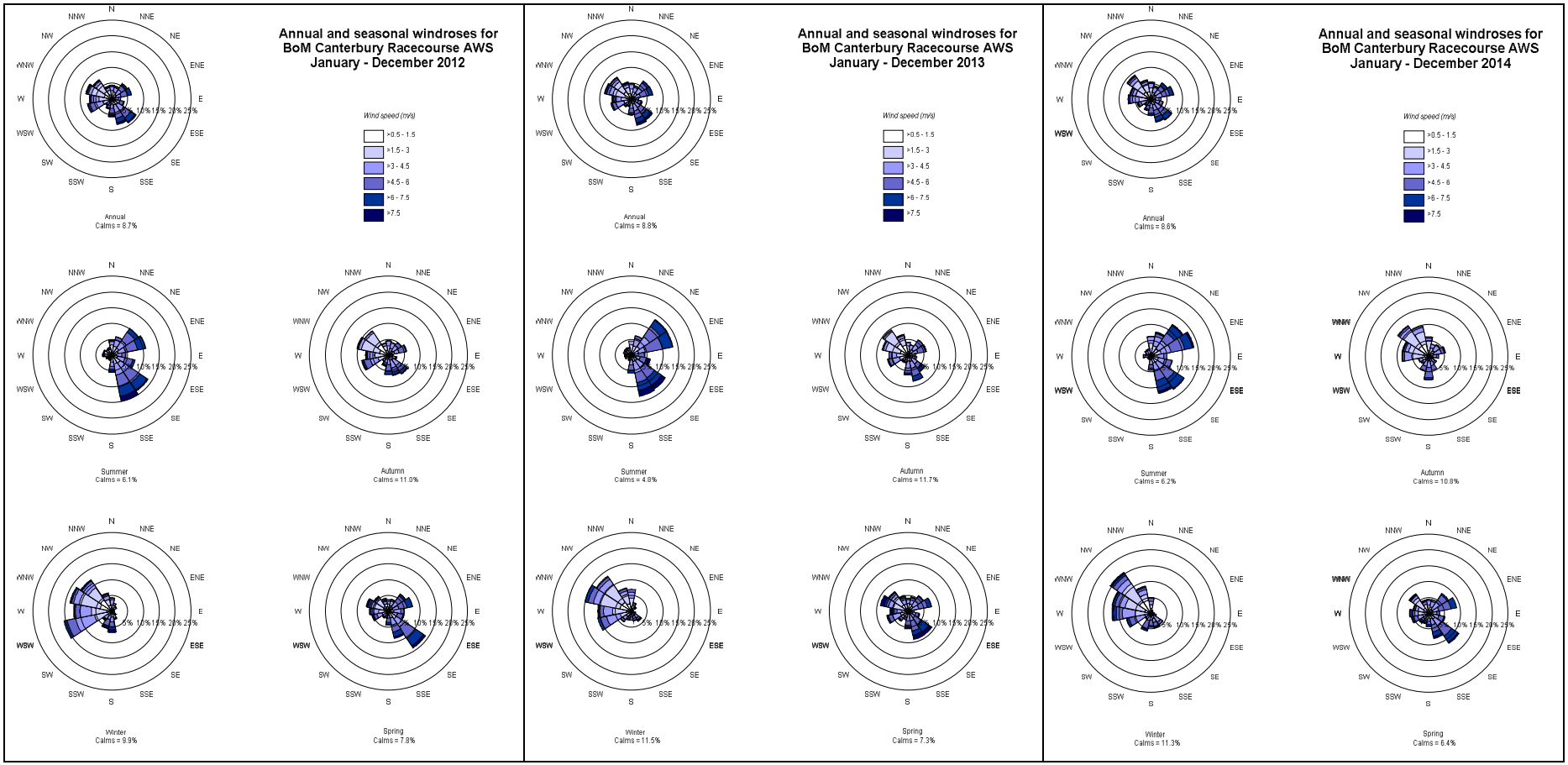


Figure H-8 Annual and seasonal wind roses for BoM Canterbury Racecourse AWS (2012 – 2014)

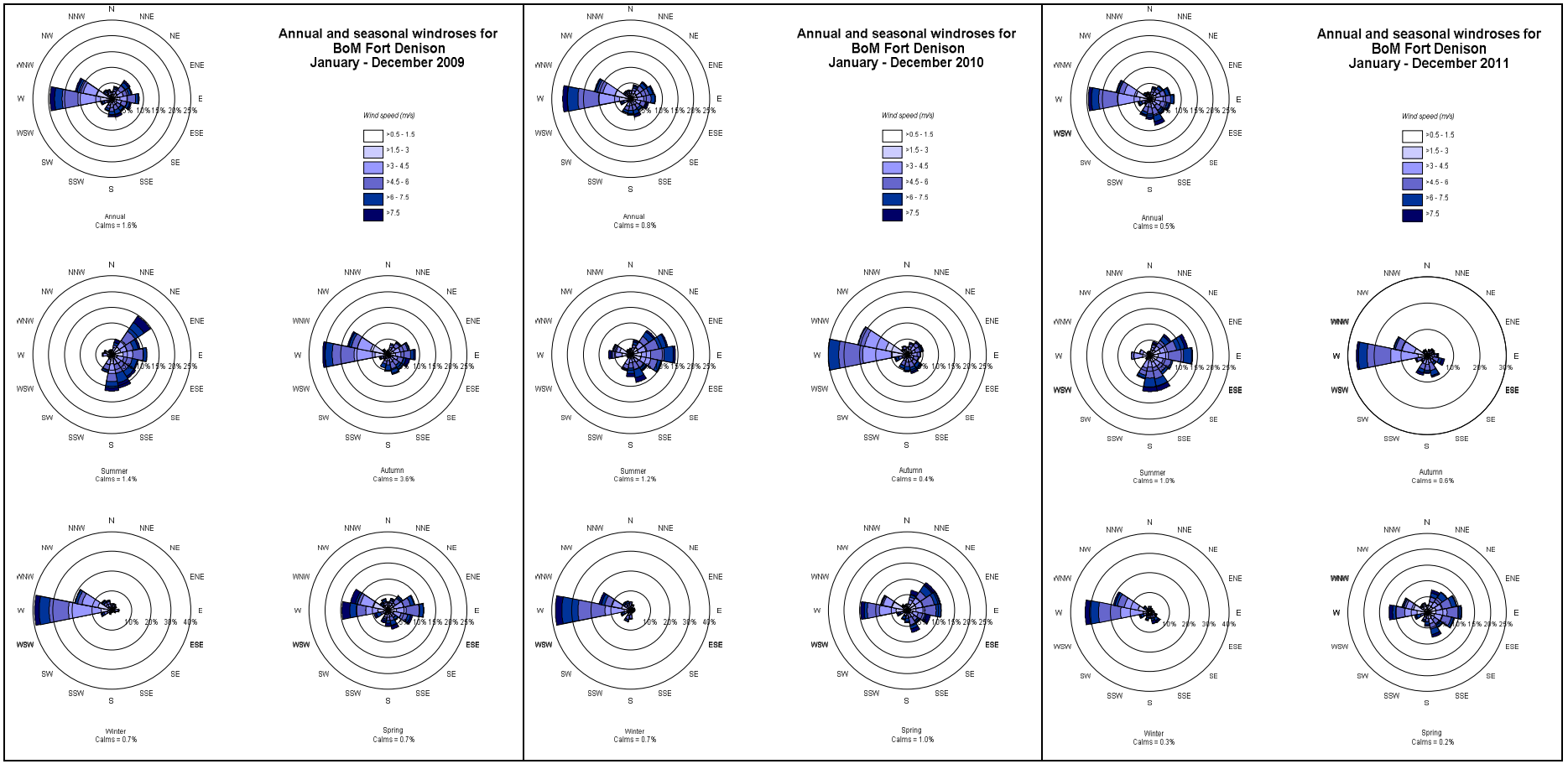


Figure H-9 Annual and seasonal wind roses for BoM Fort Denison AWS (2009 – 2011)

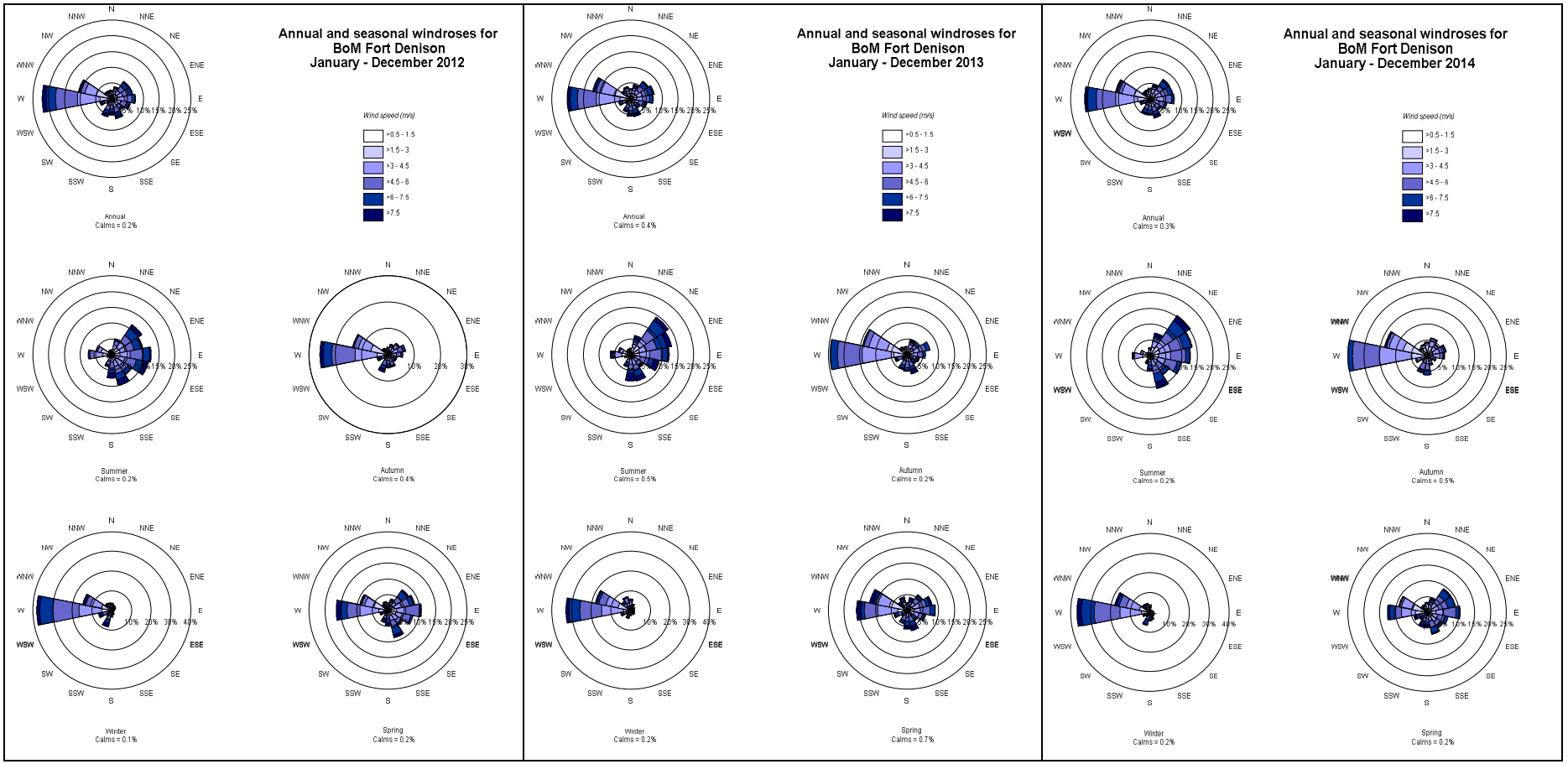


Figure H-10 Annual and seasonal wind roses for BoM Fort Denison AWS (2012 – 2014)

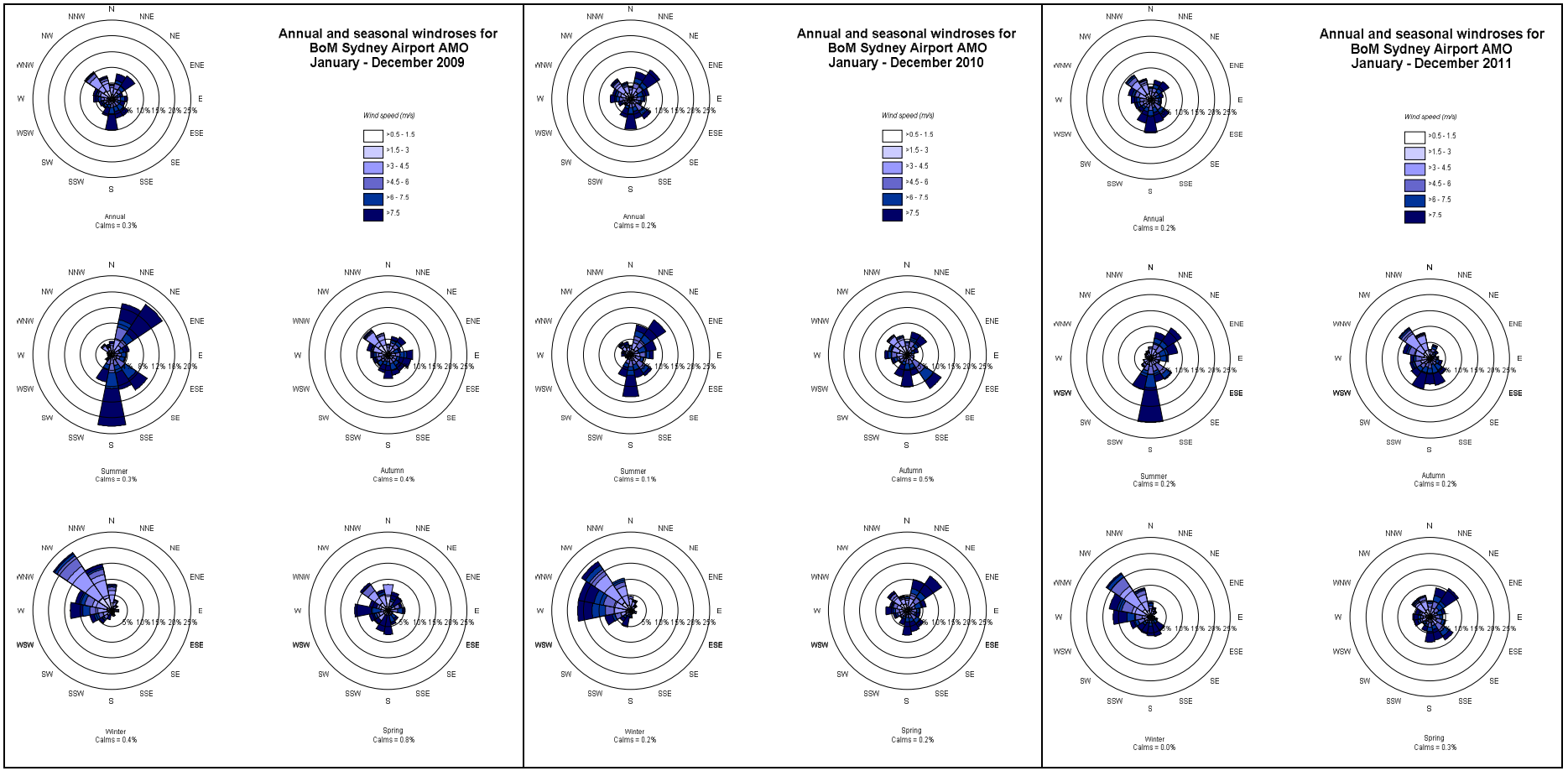


Figure H-11 Annual and seasonal wind roses for BoM Sydney Airport AMO (2009 – 2011)

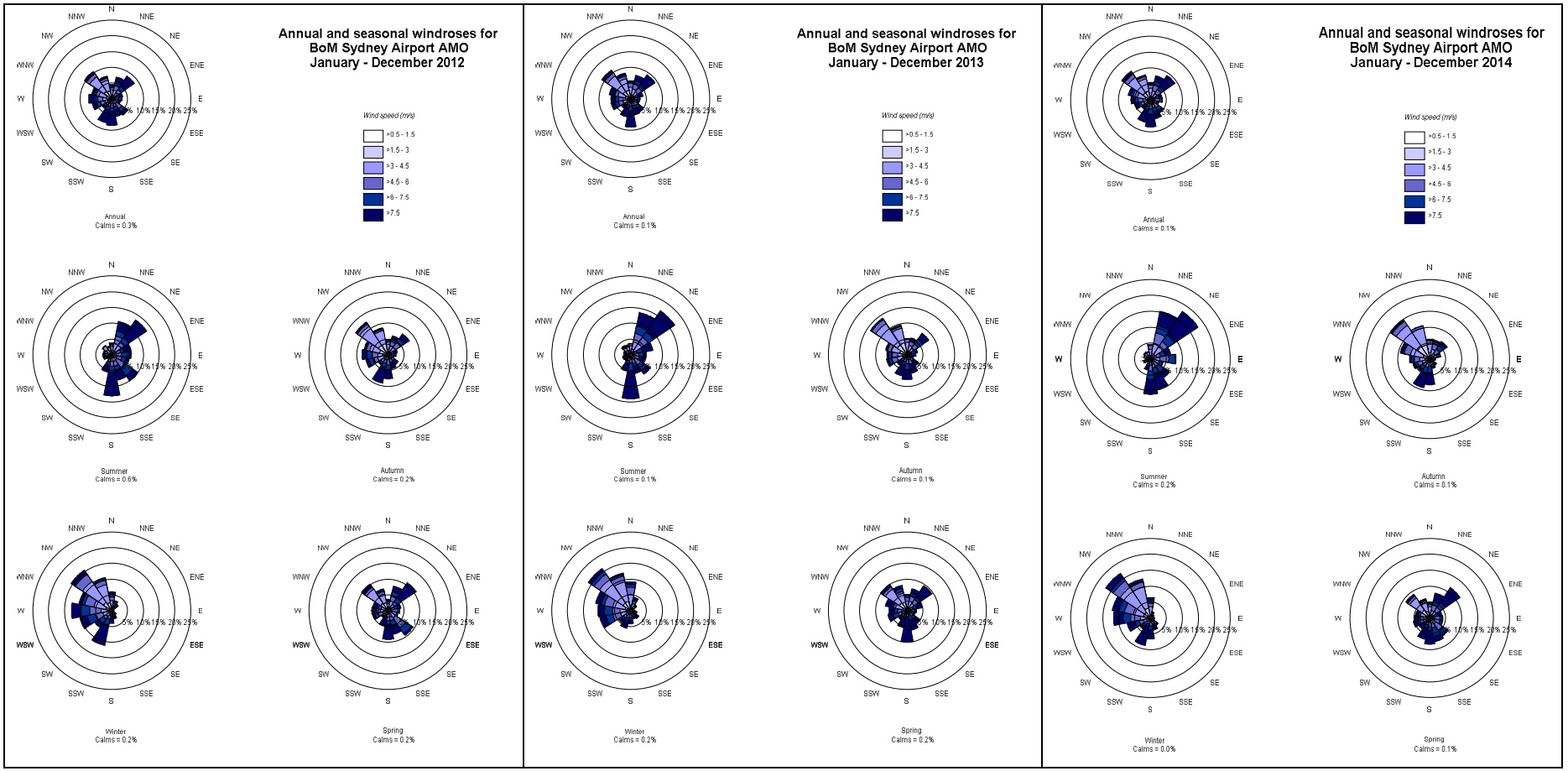


Figure H-12 Annual and seasonal wind roses for BoM Sydney Airport AMO (2012 – 2014)

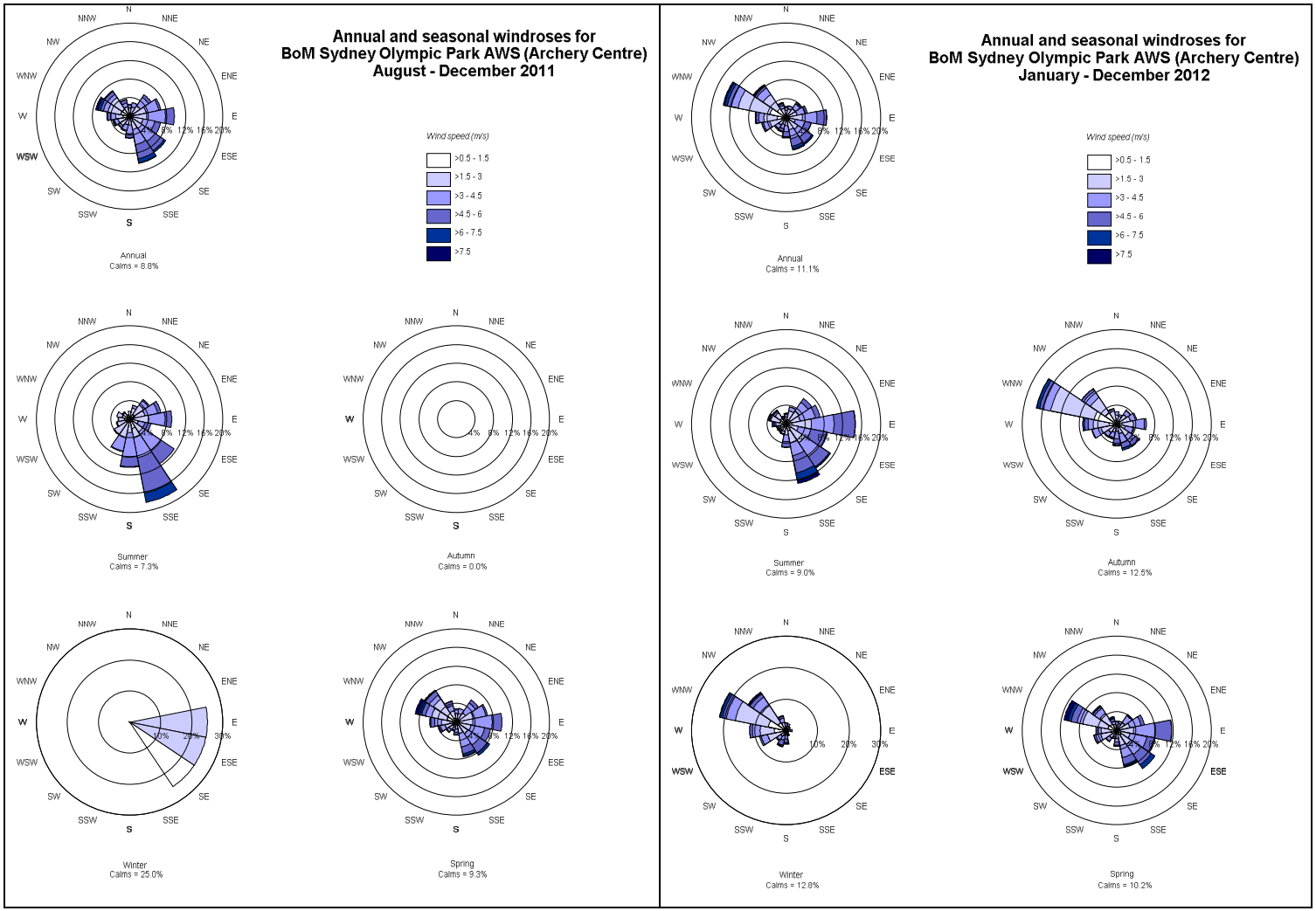


Figure H-13 Annual and seasonal wind roses for BoM Olympic Park AWS (Archery Centre) (2011 – 2012)

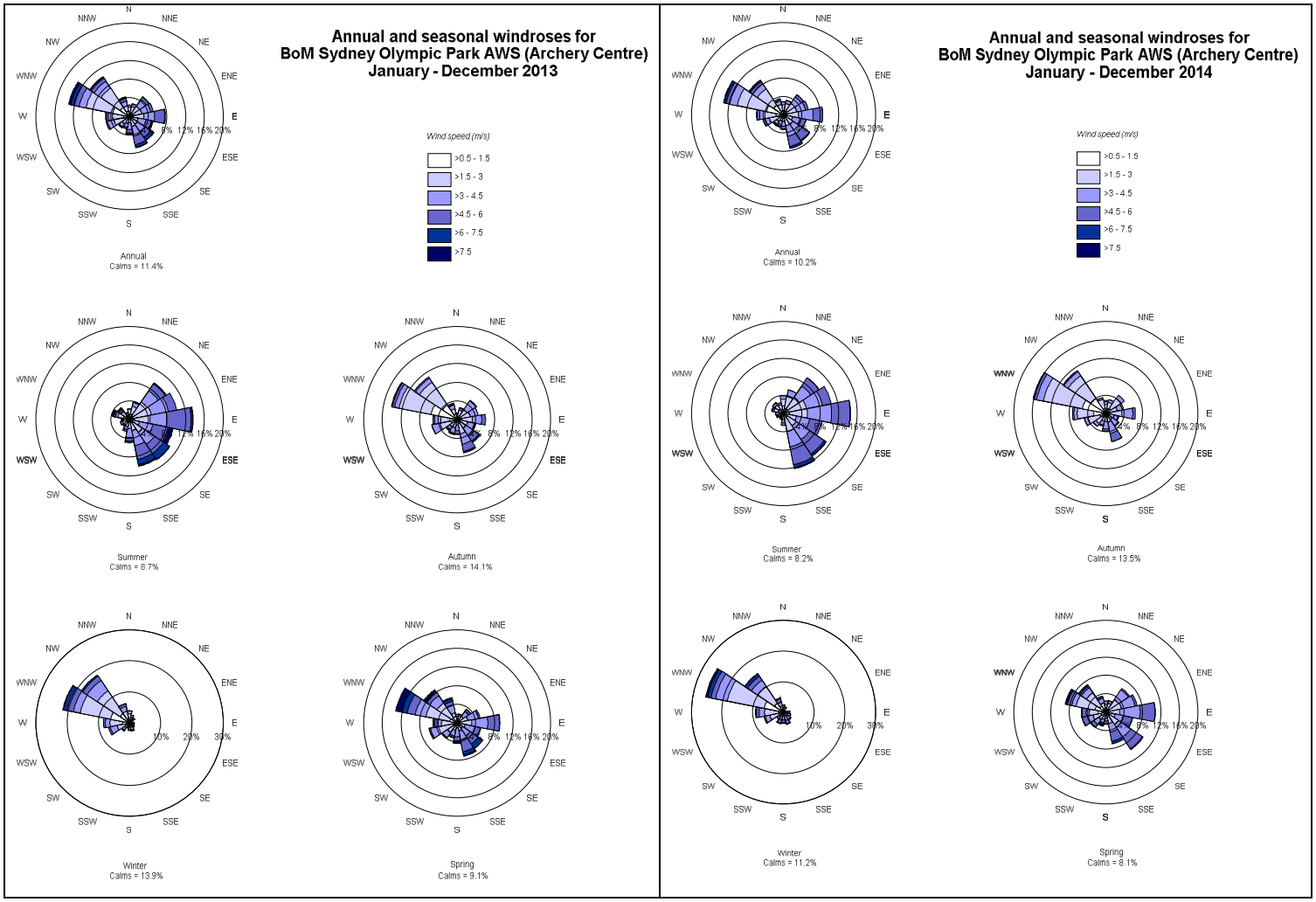


Figure H-14 Annual and seasonal wind roses for BoM Olympic Park AWS (Archery Centre) (2013 – 2014)

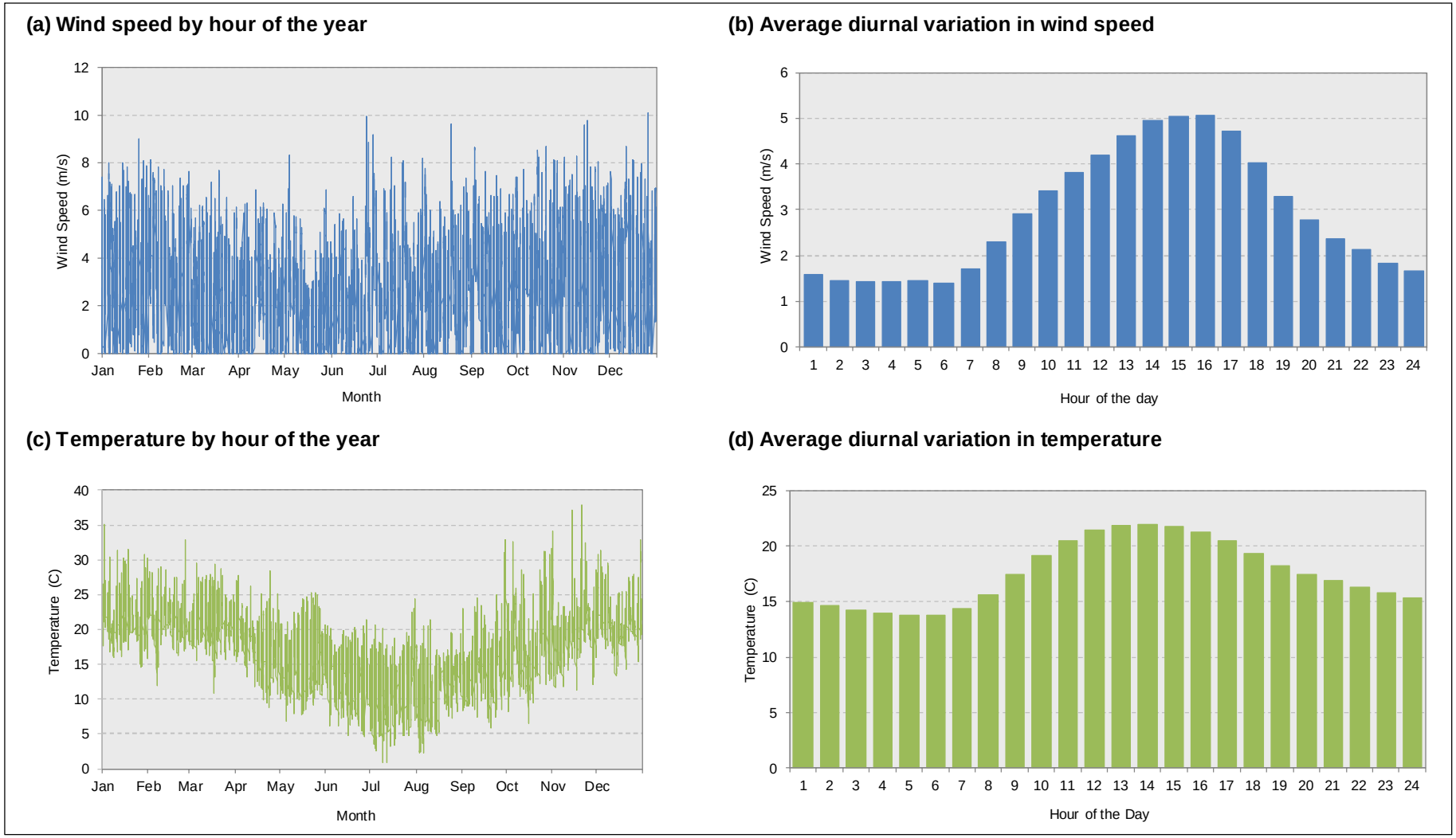


Figure H-15 Annual and diurnal plots of wind speed and temperature for BoM Canterbury Racecourse AWS, 2014

H.2 Meteorological model evaluation

H.2.1 Wind speed

For each of the GRAMM evaluation sites, time series, regression and percentile plots of wind speed are shown in Figure H-16.

Regression analysis of wind speed showed a very good agreement between predicted and observed wind speeds at the Canterbury Racecourse site, which was the site used for modelling. There was also a reasonable agreement at Sydney Olympic Park, 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 $R^2 = 0.50$

The percentile plots shown in Figure H-16 demonstrate an 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 show a much closer agreement between the measurements and predictions than for sites further away from the project.

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 New M5 study area. The regression analysis values for these other sites as shown above appear low compared to the Canterbury Racecourse site but are considered fair considering that these data were not included in the GRAMM modelling.

Whilst meteorological conditions are an important aspect of any dispersion modelling excercise, 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 100 per cent accurately at all locations across the domain, the GRAL model (for which GRAMM is an input), is predicting results at an appropriate level at varying locations in the study area.

A plot of predicted and observed average wind speeds by hour of day at Canterbury Racecourse show good agreement (Figure H-17). As mentioned previously, there is a tendency for GRAMM to underestimate the higher wind speeds during the middle of the day, but this will add a level of conservatism to the modelling. Times of peak traffic volumes when wind speeds are often lower, show better agreement.

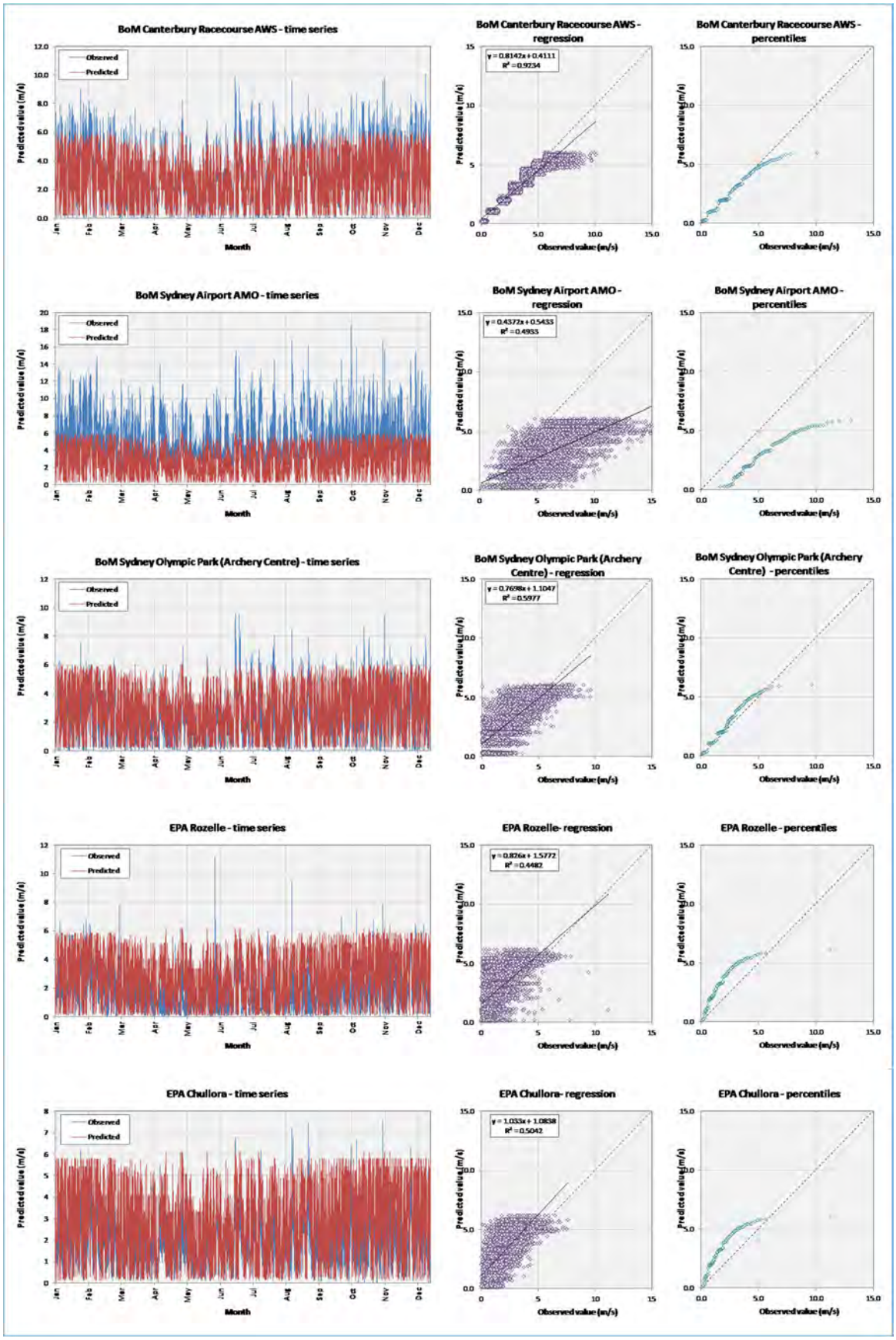


Figure H-16 GRAMM predicted and observed hourly average wind speed (time series, regression and percentile plots)

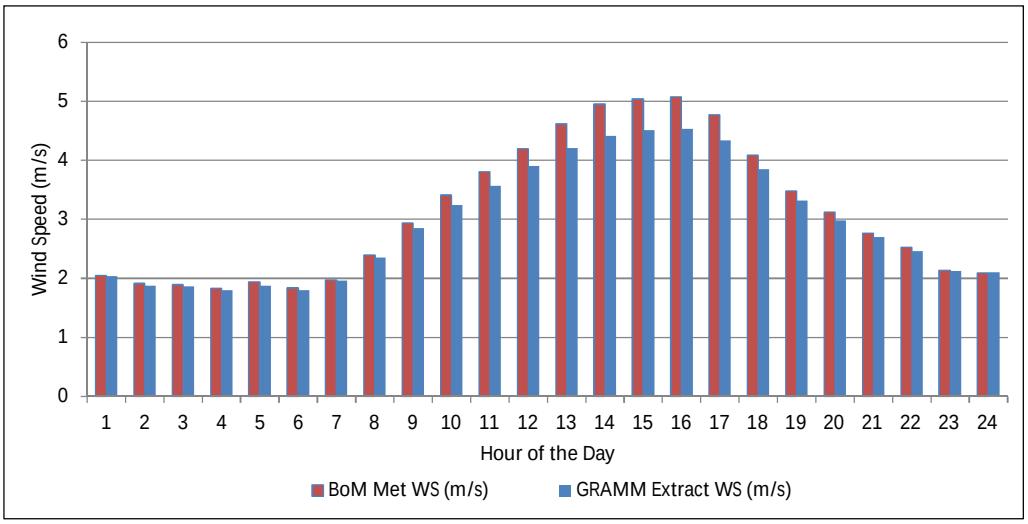


Figure H-17 Average wind speeds by hour of day for observed and predicted at Canterbury Racecourse

H.2.2 Wind direction

Annual and seasonal wind roses for the measurements at the Canterbury Racecourse site are presented in Figure H-18. The predicted winds from GRAMM are presented for comparison with observed. Both the GRAMM extract and the GRAMM extract re-ordered compare very well with the observations for annual and seasonal variations.

H.2.3 Statistical benchmarks

The statistical measures used to quantify the differences between model predictions and observations are taken from the BOOT Statistical Model Evaluation Software Package (Chang and Hanna, 2005) and assessed against the performance benchmarks set for model evaluation (Emery et al., 2001). The BoM Canterbury Racecourse data for 2014 were included in this analysis.

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.

These statistical measures are summarised in Table H-2 along with the performance benchmarks adopted for the study.

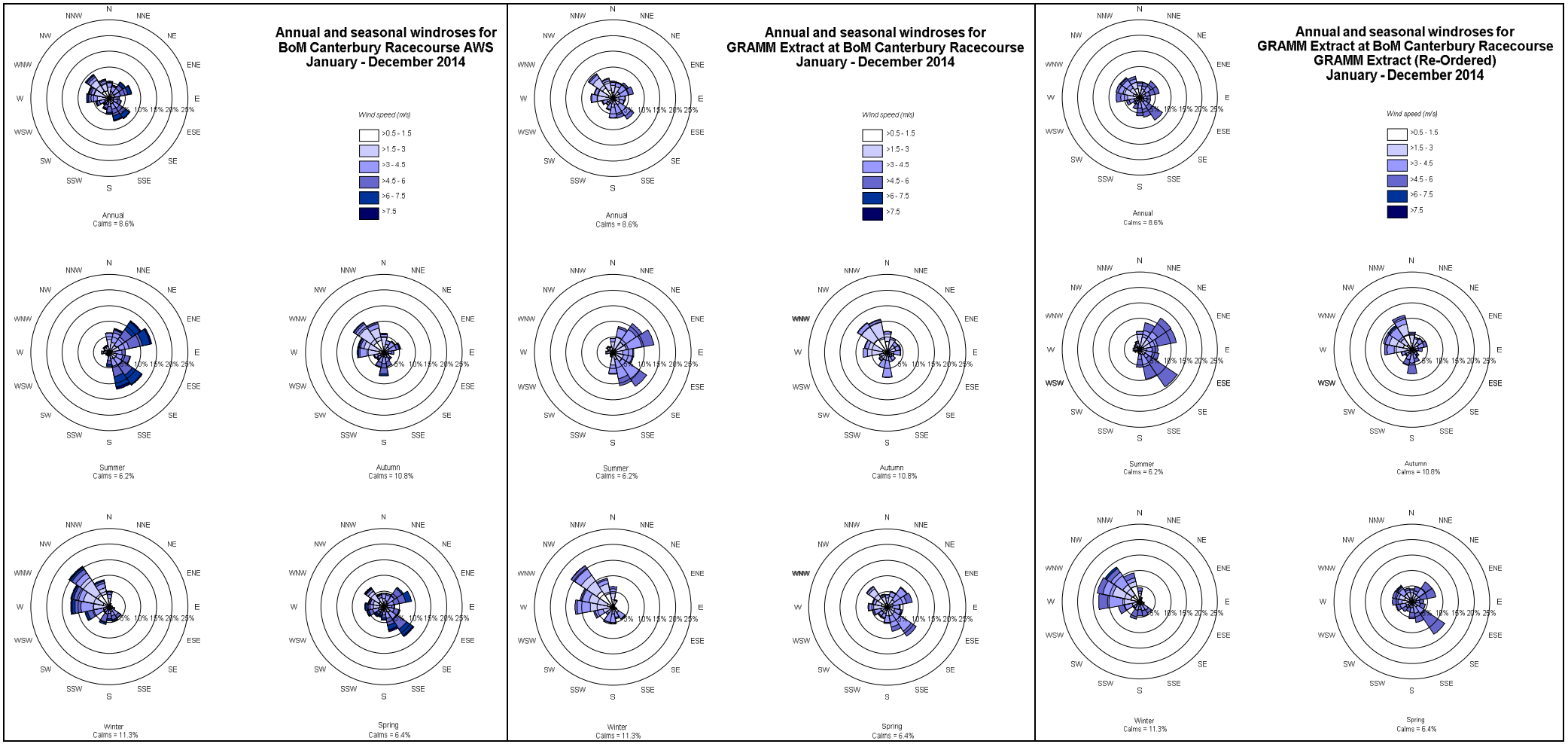


Figure H-18 Annual and seasonal wind roses for observed and predicted at Canterbury Racecourse

Table H-2 Statistical measures used to evaluate GRAMM performance

Statistical measure	Description	Parameter	Ideal value	Benchmark
Index of agreement (IOA)	$IOA = 1 - \frac{\sum_{i=1}^{n}(P_i - O_i)^2}{\sum_{i=1}^{n}(\lvert P_i - \overline{O}\rvert + \lvert O_i - \overline{O}\rvert)^2}$	Wind speed	1	≥ 0.6
Mean bias (MB)	$MB = \frac{1}{n}\sum_{i=1}^{N}\lvert P_i - O_i\rvert$	Wind speed	0	≤ ± 0.5 m/s
		Wind direction	0	≤ 10º
Mean gross error (MGE)	$MGE = \frac{1}{N}\sum_{i=1}^{N}\lvert P_i - O_i\rvert$	Wind speed	0	≤ 2 m/s
		Wind direction	0	≤ 30º
Fractional bias	$FBIAS = \frac{2}{n}\sum_{i=1}^{n}\left(\frac{P_i - O_i}{P_i - O_i}\right) \times 100\%$	Wind speed	0	≤ ± 0.67
Skill v		Wind speed	1	1
Skill r		Wind speed	-	< 1

N = number of observations $\overline{O}$ = mean of observed values
P = predicted value $\overline{P}$ = mean of predicted values
O = observed value i = time period

The evaluation of GRAMM performance against these benchmarks is presented in Table H-3. The index of agreement (IOA) compares well against the benchmark for wind speed, approaching the ideal score of 1. The fractional bias, skill v and skill r tests all fall within the acceptable range. The mean gross error (MGE) compares well against the benchmark for both variables, in particular for wind direction. Model performance against mean bias (MB) also falls within the acceptable benchmark.

Overall, it can be concluded that GRAMM simulates the meteorology with an acceptable degree of accuracy.

Table H-3 Statistical evaluation of GRAMM performance

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

Appendix I - Emissions and concentrations for ventilation outlets

I.1 Emissions from ventilation outlets

Table I-1 Emission rates: (A) Kingsgrove ventilation facility, 2021-DS (expected operation)

Hour start	NO_2 (g/s)[(a)]	NO_X (g/s)	CO (g/s)	$PM_{2.5}$ (g/s)	PM_{10} (g/s)	THC (g/s)	Notes
00	0.056	0.422	0.705	0.038	0.055	0.0270	
01	0.019	0.143	0.212	0.014	0.020	0.0091	
02	0.015	0.115	0.151	0.010	0.014	0.0074	
03	0.019	0.141	0.224	0.012	0.018	0.0090	
04	0.029	0.219	0.293	0.018	0.026	0.0140	
05	0.057	0.433	0.727	0.038	0.055	0.0276	
06	0.086	0.649	1.017	0.058	0.083	0.0414	
07	0.148	1.122	1.968	0.104	0.150	0.0716	
08	0.119	0.902	1.451	0.082	0.118	0.0576	
09	0.188	1.424	2.073	0.127	0.183	0.0909	
10	0.204	1.548	2.015	0.135	0.194	0.0988	
11	0.238	1.802	2.245	0.155	0.222	0.1151	
12	0.197	1.496	2.043	0.131	0.188	0.0955	
13	0.216	1.634	2.070	0.141	0.203	0.1044	
14	0.210	1.590	2.132	0.139	0.199	0.1015	
15	0.209	1.583	2.359	0.142	0.203	0.1011	
16	0.255	1.929	3.060	0.173	0.249	0.1232	
17	0.275	2.080	3.874	0.195	0.280	0.1328	
18	0.193	1.466	2.648	0.136	0.195	0.0936	
19	0.152	1.149	2.038	0.106	0.152	0.0734	
20	0.131	0.989	1.836	0.092	0.132	0.0631	
21	0.120	0.906	1.682	0.084	0.121	0.0578	
22	0.116	0.882	1.582	0.082	0.117	0.0564	
23	0.099	0.751	1.157	0.067	0.096	0.0479	
Average emission rates by time period used in GRAL **(kg/h)**							
Hour 00 Hour 06 to hour 09 Hour 20 to hour 23	-	**3.219**	***5.388***	**0.294**	**0.422**	**0.206**	Emissions released from 1 outlet
Hour 01 to hour 05	-	**0.757**	***1.157***	**0.067**	**0.096**	**0.048**	Emissions released from 1 outlet
Hour 10 to hour 19	-	**5.859**	***8.814***	**0.523**	**0.751**	**0.374**	Emissions released from 1 outlet

(a) Not used in dispersion model

Table I-2 Emission rates: (B) Arncliffe ventilation facility, 2021-DS (expected operation)

Hour start	NO_2 (g/s)[(a)]	NO_X (g/s)	CO (g/s)	$PM_{2.5}$ (g/s)	PM_{10} (g/s)	THC (g/s)	Notes
00	0.005	0.038	0.065	0.006	0.008	0.0024	
01	0.004	0.029	0.040	0.004	0.006	0.0019	
02	0.003	0.026	0.032	0.004	0.005	0.0017	
03	0.003	0.026	0.032	0.004	0.005	0.0017	
04	0.005	0.035	0.055	0.005	0.007	0.0022	
05	0.009	0.069	0.131	0.010	0.014	0.0044	
06	0.039	0.294	0.559	0.041	0.059	0.0188	
07	0.072	0.549	1.114	0.079	0.113	0.0351	
08	0.103	0.781	1.441	0.110	0.158	0.0499	
09	0.087	0.658	1.219	0.093	0.134	0.0420	
10	0.080	0.608	1.081	0.086	0.123	0.0388	
11	0.081	0.615	1.031	0.086	0.123	0.0392	
12	0.069	0.523	0.834	0.071	0.103	0.0334	
13	0.063	0.475	0.709	0.064	0.092	0.0303	
14	0.062	0.469	0.712	0.063	0.091	0.0299	
15	0.066	0.500	0.849	0.070	0.101	0.0319	
16	0.067	0.510	0.922	0.073	0.105	0.0326	
17	0.058	0.439	0.748	0.063	0.090	0.0280	
18	0.056	0.421	0.711	0.060	0.087	0.0269	
19	0.043	0.330	0.508	0.046	0.066	0.0210	
20	0.035	0.266	0.416	0.037	0.053	0.0170	
21	0.032	0.242	0.379	0.033	0.048	0.0154	
22	0.030	0.226	0.385	0.031	0.045	0.0145	
23	0.012	0.088	0.163	0.013	0.019	0.0056	
Average emission rates by time period used in GRAL **(kg/h)**							
Hour 00 to hour 05 Hour 19 to hour 23	-	**0.450**	**0.721**	**0.063**	**0.090**	**0.029**	Emissions distributed equally across 4 outlets
Hour 07 to hour 09	-	**2.385**	**4.528**	**0.338**	**0.486**	**0.152**	Emissions distributed equally across 4 outlets
Hour 06 Hour 10 to hour 18	-	**1.748**	**2.936**	**0.244**	**0.350**	**0.112**	Emissions distributed equally across 4 outlets

(a) Not used in dispersion model

Table I-3 Emission rates: (C) St Peters ventilation facility (New M5), 2021-DS (expected operation)

Hour start	NO_2 (g/s)[(a)]	NO_X (g/s)	CO (g/s)	$PM_{2.5}$ (g/s)	PM_{10} (g/s)	THC (g/s)	Notes
00	0.009	0.071	0.117	0.006	0.008	0.0045	
01	0.006	0.046	0.069	0.004	0.005	0.0029	
02	0.005	0.036	0.045	0.003	0.004	0.0023	
03	0.005	0.034	0.038	0.002	0.004	0.0022	
04	0.005	0.039	0.052	0.003	0.004	0.0025	
05	0.009	0.066	0.116	0.005	0.007	0.0042	
06	0.037	0.282	0.552	0.020	0.029	0.0180	
07	0.089	0.676	1.374	0.053	0.077	0.0432	
08	0.123	0.932	1.708	0.072	0.103	0.0595	
09	0.103	0.780	1.428	0.060	0.086	0.0498	
10	0.096	0.724	1.262	0.055	0.079	0.0462	
11	0.097	0.737	1.206	0.055	0.080	0.0471	
12	0.081	0.617	0.962	0.046	0.065	0.0394	
13	0.073	0.555	0.812	0.040	0.058	0.0354	
14	0.076	0.573	0.834	0.042	0.060	0.0366	
15	0.083	0.626	1.004	0.047	0.068	0.0400	
16	0.082	0.619	1.072	0.048	0.068	0.0395	
17	0.066	0.498	0.825	0.038	0.054	0.0318	
18	0.066	0.497	0.799	0.038	0.054	0.0317	
19	0.013	0.097	0.148	0.007	0.010	0.0062	
20	0.066	0.501	0.728	0.040	0.058	0.0320	
21	0.040	0.301	0.452	0.022	0.032	0.0192	
22	0.037	0.282	0.452	0.021	0.030	0.0180	
23	0.018	0.140	0.234	0.011	0.016	0.0089	
Average emission rates by time period used in GRAL **(kg/h)**							
Hour 00 to hour 05 Hour 19 Hour 23	-	**0.238**	***0.368***	**0.018**	**0.026**	**0.015**	Emissions distributed equally across 2 outlets
Hour 06 Hour 12 to hour 18 Hour 20 to hour 22	-	**1.751**	***2.779***	**0.132**	**0.189**	**0.112**	Emissions distributed equally across 2 outlets
Hour 07 to hour 11	-	**2.772**	***5.025***	**0.213**	**0.306**	**0.177**	Emissions distributed equally across 4 outlets

(a) Not used in dispersion model

Table I-4 Emission rates: (A) Kingsgrove ventilation facility, 2031-DS (expected operation)

Hour start	NO_2 (g/s)[(a)]	NO_X (g/s)	CO (g/s)	$PM_{2.5}$ (g/s)	PM_{10} (g/s)	THC (g/s)	Notes
00	0.067	0.507	0.799	0.045	0.065	0.0324	
01	0.022	0.168	0.233	0.016	0.023	0.0107	
02	0.019	0.141	0.172	0.012	0.017	0.0090	
03	0.022	0.170	0.255	0.015	0.021	0.0109	
04	0.036	0.276	0.335	0.023	0.033	0.0177	
05	0.067	0.508	0.788	0.045	0.064	0.0325	
06	0.102	0.772	1.078	0.067	0.096	0.0493	
07	0.181	1.374	2.265	0.126	0.181	0.0877	
08	0.165	1.249	1.915	0.113	0.162	0.0797	
09	0.232	1.760	2.394	0.155	0.223	0.1124	
10	0.254	1.923	2.336	0.166	0.238	0.1228	
11	0.285	2.160	2.546	0.184	0.264	0.1379	
12	0.245	1.853	2.360	0.160	0.230	0.1183	
13	0.269	2.036	2.394	0.174	0.249	0.1300	
14	0.258	1.957	2.423	0.168	0.242	0.1250	
15	0.257	1.951	2.713	0.172	0.247	0.1246	
16	0.313	2.369	3.517	0.210	0.302	0.1513	
17	0.363	2.749	4.667	0.256	0.368	0.1755	
18	0.235	1.782	3.033	0.163	0.235	0.1138	
19	0.185	1.403	2.336	0.128	0.183	0.0896	
20	0.158	1.200	2.100	0.110	0.158	0.0767	
21	0.145	1.096	1.890	0.100	0.144	0.0700	
22	0.133	1.007	1.656	0.091	0.131	0.0643	
23	0.099	0.750	1.177	0.067	0.097	0.0479	
Average emission rates by time period used in GRAL **(kg/h)**							
Hour 00 Hour 06 Hour 21 to hour 23	-	**2.975**	**4.752**	**0.267**	**0.384**	**0.190**	Emissions released from 1 outlet
Hour 01 to hour 05	-	**0.910**	**1.283**	**0.080**	**0.114**	**0.058**	Emissions released from 1 outlet
Hour 07 to hour 20	-	**6.625**	**9.514**	**0.588**	**0.844**	**0.423**	Emissions released from 1 outlet

(a) Not used in dispersion model

Table I-5 Emission rates: (B) Arncliffe ventilation facility, 2031-DS (expected operation)

Hour start	NO_2 (g/s)[(a)]	NO_X (g/s)	CO (g/s)	$PM_{2.5}$ (g/s)	PM_{10} (g/s)	THC (g/s)	Notes
00	0.007	0.050	0.077	0.007	0.010	0.0032	
01	0.005	0.034	0.047	0.005	0.007	0.0022	
02	0.004	0.031	0.038	0.004	0.006	0.0020	
03	0.004	0.030	0.038	0.004	0.006	0.0019	
04	0.006	0.046	0.065	0.006	0.009	0.0030	
05	0.012	0.087	0.155	0.012	0.017	0.0056	
06	0.048	0.364	0.655	0.050	0.072	0.0233	
07	0.089	0.672	1.313	0.096	0.137	0.0429	
08	0.129	0.978	1.665	0.136	0.196	0.0625	
09	0.108	0.819	1.442	0.115	0.165	0.0523	
10	0.100	0.761	1.284	0.106	0.153	0.0486	
11	0.100	0.758	1.188	0.104	0.149	0.0484	
12	0.087	0.659	0.989	0.089	0.128	0.0421	
13	0.080	0.603	0.843	0.080	0.115	0.0385	
14	0.078	0.593	0.842	0.079	0.114	0.0379	
15	0.083	0.628	1.011	0.087	0.125	0.0401	
16	0.085	0.641	1.098	0.091	0.131	0.0409	
17	0.080	0.603	1.027	0.086	0.124	0.0385	
18	0.070	0.533	0.851	0.075	0.108	0.0340	
19	0.055	0.419	0.606	0.058	0.083	0.0268	
20	0.044	0.336	0.481	0.045	0.065	0.0215	
21	0.040	0.304	0.449	0.041	0.059	0.0194	
22	0.036	0.272	0.440	0.037	0.054	0.0174	
23	0.014	0.103	0.175	0.015	0.022	0.0066	
Average emission rates by time period used in GRAL **(kg/h)**							
Hour 00 to hour 05 Hour 22 to hour 23	-	**0.295**	**0.466**	**0.041**	**0.059**	**0.019**	Emissions distributed equally across 4 outlets
Hour 06 Hour 12 to hour 13 Hour 18 to hour 21	-	**1.655**	**2.507**	**0.226**	**0.325**	**0.106**	Emissions distributed equally across 4 outlets
Hour 07 to hour 11 Hour 14 to hour 17	-	**2.581**	**4.348**	**0.360**	**0.518**	**0.165**	Emissions distributed equally across 4 outlets

(a) Not used in dispersion model.

Table I-6 Emission rates: (C) St Peters ventilation facility (New M5), 2031-DS (expected operation)

Hour start	NO_2 (g/s)[(a)]	NO_X (g/s)	CO (g/s)	$PM_{2.5}$ (g/s)	PM_{10} (g/s)	THC (g/s)	Notes
00	0.011	0.085	0.127	0.007	0.010	0.0054	
01	0.007	0.055	0.075	0.004	0.006	0.0035	
02	0.006	0.043	0.052	0.003	0.005	0.0027	
03	0.005	0.039	0.045	0.003	0.004	0.0025	
04	0.007	0.050	0.063	0.003	0.005	0.0032	
05	0.012	0.087	0.142	0.006	0.009	0.0056	
06	0.048	0.365	0.667	0.026	0.038	0.0233	
07	0.108	0.818	1.595	0.064	0.092	0.0522	
08	0.156	1.180	1.941	0.089	0.128	0.0754	
09	0.130	0.983	1.687	0.075	0.107	0.0628	
10	0.121	0.916	1.498	0.069	0.099	0.0585	
11	0.121	0.919	1.388	0.068	0.098	0.0587	
12	0.105	0.798	1.153	0.058	0.084	0.0510	
13	0.096	0.730	0.984	0.053	0.076	0.0466	
14	0.096	0.730	0.986	0.053	0.076	0.0466	
15	0.102	0.774	1.178	0.058	0.083	0.0494	
16	0.103	0.777	1.272	0.059	0.085	0.0496	
17	0.096	0.727	1.178	0.055	0.080	0.0464	
18	0.084	0.635	0.962	0.048	0.069	0.0405	
19	0.059	0.446	0.624	0.032	0.046	0.0285	
20	0.022	0.165	0.224	0.012	0.017	0.0105	
21	0.064	0.482	0.656	0.037	0.053	0.0307	
22	0.046	0.345	0.520	0.026	0.037	0.0220	
23	0.022	0.164	0.255	0.013	0.018	0.0105	
Average emission rates by time period used in GRAL **(kg/h)**							
Hour 00 to hour 06 Hour 19 to hour 23	-	**0.698**	**1.036**	**0.052**	**0.074**	**0.045**	Emissions distributed equally across 2 outlets
Hour 07 Hour 11 to hour 18	-	**2.763**	**4.278**	**0.206**	**0.296**	**0.176**	Emissions distributed equally across 3 outlets
Hour 08 to hour 10	-	**3.695**	**6.151**	**0.280**	**0.402**	**0.236**	Emissions distributed equally across 4 outlets

(a) Not used in dispersion model

Table I-7 Emission rates: (A) Kingsgrove ventilation facility, 2031-DSC (expected operation)

Hour start	NO_2 (g/s)[(a)]	NO_X (g/s)	CO (g/s)	$PM_{2.5}$ (g/s)	PM_{10} (g/s)	THC (g/s)	Notes
00	0.093	0.701	1.176	0.067	0.096	0.0448	
01	0.039	0.298	0.463	0.029	0.041	0.0190	
02	0.024	0.180	0.232	0.017	0.024	0.0115	
03	0.019	0.145	0.153	0.013	0.018	0.0092	
04	0.023	0.176	0.226	0.015	0.021	0.0112	
05	0.057	0.432	0.718	0.037	0.053	0.0276	
06	0.105	0.797	1.274	0.070	0.100	0.0509	
07	0.189	1.433	2.445	0.130	0.186	0.0915	
08	0.281	2.131	3.867	0.203	0.291	0.1361	
09	0.290	2.199	3.599	0.215	0.308	0.1404	
10	0.311	2.355	3.402	0.222	0.318	0.1504	
11	0.335	2.540	3.527	0.238	0.343	0.1622	
12	0.309	2.340	3.428	0.225	0.323	0.1494	
13	0.320	2.425	3.431	0.229	0.329	0.1548	
14	0.323	2.449	3.509	0.232	0.333	0.1564	
15	0.328	2.485	3.841	0.240	0.345	0.1587	
16	0.386	2.922	4.880	0.287	0.412	0.1866	
17	0.451	3.420	6.004	0.344	0.494	0.2184	
18	0.337	2.555	4.942	0.269	0.387	0.1632	
19	0.261	1.981	3.713	0.204	0.293	0.1265	
20	0.208	1.577	2.959	0.159	0.228	0.1007	
21	0.180	1.362	2.545	0.134	0.193	0.0870	
22	0.159	1.205	2.281	0.119	0.171	0.0769	
23	0.126	0.956	1.698	0.093	0.134	0.0611	
Average emission rates by time period used in GRAL **(kg/h)**							
Hour 00 to hour 06	-	**1.404**	**2.181**	**0.127**	**0.182**	**0.090**	Emissions released from 1 outlet
Hour 07 to hour 23	-	**7.694**	**12.721**	**0.750**	**1.077**	**0.491**	Emissions released from 1 outlet

(a) Not used in dispersion model

Table I-8 Emission rates: (B) Arncliffe ventilation facility, 2031-DSC (expected operation)

Hour start	NO_2 (g/s)[(a)]	NO_X (g/s)	CO (g/s)	$PM_{2.5}$ (g/s)	PM_{10} (g/s)	THC (g/s)	Notes
00	0.012	0.091	0.176	0.013	0.019	0.0058	
01	0.007	0.054	0.104	0.008	0.011	0.0035	
02	0.005	0.039	0.064	0.006	0.008	0.0025	
03	0.005	0.038	0.062	0.005	0.008	0.0024	
04	0.008	0.064	0.134	0.010	0.014	0.0041	
05	0.017	0.126	0.286	0.019	0.028	0.0081	
06	0.067	0.508	1.208	0.077	0.111	0.0324	
07	0.127	0.965	2.356	0.151	0.217	0.0616	
08	0.168	1.276	2.833	0.198	0.284	0.0815	
09	0.151	1.141	2.490	0.175	0.252	0.0729	
10	0.135	1.024	2.188	0.156	0.224	0.0654	
11	0.124	0.939	1.946	0.141	0.203	0.0600	
12	0.115	0.868	1.750	0.129	0.185	0.0554	
13	0.107	0.812	1.622	0.121	0.173	0.0518	
14	0.104	0.787	1.588	0.117	0.168	0.0503	
15	0.104	0.787	1.637	0.119	0.171	0.0502	
16	0.102	0.775	1.622	0.118	0.169	0.0495	
17	0.102	0.776	1.640	0.118	0.170	0.0495	
18	0.082	0.621	1.301	0.094	0.136	0.0396	
19	0.070	0.530	1.115	0.080	0.115	0.0339	
20	0.062	0.469	1.035	0.071	0.102	0.0299	
21	0.059	0.448	1.004	0.068	0.098	0.0286	
22	0.058	0.440	1.002	0.067	0.096	0.0281	
23	0.023	0.178	0.417	0.027	0.039	0.0113	
Average emission rates by time period used in GRAL **(kg/h)**							
Hour 00 to hour 05	-	**0.248**	***0.495***	**0.037**	**0.053**	**0.016**	Emissions distributed equally across 8 outlets
Hour 06 Hour 18 to hour 23	-	**1.642**	***3.643***	**0.250**	**0.359**	**0.105**	Emissions distributed equally across 8 outlets
Hour 07 to hour 17	-	**3.322**	***7.093***	**0.505**	**0.726**	**0.212**	Emissions distributed equally across 8 outlets

(a) Not used in dispersion model

Table I-9 Emission rates: (C) St Peters ventilation facility (New M5), 2031-DSC (expected operation)

Hour start	NO_2 (g/s)[(a)]	NO_X (g/s)	CO (g/s)	$PM_{2.5}$ (g/s)	PM_{10} (g/s)	THC (g/s)	Notes
00	0.011	0.080	0.181	0.007	0.009	0.0051	
01	0.006	0.045	0.096	0.004	0.005	0.0029	
02	0.005	0.037	0.071	0.003	0.004	0.0024	
03	0.005	0.041	0.070	0.003	0.004	0.0026	
04	0.008	0.064	0.145	0.005	0.007	0.0041	
05	0.015	0.114	0.283	0.009	0.013	0.0073	
06	0.050	0.380	1.032	0.032	0.046	0.0242	
07	0.132	1.003	2.632	0.084	0.121	0.0641	
08	0.159	1.201	2.802	0.099	0.143	0.0767	
09	0.148	1.119	2.603	0.092	0.131	0.0715	
10	0.130	0.987	2.245	0.080	0.114	0.0630	
11	0.119	0.904	2.017	0.072	0.103	0.0577	
12	0.113	0.859	1.891	0.068	0.098	0.0548	
13	0.102	0.775	1.679	0.061	0.087	0.0495	
14	0.100	0.761	1.675	0.060	0.086	0.0486	
15	0.102	0.775	1.743	0.062	0.089	0.0495	
16	0.099	0.753	1.701	0.060	0.086	0.0481	
17	0.093	0.705	1.588	0.056	0.081	0.0450	
18	0.080	0.606	1.386	0.048	0.070	0.0387	
19	0.069	0.525	1.228	0.042	0.060	0.0335	
20	0.065	0.492	1.181	0.039	0.056	0.0314	
21	0.062	0.466	1.152	0.038	0.054	0.0298	
22	0.061	0.460	1.172	0.037	0.054	0.0294	
23	0.026	0.199	0.520	0.016	0.023	0.0127	
Average emission rates by time period used in GRAL **(kg/h)**							
Hour 00 to hour 06 Hour 18 to hour 23	-	**0.972**	***1.142***	**0.038**	**0.054**	**0.030**	Emissions distributed equally across 4 outlets
Hour 07 to hour 10	-	**3.879**	***5.482***	**0.191**	**0.275**	**0.153**	Emissions distributed equally across 4 outlets
Hour 18 to hour 23	-	**2.844**	***9.252***	**0.319**	**0.459**	**0.248**	Emissions distributed equally across 4 outlets

(a) Not used in dispersion model

Table I-10 Emission rates: (D) Southern Extension ventilation facility, 2031-DSC (expected operation)

Hour start	NO_2 (g/s)[(a)]	NO_X (g/s)	CO (g/s)	$PM_{2.5}$ (g/s)	PM_{10} (g/s)	THC (g/s)	Notes
00	0.042	0.316	0.648	0.036	0.052	0.0202	
01	0.023	0.174	0.352	0.020	0.028	0.0111	
02	0.013	0.098	0.207	0.011	0.016	0.0062	
03	0.011	0.086	0.178	0.009	0.013	0.0055	
04	0.015	0.117	0.271	0.012	0.018	0.0075	
05	0.031	0.232	0.567	0.024	0.035	0.0148	
06	0.051	0.386	0.871	0.041	0.059	0.0247	
07	0.082	0.618	1.310	0.067	0.096	0.0394	
08	0.141	1.066	2.375	0.120	0.172	0.0681	
09	0.172	1.302	2.860	0.148	0.212	0.0831	
10	0.220	1.663	3.597	0.182	0.261	0.1062	
11	0.270	2.043	4.473	0.221	0.317	0.1305	
12	0.261	1.980	4.510	0.216	0.311	0.1264	
13	0.270	2.044	4.638	0.223	0.320	0.1305	
14	0.286	2.168	4.976	0.236	0.339	0.1385	
15	0.318	2.412	5.627	0.265	0.380	0.1540	
16	0.371	2.814	6.740	0.315	0.452	0.1797	
17	0.400	3.031	7.315	0.355	0.510	0.1935	
18	0.339	2.565	6.507	0.294	0.422	0.1638	
19	0.213	1.617	4.003	0.182	0.262	0.1033	
20	0.143	1.081	2.606	0.121	0.174	0.0690	
21	0.113	0.857	2.132	0.097	0.139	0.0547	
22	0.103	0.777	1.924	0.087	0.125	0.0496	
23	0.058	0.437	0.889	0.051	0.073	0.0279	
Average emission rates by time period used in GRAL **(kg/h)**							
Hour 00 to hour 06	-	**0.725**	**1.592**	**0.079**	**0.1147**	**0.046**	Emissions distributed equally across 4 outlets
Hour 07 to hour 23	-	**6.030**	**14.079**	**0.673**	**0.967**	**0.385**	Emissions distributed equally across 4 outlets

(a) Not used in dispersion model

Table I-11 Emission rates: (E) St Peters ventilation facility (M4-M5 Link), 2031-DSC (expected operation)

Hour start	NO_2 (g/s)[(a)]	NO_X (g/s)	CO (g/s)	$PM_{2.5}$ (g/s)	PM_{10} (g/s)	THC (g/s)	Notes
00	0.078	0.589	0.793	0.046	0.067	0.0376	
01	0.054	0.409	0.441	0.032	0.046	0.0261	
02	0.032	0.246	0.381	0.021	0.030	0.0157	
03	0.032	0.241	0.383	0.020	0.029	0.0154	
04	0.031	0.238	0.394	0.020	0.029	0.0152	
05	0.032	0.243	0.395	0.020	0.029	0.0155	
06	0.078	0.589	0.812	0.046	0.067	0.0376	
07	0.226	1.713	2.730	0.139	0.200	0.1094	
08	0.325	2.463	4.015	0.210	0.302	0.1573	
09	0.356	2.698	4.004	0.223	0.321	0.1723	
10	0.360	2.728	3.866	0.223	0.321	0.1742	
11	0.365	2.767	3.801	0.224	0.322	0.1767	
12	0.360	2.729	3.807	0.222	0.318	0.1743	
13	0.354	2.679	3.712	0.217	0.312	0.1711	
14	0.345	2.612	3.664	0.211	0.304	0.1668	
15	0.338	2.561	3.721	0.210	0.302	0.1635	
16	0.318	2.406	3.709	0.200	0.288	0.1537	
17	0.300	2.271	3.766	0.190	0.274	0.1450	
18	0.300	2.271	3.682	0.190	0.272	0.1450	
19	0.276	2.093	3.293	0.171	0.246	0.1336	
20	0.252	1.907	3.015	0.155	0.222	0.1218	
21	0.223	1.689	2.646	0.136	0.195	0.1078	
22	0.210	1.591	2.405	0.127	0.183	0.1016	
23	0.114	0.866	1.360	0.070	0.101	0.0553	
Average emission rates by time period used in GRAL **(kg/h)**							
Hour 00 to hour 06	-	**1.315**	**1.851**	**0.106**	**0.152**	**0.084**	Emissions distributed equally across 4 outlets
Hour 07 to hour 23	-	**8.056**	**12.112**	**0.661**	**0.949**	**0.514**	Emissions distributed equally across 4 outlets

(a) Not used in dispersion model

I.2 Concentrations in ventilation outlets

Table I-12 Concentrations in ventilation outlet: (A) Kingsgrove, 2021-DS (expected operation)

Hour start	NO_2 (mg/m^3)	NO_X (mg/m^3)	CO (mg/m^3)	$PM_{2.5}$ (mg/m^3)	PM_{10} (mg/m^3)	THC (mg/m^3)
00	0.147	1.111	1.855	0.100	0.144	0.071
01	0.075	0.571	0.849	0.056	0.081	0.036
02	0.061	0.461	0.605	0.040	0.058	0.029
03	0.075	0.566	0.895	0.049	0.071	0.036
04	0.116	0.875	1.171	0.073	0.105	0.056
05	0.228	1.730	2.907	0.153	0.220	0.110
06	0.225	1.707	2.677	0.152	0.218	0.109
07	0.390	2.952	5.179	0.275	0.395	0.188
08	0.313	2.374	3.818	0.216	0.310	0.152
09	0.495	3.748	5.454	0.335	0.481	0.239
10	0.409	3.096	4.030	0.270	0.388	0.198
11	0.476	3.603	4.490	0.309	0.445	0.230
12	0.395	2.991	4.086	0.262	0.376	0.191
13	0.431	3.269	4.140	0.282	0.405	0.209
14	0.420	3.180	4.265	0.278	0.399	0.203
15	0.418	3.167	4.717	0.283	0.407	0.202
16	0.509	3.857	6.120	0.347	0.498	0.246
17	0.549	4.160	7.749	0.390	0.560	0.266
18	0.387	2.931	5.297	0.272	0.391	0.187
19	0.303	2.299	4.076	0.212	0.304	0.147
20	0.343	2.602	4.832	0.242	0.347	0.166
21	0.315	2.384	4.427	0.222	0.319	0.152
22	0.307	2.322	4.163	0.215	0.309	0.148
23	0.261	1.976	3.044	0.176	0.252	0.126

Table I-13 Concentrations in ventilation outlet: (B) Arncliffe, 2021-DS (expected operation)

Hour start	NO_2 (mg/m^3)	NO_X (mg/m^3)	CO (mg/m^3)	$PM_{2.5}$ (mg/m^3)	PM_{10} (mg/m^3)	THC (mg/m^3)
00	0.013	0.100	0.172	0.015	0.022	0.006
01	0.010	0.077	0.105	0.011	0.015	0.005
02	0.009	0.070	0.084	0.009	0.014	0.004
03	0.009	0.069	0.083	0.009	0.013	0.004
04	0.012	0.092	0.144	0.012	0.018	0.006
05	0.024	0.181	0.344	0.025	0.036	0.012
06	0.078	0.589	1.117	0.082	0.117	0.038
07	0.121	0.915	1.856	0.131	0.188	0.058
08	0.172	1.302	2.401	0.183	0.263	0.083
09	0.145	1.096	2.031	0.155	0.223	0.070
10	0.161	1.217	2.162	0.172	0.247	0.078
11	0.162	1.229	2.063	0.171	0.246	0.078
12	0.138	1.046	1.667	0.143	0.205	0.067
13	0.125	0.950	1.418	0.128	0.184	0.061
14	0.124	0.938	1.424	0.127	0.182	0.060
15	0.132	0.999	1.699	0.140	0.202	0.064
16	0.135	1.021	1.843	0.146	0.210	0.065
17	0.116	0.878	1.496	0.125	0.180	0.056
18	0.111	0.842	1.423	0.120	0.173	0.054
19	0.114	0.867	1.338	0.120	0.173	0.055
20	0.092	0.700	1.094	0.096	0.138	0.045
21	0.084	0.637	0.997	0.087	0.125	0.041
22	0.079	0.596	1.012	0.082	0.118	0.038
23	0.031	0.232	0.429	0.035	0.050	0.015

Table I-14 Concentrations in ventilation outlet: (C) St Peters (New M5), 2021-DS (expected operation)

Hour start	NO_2 (mg/m^3)	NO_X (mg/m^3)	CO (mg/m^3)	$PM_{2.5}$ (mg/m^3)	PM_{10} (mg/m^3)	THC (mg/m^3)
00	0.072	0.543	0.899	0.044	0.063	0.035
01	0.047	0.353	0.528	0.028	0.040	0.023
02	0.037	0.279	0.349	0.021	0.030	0.018
03	0.035	0.263	0.293	0.019	0.027	0.017
04	0.040	0.303	0.397	0.022	0.031	0.019
05	0.067	0.508	0.890	0.036	0.052	0.032
06	0.186	1.411	2.760	0.102	0.147	0.090
07	0.255	1.932	3.926	0.152	0.219	0.123
08	0.352	2.664	4.881	0.204	0.294	0.170
09	0.294	2.229	4.081	0.171	0.246	0.142
10	0.273	2.068	3.605	0.158	0.227	0.132
11	0.278	2.107	3.446	0.159	0.228	0.135
12	0.407	3.083	4.810	0.228	0.327	0.197
13	0.366	2.774	4.062	0.201	0.289	0.177
14	0.378	2.864	4.170	0.210	0.301	0.183
15	0.413	3.132	5.018	0.237	0.340	0.200
16	0.408	3.093	5.358	0.238	0.342	0.198
17	0.328	2.488	4.124	0.188	0.270	0.159
18	0.328	2.485	3.995	0.188	0.271	0.159
19	0.098	0.746	1.137	0.054	0.078	0.048
20	0.331	2.505	3.639	0.202	0.290	0.160
21	0.199	1.505	2.259	0.112	0.161	0.096
22	0.186	1.410	2.259	0.106	0.152	0.090
23	0.142	1.077	1.802	0.085	0.123	0.069

Table I-15 Concentrations in ventilation outlet: (A) Kingsgrove, 2031-DS (expected operation)

Hour start	NO_2 (mg/m^3)	NO_X (mg/m^3)	CO (mg/m^3)	$PM_{2.5}$ (mg/m^3)	PM_{10} (mg/m^3)	THC (mg/m^3)
00	0.176	1.334	2.103	0.119	0.171	0.085
01	0.089	0.672	0.932	0.065	0.094	0.043
02	0.074	0.563	0.690	0.049	0.070	0.036
03	0.090	0.681	1.019	0.059	0.085	0.043
04	0.146	1.106	1.338	0.091	0.131	0.071
05	0.268	2.034	3.151	0.178	0.256	0.130
06	0.268	2.033	2.837	0.175	0.252	0.130
07	0.363	2.748	4.530	0.253	0.363	0.175
08	0.330	2.497	3.831	0.225	0.324	0.159
09	0.465	3.520	4.788	0.311	0.446	0.225
10	0.508	3.845	4.672	0.331	0.476	0.246
11	0.570	4.320	5.091	0.368	0.528	0.276
12	0.489	3.705	4.720	0.320	0.460	0.237
13	0.537	4.071	4.789	0.347	0.499	0.260
14	0.517	3.915	4.846	0.337	0.484	0.250
15	0.515	3.901	5.427	0.344	0.495	0.249
16	0.625	4.738	7.034	0.421	0.605	0.303
17	0.726	5.498	9.335	0.512	0.735	0.351
18	0.470	3.563	6.065	0.327	0.469	0.228
19	0.370	2.807	4.673	0.255	0.366	0.179
20	0.317	2.401	4.200	0.220	0.317	0.153
21	0.381	2.883	4.973	0.264	0.379	0.184
22	0.350	2.650	4.359	0.241	0.346	0.169
23	0.261	1.975	3.097	0.177	0.254	0.126

Table I-16 Concentrations in ventilation outlet: (B) Arncliffe, 2031-DS (expected operation)

Hour start	NO_2 (mg/m^3)	NO_X (mg/m^3)	CO (mg/m^3)	$PM_{2.5}$ (mg/m^3)	PM_{10} (mg/m^3)	THC (mg/m^3)
00	0.018	0.136	0.207	0.020	0.028	0.009
01	0.012	0.092	0.126	0.013	0.018	0.006
02	0.011	0.083	0.104	0.011	0.016	0.005
03	0.011	0.082	0.102	0.011	0.016	0.005
04	0.017	0.125	0.177	0.016	0.023	0.008
05	0.031	0.236	0.420	0.033	0.047	0.015
06	0.100	0.759	1.364	0.104	0.150	0.048
07	0.156	1.178	2.303	0.168	0.241	0.075
08	0.226	1.716	2.920	0.239	0.344	0.110
09	0.190	1.437	2.530	0.202	0.290	0.092
10	0.176	1.334	2.252	0.186	0.268	0.085
11	0.175	1.329	2.084	0.183	0.262	0.085
12	0.181	1.373	2.060	0.186	0.267	0.088
13	0.166	1.256	1.757	0.167	0.240	0.080
14	0.137	1.040	1.476	0.139	0.200	0.066
15	0.145	1.102	1.773	0.153	0.220	0.070
16	0.148	1.124	1.926	0.159	0.229	0.072
17	0.140	1.059	1.802	0.151	0.217	0.068
18	0.146	1.110	1.773	0.157	0.226	0.071
19	0.115	0.873	1.263	0.120	0.172	0.056
20	0.092	0.700	1.001	0.095	0.136	0.045
21	0.084	0.634	0.935	0.086	0.124	0.040
22	0.097	0.736	1.189	0.101	0.145	0.047
23	0.037	0.280	0.474	0.041	0.059	0.018

Table I-17 Concentrations in ventilation outlet: (C) St Peters (New M5), 2031-DS (expected operation)

Hour start	NO_2 (mg/m^3)	NO_X (mg/m^3)	CO (mg/m^3)	$PM_{2.5}$ (mg/m^3)	PM_{10} (mg/m^3)	THC (mg/m^3)
00	0.086	0.654	0.977	0.051	0.074	0.042
01	0.056	0.424	0.579	0.033	0.047	0.027
02	0.044	0.330	0.402	0.024	0.035	0.021
03	0.040	0.304	0.348	0.022	0.032	0.019
04	0.051	0.383	0.487	0.027	0.039	0.024
05	0.089	0.671	1.095	0.047	0.068	0.043
06	0.371	2.807	5.128	0.203	0.291	0.179
07	0.385	2.920	5.696	0.228	0.328	0.186
08	0.399	3.026	4.976	0.229	0.329	0.193
09	0.333	2.520	4.326	0.192	0.275	0.161
10	0.310	2.350	3.842	0.177	0.255	0.150
11	0.433	3.283	4.956	0.243	0.350	0.210
12	0.376	2.850	4.119	0.208	0.299	0.182
13	0.344	2.609	3.513	0.188	0.270	0.167
14	0.344	2.606	3.520	0.188	0.271	0.166
15	0.365	2.764	4.207	0.207	0.297	0.176
16	0.366	2.775	4.543	0.211	0.303	0.177
17	0.343	2.597	4.209	0.198	0.285	0.166
18	0.299	2.267	3.436	0.170	0.245	0.145
19	0.453	3.429	4.802	0.246	0.354	0.219
20	0.167	1.268	1.725	0.089	0.128	0.081
21	0.489	3.704	5.047	0.283	0.407	0.237
22	0.350	2.652	4.002	0.197	0.283	0.169
23	0.166	1.259	1.959	0.098	0.142	0.080

Table I-18 Concentrations in ventilation outlet: (A) Kingsgrove, 2031-DSC (expected operation)

Hour start	NO_2 (mg/m^3)	NO_X (mg/m^3)	CO (mg/m^3)	$PM_{2.5}$ (mg/m^3)	PM_{10} (mg/m^3)	THC (mg/m^3)
00	0.309	2.338	3.919	0.222	0.319	0.149
01	0.131	0.994	1.542	0.096	0.137	0.063
02	0.079	0.601	0.772	0.056	0.080	0.038
03	0.064	0.482	0.510	0.042	0.060	0.031
04	0.077	0.587	0.753	0.050	0.072	0.037
05	0.190	1.439	2.392	0.123	0.177	0.092
06	0.351	2.658	4.245	0.233	0.334	0.170
07	0.378	2.866	4.889	0.259	0.372	0.183
08	0.563	4.262	7.734	0.406	0.583	0.272
09	0.580	4.397	7.199	0.429	0.617	0.281
10	0.622	4.711	6.805	0.443	0.637	0.301
11	0.671	5.081	7.053	0.477	0.685	0.324
12	0.618	4.680	6.857	0.449	0.645	0.299
13	0.640	4.850	6.862	0.458	0.657	0.310
14	0.646	4.897	7.017	0.463	0.666	0.313
15	0.656	4.970	7.683	0.481	0.691	0.317
16	0.771	5.843	9.760	0.574	0.825	0.373
17	0.903	6.840	12.008	0.688	0.989	0.437
18	0.675	5.111	9.884	0.539	0.774	0.326
19	0.523	3.961	7.427	0.408	0.587	0.253
20	0.416	3.153	5.918	0.317	0.456	0.201
21	0.360	2.725	5.090	0.268	0.385	0.174
22	0.318	2.409	4.561	0.237	0.341	0.154
23	0.252	1.913	3.395	0.186	0.268	0.122

Table I-19 Concentrations in ventilation outlet: (B) Arncliffe, 2031-DSC (expected operation)

Hour start	NO_2 (mg/m^3)	NO_X (mg/m^3)	CO (mg/m^3)	$PM_{2.5}$ (mg/m^3)	PM_{10} (mg/m^3)	THC (mg/m^3)
00	0.019	0.145	0.279	0.021	0.031	0.009
01	0.011	0.086	0.165	0.013	0.018	0.005
02	0.008	0.062	0.101	0.009	0.013	0.004
03	0.008	0.061	0.098	0.009	0.012	0.004
04	0.013	0.102	0.213	0.015	0.022	0.007
05	0.026	0.201	0.453	0.031	0.044	0.013
06	0.079	0.597	1.422	0.091	0.131	0.038
07	0.127	0.965	2.356	0.151	0.217	0.062
08	0.168	1.276	2.833	0.198	0.284	0.081
09	0.151	1.141	2.490	0.175	0.252	0.073
10	0.135	1.024	2.188	0.156	0.224	0.065
11	0.124	0.939	1.946	0.141	0.203	0.060
12	0.115	0.868	1.750	0.129	0.185	0.055
13	0.107	0.812	1.622	0.121	0.173	0.052
14	0.104	0.787	1.588	0.117	0.168	0.050
15	0.104	0.787	1.637	0.119	0.171	0.050
16	0.102	0.775	1.622	0.118	0.169	0.049
17	0.102	0.776	1.640	0.118	0.170	0.050
18	0.096	0.730	1.530	0.111	0.159	0.047
19	0.082	0.624	1.312	0.094	0.135	0.040
20	0.073	0.551	1.218	0.084	0.120	0.035
21	0.070	0.527	1.182	0.080	0.115	0.034
22	0.068	0.518	1.179	0.079	0.113	0.033
23	0.028	0.209	0.491	0.032	0.046	0.013

Table I-20 Concentrations in ventilation outlet: St Peters (New M5), 2031-DSC (expected operation)

Hour start	NO_2 (mg/m^3)	NO_X (mg/m^3)	CO (mg/m^3)	$PM_{2.5}$ (mg/m^3)	PM_{10} (mg/m^3)	THC (mg/m^3)
00	0.039	0.296	0.671	0.024	0.035	0.019
01	0.022	0.168	0.355	0.014	0.019	0.011
02	0.018	0.137	0.265	0.011	0.015	0.009
03	0.020	0.151	0.258	0.011	0.016	0.010
04	0.031	0.236	0.536	0.019	0.027	0.015
05	0.056	0.423	1.048	0.035	0.050	0.027
06	0.186	1.406	3.822	0.117	0.169	0.090
07	0.294	2.229	5.848	0.187	0.269	0.142
08	0.352	2.669	6.226	0.221	0.317	0.170
09	0.328	2.487	5.784	0.203	0.292	0.159
10	0.289	2.193	4.988	0.177	0.254	0.140
11	0.331	2.510	5.602	0.200	0.287	0.160
12	0.315	2.386	5.254	0.189	0.271	0.152
13	0.284	2.152	4.663	0.168	0.242	0.137
14	0.279	2.115	4.652	0.166	0.239	0.135
15	0.284	2.153	4.843	0.171	0.246	0.137
16	0.276	2.091	4.724	0.167	0.240	0.133
17	0.258	1.958	4.411	0.157	0.225	0.125
18	0.296	2.245	5.134	0.179	0.258	0.143
19	0.256	1.943	4.549	0.155	0.222	0.124
20	0.240	1.821	4.373	0.145	0.209	0.116
21	0.228	1.727	4.268	0.139	0.200	0.110
22	0.225	1.705	4.340	0.138	0.199	0.109
23	0.097	0.738	1.924	0.060	0.086	0.047

Table I-21 Concentrations in ventilation outlet: (D) Southern Extension, 2031-DSC (expected operation)

Hour start	NO_2 (mg/m^3)	NO_X (mg/m^3)	CO (mg/m^3)	$PM_{2.5}$ (mg/m^3)	PM_{10} (mg/m^3)	THC (mg/m^3)
00	0.149	1.129	2.315	0.130	0.187	0.072
01	0.082	0.623	1.259	0.070	0.101	0.040
02	0.046	0.350	0.738	0.039	0.056	0.022
03	0.041	0.307	0.635	0.033	0.047	0.020
04	0.055	0.419	0.967	0.044	0.063	0.027
05	0.110	0.830	2.026	0.087	0.125	0.053
06	0.182	1.380	3.112	0.147	0.211	0.088
07	0.163	1.235	2.619	0.134	0.192	0.079
08	0.281	2.132	4.751	0.240	0.345	0.136
09	0.344	2.604	5.720	0.295	0.424	0.166
10	0.439	3.326	7.194	0.363	0.522	0.212
11	0.539	4.086	8.947	0.442	0.635	0.261
12	0.523	3.960	9.021	0.433	0.622	0.253
13	0.540	4.089	9.276	0.446	0.641	0.261
14	0.572	4.337	9.951	0.472	0.678	0.277
15	0.637	4.823	11.255	0.529	0.760	0.308
16	0.743	5.628	13.480	0.630	0.904	0.359
17	0.800	6.061	14.629	0.709	1.019	0.387
18	0.677	5.130	13.014	0.587	0.844	0.328
19	0.427	3.235	8.006	0.365	0.524	0.207
20	0.285	2.162	5.213	0.242	0.348	0.138
21	0.226	1.715	4.264	0.194	0.279	0.109
22	0.205	1.554	3.847	0.174	0.250	0.099
23	0.115	0.873	1.778	0.101	0.145	0.056

Table I-22 Concentrations in ventilation outlet: (E) St Peters (M4-M5 Link), 2031-DSC (expected operation)

Hour start	NO_2 (mg/m^3)	NO_X (mg/m^3)	CO (mg/m^3)	$PM_{2.5}$ (mg/m^3)	PM_{10} (mg/m^3)	THC (mg/m^3)
00	0.278	2.103	2.833	0.166	0.238	0.134
01	0.193	1.461	1.574	0.113	0.163	0.093
02	0.116	0.879	1.361	0.073	0.106	0.056
03	0.114	0.861	1.367	0.072	0.104	0.055
04	0.112	0.852	1.407	0.072	0.103	0.054
05	0.115	0.868	1.411	0.072	0.104	0.055
06	0.278	2.105	2.899	0.165	0.238	0.134
07	0.565	4.283	6.824	0.349	0.501	0.273
08	0.813	6.157	10.037	0.525	0.755	0.393
09	0.890	6.745	10.010	0.558	0.801	0.431
10	0.900	6.821	9.664	0.558	0.802	0.436
11	0.913	6.918	9.503	0.561	0.806	0.442
12	0.901	6.824	9.517	0.554	0.796	0.436
13	0.884	6.698	9.279	0.543	0.780	0.428
14	0.862	6.529	9.160	0.528	0.759	0.417
15	0.845	6.401	9.303	0.525	0.754	0.409
16	0.794	6.016	9.273	0.501	0.719	0.384
17	0.749	5.677	9.415	0.476	0.684	0.362
18	0.749	5.677	9.205	0.474	0.681	0.363
19	0.691	5.232	8.233	0.428	0.615	0.334
20	0.629	4.768	7.538	0.387	0.556	0.304
21	0.557	4.222	6.614	0.340	0.488	0.270
22	0.525	3.977	6.012	0.318	0.456	0.254
23	0.286	2.165	3.400	0.175	0.251	0.138

Appendix J - Dispersion model evaluation

J.1 Overview

The main approach for evaluating the performance of GRAL in the air quality assessment involved a comparison between the predicted and measured concentrations at OEH and RMS sites for the full 2014 base year. The results of this work are presented in Section J.2.

The performance of GRAL was not investigated for the project-specific air quality monitoring stations as data were only available for two months of 2015. However, the air quality assessment for the M4 East project showed that there was generally a good agreement with the monitoring data for that project. Overall, the results supported the application of the GRAL model in the assessment, along with the empirical conversion methods for NO_2, noting that the results tend to be quite conservative.

J.2 GRAL predictions for OEH and RMS air quality monitoring sites

GRAL was configured to provide concentration predictions for each main pollutant (CO, NO_X, NO_2 and PM_{10}) at the OEH and Roads and Maritime air quality monitoring sites in the WestConnex GRAL domain. $PM_{2.5}$ was not assessed as there were insufficient measurements for independent comparisons.

The monitoring stations included in the model evaluation were:

- OEH Chullora (background site)
- OEH Earlwood (background site)
- OEH Rozelle (background site)
- RMS CBMS (background site)
- RMS T1 (background site)
- RMS U1 (background site)
- RMS X1 (background site)
- RMS F1 (roadside site)
- RMS M1 (roadside site)

The GRAL predictions were for the surface road network and tunnel ventilation outlets, although the results from the project assessment clearly showed that the contributions of the latter were generally very small. For each monitoring site the GRAL predictions were extracted as an hourly time series of concentrations for 2014 and, in the case of PM_{10}, converted to 24-hour averages. The GRAL results were then combined with an estimated contemporaneous background contribution for each monitoring site (see Appendix F for the derivation of background concentrations).

J.2.1 CO

Figure J-1 and Figure J-2 show examples of the 1-hour mean CO concentrations predicted by GRAL for a background site (OEH Chullora) and a roadside site (RMS F1, alongside the M5 East Freeway), along with the measured CO concentrations at these sites. The GRAL predictions exclude any background contribution.

For the purpose of the project air quality assessment it was assumed that the background sites were not influenced by road transport sources, and therefore the concentrations predicted by GRAL at these sites should have been zero. In practice, dispersion models will often give non-zero values at background sites, and this was the case for Chullora in Figure J-1. The GRAL concentration was, however, generally much lower than the measured background. The measured background at Chullora also had a slight offset on the y-axis, indicating that there is a degree of uncertainty in the measured data. However, this would not have had a large impact on the results of the evaluation. At the RMS F1 site there was a much larger contribution from GRAL than at Chullora.

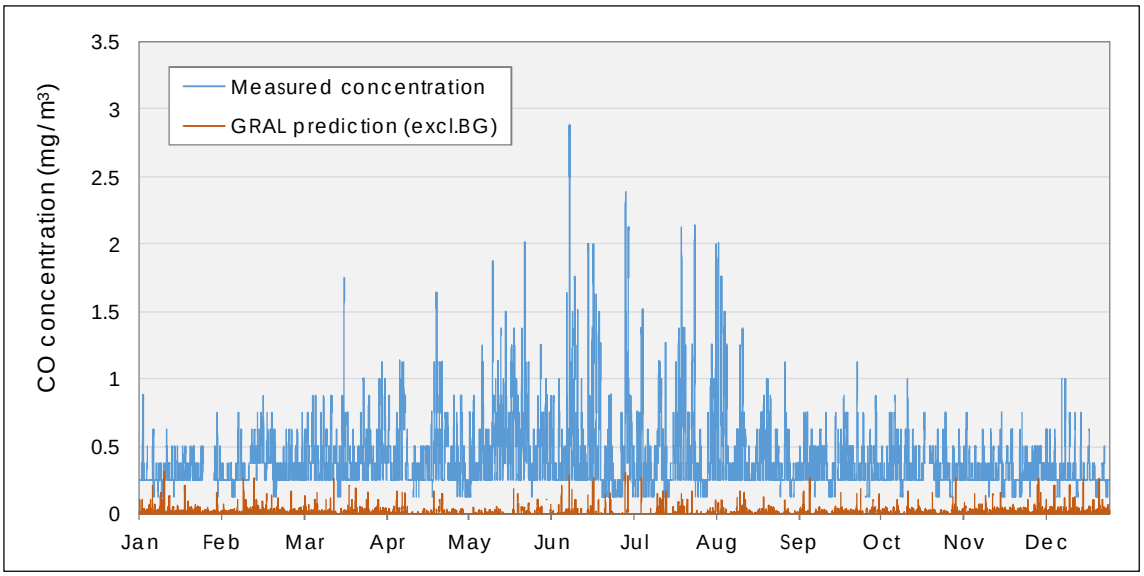


Figure J-1 **Measured 1-hour mean CO concentrations and GRAL predictions (excluding background) for the OEH Chullora background monitoring site**

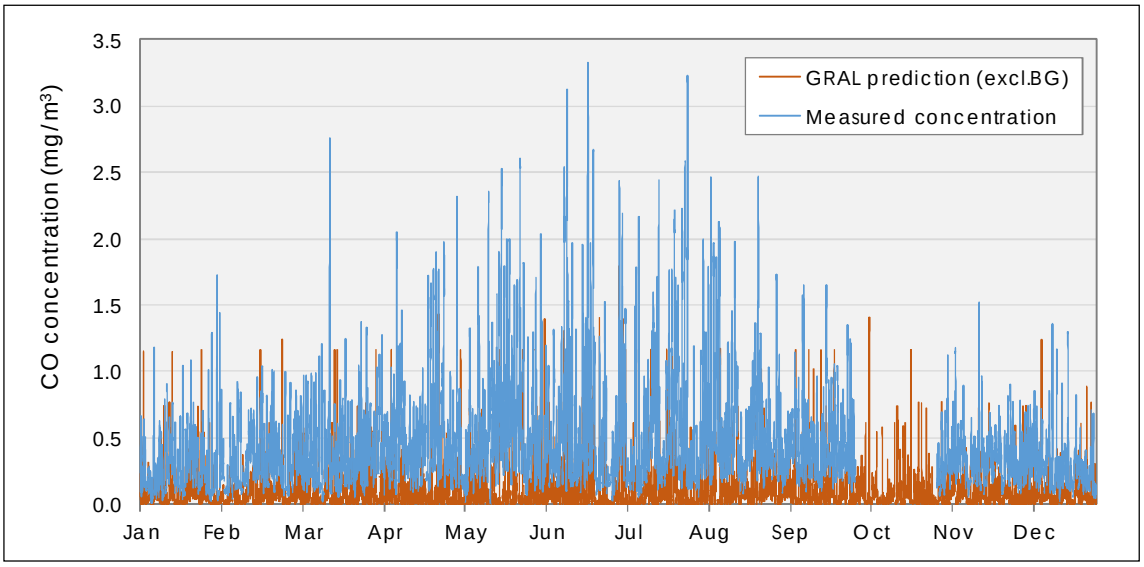


Figure J-2 **Measured 1-hour mean CO concentrations and GRAL predictions (excluding background) for the RMS F1 monitoring site**

In Figure J-3 three descriptive statistics - annual mean, maximum 1-hour mean and 98th percentile[1] 1-hour mean - for the measured and predicted total CO concentrations are compared. In this Figure the predictions include both the GRAL contribution and the estimated background contribution. The two contributions were combined using a contemporaneous approach, whereby the GRAL contribution was added to the corresponding contribution from the synthetic background profile for each hour of the year.

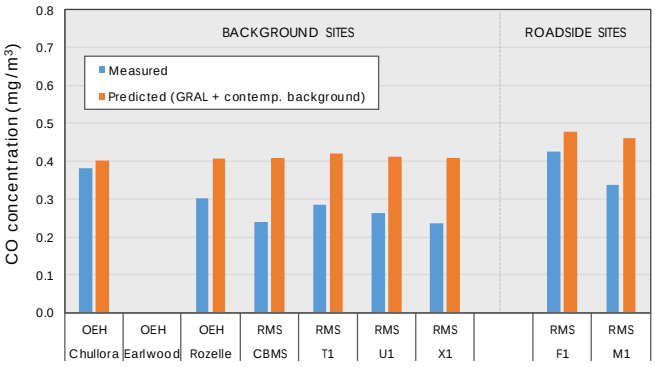
For each statistic the results for the Chullora background site should be ignored, as the data from this site featured strongly in the synthetic background profile. At all other background sites there was an overestimation of the annual mean CO concentration which ranged from 34 per cent to 73 per cent. There was also an overestimation of the annual mean at the roadside sites, though the model

[1] The selection of the 98th percentile was arbitrary. The intention of using this statistic was to provide an indication of the performance of GRAL at high concentrations, but with the most extreme values excluded.

performance was considered to be acceptable. The results suggest that the estimated CO concentrations ought to be conservative for most of the modelling domain.

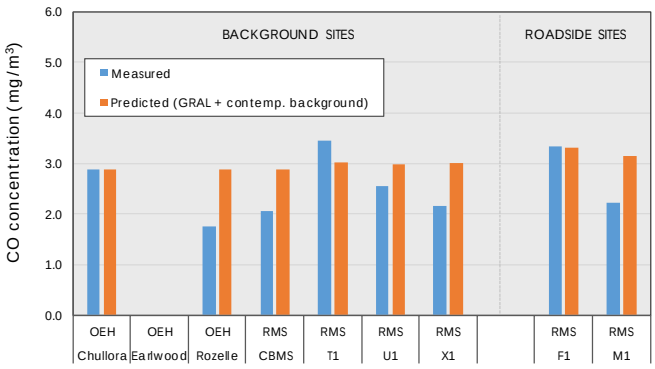
As would be expected, the results for the maximum and 98th percentile concentrations were more variable. Maximum pollutant concentrations are inherently very difficult to predict, and the comparisons here reflect this. Nevertheless, the model predictions were good at some sites, and there was a general tendency towards the overestimation concentrations.

Annual mean



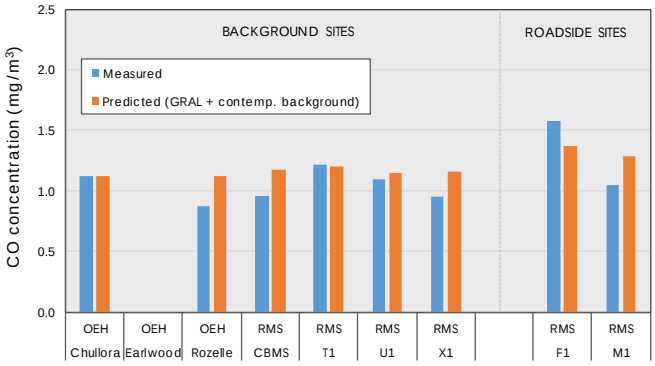
Site type	Site	Concentration (µg/m3)		Pred./ measured
		Measured	Pred. (contemp.)	
Background	OEH: Chullora	0.4	0.4	1.05
	OEH: Earlwood			
	OEH: Rozelle	0.3	0.4	1.34
	RMS: CBMS	0.2	0.4	1.72
	RMS: T1	0.3	0.4	1.47
	RMS: U1	0.3	0.4	1.56
	RMS: X1	0.2	0.4	1.73
Roadside	RMS: F1	0.4	0.5	1.12
	RMS: M1	0.3	0.5	1.36

Maximum one-hour mean



Site type	Site	Concentration (µg/m3)		Pred./ measured
		Measured	Pred. (contemp.)	
Background	OEH: Chullora	2.9	2.9	1.00
	OEH: Earlwood			
	OEH: Rozelle	1.7	2.9	1.64
	RMS: CBMS	2.1	2.9	1.39
	RMS: T1	3.4	3.0	0.87
	RMS: U1	2.6	3.0	1.16
	RMS: X1	2.2	3.0	1.40
Roadside	RMS: F1	3.3	3.3	1.00
	RMS: M1	2.2	3.1	1.42

98th %ile one-hour mean



Site type	Site	Concentration (µg/m3)		Pred./ measured
		Measured	Pred. (contemp.)	
Background	OEH: Chullora	1.1	1.1	1.00
	OEH: Earlwood			
	OEH: Rozelle	0.9	1.1	1.29
	RMS: CBMS	1.0	1.2	1.22
	RMS: T1	1.2	1.2	0.99
	RMS: U1	1.1	1.1	1.05
	RMS: X1	0.9	1.2	1.22
Roadside	RMS: F1	1.6	1.4	0.87
	RMS: M1	1.0	1.3	1.23

Figure J-3 Comparison between measured and predicted total CO concentrations at OEH and RMS air quality monitoring sites

J.2.2 NO_x

Figure J-4 shows the measured 1-hour mean NO_X concentrations and those predicted by GRAL (excluding background) for the Chullora background site. Again, there was a non-zero NO_X contribution from GRAL, but this was generally lower than the measured background. Figure J-5 shows the measured concentrations and GRAL predictions (excluding background) for the RMS F1 site alongside the M5 East Freeway. At this site there was a much larger contribution from GRAL.

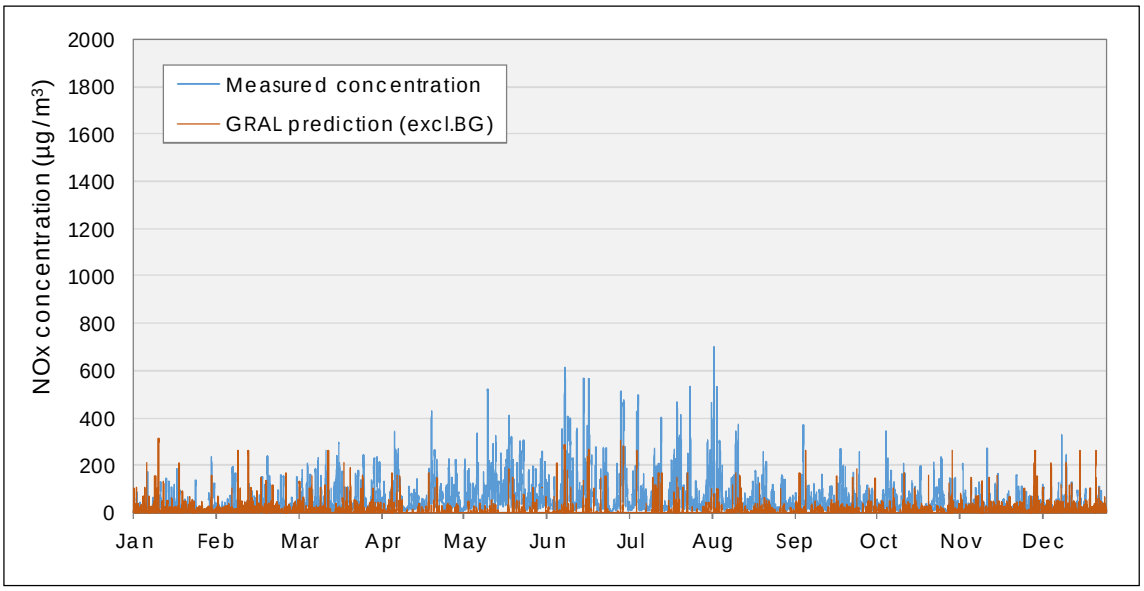


Figure J-4 **Measured 1-hour mean $_{NOX}$ concentrations and GRAL predictions (excluding background) for the OEH Chullora background monitoring site**

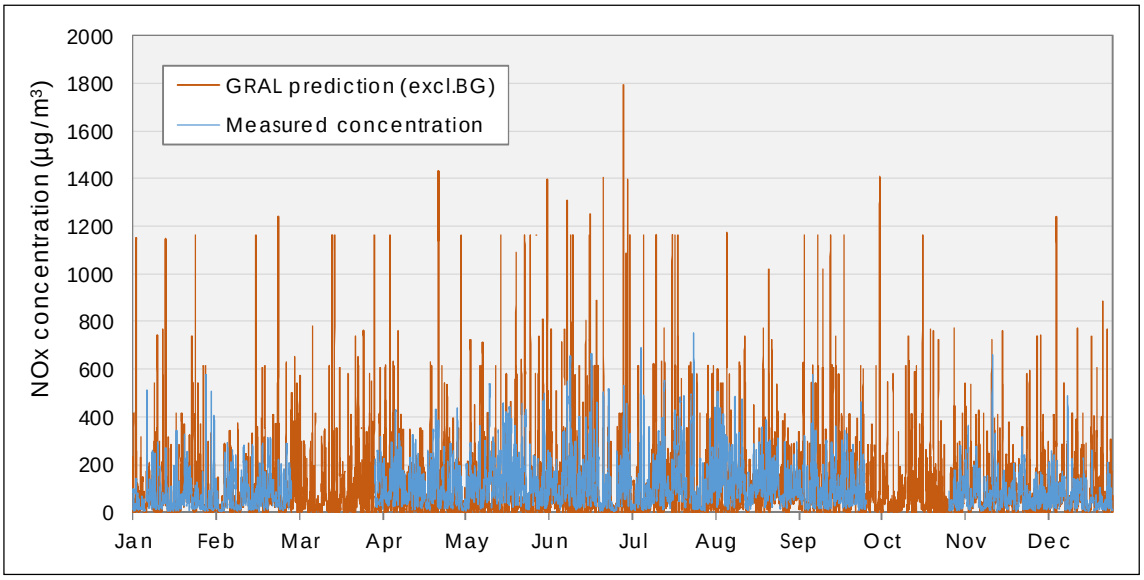
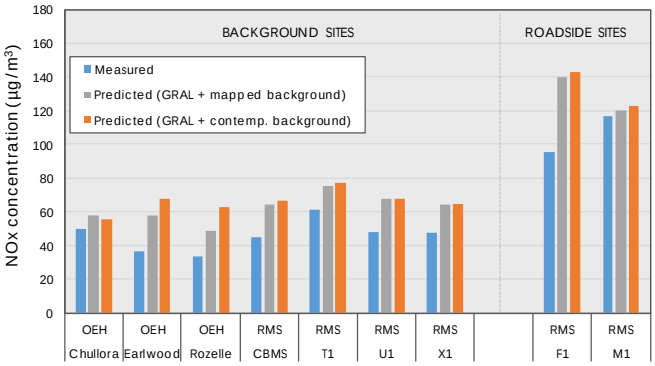


Figure J-5 **Measured 1-hour mean NO_X concentrations and GRAL predictions (excluding background) for the RMS F1 monitoring site**

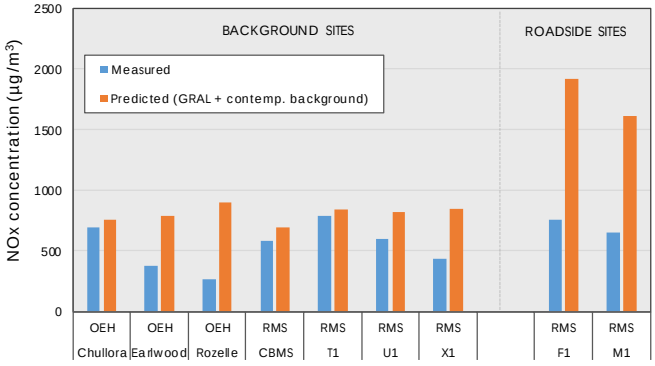
In Figure J-6 the descriptive statistics for total NO_X concentrations are compared. For the annual mean concentration the results for two methods for combining the GRAL and background contributions are shown. The first method involved the use of the NO_X background map, and the second method involved a contemporaneous approach, whereby the GRAL contribution was added to the corresponding background contribution for each hour of the year.

Annual mean



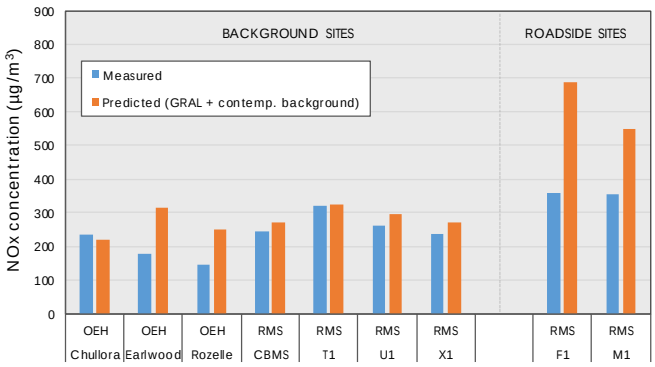
Site type	Site	Concentration (µg/m3)		Pred./ measured
		Measured	Pred. (map)	
Background	OEH: Chullora	50.2	58.1	1.16
	OEH: Earlwood	36.5	58.1	1.59
	OEH: Rozelle	33.5	48.8	1.46
	RMS: CBMS	45.2	64.3	1.42
	RMS: T1	61.1	75.5	1.23
	RMS: U1	48.2	68.1	1.41
	RMS: X1	47.3	64.1	1.36
Roadside	RMS: F1	95.6	140.2	1.47
	RMS: M1	116.4	120.2	1.03

Maximum one-hour mean



Site type	Site	Concentration (µg/m3)		Pred./ measured
		Measured	Pred. (contemp.)	
Background	OEH: Chullora	697.8	753.9	1.08
	OEH: Earlwood	375.6	792.5	2.11
	OEH: Rozelle	270.9	899.9	3.32
	RMS: CBMS	587.6	697.8	1.19
	RMS: T1	787.8	837.9	1.06
	RMS: U1	597.0	826.0	1.38
	RMS: X1	439.6	852.5	1.94
Roadside	RMS: F1	750.3	1922.4	2.56
	RMS: M1	651.9	1612.0	2.47

98th %ile one-hour mean



Site type	Site	Concentration (µg/m3)		Pred./ measured
		Measured	Pred. (contemp.)	
Background	OEH: Chullora	234.0	219.6	0.94
	OEH: Earlwood	180.6	314.1	1.74
	OEH: Rozelle	145.7	250.3	1.72
	RMS: CBMS	242.9	272.3	1.12
	RMS: T1	320.3	323.1	1.01
	RMS: U1	261.0	296.0	1.13
	RMS: X1	238.5	270.3	1.13
Roadside	RMS: F1	356.5	687.3	1.93
	RMS: M1	354.2	549.1	1.55

Figure J-6 Comparison between measured and predicted total NO_X concentrations at OEH and RMS air quality monitoring sites

The results indicate that there was a good agreement between the measured and predicted annual mean concentrations using both the mapped and contemporaneous approaches. For the OEH background monitoring sites this is unsurprising, as the background concentrations used in the assessment were based on the data from these sites. At all the background sites there was an overestimation of the annual mean NO_X concentration of between 16 per cent and 59 per cent, based on the mapped background. This suggests that the estimated total NO_X concentrations ought to be somewhat conservative for most of the modelling domain. The total NO_X concentration was overestimated (by 47 per cent) at the RMS F1 roadside site and slightly overestimated (by 3 per cent) at the RMS M1 roadside site. Whilst the results for the roadside sites are, on their own, inconclusive, the general pattern is one of slight overestimation of annual mean NO_X concentrations. There were no systematic differences between the results obtained using the mapped and contemporaneous approaches for including background NO_X.

As before, the maximum and 98th percentile concentrations were more variable. Nevertheless, there was a clear tendency towards the overestimation of maximum concentrations, which should introduce a clear margin of safety into the predictions. The performance for the 98th percentile values was better, with again there being a degree of conservatism.

Because there is generally a stronger road traffic signal for NO_X than for other criteria pollutants, the model performance at the two roadside sites (F1 and M1) was examined in more detail using the 'timeVariation' function in the Openair software. The variation of a pollutant by time of day and day of week can reveal useful information concerning the likely sources. For example, road vehicle emissions tend to follow very regular patterns both on a daily and weekly basis. The timeVariation function produces four plots: day of the week variation, mean hour of day variation and a combined hour of day – day of week plot and a monthly plot. Also shown on the plots is the 95 per cent confidence interval in the mean. For model evaluation it is important to consider the difference between observations and modelled values over these different time scales (Carslaw, 2015).

Figure J-7 and Figure J-8 show the results from the timeVariation function for the predicted ('GRAL') and monitored ('MON') hourly NO_X concentrations. The plots reveal the following:

- For the F1 site there was an overestimation of NO_X concentrations at all times of day and in all months.
- For the M1 site the concentrations tended to be overestimated in the mornings and evenings, and underestimated during the middle of the day.
- For both the F1 and M1 sites there was a more pronounced overestimation of concentrations at weekends than on weekdays. This is likely to be due in large part to the assumption of weekday traffic volumes on every day of the year in the modelling.
- The seasonal variation in concentrations was, on average, well reproduced, especially at the M1 site.

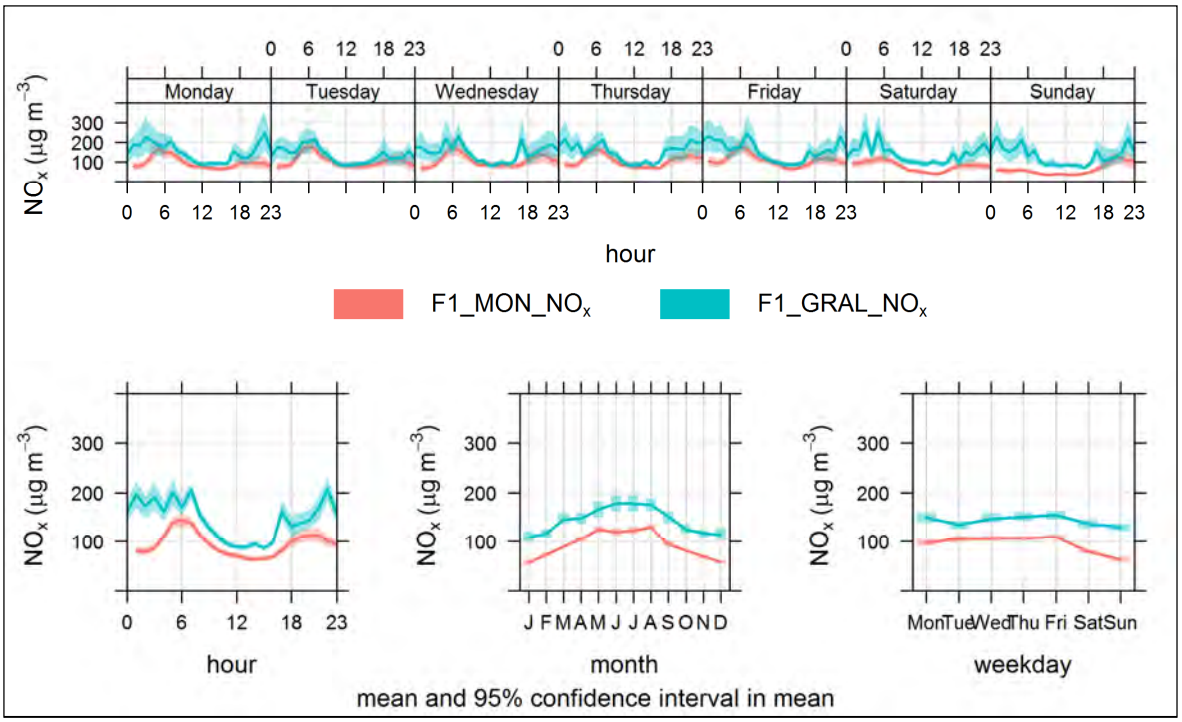


Figure J-7 **Comparison between time variation of measured and predicted total NO_X concentrations at RMS F1 monitoring site**

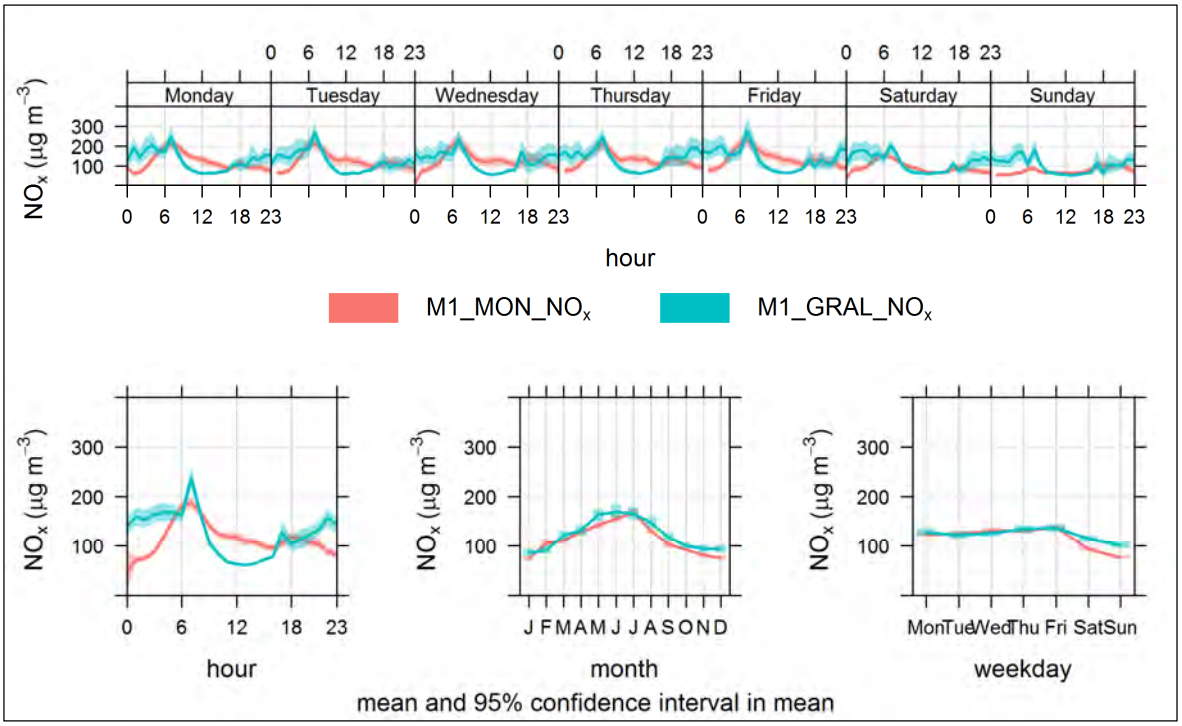
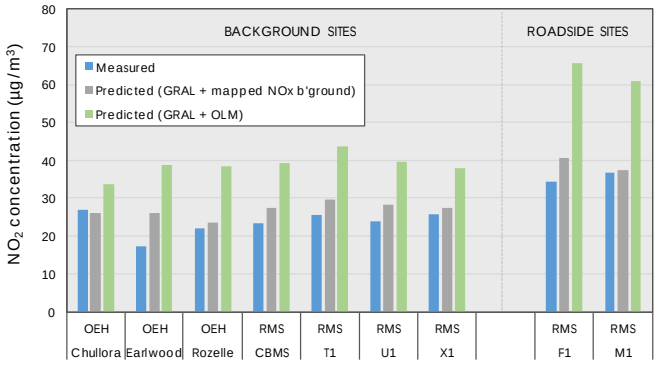


Figure J-8 **Comparison between time variation of measured and predicted total NO_X concentrations at RMS M1 monitoring site**

J.2.3 NO_2

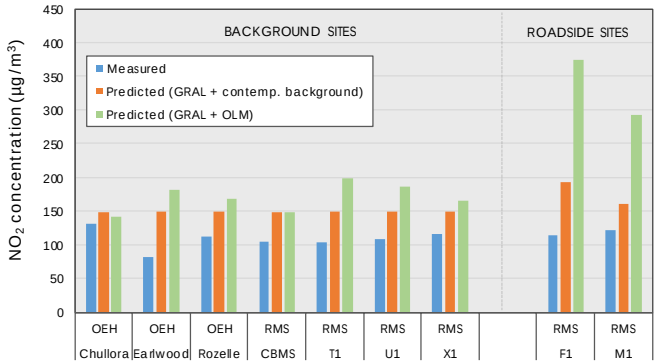
The measured and predicted values for NO_2 are shown in Figure J-9. NO_2 predictions obtained using the OLM for converting NO_X to NO_2 are also shown for comparison with the methods developed for the New M5 assessment. The annual mean NO_2 values for the assessment were obtained using a background map for NO_X. The OLM calculations were contemporaneous, based on the synthetic (and conservative) background profiles for NO_2 and O_3, and the f-NO_2 value of 0.16 recommended by NSW EPA.

Annual mean



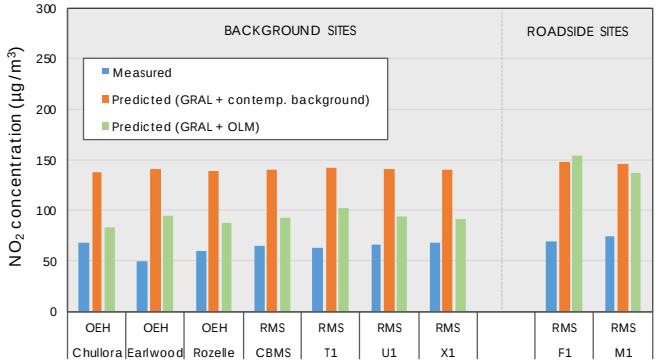
Site type	Site	Concentration (µg/m3)		Pred./ measured
		Measured	Pred. (map)	
Background	OEH: Chullora	26.9	26.0	0.96
	OEH: Earlwood	17.3	26.0	1.50
	OEH: Rozelle	21.9	23.7	1.08
	RMS: CBMS	23.4	27.3	1.17
	RMS: T1	25.5	29.6	1.16
	RMS: U1	23.8	28.1	1.18
	RMS: X1	25.8	27.3	1.06
Roadside	RMS: F1	34.3	40.5	1.18
	RMS: M1	36.8	37.4	1.02

Maximum one-hour mean



Site type	Site	Concentration (µg/m3)		Pred./ measured
		Measured	Pred. (contemp.)	
Background	OEH: Chullora	131.4	148.8	1.13
	OEH: Earlwood	82.1	149.3	1.82
	OEH: Rozelle	112.9	150.4	1.33
	RMS: CBMS	105.3	148.1	1.41
	RMS: T1	104.1	149.8	1.44
	RMS: U1	107.8	149.6	1.39
	RMS: X1	115.9	149.9	1.29
Roadside	RMS: F1	114.9	192.2	1.67
	RMS: M1	122.2	161.2	1.32

98th %ile one-hour mean



Site type	Site	Concentration (µg/m3)		Pred./ measured
		Measured	Pred. (contemp.)	
Background	OEH: Chullora	67.7	138.2	2.04
	OEH: Earlwood	49.3	141.2	2.87
	OEH: Rozelle	59.5	139.3	2.34
	RMS: CBMS	65.0	140.0	2.15
	RMS: T1	62.6	141.4	2.26
	RMS: U1	65.7	140.7	2.14
	RMS: X1	68.0	139.9	2.06
Roadside	RMS: F1	69.0	148.0	2.14
	RMS: M1	74.3	146.0	1.96

Figure J-9 Comparison between measured and predicted total NO_2 concentrations at OEH and RMS air quality monitoring sites

For annual mean NO_2 the predicted concentrations (again, based on the use of background maps for NO_X) were systematically higher than the measured values, but there was generally a good level of agreement; for all but one of the sites the overprediction was less than 20 per cent. When the OLM was used to determine NO_2 for each hour of the year, considerably higher annual mean values were predicted.

A similar pattern was observed for the maximum 1-hour mean NO_2 concentration. In this case the predicted concentrations were between 13 per cent and 82 per cent higher than the measured values, and again the OLM gave values which were higher still, with large overpredictions of concentrations at the roadside sites in particular.

