NSW GOVERNMENT

Roads and Maritime Services

F6 Extension Stage 1

New M5 Motorway at Arncliffe to President Avenue at Kogarah

Environmental Impact Statement

Appendix E
Air Quality Technical Report

Volume 4

E

Contents

Glossary of terms and abbreviations

Term	Definition
A	
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 the height above mean sea level.
Airshed	A part of the atmosphere that shares a common flow of air and is exposed to similar meteorological influences.
ANSTO	Australian Nuclear Science and Technology Organisation
AQM	air quality management
AWS	automatic weather station
B	
BAM	Beta Attenuation Monitor, a type of instrument used for measuring airborne particulate matter
BTEX	benzene, toluene, ethylbenzene and xylenes
BTS	(NSW) Bureau of Transport Statistics
C	
CALINE	California Line Source Dispersion Model, a steady-state Gaussian dispersion model designed to determine concentrations downwind of highways in relatively uncomplicated terrain
CALMET	A meteorological model that is a component of CALPUFF modelling system
CBD	central business district
COAG	Council of Australian Governments
CO	carbon monoxide
CO_2	carbon dioxide
CSA	cross-sectional area
CSIRO	Commonwealth Scientific and Industrial Research Organisation
D	
DEC	(NSW) Department of Environment and Conservation
DECCW	(NSW) Department of Environment, Climate Change and Water
Defra	(UK) Department for Environment, Food and Rural Affairs
DERM	(Queensland) Department of Environment and Resource Management
DP&E	(NSW) Department of Planning and Environment
DPF	diesel particulate filter
DSEWPC	(Commonwealth) Department of Sustainability, Environment, Water, Population and Communities

Term	Definition
E	
EC	elemental carbon
EIA	Environmental Impact Assessment
EIS	Environmental Impact Statement
Emission factor (EF)	A quantity which expresses the mass of a pollutant emitted per unit of activity. For road transport, the unit of activity is usually either distance (i.e. g/km) or fuel consumed (i.e. g/litre).
Emission rate	A quantity which expresses the mass of a pollutant emitted per unit of time (e.g. g/second)
EP&A Act	*Environmental Planning and Assessment Act 1979* (NSW)
EPHC	Environment Protection Heritage Council
ESP	electrostatic precipitator
EU	European Union
G	
GHG	greenhouse gas
GLC	ground-level concentration
GMR	(NSW) Greater Metropolitan Region
GRAL	Graz Lagrangian Model
GRAMM	Graz Mesoscale Model
GVM	gross vehicle mass
H	
HCV	heavy commercial vehicle (interchangeable with HGV)
HDV	heavy-duty vehicle, which includes heavy goods vehicles, buses and coaches
HGV	heavy goods vehicle (truck)
HVAS	high volume air sampler
I	
IAQM	(UK) Institute of Air Quality Management
L	
LCT	Lane Cove tunnel
LCV	light commercial vehicle
LDV	light-duty vehicle, which includes cars and light commercial vehicles
N	
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

Term	Definition
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	
O_3	Ozone
OC	organic carbon
OEH	(NSW) Office of Environment and Heritage
P	
PAH(s)	polycyclic aromatic hydrocarbon(s)
PIARC	Permanent International Association of Road Congresses
ppb	parts per billion (by volume)
ppm	parts per million (by volume)
PM	(airborne) particulate matter
PM_{10}	airborne particulate matter with an aerodynamic diameter of less than 10 µm
$PM_{2.5}$	airborne particulate matter with an aerodynamic diameter of less than 2.5 µm
PV	passenger vehicle
R	
RH	relative humidity
Roads and Maritime	(NSW) Roads and Maritime Services. For the purpose of presentation, the shortened form 'RMS' is used in some figures and tables of the report.
RWR	Residential, workplace and recreational (RWR). This term refers to all discrete receptor locations included in this air quality assessment, and mainly covers residential and commercial land uses.
S	
SCR	selective catalytic reduction
SEARs	Secretary's Environmental Assessment Requirements
SMC	Sydney Motorway Corporation
SMPM	Strategic Motorway Project Model
SO_2	sulfur dioxide
SO_X	sulfur oxides
SPI	St Peters interchange