The results for the 98th percentile 1-hour mean concentration were interesting, as the OLM gave results that were closer to the measurements than the contemporaneous method developed for the assessment. Because the latter is designed to give a conservative estimate for the maximum NO_2 concentration for each hour of the year, so that the overall maximum for the year is not underestimated. This means that the whole distribution is skewed towards high values. Whilst this is useful for determining the maximum value during a year, it is clearly not well suited to the estimation of other NO_2 statistics such as means and percentiles.

J.2.4 PM_{10}

Figure J-10 compares the measured 24-hour mean PM_{10} concentrations with those predicted by GRAL for the Chullora background site. In this case the GRAL concentration is much lower than the measured background, and is close to zero. Figure J-11 shows the results for the RMS F1 site. Here, there is a 24-hour mean contribution from GRAL of up to around 10 µg/m^3, which is still well below the measured values.

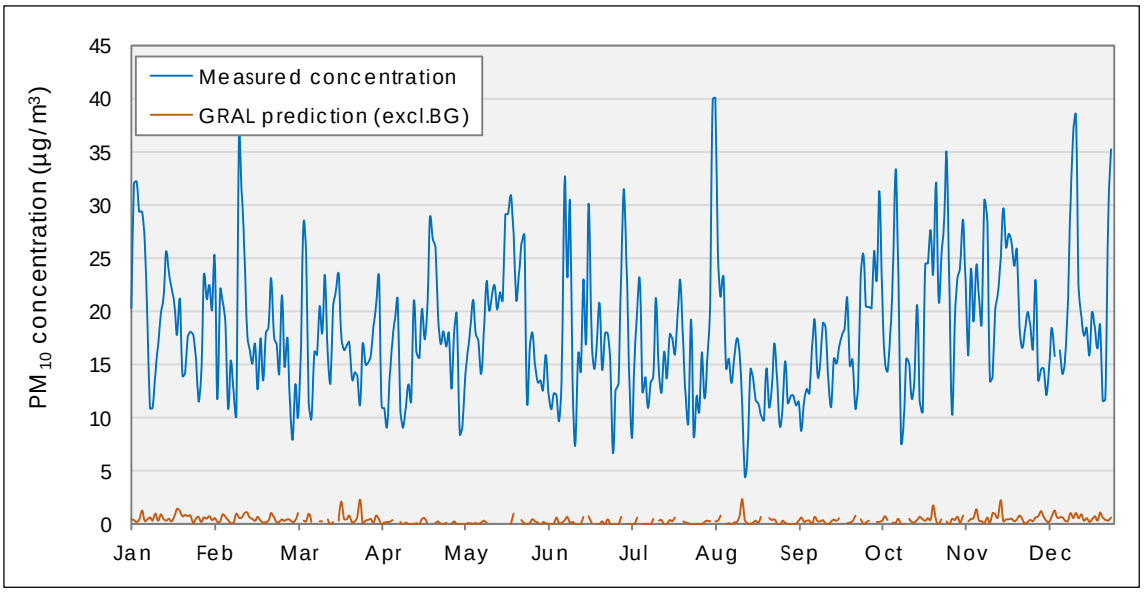


Figure J-10 **Measured 24-hour mean PM_{10} concentrations and GRAL predictions (excluding background) for the OEH Chullora background monitoring site**

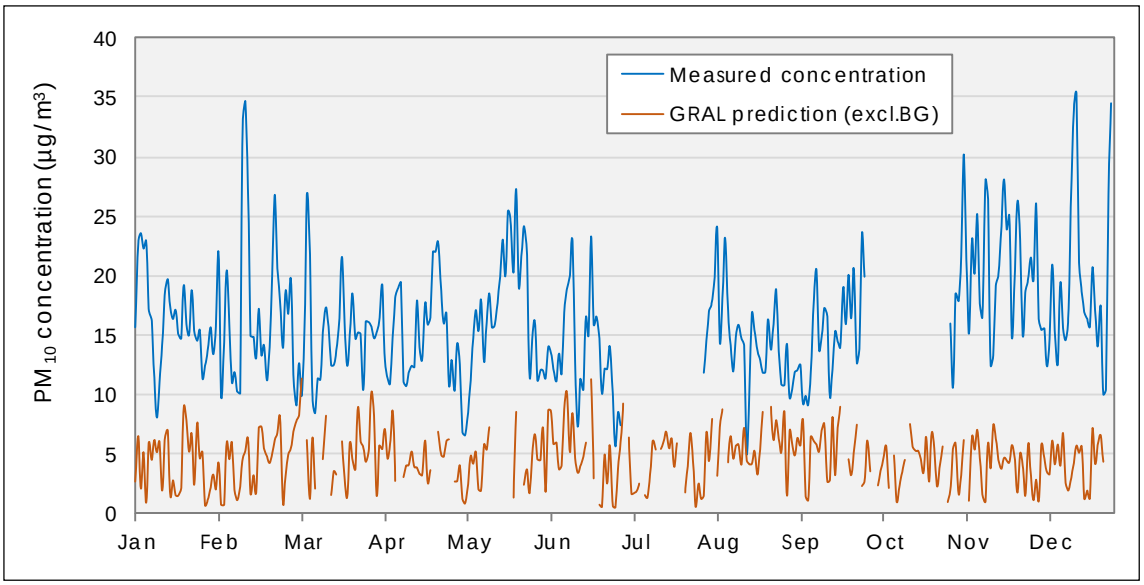


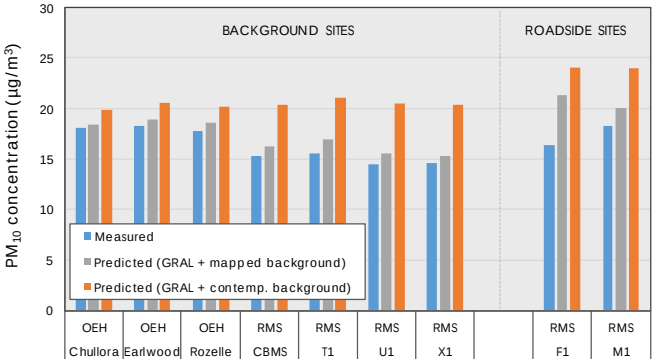
Figure J-11 **Measured 24-hour mean PM_{10} concentrations and GRAL predictions (excluding background) for the RMS F1 monitoring site**

The plots and descriptive statistics for the PM_{10} comparison are provided in Figure J-12. For the annual mean concentration at the background sites, the predicted results using the mapping approach effectively represent a combination of the values from the monitoring sites and the small GRAL contribution, so it is not surprising that they agree very well with the measurements (*i.e.* the measured and predicted values are not independent). The mapping approach resulted in a 30 per cent overestimation of PM_{10} at the roadside F1 site, and a smaller (9 per cent) overestimation at the roadside M1 site.

The contemporaneous approach gave higher predictions than the mapping approach at all sites (it is inherently more conservative). In general, the results suggest that the use of GRAL and the background mapping approach should give good (and slightly conservative) estimates of the PM_{10} concentration.

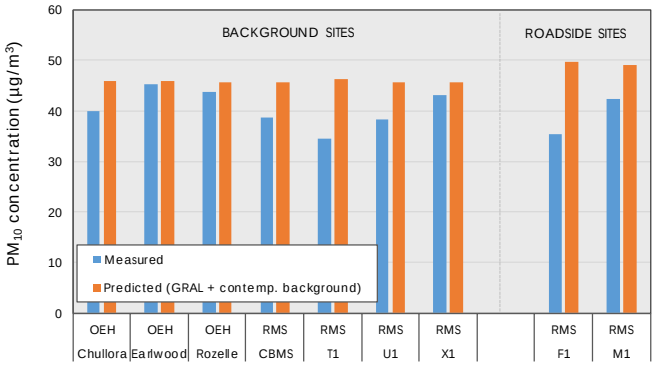
Maximum and 98th percentile 24-hour mean PM_{10} concentrations were systematically overestimated. As with NO_X, this suggests that the estimated total PM_{10} concentrations ought to be somewhat conservative for most of the modelling domain.

Annual mean



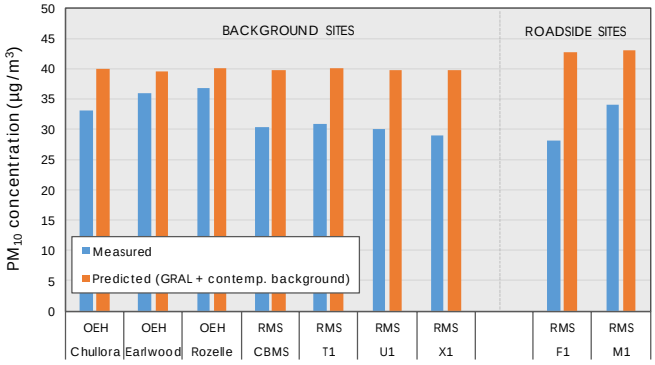
Site type	Site	Concentration (µg/m3)		Pred./ measured
		Measured	Pred. (map)	
Background	OEH: Chullora	18.1	18.4	1.02
	OEH: Earlwood	18.3	18.9	1.03
	OEH: Rozelle	17.8	18.6	1.05
	RMS: CBMS	15.4	16.3	1.06
	RMS: T1	15.5	16.9	1.09
	RMS: U1	14.5	15.5	1.07
	RMS: X1	14.6	15.3	1.05
Roadside	RMS: F1	16.3	21.2	1.30
	RMS: M1	18.3	20.0	1.09

Maximum 24-hour mean



Site type	Site	Concentration (µg/m3)		Pred./ measured
		Measured	Pred. (contemp.)	
Background	OEH: Chullora	40.0	45.8	1.15
	OEH: Earlwood	45.2	45.9	1.02
	OEH: Rozelle	43.8	45.7	1.04
	RMS: CBMS	38.6	45.6	1.18
	RMS: T1	34.5	46.3	1.34
	RMS: U1	38.2	45.7	1.20
	RMS: X1	43.2	45.7	1.06
Roadside	RMS: F1	35.3	49.8	1.41
	RMS: M1	42.3	49.0	1.16

98th %ile 24-hour mean



Site type	Site	Concentration (µg/m3)		Pred./ measured
		Measured	Pred. (contemp.)	
Background	OEH: Chullora	33.1	39.9	1.21
	OEH: Earlwood	36.0	39.6	1.10
	OEH: Rozelle	36.8	40.1	1.09
	RMS: CBMS	30.4	39.7	1.31
	RMS: T1	30.8	40.1	1.30
	RMS: U1	30.1	39.8	1.32
	RMS: X1	29.0	39.7	1.37
Roadside	RMS: F1	28.1	42.7	1.52
	RMS: M1	34.1	43.0	1.26

Figure J-12 Comparison between measured and predicted total PM_{10} concentrations at OEH and RMS air quality monitoring sites

Appendix K - All results of dispersion modelling

The following notes apply to this Appendix:

- In the Tables any grey shading indicates where no value was obtained. For example, where the top ten increases in concentration are ranked, there may have been fewer than ten receptors that actually had an increase in concentration.
- In the contour plots for the full New M5 modelling domain, minor road tunnels are shown as surface roads. These include the Airport Tunnel on General Holmes Drive and the Cooks River Tunnel. These tunnels are located well away from sensitive receptors, and therefore this was not considered to be important.
- For short-term air quality criteria, such as the maximum one-hour NO_2 concentrations, the contour plots should be viewed as indicative. This is a consequence of the difficulties associated with the prediction of short-term concentrations.

K.1 Carbon monoxide (maximum one-hour mean)

Table K-1 Maximum one-hour CO concentration at community receptors

Receptor	Maximum one-hour CO concentration (mg/m^3)						Change with project (mg/m^3)			Change with project (%)		
	2014-BY	2021-DM	2021 DS	2031-DM	2031-DS	2031-DSC	2021	2031	2031-DSC	2021	2031	2031-DSC
SR01	2.9	3.6	3.2	4.0	3.59	3.30	-0.4	-0.4	-0.7	-12.1%	-10.2%	-17.5%
SR02	3.0	3.5	3.4	3.3	3.11	2.91	-0.1	-0.1	-0.3	-3.2%	-4.4%	-10.5%
SR03	3.2	4.0	3.5	2.9	3.03	3.22	-0.5	0.1	0.3	-11.4%	3.6%	9.9%
SR04	3.4	3.3	3.6	3.0	3.31	3.10	0.3	0.3	0.1	10.1%	10.0%	2.9%
SR05	3.2	3.2	3.2	3.0	2.94	3.16	-0.1	-0.1	0.1	-2.0%	-2.9%	4.5%
SR06	3.3	3.4	4.3	3.1	3.10	3.25	0.9	0.0	0.1	25.1%	-0.5%	4.5%
SR07	3.2	3.3	3.4	3.5	3.45	3.01	0.1	-0.1	-0.5	2.4%	-2.3%	-14.7%
SR08	3.0	3.1	3.2	3.1	2.93	3.17	0.1	-0.2	0.1	3.3%	-4.9%	3.2%
SR09	2.9	2.9	2.9	2.9	3.04	3.08	0.0	0.1	0.1	0.0%	3.6%	4.9%
SR10	3.3	3.0	3.4	3.1	2.98	3.34	0.4	-0.2	0.2	13.9%	-5.3%	6.1%
SR11	2.9	3.0	3.0	3.0	2.90	2.87	0.0	-0.1	-0.1	0.8%	-2.2%	-3.0%
SR12	3.1	3.1	2.9	2.9	3.35	3.07	-0.2	0.5	0.2	-6.7%	16.8%	7.0%
SR13	3.1	3.2	3.3	3.1	2.98	3.40	0.1	-0.1	0.3	3.5%	-2.6%	11.1%
SR14	3.1	2.9	2.9	3.0	2.87	2.95	0.0	-0.2	-0.1	1.4%	-5.2%	-2.7%
SR15	2.9	3.4	2.9	2.9	3.01	2.92	-0.5	0.1	0.0	-14.3%	3.9%	0.9%
SR16	3.0	3.1	3.1	3.0	2.93	3.10	0.1	-0.1	0.1	2.6%	-2.5%	3.1%
SR17	2.9	2.9	3.1	2.9	2.90	3.01	0.2	0.0	0.1	6.6%	0.8%	4.6%
SR18	2.9	3.1	3.1	3.0	2.97	3.10	0.0	-0.1	0.1	-0.5%	-2.1%	2.3%
SR19	2.9	3.0	3.0	2.9	2.93	2.98	0.0	0.0	0.0	1.2%	0.0%	1.7%
SR20	2.9	2.9	2.9	2.9	2.95	2.89	0.0	0.1	0.0	0.0%	2.6%	0.7%
SR21	3.0	2.9	3.0	2.9	2.96	3.06	0.1	0.1	0.2	2.7%	2.2%	5.4%
SR22	2.9	2.9	2.9	2.9	2.96	2.93	0.0	0.0	0.0	0.3%	0.8%	0.0%
SR23	3.0	3.2	3.6	2.9	2.99	2.97	0.4	0.0	0.0	11.3%	1.3%	0.6%
SR24	3.1	3.4	3.2	3.0	3.03	2.93	-0.2	0.0	-0.1	-6.3%	-0.3%	-3.7%
SR25	2.9	2.9	3.3	2.9	2.87	3.04	0.3	0.0	0.2	11.8%	0.0%	5.8%
SR26	3.0	3.0	2.9	2.9	3.04	3.11	-0.2	0.1	0.2	-5.0%	4.8%	7.3%
SR27	3.0	2.9	3.0	3.1	3.01	3.05	0.0	-0.1	-0.1	1.7%	-3.4%	-1.9%
SR28	3.3	3.0	2.9	3.0	3.42	2.94	-0.1	0.4	-0.1	-3.8%	12.4%	-3.2%
SR29	3.0	3.0	3.1	3.0	2.87	2.87	0.2	-0.2	-0.2	5.4%	-5.0%	-5.0%
SR30	2.9	3.0	3.1	3.0	2.89	2.91	0.1	-0.1	-0.1	2.4%	-4.8%	-4.3%
SR31	3.0	3.9	3.2	3.2	2.90	3.20	-0.7	-0.3	0.0	-17.4%	-9.7%	-0.5%
SR32	3.1	3.2	3.3	2.9	3.07	3.34	0.1	0.2	0.5	4.0%	6.8%	16.3%
SR33	3.0	3.1	3.9	2.9	3.08	2.92	0.8	0.2	0.0	27.3%	7.3%	1.6%
SR34	3.0	2.9	3.2	2.9	3.07	2.92	0.3	0.2	0.0	11.2%	5.3%	0.1%
SR35	3.0	2.9	2.9	3.2	3.00	3.09	0.1	-0.2	-0.1	2.6%	-7.5%	-4.6%

Table K-2 Maximum one-hour CO concentrations at community receptors, ranked by total concentration

Rank	Ranking by concentration (mg/m^3)					
	2014-BY	2021-DM	2021 DS	2031-DM	2031-DS	2031-DSC
1	3.4	4.0	4.3	4.0	3.6	3.4
2	3.3	3.9	3.9	3.5	3.5	3.3
3	3.3	3.6	3.6	3.3	3.4	3.3
4	3.3	3.5	3.6	3.2	3.4	3.3
5	3.2	3.4	3.5	3.2	3.3	3.3
6	3.2	3.4	3.4	3.1	3.1	3.2
7	3.2	3.4	3.4	3.1	3.1	3.2
8	3.1	3.3	3.4	3.1	3.1	3.2
9	3.1	3.3	3.3	3.1	3.1	3.2
10	3.1	3.2	3.3	3.1	3.1	3.1

Table K-3 Maximum one-hour CO concentrations at community receptors, ranked by increase and by decrease in concentration with project

Rank	Ranking by increase in concentration with project (mg/m^3)			Ranking by decrease in concentration with project (mg/m^3)		
	2021	2031	2031-DSC	2021	2031	2031-DSC
1	0.9	0.5	0.5	-0.7	-0.4	-0.7
2	0.8	0.4	0.3	-0.5	-0.3	-0.5
3	0.4	0.3	0.3	-0.5	-0.2	-0.3
4	0.4	0.2	0.2	-0.4	-0.2	-0.2
5	0.3	0.2	0.2	-0.2	-0.2	-0.1
6	0.3	0.2	0.2	-0.2	-0.2	-0.1
7	0.3	0.1	0.2	-0.2	-0.2	-0.1
8	0.2	0.1	0.2	-0.1	-0.1	-0.1
9	0.2	0.1	0.1	-0.1	-0.1	-0.1
10	0.1	0.1	0.1	-0.1	-0.1	-0.1

Table K-4 Maximum one-hour CO concentrations at community receptors, ranked by percentage increase and by decrease in concentration with project

Rank	Ranking by % increase in concentration with project (mg/m^3)			Ranking by % decrease in concentration with project (mg/m^3)		
	2021	2031	2031-DSC	2021	2031	2031-DSC
1	27.3%	16.8%	16.3%	-17.4%	-10.2%	-17.5%
2	25.1%	12.4%	11.1%	-14.3%	-9.7%	-14.7%
3	13.9%	10.0%	9.9%	-12.1%	-7.5%	-10.5%
4	11.8%	7.3%	7.3%	-11.4%	-5.3%	-5.0%
5	11.3%	6.8%	7.0%	-6.7%	-5.2%	-4.6%
6	11.2%	5.3%	6.1%	-6.3%	-5.0%	-4.3%
7	10.1%	4.8%	5.8%	-5.0%	-4.9%	-3.7%
8	6.6%	3.9%	5.4%	-3.8%	-4.8%	-3.2%
9	5.4%	3.6%	4.9%	-3.2%	-4.4%	-3.0%
10	4.0%	3.6%	4.6%	-2.0%	-3.4%	-2.7%

Table K-5 Maximum one-hour CO concentrations at RWR receptors, ranked by concentration

Rank	Ranking by concentration (mg/m^3)					
	2014-BY	2021-DM	2021 DS	2031-DM	2031-DS	2031-DSC
1	11.5	8.0	8.7	7.7	8.5	7.8
2	11.5	8.0	8.4	7.3	7.5	7.4
3	11.3	7.8	8.4	7.2	7.3	7.4
4	11.1	7.8	8.4	7.1	7.2	7.2
5	11.1	7.8	8.3	6.7	7.1	7.1
6	11.0	7.8	8.3	6.7	7.1	7.1
7	11.0	7.7	8.2	6.6	7.1	6.8
8	11.0	7.7	8.1	6.6	7.0	6.8
9	10.9	7.7	8.1	6.6	7.0	6.7
10	10.8	7.7	8.1	6.6	6.9	6.7

Table K-6 Maximum one-hour CO concentrations at RWR receptors, ranked by increase and by decrease in concentration with project

Rank	Ranking by increase in concentration with project (mg/m^3)			Ranking by decrease in concentration with project (mg/m^3)		
	2021-DS	2031-DS	2031-DSC	2021-DS	2031-DS	2031-DSC
1	3.3	3.5	2.8	-2.1	-1.8	-1.8
2	2.2	2.1	1.8	-2.0	-1.4	-1.8
3	2.1	1.9	1.8	-2.0	-1.3	-1.6
4	2.1	1.8	1.6	-2.0	-1.3	-1.6
5	2.0	1.7	1.5	-1.9	-1.2	-1.5
6	2.0	1.7	1.5	-1.8	-1.2	-1.5
7	1.9	1.6	1.5	-1.8	-1.2	-1.5
8	1.9	1.6	1.5	-1.7	-1.2	-1.5
9	1.9	1.6	1.4	-1.7	-1.2	-1.5
10	1.8	1.6	1.4	-1.6	-1.2	-1.5

Table K-7 Maximum one-hour CO concentrations at RWR receptors, ranked by percentage increase and by decrease in concentration with project

Rank	Ranking by % increase in concentration with project (mg/m^3)			Ranking by % decrease in concentration with project (mg/m^3)		
	2021-DS	2031-DS	2031-DSC	2021-DS	2031-DS	2031-DSC
1	68.6%	69.7%	54.1%	-32.1%	-25.8%	-31.6%
2	50.9%	43.8%	39.6%	-31.2%	-25.0%	-28.9%
3	50.0%	41.4%	38.4%	-29.2%	-24.9%	-28.9%
4	45.0%	39.8%	35.3%	-28.7%	-23.7%	-28.3%
5	41.4%	38.3%	31.9%	-28.4%	-23.2%	-27.8%
6	40.2%	37.5%	31.9%	-28.2%	-22.9%	-27.3%
7	39.5%	36.7%	31.8%	-27.8%	-22.7%	-27.3%
8	39.5%	36.5%	31.7%	-27.5%	-22.7%	-27.3%
9	39.0%	36.1%	30.6%	-27.4%	-22.3%	-27.3%
10	38.9%	35.8%	29.6%	-27.2%	-21.9%	-27.0%

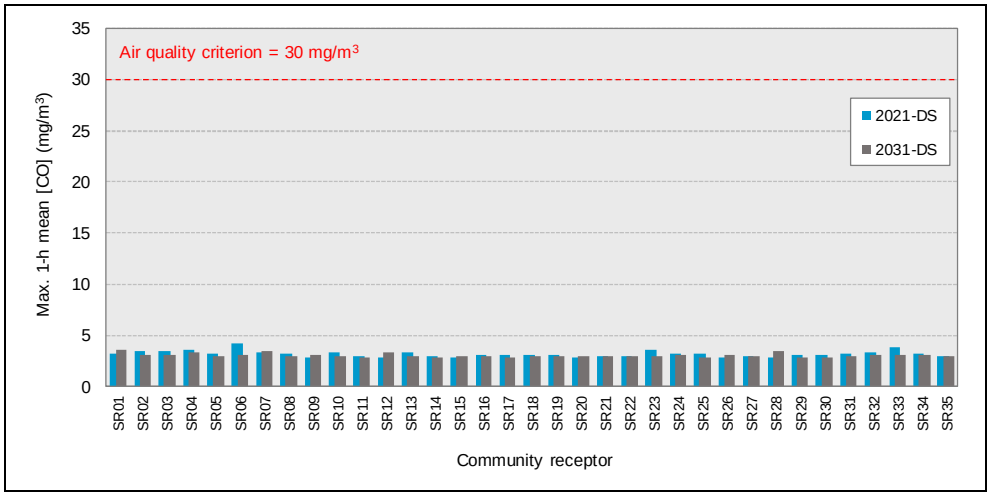


Figure K-1 Maximum one-hour CO at community receptors (2021-DS and 2031-DS)

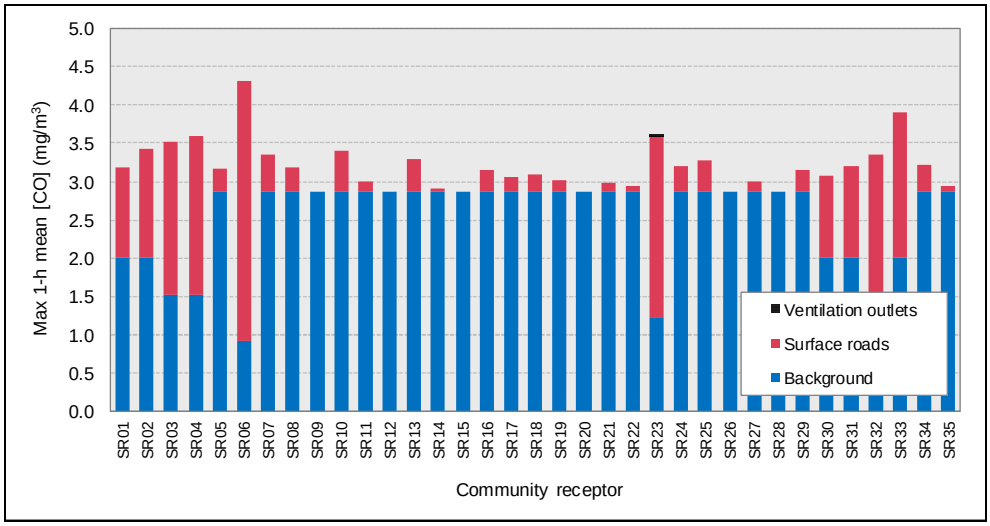


Figure K-2 Source contributions to maximum one-hour mean CO at community receptors (2021-DS)

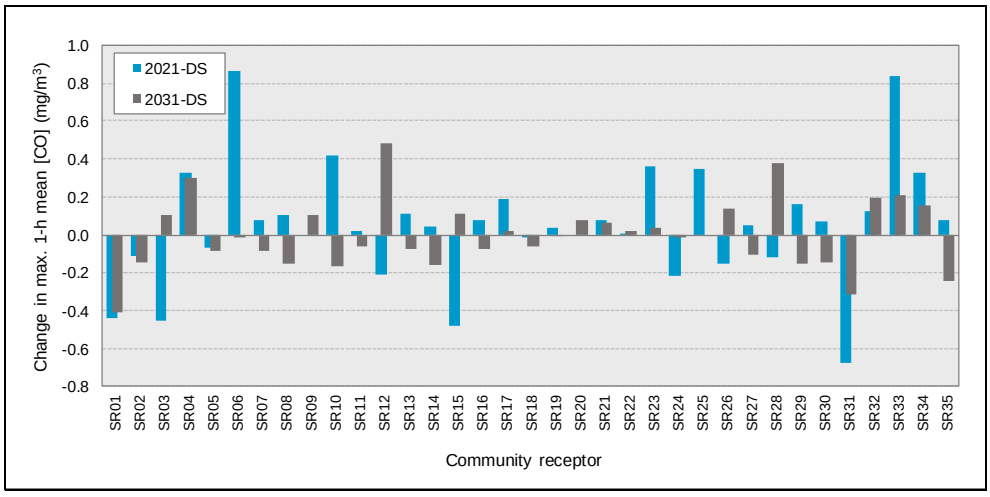


Figure K-3 Changes in maximum one-hour CO at community receptors (2021-DS and 2031-DS)

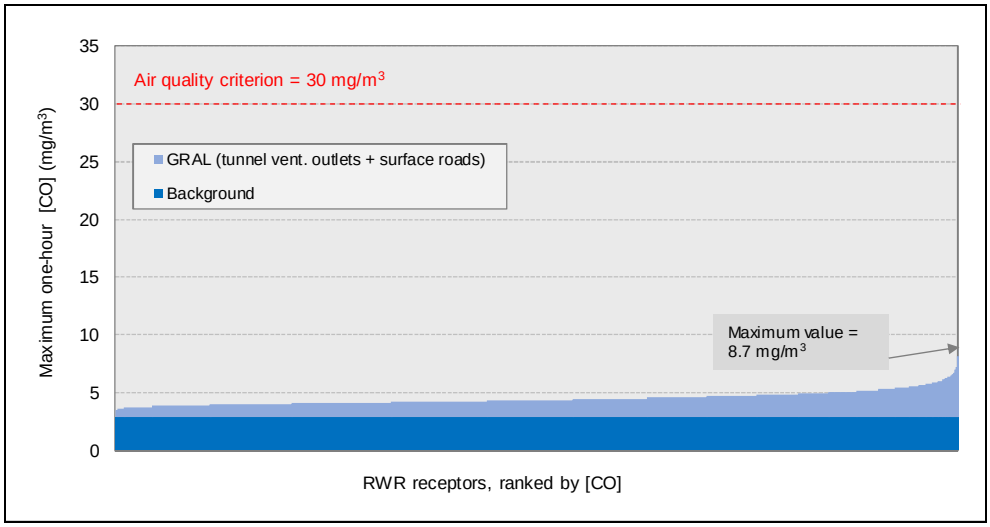


Figure K-4 Source contributions to maximum one-hour CO at RWR receptors (2021-DS)

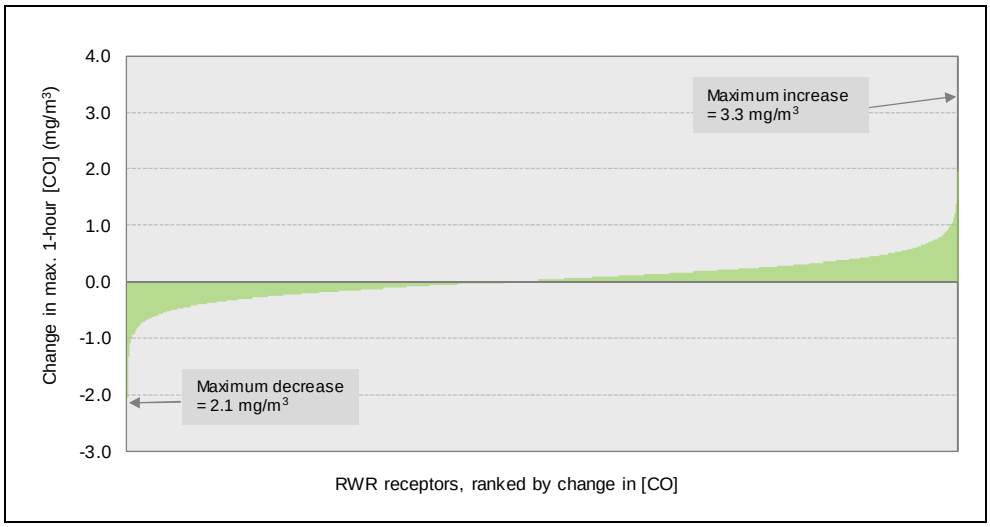


Figure K-5 Changes in maximum one-hour CO at RWR receptors (2021-DS)

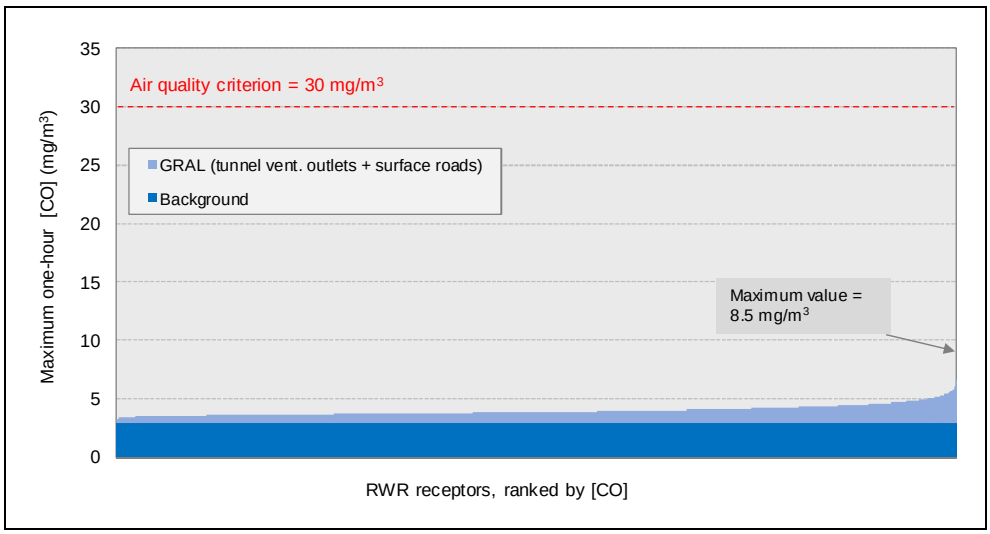


Figure K-6 Source contributions to maximum one-hour CO at RWR receptors (2031-DS)

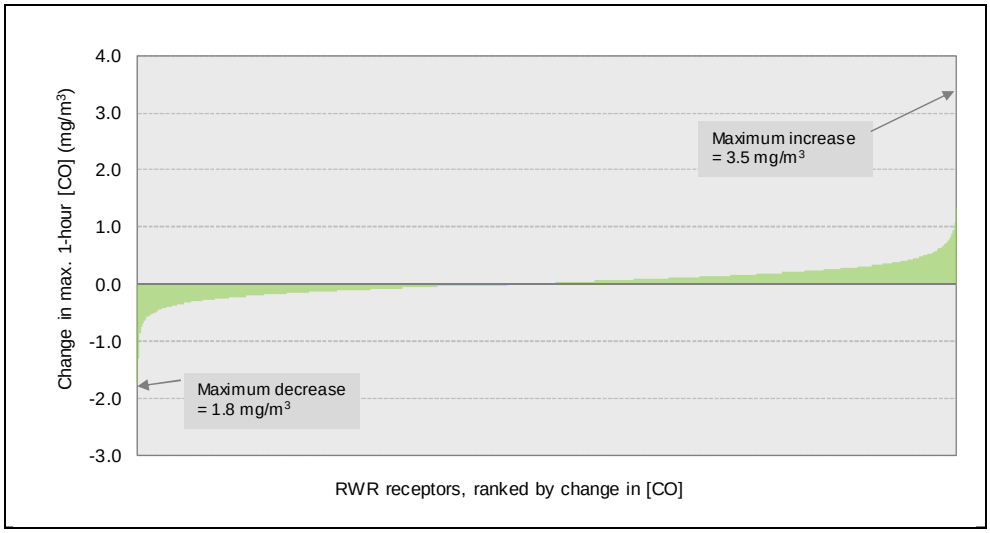


Figure K-7 Changes in maximum one-hour CO at RWR receptors (2031-DS)

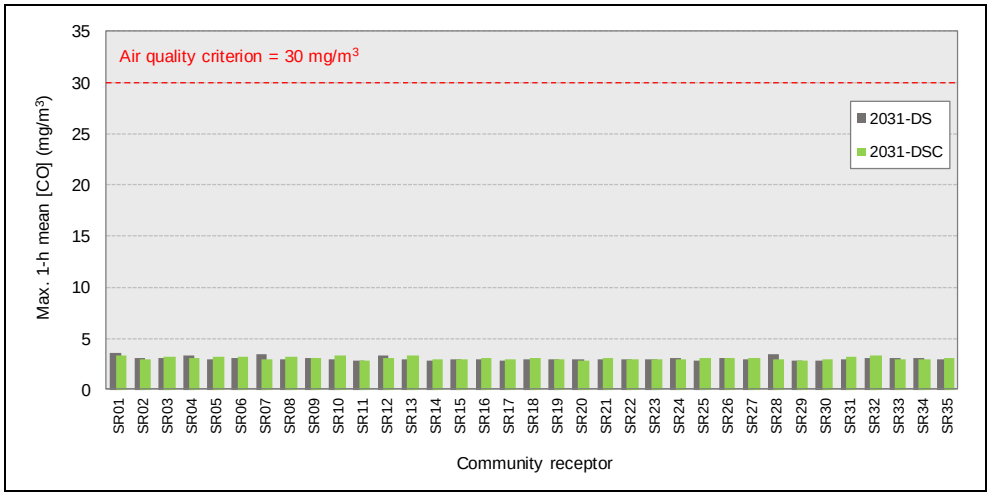


Figure K-8 Maximum one-hour mean CO at community receptors (2031-DS and 2031-DSC)

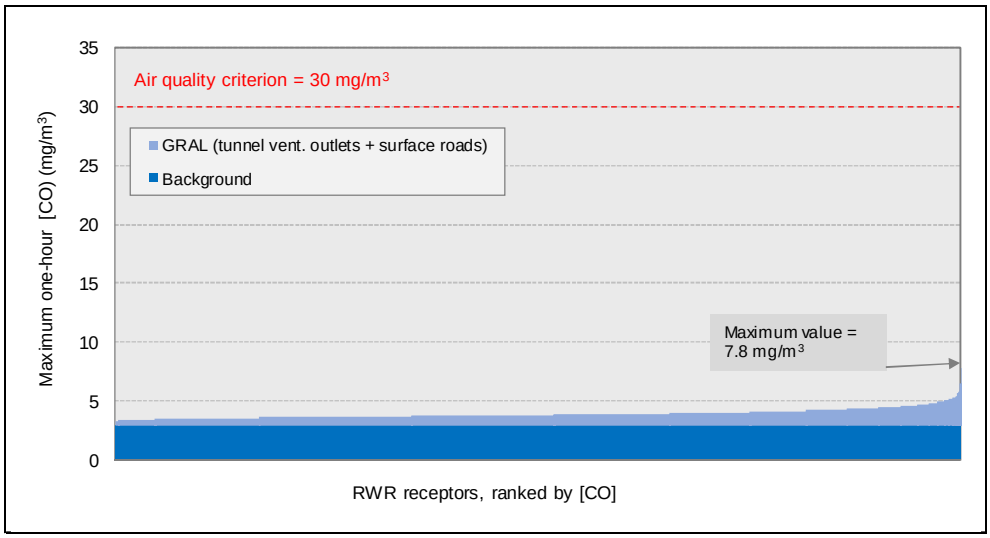


Figure K-9 Source contributions to maximum one-hour CO at RWR receptors (2031-DSC)

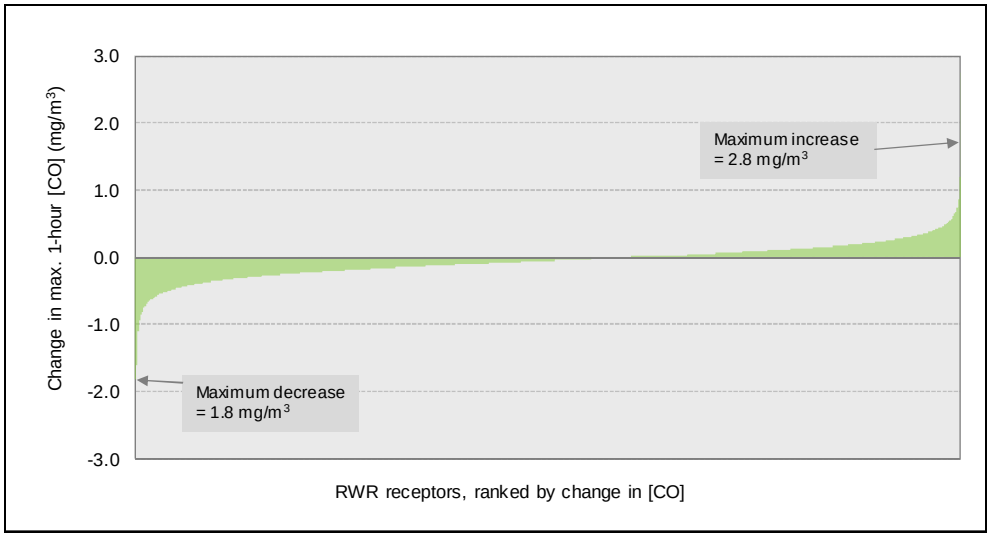


Figure K-10 Changes in maximum one-hour CO at RWR receptors (2031-DSC)

K.2 Carbon monoxide (maximum rolling 8-hour mean)

Table K-8 Maximum rolling 8-hour CO concentration at community receptors

Receptor	Maximum rolling 8-hour CO concentration (mg/m^3)						Change with project (mg/m^3)			Change with project (%)		
	2014-BY	2021-DM	2021 DS	2031-DM	2031-DS	2031-DSC	2021	2031	2031-DSC	2021	2031	2031-DSC
SR01	2.4	2.8	2.6	2.7	2.6	2.5	-0.2	-0.1	-0.2	-8.1%	-3.0%	-5.7%
SR02	2.4	2.6	2.6	2.5	2.4	2.4	0.0	-0.1	-0.1	0.9%	-2.6%	-3.0%
SR03	2.5	2.9	2.5	2.6	2.4	2.5	-0.4	-0.1	-0.1	-13.2%	-5.4%	-3.5%
SR04	2.7	2.6	2.7	2.5	2.6	2.5	0.1	0.0	-0.1	3.1%	1.8%	-2.2%
SR05	2.4	2.5	2.5	2.4	2.4	2.3	0.0	0.0	0.0	0.2%	0.7%	-0.6%
SR06	2.5	2.8	2.7	2.5	2.6	2.5	0.0	0.1	0.0	-1.4%	4.6%	1.3%
SR07	2.6	2.5	2.7	2.7	2.5	2.5	0.1	-0.1	-0.2	4.3%	-5.0%	-7.2%
SR08	2.5	2.5	2.6	2.4	2.4	2.4	0.0	0.0	0.0	1.3%	1.6%	1.0%
SR09	2.3	2.4	2.4	2.4	2.3	2.3	0.0	-0.1	-0.1	1.3%	-4.5%	-3.5%
SR10	2.4	2.6	2.5	2.4	2.4	2.4	-0.1	0.0	0.0	-4.3%	0.0%	1.9%
SR11	2.3	2.3	2.3	2.3	2.3	2.3	0.0	0.0	0.1	-0.7%	-0.2%	2.2%
SR12	2.4	2.4	2.4	2.4	2.4	2.3	0.0	0.0	-0.1	-0.6%	0.0%	-3.2%
SR13	2.5	2.5	2.5	2.4	2.4	2.4	0.0	-0.1	-0.1	0.9%	-3.6%	-3.3%
SR14	2.5	2.4	2.5	2.4	2.3	2.3	0.1	-0.1	-0.1	4.6%	-2.4%	-3.7%
SR15	2.4	2.4	2.4	2.3	2.3	2.5	0.0	0.0	0.2	-1.3%	-1.1%	8.8%
SR16	2.6	2.6	2.5	2.4	2.3	2.3	-0.2	-0.1	-0.1	-6.4%	-3.4%	-4.7%
SR17	2.4	2.4	2.4	2.4	2.3	2.3	0.0	0.0	-0.1	1.8%	-1.6%	-3.7%
SR18	2.3	2.4	2.3	2.4	2.3	2.4	-0.1	-0.1	0.0	-5.1%	-4.1%	1.9%
SR19	2.3	2.3	2.4	2.2	2.2	2.2	0.1	0.0	0.0	4.8%	0.7%	-0.4%
SR20	2.3	2.4	2.4	2.3	2.2	2.4	-0.1	-0.1	0.1	-2.6%	-2.9%	3.2%
SR21	2.3	2.6	2.5	2.3	2.3	2.3	-0.1	0.0	0.0	-4.7%	-0.2%	0.3%
SR22	2.3	2.4	2.5	2.3	2.3	2.3	0.1	0.0	-0.1	4.4%	-1.1%	-3.1%
SR23	2.4	2.5	2.5	2.3	2.4	2.3	0.0	0.0	0.0	1.8%	1.8%	-1.5%
SR24	2.4	2.7	2.7	2.5	2.4	2.3	0.0	0.0	-0.1	-0.2%	-1.5%	-5.0%
SR25	2.4	2.4	2.5	2.4	2.5	2.4	0.0	0.1	0.0	0.5%	4.0%	-0.1%
SR26	2.3	2.5	2.4	2.4	2.4	2.3	0.0	-0.1	-0.1	-1.7%	-2.8%	-4.3%
SR27	2.3	2.4	2.5	2.3	2.3	2.3	0.0	0.0	0.0	0.2%	-0.5%	0.7%
SR28	2.3	2.4	2.4	2.3	2.4	2.4	0.0	0.1	0.1	0.9%	4.3%	4.4%
SR29	2.3	2.4	2.4	2.3	2.3	2.3	0.0	0.0	0.0	0.6%	-0.8%	-0.5%
SR30	2.4	2.4	2.5	2.3	2.3	2.3	0.1	0.0	0.0	3.7%	0.1%	-0.3%
SR31	2.4	2.9	2.8	2.4	2.4	2.4	-0.1	0.0	0.0	-2.1%	-0.9%	0.2%
SR32	2.4	2.7	2.6	2.5	2.6	2.5	-0.1	0.1	0.0	-2.8%	2.5%	-0.7%
SR33	2.4	2.5	2.5	2.3	2.4	2.3	0.0	0.1	0.0	-1.8%	4.4%	1.1%
SR34	2.4	2.5	2.5	2.5	2.4	2.4	0.0	-0.1	-0.1	2.0%	-4.5%	-2.8%
SR35	2.3	2.4	2.4	2.4	2.4	2.4	0.0	0.0	0.0	-0.7%	0.2%	-0.3%

Table K-9 Maximum rolling 8-hour CO concentrations at community receptors, ranked by concentration

Rank	Ranking by concentration (mg/m^3)					
	2014-BY	2021-DM	2021 DS	2031-DM	2031-DS	2031-DSC
1	2.7	2.9	2.8	2.7	2.6	2.5
2	2.6	2.9	2.7	2.7	2.6	2.5
3	2.6	2.8	2.7	2.6	2.6	2.5
4	2.5	2.8	2.7	2.5	2.6	2.5
5	2.5	2.7	2.7	2.5	2.5	2.5
6	2.5	2.7	2.6	2.5	2.5	2.5
7	2.5	2.6	2.6	2.5	2.4	2.5
8	2.5	2.6	2.6	2.5	2.4	2.4
9	2.4	2.6	2.6	2.5	2.4	2.4
10	2.4	2.6	2.5	2.4	2.4	2.4

Table K-10 Maximum rolling 8-hour CO concentrations at community receptors, ranked by increase and by decrease in concentration with project

Rank	Ranking by increase in concentration with project (mg/m^3)			Ranking by decrease in concentration with project (mg/m^3)		
	2021-DS	2031-DS	2031-DSC	2021-DS	2031-DS	2031-DSC
1	0.1	0.1	0.2	-0.4	-0.1	-0.2
2	0.1	0.1	0.1	-0.2	-0.1	-0.2
3	0.1	0.1	0.1	-0.2	-0.1	-0.1
4	0.1	0.1	0.1	-0.1	-0.1	-0.1
5	0.1	0.1	0.0	-0.1	-0.1	-0.1
6	0.1	0.0	0.0	-0.1	-0.1	-0.1
7	0.0	0.0	0.0	-0.1	-0.1	-0.1
8	0.0	0.0	0.0	-0.1	-0.1	-0.1
9	0.0	0.0	0.0	-0.1	-0.1	-0.1
10	0.0	0.0	0.0	0.0	-0.1	-0.1

Table K-11 Maximum rolling 8-hour CO concentrations at community receptors, ranked by percentage increase and by decrease in concentration with project

Rank	Ranking by % increase in concentration with project (mg/m^3)			Ranking by % decrease in concentration with project (mg/m^3)		
	2021-DS	2031-DS	2031-DSC	2021-DS	2031-DS	2031-DSC
1	4.8%	4.6%	8.8%	-13.2%	-5.4%	-7.2%
2	4.6%	4.4%	4.4%	-8.1%	-5.0%	-5.7%
3	4.4%	4.3%	3.2%	-6.4%	-4.5%	-5.0%
4	4.3%	4.0%	2.2%	-5.1%	-4.5%	-4.7%
5	3.7%	2.5%	1.9%	-4.7%	-4.1%	-4.3%
6	3.1%	1.8%	1.9%	-4.3%	-3.6%	-3.7%
7	2.0%	1.8%	1.3%	-2.8%	-3.4%	-3.7%
8	1.8%	1.6%	1.1%	-2.6%	-3.0%	-3.5%
9	1.8%	0.7%	1.0%	-2.1%	-2.9%	-3.5%
10	1.3%	0.7%	0.7%	-1.8%	-2.8%	-3.3%

Table K-12 Maximum rolling 8-hour CO concentrations at RWR receptors, ranked by concentration

Rank	Ranking by concentration (mg/m^3)					
	2014-BY	2021-DM	2021 DS	2031-DM	2031-DS	2031-DSC
1	7.9	5.5	6.0	5.3	5.8	5.4
2	7.9	5.5	5.8	5.0	5.2	5.1
3	7.7	5.4	5.8	5.0	5.0	5.1
4	7.6	5.4	5.7	4.9	4.9	4.9
5	7.6	5.3	5.7	4.6	4.9	4.9
6	7.6	5.3	5.7	4.6	4.9	4.9
7	7.5	5.3	5.6	4.6	4.9	4.7
8	7.5	5.3	5.6	4.5	4.8	4.6
9	7.5	5.3	5.6	4.5	4.8	4.6
10	7.4	5.3	5.6	4.5	4.7	4.6

Table K-13 Maximum rolling 8-hour CO concentrations at RWR receptors, ranked by increase and by decrease in concentration with project

Rank	Ranking by increase in concentration with project (mg/m^3)			Ranking by decrease in concentration with project (mg/m^3)		
	2021-DS	2031-DS	2031-DSC	2021-DS	2031-DS	2031-DSC
1	2.3	2.4	1.9	-1.4	-1.2	-1.2
2	1.5	1.4	1.2	-1.4	-0.9	-1.2
3	1.5	1.3	1.2	-1.3	-0.9	-1.1
4	1.4	1.2	1.1	-1.3	-0.9	-1.1
5	1.4	1.2	1.0	-1.3	-0.9	-1.1
6	1.3	1.1	1.0	-1.3	-0.8	-1.0
7	1.3	1.1	1.0	-1.2	-0.8	-1.0
8	1.3	1.1	1.0	-1.2	-0.8	-1.0
9	1.3	1.1	1.0	-1.2	-0.8	-1.0
10	1.3	1.1	0.9	-1.1	-0.8	-1.0

Table K-14 Maximum rolling 8-hour CO concentrations at RWR receptors, ranked by percentage increase and by decrease in concentration with project

Rank	Ranking by % increase in concentration with project (mg/m^3)			Ranking by % decrease in concentration with project (mg/m^3)		
	2021-DS	2031-DS	2031-DSC	2021-DS	2031-DS	2031-DSC
1	68.6%	69.7%	54.1%	-32.1%	-25.8%	-31.6%
2	50.9%	43.8%	39.6%	-31.2%	-25.0%	-28.9%
3	50.0%	41.4%	38.4%	-29.2%	-24.9%	-28.9%
4	45.0%	39.8%	35.3%	-28.7%	-23.7%	-28.3%
5	41.4%	38.3%	31.9%	-28.4%	-23.2%	-27.8%
6	40.2%	37.5%	31.9%	-28.2%	-22.9%	-27.3%
7	39.5%	36.7%	31.8%	-27.8%	-22.7%	-27.3%
8	39.5%	36.5%	31.7%	-27.5%	-22.7%	-27.3%
9	39.0%	36.1%	30.6%	-27.4%	-22.3%	-27.3%
10	38.9%	35.8%	29.6%	-27.2%	-21.9%	-27.0%

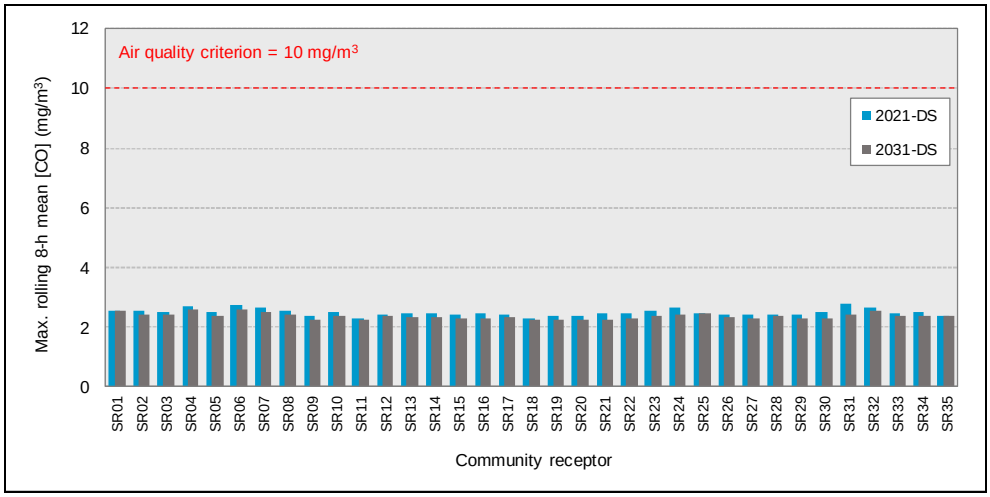


Figure K-11 Maximum rolling 8-hour mean CO at community receptors (2021-DS and 2031-DS)

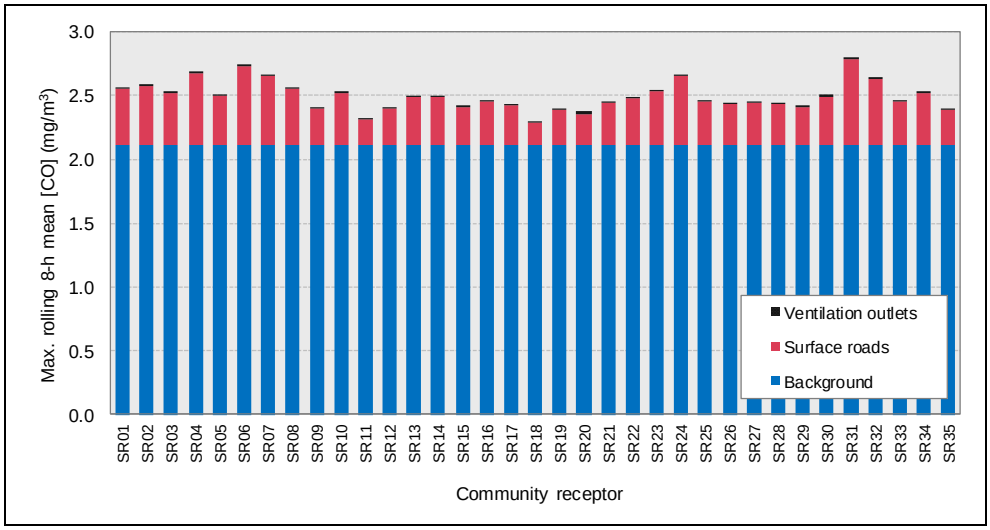


Figure K-12 Source contributions to max. rolling 8-hour mean CO at community receptors (2021-DS)

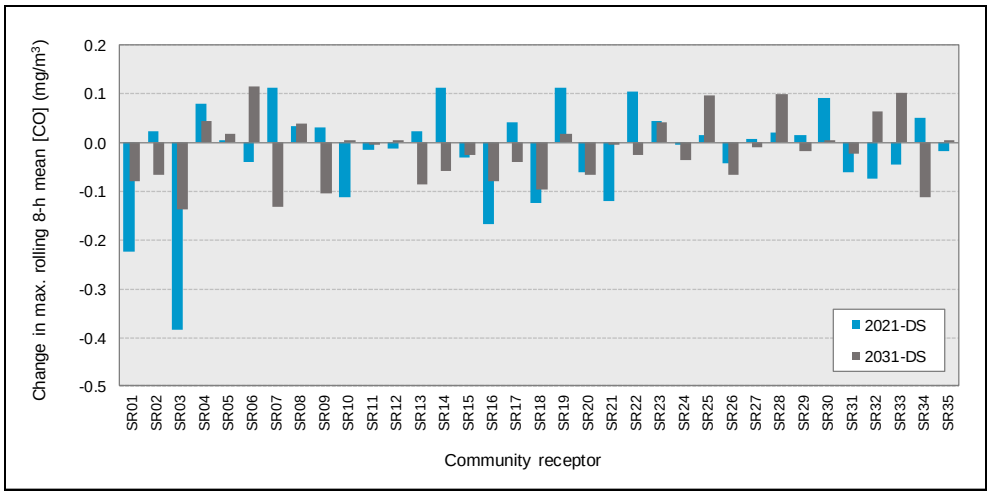


Figure K-13 Change in max. rolling 8-hour mean CO at community receptors (2021-DS and 2031-DS)

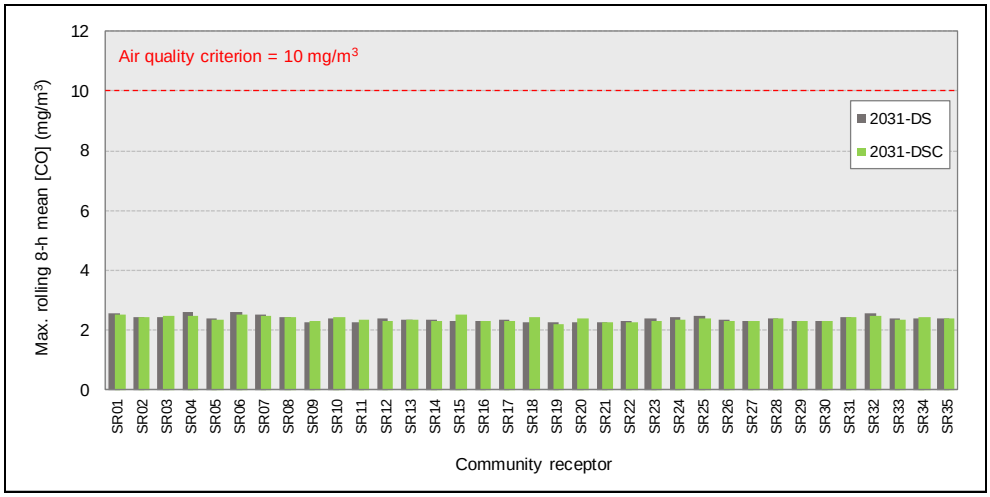


Figure K-14 Maximum rolling 8-hour mean CO at community receptors (2031-DS and 2031-DSC)

K.3 Nitrogen dioxide (annual mean)

Table K-15 Annual mean NO_2 concentrations at community receptors

Receptor	Annual mean NO_2 concentration (µg/m^3)						Change with project (µg/m^3)			Change with project (%)		
	2014-BY	2021-DM	2021 DS	2031-DM	2031-DS	2031-DSC	2021	2031	2031-DSC	2021	2031	2031-DSC
SR01	33.3	30.7	30.1	28.9	29.1	28.2	-0.6	0.2	-0.7	-2.1%	0.6%	-2.4%
SR02	33.1	30.3	29.8	29.1	28.8	28.4	-0.5	-0.3	-0.7	-1.8%	-1.0%	-2.2%
SR03	34.5	31.5	30.8	29.8	29.1	28.8	-0.6	-0.8	-1.0	-1.9%	-2.5%	-3.4%
SR04	35.1	30.8	31.1	28.9	28.7	28.3	0.3	-0.3	-0.6	1.0%	-0.9%	-2.1%
SR05	33.1	29.9	30.1	28.5	28.8	28.4	0.2	0.2	-0.1	0.6%	0.9%	-0.4%
SR06	36.5	32.5	33.2	30.8	31.0	30.1	0.7	0.2	-0.7	2.0%	0.5%	-2.4%
SR07	35.0	30.9	31.3	29.4	29.8	29.5	0.4	0.4	0.1	1.3%	1.3%	0.3%
SR08	34.5	30.8	31.6	29.3	29.3	28.7	0.8	0.0	-0.6	2.7%	0.1%	-1.9%
SR09	29.1	26.7	27.2	26.1	26.2	25.7	0.4	0.1	-0.4	1.7%	0.2%	-1.6%
SR10	31.1	28.5	28.8	28.2	27.9	27.4	0.4	-0.3	-0.8	1.3%	-1.1%	-2.8%
SR11	28.4	26.8	26.3	26.1	25.7	25.6	-0.5	-0.5	-0.5	-1.8%	-1.7%	-2.1%
SR12	31.6	28.2	27.9	27.2	26.7	25.9	-0.3	-0.6	-1.4	-1.2%	-2.0%	-5.0%
SR13	33.9	30.5	27.8	28.7	26.8	26.5	-2.7	-1.9	-2.3	-9.0%	-6.7%	-7.8%
SR14	31.5	28.3	27.2	27.0	26.2	26.3	-1.1	-0.8	-0.6	-4.0%	-2.9%	-2.3%
SR15	29.9	27.3	27.9	26.3	25.9	26.0	0.7	-0.4	-0.3	2.4%	-1.7%	-1.0%
SR16	32.8	29.4	28.2	28.7	26.7	25.8	-1.1	-2.0	-2.9	-3.8%	-6.9%	-10.2%
SR17	29.5	26.8	26.8	25.7	25.6	25.2	0.1	-0.1	-0.5	0.2%	-0.4%	-1.9%
SR18	29.2	26.9	27.0	25.4	25.6	25.3	0.1	0.2	0.0	0.2%	0.8%	-0.1%
SR19	27.1	26.0	26.4	24.8	25.1	25.1	0.4	0.3	0.3	1.5%	1.2%	1.1%
SR20	28.2	26.2	26.5	24.8	25.2	24.9	0.3	0.4	0.1	1.2%	1.7%	0.4%
SR21	28.2	26.3	26.6	25.4	25.5	25.5	0.3	0.0	0.1	1.1%	0.2%	0.4%
SR22	27.4	26.2	26.2	25.2	25.3	24.8	0.0	0.1	-0.4	-0.1%	0.3%	-1.7%
SR23	30.0	27.6	27.8	26.1	25.8	26.0	0.3	-0.3	-0.2	1.0%	-1.1%	-0.7%
SR24	31.0	28.3	28.9	26.3	27.3	26.1	0.7	1.0	-0.2	2.4%	3.7%	-0.6%
SR25	27.3	25.8	26.5	24.8	24.7	24.1	0.7	-0.1	-0.7	2.9%	-0.3%	-2.7%
SR26	29.3	26.3	26.5	24.8	25.2	24.7	0.2	0.4	-0.1	0.7%	1.8%	-0.3%
SR27	27.8	24.7	24.9	23.9	23.6	23.6	0.2	-0.3	-0.3	0.7%	-1.1%	-1.1%
SR28	26.5	24.4	24.5	23.1	23.1	22.8	0.1	0.0	-0.3	0.3%	0.0%	-1.3%
SR29	26.4	24.1	24.9	23.2	23.3	22.9	0.7	0.1	-0.3	3.1%	0.5%	-1.3%
SR30	27.6	25.4	26.0	23.7	24.4	24.6	0.7	0.6	0.9	2.7%	2.6%	3.6%
SR31	29.5	26.2	25.5	24.0	23.8	23.6	-0.6	-0.2	-0.4	-2.5%	-0.8%	-1.5%
SR32	29.5	27.0	25.6	24.7	24.2	24.2	-1.4	-0.6	-0.5	-5.3%	-2.3%	-2.2%
SR33	27.1	24.0	24.0	22.8	22.7	22.5	0.1	-0.1	-0.4	0.4%	-0.6%	-1.6%
SR34	29.1	26.4	26.5	25.0	25.2	25.2	0.1	0.3	0.3	0.5%	1.1%	1.1%
SR35	25.9	24.0	23.5	22.6	22.9	23.2	-0.6	0.3	0.6	-2.4%	1.1%	2.5%

Table K-16 Annual mean NO_2 concentrations at community receptors, ranked by concentration

Rank	Ranking by concentration (µg/m^3)					
	2014-BY	2021-DM	2021 DS	2031-DM	2031-DS	2031-DSC
1	36.5	32.5	33.2	30.8	31.0	30.1
2	35.1	31.5	31.6	29.8	29.8	29.5
3	35.0	30.9	31.3	29.4	29.3	28.8
4	34.5	30.8	31.1	29.3	29.1	28.7
5	34.5	30.8	30.8	29.1	29.1	28.4
6	33.9	30.7	30.1	28.9	28.8	28.4
7	33.3	30.5	30.1	28.9	28.8	28.3
8	33.1	30.3	29.8	28.7	28.7	28.2
9	33.1	29.9	28.9	28.7	27.9	27.4
10	32.8	29.4	28.8	28.5	27.3	26.5

Table K-17 Annual mean NO_2 concentrations at community receptors, ranked by increase and by decrease in concentration with project

Rank	Ranking by increase in concentration with project (µg/m^3)			Ranking by decrease in concentration with project (µg/m^3)		
	2021-DS	2031-DS	2031-DSC	2021-DS	2031-DS	2031-DSC
1	0.8	1.0	0.9	-2.7	-2.0	-2.9
2	0.7	0.6	0.6	-1.4	-1.9	-2.3
3	0.7	0.4	0.3	-1.1	-0.8	-1.4
4	0.7	0.4	0.3	-1.1	-0.8	-1.0
5	0.7	0.4	0.1	-0.6	-0.6	-0.8
6	0.7	0.3	0.1	-0.6	-0.6	-0.7
7	0.7	0.3	0.1	-0.6	-0.5	-0.7
8	0.4	0.3		-0.6	-0.4	-0.7
9	0.4	0.2		-0.5	-0.3	-0.7
10	0.4	0.2		-0.5	-0.3	-0.6

Table K-18 Annual mean NO_2 concentrations at community receptors, ranked by percentage increase and by decrease in concentration with project

Rank	Ranking by % increase in concentration with project (µg/m^3)			Ranking by % decrease in concentration with project (µg/m^3)		
	2021-DS	2031-DS	2031-DSC	2021-DS	2031-DS	2031-DSC
1	3.1%	3.7%	3.6%	-9.0%	-6.9%	-10.2%
2	2.9%	2.6%	2.5%	-5.3%	-6.7%	-7.8%
3	2.7%	1.8%	1.1%	-4.0%	-2.9%	-5.0%
4	2.7%	1.7%	1.1%	-3.8%	-2.5%	-3.4%
5	2.4%	1.3%	0.4%	-2.5%	-2.3%	-2.8%
6	2.4%	1.2%	0.4%	-2.4%	-2.0%	-2.7%
7	2.0%	1.1%	0.3%	-2.1%	-1.7%	-2.4%
8	1.7%	1.1%		-1.9%	-1.7%	-2.4%
9	1.5%	0.9%		-1.8%	-1.1%	-2.3%
10	1.3%	0.8%		-1.8%	-1.1%	-2.2%

Table K-19 Annual mean NO_2 concentrations at RWR receptors, ranked by concentration

Rank	Ranking by concentration (µg/m^3)					
	2014-BY	2021-DM	2021 DS	2031-DM	2031-DS	2031-DSC
1	61.4	47.4	43.0	43.4	39.8	36.8
2	54.3	47.3	42.9	41.3	38.9	36.5
3	54.2	45.2	40.9	39.4	38.4	35.8
4	51.9	45.2	40.9	39.3	38.4	35.6
5	51.2	45.1	40.9	39.3	38.3	35.5
6	50.8	44.4	40.9	39.1	38.3	35.4
7	50.7	44.1	40.7	38.9	38.3	35.4
8	50.4	43.0	40.6	38.8	38.1	35.3
9	50.3	42.6	40.6	38.5	38.0	35.3
10	50.2	42.5	40.5	38.5	37.9	35.3

Table K-20 Annual mean NO_2 concentrations at RWR receptors, ranked by increase and by decrease in concentration with project

Rank	Ranking by increase in concentration with project (µg/m^3)			Ranking by decrease in concentration with project (µg/m^3)		
	2021-DS	2031-DS	2031-DSC	2021-DS	2031-DS	2031-DSC
1	5.5	4.0	6.6	-14.8	-11.9	-13.5
2	4.8	3.8	5.6	-14.7	-11.6	-13.2
3	4.7	3.6	4.8	-14.4	-9.9	-10.2
4	4.6	3.4	4.7	-14.1	-8.3	-9.1
5	4.5	3.4	4.5	-13.4	-8.0	-8.8
6	4.5	3.1	4.3	-13.0	-7.0	-8.3
7	4.5	3.1	4.3	-11.4	-6.9	-8.2
8	4.3	3.0	4.2	-11.3	-6.3	-7.8
9	4.2	3.0	4.1	-11.2	-6.0	-7.4
10	4.2	3.0	4.0	-10.8	-5.8	-7.1

Table K-21 Annual mean NO_2 concentrations at RWR receptors, ranked by percentage increase and by decrease in concentration with project

Rank	Ranking by % increase in concentration with project (µg/m^3)			Ranking by % decrease in concentration with project (µg/m^3)		
	2021-DS	2031-DS	2031-DSC	2021-DS	2031-DS	2031-DSC
1	22.0%	16.1%	27.4%	-32.7%	-28.8%	-32.0%
2	18.3%	12.9%	23.3%	-32.5%	-27.3%	-31.0%
3	16.8%	11.7%	20.3%	-31.9%	-26.7%	-28.1%
4	16.0%	11.5%	20.0%	-29.7%	-23.6%	-26.0%
5	14.8%	11.5%	17.9%	-29.5%	-22.0%	-24.2%
6	14.7%	11.3%	17.7%	-28.2%	-20.9%	-23.1%
7	14.6%	11.2%	17.6%	-27.6%	-18.8%	-22.9%
8	14.4%	11.0%	17.5%	-27.1%	-17.3%	-22.3%
9	14.3%	10.8%	17.0%	-27.1%	-17.2%	-21.0%
10	14.3%	10.8%	16.6%	-26.4%	-16.9%	-20.4%

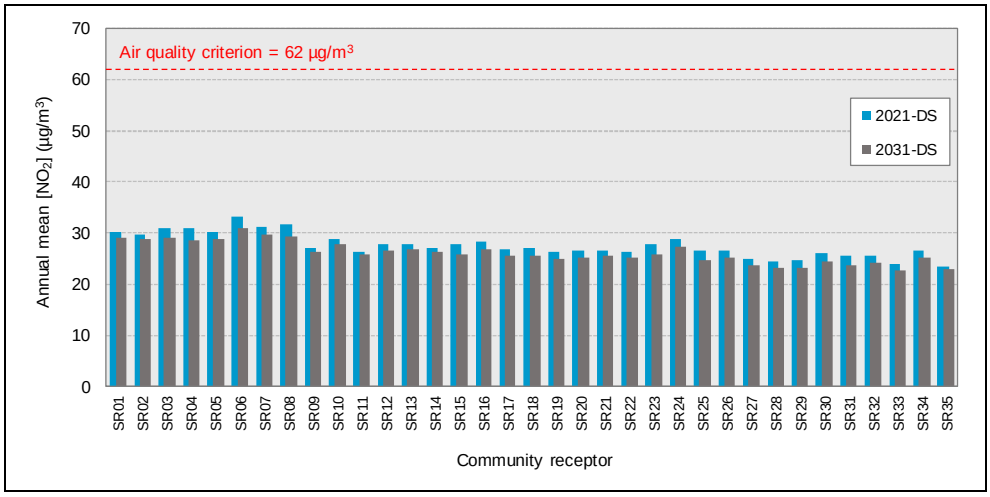


Figure K-15 Annual mean NO_2 at community receptors (2021-DS and 2031-DS)

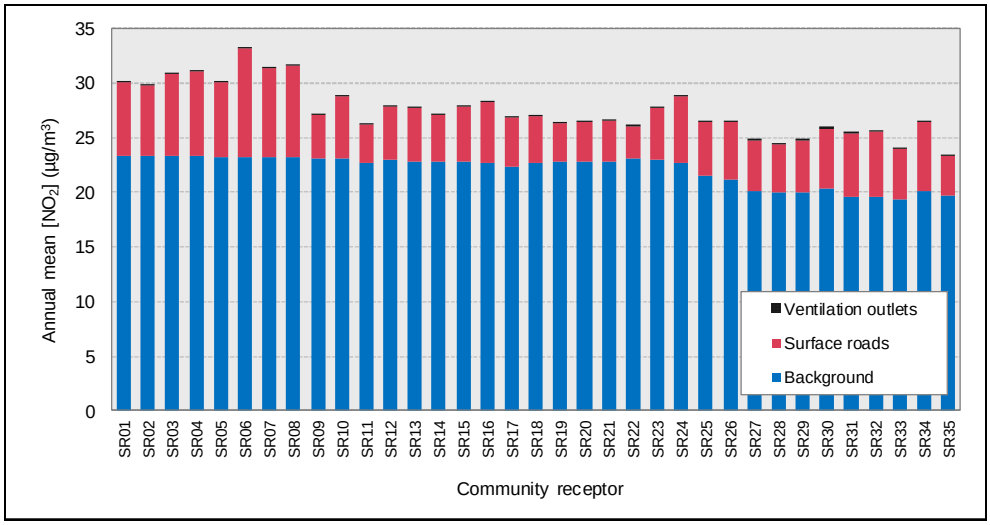


Figure K-16 Source contributions to annual mean NO_2 at community receptors (2021-DS)

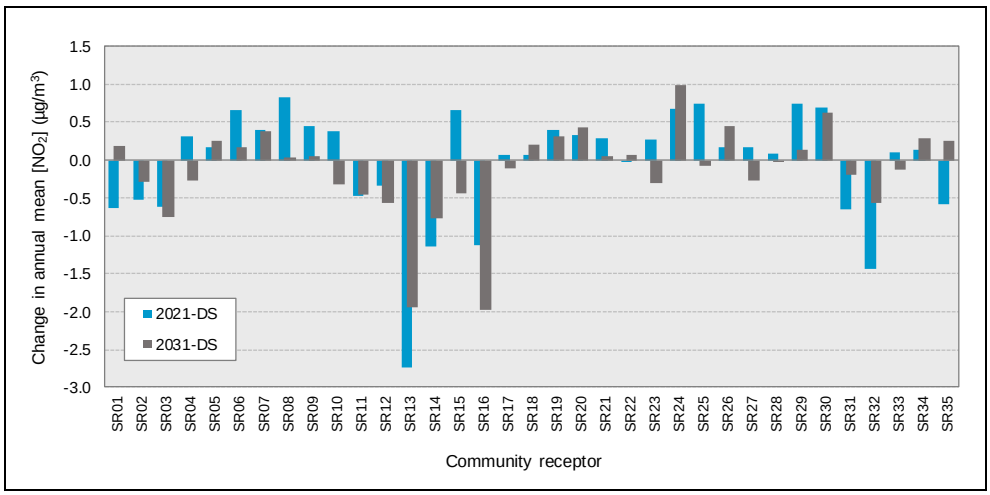


Figure K-17 Change in annual mean NO_2 at community receptors (2021-DS and 2031-DS)

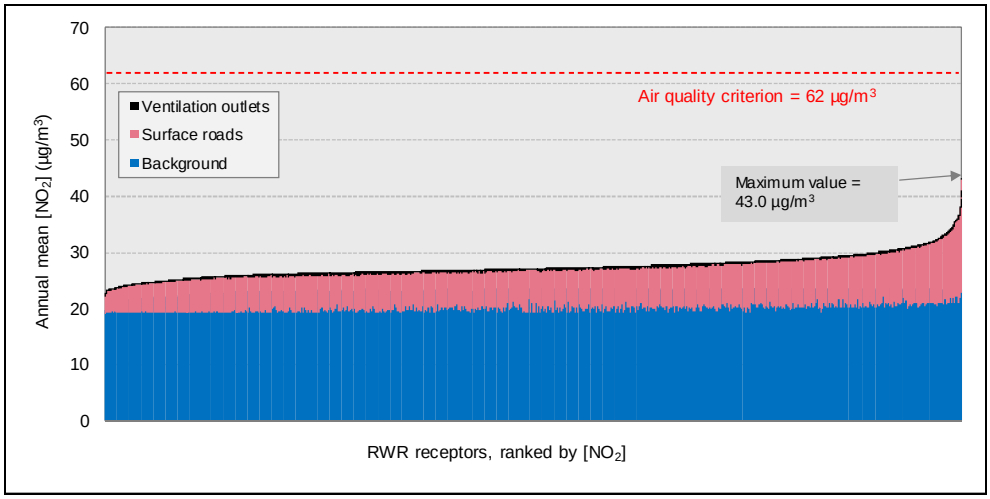


Figure K-18 Source contributions to annual mean NO_2 at RWR receptors (2021-DS)

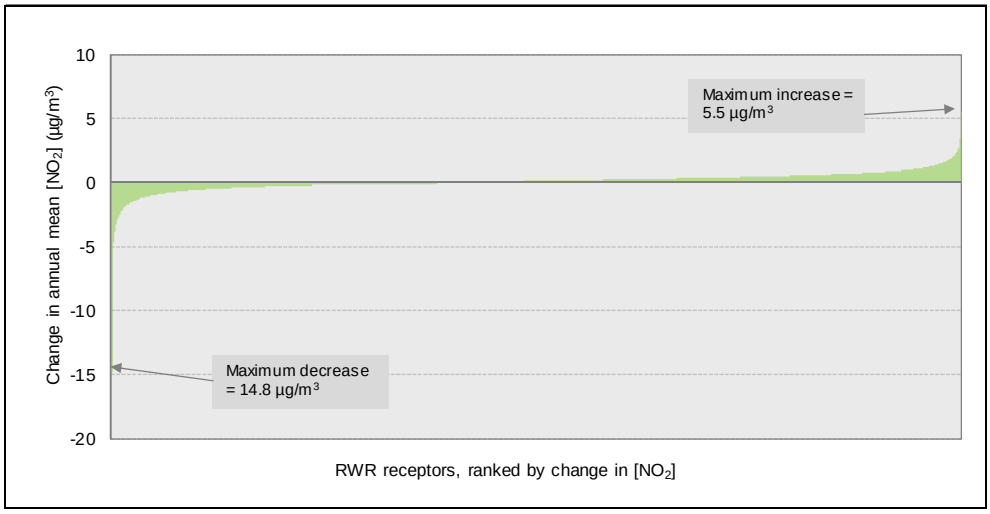


Figure K-19 Changes in annual mean NO_2 at RWR receptors (2021-DS)

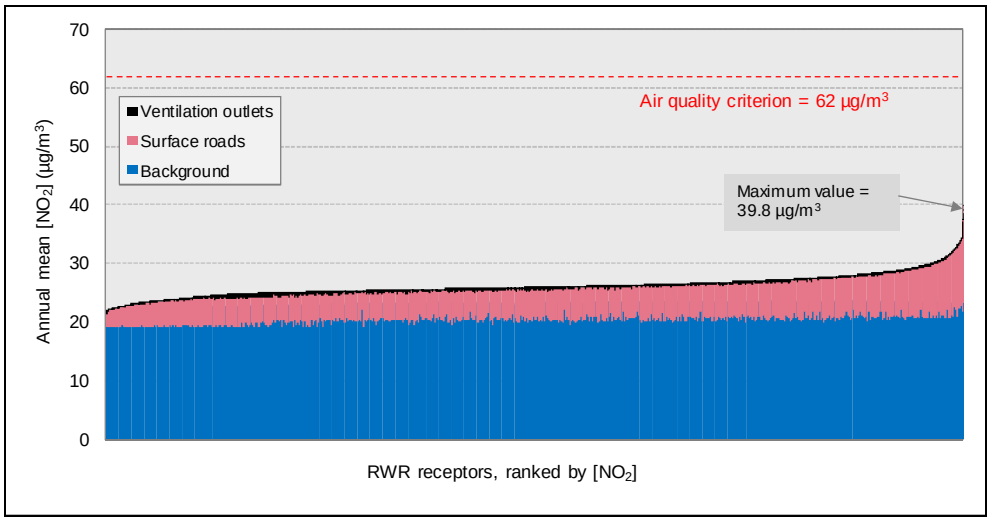


Figure K-20 Source contributions to annual mean NO_2 at RWR receptors (2031-DS)

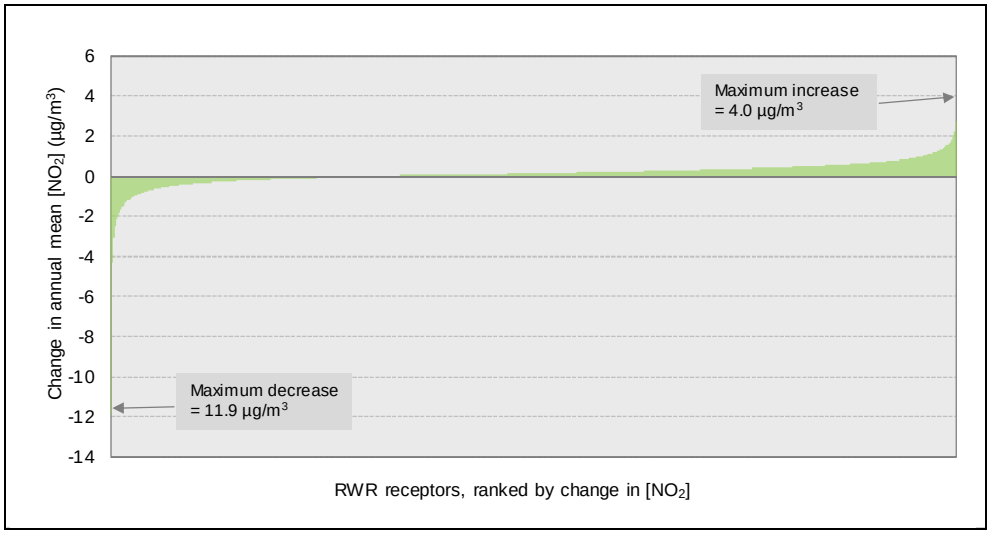


Figure K-21 Changes in annual mean NO_2 at RWR receptors (2031-DS)

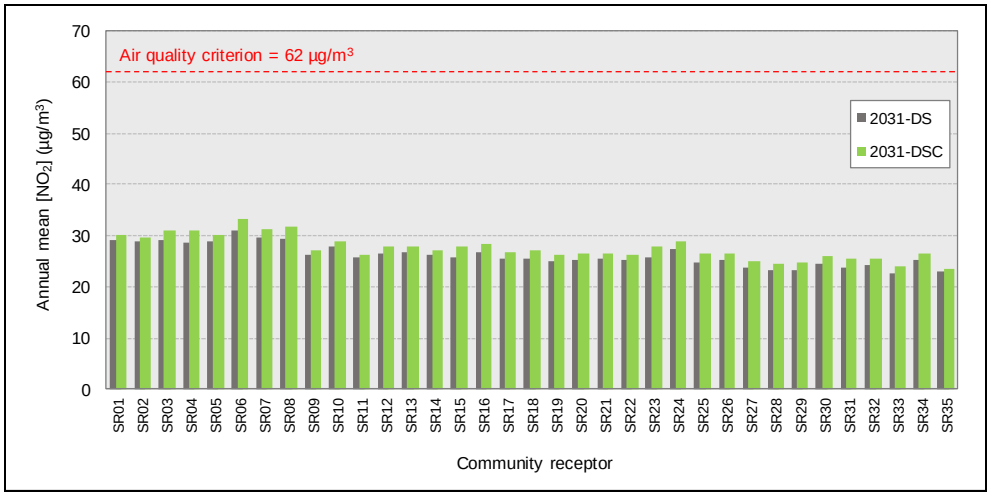


Figure K-22 Annual mean NO_2 at community receptors (2031-DS and 2031-DSC)

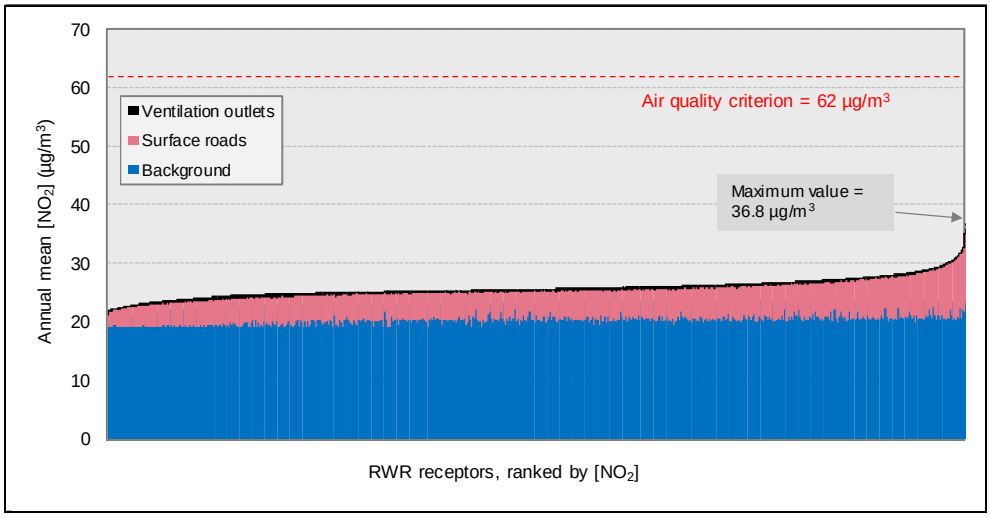


Figure K-23 Source contributions to annual mean NO_2 at RWR receptors (2031-DSC)

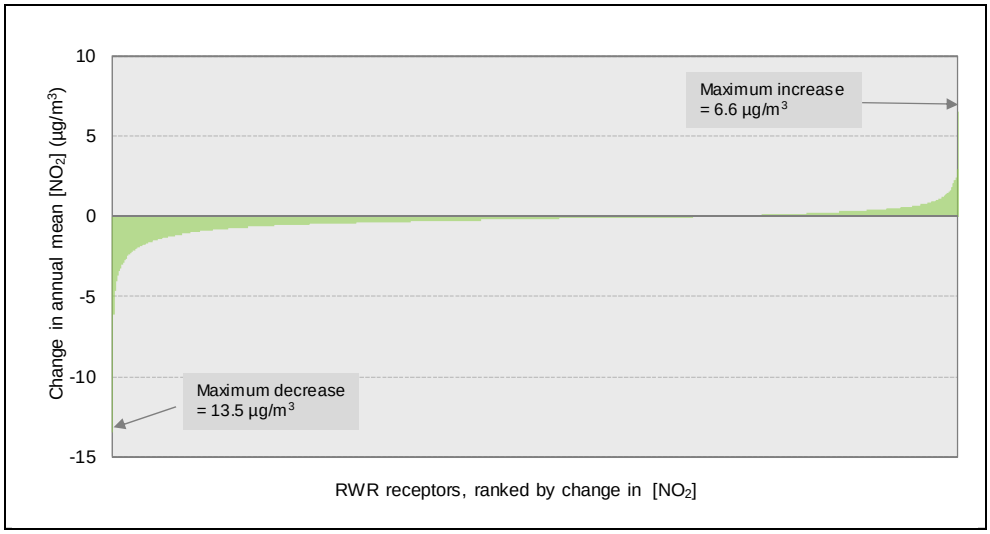


Figure K-24 Changes in annual mean NO_2 at RWR receptors (2031-DSC)

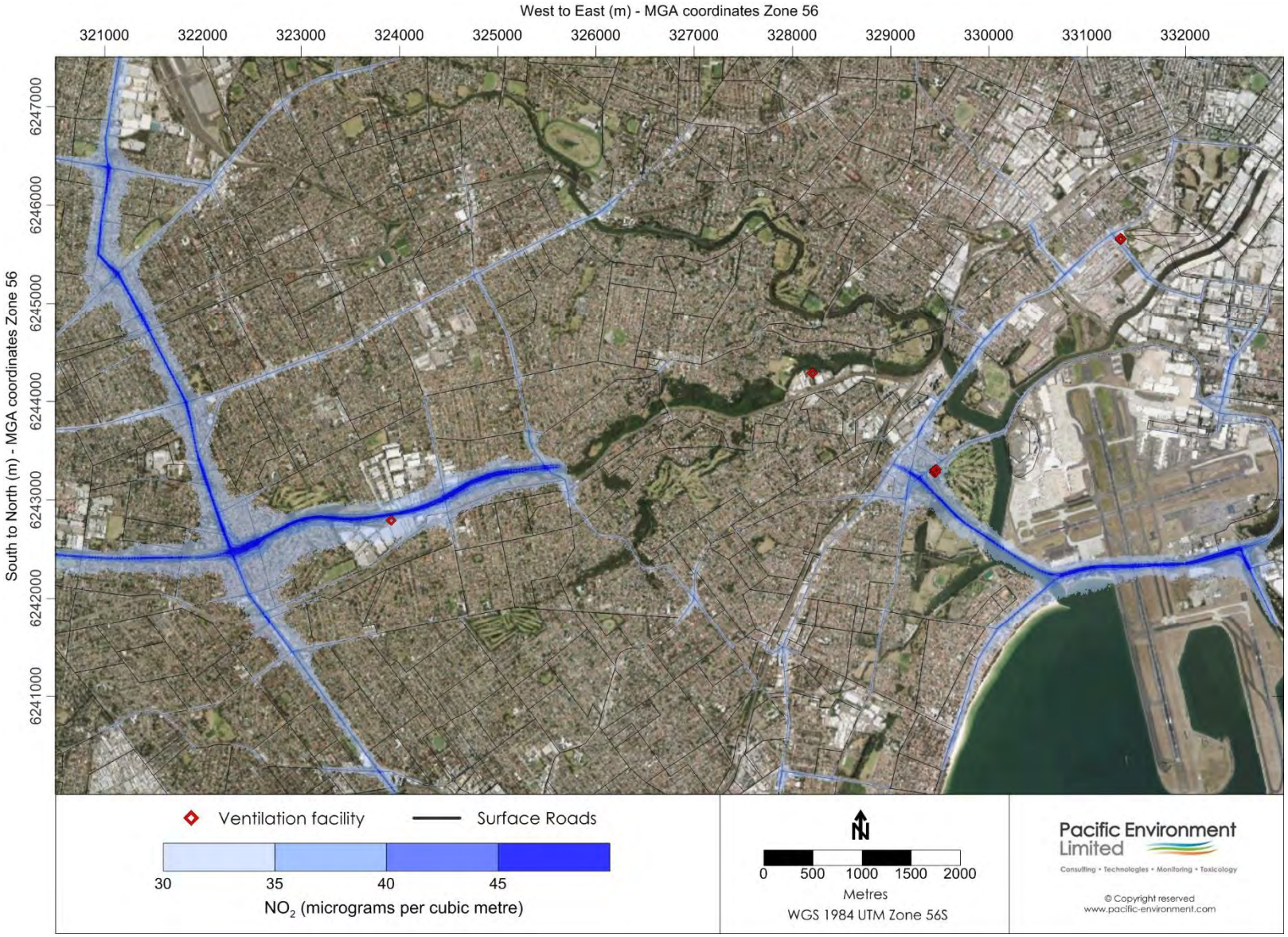


Figure K-25 Contour plot showing annual mean NO_2 without the project (2021-DM)



Figure K-26 Contour plot showing annual mean NO_2 with the project (2021-DS)

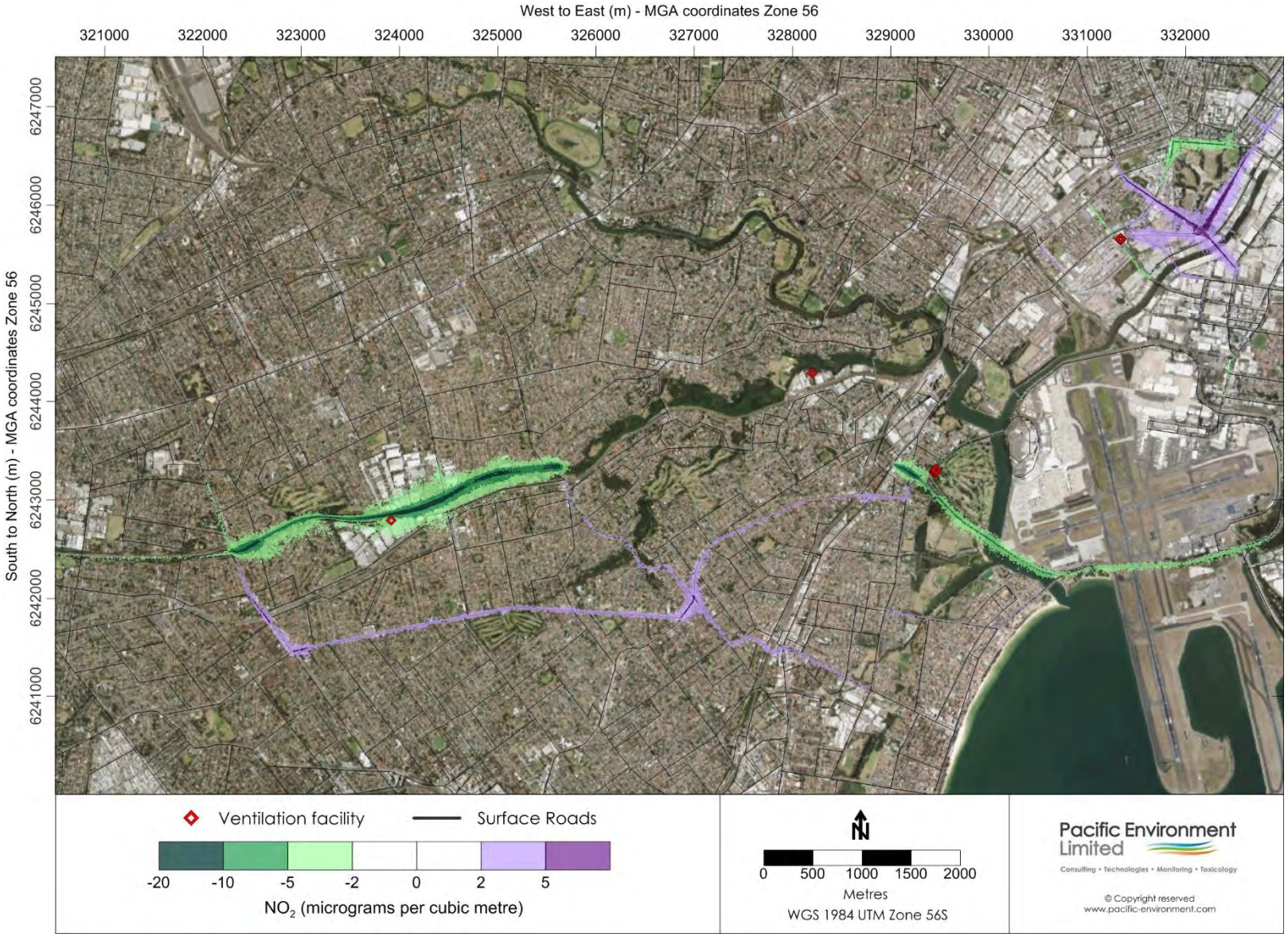


Figure K-27 Contour plot showing change in annual mean NO_2 with the project (2021-DS)



Figure K-28 Contour map showing annual mean NO_2 without the project (2031-DM)



Figure K-29 Contour map showing annual mean NO_2 with the project (2031-DS)



Figure K-30 Contour map showing change in annual mean NO_2 with the project (2031-DS)



Figure K-31 Contour map showing annual mean NO_2 with the project (2031-DSC)

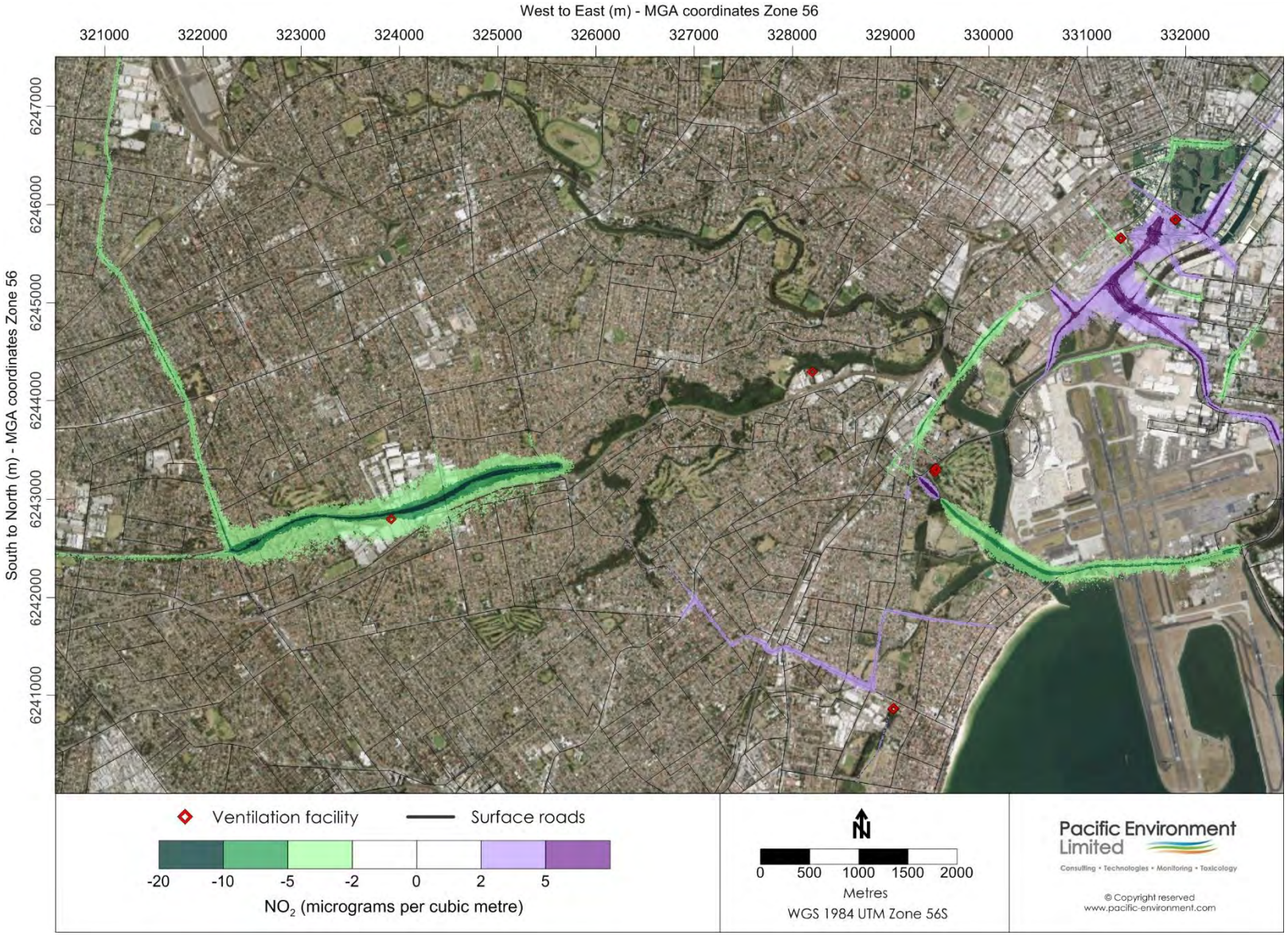


Figure K-32 Contour map showing change in annual mean NO_2 with the project (2031-DSC)

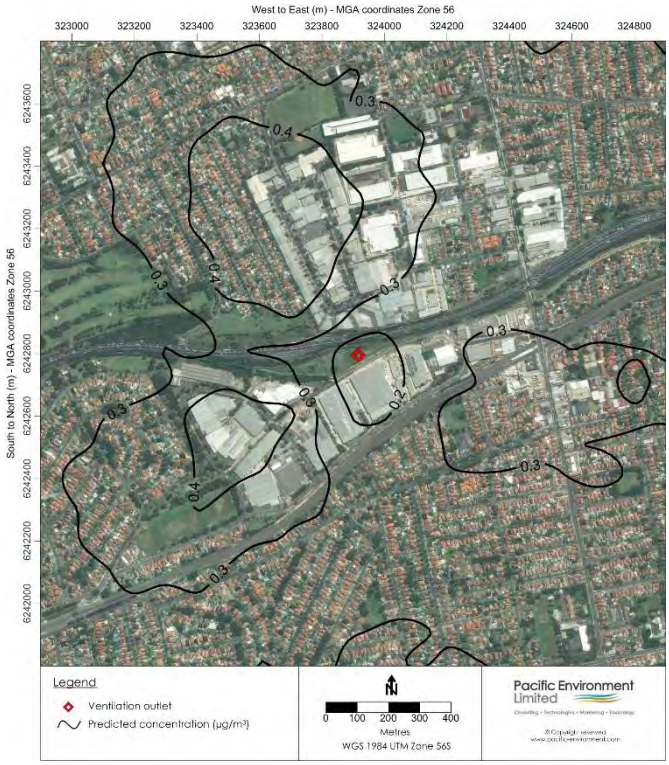


Figure K-33 Contour map showing annual mean NO_X with the project for ventilation outlets only (Kingsgrove outlet, 2021-DS)



Figure K-34 Contour map showing annual mean NO_X with the project for ventilation outlets only (Kingsgrove outlet, 2031-DS)



Figure K-35 Contour map showing annual mean NO_X with the project for ventilation outlets only (Kingsgrove outlet, 2031-DSC)

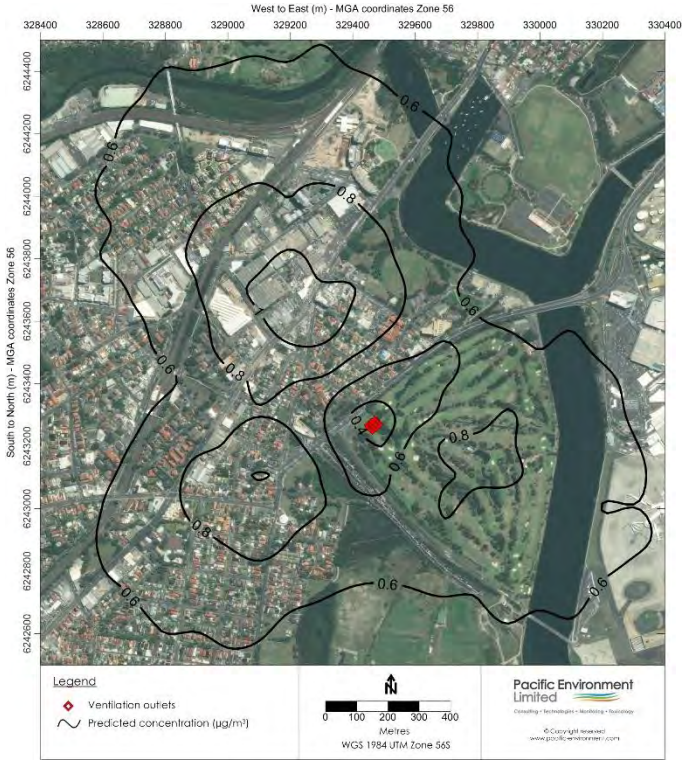


Figure K-36 Contour map showing annual mean NO_X with the project for ventilation outlets only (Arncliffe outlet, 2021-DS)

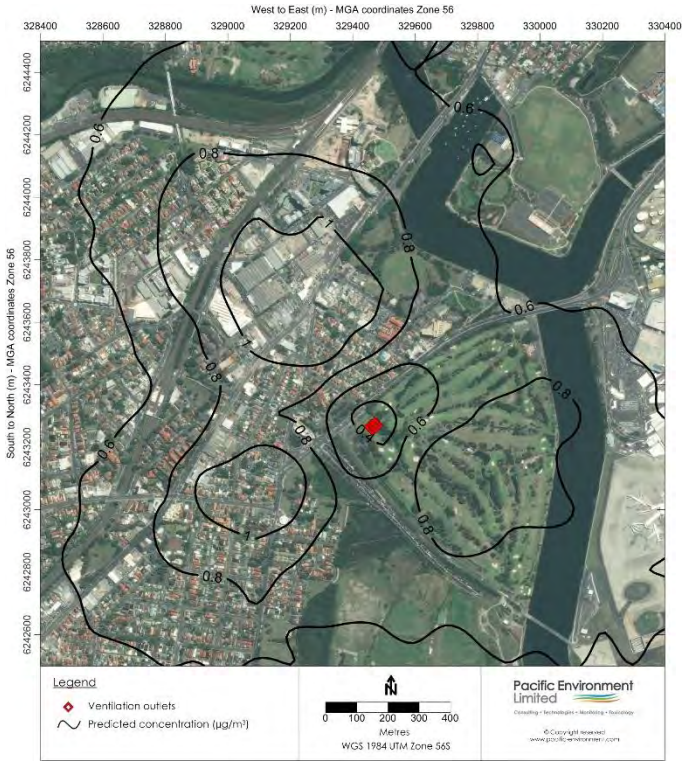


Figure K-37 Contour map showing annual mean NO_X with the project for ventilation outlets only (Arncliffe outlet, 2031-DS)

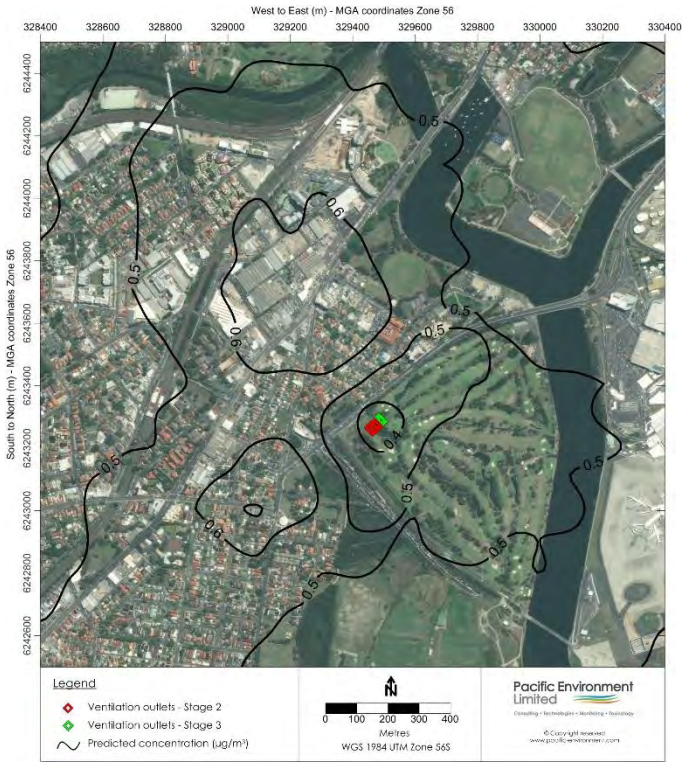


Figure K-38 Contour map showing annual mean NO_X with the project for ventilation outlets only (Arncliffe outlet, 2031-DSC)

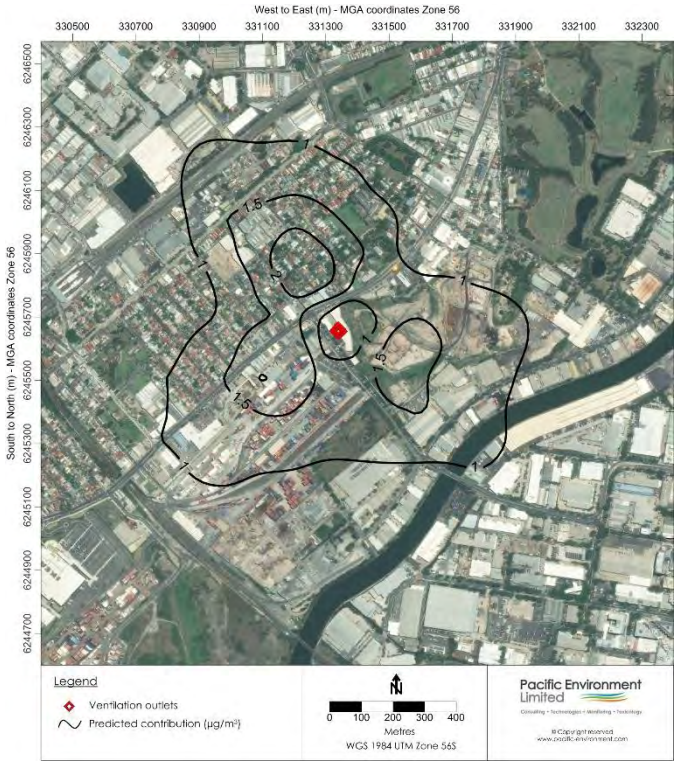


Figure K-39 Contour map showing annual mean NO_X with the project for ventilation outlets only (SPI New M5 outlet, 2021-DS)

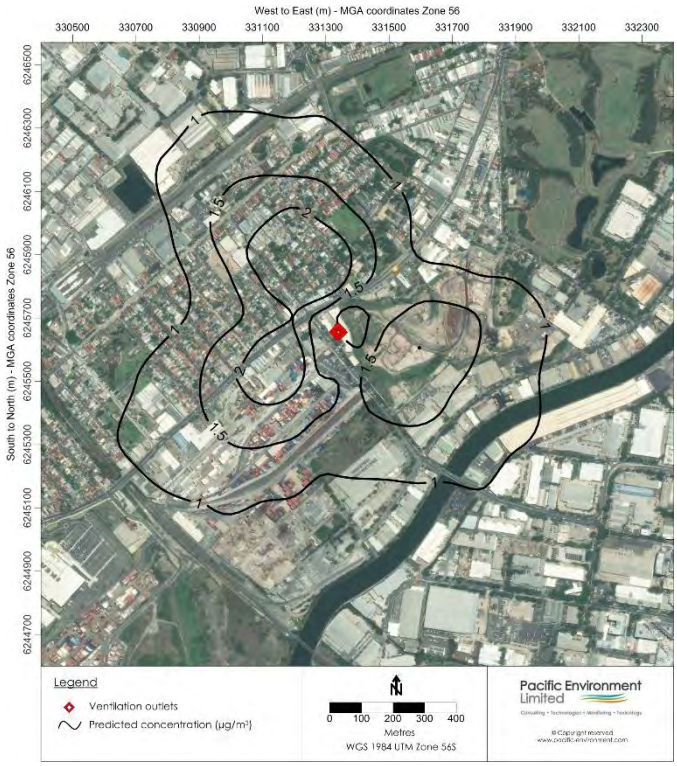


Figure K-40 Contour map showing annual mean NO_X with the project for ventilation outlets only (SPI New M5 outlet, 2031-DS)

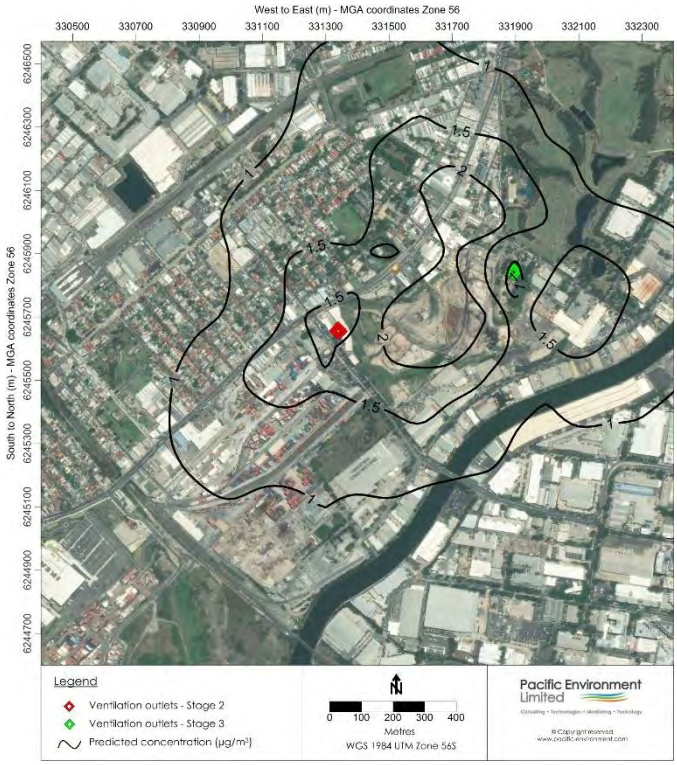


Figure K-41 Contour map showing annual mean NO_X with the project for ventilation outlets only (SPI New M5 outlet, 2031-DSC)

K.4 Nitrogen dioxide (maximum one-hour mean)

Table K-22 Maximum one-hour mean NO_2 concentrations at community receptors

Receptor	Maximum one-hour mean NO_2 concentration (µg/m^3)						Change with project (µg/m^3)			Change with project (%)		
	2014-BY	2021-DM	2021 DS	2031-DM	2031-DS	2031-DSC	2021	2031	2031-DSC	2021	2031	2031-DSC
SR01	153.3	204.3	204.3	200.3	197.9	199.4	0.0	-2.5	-1.0	0.0%	-1.2%	-0.5%
SR02	154.1	213.8	207.2	203.3	200.3	197.7	-6.6	-3.0	-5.6	-3.1%	-1.5%	-2.8%
SR03	224.2	215.4	214.5	206.6	207.2	203.4	-1.0	0.7	-3.2	-0.5%	0.3%	-1.5%
SR04	203.3	208.3	229.3	200.0	199.2	209.2	21.0	-0.8	9.2	10.1%	-0.4%	4.6%
SR05	153.9	213.6	207.9	202.2	200.4	205.7	-5.7	-1.8	3.4	-2.7%	-0.9%	1.7%
SR06	174.6	213.7	205.1	212.3	204.0	207.8	-8.5	-8.4	-4.5	-4.0%	-3.9%	-2.1%
SR07	154.0	201.0	208.7	200.3	196.8	198.4	7.6	-3.5	-1.9	3.8%	-1.7%	-0.9%
SR08	159.3	206.0	211.4	197.8	198.2	195.3	5.4	0.4	-2.5	2.6%	0.2%	-1.3%
SR09	150.2	197.0	197.1	194.9	195.4	195.0	0.1	0.5	0.0	0.0%	0.3%	0.0%
SR10	152.3	215.1	198.4	198.3	199.0	193.8	-16.7	0.7	-4.5	-7.8%	0.4%	-2.3%
SR11	151.3	197.1	194.4	198.9	196.4	197.3	-2.7	-2.5	-1.6	-1.4%	-1.3%	-0.8%
SR12	151.8	198.6	199.3	192.6	193.9	192.6	0.7	1.3	0.0	0.4%	0.7%	0.0%
SR13	193.5	220.3	208.1	215.4	200.6	199.1	-12.2	-14.9	-16.3	-5.5%	-6.9%	-7.6%
SR14	153.0	207.1	205.8	200.4	196.3	194.9	-1.3	-4.0	-5.5	-0.7%	-2.0%	-2.8%
SR15	151.8	211.5	202.0	192.6	193.0	196.6	-9.6	0.4	3.9	-4.5%	0.2%	2.0%
SR16	153.3	201.5	198.6	200.3	201.1	194.4	-2.9	0.8	-5.9	-1.4%	0.4%	-2.9%
SR17	151.7	198.7	198.2	195.0	195.6	196.6	-0.5	0.6	1.5	-0.2%	0.3%	0.8%
SR18	149.9	192.6	196.5	192.6	196.7	193.5	3.8	4.0	0.8	2.0%	2.1%	0.4%
SR19	148.8	194.0	195.8	192.6	195.1	194.2	1.8	2.5	1.5	0.9%	1.3%	0.8%
SR20	153.6	194.4	197.9	193.1	195.8	195.4	3.4	2.7	2.3	1.8%	1.4%	1.2%
SR21	150.7	192.6	201.6	195.1	193.8	192.6	9.0	-1.2	-2.4	4.7%	-0.6%	-1.2%
SR22	150.0	202.6	195.0	192.6	197.2	194.5	-7.6	4.5	1.9	-3.7%	2.4%	1.0%
SR23	153.2	202.6	204.3	199.1	198.5	195.7	1.7	-0.6	-3.4	0.8%	-0.3%	-1.7%
SR24	153.8	210.6	205.6	210.7	199.3	195.2	-4.9	-11.4	-15.5	-2.3%	-5.4%	-7.3%
SR25	154.0	205.3	197.8	194.5	210.4	193.2	-7.5	15.9	-1.3	-3.7%	8.2%	-0.7%
SR26	153.4	196.3	203.9	195.5	194.7	196.6	7.6	-0.9	1.1	3.9%	-0.4%	0.5%
SR27	151.9	204.0	205.0	202.6	194.9	197.0	1.0	-7.6	-5.6	0.5%	-3.8%	-2.7%
SR28	151.8	202.5	201.5	197.2	203.8	199.2	-1.0	6.6	1.9	-0.5%	3.3%	1.0%
SR29	151.8	198.0	200.1	194.6	197.4	196.5	2.1	2.9	2.0	1.1%	1.5%	1.0%
SR30	150.3	203.9	193.4	206.7	199.7	205.9	-10.5	-6.9	-0.7	-5.2%	-3.4%	-0.3%
SR31	161.4	203.0	204.4	200.0	201.0	199.8	1.4	0.9	-0.3	0.7%	0.5%	-0.1%
SR32	177.0	210.5	215.8	217.9	205.1	195.5	5.2	-12.8	-22.3	2.5%	-5.9%	-10.3%
SR33	153.0	205.8	200.8	195.2	195.1	196.0	-5.0	0.0	0.8	-2.4%	0.0%	0.4%
SR34	152.3	199.7	213.2	192.6	197.4	208.3	13.5	4.8	15.7	6.8%	2.5%	8.1%
SR35	151.8	202.7	197.2	193.5	192.6	197.1	-5.5	-0.8	3.7	-2.7%	-0.4%	1.9%

Table K-23 Maximum one-hour mean NO_2 concentrations at community receptors, ranked by concentration

Rank	Ranking by concentration (µg/m^3)					
	2014-BY	2021-DM	2021 DS	2031-DM	2031-DS	2031-DSC
1	224.2	220.3	229.3	217.9	210.4	209.2
2	203.3	215.4	215.8	215.4	207.2	208.3
3	193.5	215.1	214.5	212.3	205.1	207.8
4	177.0	213.8	213.2	210.7	204.0	205.9
5	174.6	213.7	211.4	206.7	203.8	205.7
6	161.4	213.6	208.7	206.6	201.1	203.4
7	159.3	211.5	208.1	203.3	201.0	199.8
8	154.1	210.6	207.9	202.6	200.6	199.4
9	154.0	210.5	207.2	202.2	200.4	199.2
10	154.0	208.3	205.8	200.4	200.3	199.1

Table K-24 Maximum one-hour mean NO_2 concentrations at community receptors, ranked by increase and by decrease in concentration with project

Rank	Ranking by increase in concentration with project (µg/m^3)			Ranking by decrease in concentration with project (µg/m^3)		
	2021-DS	2031-DS	2031-DSC	2021-DS	2031-DS	2031-DSC
1	21.0	15.9	15.7	-16.7	-14.9	-22.3
2	13.5	6.6	9.2	-12.2	-12.8	-16.3
3	9.0	4.8	3.9	-10.5	-11.4	-15.5
4	7.6	4.5	3.7	-9.6	-8.4	-5.9
5	7.6	4.0	3.4	-8.5	-7.6	-5.6
6	5.4	2.9	2.3	-7.6	-6.9	-5.6
7	5.2	2.7	2.0	-7.5	-4.0	-5.5
8	3.8	2.5	1.9	-6.6	-3.5	-4.5
9	3.4	1.3	1.9	-5.7	-3.0	-4.5
10	2.1	0.9	1.5	-5.5	-2.5	-3.4

Table K-25 Maximum one-hour mean NO_2 concentrations at community receptors, ranked by percentage increase and by decrease in concentration with project

Rank	Ranking by % increase in concentration with project (µg/m^3)			Ranking by % decrease in concentration with project (µg/m^3)		
	2021-DS	2031-DS	2031-DSC	2021-DS	2031-DS	2031-DSC
1	10.1%	8.2%	8.1%	-7.8%	-6.9%	-10.3%
2	6.8%	3.3%	4.6%	-5.5%	-5.9%	-7.6%
3	4.7%	2.5%	2.0%	-5.2%	-5.4%	-7.3%
4	3.9%	2.4%	1.9%	-4.5%	-3.9%	-2.9%
5	3.8%	2.1%	1.7%	-4.0%	-3.8%	-2.8%
6	2.6%	1.5%	1.2%	-3.7%	-3.4%	-2.8%
7	2.5%	1.4%	1.0%	-3.7%	-2.0%	-2.7%
8	2.0%	1.3%	1.0%	-3.1%	-1.7%	-2.3%
9	1.8%	0.7%	1.0%	-2.7%	-1.5%	-2.1%
10	1.1%	0.5%	0.8%	-2.7%	-1.3%	-1.7%

Table K-26 Maximum one-hour mean NO_2 concentrations at RWR receptors, ranked by concentration

Rank	Ranking by concentration (µg/m^3)					
	2014-BY	2021-DM	2021 DS	2031-DM	2031-DS	2031-DSC
1	463.4	473.4	457.5	477.2	383.5	312.3
2	455.0	463.3	436.3	412.6	349.4	298.5
3	445.5	454.5	424.4	411.9	343.7	280.2
4	442.5	453.7	418.9	400.7	335.2	278.7
5	438.3	451.7	416.4	399.4	330.8	277.6
6	425.1	451.5	404.2	395.1	330.7	277.3
7	419.2	450.9	398.6	393.4	322.8	273.8
8	417.4	445.1	396.3	393.2	321.2	273.5
9	412.2	444.2	391.0	392.6	321.1	273.4
10	411.0	443.0	389.9	391.7	319.7	272.2

Table K-27 Maximum one-hour mean NO_2 concentrations at RWR receptors, ranked by increase and by decrease in concentration with project

Rank	Ranking by increase in concentration with project (µg/m^3)			Ranking by decrease in concentration with project (µg/m^3)		
	2021-DS	2031-DS	2031-DSC	2021-DS	2031-DS	2031-DSC
1	173.5	123.9	66.3	-217.3	-198.7	-256.7
2	164.8	103.8	62.8	-213.3	-190.2	-195.3
3	164.2	96.0	59.4	-208.3	-175.2	-189.0
4	155.9	93.3	57.8	-206.8	-158.2	-189.0
5	148.8	91.4	56.0	-201.3	-154.6	-188.6
6	145.8	86.0	52.3	-200.7	-146.0	-178.9
7	139.1	78.2	48.7	-200.0	-145.7	-177.8
8	128.6	72.0	46.9	-195.4	-144.5	-175.0
9	126.5	71.8	46.9	-184.9	-142.7	-172.1
10	123.2	70.4	44.3	-184.5	-137.9	-170.2

Table K-28 Maximum one-hour mean NO_2 concentrations at RWR receptors, ranked by percentage increase and by decrease in concentration with project

Rank	Ranking by % increase in concentration with project (µg/m^3)			Ranking by % decrease in concentration with project (µg/m^3)		
	2021-DS	2031-DS	2031-DSC	2021-DS	2031-DS	2031-DSC
1	75.7%	59.9%	31.0%	-50.8%	-47.5%	-53.8%
2	75.5%	47.7%	29.2%	-48.0%	-44.6%	-47.4%
3	69.2%	43.6%	27.7%	-47.6%	-41.6%	-47.2%
4	66.8%	42.6%	26.4%	-46.9%	-41.2%	-47.2%
5	64.1%	42.3%	25.8%	-46.0%	-40.9%	-45.8%
6	63.1%	40.4%	23.1%	-45.8%	-39.6%	-45.6%
7	59.0%	34.8%	22.8%	-45.8%	-38.7%	-45.0%
8	57.7%	32.6%	21.7%	-45.2%	-38.6%	-44.7%
9	55.9%	32.2%	21.3%	-45.0%	-38.3%	-44.6%
10	52.6%	30.5%	20.7%	-45.0%	-38.3%	-43.9%

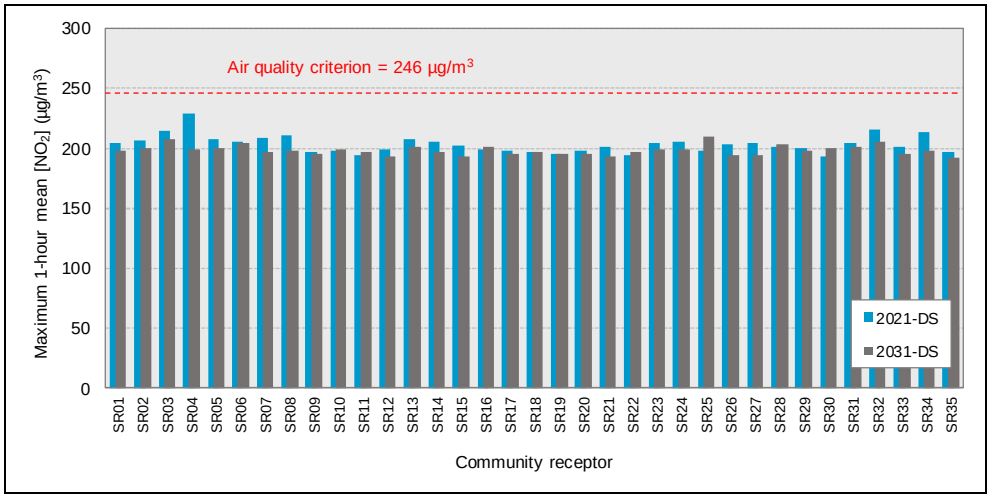


Figure K-42 Maximum one-hour NO_2 at community receptors (2021-DS and 2031-DS)

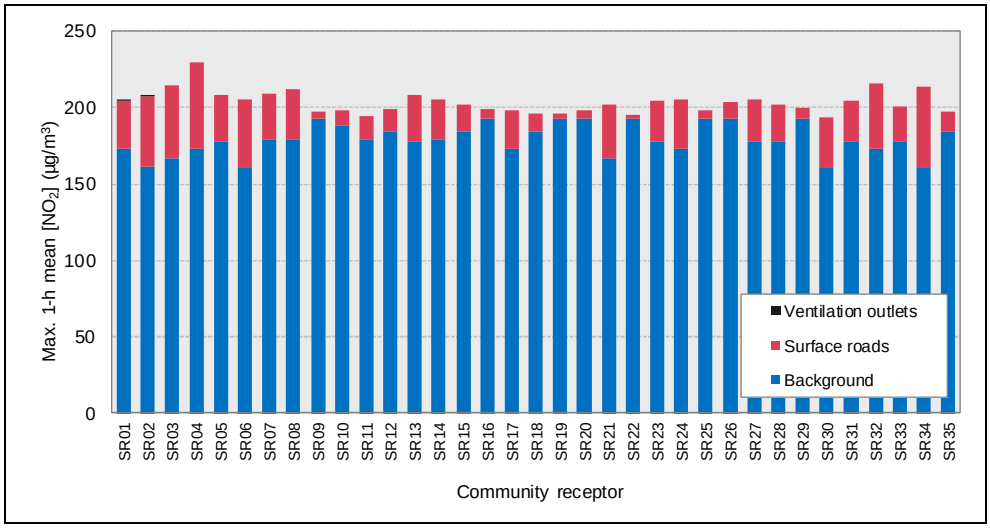


Figure K-43 Source contributions to maximum one-hour NO_2 at community receptors (2021-DS)

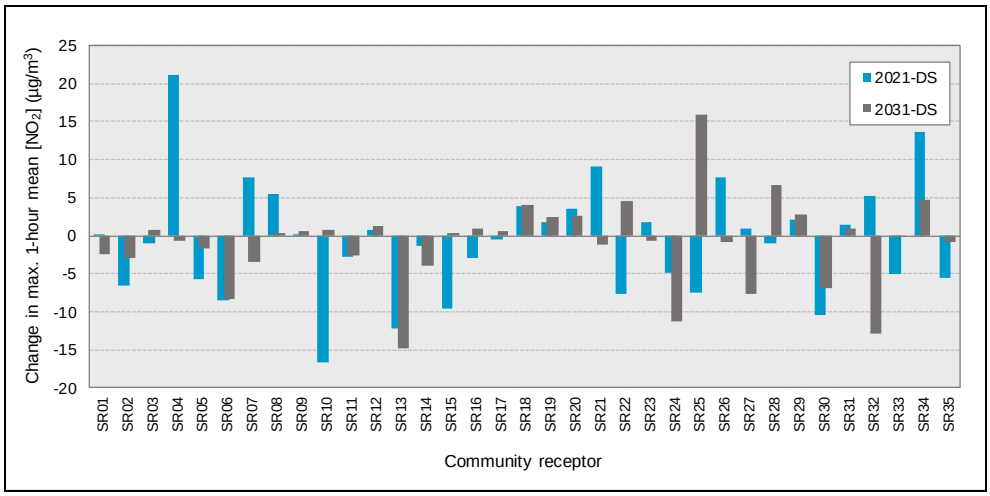


Figure K-44 Change in maximum one-hour NO_2 at community receptors (2021-DS and 2031-DS)

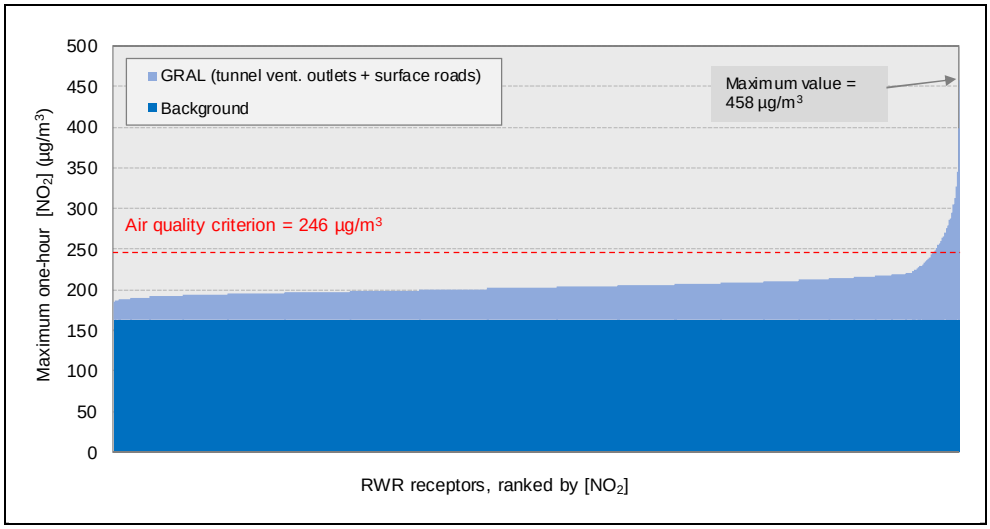


Figure K-45 Source contributions to maximum one-hour NO_2 at RWR receptors (2021-DS)

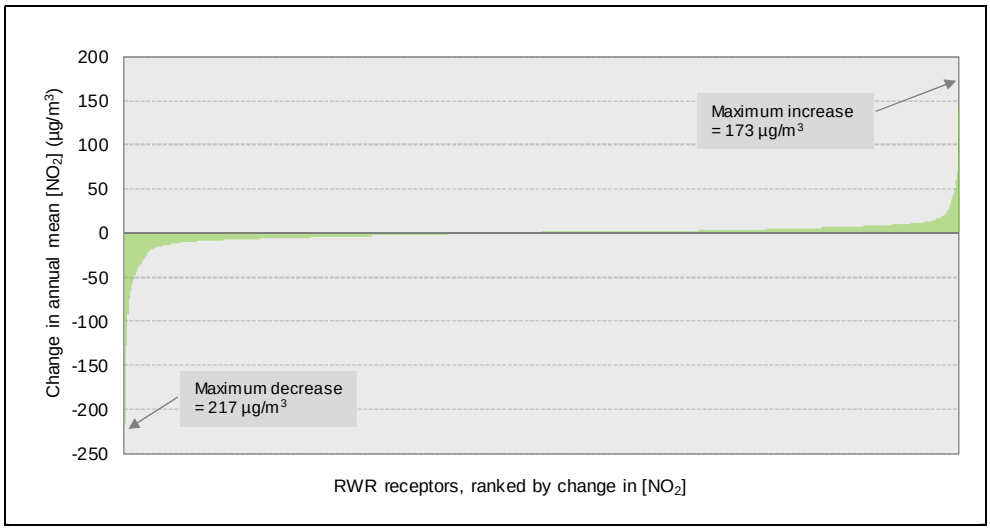


Figure K-46 Changes in maximum one-hour NO_2 at RWR receptors (2021-DS)

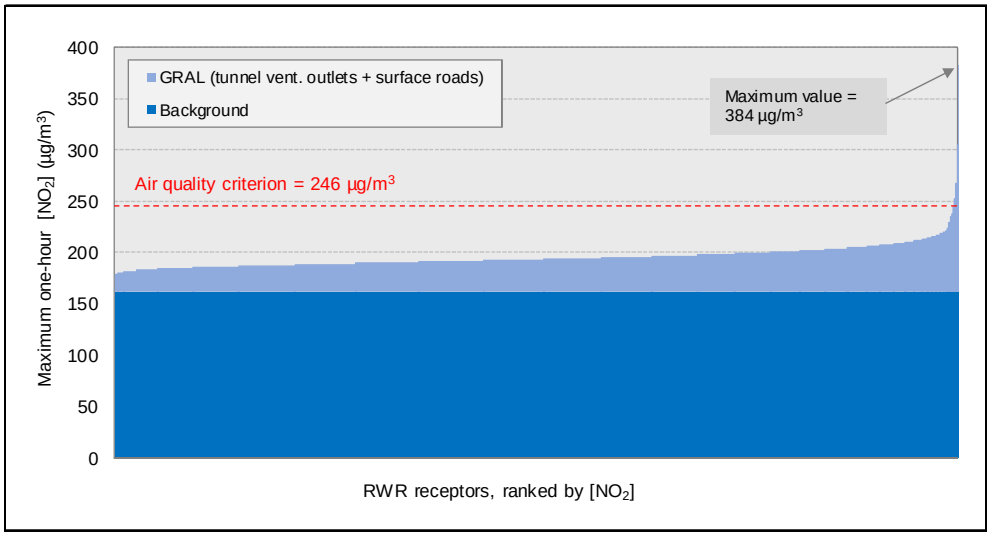


Figure K-47 Source contributions to maximum one-hour NO_2 at RWR receptors (2031-DS)

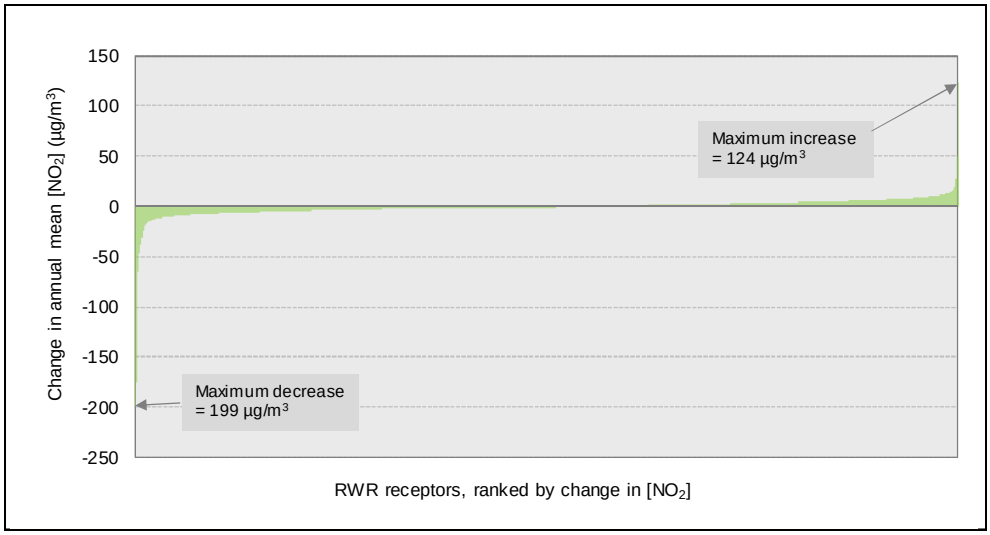


Figure K-48 Changes in maximum one-hour NO_2 at RWR receptors (2031-DS)

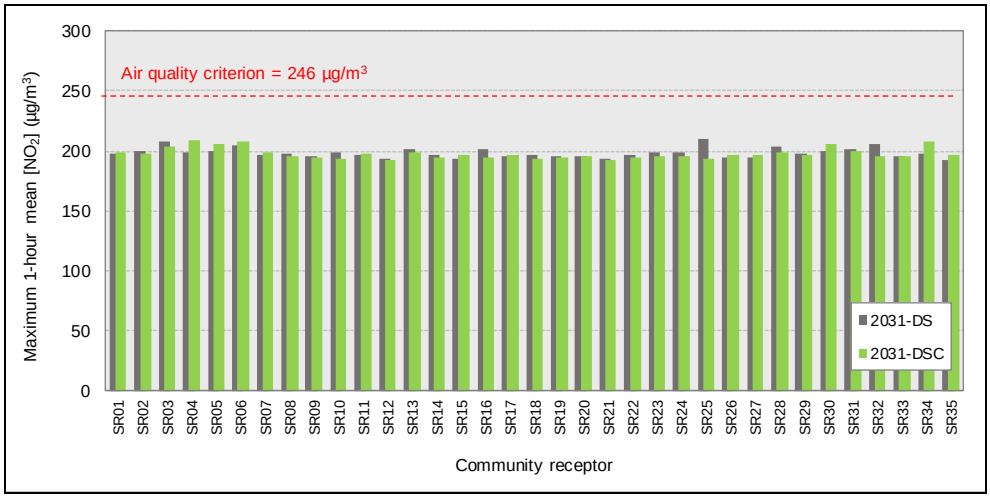


Figure K-49 Maximum one-hour mean NO_2 at community receptors (2031-DS and 2031-DSC)

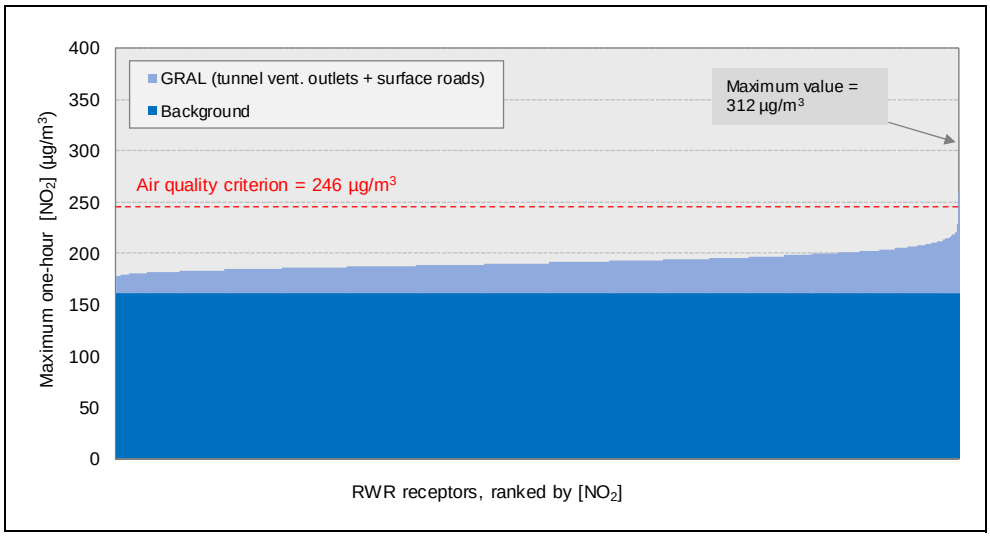


Figure K-50 Source contributions to maximum one-hour NO_2 at RWR receptors (2031-DSC)

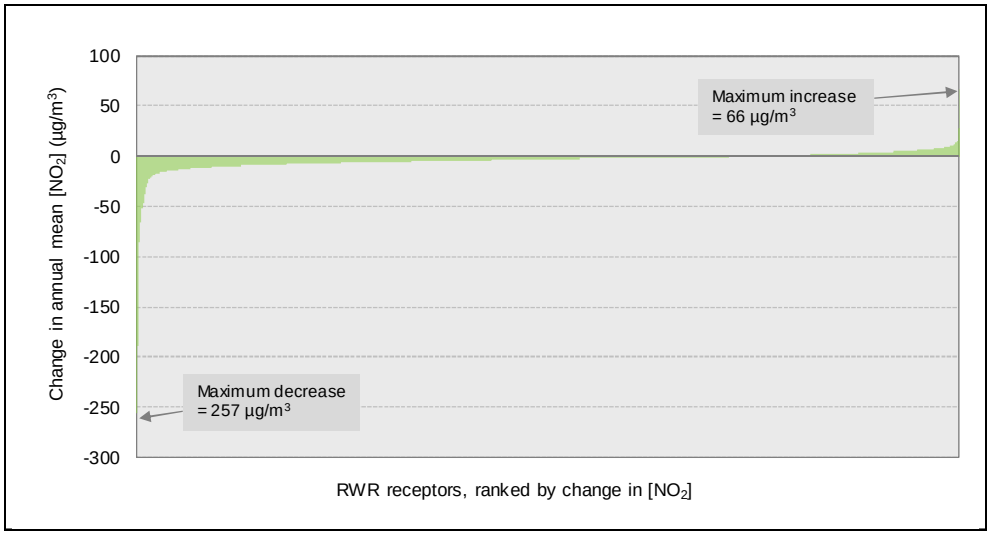


Figure K-51 Changes in maximum one-hour NO_2 at RWR receptors (2031-DSC)

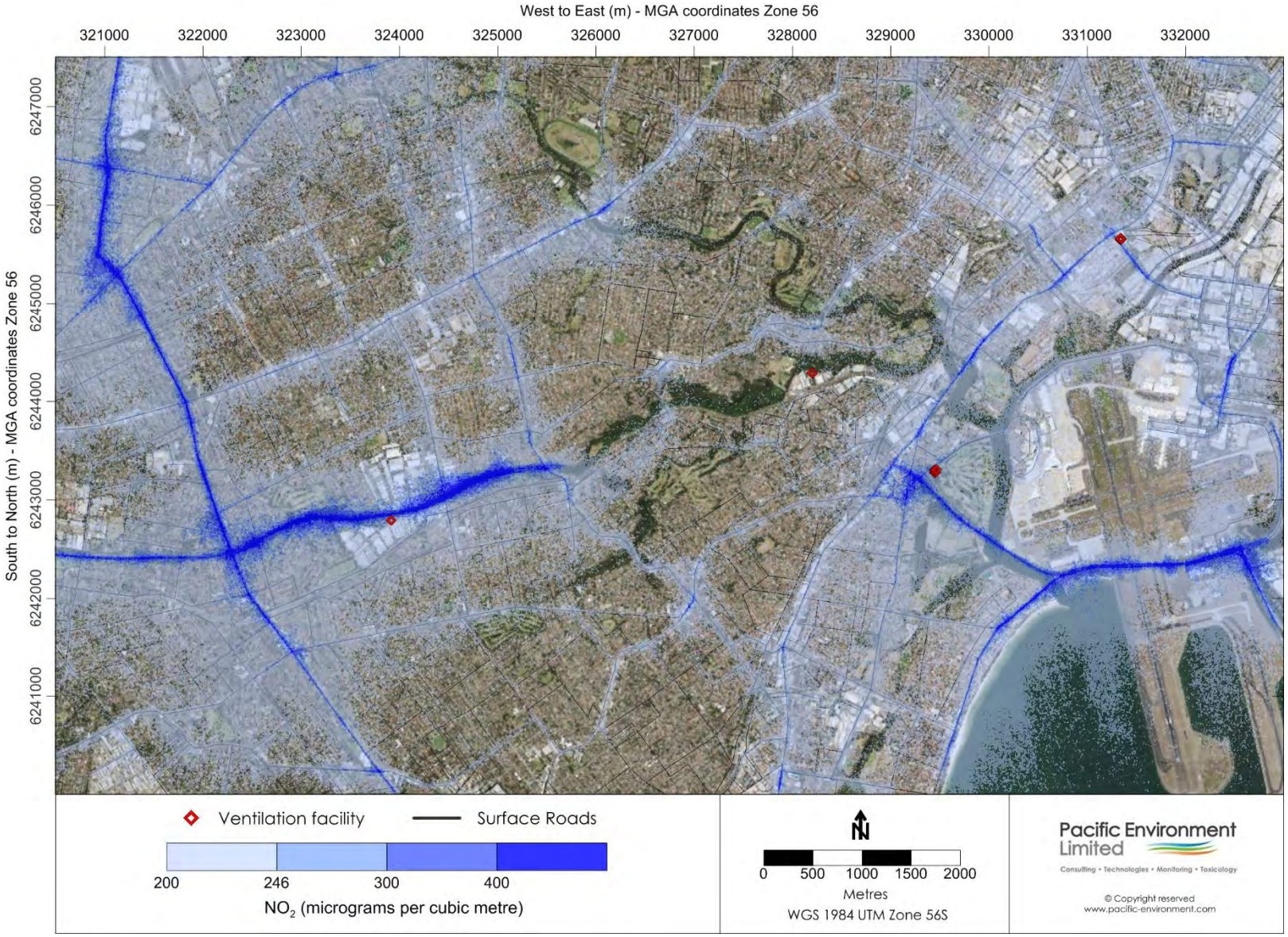


Figure K-52 Contour plot showing maximum one-hour NO_2 (2021-DM)

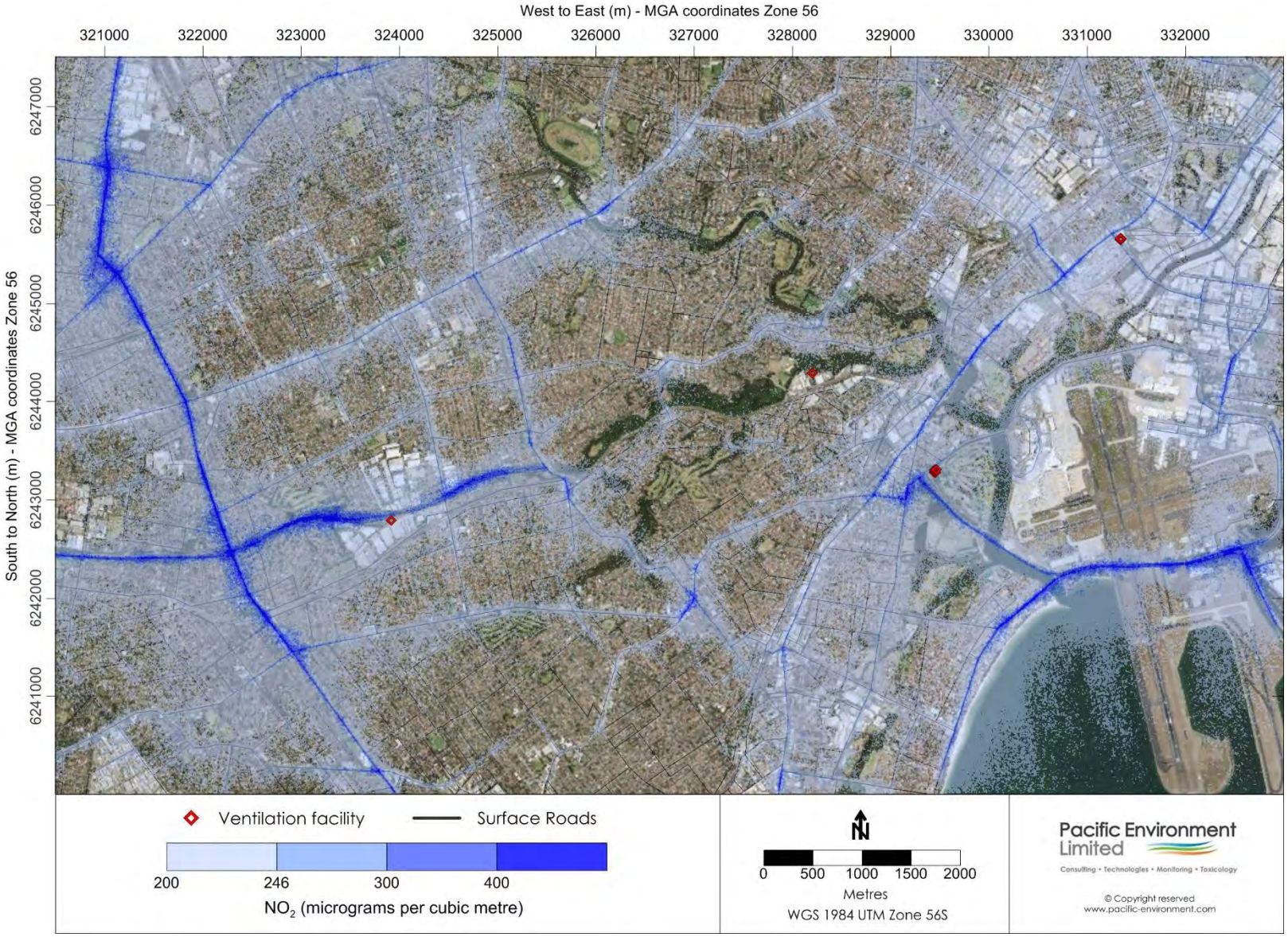


Figure K-53 Contour plot showing maximum one-hour NO_2 (2021-DS)



Figure K-54 Contour plot showing change in maximum one-hour NO_2 with the project (2021-DS)

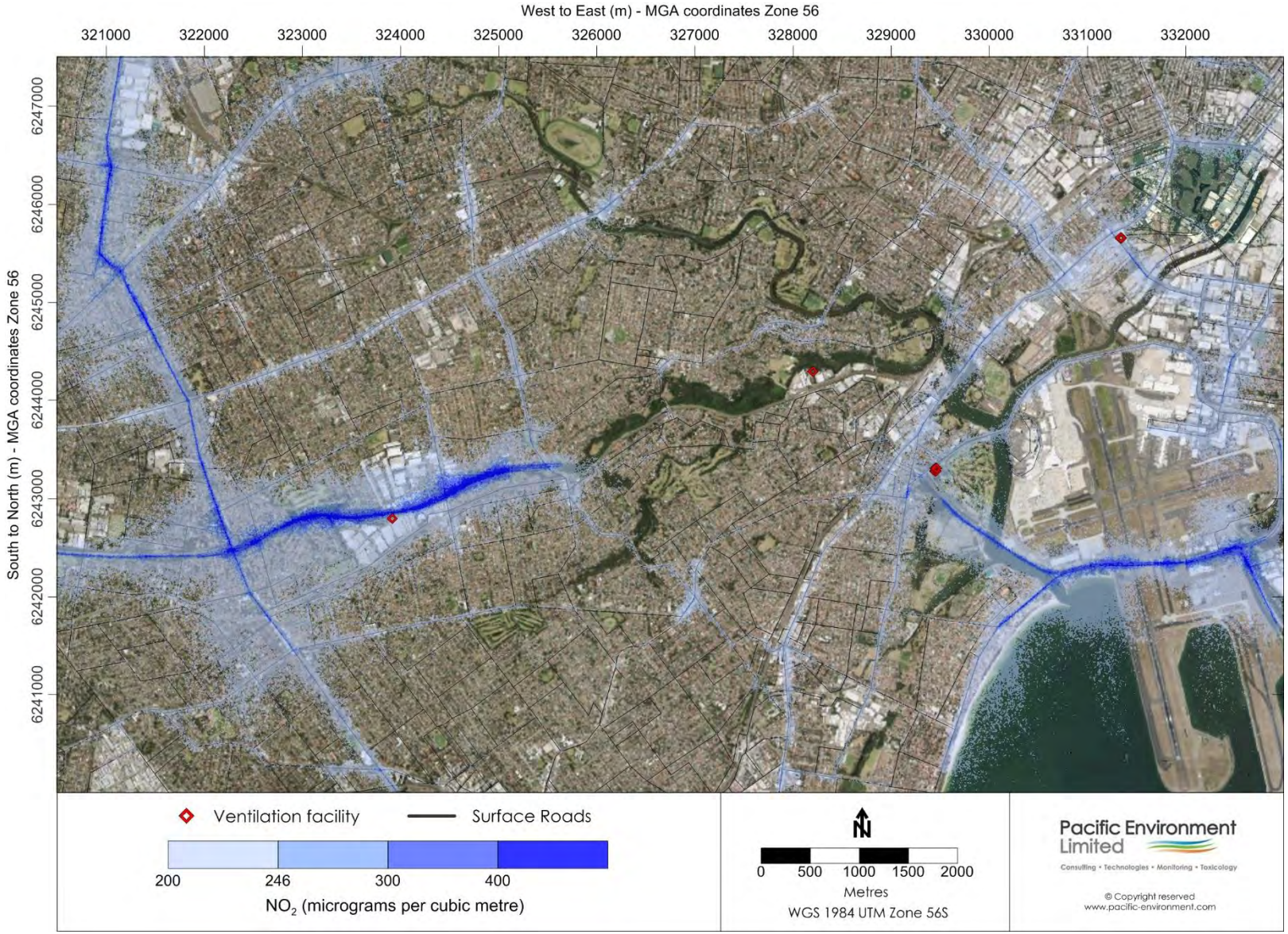


Figure K-55 Contour map showing maximum one-hour mean NO_2 (2031-DM)

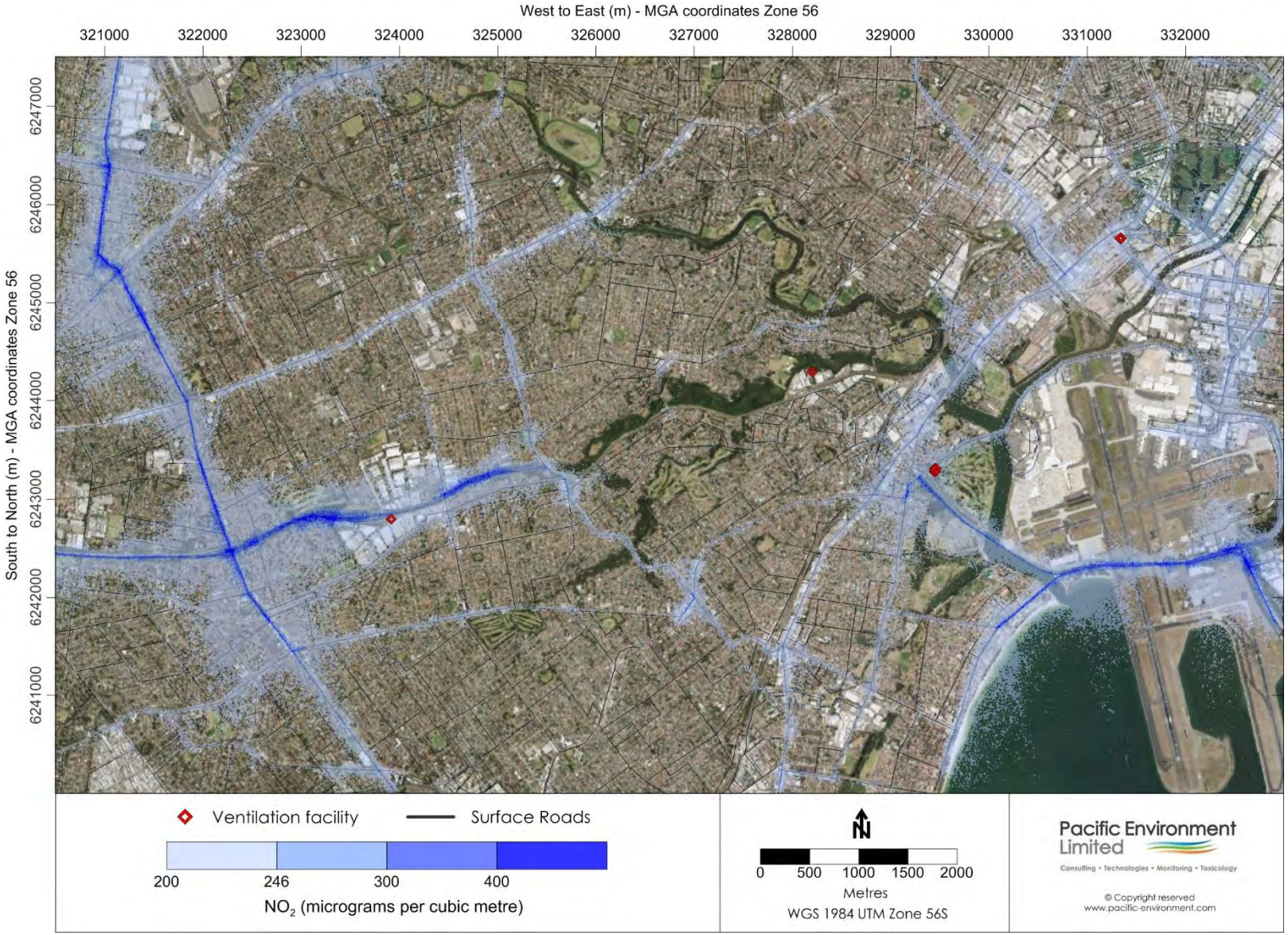


Figure K-56 Contour map showing maximum one-hour mean NO_2 (2031-DS)



Figure K-57 Contour map showing change in maximum one-hour NO_2 with the project (2031-DS)

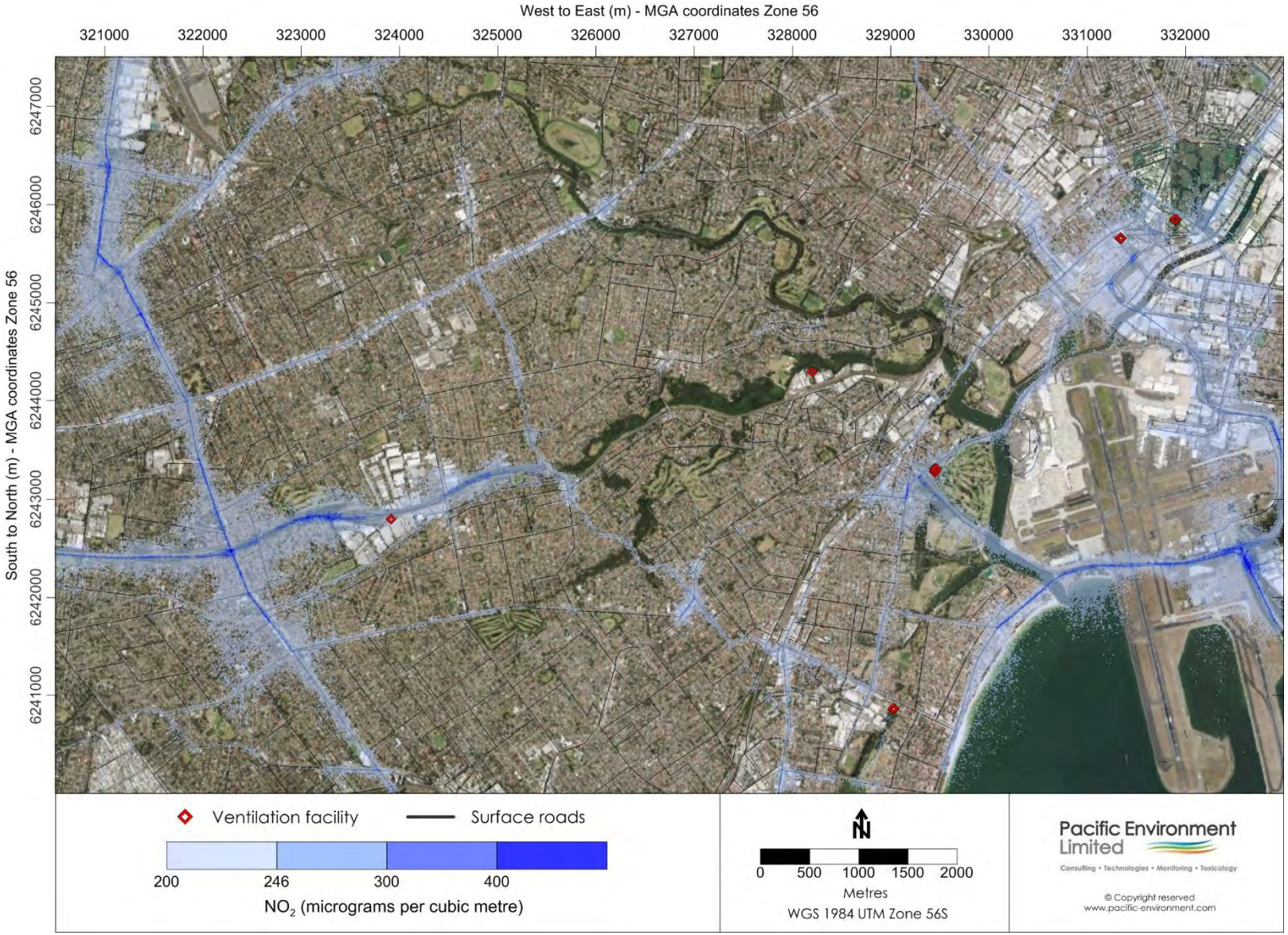


Figure K-58 Contour map showing maximum one-hour mean NO_2 (2031-DSC)



Figure K-59 Contour map showing change in maximum one-hour NO_2 with the project (2031-DSC)

For the Kingsgrove and Arncliffe ventilation outlets the contour plots for maximum 1-hour NO_X are not presented. This is because the range of values was both narrow and low (typically in the range of 10-20 µg/m^3). When combined with the range of meteorological conditions associated with the maximum values for the different locations, this resulted in artefacts in the isopleths. Moreover, these values would equate to low NO_2 increments. The results for the SPI ventilation outlets are given below.

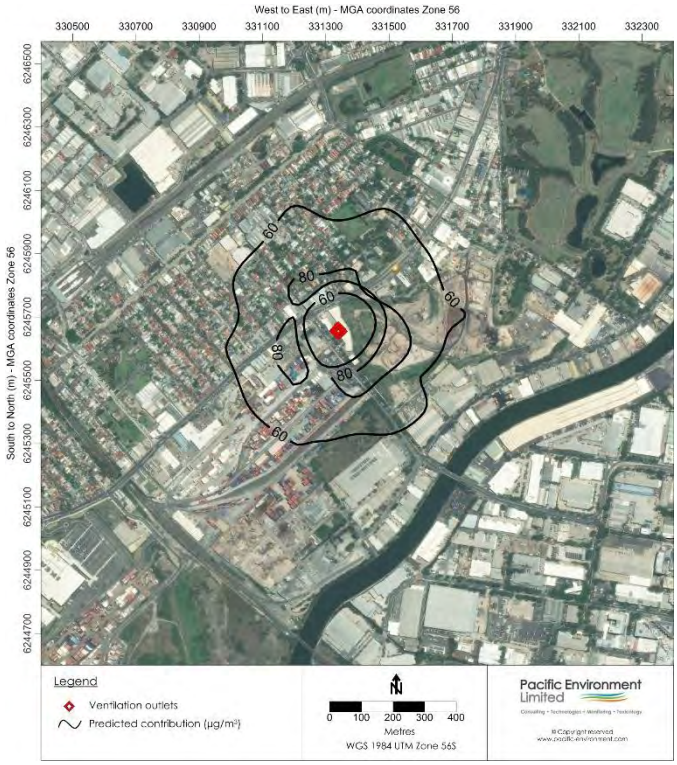


Figure K-60 Contour map showing maximum one-hour NO_X with the project for ventilation outlets only (SPI New M5 outlet, 2021-DS)

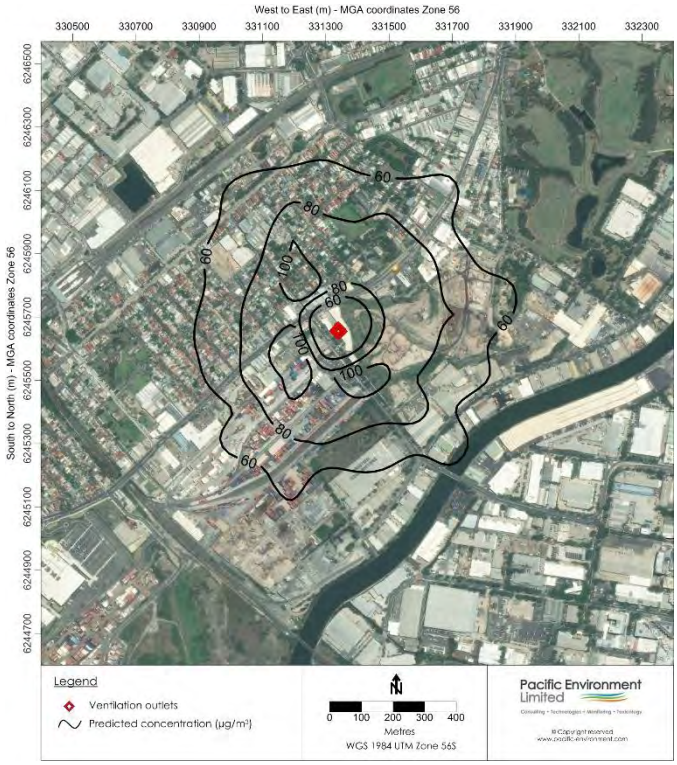


Figure K-61 Contour map showing maximum one-hour NO_X with the project for ventilation outlets only (SPI New M5 outlet, 2031-DS)

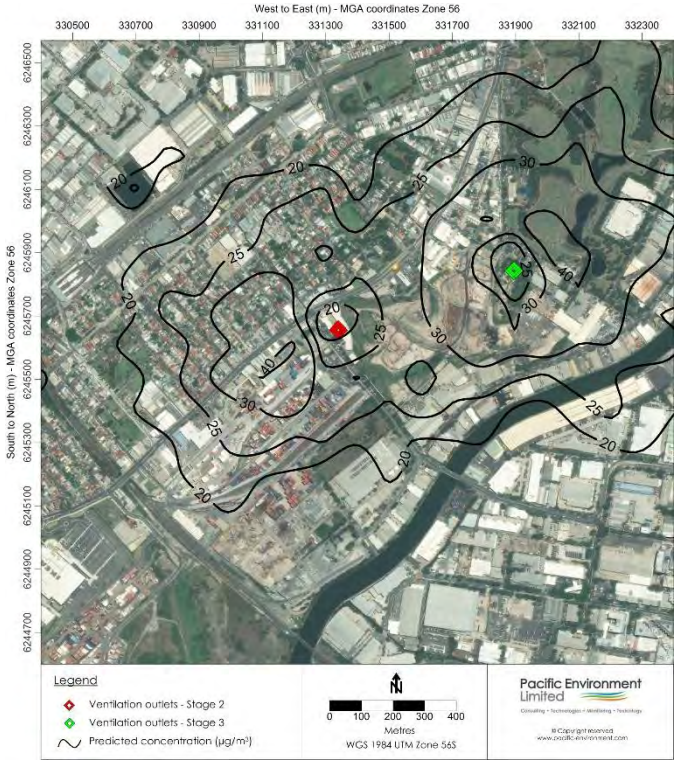


Figure K-62 Contour map showing maximum one-hour NO_X with the project for ventilation outlets only (SPI New M5 outlet, 2031-DSC)

K.5 PM_{10} (annual mean)

Table K-29 Annual mean PM_{10} concentrations at community receptors

Receptor	Annual mean PM_{10} concentration (µg/m^3)						Change with project (µg/m^3)			Change with project (%)		
	2014-BY	2021-DM	2021 DS	2031-DM	2031-DS	2031-DSC	2021	2031	2031-DSC	2021	2031	2031-DSC
SR01	19.6	19.3	19.0	19.3	19.2	19.1	-0.3	-0.1	-0.2	-1.6%	-0.6%	-1.1%
SR02	19.6	19.3	19.1	19.1	19.3	19.1	-0.2	0.1	-0.1	-1.0%	0.6%	-0.4%
SR03	20.3	19.8	19.5	19.7	19.7	19.4	-0.3	0.0	-0.3	-1.5%	0.1%	-1.5%
SR04	19.4	19.2	19.4	19.3	19.4	19.4	0.2	0.1	0.1	1.3%	0.7%	0.6%
SR05	19.7	19.4	19.2	19.3	19.3	18.9	-0.2	0.0	-0.4	-1.1%	0.0%	-1.9%
SR06	20.6	20.1	20.2	19.9	20.0	20.2	0.1	0.1	0.4	0.4%	0.7%	1.9%
SR07	19.8	19.6	19.8	19.6	19.8	19.7	0.2	0.2	0.1	1.3%	1.2%	0.6%
SR08	20.1	19.4	19.4	19.5	19.5	19.5	0.1	0.0	0.1	0.5%	0.2%	0.3%
SR09	18.4	18.2	18.3	18.4	18.5	18.3	0.0	0.1	-0.1	0.2%	0.6%	-0.5%
SR10	18.8	18.5	18.6	18.6	18.6	18.5	0.1	0.0	-0.1	0.8%	0.0%	-0.6%
SR11	18.4	18.2	18.0	18.1	18.2	18.0	-0.1	0.1	-0.1	-0.6%	0.3%	-0.5%
SR12	18.5	18.1	18.3	18.4	18.2	18.1	0.2	-0.1	-0.2	1.1%	-0.7%	-1.3%
SR13	19.3	19.0	18.2	19.2	18.3	18.0	-0.9	-0.9	-1.2	-4.5%	-4.6%	-6.2%
SR14	18.2	18.2	18.2	18.2	18.4	17.9	0.0	0.2	-0.3	-0.1%	1.0%	-1.7%
SR15	18.1	17.8	18.2	17.8	17.9	17.9	0.3	0.0	0.0	1.8%	0.1%	0.1%
SR16	18.8	18.4	17.9	18.5	18.0	17.9	-0.5	-0.5	-0.6	-2.6%	-2.5%	-3.1%
SR17	18.3	18.3	18.3	18.2	18.1	18.1	0.0	-0.1	-0.1	-0.2%	-0.8%	-0.7%
SR18	17.3	17.2	17.3	17.2	17.3	17.2	0.1	0.0	0.0	0.5%	0.2%	-0.2%
SR19	16.3	16.3	16.5	16.5	16.5	16.4	0.1	0.0	-0.1	0.8%	0.2%	-0.4%
SR20	16.3	16.3	16.4	16.3	16.3	16.2	0.0	0.0	0.0	0.3%	0.1%	-0.1%
SR21	16.5	16.6	16.4	16.3	16.6	16.5	-0.1	0.3	0.2	-0.9%	1.6%	1.0%
SR22	15.9	15.9	15.8	16.0	16.0	15.9	-0.1	0.0	-0.1	-0.6%	0.1%	-0.6%
SR23	16.7	16.6	16.6	16.6	16.6	16.6	0.0	0.0	0.0	0.1%	-0.1%	0.2%
SR24	17.0	17.0	17.2	17.0	17.4	17.0	0.1	0.5	0.0	0.8%	2.8%	-0.1%
SR25	17.8	17.7	17.8	17.8	17.9	17.5	0.1	0.1	-0.3	0.6%	0.5%	-1.5%
SR26	18.3	18.1	18.1	18.1	18.3	18.3	0.0	0.1	0.1	0.1%	0.8%	0.6%
SR27	18.5	18.5	18.5	18.5	18.5	18.4	0.0	-0.1	-0.1	0.1%	-0.3%	-0.6%
SR28	18.5	18.4	18.4	18.4	18.4	18.4	0.0	0.1	0.0	0.1%	0.3%	0.0%
SR29	18.4	18.3	18.5	18.3	18.4	18.4	0.2	0.2	0.1	0.9%	0.9%	0.6%
SR30	18.5	18.4	18.5	18.4	18.6	18.7	0.1	0.2	0.3	0.4%	1.2%	1.6%
SR31	19.3	19.1	18.7	19.1	18.7	18.8	-0.4	-0.4	-0.3	-2.1%	-2.0%	-1.3%
SR32	19.1	19.1	19.0	19.3	19.0	19.0	-0.1	-0.3	-0.2	-0.5%	-1.5%	-1.2%
SR33	18.6	18.5	18.7	18.4	18.5	18.6	0.3	0.1	0.2	1.5%	0.7%	1.2%
SR34	18.6	18.8	18.6	18.7	19.0	18.8	-0.2	0.3	0.1	-0.9%	1.6%	0.8%
SR35	18.3	18.2	18.1	18.4	18.4	18.5	-0.1	0.0	0.1	-0.8%	0.2%	0.7%

Table K-30 Annual mean PM_{10} concentrations at community receptors, ranked by concentration

Rank	Ranking by concentration (µg/m^3)					
	2014-BY	2021-DM	2021 DS	2031-DM	2031-DS	2031-DSC
1	20.6	20.1	20.2	19.9	20.0	20.2
2	20.3	19.8	19.8	19.7	19.8	19.7
3	20.1	19.6	19.5	19.6	19.7	19.5
4	19.8	19.4	19.4	19.5	19.5	19.4
5	19.7	19.4	19.4	19.3	19.4	19.4
6	19.6	19.3	19.2	19.3	19.3	19.1
7	19.6	19.3	19.1	19.3	19.3	19.1
8	19.4	19.2	19.0	19.3	19.2	19.0
9	19.3	19.1	19.0	19.2	19.0	18.9
10	19.3	19.1	18.7	19.1	19.0	18.8

Table K-31 Annual mean PM_{10} concentrations at community receptors, ranked by increase and by decrease in concentration with project

Rank	Ranking by increase in concentration with project (µg/m^3)			Ranking by decrease in concentration with project (µg/m^3)		
	2021-DS	2031-DS	2031-DSC	2021-DS	2031-DS	2031-DSC
1	0.3	0.5	0.4	-0.9	-0.9	-1.2
2	0.3	0.3	0.3	-0.5	-0.5	-0.6
3	0.2	0.3	0.2	-0.4	-0.4	-0.4
4	0.2	0.2	0.2	-0.3	-0.3	-0.3
5	0.2	0.2	0.1	-0.3	-0.1	-0.3
6	0.2	0.2	0.1	-0.2	-0.1	-0.3
7	0.1	0.2	0.1	-0.2	-0.1	-0.3
8	0.1	0.1	0.1	-0.2	-0.1	-0.2
9	0.1	0.1	0.1	-0.1	0.0	-0.2
10	0.1	0.1	0.1	-0.1		-0.2

Table K-32 Annual mean PM_{10} concentrations at community receptors, ranked by percentage increase and by decrease in concentration with project

Rank	Ranking by % increase in concentration with project (µg/m^3)			Ranking by % decrease in concentration with project (µg/m^3)		
	2021-DS	2031-DS	2031-DSC	2021-DS	2031-DS	2031-DSC
1	1.8%	2.8%	1.9%	-4.5%	-4.6%	-6.2%
2	1.5%	1.6%	1.6%	-2.6%	-2.5%	-3.1%
3	1.3%	1.6%	1.2%	-2.1%	-2.0%	-1.9%
4	1.3%	1.2%	1.0%	-1.6%	-1.5%	-1.7%
5	1.1%	1.2%	0.8%	-1.5%	-0.8%	-1.5%
6	0.9%	1.0%	0.7%	-1.1%	-0.7%	-1.5%
7	0.8%	0.9%	0.6%	-1.0%	-0.6%	-1.3%
8	0.8%	0.8%	0.6%	-0.9%	-0.3%	-1.3%
9	0.8%	0.7%	0.6%	-0.9%	-0.1%	-1.2%
10	0.6%	0.7%	0.6%	-0.8%		-1.1%

Table K-33 Annual mean PM_{10} concentrations at RWR receptors, ranked by concentration

Rank	Ranking by concentration (µg/m^3)					
	2014-BY	2021-DM	2021 DS	2031-DM	2031-DS	2031-DSC
1	27.8	25.7	24.6	25.8	24.3	23.8
2	25.8	24.4	23.8	24.5	24.2	22.8
3	25.8	24.2	23.7	24.3	24.2	22.7
4	25.7	24.2	23.6	24.2	23.9	22.7
5	25.7	24.2	23.5	24.2	23.9	22.7
6	25.7	23.9	23.5	24.2	23.9	22.6
7	25.6	23.9	23.4	24.0	23.8	22.6
8	25.6	23.8	23.3	24.0	23.7	22.6
9	25.5	23.8	23.3	23.9	23.5	22.5
10	25.2	23.6	23.2	23.9	23.5	22.4

Table K-34 Annual mean PM_{10} concentrations at RWR receptors, ranked by increase and by decrease in concentration with project

Rank	Ranking by increase in concentration with project (µg/m^3)			Ranking by decrease in concentration with project (µg/m^3)		
	2021-DS	2031-DS	2031-DSC	2021-DS	2031-DS	2031-DSC
1	1.7	1.8	3.0	-5.3	-5.5	-6.1
2	1.6	1.4	2.2	-5.0	-4.6	-5.1
3	1.5	1.4	2.2	-4.8	-3.5	-3.7
4	1.4	1.3	2.1	-4.7	-3.2	-3.4
5	1.3	1.3	2.0	-4.6	-3.0	-3.3
6	1.3	1.3	2.0	-4.4	-2.6	-3.2
7	1.3	1.3	1.5	-3.7	-2.6	-3.0
8	1.3	1.2	1.5	-3.6	-2.5	-2.9
9	1.3	1.2	1.5	-3.5	-2.3	-2.8
10	1.3	1.2	1.4	-3.5	-2.2	-2.8

Table K-35 Annual mean PM_{10} concentrations at RWR receptors, ranked by percentage increase and by decrease in concentration with project

Rank	Ranking by % increase in concentration with project (µg/m^3)			Ranking by % decrease in concentration with project (µg/m^3)		
	2021-DS	2031-DS	2031-DSC	2021-DS	2031-DS	2031-DSC
1	9.5%	9.7%	16.6%	-21.2%	-21.2%	-23.5%
2	8.3%	7.6%	12.1%	-21.2%	-19.1%	-21.1%
3	7.7%	7.6%	11.9%	-20.6%	-16.4%	-17.2%
4	7.1%	7.0%	11.5%	-20.6%	-14.9%	-15.7%
5	7.0%	6.9%	11.0%	-20.6%	-13.8%	-15.3%
6	6.9%	6.9%	10.5%	-18.9%	-12.1%	-14.4%
7	6.9%	6.8%	8.5%	-17.2%	-12.1%	-13.6%
8	6.8%	6.8%	8.2%	-16.8%	-12.0%	-13.5%
9	6.8%	6.6%	8.0%	-16.4%	-10.7%	-13.2%
10	6.7%	6.5%	8.0%	-16.2%	-10.5%	-13.1%

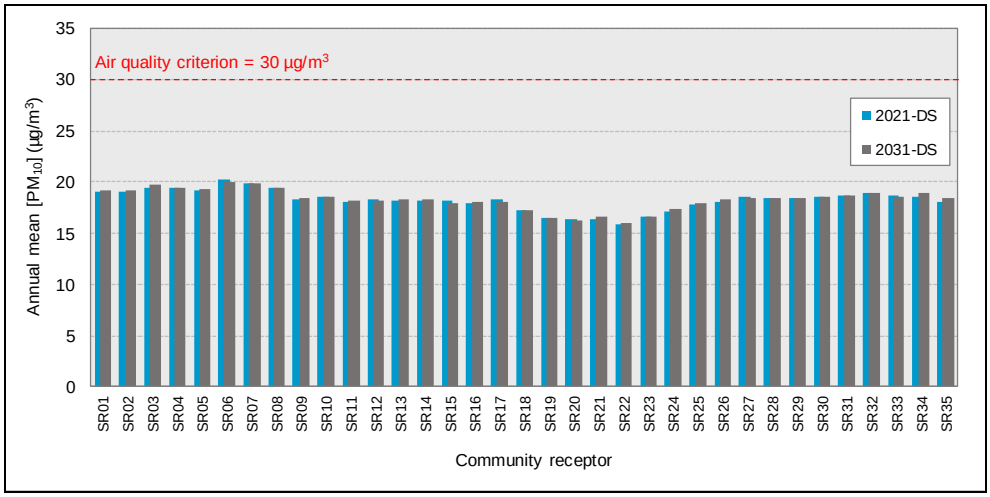


Figure K-63 Annual mean PM_{10} at community receptors (2021-DS and 2031-DS)

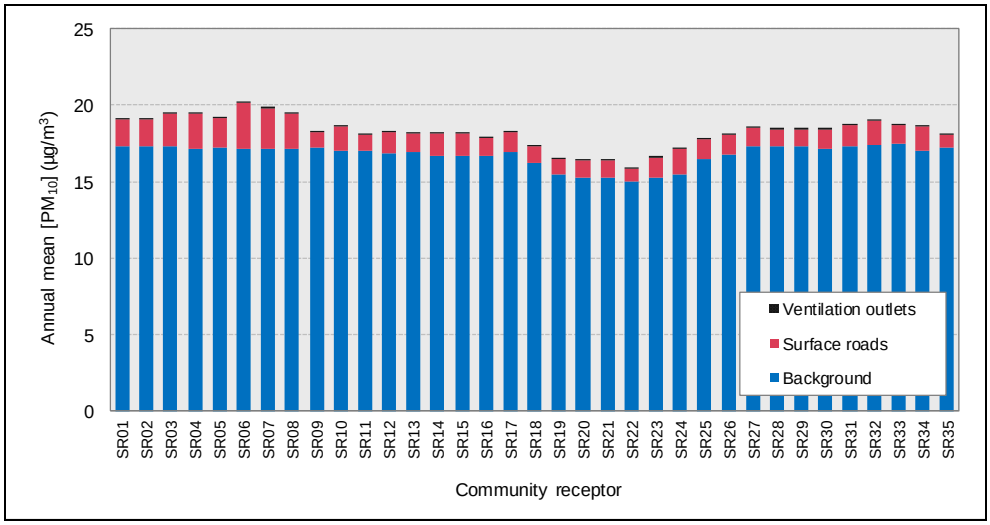


Figure K-64 Source contributions to annual mean PM_{10} at community receptors (2021-DS)

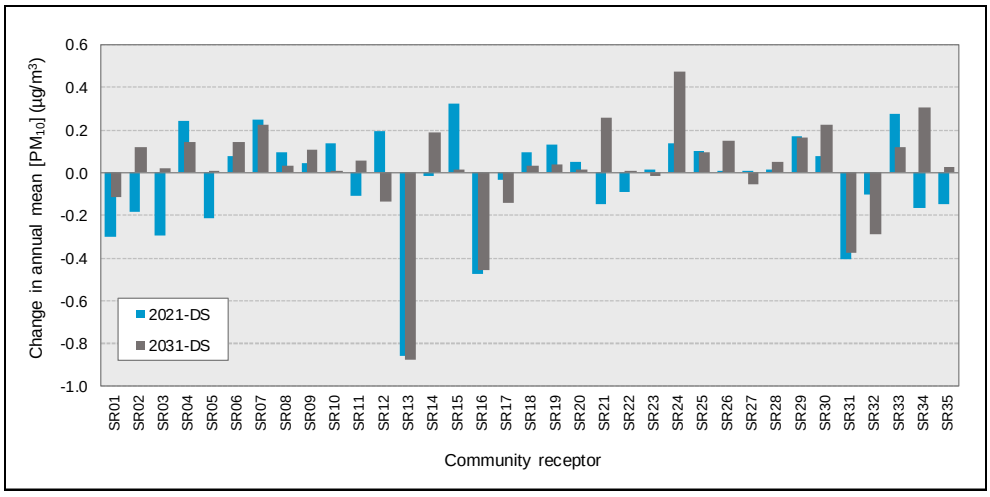


Figure K-65 Change in annual mean PM_{10} at community receptors (2021-DS and 2031-DS)

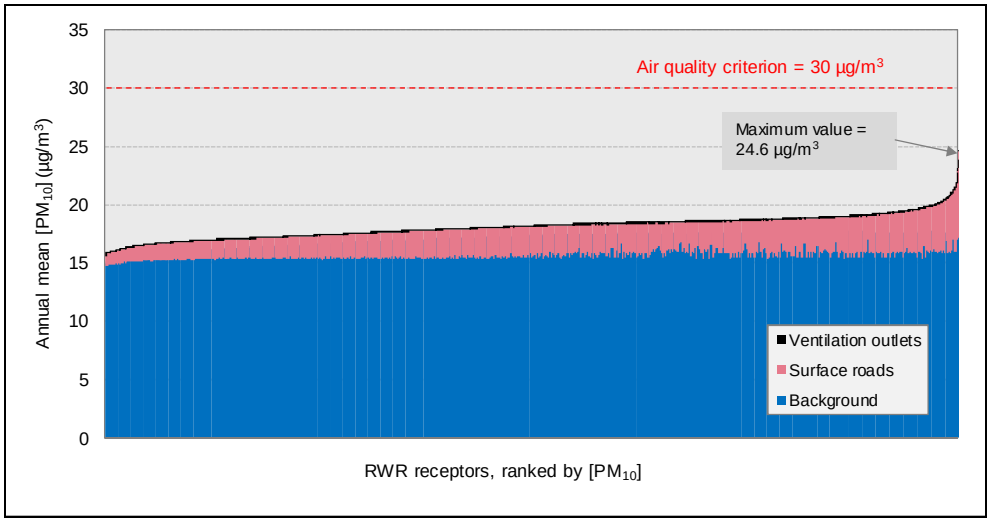


Figure K-66 Source contributions to annual mean PM_{10} at RWR receptors (2021-DS)

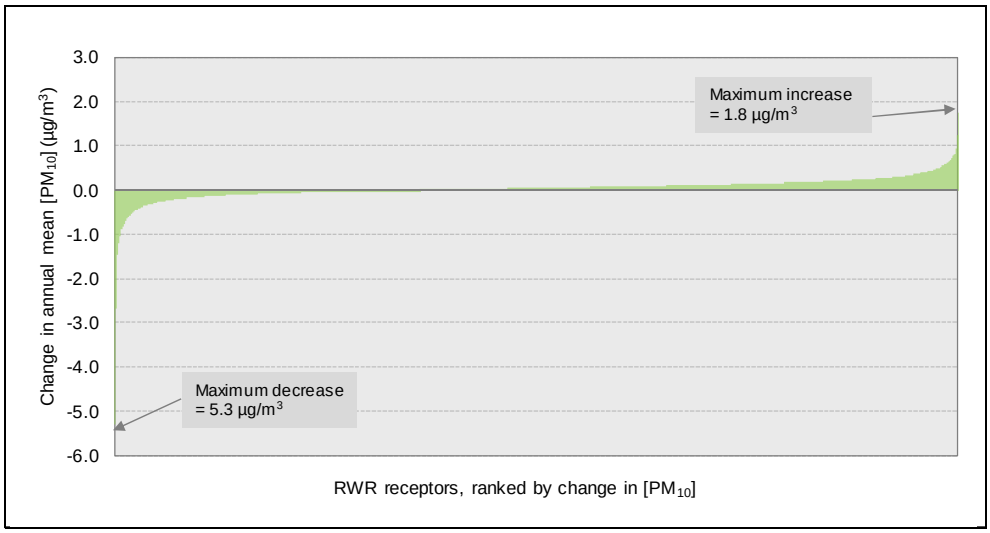


Figure K-67 Changes in annual mean PM_{10} at RWR receptors (2021-DS)

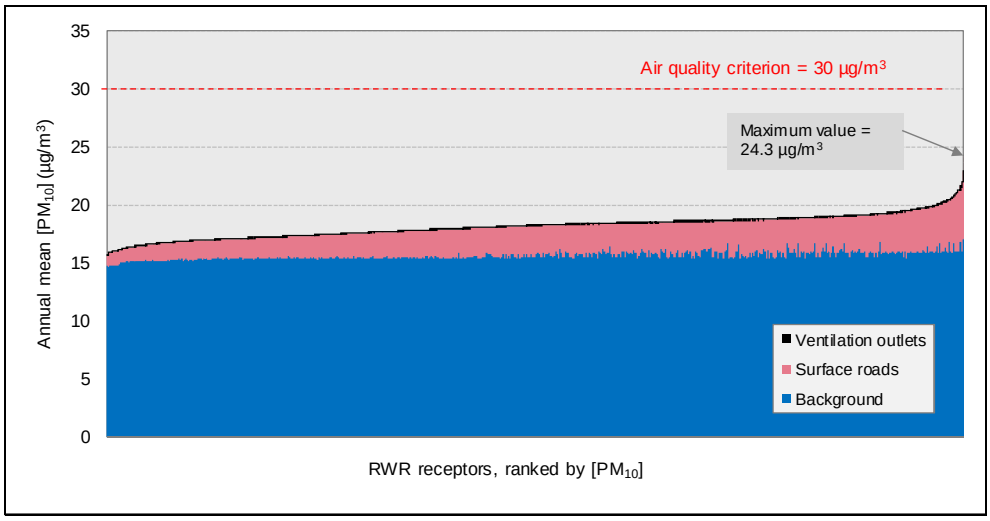


Figure K-68 Source contributions to annual mean PM_{10} at RWR receptors (2031-DS)

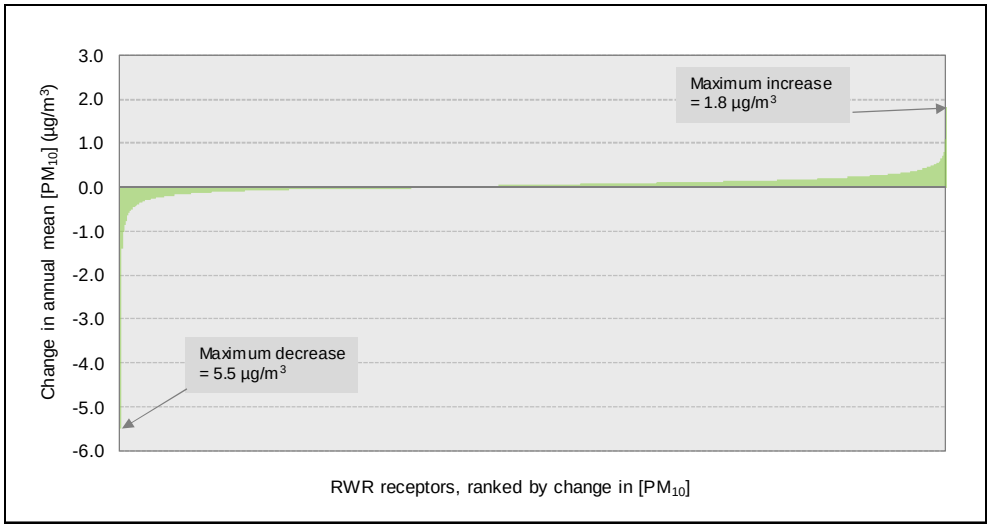


Figure K-69 Changes in annual mean PM_{10} at RWR receptors (2031-DS)

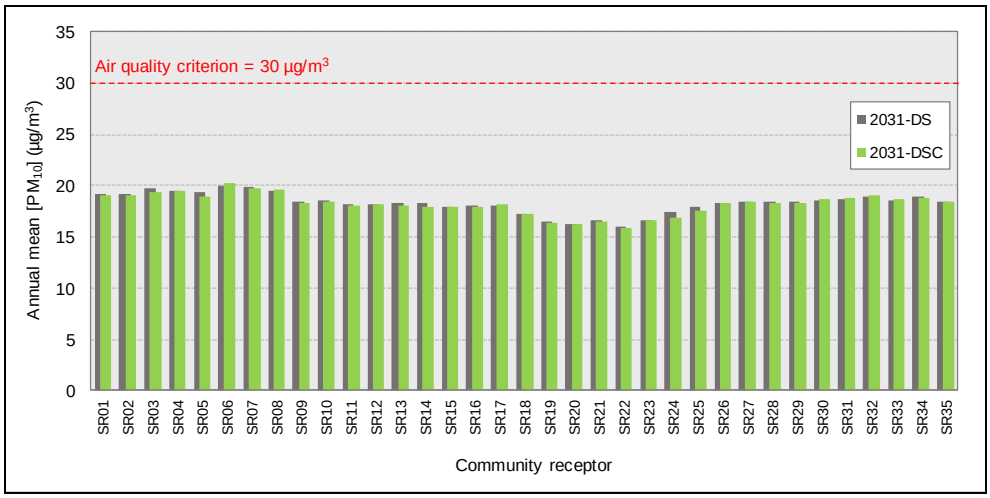


Figure K-70 Annual mean PM_{10} at community receptors (2031-DS and 2031-DSC)

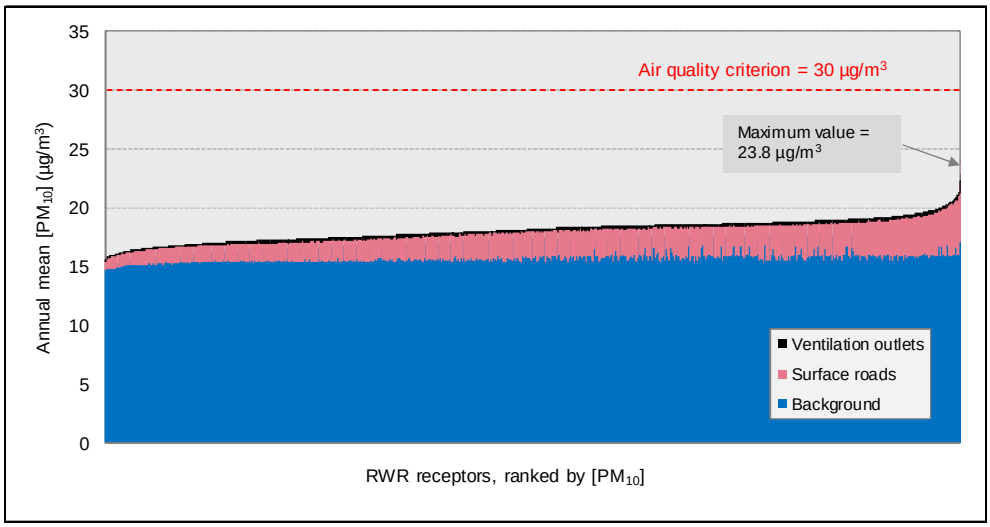


Figure K-71 Source contributions to annual mean PM_{10} at RWR receptors (2031-DSC)

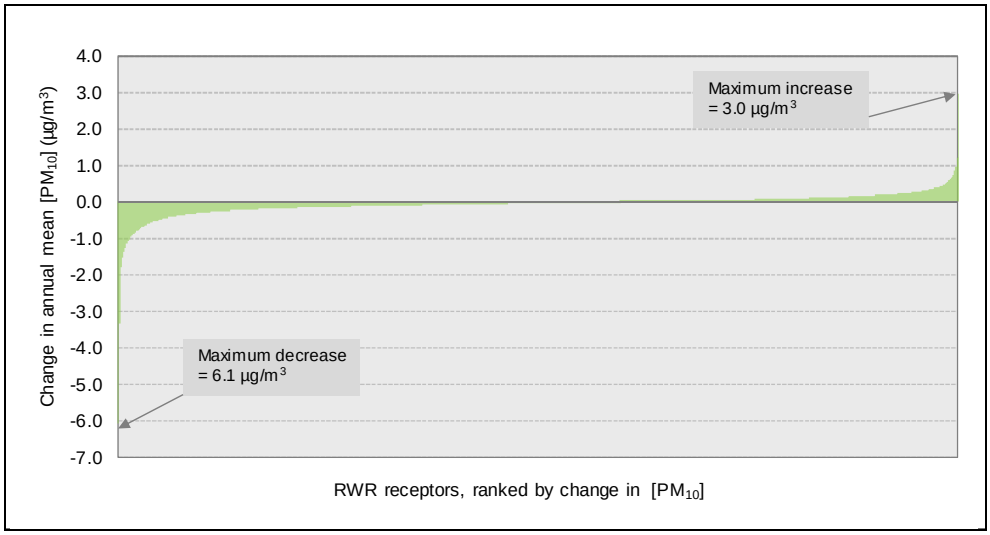


Figure K-72 Changes in annual mean PM_{10} at RWR receptors (2031-DSC)

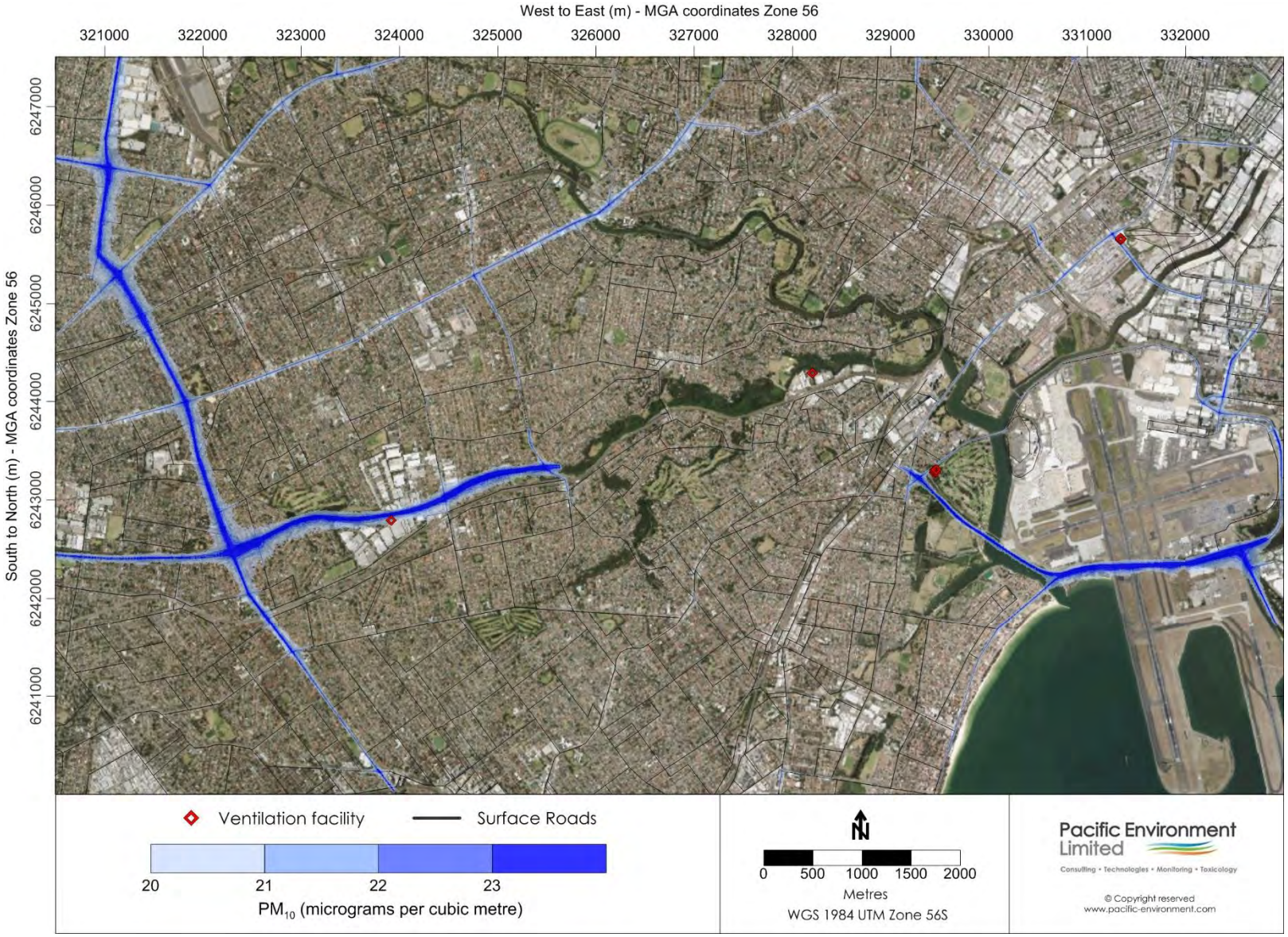


Figure K-73 Contour plot showing annual mean PM_{10} (2021-DM)

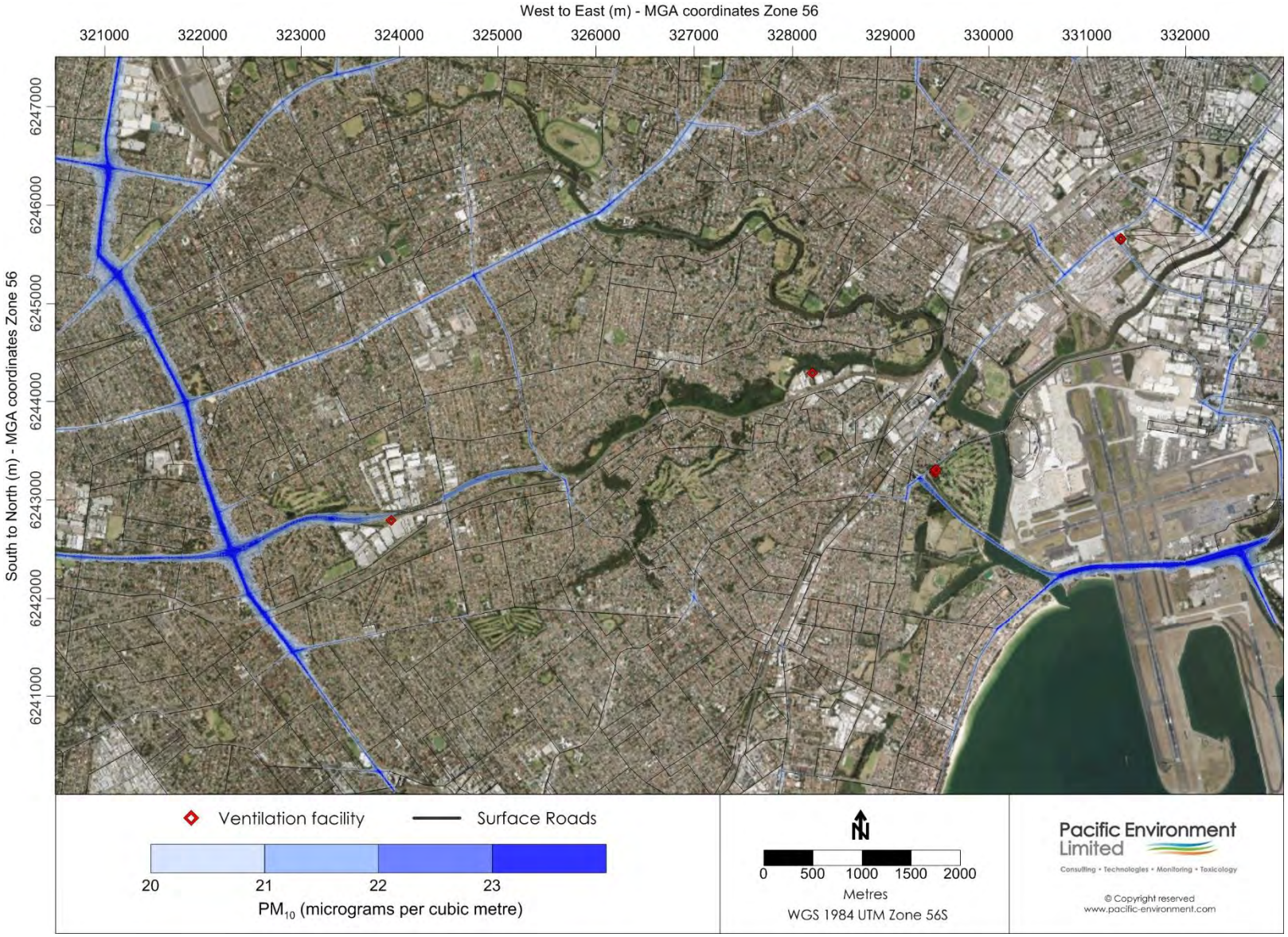


Figure K-74 Contour plot showing annual mean PM_{10} (2021-DS)



Figure K-75 Contour plot showing change in annual mean PM_{10} with the project (2021-DS)

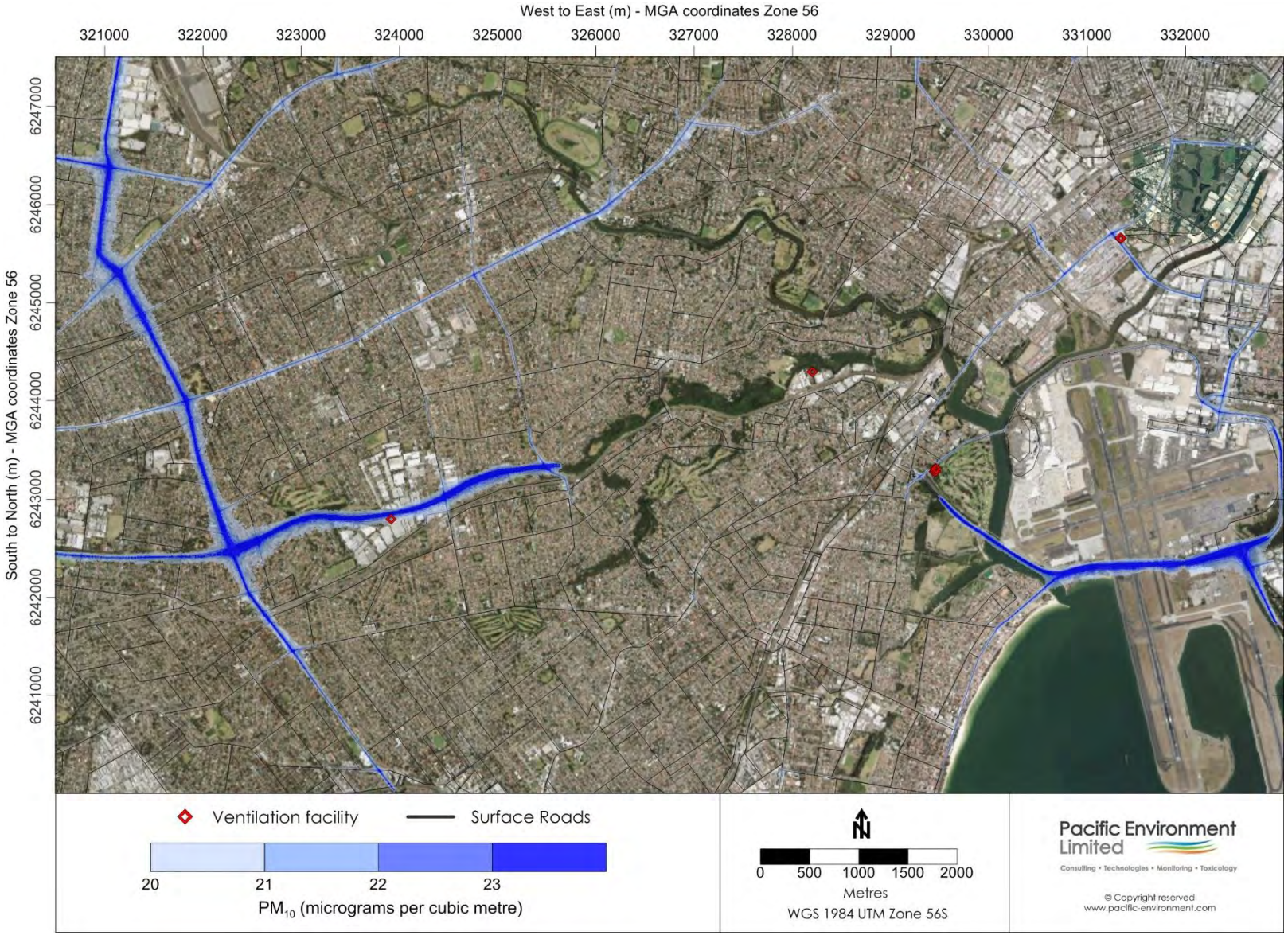


Figure K-76 Contour map showing annual mean PM_{10} (2031-DM)



Figure K-77 Contour map showing annual mean PM_{10} (2031-DS)



Figure K-78 Contour map showing change in annual mean PM_{10} with the project (2031-DS)



Figure K-79 Contour map showing annual mean PM_{10} (2031-DSC)

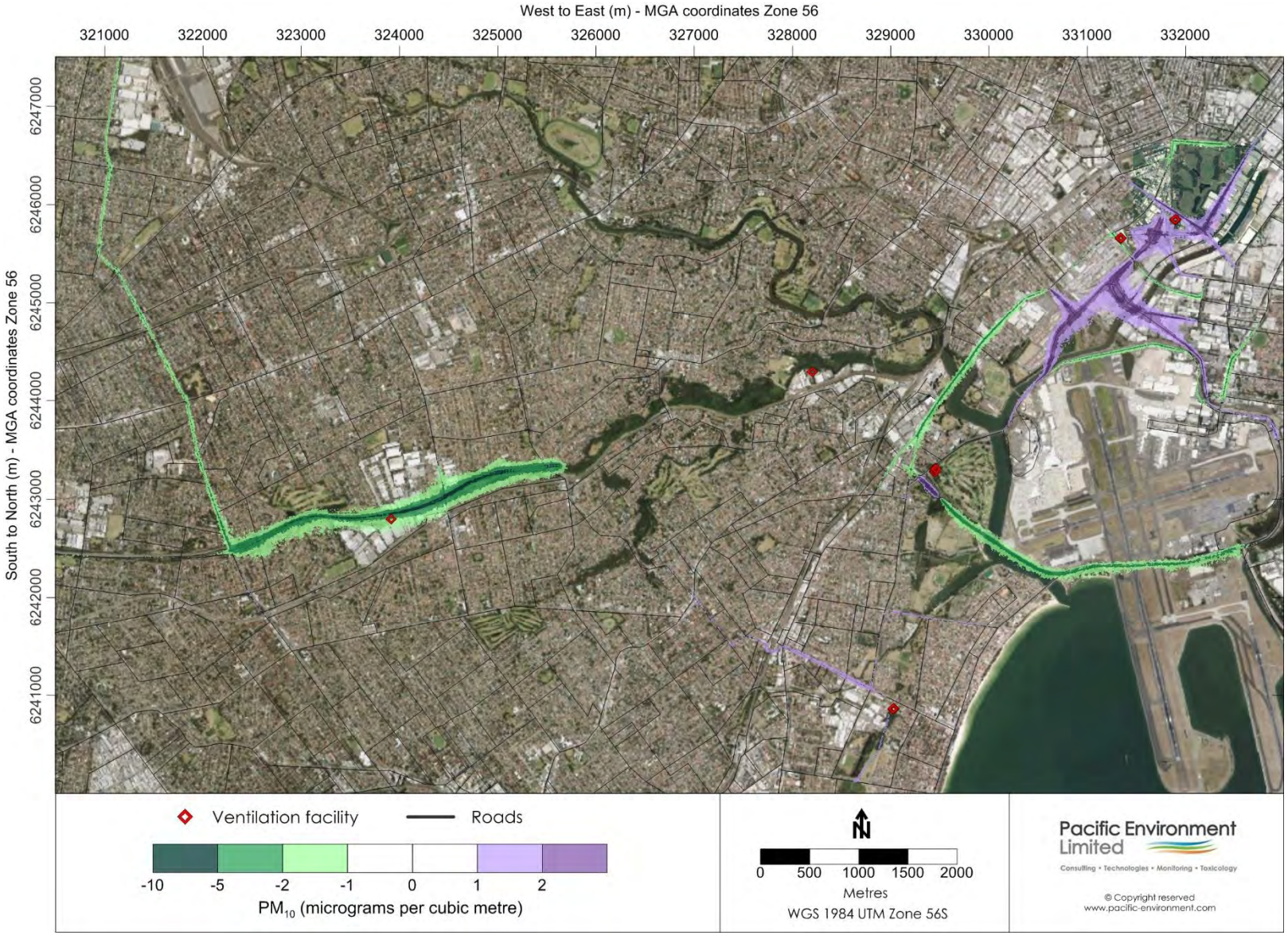


Figure K-80 Contour map showing change in annual mean PM_{10} with the project (2031-DSC)



Figure K-81 Contour map showing annual mean PM_{10} with the project for ventilation outlets only (Kingsgrove outlet, 2021-DS)

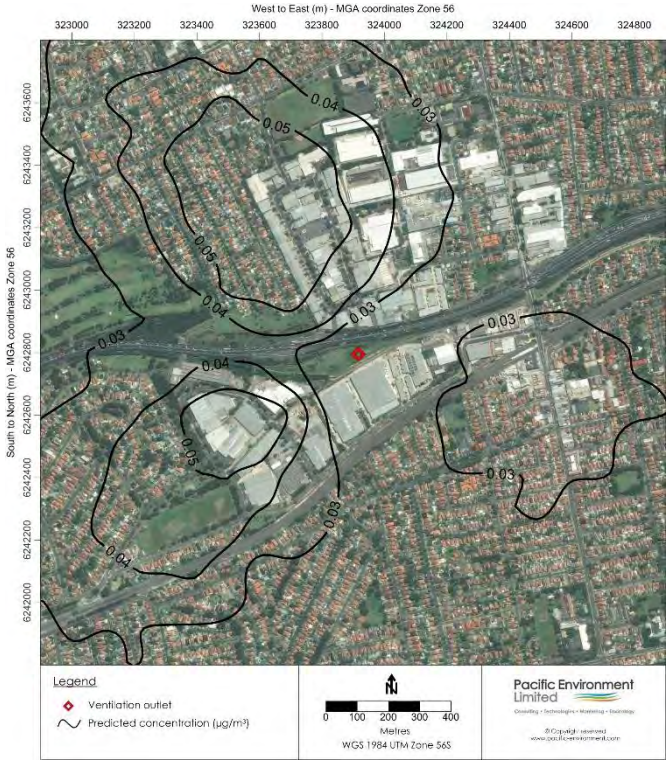


Figure K-82 Contour map showing annual mean PM_{10} with the project for ventilation outlets only (Kingsgrove outlet, 2031-DS)

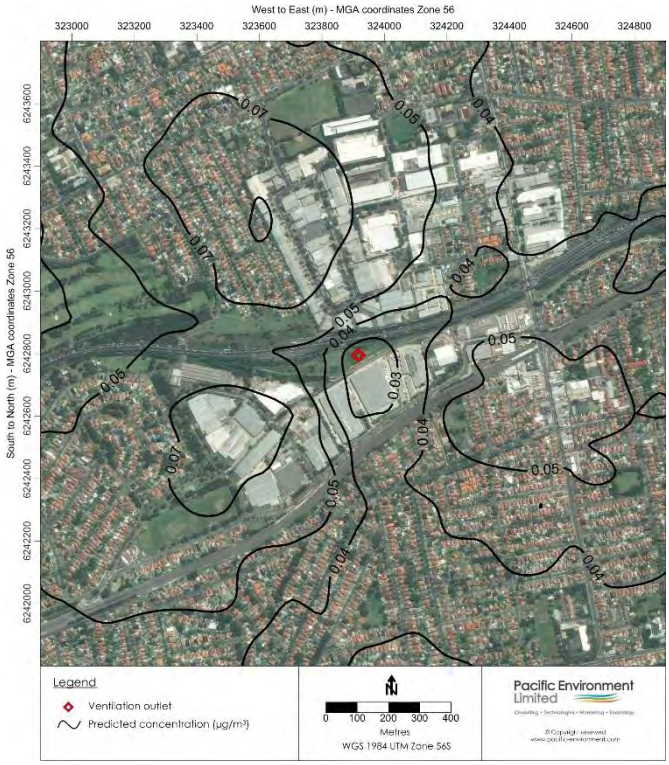


Figure K-83 Contour map showing annual mean PM_{10} with the project for ventilation outlets only (Kingsgrove outlet, 2031-DSC)

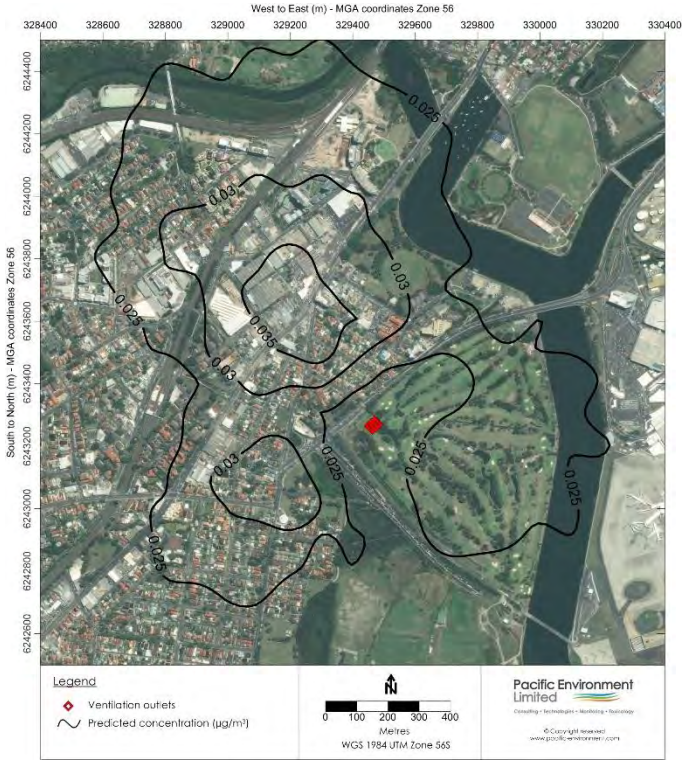


Figure K-84 Contour map showing annual mean PM_{10} with the project for ventilation outlets only (Arncliffe outlet, 2021-DS)

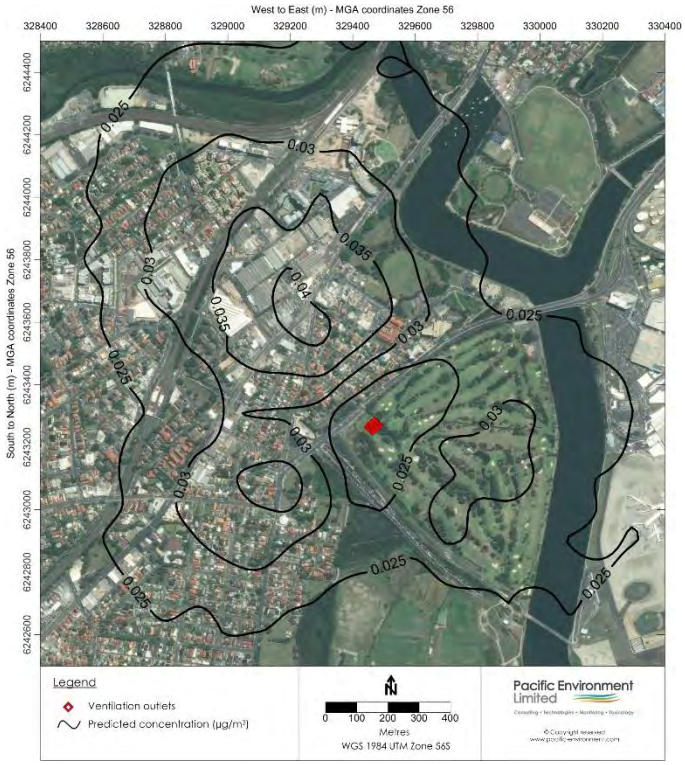


Figure K-85 Contour map showing annual mean PM_{10} with the project for ventilation outlets only (Arncliffe outlet, 2031-DS)

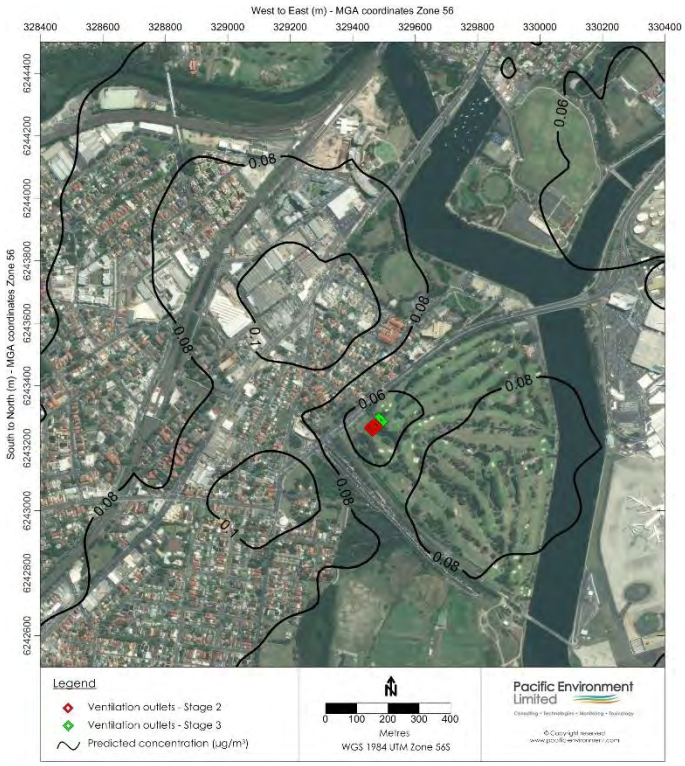


Figure K-86 Contour map showing annual mean PM_{10} with the project for ventilation outlets only (Arncliffe outlet, 2031-DSC)

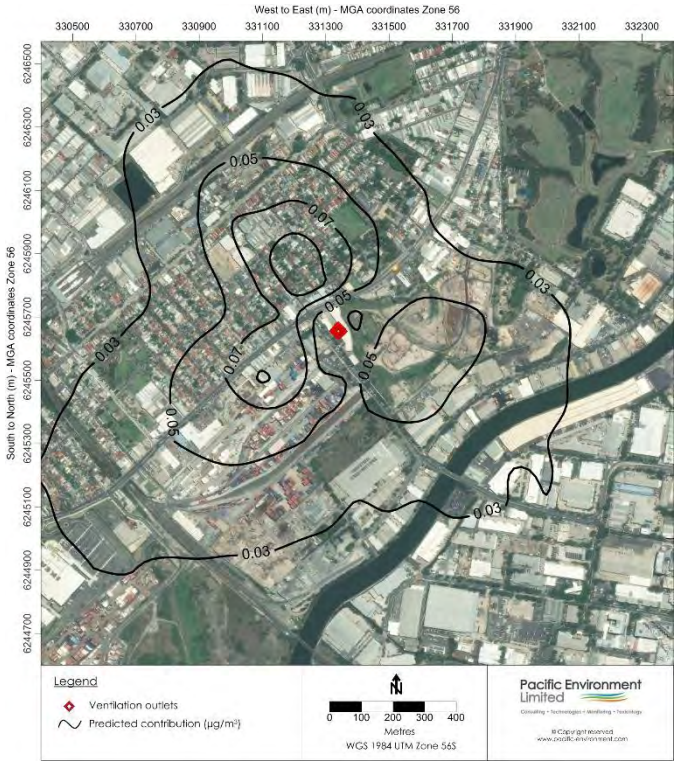


Figure K-87 Contour map showing annual mean PM_{10} with the project for ventilation outlets only (SPI New M5 outlet, 2021-DS)

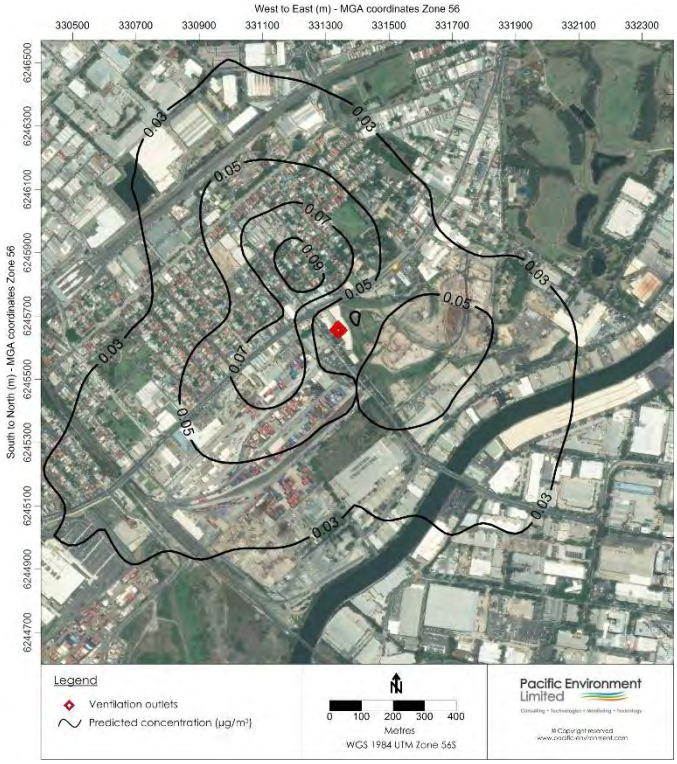


Figure K-88 Contour map showing annual mean PM_{10} with the project for ventilation outlets only (SPI New M5 outlet, 2031-DS)

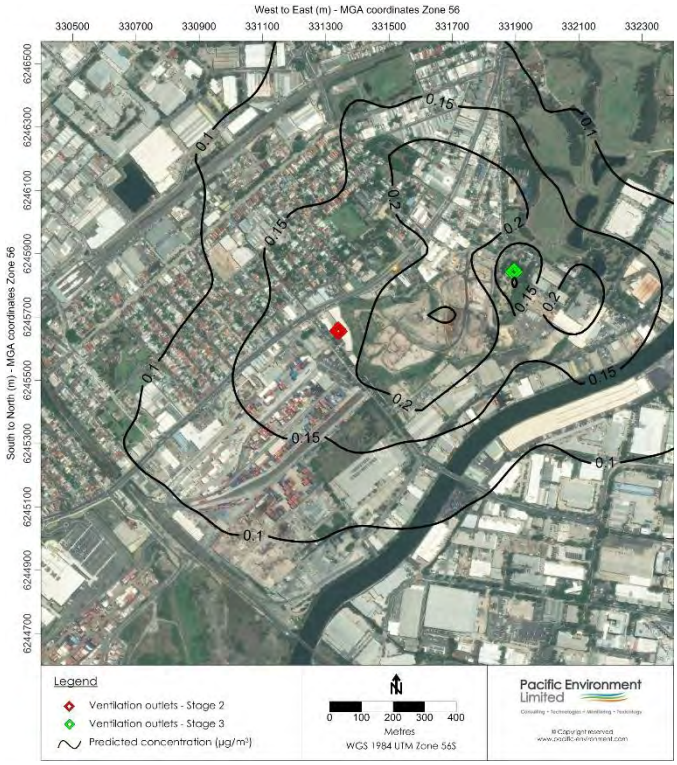


Figure K-89 Contour map showing annual mean PM_{10} with the project for ventilation outlets only (SPI New M5 outlet, 2031-DSC)

K.6 PM_{10} (maximum 24-hour mean)

Table K-36 Maximum 24-hour PM_{10} concentrations at community receptors

Receptor	Maximum 24-hour PM_{10} concentration (µg/m^3)						Change with project (µg/m^3)			Change with project (%)		
	2014-BY	2021-DM	2021 DS	2031-DM	2031-DS	2031-DSC	2021	2031	2031-DSC	2021	2031	2031-DSC
SR01	48.7	47.8	47.5	48.1	47.9	47.2	-0.3	-0.2	-0.9	-0.6%	-0.4%	-1.8%
SR02	47.9	48.1	47.3	47.7	47.0	47.7	-0.8	-0.7	0.0	-1.7%	-1.4%	0.0%
SR03	48.8	48.6	48.6	48.3	47.8	48.5	0.0	-0.5	0.2	-0.1%	-1.0%	0.3%
SR04	46.8	46.6	47.5	46.9	46.9	47.2	0.8	0.0	0.3	1.8%	0.0%	0.6%
SR05	47.9	47.3	46.7	47.7	47.8	47.0	-0.6	0.1	-0.7	-1.3%	0.1%	-1.5%
SR06	48.2	48.1	48.1	47.8	47.4	48.1	0.1	-0.4	0.3	0.1%	-0.8%	0.6%
SR07	47.3	47.6	47.1	47.1	47.1	47.5	-0.4	0.0	0.4	-0.9%	-0.1%	0.9%
SR08	48.9	47.1	47.5	47.3	47.4	47.0	0.4	0.0	-0.3	1.0%	0.1%	-0.6%
SR09	47.3	47.2	47.0	47.0	47.0	47.1	-0.2	0.1	0.1	-0.4%	0.1%	0.3%
SR10	46.7	46.8	46.6	46.7	46.9	46.9	-0.2	0.2	0.2	-0.4%	0.4%	0.4%
SR11	47.1	47.6	47.1	46.9	46.6	46.4	-0.5	-0.3	-0.5	-1.0%	-0.6%	-1.0%
SR12	46.5	46.4	46.8	46.8	47.0	46.4	0.4	0.3	-0.3	0.8%	0.6%	-0.7%
SR13	48.3	48.4	47.3	48.6	47.7	46.9	-1.1	-0.9	-1.7	-2.3%	-1.9%	-3.5%
SR14	46.9	47.1	46.7	46.5	46.4	46.4	-0.4	-0.1	0.0	-0.9%	-0.2%	-0.1%
SR15	46.4	46.7	46.4	46.7	46.4	46.4	-0.3	-0.3	-0.3	-0.6%	-0.6%	-0.6%
SR16	46.6	46.5	46.3	46.4	46.7	46.5	-0.2	0.3	0.2	-0.4%	0.7%	0.4%
SR17	47.1	47.4	46.9	47.1	46.8	46.8	-0.5	-0.3	-0.3	-1.0%	-0.7%	-0.7%
SR18	46.8	46.6	46.4	46.4	46.5	46.6	-0.2	0.1	0.2	-0.5%	0.2%	0.3%
SR19	46.4	46.9	46.5	46.4	47.3	47.1	-0.3	1.0	0.7	-0.7%	2.1%	1.5%
SR20	46.7	47.3	47.2	46.7	46.9	47.3	-0.1	0.3	0.6	-0.2%	0.6%	1.2%
SR21	46.8	46.9	46.7	46.7	47.4	47.3	-0.2	0.6	0.6	-0.4%	1.4%	1.2%
SR22	46.5	46.6	47.1	47.0	46.9	46.6	0.6	0.0	-0.3	1.2%	0.0%	-0.7%
SR23	48.2	47.3	47.1	47.9	47.0	47.7	-0.3	-0.9	-0.2	-0.6%	-1.9%	-0.5%
SR24	46.9	47.0	47.0	46.6	46.6	46.6	0.0	0.1	0.1	0.0%	0.2%	0.2%
SR25	47.2	47.3	47.1	47.5	47.2	47.0	-0.2	-0.4	-0.5	-0.4%	-0.8%	-1.1%
SR26	47.7	47.0	47.3	47.1	46.9	47.2	0.3	-0.2	0.1	0.6%	-0.3%	0.3%
SR27	47.4	47.0	46.9	46.9	46.8	47.3	-0.1	0.0	0.5	-0.1%	-0.1%	1.0%
SR28	46.6	46.6	46.6	47.4	47.6	47.1	0.0	0.2	-0.3	0.0%	0.4%	-0.6%
SR29	46.7	46.5	46.8	47.1	46.8	47.2	0.2	-0.3	0.1	0.5%	-0.6%	0.2%
SR30	47.2	46.9	47.1	46.8	47.1	47.5	0.2	0.3	0.7	0.4%	0.7%	1.5%
SR31	47.6	47.3	46.7	47.6	47.0	47.0	-0.5	-0.6	-0.6	-1.2%	-1.3%	-1.3%
SR32	47.3	46.9	47.2	47.1	47.3	47.3	0.3	0.3	0.2	0.6%	0.5%	0.4%
SR33	46.4	46.5	46.8	46.5	46.4	47.1	0.3	-0.1	0.6	0.6%	-0.1%	1.2%
SR34	47.0	46.7	46.7	46.7	47.4	46.5	0.0	0.7	-0.2	0.1%	1.5%	-0.5%
SR35	46.4	46.2	46.3	46.2	46.3	46.2	0.0	0.1	0.0	0.1%	0.2%	0.0%

Table K-37 Maximum 24-hour PM_{10} concentrations at community receptors, ranked by concentration

Rank	Ranking by concentration (µg/m^3)					
	2014-BY	2021-DM	2021 DS	2031-DM	2031-DS	2031-DSC
1	48.9	48.6	48.6	48.6	47.9	48.5
2	48.8	48.4	48.1	48.3	47.8	48.1
3	48.7	48.1	47.5	48.1	47.8	47.7
4	48.3	48.1	47.5	47.9	47.7	47.7
5	48.2	47.8	47.5	47.8	47.6	47.5
6	48.2	47.6	47.3	47.7	47.4	47.5
7	47.9	47.6	47.3	47.7	47.4	47.3
8	47.9	47.4	47.3	47.6	47.4	47.3
9	47.7	47.3	47.2	47.5	47.4	47.3
10	47.6	47.3	47.2	47.4	47.3	47.3

Table K-38 Maximum 24-hour PM_{10} concentrations at community receptors, ranked by increase and by decrease in concentration with project

Rank	Ranking by increase in concentration with project (µg/m^3)			Ranking by decrease in concentration with project (µg/m^3)		
	2021-DS	2031-DS	2031-DSC	2021-DS	2031-DS	2031-DSC
1	0.8	1.0	0.7	-1.1	-0.9	-1.7
2	0.6	0.7	0.7	-0.8	-0.9	-0.9
3	0.4	0.6	0.6	-0.6	-0.7	-0.7
4	0.4	0.3	0.6	-0.5	-0.6	-0.6
5	0.3	0.3	0.6	-0.5	-0.5	-0.5
6	0.3	0.3	0.5	-0.5	-0.4	-0.5
7	0.3	0.3	0.4	-0.4	-0.4	-0.3
8	0.2	0.3	0.3	-0.4	-0.3	-0.3
9	0.2	0.2	0.3	-0.3	-0.3	-0.3
10	0.1	0.2	0.2	-0.3	-0.3	-0.3

Table K-39 Maximum 24-hour PM_{10} concentrations at community receptors, ranked by percentage increase and by decrease in concentration with project

Rank	Ranking by % increase in concentration with project (µg/m^3)			Ranking by % decrease in concentration with project (µg/m^3)		
	2021-DS	2031-DS	2031-DSC	2021-DS	2031-DS	2031-DSC
1	1.8%	2.1%	1.5%	-2.3%	-1.9%	-3.5%
2	1.2%	1.5%	1.5%	-1.7%	-1.9%	-1.8%
3	1.0%	1.4%	1.2%	-1.3%	-1.4%	-1.5%
4	0.8%	0.7%	1.2%	-1.2%	-1.3%	-1.3%
5	0.6%	0.7%	1.2%	-1.0%	-1.0%	-1.1%
6	0.6%	0.6%	1.0%	-1.0%	-0.8%	-1.0%
7	0.6%	0.6%	0.9%	-0.9%	-0.8%	-0.7%
8	0.5%	0.5%	0.6%	-0.9%	-0.7%	-0.7%
9	0.4%	0.4%	0.6%	-0.7%	-0.6%	-0.7%
10	0.1%	0.4%	0.4%	-0.6%	-0.6%	-0.6%

Table K-40 Maximum 24-hour PM_{10} concentrations at RWR receptors, ranked by concentration

Rank	Ranking by concentration (µg/m^3)					
	2014-BY	2021-DM	2021 DS	2031-DM	2031-DS	2031-DSC
1	72.8	68.9	62.4	65.6	61.3	60.6
2	67.4	62.6	59.4	62.2	60.5	57.9
3	65.9	62.3	59.2	61.6	60.3	57.8
4	65.1	62.0	59.2	61.4	60.0	57.6
5	64.7	61.1	59.1	61.3	59.7	57.2
6	64.6	60.7	58.9	61.3	59.6	57.2
7	64.5	60.6	58.8	60.1	59.6	57.2
8	64.5	60.5	58.8	59.8	59.3	57.0
9	64.4	60.4	58.8	59.7	58.8	56.6
10	64.3	60.4	58.3	59.4	58.8	56.4

Table K-41 Maximum 24-hour PM_{10} concentrations at RWR receptors, ranked by increase and by decrease in concentration with project

Rank	Ranking by increase in concentration with project (µg/m^3)			Ranking by decrease in concentration with project (µg/m^3)		
	2021-DS	2031-DS	2031-DSC	2021-DS	2031-DS	2031-DSC
1	6.8	6.7	7.2	-18.3	-13.2	-16.1
2	6.1	6.2	6.9	-14.4	-12.7	-14.1
3	5.8	6.1	6.0	-14.0	-9.7	-11.6
4	5.7	5.4	5.8	-13.4	-9.2	-11.5
5	5.5	5.4	5.7	-13.0	-9.2	-11.0
6	5.5	5.4	5.5	-12.7	-8.9	-10.7
7	5.2	5.2	5.2	-10.1	-8.9	-10.4
8	5.2	5.0	4.8	-9.8	-8.3	-10.4
9	5.1	5.0	4.7	-9.6	-8.2	-10.1
10	4.9	4.8	4.6	-9.4	-8.2	-10.0

Table K-42 Maximum 24-hour PM_{10} concentrations at RWR receptors, ranked by percentage increase and by decrease in concentration with project

Rank	Ranking by % increase in concentration with project (µg/m^3)			Ranking by % decrease in concentration with project (µg/m^3)		
	2021-DS	2031-DS	2031-DSC	2021-DS	2031-DS	2031-DSC
1	14.0%	13.9%	16.0%	-26.5%	-20.8%	-24.5%
2	13.2%	13.4%	14.7%	-24.0%	-20.1%	-23.0%
3	12.7%	12.3%	13.3%	-23.1%	-16.9%	-19.7%
4	12.6%	12.3%	13.0%	-21.4%	-16.2%	-19.2%
5	11.7%	11.9%	12.5%	-21.4%	-15.8%	-18.8%
6	11.0%	11.8%	12.5%	-20.8%	-15.7%	-18.2%
7	11.0%	11.6%	11.6%	-18.1%	-15.3%	-18.0%
8	11.0%	11.0%	10.7%	-17.5%	-14.8%	-18.0%
9	10.9%	10.9%	10.7%	-16.9%	-14.7%	-17.9%
10	10.8%	10.5%	10.3%	-16.8%	-14.4%	-17.8%

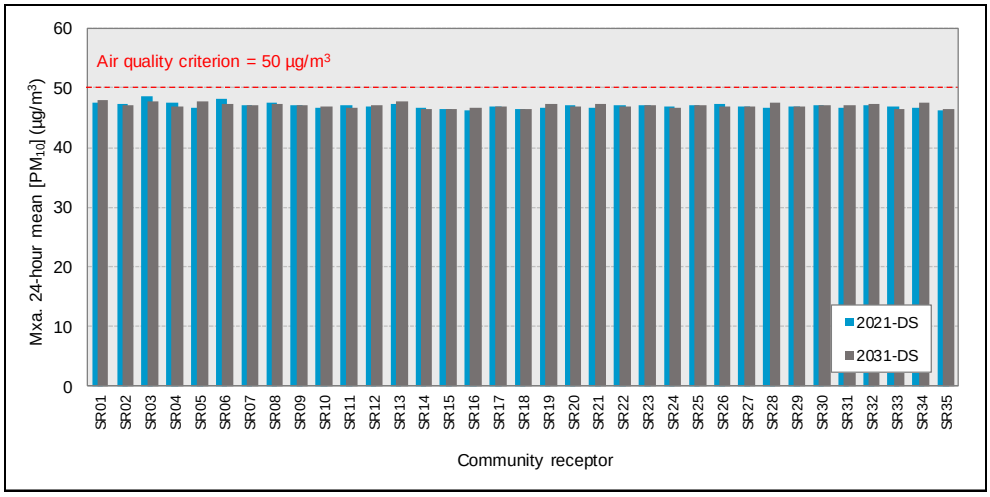


Figure K-90 Maximum 24-hour PM_{10} at community receptors (2021-DS and 2031-DS)

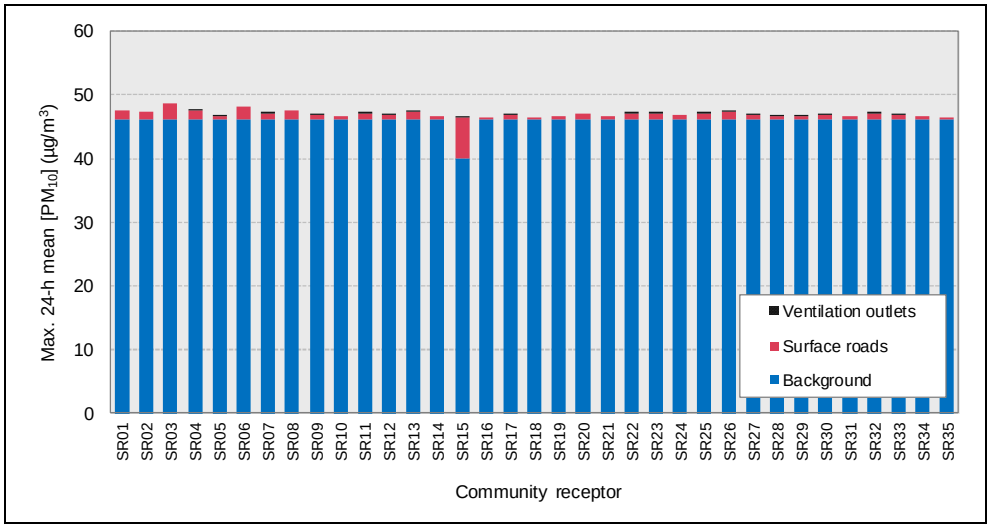


Figure K-91 Source contributions to maximum 24-hour PM_{10} at community receptors (2021-DS)

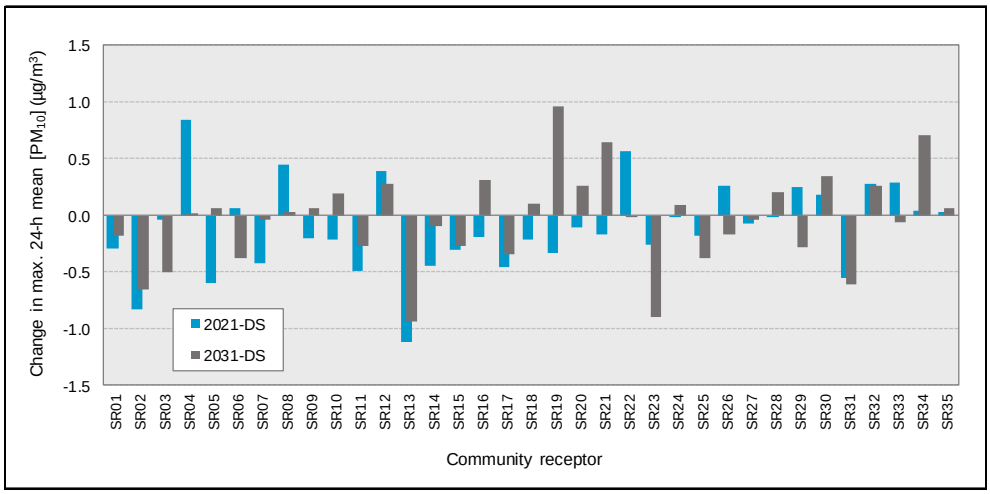


Figure K-92 Change in maximum 24-hour PM_{10} at community receptors (2021-DS and 2031-DS)

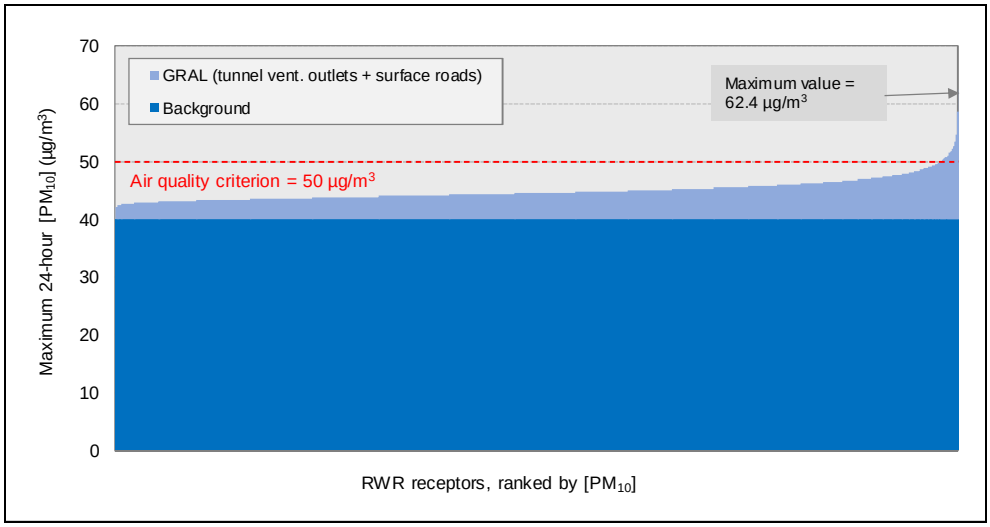


Figure K-93 Source contributions to maximum 24-hour PM_{10} at RWR receptors (2021-DS)

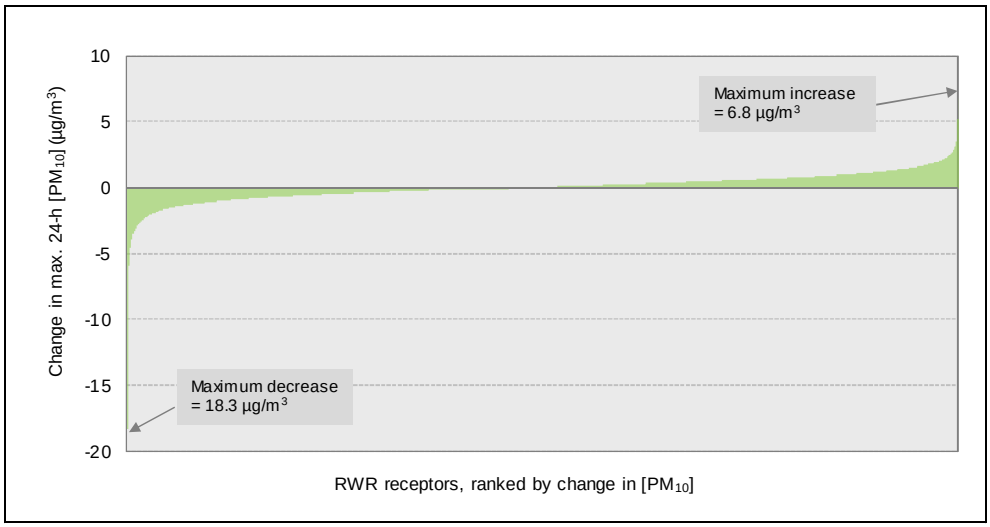


Figure K-94 Changes in maximum 24-hour PM_{10} at RWR receptors (2021-DS)

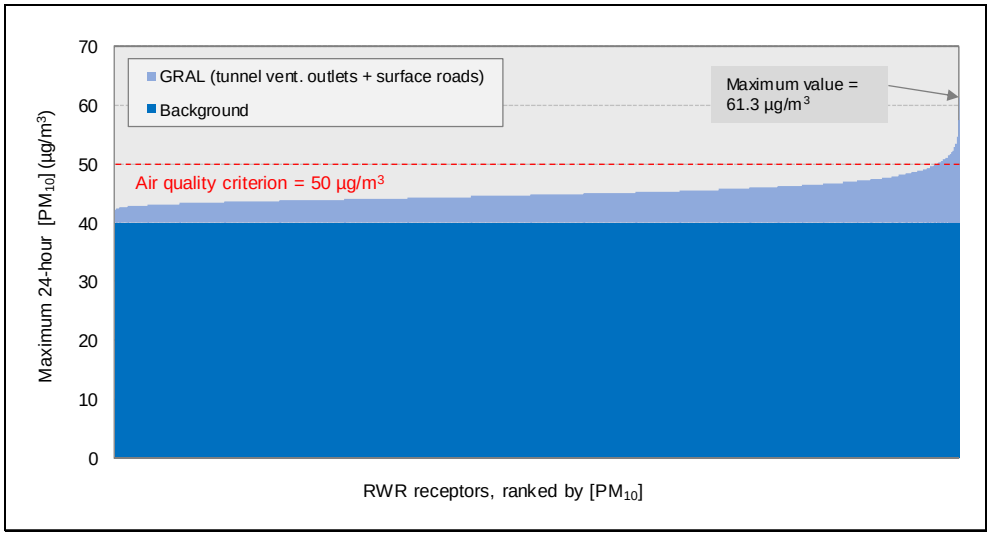


Figure K-95 Source contributions to maximum 24-hour PM_{10} at RWR receptors (2031-DS)

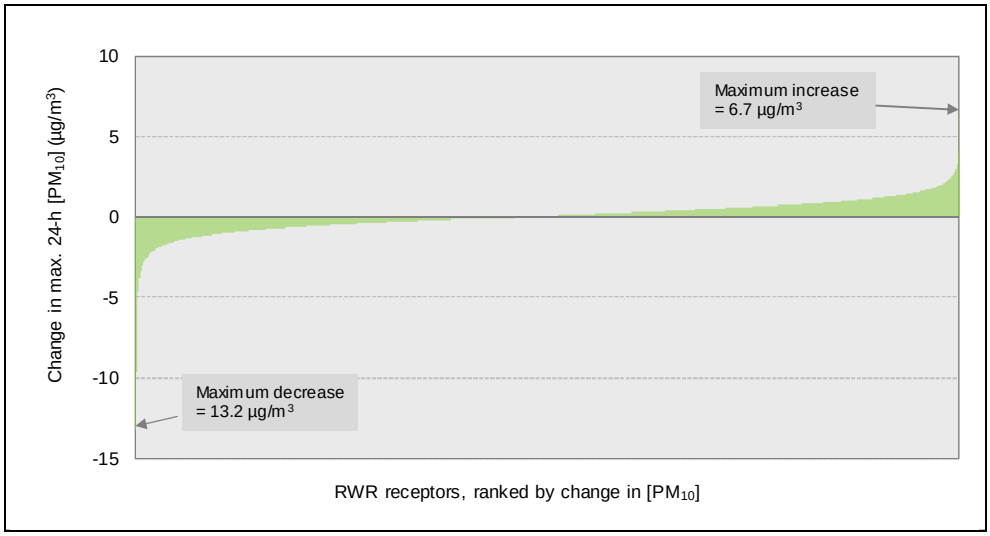


Figure K-96 Changes in maximum 24-hour PM_{10} at RWR receptors (2031-DS)

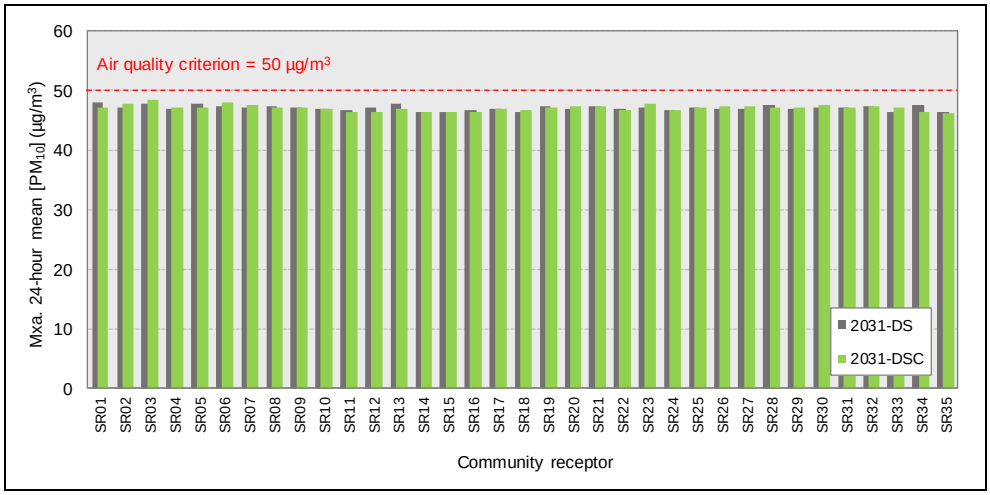


Figure K-97 Maximum 24-hour mean PM_{10} at community receptors (2031-DS and 2031-DSC)

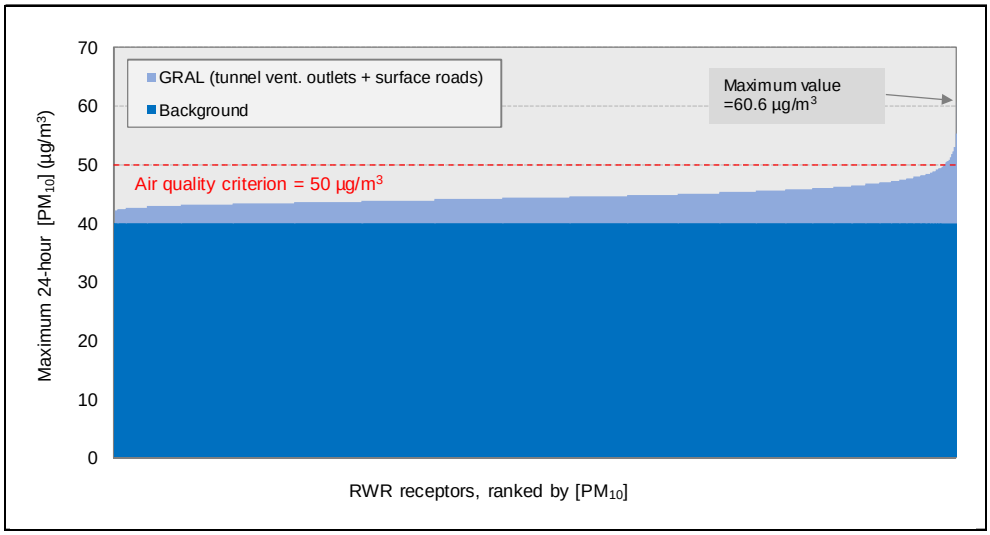


Figure K-98 Source contributions to maximum 24-hour PM_{10} at RWR receptors (2031-DSC)