Term	Definition
T	
TAPM	The Air Pollution Model
TEOM	Tapered Element Oscillating Microbalance, a type of instrument used for measuring airborne particulate matter
THC	total hydrocarbons
TRAQ	Tool for Roadside Air Quality, an air pollution screening tool developed by Roads and Maritime
TSP	total suspended particulate (matter)
U	
UFP	ultrafine particles (particles with a diameter of less than 0.1 µm)
UK	United Kingdom
UN	United Nations
USA	United States of America
USEPA	United States Environmental Protection Agency
V	
VKT	vehicle-kilometres travelled
VOCs	volatile organic compounds
W	
WHO	World Health Organization
WHTBL	Western Harbour Tunnel and Beaches Link
Other	
$\mu g/m^3$	micrograms per cubic metre

Executive summary

The project

NSW Roads and Maritime Services (Roads and Maritime) is seeking approval under Division 5.2 of the *Environmental Planning and Assessment Act 1979* (EP&A Act) to construct and operate the F6 Extension Stage 1 project. The project would comprise a new multi-lane road between the New M5 Motorway at Arncliffe and President Avenue at Kogarah. The project would connect underground with the New M5 Motorway tunnel and to a new surface-level intersection at President Avenue, Kogarah.

The purpose of this report

This report has been prepared to support the environmental impact statement for the F6 Extension Stage 1 project. The environmental impact statement has been prepared to accompany the application for approval of the project, and to address the requirements of the air quality section of the Secretary's Environmental Assessment Requirements (SEARs) for the project (SSI 7485), issued on 23 January 2018. The report presents an assessment of the construction and operational activities for the project that have the potential to affect in-tunnel, local ambient and regional ambient air quality.

Construction impacts

The potential impacts of the construction phase of the project were assessed using guidance published by the UK Institute of Air Quality Management[1]. The UK guidance was adapted for use in NSW, taking into account factors such as the assessment criteria for ambient particulate matter (PM_{10}) concentrations.

The risks associated with construction dust emissions were assessed for four types of activity: demolition, earthworks, construction, and track-out (the transport of dust and dirt by heavy-duty vehicles from the work sites onto the public road network, where it may be deposited and then re-suspended by other vehicles). The assessment methodology considered three separate dust impacts: annoyance due to dust soiling, the risk of health effects due to an increase in human exposure, and harm to ecological receptors.

Above-ground construction activities for the project would take place at a number of separate locations, and these were grouped into five distinct construction assessment zones for the purpose of the assessment. Several locations and activities were determined to be of high risk. Consequently, a wide range of management measures has been recommended to mitigate the effects of construction works on local air quality at the nearest receptors. Most of the recommended measures are routinely employed as 'good practice' on construction sites.

Dispersion modelling for odour assessment, with conservative assumptions, resulted in marginal short-term nuisance impacts, and the emphasis should therefore focus on management and mitigation.

Operational impacts – in tunnel air quality

The scenarios evaluated for in-tunnel air quality reflected the potential modes of operation of the tunnel ventilation system, as well as a worst-case trip scenario for in-tunnel exposure to nitrogen dioxide (NO_2). NO_2 was used for the worst-case trip scenarios because it has become the critical vehicle exhaust pollutant for ventilation control. These scenarios were:

- Expected traffic scenarios. These scenarios represented the 24-hour operation of the tunnel ventilation system under day-to-day conditions of expected traffic demand in 2026 and 2036
- Worst-case traffic scenarios. These scenarios addressed the most onerous traffic conditions for the ventilation system to manage air quality, based on capacity traffic conditions at speeds of between 20 and 80 kilometres per hour, vehicle breakdown, and free-flowing traffic at maximum capacity

[1] IAQM (2014).*Guidance on the assessment of dust from demolition and construction*. Institute of Air Quality Management, London

- Travel route scenarios. All possible travel routes through the project and the adjoining tunnels were identified for each direction of travel, and these were assessed against the in-tunnel criterion for NO_2.

In-tunnel air quality for the project was modelled using the IDA Tunnel software and emission factors from the Permanent International Association of Road Congresses (PIARC). Traffic volume projections were taken from the Strategic Motorway Project Model (SMPM) version 1.0, 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 NO_2, as well as the peak extinction coefficient (for visibility). The information presented in the report has confirmed that the tunnel ventilation system would be designed to maintain in-tunnel air quality well within operational limits for all scenarios.