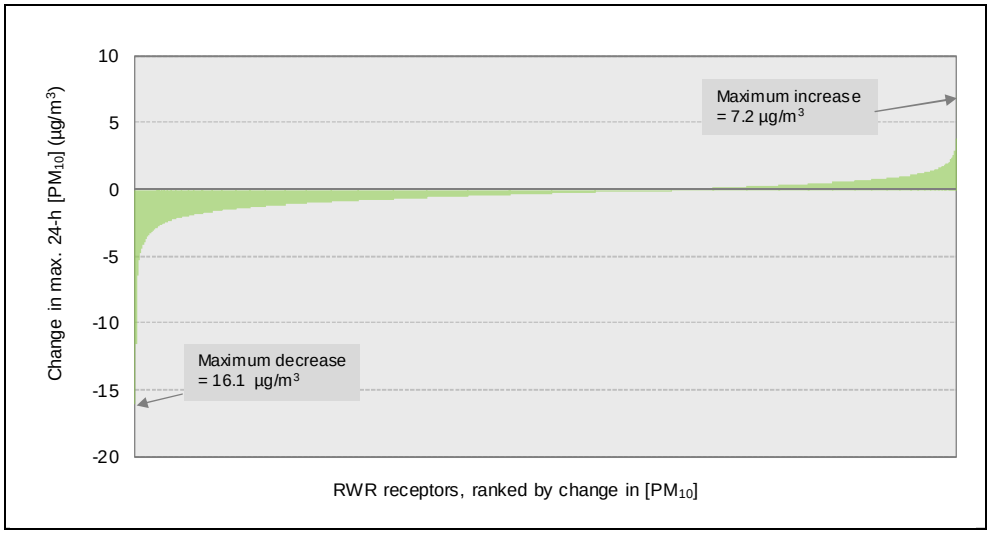


Figure K-99 Changes in maximum 24-hour PM_{10} at RWR receptors (2031-DSC)

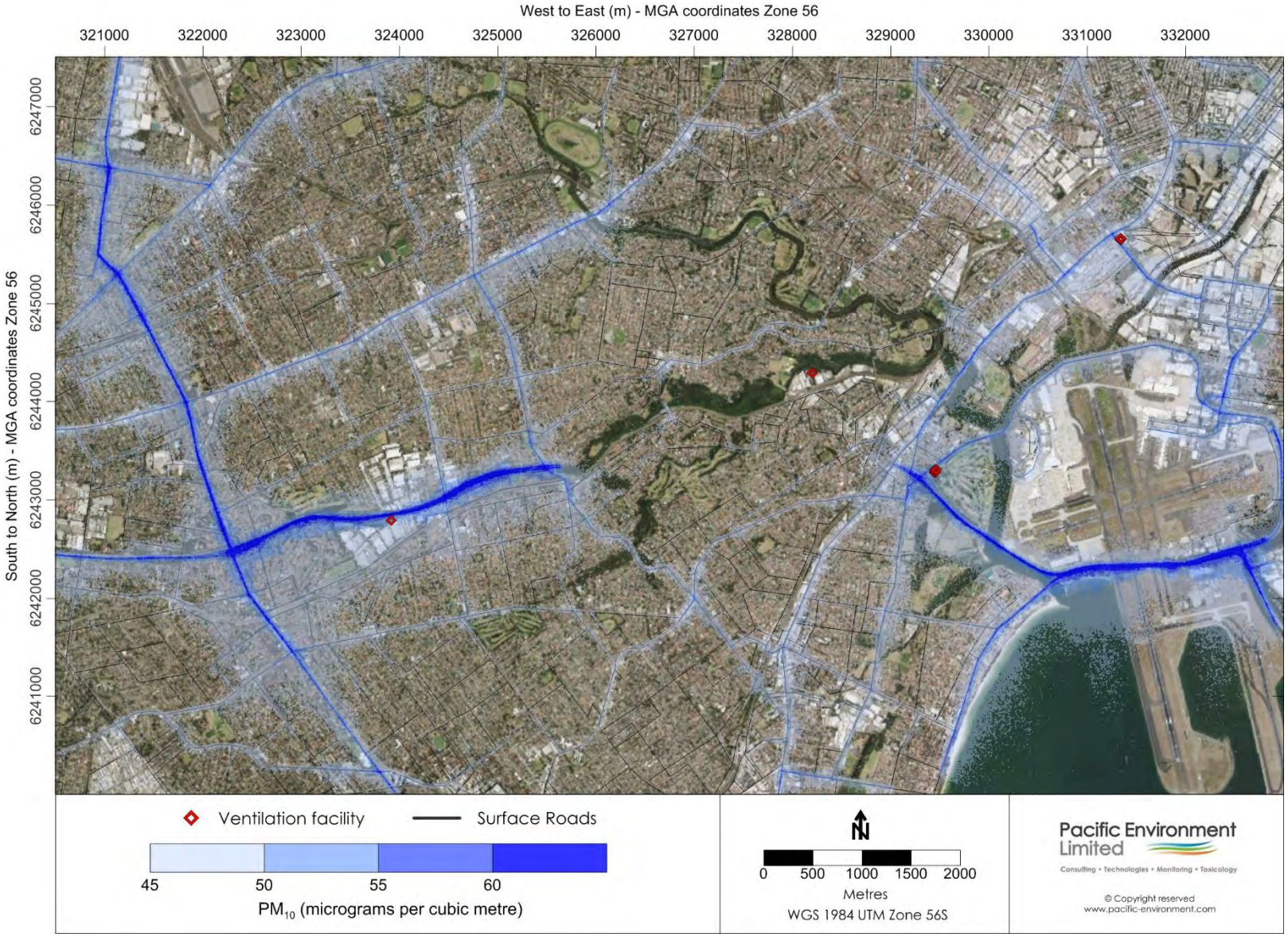


Figure K-100 Contour plot showing maximum 24-hour average PM_{10} (2021-DM)

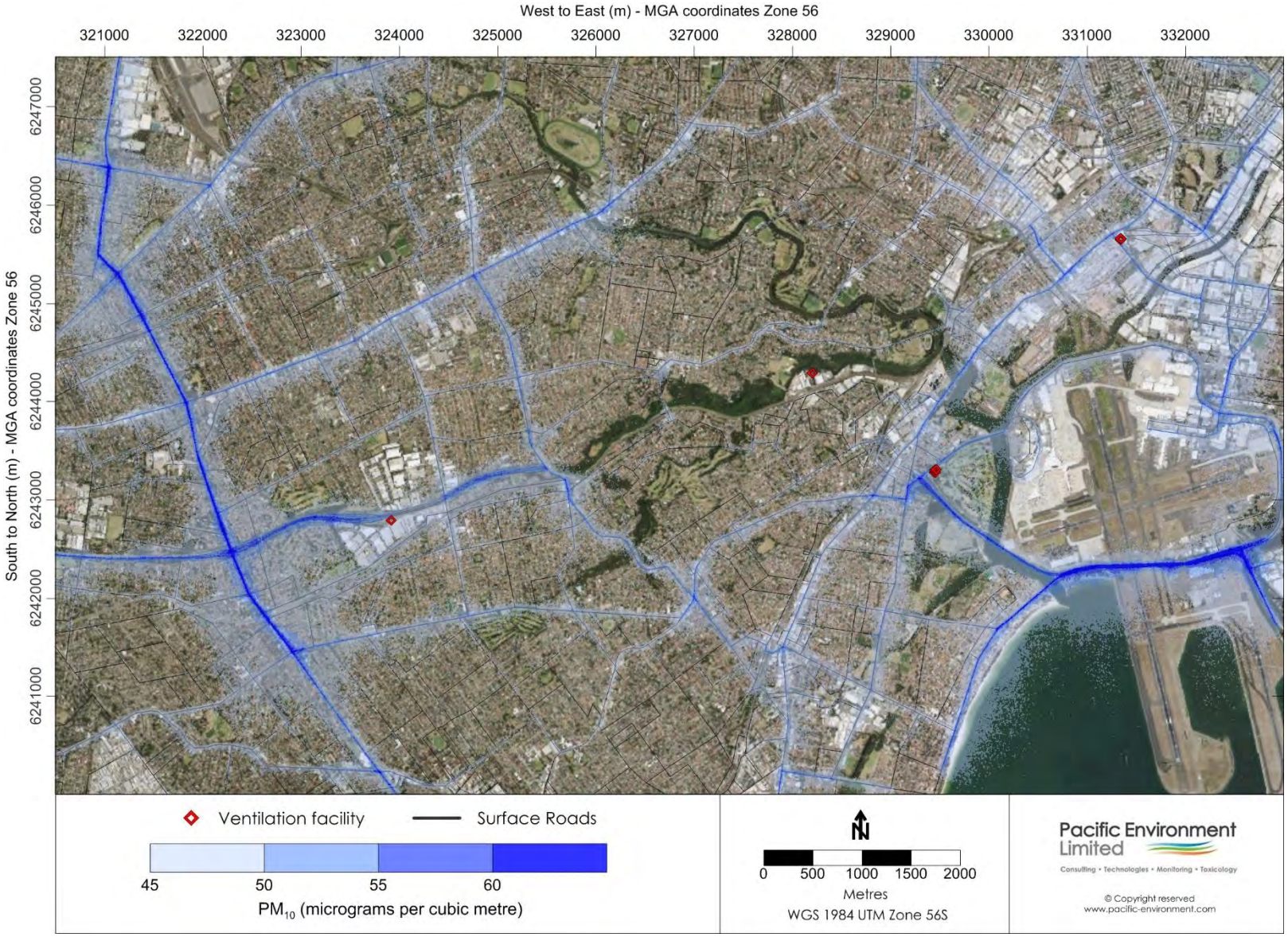


Figure K-101 Contour plot showing maximum 24-hour average PM_{10} (2021-DS)

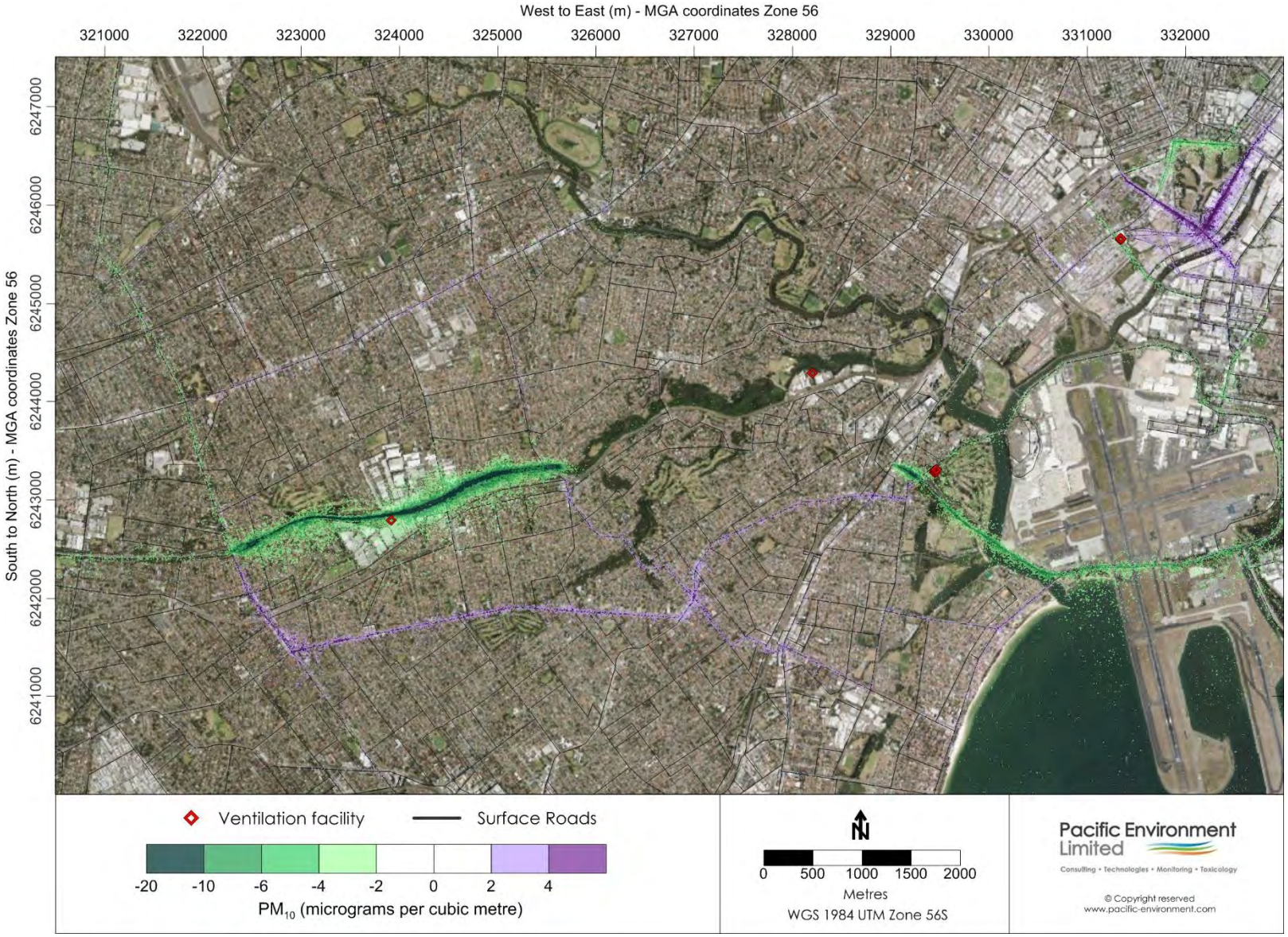


Figure K-102 Contour plot showing change in maximum 24-hour PM_{10} with the project (2021-DS)



Figure K-103 Contour map showing maximum 24-hour average PM_{10} (2031-DM)

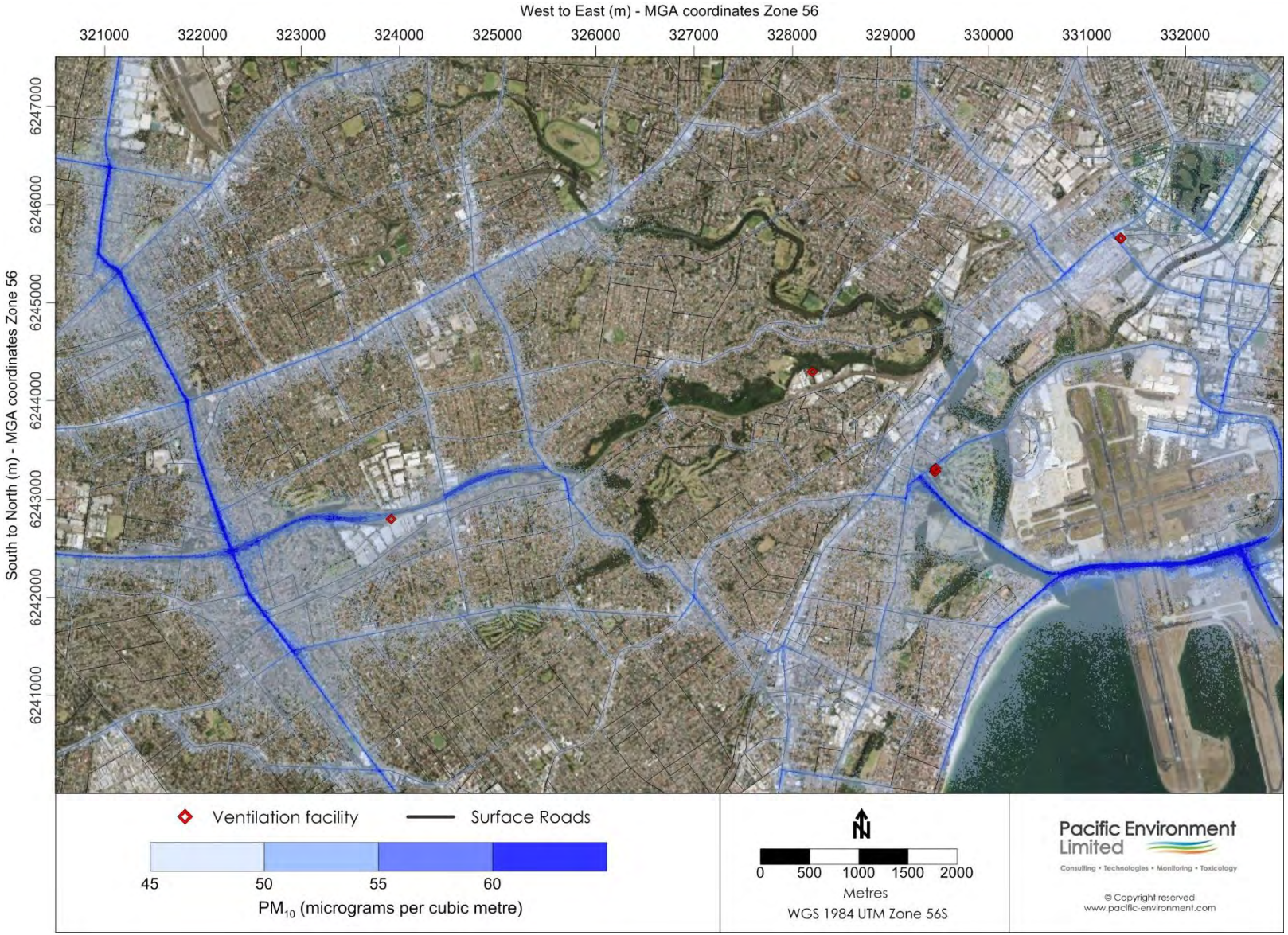


Figure K-104 Contour map showing maximum 24-hour average PM_{10} (2031-DS)

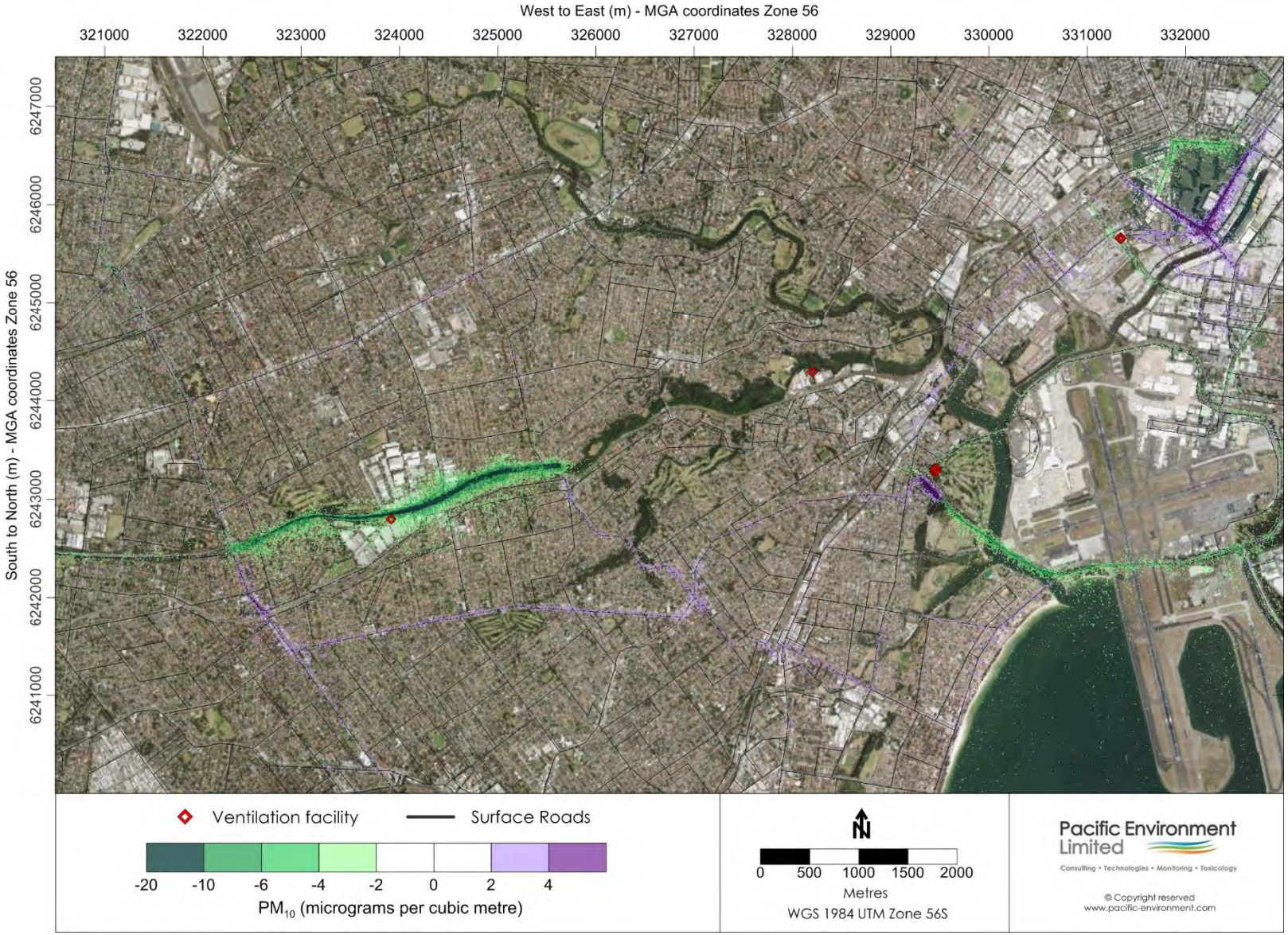


Table K-105 Contour map showing change in maximum 24-hour average PM_{10} with the project (2031-DS)



Figure K-106 Contour map showing maximum 24-hour average PM_{10} (2031-DSC)

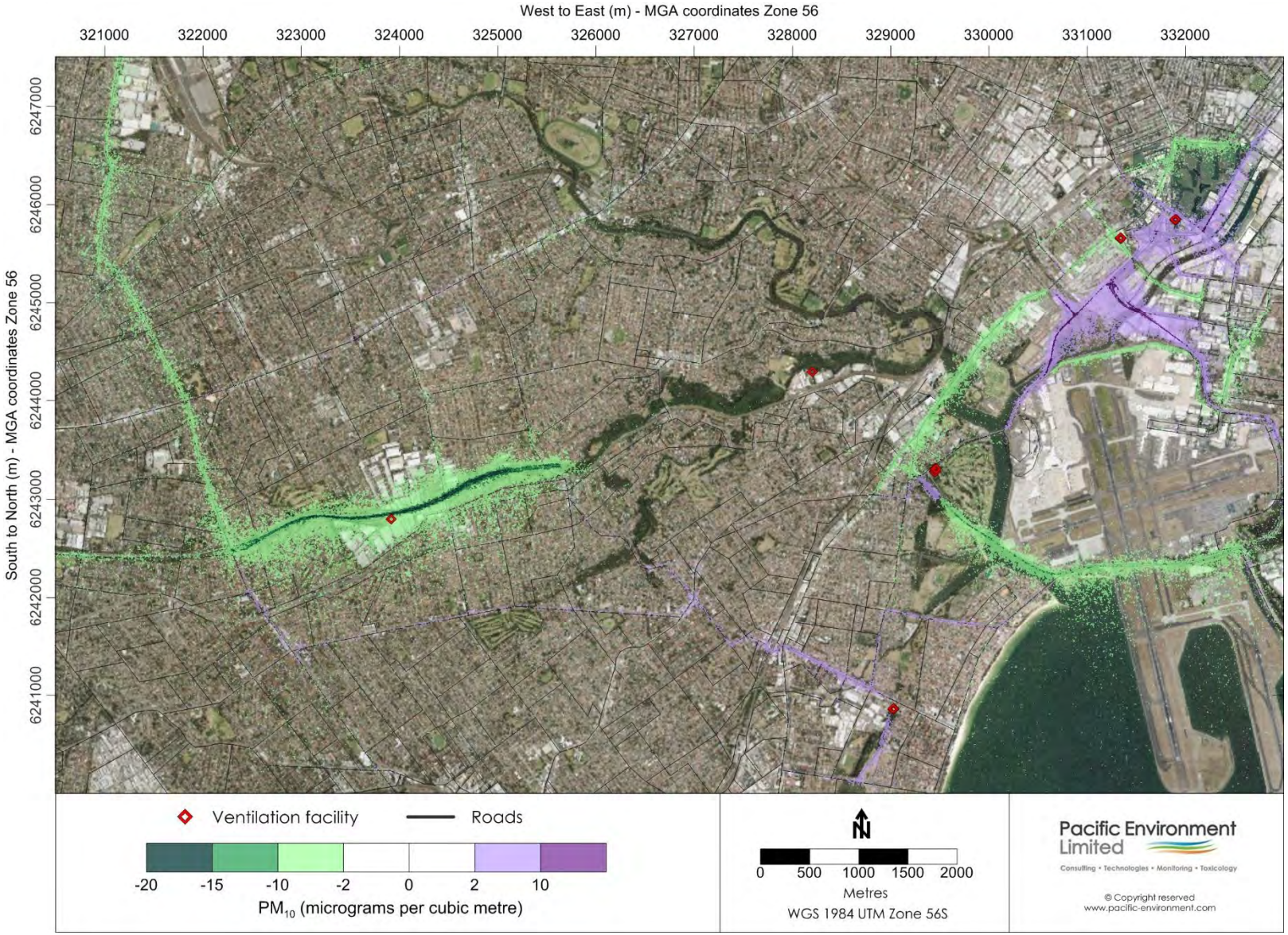


Table K-107 Contour map showing change in maximum 24-hour average PM_{10} with the project (2031-DSC)



Figure K-108 Contour map showing maximum 24-hour PM_{10} with the project for ventilation outlets only (Kingsgrove outlet, 2021-DS)

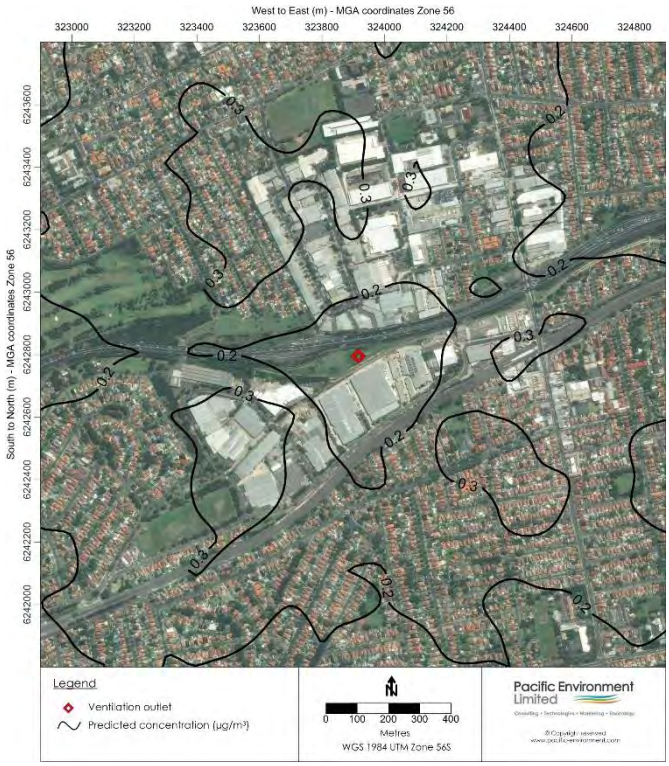


Figure K-109 Contour map showing maximum 24-hour PM_{10} with the project for ventilation outlets only (Kingsgrove outlet, 2031-DS)

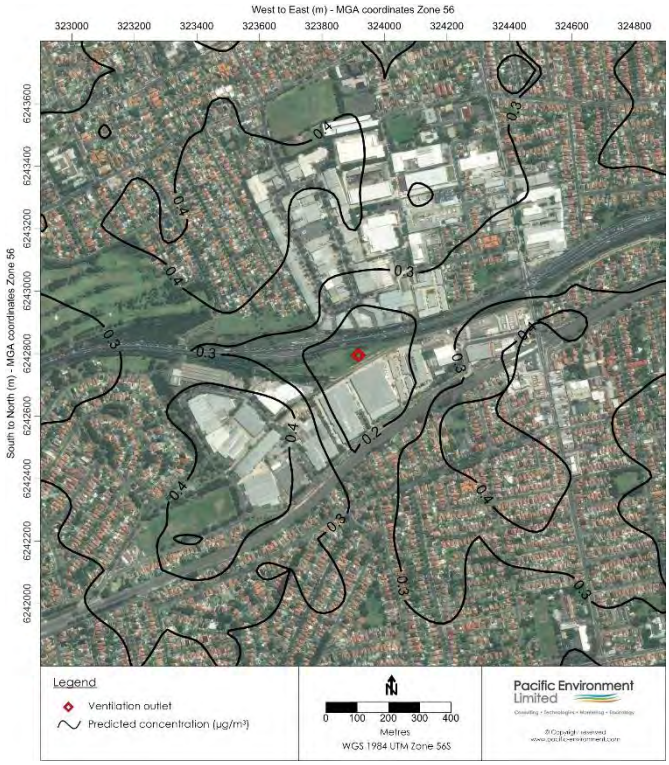


Figure K-110 Contour map showing maximum 24-hour PM_{10} with the project for ventilation outlets only (Kingsgrove outlet, 2031-DSC)

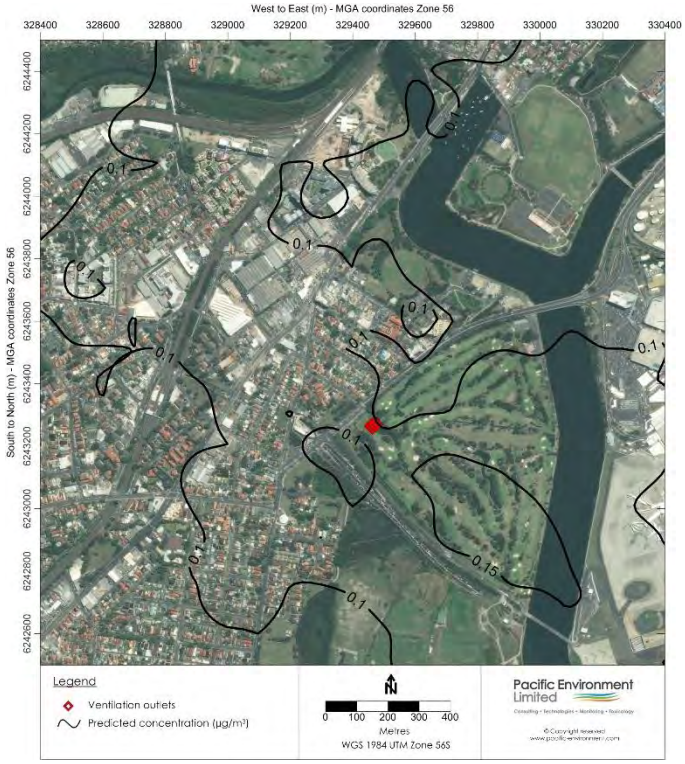


Figure K-111 Contour map showing maximum 24-hour PM_{10} with the project for ventilation outlets only (Arncliffe outlet, 2021-DS)

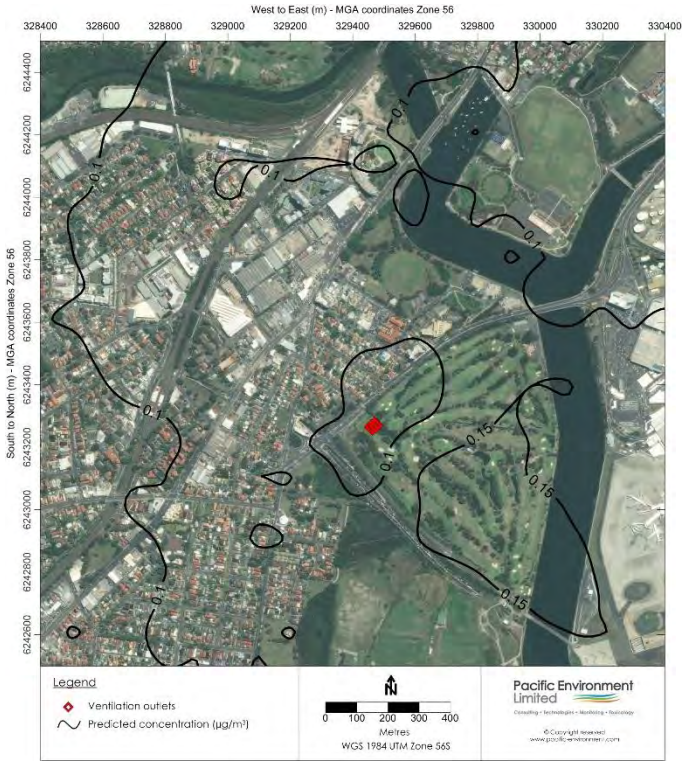


Figure K-112 Contour map showing maximum 24-hour PM_{10} with the project for ventilation outlets only (Arncliffe outlet, 2031-DS)

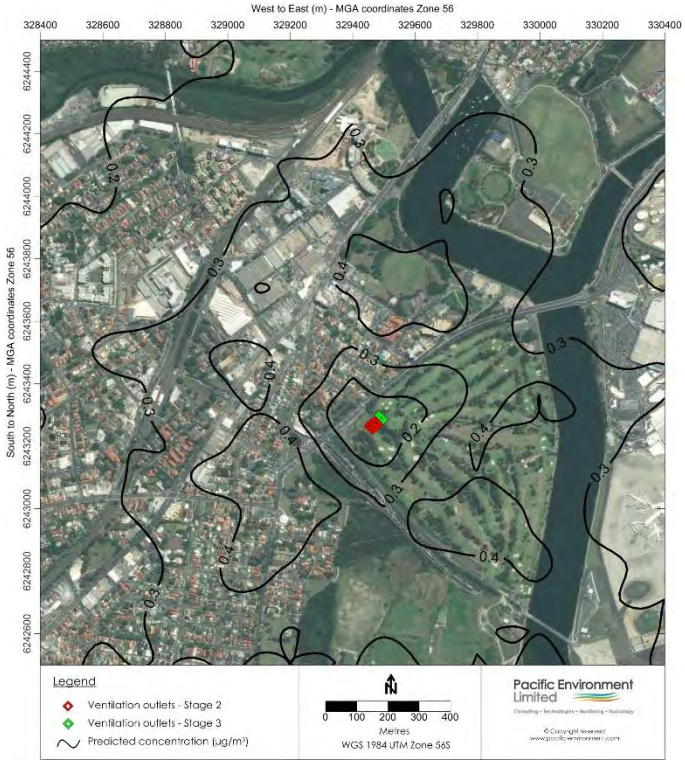


Figure K-113 Contour map showing maximum 24-hour PM_{10} with the project for ventilation outlets only (Arncliffe outlet, 2031-DSC)

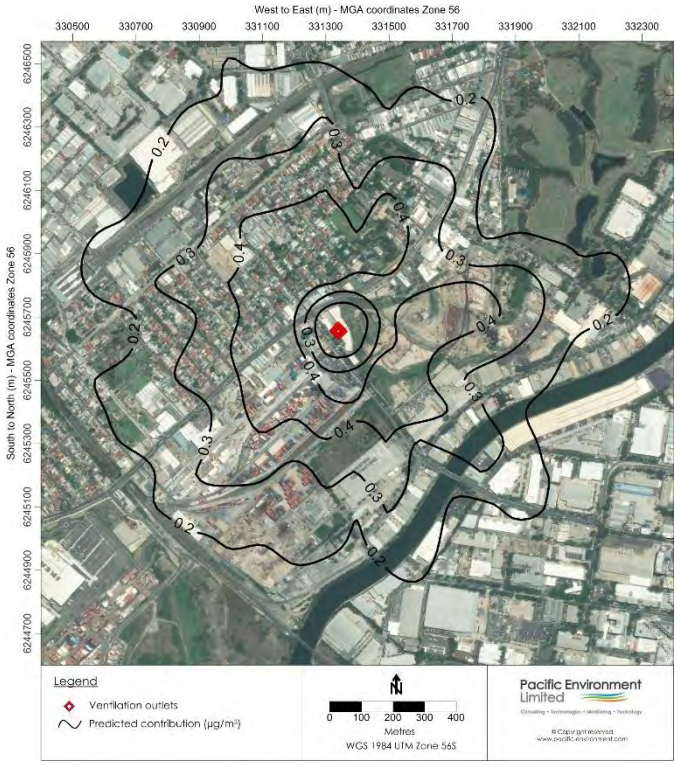


Figure K-114 Contour map showing maximum 24-hour PM_{10} with the project for ventilation outlets only (SPI New M5 outlet, 2021-DS)

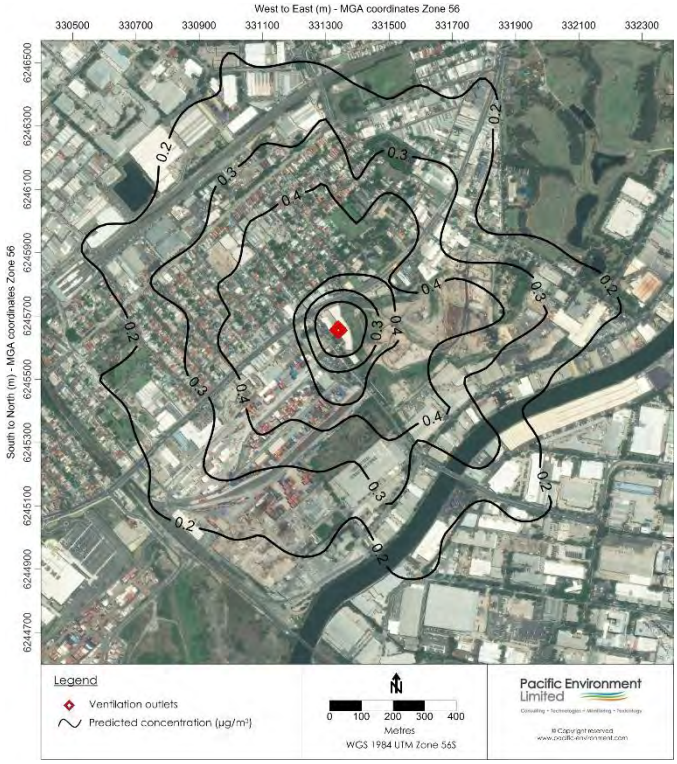


Figure K-115 Contour map showing maximum 24-hour PM_{10} with the project for ventilation outlets only (SPI New M5 outlet, 2031-DS)

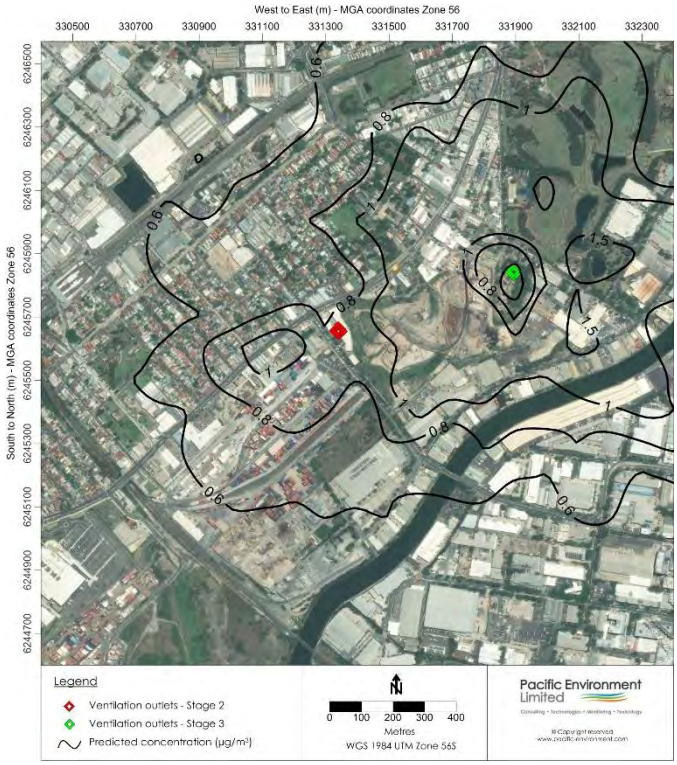


Figure K-116 Contour map showing maximum 24-hour PM10 with the project for ventilation outlets only (SPI New M5 outlet, 2031-DSC)

K.7 $PM_{2.5}$ (annual mean)

Table K-43 Annual mean $PM_{2.5}$ concentrations at community receptors

Receptor	Annual mean $PM_{2.5}$ concentration (µg/m^3)						Change with project (µg/m^3)			Change with project (%)		
	2014-BY	2021-DM	2021 DS	2031-DM	2031-DS	2031-DSC	2021	2031	2031-DSC	2021	2031	2031-DSC
SR01	9.7	9.3	9.2	9.2	9.1	9.0	-0.1	-0.2	-0.2	-1.5%	-1.7%	-2.2%
SR02	9.5	9.2	9.3	9.2	9.2	9.0	0.0	-0.1	-0.2	0.3%	-0.9%	-2.4%
SR03	10.1	9.6	9.6	9.6	9.6	9.3	-0.1	0.0	-0.2	-0.9%	0.1%	-2.6%
SR04	9.7	9.4	9.7	9.2	9.5	9.3	0.3	0.4	0.1	2.8%	4.0%	1.3%
SR05	9.6	9.3	9.3	9.3	9.4	9.2	0.0	0.1	-0.1	0.0%	0.6%	-1.0%
SR06	10.4	9.7	10.1	9.9	10.0	9.7	0.5	0.1	-0.2	4.8%	1.2%	-2.1%
SR07	10.2	9.7	9.8	9.4	9.6	9.6	0.1	0.2	0.2	1.2%	2.0%	1.9%
SR08	9.7	9.4	9.6	9.6	9.5	9.5	0.2	-0.1	-0.1	1.7%	-1.1%	-1.3%
SR09	8.8	8.7	8.8	8.7	8.7	8.6	0.0	0.0	0.0	0.4%	0.3%	-0.3%
SR10	9.3	9.0	8.9	9.0	9.0	9.0	-0.1	0.0	0.0	-1.0%	-0.4%	-0.1%
SR11	8.9	8.7	8.7	8.8	8.7	8.7	0.0	-0.1	-0.1	-0.2%	-0.8%	-1.1%
SR12	9.3	9.0	8.8	8.8	8.9	8.7	-0.2	0.0	-0.1	-2.3%	0.5%	-0.9%
SR13	9.6	9.3	8.8	9.5	9.0	8.9	-0.5	-0.6	-0.7	-5.6%	-6.2%	-7.2%
SR14	9.0	9.0	8.9	8.9	8.8	8.8	-0.1	-0.1	-0.1	-0.9%	-1.1%	-0.8%
SR15	8.9	8.9	8.9	8.9	8.7	8.7	0.0	-0.2	-0.2	-0.3%	-2.1%	-2.2%
SR16	9.5	9.3	8.9	9.0	8.9	9.0	-0.4	0.0	0.1	-4.0%	-0.1%	0.7%
SR17	9.0	8.9	8.8	8.9	8.8	8.8	0.0	-0.1	-0.1	-0.1%	-1.1%	-0.9%
SR18	8.7	8.7	8.6	8.7	8.6	8.7	0.0	-0.1	0.0	-0.4%	-0.8%	-0.2%
SR19	8.7	8.5	8.6	8.5	8.6	8.6	0.1	0.1	0.0	1.6%	0.9%	0.5%
SR20	8.7	8.6	8.6	8.6	8.7	8.7	0.1	0.2	0.1	0.6%	1.9%	1.3%
SR21	8.8	8.8	8.8	8.7	8.7	8.8	0.0	0.1	0.1	-0.2%	0.8%	1.0%
SR22	8.7	8.6	8.6	8.5	8.6	8.5	0.0	0.0	0.0	0.4%	0.4%	-0.2%
SR23	9.1	8.9	8.9	8.9	8.8	8.7	0.0	-0.1	-0.2	0.1%	-0.6%	-1.9%
SR24	9.1	9.1	9.3	8.9	9.1	8.9	0.2	0.2	0.0	2.0%	2.7%	0.4%
SR25	8.9	8.8	8.8	8.7	8.7	8.7	0.0	0.1	0.0	-0.4%	0.8%	0.5%
SR26	9.1	9.0	9.0	8.9	9.0	8.9	0.1	0.1	0.0	0.9%	1.5%	-0.2%
SR27	8.9	8.8	8.8	8.8	8.8	8.8	0.0	0.0	0.0	0.3%	-0.3%	-0.2%
SR28	8.8	8.7	8.7	8.7	8.7	8.7	0.0	0.0	0.1	-0.1%	-0.1%	1.0%
SR29	8.8	8.7	8.8	8.7	8.7	8.7	0.1	0.0	0.1	1.0%	0.4%	0.6%
SR30	8.8	8.8	8.9	8.8	8.9	9.0	0.1	0.1	0.2	1.4%	1.1%	2.3%
SR31	9.1	9.1	8.9	9.2	8.9	9.0	-0.3	-0.2	-0.2	-2.8%	-2.7%	-2.0%
SR32	9.3	9.1	9.0	9.0	9.0	9.0	0.0	0.0	0.0	-0.5%	0.0%	0.3%
SR33	8.8	8.8	8.8	8.7	8.8	8.7	0.0	0.1	0.0	0.1%	1.4%	0.4%
SR34	9.1	9.0	9.2	9.0	9.1	9.1	0.2	0.2	0.1	2.6%	2.1%	1.1%
SR35	8.7	8.7	8.7	8.7	8.6	8.7	0.0	-0.1	0.1	-0.3%	-0.6%	0.6%

Table K-44 Annual mean $PM_{2.5}$ concentrations at community receptors, ranked by concentration

Rank	Ranking by concentration (µg/m^3)					
	2014-BY	2021-DM	2021 DS	2031-DM	2031-DS	2031-DSC
1	10.4	9.7	10.1	9.9	10.0	9.7
2	10.2	9.7	9.8	9.6	9.6	9.6
3	10.1	9.6	9.7	9.6	9.6	9.5
4	9.7	9.4	9.6	9.5	9.5	9.3
5	9.7	9.4	9.6	9.4	9.5	9.3
6	9.7	9.3	9.3	9.3	9.4	9.2
7	9.6	9.3	9.3	9.2	9.2	9.1
8	9.6	9.3	9.3	9.2	9.1	9.0
9	9.5	9.3	9.2	9.2	9.1	9.0
10	9.5	9.2	9.2	9.2	9.1	9.0

Table K-45 Annual mean $PM_{2.5}$ concentrations at community receptors, ranked by increase and by decrease in concentration with project

Rank	Ranking by increase in concentration with project (µg/m^3)			Ranking by decrease in concentration with project (µg/m^3)		
	2021-DS	2031-DS	2031-DSC	2021-DS	2031-DS	2031-DSC
1	0.5	0.4	0.2	-0.5	-0.6	-0.7
2	0.3	0.2	0.2	-0.4	-0.2	-0.2
3	0.2	0.2	0.1	-0.3	-0.2	-0.2
4	0.2	0.2	0.1	-0.2	-0.2	-0.2
5	0.2	0.2	0.1	-0.1	-0.1	-0.2
6	0.1	0.1	0.1	-0.1	-0.1	-0.2
7	0.1	0.1	0.1	-0.1	-0.1	-0.2
8	0.1	0.1	0.1	-0.1	-0.1	-0.2
9	0.1	0.1	0.1	0.0	-0.1	-0.1
10	0.1	0.1	0.1	0.0	-0.1	-0.1

Table K-46 Annual mean $PM_{2.5}$ concentrations at community receptors, ranked by percentage increase and by decrease in concentration with project

Rank	Ranking by % increase in concentration with project (µg/m^3)			Ranking by % decrease in concentration with project (µg/m^3)		
	2021-DS	2031-DS	2031-DSC	2021-DS	2031-DS	2031-DSC
1	4.8%	4.0%	2.3%	-5.6%	-6.2%	-7.2%
2	2.8%	2.7%	1.9%	-4.0%	-2.7%	-2.6%
3	2.6%	2.1%	1.3%	-2.8%	-2.1%	-2.4%
4	2.0%	2.0%	1.3%	-2.3%	-1.7%	-2.2%
5	1.7%	1.9%	1.1%	-1.5%	-1.1%	-2.2%
6	1.6%	1.5%	1.0%	-1.0%	-1.1%	-2.1%
7	1.4%	1.4%	1.0%	-0.9%	-1.1%	-2.0%
8	1.2%	1.2%	0.7%	-0.9%	-0.9%	-1.9%
9	1.0%	1.1%	0.6%	-0.5%	-0.8%	-1.3%
10	0.9%	0.9%	0.6%	-0.4%	-0.8%	-1.1%

Table K-47 Annual mean $PM_{2.5}$ concentrations at RWR receptors, ranked by concentration

Rank	Ranking by concentration (µg/m^3)					
	2014-BY	2021-DM	2021 DS	2031-DM	2031-DS	2031-DSC
1	16.2	13.8	12.7	13.7	12.6	12.3
2	14.8	13.5	12.3	12.8	12.4	11.6
3	14.7	12.9	12.2	12.5	12.4	11.6
4	14.7	12.8	12.2	12.4	12.2	11.5
5	14.6	12.8	12.1	12.4	12.2	11.4
6	14.4	12.8	12.1	12.2	12.2	11.4
7	14.4	12.8	12.1	12.2	12.1	11.4
8	14.3	12.8	12.0	12.2	12.1	11.3
9	14.3	12.7	12.0	12.2	12.1	11.3
10	14.3	12.7	12.0	12.2	12.0	11.3

Table K-48 Annual mean $PM_{2.5}$ concentrations at RWR receptors, ranked by increase and by decrease in concentration with project

Rank	Ranking by increase in concentration with project (µg/m^3)			Ranking by decrease in concentration with project (µg/m^3)		
	2021-DS	2031-DS	2031-DSC	2021-DS	2031-DS	2031-DSC
1	1.1	1.2	1.9	-3.5	-3.2	-3.7
2	1.0	0.9	1.5	-3.3	-3.0	-3.3
3	1.0	0.9	1.4	-3.3	-2.2	-2.3
4	1.0	0.8	1.4	-3.2	-1.9	-2.1
5	1.0	0.8	1.3	-3.2	-1.9	-2.1
6	0.9	0.8	1.2	-3.1	-1.7	-2.0
7	0.9	0.8	1.0	-2.6	-1.7	-2.0
8	0.9	0.7	1.0	-2.5	-1.6	-2.0
9	0.9	0.7	0.9	-2.5	-1.6	-1.8
10	0.9	0.7	0.9	-2.5	-1.6	-1.8

Table K-49 Annual mean $PM_{2.5}$ concentrations at RWR receptors, ranked by percentage increase and by decrease in concentration with project

Rank	Ranking by % increase in concentration with project (µg/m^3)			Ranking by % decrease in concentration with project (µg/m^3)		
	2021-DS	2031-DS	2031-DSC	2021-DS	2031-DS	2031-DSC
1	11.6%	13.3%	22.0%	-25.8%	-23.2%	-27.3%
2	11.2%	8.9%	16.7%	-25.6%	-23.2%	-26.0%
3	10.0%	8.6%	15.7%	-25.4%	-19.8%	-20.9%
4	9.7%	8.5%	15.2%	-25.1%	-17.4%	-18.8%
5	9.7%	8.3%	14.0%	-24.3%	-16.9%	-18.6%
6	9.5%	8.0%	13.6%	-23.6%	-15.3%	-18.6%
7	9.3%	8.0%	11.8%	-21.6%	-15.3%	-17.8%
8	9.2%	7.9%	11.7%	-20.9%	-15.1%	-17.1%
9	9.1%	7.8%	10.8%	-20.8%	-14.7%	-16.2%
10	9.1%	7.6%	10.4%	-20.8%	-13.9%	-16.2%

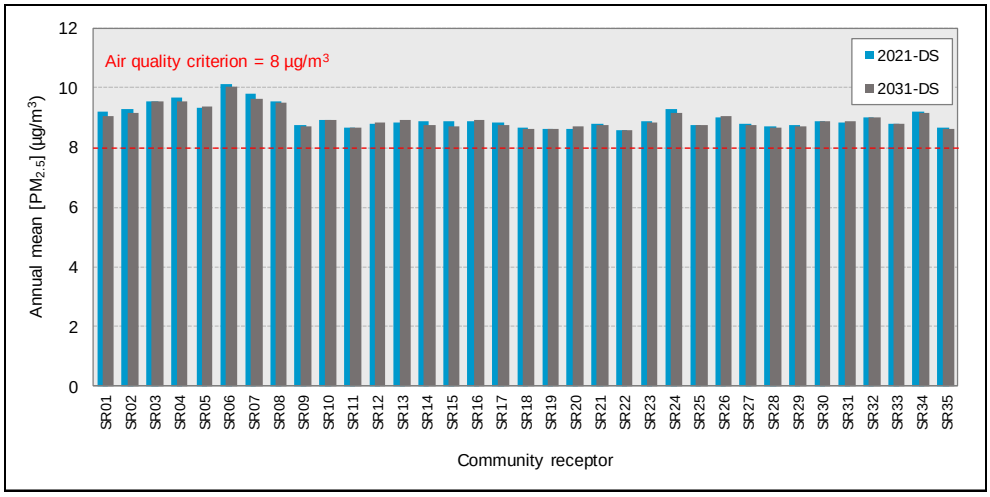


Figure K-117 Annual mean $PM_{2.5}$ at community receptors (2021-DS and 2031-DS)

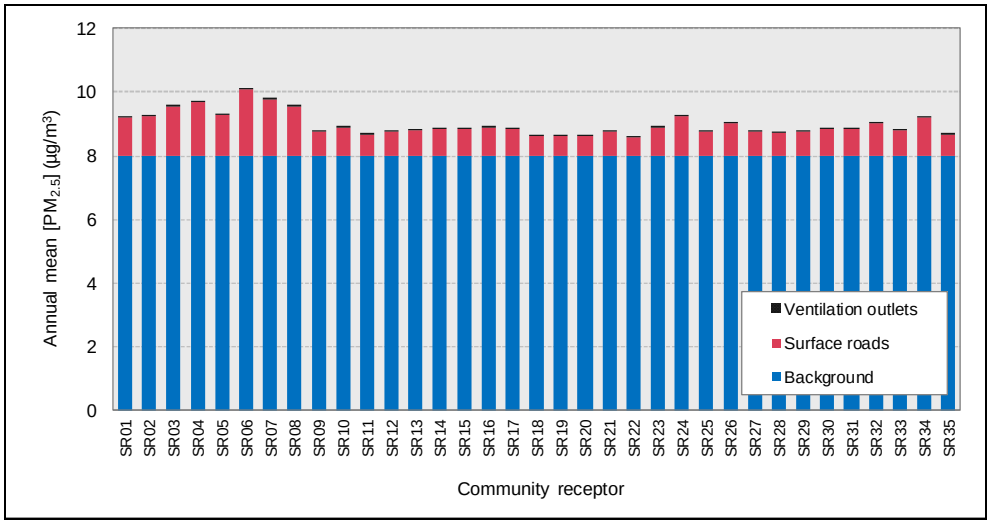


Figure K-118 Source contributions to annual mean $PM_{2.5}$ at community receptors (2021-DS)

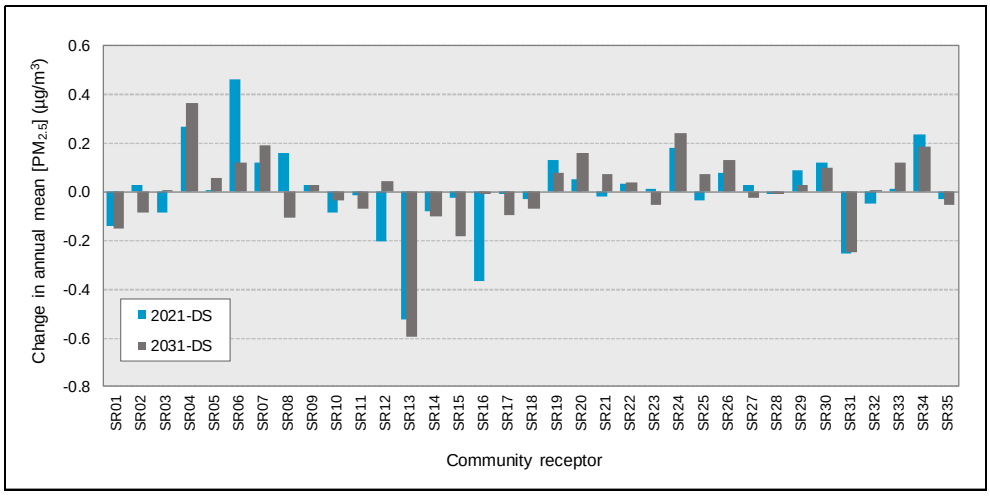


Figure K-119 Change in annual mean $PM_{2.5}$ at community receptors (2021-DS and 2031-DS)

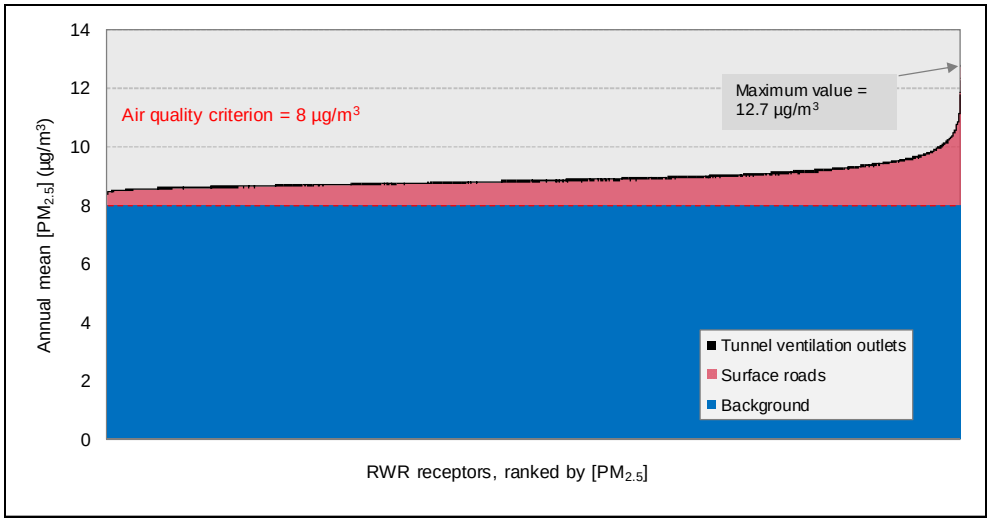


Figure K-120 Source contributions to annual mean $PM_{2.5}$ at RWR receptors (2021-DS)

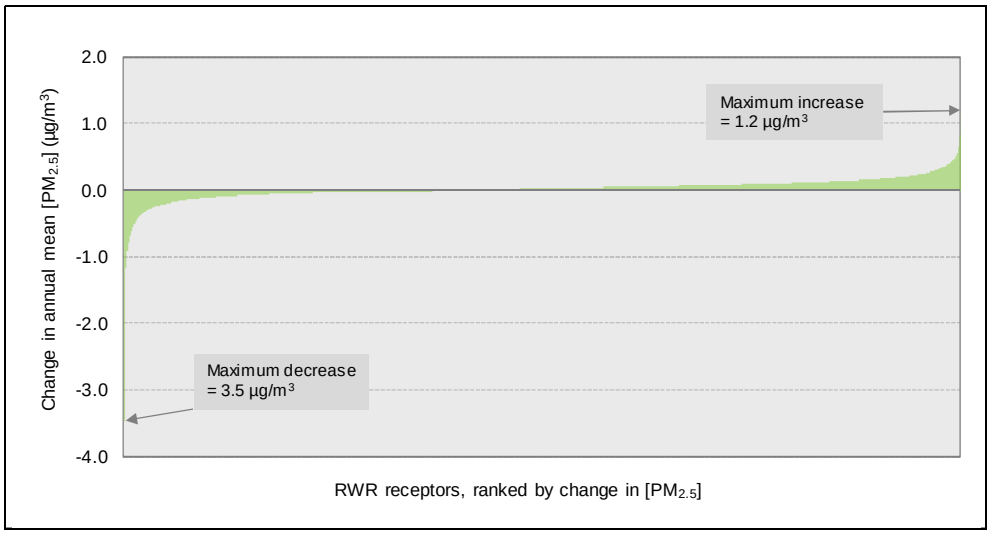


Figure K-121 Changes in annual mean $PM_{2.5}$ at RWR receptors (2021-DS)

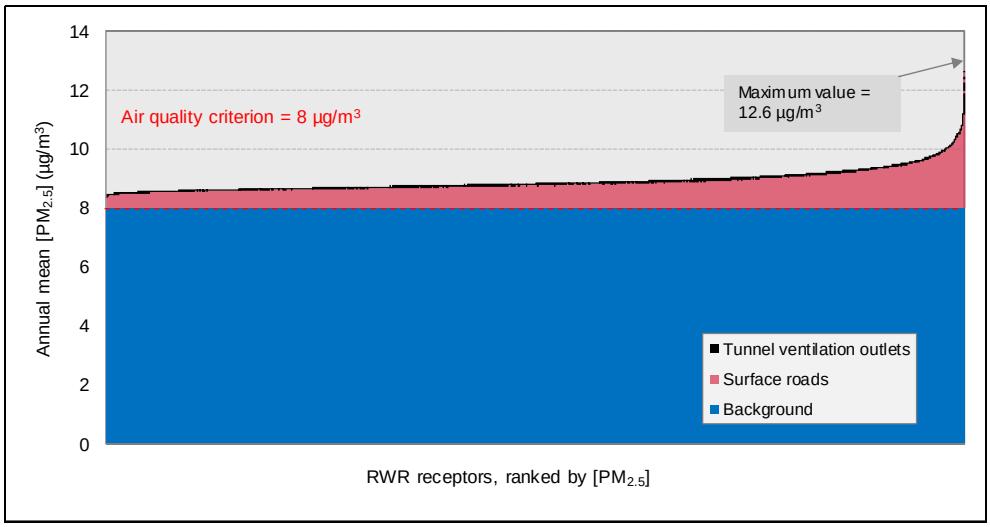


Figure K-122 Source contributions to annual mean $PM_{2.5}$ at RWR receptors (2031-DS)

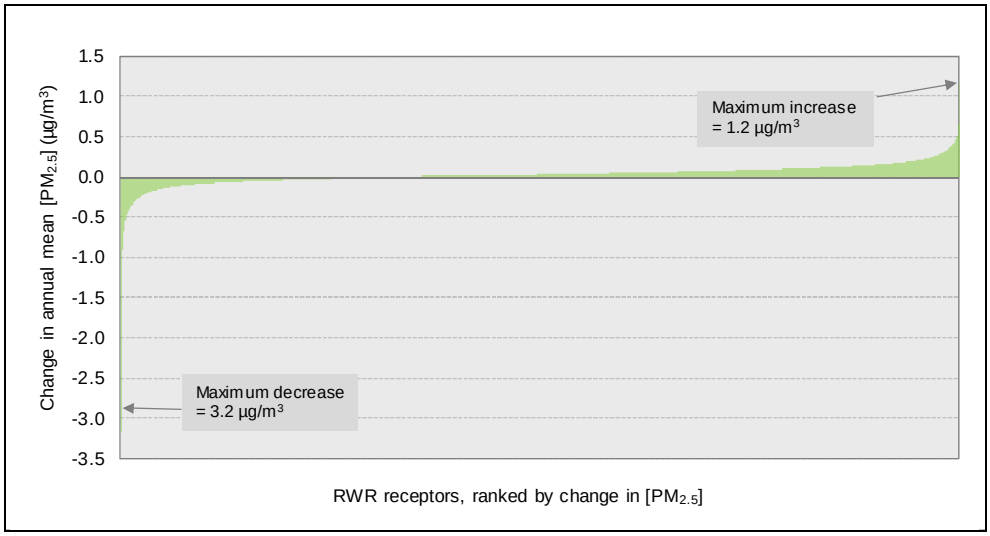


Figure K-123 Changes in annual mean $PM_{2.5}$ at RWR receptors (2031-DS)

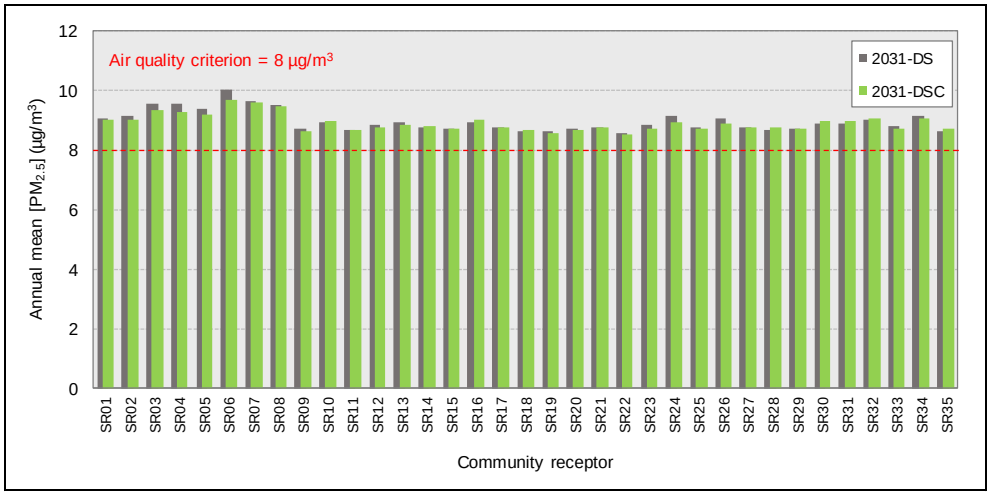


Figure K-124 Annual mean $PM_{2.5}$ at community receptors (2031-DS and 2031-DSC)

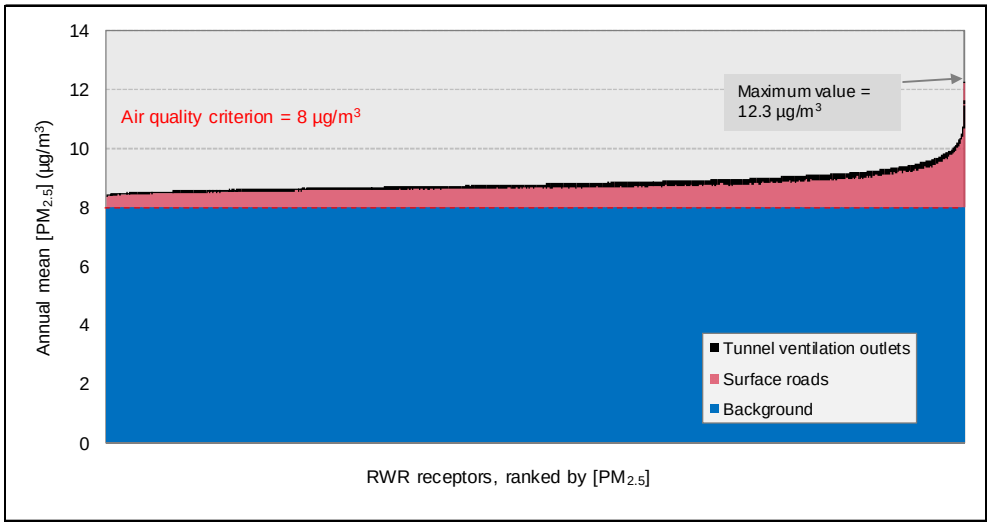


Figure K-125 Source contributions to annual mean $PM_{2.5}$ at RWR receptors (2031-DSC)

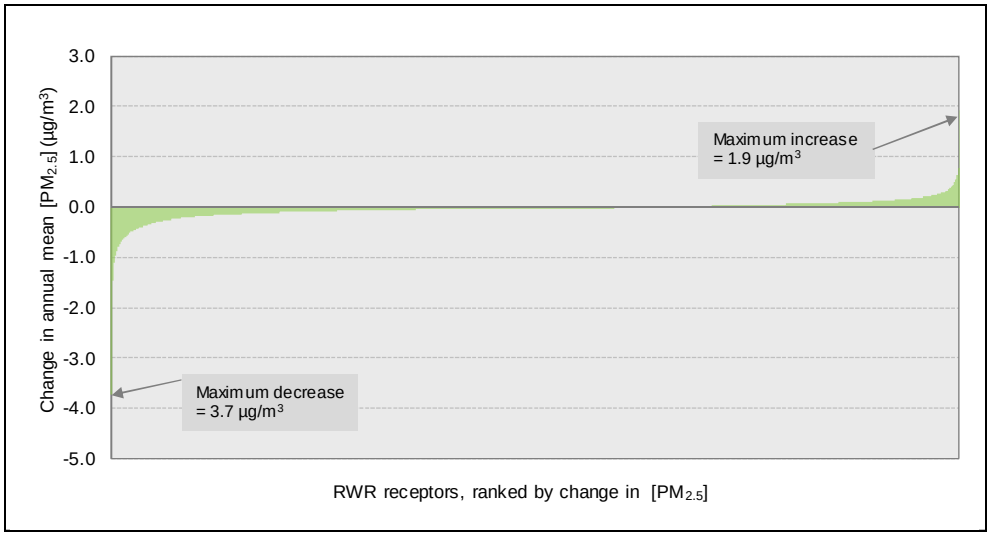


Figure K-126 Changes in annual mean $PM_{2.5}$ at RWR receptors (2031-DSC)



Figure K-127 Contour plot showing annual mean $PM_{2.5}$ (2021-DM)



Figure K-128 Contour plot showing annual mean $PM_{2.5}$ (2021-DS)

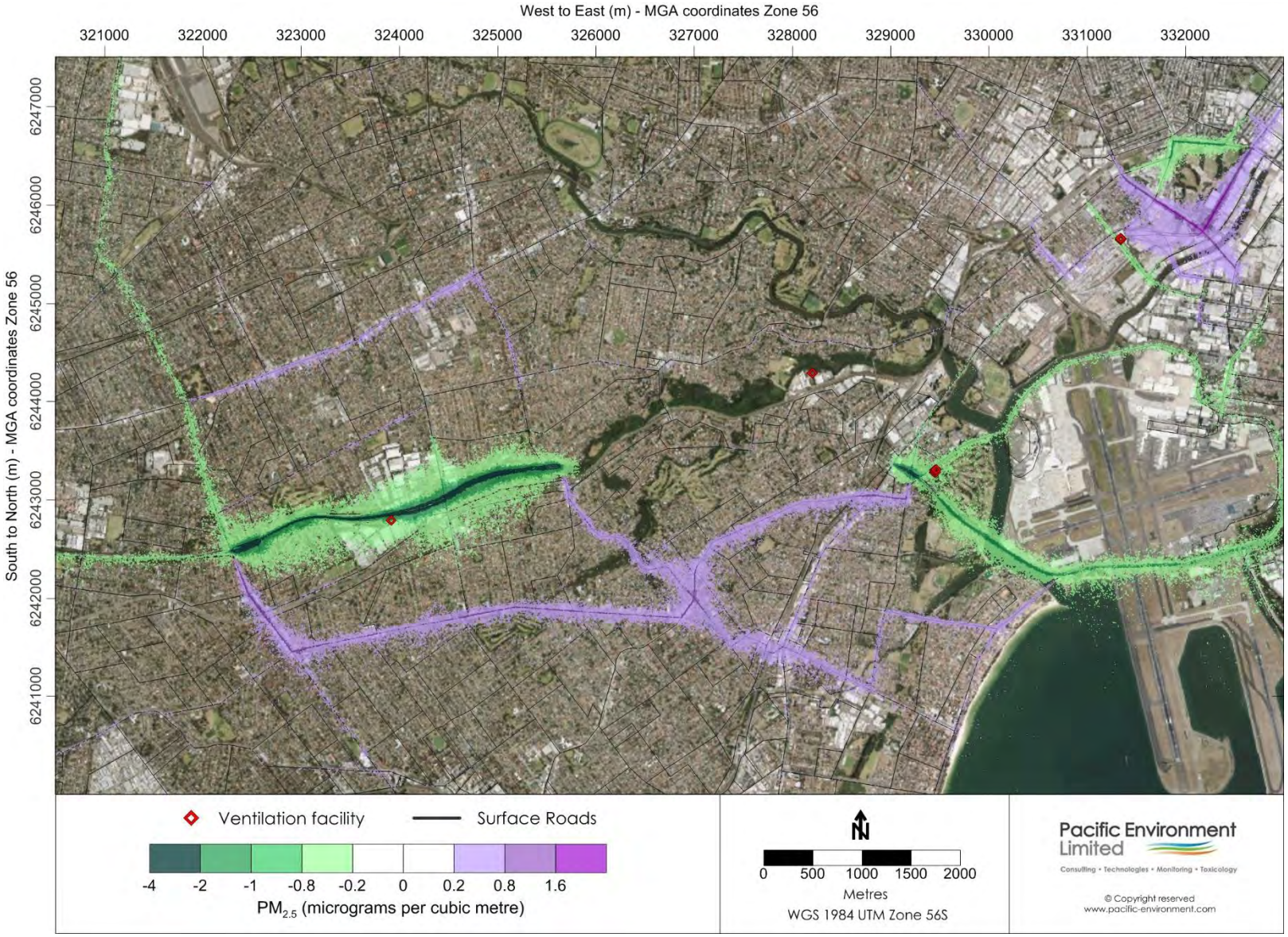


Figure K-129 Contour plot showing change in annual mean $PM_{2.5}$ with the project (2021-DS)



Figure K-130 Contour map showing annual mean $PM_{2.5}$ (2031-DM)



Figure K-131 Contour map showing annual mean $PM_{2.5}$ (2031-DS)



Figure K-132 Contour map showing change in annual mean $PM_{2.5}$ with the project (2031-DS)

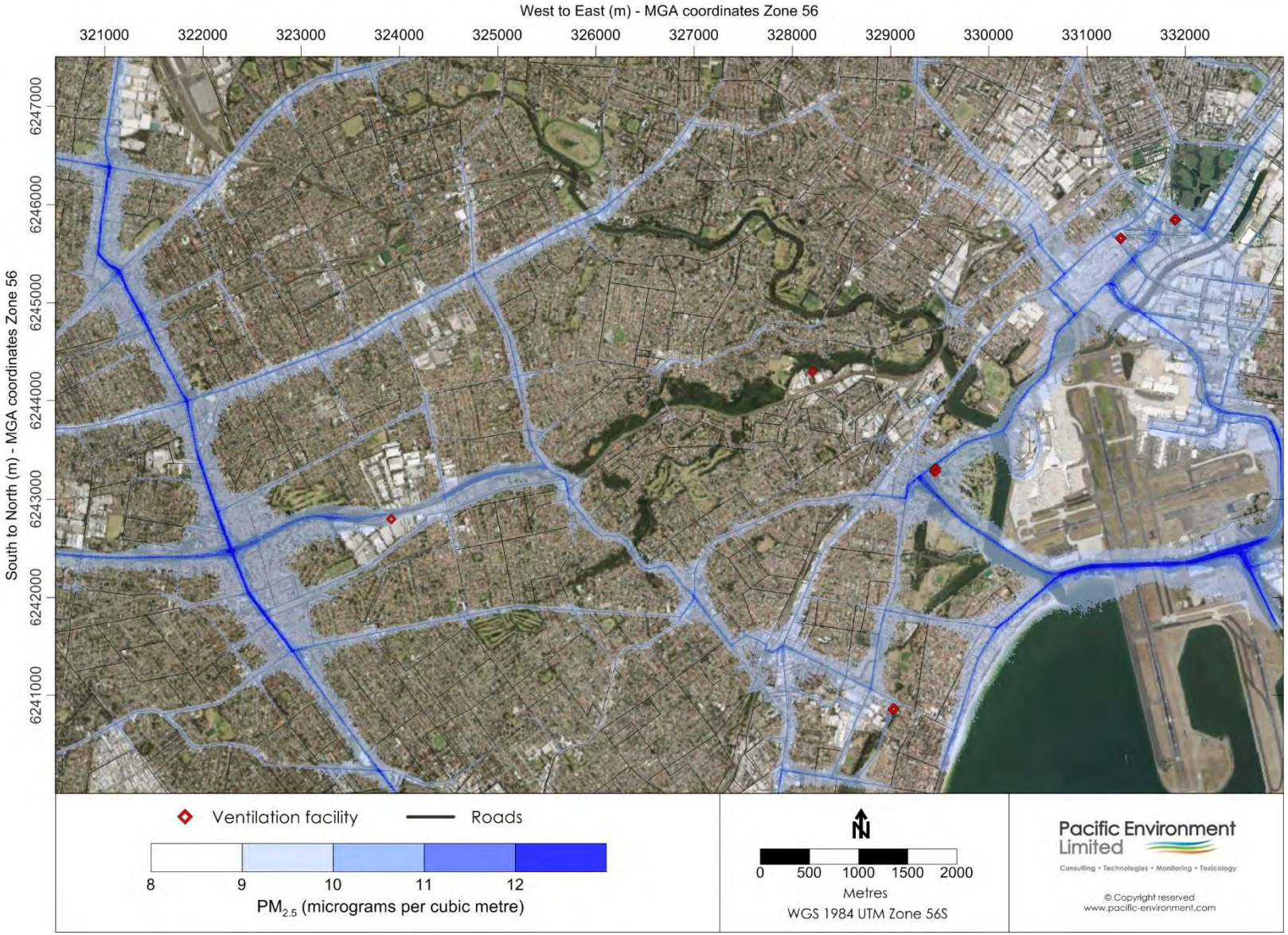


Figure K-133 Contour map showing annual mean $PM_{2.5}$ (2031-DSC)

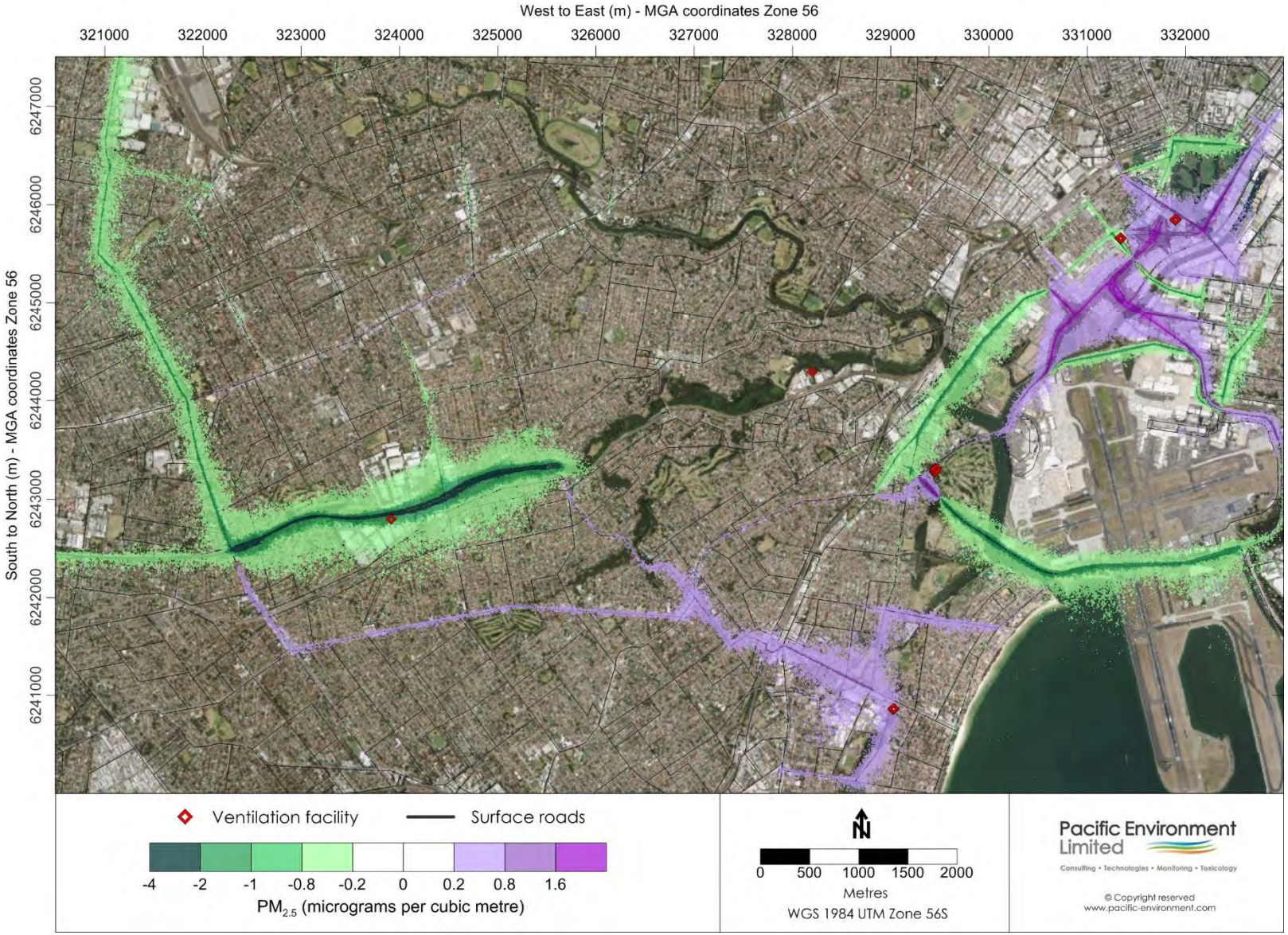


Figure K-134 Contour map showing change in annual mean $PM_{2.5}$ with the project (2031-DSC)



Figure K-135 Contour map showing annual mean $PM_{2.5}$ with the project for ventilation outlets only (Kingsgrove outlet, 2021-DS)



Figure K-136 Contour map showing annual mean $PM_{2.5}$ with the project for ventilation outlets only (Kingsgrove outlet, 2031-DS)

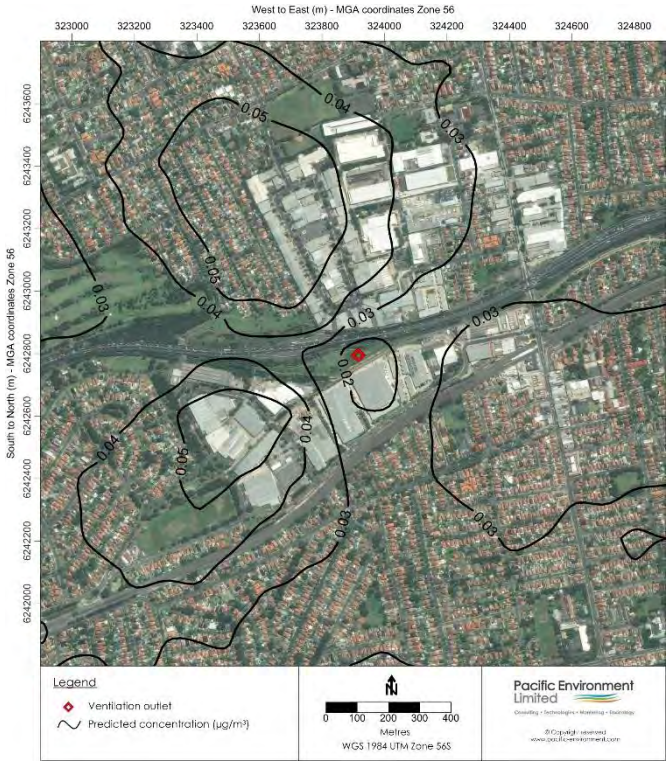


Figure K-137 Contour map showing annual mean $PM_{2.5}$ with the project for ventilation outlets only (Kingsgrove outlet, 2031-DSC)

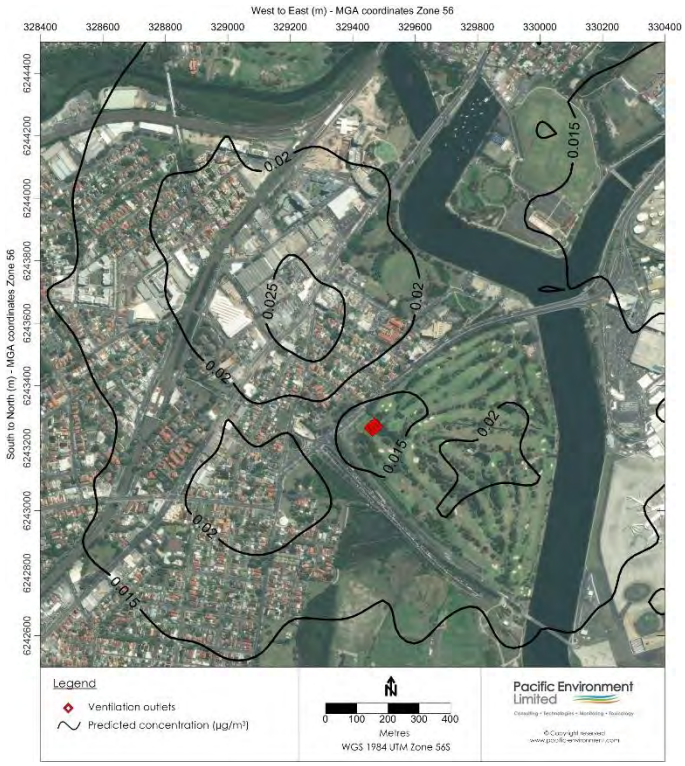


Figure K-138 Contour map showing annual mean $PM_{2.5}$ with the project for ventilation outlets only (Arncliffe outlet, 2021-DS)

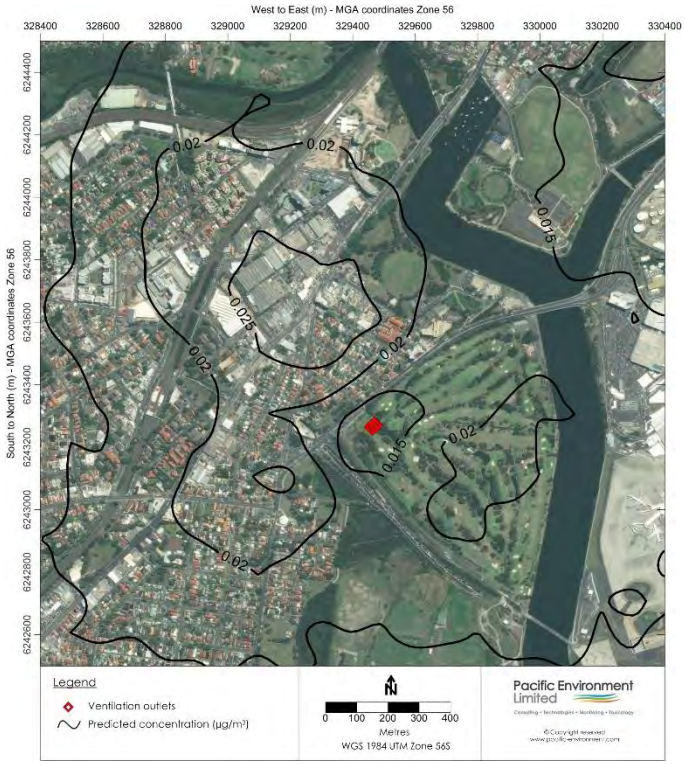


Figure K-139 Contour map showing annual mean $PM_{2.5}$ with the project for ventilation outlets only (Arncliffe outlet, 2031-DS)

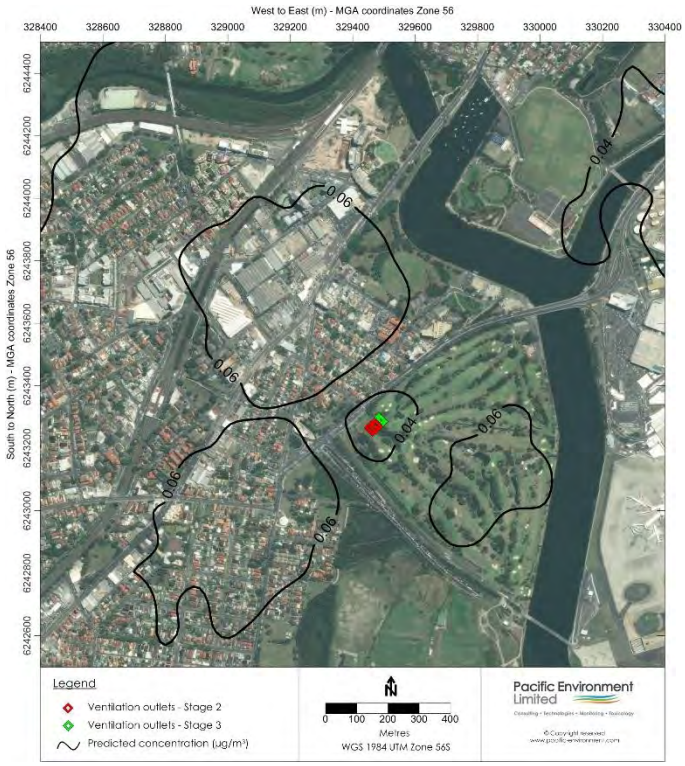


Figure K-140 Contour map showing annual mean $PM_{2.5}$ with the project for ventilation outlets only (Arncliffe outlet, 2031-DSC)

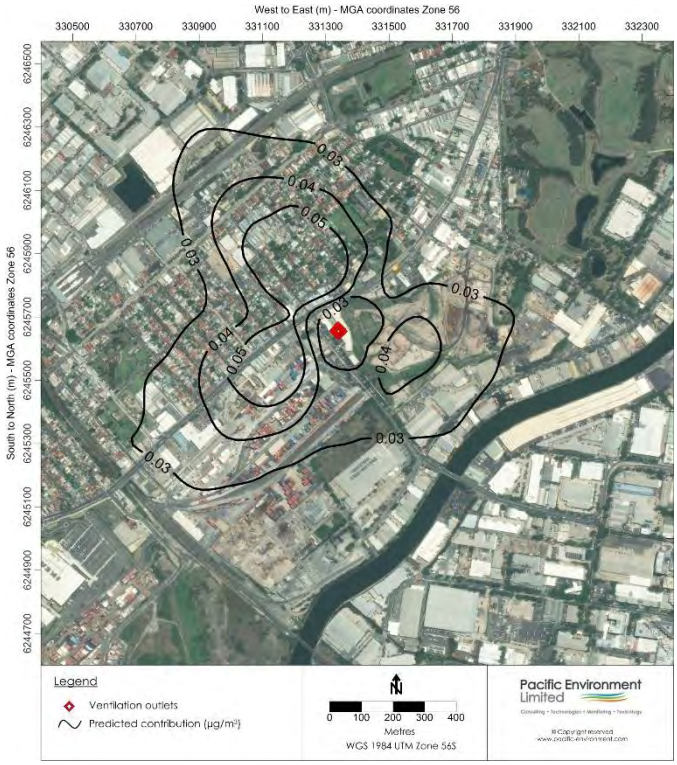


Figure K-141 Contour map showing annual mean $PM_{2.5}$ with the project for ventilation outlets only (SPI New M5 outlet, 2021-DS)

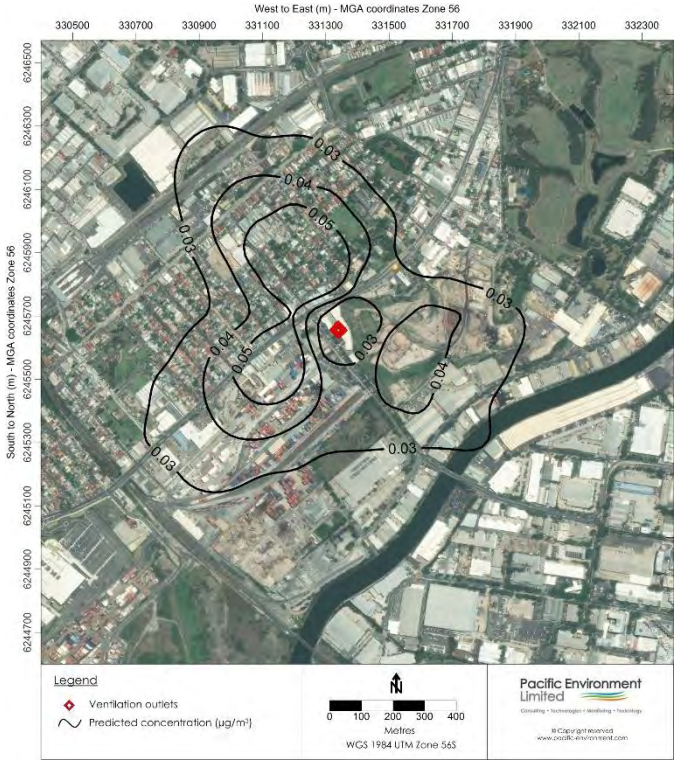


Figure K-142 Contour map showing annual mean $PM_{2.5}$ with the project for ventilation outlets only (SPI New M5 outlet, 2031-DS)

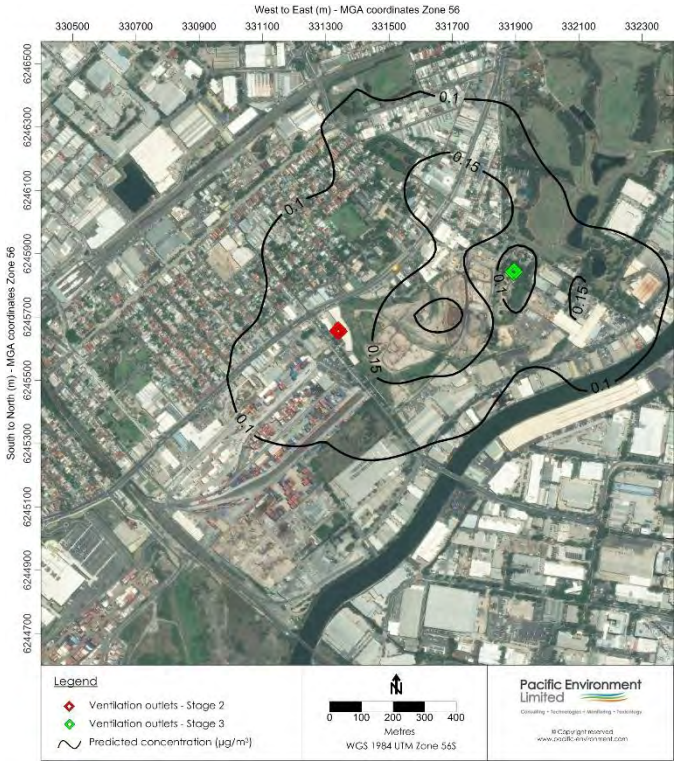


Figure K-143 Contour map showing annual mean PM2.5 with the project for ventilation outlets only (SPI New M5 outlet, 2031-DSC)

K.8 $PM_{2.5}$ (maximum 24-hour mean)

Table K-50 Maximum 24-hour $PM_{2.5}$ concentrations at community receptors

Receptor	Maximum 24-hour $PM_{2.5}$ concentration (µg/m^3)						Change with project (µg/m^3)			Change with project (%)		
	2014-BY	2021-DM	2021 DS	2031-DM	2031-DS	2031-DSC	2021	2031	2031-DSC	2021	2031	2031-DSC
SR01	23.9	23.8	23.7	23.9	23.8	24.0	0.0	-0.1	0.1	-0.2%	-0.3%	0.5%
SR02	24.6	24.1	24.2	24.1	23.9	24.1	0.1	-0.2	0.0	0.4%	-0.9%	0.1%
SR03	24.6	24.5	24.5	25.4	24.3	24.2	0.0	-1.1	-1.2	0.0%	-4.4%	-4.8%
SR04	25.0	24.9	27.9	24.4	25.5	25.1	3.0	1.1	0.7	12.1%	4.4%	3.0%
SR05	23.8	24.1	24.2	23.7	24.0	23.9	0.1	0.3	0.1	0.6%	1.1%	0.5%
SR06	25.8	25.6	25.1	26.5	26.3	25.2	-0.5	-0.1	-1.3	-1.9%	-0.5%	-4.8%
SR07	26.6	25.0	25.1	24.3	24.3	24.6	0.1	0.0	0.3	0.6%	-0.2%	1.1%
SR08	25.2	24.2	25.3	26.7	24.7	24.1	1.2	-2.0	-2.6	4.8%	-7.4%	-9.6%
SR09	23.5	23.4	23.6	23.6	23.6	23.6	0.2	0.0	0.0	0.8%	0.1%	0.1%
SR10	24.1	23.7	23.8	23.8	23.8	24.0	0.1	0.0	0.2	0.4%	0.0%	1.0%
SR11	23.6	23.7	23.5	23.6	23.7	23.6	-0.2	0.0	-0.1	-0.9%	0.2%	-0.3%
SR12	25.3	24.0	23.7	23.9	24.0	24.0	-0.2	0.1	0.0	-0.9%	0.4%	0.2%
SR13	23.9	23.9	23.5	26.2	23.9	23.7	-0.4	-2.3	-2.4	-1.6%	-8.7%	-9.3%
SR14	23.9	24.0	23.8	24.0	23.6	23.8	-0.2	-0.4	-0.1	-0.8%	-1.7%	-0.6%
SR15	23.8	24.2	23.6	23.8	23.8	24.0	-0.6	0.1	0.2	-2.5%	0.2%	1.0%
SR16	24.5	24.6	23.9	23.9	23.6	25.8	-0.7	-0.3	1.9	-3.0%	-1.2%	7.9%
SR17	23.9	23.8	23.8	23.6	23.7	23.6	0.0	0.1	0.0	0.1%	0.2%	-0.1%
SR18	23.7	23.5	23.4	23.4	23.4	24.8	-0.1	0.0	1.4	-0.5%	0.2%	6.1%
SR19	23.7	23.4	23.6	23.6	23.6	23.5	0.2	0.0	-0.1	0.8%	0.0%	-0.5%
SR20	23.7	23.5	23.6	23.4	23.5	23.6	0.0	0.1	0.2	0.2%	0.3%	0.7%
SR21	23.8	23.7	23.5	23.8	23.8	23.6	-0.2	0.0	-0.2	-1.0%	-0.1%	-0.8%
SR22	23.6	23.5	23.5	23.5	23.4	23.5	-0.1	-0.1	-0.1	-0.3%	-0.5%	-0.3%
SR23	23.9	23.8	23.6	23.5	23.7	23.7	-0.2	0.2	0.2	-1.0%	0.8%	0.9%
SR24	24.3	24.2	24.4	24.2	24.5	24.2	0.2	0.2	0.0	0.8%	1.0%	0.1%
SR25	23.8	23.5	23.8	23.6	23.7	23.5	0.3	0.1	-0.1	1.3%	0.5%	-0.5%
SR26	24.0	23.7	23.9	23.7	23.9	23.7	0.2	0.1	0.0	0.9%	0.6%	-0.1%
SR27	23.6	23.4	23.6	23.4	23.6	23.4	0.2	0.2	0.0	1.0%	0.8%	0.1%
SR28	23.5	23.5	23.5	23.4	23.4	23.5	-0.1	0.0	0.1	-0.2%	-0.1%	0.4%
SR29	23.3	23.4	23.5	23.3	23.5	23.3	0.1	0.2	0.0	0.4%	0.9%	0.1%
SR30	23.4	23.4	23.6	23.5	23.5	23.5	0.3	-0.1	-0.1	1.1%	-0.2%	-0.3%
SR31	23.8	23.5	23.4	23.5	23.6	23.5	-0.1	0.1	0.0	-0.3%	0.6%	0.1%
SR32	24.3	23.8	23.8	23.8	23.8	23.7	0.0	0.0	-0.1	-0.1%	-0.1%	-0.4%
SR33	23.7	23.9	23.3	23.4	24.1	23.4	-0.5	0.7	0.1	-2.3%	3.2%	0.3%
SR34	23.9	23.6	25.6	23.5	24.4	23.6	2.0	0.8	0.1	8.4%	3.5%	0.3%
SR35	23.4	23.3	23.4	23.4	23.3	23.4	0.1	-0.1	0.0	0.3%	-0.6%	0.0%

Table K-51 Maximum 24-hour $PM_{2.5}$ concentrations at community receptors, ranked by concentration

Rank	Ranking by concentration (µg/m^3)					
	2014-BY	2021-DM	2021 DS	2031-DM	2031-DS	2031-DSC
1	26.6	25.6	27.9	26.7	26.3	25.8
2	25.8	25.0	25.6	26.5	25.5	25.2
3	25.3	24.9	25.3	26.2	24.7	25.1
4	25.2	24.6	25.1	25.4	24.5	24.8
5	25.0	24.5	25.1	24.4	24.4	24.6
6	24.6	24.2	24.5	24.3	24.3	24.2
7	24.6	24.2	24.4	24.2	24.3	24.2
8	24.5	24.2	24.2	24.1	24.1	24.1
9	24.3	24.1	24.2	24.0	24.0	24.1
10	24.3	24.1	23.9	23.9	24.0	24.0

Table K-52 Maximum 24-hour $PM_{2.5}$ concentrations at community receptors, ranked by increase and by decrease in concentration with project

Rank	Ranking by increase in concentration with project (µg/m^3)			Ranking by decrease in concentration with project (µg/m^3)		
	2021-DS	2031-DS	2031-DSC	2021-DS	2031-DS	2031-DSC
1	3.0	1.1	1.9	-0.7	-2.3	-2.6
2	2.0	0.8	1.4	-0.6	-2.0	-2.4
3	1.2	0.7	0.7	-0.5	-1.1	-1.3
4	0.3	0.3	0.3	-0.5	-0.4	-1.2
5	0.3	0.2	0.2	-0.4	-0.3	-0.2
6	0.2	0.2	0.2	-0.2	-0.2	-0.1
7	0.2	0.2	0.2	-0.2	-0.1	-0.1
8	0.2	0.2	0.2	-0.2	-0.1	-0.1
9	0.2	0.1	0.1	-0.2	-0.1	-0.1
10	0.2	0.1	0.1	-0.2	-0.1	-0.1

Table K-53 Maximum 24-hour $PM_{2.5}$ concentrations at community receptors, ranked by percentage increase and by decrease in concentration with project

Rank	Ranking by % increase in concentration with project (µg/m^3)			Ranking by % decrease in concentration with project (µg/m^3)		
	2021-DS	2031-DS	2031-DSC	2021-DS	2031-DS	2031-DSC
1	12.1%	4.4%	7.9%	-3.0%	-8.7%	-9.6%
2	8.4%	3.5%	6.1%	-2.5%	-7.4%	-9.3%
3	4.8%	3.2%	3.0%	-2.3%	-4.4%	-4.8%
4	1.3%	1.1%	1.1%	-1.9%	-1.7%	-4.8%
5	1.1%	1.0%	1.0%	-1.6%	-1.2%	-0.8%
6	1.0%	0.9%	1.0%	-1.0%	-0.9%	-0.6%
7	0.9%	0.8%	0.9%	-1.0%	-0.6%	-0.5%
8	0.8%	0.8%	0.7%	-0.9%	-0.5%	-0.5%
9	0.8%	0.6%	0.5%	-0.9%	-0.5%	-0.4%
10	0.8%	0.6%	0.5%	-0.8%	-0.3%	-0.3%

Table K-54 Maximum 24-hour $PM_{2.5}$ concentrations at RWR receptors, ranked by concentration

Rank	Ranking by concentration (µg/m^3)					
	2014-BY	2021-DM	2021 DS	2031-DM	2031-DS	2031-DSC
1	44.3	36.0	33.6	36.3	33.2	32.0
2	39.5	34.4	31.6	33.8	32.4	29.7
3	38.9	34.3	31.6	32.7	32.2	29.5
4	38.7	33.8	31.5	32.2	31.7	29.5
5	38.5	33.2	31.4	31.9	31.6	29.4
6	38.3	33.1	31.2	31.9	31.5	29.4
7	38.2	32.5	31.1	31.8	31.5	29.3
8	37.9	32.5	31.1	31.8	31.4	29.2
9	37.7	32.4	31.1	31.8	31.2	29.2
10	37.4	32.3	30.8	31.5	31.2	29.2

Table K-55 Maximum 24-hour $PM_{2.5}$ concentrations at RWR receptors, ranked by increase and by decrease in concentration with project

Rank	Ranking by increase in concentration with project (µg/m^3)			Ranking by decrease in concentration with project (µg/m^3)		
	2021-DS	2031-DS	2031-DSC	2021-DS	2031-DS	2031-DSC
1	4.9	4.2	4.5	-10.6	-10.2	-11.8
2	3.9	3.5	4.5	-9.0	-9.4	-10.4
3	3.8	3.1	3.9	-8.8	-6.3	-7.1
4	3.7	3.1	3.6	-8.7	-6.3	-6.9
5	3.7	3.1	3.5	-8.4	-5.7	-6.8
6	3.4	3.1	3.5	-8.2	-5.3	-6.7
7	3.4	3.1	3.3	-8.1	-5.1	-6.2
8	3.2	2.8	3.2	-7.4	-5.0	-6.0
9	3.2	2.8	3.1	-6.7	-4.8	-6.0
10	3.1	2.8	3.0	-6.5	-4.7	-5.9

Table K-56 Maximum 24-hour $PM_{2.5}$ concentrations at RWR receptors, ranked by percentage increase and by decrease in concentration with project

Rank	Ranking by % increase in concentration with project (µg/m^3)			Ranking by % decrease in concentration with project (µg/m^3)		
	2021-DS	2031-DS	2031-DSC	2021-DS	2031-DS	2031-DSC
1	18.3%	19.0%	20.8%	-29.5%	-28.1%	-32.5%
2	17.4%	14.4%	20.4%	-28.5%	-27.8%	-30.8%
3	15.9%	14.2%	17.6%	-27.7%	-22.1%	-23.8%
4	15.4%	13.3%	15.5%	-26.6%	-20.5%	-23.4%
5	15.1%	13.3%	14.9%	-26.4%	-20.0%	-22.7%
6	15.1%	12.7%	14.8%	-25.7%	-18.6%	-22.0%
7	14.4%	12.7%	14.7%	-25.3%	-17.4%	-21.9%
8	14.1%	12.7%	14.7%	-24.1%	-17.3%	-21.1%
9	13.9%	12.6%	14.0%	-22.5%	-16.6%	-21.0%
10	13.8%	12.2%	13.5%	-21.9%	-16.5%	-20.1%

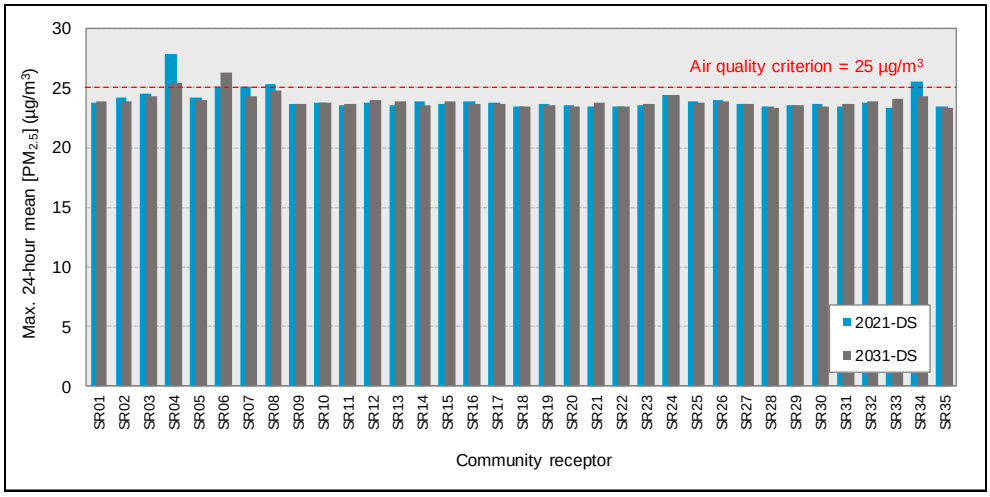


Figure K-144 Maximum 24-hour mean $PM_{2.5}$ at community receptors (2021-DS and 2031-DS)

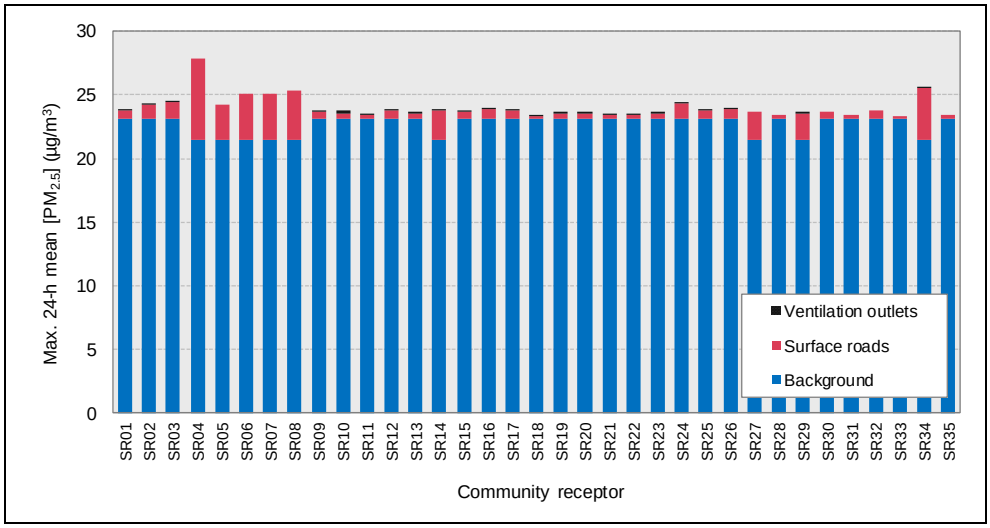


Figure K-145 Source contributions to maximum 24-hour $PM_{2.5}$ at community receptors (2021-DS)

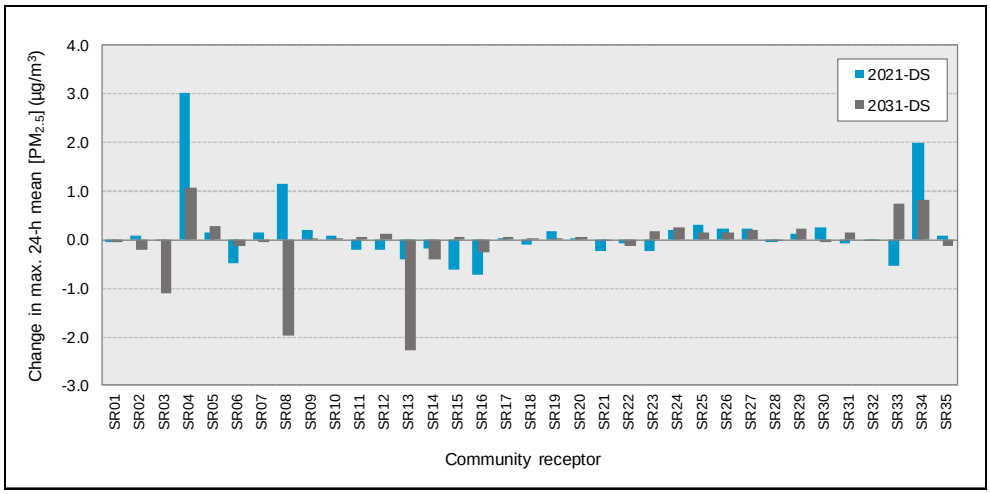


Figure K-146 Change in maximum 24-hour mean $PM_{2.5}$ at community receptors (2021-DS and 2031-DS)

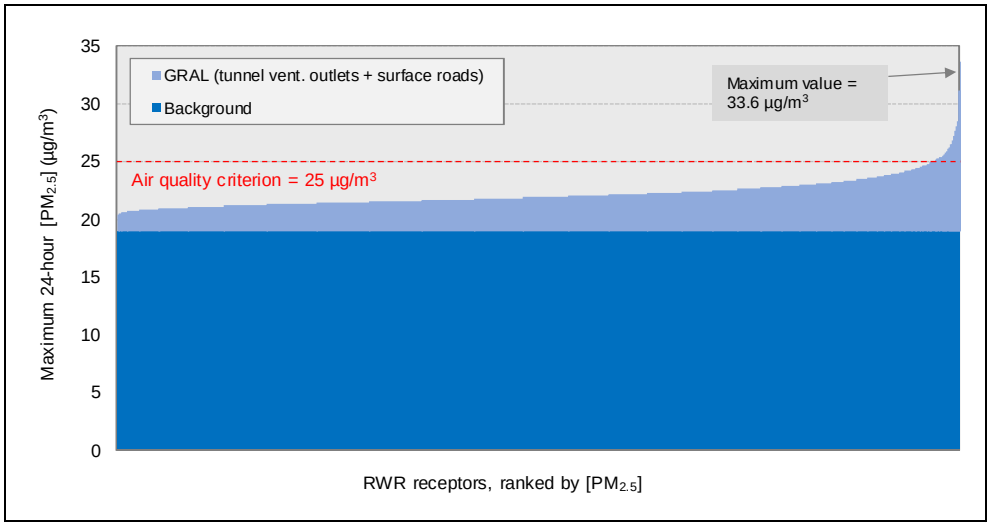


Figure K-147 Source contributions to maximum 24-hour $PM_{2.5}$ at RWR receptors (2021-DS)

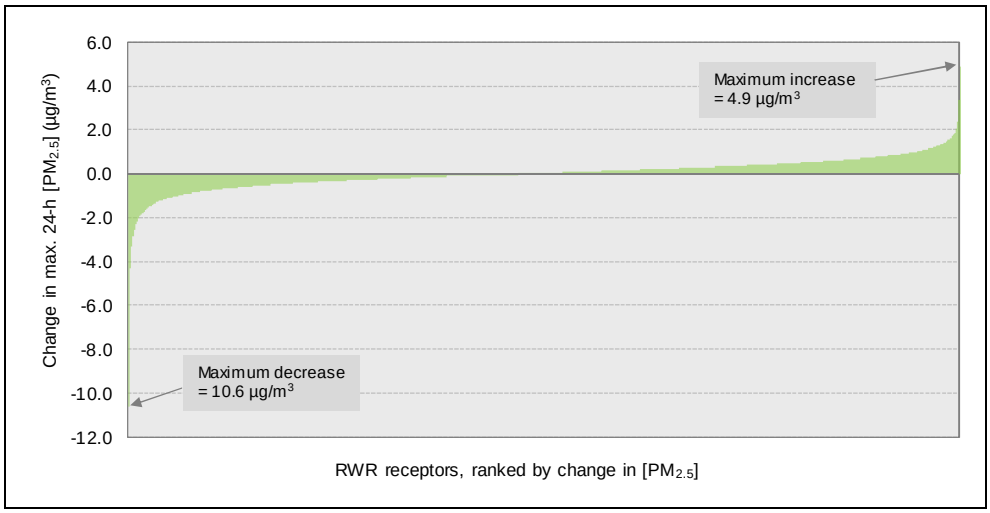


Figure K-148 Changes in maximum 24-hour $PM_{2.5}$ at RWR receptors (2021-DS)

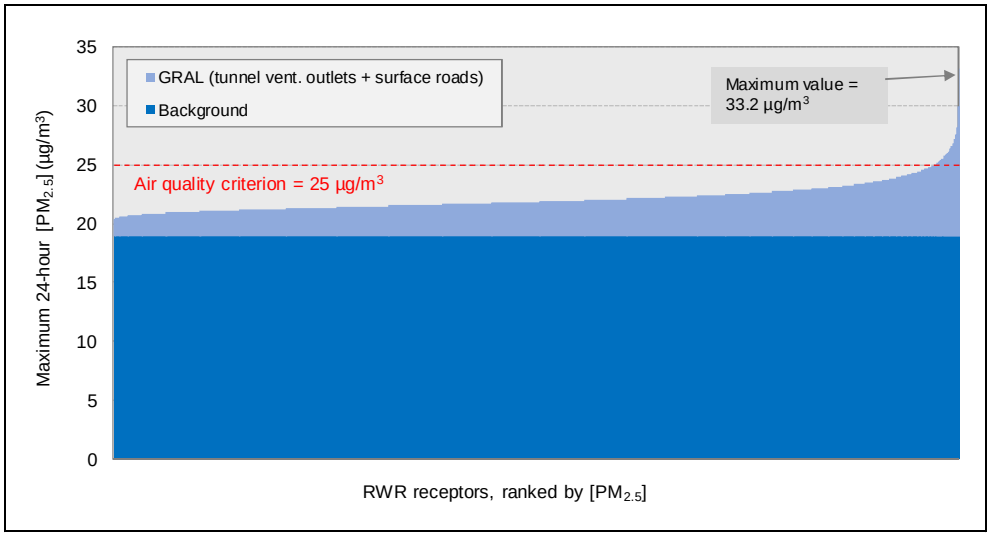


Figure K-149 Source contributions to maximum 24-hour $PM_{2.5}$ at RWR receptors (2031-DS)

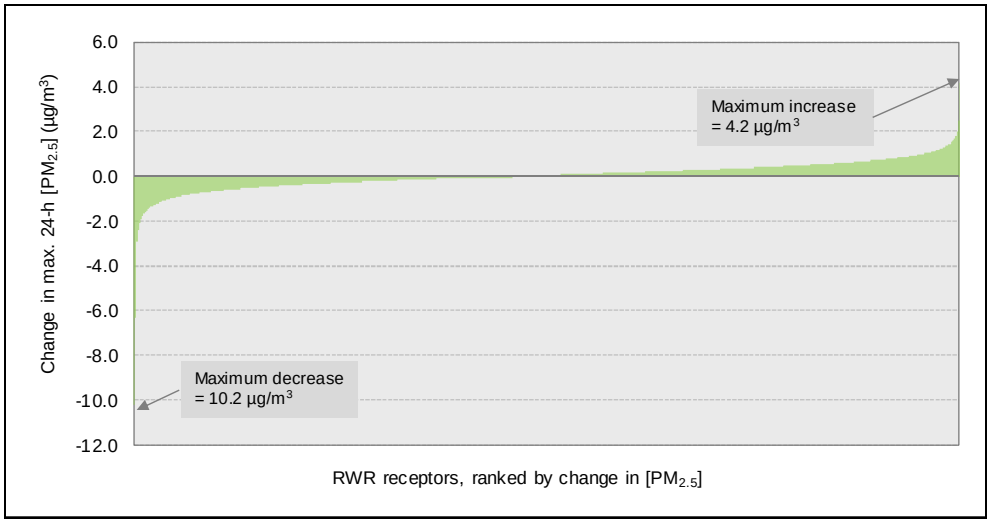


Figure K-150 Change in maximum 24-hour $PM_{2.5}$ at RWR receptors (2031-DS)

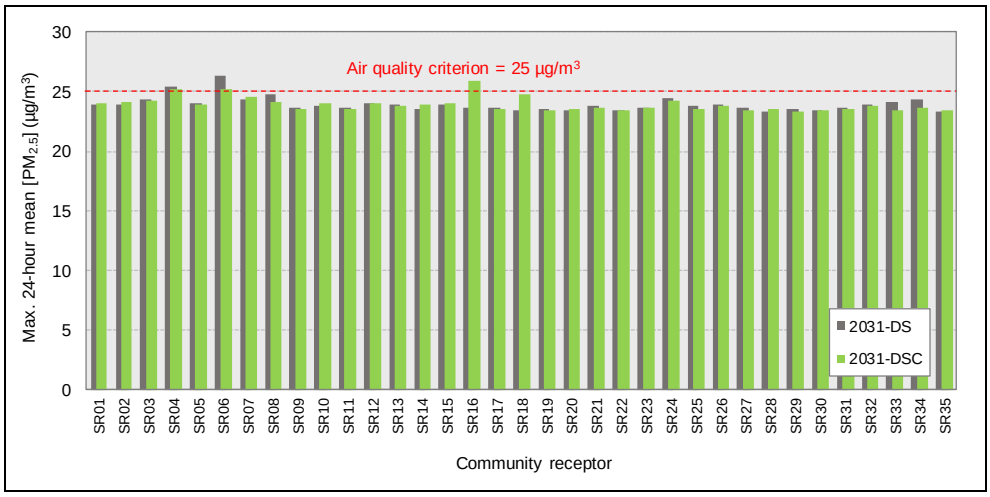


Figure K-151 Maximum 24-hour mean $PM_{2.5}$ at community receptors (2031-DS and 2031-DSC)

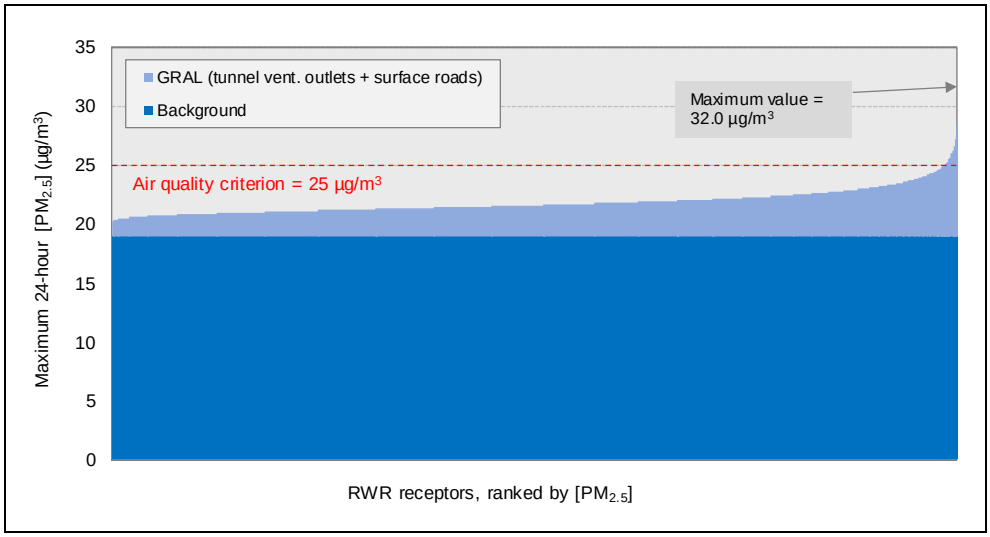


Figure K-152 Source contributions to maximum 24-hour $PM_{2.5}$ at RWR receptors (2031-DSC)

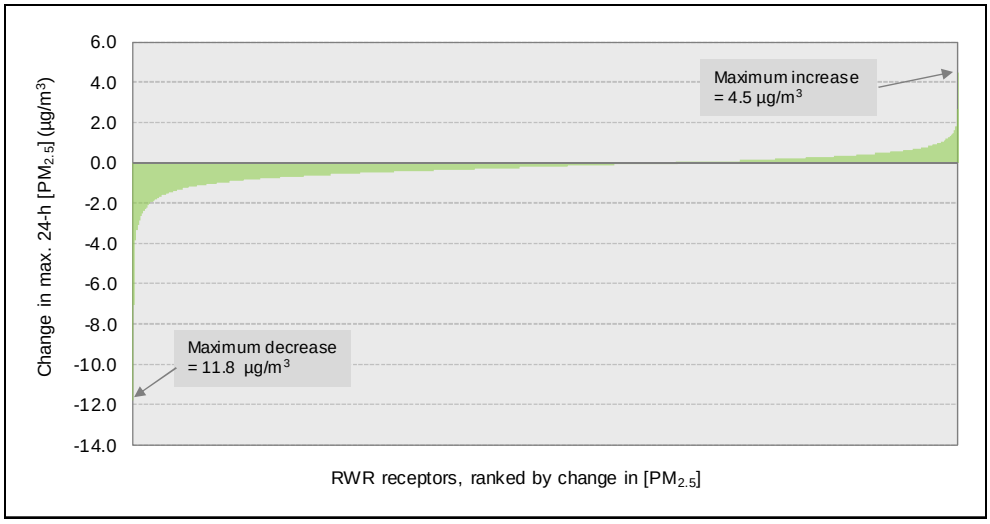


Figure K-153 Change in maximum 24-hour $PM_{2.5}$ at RWR receptors (2031-DSC)

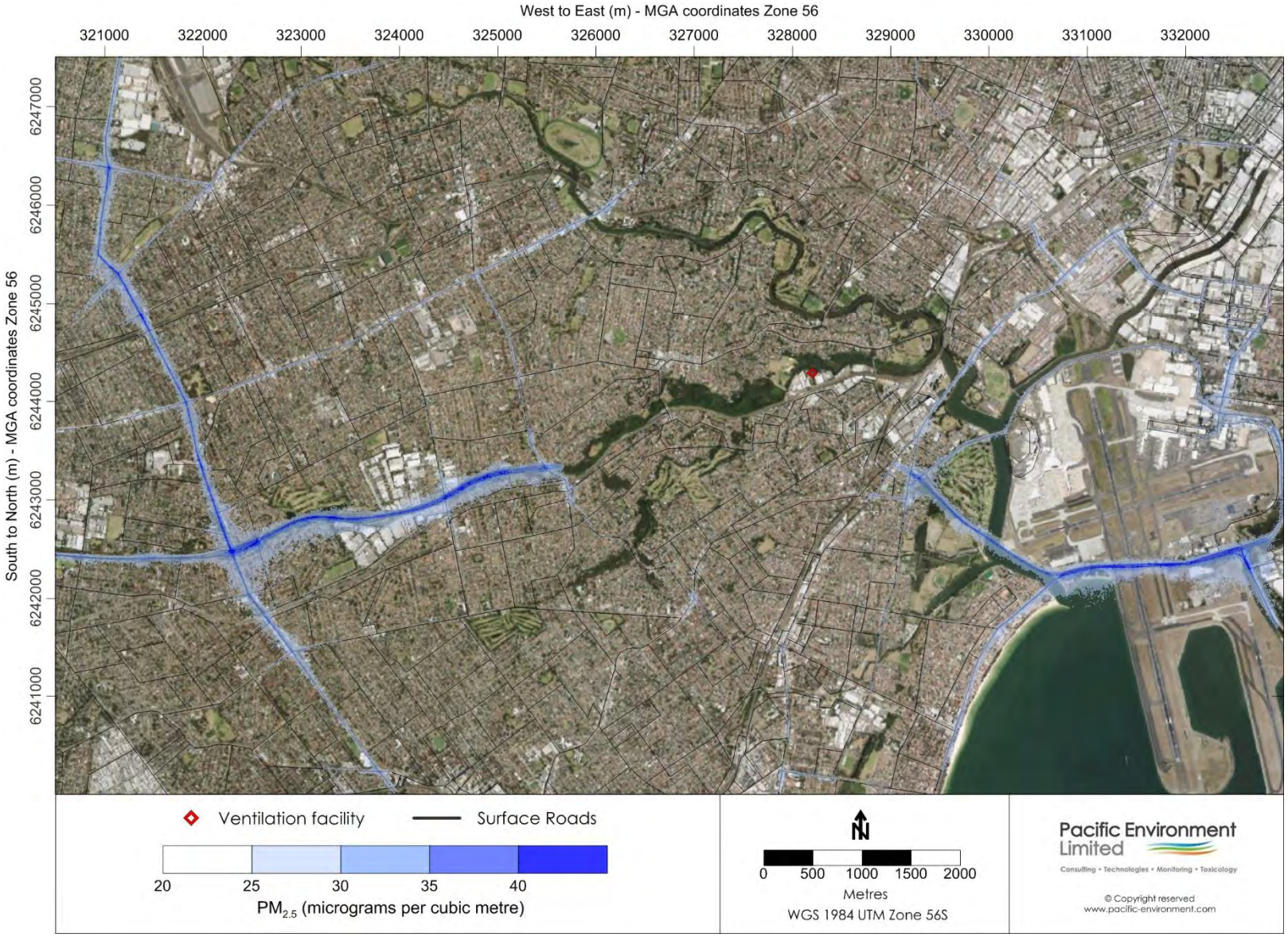


Figure K-154 Contour plot showing maximum 24-hour average $PM_{2.5}$ (2021-DM)

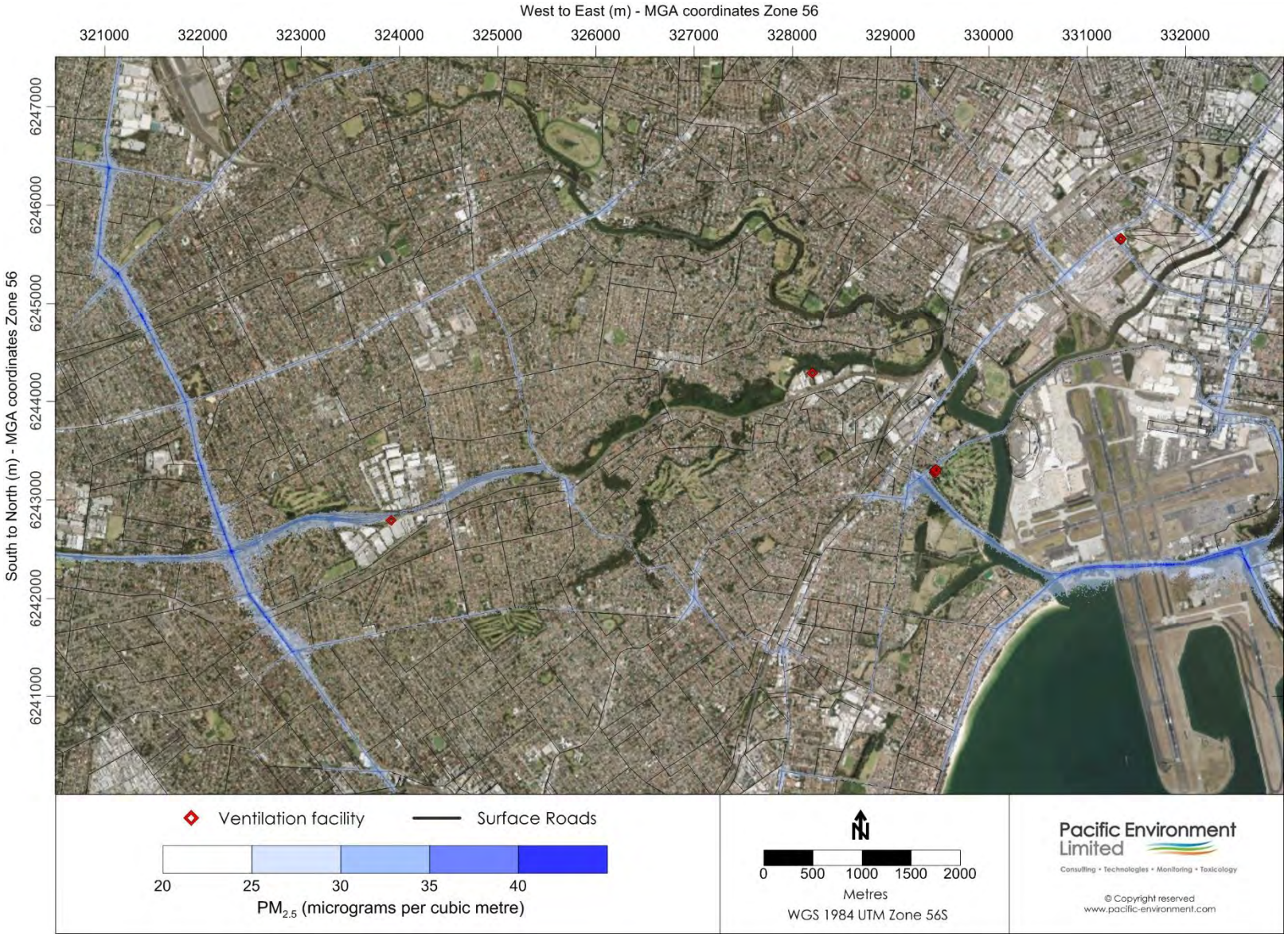


Figure K-155 Contour plot showing maximum 24-hour average $PM_{2.5}$ (2021-DS)



Figure K-156 Contour plot showing change in maximum 24-hour $PM_{2.5}$ with the project (2021-DS)

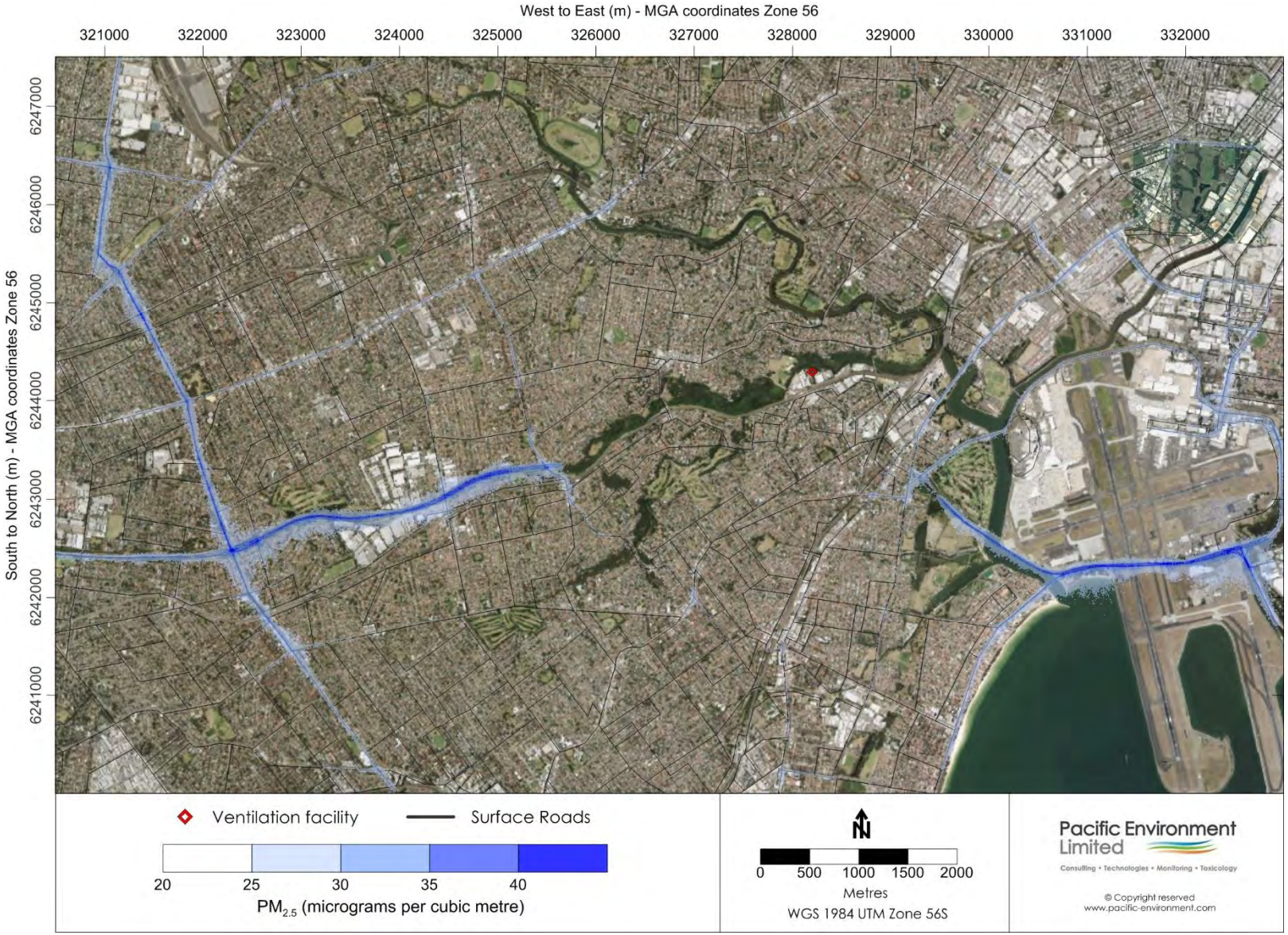


Figure K-157 Contour map showing maximum 24-hour average $PM_{2.5}$ (2031-DM)

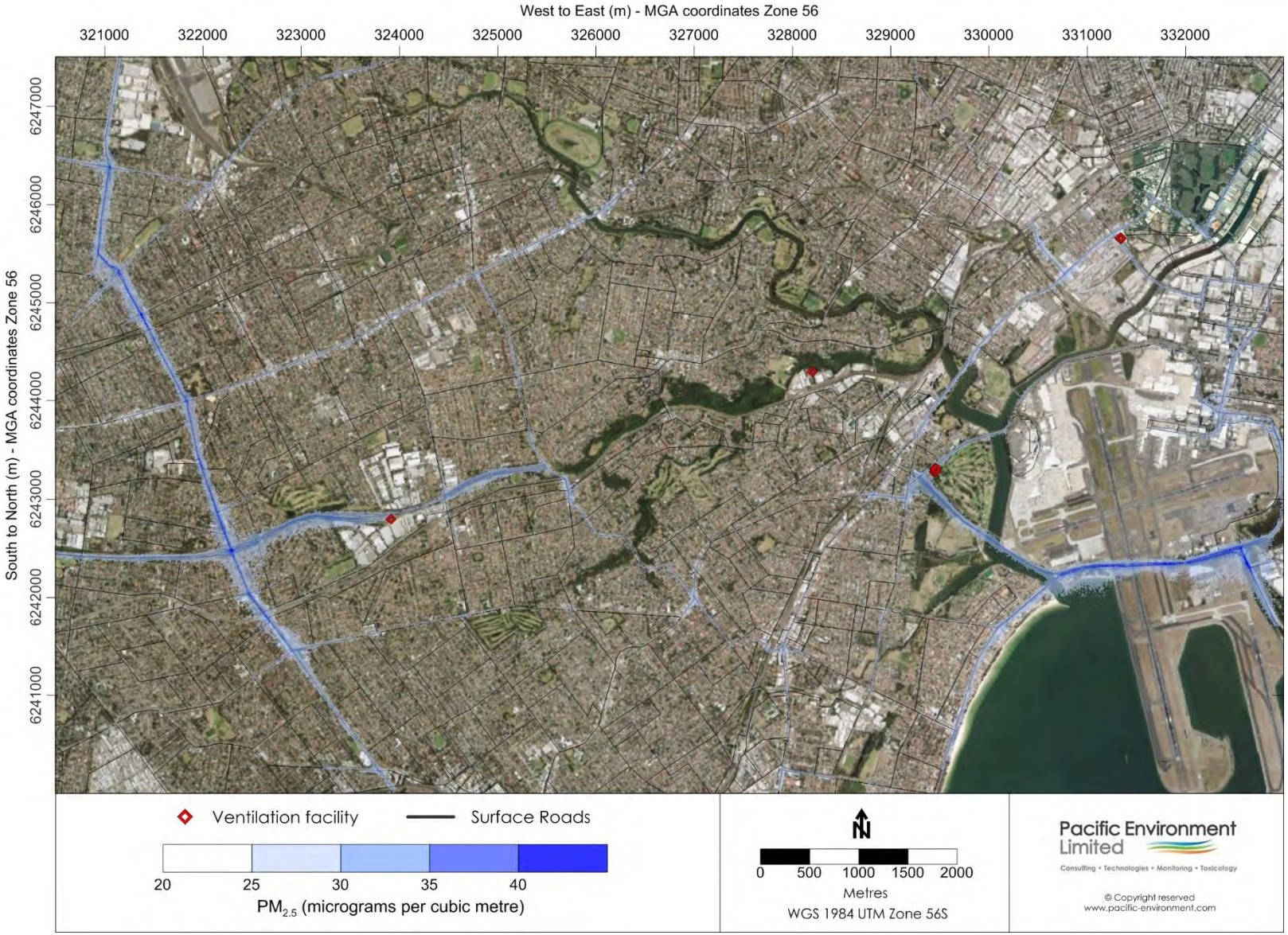


Figure K-158 Contour map showing maximum 24-hour average $PM_{2.5}$ (2031-DS)

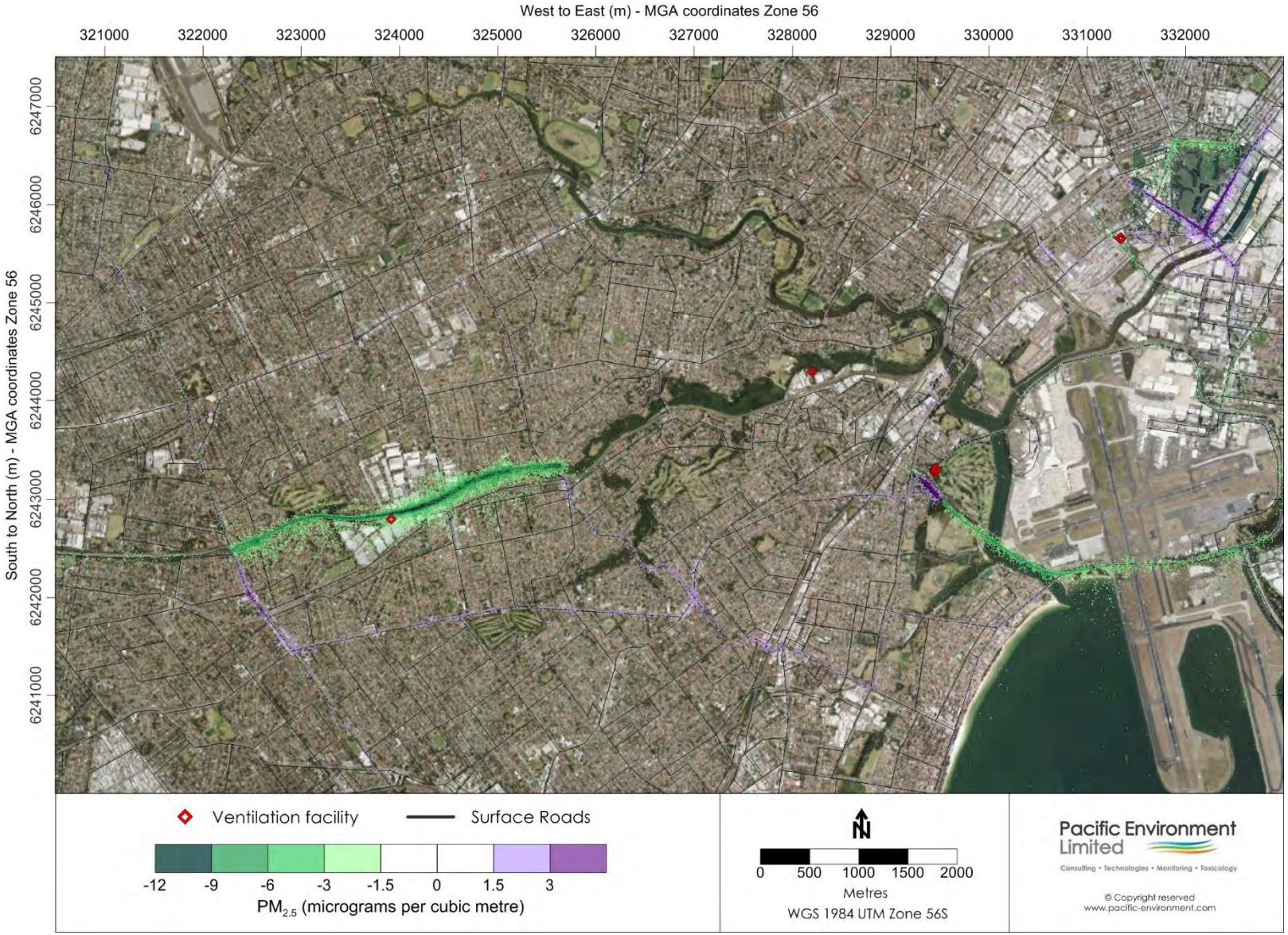


Figure K-159 Contour map showing change in maximum 24-hour average $PM_{2.5}$ with the project (2031-DS)

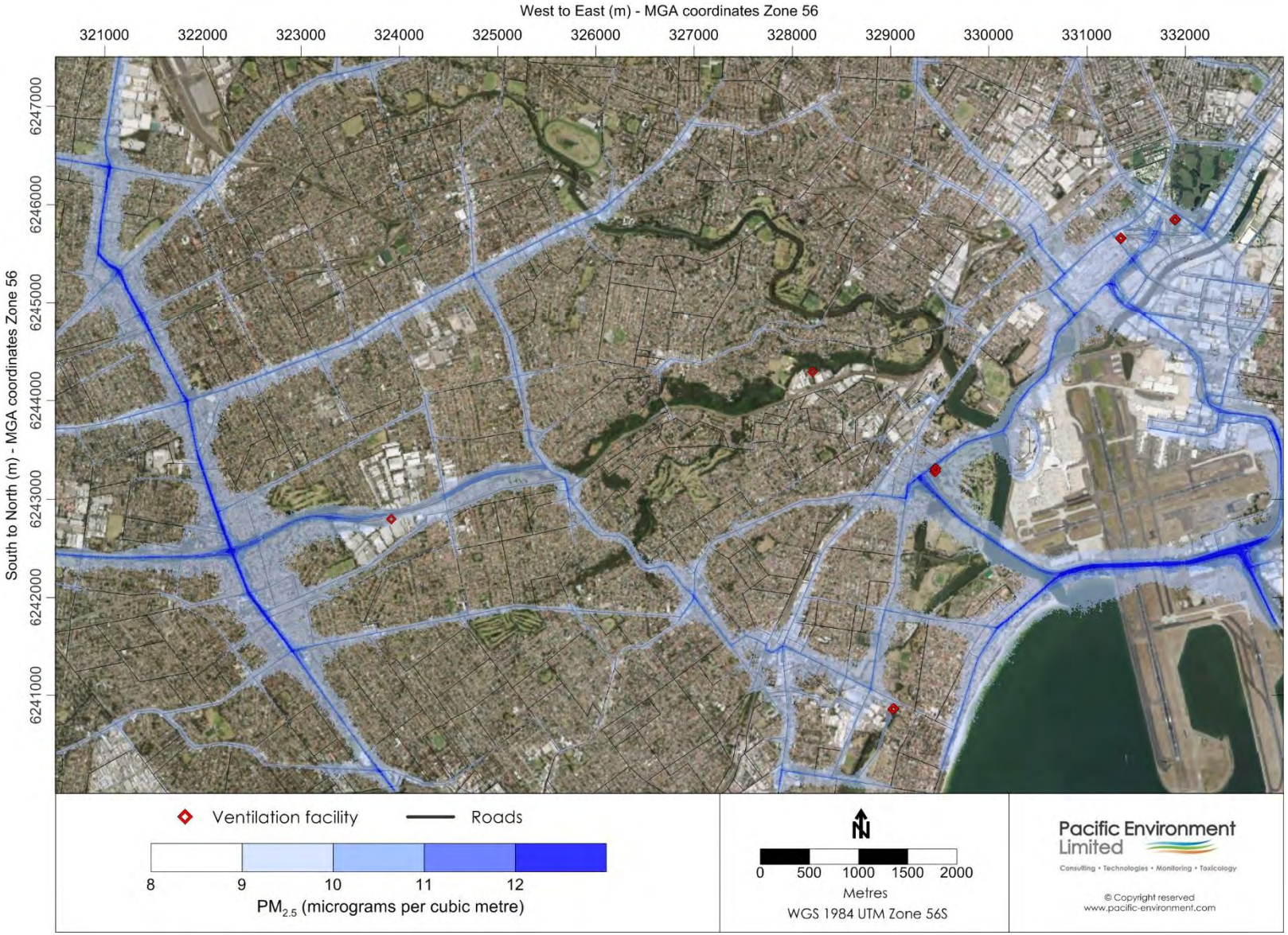


Table K-160 Contour map showing maximum 24-hour average $PM_{2.5}$ (2031-DSC)

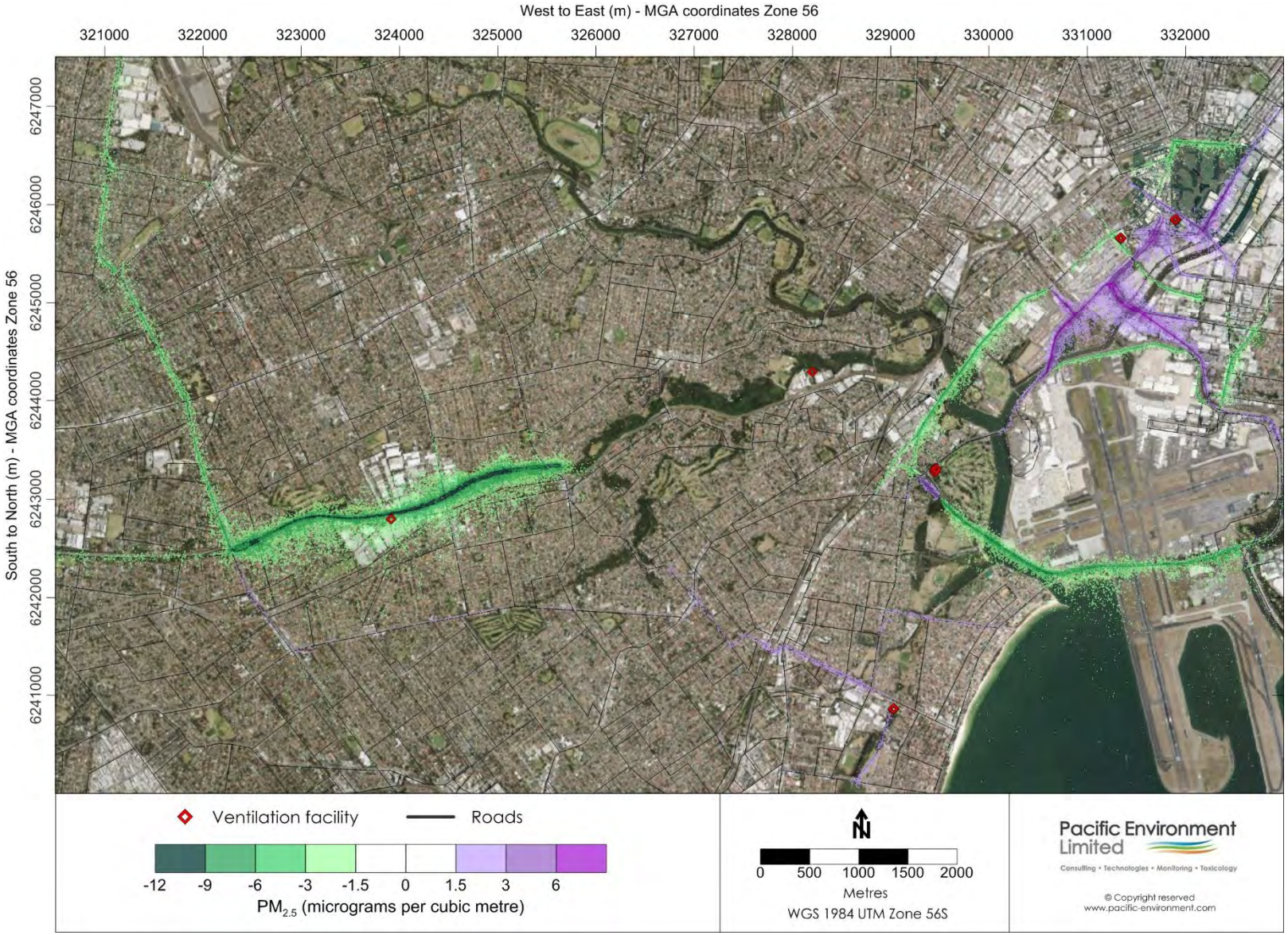


Figure K-161 Contour map showing change in maximum 24-hour average $PM_{2.5}$ with the project (2031-DSC)

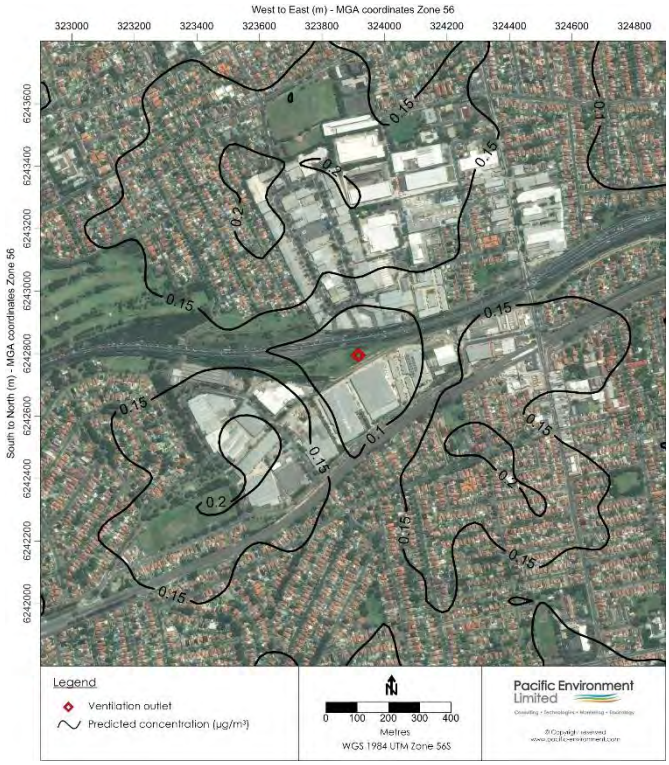


Figure K-162 Contour map showing maximum 24-hour $PM_{2.5}$ with the project for ventilation outlets only (Kingsgrove outlet, 2021-DS)

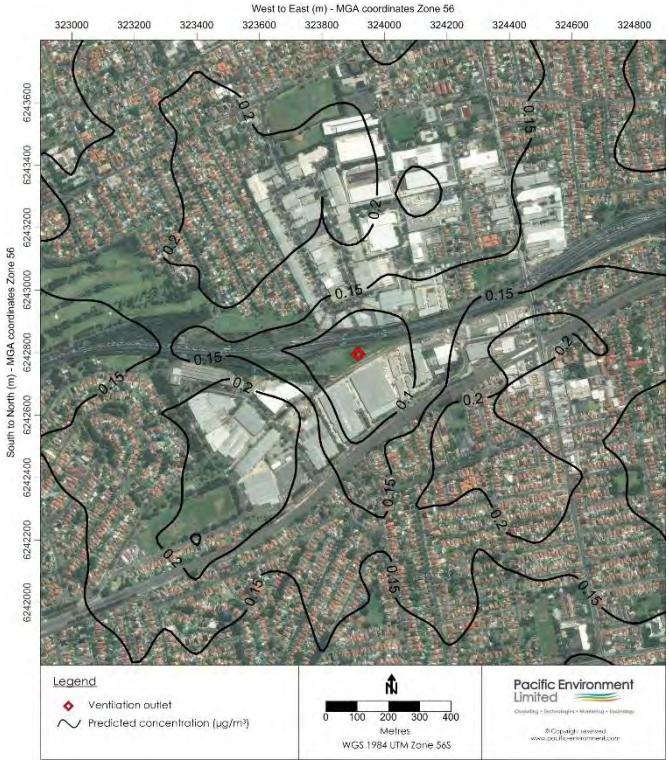


Figure K-163 Contour map showing maximum 24-hour $PM_{2.5}$ with the project for ventilation outlets only (Kingsgrove outlet, 2031-DS)



Figure K-164 Contour map showing maximum 24-hour $PM_{2.5}$ with the project for ventilation outlets only (Kingsgrove outlet, 2031-DSC)



Figure K-165 Contour map showing maximum 24-hour $PM_{2.5}$ with the project for ventilation outlets only (Arncliffe outlet, 2021-DS)

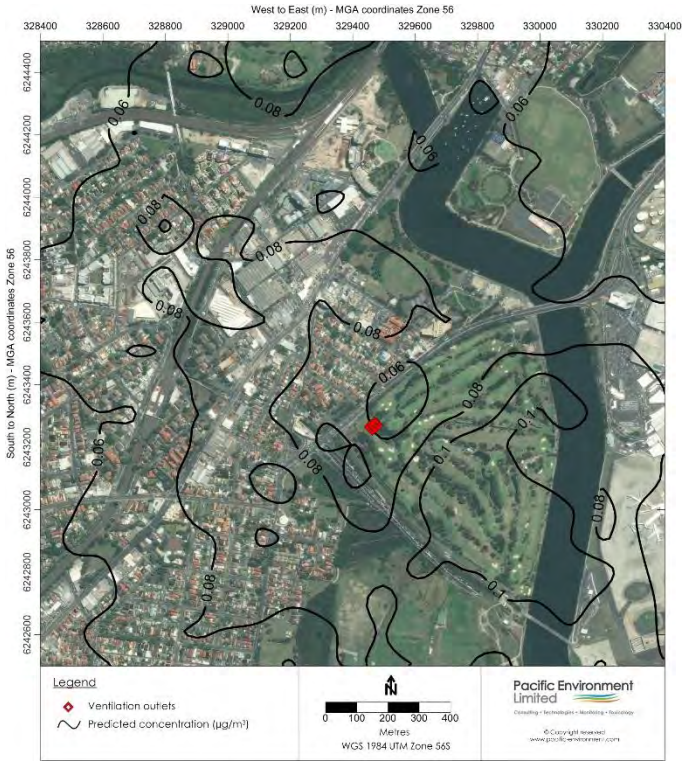


Figure K-166 Contour map showing maximum 24-hour $PM_{2.5}$ with the project for ventilation outlets only (Arncliffe outlet, 2031-DS)

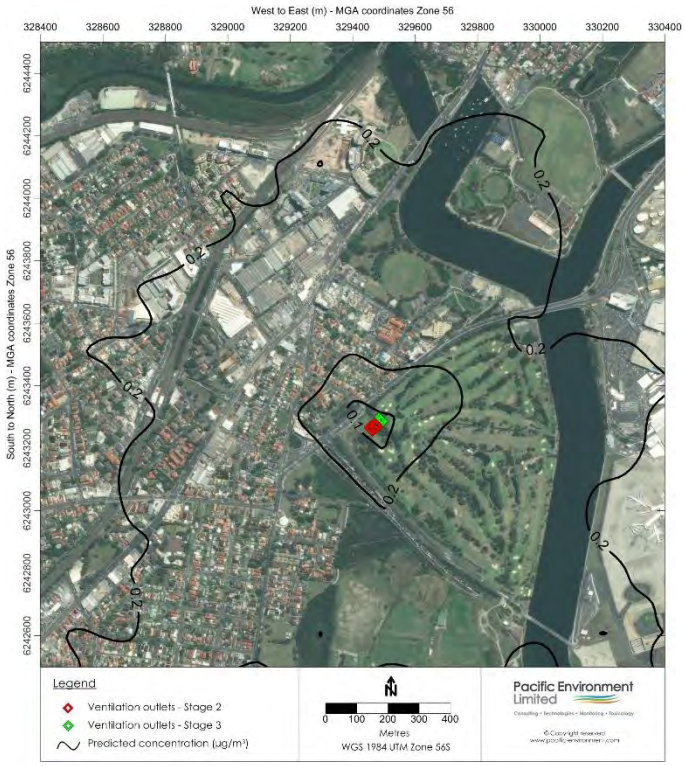


Figure K-167 Contour map showing maximum 24-hour $PM_{2.5}$ with the project for ventilation outlets only (Arncliffe outlet, 2031-DSC)

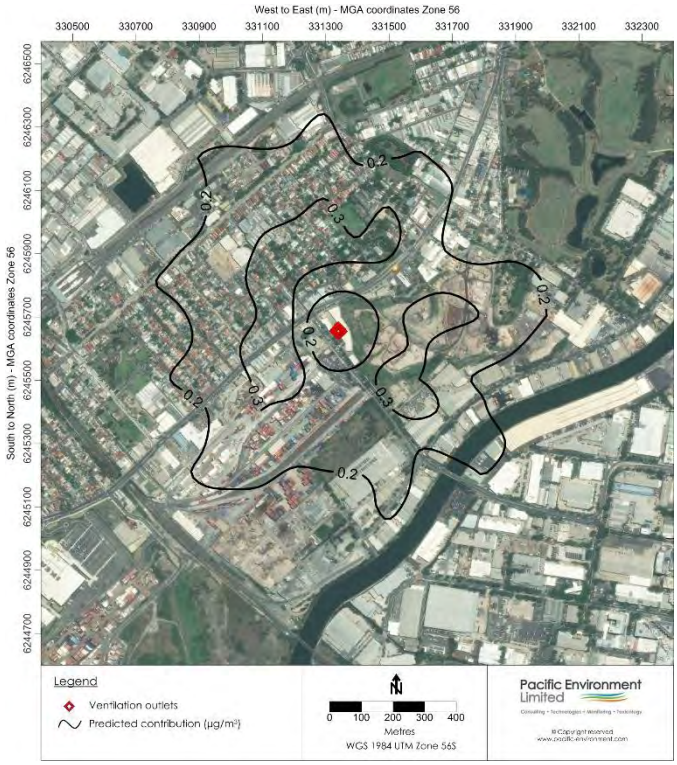


Figure K-168 Contour map showing maximum 24-hour $PM_{2.5}$ with the project for ventilation outlets only (SPI New M5 outlet, 2021-DS)

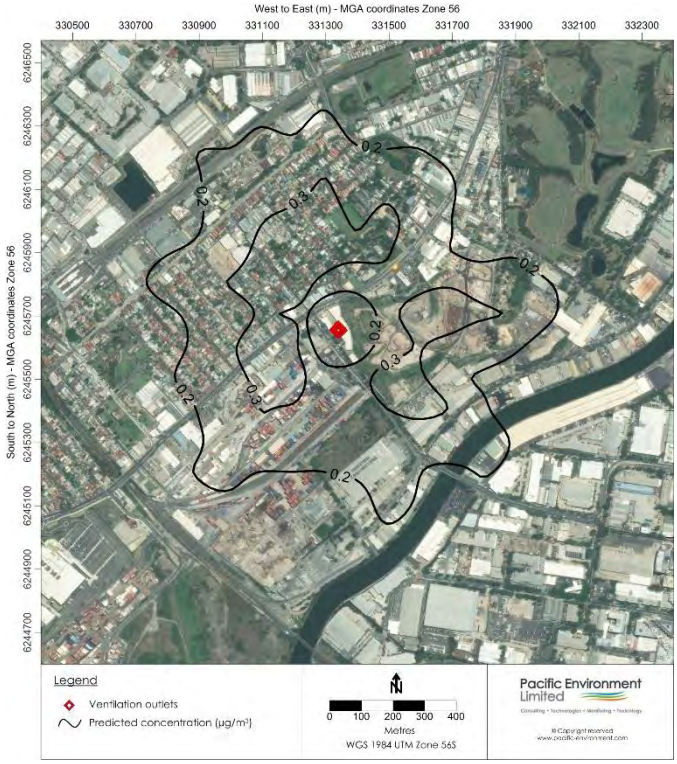


Figure K-169 Contour map showing maximum 24-hour $PM_{2.5}$ with the project for ventilation outlets only (SPI New M5 outlet, 2031-DS)

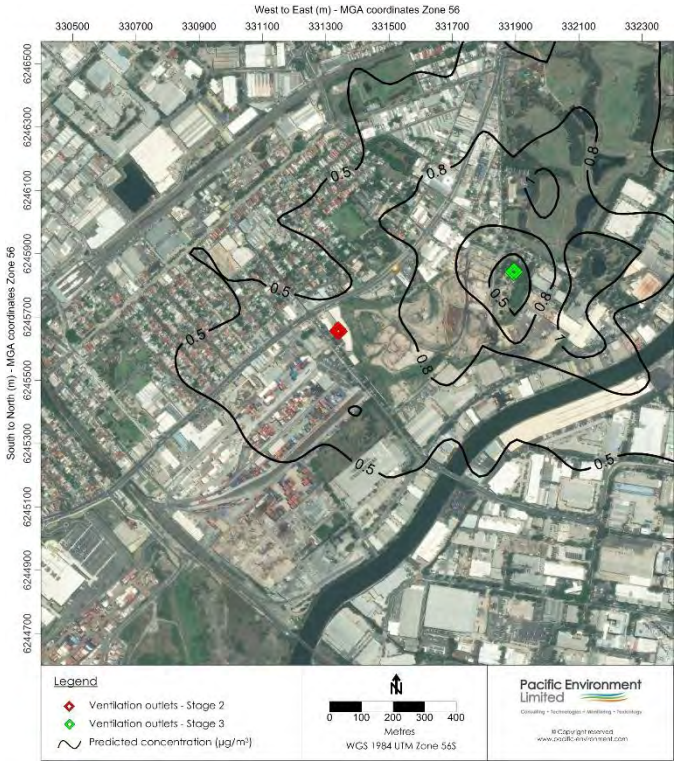


Figure K-170 Contour map showing maximum 24-hour $PM_{2.5}$ with the project for ventilation outlets only (SPI New M5 outlet, 2031-DSC)

K.9 Air toxics: benzene (maximum one-hour)

Table K-57 Maximum one-hour benzene concentrations (excluding background) at community receptors

Receptor	Maximum one-hour benzene concentration (µg/m^3)						Change with project (µg/m^3)		
	2014-BY[(a)]	2021-DM	2021 DS	2031-DM	2031-DS	2031-DSC	2021	2031	2031-DSC
SR01	-	4.6	6.8	3.7	3.5	4.1	2.2	-0.2	0.4
SR02	-	7.0	7.6	5.4	3.5	4.7	0.6	-1.9	-0.7
SR03	-	10.9	7.9	6.8	5.7	4.4	-3.0	-1.1	-2.4
SR04	-	10.9	9.3	5.1	4.8	4.1	-1.6	-0.3	-1.0
SR05	-	5.4	6.5	4.9	4.0	3.7	1.1	-0.9	-1.3
SR06	-	7.9	10.6	5.0	5.2	3.8	2.7	0.2	-1.2
SR07	-	8.1	6.3	4.1	4.0	4.9	-1.8	0.0	0.8
SR08	-	5.9	6.8	4.2	3.1	3.8	0.9	-1.0	-0.4
SR09	-	4.9	5.4	3.4	4.0	3.9	0.5	0.6	0.6
SR10	-	5.2	7.4	3.1	2.6	2.5	2.3	-0.5	-0.6
SR11	-	4.3	4.6	4.3	4.6	2.6	0.3	0.3	-1.7
SR12	-	3.7	4.0	3.0	3.0	3.2	0.2	0.0	0.2
SR13	-	10.0	7.3	4.5	4.1	2.7	-2.8	-0.4	-1.9
SR14	-	4.7	6.1	3.0	2.8	3.9	1.4	-0.2	1.0
SR15	-	5.4	4.7	3.2	2.8	2.8	-0.6	-0.3	-0.3
SR16	-	5.9	6.0	4.6	4.1	4.1	0.1	-0.5	-0.5
SR17	-	5.8	8.2	3.3	5.9	2.5	2.5	2.6	-0.7
SR18	-	4.5	4.8	1.8	2.8	2.5	0.3	1.0	0.7
SR19	-	4.3	3.2	2.3	2.5	2.6	-1.0	0.1	0.3
SR20	-	6.5	6.2	3.2	2.3	3.9	-0.3	-0.9	0.6
SR21	-	5.7	5.2	4.1	4.3	3.8	-0.5	0.2	-0.3
SR22	-	5.8	4.8	3.1	2.8	2.7	-1.0	-0.3	-0.5
SR23	-	9.3	7.0	4.3	5.1	5.5	-2.3	0.8	1.2
SR24	-	9.9	9.1	5.1	6.1	3.5	-0.7	0.9	-1.6
SR25	-	6.0	5.9	4.0	4.6	3.8	-0.1	0.6	-0.2
SR26	-	8.3	7.9	3.5	4.5	6.4	-0.3	1.0	2.9
SR27	-	5.0	5.8	2.7	3.4	3.1	0.8	0.7	0.3
SR28	-	5.2	4.5	2.7	3.8	4.7	-0.7	1.1	2.0
SR29	-	6.2	4.5	3.8	2.7	2.7	-1.6	-1.0	-1.1
SR30	-	8.3	5.1	3.1	4.3	2.5	-3.2	1.2	-0.6
SR31	-	7.8	6.5	4.6	3.2	5.7	-1.2	-1.4	1.1
SR32	-	7.5	5.9	4.3	3.7	4.4	-1.6	-0.6	0.1
SR33	-	6.8	8.2	4.2	4.1	3.0	1.3	-0.2	-1.2
SR34	-	8.9	6.1	4.1	3.0	6.3	-2.8	-1.0	2.2
SR35	-	5.7	3.9	3.1	4.6	3.4	-1.8	1.5	0.3

(a) THC was not modelled for the 2014-BY scenario as no monitoring data were available for model validation.

Table K-58 Maximum one-hour benzene concentrations (excluding background) at community receptors, ranked by concentration

Rank	Ranking by concentration (µg/m^3)					
	2014-BY	2021-DM	2021 DS	2031-DM	2031-DS	2031-DSC
1	-	10.9	10.6	6.8	6.1	6.4
2	-	10.9	9.3	5.4	5.9	6.3
3	-	10.0	9.1	5.1	5.7	5.7
4	-	9.9	8.2	5.1	5.2	5.5
5	-	9.3	8.2	5.0	5.1	4.9
6	-	8.9	7.9	4.9	4.8	4.7
7	-	8.3	7.9	4.6	4.6	4.7
8	-	8.3	7.6	4.6	4.6	4.4
9	-	8.1	7.4	4.5	4.6	4.4
10	-	7.9	7.3	4.3	4.5	4.1

Table K-59 Maximum one-hour benzene concentrations (excluding background) at community receptors, ranked by increase and by decrease in concentration with project

Rank	Ranking by increase in concentration with project (µg/m^3)			Ranking by decrease in concentration with project (µg/m^3)		
	2021-DS	2031-DS	2031-DSC	2021-DS	2031-DS	2031-DSC
1	2.7	2.6	2.9	-3.2	-1.9	-2.4
2	2.5	1.5	2.2	-3.0	-1.4	-1.9
3	2.3	1.2	2.0	-2.8	-1.1	-1.7
4	2.2	1.1	1.2	-2.8	-1.0	-1.6
5	1.4	1.0	1.1	-2.3	-1.0	-1.3
6	1.3	1.0	1.0	-1.8	-1.0	-1.2
7	1.1	0.9	0.8	-1.8	-0.9	-1.2
8	0.9	0.8	0.7	-1.6	-0.9	-1.1
9	0.8	0.7	0.6	-1.6	-0.6	-1.0
10	0.6	0.6	0.6	-1.6	-0.5	-0.7

Table K-60 Maximum one-hour benzene concentrations (excluding background) at RWR receptors, ranked by concentration

Rank	Ranking by concentration (µg/m^3)					
	2014-BY	2021-DM	2021 DS	2031-DM	2031-DS	2031-DSC
1	-	21.5	26.5	14.8	14.1	13.6
2	-	21.3	23.7	12.6	13.4	12.6
3	-	20.8	23.1	12.2	13.3	12.6
4	-	20.7	22.9	12.2	13.2	12.0
5	-	20.2	22.8	11.9	12.7	11.9
6	-	20.1	22.8	11.9	12.4	11.7
7	-	19.9	22.5	11.7	12.3	11.7
8	-	19.8	22.0	11.7	12.3	11.6
9	-	19.8	21.9	11.6	12.2	11.5
10	-	19.4	21.9	11.5	12.2	11.5

Table K-61 Maximum one-hour benzene concentrations (excluding background) at RWR receptors, ranked by increase and by decrease in concentration with project

Rank	Ranking by increase in concentration with project (µg/m^3)			Ranking by decrease in concentration with project (µg/m^3)		
	2021-DS	2031-DS	2031-DSC	2021-DS	2031-DS	2031-DSC
1	10.5	6.8	5.8	-9.9	-6.4	-6.7
2	10.3	5.7	5.3	-8.5	-5.1	-6.4
3	9.7	5.2	4.6	-7.9	-4.9	-6.3
4	9.1	5.1	4.5	-7.7	-4.4	-6.2
5	9.0	5.0	4.5	-7.4	-4.3	-5.9
6	9.0	4.8	4.4	-7.1	-4.3	-5.6
7	8.8	4.8	4.3	-7.0	-4.2	-5.5
8	8.6	4.7	4.2	-7.0	-4.2	-5.4
9	8.6	4.7	4.2	-6.9	-4.1	-5.3
10	8.5	4.6	4.1	-6.9	-4.1	-5.3

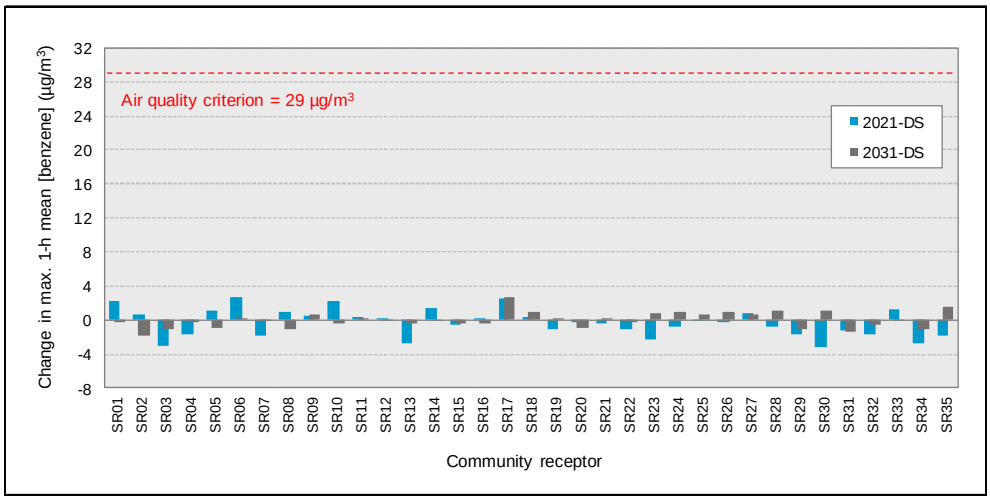


Figure K-171 Change in maximum one-hour mean benzene at community receptors (2021-DS and 2031-DS)

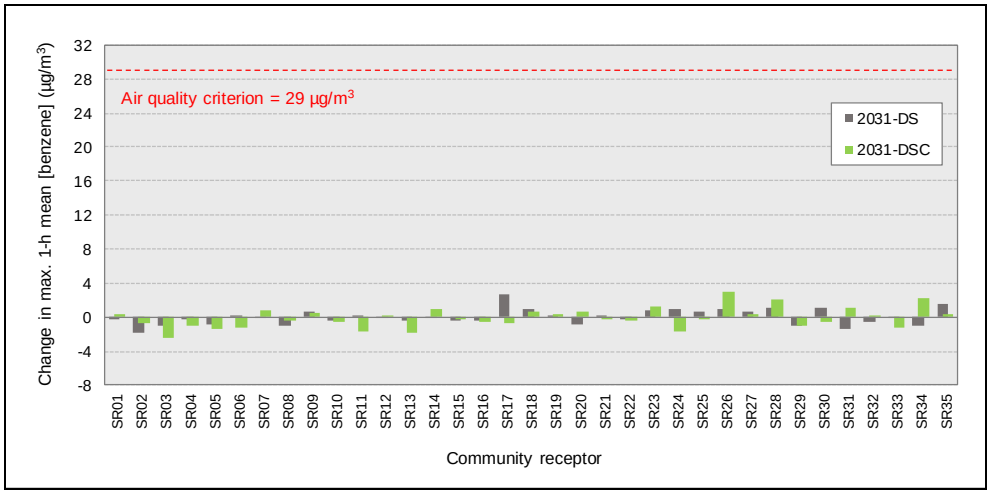


Figure K-172 Change in maximum one-hour mean benzene at community receptors (2031-DS and 2031-DSC)

K.10 Air toxics: benzo(a)pyrene (maximum one-hour)

Table K-62 Maximum one-hour benzo(a)pyrene concentrations (excluding background) at community receptors

Receptor	Maximum one-hour b(a)p concentration (µg/m^3)						Change with project (µg/m^3)		
	2014-BY	2021-DM	2021 DS	2031-DM	2031-DS	2031-DSC	2021	2031	2031-DSC
SR01	-	0.032	0.048	0.028	0.027	0.032	0.016	-0.002	0.003
SR02	-	0.049	0.054	0.041	0.027	0.036	0.004	-0.014	-0.006
SR03	-	0.077	0.056	0.052	0.043	0.033	-0.021	-0.008	-0.018
SR04	-	0.077	0.066	0.039	0.037	0.031	-0.011	-0.002	-0.008
SR05	-	0.038	0.046	0.038	0.031	0.028	0.008	-0.007	-0.010
SR06	-	0.056	0.075	0.038	0.040	0.029	0.019	0.002	-0.009
SR07	-	0.057	0.044	0.031	0.031	0.038	-0.013	0.000	0.006
SR08	-	0.042	0.048	0.032	0.024	0.029	0.007	-0.008	-0.003
SR09	-	0.035	0.038	0.026	0.030	0.030	0.004	0.005	0.004
SR10	-	0.037	0.053	0.024	0.020	0.019	0.016	-0.004	-0.005
SR11	-	0.031	0.033	0.033	0.035	0.020	0.002	0.002	-0.013
SR12	-	0.027	0.028	0.023	0.023	0.025	0.002	0.000	0.002
SR13	-	0.071	0.051	0.035	0.032	0.021	-0.020	-0.003	-0.014
SR14	-	0.033	0.043	0.023	0.022	0.030	0.010	-0.001	0.007
SR15	-	0.038	0.033	0.024	0.022	0.022	-0.004	-0.003	-0.003
SR16	-	0.041	0.043	0.036	0.032	0.032	0.001	-0.004	-0.004
SR17	-	0.041	0.058	0.025	0.045	0.019	0.017	0.020	-0.006
SR18	-	0.032	0.034	0.014	0.021	0.019	0.002	0.008	0.006
SR19	-	0.030	0.023	0.018	0.019	0.020	-0.007	0.001	0.002
SR20	-	0.046	0.044	0.025	0.018	0.030	-0.002	-0.007	0.005
SR21	-	0.041	0.037	0.031	0.033	0.029	-0.004	0.002	-0.002
SR22	-	0.041	0.034	0.024	0.022	0.020	-0.007	-0.002	-0.003
SR23	-	0.066	0.050	0.033	0.039	0.042	-0.016	0.006	0.010
SR24	-	0.070	0.065	0.039	0.047	0.027	-0.005	0.007	-0.012
SR25	-	0.043	0.042	0.031	0.035	0.029	-0.001	0.005	-0.002
SR26	-	0.058	0.056	0.027	0.034	0.049	-0.002	0.007	0.022
SR27	-	0.036	0.041	0.021	0.026	0.024	0.006	0.005	0.003
SR28	-	0.037	0.032	0.021	0.029	0.036	-0.005	0.008	0.015
SR29	-	0.044	0.032	0.029	0.021	0.021	-0.012	-0.008	-0.008
SR30	-	0.059	0.036	0.024	0.033	0.020	-0.023	0.009	-0.005
SR31	-	0.055	0.046	0.035	0.024	0.043	-0.009	-0.011	0.008
SR32	-	0.053	0.042	0.033	0.028	0.034	-0.012	-0.005	0.001
SR33	-	0.048	0.058	0.033	0.031	0.023	0.010	-0.001	-0.009
SR34	-	0.063	0.043	0.031	0.023	0.048	-0.019	-0.008	0.017
SR35	-	0.040	0.027	0.024	0.036	0.026	-0.013	0.012	0.002

Table K-63 Maximum one-hour benzo(a)pyrene concentrations (excluding background) at community receptors, ranked by concentration

Rank	Ranking by concentration (µg/m^3)					
	2014-BY	2021-DM	2021 DS	2031-DM	2031-DS	2031-DSC
1	-	0.077	0.075	0.052	0.047	0.049
2	-	0.077	0.066	0.041	0.045	0.048
3	-	0.071	0.065	0.039	0.043	0.043
4	-	0.070	0.058	0.039	0.040	0.042
5	-	0.066	0.058	0.038	0.039	0.038
6	-	0.063	0.056	0.038	0.037	0.036
7	-	0.059	0.056	0.036	0.036	0.036
8	-	0.058	0.054	0.035	0.035	0.034
9	-	0.057	0.053	0.035	0.035	0.033
10	-	0.056	0.051	0.033	0.034	0.032

Table K-64 Maximum one-hour benzo(a)pyrene concentrations (excluding background) at community receptors, ranked by increase and by decrease in concentration with project

Rank	Ranking by increase in concentration with project (µg/m^3)			Ranking by decrease in concentration with project (µg/m^3)		
	2021-DS	2031-DS	2031-DSC	2021-DS	2031-DS	2031-DSC
1	0.019	0.020	0.022	-0.02	-0.01	-0.02
2	0.017	0.012	0.017	-0.02	-0.01	-0.01
3	0.016	0.009	0.015	-0.02	-0.01	-0.01
4	0.016	0.008	0.010	-0.02	-0.01	-0.01
5	0.010	0.008	0.008	-0.02	-0.01	-0.01
6	0.010	0.007	0.007	-0.01	-0.01	-0.01
7	0.008	0.007	0.006	-0.01	-0.01	-0.01
8	0.007	0.006	0.006	-0.01	-0.01	-0.01
9	0.006	0.005	0.005	-0.01	0.00	-0.01
10	0.004	0.005	0.004	-0.01	0.00	-0.01

Table K-65 Maximum one-hour benzo(a)pyrene concentrations (excluding background) at RWR receptors, ranked by concentration

Rank	Ranking by concentration (µg/m^3)					
	2014-BY	2021-DM	2021 DS	2031-DM	2031-DS	2031-DSC
1	-	0.15	0.19	0.11	0.11	0.10
2	-	0.15	0.17	0.10	0.10	0.10
3	-	0.15	0.16	0.09	0.10	0.10
4	-	0.15	0.16	0.09	0.10	0.09
5	-	0.14	0.16	0.09	0.10	0.09
6	-	0.14	0.16	0.09	0.10	0.09
7	-	0.14	0.16	0.09	0.09	0.09
8	-	0.14	0.16	0.09	0.09	0.09
9	-	0.14	0.15	0.09	0.09	0.09
10	-	0.14	0.15	0.09	0.09	0.09

Table K-66 Maximum one-hour benzo(a)pyrene concentrations (excluding background) at RWR receptors, ranked by increase and by decrease in concentration with project

Rank	Ranking by increase in concentration with project (µg/m^3)			Ranking by decrease in concentration with project (µg/m^3)		
	2021-DS	2031-DS	2031-DSC	2021-DS	2031-DS	2031-DSC
1	0.07	0.05	0.04	-0.07	-0.05	-0.05
2	0.07	0.04	0.04	-0.06	-0.04	-0.05
3	0.07	0.04	0.04	-0.06	-0.04	-0.05
4	0.06	0.04	0.03	-0.05	-0.03	-0.05
5	0.06	0.04	0.03	-0.05	-0.03	-0.05
6	0.06	0.04	0.03	-0.05	-0.03	-0.04
7	0.06	0.04	0.03	-0.05	-0.03	-0.04
8	0.06	0.04	0.03	-0.05	-0.03	-0.04
9	0.06	0.04	0.03	-0.05	-0.03	-0.04
10	0.06	0.04	0.03	-0.05	-0.03	-0.04

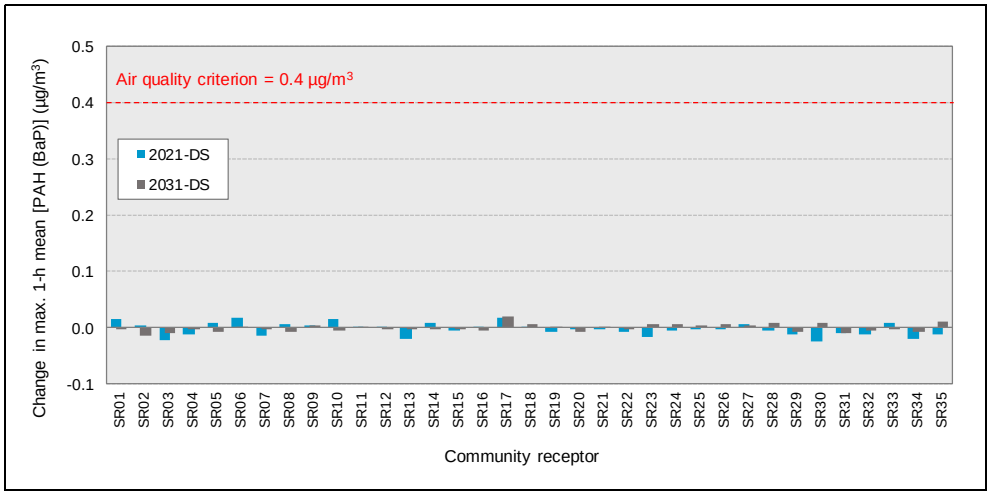


Figure K-173 Change in maximum one-hour mean b(a)p at community receptors (2021-DS, 2031-DS)

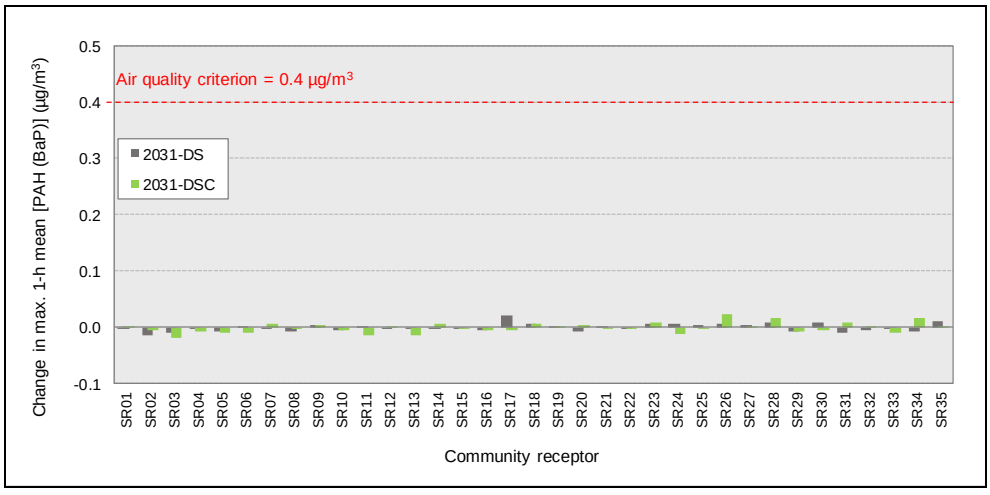


Figure K-174 Change in maximum one-hour mean b(a)p at community receptors (2031-DS, 2031-DSC)

K.11 Air toxics: formaldehyde (maximum one-hour)

Table K-67 Maximum one-hour formaldehyde concentrations (excluding background) at community receptors

Receptor	Maximum one-hour formaldehyde concentration (µg/m^3)						Change with project (µg/m^3)		
	2014-BY	2021-DM	2021 DS	2031-DM	2031-DS	2031-DSC	2021	2031	2031-DSC
SR01	-	2.7	4.0	3.1	2.9	3.4	1.3	-0.2	0.3
SR02	-	4.1	4.5	4.5	3.0	3.9	0.4	-1.6	-0.6
SR03	-	6.4	4.6	5.6	4.7	3.6	-1.8	-0.9	-2.0
SR04	-	6.4	5.5	4.3	4.0	3.4	-1.0	-0.2	-0.9
SR05	-	3.2	3.8	4.1	3.3	3.0	0.7	-0.8	-1.1
SR06	-	4.7	6.2	4.2	4.3	3.2	1.6	0.2	-1.0
SR07	-	4.8	3.7	3.4	3.4	4.1	-1.1	0.0	0.7
SR08	-	3.5	4.0	3.5	2.6	3.1	0.5	-0.9	-0.3
SR09	-	2.9	3.2	2.8	3.3	3.3	0.3	0.5	0.5
SR10	-	3.1	4.4	2.6	2.2	2.0	1.3	-0.4	-0.5
SR11	-	2.6	2.7	3.6	3.8	2.2	0.2	0.2	-1.4
SR12	-	2.2	2.4	2.5	2.5	2.7	0.1	0.0	0.2
SR13	-	5.9	4.3	3.8	3.4	2.2	-1.6	-0.3	-1.6
SR14	-	2.8	3.6	2.5	2.3	3.3	0.8	-0.1	0.8
SR15	-	3.2	2.8	2.6	2.4	2.4	-0.4	-0.3	-0.3
SR16	-	3.5	3.5	3.9	3.5	3.4	0.1	-0.4	-0.5
SR17	-	3.4	4.9	2.7	4.9	2.1	1.5	2.2	-0.6
SR18	-	2.7	2.8	1.5	2.3	2.1	0.2	0.8	0.6
SR19	-	2.5	1.9	1.9	2.0	2.2	-0.6	0.1	0.3
SR20	-	3.9	3.7	2.7	2.0	3.2	-0.2	-0.7	0.5
SR21	-	3.4	3.1	3.4	3.6	3.2	-0.3	0.2	-0.3
SR22	-	3.4	2.8	2.6	2.4	2.2	-0.6	-0.2	-0.4
SR23	-	5.5	4.2	3.6	4.2	4.6	-1.4	0.7	1.0
SR24	-	5.8	5.4	4.3	5.1	2.9	-0.4	0.8	-1.4
SR25	-	3.6	3.5	3.3	3.8	3.2	-0.1	0.5	-0.2
SR26	-	4.9	4.7	2.9	3.7	5.4	-0.2	0.8	2.4
SR27	-	3.0	3.4	2.3	2.9	2.6	0.5	0.6	0.3
SR28	-	3.1	2.7	2.3	3.2	3.9	-0.4	0.9	1.7
SR29	-	3.6	2.7	3.2	2.3	2.3	-1.0	-0.9	-0.9
SR30	-	4.9	3.0	2.6	3.6	2.1	-1.9	1.0	-0.5
SR31	-	4.6	3.9	3.8	2.6	4.7	-0.7	-1.2	0.9
SR32	-	4.4	3.5	3.6	3.1	3.6	-1.0	-0.5	0.1
SR33	-	4.0	4.8	3.5	3.4	2.5	0.8	-0.1	-1.0
SR34	-	5.2	3.6	3.4	2.5	5.3	-1.6	-0.9	1.9
SR35	-	3.4	2.3	2.6	3.9	2.8	-1.1	1.3	0.3

Table K-68 Maximum one-hour formaldehyde concentrations (excluding background) at community receptors, ranked by concentration

Rank	Ranking by concentration (µg/m^3)					
	2014-BY	2021-DM	2021 DS	2031-DM	2031-DS	2031-DSC
1	-	6.4	6.2	5.6	5.1	5.4
2	-	6.4	5.5	4.5	4.9	5.3
3	-	5.9	5.4	4.3	4.7	4.7
4	-	5.8	4.9	4.3	4.3	4.6
5	-	5.5	4.8	4.2	4.2	4.1
6	-	5.2	4.7	4.1	4.0	3.9
7	-	4.9	4.6	3.9	3.9	3.9
8	-	4.9	4.5	3.8	3.8	3.6
9	-	4.8	4.4	3.8	3.8	3.6
10	-	4.7	4.3	3.6	3.7	3.4

Table K-69 Maximum one-hour formaldehyde concentrations (excluding background) at community receptors, ranked by increase and by decrease in concentration with project

Rank	Ranking by increase in concentration with project (µg/m^3)			Ranking by decrease in concentration with project (µg/m^3)		
	2021-DS	2031-DS	2031-DSC	2021-DS	2031-DS	2031-DSC
1	1.6	2.2	2.4	-1.9	-1.6	-2.0
2	1.5	1.3	1.9	-1.8	-1.2	-1.6
3	1.3	1.0	1.7	-1.6	-0.9	-1.4
4	1.3	0.9	1.0	-1.6	-0.9	-1.4
5	0.8	0.8	0.9	-1.4	-0.9	-1.1
6	0.8	0.8	0.8	-1.1	-0.9	-1.0
7	0.7	0.8	0.7	-1.1	-0.8	-1.0
8	0.5	0.7	0.6	-1.0	-0.7	-0.9
9	0.5	0.6	0.5	-1.0	-0.5	-0.9
10	0.4	0.5	0.5	-1.0	-0.4	-0.6

Table K-70 Maximum one-hour formaldehyde concentrations (excluding background) at RWR receptors, ranked by concentration

Rank	Ranking by concentration (µg/m^3)					
	2014-BY	2021-DM	2021 DS	2031-DM	2031-DS	2031-DSC
1	-	12.7	15.6	12.3	11.7	11.3
2	-	12.6	14.0	10.5	11.2	10.5
3	-	12.3	13.6	10.2	11.1	10.5
4	-	12.2	13.5	10.2	11.0	10.0
5	-	12.0	13.4	9.9	10.6	9.9
6	-	11.9	13.4	9.9	10.4	9.8
7	-	11.7	13.3	9.8	10.3	9.7
8	-	11.7	13.0	9.7	10.2	9.6
9	-	11.7	12.9	9.6	10.2	9.6
10	-	11.5	12.9	9.6	10.2	9.6

Table K-71 Maximum one-hour formaldehyde concentrations (excluding background) at RWR receptors, ranked by increase and by decrease in concentration with project

Rank	Ranking by increase in concentration with project (µg/m^3)			Ranking by decrease in concentration with project (µg/m^3)		
	2021-DS	2031-DS	2031-DSC	2021-DS	2031-DS	2031-DSC
1	6.2	5.7	4.8	-5.8	-5.3	-5.6
2	6.1	4.8	4.4	-5.0	-4.2	-5.3
3	5.7	4.3	3.9	-4.7	-4.1	-5.2
4	5.4	4.3	3.8	-4.5	-3.7	-5.2
5	5.3	4.2	3.8	-4.3	-3.6	-5.0
6	5.3	4.0	3.7	-4.2	-3.6	-4.6
7	5.2	4.0	3.6	-4.2	-3.5	-4.6
8	5.1	3.9	3.5	-4.1	-3.5	-4.5
9	5.1	3.9	3.5	-4.1	-3.5	-4.5
10	5.0	3.8	3.4	-4.1	-3.4	-4.4

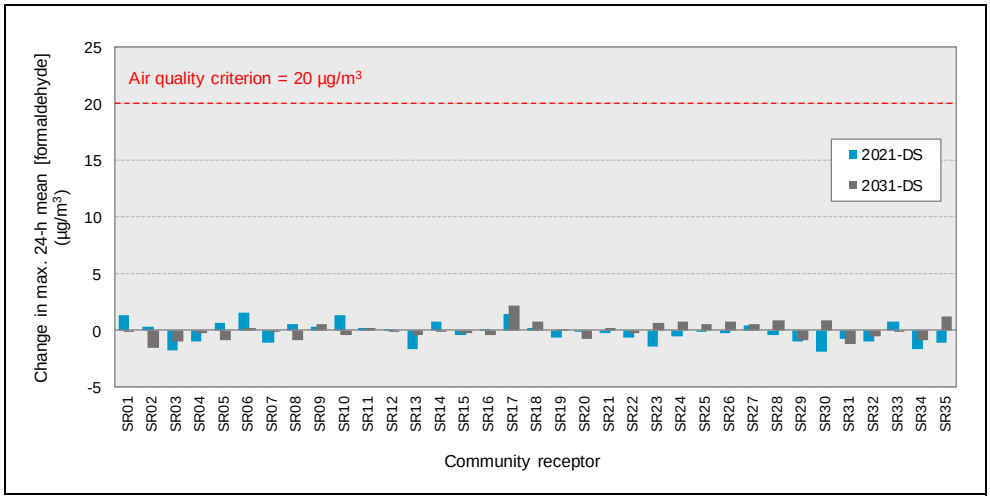


Figure K-175 Change in max. one-hour formaldehyde at community receptors (2021-DS, 2031-DS)

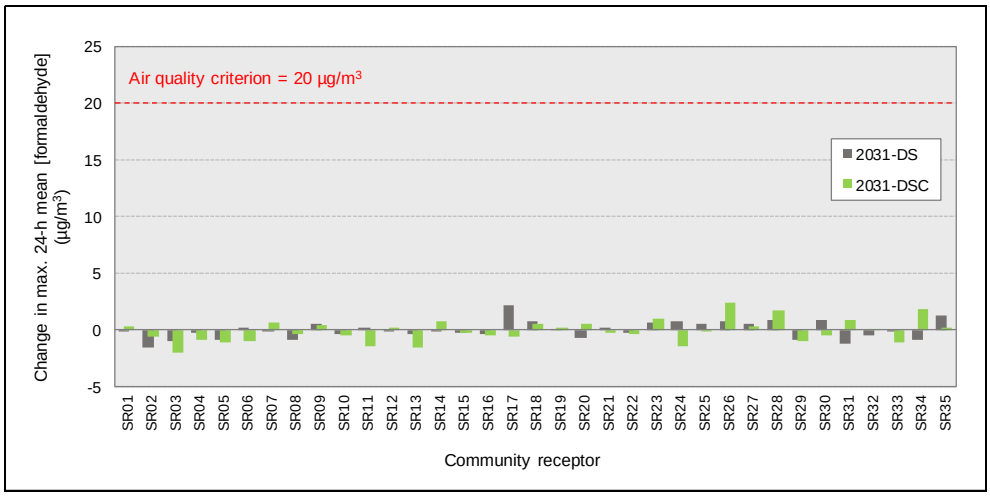


Figure K-176 Change in max. one-hour formaldehyde at community receptors (2031-DS, 2031-DSC)

K.12 Air toxics: 1,3-butadiene (maximum one-hour)

Table K-72 Maximum one-hour 1,3-butadiene concentrations (excluding background) at community receptors

Receptor	Maximum one-hour 1,3-butadiene concentration (µg/m^3)						Change with project (µg/m^3)		
	2014-BY	2021-DM	2021 DS	2031-DM	2031-DS	2031-DSC	2021	2031	2031-DSC
SR01	-	1.2	1.8	1.0	0.9	1.1	0.6	-0.1	0.1
SR02	-	1.8	2.0	1.4	0.9	1.2	0.2	-0.5	-0.2
SR03	-	2.9	2.1	1.8	1.5	1.2	-0.8	-0.3	-0.6
SR04	-	2.9	2.4	1.4	1.3	1.1	-0.4	-0.1	-0.3
SR05	-	1.4	1.7	1.3	1.1	1.0	0.3	-0.3	-0.3
SR06	-	2.1	2.8	1.3	1.4	1.0	0.7	0.1	-0.3
SR07	-	2.1	1.7	1.1	1.1	1.3	-0.5	0.0	0.2
SR08	-	1.6	1.8	1.1	0.8	1.0	0.2	-0.3	-0.1
SR09	-	1.3	1.4	0.9	1.1	1.0	0.1	0.2	0.1
SR10	-	1.4	2.0	0.8	0.7	0.7	0.6	-0.1	-0.2
SR11	-	1.1	1.2	1.2	1.2	0.7	0.1	0.1	-0.5
SR12	-	1.0	1.1	0.8	0.8	0.9	0.1	0.0	0.1
SR13	-	2.6	1.9	1.2	1.1	0.7	-0.7	-0.1	-0.5
SR14	-	1.2	1.6	0.8	0.8	1.1	0.4	0.0	0.3
SR15	-	1.4	1.2	0.8	0.8	0.8	-0.2	-0.1	-0.1
SR16	-	1.5	1.6	1.2	1.1	1.1	0.0	-0.1	-0.1
SR17	-	1.5	2.2	0.9	1.6	0.7	0.6	0.7	-0.2
SR18	-	1.2	1.3	0.5	0.7	0.7	0.1	0.3	0.2
SR19	-	1.1	0.8	0.6	0.7	0.7	-0.3	0.0	0.1
SR20	-	1.7	1.6	0.9	0.6	1.0	-0.1	-0.2	0.2
SR21	-	1.5	1.4	1.1	1.1	1.0	-0.1	0.1	-0.1
SR22	-	1.5	1.3	0.8	0.8	0.7	-0.3	-0.1	-0.1
SR23	-	2.5	1.9	1.1	1.4	1.5	-0.6	0.2	0.3
SR24	-	2.6	2.4	1.4	1.6	0.9	-0.2	0.2	-0.4
SR25	-	1.6	1.6	1.1	1.2	1.0	0.0	0.2	-0.1
SR26	-	2.2	2.1	0.9	1.2	1.7	-0.1	0.3	0.8
SR27	-	1.3	1.5	0.7	0.9	0.8	0.2	0.2	0.1
SR28	-	1.4	1.2	0.7	1.0	1.3	-0.2	0.3	0.5
SR29	-	1.6	1.2	1.0	0.7	0.7	-0.4	-0.3	-0.3
SR30	-	2.2	1.3	0.8	1.1	0.7	-0.9	0.3	-0.2
SR31	-	2.1	1.7	1.2	0.8	1.5	-0.3	-0.4	0.3
SR32	-	2.0	1.6	1.1	1.0	1.2	-0.4	-0.2	0.0
SR33	-	1.8	2.2	1.1	1.1	0.8	0.4	0.0	-0.3
SR34	-	2.3	1.6	1.1	0.8	1.7	-0.7	-0.3	0.6
SR35	-	1.5	1.0	0.8	1.2	0.9	-0.5	0.4	0.1

Table K-73 Maximum one-hour 1,3-butadiene concentrations (excluding background) at community receptors, ranked by concentration

Rank	Ranking by concentration (µg/m^3)					
	2014-BY	2021-DM	2021 DS	2031-DM	2031-DS	2031-DSC
1	-	2.9	2.8	1.8	1.6	1.7
2	-	2.9	2.4	1.4	1.6	1.7
3	-	2.6	2.4	1.4	1.5	1.5
4	-	2.6	2.2	1.4	1.4	1.5
5	-	2.5	2.2	1.3	1.4	1.3
6	-	2.3	2.1	1.3	1.3	1.3
7	-	2.2	2.1	1.2	1.2	1.2
8	-	2.2	2.0	1.2	1.2	1.2
9	-	2.1	2.0	1.2	1.2	1.2
10	-	2.1	1.9	1.2	1.2	1.1

Table K-74 Maximum one-hour 1,3-butadiene concentrations (excluding background) at community receptors, ranked by increase and by decrease in concentration with project

Rank	Ranking by increase in concentration with project (µg/m^3)			Ranking by decrease in concentration with project (µg/m^3)		
	2021-DS	2031-DS	2031-DSC	2021-DS	2031-DS	2031-DSC
1	0.7	0.7	0.8	-0.9	-0.5	-0.6
2	0.6	0.4	0.6	-0.8	-0.4	-0.5
3	0.6	0.3	0.5	-0.7	-0.3	-0.5
4	0.6	0.3	0.3	-0.7	-0.3	-0.4
5	0.4	0.3	0.3	-0.6	-0.3	-0.3
6	0.4	0.3	0.3	-0.5	-0.3	-0.3
7	0.3	0.2	0.2	-0.5	-0.3	-0.3
8	0.2	0.2	0.2	-0.4	-0.2	-0.3
9	0.2	0.2	0.2	-0.4	-0.2	-0.3
10	0.2	0.2	0.1	-0.4	-0.1	-0.2

Table K-75 Maximum one-hour 1,3-butadiene concentrations (excluding background) at RWR receptors, ranked by concentration

Rank	Ranking by concentration (µg/m^3)					
	2014-BY	2021-DM	2021 DS	2031-DM	2031-DS	2031-DSC
1	-	5.7	7.0	4.0	3.8	3.6
2	-	5.6	6.3	3.4	3.6	3.4
3	-	5.5	6.1	3.3	3.6	3.4
4	-	5.5	6.1	3.3	3.5	3.2
5	-	5.3	6.0	3.2	3.4	3.2
6	-	5.3	6.0	3.2	3.3	3.1
7	-	5.2	5.9	3.1	3.3	3.1
8	-	5.2	5.8	3.1	3.3	3.1
9	-	5.2	5.8	3.1	3.3	3.1
10	-	5.1	5.8	3.1	3.3	3.1

Table K-76 Maximum one-hour 1,3-butadiene concentrations (excluding background) at RWR receptors, ranked by increase and by decrease in concentration with project

Rank	Ranking by increase in concentration with project (µg/m^3)			Ranking by decrease in concentration with project (µg/m^3)		
	2021-DS	2031-DS	2031-DSC	2021-DS	2031-DS	2031-DSC
1	2.8	1.8	1.5	-2.6	-1.7	-1.8
2	2.7	1.5	1.4	-2.2	-1.4	-1.7
3	2.5	1.4	1.2	-2.1	-1.3	-1.7
4	2.4	1.4	1.2	-2.0	-1.2	-1.7
5	2.4	1.3	1.2	-1.9	-1.1	-1.6
6	2.4	1.3	1.2	-1.9	-1.1	-1.5
7	2.3	1.3	1.2	-1.9	-1.1	-1.5
8	2.3	1.3	1.1	-1.8	-1.1	-1.4
9	2.3	1.2	1.1	-1.8	-1.1	-1.4
10	2.2	1.2	1.1	-1.8	-1.1	-1.4

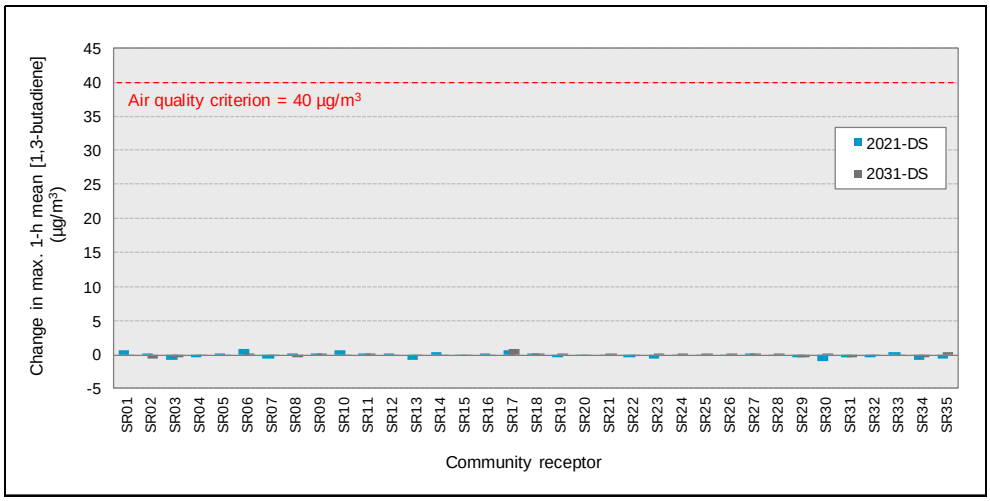


Figure K-177 Change in max. one-hour 1,3-butadiene at community receptors (2021-DS, 2031-DS)

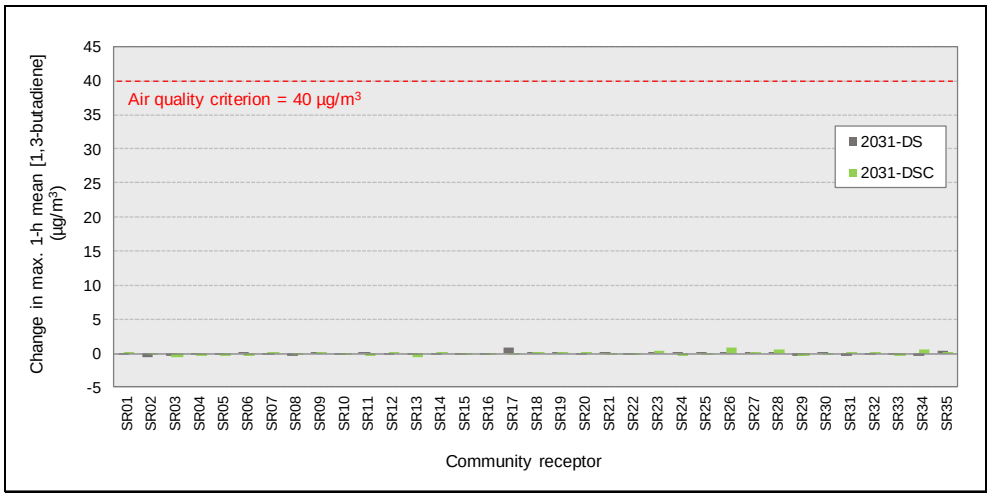


Figure K-178 Change in max. one-hour 1,3-butadiene at community receptors (2031-DS, 2031-DSC)

Appendix L - Ventilation report

WESTCONNEX

NEW M5 VENTILATION REPORT

for WestConnex Delivery Authority
10TH NOVEMBER 2015

Ref 1505

REVISION HISTORY			
No.	**Date**	**Comment**	**Signed**
1	28 September 2015	First draft issue.	
2	20 October 2015	New M5 internal review addressed	
3	3 November 2015	Further internal comments addressed	
4	9 November 2015	Further internal comments addressed	
5	10 November 2015	Figures 11.35 to 11.40 added	

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EXECUTIVE SUMMARY

Stacey Agnew was commissioned by the WestConnex Delivery Authority (WDA), now transferred to Sydney Motorway Corporation (SMC), to model in-tunnel airflow, pollution levels and temperature resulting from traffic operations in the WestConnex New M5 project (the project) and the future M4-M5 Link project to Rozelle (which will be subject to separate assessment and planning approval).

This report documents the input data used in the tunnel ventilation simulation, and the predicted in-tunnel and vent outlet air flow, temperature and pollution levels for the New M5 project, and for the connected M4-M5 Link tunnel as far north as Rozelle.

Modelling was undertaken using the IDA Tunnel software by EQUA AB[1]. IDA Tunnel solves aerodynamic and thermodynamic equations to calculate the tunnel and outlet air flow and temperature over time, given the vehicle forcing and the vehicle heat generation within the surrounding ground heat sink. Pollutant generation and advection is computed based on the input fleet mix.

Data on traffic volume and fleet mix for the project were taken from the WestConnex Road Traffic Model (WRTM). The fleet mix based on registration type was then transformed in this work to be relevant to pollution generation. The traffic model within the simulation applies traffic continuity and realistic models on traffic flow versus speed, to predict the traffic density and speed throughout the tunnel. Airflows resulting from the modelled traffic scenarios, in combination with the vehicle emissions, determine the pollutant levels in the tunnel. The air flows and pollution levels are not substantially different between summer and winter condition, however there are substantial differences in tunnel and outlet air temperatures.

The important conclusion derived from these results is that the New M5 and M4-M5 Link tunnels would be self-ventilating for the predicted traffic. This is because the 'piston effect' of vehicles (without the aid of jet fans) drives sufficient air along the mainline tunnel to maintain pollutant levels below the specified design limits. Jet fans are still required to move smoke longitudinally during a tunnel fire (vehicles will be stopped) and any other exceptional stopped traffic events. Air exchange at the Kogarah intersection with the future Southern Extension is not required for in-tunnel pollution control. Similarly, mainline air exchange is not required at St Peters Interchange as the on and off-ramps provide sufficient exchange.

Plots of results are provided in Section 11 for free flowing and congested traffic. The detailed outputs for free flowing daily (24 hour) 2021 and 2031 traffic in summer and winter are provided in Appendices A, B and C. Appendix D gives the congested traffic outputs.

The congested traffic results are for steady state traffic demand where the traffic in the downstream tunnel segments is reduced to nominal limits of 20 km/h, 40 km/h and 60 km/h. Demand is increased in steps until capacity is exceeded. These congested case results are compared with the 80 km/h (free flowing) case.

Results show that in-tunnel pollution levels can still be maintained at levels below the limits which are anticipated to be imposed, without running mainline jet fans. The tabulated results for eastbound simulations show a number of jet fans running overnight. This is a result of a control policy to maintain minimum airspeeds, in this case 3 m/s. The pollution results show that minimum to be unnecessarily high and so the next iteration will use a lower minimum, likely requiring no mainline jet fans. For fire safety reasons it is recommended that normal operation traffic speeds below 20 km/h should be prevented using traffic management.

[1] http://www.equa.se/en/tunnel/ida-tunnel/road-tunnels

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1 INTRODUCTION

NSW Roads and Maritime Services (Roads and Maritime) is seeking approval to construct and operate the New M5 (the project). The proposed works are described more fully in the main body of the EIS.

The project is a component of WestConnex, which is a proposal for a 33 kilometre motorway linking Sydney's west and south-west with Sydney Airport and the Port Botany precincts. The WestConnex project includes 21 kilometres of twin-bore tunnels, plus ramps. The individual components of WestConnex are:

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

A proposed Southern Extension from Arncliffe to Kogarah is currently being investigated by Transport for NSW. The Southern Extension would connect the New M5 to the southern and bayside suburbs of Sydney, and the proposed F6 extension..

This report addresses only the New M5 Project, considering also the effect of the future M4-M5 Link on the New M5 ventilation, and on emissions in the project area. The M4-M5 Link design is currently being developed and is subject to further design refinement. Modelling of the interchange at Rozelle includes a complete air break that effectively separates the tunnel ventilation systems either side of the interchange.

This report has been prepared to support the assessment of air quality for the environmental impact statement (EIS).

In ventilation terms, the New M5 project and the M4-M5 Link up to Rozelle are one system. The connected M4-M5 Link tunnels north of St. Peters will affect the ventilation and emissions within the New M5 project area. With the M4-M5 Link motorway surfacing at Rozelle, parts of the M4-M5 Link beyond Rozelle are not relevant to this assessment. If the Rozelle connection were later to be designed as an underground connection, some of the results may need to be revisited. With the surface interchange at Rozelle, and the inherently integrated ventilation operation south of Rozelle, there is a need for nomenclature to describe the functional tunnel sections quite separately from the WestConnex project scope descriptors. The overall schematic is shown in Figure 4.1. In this report we use the following terms:

- New M5 – the motorway tunnel from Beverly Hills to St Peters, including ramps which connect to that section. As above, New M5 is the scope of the EIS which this report is part of.
- SPI to Rozelle – that part of M4-M5 Link that connects New M5 at St Peters Interchange (SPI) to Rozelle, including ramps.
- M5 to Rozelle – the motorway tunnel from Beverly Hills to Rozelle, including ramps which connect to that section. This is the combination of the New M5 and SPI to Rozelle as one system.
- Southern Extension – the ramp which connects to the New M5 at Kogarah. This has also been known as the Southern Connector.

2 SCOPE

The aim of this report is to document the input data used in the tunnel ventilation simulation model, and the predicted in-tunnel and ventilation outlet air flow, temperature and pollution levels for the New M5 project, both before and after the future M4-M5 Link tunnel development. This report is focused on pollution estimation for EIS purposes, however the ventilation design for emergency response is also mentioned here.

The ventilation outputs for the New M5 project and SPI to Rozelle are included in Section 11, with appendices tabulating the numerical results in detail.

References to design inputs and assumptions in this report are listed in Table 2.1 below.

Table 2.1. Summary of design inputs and assumptions used in simulation.

Input	Value	Reference
NO_2 limits	0.5 ppm average	Section 6.1, Table 6.1
CO limits	87 ppm over 15 min. avg. 50 ppm over 30 min. avg.	Table 6.2

Extinction coefficient limits	0.005 /m	Table 6.2
Vertical alignment (New M5 and SPI to Rozelle)		Figure 4.2 and Figure 4.3
Cross section (New M5)	Beverly Hills to Kogarah: 100m^2 Kogarah to SPI off-ramp: 135 m^2 SPI to Rozelle: 100 m^2	Table 4.1
Vehicle sizes		Table 7.4
Fleet fuel mix		Figure 7.8
Fleet age profile		Figure 7.7
Traffic demand		Table 7.5 and Table 7.6
Ramp traffic splits (New M5)		Table 7.8 to Table 7.12
Vehicle aerodynamic drag coefficients		Table 8.2
Vehicle parameters for heat generation		Table 9.5
Vehicle emission factors, for NO_2, CO and PM.	PIARC (2012) Australian tables, with fleet taken to year 2020 for 2021 and 2031 traffic flows.	Table 9.1, Table 9.2, Table 9.4, Table 9.6, Table 9.7
Vehicle heat emission factors		Table 9.8

It is noted that the analysis conservatively adopts 2020 emission values for both 2021 and 2031 simulations. Ongoing work to re-estimate future emissions may, when complete, allow estimation of the degree of conservatism included through use of 2020 figures.

3 ALIGNMENT

Figure 4.1 is a schematic of the combined New M5 (red) and M4-M5 Link (blue). Also included in this schematic is the Southern Extension which may be added with the M4-M5 Link. The ramps which form the Arundel Interchange, shown as a dashed line in Figure 4.1, are not included in the ventilation model. Their provision is now part of M4-M5 Link project. With the distance of the Arundel Interchange from SPI, they will have little impact on New M5 air flows. To the extent that the Arundel Interchange will necessarily involve some exchange of tunnel air, omitting them from the New M5 assessment adds conservatism for estimating pollution flux into the westbound tube of New M5. There will be no impact on the eastbound tube of New M5.

The modelling is based on the reference design alignment. Vertical alignment of New M5 and the M4-M5 Link up to Rozelle is shown in Figure 4.2 and Figure 4.3. The western end adjacent to the portal reaches 4% gradient, while the St Peters off-ramp reaches 5% for a 450 m long section. Gradient in the majority of both tubes is between -1% and 1%.

While the impact assessment is for Stage 2 (the red tunnel sections in Figure 4.1), it necessarily also considers the combined effect on the Stage 2 environs after Stage 3 (the blue sections in Figure 4.1) is added.

4 CROSS SECTION

Table 4.1 gives tunnel airflow parameters based on the cross-section. The friction factor in Table 4.1 is the Darcy-Weisbach friction factor, used in the calculation of flows and pressures. The value noted is a value selected by SMC on the basis of experience with previous similar tunnels.

Table 4.1. Tunnel parameters.

Lanes	Flow area (m^2)	Hydraulic diameter (m)	Friction factor
1	60	7.7	0.035
2	80	8.9	0.035
3	100	10.0	0.035
4	135	10.5	0.035

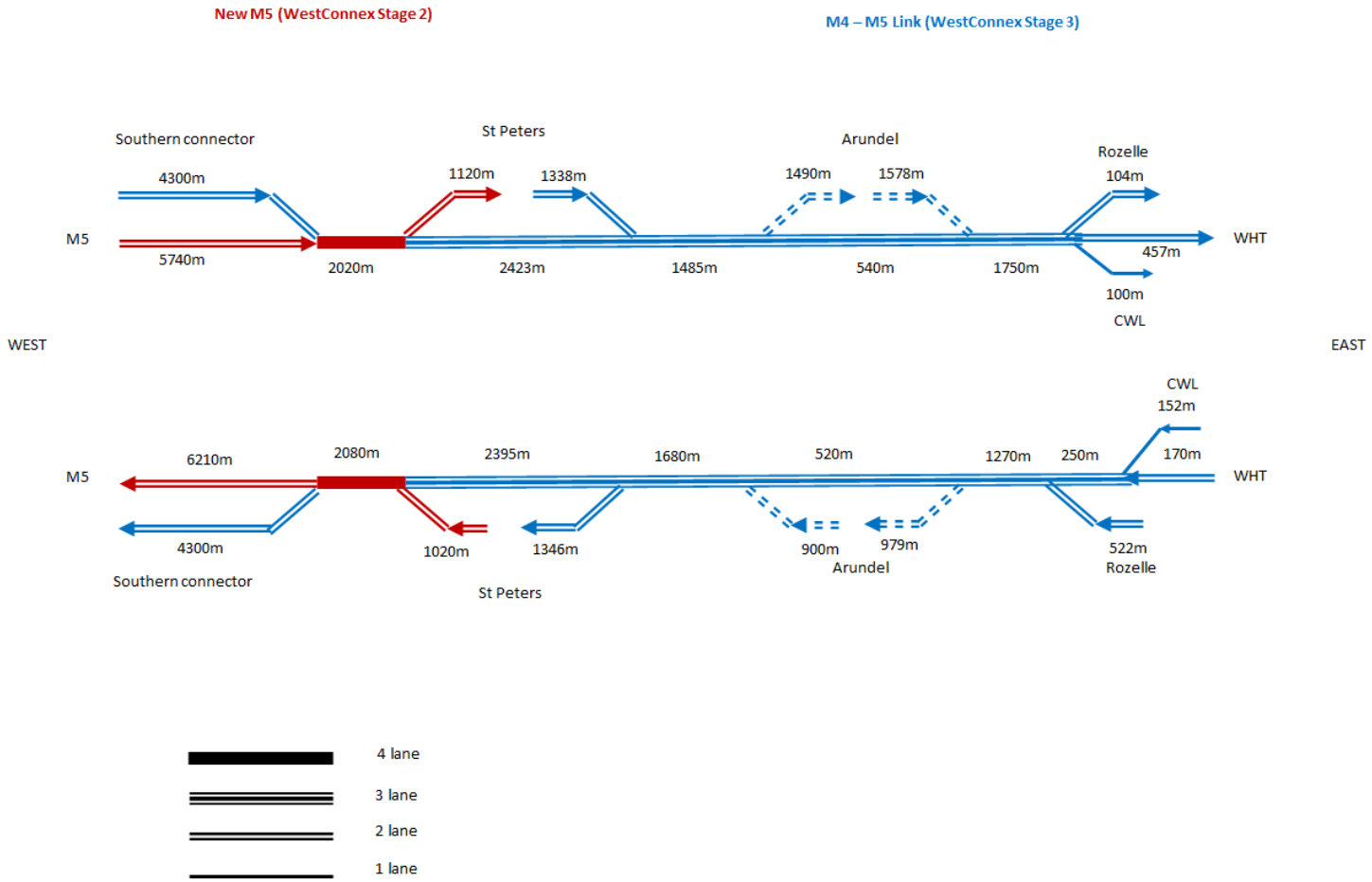


Figure 4.1. Schematic layout of WestConnex New M5 and M4-M5 Link projects up to Rozelle. The "4 lane" section will be marked and operated as 2 lanes for the New M5 project, but will have a cross section excavated for 4 lanes and a breakdown lane. This is acknowledged in the aerodynamic modelling.

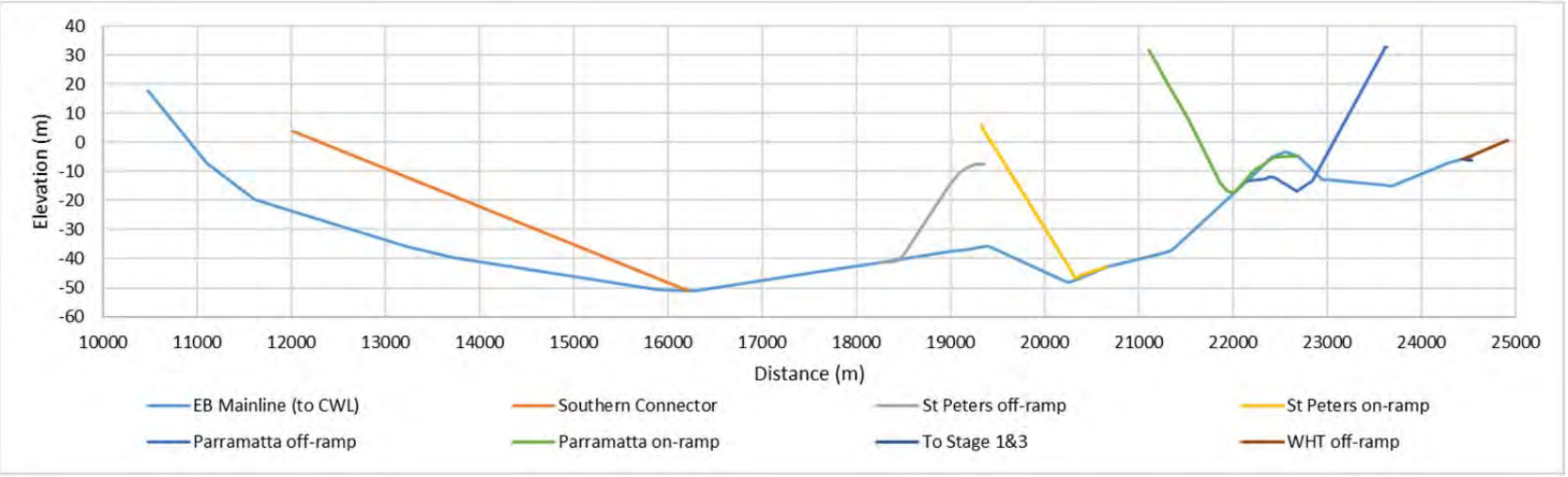


Figure 4.2. Eastbound vertical alignment of New M5 and the M4-M5 Link up to Rozelle.

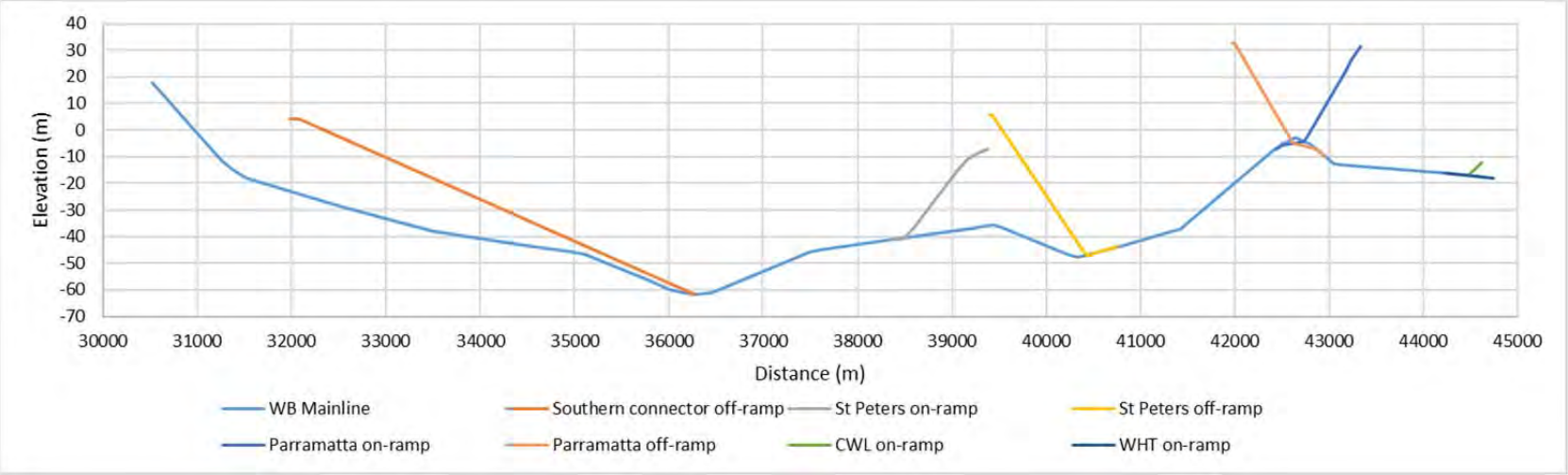


Figure 4.3. Westbound vertical alignment of New M5 and the M4-M5 Link up to Rozelle.

5 VENTILATION SCHEMES

The ventilation schemes for the New M5 and M4-M5 Link were developed to satisfy the anticipated conditions of approval. They have the capacity to generate net portal inflow at all portals. The schemes to satisfy those objectives are described below.

5.1 New M5

One particular reference ventilation scheme is considered for New M5, for which Figure 5.1 is the ventilation schematic of the tunnels. The blind stub tunnels on the eastern end of both mainline tubes are mined in preparation for the M4-M5 Link.

Extraction points are located near the St Peters Interchange (SPI) off-ramp portal on the eastbound tube and at the west portal of the westbound tube. Their role is to extract all of the airflow induced by the vehicle flow, plus sufficient additional air to ensure net inflow at each of the exit portals, nominally at 1 m/s. Eastbound air exchange is allowed for at Kogarah with an extraction point adjacent to the future Southern Extension junction, followed by a supply air station.

The fans in the main ventilation stations which exhaust or supply air to and from the tunnels are large axial flow fans. In different documents, they may be called vent station fans, extraction fans, supply fans, air exchange fans, or axial fans, all of which are correct descriptions. The use of the term “axial” is confusing as the jet fans mounted inside the tunnel are also axial fans but perform quite differently. Jet fans are smaller fans (up to about 1.6 m diameter) which are mounted under the tunnel ceiling. By accelerating a high speed stream of air which them mixes with the tunnel air, the jet fans transfer momentum to promote (or retard) the tunnel air flow.

Under most circumstances, the piston effect of vehicles along the tunnel will be sufficient to create on-ramp inflow without the aid of jet fans.

Jet fans are provided in the main tube to augment the longitudinal air flow in the event of fire. The same jet fans would assist, if required, to augment the tunnel air flow during congested traffic, to comply with the pollution limits.

5.2 New M5 with M4-M5 Link

The ventilation scheme for the combined system up to Rozelle, including part of the M4-M5 Link tunnels, is shown in Figure 5.2. The off-ramps at City West Link, Western Harbour Tunnel, Rozelle and SPI have air extraction points close to the daylight portals, ensuring portal inflow airspeed at nominally 1 m/s. The flows from City West Link and Rozelle extraction points may be combined to discharge to the atmosphere though a single outlet. The air extracted from the southbound SPI off-ramp will be discharged through a northern SPI ventilation outlet.

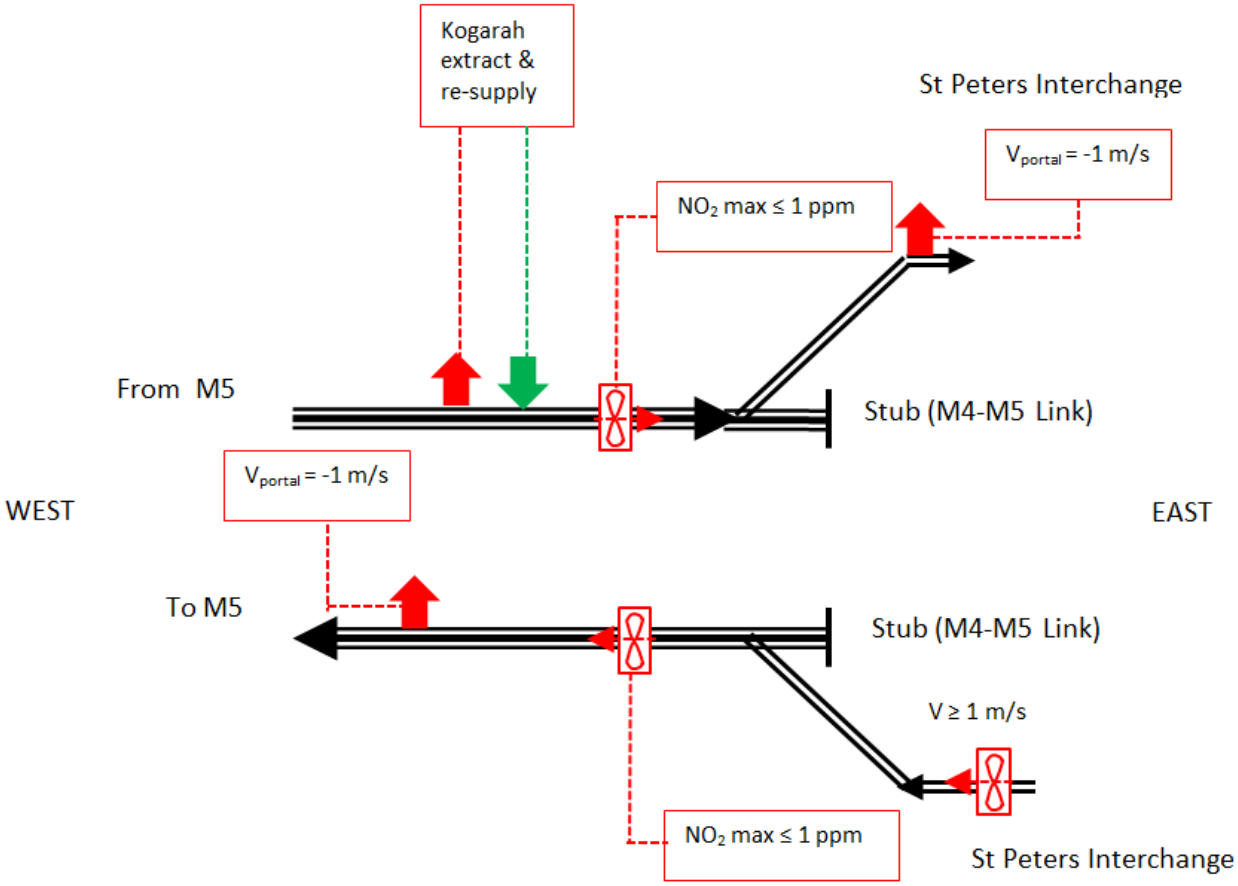


Figure 5.1. Ventilation scheme for New M5.

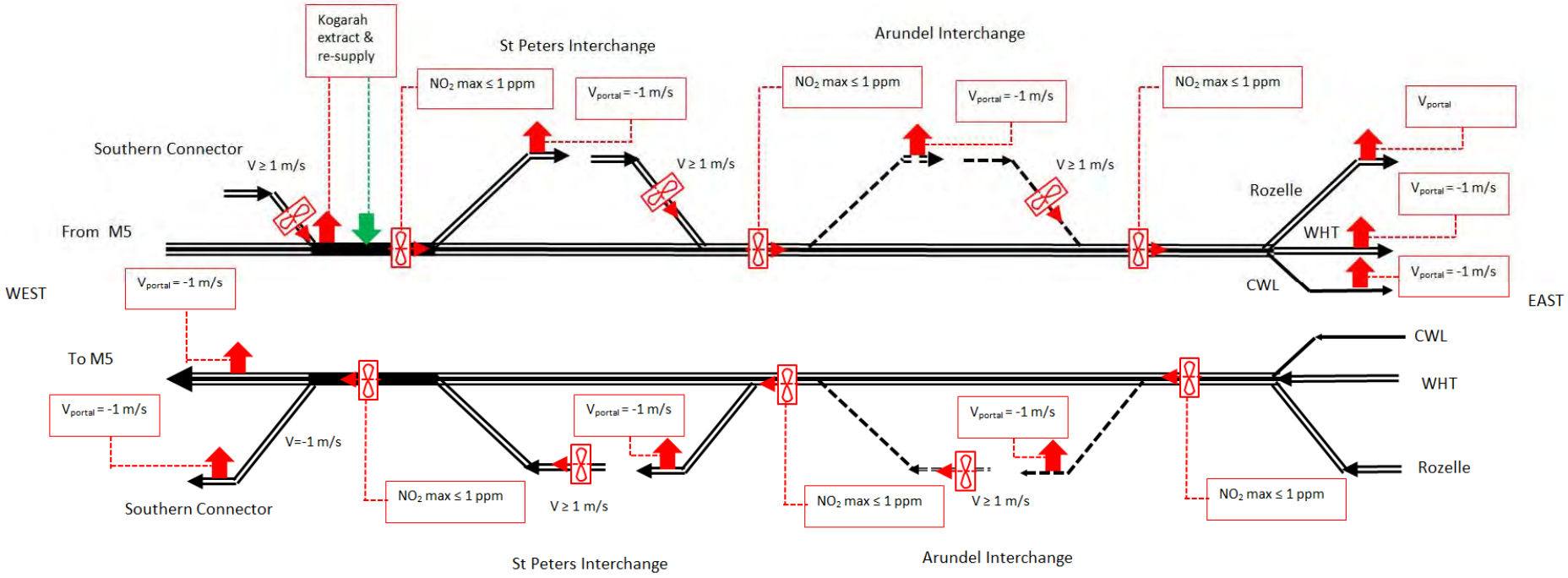


Figure 5.2. Ventilation scheme for New M5 including M4-M5 Link up to Rozelle.

5.3 Fire ventilation

Except for short sections at exit portals, prior to an incident the air will be flowing strongly with the traffic. At the onset of a fire, any exit portal flow against traffic will be reversed, with the flow direction maintained for the majority of the tunnel. Exit portal inflows can be reversed quickly by turning off the ventilation station fans which extract the tunnel air prior to the portal.

Jet fans maintain an air flow in the traffic direction in order to prevent people held behind the fire from being affected by smoke. Sufficient jet fans will be provided to control backlayering of the smoke at the fire-site.

Under normal operation, traffic control measures will be applied to ensure that the traffic speed in the tunnel does not drop below 20 km/h for any significant period. This will ensure that, if a vehicle ignites, the smoke movement does not overtake downstream traffic.

Depending on the fire location, the smoke may be discharged through the normal ventilation outlet, using the ventilation station fans. The alternative is to drive the smoke out the exit portal. The non-incident tube will be closed to traffic and the airflow in that tube will be reversed using jet fans. This is to ensure that smoke issuing from a portal is not drawn into the adjacent portal of the non-incident tube. The jet fans will also be used to maintain the non-incident tube at a higher pressure than the incident tube, to prevent smoke flow through cross passages.

6 POLLUTION CRITERIA

6.1 In-tunnel air quality

The three pollutants assessed in-tunnel are nitrogen dioxide (NO_2), carbon monoxide (CO) and particulate matter (PM). For the operating years of the WestConnex project, NO_2 will be the pollutant that determines the required airflow and drives the design of ventilation for in-tunnel pollution.

The NSW Department of Planning and Environment issued a report that included discussion on this topic for the NorthConnex project in January 2015. From the Secretary's Environmental Assessment Report[2] for the NorthConnex project:

> *"The Department considers that nitrogen dioxide (NO_2) is now the key pollutant of concern for in-tunnel air quality. While carbon monoxide has historically been the basis for in-tunnel criteria in NSW and internationally, improvements in modern vehicle technology mean that NorthConnex will comply with existing health based carbon monoxide standards. By contrast, vehicle emissions of NO_2 have fallen less quickly, and uptake of diesel vehicles (which produce more NO_2 than petrol based vehicles) has risen.*
> ……..
> *"…..Accordingly, it is recommended that the Proponent's design criteria for NO_2 of 0.5 ppm (averaged over 15 minutes) be applied as an average across the tunnel under <u>all</u> operating conditions."*

The Environmental Assessment Report refers to 'average across the tunnel'. It is understood that this is a spatial average along the tunnel from entry portal to exit portal. This spatial average is a proxy for the average level experienced by motorists while travelling through the tunnel. For constant vehicle speed, the two are identical. Whereas the spatial average can be estimated readily from tunnel instruments and so is a practical measure, exposure estimates in congested traffic require the progress of motorists to be monitored, which is not practical from a control or regulatory perspective.

If the pollutant level increases linearly from nearly zero at the entry to the maximum near the exit, then the spatial average level is half the peak level. Because most urban road tunnels, including WestConnex, have portals higher than the general tunnel, pollutant generation is higher when climbing toward the exit, biasing the exposure towards the end of the tunnel trip. This means that the average level is somewhat less than half the peak level near the exit. With an average NO_2 limit of 0.5 ppm, a peak limit of 1.0 ppm is used as a useful initial reckoning tool, acknowledging that it will generally be slightly conservative.

The NO_2 limits as proposed by the NorthConnex Proponent and as recommended in the Secretary's Environmental Assessment Report (SEAR) are contained in Table 6.1 and Table 6.2.

[2] NSW Government Planning and Environment, State Significant Infrastructure Assessment: NorthConnex M1-M2 project SSI 6136, Secretary's Environmental Assessment Report, Section 115ZA of the Environmental Planning and Assessment Act 1979, January 2015.

Table 6.1. NO_2 limits from NorthConnex.

Traffic speed along the whole tube	Proposed limit on NO_2 as an average over the whole tunnel and over 15 minutes	
	NorthConnex Proponent	NorthConnex Environmental Assessment Report
60 – 80 km/h	0.5 ppm	0.5 ppm
40 km/h	0.8 ppm	0.5 ppm
0 – 20 km/h	1.0 ppm	0.5 ppm

Table 6.2. Pollutant limits summary from NorthConnex.

In-Tunnel Air Quality — Limits

E2 The tunnel ventilation system must be designed and operated so that the average concentration of CO and NO_2, calculated along the length of the tunnel, does not exceed the concentration limit specified for that pollutant in **Table 5**.

Table 5 – In-tunnel average limits along length of tunnel

Pollutant	Concentration Limit	Units of measurement	Averaging period
CO	87	ppm	Rolling 15-minute
CO	50	ppm	Rolling 30–minute
NO_2	0.5	ppm	Rolling 15-minute

E3 The tunnel ventilation system must be designed and operated so that the concentration of CO as measured at any single point in the tunnel must not exceed the concentration limit specified for that pollutant in **Table 6** under all conditions (including congested conditions).

Table 6 – In-tunnel single point exposure limits

Pollutant	Concentration Limit	Units of measurement	Averaging period
CO	200	ppm	Rolling 3–minute

E4 The tunnel ventilation system must be designed and operated so that the visibility in the tunnel does not exceed the level specified in **Table 7**.

Table 7 — In-tunnel visibility limits along length of tunnel

Parameter	Average extinction co-efficient Limit	Units of measurement	Averaging period
Visibility	0.005	m^{-1}	Rolling 15–minute

6.2 Interaction of traffic and pollution limits

The risk of harm from pollutants is treated like any other risk; we seek to reduce it to a level that is as low as reasonably practicable. The risk is taken as being as low as reasonably practicable when the cost of making further risk reduction is disproportionate to the benefit of the further risk reduction achieved.

It is the extreme congestion cases that determine the ventilation provisions and hence they have a strong influence on cost in tunnels. In a risk context, we might allow higher pollution levels in rare events, if catering to the same level for those events were to cause high costs. This is particularly so if the pollution limits are set at the low end of the band in which health

effects might start to be significant. There is no sharp transition from un-harmful to harmful as NO_2 levels rise. In a review for the NorthConnex project, Todoroski[3] noted that the available literature "*…indicates an upper bound above 4 ppm may not be reasonable to manage potential health effects, and that the potential upper bound for NO_2 levels could reasonably lie in the range 0.5 to 4 ppm*".

In this context, the Proponent's limits initially proposed for NorthConnex in Table 6.1 had merit. Risk was to be rationally managed with a slight increase in level for rare slow speed events. However, the information that was not available to the NorthConnex environmental assessment was the likely frequency of the very slow speed traffic. Without the risk context given by probability of the low speed traffic scenario, no concession on pollution limit was made for low speed cases. Further, it was found that the design could comply with the same criterion at speeds right down to 20 km/h, and so there was insufficient incentive to substantiate the view that such slow traffic would be rare, with the project accepting the more stringent constant NO_2 criterion.

The NorthConnex outcome did not deny the risk context, but simply responded to the lack of frequency data available and to the design opportunities. Consequently, it does not form a precedent for avoiding the risk context on WestConnex should the data become available. However, the New M5 design and procurement process has not completed documented expectations of low speed traffic frequency in a way that could be used to justify a different in-tunnel NO_2 limit for low speed scenarios. Consequently, the New M5 project has adopted an NO_2 limit of 0.5 ppm as a spatial and time average for all design traffic cases.

With the adopted approach to the NO_2 limit perhaps embodying an element of risk conservatism, it is undesirable to introduce yet more conservatism in the calculation of the low speed traffic cases. It is simple to base a spreadsheet calculation on traffic travelling at maximum density for a given constant speed along a whole tube. This can be applied as a screening method, and is sometimes applied as a design method, however it is considered to be an over-simplification and does not reflect realistic traffic flow.

Traffic obeys rules of continuity in that vehicles are not lost or created at intersections. Continuity of flow means that, at any intersection where the number of lanes changes, the traffic speed and density cannot be the same in all legs connected to the intersection. That means that a uniform congestion assumption must be unrealistically conservative for any tunnel with intersections, which includes New M5 and M4-M5 Link. Further, real driver behaviour generates waves in the traffic speed; moving the traffic further from idealised congestion where the traffic is assumed to travel at a constant speed.

In the present work, the limiting traffic flow for the congested cases has been treated realistically. Congested cases have been modelled with unlimited inflow traffic demand, and speed restrictions placed in downstream sections to limit flow to the nominated speeds. In the tunnel behind the blockage, the traffic behaves as modelled by IDA Tunnel (Chapter 10), including obeying continuity.

[3] Todoroski Air Sciences; Independent Air Quality Review NorthConnex (M1-M2) Project SSI-6136, 12th January 2015.

7 TRAFFIC

7.1 Demand

7.1.1 Normal and regulatory traffic demand

Traffic for “normal” operation is the predicted weekday traffic demand. The traffic data provided indicates that the peak in this traffic flow falls short of the theoretical maximum 2200 pcu/lane.h (“pcu” is “passenger car units”, a measure used to standardise road capacity for different traffic mixes). To cover the possibility of the traffic being under-predicted, a limiting traffic case was sought, relating to the maximum capacity of the tunnel. For the purposes of this limiting case ventilation design, the normal daily traffic demand was scaled to increase the demand to so that the peak traffic flow reached in the most congested parts of the tunnel is 2200 pcu/lane.h. This scaled daily demand is referred to in this report as “regulatory case” or just “regulatory” daily traffic demand.

7.1.2 Congested traffic

Congested cases have been generated by applying speed limits (20, 40, 60 & 80 km/h) in critical sections which are likely to cause traffic to back-up in the tunnel. Using the regulatory daily traffic demand with the ramp inflows and outflows held in the same proportions as the normal peak hour traffic, some parts of the tunnel network will saturate before others. The ventilation system model incorporates the aerodynamic response to the locally saturated traffic in order to correctly assess the tunnel air flow and temperature as well as pollution levels.

7.1.3 Breakdown scenario

In order to attend to and remove a broken down vehicle, tunnel operators may close one lane upstream of the disabled vehicle to clear a path for the road patroller. With one lane closed, the number of vehicles in the tunnel will decrease and the average speed will not fall as far as it would without the lane closure, maintaining some benefit from the piston effect. If the breakdown occurs near the exit of the tunnel, and the operators were to take no action, the traffic would bank up and over time might look like that in the congested scenario above. With normal operator control, the traffic case will be less onerous than the congested case.

That is; the foreseeable breakdown scenario is no more onerous than the congested case. The congested case results may be applied to the breakdown scenario, including some conservatism. Given the low frequency of occurrence, the added conservatism in breakdown cases will not be significant.

7.2 Vehicle classification

Fleet characterization used in the WestConnex Road Traffic Model (WRTM) needed to be modified for ventilation design calculations based on PIARC[4] emission factors (or for any method that treats the fleet according to its makeup by emissions characteristics). For current purposes, the WRTM over-estimates the fraction of light duty vehicles (LDV) and heavy goods vehicles (HGV) in two ways.

Firstly, the WRTM split of vehicle classifications in the WRTM traffic data was produced using automatic number plate recognition, based on the type of registration (private or commercial). In this way, a courier’s Hyundai i30 (small hatch-back) would be a light duty

[4] Road Tunnels: Vehicles, Emissions and Air Demand for Ventilation. Document 2012R05EN, Permanent International Association of Road Congresses (PIARC) Technical Committee C4 Road Tunnels Operation. December 2012.

vehicle, and a VW Multivan (large carrier) could be a passenger car if privately owned. When PIARC definitions of passenger cars (PC), light duty vehicles (LDV) and heavy goods vehicles (HGV) are applied to traffic in the WestConnex corridors, the fleet typically has 10% to 20% LDVs, compared with the estimate of 35% to 55% commercial vehicles published from the WRTM.

Secondly, the WRTM traffic predictions assign all vehicles in Austroads Classes 3–12 to be HGVs. Some of the Class 3 vehicles should be removed from the HGV classification and included in the LDV fraction for the purpose of emissions assessment.

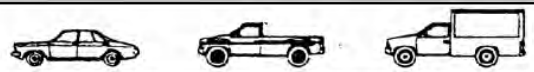
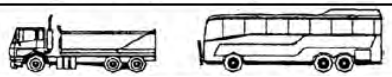
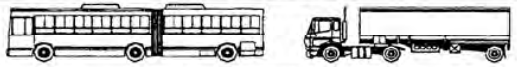
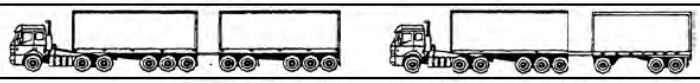
This section revises the WRTM fleet fractions to follow PIARC definitions of PC, LDV and HGV. The following sub-sections describe the data sources and methodology used to re-categorise the fleet for the purpose of ventilation design, with the conclusion on fleet mix given in Section 7.2.5.

There are four possible additional sources of information to characterise the WestConnex fleet:

- NSW Roads and Maritime Services fixed counting network data;
- weigh-in-motion (WIM) stations in the relevant corridors, weighing passing vehicles;
- typical values published by PIARC, and;
- noted fleet compositions in the Sydney air-shed more generally[5].

Data from the first source references Austroads vehicle classifications, which are shown in Figure 7.1.

[5] Personal communication, Paul Boulter, Pacific Environment.

Level 1	Level 2		Level 3	AUSTROADS Classification		
Length (indicative)	Axles and Axle Groups		Vehicle Type			
Type	Axles	Groups	Typical Description	Class	Parameters	Typical Configuration
	LIGHT VEHICLES					
Short up to 5.5m		1 or 2	**Short** Sedan, Wagon, 4WD, Utility, Light Van, Bicycle, Motorcycle, etc	1	d(1) ≤ 3.2m and axles = 2	
	3, 4 or 5	3	**Short - Towing** Trailer, Caravan, Boat, etc	2	groups = 3 d(1) ≥ 2.1m, d(1) ≤ 3.2m, d(2) ≥ 2.1m and axles = 3, 4 or 5	
	HEAVY VEHICLES					
Medium 5.5m to 14.5m	2	2	**Two Axle Truck or Bus**	3	d(1) > 3.2m and axles = 2	
	3	2	**Three Axle Truck or Bus**	4	axles = 3 and groups = 2	
	> 3	2	**Four Axle Truck**	5	axles > 3 and groups = 2	
Long 11.5m to 19.0m	3	3	**Three Axle Articulated** Three axle articulated vehicle, or Rigid vehicle and trailer	6	d(1) > 3.2m, axles = 3 and groups = 3	
	4	> 2	**Four Axle Articulated** Four axle articulated vehicle, or Rigid vehicle and trailer	7	d(2) < 2.1m or d(1) < 2.1m or d(1) > 3.2m axles = 4 and groups > 2	
	5	> 2	**Five Axle Articulated** Five axle articulated vehicle, or Rigid vehicle and trailer	8	d(2) < 2.1m or d(1) < 2.1m or d(1) > 3.2m axles = 5 and groups > 2	
	≥ 6	> 2	**Six Axle Articulated** Six axle articulated vehicle, or Rigid vehicle and trailer	9	axles = 6 and groups > 2 or axles > 6 and groups = 3	
Medium Combination 17.5m to 36.5m	> 6	4	**B Double** B Double, or Heavy truck and trailer	10	groups = 4 and axles > 6	
	> 6	5 or 6	**Double Road Train** Double road train, or Medium articulated vehicle and one dog trailer (M.A.D.)	11	groups = 5 or 6 and axles > 6	
Large Combination Over 33.0m	> 6	> 6	**Triple Road Train** Triple road train, or Heavy truck and three trailers	12	groups > 6 and axles > 6	

Definitions:
Group: Axle group, where adjacent axles are less than 2.1m apart
Groups: Number of axle groups
Axles: Number of axles (maximum axle spacing of 10.0m)

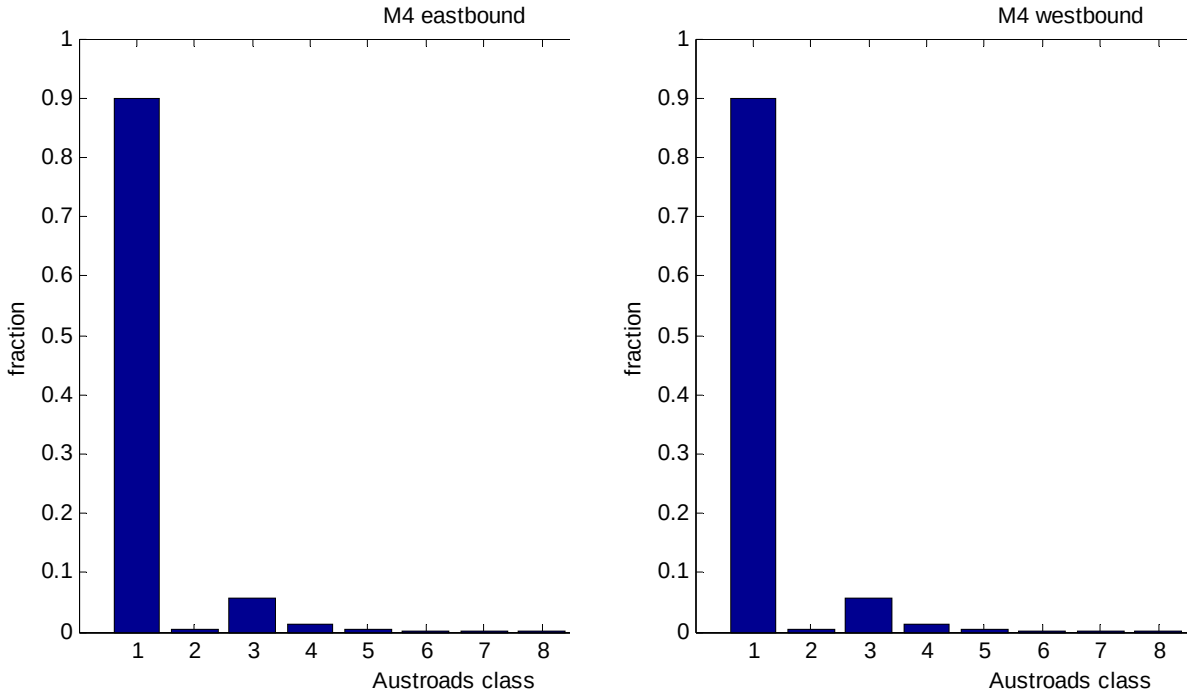
d(1): Distance between first and second axle
d(2): Distance between second and third axle

Figure 7.1. Austroads vehicle classification.