Operational impacts – local air quality (expected traffic)

Scenarios

Two types of scenario were considered for local ambient air quality, as described below:

- Expected traffic scenarios. These were:
  - 2016 Base Year. This scenario represented the current road network with no new projects/upgrades, and was used to establish existing conditions. The main purpose was to enable the dispersion modelling methodology to be verified against actual air quality monitoring data
  - 2026 Do Minimum. This scenario represented conditions in the opening year of the project, but without the project.
  - 2026 Do Something. As 2026 Do Minimum, but with F6 Extension – Stage 1 also completed.
  - 2036 Do Minimum. As 2026 Do Minimum, but for 10 years after project opening and without the project.
  - 2036 Do Something. As 2026 Do Something, but for 10 years after project opening.
  - 2036 Do Something Cumulative. As 2026 Do Something Cumulative, but with all stages of the F6 Extension, Western Harbour Tunnel and Beaches Link also completed.
- Regulatory worst case scenarios. These assessed emissions from the ventilation outlets only, with pollutant concentrations fixed at the regulatory limits. The scenarios 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.

Methodology

For each scenario, a spatial emissions inventory was developed for road traffic sources in the dispersion modelling domain. The following components were treated separately:

- Emissions from the traffic on the surface road network, including any new roads associated with the project (or projects in the cumulative scenarios)
- Emissions from existing and proposed tunnel ventilation outlets.

Emission modelling – tunnel ventilation outlets

The assessment was conducted assuming no emissions from any project tunnel portals. All emissions from the traffic in tunnels were assumed to be released to the atmosphere via ventilation outlets.

In total, seven separate tunnel ventilation outlets were included in the assessment. These included outlets associated with the project as well as existing or future projects (M4-M5 Link, M5 East and New M5 Motorway). The outlets associated with existing or future projects were included to assess potential cumulative impacts only. Further details of the project ventilation facilities, including the locations and surrounding environments, are provided in Chapter 6 (Project description) of the environmental impact statement.

Emission modelling – surface roads

The road network (including tunnels) had between 2,007 and 2,131 individual road links, depending on the scenario. Data on traffic volume, composition and speed were taken from SMPM.

Comparing the Do Something scenarios with the Do Minimum scenarios in 2026, emissions of all pollutants decreased by between around 2 and 3 per cent in 2026. In 2036 emissions of CO, NOX, PM10 and PM2.5 increased slightly, whereas THC emissions decreased slightly. For the cumulative scenario, emissions of CO, NOX, PM10 and PM2.5 increased by 2.5 to 3.9 per cent, whereas THC emissions decreased by 2 per cent.

The overall changes in emissions associated with the project in a given future scenario year (2026 or 2036) would be smaller than the underlying reductions in emissions from the traffic on the network between 2016 and the scenario year as a result of improvements in emission-control technology.

Dispersion modelling

The dispersion modelling was conducted using the GRAMM/GRAL system (version 18.1). The system consists of two main modules: a prognostic wind field model (Graz Mesoscale Model - GRAMM) and a dispersion model (Graz Lagrangian Model - GRAL).

The GRAMM domain was defined so that it covered the F6 Extension Stage 1 project with a sufficient buffer zone to minimise boundary effects in GRAL. Reference meteorological data from several meteorological stations in 2016 were selected for use in GRAMM to determine three-dimensional wind fields across the modelling domain.

Two types of discrete receptor location were defined for use in the dispersion modelling:

- 30 'community receptors'. These were taken to be representative of particularly sensitive locations such as schools, child care centres and hospitals within a zone of up to 600 metres either side of the project corridor. For these receptors, a detailed 'contemporaneous' approach was used to calculate the total concentration of each pollutant by combining the model prediction with the background concentration on an hour-by-hour basis.
- 17,509 'residential, workplace and recreational (RWR) receptors'. These were all discrete receptor locations along the project corridor, and mainly covered residential and commercial land uses. For these receptors, a simpler approach was used to combine a concentration statistic for the modelled roads, portals and ventilation outlets with a background statistic.

The main reason for the distinction was to permit a more detailed analysis of short-term impacts on community receptors.

Conclusions

Ground-level receptors

The following general conclusions have been drawn from the dispersion modelling:

- The predicted total concentrations of all criteria pollutants at receptors were usually dominated by the existing background contribution
- 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 predicted 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
- For some short-term air quality metrics (1-hour NO_2, 24-hour $PM_{2.5}$ and 24-hour PM_{10}), exceedances of the criteria were predicted to occur both with and without the project. However, where this was the case the total numbers of receptors with exceedances generally decreased slightly with the project and in the cumulative scenarios
- 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. However, it is likely that the predictions at these locations were overly conservative
- Concerning the redistribution of impacts, the spatial changes in air quality as a result of the project were complex, reflecting the changes in traffic on the network.