7.2.1 M4 fixed network vehicle counts

The traffic composition on the existing M4 Motorway is a guide for fleet composition expected in the New M5 tunnel. Data for the M4 Motorway given in Figure 7.2 shows that Austroads Classes 1-2 (light vehicles) comprise 90% of the fleet, with Class 3 being 5.8% and the remainder being Classes 4-12 heavy vehicles (4.2%).

The lower length limit for Class 3 vehicles (5.5 metres) is only just longer than a family station wagon, and so some of the Class 3 vehicles would be categorized by PIARC as LDVs, not HGVs. However the fraction of the vehicles in Classes 1 and 2 which should be classified as LDVs by the PIARC definition cannot be identified from the dataset in Figure 7.2.



Austroads Class	1	2	3	4	5	6	7	8	9	10	11	12
Eastbound %	90.0	0.4	5.8	1.3	0.4	0.1	0.1	0.2	1.4	0.2	0.0	0.0
Westbound %	89.9	0.4	5.8	1.3	0.4	0.1	0.1	0.2	1.5	0.2	0.0	0.0

Figure 7.2. Traffic split by Austroad vehicle class for the M4 freeway (Roads and Maritime fixed counting network).

7.2.2 M5 weigh-in-motion data

Weigh in motion (WIM) data obtained from the existing M5 East Motorway eastbound (lane 1) is shown in Figure 7.3 to Figure 7.5. Only data for Austroads Classes 3 and above are reported in this data set. Figure 7.3 shows the mass distribution taken from the WIM data, with Figure 7.4 and Figure 7.5 giving the cumulative distribution.

Using the 3.5 tonne upper limit prescribed by PIARC for LDVs; 7% of Class 3-12 could be categorized as LDVs. The HGV counts in the WRTM and associated traffic modelling need to be multiplied by 0.93 if numbers were originally assessed by including Class 3 as HGVs.

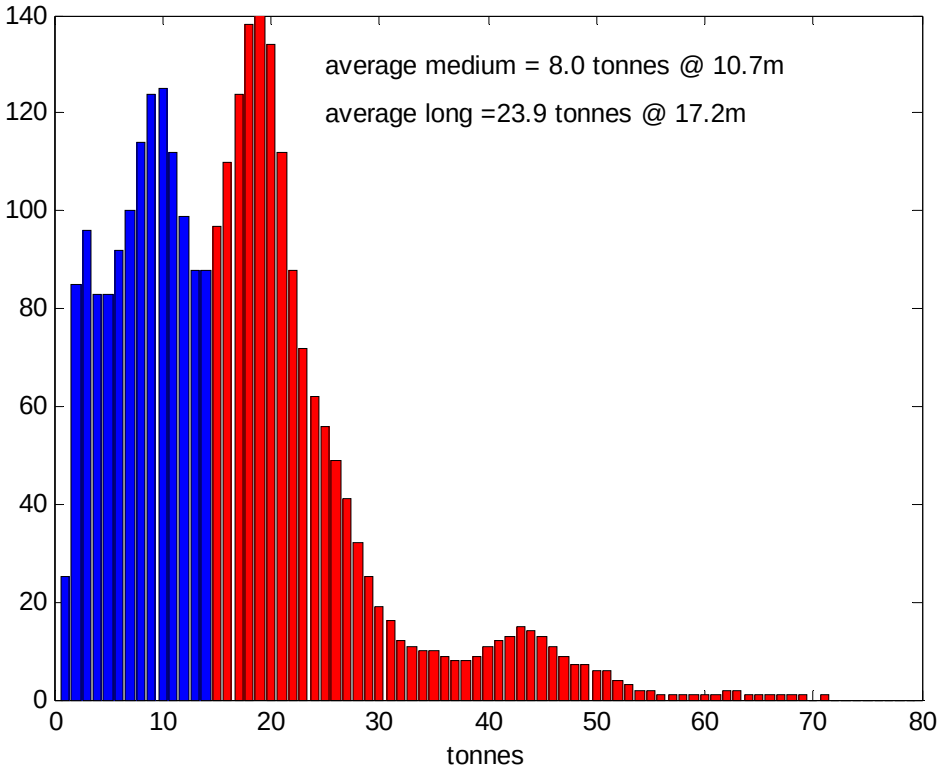


Figure 7.3. Mass distributions of medium (blue) and long (red) heavy vehicles (M5East eastbound). Only Class 3-12 are included in the data set. The vertical axis is vehicle counts in each bin.

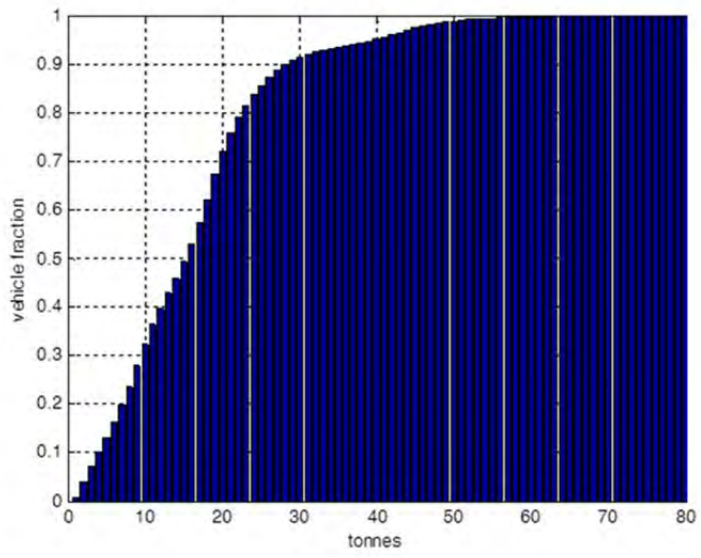


Figure 7.4. Cumulative distribution of vehicle mass on M5 eastbound. Only Class 3-12 are included in the data set.

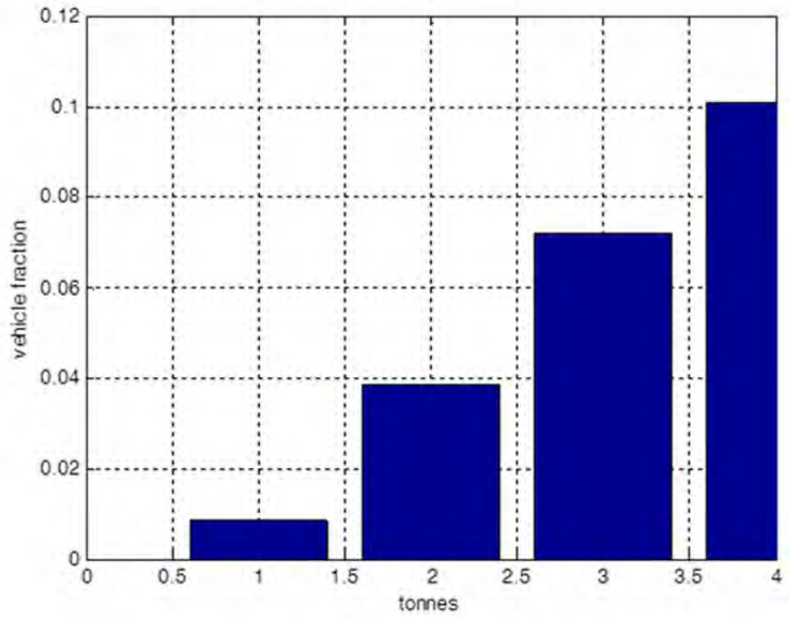


Figure 7.5. Cumulative distribution of vehicle mass on M5 eastbound in Classes 3 and up, shown up to 4 tonnes.

7.2.3 PIARC expectation

In a report section specific to Australia, PIARC[6] suggests that, for the purposes of calculation of the required ventilation capacity, the split of light (non-HGV) vehicles between PCs and LDVs is typically PC:LDV; 84%:16%. This information should be seen as a generalization which may not necessarily be applicable to the road corridors in question.

7.2.4 Air-shed studies

The NSW Greater Metropolitan Region emissions inventory adopts fleet makeups for each of several different road types. The table for commercial highways is reproduced below. When aggregated, it gives, for 2014; 74.5%PC, 18.3% LDVs, 6.8% HGVs and 0.5% motorcycles. Predictions for future years have an approximately constant LDV fraction, with a shift to diesel fuel.

Table 7.1. Adopted split within the NSW emissions inventory for a commercial highway (via Paul Boulter, Pacific Environment).

	Traffic mix (%)*											
	Passenger cars			Light commercial vehicles			Heavy goods vehicles					Motor-cycles
Commercial highway	CP	CD	All cars	LDCP	LDCD	All LCVs	HDCP	RT	AT	BusD	All HGVs	MC
2014	67.0	7.5	74.5	11.4	6.9	18.3	0.1	4.6	1.6	0.4	6.8	0.5
2021	58.8	14.5	73.3	8.9	9.8	18.7	0.1	5.2	1.8	0.4	7.5	0.5

[6] Road Tunnels: Vehicles, Emissions and Air Demand For Ventilation. Document 2012R05EN, PIARC Technical Committee C4 Road Tunnels Operation. December 2012. See Table 35

2031	52.2	20.6	72.9	6.4	12.3	18.7	0.1	5.5	1.9	0.4	7.9	0.5

NOTE: * CP = petrol passenger vehicles; CD = diesel passenger vehicles; LDCP = light-duty commercial petrol vehicles (<=3500 kg); LDCD = light-duty commercial diesel vehicles (<=3500 kg); HDCP = heavy-duty commercial petrol vehicles (>3500kg); RT = rigid trucks (3.5-25 tonnes, diesel only); AT = articulated trucks (> 25 tonnes, diesel only); BusD = heavy public transport buses (diesel only); MC = motorcycles.

7.2.5 Conclusion on vehicle type split

Daily fleet mixes derived from the notes above are given in Table 7.2. This table compares the WRTM vehicle fractions to the same fractions obtained when the LDVs and HGVs are re-categorised using rules consistent with PIARC definitions. A comparison is also made with air-shed data for a commercial highway.

Table 7.2. Vehicle splits approached in several ways.

	Eastbound			Westbound			
	PC	LDV	HGV	PC	LDV	HGV	Derivation notes
WRTM (New M5 2021)	52.9%	39.2%	8.0%	52.0%	40.6%	7.4%	Reduced data from tables in the WRTM.
WRTM (New M5 2031)	54.3%	31.3%	14.4%	54.0%	32.6%	13.4%	
PIARC (New M5 2021)	77.3%	15.3%	7.4%	77.8%	15.3%	6.9%	$PC=0.84*(PC+LDV)_{WRTM}$ $LDV=0.16*(PC+LDV)_{WRTM}$ +0.07*(Class3-12) $HGV=0.93*(HGV)_{WRTM}$
PIARC (New M5 2031)	71.9%	14.7%	13.4%	72.7%	14.8%	12.5%	
M4 fixed network count data (2012-2014)	75.9%	15.1%	8.9%	75.9%	15.1%	9.0%	PC=0.84*(Class1+Class2) LDV=0.16*(Class1+Class 2)+0.07*(Class3-12) HGV=0.93*(Classes 3-12)
Air-shed (Commercial highway 2014)	74.8%	18.4%	6.8%	74.8%	18.4%	6.8%	

Noting the WRTM splits to be inappropriate for ventilation purposes, there are really only two independent sources of the LDV fraction in the table above; the PIARC expectation and the generic commercial highway figures derived through the work by NSW Environmental Protection Authority (EPA). While they are not so different from each other, they are still uncertain, and it seems prudent to take the most conservative of these.

This is done by looking at the cumulative fractions coming down in vehicle size, making sure that the vehicle numbers above each size cutoff are as great in the adopted numbers as in any of the candidate distributions. The result is:

Table 7.3. Adopted vehicle type split for daily total flows on the corridor 2012 to 2021, based on all data above.

PC	LDV	HGV
74.8%	16.2%	9.0%

With a daily average adopted, a method of distributing the vehicle types through the day is still required. There is little doubt about the HGV fraction, as it is well recorded by the fixed count network to support the modelling that went into the WRTM, and only a small adjustment (7%) was made, based on the M5 data above and PIARC category weights. The

issue is the fraction of the lighter vehicles which fit within the PIARC understanding of an LDV.

WRTM numbers for LDVs are actually commercially registered vehicles of all light body types. It was assumed that no PIARC-defined LDVs are actually privately registered. The task is then to estimate the fraction of commercially registered vehicles that would fit the PIARC LDV understanding. This has been done by matching the proportion of non-HGVs that are LDVs (LDV/(PC+LDV)) to that proportion in the distribution in Table 7.3. The value from Table 7.3 is 17.8%. It is noted again that the figures being used are specifically relevant to the M4 corridor rather than being simply Sydney or NSW averages.

The daily LDV totals of the project WRTM traffic data were adjusted by reducing the WRTM LDV numbers by a fixed fraction and adding 7% of the WRTM HGV numbers to the LDVs. A value of 40% for the PIARC LDVs within the WRTM LDVs was found to match the daily project fleet LDV/PC split to that in Table 7.3.

All the WestConnex traffic predictions to date have been prepared in a consistent way in so far as Class 3 has been taken as the lower bound of HGV sizing and all commercially registered Class 1 and 2 vehicles have been taken as being LDVs. The above analysis suggests an approach for converting all such data into a form which may be used for pollution estimation. It is:

- Take the HGV numbers as 93% of the numbers given earlier.
- Take the remaining (7%) of the earlier HGVs to in fact be LDVs.
- Additionally, take 40% of the previous LDVs to actually be LDVs.
- Take the remainder to be PCs. (This will be the previous PCs, plus 60% of the previous LDVs).

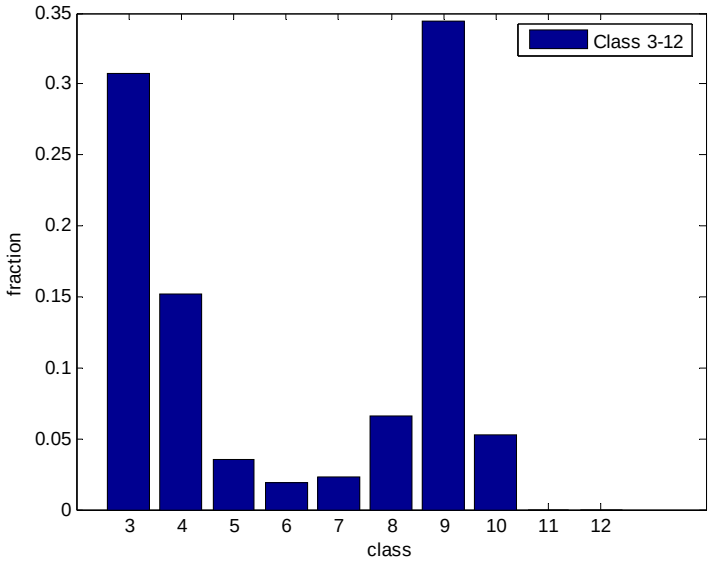
This allows the hour by hour WRTM traffic data to be transformed for ventilation purposes in a way that preserves the total hourly flows, the changing fleet mix over the 24 hours and through the years, and is also consistent with the methods proposed for pollution assessment.

7.3 Size of vehicles

Vehicle mass is important to estimating pollution generation and vehicle length affects the traffic lane density.

The mass of a large passenger car is typically 1.7 tonnes (Holden Commodore) and a small car can be less than 1.0 tonne. For this study a nominal passenger car mass of 1.5 tonnes has been adopted.

Heavy vehicle mass data obtained from lane 1 (slow lane) of M5 East tunnel is used here to categorize the heavy vehicles. Distribution of heavy vehicles by Austroads Class is shown in Figure 7.6. Classes 3-5 ("medium") comprise 49.5% of the heavy vehicle fleet and with the remainder ("long") lying in Class 6-12.



Class	3	4	5	6	7	8	9	10	11	12
%	30.7	15.2	3.6	1.9	2.3	6.6	34.5	5.3	0.0	0.0

Figure 7.6. Distribution of heavy vehicles by Austroads class (M5 East eastbound).

Weight distributions of medium (blue) and long (red) vehicles plotted in Figure 7.3 give average masses of 8.0 tonnes and 23.9 tonnes respectively. Estimates of average lengths 10.7 m and 17.2 m for medium and long vehicles are made using the assumption that lengths are in proportion to the weights and that medium vehicles range in length from 5.5 m to 14.5 m and long vehicles range from 14.5 m to 40 m. The nominal vehicle sizes are summarised in Table 7.4. The standing length includes an allowance for gaps between stopped vehicles.

Table 7.4. Adopted sizes for each vehicle category.

		PC	LDV	HGV	
				medium	long
Mass	tonne	1.5	3.0	8.0	24.0
Standing length per vehicle	m	6	10	12	20

7.4 Vehicle age

Figure 7.7 plots a typical vehicle age profile used in the estimation of emission factors.

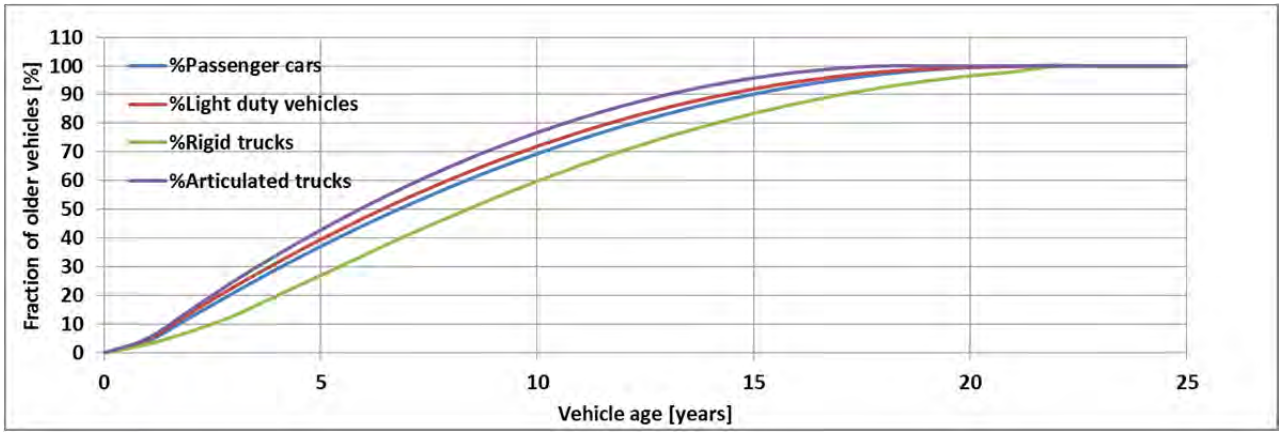


Figure 7.7. Typical age distribution plot (Australian Bureau of Statistics Motor Vehicle Census 2014).

7.5 Fuel mix

A plot of the fraction of New registrations which are fuelled with diesel is plotted for PC, LDV and HGV. The percentage of New diesel cars appears to plateau at 20% whilst New LDVs are approximately 90% diesel. New heavy vehicles are 100% diesel.

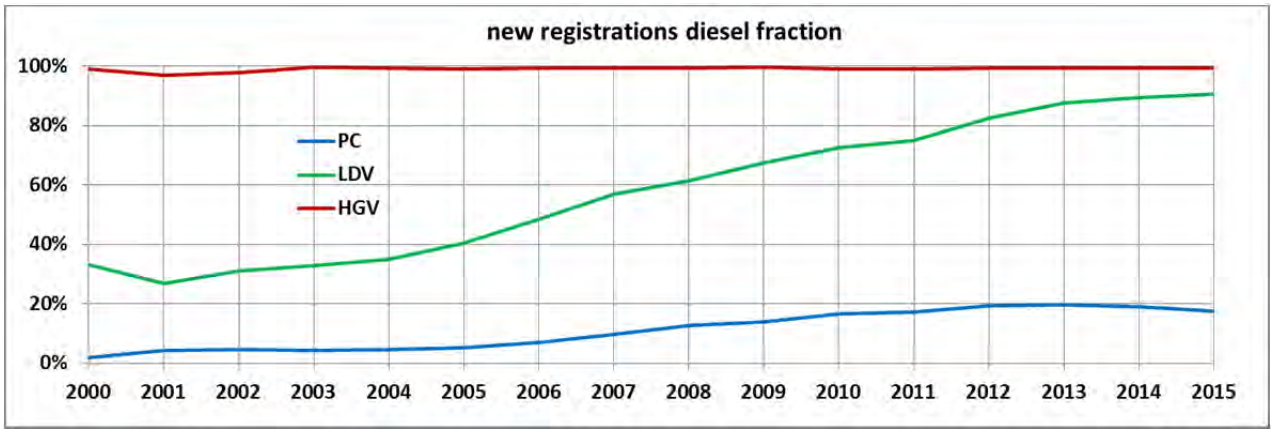


Figure 7.8. Percentage of New vehicles which are diesel-fuelled.

When the age distribution of the fleet is considered the diesel fractions adopted for the year 2020 fleet are calculated to be; PC 17.5%, LDV 91 %, HGV 100%. It should be noted that the PIARC emissions tables for Australia make the assumption that only 50% of the LDV are diesel. As there is not yet a basis on which to make an adjustment to the PIARC LDV emissions tables to account for the apparently higher LDV fraction, the existing tables have been used without modification.

7.6 Traffic flow for the New M5

Traffic flow and vehicle fractions for 2021 and 2031 are contained in Table 7.5 and Table 7.6. These figures are derived using WRTM values modified using the PIARC definitions of PC, LDV and HGV and the approach given at the end of Section 7.2.5.

Table 7.5. New M5 2021 normal traffic demand.

Hour Beginning	Eastbound				Westbound			
	Car	LDV	HGV	Total	Car	LDV	HGV	Total
0:00	41	7	8	57	177	53	33	262
1:00	25	6	8	39	45	8	11	65
2:00	23	3	8	34	35	11	11	57
3:00	24	3	8	35	50	21	11	82
4:00	37	12	8	58	58	27	21	106
5:00	100	24	13	137	161	65	33	259
6:00	375	119	53	547	247	79	54	380
7:00	786	214	90	1091	564	119	86	769
8:00	1006	267	151	1424	403	90	75	568
9:00	864	217	127	1209	578	123	129	830
10:00	775	183	126	1084	538	124	151	813
11:00	724	178	136	1038	557	154	179	891
12:00	550	159	120	829	530	136	140	806
13:00	454	138	116	708	524	138	161	823
14:00	467	135	113	715	557	139	151	847
15:00	617	137	110	864	643	149	140	931
16:00	697	137	106	940	804	213	161	1178
17:00	571	101	99	771	1078	258	148	1483
18:00	557	88	97	742	725	179	108	1012
19:00	364	75	81	520	542	144	86	772
20:00	283	72	63	418	490	131	70	691
21:00	257	67	57	380	450	118	64	632
22:00	260	73	48	381	423	109	65	597
23:00	109	22	16	146	288	85	64	437

Table 7.6. New M5 2031 normal traffic demand.

Hour Beginning	Eastbound				Westbound			
	Car	LDV	HGV	Total	Car	LDV	HGV	Total
0:00	48	9	12	69	200	59	42	301
1:00	29	7	9	45	52	9	14	75
2:00	28	4	9	41	40	12	14	66
3:00	28	4	9	41	57	23	14	94
4:00	43	14	12	69	65	30	28	123
5:00	117	28	18	163	175	68	42	284
6:00	432	139	71	641	242	89	70	401
7:00	925	248	118	1292	647	134	112	893
8:00	1161	298	213	1672	534	115	108	757
9:00	1018	252	170	1441	662	139	167	968
10:00	914	214	168	1296	616	141	195	952
11:00	818	205	180	1203	623	173	221	1017
12:00	647	185	161	993	606	154	181	941
13:00	534	161	156	851	599	156	209	964
14:00	542	158	152	851	617	158	195	970
15:00	728	160	147	1035	735	168	181	1084
16:00	825	160	142	1127	919	240	209	1368
17:00	794	134	137	1065	1321	308	218	1847
18:00	659	103	130	892	829	201	140	1169
19:00	430	88	109	627	619	162	112	893
20:00	317	84	86	486	559	147	91	797
21:00	302	78	76	456	499	132	84	715
22:00	292	84	61	437	439	112	81	632
23:00	112	25	21	159	306	81	63	450

Table 7.7. Normal traffic demand in 2031, including M4-M5 Link up to Rozelle.

Hour Beginnin	Eastbound				Southern Extension				Westbound			
	Ca	LD	HG	Tota	Car	LD	HG	Tota	Car	LD	HG	Tota
0:00	32	6	15	54	114	37	3	154	216	53	38	307
1:00	20	5	7	32	61	25	3	88	42	7	13	62
2:00	18	2	7	28	33	13	3	48	19	7	13	39
3:00	18	2	7	28	33	13	3	48	19	7	13	39
4:00	29	9	7	45	96	25	5	125	47	26	13	86
5:00	79	18	11	108	191	50	10	252	184	63	38	285
6:00	29	89	45	428	799	223	20	1042	300	81	63	444
7:00	62	161	77	859	158	397	49	2026	716	121	100	937
8:00	68	165	110	963	193	512	124	2569	984	182	128	1294
9:00	68	163	108	956	160	404	103	2111	730	125	152	1007
10:00	61	138	106	860	139	353	88	1836	683	127	177	988
11:00	53	130	105	771	120	323	78	1605	629	138	197	964
12:00	43	119	102	655	111	302	73	1491	646	132	159	937
13:00	35	104	99	561	109	290	66	1448	646	134	190	971
14:00	36	102	96	567	106	277	61	1400	680	142	177	999
15:00	49	103	93	687	101	252	59	1323	771	151	165	1087
16:00	55	103	90	750	941	227	61	1229	100	216	184	1402
17:00	62	117	87	830	878	204	63	1146	120	253	206	1661

18:00	44	66	82	596	752	201	34	987	909	180	127	1215
19:00	29	57	69	416	728	200	26	954	675	147	101	923
20:00	22	54	54	332	728	199	20	947	609	133	81	823
21:00	20	50	52	306	728	199	15	942	562	120	76	758
22:00	19	51	52	300	736	198	10	945	516	105	65	686
23:00	77	17	15	108	271	99	5	374	328	68	58	454

7.7 Ramp splits M5 with M4-M5 Link

7.7.1 Eastbound

The fraction of traffic in each category departing the New M5 at SPI for 2031 traffic is given in Table 7.8. Traffic entering the eastbound M4-M5 Link tube at SPI is given in Table 7.9.

Table 7.8. Eastbound traffic split at SPI

Hour beginning	PC	LDV	HGV
0	73%	60%	42%
1	73%	60%	42%
2	61%	51%	45%
3	79%	89%	45%
4	79%	90%	72%
5	75%	77%	61%
6	74%	62%	52%
7	74%	42%	45%
8	82%	84%	61%
9	76%	73%	53%
10	78%	83%	54%
11	76%	80%	57%
12	79%	77%	58%
13	85%	75%	59%
14	76%	74%	60%
15	79%	81%	61%
16	81%	80%	59%
17	77%	72%	57%
18	83%	79%	62%
19	83%	80%	62%
20	82%	81%	74%
21	82%	78%	72%
22	83%	81%	69%
23	84%	89%	76%

Table 7.9. Eastbound traffic (vph) entering M4-M5 Link at SPI

Hour beginning	PC	LDV	HGV
0	256	27	94
1	256	27	94
2	132	17	94
3	132	17	94
4	132	17	94
5	760	47	93
6	760	47	93
7	1931	152	407
8	3086	232	534
9	2910	276	607
10	2852	278	635
11	2811	278	655
12	2825	280	647
13	2838	278	642
14	2837	278	642
15	2853	267	640
16	2883	253	632
17	2864	249	643
18	2571	270	640
19	2446	244	581
20	2131	212	465
21	2101	191	442
22	2052	182	424
23	1086	88	102

It is assumed that 50% of the M4-M5 Link exits to the Rozelle interchange and the balance is evenly split between the CWL and WHT ramps.

7.7.2 Westbound

The ramp splits for the westbound traffic are given in Table 7.10 to Table 7.12.

Table 7.10 Westbound traffic exiting at SPI.

Hour beginning	PC	LDV	HGV
0	65%	45%	83%
1	82%	78%	98%
2	91%	75%	88%
3	91%	75%	88%
4	75%	44%	84%
5	52%	24%	52%
6	63%	41%	72%
7	78%	58%	84%
8	81%	62%	86%
9	87%	65%	85%
10	82%	60%	86%
11	82%	63%	84%
12	83%	72%	89%
13	85%	71%	83%
14	83%	64%	82%
15	82%	58%	79%
16	75%	50%	74%
17	67%	45%	80%
18	68%	54%	81%
19	77%	63%	88%
20	87%	63%	94%
21	84%	65%	93%
22	85%	67%	94%
23	70%	56%	83%

Table 7.11 Westbound traffic (vph) entering at SPI.

Hour beginning	PC	LDV	HGV
0	143	32	23
1	62	16	15
2	62	16	12
3	62	16	12
4	104	32	12
5	187	61	12
6	332	95	35
7	656	128	70
8	1090	202	104
9	1165	206	128
10	1239	259	174
11	1624	380	196
12	1805	444	186
13	1948	474	174
14	2090	504	162
15	2426	532	133
16	2855	624	129
17	3265	680	227
18	2376	562	116
19	1625	318	104
20	1239	253	99
21	1008	227	81
22	938	222	72
23	246	35	46

Table 7.12 Westbound traffic exiting at SE.

Hour beginning	PC	LDV	HGV
0	32%	33%	9%
1	55%	65%	13%
2	73%	65%	13%
3	73%	65%	13%
4	68%	50%	22%
5	44%	46%	13%
6	40%	47%	11%
7	27%	47%	13%
8	36%	45%	15%
9	45%	61%	17%
10	57%	68%	21%
11	67%	72%	24%
12	67%	73%	27%
13	69%	74%	24%
14	69%	75%	26%
15	70%	76%	30%
16	69%	72%	30%
17	70%	71%	30%
18	70%	73%	34%
19	65%	62%	27%
20	53%	59%	22%
21	50%	57%	14%
22	49%	59%	17%
23	34%	29%	15%

8 VEHICLE-INDUCED AIR FLOWS

8.1 Piston effect

Vehicle induced air flows in a tunnel are determined from the vehicle flow and speed, along with vehicle drag parameters. The pollutant concentrations in the tunnel are determined by how the vehicle emissions are diluted by the tunnel air flows. Hence knowing the vehicle drag is central to estimating the in-tunnel pollutant concentrations.

8.2 Vehicle drag

Vehicle aerodynamic drag force on an isolated vehicle in open air is expressed by the equation: $F_d = \frac{1}{2}\rho C_d A_v (v-U)^2$, where;

- ρ is the density of air which is dependent on temperature [kg/m^3];
- C_d is the drag coefficient measured in open air. Typical drag coefficients for isolated vehicles in open air facing an oncoming air stream are given in Figure 8.1. The error bars in this graph indicate that drag coefficients are highly variable.

  When the airstream comes from the rear of the vehicle, as would occur with stopped traffic, the drag coefficient may be larger than when the airstream is coming from the front;
- A_v is the frontal area [m^2] of the vehicle;
- v is the vehicle speed [m/s], and;
- U is the tunnel air speed [m/s].

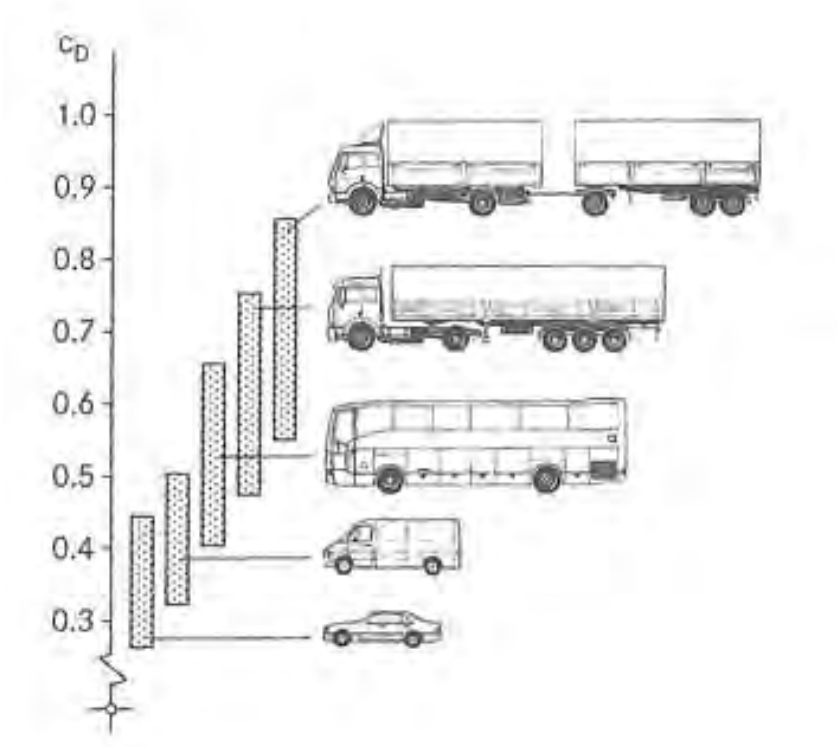


Figure 8.1. Typical drag coefficients for isolated vehicles in open air. (http://www.part20.eu/en/background/aerodynamics/)

With the tunnel walls affecting both the airspeed around the vehicle and the nature of the vehicle wake, the drag is different from that in open air. Aerodynamic drag exerted by a vehicle in a tunnel with cross sectional area A is estimated using from the modified formula:

$$F_d = \frac{1}{2}\rho C_d{}^* A_v (v-U)^2$$

where the effective drag factor

$$C_d{}^* = \frac{s_f C_d}{\left(1-\frac{A_v}{A}\right)^2}$$

is influenced by;

- the ratio of frontal area of the vehicle relative to the tunnel area. The restriction of the air between the vehicle and the walls tends to increase the effective drag coefficient by increasing the air speed local to the vehicle.
- spacing factor s_f which is used to account for the proximity of other vehicles in front and behind, and the tunnel walls. This factor has a significant effect in decreasing the effective drag coefficient with closer vehicle spacing. As the vehicle separation decreases, the spacing factor decreases due to sheltering of the vehicles by those in front. Figure 8.2 shows the effect of vehicle separation on leading and trailing vehicle drag coefficients of a typical passenger car[7]. The distance between vehicles is denoted 'x', with the vehicle length being 'L'. This graph suggests that the spacing factor is in the range $0.73 \leq s_f \leq 0.85$, as the separation increases up to at least four car lengths, corresponding to a traffic speed of 50 km/h. Being only a fraction of the tunnel fleet, large vehicles are more likely to be widely separated from each other and would not be shielded significantly by the surrounding cars.

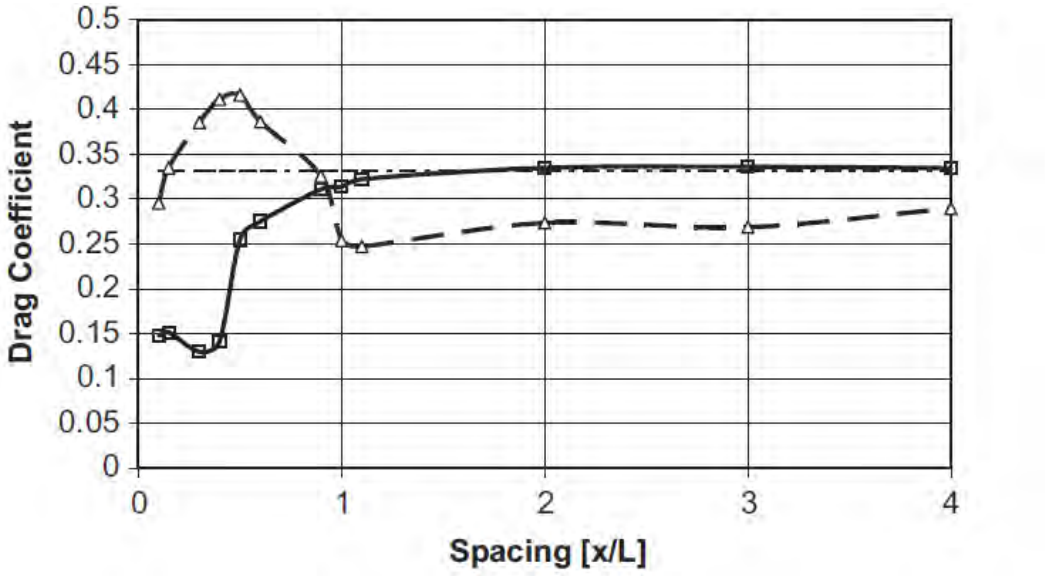


Figure 8.2. Effect of vehicle spacing (separation) on vehicle drag coefficients of the lead (square) and trailing (triangle) vehicle (Watkins & Gino 2007).

Proximity of the tunnel walls and traffic in adjacent lanes has the effect of suppressing the wake being shed from a vehicle, thus reducing its effective drag coefficient.

[7] Watkins S., Vino G., The effect of vehicle spacing on the aerodynamics of a representative car shape. J. Wind Eng. Ind. Aerodyn. (2007), doi: 10.1016/j.jweia.2007.06.042

The shaded area in Table 8.1 summarises the results derived from in-tunnel experimentation[8] by Jang and Chen. The un-shaded area is a calculation of the spacing factors which give the Jang and Chen numbers, starting from nominal open air vehicle drag coefficients for small and large vehicles in high and low density traffic.

The spacing factor (s_f = 0.54) for high density small vehicle traffic is significantly smaller than predicted from Figure 8.2 which only applies to a single following vehicle in an open air environment. Spacing factors for low density small vehicle traffic $0.87 \le s_f \le 0.95$ are slightly higher than predicted from Figure 8.2. Low spacing factors $0.29 \le s_f \le 0.49$ for large vehicles predicted from the Jang and Chen data are associated with the proximity of the tunnel walls and the resulting suppression of the vehicle wake.

Effective drag coefficients estimated for a 100 m^2 tunnel are summarised in Table 8.2 on the basis of the nominal drag coefficients and shading factors given in Table 8.1. Figures for 60-80 km/h traffic have been adopted for general use in simulations undertaken for this report.

Table 8.1. Estimation of spacing factor from tunnel data.

C_d* (Jang & Chen)						Cd (nominal)	$\left(1-\frac{A_v}{A}\right)^2$	spacing factor (high density)	spacing factor (low density)	
Vehicle	A_T	A_V	High density 8-23 veh./lane-km	Low density < 8 veh./lane-km						
	m^2	m^2	average	min	max				min	max
small	94	2.5	0.20	0.32	0.35	0.35	0.95	0.54	0.87	0.95
large	94	7.1	0.24	0.36	0.40	0.70	0.85	0.29	0.44	0.49

Table 8.2. Vehicle drag coefficients.

	Tunnel	PC				LDV				HGV			
	A	A_v	C_d	s_f	C_d*	A_v	C_d	s_f	C_d*	A_v	C_d	s_f	C_d*
km/h	m^2	m^2				m^2				m^2			
0-10	100	2.5	0.32	0.54	0.18	4.8	0.5	0.54	0.30	7.1	0.8	0.29	0.27
20-40	100	2.5	0.32	0.87	0.29	4.8	0.5	0.87	0.48	7.1	0.8	0.44	0.41
60-80	100	2.5	0.32	0.95	0.32	4.8	0.5	0.95	0.52	7.1	0.8	0.49	0.45
reverse flow	100	2.5	0.60	0.54	0.34	2.5	0.8	0.54	0.46	2.5	1	0.29	0.31

These effective in-tunnel drag coefficients are lower than those often used in Australian design practice. Over-estimating the drag coefficient results in predictions of tunnel air flows which may be higher than those which actually occur. Over-prediction of tunnel air flow results in both an under-prediction of the in-tunnel pollutant concentrations, and oversizing of vent station capacity for portal emissions control.

[8] Jang H., Chen F., On the determination of aerodynamic coefficients of highway tunnels. Journal of Wind Engineering and Industrial Aerodynamics 90 (2002) pp 869 – 896.

9 EMISSION FACTORS

9.1 Variation of emission factors with time.

Average emission factors for the Australian vehicle fleet are continually decreasing as new emissions control technologies are supplied on new vehicles, and old vehicles pass out of service. However PIARC[9] emissions tables do not provide extrapolation factors beyond 2020. This report uses the PIARC 2010 emissions factors specific to the Australian fleet, and also uses the PIARC extrapolation to year 2020, for all simulations, including those designated as 2031 traffic. Hence the predictions made of pollution concentrations will be increasingly conservative for tunnel opening years past 2020.

A project to assess the applicability of PIARC emission factors in 2015 is nearing completion. Initial results suggest that the PIARC Australian tables as used here are a reasonably close representation of the current Sydney fleet. The PIARC tables appear to over-predict 2015 CO production and may slightly under-predict 2015 NO_2 production, when the NO_2:NO_X ratio is taken from the work of Carslaw and Rhys-Tylor[10]. Any adjustments required are unlikely to be large enough to affect conclusions.

9.2 CO emissions

Carbon monoxide emissions factors used in this report are contained in Table 9.1.

[9] PIARC Technical Committee C4 Road Tunnels Operation. Road Tunnels: Vehicle Emissions and Air Demand for Ventilation, World Road Association, document 2012R05EN, revised December 2012.

[10] Carslaw D., Rhys-Tylor G. New insights from comprehensive on-road measurements of NO_x, NO_2 and NH_3 from vehicle emission remote sensing. Atmospheric Environment 81 (2013) pp339-347.

Table 9.1. CO emissions factors 2020. The column headers in each table are roadway gradient.

v	PC CO [g/h] 2020						
km/h	-6%	-4%	-2%	0%	2%	4%	6%
0	14.0	14.0	14.0	14.0	14.0	14.0	14.0
10	16.7	17.8	19.2	20.6	22.7	24.9	29.3
20	18.9	21.3	24.1	26.9	30.9	35.2	44.0
30	19.0	22.4	26.7	32.1	38.4	45.6	60.0
40	18.9	23.5	29.7	38.4	49.1	63.7	81.2
50	18.5	24.1	32.2	43.6	59.3	81.5	109.4
60	17.9	24.2	34.0	47.8	68.7	97.8	145.3
70	17.4	24.1	35.1	52.3	79.3	116.3	189.2
80	17.2	24.0	36.1	57.9	93.5	145.2	240.8
90	17.5	24.5	38.0	65.2	113.4	193.4	301.7
100	18.4	26.2	41.9	74.2	140.9	267.9	372.8
110	20.0	29.6	48.7	85.6	178.2	369.4	464.2
120	22.2	34.8	58.8	101.4	228.9	462.5	596.4
130	24.4	41.7	71.4	126.9	299.8	564.2	768.0

v	LDV diesel/gasoline CO [g/h] 2020						
km/h	-6%	-4%	-2%	0%	2%	4%	6%
0	5.5	5.5	5.5	5.5	5.5	5.5	5.5
10	17.7	17.7	19.6	37.6	51.2	63.5	64.3
20	17.7	17.7	27.2	55.3	49.4	27.5	32.2
30	17.7	17.7	36.0	59.2	26.1	40.0	74.1
40	17.7	17.7	43.8	37.1	33.8	75.8	140.0
50	17.7	17.7	47.2	27.9	54.0	121.9	224.2
60	17.7	17.7	58.7	28.8	91.5	200.5	314.6
70	17.7	17.7	61.2	52.5	152.9	289.6	424.0
80	17.7	17.7	66.3	92.5	242.1	387.0	555.7
90	17.7	39.2	71.4	155.4	325.2	504.1	710.5
100	17.7	53.6	78.2	254.3	437.9	656.2	905.4
110	17.7	61.1	153.4	356.3	580.4	842.5	1138.9
120	44.0	65.4	265.5	488.2	757.5	1068.0	1220.9
130	29.6	149.7	385.3	655.1	974.4	1119.3	1321.9

Table 9.1 cont.

v	HGV CO [g/h] 2020						
km/h	-6%	-4%	-2%	0%	2%	4%	6%
0	15.2	15.2	15.2	15.2	15.2	15.2	15.2
10	9.9	10.9	14.9	18.0	20.7	23.5	26.0
20	7.1	10.2	14.3	19.4	24.0	28.8	34.0
30	6.4	10.3	17.4	21.5	27.4	35.6	43.9
40	5.8	9.6	17.9	23.5	31.4	43.1	53.5
50	5.8	9.0	17.6	24.7	36.5	50.2	64.0
60	5.8	8.1	16.8	26.1	42.1	57.8	74.7
70	5.8	7.0	16.9	28.2	47.4	66.0	85.7
80	5.8	6.5	16.8	31.6	53.5	74.7	97.4
90	5.8	7.4	19.2	36.7	60.1	83.4	109.0
100	5.8	9.1	21.8	42.9	66.5	92.0	120.5
110	5.8	9.6	25.2	48.5	72.4	100.5	132.0
120	5.8	13.9	29.1	52.7	78.2	108.9	143.4
130	6.7	16.6	33.7	56.2	84.0	117.3	154.9

9.3 NO_2 emissions

PIARC tables give NO_X generation rates as a function of vehicle speed and road gradient. Since NO_2 is the dominant design pollutant, the mass ratio NO_2:NO_X is a key parameter in the PIARC method. It is highly desirable to have tables of NO_2 evolution rather than its proxy NO_X which bundles together the NO and NO_2.

NO_2:NO_x mass ratios for the various vehicle classes given in Table 9.2 are calculated using the fleet age profile given in Figure 7.7.

Table 9.2. Mass fraction NO_2:NO_X contained in vehicle exhaust.

Vehicle class	NO_2 (gram):NO_x (gram)
PC_{petrol} & LDV_{petrol}	0.08
PC_{diesel}	0.32
LDV_{diesel}	0.31
HGV	0.11

The input data to these estimates comes from Carslaw and Rhys-Tylor (2013)[11] who used remote sensing of travelling surface vehicle's emissions (measured at the vehicle tailpipe), to determine the ratio of vehicle pollutants NO_2, NO_X and NH_3 to CO_2 emissions.

It is considered that applying Carslaw and Rhys-Tyler's data (obtained from surface running vehicles) to a tunnel scenario is valid. NO from the exhaust is converted to NO_2 in the presence of ozone O_3 when it enters the atmosphere. However in a tunnel environment (remote from the entry portal), where the ozone has been depleted, NO_2 levels should be unaffected by the further conversion of NO to NO_2. Hence readings taken at the tailpipe of a vehicle (prior to conversion of NO to NO_2) should be a reasonable approximation for estimates of the resulting NO_2 in a tunnel.

Another issue which increases the uncertainty of the rate of NO_2 generation, is that the evolution of pollutants is a function of the vehicle operating power. Carslaw and Rhys-Tyler's paper does not attempt to quantify this relationship.

NO_2 emissions given in Table 9.4 for each of the three vehicle classes, are predicted from PIARC NO_X tables multiplied by the appropriate NO_2:NO_X mass ratio predicted from the Carslaw data. This introduces an additional uncertainty in that the accuracy of the PIARC NO_X emission rates is unknown. The PIARC data are used as a de-facto standard, however the PIARC document itself says the figures can be applied "if emission data for the project cannot be provided by a locally valid data base".

An average fleet conversion ratio can be calculated for an assumed distribution PC:LDV:HGV (75%:15%:10%) based on the NO_2 data given in Table 9.2 and PIARC emissions data for NO_X for the same fleet composition. The average NO_2:NO_X mass ratio for the WestConnex fleet is predicted to lie in the range 13.1% to 15.6% as shown Table 9.3. Note that the simulations follow the hourly varying fleet mix. The fleet average numbers here are simply to see the order of magnitude.

[11] Carslaw D., Rhys-Tyler G. New insights from comprehensive on-road measurements of NO_x, NO_2 and NH_3 from vehicle emission remote sensing. Atmospheric Environment 81 (2013) pp339-347.

Table 9.3. WestConnex fleet average NO_2:NO_x ratios for 2020.

	Tunnel gradient						
Speed (km/h)	-6%	-4%	-2%	0	2%	4%	6%
0	14.2%	14.2%	14.2%	14.2%	14.2%	14.2%	14.2%
10	14.1%	13.8%	12.8%	13.4%	13.7%	13.7%	13.5%
20	14.8%	14.1%	13.1%	13.9%	13.8%	13.3%	13.1%
30	14.9%	14.0%	13.3%	14.1%	13.3%	13.1%	13.3%
40	15.1%	14.2%	13.4%	13.7%	13.2%	13.3%	13.5%
50	15.1%	14.4%	13.5%	13.5%	13.2%	13.4%	13.6%
60	15.1%	14.7%	14.1%	13.4%	13.4%	13.6%	13.7%
70	15.1%	15.0%	14.4%	13.5%	13.4%	13.8%	13.8%
80	15.1%	14.9%	14.6%	13.8%	13.6%	13.9%	13.9%
90	15.1%	15.6%	14.2%	14.0%	14.0%	14.0%	14.1%
100	15.1%	15.0%	14.2%	14.2%	14.2%	14.2%	14.2%
110	15.1%	14.5%	14.6%	14.4%	14.4%	14.4%	14.3%
120	16.2%	14.9%	15.0%	14.7%	14.6%	14.6%	14.4%
130	15.8%	15.2%	15.3%	15.0%	14.9%	14.6%	14.4%

Table 9.4. NO_2 emissions factors 2020 (using NO_X tables from PIARC2012 and NO_2: NO_X ratios estimated from Carslaw and Rhys-Tyler). The column headers in each table are tunnel gradient.

v	PC NO_2 [g/h] 2020						
km/h	-6%	-4%	-2%	0%	2%	4%	6%
0	0.33	0.33	0.33	0.33	0.33	0.33	0.33
10	0.38	0.38	0.38	0.60	0.77	0.92	1.06
20	0.38	0.38	0.41	0.80	1.05	1.33	1.76
30	0.38	0.38	0.51	0.97	1.35	1.87	2.40
40	0.38	0.38	0.55	1.09	1.68	2.33	3.03
50	0.38	0.38	0.52	1.21	1.97	2.79	3.61
60	0.38	0.38	0.60	1.40	2.36	3.34	4.45
70	0.38	0.38	0.74	1.74	2.84	3.99	5.52
80	0.38	0.38	0.95	2.10	3.36	4.90	6.70
90	0.38	0.38	1.25	2.54	4.00	5.93	8.00
100	0.38	0.42	1.64	3.10	4.94	7.16	9.50
110	0.38	0.56	2.09	3.80	6.07	8.56	11.18
120	0.38	1.15	2.70	4.79	7.39	10.16	13.07
130	0.39	1.65	3.49	6.05	8.93	11.99	15.18

v	LDV diesel/gasoline NO_2 [g/h] 2020						
km/h	-6%	-4%	-2%	0%	2%	4%	6%
0	0.9	0.9	0.9	0.9	0.9	0.9	0.9
10	0.9	0.9	1.0	1.9	2.8	3.7	3.4
20	0.9	0.9	1.4	3.1	3.4	3.6	3.1
30	0.9	0.9	1.8	3.7	2.6	3.6	5.3
40	0.9	0.9	2.3	3.0	3.2	5.4	7.9
50	0.9	0.9	2.5	2.6	4.4	7.3	10.6
60	0.9	0.9	3.3	2.9	6.1	9.9	13.8
70	0.9	0.9	3.4	4.3	6.2	12.9	17.5
80	0.9	0.9	3.4	6.1	8.4	16.3	21.8
90	0.9	1.8	3.4	8.5	14.2	20.1	26.6
100	0.9	2.3	5.5	11.6	18.0	25.0	32.5
110	0.9	2.9	8.4	15.2	22.6	30.6	39.3
120	2.3	4.9	12.0	19.6	28.1	37.3	41.9
130	2.7	8.3	16.2	24.9	34.5	38.8	45.2

Table 9.4 cont.

v	HGV diesel 23t NO_2 [g/h] 2020						
km/h	-6%	-4%	-2%	0%	2%	4%	6%
0	3.9	3.9	3.9	3.9	3.9	3.9	3.9
10	2.3	3.0	6.1	8.7	10.9	13.5	16.3
20	1.5	2.4	6.9	9.9	14.0	19.8	25.2
30	1.3	2.5	8.0	11.7	18.0	26.9	35.2
40	1.2	2.2	8.4	13.5	22.6	34.4	45.1
50	1.2	1.9	8.1	14.8	27.8	41.7	55.5
60	1.2	1.5	7.1	16.4	33.3	49.4	66.0
70	1.2	1.2	7.1	19.0	38.8	57.7	76.7
80	1.2	1.3	7.5	22.9	45.2	66.1	87.5
90	1.2	1.4	9.1	27.8	51.7	74.3	98.2
100	1.2	1.9	11.9	33.9	57.9	82.2	108.8
110	1.2	2.8	15.4	39.8	63.6	90.1	119.3
120	1.2	4.9	19.6	44.3	69.0	97.8	129.8
130	1.5	7.4	24.4	47.7	74.3	105.5	140.2

9.4 Particulate matter

Exhaust (soot) and non-exhaust (from brakes, tyres, etc) particulate matter is considered in this analysis. The emissions factors are contained in Table 9.6 and Table 9.7 respectively. Exhaust particulates which are typically of the order of 0.2 µm in diameter, are in the size range which contributes to reduction in visibility in the tunnel (0.1 to 4 µm). In this report, the 4.7 m^2/g conversion factor recommended by PIARC is used to convert between light extinction coefficient (m^{-1}) and particulate concentration (g/m^3) for exhaust particulates. Non-exhaust particulates which are typically much larger than 1 µm do not contribute significantly to loss of visibility. The smaller non-exhaust particulates are estimated in this report following the PIARC approach for non-exhaust $PM_{2.5}$, for which the 4.7 m^2/g conversion factor could apparently also be applied, however that approach may not be appropriate, for the reasons set out below. Emission rates for particulates above 2.5 µm are not estimated here.

In looking at particulate emissions in vehicle tunnels, the primary focus has always been on those emitted directly from the tailpipe. Airborne particulates are also generated from wear of brakes, tyres and the road surface. Historically, no one paid too much attention to this second source, as the exhaust-sourced emissions dominated. It is welcome that the changes in vehicle design rules and the consequent improving fleet cleanliness have reduced exhaust particulate emissions greatly, and continue to do so. A consequence of the reducing exhaust emissions is that the level of non-exhaust particulates may become relatively more significant.

PIARC (2012)[12] gives a method for estimating the generation rate of non-exhaust particulates and that approach has been applied within the IDA Tunnel models of the tunnel to give the pollutant concentrations and flows noted in Appendices A and B. The PIARC approach to non-exhaust particulates is seen as a somewhat arbitrary upper bound for $PM_{2.5}$ generation, established from data, perhaps as late as 2009, when tailpipe particulate emissions still had a way to fall, carbon monoxide was much higher, and it was not so critical what non-exhaust particulates were generated. Perhaps for those reasons, the PIARC approach to estimating non-exhaust particulates was very 'broad brush' and was arguably conservative but without consequences for being so. The PIARC document notes that:

> The emission factors given in this document serve calculation design purposes. Therefore, they tend to be conservative in terms of emissions quantities.
>
> A large uncertainty is related to the quantification of non-exhaust particulate matter (PM) emissions (re-suspension of road dust, abrasion).

The combination of large uncertainty and conservatism means that the emissions are likely to be well above actual levels. To understand how conservative the non-exhaust particulate levels in the appendices might be, notes are made below on some of the most recent testing literature.

The first point is that particulates generated by abrasion tend to have a much larger size distribution than exhaust material. This is self-evident to the extent that wear particles go up in size to grit that would not be suspended in air. The difference in size distribution is

[12] Road Tunnels: Vehicles, Emissions and Air Demand for Ventilation. Document 2012R05EN, Permanent International Association of Road Congresses (PIARC) Technical Committee C4 Road Tunnels Operation. December 2012.

recognised as aiding the understanding of particulate generation by Henn et.al. (2009)[13]: *"Based on the fact that internal combustion in the motor produces particles with a diameter smaller than 2.5 µm, the difference between measured PM_{10} and $PM_{2.5}$ concentrations is an indicator for abrasion and resuspension"*. That is; material in the size range 2.5 µm to 10 µm is almost certainly non-exhaust in its origin.

The issue of re-suspension of road dust is an interesting one. It gets mentioned in many sources, including in PIARC (2012) and Henn et.al. (2009), as above, and Hinterhofer (2014)[14]. The term is sometimes used to include also ambient suspended material drawn into the tunnel by the vehicle-induced air flow. This is generally small and becomes insignificant in a long tunnel. Considering just the narrower, literal meaning of re-suspension, it is not clear how re-suspension in a tunnel can have any net positive contribution to airborne dust. Any material on the roadway available for re-suspension, by the narrow definition of re-suspension, must have been suspended earlier and been deposited. If the re-suspension is to be considered as a source of material, so the deposition must be accounted for as a loss. In the long term, the rate of resuspension cannot be greater than the rate of deposition and so considering neither makes the airborne pollution estimate conservative. The only possible effect of deposition and resuspension might be to shift the pollution in time relative to the generating vehicle flow. It is not proposed to consider either resuspension or deposition further.

The understanding of the 2.5 to 10 µm size range as a marker for non-exhaust contribution was extended by Hinterhofer (2014)[15] and Hinterhofer et. al. (2014)[16], in conjunction with other facts below, to make some important conclusions.

The exhaust emission rates of vehicles in Austria are well predicted by a model called NEMO (Rexeis, Hausberger (2005)). Hinterhofer, like Henn et. al. earlier, found that the $PM_{2.5}$ emissions predicted by NEMO were sufficient on their own to account for all the $PM_{2.5}$ measured in the tunnel, meaning that the quantity of non-exhaust material below 2.5 µm in size was insignificant. This is a really important conclusion. It is saying that essentially all of the material suspended following wear and abrasion is too large to affect visibility strongly.

The conclusion that there is very little non-exhaust $PM_{2.5}$ material is at odds with PIARC (2012). Being focussed on visibility, PIARC provides estimates only for the $PM_{2.5}$ fraction of non-exhaust material, which, for the year 2020, are very significant relative to the exhaust material. The fraction of the PM_{10} material that is also $PM_{2.5}$ is generally quite high, noted at many Austrian roadside locations and in the Plabutschtunnel as being around 0.7 (Hinterhofer (2014)). PIARC references Henn et al (2009). In the context of Henn et al, the numbers given by PIARC are consistent with total $PM_{2.5}$, being around 70% of the total PM_{10}

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[13] Henn M, Rodler J, Sturm PJ (2009) PM10 non-exhaust particle emissions – determination and quantification, in: ETTAP 2009 Transport and air pollution symposium, environment and transport symposium, Toulouse, France, 2009.

[14] M Hinterhofer, Anteil der verkehrsbedingten PM_{10} und $PM_{2.5}$ Emissionen aus Abrieb und Wiederaufwirbelung an der Feinstaubbelastung in Österreich. (Emissions from abrasion and resuspension of particulate pollution in Austria) doctoral dissertation, Technical University of Graz, June 2014.

[15] M Hinterhofer, Anteil der verkehrsbedingten PM_{10} und $PM_{2.5}$ Emissionen aus Abrieb und Wiederaufwirbelung an der Feinstaubbelastung in Österreich. (Emissions from abrasion and resuspension of particulate pollution in Austria) doctoral dissertation, Technical University of Graz, June 2014.

[16] M Hinterhofer, PJ Sturm, T Nöst, K Niederl, Evaluation of emissions factors based on tunnel measurements with key aspects on Heavy Metals and PM10 non-exhaust, 20th International Symposium on Transport and Air Pollution, Technical University of Graz, September 2014.

reported in Henn et al. They must then be too high for non-exhaust $PM_{2.5}$ which is clearly less than total $PM_{2.5}$ and possibly so low as to be neglected, as above.

Accepting the conclusion based on NEMO that there is very little non-exhaust material below 2.5 µm, and based on knowledge that essentially all exhaust material is below 2.5 µm, the observation by Hinterhofer and others that 70% of the PM_{10} is $PM_{2.5}$ leads to the first approximation that the non-exhaust size fractions between 2.5 µm and 10 µm are, by mass, of the order of 43% of the exhaust particulates. The PIARC-based predictions in Appendices A and B suggest that the non-exhaust mass flux is 2 or 3 times that of the exhaust particulates. With the above information, that does not seem credible. With the qualification offered in the PIARC document itself (quoted above), the non-exhaust particulate predictions in Appendices A and B can be seen as extreme upper bound figures. They serve the purpose of demonstrating compliance with pollutant criteria, albeit with a conservatism in total $PM_{2.5}$ which may be a factor of 3 or 4.

Results from the pilot filtration trial conducted in the M5 East Tunnel in 2011[17] showed that around 83% of the PM_{10} in the tunnel air was $PM_{2.5}$. This is not far from the 70% reported from European data noted above. The difference could be due to a greater rate of emission of exhaust particulates in the 2011 M5 East compared to the 2013 Austrian fleet. The small fraction in the size range 2.5 to 10 µm again points to the rate of generation of non-exhaust particulates being much lower than the rate of exhaust particulate generation.

The conclusion is that the PIARC (2012) approach to calculating non-exhaust particulate generation is certainly conservative, as the report itself notes, and probably too conservative to offer reliable guidance as to what to expect from a new tunnel. The relative uncertainty and conservatism in the non-exhaust particulate predictions is the reason why they have been noted separately in Appendices A and B, rather than being combined into a single total $PM_{2.5}$ number, and why the noted visibility figures are assessed on exhaust particulates alone.

9.5 Heat emissions and tunnel air temperature.

The temperature of the ventilation outlet streams is relevant in the dispersion assessments and the in-tunnel temperatures are also of interest. The vehicle heat generation is central to estimating air temperatures. Vehicle parameters given in Table 9.5 are used to calculate the vehicle heat emissions, on the basis of the vehicle speed and road gradient, as shown in Table 9.8. The HGV mass is the weighted average of that for the the medium and long HGV subclasses.

Table 9.5. Nominal vehicle parameters for heat generation.

	units	PC	LDV	HGV
gross mass	tonnes	1.5	3.0	15.5
engine efficiency	%	30	30	30
Idle power	kW	11	19	38
drag coefficient		0.35	0.53	0.40
frontal area	m^2	2.5	4.8	7.1

Tunnel air temperatures are determined by the heat load from vehicles and the ability of the surrounding ground to absorb heat through the tunnel walls. In the simulations it has been assumed that the ground temperatures, 10 m from the tunnel wall, in summer and winter are

[17] M5 East tunnel filtration trial evaluation program – review of operational performance. AMOG Consulting, Feb 2012 http://www.rms.nsw.gov.au/documents/projects/sydney-west/m5-east-tunnel/m5e_tunnel_air_filtration_trial_evaluation_amog_report_february_2012.pdf

20°C and 16°C respectively. These are values taken from measurements in the Sydney environs for other projects.

9.6 Climate assumptions

It is the temperature difference between the outlet air and ambient air that is most important to the dispersion and plume rise results. The ambient temperature has some effect on that difference and so simulations were done for both summer and winter conditions.

Climate data used in the ventilation simulations are from the ASHRAE IWEC database developed through Research Project RP-1477. See Yu, Huang, Donghyun and Krarti (2014)[18]. International Weather for Energy Calculations (IWEC) contains "typical" weather files, suitable for use with simulation programs, for 3,012 locations outside the USA and Canada.

In running the ventilation model to predict tunnel air temperatures, a long-term model was first run in order to bring the ground temperature to an equilibrium state using a far field ground temperature of 20°C in summer and 16°C in winter. January was the target month for summer simulations as this coincides with the highest tunnel wall temperatures along with high ambient temperature and humidity. July was chosen as the winter month.

The hottest January summer day in the climate file was chosen as the input for simulation of daily temperature variations in the tunnel. Care was taken to start the simulation 24 hours prior to the commencement of the hottest day so that an appropriate thermal initial condition could be achieved prior to the commencement of the test period.

[18] Yu J; Huang F; Donghyun S; Krarti, M; 2014, Development of 3012 IWEC2 Weather Files for International Locations (RP-1477). ASHRAE Transactions, 2014, Vol. 120 Issue 1, p340-355.

Table 9.6. Opacity emissions factors for exhaust particulates in 2020. The column headers in each table are tunnel gradient.

v	PC opacity [m^2/h] 2020						
km/h	-6%	-4%	-2%	0%	2%	4%	6%
0	0.16	0.16	0.16	0.16	0.16	0.16	0.16
10	0.13	0.13	0.13	0.29	0.44	0.59	0.75
20	0.13	0.13	0.16	0.47	0.73	0.97	1.25
30	0.13	0.13	0.23	0.64	0.98	1.32	1.70
40	0.13	0.13	0.25	0.77	1.19	1.66	2.14
50	0.13	0.13	0.26	0.85	1.39	1.96	2.52
60	0.13	0.13	0.27	0.98	1.66	2.34	2.98
70	0.13	0.13	0.39	1.19	1.99	2.74	3.50
80	0.13	0.13	0.58	1.46	2.34	3.19	4.03
90	0.13	0.13	0.80	1.77	2.71	3.67	4.59
100	0.13	0.13	1.08	2.14	3.17	4.21	5.21
110	0.13	0.18	1.41	2.56	3.69	4.80	5.86
120	0.13	0.61	1.84	3.06	4.27	5.44	6.57
130	0.13	1.04	2.34	3.64	4.91	6.14	7.34

v	LDV diesel/gasoline opacity [m^2/h] 2020						
km/h	-6%	-4%	-2%	0%	2%	4%	6%
0	2.4	2.4	2.4	2.4	2.4	2.4	2.4
10	0.5	0.5	0.6	1.4	2.1	2.7	3.4
20	0.5	0.5	0.9	2.3	3.4	4.6	5.8
30	0.5	0.5	1.3	3.2	4.7	6.4	8.1
40	0.5	0.5	1.7	3.9	5.9	8.1	10.3
50	0.5	0.5	1.9	4.6	7.1	9.8	12.3
60	0.5	0.5	2.5	5.6	8.7	11.8	15.0
70	0.5	0.5	3.4	7.1	10.6	14.2	17.8
80	0.5	0.5	4.7	8.8	12.8	16.9	20.8
90	0.5	1.5	6.2	10.7	15.3	19.7	24.0
100	0.5	3.3	8.2	13.2	18.1	23.0	27.7
110	0.5	5.3	10.6	16.1	21.4	26.5	31.6
120	1.7	7.7	13.5	19.3	25.0	30.5	33.4
130	4.4	10.5	16.9	22.9	28.9	31.3	35.8

Table 9.6 cont.

v	HGV opacity [m^2/h] 2020						
km/h	-6%	-4%	-2%	0%	2%	4%	6%
0	15.2	15.2	15.2	15.2	15.2	15.2	15.2
10	9.9	10.9	14.9	18.0	20.7	23.5	26.0
20	7.1	10.2	14.3	19.4	24.0	28.8	34.0
30	6.4	10.3	17.4	21.5	27.4	35.6	43.9
40	5.8	9.6	17.9	23.5	31.4	43.1	53.5
50	5.8	9.0	17.6	24.7	36.5	50.2	64.0
60	5.8	8.1	16.8	26.1	42.1	57.8	74.7
70	5.8	7.0	16.9	28.2	47.4	66.0	85.7
80	5.8	6.5	16.8	31.6	53.5	74.7	97.4
90	5.8	7.4	19.2	36.7	60.1	83.4	109.0
100	5.8	9.1	21.8	42.9	66.5	92.0	120.5
110	5.8	9.6	25.2	48.5	72.4	100.5	132.0
120	5.8	13.9	29.1	52.7	78.2	108.9	143.4
130	6.7	16.6	33.7	56.2	84.0	117.3	154.9

Table 9.7. Non exhaust particulates (PM2.5) factors 2020. The column headers in each table are tunnel gradient.

v				PC non-exhaust PM [g/h]			
km/h	-6%	-4%	-2%	0%	2%	4%	6%
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	0.28	0.28	0.28	0.28	0.28	0.28	0.28
20	0.56	0.56	0.56	0.56	0.56	0.56	0.56
30	0.84	0.84	0.84	0.84	0.84	0.84	0.84
40	1.12	1.12	1.12	1.12	1.12	1.12	1.12
50	1.40	1.40	1.40	1.40	1.40	1.40	1.40
60	1.68	1.68	1.68	1.68	1.68	1.68	1.68
70	1.96	1.96	1.96	1.96	1.96	1.96	1.96
80	2.24	2.24	2.24	2.24	2.24	2.24	2.24
90	2.52	2.52	2.52	2.52	2.52	2.52	2.52
100	2.80	2.80	2.80	2.80	2.80	2.80	2.80
110	3.08	3.08	3.08	3.08	3.08	3.08	3.08
120	3.36	3.36	3.36	3.36	3.36	3.36	3.36
130	3.64	3.64	3.64	3.64	3.64	3.64	3.64

v	LDV diesel/gasoline non-exhaust PM [g/h] 2020						
km/h	-6%	-4%	-2%	0%	2%	4%	6%
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	0.28	0.28	0.28	0.28	0.28	0.28	0.28
20	0.56	0.56	0.56	0.56	0.56	0.56	0.56
30	0.84	0.84	0.84	0.84	0.84	0.84	0.84
40	1.12	1.12	1.12	1.12	1.12	1.12	1.12
50	1.40	1.40	1.40	1.40	1.40	1.40	1.40
60	1.68	1.68	1.68	1.68	1.68	1.68	1.68
70	1.96	1.96	1.96	1.96	1.96	1.96	1.96
80	2.24	2.24	2.24	2.24	2.24	2.24	2.24
90	2.52	2.52	2.52	2.52	2.52	2.52	2.52
100	2.80	2.80	2.80	2.80	2.80	2.80	2.80
110	3.08	3.08	3.08	3.08	3.08	3.08	3.08
120	3.36	3.36	3.36	3.36	3.36	3.36	3.36
130	3.64	3.64	3.64	3.64	3.64	3.64	3.64

Table 9.7 cont.

v	HGV non-exhaust PM [g/h] 2020						
km/h	-6%	-4%	-2%	0%	2%	4%	6%
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	1.04	1.04	1.04	1.04	1.04	1.04	1.04
20	2.08	2.08	2.08	2.08	2.08	2.08	2.08
30	3.12	3.12	3.12	3.12	3.12	3.12	3.12
40	4.16	4.16	4.16	4.16	4.16	4.16	4.16
50	5.20	5.20	5.20	5.20	5.20	5.20	5.20
60	6.24	6.24	6.24	6.24	6.24	6.24	6.24
70	7.28	7.28	7.28	7.28	7.28	7.28	7.28
80	8.32	8.32	8.32	8.32	8.32	8.32	8.32
90	9.36	9.36	9.36	9.36	9.36	9.36	9.36
100	10.40	10.40	10.40	10.40	10.40	10.40	10.40
110	11.44	11.44	11.44	11.44	11.44	11.44	11.44
120	12.48	12.48	12.48	12.48	12.48	12.48	12.48
130	13.52	13.52	13.52	13.52	13.52	13.52	13.52

Table 9.8. Vehicle heat emissions. The column headers in each table are tunnel gradient.

v	PC heat [kW]						
km	-6%	-4%	-2%	0%	2%	4%	6%
0	11.	11.	11.	11.	11.	11.	11.2
10	12.	11.	12.	14.	16.	18.	20.7
20	13.	12.	13.	17.	21.	26.	30.3
30	14.	12.	15.	21.	27.	33.	40.2
40	15.	12.	17.	25.	33.	42.	50.6
50	16.	12.	19.	30.	40.	51.	61.7
60	16.	11.	23.	35.	48.	60.	73.5
70	16.	12.	27.	42.	56.	71.	86.3
80	16.	16.	33.	49.	66.	83.	100.
90	15.	20.	39.	58.	77.	96.	115.
10	13.	27.	47.	68.	89.	110	131.
11	11.	34.	57.	80.	103	126	150.
12	18.	44.	69.	94.	119	144	169.
13	28.	55.	82.	109	137	164	191.

v	LDV heat [kW]						
km	-6%	-4%	-	0%	2%	4%	6%
0	19.	19.	19.	19.	19.2	19.2	19.2
10	21.	20.	21.	25.	29.3	33.3	37.3
20	24.	20.	23.	31.	39.8	47.8	55.8
30	26.	21.	26.	39.	51.0	63.0	75.0
40	27.	20.	31.	47.	63.3	79.4	95.4
50	28.	20.	37.	57.	77.2	97.3	117.
60	28.	20.	45.	69.	93.0	117.	141.
70	27.	27.	55.	83.	111.	139.	167.
80	25.	35.	67.	99.	131.	163.	196.
90	22.	47.	83.	11	155.	191.	227.
10	22.	62.	10	14	183.	223.	263.
11	37.	81.	12	17	214.	258.	302.
12	57.	105	15	20	249.	297.	345.
13	80.	132	18	23	289.	341.	393.

v	HGV heat [kW]						
km	-6%	-4%	-2%	0%	2%	4%	6%
0	38.	38.	38.	38.	38.	38.	38.4
10	59.	51.	42.	48.	68.	88.	108.
20	80.	63.	46.	59.	98.	138	178.
30	101	75.	50.	70.	130	190	249.
40	121	87.	53.	83.	163	242	322.
50	140	97.	55.	98.	198	297	397.
60	158	107	56.	116	235	355	474.
70	175	115	55.	137	276	415	555.
80	190	122	53.	161	320	480	639.
90	203	126	50.	190	369	548	727.
10	215	129	44.	223	422	621	820.
11	224	130	42.	261	480	699	918.
12	231	128	66.	305	543	782	1021
13	235	124	96.	355	613	872	1131

10 SIMULATION SOFTWARE

For analysing the in-tunnel airflow, pollution levels and temperature, software called IDA Tunnel, developed by EQUA AB in Sweden has been used.

IDA Tunnel is comprehensive road and rail tunnel ventilation and smoke control simulation software. Specific to road tunnels, IDA Tunnel includes traffic flow simulation, so that there is realism in the traffic behaviour as roads reach capacity or as lane numbers change. A traffic model within the simulation applies traffic continuity, and realistic rules on traffic flow versus speed, to predict the traffic density and speed throughout the tunnel. This avoids the assumptions involved in 'hard-coding' the traffic movement in input files before the simulation starts. The airflows resulting from traffic movement, in combination with the vehicle emissions, determine the pollutant levels in the tunnel.

IDA Tunnel is a one-dimensional network analysis program, meaning that entire underground systems can be analysed as one, with all the traffic and air flows being resolved. Being one-dimensional, all quantities are cross section averages. Sub-models within the IDA Tunnel package deal with the traffic speed and flow, aerodynamics of vehicles, the effect of jet fans on air flow, the tunnel flow resistance and the network flow balance, the generation of pollutants and heat by vehicles, the stack effect within tunnels with non-zero gradient, the heat flow from the air to the walls and on to the ground, and the thermal inertia of the walls.

Development of IDA Tunnel began around 2000, with the ambition to encompass the best and most trusted mathematical models for environmental conditions in road and rail tunnels that are available in the literature and that can be simulated with acceptable efficiency and with a manageable amount of input data. Early versions became available around 2003. The software has been mature for some time. The package is actively supported by EQUA AB.

There are other software packages for simulation of road tunnel aero-thermodynamics. The Subway Environmental Simulation (SES) software was first written in the 1970s and was the leading tunnel ventilation program for several decades, being supported by the US Department of Transportation. With advances in computing and simulation generally, it became harder to maintain and for some years now DoT support has been unavailable, with the program still used privately by some firms who maintain their own versions of the code. Other firms have independently developed in-house software, generally to address specific behaviours such as air compressibility for high speed trains. To our knowledge, IDA Tunnel is the only openly available tunnel ventilation simulation package.

IDA Tunnel was developed from scratch using the Modelica simulation environment, an advantage over the Fortran 77 base of SES. Development was informed by SES and comparative assessments of the two programs have been done, including by London Underground.

Compared to the SES program, IDA Tunnel includes more sophisticated modelling of the wall and ground temperatures and heat flows. On the thermal response of tunnels, Stacey Agnew has used IDA Tunnel to model and calibrate against wall and air temperatures of several cable and rail tunnels, three of which were in Sydney sandstone[19]. IDA Tunnel also includes thermal buoyancy (stack effect) in non-fire simulations, which SES did not do.

[19] Reference tunnels in Sydney; Epping Chatswood Rail Link, City West Cable Tunnel, City South Cable Tunnel, and in Auckland; Vector Cable Tunnel.

11 SIMULATION RESULTS

11.1 Free flowing traffic

11.1.1 New M5 alone with 2021 and 2031 normal daily traffic

A comprehensive set of ventilation simulation results for normal free-flowing traffic in the New M5 tunnel alone (prior to the M4-M5 Link) are tabulated in Appendix A (for 2021 traffic, Table 7.5) and Appendix B (for 2031 traffic, Table 7.6). The normal free flowing traffic for the eastbound and westbound tubes was given at hourly increments over 24 hours. Simulations were done for both a summer day and a winter day.

11.1.2 New M5 and M4-M5 Link with 2031 traffic

Ventilation outputs for the New M5 combined with the M4-M5 Link tunnel with normal 2031 traffic (Table 7.7) are tabulated in Appendix C and also plotted in Figure 11.1 to Figure 11.5.

Air flows and pollution levels are not substantially different between summer and winter condition, however there are substantial differences in tunnel and outlet air temperatures.

Tunnel air temperature predictions are made on the basis of hourly varying ambient temperature and seasonally varying ground temperature inputs, in combination with the hourly varying vehicle heat load resulting from the traffic. Changes in tunnel air temperature remote from the portals are not strongly influenced by ambient conditions. Rather; air temperature is set by a balance between the vehicle heat and the seasonally varying wall temperature, which varies along the length of the tunnel according to average traffic and air flow conditions.

Hence outlet air temperature is not subject to rapid variation due to changes in ambient air temperature. However the temperature difference between outlet and ambient air may vary quite widely and rapidly as ambient conditions change.

The important conclusion derived from these results is that the New M5 and M4-M5 Link tunnels are self-ventilating for the predicted traffic. Piston effect of vehicles (without the aid of jet fans) drives sufficient air along the tunnel to maintain pollutant levels below the design limits specified in Table 6.2.

11.2 Regulatory traffic

Ventilation outputs for the regulatory traffic flows in the New M5 combined with the M4-M5 Link tunnel, based on scaling 2031 traffic (Table 7.7) are also tabulated in Appendix C. The regulatory outputs are plotted in Figure 11.6 to Figure 11.10.

Figure 11.1. Modelled 2031 daily normal traffic demand for New M5 and M4-M5 Link west of Rozelle. "SC" means Southern Extension.

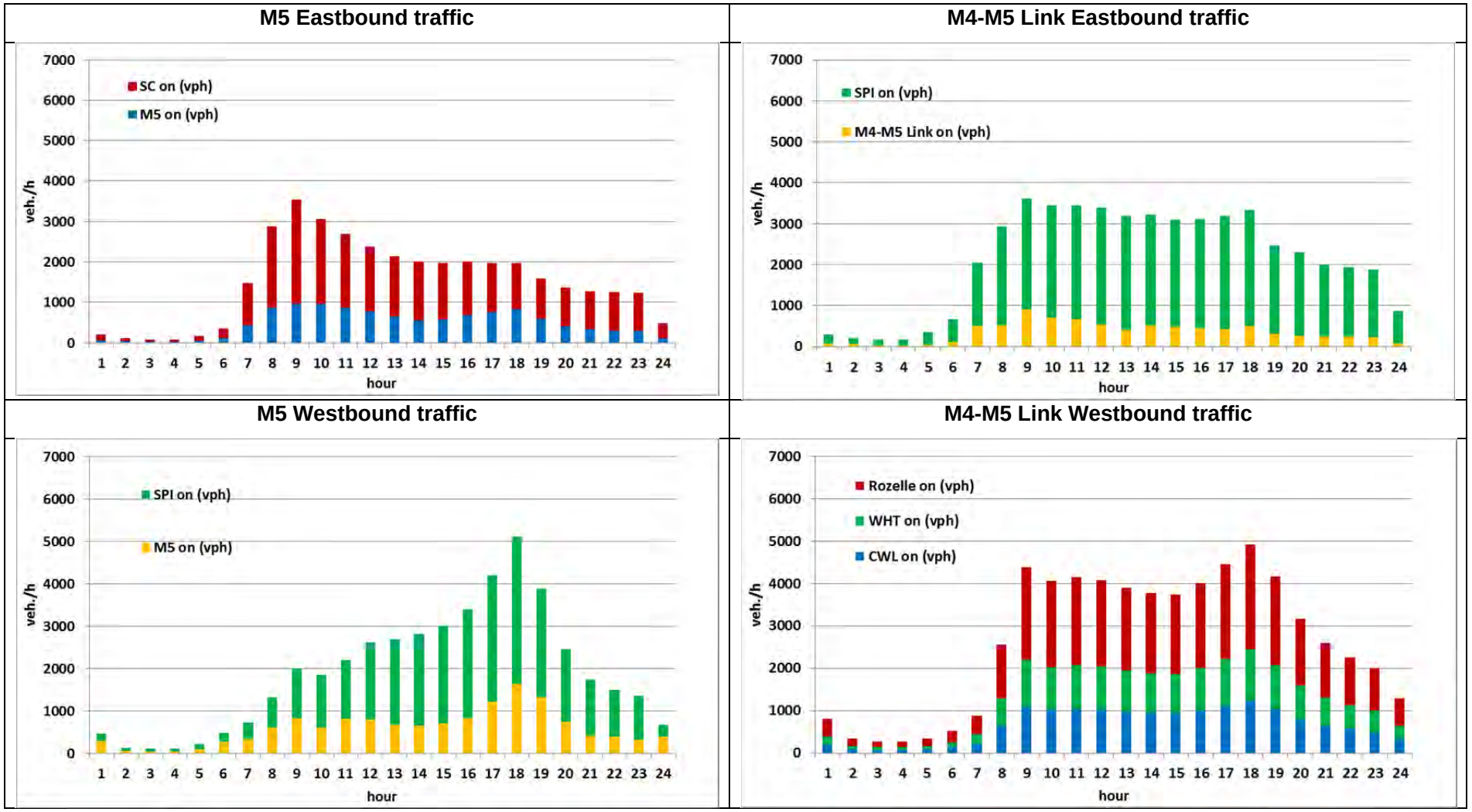
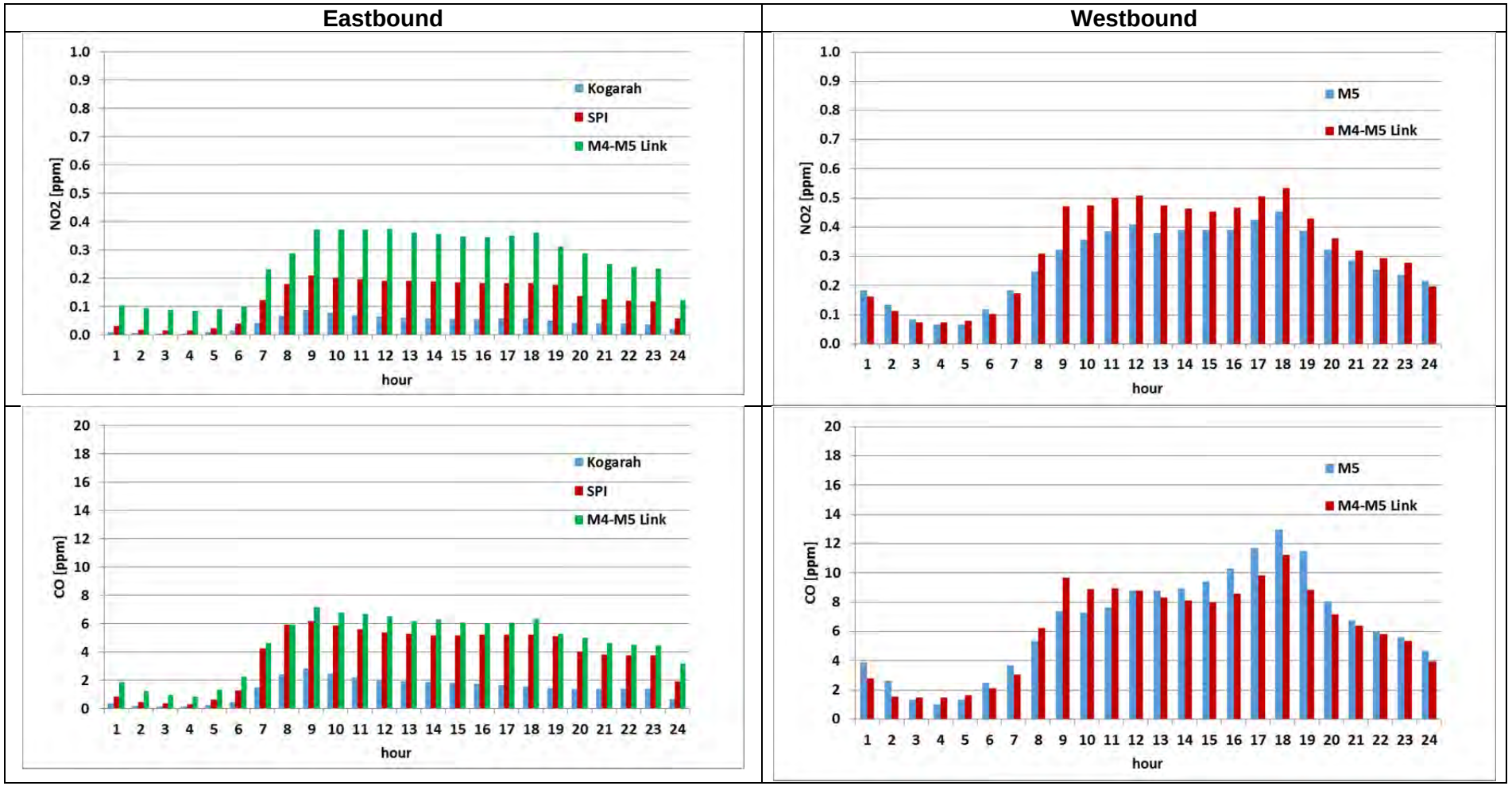
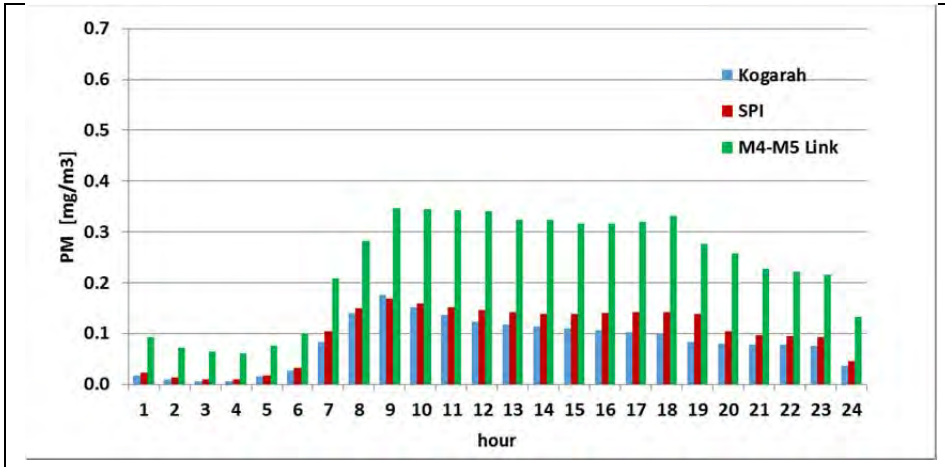
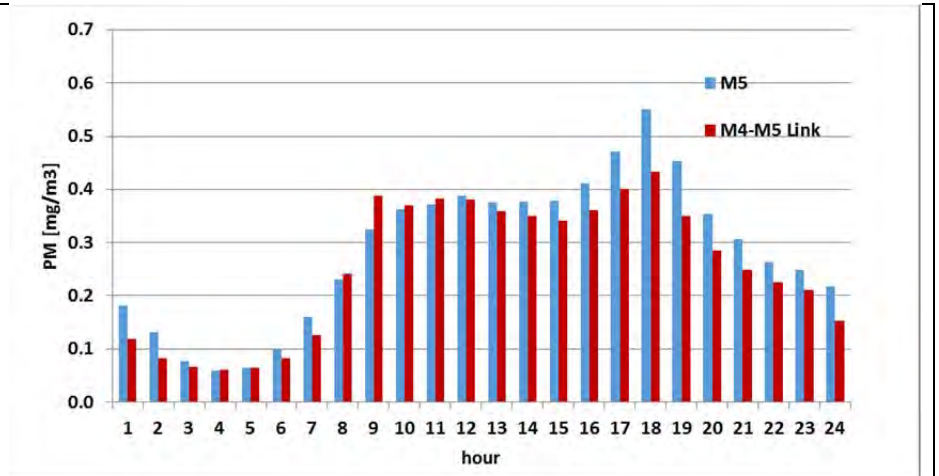
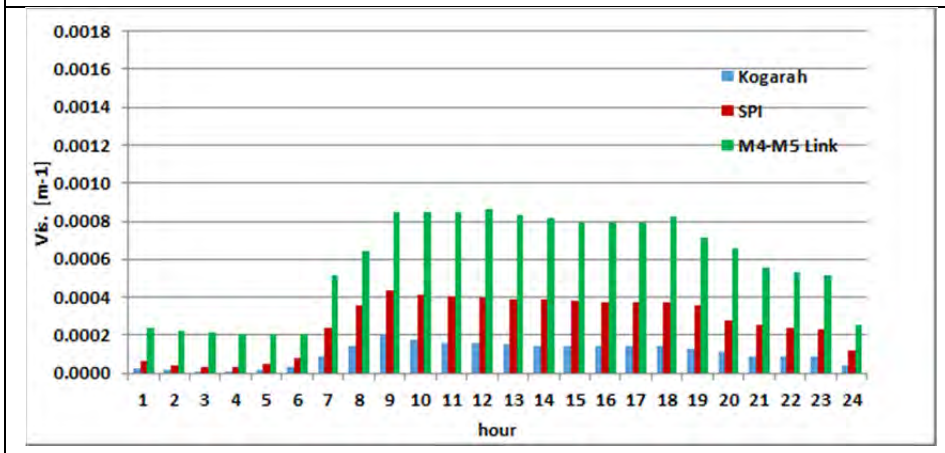


Figure 11.2. Maximum hourly in-tunnel pollution levels for normal traffic in 2031.




0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
PM [mg/m3]
Kogarah
SPI
M4-M5 Link
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
hour


0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
PM [mg/m3]
M5
M4-M5 Link
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
hour


0.0018
0.0016
0.0014
0.0012
0.0010
0.0008
0.0006
0.0004
0.0002
0.0000
Vis. [m-1]
Kogarah
SPI
M4-M5 Link
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
hour

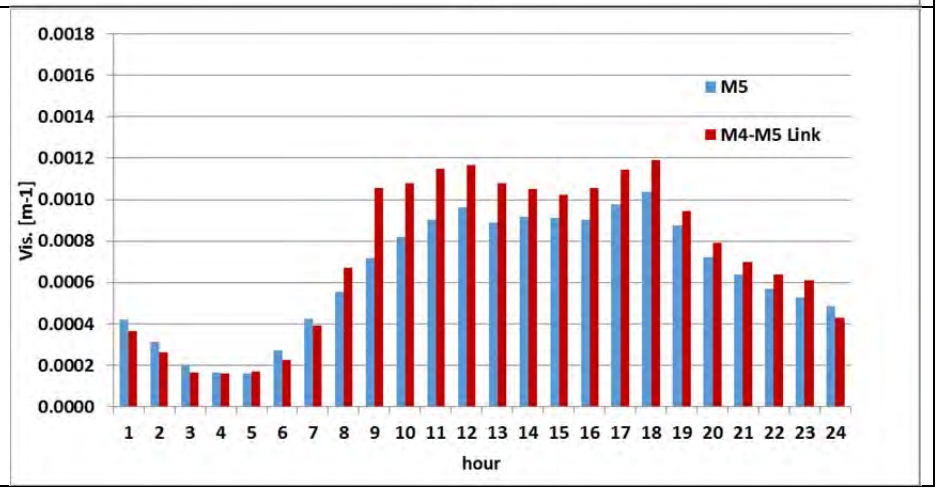

0.0018
0.0016
0.0014
0.0012
0.0010
0.0008
0.0006
0.0004
0.0002
0.0000
Vis. [m-1]
M5
M4-M5 Link
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
hour

Figure 11.3. Outlet flows for normal traffic in 2031. "SC" means Southern Extension.

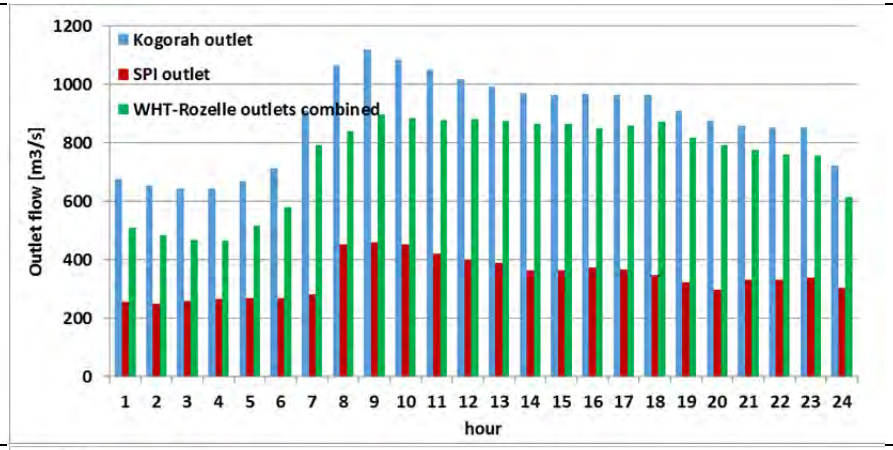
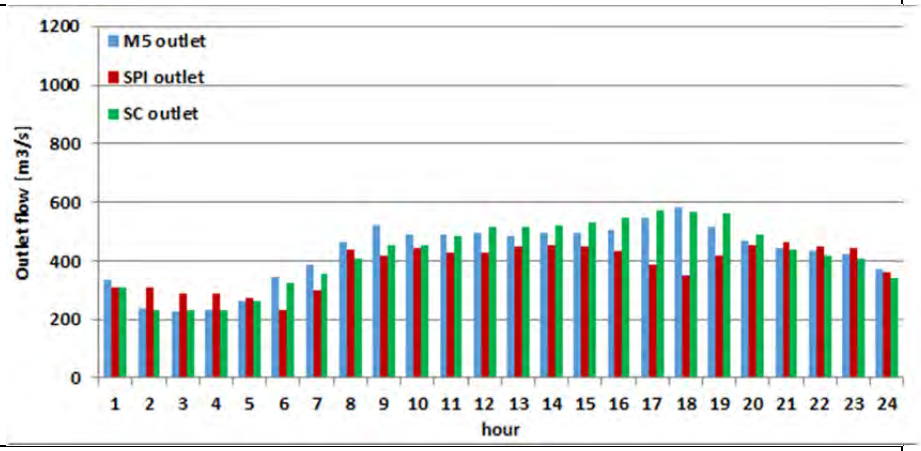
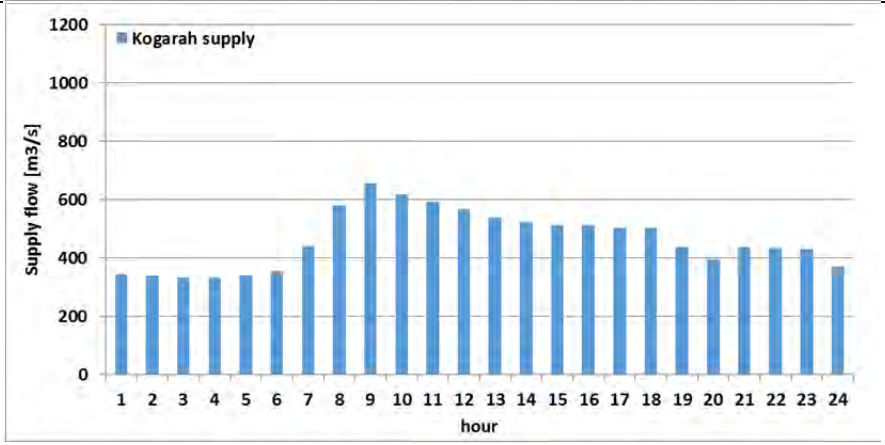
	Eastbound	Westbound
Extraction		
Supply		

Figure 11.4. Outlet temperature (summer and winter) for normal traffic in 2031. "SC" means Southern Extension.

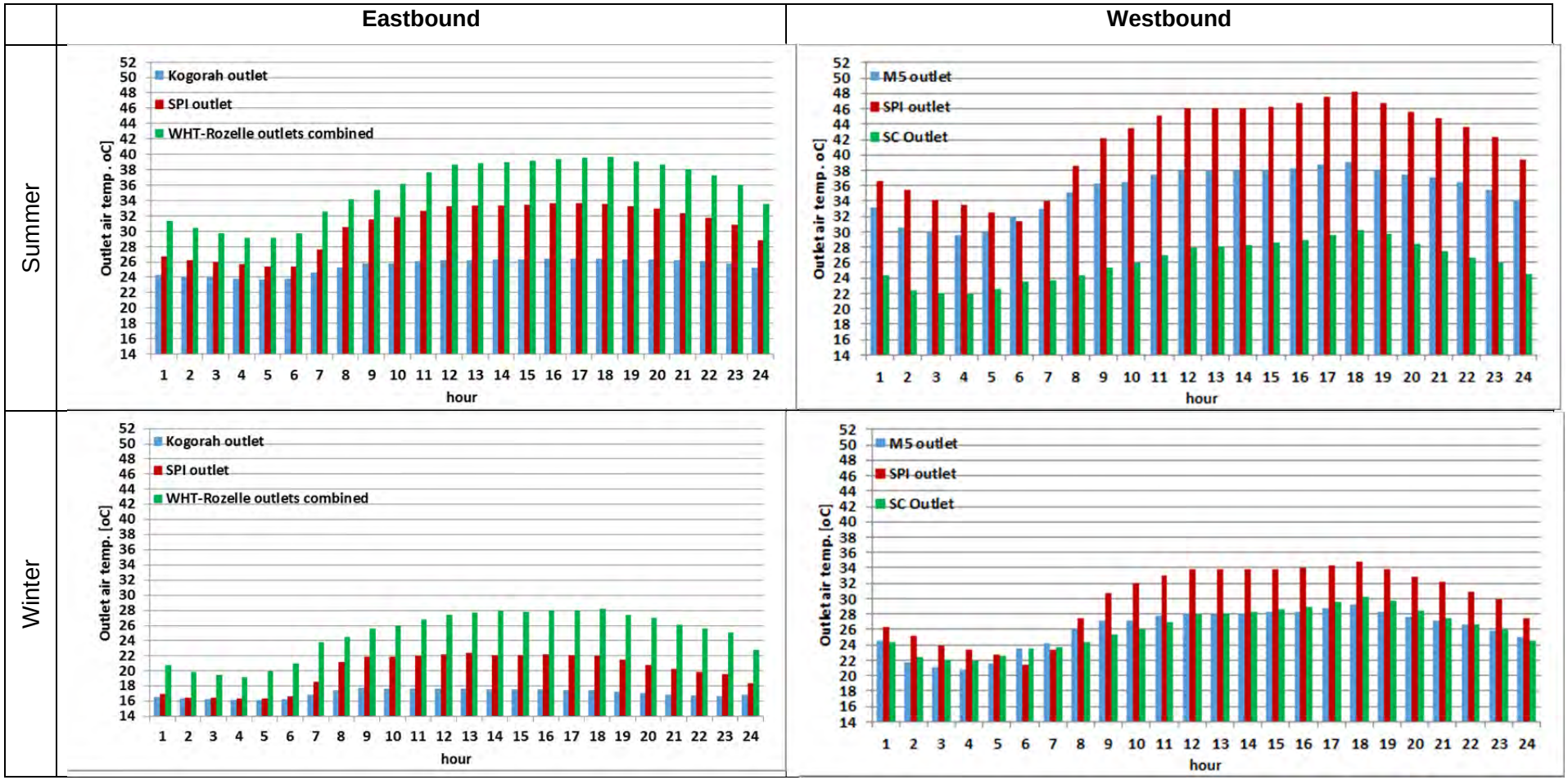
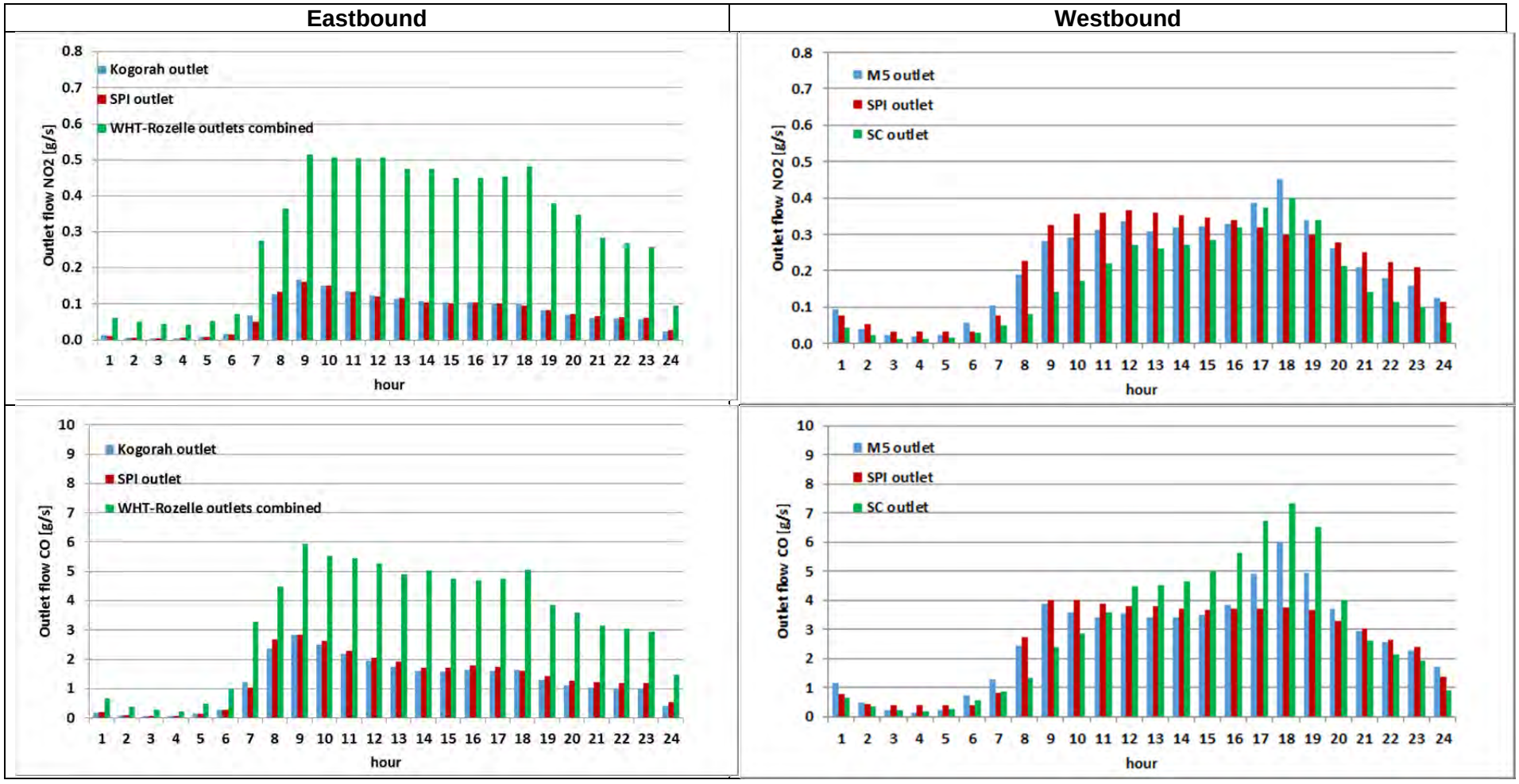


Figure 11.5. Outlet discharge for normal traffic in 2031. "SC" means Southern Extension.



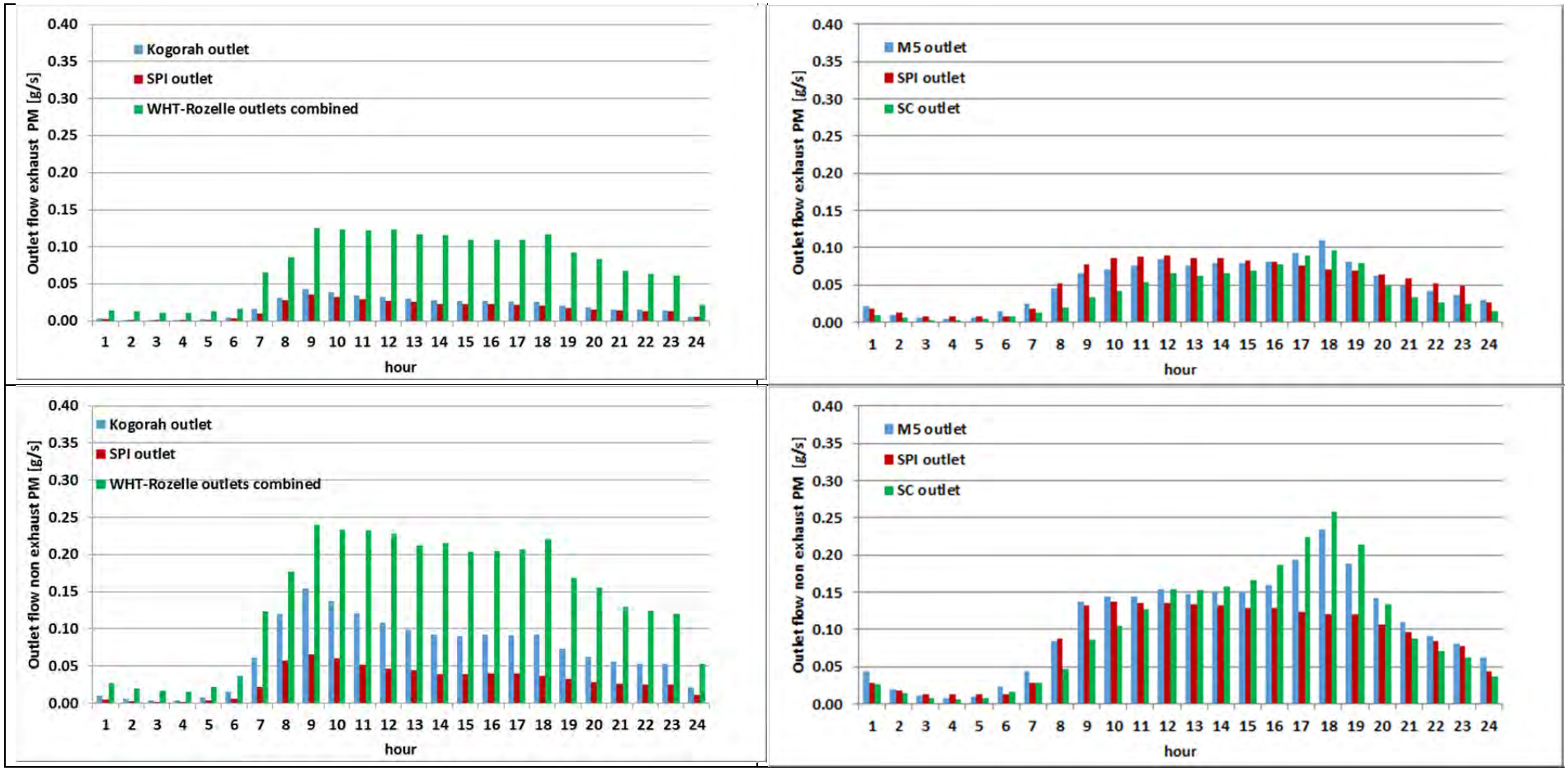

Outlet flow exhaust PM [g/s]
Kogorah outlet
SPI outlet
WHT-Rozelle outlets combined
hour
Outlet flow exhaust PM [g/s]
M5 outlet
SPI outlet
SC outlet
hour
Outlet flow non exhaust PM [g/s]
Kogorah outlet
SPI outlet
WHT-Rozelle outlets combined
hour
Outlet flow non exhaust PM [g/s]
M5 outlet
SPI outlet
SC outlet
hour

Figure 11.6. Modelled 2031 daily regulatory traffic demand for New M5 and M4-M5 Link west of Rozelle. "SC" means Southern Extension.

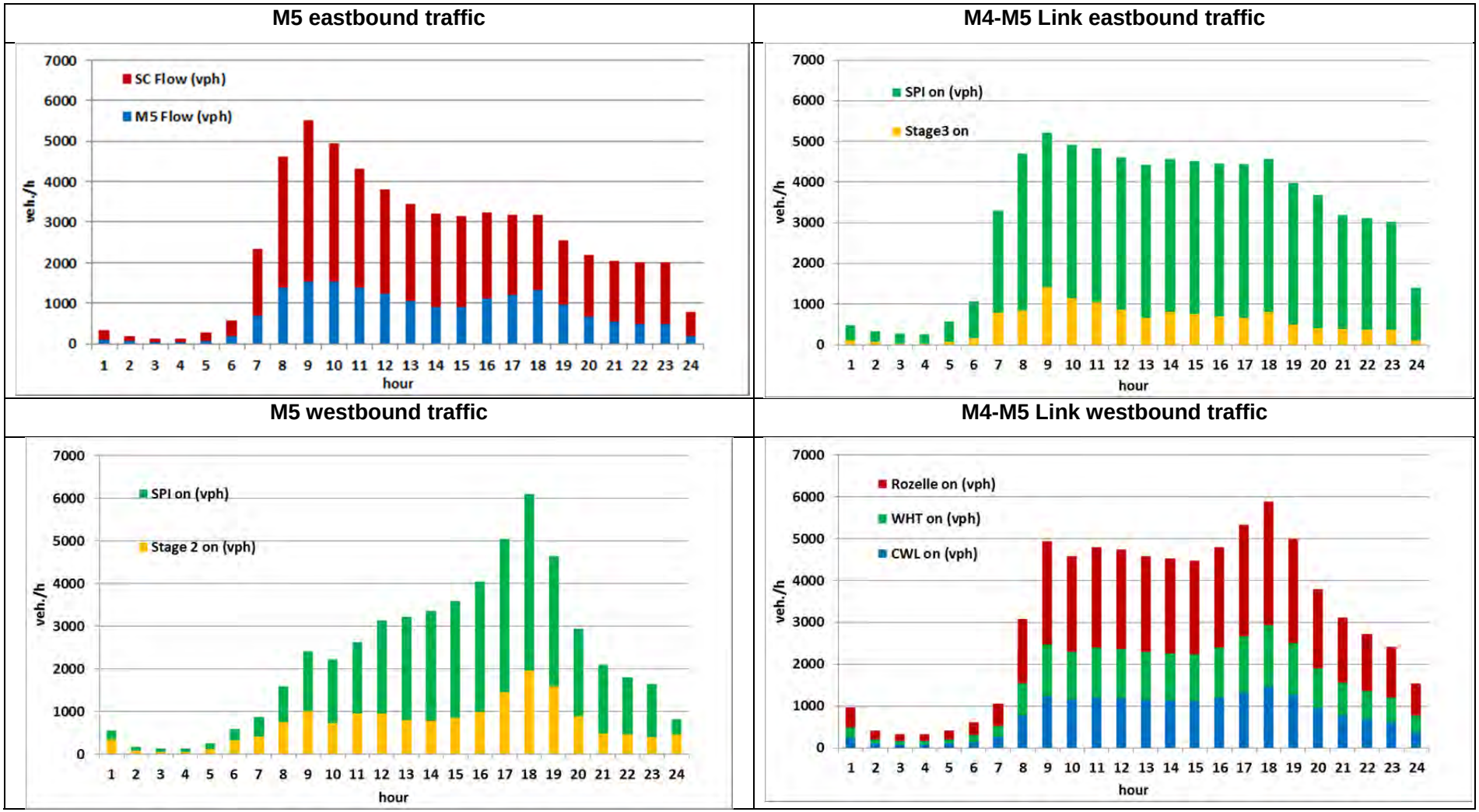
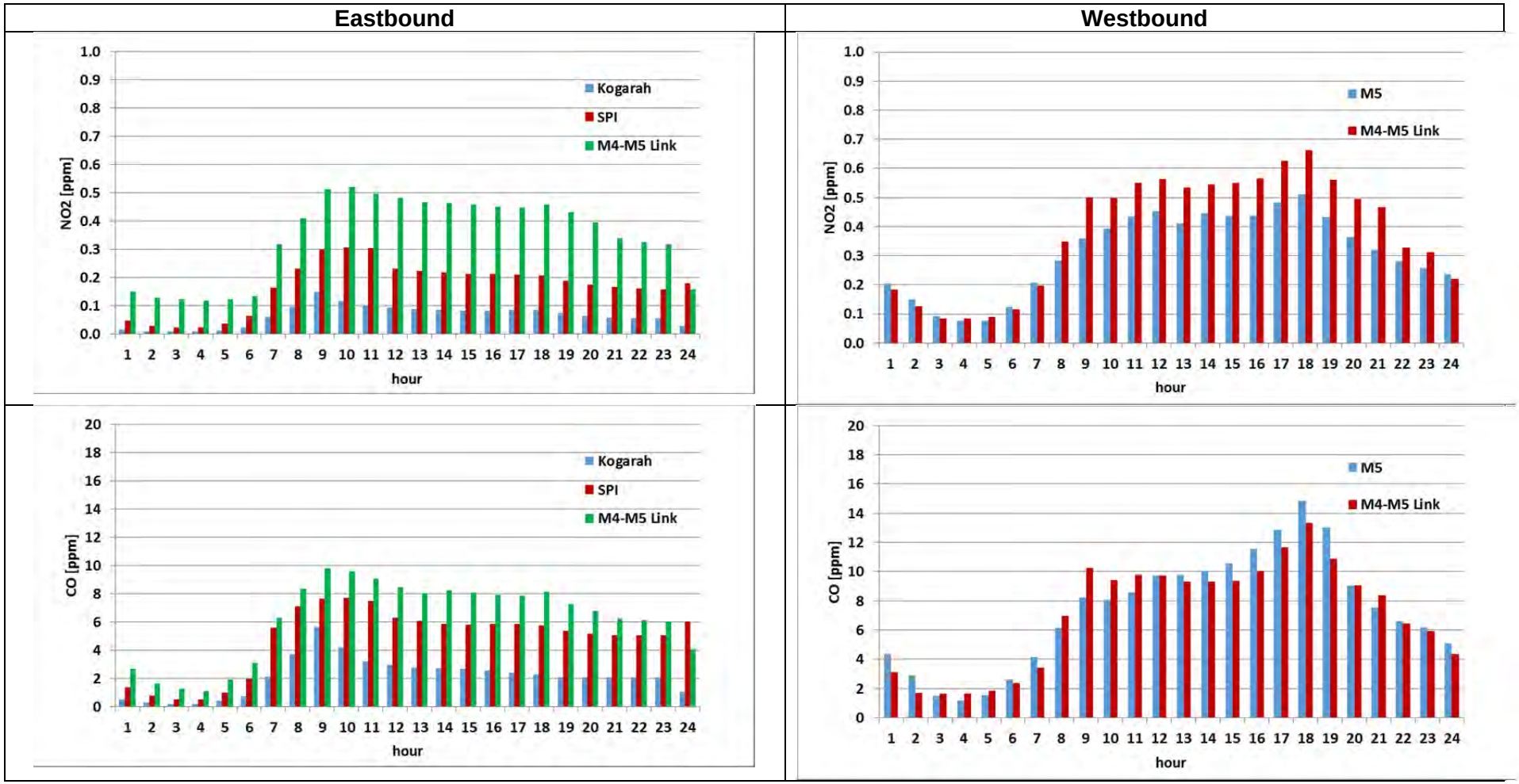


Figure 11.7. Maximum hourly in-tunnel pollution levels for regulatory traffic in 2031.



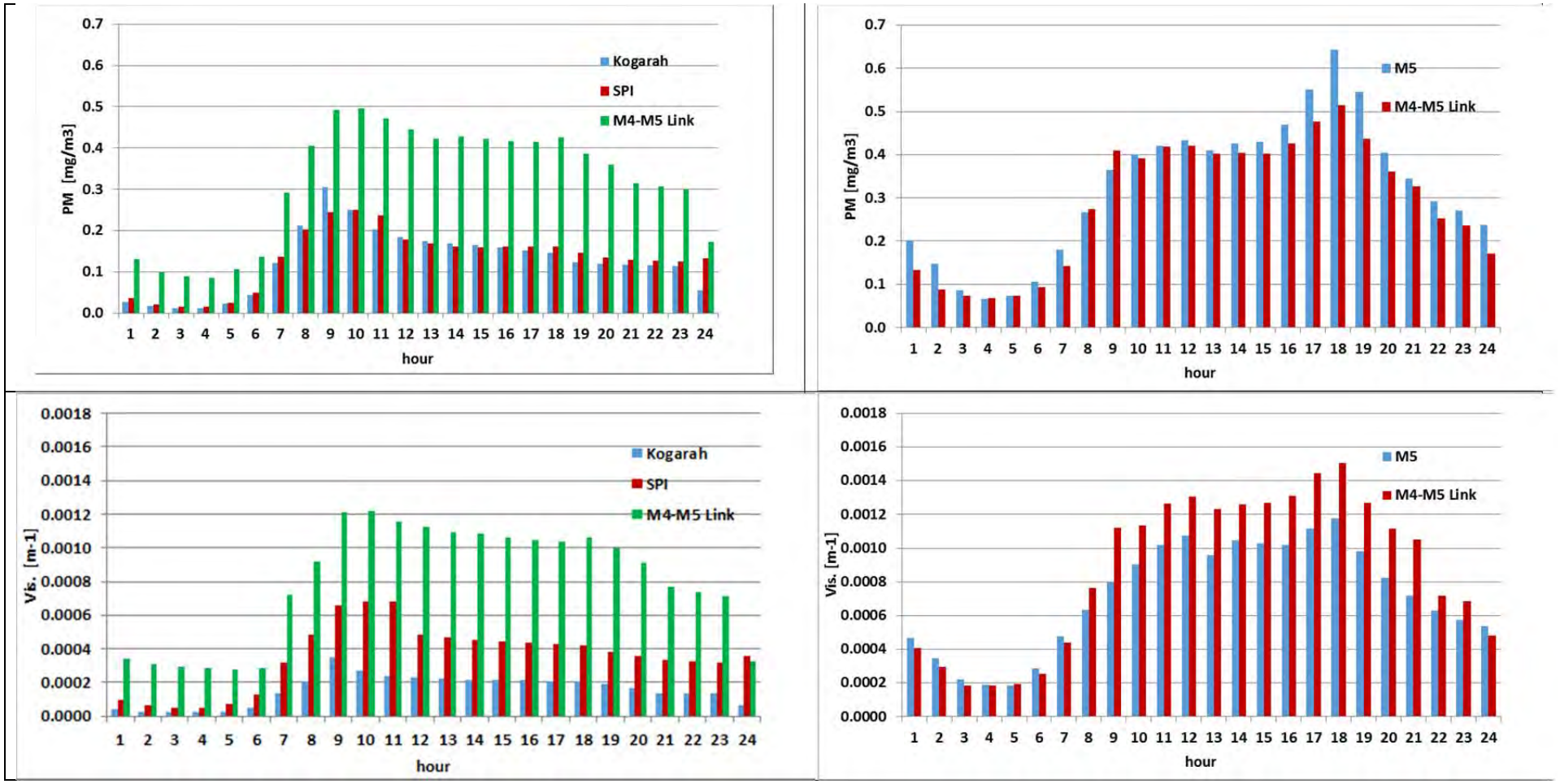

PM [mg/m3]
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
hour
Kogarah
SPI
M4-M5 Link
PM [mg/m3]
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
hour
M5
M4-M5 Link
Vis. [m-1]
0.0018
0.0016
0.0014
0.0012
0.0010
0.0008
0.0006
0.0004
0.0002
0.0000
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
hour
Kogarah
SPI
M4-M5 Link
Vis. [m-1]
0.0018
0.0016
0.0014
0.0012
0.0010
0.0008
0.0006
0.0004
0.0002
0.0000
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
hour
M5
M4-M5 Link

Figure 11.8. Extraction and supply station flows for regulatory traffic in 2031. "SC" means Southern Extension.

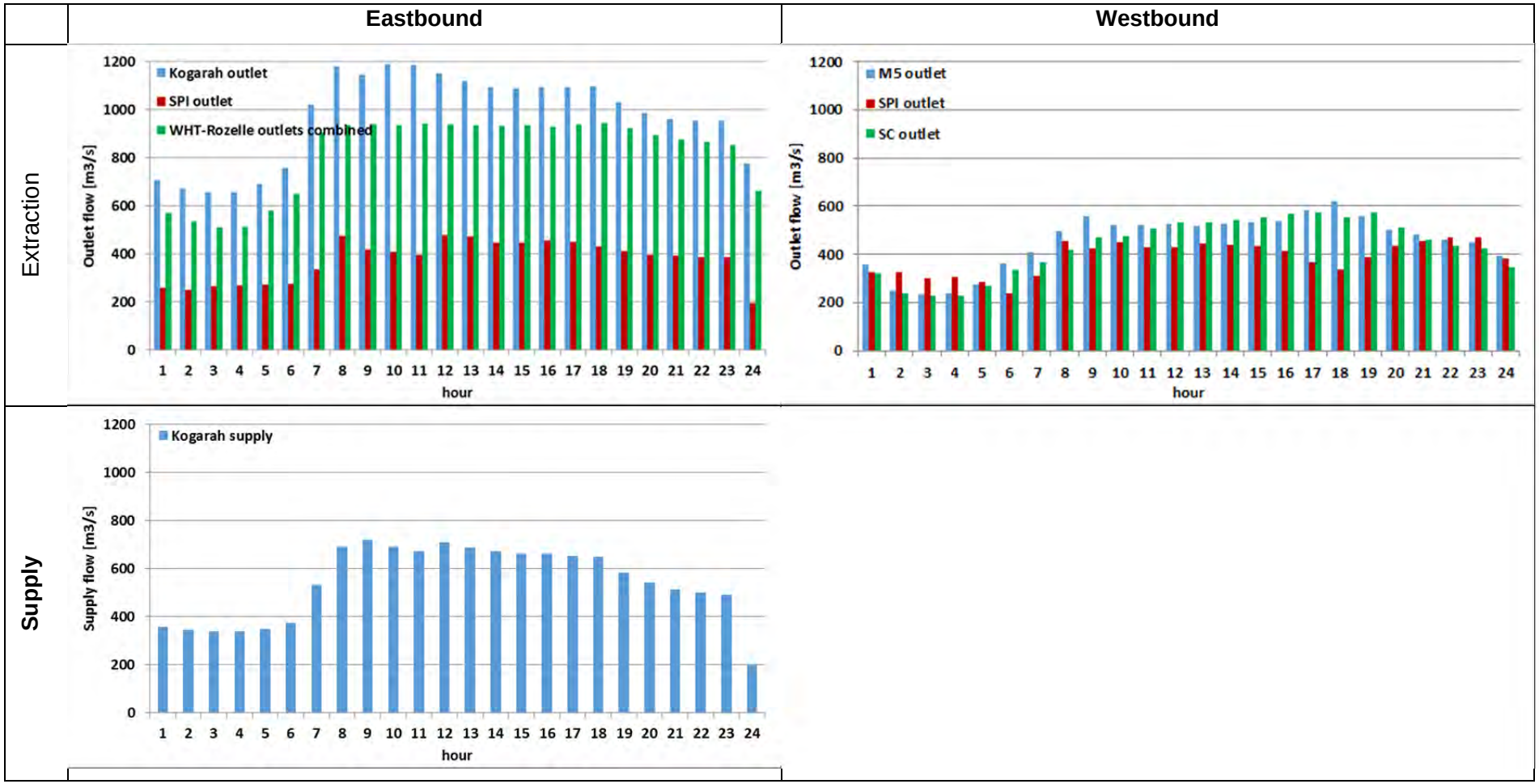


Figure 11.9. Outlet temperature (summer and winter) for regulatory traffic in 2031. "SC" means Southern Extension.