More detailed pollutant-specific conclusions are presented in the report.

Elevated receptors

Changes in concentrations at four additional heights (10, 20, 30 and 45 metres) were considered for annual mean and maximum 24-hour $PM_{2.5}$. In each case the change was determined by comparing the modelled concentrations at RWR receptor locations in the 2036 Do Something Cumulative scenario with the 2036 Do Minimum scenario. However, it was not necessarily the case that there were existing buildings at these heights at the receptor locations. For both annual mean and 24-hour $PM_{2.5}$ the patterns in the contour plots showed the surface road influence diminishing with height and the ventilation outlet influence becoming more distinct. The largest increases in concentration at the heights of 10 metres, 20 metres and 30 metres were lower than at ground level, whereas at a height of 45 metres the maximum increases were markedly higher than at ground level. However, none of the receptor locations with the largest increases in concentration had a building height of more than 20 metres. The implications of these results for existing receptors and future developments are described in the report.

Operational impacts – local air quality (regulatory worst case)

The regulatory worst case only applied to the ambient air quality impacts of the tunnel ventilation outlets. The concentrations from the ventilation outlets in the regulatory worst case scenarios were, of course, higher than those for the expected traffic scenarios in all cases. The following points are noted in relation to the regulatory worst case scenarios:

- The maximum 1-hour CO concentration was negligible, especially taking into account the fact that CO concentrations are well below the NSW impact assessment criterion. For example, the maximum 1-hour outlet contribution in the regulatory worst case scenario (0.76 mg/m3) was a very small fraction of the criterion (30 mg/m3). The maximum background 1-hour CO concentration (3.13 mg/m3) was also well below the criterion. Exceedances of the criterion due to the ventilation outlets are therefore highly unlikely to occur
- For PM10 the maximum contribution of the ventilation outlets would be small. For the annual mean and maximum 24-hour metrics the outlet contributions were 7 per cent and 20 per cent of the respective criteria. This would be significant for some receptors, but any exceedances of the criteria would be dominated by background concentrations.
- The ventilation outlet contribution would be most important for PM2.5, with the maximum contributions equating to 22 per cent and 40 per cent of the annual mean and 24-hour criteria respectively. Again, any exceedances of the criteria would be dominated by background concentrations.
- 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 used in the regulatory worst case assessment.

Operational impacts – regional air quality

The potential regional impacts of the project on air quality were assessed through consideration of the changes in emissions across the road network (as a proxy), and the capacity of the project to influence ozone production. Overall, it is concluded that the regional impacts of the project would be negligible, and undetectable in ambient air quality measurements at background locations.

Management of impacts

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 project. This should contain details of the site-specific mitigation measures to be applied.

Operational impacts

The report has provided a review of the measures that are available for improving tunnel-related air quality (both in-tunnel and ambient), and then describes their potential application in the context of the project.

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

- Minimal gradients. The main alignment tunnels would have a maximum gradient of less than four per cent
- Large main line tunnel cross-sectional area. The mainline tunnels would have widths varying between 10.5 to 16.0 metres and be higher than most previous tunnels
- Increased height to reduce the risk of incidents involving high vehicles blocking the tunnel and disrupting traffic.

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, except in emergency conditions when emissions from the portals may be necessary in the unlikely event of a fire within the tunnel or during maintenance procedures.

The ventilation system would be automatically controlled using real-time air velocity and air quality sensor data to ensure that 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 provided in the report.

1 Introduction

The project would comprise a new multi-lane road between the New M5 Motorway at Arncliffe and President Avenue at Kogarah. The project would connect underground with the New M5 Motorway tunnel and to a new surface level intersection at President Avenue, Kogarah.

1.1 Overview of the project

Key components of the project would include:

- An underground connection to the existing stub tunnels at the New M5 Motorway at Arncliffe
- Twin motorway tunnels (around four kilometres in length) between the New M5 Motorway at Arncliffe and President Avenue, Kogarah
- A tunnel portal and entry and exit ramps connecting the tunnels to a surface intersection with President Avenue
- Intersection improvements at the President Avenue / Princes Highway intersection
- Mainline tunnel stubs to allow for connections to future stages of the F6 Extension
- Shared pedestrian and cycle pathways connecting Bestic Street, Rockdale to Civic Avenue, Kogarah via Rockdale Bicentennial Park (including an on-road cycleway)
- An Operational Motorway Control Centre to be located off West Botany Street, Rockdale
- Ancillary infrastructure and operational facilities for signage (including electronic signage), ventilation structures and systems at Rockdale, fire and safety systems, and emergency evacuation and smoke extraction infrastructure
- A proposed permanent power supply connection from the Ausgrid Canterbury subtransmission substation
- Temporary construction ancillary facilities and temporary works to facilitate the construction of the project.