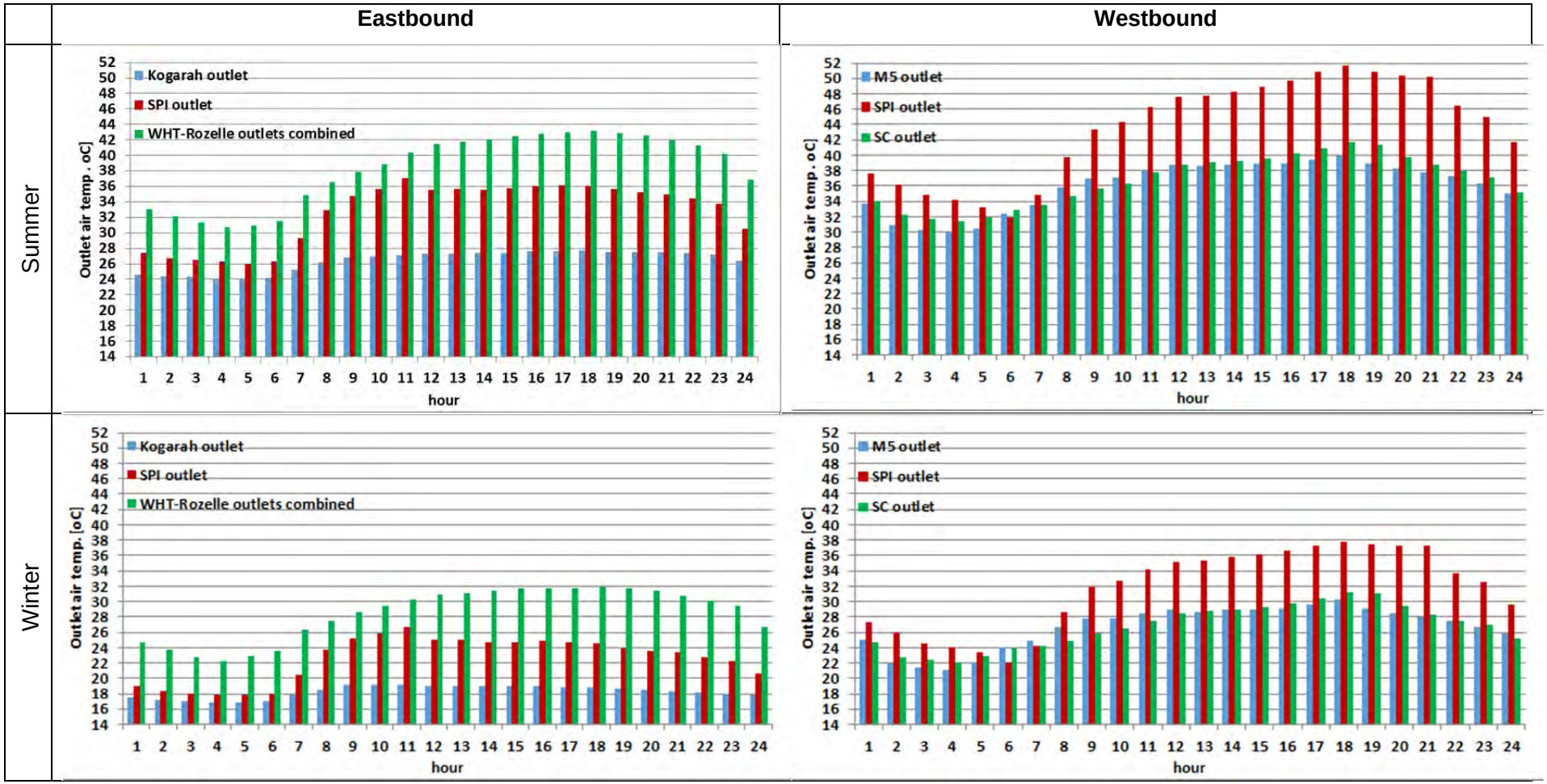
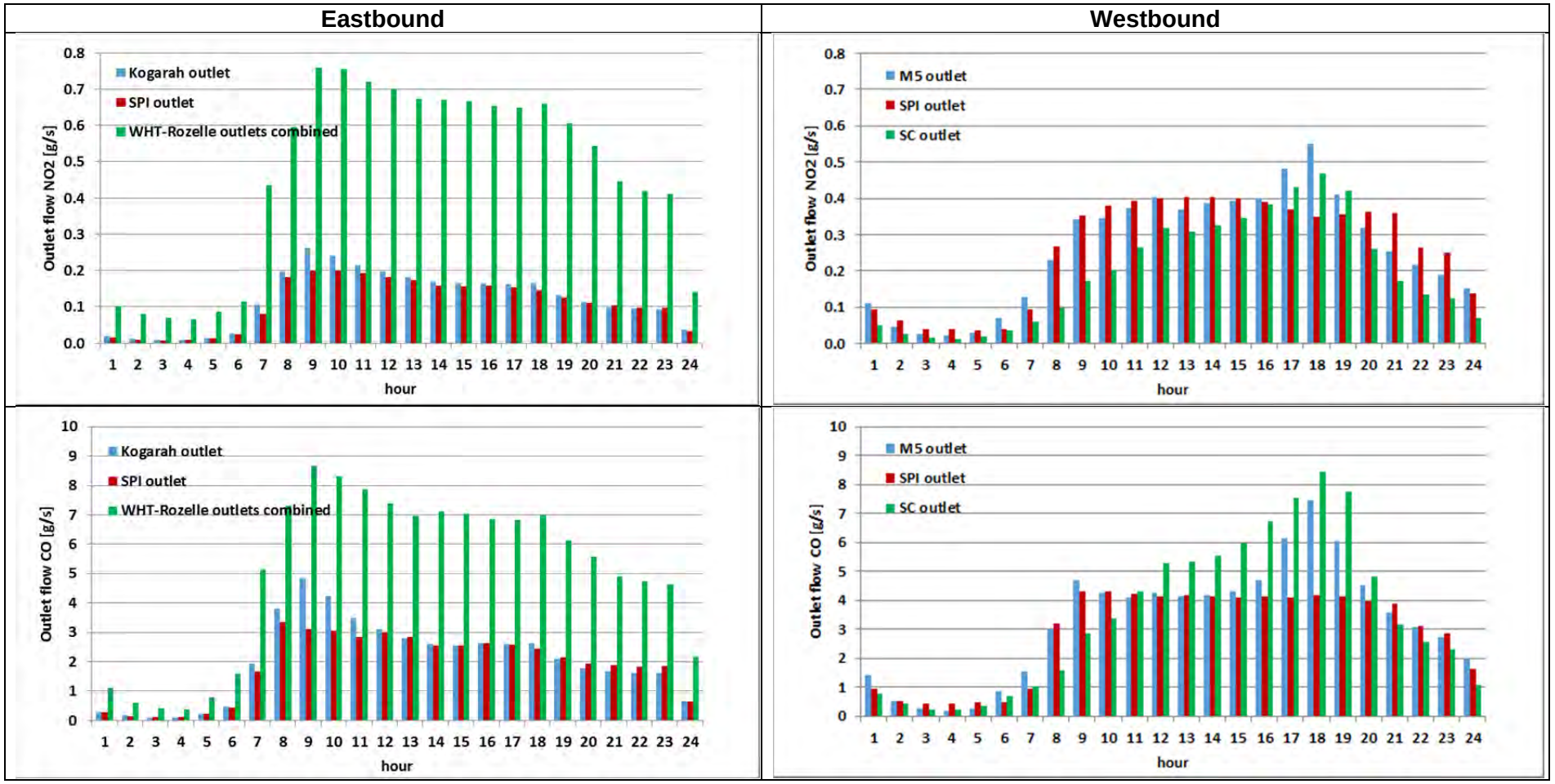
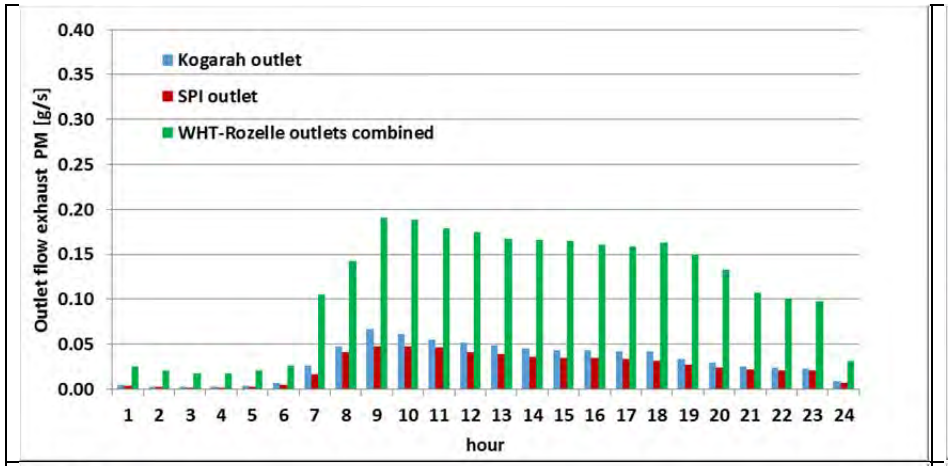
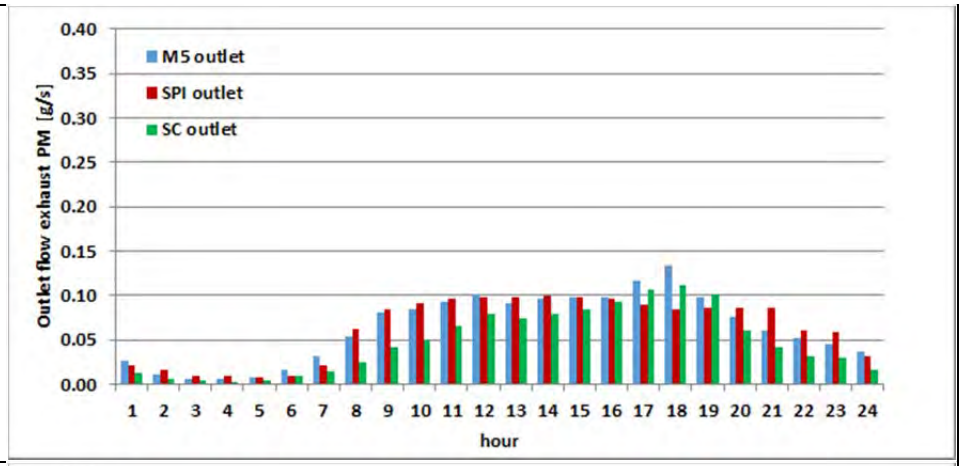
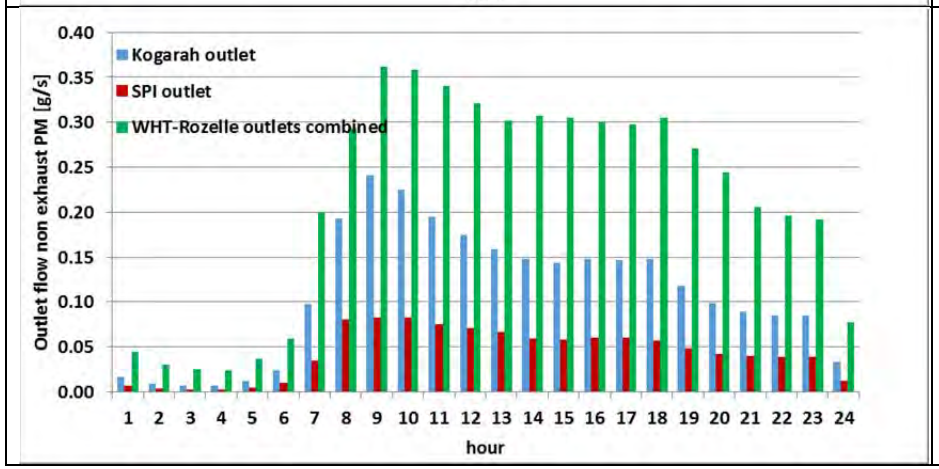


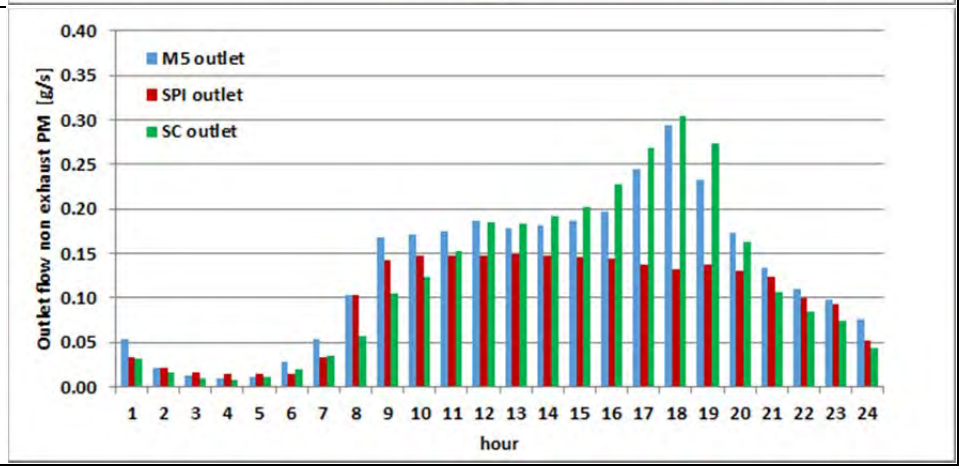
Figure 11.10. Outlet discharge for regulatory traffic in 2031. "SC" means Southern Extension.




Kogarah outlet
SPI outlet
WHT-Rozelle outlets combined
Outlet flow exhaust PM [g/s]
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
hour


M5 outlet
SPI outlet
SC outlet
Outlet flow exhaust PM [g/s]
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
hour


Kogarah outlet
SPI outlet
WHT-Rozelle outlets combined
Outlet flow non exhaust PM [g/s]
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
hour


M5 outlet
SPI outlet
SC outlet
Outlet flow non exhaust PM [g/s]
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
hour

11.3 Congested traffic

Multi-lane tunnels have an advantage in mitigating congestion in that slow vehicles can occupy the left lane, allowing the remaining lanes to accommodate faster moving traffic. As discussed in Section 6.1, the notion of uniformly slow moving traffic throughout a tunnel is unrealistic. The speed difference between lanes introduces another complexity. Since ventilation simulation software and other calculation methods do not consider this speed difference between lanes, they underestimate the vehicle piston effect and produce lower estimates of tunnel air flow and higher estimates of in-tunnel pollution; especially for congested cases where the speed difference between lanes is large.

When congestion does occur in the simulations, it is associated with high traffic demand at entry portals and occurs locally at merges, or at steep exit ramps where congestion may extend back into the mainline. Since traffic flow is compressible, especially in a long tunnel, some sections can flow freely while others are congested.

Traffic congestion is created in the simulation by placing traffic speed limits (20, 40, 60 and 80 km/h) at strategic locations within the model. For the eastbound tube, a speed limit was placed on the last 500 m of the SPI off-ramp, to simulate backup of traffic from the SPI interchange. A second speed limit zone was placed in the main tube between the SPI on-ramp merge and the diverge at the Rozelle end of the M4-M5 Link; a distance of 3775 m. For the westbound tube, speed limits were placed on the last 500 m prior to the three exit portals; SPI off-ramp, M5 exit and Southern Extension exit.

When regulatory traffic flows were applied to the model, results show that significant congestion in the main tube only occurs where the speed limits have been applied (Figure 11.11 and Figure 11.12). There is no back-up of traffic throughout the main tunnel. However the ramps (Southern Extension and SPI) become congested as the traffic backs-up in these locations (Figure 11.13 and Figure 11.14).

Pollution and temperature profiles along M5 and M4-M5 Link for the peak congestion cases are plotted in Figure 11.15 to Figure 11.19 for the eastbound route and Figure 11.20 and Figure 11.24 for the westbound route.

These results show that the eastbound tube has a higher pollutant level than the westbound tube, with the NO_2 level peaking up to 1.0 ppm at Rozelle and the peak summer air temperature reaching 47°C.

Longitudinal profiles of pollutant levels from the Southern Extension portal to the SPI portal are plotted in Figure 11.25 to Figure 11.29 for the eastbound tube and Figure 11.30 to Figure 11.34 for the westbound tube. Equivalent plots for the eastbound New M5 on its own, without M4-M5 Link, are given in Figure 11.35 to Figure 11.40. For the westbound case with New M5 alone, the combined system plots can be referenced, as M4-M5 Link simply acts as the traffic source, conservatively also contributing some pollution into New M5.

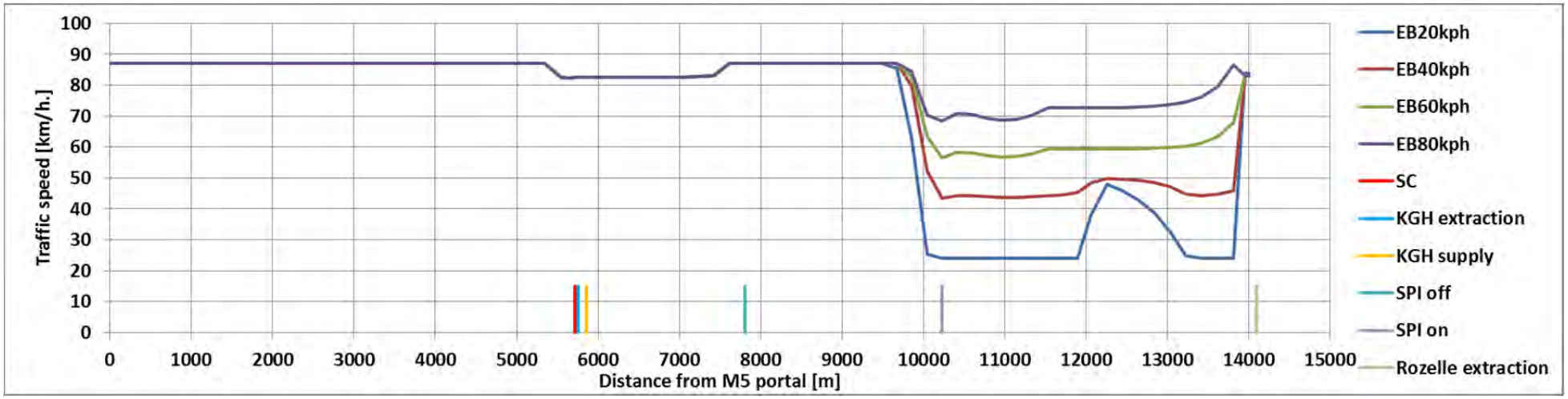


Figure 11.11. Eastbound 2031 regulatory traffic speed profile; M5 to Rozelle; 9 am peak. "SC" means Southern Extension.

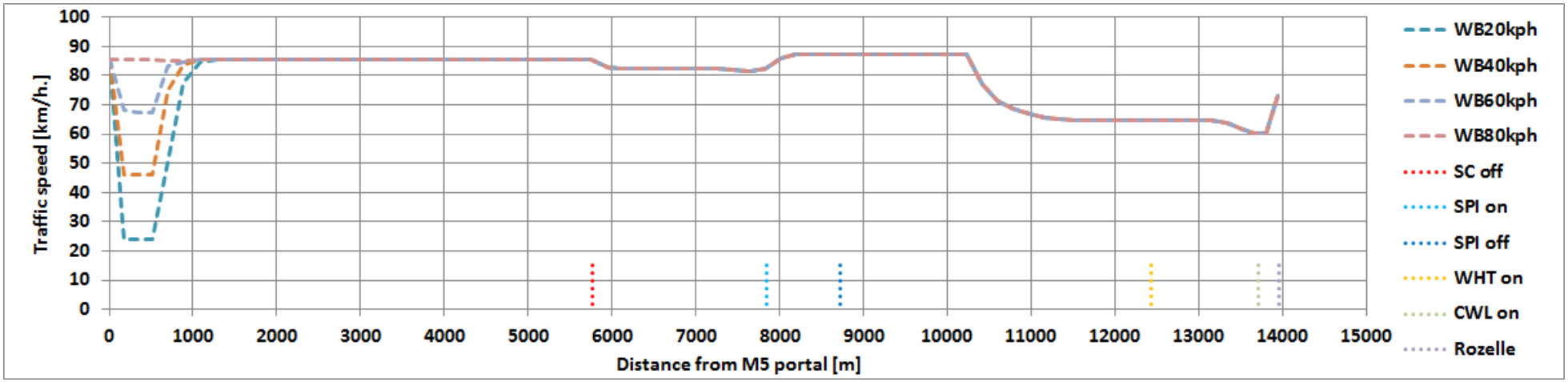


Figure 11.12. Westbound 2031 regulatory traffic speed profile; M5 to Rozelle; 6 pm peak. "SC" means Southern Extension.

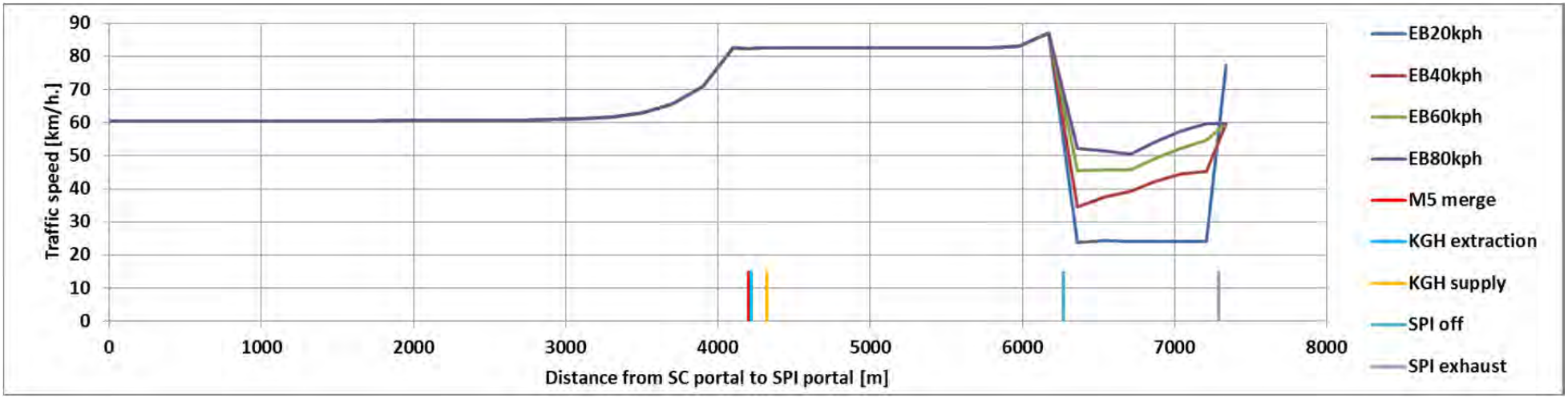


Figure 11.13. Eastbound 2031 regulatory traffic speed profile; Southern Connector (Southern Extension) to SPI; 9 am peak.

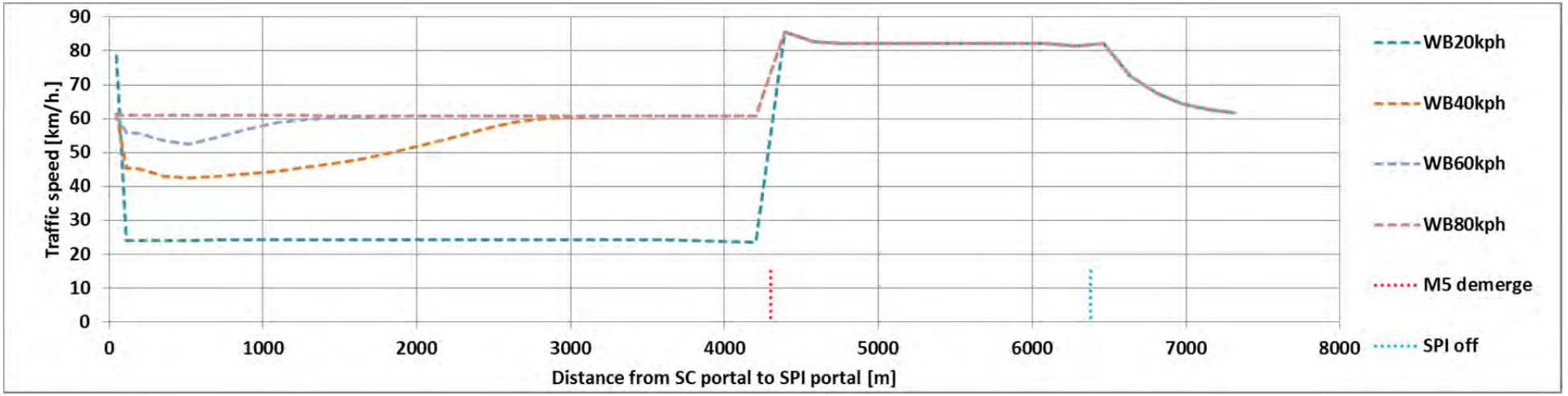


Figure 11.14. Westbound 2031 regulatory traffic speed profile; Southern Connector (Southern Extension) to SPI 6 pm peak.

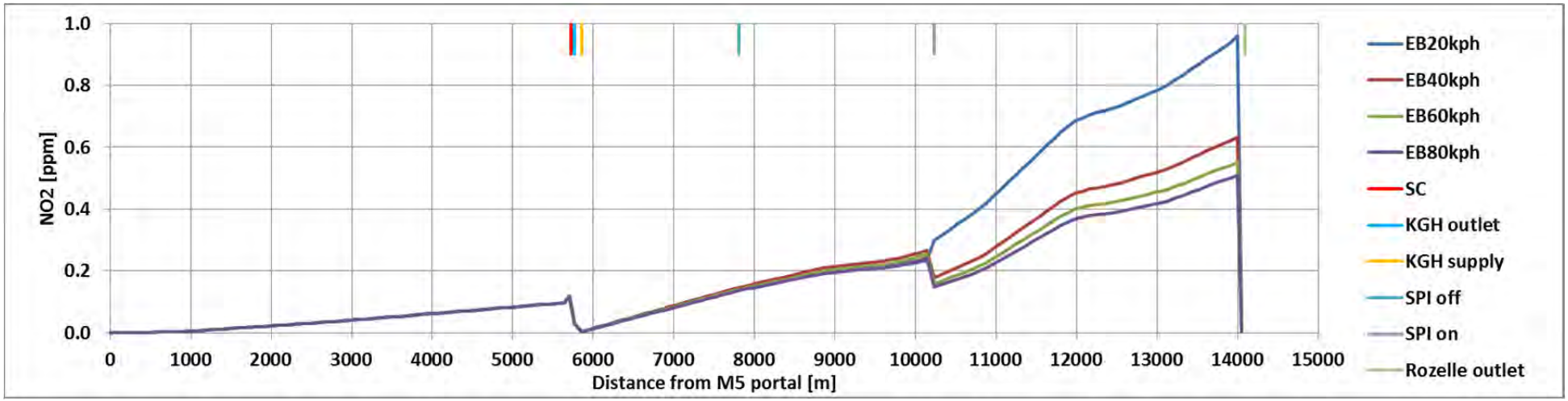


Figure 11.15. Eastbound 2031 regulatory traffic NO_2 profile; M5 to Rozelle; 9 am peak. "SC" means Southern Extension.

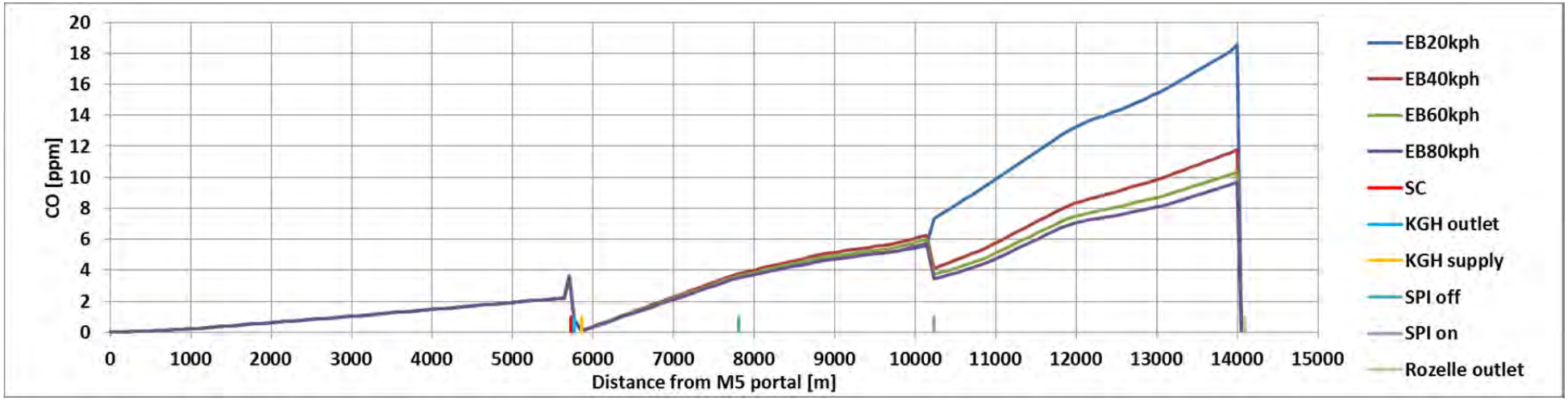


Figure 11.16. Eastbound 2031 regulatory traffic CO profile; M5 to Rozelle; 9 am peak. "SC" means Southern Extension.

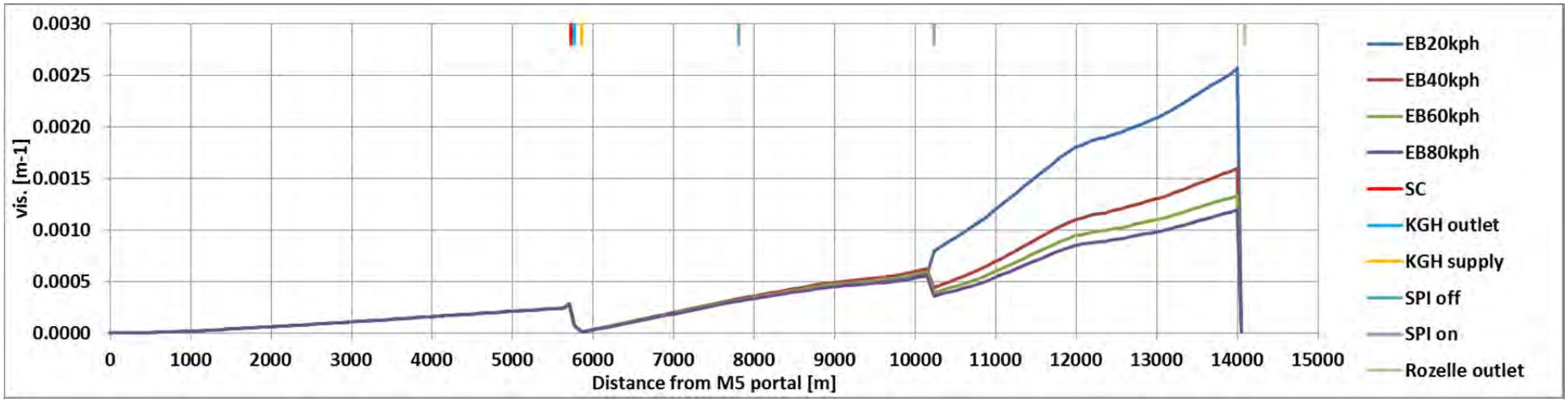


Figure 11.17. Eastbound 2031 regulatory traffic extinction coefficient profile; M5 to Rozelle; 9 am peak. "SC" means Southern Extension.

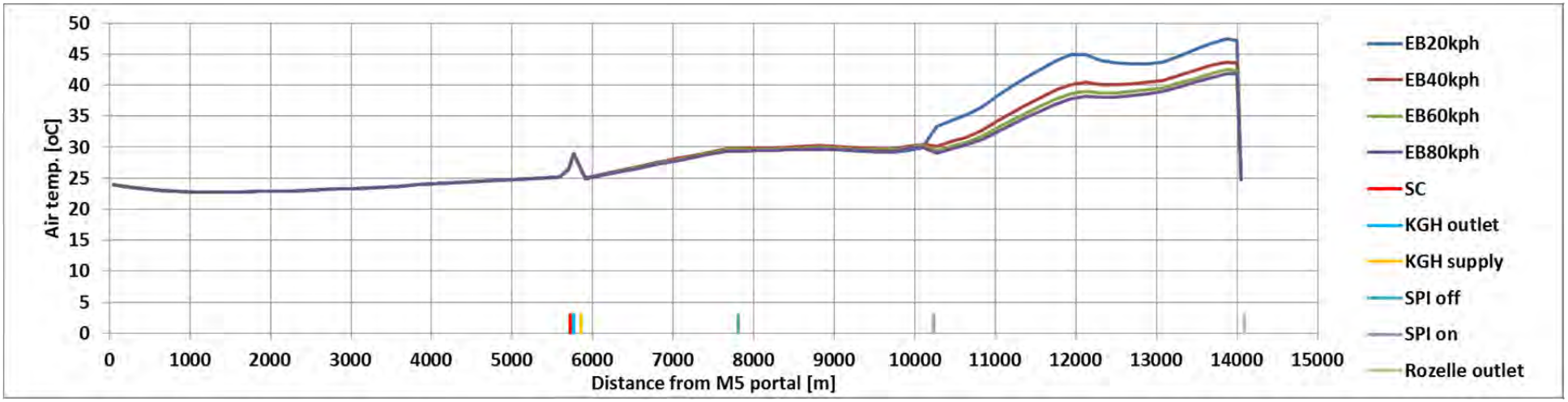


Figure 11.18 Eastbound 2031 regulatory traffic air temperature (summer) profile; M5 to Rozelle; 9 am peak. "SC" means Southern Extension.

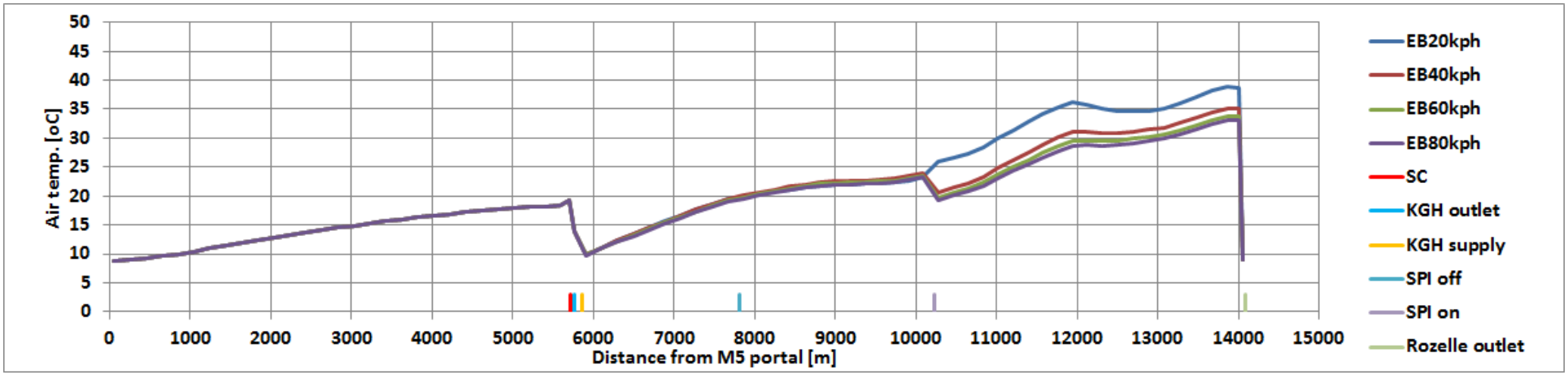


Figure 11.19. Eastbound 2031 regulatory traffic air temperature (winter) profile; M5 to Rozelle; 9 am peak. "SC" means Southern Extension.

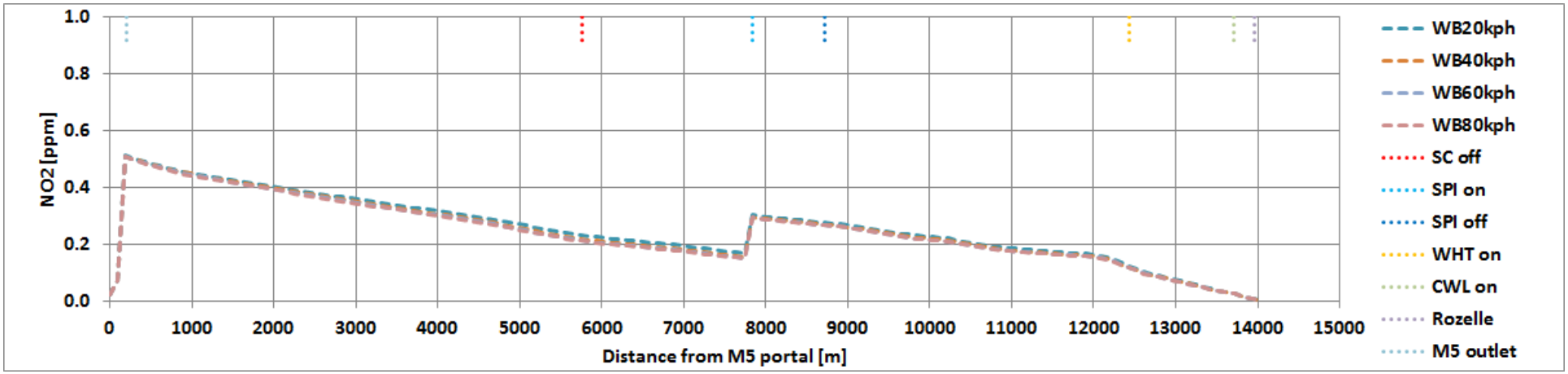


Figure 11.20. Westbound 2031 regulatory traffic NO_2 profile; M5 to Rozelle 6 pm peak. "SC" means Southern Extension.

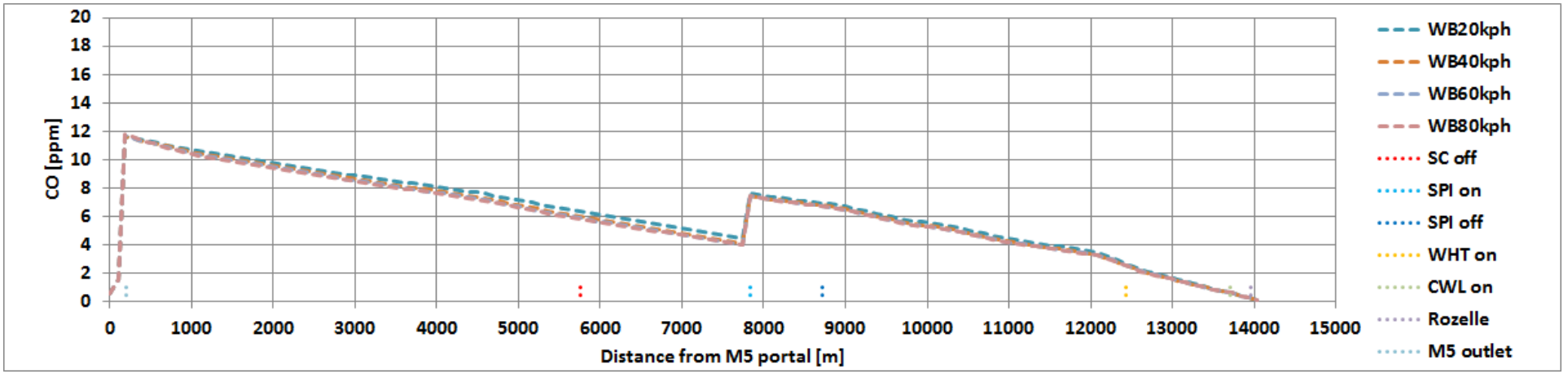


Figure 11.21. Westbound 2031 regulatory traffic CO profile; M5 to Rozelle 6 pm peak. "SC" means Southern Extension.

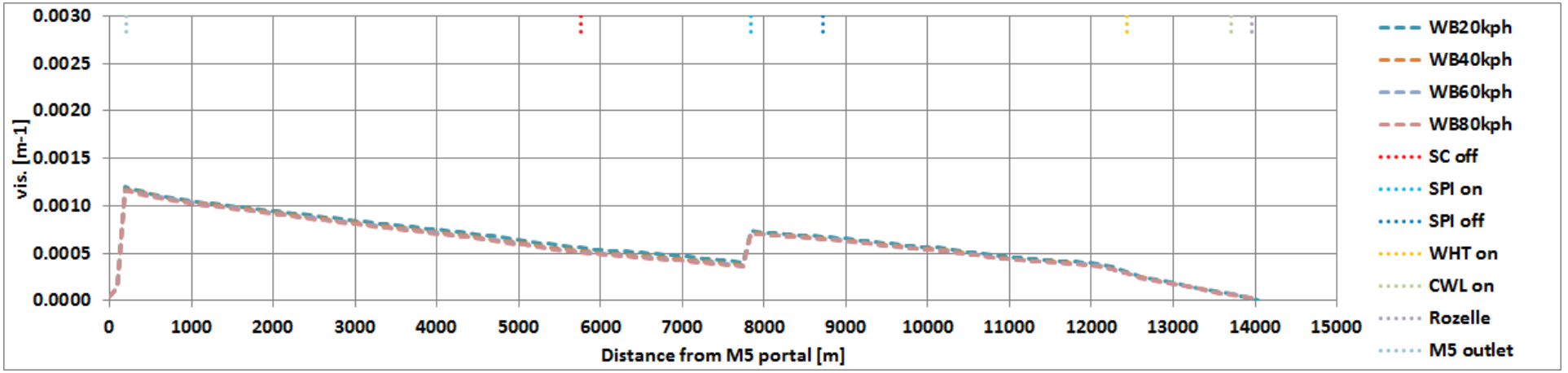


Figure 11.22. Westbound 2031 regulatory traffic extinction coefficient profile; M5 to Rozelle 6 pm peak. "SC" means Southern Extension.

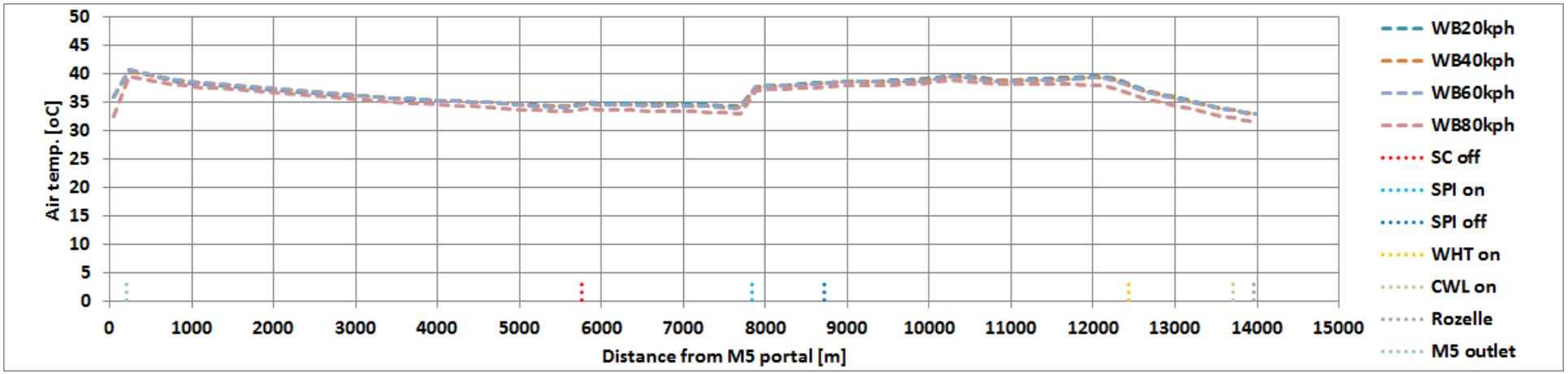


Figure 11.23. Westbound 2031 regulatory traffic air temperature (summer) profile; M5 to Rozelle 6 pm peak. "SC" means Southern Extension.

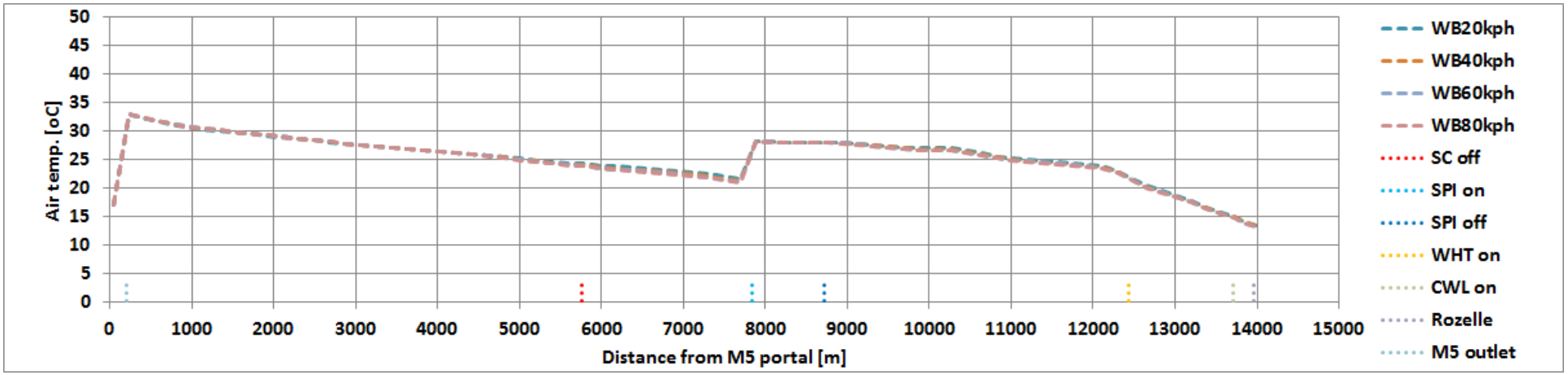


Figure 11.24. Westbound 2031 regulatory traffic air temperature (winter) profile; M5 to Rozelle 6 pm peak. "SC" means Southern Extension.

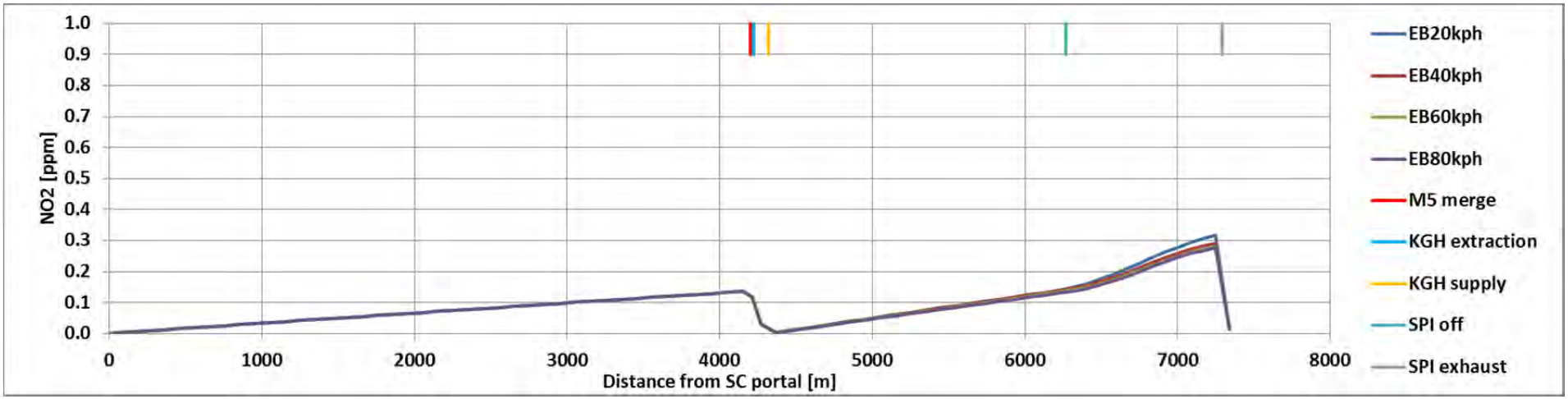


Figure 11.25. Eastbound 2031 regulatory traffic NO_2 profile; Southern Connector (Southern Extension) to SPI; 9 am peak.

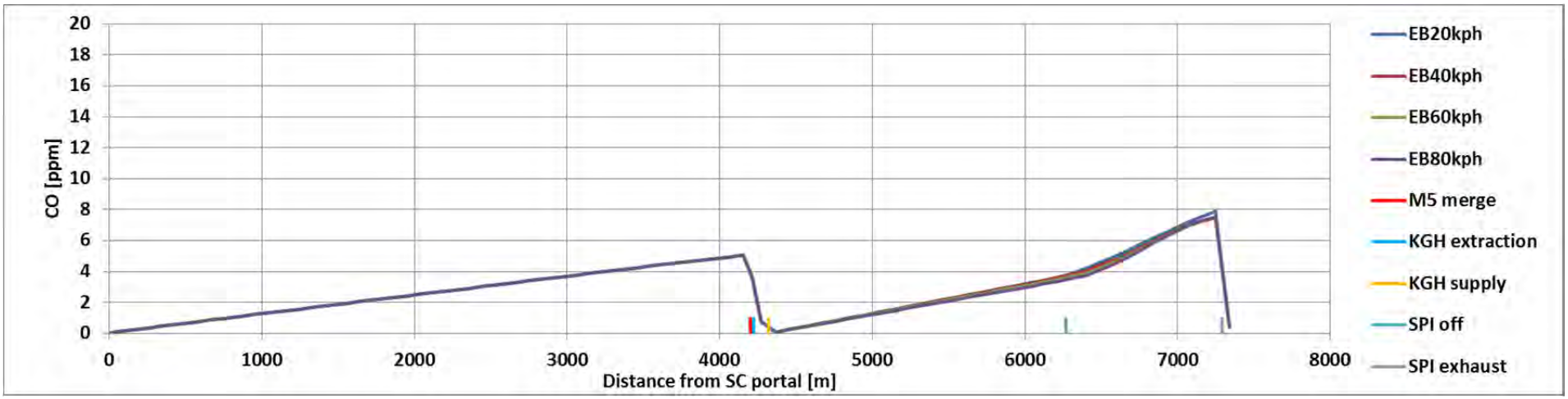


Figure 11.26. Eastbound 2031 regulatory traffic CO profile; Southern Connector (Southern Extension) to SPI; 9 am peak.

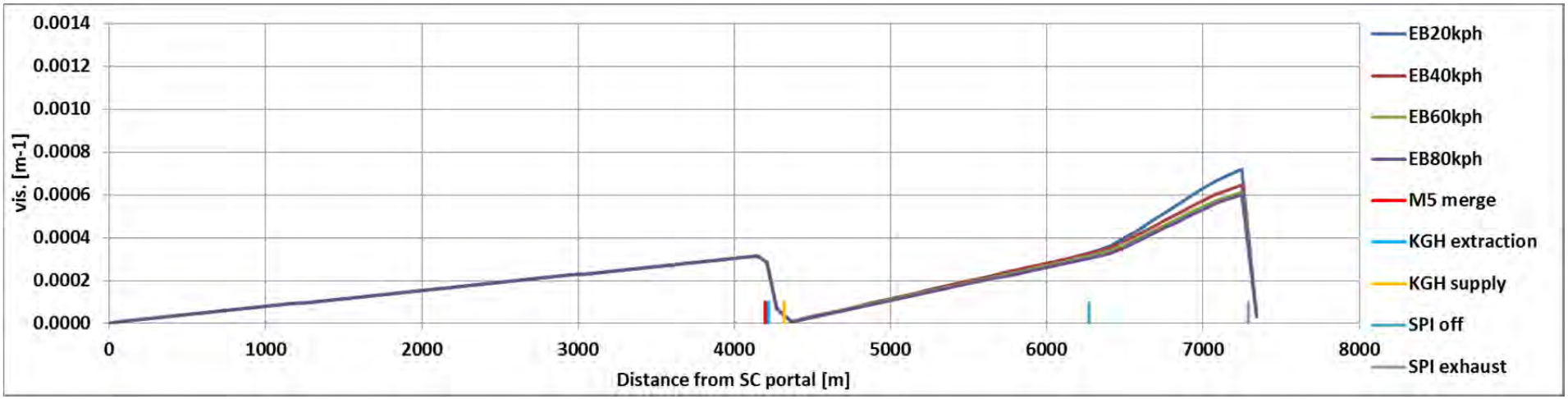


Figure 11.27. Eastbound 2031 regulatory traffic extinction coefficient profile; Southern Connector (Southern Extension) to SPI; 9 am peak.

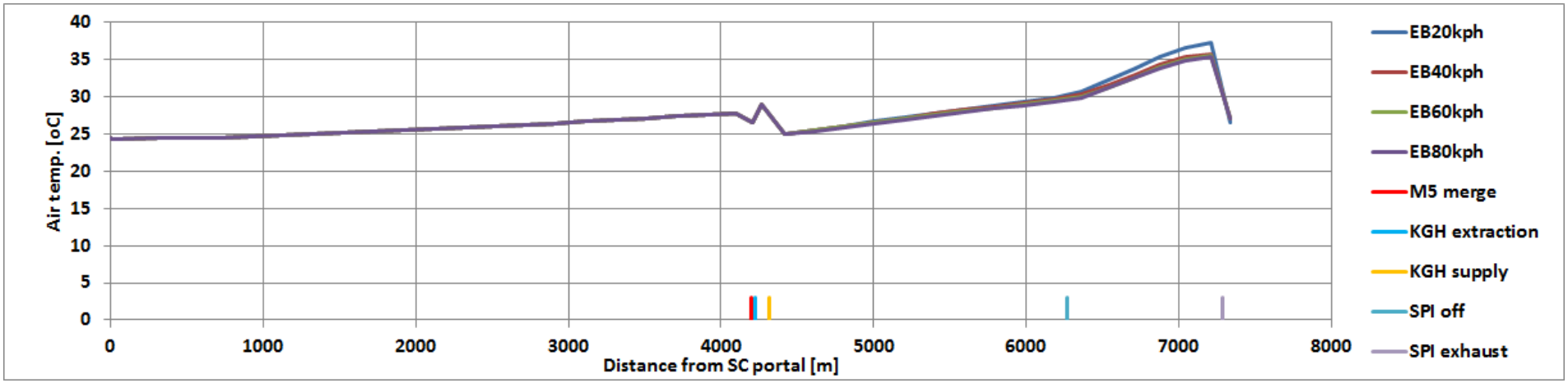


Figure 11.28. Eastbound 2031 regulatory air temperature (summer) profile; Southern Connector (Southern Extension) to SPI; 9 am peak.

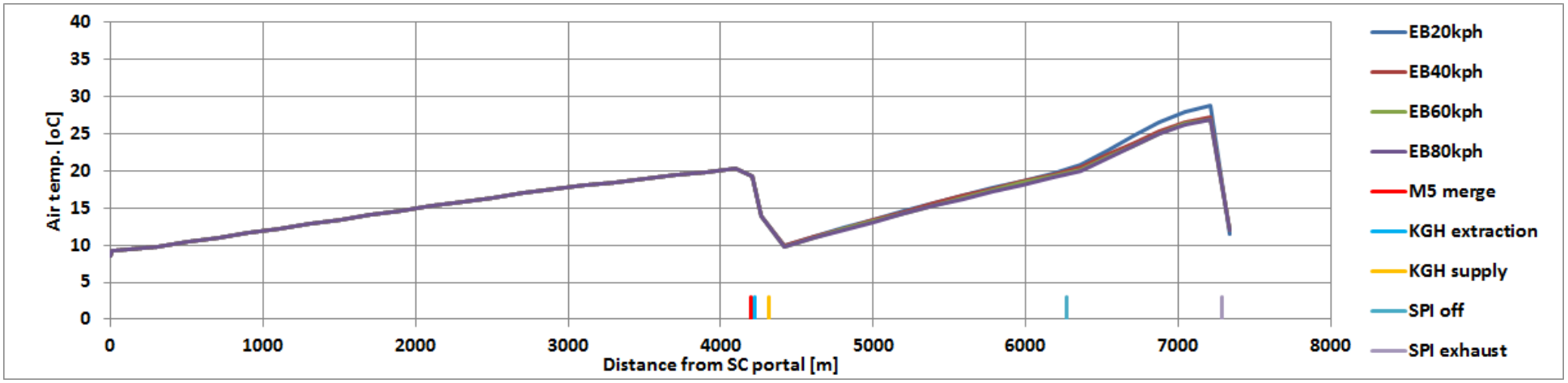


Figure 11.29. Eastbound 2031 regulatory air temperature (winter) profile; Southern Connector (Southern Extension) to SPI; 9 am peak.

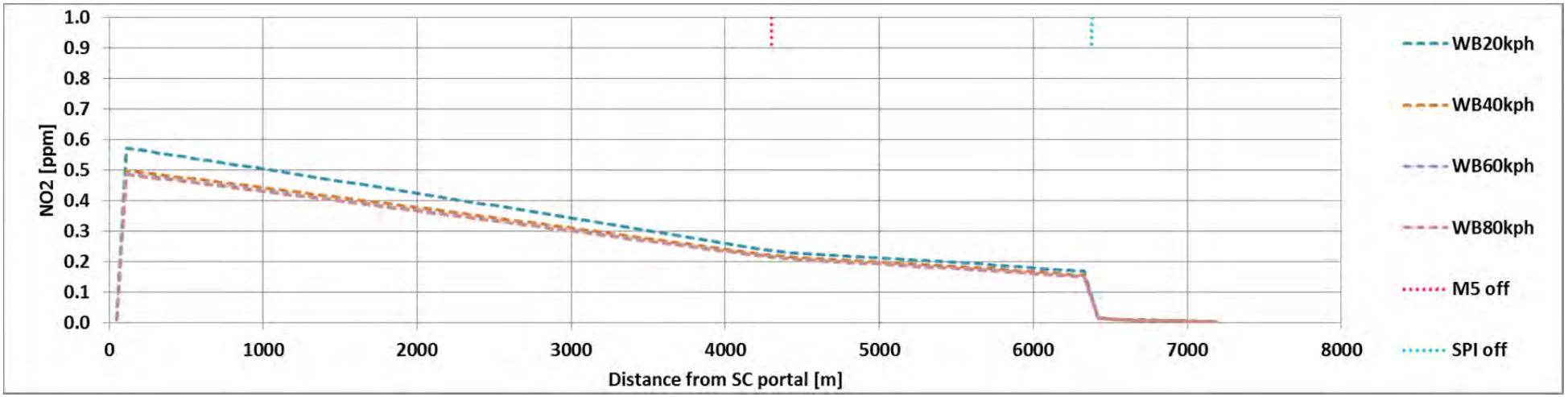


Figure 11.30. Westbound 2031 regulatory traffic NO_2 profile; Southern Connector (Southern Extension) to SPI 6 pm peak.

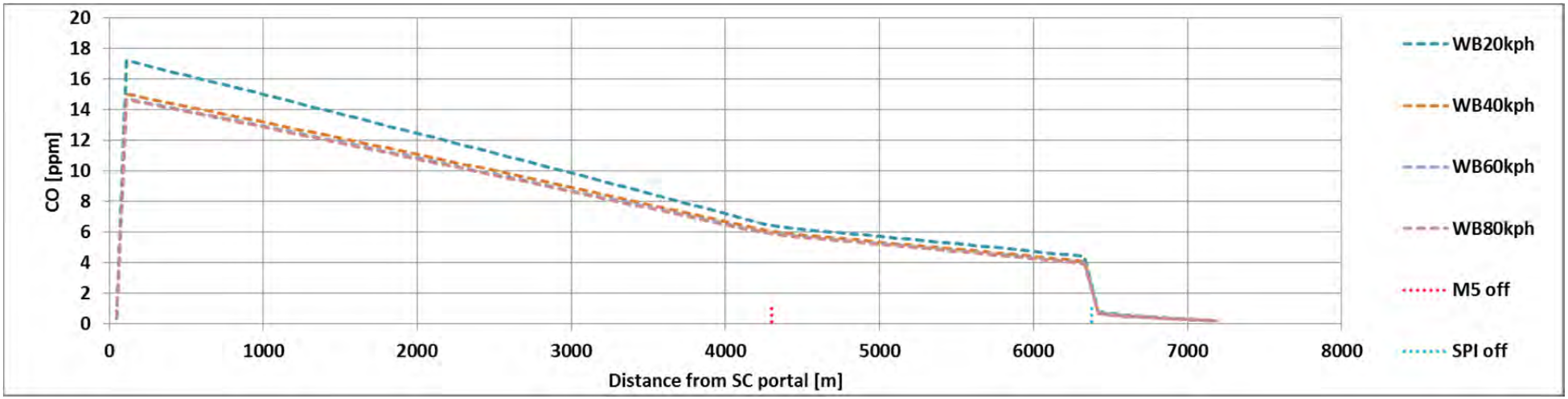


Figure 11.31. Westbound 2031 regulatory traffic CO profile; Southern Connector (Southern Extension) to SPI 6 pm peak.

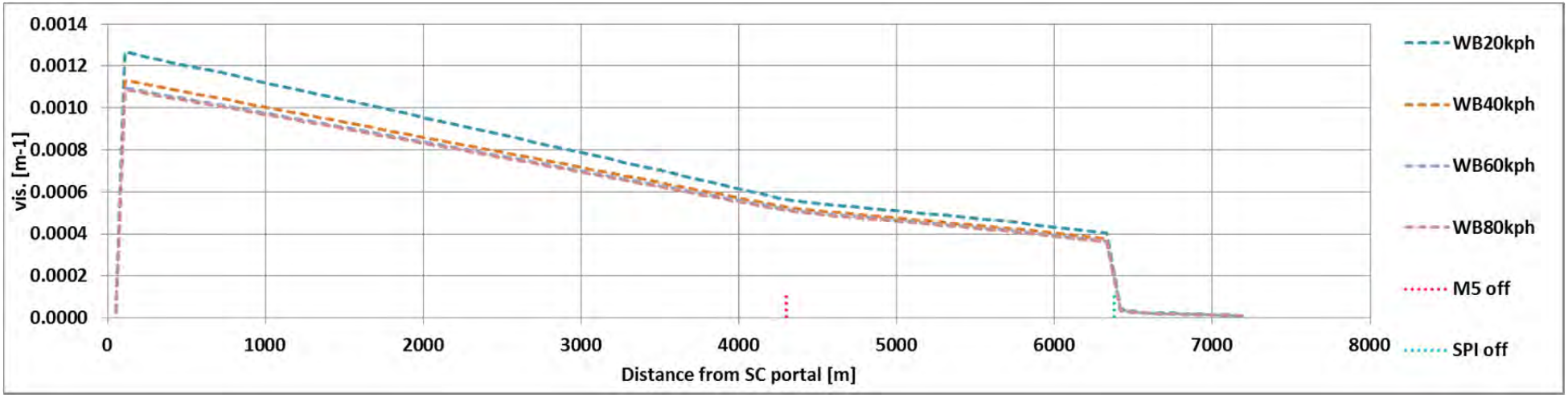


Figure 11.32. Westbound 2031 regulatory traffic extinction coefficient profile; Southern Connector (Southern Extension) to SPI 6 pm peak.

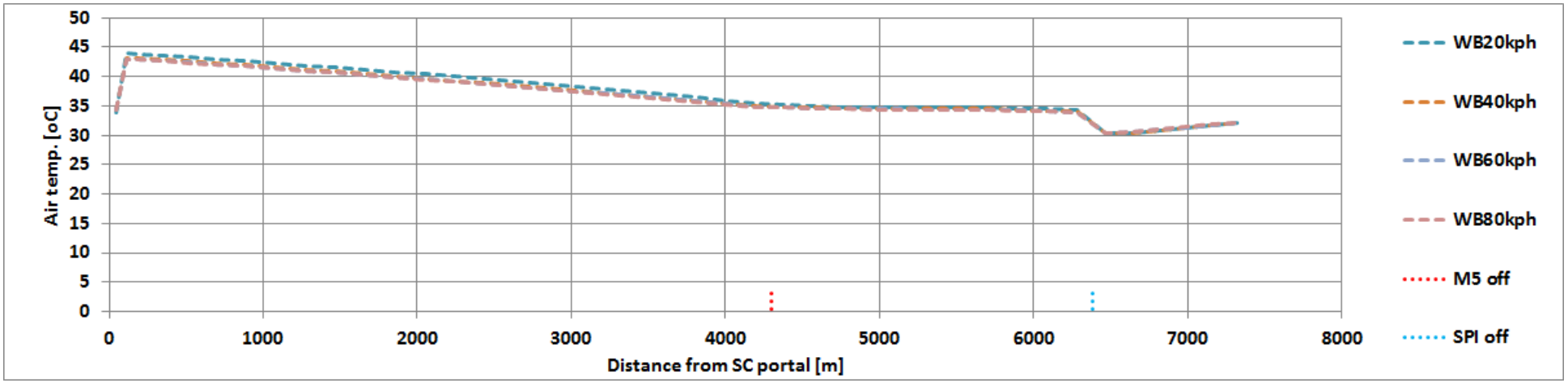


Figure 11.33. Westbound 2031 regulatory traffic air temperature (summer) profile; Southern Connector (Southern Extension) to SPI 6 pm peak.

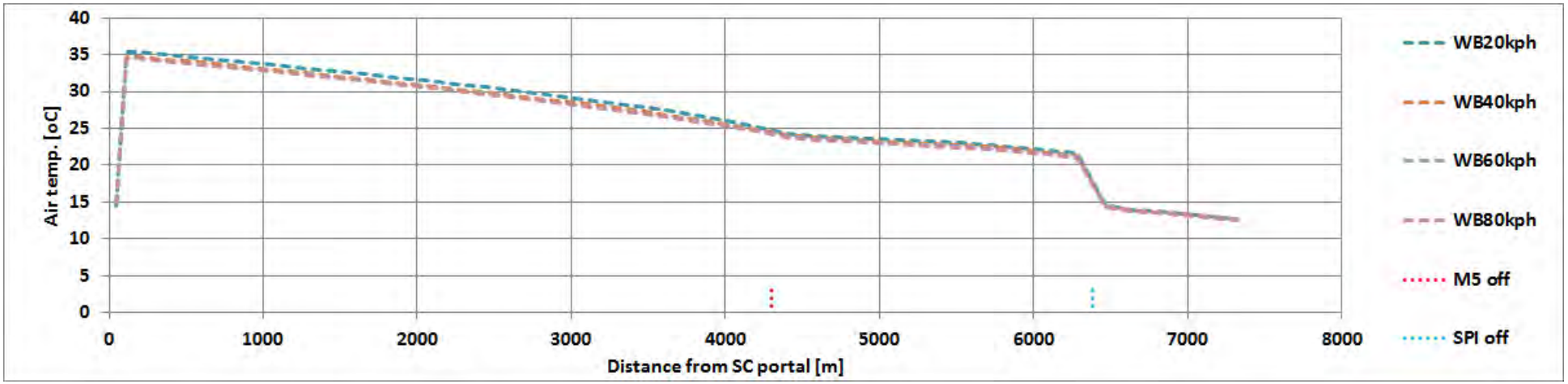


Figure 11.34. Westbound 2031 regulatory traffic air temperature (winter) profile; Southern Connector (Southern Extension) to SPI 6 pm peak.

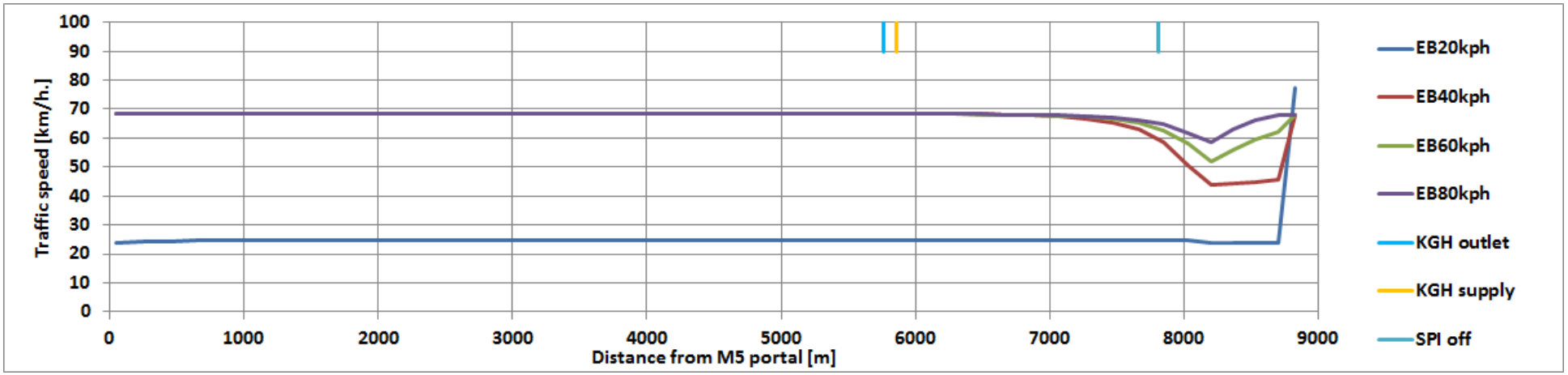


Figure 11.35. New M5 alone eastbound 2021 regulatory traffic speed profile; M5 to St Peters 9 am peak.

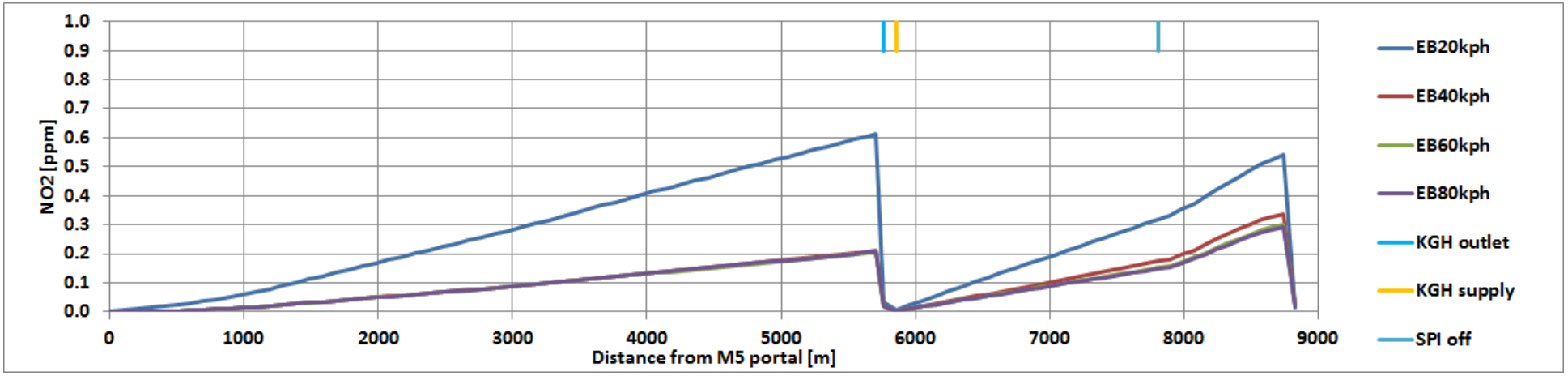


Figure 11.36. New M5 alone eastbound 2021 regulatory traffic NO_2 profile; M5 to St Peters 9 am peak.

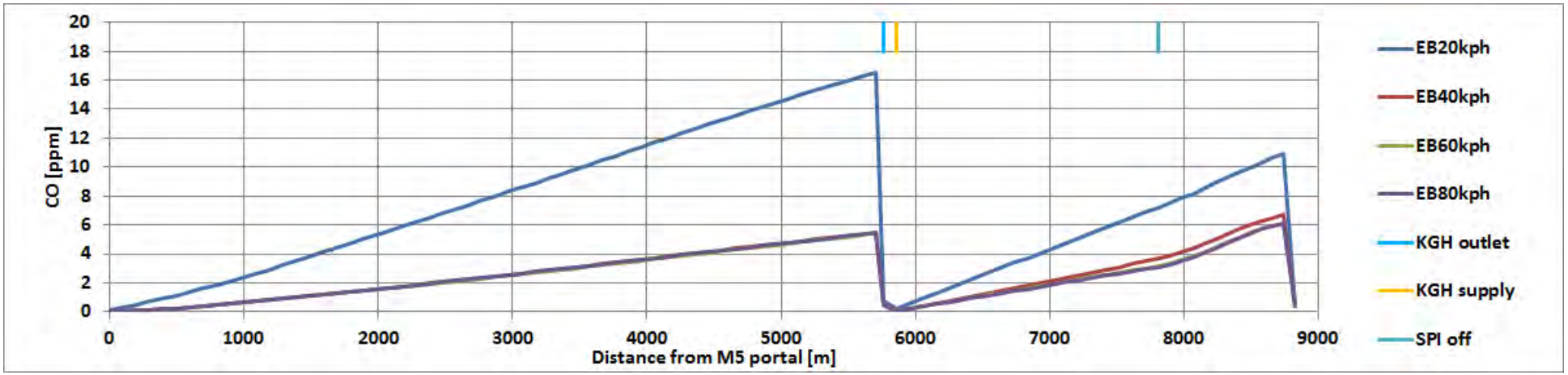


Figure 11.37. New M5 alone eastbound 2021 regulatory traffic CO profile; M5 to St Peters 9 am peak.

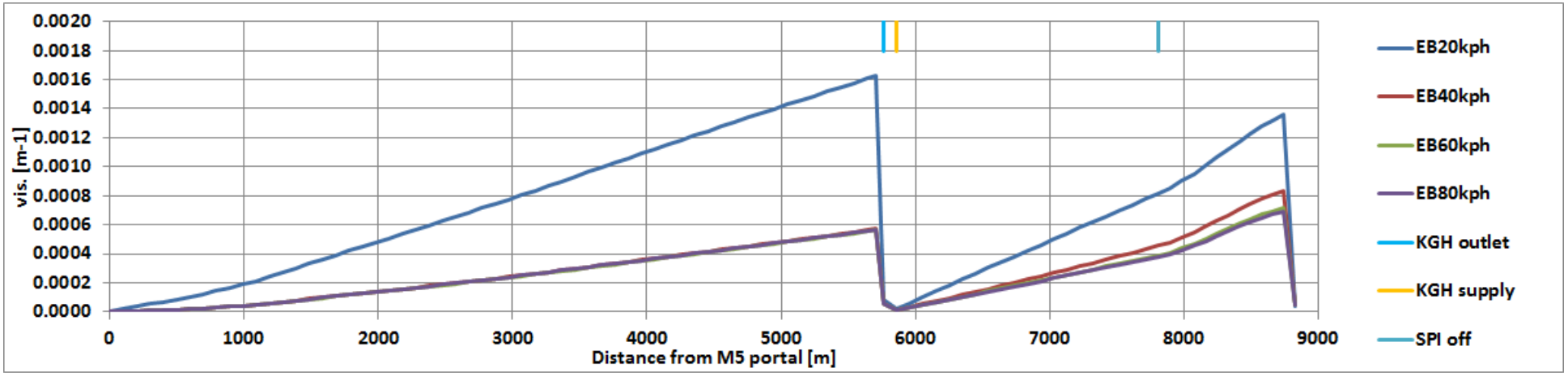


Figure 11.38. New M5 alone Eastbound 2021 regulatory traffic exhaust PM extinction coefficient profile; M5 to St Peters 9 am peak.

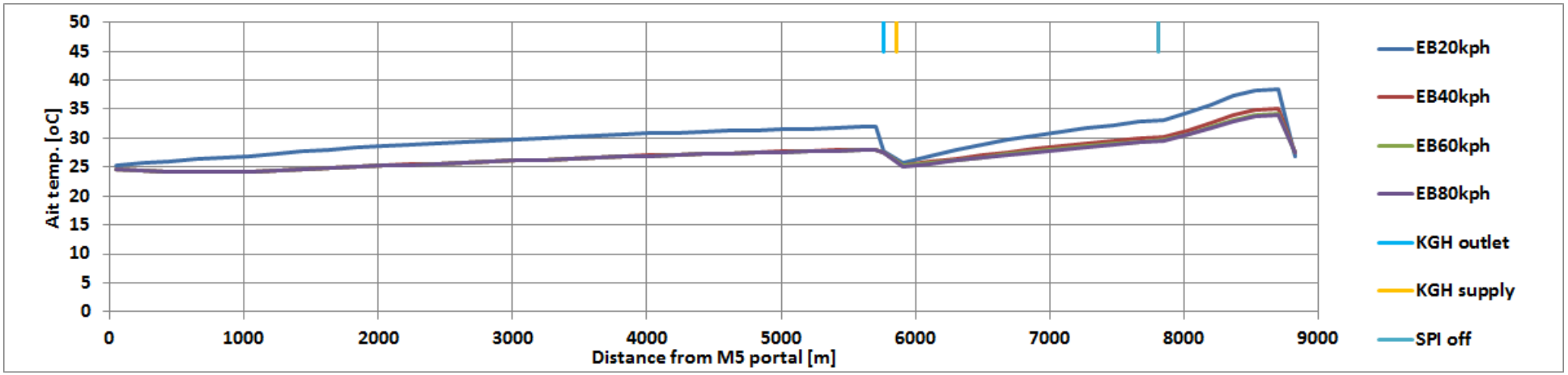


Figure 11.39. New M5 alone eastbound 2021 regulatory traffic air temperature (summer) profile; M5 to St Peters 9 am peak.

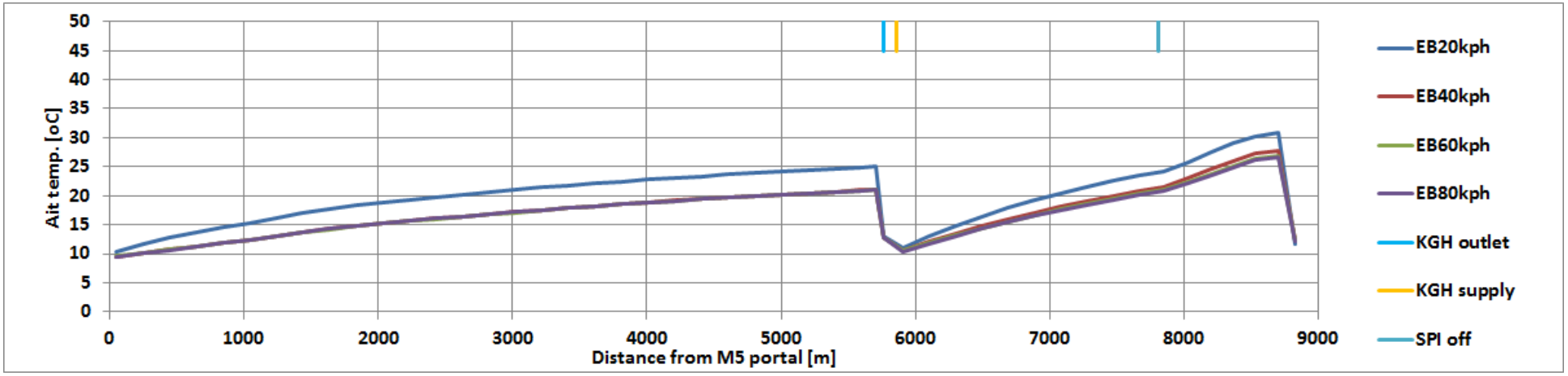


Figure 11.40. New M5 alone Eastbound 2021 regulatory traffic air temperature (winter) profile; M5 to St Peters 9 am peak.

APPENDIX A - NEW M5 ALONE 2021 SIMULATION RESULTS

Results from the simulation of New M5 alone for 2021 normal traffic.

Table A.1. New M5 normal eastbound 2021 traffic (summer). Stage 2 Eastbound 2021 24hrs Normal.xlsx

Hour	New M5 traffic		Number of Jet Fans Main tube	Ambient	Peak in-tunnel levels (before Kogarah outlet)					Kogarah outlet								Peak in-tunnel levels (before SPI outlet)					SPI outlet						
	M5 Flow (vph)	SPI off (vph)		(°C)	NO2 (ppm)	CO (ppm)	Non-exhaust PM (mg/m3)	Exhaust PM Vis. (m-1)	Temp (°C)	supply flow (m3/s)	exhaust flow (m3/s)	NO2 (g/s)	CO (g/s)	Non-exhaust PM (g/s)	Exhaust PM (g/s)	T (°C)	Delta T Ambient (°C)	NO2 (ppm)	CO (ppm)	Non-exhaust PM (mg/m3)	Exhaust PM Vis. (m-1)	Temp (°C)	flow (m3/s)	NO2 (g/s)	CO (g/s)	Non-exhaust PM (g/s)	Exhaust PM (g/s)	T (°C)	Delta T Ambient (°C)
0	56	56	13.5	22.3	0.01	0.2	0.01	0.0000	24.5	112	370	0.005	0.07	0.004	0.0014	24.1	1.9	0.10	2.1	0.08	0.0002	29.1	125	0.009	0.12	0.004	0.0022	24.8	2.5
1	39	39	13.8	21.5	0.01	0.1	0.01	0.0000	24.4	109	366	0.004	0.04	0.003	0.0011	23.9	2.4	0.07	1.3	0.05	0.0001	28.6	123	0.006	0.07	0.002	0.0014	24.1	2.6
2	34	34	14.0	21.0	0.01	0.1	0.01	0.0000	24.4	108	365	0.003	0.03	0.003	0.0010	23.8	2.8	0.06	0.9	0.04	0.0001	28.5	121	0.005	0.05	0.002	0.0011	23.7	2.7
3	35	35	14.0	20.0	0.01	0.1	0.01	0.0000	24.3	108	365	0.003	0.03	0.003	0.0010	23.6	3.7	0.05	0.7	0.03	0.0001	28.4	121	0.005	0.04	0.001	0.0011	23.1	3.2
4	57	57	13.5	18.5	0.01	0.1	0.01	0.0000	24.3	111	374	0.005	0.05	0.003	0.0013	23.4	4.9	0.06	0.9	0.03	0.0001	28.5	125	0.005	0.05	0.002	0.0012	22.5	4.0
5	137	137	12.0	18.0	0.01	0.3	0.02	0.0000	24.4	122	395	0.009	0.13	0.007	0.0024	23.4	5.4	0.07	1.6	0.05	0.0002	29.1	136	0.009	0.12	0.003	0.0020	23.0	5.0
6	547	546	3.8	19.5	0.05	1.1	0.07	0.0001	24.9	177	490	0.039	0.56	0.031	0.0103	24.2	4.7	0.16	3.9	0.10	0.0003	31.0	193	0.037	0.55	0.012	0.0083	26.6	7.1
7	1,089	1,089	0.0	22.5	0.07	1.8	0.12	0.0002	25.4	297	569	0.072	1.11	0.060	0.0187	25.1	2.6	0.18	4.7	0.14	0.0004	31.0	316	0.089	1.37	0.033	0.0201	29.1	6.6
8	1,424	1,423	0.0	24.2	0.09	2.2	0.15	0.0002	25.8	374	613	0.103	1.44	0.083	0.0274	25.7	1.5	0.19	4.4	0.13	0.0004	31.3	395	0.123	1.71	0.043	0.0281	30.1	5.9
9	1,208	1,209	0.0	26.8	0.08	2.0	0.14	0.0002	25.7	334	585	0.087	1.22	0.070	0.0230	25.9	-0.9	0.19	4.3	0.13	0.0004	31.4	350	0.103	1.43	0.036	0.0235	30.4	3.6
10	1,084	1,084	0.0	31.6	0.08	1.8	0.13	0.0002	25.7	313	567	0.080	1.08	0.064	0.0215	26.3	-5.3	0.19	4.2	0.13	0.0004	31.6	326	0.096	1.26	0.033	0.0219	31.5	-0.1
11	1,038	1,038	0.0	34.3	0.08	1.7	0.13	0.0002	25.8	311	562	0.081	1.03	0.063	0.0221	26.7	-7.6	0.20	4.1	0.13	0.0004	33.6	322	0.097	1.21	0.033	0.0225	32.3	-1.9
12	829	830	0.0	34.3	0.07	1.5	0.11	0.0002	25.7	261	536	0.069	0.83	0.052	0.0192	26.6	-7.6	0.21	4.1	0.13	0.0005	33.5	272	0.081	0.96	0.026	0.0191	32.5	-1.7
13	708	708	0.0	34.1	0.07	1.3	0.10	0.0002	25.6	222	519	0.063	0.71	0.046	0.0177	26.6	-7.5	0.23	4.3	0.14	0.0005	33.2	234	0.073	0.81	0.023	0.0173	32.8	-1.2
14	715	715	0.0	34.2	0.07	1.3	0.10	0.0002	25.7	222	518	0.062	0.71	0.046	0.0174	26.6	-7.5	0.24	4.4	0.15	0.0005	33.3	233	0.076	0.83	0.024	0.0179	32.9	-1.2
15	864	864	0.0	34.2	0.07	1.5	0.11	0.0002	25.8	257	532	0.066	0.85	0.052	0.0178	26.8	-7.4	0.21	4.3	0.15	0.0005	33.5	268	0.083	1.00	0.028	0.0192	32.7	-1.5
16	940	940	0.0	33.8	0.07	1.6	0.12	0.0002	25.9	271	539	0.067	0.92	0.055	0.0178	26.8	-6.9	0.20	4.3	0.14	0.0004	33.2	283	0.082	1.07	0.029	0.0186	32.6	-1.1
17	771	771	0.0	32.9	0.06	1.4	0.11	0.0002	25.9	214	514	0.058	0.75	0.047	0.0155	26.7	-6.2	0.22	4.6	0.15	0.0005	33.0	226	0.066	0.82	0.023	0.0149	32.7	-0.1
18	742	742	0.0	31.9	0.06	1.3	0.10	0.0002	25.9	197	508	0.056	0.71	0.045	0.0149	26.6	-5.3	0.24	5.0	0.17	0.0005	33.4	210	0.066	0.80	0.023	0.0149	32.7	0.8
19	520	521	0.0	31.0	0.05	1.0	0.08	0.0001	25.7	83	476	0.043	0.51	0.034	0.0120	26.4	-4.5	0.41	8.0	0.24	0.0008	36.7	96	0.013	0.15	0.004	0.0029	31.5	0.6
20	418	418	5.2	30.1	0.04	0.9	0.07	0.0001	25.6	168	458	0.035	0.42	0.027	0.0098	26.3	-3.8	0.32	5.9	0.24	0.0007	32.4	181	0.066	0.73	0.025	0.0158	31.2	1.2
21	381	381	6.1	27.7	0.04	0.8	0.06	0.0001	25.6	163	450	0.032	0.38	0.024	0.0089	26.0	-1.7	0.20	3.8	0.13	0.0004	32.2	176	0.040	0.45	0.013	0.0093	30.1	2.4
22	381	381	6.3	23.9	0.04	0.8	0.06	0.0001	25.6	160	450	0.030	0.38	0.023	0.0082	25.4	1.5	0.19	3.8	0.13	0.0004	32.0	175	0.037	0.45	0.012	0.0087	28.5	4.6
23	147	148	11.4	21.8	0.02	0.4	0.03	0.0000	25.3	126	391	0.012	0.16	0.010	0.0031	24.7	3.0	0.15	3.1	0.11	0.0003	30.7	140	0.018	0.23	0.007	0.0043	25.8	4.1

Table A.2. New M5 normal eastbound 2021 traffic (winter). Stage 2 Eastbound 2021 24hrs Normal.xlsx

Hour	New M5 traffic		Number of Jet Fans Main tube	Ambient	Peak in-tunnel levels (before Kogarah outlet)					Kogarah outlet								Peak in-tunnel levels (before SPI outlet)					SPI outlet						
	M5 Flow (vph)	SPI off (vph)		(°C)	NO2 (ppm)	CO (ppm)	Non-exhaust PM (mg/m3)	Exhaust PM Vis. (m-1)	Temp (°C)	supply flow (m3/s)	exhaust flow (m3/s)	NO2 (g/s)	CO (g/s)	Non-exhaust PM (g/s)	Exhaust PM (g/s)	T (°C)	Delta T Ambient (°C)	NO2 (ppm)	CO (ppm)	Non-exhaust PM (mg/m3)	Exhaust PM Vis. (m-1)	Temp (°C)	flow (m3/s)	NO2 (g/s)	CO (g/s)	Non-exhaust PM (g/s)	Exhaust PM (g/s)	T (°C)	Delta T Ambient (°C)
0	56	56	15.2	10.8	0.01	0.2	0.01	0.0000	16.1	100	396	0.005	0.06	0.004	0.0013	15.2	4.5	0.13	2.8	0.10	0.0003	23.1	114	0.010	0.12	0.004	0.0022	14.6	3.9
1	39	39	15.5	10.3	0.01	0.1	0.01	0.0000	16.0	98	393	0.004	0.04	0.003	0.0011	15.1	4.8	0.10	1.9	0.07	0.0002	22.7	112	0.007	0.08	0.002	0.0015	14.0	3.8
2	34	34	15.6	9.6	0.01	0.1	0.01	0.0000	16.0	97	391	0.003	0.03	0.003	0.0010	14.9	5.4	0.08	1.4	0.05	0.0002	22.5	111	0.005	0.05	0.002	0.0012	13.5	3.9
3	35	35	15.6	9.1	0.01	0.1	0.01	0.0000	15.9	97	392	0.003	0.03	0.003	0.0010	14.8	5.8	0.07	1.1	0.05	0.0002	22.5	111	0.005	0.04	0.001	0.0011	13.1	4.1
4	57	57	15.1	8.5	0.01	0.1	0.01	0.0000	15.9	100	399	0.005	0.06	0.003	0.0013	14.8	6.3	0.07	1.2	0.04	0.0002	22.6	114	0.005	0.05	0.002	0.0013	13.1	4.6
5	137	137	13.6	7.5	0.01	0.3	0.02	0.0000	16.0	111	419	0.009	0.13	0.007	0.0024	14.7	7.2	0.09	1.9	0.06	0.0002	23.2	125	0.009	0.11	0.003	0.0020	13.7	6.2
6	547	546	5.5	6.5	0.04	1.1	0.07	0.0001	16.4	165	509	0.039	0.56	0.031	0.0103	15.3	8.8	0.17	4.2	0.11	0.0004	24.9	184	0.038	0.56	0.012	0.0085	17.4	10.9
7	1,089	1,089	0.0	6.5	0.07	1.8	0.12	0.0002	16.8	260	587	0.073	1.12	0.060	0.0187	15.8	9.3	0.21	5.4	0.16	0.0004	25.0	284	0.090	1.38	0.033	0.0203	20.2	13.7
8	1,424	1,423	0.0	7.8	0.09	2.1	0.15	0.0002	17.2	342	630	0.103	1.44	0.083	0.0274	16.3	8.5	0.21	4.8	0.15	0.0004	24.9	371	0.124	1.73	0.044	0.0284	21.5	13.7
9	1,208	1,209	0.0	10.0	0.08	1.9	0.13	0.0002	17.1	298	603	0.087	1.22	0.070	0.0230	16.4	6.5	0.21	4.8	0.14	0.0004	25.0	322	0.103	1.43	0.036	0.0235	21.5	11.6
10	1,084	1,084	0.0	12.7	0.08	1.7	0.12	0.0002	17.0	271	586	0.080	1.08	0.064	0.0215	16.6	4.0	0.22	4.8	0.15	0.0005	25.3	292	0.096	1.27	0.033	0.0219	22.0	9.4
11	1,038	1,038	0.0	13.9	0.08	1.7	0.12	0.0002	17.1	267	582	0.081	1.03	0.064	0.0221	16.8	2.9	0.23	4.8	0.15	0.0005	25.5	287	0.098	1.22	0.033	0.0227	22.4	8.5
12	829	830	0.0	13.9	0.07	1.4	0.11	0.0002	17.0	209	557	0.069	0.84	0.052	0.0192	16.7	2.8	0.26	5.2	0.17	0.0006	26.2	227	0.080	0.95	0.026	0.0186	22.0	8.1
13	708	708	0.0	14.0	0.07	1.2	0.10	0.0002	16.9	164	541	0.063	0.71	0.046	0.0178	16.6	2.6	0.33	6.2	0.20	0.0007	27.6	180	0.069	0.78	0.021	0.0163	21.7	7.7
14	715	715	0.0	14.0	0.07	1.3	0.10	0.0002	16.9	164	540	0.062	0.71	0.046	0.0174	16.6	2.6	0.37	6.7	0.23	0.0008	27.8	180	0.077	0.85	0.024	0.0183	21.8	7.8
15	864	864	0.0	13.5	0.07	1.4	0.11	0.0002	17.0	204	555	0.066	0.85	0.052	0.0179	16.7	3.2	0.30	6.0	0.21	0.0007	26.5	222	0.090	1.07	0.031	0.0211	22.0	8.5
16	940	940	0.0	13.0	0.07	1.6	0.11	0.0002	17.1	220	562	0.068	0.92	0.055	0.0178	16.7	3.7	0.26	5.6	0.18	0.0005	26.2	238	0.084	1.10	0.030	0.0193	22.0	9.0
17	771	771	0.0	12.5	0.06	1.3	0.10	0.0002	17.0	153	538	0.058	0.75	0.047	0.0156	16.5	4.0	0.32	6.7	0.21	0.0007	28.1	169	0.060	0.76	0.020	0.0134	21.0	8.5
18	742	742	2.5	12.0	0.06	1.3	0.10	0.0001	16.9	186	532	0.056	0.71	0.045	0.0149	16.4	4.4	0.28	5.7	0.20	0.0006	26.4	204	0.072	0.88	0.026	0.0166	21.0	9.0
19	520	521	5.6	12.0	0.05	1.0	0.08	0.0001	16.8	165	501	0.044	0.51	0.034	0.0121	16.2	4.2	0.26	4.9	0.18	0.0006	26.0	181	0.055	0.63	0.019	0.0127	20.0	8.0
20	418	418	7.4	11.9	0.04	0.8	0.06	0.0001	16.7	153	484	0.035	0.42	0.027	0.0098	16.1	4.2	0.24	4.5	0.16	0.0005	25.6	169	0.045	0.51	0.015	0.0106	19.3	7.5
21	381	381	8.1	9.9	0.04	0.8	0.06	0.0001	16.6	148	477	0.032	0.38	0.024	0.0089	15.8	5.9	0.23	4.3	0.15	0.0005	25.4	164	0.040	0.46	0.013	0.0095	18.2	8.3
22	381	381	8.3	8.0	0.04	0.8	0.06	0.0001	16.6	146	477	0.030	0.39	0.023	0.0082	15.5	7.5	0.22	4.4	0.14	0.0005	25.2	163	0.038	0.46	0.013	0.0089	17.2	9.2
23	147	148	13.3	8.0	0.02	0.4	0.03	0.0000	16.3	113	421	0.011	0.16	0.010	0.0030	15.0	7.0	0.18	3.8	0.13	0.0004	24.1	128	0.018	0.23	0.007	0.0043	14.4	6.4

Table A.3. New M5 normal westbound 2021 traffic (summer). Stage 2 Westbound 2021 24hr Normal.xlsx

Hour	Stage 2 traffic		No. of jet fans running	Ambient	Peak in-tunnel levels (Stage 2)					M5 stack						
	M5 off (vph)	SPI on (vph)		(°C)	NO2 (ppm)	CO (ppm)	Non-exhaust PM (mg/m3)	Exhaust PM Vis. (m-1)	Temp (°C)	flow (m3/s)	NO2 (g/s)	CO (g/s)	Non-exhaust PM (g/s)	Exhaust PM (g/s)	T (°C)	Delta T Ambient (°C)
0	263	263	0	22.0	0.10	2.2	0.09	0.0002	31.5	342	0.056	0.70	0.025	0.014	29.1	7.1
1	64	64	0	21.0	0.06	1.0	0.06	0.0001	30.8	253	0.019	0.21	0.009	0.005	27.2	6.2
2	57	57	0	20.9	0.05	0.8	0.04	0.0001	30.8	263	0.015	0.15	0.006	0.004	27.1	6.2
3	82	82	0	19.0	0.06	1.1	0.05	0.0001	30.8	288	0.019	0.22	0.008	0.005	26.9	7.9
4	105	106	0	18.0	0.07	1.2	0.05	0.0002	30.8	296	0.029	0.29	0.011	0.007	26.9	8.9
5	259	259	0	18.0	0.10	2.2	0.09	0.0002	31.2	366	0.057	0.73	0.024	0.014	28.0	10.0
6	380	380	0	21.0	0.14	2.7	0.12	0.0003	31.5	414	0.086	1.02	0.036	0.021	29.1	8.1
7	768	769	0	24.0	0.18	4.1	0.18	0.0004	32.1	471	0.148	1.97	0.069	0.035	30.7	6.7
8	569	568	0	24.4	0.17	3.4	0.16	0.0004	31.9	455	0.119	1.45	0.053	0.029	30.4	6.0
9	829	830	0	29.2	0.23	4.1	0.20	0.0005	32.5	492	0.188	2.07	0.081	0.046	32.0	2.8
10	813	813	0	34.0	0.26	4.2	0.22	0.0006	34.5	505	0.204	2.02	0.084	0.051	32.9	-1.1
11	888	890	0	34.5	0.26	4.2	0.22	0.0006	34.7	497	0.238	2.25	0.095	0.060	33.3	-1.2
12	808	806	0	34.0	0.24	4.1	0.21	0.0006	34.3	492	0.197	2.04	0.082	0.049	33.0	-1.0
13	823	823	0	34.1	0.25	4.2	0.21	0.0006	34.5	496	0.216	2.07	0.087	0.054	33.2	-0.9
14	847	847	0	34.2	0.25	4.4	0.22	0.0006	34.6	502	0.210	2.13	0.087	0.052	33.2	-1.0
15	931	932	0	34.2	0.26	5.0	0.23	0.0006	34.8	535	0.209	2.36	0.090	0.051	33.3	-0.9
16	1175	1177	0	33.3	0.27	5.7	0.25	0.0006	34.6	572	0.255	3.06	0.111	0.062	33.6	0.3
17	1481	1483	0	32.4	0.26	6.0	0.25	0.0006	33.9	554	0.275	3.87	0.130	0.065	33.8	1.4
18	1014	1012	0	31.4	0.22	5.0	0.21	0.0005	33.2	513	0.193	2.65	0.090	0.046	33.0	1.6
19	772	772	0	30.5	0.19	4.2	0.18	0.0004	32.8	469	0.152	2.04	0.069	0.036	32.5	2.0
20	692	691	0	29.6	0.17	4.0	0.17	0.0004	32.6	451	0.131	1.84	0.061	0.031	32.2	2.6
21	633	632	0	25.8	0.16	3.7	0.16	0.0004	32.5	444	0.120	1.68	0.056	0.028	31.4	5.6
22	598	597	0	22.0	0.16	3.4	0.15	0.0004	32.4	427	0.116	1.58	0.054	0.028	30.6	8.6
23	439	437	0	22.5	0.15	2.9	0.13	0.0003	32.0	411	0.099	1.16	0.042	0.024	30.0	7.5

Table A.4. New M5 normal westbound 2021 traffic (winter). Stage 2 Westbound 2021 24hr Normal.xlsx

Hour	New M5 traffic		No. of jet fans running	Ambient	Peak in-tunnel levels (New M5)					M5 outlet						
	M5 off (vph)	SPI on (vph)		(°C)	NO2 (ppm)	CO (ppm)	Non-exhaust PM (mg/m3)	Exhaust PM Vis. (m-1)	Temp (°C)	flow (m3/s)	NO2 (g/s)	CO (g/s)	Non-exhaust PM (g/s)	Exhaust PM (g/s)	T (°C)	Delta T Ambient (°C)
0	263	263	0	10.5	0.10	2.1	0.09	0.0002	23.8	344	0.056	0.71	0.025	0.014	20.4	9.9
1	64	64	0	10.0	0.05	0.9	0.05	0.0001	23.2	265	0.019	0.21	0.009	0.005	18.5	8.5
2	57	57	0	9.1	0.04	0.8	0.04	0.0001	23.1	276	0.015	0.15	0.006	0.004	18.2	9.1
3	82	82	0	9.0	0.05	1.0	0.04	0.0001	23.2	296	0.019	0.22	0.008	0.005	18.5	9.5
4	105	106	0	8.0	0.08	1.4	0.06	0.0002	23.3	345	0.029	0.29	0.011	0.007	18.6	10.6
5	258	259	0	7.0	0.10	2.2	0.09	0.0002	23.6	390	0.058	0.73	0.024	0.014	19.5	12.5
6	379	380	0	6.0	0.13	2.6	0.12	0.0003	23.8	415	0.086	1.03	0.037	0.021	19.9	13.9
7	768	769	0	7.0	0.18	3.9	0.17	0.0004	24.4	486	0.149	1.98	0.070	0.035	21.3	14.3
8	569	568	0	8.6	0.16	3.3	0.15	0.0004	24.2	469	0.120	1.46	0.054	0.029	21.1	12.5
9	829	830	0	11.3	0.22	4.0	0.20	0.0005	24.7	508	0.189	2.08	0.082	0.046	22.4	11.1
10	813	813	0	14.0	0.25	4.1	0.21	0.0006	24.9	522	0.206	2.03	0.085	0.051	23.0	9.0
11	888	890	0	13.8	0.25	4.0	0.21	0.0006	25.0	515	0.239	2.26	0.095	0.060	23.4	9.6
12	808	806	0	14.0	0.24	4.0	0.20	0.0006	24.9	510	0.198	2.05	0.082	0.049	23.1	9.1
13	823	823	0	14.0	0.24	4.0	0.21	0.0006	25.0	514	0.217	2.08	0.087	0.055	23.3	9.3
14	847	847	0	14.0	0.24	4.2	0.21	0.0006	25.1	521	0.211	2.14	0.087	0.053	23.3	9.3
15	931	932	0	13.0	0.25	4.9	0.22	0.0006	25.3	554	0.210	2.37	0.091	0.051	23.2	10.2
16	1175	1177	0	13.0	0.26	5.6	0.24	0.0006	25.6	590	0.256	3.07	0.112	0.062	23.7	10.7
17	1481	1483	0	12.0	0.25	5.8	0.25	0.0006	25.6	572	0.276	3.89	0.131	0.065	24.0	12.0
18	1014	1012	0	12.0	0.21	4.7	0.20	0.0005	25.2	522	0.194	2.66	0.090	0.046	23.2	11.2
19	773	772	0	12.0	0.18	4.1	0.17	0.0004	24.9	487	0.152	2.05	0.070	0.037	22.7	10.7
20	692	691	0	11.7	0.16	3.8	0.16	0.0004	24.7	469	0.131	1.85	0.061	0.031	22.4	10.7
21	633	632	0	8.0	0.15	3.5	0.15	0.0003	24.6	462	0.120	1.69	0.056	0.029	21.5	13.5
22	598	597	0	8.0	0.15	3.3	0.14	0.0003	24.5	441	0.117	1.58	0.054	0.028	21.4	13.4
23	438	437	0	11.0	0.15	2.8	0.13	0.0003	24.3	421	0.099	1.16	0.042	0.024	21.4	10.4

APPENDIX B - NEW M5 ALONE 2031 SIMULATION RESULTS

Results from the simulation of New M5 alone for 2031 normal traffic.

Table B.1. New M5 alone normal eastbound 2031 traffic (summer). Stage 2 Eastbound with Kogarah 2031 24hr summary.xls

Hour	New M5 traffic		Number of Jet Fans Main tube	Ambient	Peak in-tunnel levels (before Kogorah outlet)					Kogorah outlet								Peak in-tunnel levels (before SPI outlet)					SPI outlet						
	M5 Flow (vph)	SPI off (vph)		(°C)	NO2 (ppm)	CO (ppm)	Non-exhaust PM (mg/m3)	Exhaust PM Vis. (m-1)	Temp (°C)	supply flow (m3/s)	exhaust flow (m3/s)	NO2 (g/s)	CO (g/s)	Non-exhaust PM (g/s)	Exhaust PM (g/s)	T (°C)	Delta T Ambient (°C)	NO2 (ppm)	CO (ppm)	Non-exhaust PM (mg/m3)	Exhaust PM Vis. (m-1)	Temp (°C)	flow (m3/s)	NO2 (g/s)	CO (g/s)	Non-exhaust PM (g/s)	Exhaust PM (g/s)	T (°C)	Delta T Ambient (°C)
0	69	69	12.9	22.3	0.01	0.2	0.02	0.0000	25.5	116	373	0.007	0.08	0.005	0.0019	24.9	2.7	0.11	2.0	0.08	0.0002	30.7	130	0.011	0.13	0.004	0.0027	25.6	3.4
1	45	45	13.4	21.5	0.01	0.1	0.01	0.0000	25.4	112	367	0.005	0.05	0.003	0.0013	24.7	3.2	0.08	1.3	0.05	0.0002	30.2	126	0.007	0.08	0.003	0.0017	24.9	3.4
2	41	41	13.6	21.0	0.01	0.1	0.01	0.0000	25.3	111	365	0.004	0.04	0.003	0.0012	24.6	3.6	0.06	0.9	0.04	0.0001	30.0	125	0.006	0.05	0.002	0.0014	24.4	3.5
3	41	41	13.6	20.0	0.01	0.1	0.01	0.0000	25.3	111	366	0.004	0.04	0.003	0.0012	24.4	4.4	0.06	0.8	0.03	0.0001	30.0	125	0.005	0.05	0.002	0.0012	23.9	3.9
4	69	69	12.9	18.5	0.01	0.2	0.01	0.0000	25.3	115	377	0.006	0.07	0.004	0.0017	24.2	5.7	0.06	1.0	0.04	0.0001	30.2	129	0.007	0.06	0.002	0.0016	23.4	4.9
5	163	163	11.1	18.0	0.02	0.4	0.03	0.0000	25.4	127	402	0.012	0.16	0.009	0.0031	24.3	6.3	0.09	1.8	0.05	0.0002	30.8	142	0.012	0.14	0.004	0.0026	24.0	6.0
6	642	641	1.8	19.5	0.05	1.2	0.08	0.0001	26.0	191	508	0.048	0.65	0.037	0.0130	25.2	5.7	0.18	4.2	0.11	0.0004	32.9	208	0.048	0.67	0.015	0.0109	28.1	8.6
7	1,290	1,289	0.0	22.5	0.08	2.1	0.14	0.0002	26.5	345	596	0.089	1.31	0.072	0.0231	26.2	3.7	0.18	4.5	0.13	0.0004	32.5	367	0.108	1.59	0.039	0.0245	30.6	8.1
8	1,672	1,671	0.0	24.2	0.11	2.4	0.18	0.0003	27.0	417	640	0.129	1.66	0.101	0.0351	26.8	2.6	0.21	4.4	0.14	0.0005	33.2	441	0.156	1.94	0.053	0.0362	31.8	7.6
9	1,440	1,441	0.0	26.8	0.10	2.2	0.16	0.0002	26.9	383	614	0.108	1.44	0.086	0.0290	27.0	0.2	0.20	4.3	0.13	0.0004	33.1	402	0.130	1.69	0.045	0.0299	31.9	5.1
10	1,296	1,296	0.0	31.6	0.09	2.0	0.15	0.0002	26.9	364	596	0.100	1.28	0.079	0.0272	27.4	-4.2	0.20	4.1	0.13	0.0004	33.3	379	0.121	1.50	0.041	0.0280	32.9	1.3
11	1,203	1,203	0.0	34.3	0.10	1.9	0.15	0.0003	27.0	357	587	0.100	1.19	0.076	0.0277	27.7	-6.5	0.21	3.9	0.13	0.0005	33.8	369	0.121	1.39	0.040	0.0284	33.6	-0.6
12	993	994	0.0	34.3	0.09	1.7	0.13	0.0002	26.9	316	562	0.087	0.99	0.065	0.0245	27.7	-6.6	0.21	3.8	0.13	0.0005	33.7	328	0.105	1.15	0.033	0.0250	33.7	-0.6
13	851	851	0.0	34.1	0.08	1.5	0.12	0.0002	26.9	282	544	0.080	0.84	0.058	0.0228	27.7	-6.4	0.22	3.7	0.13	0.0005	33.9	295	0.096	0.98	0.030	0.0231	33.8	-0.3
14	852	852	0.0	34.2	0.08	1.5	0.12	0.0002	26.9	280	542	0.078	0.84	0.057	0.0223	27.7	-6.4	0.22	3.8	0.14	0.0005	33.9	293	0.096	0.99	0.030	0.0230	33.8	-0.3
15	1,035	1,035	0.0	34.2	0.08	1.7	0.13	0.0002	27.1	312	559	0.083	1.01	0.065	0.0227	27.9	-6.3	0.20	3.9	0.13	0.0004	33.9	325	0.102	1.18	0.034	0.0238	33.9	-0.3
16	1,127	1,127	0.0	33.8	0.08	1.8	0.14	0.0002	27.2	325	566	0.085	1.10	0.068	0.0227	28.0	-5.8	0.19	4.0	0.13	0.0004	33.9	338	0.103	1.27	0.036	0.0235	33.8	0.1
17	1,065	1,065	0.0	32.9	0.08	1.7	0.13	0.0002	27.3	306	556	0.080	1.03	0.065	0.0213	27.9	-4.9	0.20	4.0	0.14	0.0004	34.1	319	0.096	1.18	0.034	0.0219	33.7	0.9
18	892	892	0.0	31.9	0.08	1.5	0.12	0.0002	27.2	260	533	0.070	0.85	0.056	0.0191	27.8	-4.1	0.21	4.0	0.14	0.0005	34.4	274	0.084	0.96	0.028	0.0192	33.6	1.7
19	627	628	0.0	31.0	0.06	1.2	0.10	0.0002	27.0	173	497	0.055	0.61	0.042	0.0155	27.5	-3.4	0.27	4.7	0.17	0.0006	35.7	187	0.059	0.62	0.018	0.0136	33.5	2.6
20	487	487	0.0	30.1	0.05	1.0	0.08	0.0001	26.9	91	474	0.044	0.48	0.033	0.0126	27.3	-2.7	0.44	7.7	0.25	0.0010	38.8	104	0.022	0.22	0.006	0.0051	31.9	1.8
21	456	456	4.2	27.7	0.05	0.9	0.07	0.0001	26.9	175	467	0.040	0.45	0.030	0.0113	27.1	-0.6	0.28	4.8	0.19	0.0006	34.3	189	0.064	0.66	0.022	0.0153	31.5	3.8
22	437	437	4.9	23.9	0.05	0.9	0.07	0.0001	26.8	170	463	0.036	0.44	0.027	0.0100	26.5	2.6	0.21	3.9	0.13	0.0005	34.0	186	0.046	0.52	0.015	0.0107	29.9	6.0
23	158	159	10.7	21.8	0.02	0.4	0.03	0.0001	26.5	130	394	0.014	0.18	0.011	0.0038	25.8	4.0	0.16	3.1	0.11	0.0004	32.5	145	0.022	0.25	0.008	0.0051	26.9	5.1

Table B.2. New M5 alone normal eastbound 2031 traffic (winter). Stage 2 Eastbound with Kogarah 2031 24hr summary.xls

Hour	New M5 traffic		Number of Jet Fans Main tube	Ambient	Peak in-tunnel levels (before Kogorah outlet)					Kogorah outlet								Peak in-tunnel levels (before SPI outlet)					SPI outlet						
	M5 Flow (vph)	SPI off (vph)		(°C)	NO2 (ppm)	CO (ppm)	Non-exhaust PM (mg/m3)	Exhaust PM Vis. (m-1)	Temp (°C)	supply flow (m3/s)	exhaust flow (m3/s)	NO2 (g/s)	CO (g/s)	Non-exhaust PM (g/s)	Exhaust PM (g/s)	T (°C)	Delta T Ambient (°C)	NO2 (ppm)	CO (ppm)	Non-exhaust PM (mg/m3)	Exhaust PM Vis. (m-1)	Temp (°C)	flow (m3/s)	NO2 (g/s)	CO (g/s)	Non-exhaust PM (g/s)	Exhaust PM (g/s)	T (°C)	Delta T Ambient (°C)
0	69	69	14.7	10.8	0.01	0.2	0.02	0.0000	15.7	103	400	0.006	0.07	0.005	0.0018	14.9	4.2	0.15	2.8	0.10	0.0003	24.2	117	0.012	0.13	0.004	0.0028	15.2	4.5
1	45	45	15.2	10.3	0.01	0.1	0.01	0.0000	15.6	100	394	0.004	0.05	0.003	0.0013	14.8	4.5	0.11	1.9	0.08	0.0002	23.7	114	0.008	0.08	0.003	0.0018	14.5	4.2
2	41	41	15.4	9.6	0.01	0.1	0.01	0.0000	15.6	99	393	0.004	0.04	0.003	0.0012	14.6	5.1	0.09	1.4	0.06	0.0002	23.5	113	0.006	0.06	0.002	0.0015	13.9	4.3
3	41	41	15.4	9.1	0.01	0.1	0.01	0.0000	15.6	99	393	0.004	0.04	0.003	0.0012	14.5	5.5	0.08	1.2	0.05	0.0002	23.5	113	0.005	0.05	0.002	0.0013	13.6	4.5
4	69	69	14.6	8.5	0.01	0.2	0.01	0.0000	15.6	103	403	0.006	0.07	0.004	0.0018	14.5	6.0	0.08	1.3	0.05	0.0002	23.7	118	0.007	0.06	0.002	0.0016	13.7	5.2
5	163	163	12.9	7.5	0.02	0.4	0.03	0.0000	15.6	115	426	0.012	0.16	0.009	0.0031	14.5	7.0	0.11	2.1	0.06	0.0002	24.3	130	0.012	0.14	0.003	0.0027	14.5	7.0
6	642	641	3.5	6.5	0.05	1.2	0.08	0.0001	16.2	178	527	0.048	0.66	0.037	0.0130	15.1	8.6	0.20	4.5	0.13	0.0004	26.2	198	0.049	0.67	0.016	0.0111	18.7	12.2
7	1,290	1,289	0.0	6.5	0.08	2.0	0.13	0.0002	16.7	311	613	0.089	1.31	0.073	0.0232	15.7	9.2	0.20	5.0	0.15	0.0004	25.7	339	0.110	1.62	0.040	0.0251	21.5	15.0
8	1,672	1,671	0.0	7.8	0.11	2.4	0.17	0.0003	17.1	387	657	0.129	1.67	0.101	0.0352	16.3	8.5	0.22	4.6	0.15	0.0005	26.0	420	0.157	1.96	0.053	0.0364	22.8	15.0
9	1,440	1,441	0.0	10.0	0.10	2.1	0.15	0.0002	17.0	350	632	0.108	1.44	0.086	0.0291	16.4	6.4	0.21	4.6	0.15	0.0005	25.9	377	0.130	1.69	0.045	0.0300	22.8	12.8
10	1,296	1,296	0.0	12.7	0.09	2.0	0.14	0.0002	17.0	326	614	0.101	1.29	0.079	0.0273	16.6	4.0	0.22	4.5	0.15	0.0005	26.0	350	0.122	1.51	0.041	0.0281	23.2	10.5
11	1,203	1,203	0.0	13.9	0.09	1.8	0.14	0.0002	17.0	316	607	0.100	1.19	0.076	0.0278	16.8	2.9	0.23	4.4	0.15	0.0005	26.2	338	0.122	1.40	0.040	0.0286	23.5	9.6
12	993	994	0.0	13.9	0.08	1.6	0.13	0.0002	16.9	270	583	0.087	0.99	0.065	0.0245	16.7	2.8	0.24	4.4	0.15	0.0005	26.4	291	0.105	1.16	0.033	0.0249	23.1	9.2
13	851	851	0.0	14.0	0.08	1.4	0.12	0.0002	16.9	232	565	0.080	0.84	0.058	0.0228	16.6	2.6	0.27	4.6	0.16	0.0006	26.9	251	0.096	0.98	0.029	0.0228	22.9	8.9
14	852	852	0.0	14.0	0.08	1.4	0.11	0.0002	16.9	230	564	0.078	0.84	0.057	0.0224	16.6	2.6	0.28	4.7	0.17	0.0006	27.0	249	0.097	1.00	0.030	0.0233	23.0	9.0
15	1,035	1,035	0.0	13.5	0.08	1.6	0.13	0.0002	17.0	265	581	0.083	1.01	0.065	0.0228	16.7	3.2	0.25	4.7	0.16	0.0005	26.5	286	0.105	1.20	0.035	0.0247	23.1	9.6
16	1,127	1,127	0.0	13.0	0.08	1.8	0.13	0.0002	17.1	280	588	0.085	1.10	0.068	0.0227	16.8	3.8	0.23	4.7	0.16	0.0005	26.4	301	0.104	1.29	0.036	0.0239	23.1	10.1
17	1,065	1,065	0.0	12.5	0.08	1.7	0.13	0.0002	17.1	258	578	0.080	1.03	0.065	0.0214	16.7	4.2	0.23	4.8	0.16	0.0005	26.6	279	0.096	1.18	0.034	0.0220	22.8	10.3
18	892	892	0.0	12.0	0.07	1.4	0.12	0.0002	17.0	206	556	0.070	0.85	0.056	0.0192	16.5	4.5	0.27	5.2	0.18	0.0006	27.4	225	0.082	0.95	0.027	0.0187	22.2	10.2
19	627	628	0.0	12.0	0.06	1.1	0.09	0.0002	16.9	101	522	0.055	0.61	0.042	0.0156	16.3	4.3	0.46	8.3	0.26	0.0010	32.3	116	0.036	0.39	0.011	0.0082	18.7	6.7
20	487	487	5.6	11.9	0.05	0.9	0.08	0.0001	16.7	165	500	0.044	0.48	0.033	0.0126	16.1	4.3	0.40	6.8	0.29	0.0009	27.2	182	0.086	0.87	0.031	0.0207	20.7	8.8
21	456	456	6.5	9.9	0.05	0.9	0.07	0.0001	16.7	159	493	0.040	0.45	0.030	0.0113	15.9	6.0	0.25	4.4	0.16	0.0006	26.6	176	0.051	0.54	0.016	0.0122	19.4	9.5
22	437	437	7.0	8.0	0.04	0.9	0.06	0.0001	16.6	155	490	0.036	0.44	0.027	0.0099	15.6	7.6	0.24	4.5	0.15	0.0005	26.3	172	0.046	0.53	0.015	0.0109	18.2	10.2
23	158	159	12.8	8.0	0.02	0.4	0.03	0.0000	16.3	116	425	0.013	0.17	0.011	0.0037	15.0	7.0	0.20	3.8	0.14	0.0004	25.1	131	0.021	0.25	0.007	0.0050	15.1	7.1

Table B.3. New M5 alone normal westbound 2031 traffic (summer). Stage 2 Westbound 2031 24hr summary.xlsx

Hour	New M5 traffic		No. of jet fans running	Ambient	Peak in-tunnel levels (New M5)					M5 outlet						
	M5 off (vph)	SPI on (vph)		(°C)	NO2 (ppm)	CO (ppm)	Non-exhaust PM (mg/m3)	Exhaust PM Vis. (m-1)	Temp (°C)	flow (m3/s)	NO2 (g/s)	CO (g/s)	Non-exhaust PM (g/s)	Exhaust PM (g/s)	T (°C)	Delta T Ambient (°C)
0	301	301	0	22.0	0.11	2.3	0.10	0.0003	33.2	360	0.067	0.80	0.029	0.016	30.5	8.5
1	75	75	0	21.0	0.06	1.0	0.06	0.0001	32.5	267	0.022	0.23	0.011	0.006	28.5	7.5
2	66	66	0	20.9	0.05	0.9	0.04	0.0001	32.4	276	0.019	0.17	0.007	0.005	28.4	7.5
3	94	94	0	19.0	0.06	1.1	0.05	0.0002	32.5	303	0.022	0.25	0.009	0.006	28.1	9.1
4	122	123	0	18.0	0.08	1.2	0.06	0.0002	32.5	312	0.036	0.33	0.013	0.009	28.3	10.3
5	285	285	0	18.0	0.11	2.2	0.10	0.0003	32.9	381	0.067	0.79	0.028	0.017	29.4	11.4
6	401	401	0	21.0	0.16	2.9	0.13	0.0004	33.3	454	0.102	1.08	0.041	0.026	30.6	9.6
7	892	893	0	24.0	0.21	4.3	0.20	0.0005	33.9	501	0.181	2.27	0.083	0.043	32.3	8.3
8	758	757	0	24.4	0.21	4.0	0.19	0.0005	33.9	501	0.165	1.92	0.073	0.040	32.2	7.8
9	967	968	0	29.2	0.26	4.4	0.23	0.0006	34.4	525	0.232	2.39	0.098	0.057	33.6	4.4
10	952	952	0	34.0	0.29	4.4	0.24	0.0007	34.9	534	0.254	2.34	0.102	0.064	34.5	0.5
11	1016	1017	0	34.5	0.28	4.4	0.23	0.0007	35.2	527	0.285	2.55	0.111	0.072	34.9	0.4
12	943	941	0	34.0	0.28	4.4	0.23	0.0007	34.9	526	0.245	2.36	0.099	0.061	34.6	0.6
13	963	964	0	34.1	0.29	4.4	0.24	0.0007	35.1	528	0.269	2.39	0.106	0.068	34.9	0.8
14	970	970	0	34.2	0.28	4.7	0.24	0.0007	35.2	535	0.258	2.42	0.103	0.065	34.9	0.7
15	1082	1083	0	34.2	0.30	5.4	0.26	0.0007	35.5	569	0.257	2.71	0.109	0.064	35.0	0.8
16	1365	1367	0	33.3	0.31	5.9	0.27	0.0007	35.4	604	0.313	3.52	0.133	0.077	35.3	2.0
17	1846	1847	0	32.4	0.32	6.9	0.31	0.0007	35.9	614	0.363	4.67	0.168	0.088	35.8	3.4
18	1169	1170	0	31.4	0.25	5.3	0.23	0.0006	35.1	543	0.235	3.03	0.107	0.056	34.7	3.3
19	893	893	0	30.5	0.22	4.5	0.20	0.0005	34.7	501	0.185	2.34	0.083	0.045	34.1	3.6
20	797	797	0	29.6	0.19	4.2	0.18	0.0004	34.5	476	0.158	2.10	0.072	0.038	33.8	4.2
21	716	715	0	25.8	0.18	3.9	0.17	0.0004	34.3	462	0.145	1.89	0.065	0.035	33.0	7.2
22	633	632	0	22.0	0.16	3.2	0.15	0.0004	34.1	429	0.133	1.66	0.059	0.032	32.1	10.1
23	452	451	0	22.5	0.15	2.9	0.13	0.0003	33.6	416	0.099	1.18	0.043	0.024	31.3	8.8

Table B.4. New M5 alone normal westbound 2031 traffic (winter). Stage 2 Westbound 2031 24hr summary.xlsx

Hour	New M5 traffic		No. of jet fans running	Ambient	Peak in-tunnel levels (New M5)					M5 outlet						
	M5 off (vph)	SPI on (vph)		(°C)	NO2 (ppm)	CO (ppm)	Non-exhaust PM (mg/m3)	Exhaust PM Vis. (m-1)	Temp (°C)	flow (m3/s)	NO2 (g/s)	CO (g/s)	Non-exhaust PM (g/s)	Exhaust PM (g/s)	T (°C)	Delta T Ambient (°C)
0	301	301	0	10.5	0.11	2.2	0.10	0.0003	25.2	361	0.067	0.80	0.029	0.016	21.6	11.1
1	75	75	0	10.0	0.06	1.0	0.05	0.0001	24.5	277	0.022	0.23	0.011	0.005	19.6	9.6
2	66	66	0	9.1	0.05	0.8	0.04	0.0001	24.4	287	0.019	0.17	0.008	0.005	19.2	10.1
3	94	94	0	9.0	0.06	1.1	0.05	0.0001	24.5	310	0.022	0.25	0.009	0.006	19.5	10.5
4	122	123	0	8.0	0.09	1.5	0.07	0.0002	24.7	359	0.037	0.34	0.013	0.009	19.7	11.7
5	284	285	0	7.0	0.12	2.3	0.10	0.0003	24.9	405	0.068	0.79	0.028	0.017	20.6	13.6
6	400	401	0	6.0	0.15	2.6	0.12	0.0004	25.1	430	0.103	1.09	0.041	0.026	21.1	15.1
7	892	893	0	7.0	0.20	4.3	0.19	0.0005	25.8	519	0.182	2.28	0.083	0.044	22.7	15.7
8	758	757	0	8.6	0.20	3.8	0.18	0.0005	25.7	502	0.165	1.92	0.073	0.040	22.7	14.1
9	967	968	0	11.3	0.25	4.3	0.22	0.0006	26.2	539	0.234	2.41	0.099	0.058	23.9	12.6
10	952	952	0	14.0	0.28	4.3	0.23	0.0007	26.5	550	0.255	2.35	0.103	0.064	24.5	10.5
11	1016	1017	0	13.8	0.29	4.3	0.24	0.0007	26.5	547	0.287	2.56	0.112	0.073	24.8	11.0
12	942	941	0	14.0	0.28	4.3	0.23	0.0007	26.5	543	0.245	2.37	0.099	0.062	24.5	10.5
13	963	964	0	14.0	0.28	4.3	0.23	0.0007	26.6	545	0.270	2.41	0.106	0.068	24.7	10.7
14	970	970	0	14.0	0.27	4.4	0.23	0.0007	26.6	551	0.260	2.44	0.104	0.065	24.7	10.7
15	1083	1084	0	13.0	0.28	5.0	0.24	0.0007	26.8	583	0.259	2.73	0.109	0.064	24.7	11.7
16	1365	1367	0	13.0	0.30	5.7	0.27	0.0007	27.2	622	0.314	3.53	0.134	0.077	25.3	12.3
17	1846	1847	0	12.0	0.31	6.7	0.30	0.0007	27.6	631	0.364	4.69	0.169	0.088	25.9	13.9
18	1169	1170	0	12.0	0.24	5.1	0.23	0.0005	26.8	559	0.236	3.05	0.107	0.057	24.7	12.7
19	894	893	0	12.0	0.21	4.4	0.19	0.0005	26.4	516	0.186	2.35	0.083	0.045	24.1	12.1
20	798	797	0	11.7	0.19	4.1	0.18	0.0004	26.2	496	0.159	2.11	0.073	0.038	23.7	12.0
21	716	715	0	8.0	0.17	3.7	0.16	0.0004	26.1	481	0.145	1.90	0.066	0.035	22.9	14.9
22	633	632	0	8.0	0.16	3.2	0.15	0.0004	25.8	446	0.133	1.66	0.059	0.032	22.6	14.6
23	452	450	0	11.0	0.14	2.8	0.13	0.0003	25.6	424	0.099	1.18	0.043	0.024	22.5	11.5

APPENDIX C - NEW M5 WITH M4-M5 LINK 2031 SIMULATION RESULTS

Results from the simulation of New M5 and M4-M5 Link for 2031 normal traffic.

Table C.1. New M5 with M4-M5 Link normal eastbound 2031 traffic (summer). Stage 2 and 3 normal EB 2031.xlsx

Hour	New M5 traffic			No. of jet fans running		Ambient	Peak in-tunnel levels (before Kogarah outlet)					Kogarah outlet								Peak in-tunnel levels (before SPI outlet)					SPI outlet						
	M5 on (vph)	SC on (vph)	SPI off (vph)	SC	Main tube	(°C)	NO2 (ppm)	CO (ppm)	Non-exhaust PM (mg/m3)	Exhaust PM Vis. (m-1)	Temp (°C)	supply flow (m3/s)	exhaust flow (m3/s)	NO2 (g/s)	CO (g/s)	Non-exhaust PM (g/s)	Exhaust PM (g/s)	T (°C)	Delta T Ambient (°C)	NO2 (ppm)	CO (ppm)	Non-exhaust PM (mg/m3)	Exhaust PM Vis. (m-1)	Temp (°C)	flow (m3/s)	NO2 (g/s)	CO (g/s)	Non-exhaust PM (g/s)	Exhaust PM (g/s)	T (°C)	Delta T Ambient (°C)
0	53	154	140	0.0	19.1	22.3	0.01	0.3	0.02	0.0000	25.2	345	674	0.012	0.18	0.010	0.0032	24.3	2.0	0.03	0.8	0.02	0.0001	28.7	256	0.011	0.18	0.004	0.0023	26.7	4.5
1	32	89	69	0.0	20.2	21.5	0.01	0.2	0.01	0.0000	25.1	337	653	0.007	0.10	0.006	0.0020	24.1	2.6	0.02	0.5	0.01	0.0000	28.3	248	0.006	0.10	0.002	0.0014	26.2	4.7
2	27	49	58	0.0	21.0	21.0	0.00	0.1	0.01	0.0000	25.0	332	641	0.005	0.06	0.004	0.0014	24.0	3.0	0.01	0.3	0.01	0.0000	28.1	260	0.005	0.07	0.002	0.0011	26.0	5.0
3	27	49	61	0.0	21.1	20.0	0.00	0.1	0.01	0.0000	24.9	332	642	0.005	0.06	0.004	0.0014	23.8	3.9	0.01	0.3	0.01	0.0000	28.0	264	0.005	0.07	0.002	0.0013	25.7	5.7
4	45	126	127	0.0	19.9	18.5	0.01	0.3	0.02	0.0000	24.9	339	666	0.008	0.13	0.007	0.0022	23.7	5.2	0.02	0.6	0.02	0.0000	28.1	267	0.008	0.14	0.003	0.0018	25.4	6.9
5	108	251	252	0.0	17.7	18.0	0.01	0.5	0.03	0.0000	25.0	354	710	0.017	0.29	0.015	0.0042	23.8	5.8	0.04	1.2	0.03	0.0001	28.3	267	0.015	0.28	0.006	0.0032	25.4	7.4
6	427	1,041	966	0.0	5.0	19.5	0.04	1.5	0.09	0.0001	25.6	440	907	0.067	1.21	0.061	0.0166	24.5	5.0	0.12	4.2	0.10	0.0002	30.5	279	0.050	1.03	0.021	0.0104	27.6	8.1
7	860	2,025	2,356	0.0	0.0	22.5	0.07	2.4	0.14	0.0001	26.2	580	1,063	0.127	2.36	0.120	0.0311	25.3	2.8	0.17	5.7	0.15	0.0003	31.9	453	0.132	2.63	0.056	0.0282	30.5	8.0
8	963	2,569	2,620	0.0	0.0	24.2	0.09	2.9	0.18	0.0002	26.7	654	1,117	0.168	2.83	0.154	0.0433	25.8	1.6	0.20	6.0	0.16	0.0004	32.8	458	0.159	2.80	0.064	0.0350	31.5	7.3
9	957	2,111	2,373	0.0	0.0	26.8	0.08	2.5	0.16	0.0002	26.6	617	1,085	0.151	2.49	0.137	0.0387	25.8	-1.0	0.19	5.7	0.15	0.0004	32.7	451	0.148	2.60	0.059	0.0324	31.8	5.0
10	860	1,835	2,037	0.0	0.0	31.6	0.07	2.3	0.14	0.0002	26.6	592	1,048	0.135	2.19	0.121	0.0349	26.1	-5.5	0.19	5.4	0.15	0.0004	32.8	420	0.130	2.24	0.051	0.0286	32.6	1.0
11	771	1,605	1,835	0.0	0.0	34.3	0.07	2.1	0.13	0.0002	26.6	566	1,018	0.124	1.95	0.109	0.0324	26.2	-8.0	0.18	5.2	0.14	0.0004	34.4	399	0.119	2.02	0.046	0.0263	33.2	-1.0
12	655	1,491	1,731	0.0	0.0	34.3	0.06	2.0	0.12	0.0002	26.6	538	991	0.115	1.75	0.099	0.0303	26.2	-8.0	0.18	5.0	0.13	0.0004	34.4	389	0.113	1.89	0.043	0.0250	33.3	-0.9
13	561	1,448	1,497	0.0	0.0	34.1	0.06	1.9	0.12	0.0002	26.7	521	970	0.107	1.62	0.092	0.0284	26.3	-7.8	0.18	4.9	0.13	0.0004	34.2	362	0.102	1.68	0.038	0.0226	33.3	-0.7
14	567	1,400	1,493	0.0	0.0	34.2	0.06	1.9	0.12	0.0002	26.8	513	963	0.104	1.59	0.090	0.0274	26.3	-7.8	0.17	4.8	0.13	0.0004	34.3	362	0.100	1.67	0.038	0.0222	33.4	-0.7
15	687	1,324	1,574	0.0	0.0	34.2	0.06	1.8	0.11	0.0002	26.8	512	967	0.104	1.64	0.092	0.0269	26.4	-7.8	0.17	4.9	0.13	0.0004	34.4	371	0.102	1.74	0.039	0.0223	33.6	-0.6
16	750	1,229	1,559	0.0	0.0	33.8	0.06	1.7	0.11	0.0001	26.9	504	963	0.102	1.62	0.092	0.0263	26.4	-7.3	0.17	4.9	0.13	0.0003	34.1	365	0.099	1.70	0.039	0.0215	33.7	-0.1
17	830	1,145	1,470	0.0	0.0	32.9	0.06	1.6	0.10	0.0001	26.9	502	964	0.102	1.64	0.092	0.0262	26.4	-6.4	0.17	4.8	0.13	0.0003	33.8	346	0.093	1.59	0.036	0.0201	33.6	0.7
18	595	987	1,275	0.0	0.0	31.9	0.05	1.5	0.09	0.0001	26.9	435	908	0.082	1.30	0.073	0.0210	26.3	-5.6	0.16	4.6	0.12	0.0003	33.7	323	0.080	1.39	0.031	0.0173	33.2	1.3
19	417	954	1,111	0.0	0.0	31.0	0.04	1.4	0.08	0.0001	26.9	396	875	0.070	1.12	0.062	0.0181	26.3	-4.7	0.16	4.6	0.12	0.0003	33.7	297	0.069	1.23	0.027	0.0150	32.9	2.0
20	333	947	1,037	0.0	5.6	30.1	0.04	1.4	0.08	0.0001	27.0	437	857	0.062	1.04	0.056	0.0157	26.2	-3.8	0.12	3.8	0.10	0.0003	33.0	333	0.065	1.18	0.025	0.0140	32.3	2.3
21	305	942	1,011	0.0	6.2	27.7	0.04	1.4	0.08	0.0001	27.0	433	851	0.059	1.00	0.053	0.0149	26.1	-1.6	0.12	3.7	0.09	0.0002	32.9	331	0.062	1.15	0.024	0.0132	31.7	4.0
22	300	944	1,016	0.0	6.7	23.9	0.04	1.4	0.08	0.0001	27.1	429	852	0.058	1.00	0.053	0.0146	25.8	1.9	0.11	3.7	0.09	0.0002	32.7	337	0.061	1.17	0.024	0.0130	30.9	7.0
23	109	376	411	0.0	15.3	21.8	0.02	0.7	0.04	0.0000	26.7	370	721	0.023	0.42	0.022	0.0059	25.2	3.5	0.06	1.9	0.04	0.0001	31.2	303	0.026	0.52	0.010	0.0057	28.8	7.1

Hour	M4 - M5 Link traffic					No. of jet fans running		Ambient	Peak in-tunnel levels (M4 - M5 Link)					WHT-Rozelle outlets combined						
	M4-M5 Link on (vph)	SPI on (vph)	CWL off	WHT off	Rozelle off	St Peters On	CWL	T (°C)	NO2 (ppm)	CO (ppm)	Non-exhaust PM (mg/m3)	Exhaust PM Vis. (m-1)	Temp (°C)	flow (m3/s)	NO2 (g/s)	CO (g/s)	Non-exhaust PM (g/s)	Exhaust PM (g/s)	T (°C)	Delta T Ambient (°C)
1	68	236	76	76	152	0	0	22.3	0.10	1.9	0.09	0.0002	37.6	509	0.060	0.64	0.027	0.0145	31.3	9.0
2	52	152	51	51	102	0	0	21.5	0.10	1.2	0.07	0.0002	37.2	483	0.050	0.38	0.019	0.0127	30.4	8.9
3	18	152	43	43	85	0	0	21.0	0.09	1.0	0.07	0.0002	36.8	466	0.044	0.28	0.016	0.0113	29.7	8.8
4	15	152	42	42	84	0	0	20.0	0.09	0.8	0.06	0.0002	36.5	465	0.041	0.24	0.015	0.0107	29.1	9.2
5	43	317	90	90	180	0	1	18.5	0.09	1.4	0.08	0.0002	36.4	516	0.053	0.47	0.022	0.0130	29.2	10.7
6	107	562	167	167	334	0	1	18.0	0.10	2.3	0.10	0.0002	36.3	579	0.072	0.97	0.036	0.0163	29.7	11.7
7	501	1,552	513	513	1,025	0	2	19.5	0.23	4.6	0.21	0.0005	37.5	792	0.270	3.22	0.122	0.0647	32.6	13.1
8	526	2,401	732	732	1,463	0	0	22.5	0.29	6.0	0.28	0.0006	38.3	840	0.368	4.52	0.179	0.0869	34.1	11.6
9	910	2,708	904	904	1,808	0	3	24.2	0.37	7.1	0.35	0.0008	39.3	897	0.514	5.92	0.239	0.1245	35.4	11.2
10	696	2,752	862	862	1,724	0	0	26.8	0.37	6.8	0.35	0.0009	39.7	884	0.505	5.50	0.233	0.1227	36.2	9.4
11	659	2,796	864	864	1,728	0	2	31.6	0.37	6.7	0.35	0.0009	40.3	878	0.500	5.40	0.230	0.1214	37.6	6.0
12	542	2,858	850	850	1,700	0	0	34.3	0.38	6.6	0.34	0.0009	40.8	879	0.507	5.30	0.229	0.1241	38.6	4.4
13	416	2,775	798	798	1,596	0	0	34.3	0.36	6.2	0.33	0.0008	41.1	872	0.482	4.96	0.215	0.1183	38.8	4.6
14	512	2,717	807	807	1,615	0	3	34.1	0.36	6.3	0.33	0.0008	41.4	865	0.467	4.94	0.211	0.1140	39.0	4.9
15	474	2,631	776	776	1,553	0	0	34.2	0.35	6.1	0.32	0.0008	41.7	863	0.455	4.81	0.206	0.1110	39.2	5.0
16	437	2,684	780	780	1,561	0	3	34.2	0.35	6.1	0.32	0.0008	42.0	849	0.445	4.66	0.203	0.1081	39.4	5.2
17	420	2,766	796	796	1,593	0	0	33.8	0.35	6.1	0.32	0.0008	42.3	857	0.456	4.78	0.209	0.1108	39.6	5.8
18	505	2,834	835	835	1,669	0	0	32.9	0.36	6.3	0.33	0.0008	42.6	871	0.480	5.05	0.220	0.1168	39.6	6.8
19	308	2,172	620	620	1,240	0	0	31.9	0.31	5.3	0.28	0.0007	42.2	817	0.381	3.86	0.169	0.0928	39.0	7.1
20	260	2,041	575	575	1,151	0	2	31.0	0.29	5.0	0.26	0.0007	42.1	790	0.340	3.51	0.152	0.0824	38.6	7.7
21	243	1,752	499	499	998	0	0	30.1	0.25	4.7	0.23	0.0006	41.7	775	0.287	3.20	0.131	0.0686	38.1	8.0
22	236	1,705	485	485	971	0	2	27.7	0.24	4.6	0.22	0.0005	41.5	759	0.265	3.01	0.123	0.0631	37.3	9.6
23	228	1,656	471	471	942	0	1	23.9	0.23	4.5	0.22	0.0005	41.2	756	0.258	2.94	0.120	0.0611	36.1	12.2
24	74	796	218	218	436	0	0	21.8	0.12	3.2	0.14	0.0003	39.8	614	0.099	1.53	0.054	0.0221	33.5	11.7

Table C.2. New M5 with M4-M5 Link normal eastbound 2031 traffic (winter). Stage 2 and 3 normal EB 2031.xlsx

Hour	New M5 traffic			No. of jet fans running		Ambient	Peak in-tunnel levels (before Kogarah outlet)					Kogarah outlet								Peak in-tunnel levels (before SPI outlet)					SPI outlet						
	M5 Flow (vph)	SC Flow (vph)	SPI off (vph)	SC	Main tube	(°C)	NO2 (ppm)	CO (ppm)	Non-exhaust PM (mg/m3)	Exhaust PM Vis. (m-1)	Temp (°C)	supply flow (m3/s)	exhaust flow (m3/s)	NO2 (g/s)	CO (g/s)	Non-exhaust PM (g/s)	Exhaust PM (g/s)	T (°C)	Delta T Ambient (°C)	NO2 (ppm)	CO (ppm)	Non-exhaust PM (mg/m3)	Exhaust PM Vis. (m-1)	Temp (°C)	flow (m3/s)	NO2 (g/s)	CO (g/s)	Non-exhaust PM (g/s)	Exhaust PM (g/s)	T (°C)	Delta T Ambient (°C)
0	53	154	140	0.0	21.2	7.5	0.01	0.3	0.02	0.0000	17.7	330	721	0.012	0.17	0.010	0.0032	16.6	9.1	0.03	0.8	0.02	0.0001	20.8	261	0.011	0.19	0.004	0.0025	17.0	9.5
1	32	89	69	0.0	22.3	7.0	0.01	0.2	0.01	0.0000	17.5	322	701	0.007	0.10	0.006	0.0019	16.4	9.4	0.02	0.5	0.01	0.0000	20.4	254	0.006	0.10	0.002	0.0014	16.4	9.4
2	27	49	58	0.0	23.1	7.1	0.00	0.1	0.01	0.0000	17.3	317	690	0.005	0.06	0.004	0.0014	16.2	9.2	0.01	0.3	0.01	0.0000	20.1	265	0.005	0.07	0.002	0.0012	16.4	9.4
3	27	49	61	0.0	23.1	7.1	0.00	0.1	0.01	0.0000	17.2	317	691	0.005	0.06	0.004	0.0014	16.2	9.1	0.01	0.3	0.01	0.0000	20.0	268	0.006	0.07	0.002	0.0013	16.4	9.3
4	45	126	127	0.0	21.9	7.0	0.01	0.2	0.01	0.0000	17.2	325	713	0.009	0.14	0.007	0.0022	16.2	9.2	0.02	0.6	0.02	0.0000	20.0	268	0.009	0.15	0.003	0.0019	16.4	9.4
5	108	251	252	0.0	19.5	7.3	0.01	0.5	0.03	0.0000	17.2	341	754	0.017	0.29	0.015	0.0042	16.2	8.9	0.04	1.2	0.03	0.0001	20.3	266	0.015	0.29	0.006	0.0033	16.7	9.4
6	427	1,041	966	0.0	6.9	7.8	0.04	1.5	0.08	0.0001	17.7	427	943	0.067	1.21	0.061	0.0166	16.9	9.1	0.12	4.2	0.10	0.0002	22.3	279	0.051	1.04	0.022	0.0105	18.5	10.7
7	860	2,025	2,356	0.0	0.0	8.0	0.07	2.4	0.14	0.0001	18.2	547	1,098	0.127	2.36	0.120	0.0311	17.5	9.5	0.18	5.9	0.15	0.0004	23.6	446	0.134	2.67	0.057	0.0287	21.2	13.2
8	963	2,569	2,620	0.0	0.0	8.4	0.09	2.8	0.18	0.0002	18.5	621	1,152	0.169	2.83	0.154	0.0433	17.7	9.3	0.21	6.2	0.17	0.0004	24.3	452	0.161	2.83	0.065	0.0355	21.9	13.5
9	957	2,111	2,373	0.0	0.0	9.9	0.08	2.4	0.15	0.0002	18.3	580	1,122	0.151	2.49	0.137	0.0387	17.7	7.8	0.20	5.9	0.16	0.0004	24.1	444	0.150	2.64	0.060	0.0330	21.9	12.0
10	860	1,835	2,037	0.0	0.0	12.0	0.07	2.2	0.14	0.0002	18.2	549	1,088	0.135	2.19	0.121	0.0349	17.7	5.7	0.19	5.6	0.15	0.0004	24.0	412	0.133	2.28	0.052	0.0292	22.0	10.0
11	771	1,605	1,835	0.0	0.0	13.9	0.06	2.0	0.12	0.0002	18.1	520	1,060	0.124	1.95	0.109	0.0325	17.7	3.8	0.19	5.4	0.15	0.0004	24.1	390	0.122	2.06	0.047	0.0269	22.2	8.3
12	655	1,491	1,731	0.0	0.0	14.9	0.06	1.9	0.12	0.0002	18.0	493	1,033	0.115	1.75	0.099	0.0304	17.7	2.8	0.19	5.2	0.14	0.0004	24.1	378	0.116	1.93	0.044	0.0256	22.4	7.5
13	561	1,448	1,497	0.0	0.0	14.5	0.06	1.8	0.11	0.0001	18.0	474	1,014	0.107	1.62	0.092	0.0285	17.6	3.1	0.19	5.1	0.14	0.0004	24.1	349	0.104	1.71	0.039	0.0232	22.1	7.6
14	567	1,400	1,493	0.0	0.0	14.4	0.06	1.8	0.11	0.0001	18.0	465	1,008	0.104	1.59	0.090	0.0275	17.5	3.1	0.19	5.1	0.14	0.0004	24.1	349	0.103	1.71	0.039	0.0227	22.1	7.7
15	687	1,324	1,574	0.0	0.0	14.4	0.06	1.7	0.11	0.0001	17.9	464	1,012	0.104	1.64	0.092	0.0270	17.6	3.2	0.18	5.2	0.14	0.0004	24.2	358	0.105	1.78	0.040	0.0229	22.2	7.8
16	750	1,229	1,559	0.0	0.0	14.0	0.06	1.6	0.10	0.0001	17.8	455	1,008	0.102	1.62	0.092	0.0264	17.5	3.5	0.18	5.2	0.14	0.0004	24.2	351	0.102	1.74	0.040	0.0221	22.1	8.1
17	830	1,145	1,470	0.0	0.0	13.5	0.06	1.5	0.10	0.0001	17.8	453	1,010	0.103	1.64	0.092	0.0263	17.5	4.0	0.18	5.2	0.14	0.0004	24.3	332	0.095	1.62	0.037	0.0205	21.9	8.4
18	595	987	1,275	0.0	0.0	13.0	0.05	1.4	0.08	0.0001	17.7	382	955	0.082	1.30	0.073	0.0210	17.3	4.3	0.18	5.1	0.14	0.0004	24.2	304	0.082	1.42	0.032	0.0177	21.5	8.5
19	417	954	1,111	0.0	7.2	12.0	0.04	1.4	0.08	0.0001	17.6	425	924	0.070	1.12	0.062	0.0181	17.1	5.1	0.14	4.0	0.11	0.0003	23.2	335	0.072	1.27	0.028	0.0155	20.8	8.8
20	333	947	1,037	0.0	8.5	10.6	0.04	1.4	0.08	0.0001	17.6	417	907	0.062	1.03	0.055	0.0157	16.9	6.3	0.13	3.8	0.10	0.0003	22.9	338	0.067	1.21	0.026	0.0144	20.3	9.7
21	305	942	1,011	0.0	9.0	9.6	0.04	1.4	0.08	0.0001	17.5	413	901	0.059	1.00	0.053	0.0149	16.8	7.2	0.12	3.7	0.09	0.0002	22.8	335	0.063	1.18	0.025	0.0136	19.9	10.3
22	300	944	1,016	0.0	9.2	8.5	0.04	1.4	0.08	0.0001	17.5	411	901	0.058	1.00	0.053	0.0146	16.6	8.1	0.12	3.7	0.09	0.0002	22.6	339	0.062	1.19	0.025	0.0133	19.6	11.1
23	109	376	411	0.0	17.8	8.0	0.02	0.7	0.04	0.0000	18.0	353	777	0.023	0.41	0.021	0.0058	16.9	8.9	0.06	1.9	0.05	0.0001	21.7	306	0.027	0.54	0.011	0.0059	18.3	10.3

Hour	M4 - M5 Link traffic					No. of jet fans running		Ambient	Peak in-tunnel levels (M4 - M5 Link)					WHT-Rozelle outlets combined						
	M4-M5 Link on	SPI on (vph)	CWL off	WHT off	Rozelle off	St Peters On	CWL	T (°C)	NO2 (ppm)	CO (ppm)	Non-exhaust PM (mg/m3)	Exhaust PM Vis. (m-1)	Temp (°C)	flow (m3/s)	NO2 (g/s)	CO (g/s)	Non-exhaust PM (g/s)	Exhaust PM (g/s)	T (°C)	Delta T Ambient (°C)
1	68	236	76	76	152	0	0	7.5	0.10	1.9	0.09	0.0002	29.8	514	0.061	0.66	0.027	0.0148	20.8	13.3
2	52	152	51	51	102	0	0	7.0	0.09	1.2	0.07	0.0002	29.4	489	0.050	0.39	0.019	0.0128	19.9	12.9
3	18	152	43	43	85	0	0	7.1	0.09	0.9	0.06	0.0002	29.0	474	0.045	0.28	0.016	0.0115	19.5	12.4
4	15	152	42	42	84	0	0	7.1	0.08	0.8	0.06	0.0002	28.7	471	0.042	0.24	0.015	0.0108	19.2	12.2
5	43	317	90	90	180	0	0	7.0	0.09	1.3	0.08	0.0002	28.6	520	0.053	0.48	0.022	0.0131	20.0	13.0
6	107	562	167	167	334	0	0	7.3	0.10	2.2	0.10	0.0002	28.6	587	0.073	0.98	0.037	0.0165	21.0	13.7
7	501	1,552	513	513	1,025	0	0	7.8	0.23	4.6	0.21	0.0005	29.7	803	0.275	3.27	0.124	0.0658	23.8	16.0
8	526	2,401	732	732	1,463	0	1	8.0	0.29	5.9	0.28	0.0006	30.4	839	0.365	4.48	0.177	0.0862	24.5	16.5
9	910	2,708	904	904	1,808	0	2	8.4	0.37	7.1	0.35	0.0008	31.2	900	0.516	5.95	0.240	0.1251	25.6	17.2
10	696	2,752	862	862	1,724	0	2	9.9	0.37	6.7	0.34	0.0008	31.5	886	0.506	5.52	0.234	0.1230	26.0	16.2
11	659	2,796	864	864	1,728	0	1	12.0	0.37	6.7	0.34	0.0008	31.9	883	0.505	5.45	0.232	0.1227	26.8	14.8
12	542	2,858	850	850	1,700	0	2	13.9	0.37	6.5	0.34	0.0009	32.3	879	0.506	5.28	0.229	0.1238	27.5	13.6
13	416	2,775	798	798	1,596	0	3	14.9	0.36	6.2	0.32	0.0008	32.5	863	0.475	4.89	0.212	0.1168	27.8	12.9
14	512	2,717	807	807	1,615	0	0	14.5	0.35	6.3	0.32	0.0008	32.7	874	0.475	5.02	0.215	0.1162	27.9	13.4
15	474	2,631	776	776	1,553	0	3	14.4	0.35	6.1	0.32	0.0008	32.8	858	0.450	4.75	0.204	0.1097	27.8	13.4
16	437	2,684	780	780	1,561	0	1	14.4	0.34	6.0	0.32	0.0008	33.0	853	0.449	4.70	0.205	0.1093	28.0	13.6
17	420	2,766	796	796	1,593	0	2	14.0	0.35	6.1	0.32	0.0008	33.2	855	0.453	4.74	0.207	0.1100	28.0	14.0
18	505	2,834	835	835	1,669	0	1	13.5	0.36	6.3	0.33	0.0008	33.5	874	0.482	5.07	0.220	0.1173	28.2	14.7
19	308	2,172	620	620	1,240	0	0	13.0	0.31	5.2	0.28	0.0007	33.0	817	0.381	3.85	0.169	0.0927	27.5	14.5
20	260	2,041	575	575	1,151	0	0	12.0	0.29	5.0	0.26	0.0007	32.8	807	0.348	3.58	0.155	0.0842	27.0	15.0
21	243	1,752	499	499	998	0	0	10.6	0.25	4.6	0.23	0.0006	32.3	780	0.284	3.15	0.130	0.0678	26.1	15.5
22	236	1,705	485	485	971	0	0	9.6	0.24	4.5	0.22	0.0005	32.0	771	0.269	3.05	0.124	0.0640	25.6	16.0
23	228	1,656	471	471	942	0	0	8.5	0.23	4.4	0.22	0.0005	31.8	765	0.259	2.96	0.120	0.0615	25.1	16.6
24	74	796	218	218	436	0	1	8.0	0.12	3.1	0.13	0.0003	30.6	605	0.096	1.48	0.053	0.0214	22.7	14.7

Table C.3. New M5 with M4-M5 Link normal westbound 2031 traffic (summer). Stage 2 and 3 normal WB 2031.xlsx

Hour	New M5 traffic				No. of jet fans running SC	Ambient	Peak in-tunnel levels (New M5)					M5 outlet							Southern Connector outlet						
	M5 off (vph)	SC off (vph)	SPI on (vph)	M5 on (vph)		(°C)	NO2 (ppm)	CO (ppm)	Non-exhaust PM (mg/m3)	Exhaust PM Vis. (m-1)	Temp (°C)	flow (m3/s)	NO2 (g/s)	CO (g/s)	Non-exhaust PM (g/s)	Exhaust PM (g/s)	T (°C)	Delta T Ambient (°C)	flow (m3/s)	NO2 (g/s)	CO (g/s)	Non-exhaust PM (g/s)	Exhaust PM (g/s)	T (°C)	Delta T Ambient (°C)
0	333	142	167	283	7	22.3	0.18	3.9	0.18	0.0004	37.8	337	0.093	1.18	0.044	0.022	33.3	11.0	305	0.04	0.65	0.03	0.010	33.6	11.4
1	71	72	79	54	2	21.5	0.13	2.6	0.13	0.0003	37.6	238	0.039	0.46	0.019	0.010	30.6	9.1	229	0.02	0.35	0.01	0.006	31.9	10.4
2	43	68	75	33	1	21.0	0.08	1.3	0.08	0.0002	37.5	229	0.024	0.23	0.011	0.006	29.9	9.0	221	0.01	0.21	0.01	0.003	31.4	10.5
3	40	66	75	31	2	20.0	0.07	1.0	0.06	0.0002	37.4	231	0.019	0.15	0.008	0.005	29.6	9.6	223	0.01	0.18	0.01	0.003	31.0	11.1
4	81	126	122	94	2	18.5	0.07	1.3	0.07	0.0002	37.4	264	0.023	0.23	0.009	0.006	30.0	11.5	258	0.02	0.27	0.01	0.004	31.4	12.9
5	280	202	216	268	6	18.0	0.12	2.5	0.10	0.0003	37.4	345	0.057	0.72	0.023	0.014	31.9	13.9	320	0.03	0.57	0.02	0.007	32.5	14.5
6	421	271	381	337	9	19.5	0.19	3.7	0.16	0.0004	37.4	384	0.105	1.27	0.044	0.026	33.0	13.5	349	0.05	0.87	0.03	0.013	33.2	13.7
7	905	382	708	608	15	22.5	0.25	5.4	0.23	0.0006	38.1	466	0.189	2.44	0.085	0.045	35.2	12.7	399	0.08	1.31	0.05	0.020	34.4	11.9
8	1282	708	1161	834	17	24.2	0.32	7.4	0.33	0.0007	38.7	523	0.281	3.87	0.137	0.066	36.4	12.2	449	0.14	2.38	0.09	0.034	35.3	11.1
9	1016	834	1249	591	13	26.8	0.36	7.3	0.36	0.0008	38.6	490	0.290	3.60	0.144	0.070	36.5	9.7	448	0.17	2.86	0.11	0.042	35.9	9.1
10	982	1206	1393	808	10	31.6	0.39	7.6	0.37	0.0009	38.7	491	0.311	3.40	0.145	0.077	37.4	5.8	476	0.22	3.60	0.13	0.054	37.3	5.7
11	960	1626	1822	795	7	34.3	0.41	8.8	0.39	0.0010	39.1	496	0.335	3.53	0.155	0.084	38.1	3.8	505	0.27	4.47	0.15	0.066	38.3	4.0
12	944	1744	2025	661	5	34.3	0.38	8.8	0.38	0.0009	39.3	485	0.309	3.43	0.148	0.077	37.9	3.7	505	0.26	4.51	0.15	0.063	38.5	4.2
13	961	1828	2157	649	6	34.1	0.39	9.0	0.38	0.0009	39.5	493	0.320	3.43	0.150	0.079	38.1	4.0	512	0.27	4.64	0.16	0.066	38.6	4.6
14	989	1977	2292	704	5	34.2	0.39	9.4	0.38	0.0009	39.9	496	0.323	3.51	0.152	0.080	38.2	4.0	522	0.29	4.98	0.17	0.070	39.0	4.8
15	1061	2259	2558	827	4	34.2	0.39	10.3	0.41	0.0009	40.3	505	0.328	3.84	0.160	0.080	38.2	4.0	538	0.32	5.63	0.19	0.077	39.4	5.2
16	1340	2758	2992	1213	6	33.8	0.42	11.7	0.47	0.0010	40.9	544	0.386	4.88	0.193	0.094	38.7	4.9	565	0.37	6.74	0.22	0.090	40.0	6.2
17	1620	3326	3471	1639	13	32.9	0.45	13.0	0.55	0.0010	41.9	581	0.451	6.00	0.235	0.109	39.1	6.2	556	0.40	7.31	0.26	0.096	40.6	7.8
18	1227	2631	2554	1321	4	31.9	0.39	11.5	0.45	0.0009	41.3	517	0.337	4.94	0.189	0.081	38.1	6.2	551	0.34	6.51	0.21	0.080	40.0	8.1
19	954	1563	1719	734	6	31.0	0.32	8.0	0.35	0.0007	40.3	469	0.261	3.71	0.142	0.062	37.5	6.5	478	0.21	4.00	0.13	0.049	38.8	7.8
20	851	937	1335	405	9	30.1	0.28	6.7	0.31	0.0006	39.6	446	0.208	2.96	0.109	0.049	37.0	7.0	429	0.14	2.61	0.09	0.034	37.8	7.8
21	774	745	1106	389	9	27.7	0.25	6.0	0.26	0.0006	39.3	434	0.180	2.55	0.092	0.043	36.4	8.7	410	0.11	2.13	0.07	0.027	37.0	9.3
22	701	675	1031	327	8	23.9	0.24	5.6	0.25	0.0005	39.2	421	0.159	2.28	0.081	0.037	35.4	11.5	400	0.10	1.92	0.06	0.024	36.2	12.3
23	494	223	285	389	10	21.8	0.21	4.7	0.22	0.0005	38.3	373	0.126	1.70	0.063	0.030	34.2	12.5	330	0.06	0.89	0.04	0.014	34.3	12.6

Hour	M4 - M5 Link Traffic				No. of jet fans running	Ambient	M4 - M5 Link Peak in-tunnel levels					SPI outlet						
	CWL on (vph)	WHT on (vph)	Rozelle on (vph)	SPI off (vph)		T (°C)	NO2 (ppm)	CO (ppm)	Non-exhaust PM (mg/m3)	Exhaust PM Vis. (m-1)	Temp (°C)	flow (m3/s)	NO2 (g/s)	CO (g/s)	Non-exhaust PM (g/s)	Exhaust PM (g/s)	T (°C)	Delta T Ambient (°C)
0	201	201	401	540	0	22.3	0.16	2.77	0.12	0.0004	41.8	311	0.078	0.79	0.03	0.018	36.7	14.4
1	86	86	172	299	0	21.5	0.11	1.53	0.08	0.0003	40.4	311	0.054	0.44	0.02	0.013	35.4	13.9
2	69	69	138	251	0	21.0	0.07	1.47	0.07	0.0002	39.3	289	0.032	0.38	0.01	0.008	34.1	13.2
3	69	69	138	244	0	20.0	0.07	1.48	0.06	0.0002	38.8	289	0.032	0.38	0.01	0.007	33.5	13.6
4	85	85	170	243	0	18.5	0.08	1.66	0.06	0.0002	38.6	271	0.031	0.39	0.01	0.007	32.5	14.0
5	129	129	258	246	0	18.0	0.10	2.11	0.08	0.0002	38.6	232	0.032	0.40	0.01	0.008	31.3	13.3
6	221	221	443	528	0	19.5	0.17	3.03	0.13	0.0004	39.5	296	0.078	0.81	0.03	0.019	34.0	14.5
7	641	641	1283	1919	0	22.5	0.31	6.22	0.24	0.0007	42.2	436	0.226	2.73	0.09	0.052	38.5	16.0
8	1098	1098	2195	3421	0	24.2	0.47	9.68	0.39	0.0011	46.8	418	0.325	4.01	0.13	0.077	42.2	18.0
9	1015	1015	2029	3477	0	26.8	0.47	8.90	0.37	0.0011	47.2	445	0.356	4.00	0.14	0.086	43.4	16.6
10	1038	1038	2077	3363	0	31.6	0.50	8.96	0.38	0.0011	48.3	430	0.360	3.87	0.14	0.088	45.1	13.5
11	1021	1021	2043	3305	0	34.3	0.51	8.82	0.38	0.0012	48.9	430	0.365	3.80	0.14	0.089	46.1	11.9
12	974	974	1949	3287	0	34.3	0.47	8.35	0.36	0.0011	48.7	450	0.360	3.81	0.13	0.087	46.1	11.9
13	944	944	1888	3158	0	34.1	0.46	8.10	0.35	0.0011	48.8	452	0.354	3.71	0.13	0.085	46.1	12.1
14	935	935	1869	3047	0	34.2	0.45	8.02	0.34	0.0010	49.0	451	0.345	3.66	0.13	0.083	46.2	12.1
15	1002	1002	2003	3111	0	34.2	0.47	8.58	0.36	0.0011	49.8	432	0.338	3.72	0.13	0.081	46.8	12.6
16	1114	1114	2227	3144	0	33.8	0.51	9.86	0.40	0.0011	51.4	385	0.318	3.71	0.12	0.076	47.6	13.8
17	1228	1228	2457	3214	0	32.9	0.53	11.22	0.43	0.0012	53.1	352	0.300	3.77	0.12	0.071	48.2	15.4
18	1043	1043	2085	2862	0	31.9	0.43	8.83	0.35	0.0009	50.4	417	0.300	3.68	0.12	0.070	46.8	14.9
19	793	793	1587	2472	0	31.0	0.36	7.18	0.28	0.0008	48.8	452	0.276	3.29	0.11	0.064	45.6	14.7
20	650	650	1301	2228	0	30.1	0.32	6.41	0.25	0.0007	47.9	461	0.252	3.02	0.10	0.058	44.8	14.7
21	566	566	1133	1904	0	27.7	0.29	5.81	0.23	0.0006	47.1	449	0.223	2.65	0.08	0.051	43.6	15.9
22	503	503	1006	1709	0	23.9	0.28	5.33	0.21	0.0006	46.6	445	0.210	2.40	0.08	0.049	42.4	18.5
23	322	322	643	920	0	21.8	0.20	3.92	0.15	0.0004	44.6	360	0.114	1.36	0.04	0.026	39.4	17.6

Table C.4. New M5 with M4-M5 Link normal westbound 2031 traffic (winter). Stage 2 and 3 normal WB 2031.xlsx

Hour	New M5 traffic				No. of jet fans running SC	Ambient	Peak in-tunnel levels (New M5)					M5 outlet							Southern Connector outlet						
	M5 off (vph)	SC off (vph)	SPI on (vph)	New M5 on (vph)		(°C)	NO2 (ppm)	CO (ppm)	Non-exhaust PM (mg/m3)	Exhaust PM Vis. (m-1)	Temp (°C)	flow (m3/s)	NO2 (g/s)	CO (g/s)	Non-exhaust PM (g/s)	Exhaust PM (g/s)	T (°C)	Delta T Ambient (°C)	flow (m3/s)	NO2 (g/s)	CO (g/s)	Non-exhaust PM (g/s)	Exhaust PM (g/s)	T (°C)	Delta T Ambient (°C)
0	333	142	167	283	8	10.8	0.17	3.7	0.17	0.0004	29.9	343	0.093	1.18	0.045	0.022	24.6	13.8	308	0.04	0.65	0.03	0.010	24.3	13.6
1	64	68	79	52	2	10.3	0.13	2.6	0.13	0.0003	29.1	246	0.040	0.47	0.019	0.010	21.7	11.4	234	0.02	0.35	0.01	0.006	22.5	12.2
2	39	66	75	31	2	9.6	0.08	1.2	0.07	0.0002	28.9	238	0.023	0.23	0.011	0.006	21.0	11.5	229	0.01	0.21	0.01	0.003	22.0	12.5
3	40	66	75	31	2	9.1	0.06	1.0	0.06	0.0002	28.8	239	0.019	0.15	0.008	0.005	20.8	11.8	230	0.01	0.18	0.01	0.003	21.8	12.8
4	82	127	122	94	3	8.5	0.06	1.3	0.06	0.0002	28.9	271	0.023	0.23	0.009	0.006	21.6	13.1	263	0.02	0.27	0.01	0.004	22.6	14.1
5	285	202	216	270	7	7.5	0.11	2.3	0.09	0.0003	29.4	351	0.056	0.72	0.023	0.014	23.5	16.0	324	0.03	0.56	0.02	0.007	23.5	16.0
6	442	280	384	342	9	6.5	0.17	3.5	0.15	0.0004	29.8	393	0.107	1.29	0.045	0.026	24.2	17.7	355	0.05	0.88	0.03	0.013	23.8	17.3
7	938	390	710	613	15	6.5	0.25	5.4	0.23	0.0006	30.5	476	0.191	2.47	0.085	0.045	26.0	19.5	405	0.08	1.31	0.05	0.020	24.4	17.9
8	1263	699	1161	831	18	7.8	0.32	7.3	0.32	0.0007	31.0	532	0.281	3.87	0.137	0.066	27.1	19.3	455	0.14	2.35	0.09	0.034	25.4	17.6
9	1020	834	1249	593	13	10.0	0.35	7.1	0.35	0.0008	30.9	501	0.293	3.63	0.146	0.071	27.2	17.2	455	0.17	2.86	0.11	0.042	26.0	16.0
10	986	1214	1393	809	10	12.7	0.37	7.5	0.36	0.0009	31.0	504	0.314	3.43	0.146	0.077	27.8	15.1	484	0.22	3.60	0.13	0.054	27.0	14.4
11	961	1629	1824	795	7	13.9	0.40	8.6	0.38	0.0009	31.1	509	0.338	3.56	0.156	0.084	28.2	14.3	513	0.27	4.47	0.15	0.066	27.9	14.0
12	944	1744	2025	661	6	13.9	0.37	8.6	0.37	0.0009	31.0	499	0.310	3.45	0.149	0.077	27.9	14.0	513	0.26	4.51	0.15	0.063	28.1	14.2
13	961	1828	2158	649	6	14.0	0.38	8.8	0.37	0.0009	31.2	507	0.323	3.45	0.151	0.080	28.2	14.2	520	0.27	4.64	0.16	0.065	28.3	14.3
14	989	1977	2292	704	5	14.0	0.38	9.3	0.37	0.0009	31.2	510	0.325	3.54	0.153	0.081	28.2	14.2	530	0.29	4.97	0.17	0.070	28.6	14.6
15	1061	2259	2559	827	5	13.5	0.38	10.1	0.40	0.0009	31.6	520	0.331	3.88	0.161	0.081	28.2	14.7	547	0.32	5.63	0.19	0.077	29.0	15.5
16	1340	2758	2992	1213	7	13.0	0.41	11.5	0.46	0.0010	32.2	558	0.388	4.92	0.195	0.094	28.8	15.8	574	0.37	6.74	0.22	0.090	29.6	16.6
17	1620	3325	3471	1639	13	12.5	0.44	12.8	0.54	0.0010	33.1	595	0.454	6.05	0.236	0.110	29.3	16.8	564	0.40	7.32	0.26	0.096	30.2	17.7
18	1227	2631	2554	1321	5	12.0	0.38	11.3	0.44	0.0009	32.5	531	0.339	4.97	0.190	0.081	28.2	16.2	560	0.34	6.50	0.21	0.080	29.7	17.7
19	956	1568	1719	735	7	12.0	0.32	8.0	0.36	0.0007	31.6	484	0.263	3.73	0.142	0.062	27.6	15.6	488	0.21	4.00	0.13	0.049	28.4	16.4
20	849	935	1334	405	9	11.9	0.27	6.3	0.28	0.0006	31.0	460	0.210	2.98	0.110	0.050	27.2	15.3	438	0.14	2.60	0.09	0.034	27.4	15.5
21	774	745	1106	389	10	9.9	0.25	5.8	0.26	0.0005	30.8	448	0.181	2.56	0.092	0.043	26.6	16.7	420	0.11	2.13	0.07	0.027	26.6	16.8
22	701	676	1031	327	9	8.0	0.22	5.3	0.23	0.0005	30.7	434	0.160	2.29	0.082	0.038	25.8	17.8	409	0.10	1.92	0.06	0.024	26.0	18.0
23	497	225	287	389	10	8.0	0.21	4.7	0.22	0.0005	30.4	388	0.128	1.72	0.064	0.031	25.0	17.0	342	0.06	0.90	0.04	0.014	24.5	16.5

Hour	M4 - M5 Link Traffic				No. of jet fans running	Ambient	M4 - M5 Link Peak in-tunnel levels					SPI outlet						
	CWL on (vph)	WHT on (vph)	Rozelle on (vph)	SPI off (vph)		T (°C)	NO2 (ppm)	CO (ppm)	Non-exhaust PM (mg/m3)	Exhaust PM Vis. (m-1)	Temp (°C)	flow (m3/s)	NO2 (g/s)	CO (g/s)	Non-exhaust PM (g/s)	Exhaust PM (g/s)	T (°C)	Delta T Ambient (°C)
0	201	201	401	540	0	10.8	0.16	2.74	0.12	0.0004	31.8	314	0.078	0.80	0.03	0.019	26.3	15.6
1	86	86	172	294	0	10.3	0.11	1.53	0.08	0.0003	30.5	313	0.054	0.44	0.02	0.013	25.1	14.9
2	69	69	138	244	0	9.6	0.07	1.46	0.06	0.0002	29.5	290	0.032	0.38	0.01	0.008	23.9	14.3
3	69	69	138	244	0	9.1	0.07	1.47	0.06	0.0002	29.1	290	0.032	0.38	0.01	0.007	23.4	14.4
4	85	85	170	244	0	8.5	0.08	1.65	0.06	0.0002	28.9	272	0.031	0.39	0.01	0.007	22.7	14.2
5	129	129	258	245	0	7.5	0.10	2.08	0.08	0.0002	28.9	235	0.032	0.40	0.01	0.008	21.4	13.9
6	222	222	444	542	0	6.5	0.17	2.98	0.12	0.0004	29.8	303	0.079	0.83	0.03	0.019	23.4	16.9
7	642	642	1284	1946	0	6.5	0.31	6.14	0.24	0.0007	32.3	444	0.229	2.76	0.09	0.053	27.5	21.0
8	1097	1097	2195	3404	0	7.8	0.46	9.49	0.38	0.0010	36.6	427	0.328	4.05	0.13	0.078	30.8	23.0
9	1015	1015	2029	3479	0	10.0	0.47	8.76	0.37	0.0011	36.9	454	0.359	4.05	0.14	0.087	32.0	22.0
10	1038	1038	2077	3348	0	12.7	0.49	8.76	0.38	0.0011	37.8	442	0.364	3.92	0.14	0.089	33.1	20.4
11	1021	1021	2043	3305	0	13.9	0.50	8.61	0.37	0.0011	38.3	443	0.371	3.86	0.14	0.091	33.8	19.9
12	974	974	1949	3287	0	13.9	0.46	8.15	0.35	0.0011	38.1	464	0.365	3.86	0.14	0.088	33.8	19.9
13	944	944	1888	3158	0	14.0	0.45	7.90	0.34	0.0010	38.0	466	0.359	3.77	0.13	0.087	33.8	19.8
14	935	935	1869	3047	0	14.0	0.44	7.82	0.34	0.0010	38.1	465	0.350	3.72	0.13	0.084	33.8	19.8
15	1002	1002	2003	3112	0	13.5	0.45	8.34	0.35	0.0010	38.7	447	0.343	3.78	0.13	0.083	34.0	20.5
16	1114	1114	2227	3144	0	13.0	0.49	9.54	0.39	0.0011	40.0	401	0.324	3.79	0.13	0.078	34.4	21.4
17	1229	1229	2457	3214	0	12.5	0.51	10.82	0.42	0.0011	41.4	368	0.306	3.86	0.12	0.073	34.8	22.3
18	1043	1043	2085	2862	0	12.0	0.42	8.57	0.34	0.0009	39.0	433	0.305	3.74	0.12	0.071	33.8	21.8
19	793	793	1587	2474	0	12.0	0.35	7.01	0.28	0.0008	37.4	465	0.280	3.34	0.11	0.065	32.9	20.9
20	650	650	1300	2226	0	11.9	0.31	6.25	0.24	0.0007	36.4	474	0.254	3.04	0.10	0.059	32.2	20.3
21	566	566	1133	1904	0	9.9	0.29	5.67	0.22	0.0006	35.6	461	0.225	2.67	0.09	0.052	31.0	21.1
22	503	503	1006	1709	0	8.0	0.27	5.21	0.21	0.0006	34.8	455	0.211	2.42	0.08	0.049	30.0	22.0
23	322	322	643	923	0	8.0	0.19	3.86	0.15	0.0004	33.1	367	0.115	1.37	0.04	0.027	27.4	19.4

APPENDIX D - REGULATORY TRAFFIC SIMULATION RESULTS

Results from the simulation of regulatory traffic in New M5, and New M5 with connected M4-M5 Link, up to Rozelle.

Table D.1. New M5 with M4-M5 Link eastbound 2031 regulatory traffic (summer). Stage 2 and 3 regulatory EB 2031.xlsx

Hour	New M5 traffic			No. of jet fans running		Ambient	Peak in-tunnel levels (before Kogarah outlet)					Kogarah outlet								Peak in-tunnel levels (before SPI outlet)					SPI outlet						
	M5 on (vph)	SC on (vph)	SPI off (vph)	SC	Main tube	(°C)	NO2 (ppm)	CO (ppm)	Non-exhaust PM (mg/m3)	Exhaust PM Vis. (m-1)	Temp (°C)	supply flow (m3/s)	exhaust flow (m3/s)	NO2 (g/s)	CO (g/s)	Non-exhaust PM (g/s)	Exhaust PM (g/s)	T (°C)	Delta T Ambient (°C)	NO2 (ppm)	CO (ppm)	Non-exhaust PM (mg/m3)	Exhaust PM Vis. (m-1)	Temp (°C)	flow (m3/s)	NO2 (g/s)	CO (g/s)	Non-exhaust PM (g/s)	Exhaust PM (g/s)	T (°C)	Delta T Ambient (°C)
0	86	247	225	0.0	17.3	22.3	0.02	0.5	0.03	0.0000	25.7	357	704	0.019	0.28	0.016	0.0051	24.6	2.4	0.04	1.3	0.03	0.0001	29.7	259	0.016	0.28	0.006	0.0036	27.4	5.2
1	52	141	111	0.0	19.1	21.5	0.01	0.3	0.02	0.0000	25.5	345	672	0.011	0.16	0.009	0.0031	24.4	2.9	0.03	0.7	0.02	0.0001	29.1	248	0.009	0.15	0.004	0.0021	26.7	5.2
2	45	76	92	0.0	20.3	21.0	0.01	0.2	0.01	0.0000	25.4	337	653	0.008	0.10	0.007	0.0023	24.3	3.3	0.02	0.5	0.01	0.0000	28.9	264	0.008	0.11	0.003	0.0018	26.5	5.6
3	45	76	97	0.0	20.3	20.0	0.01	0.2	0.01	0.0000	25.3	336	654	0.008	0.10	0.006	0.0023	24.1	4.2	0.02	0.5	0.01	0.0000	28.8	269	0.009	0.11	0.003	0.0020	26.3	6.3
4	72	200	203	0.0	18.5	18.5	0.01	0.4	0.02	0.0000	25.4	348	690	0.014	0.21	0.012	0.0036	24.1	5.6	0.03	1.0	0.03	0.0001	28.9	273	0.013	0.23	0.005	0.0029	26.0	7.5
5	174	403	405	0.0	14.9	18.0	0.02	0.7	0.04	0.0001	25.5	373	756	0.027	0.46	0.024	0.0068	24.2	6.2	0.06	1.9	0.05	0.0001	29.4	275	0.024	0.45	0.010	0.0052	26.3	8.3
6	684	1,669	1,548	0.0	0.0	19.5	0.06	2.1	0.12	0.0001	26.3	530	1,021	0.108	1.94	0.098	0.0266	25.2	5.7	0.16	5.4	0.13	0.0003	31.9	334	0.083	1.70	0.035	0.0171	29.3	9.8
7	1,376	3,245	3,762	0.0	0.0	22.5	0.10	3.7	0.21	0.0002	27.3	689	1,179	0.198	3.80	0.192	0.0480	26.2	3.7	0.23	7.0	0.20	0.0005	34.6	473	0.183	3.38	0.082	0.0410	32.9	10.4
8	1,544	3,969	3,817	0.0	0.0	24.2	0.15	5.6	0.30	0.0003	28.3	717	1,143	0.262	4.86	0.241	0.0671	26.8	2.6	0.29	7.5	0.24	0.0006	36.6	416	0.202	3.13	0.084	0.0479	34.7	10.5
9	1,533	3,400	3,709	0.0	0.0	26.8	0.12	4.2	0.25	0.0003	28.0	688	1,188	0.240	4.24	0.225	0.0613	26.9	0.1	0.30	7.6	0.25	0.0007	37.3	407	0.202	3.07	0.083	0.0482	35.6	8.8
10	1,378	2,944	3,745	0.0	0.0	31.6	0.10	3.2	0.20	0.0002	27.9	670	1,185	0.215	3.50	0.195	0.0555	27.1	-4.5	0.30	7.3	0.23	0.0007	38.1	395	0.194	2.87	0.076	0.0463	37.1	5.5
11	1,237	2,573	2,943	0.0	0.0	34.3	0.09	2.9	0.18	0.0002	27.9	708	1,149	0.197	3.10	0.174	0.0515	27.3	-7.0	0.23	6.2	0.18	0.0005	35.7	477	0.184	3.01	0.072	0.0411	35.5	1.3
12	1,050	2,392	2,776	0.0	0.0	34.3	0.09	2.8	0.17	0.0002	28.0	686	1,118	0.182	2.80	0.158	0.0482	27.3	-6.9	0.22	6.0	0.17	0.0005	35.8	471	0.175	2.86	0.067	0.0391	35.6	1.4
13	899	2,322	2,401	0.0	0.0	34.1	0.08	2.7	0.17	0.0002	28.2	669	1,093	0.170	2.59	0.148	0.0451	27.4	-6.7	0.21	5.7	0.16	0.0004	35.8	445	0.159	2.57	0.060	0.0356	35.6	1.5
14	910	2,244	2,394	0.0	0.0	34.2	0.08	2.7	0.16	0.0002	28.3	661	1,086	0.165	2.54	0.144	0.0436	27.5	-6.7	0.21	5.7	0.16	0.0004	36.0	445	0.156	2.56	0.059	0.0348	35.7	1.6
15	1,103	2,122	2,524	0.0	0.0	34.2	0.08	2.5	0.16	0.0002	28.4	660	1,094	0.165	2.62	0.148	0.0429	27.6	-6.6	0.21	5.8	0.16	0.0004	36.3	454	0.158	2.65	0.061	0.0348	36.0	1.8
16	1,203	1,971	2,501	0.0	0.0	33.8	0.08	2.4	0.15	0.0002	28.4	652	1,092	0.163	2.60	0.147	0.0420	27.6	-6.1	0.20	5.7	0.16	0.0004	36.5	448	0.154	2.59	0.060	0.0337	36.1	2.4
17	1,331	1,838	2,358	0.0	0.0	32.9	0.09	2.3	0.15	0.0002	28.5	649	1,097	0.164	2.63	0.148	0.0420	27.7	-5.2	0.20	5.7	0.16	0.0004	36.7	431	0.146	2.45	0.057	0.0318	36.1	3.2
18	955	1,583	2,045	0.0	0.0	31.9	0.07	2.1	0.12	0.0002	28.5	581	1,028	0.132	2.08	0.118	0.0337	27.5	-4.4	0.18	5.3	0.14	0.0004	36.4	412	0.126	2.15	0.049	0.0273	35.6	3.7
19	667	1,531	1,782	0.0	0.0	31.0	0.06	2.0	0.12	0.0002	28.5	540	984	0.112	1.79	0.099	0.0289	27.5	-3.5	0.17	5.1	0.13	0.0003	36.2	394	0.111	1.95	0.043	0.0240	35.2	4.3
20	534	1,519	1,664	0.0	0.0	30.1	0.06	2.0	0.12	0.0001	28.6	512	960	0.099	1.66	0.089	0.0251	27.5	-2.6	0.16	4.9	0.13	0.0003	36.1	392	0.104	1.90	0.041	0.0225	34.9	4.9
21	490	1,511	1,622	0.0	0.0	27.7	0.06	2.0	0.12	0.0001	28.7	500	952	0.095	1.61	0.085	0.0240	27.4	-0.3	0.16	4.9	0.12	0.0003	36.0	384	0.099	1.85	0.039	0.0213	34.5	6.8
22	481	1,515	1,629	0.0	0.0	23.9	0.05	2.0	0.11	0.0001	28.8	490	953	0.093	1.61	0.084	0.0234	27.2	3.3	0.15	5.0	0.12	0.0003	35.9	386	0.098	1.88	0.039	0.0209	33.7	9.8
23	174	601	658	0.0	0.0	21.8	0.03	1.1	0.06	0.0001	28.2	203	776	0.037	0.66	0.034	0.0093	26.4	4.7	0.15	5.0	0.11	0.0003	35.9	196	0.037	0.73	0.014	0.0079	30.5	8.7

Hour	M4 - M5 Link traffic					No. of jet fans running		Ambient	Peak in-tunnel levels (M4 - M5 Link)					WHT-Rozelle outlets combined						
	M4-M5 Link on (vph)	SPI on (vph)	CWL off	WHT off	Rozelle off	St Peters On	CWL	T (°C)	NO2 (ppm)	CO (ppm)	Non-exhaust PM (mg/m3)	Exhaust PM Vis. (m-1)	Temp (°C)	flow (m3/s)	NO2 (g/s)	CO (g/s)	Non-exhaust PM (g/s)	Exhaust PM (g/s)	T (°C)	Delta T Ambient (°C)
1	109	378	122	122	244	0	0	22.3	0.15	2.6	0.13	0.0003	39.7	568	0.102	1.10	0.045	0.0248	33.1	10.8
2	83	243	82	82	163	0	0	21.5	0.13	1.6	0.10	0.0003	39.1	533	0.079	0.60	0.030	0.0203	32.1	10.6
3	29	243	68	68	136	0	1	21.0	0.12	1.2	0.09	0.0003	38.6	510	0.069	0.42	0.025	0.0179	31.3	10.4
4	24	243	67	67	134	0	0	20.0	0.11	1.1	0.08	0.0003	38.2	511	0.066	0.37	0.024	0.0171	30.7	10.8
5	69	510	145	145	289	0	0	18.5	0.12	1.9	0.10	0.0003	38.1	579	0.087	0.80	0.037	0.0213	30.9	12.4
6	171	900	268	268	535	0	1	18.0	0.13	3.0	0.14	0.0003	38.1	650	0.116	1.58	0.059	0.0262	31.5	13.5
7	803	2,489	822	822	1,643	0	-1	19.5	0.32	6.3	0.29	0.0007	39.9	902	0.440	5.21	0.201	0.1067	34.8	15.3
8	842	3,851	1,169	1,169	2,338	0	0	22.5	0.41	8.3	0.40	0.0009	41.3	934	0.594	7.28	0.293	0.1423	36.6	14.1
9	1,419	3,793	1,299	1,299	2,598	0	2	24.2	0.51	9.7	0.49	0.0012	42.7	938	0.748	8.54	0.357	0.1877	37.9	13.7
10	1,142	3,783	1,257	1,257	2,514	0	2	26.8	0.52	9.5	0.49	0.0012	43.3	933	0.755	8.32	0.358	0.1887	38.9	12.1
11	1,058	3,765	1,207	1,207	2,415	0	2	31.6	0.49	9.0	0.47	0.0012	44.0	940	0.724	7.89	0.341	0.1799	40.4	8.8
12	869	3,744	1,154	1,154	2,308	0	0	34.3	0.48	8.4	0.44	0.0011	44.6	938	0.704	7.39	0.322	0.1750	41.4	7.2
13	667	3,752	1,105	1,105	2,210	0	1	34.3	0.46	8.0	0.42	0.0011	45.0	934	0.676	6.98	0.304	0.1682	41.7	7.5
14	821	3,758	1,145	1,145	2,290	0	2	34.1	0.46	8.2	0.43	0.0011	45.6	931	0.672	7.14	0.308	0.1665	42.1	8.1
15	760	3,757	1,129	1,129	2,259	0	0	34.2	0.46	8.0	0.42	0.0011	46.1	934	0.666	7.03	0.304	0.1645	42.5	8.3
16	701	3,760	1,115	1,115	2,231	0	2	34.2	0.45	7.9	0.41	0.0010	46.4	927	0.648	6.81	0.297	0.1594	42.8	8.6
17	673	3,768	1,110	1,110	2,221	0	0	33.8	0.45	7.8	0.41	0.0010	46.8	938	0.654	6.88	0.301	0.1605	43.0	9.2
18	811	3,756	1,142	1,142	2,283	0	0	32.9	0.46	8.0	0.42	0.0011	47.3	944	0.674	7.13	0.311	0.1659	43.2	10.3
19	495	3,481	994	994	1,989	0	0	31.9	0.43	7.2	0.38	0.0010	47.2	921	0.615	6.21	0.275	0.1516	42.9	11.0
20	417	3,271	922	922	1,844	0	1	31.0	0.39	6.7	0.36	0.0009	47.1	894	0.545	5.58	0.245	0.1336	42.5	11.6
21	390	2,808	800	800	1,599	0	0	30.1	0.34	6.2	0.31	0.0008	46.6	872	0.448	4.93	0.207	0.1081	41.9	11.9
22	380	2,734	778	778	1,557	0	0	27.7	0.32	6.1	0.30	0.0007	46.4	864	0.428	4.83	0.200	0.1028	41.2	13.5
23	367	2,658	756	756	1,512	0	0	23.9	0.32	6.0	0.30	0.0007	46.1	852	0.413	4.67	0.193	0.0987	40.1	16.2
24	119	1,277	349	349	699	0	0	21.8	0.15	4.0	0.17	0.0003	44.3	660	0.140	2.16	0.077	0.0309	36.8	15.1

Table D.2. New M5 with M4-M5 Link eastbound 2031 regulatory traffic (winter). Stage 2 and 3 regulatory EB 2031.xlsx

Hour	New M5 traffic			No. of jet fans running		Ambient	Peak in-tunnel levels (before Kogarah outlet)					Kogarah outlet								Peak in-tunnel levels (before SPI outlet)					SPI outlet						
	M5 on (vph)	SC on (vph)	SPI off (vph)	SC	Main tube	(°C)	NO2 (ppm)	CO (ppm)	Non-exhaust PM (mg/m3)	Exhaust PM Vis. (m-1)	Temp (°C)	supply flow (m3/s)	exhaust flow (m3/s)	NO2 (g/s)	CO (g/s)	Non-exhaust PM (g/s)	Exhaust PM (g/s)	T (°C)	Delta T Ambient (°C)	NO2 (ppm)	CO (ppm)	Non-exhaust PM (mg/m3)	Exhaust PM Vis. (m-1)	Temp (°C)	flow (m3/s)	NO2 (g/s)	CO (g/s)	Non-exhaust PM (g/s)	Exhaust PM (g/s)	T (°C)	Delta T Ambient (°C)
0	86	247	225	0.0	19.2	10.8	0.01	0.5	0.03	0.0000	18.5	344	745	0.019	0.28	0.016	0.0051	17.5	6.7	0.04	1.3	0.04	0.0001	22.4	261	0.017	0.29	0.007	0.0037	19.0	8.2
1	52	141	111	0.0	21.0	10.3	0.01	0.3	0.02	0.0000	18.3	332	715	0.011	0.16	0.009	0.0031	17.2	7.0	0.03	0.7	0.02	0.0001	21.8	250	0.010	0.15	0.004	0.0022	18.3	8.0
2	45	76	92	0.0	22.1	9.6	0.01	0.2	0.01	0.0000	18.1	324	698	0.008	0.10	0.007	0.0023	17.0	7.5	0.02	0.5	0.01	0.0000	21.5	266	0.008	0.12	0.003	0.0018	18.1	8.5
3	45	76	97	0.0	22.2	9.1	0.01	0.2	0.01	0.0000	18.0	323	698	0.008	0.10	0.006	0.0023	16.9	7.9	0.02	0.5	0.01	0.0000	21.3	271	0.009	0.11	0.003	0.0020	17.9	8.9
4	72	200	203	0.0	20.3	8.5	0.01	0.4	0.02	0.0000	18.0	336	732	0.014	0.22	0.012	0.0036	16.9	8.4	0.03	1.0	0.03	0.0001	21.5	272	0.014	0.23	0.005	0.0030	17.9	9.4
5	174	403	405	0.0	16.7	7.5	0.02	0.7	0.04	0.0000	18.1	360	794	0.027	0.46	0.025	0.0069	17.0	9.5	0.06	1.9	0.05	0.0001	22.0	274	0.025	0.46	0.010	0.0053	18.0	10.5
6	684	1,669	1,548	0.0	0.0	6.5	0.06	2.1	0.12	0.0001	18.8	499	1,053	0.108	1.95	0.098	0.0266	17.8	11.3	0.16	5.6	0.14	0.0003	24.5	323	0.083	1.71	0.036	0.0172	20.5	14.0
7	1,376	3,245	3,762	0.0	0.0	6.5	0.09	3.6	0.21	0.0002	19.6	657	1,212	0.198	3.80	0.193	0.0481	18.6	12.1	0.23	7.1	0.20	0.0005	26.6	470	0.186	3.42	0.083	0.0415	23.8	17.3
8	1,544	3,969	3,816	0.0	0.0	7.8	0.15	5.5	0.30	0.0003	20.5	686	1,176	0.262	4.86	0.241	0.0672	19.1	11.3	0.30	7.6	0.24	0.0007	28.5	413	0.204	3.17	0.085	0.0484	25.1	17.3
9	1,533	3,400	3,709	0.0	0.0	10.0	0.11	4.1	0.24	0.0003	20.1	656	1,222	0.239	4.23	0.225	0.0613	19.1	9.1	0.30	7.7	0.25	0.0007	29.0	403	0.204	3.11	0.084	0.0487	25.8	15.9
10	1,378	2,944	3,745	0.0	0.0	12.7	0.10	3.1	0.20	0.0002	19.9	633	1,223	0.215	3.50	0.195	0.0555	19.1	6.4	0.30	7.5	0.24	0.0007	29.7	391	0.197	2.91	0.077	0.0469	26.7	14.1
11	1,237	2,573	2,943	0.0	0.0	13.9	0.09	2.8	0.18	0.0002	19.8	667	1,189	0.197	3.10	0.174	0.0516	19.1	5.2	0.23	6.3	0.18	0.0005	27.0	474	0.186	3.06	0.073	0.0418	25.1	11.2
12	1,050	2,392	2,776	0.0	0.0	13.9	0.08	2.7	0.17	0.0002	19.7	645	1,159	0.182	2.80	0.159	0.0483	19.0	5.1	0.22	6.1	0.17	0.0005	26.9	467	0.178	2.91	0.068	0.0398	25.0	11.1
13	899	2,322	2,401	0.0	0.0	14.0	0.08	2.6	0.16	0.0002	19.7	628	1,135	0.170	2.59	0.148	0.0452	18.9	4.9	0.22	5.9	0.16	0.0005	26.8	440	0.162	2.61	0.061	0.0362	24.7	10.7
14	910	2,244	2,394	0.0	0.0	14.0	0.08	2.6	0.16	0.0002	19.7	619	1,129	0.165	2.54	0.144	0.0437	18.9	4.9	0.21	5.9	0.16	0.0004	26.8	439	0.159	2.60	0.060	0.0354	24.8	10.8
15	1,103	2,122	2,524	0.0	0.0	13.5	0.08	2.4	0.15	0.0002	19.7	617	1,138	0.166	2.62	0.148	0.0429	18.9	5.4	0.21	5.9	0.16	0.0004	26.9	449	0.161	2.70	0.063	0.0355	24.8	11.3
16	1,203	1,971	2,501	0.0	0.0	13.0	0.08	2.3	0.15	0.0002	19.6	608	1,137	0.163	2.60	0.147	0.0421	18.9	5.9	0.21	5.9	0.16	0.0004	26.9	442	0.157	2.63	0.062	0.0343	24.7	11.7
17	1,331	1,838	2,358	0.0	0.0	12.5	0.08	2.2	0.14	0.0002	19.5	606	1,142	0.164	2.63	0.148	0.0421	18.9	6.4	0.21	5.8	0.16	0.0004	26.9	425	0.148	2.49	0.059	0.0324	24.5	12.0
18	955	1,583	2,045	0.0	0.0	12.0	0.07	2.0	0.12	0.0002	19.4	536	1,074	0.132	2.08	0.118	0.0338	18.6	6.6	0.19	5.5	0.15	0.0004	26.5	403	0.128	2.19	0.050	0.0279	24.0	12.0
19	667	1,531	1,782	0.0	0.0	12.0	0.06	2.0	0.11	0.0002	19.4	495	1,032	0.112	1.79	0.099	0.0289	18.5	6.5	0.18	5.3	0.14	0.0004	26.2	382	0.113	1.99	0.044	0.0246	23.6	11.6
20	534	1,519	1,664	0.0	0.0	11.9	0.05	2.0	0.11	0.0001	19.3	467	1,008	0.099	1.66	0.089	0.0251	18.4	6.5	0.17	5.2	0.14	0.0004	26.0	378	0.106	1.94	0.042	0.0230	23.3	11.5
21	490	1,511	1,622	0.0	0.0	9.9	0.05	1.9	0.11	0.0001	19.3	454	1,000	0.095	1.61	0.085	0.0240	18.2	8.3	0.17	5.2	0.13	0.0003	25.9	370	0.102	1.89	0.040	0.0219	22.8	13.0
22	481	1,515	1,629	0.0	0.0	8.0	0.05	2.0	0.11	0.0001	19.2	448	1,000	0.093	1.61	0.084	0.0234	18.0	10.0	0.17	5.3	0.13	0.0003	25.7	371	0.100	1.92	0.041	0.0214	22.3	14.3
23	174	601	658	0.0	13.9	10.5	0.03	1.0	0.05	0.0001	18.9	380	827	0.036	0.65	0.033	0.0091	17.8	7.3	0.11	3.5	0.09	0.0002	23.6	327	0.056	1.07	0.024	0.0124	20.6	10.1

Hour	M4 - M5 Link traffic					No. of jet fans running		Ambient	Peak in-tunnel levels (M4 - M5 Link)					WHT-Rozelle outlets combined						
	M4-M5 Link on (vph)	SPI on (vph)	CWL off	WHT off	Rozelle off	St Peters On	CWL	T (°C)	NO2 (ppm)	CO (ppm)	Non-exhaust PM (mg/m3)	Exhaust PM Vis. (m-1)	Temp (°C)	flow (m3/s)	NO2 (g/s)	CO (g/s)	Non-exhaust PM (g/s)	Exhaust PM (g/s)	T (°C)	Delta T Ambient (°C)
1	109	378	122	122	244	0	0	10.8	0.14	2.5	0.12	0.0003	33.1	572	0.101	1.07	0.044	0.0246	24.8	14.0
2	83	243	82	82	163	0	0	10.3	0.12	1.6	0.09	0.0003	32.4	537	0.079	0.60	0.030	0.0203	23.7	13.5
3	29	243	68	68	136	0	1	9.6	0.12	1.2	0.09	0.0003	31.9	514	0.069	0.42	0.025	0.0179	22.8	13.2
4	24	243	67	67	134	0	0	9.1	0.11	1.1	0.08	0.0003	31.5	512	0.066	0.37	0.024	0.0171	22.3	13.3
5	69	510	145	145	289	0	1	8.5	0.12	1.8	0.10	0.0003	31.3	574	0.086	0.79	0.037	0.0210	23.0	14.5
6	171	900	268	268	535	0	0	7.5	0.13	3.0	0.13	0.0003	31.2	653	0.116	1.59	0.059	0.0264	23.5	16.0
7	803	2,489	822	822	1,643	0	2	6.5	0.31	6.2	0.29	0.0007	32.9	893	0.436	5.16	0.199	0.1058	26.4	19.9
8	842	3,851	1,169	1,169	2,338	0	0	6.5	0.40	8.3	0.40	0.0009	34.0	938	0.600	7.35	0.295	0.1436	27.5	21.0
9	1,419	3,793	1,299	1,299	2,598	0	0	7.8	0.51	9.7	0.49	0.0012	35.2	947	0.756	8.64	0.361	0.1898	28.6	20.8
10	1,142	3,783	1,257	1,257	2,514	0	1	10.0	0.51	9.5	0.49	0.0012	35.7	943	0.764	8.42	0.363	0.1909	29.4	19.5
11	1,058	3,765	1,207	1,207	2,415	0	0	12.7	0.49	8.9	0.46	0.0011	36.2	949	0.731	7.96	0.344	0.1817	30.3	17.7
12	869	3,744	1,154	1,154	2,308	0	0	13.9	0.48	8.3	0.44	0.0011	36.6	943	0.708	7.43	0.324	0.1759	30.9	17.0
13	667	3,752	1,105	1,105	2,210	0	1	13.9	0.46	7.9	0.42	0.0011	36.9	938	0.680	7.01	0.305	0.1690	31.1	17.2
14	821	3,758	1,145	1,145	2,290	0	0	14.0	0.46	8.1	0.42	0.0011	37.4	940	0.681	7.22	0.311	0.1686	31.5	17.5
15	760	3,757	1,129	1,129	2,259	0	0	14.0	0.45	8.0	0.42	0.0011	37.7	941	0.671	7.08	0.307	0.1658	31.7	17.7
16	701	3,760	1,115	1,115	2,231	0	2	13.5	0.44	7.8	0.41	0.0010	37.9	930	0.650	6.82	0.298	0.1598	31.7	18.2
17	673	3,768	1,110	1,110	2,221	0	2	13.0	0.44	7.8	0.41	0.0010	38.1	929	0.647	6.80	0.297	0.1586	31.8	18.8
18	811	3,756	1,142	1,142	2,283	0	2	12.5	0.45	8.0	0.42	0.0010	38.5	932	0.664	7.03	0.306	0.1635	31.9	19.4
19	495	3,481	994	994	1,989	0	0	12.0	0.42	7.1	0.38	0.0010	38.3	923	0.616	6.22	0.275	0.1520	31.7	19.7
20	417	3,271	922	922	1,844	0	-1	12.0	0.39	6.7	0.35	0.0009	38.1	904	0.551	5.64	0.248	0.1351	31.4	19.4
21	390	2,808	800	800	1,599	0	2	11.9	0.33	6.1	0.31	0.0008	37.6	862	0.440	4.84	0.203	0.1063	30.7	18.9
22	380	2,734	778	778	1,557	0	0	9.9	0.32	6.0	0.30	0.0007	37.3	868	0.430	4.84	0.201	0.1032	30.1	20.3
23	367	2,658	756	756	1,512	0	0	8.0	0.31	5.9	0.30	0.0007	36.9	857	0.413	4.67	0.193	0.0989	29.4	21.4
24	119	1,277	349	349	699	0	1	10.5	0.14	3.8	0.16	0.0003	34.2	683	0.138	2.13	0.076	0.0303	26.6	16.1

Table D.3. New M5 with M4-M5 Link westbound 2031 regulatory traffic (summer). Stage 2 and 3 regulatory WB 2031_v1.xlsx

Hour	New M5 traffic				No. of jet fans running	Ambient	Peak in-tunnel levels (New M5)					M5 outlet							Southern Connector outlet						
	M5 off (vph)	SC off (vph)	SPI on (vph)	M5 on (vph)		(°C)	NO2 (ppm)	CO (ppm)	Non-exhaust PM (mg/m3)	Exhaust PM Vis. (m-1)	Temp (°C)	flow (m3/s)	NO2 (g/s)	CO (g/s)	Non-exhaust PM (g/s)	Exhaust PM (g/s)	T (°C)	Delta T Ambient (°C)	flow (m3/s)	NO2 (g/s)	CO (g/s)	Non-exhaust PM (g/s)	Exhaust PM (g/s)	T (°C)	Delta T Ambient (°C)
0	394	169	200	338	8	22.3	0.20	4.3	0.20	0.0005	38.0	356	0.111	1.41	0.053	0.027	33.7	11.5	319	0.05	0.77	0.03	0.012	33.9	11.7
1	85	87	94	65	2	21.5	0.15	2.9	0.15	0.0003	37.8	246	0.046	0.54	0.022	0.011	30.9	9.4	236	0.03	0.42	0.02	0.007	32.2	10.7
2	51	82	90	39	2	21.0	0.09	1.5	0.09	0.0002	37.7	235	0.027	0.26	0.012	0.007	30.3	9.3	229	0.02	0.24	0.01	0.004	31.8	10.8
3	47	80	90	37	2	20.0	0.08	1.2	0.07	0.0002	37.6	237	0.023	0.18	0.009	0.006	29.9	9.9	230	0.01	0.21	0.01	0.003	31.4	11.4
4	95	149	146	111	2	18.5	0.08	1.6	0.07	0.0002	37.6	274	0.028	0.27	0.011	0.007	30.4	11.9	269	0.02	0.33	0.01	0.005	31.8	13.3
5	325	237	259	320	7	18.0	0.12	2.6	0.11	0.0003	37.6	362	0.069	0.87	0.028	0.017	32.3	14.3	335	0.04	0.68	0.02	0.009	32.9	14.9
6	505	325	457	404	10	19.5	0.21	4.1	0.18	0.0005	37.7	406	0.128	1.54	0.054	0.031	33.5	14.0	367	0.06	1.05	0.03	0.015	33.6	14.1
7	1097	461	851	732	17	22.5	0.28	6.1	0.27	0.0006	38.6	495	0.231	2.99	0.104	0.055	35.8	13.3	419	0.10	1.59	0.06	0.025	34.8	12.3
8	1539	850	1393	1008	19	24.2	0.36	8.2	0.36	0.0008	39.2	557	0.342	4.70	0.167	0.080	37.0	12.8	472	0.17	2.88	0.10	0.041	35.7	11.5
9	1240	1002	1496	719	14	26.8	0.39	8.1	0.40	0.0009	39.1	522	0.347	4.27	0.172	0.084	37.1	10.3	474	0.20	3.35	0.12	0.051	36.4	9.6
10	1169	1416	1667	956	11	31.6	0.43	8.6	0.42	0.0010	39.3	523	0.374	4.09	0.174	0.092	38.1	6.5	504	0.26	4.31	0.15	0.065	37.7	6.1
11	1149	1945	2184	949	8	34.3	0.45	9.7	0.43	0.0011	39.7	529	0.404	4.24	0.187	0.101	38.7	4.5	534	0.32	5.29	0.19	0.079	38.8	4.6
12	1132	2086	2424	794	6	34.3	0.41	9.8	0.41	0.0010	39.9	517	0.371	4.13	0.178	0.092	38.6	4.3	534	0.31	5.34	0.18	0.075	39.1	4.8
13	1148	2184	2584	775	7	34.1	0.44	10.0	0.43	0.0010	40.2	527	0.388	4.17	0.183	0.096	38.8	4.7	542	0.33	5.54	0.19	0.080	39.3	5.2
14	1182	2351	2739	840	6	34.2	0.44	10.6	0.43	0.0010	40.6	530	0.394	4.29	0.186	0.098	38.9	4.7	553	0.35	5.95	0.20	0.085	39.7	5.5
15	1266	2701	3062	986	5	34.2	0.44	11.6	0.47	0.0010	41.1	539	0.399	4.69	0.197	0.098	39.0	4.8	570	0.38	6.73	0.23	0.094	40.2	6.0
16	1600	3224	3581	1450	11	33.8	0.48	12.8	0.55	0.0011	41.9	585	0.480	6.14	0.245	0.118	39.5	5.7	574	0.43	7.54	0.27	0.106	40.9	7.1
17	1919	3911	4149	1948	19	32.9	0.51	14.8	0.64	0.0012	43.1	622	0.550	7.47	0.294	0.134	39.9	7.1	555	0.47	8.42	0.30	0.112	41.8	8.9
18	1467	3606	3057	1583	7	31.9	0.43	13.0	0.55	0.0010	42.5	556	0.411	6.06	0.233	0.099	39.0	7.1	575	0.42	7.75	0.27	0.101	41.4	9.5
19	1140	1871	2058	878	7	31.0	0.36	9.1	0.40	0.0008	41.3	503	0.318	4.51	0.174	0.076	38.3	7.4	509	0.26	4.84	0.16	0.060	39.7	8.8
20	1017	1118	1600	484	10	30.1	0.32	7.5	0.34	0.0007	40.5	478	0.253	3.59	0.134	0.060	37.9	7.8	457	0.17	3.15	0.11	0.041	38.7	8.7
21	924	888	1323	465	10	27.7	0.28	6.6	0.29	0.0006	40.2	461	0.217	3.06	0.110	0.051	37.3	9.6	433	0.14	2.55	0.08	0.032	37.9	10.2
22	840	809	1236	392	9	23.9	0.26	6.2	0.27	0.0006	40.1	447	0.191	2.73	0.098	0.045	36.3	12.4	423	0.12	2.31	0.08	0.029	37.1	13.2
23	595	270	343	466	11	21.8	0.24	5.1	0.24	0.0005	39.1	394	0.151	2.02	0.075	0.036	35.0	13.3	345	0.07	1.05	0.04	0.017	35.1	13.4

Hour	M4 - M5 Link Traffic				No. of jet fans running	Ambient	M4 - M5 Link Peak in-tunnel levels					SPI outlet						
	CWL on (vph)	WHT on (vph)	Rozelle on (vph)	SPI off (vph)		T (°C)	NO2 (ppm)	CO (ppm)	Non-exhaust PM (mg/m3)	Exhaust PM Vis. (m-1)	Temp (°C)	flow (m3/s)	NO2 (g/s)	CO (g/s)	Non-exhaust PM (g/s)	Exhaust PM (g/s)	T (°C)	Delta T Ambient (°C)
0	241	241	481	644	0	22.3	0.18	3.11	0.13	0.0004	42.8	325	0.093	0.95	0.03	0.022	37.6	15.3
1	103	103	206	359	0	21.5	0.13	1.72	0.09	0.0003	41.1	326	0.064	0.53	0.02	0.016	36.2	14.7
2	83	83	166	299	0	21.0	0.08	1.66	0.07	0.0002	40.0	302	0.039	0.46	0.02	0.009	34.9	13.9
3	83	83	166	294	0	20.0	0.08	1.66	0.07	0.0002	39.4	303	0.038	0.46	0.02	0.009	34.2	14.2
4	102	102	204	292	0	18.5	0.09	1.87	0.07	0.0002	39.2	282	0.038	0.47	0.02	0.009	33.2	14.7
5	154	154	309	293	0	18.0	0.12	2.36	0.09	0.0003	39.3	240	0.038	0.47	0.02	0.009	32.0	14.0
6	265	265	530	633	0	19.5	0.20	3.40	0.14	0.0004	40.3	310	0.093	0.97	0.03	0.022	34.8	15.3
7	769	769	1538	2314	0	22.5	0.35	6.98	0.27	0.0008	43.5	454	0.269	3.21	0.10	0.062	39.7	17.2
8	1234	1234	2468	3756	0	24.2	0.50	10.23	0.41	0.0011	48.0	422	0.352	4.32	0.14	0.084	43.3	19.1
9	1145	1145	2290	3699	0	26.8	0.50	9.40	0.39	0.0011	48.1	452	0.381	4.30	0.15	0.092	44.3	17.5
10	1197	1197	2394	3643	0	31.6	0.55	9.80	0.42	0.0013	50.0	428	0.392	4.21	0.15	0.096	46.3	14.7
11	1186	1186	2372	3612	0	34.3	0.56	9.73	0.42	0.0013	50.8	426	0.401	4.15	0.15	0.099	47.6	13.4
12	1146	1146	2292	3602	0	34.3	0.54	9.32	0.40	0.0012	51.0	446	0.403	4.20	0.15	0.098	47.8	13.6
13	1131	1131	2262	3607	0	34.1	0.55	9.31	0.40	0.0013	51.7	441	0.404	4.14	0.15	0.099	48.3	14.3
14	1121	1121	2241	3600	0	34.2	0.55	9.38	0.40	0.0013	52.4	435	0.401	4.10	0.15	0.098	48.9	14.8
15	1200	1200	2401	3621	0	34.2	0.57	10.03	0.43	0.0013	53.5	414	0.390	4.13	0.14	0.096	49.7	15.5
16	1334	1334	2669	3670	0	33.8	0.63	11.69	0.48	0.0014	55.9	364	0.368	4.11	0.14	0.090	50.8	17.1
17	1472	1472	2944	3709	0	32.9	0.66	13.32	0.51	0.0015	57.9	334	0.348	4.17	0.13	0.084	51.7	18.8
18	1250	1250	2500	3708	0	31.9	0.56	10.87	0.44	0.0013	55.9	388	0.357	4.14	0.14	0.086	50.8	18.9
19	951	951	1901	3672	0	31.0	0.50	9.05	0.36	0.0011	54.9	436	0.364	3.99	0.13	0.087	50.3	19.4
20	779	779	1558	3648	0	30.1	0.47	8.36	0.33	0.0011	54.6	454	0.360	3.86	0.12	0.086	50.2	20.1
21	679	679	1357	2275	0	27.7	0.33	6.45	0.25	0.0007	50.3	472	0.265	3.12	0.10	0.061	46.4	18.7
22	603	603	1206	2049	0	23.9	0.31	5.91	0.24	0.0007	49.5	470	0.250	2.85	0.09	0.058	45.0	21.1
23	385	385	770	1106	0	21.8	0.22	4.36	0.17	0.0005	47.2	381	0.137	1.63	0.05	0.032	41.7	20.0

Table D.4. New M5 with M4-M5 Link westbound 2031 regulatory traffic (winter). Stage 2 and 3 regulatory WB 2031_v1.xlsx

Hour	New M5 traffic				No. of jet fans running	Ambient	Peak in-tunnel levels (New M5)					M5 outlet							Southern Connector outlet						
	M5 off (vph)	SC off (vph)	SPI on (vph)	New M5 on (vph)		(°C)	NO2 (ppm)	CO (ppm)	Non-exhaust PM (mg/m3)	Exhaust PM Vis. (m-1)	Temp (°C)	flow (m3/s)	NO2 (g/s)	CO (g/s)	Non-exhaust PM (g/s)	Exhaust PM (g/s)	T (°C)	Delta T Ambient (°C)	flow (m3/s)	NO2 (g/s)	CO (g/s)	Non-exhaust PM (g/s)	Exhaust PM (g/s)	T (°C)	Delta T Ambient (°C)
0	401	171	201	341	9	10.8	0.19	4.1	0.19	0.0004	30.1	362	0.111	1.42	0.053	0.027	25.1	14.4	322	0.05	0.77	0.03	0.012	24.7	13.9
1	77	81	94	62	3	10.3	0.14	2.8	0.14	0.0003	29.3	253	0.047	0.55	0.023	0.012	22.0	11.8	242	0.03	0.42	0.02	0.007	22.8	12.5
2	50	81	90	38	2	9.6	0.08	1.3	0.08	0.0002	29.1	245	0.027	0.26	0.012	0.007	21.4	11.8	236	0.02	0.25	0.01	0.004	22.4	12.8
3	47	80	90	37	2	9.1	0.07	1.1	0.06	0.0002	29.0	246	0.023	0.18	0.009	0.006	21.2	12.1	237	0.01	0.21	0.01	0.003	22.1	13.1
4	101	156	147	114	3	8.5	0.07	1.5	0.07	0.0002	29.1	282	0.028	0.28	0.011	0.007	22.0	13.5	274	0.02	0.34	0.01	0.005	23.0	14.5
5	338	241	259	322	8	7.5	0.12	2.6	0.10	0.0003	29.7	369	0.069	0.88	0.028	0.017	24.0	16.5	338	0.04	0.68	0.02	0.009	23.9	16.4
6	533	338	461	410	10	6.5	0.20	4.0	0.17	0.0005	30.1	415	0.130	1.57	0.055	0.032	24.8	18.3	372	0.06	1.06	0.03	0.015	24.2	17.7
7	1123	467	852	735	17	6.5	0.27	5.9	0.26	0.0006	30.9	505	0.232	3.01	0.105	0.055	26.6	20.1	425	0.10	1.58	0.06	0.025	24.8	18.3
8	1538	850	1394	1009	20	7.8	0.35	8.1	0.36	0.0008	31.5	567	0.342	4.72	0.168	0.081	27.9	20.1	478	0.17	2.87	0.10	0.041	25.9	18.1
9	1241	1002	1496	720	15	10.0	0.39	7.7	0.39	0.0009	31.4	532	0.350	4.30	0.173	0.085	27.9	17.9	480	0.20	3.36	0.12	0.050	26.4	16.5
10	1168	1413	1667	955	11	12.7	0.42	8.4	0.41	0.0010	31.6	536	0.376	4.11	0.175	0.093	28.5	15.8	512	0.26	4.29	0.15	0.064	27.6	14.9
11	1150	1957	2188	948	9	13.9	0.44	9.6	0.42	0.0010	31.7	542	0.407	4.28	0.188	0.102	28.9	15.0	541	0.32	5.30	0.19	0.079	28.5	14.6
12	1132	2087	2425	793	7	13.9	0.41	9.6	0.41	0.0010	31.6	531	0.370	4.14	0.178	0.092	28.7	14.8	542	0.31	5.34	0.18	0.075	28.7	14.8
13	1148	2182	2583	776	7	14.0	0.43	9.9	0.42	0.0010	31.8	541	0.390	4.18	0.183	0.097	28.9	14.9	550	0.32	5.54	0.19	0.079	29.0	15.0
14	1183	2357	2741	841	7	14.0	0.43	10.4	0.42	0.0010	31.8	544	0.396	4.33	0.188	0.098	29.0	15.0	561	0.35	5.96	0.20	0.085	29.3	15.3
15	1267	2706	3064	988	6	13.5	0.43	11.4	0.46	0.0010	32.4	553	0.401	4.73	0.198	0.099	29.1	15.6	578	0.38	6.74	0.23	0.094	29.8	16.3
16	1606	3232	3584	1454	12	13.0	0.47	12.6	0.54	0.0011	33.1	599	0.483	6.17	0.247	0.118	29.7	16.7	582	0.43	7.54	0.27	0.106	30.5	17.5
17	1920	3913	4149	1949	19	12.5	0.50	14.6	0.63	0.0012	34.3	636	0.553	7.51	0.296	0.135	30.2	17.7	564	0.47	8.42	0.30	0.112	31.3	18.8
18	1472	3647	3057	1585	8	12.0	0.42	12.8	0.53	0.0010	33.8	572	0.416	6.14	0.236	0.100	29.2	17.2	583	0.42	7.79	0.27	0.101	31.0	19.0
19	1139	1869	2058	877	8	12.0	0.36	9.1	0.41	0.0008	32.5	518	0.319	4.51	0.174	0.076	28.5	16.5	519	0.26	4.82	0.16	0.060	29.4	17.4
20	1019	1121	1600	485	10	11.9	0.30	7.2	0.33	0.0007	31.8	492	0.254	3.61	0.134	0.060	28.1	16.2	467	0.17	3.15	0.11	0.041	28.3	16.5
21	924	888	1323	465	11	9.9	0.28	6.5	0.29	0.0006	31.6	475	0.218	3.07	0.111	0.052	27.5	17.6	443	0.14	2.56	0.08	0.032	27.5	17.7
22	840	809	1236	392	10	8.0	0.25	5.9	0.26	0.0006	31.4	460	0.191	2.74	0.098	0.045	26.7	18.7	432	0.12	2.31	0.07	0.029	27.0	19.0
23	597	270	343	467	11	8.0	0.23	5.2	0.24	0.0005	31.1	408	0.152	2.03	0.076	0.036	25.8	17.8	357	0.07	1.06	0.04	0.017	25.3	17.3

Hour	M4 - M5 Link Traffic				No. of jet fans running	Ambient	M4 - M5 Link Peak in-tunnel levels					SPI outlet						
	CWL on (vph)	WHT on (vph)	Rozelle on (vph)	SPI off (vph)		T (°C)	NO2 (ppm)	CO (ppm)	Non-exhaust PM (mg/m3)	Exhaust PM Vis. (m-1)	Temp (°C)	flow (m3/s)	NO2 (g/s)	CO (g/s)	Non-exhaust PM (g/s)	Exhaust PM (g/s)	T (°C)	Delta T Ambient (°C)
0	241	241	482	649	0	10.8	0.18	3.08	0.13	0.0004	32.7	328	0.093	0.95	0.03	0.022	27.2	16.5
1	103	103	206	352	0	10.3	0.13	1.70	0.09	0.0003	31.2	328	0.064	0.52	0.02	0.016	25.9	15.7
2	83	83	166	298	0	9.6	0.08	1.65	0.07	0.0002	30.1	304	0.039	0.46	0.02	0.009	24.6	15.1
3	83	83	166	294	0	9.1	0.08	1.65	0.07	0.0002	29.7	303	0.038	0.46	0.02	0.009	24.1	15.0
4	102	102	204	293	0	8.5	0.09	1.86	0.07	0.0002	29.5	282	0.037	0.47	0.01	0.009	23.3	14.8
5	154	154	309	294	0	7.5	0.11	2.34	0.09	0.0003	29.5	243	0.038	0.47	0.02	0.009	22.0	14.5
6	266	266	531	651	0	6.5	0.19	3.35	0.14	0.0004	30.5	317	0.094	0.98	0.03	0.022	24.2	17.7
7	769	769	1539	2330	0	6.5	0.34	6.88	0.27	0.0008	33.5	462	0.271	3.25	0.10	0.063	28.6	22.1
8	1234	1234	2468	3756	0	7.8	0.49	10.07	0.40	0.0011	37.7	432	0.356	4.37	0.14	0.085	31.9	24.1
9	1145	1145	2290	3699	0	10.0	0.49	9.24	0.39	0.0011	37.9	461	0.385	4.35	0.15	0.093	32.8	22.8
10	1197	1197	2394	3644	0	12.7	0.54	9.59	0.41	0.0012	39.4	441	0.398	4.27	0.15	0.097	34.2	21.6
11	1186	1186	2372	3611	0	13.9	0.55	9.50	0.41	0.0013	40.0	440	0.407	4.22	0.15	0.100	35.1	21.2
12	1146	1146	2292	3602	0	13.9	0.52	9.10	0.39	0.0012	40.1	460	0.408	4.26	0.15	0.100	35.3	21.4
13	1131	1131	2262	3607	0	14.0	0.53	9.07	0.40	0.0012	40.7	456	0.410	4.21	0.15	0.101	35.8	21.8
14	1121	1121	2241	3600	0	14.0	0.53	9.13	0.39	0.0012	41.3	450	0.407	4.17	0.15	0.100	36.2	22.2
15	1201	1201	2401	3622	0	13.5	0.55	9.73	0.42	0.0013	42.2	430	0.397	4.20	0.15	0.097	36.6	23.1
16	1335	1335	2669	3670	0	13.0	0.60	11.27	0.46	0.0014	44.1	381	0.376	4.20	0.14	0.092	37.3	24.3
17	1472	1472	2944	3709	0	12.5	0.63	12.80	0.50	0.0014	45.9	350	0.356	4.28	0.14	0.086	37.9	25.4
18	1250	1250	2500	3708	0	12.0	0.54	10.50	0.42	0.0012	44.1	404	0.364	4.23	0.14	0.087	37.4	25.4
19	951	951	1901	3672	0	12.0	0.48	8.81	0.35	0.0011	43.1	450	0.368	4.04	0.13	0.088	37.3	25.3
20	779	779	1558	3648	0	11.9	0.45	8.15	0.32	0.0010	42.8	466	0.363	3.90	0.13	0.087	37.2	25.4
21	679	679	1357	2276	0	9.9	0.32	6.32	0.25	0.0007	38.7	484	0.268	3.15	0.10	0.062	33.7	23.8
22	603	603	1206	2049	0	8.0	0.31	5.80	0.23	0.0007	37.7	480	0.252	2.87	0.09	0.059	32.5	24.5
23	385	385	770	1106	0	8.0	0.22	4.29	0.17	0.0005	35.5	388	0.138	1.64	0.05	0.032	29.6	21.6

Table D.5. New M5 eastbound 2021 regulatory traffic (summer). Stage 2 Eastbound 2021 24hrs Regulatory.xlsx

Hour	New M5		Number of Jet Fans Main tube	Ambient	Peak in-tunnel levels (before Kogarah outlet)					Kogarah outlet								Peak in-tunnel levels (before SPI outlet)					SPI outlet						
	M5 Flow (vph)	SPI off (vph)		(°C)	NO_2 (ppm)	CO (ppm)	Non-exhaust PM (mg/m3)	Exhaust PM Vis. (m-1)	Temp (°C)	supply flow (m3/s)	exhaust flow (m3/s)	NO_2 (g/s)	CO (g/s)	Non-exhaust PM (g/s)	Exhaust PM (g/s)	T (°C)	Delta T Ambient (°C)	NO_2 (ppm)	CO (ppm)	Non-exhaust PM (mg/m3)	Exhaust PM Vis. (m-1)	Temp (°C)	flow (m3/s)	NO_2 (g/s)	CO (g/s)	Non-exhaust PM (g/s)	Exhaust PM (g/s)	T (°C)	Delta T Ambient (°C)
0	222	235	0.0	22.3	0.04	0.7	0.06	0.0001	24.6	250	317	0.023	0.23	0.017	0.0066	24.1	1.8	0.07	1.0	0.04	0.0002	28.2	266	0.028	0.25	0.008	0.0068	26.5	4.2
1	156	168	0.0	21.5	0.04	0.5	0.06	0.0001	24.5	230	285	0.019	0.14	0.013	0.0056	23.8	2.3	0.07	0.7	0.04	0.0002	28.0	246	0.024	0.16	0.007	0.0060	26.0	4.5
2	138	138	0.0	21.0	0.04	0.5	0.06	0.0001	24.5	229	280	0.019	0.13	0.012	0.0058	23.7	2.7	0.07	0.7	0.04	0.0002	27.9	245	0.024	0.14	0.006	0.0060	25.7	4.8
3	138	138	0.0	20.0	0.04	0.5	0.06	0.0001	24.4	234	278	0.019	0.12	0.012	0.0057	23.5	3.5	0.07	0.7	0.04	0.0002	27.7	251	0.024	0.15	0.006	0.0061	25.4	5.4
4	145	144	0.0	18.5	0.05	0.6	0.06	0.0001	24.5	250	291	0.021	0.16	0.014	0.0063	23.2	4.7	0.07	0.9	0.04	0.0002	27.6	268	0.026	0.19	0.007	0.0065	25.1	6.6
5	284	265	0.0	18.0	0.05	0.9	0.07	0.0001	24.6	285	342	0.027	0.28	0.019	0.0077	23.4	5.4	0.07	1.3	0.04	0.0002	27.7	304	0.033	0.35	0.010	0.0078	25.3	7.3
6	1,636	1,494	0.0	19.5	0.10	2.7	0.18	0.0003	25.7	487	614	0.114	1.77	0.096	0.0292	25.1	5.6	0.15	3.8	0.11	0.0003	29.6	515	0.130	2.02	0.049	0.0291	28.1	8.6
7	3,419	3,068	0.0	22.5	0.16	5.1	0.32	0.0004	27.1	542	671	0.192	3.53	0.184	0.0508	26.8	4.3	0.22	5.7	0.19	0.0005	32.0	571	0.214	3.36	0.093	0.0506	30.7	8.2
8	3,877	3,764	0.0	24.2	0.23	6.1	0.39	0.0006	28.1	512	627	0.251	4.06	0.217	0.0738	27.9	3.7	0.30	6.3	0.24	0.0007	34.0	541	0.285	3.56	0.112	0.0726	32.9	8.7
9	3,801	3,788	0.0	26.8	0.27	7.3	0.43	0.0008	28.7	500	587	0.285	4.58	0.223	0.0857	28.7	1.9	0.33	6.7	0.25	0.0008	34.9	525	0.297	3.63	0.115	0.0767	34.0	7.2
10	2,864	2,945	0.0	31.6	0.17	3.6	0.27	0.0004	27.6	573	723	0.220	2.81	0.178	0.0618	28.0	-3.6	0.25	4.9	0.18	0.0006	33.5	591	0.268	3.10	0.096	0.0647	33.4	1.8
11	2,691	2,737	0.0	34.3	0.16	3.3	0.26	0.0004	27.7	561	708	0.205	2.54	0.165	0.0575	28.3	-5.9	0.25	4.6	0.17	0.0005	34.9	575	0.250	2.82	0.086	0.0593	33.9	-0.4
12	2,475	2,515	0.0	34.3	0.15	3.1	0.24	0.0004	27.8	548	694	0.192	2.34	0.151	0.0539	28.4	-5.8	0.24	4.4	0.16	0.0005	34.6	563	0.234	2.64	0.079	0.0556	33.9	-0.3
13	2,330	2,345	0.0	34.1	0.15	2.9	0.23	0.0004	27.9	537	682	0.181	2.17	0.140	0.0509	28.5	-5.6	0.23	4.3	0.15	0.0005	34.5	552	0.220	2.49	0.074	0.0526	33.9	-0.1
14	2,052	2,088	0.0	34.2	0.14	2.7	0.21	0.0004	27.9	518	659	0.165	1.90	0.127	0.0465	28.5	-5.6	0.22	3.9	0.14	0.0005	34.4	532	0.203	2.19	0.067	0.0483	33.9	-0.2
15	1,878	1,897	0.0	34.2	0.13	2.6	0.21	0.0003	28.0	503	644	0.153	1.78	0.119	0.0428	28.6	-5.6	0.21	3.8	0.14	0.0005	34.3	517	0.188	2.04	0.062	0.0444	34.0	-0.2
16	1,873	1,869	0.0	33.8	0.13	2.7	0.21	0.0003	28.1	503	642	0.150	1.83	0.120	0.0412	28.7	-5.1	0.20	3.9	0.14	0.0004	34.1	518	0.183	2.07	0.063	0.0427	34.0	0.3
17	2,050	2,022	0.0	32.9	0.13	2.9	0.22	0.0003	28.3	515	654	0.155	2.03	0.129	0.0420	28.8	-4.0	0.20	4.1	0.14	0.0004	34.3	532	0.187	2.27	0.067	0.0432	34.1	1.3
18	1,886	1,949	0.0	31.9	0.11	2.6	0.18	0.0003	28.2	487	624	0.121	1.77	0.103	0.0314	28.7	-3.2	0.16	3.9	0.12	0.0003	33.8	504	0.147	2.05	0.054	0.0330	33.7	1.8
19	1,486	1,511	0.0	31.0	0.10	2.4	0.16	0.0002	28.1	459	588	0.101	1.48	0.084	0.0263	28.5	-2.4	0.15	3.6	0.11	0.0003	33.5	476	0.120	1.73	0.044	0.0270	33.1	2.2
20	1,237	1,285	0.0	30.1	0.09	2.0	0.14	0.0002	28.0	429	553	0.087	1.19	0.069	0.0235	28.3	-1.7	0.14	3.1	0.09	0.0003	33.2	446	0.105	1.42	0.036	0.0242	32.7	2.7
21	1,118	1,124	0.0	27.7	0.09	2.0	0.14	0.0002	28.0	424	540	0.084	1.12	0.066	0.0228	28.1	0.4	0.14	3.0	0.09	0.0003	33.1	443	0.102	1.33	0.035	0.0235	32.2	4.5
22	1,055	1,066	0.0	23.9	0.09	1.9	0.14	0.0002	28.1	418	526	0.081	1.05	0.063	0.0219	27.7	3.8	0.13	2.8	0.09	0.0003	32.8	443	0.097	1.24	0.033	0.0226	31.4	7.5
23	464	562	0.0	21.8	0.05	1.0	0.08	0.0001	27.5	300	374	0.033	0.39	0.025	0.0093	26.7	5.0	0.08	1.4	0.05	0.0002	31.6	320	0.043	0.47	0.014	0.0101	29.5	7.8

Table D.6. New M5 eastbound 2021 regulatory traffic (winter). Stage 2 Eastbound 2021 24hrs Regulatory.xlsx

Hour	New M5		Number of Jet Fans Main tube	Ambient	Peak in-tunnel levels (before Kogarah outlet)					Kogarah outlet								Peak in-tunnel levels (before SPI outlet)					SPI outlet						
	M5 Flow (vph)	SPI off (vph)		(°C)	NO_2 (ppm)	CO (ppm)	Non-exhaust PM (mg/m3)	Exhaust PM Vis. (m-1)	Temp (°C)	supply flow (m3/s)	exhaust flow (m3/s)	NO_2 (g/s)	CO (g/s)	Non-exhaust PM (g/s)	Exhaust PM (g/s)	T (°C)	Delta T Ambient (°C)	NO_2 (ppm)	CO (ppm)	Non-exhaust PM (mg/m3)	Exhaust PM Vis. (m-1)	Temp (°C)	flow (m3/s)	NO_2 (g/s)	CO (g/s)	Non-exhaust PM (g/s)	Exhaust PM (g/s)	T (°C)	Delta T Ambient (°C)
0	217	222	0.0	10.8	0.05	0.7	0.07	0.0001	17.8	265	313	0.022	0.22	0.016	0.0065	16.5	5.7	0.07	1.0	0.04	0.0002	22.1	285	0.028	0.25	0.008	0.0068	19.0	8.3
1	141	146	0.0	10.3	0.04	0.5	0.06	0.0001	17.7	245	279	0.019	0.14	0.013	0.0056	16.1	5.8	0.06	0.7	0.03	0.0001	21.8	263	0.024	0.16	0.007	0.0060	18.5	8.2
2	138	138	0.0	9.6	0.04	0.5	0.06	0.0001	17.7	247	276	0.019	0.13	0.012	0.0058	15.9	6.4	0.06	0.6	0.03	0.0001	21.6	266	0.024	0.15	0.006	0.0061	18.2	8.6
3	138	138	0.0	9.1	0.04	0.5	0.06	0.0001	17.7	247	275	0.019	0.13	0.012	0.0058	15.8	6.7	0.06	0.6	0.03	0.0001	21.5	267	0.024	0.15	0.006	0.0061	18.0	8.9
4	172	168	0.0	8.5	0.05	0.6	0.06	0.0001	17.7	261	294	0.021	0.16	0.014	0.0064	15.8	7.3	0.06	0.8	0.03	0.0001	21.4	282	0.027	0.20	0.007	0.0066	17.9	9.4
5	290	280	0.0	7.5	0.05	0.9	0.07	0.0001	17.8	294	341	0.027	0.28	0.019	0.0078	16.0	8.5	0.07	1.2	0.04	0.0002	21.4	317	0.033	0.35	0.010	0.0078	18.1	10.6
6	1,741	1,721	0.0	6.5	0.10	2.7	0.17	0.0002	18.8	495	619	0.114	1.78	0.096	0.0293	17.7	11.2	0.14	3.7	0.11	0.0003	23.1	534	0.134	2.08	0.050	0.0299	20.9	14.4
7	3,679	3,514	0.0	6.5	0.17	5.2	0.32	0.0004	20.2	580	672	0.200	3.76	0.192	0.0533	19.2	12.7	0.22	5.6	0.18	0.0005	25.0	628	0.241	3.75	0.100	0.0558	23.0	16.5
8	3,880	3,825	0.0	7.8	0.22	5.9	0.38	0.0006	21.0	577	641	0.255	4.09	0.219	0.0748	20.0	12.2	0.28	5.7	0.21	0.0006	26.2	624	0.306	3.81	0.115	0.0747	24.2	16.4
9	3,833	3,726	0.0	10.0	0.24	6.3	0.39	0.0007	21.2	526	651	0.278	4.46	0.231	0.0829	20.5	10.5	0.32	6.2	0.23	0.0008	27.3	567	0.318	3.75	0.113	0.0807	25.2	15.3
10	2,862	3,299	0.0	12.7	0.17	3.6	0.28	0.0005	20.5	455	709	0.220	2.80	0.177	0.0618	20.0	7.3	0.44	7.7	0.24	0.0011	29.8	489	0.374	3.99	0.103	0.1030	27.5	14.9
11	2,633	2,634	0.0	13.9	0.16	3.3	0.26	0.0004	20.5	568	708	0.205	2.53	0.164	0.0573	20.1	6.2	0.24	4.5	0.16	0.0005	25.9	603	0.252	2.86	0.086	0.0592	24.6	10.7
12	2,409	2,421	0.0	13.9	0.15	3.1	0.24	0.0004	20.5	556	695	0.191	2.33	0.151	0.0538	20.1	6.2	0.23	4.3	0.15	0.0005	25.8	591	0.236	2.68	0.079	0.0556	24.4	10.5
13	2,204	2,217	0.0	14.0	0.15	2.9	0.23	0.0004	20.5	544	682	0.180	2.15	0.139	0.0506	20.1	6.1	0.22	4.1	0.14	0.0005	25.7	577	0.221	2.50	0.073	0.0523	24.3	10.3
14	1,960	1,978	0.0	14.0	0.14	2.7	0.21	0.0004	20.5	521	657	0.164	1.88	0.126	0.0463	20.0	6.0	0.21	3.7	0.14	0.0005	25.5	553	0.203	2.18	0.066	0.0481	24.0	10.0
15	1,854	1,869	0.0	13.5	0.13	2.6	0.21	0.0003	20.5	510	644	0.153	1.78	0.119	0.0427	19.9	6.4	0.20	3.6	0.13	0.0004	25.3	542	0.189	2.05	0.062	0.0444	23.8	10.3
16	1,927	1,920	0.0	13.0	0.13	2.7	0.21	0.0003	20.5	510	643	0.150	1.84	0.121	0.0411	19.9	6.9	0.19	3.7	0.13	0.0004	25.3	543	0.184	2.10	0.063	0.0427	23.7	10.7
17	2,133	2,119	0.0	12.5	0.13	2.9	0.22	0.0003	20.7	524	658	0.156	2.05	0.129	0.0421	20.1	7.6	0.19	4.0	0.14	0.0004	25.4	559	0.190	2.33	0.068	0.0436	23.8	11.3
18	1,779	1,797	0.0	12.0	0.11	2.6	0.18	0.0003	20.5	492	621	0.119	1.76	0.101	0.0307	19.8	7.8	0.16	3.7	0.12	0.0003	24.7	525	0.142	2.03	0.053	0.0317	23.0	11.0
19	1,475	1,485	0.0	12.0	0.10	2.3	0.16	0.0002	20.4	466	589	0.101	1.47	0.084	0.0263	19.6	7.6	0.14	3.4	0.10	0.0003	24.3	496	0.120	1.73	0.044	0.0271	22.5	10.5
20	1,153	1,166	0.0	11.9	0.09	2.0	0.14	0.0002	20.2	436	550	0.087	1.17	0.068	0.0234	19.3	7.5	0.13	2.9	0.09	0.0003	23.9	464	0.104	1.39	0.036	0.0241	22.0	10.2
21	1,108	1,115	0.0	9.9	0.09	2.0	0.14	0.0002	20.2	431	541	0.085	1.12	0.066	0.0229	19.1	9.3	0.13	2.8	0.09	0.0003	23.7	462	0.102	1.33	0.035	0.0236	21.5	11.7
22	1,046	1,055	0.0	8.0	0.09	1.9	0.14	0.0002	20.1	424	528	0.081	1.05	0.063	0.0219	18.8	10.8	0.13	2.7	0.08	0.0003	23.4	456	0.097	1.24	0.033	0.0226	21.0	13.0
23	361	375	0.0	8.0	0.05	1.0	0.08	0.0001	19.5	307	362	0.032	0.37	0.025	0.0090	17.6	9.6	0.08	1.4	0.05	0.0002	22.2	331	0.040	0.43	0.013	0.0094	19.0	11.0

APPENDIX E - REGULATORY CONGESTED TRAFFIC SIMULATION RESULTS

Results from the simulation of regulatory congested traffic in New M5, and New M5 with connected M4-M5 Link, up to Rozelle.

Table E.1. New M5 with M4-M5 Link eastbound 2031 regulatory traffic congested 9am (summer). Stage 2 and 3 regulatory EB 2031 congested.xlsx

Case	New M5 traffic			No. of jet fans running		Ambient	Peak in-tunnel levels (before Kogarah outlet)					Kogarah outlet								Peak in-tunnel levels (before SPI outlet)					SPI outlet						
	M5 on (vph)	SC on (vph)	SPI off (vph)	SC	Main tube	(°C)	NO2 (ppm)	CO (ppm)	Non-exhaust PM (mg/m3)	Exhaust PM Vis. (m-1)	Temp (°C)	supply flow (m3/s)	exhaust flow (m3/s)	NO2 (g/s)	CO (g/s)	Non-exhaust PM (g/s)	Exhaust PM (g/s)	T (°C)	Delta T Ambient (°C)	NO2 (ppm)	CO (ppm)	Non-exhaust PM (mg/m3)	Exhaust PM Vis. (m-1)	Temp (°C)	flow (m3/s)	NO2 (g/s)	CO (g/s)	Non-exhaust PM (g/s)	Exhaust PM (g/s)	T (°C)	Delta T Ambient (°C)
20 km/hr	1,544	4,117	3,392	0.0	0.0	24.2	0.14	5.0	0.29	0.0003	27.7	714	1,193	0.262	4.79	0.247	0.0667	26.5	2.3	0.32	7.9	0.25	0.0007	36.9	375	0.193	2.89	0.077	0.0463	34.6	10.4
40 km/hr	1,544	4,117	4,180	0.0	0.0	24.2	0.14	5.0	0.29	0.0003	27.7	717	1,193	0.262	4.79	0.247	0.0667	26.5	2.3	0.29	7.5	0.24	0.0006	35.4	473	0.232	3.62	0.098	0.0548	34.0	9.8
60 km/hr	1,544	4,117	4,185	0.0	0.0	24.2	0.14	5.0	0.29	0.0003	27.7	742	1,193	0.262	4.79	0.247	0.0667	26.5	2.3	0.28	7.4	0.23	0.0006	35.1	481	0.228	3.67	0.097	0.0531	33.7	9.5
80 km/hr	1,544	4,117	4,188	0.0	0.0	24.2	0.14	5.0	0.29	0.0003	27.7	763	1,193	0.262	4.79	0.247	0.0667	26.5	2.3	0.28	7.5	0.23	0.0006	35.1	479	0.226	3.69	0.095	0.0519	33.7	9.5

Case	M4 - M5 Link traffic					No. of jet fans running		Ambient	Peak in-tunnel levels (M4 - M5 Link)					WHT-Rozelle outlets combined						
	M4-M5 Link on (vph)	SPI on (vph)	CWL off	WHT off	Rozelle off	St Peters On	CWL	T (°C)	NO2 (ppm)	CO (ppm)	Non-exhaust PM (mg/m3)	Exhaust PM Vis. (m-1)	Temp (°C)	flow (m3/s)	NO2 (g/s)	CO (g/s)	Non-exhaust PM (g/s)	Exhaust PM (g/s)	T (°C)	Delta T Ambient (°C)
20 km/hr	1,458	3,420	1,209	1,208	2,417	0	0	24.2	0.88	17.3	0.70	0.0023	46.7	676	0.822	9.65	0.327	0.2313	38.1	13.9
40 km/hr	1,458	3,793	1,306	1,305	2,612	0	0	24.2	0.61	11.5	0.57	0.0015	43.2	831	0.761	8.61	0.356	0.2029	37.5	13.3
60 km/hr	1,458	3,793	1,305	1,305	2,610	0	0	24.2	0.53	10.0	0.51	0.0013	42.0	903	0.741	8.39	0.356	0.1895	37.1	12.9
80 km/hr	1,458	3,793	1,306	1,306	2,612	0	0	24.2	0.49	9.4	0.47	0.0011	41.4	972	0.756	8.66	0.358	0.1867	37.0	12.8

Table E.2. New M5 with M4-M5 Link eastbound 2031 regulatory traffic congested 9am (winter). Stage 2 and 3 regulatory EB 2031 congested.xlsx

Case	New M5 traffic			No. of jet fans running		Ambient	Peak in-tunnel levels (before Kogarah outlet)					Kogarah outlet								Peak in-tunnel levels (before SPI outlet)					SPI outlet						
	M5 on (vph)	SC on (vph)	SPI off (vph)	SC	Main tube	(°C)	NO2 (ppm)	CO (ppm)	Non-exhaust PM (mg/m3)	Exhaust PM Vis. (m-1)	Temp (°C)	supply flow (m3/s)	exhaust flow (m3/s)	NO2 (g/s)	CO (g/s)	Non-exhaust PM (g/s)	Exhaust PM (g/s)	T (°C)	Delta T Ambient (°C)	NO2 (ppm)	CO (ppm)	Non-exhaust PM (mg/m3)	Exhaust PM Vis. (m-1)	Temp (°C)	flow (m3/s)	NO2 (g/s)	CO (g/s)	Non-exhaust PM (g/s)	Exhaust PM (g/s)	T (°C)	Delta T Ambient (°C)
20 km/hr	1,544	4,117	3,392	0.0	0.0	7.8	0.13	4.9	0.28	0.0003	20.2	682	1,228	0.262	4.79	0.247	0.0667	18.9	11.1	0.32	8.0	0.25	0.0007	28.4	374	0.196	2.93	0.078	0.0470	24.7	16.9
40 km/hr	1,544	4,117	4,180	0.0	0.0	7.8	0.13	4.9	0.28	0.0003	20.2	686	1,227	0.262	4.79	0.247	0.0667	18.9	11.1	0.29	7.6	0.25	0.0006	27.0	471	0.235	3.67	0.100	0.0555	24.3	16.5
60 km/hr	1,544	4,117	4,185	0.0	0.0	7.8	0.13	4.9	0.28	0.0003	20.2	711	1,227	0.262	4.79	0.247	0.0667	18.9	11.1	0.28	7.5	0.24	0.0006	26.7	479	0.231	3.71	0.098	0.0537	24.1	16.3
80 km/hr	1,544	4,117	4,188	0.0	0.0	7.8	0.13	4.9	0.28	0.0003	20.2	732	1,227	0.262	4.79	0.247	0.0667	18.9	11.1	0.28	7.6	0.23	0.0006	26.7	477	0.228	3.73	0.096	0.0525	24.1	16.3

Case	M4 - M5 Link traffic					No. of jet fans running		Ambient	Peak in-tunnel levels (M4 - M5 Link)					WHT-Rozelle outlets combined						
	M4-M5 Link on (vph)	SPI on (vph)	CWL off	WHT off	Rozelle off	St Peters On	CWL	T (°C)	NO2 (ppm)	CO (ppm)	Non-exhaust PM (mg/m3)	Exhaust PM Vis. (m-1)	Temp (°C)	flow (m3/s)	NO2 (g/s)	CO (g/s)	Non-exhaust PM (g/s)	Exhaust PM (g/s)	T (°C)	Delta T Ambient (°C)
20 km/hr	1,458	3,420	1,209	1,208	2,417	0	0	7.8	0.88	17.2	0.70	0.0023	38.1	682	0.832	9.77	0.332	0.2342	27.3	19.5
40 km/hr	1,458	3,793	1,306	1,305	2,611	0	1	7.8	0.61	11.5	0.57	0.0015	34.6	826	0.759	8.58	0.355	0.2023	27.0	19.2
60 km/hr	1,458	3,793	1,305	1,305	2,610	0	2	7.8	0.53	10.0	0.51	0.0013	33.3	898	0.737	8.35	0.354	0.1885	26.7	18.9
80 km/hr	1,458	3,793	1,306	1,306	2,612	0	3	7.8	0.49	9.4	0.47	0.0011	32.7	966	0.752	8.62	0.356	0.1857	26.7	18.9

Table E.3. New M5 with M4-M5 Link westbound 2031 regulatory traffic congested 6pm (summer). Stage 2 and 3 regulatory WB 2031 congested.xlsx

Case	New M5 traffic				No. of jet fans running	Ambient	Peak in-tunnel levels (New M5)					M5 outlet							Southern Connector outlet						
	M5 off (vph)	SC off (vph)	SPI on (vph)	M5 on (vph)		(°C)	NO2 (ppm)	CO (ppm)	Non-exhaust PM (mg/m3)	Exhaust PM Vis. (m-1)	Temp (°C)	flow (m3/s)	NO2 (g/s)	CO (g/s)	Non-exhaust PM (g/s)	Exhaust PM (g/s)	T (°C)	Delta T Ambient (°C)	flow (m3/s)	NO2 (g/s)	CO (g/s)	Non-exhaust PM (g/s)	Exhaust PM (g/s)	T (°C)	Delta T Ambient (°C)
20 km/hr	1976	3399	4170	1991	29	32.9	0.55	16.2	0.64	0.0012	43.7	648	0.576	7.45	0.309	0.143	39.9	7.0	509	0.47	8.32	0.27	0.112	42.1	9.3
40 km/hr	1917	3910	4150	1946	17	32.9	0.51	14.8	0.64	0.0012	42.9	622	0.547	7.26	0.293	0.134	39.7	6.9	570	0.48	8.64	0.31	0.115	41.5	8.7
60 km/hr	1937	3969	4159	1962	16	32.9	0.51	14.7	0.63	0.0012	42.7	619	0.543	7.19	0.288	0.132	39.8	6.9	579	0.48	8.66	0.31	0.114	41.5	8.6
80 km/hr	1938	3974	4159	1962	16	32.9	0.51	14.6	0.63	0.0012	42.7	621	0.545	7.29	0.286	0.132	39.8	7.0	581	0.48	8.66	0.31	0.114	41.5	8.6

Case	M4 - M5 Link Traffic				No. of jet fans running	Ambient	M4 - M5 Link Peak in-tunnel levels					SPI outlet						
	CWL on (vph)	WHT on (vph)	Rozelle on (vph)	SPI off (vph)		T (°C)	NO2 (ppm)	CO (ppm)	Non-exhaust PM (mg/m3)	Exhaust PM Vis. (m-1)	Temp (°C)	flow (m3/s)	NO2 (g/s)	CO (g/s)	Non-exhaust PM (g/s)	Exhaust PM (g/s)	T (°C)	Delta T Ambient (°C)
20 km/hr	1473	1473	2946	3141	0	32.9	0.72	12.67	0.52	0.0017	59.5	300	0.328	3.44	0.12	0.084	52.2	19.3
40 km/hr	1472	1472	2944	3822	0	32.9	0.68	13.04	0.51	0.0015	58.5	333	0.354	4.06	0.13	0.086	52.1	19.3
60 km/hr	1473	1473	2945	3843	0	32.9	0.63	12.72	0.49	0.0014	56.7	356	0.355	4.31	0.14	0.085	51.0	18.2
80 km/hr	1473	1473	2945	3845	0	32.9	0.61	12.68	0.49	0.0014	56.2	363	0.357	4.41	0.14	0.085	50.7	17.9

Table E.4. New M5 with M4-M5 Link westbound 2031 regulatory traffic congested 6pm (winter). Stage 2 and 3 regulatory WB 2031 congested.xlsx

Hour	New M5 traffic				No. of jet fans running	Ambient	Peak in-tunnel levels (New M5)					M5 outlet							Southern Connector outlet						
	M5 off (vph)	SC off (vph)	SPI on (vph)	New M5 on (vph)		(°C)	NO2 (ppm)	CO (ppm)	Non-exhaust PM (mg/m3)	Exhaust PM Vis. (m-1)	Temp (°C)	flow (m3/s)	NO2 (g/s)	CO (g/s)	Non-exhaust PM (g/s)	Exhaust PM (g/s)	T (°C)	Delta T Ambient (°C)	flow (m3/s)	NO2 (g/s)	CO (g/s)	Non-exhaust PM (g/s)	Exhaust PM (g/s)	T (°C)	Delta T Ambient (°C)
20 km/hr	1976	3399	4170	1991	29	12.5	0.54	15.9	0.63	0.0012	35.1	662	0.577	7.47	0.310	0.143	30.4	17.9	519	0.47	8.35	0.27	0.113	31.8	19.3
40 km/hr	1938	3951	4161	1966	18	12.5	0.50	14.5	0.63	0.0012	34.3	636	0.552	7.25	0.295	0.135	30.2	17.7	579	0.48	8.64	0.31	0.115	31.5	19.0
60 km/hr	1936	3967	4158	1961	16	12.5	0.49	14.3	0.62	0.0011	34.2	633	0.545	7.25	0.289	0.133	30.2	17.7	588	0.48	8.67	0.31	0.114	31.4	18.9
80 km/hr	1938	3972	4159	1962	16	12.5	0.50	14.4	0.62	0.0011	34.2	635	0.547	7.34	0.288	0.132	30.3	17.8	590	0.48	8.68	0.31	0.114	31.4	18.9

Hour	M4 - M5 Link Traffic				No. of jet fans running	Ambient	M4 - M5 Link Peak in-tunnel levels					SPI outlet						
	CWL on (vph)	WHT on (vph)	Rozelle on (vph)	SPI off (vph)		T (°C)	NO2 (ppm)	CO (ppm)	Non-exhaust PM (mg/m3)	Exhaust PM Vis. (m-1)	Temp (°C)	flow (m3/s)	NO2 (g/s)	CO (g/s)	Non-exhaust PM (g/s)	Exhaust PM (g/s)	T (°C)	Delta T Ambient (°C)
20 km/hr	1473	1473	2946	3141	0	12.5	0.68	12.04	0.50	0.0016	47.8	319	0.337	3.56	0.12	0.086	38.5	26.0
40 km/hr	1473	1473	2946	3825	0	12.5	0.65	12.48	0.50	0.0015	47.0	351	0.362	4.17	0.14	0.088	38.7	26.2
60 km/hr	1473	1473	2945	3843	0	12.5	0.60	12.14	0.48	0.0013	45.1	374	0.363	4.42	0.14	0.087	37.8	25.3
80 km/hr	1473	1473	2945	3844	0	12.5	0.59	12.20	0.47	0.0013	44.7	380	0.365	4.52	0.15	0.087	37.5	25.0

Table E.5. New M5 eastbound 2021 regulatory traffic congested 9am (summer). Stage 2 regulatory EB 2021 congested.xlsx

Case	New M5		Number of Jet Fans Main tube	Ambient	Peak in-tunnel levels (before Kogarah outlet)					Kogarah outlet								Peak in-tunnel levels (before SPI outlet)					SPI outlet						
	M5 Flow (vph)	SPI off (vph)		(°C)	NO_2 (ppm)	CO (ppm)	Non-exhaust PM (mg/m3)	Exhaust PM Vis. (m-1)	Temp (°C)	supply flow (m3/s)	exhaust flow (m3/s)	NO_2 (g/s)	CO (g/s)	Non-exhaust PM (g/s)	Exhaust PM (g/s)	T (°C)	Delta T Ambient (°C)	NO_2 (ppm)	CO (ppm)	Non-exhaust PM (mg/m3)	Exhaust PM Vis. (m-1)	Temp (°C)	flow (m3/s)	NO_2 (g/s)	CO (g/s)	Non-exhaust PM (g/s)	Exhaust PM (g/s)	T (°C)	Delta T Ambient (°C)
20 km/hr	3,504	3,308	0.0	24.2	0.38	10.1	0.45	0.0010	30.3	355	467	0.283	4.53	0.173	0.0791	29.4	5.2	0.53	11.0	0.32	0.0013	38.1	380	0.325	4.08	0.099	0.0855	35.6	11.4
40 km/hr	3,892	3,761	0.0	24.2	0.21	5.5	0.37	0.0006	27.9	516	683	0.253	4.02	0.225	0.0729	27.7	3.5	0.31	6.2	0.24	0.0008	34.3	545	0.289	3.52	0.115	0.0743	33.0	8.8
60 km/hr	3,887	3,764	0.0	24.2	0.21	5.5	0.37	0.0006	27.9	544	687	0.253	4.01	0.225	0.0729	27.7	3.5	0.30	6.0	0.23	0.0007	33.9	573	0.290	3.62	0.116	0.0726	32.7	8.5
80 km/hr	3,889	3,764	0.0	24.2	0.21	5.5	0.37	0.0006	27.8	556	688	0.253	4.02	0.226	0.0730	27.7	3.5	0.29	6.0	0.23	0.0007	33.6	586	0.291	3.71	0.116	0.0725	32.6	8.4

Table E.6. New M5 eastbound 2021 regulatory traffic congested 9am (winter). Stage 2 regulatory EB 2021 congested.xlsx

Case	New M5		Number of Jet Fans Main tube	Ambient	Peak in-tunnel levels (before Kogarah outlet)					Kogarah outlet								Peak in-tunnel levels (before SPI outlet)					SPI outlet						
	M5 Flow (vph)	SPI off (vph)		(°C)	NO_2 (ppm)	CO (ppm)	Non-exhaust PM (mg/m3)	Exhaust PM Vis. (m-1)	Temp (°C)	supply flow (m3/s)	exhaust flow (m3/s)	NO_2 (g/s)	CO (g/s)	Non-exhaust PM (g/s)	Exhaust PM (g/s)	T (°C)	Delta T Ambient (°C)	NO_2 (ppm)	CO (ppm)	Non-exhaust PM (mg/m3)	Exhaust PM Vis. (m-1)	Temp (°C)	flow (m3/s)	NO_2 (g/s)	CO (g/s)	Non-exhaust PM (g/s)	Exhaust PM (g/s)	T (°C)	Delta T Ambient (°C)
20 km/hr	3,503	3,308	0.0	7.8	0.38	10.0	0.45	0.0010	23.1	372	457	0.282	4.51	0.171	0.0787	21.3	13.5	0.49	10.1	0.29	0.0012	30.5	407	0.327	4.09	0.099	0.0864	26.6	18.8
40 km/hr	3,903	3,759	0.0	7.8	0.21	5.5	0.38	0.0006	21.0	512	684	0.256	4.04	0.227	0.0739	19.9	12.1	0.31	6.2	0.24	0.0008	27.4	555	0.293	3.53	0.116	0.0753	24.7	16.9
60 km/hr	3,890	3,770	0.0	7.8	0.21	5.5	0.37	0.0006	20.9	549	688	0.254	4.02	0.226	0.0732	19.9	12.1	0.28	5.8	0.22	0.0007	26.6	594	0.291	3.64	0.116	0.0731	24.3	16.5
80 km/hr	3,893	3,764	0.0	7.8	0.21	5.4	0.37	0.0006	20.8	561	689	0.254	4.03	0.226	0.0733	19.9	12.1	0.27	5.8	0.22	0.0006	26.2	607	0.293	3.73	0.116	0.0729	24.2	16.4

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