Once complete, the F6 Extension Stage 1 would improve connections and travel times between Sydney and the Princes Highway and enhance connections for residents and businesses within the broader regional area as well as promote and support economic development in areas to the south, such as Sutherland and the Illawarra.

Approval for the project is being sought under Part 5, Division 5.2 of the EP&A Act. Future stages of the F6 Extension would be subject to separate planning applications and assessments would be undertaken accordingly.

The configuration and design of the project will be further developed to take into consideration the outcomes of community and stakeholder engagement.

1.2 Project location

This project would be generally located within the Bayside local government area. The project commences about 8 kilometres south west of the Sydney central business district (CBD). The proposed President Avenue intersection would be located about 11 kilometres south east of the Sydney CBD.

1.3 Purpose of this report

The general purpose of this report is to address the requirements of the air quality section of the Secretary's Environmental Assessment Requirements (SEARs) for the project (SSI 7485), issued on 23 January 2018.

In recent years, urban road tunnels in Australia have been subjected to considerable scrutiny, with the following being areas of community focus: in-tunnel air quality, emissions from tunnel portals, and ambient air quality. Specific emphasis has therefore been placed on the assessment and management of these in the report:

- In-tunnel air quality:
  - The report demonstrates that the proposed ventilation system and management approaches would achieve some of the most stringent standards in the world for operational in-tunnel air quality
- Portal emissions:
  - 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. No portal emissions are proposed for the F6 Extension Stage 1 project, and the report demonstrates that the design of the ventilation system would achieve this
- Ambient air quality:
  - The potential for ambient air quality impacts during project construction is assessed in the report, and a comprehensive range of management measures is recommended
  - The potential for ambient air quality impacts during project operation is assessed in detail, and the report demonstrates that the proposed ventilation system would be effective at maintaining ambient air quality.

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:

- Understanding the existing conditions
- Characterising the changes in traffic
- Characterising the tunnel ventilation
- Quantifying in-tunnel pollution
- 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 would 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 or vehicles. This is because air quality criteria apply to outdoor locations, and ambient air quality monitoring is conducted at such locations
- Health risks associated with air quality (refer to **Chapter 10** (Health, safety and hazards) and **Appendix F** (Human health technical report)
- Greenhouse gas emissions (assessed in **Chapter 22** (Greenhouse gas) of the EIS).

1.4 SEARs and agency comments

Table 1-1 displays the sections of the SEARs that are specific to air quality, and also provides a cross-reference to the sections of this report which address these requirements.

Table 1-1 Requirements of SEARs addressed in this report

Requirement of SEARs (air quality)	Section where requirement is addressed
The project is designed, constructed and operated in a manner that minimises air quality impacts (including nuisance dust and odour) to minimise risks to human health and the environment to the greatest extent practicable.	A description of how potential air quality impacts have been minimised through the design of the project is provided in section 9
1. The Proponent must undertake an air quality impact assessment (AQIA) addressing local and regional air quality impacts for construction and operation of the project in accordance with the current guidelines. • Approved Methods for the Modelling and Assessment of Air Pollutants in New South Wales (NSW EPA, 2016) • Approved Methods for the Sampling and Analysis of Air Pollutants in NSW (DEC, 2007) • Technical Framework - Assessment and Management of Odour from Stationary Sources in NSW (DEC, 2006) • In-Tunnel Air Quality (Nitrogen Dioxide) Policy (ACTAQ, 2016) • Optimisation of the Application of GRAL in the Australian Context (Manansala et al., 2017)	An air quality impact assessment for the project has been undertaken in and is presented in section 7, section 8 and Annexure K. Section 4 and section 5 outline the relevant guidelines considered for the air quality impact assessment. A summary of the GRAL optimisation study is provided in section 8.4.4.
2. The Proponent must ensure the AQIA also includes the following:	
(a) demonstrated ability to comply with the relevant regulatory framework, specifically the Protection of the Environment Operations Act 1997 and the Protection of the Environment Operations (Clean Air) Regulation 2010;	Compliance with the regulatory framework is outlined in section 4.4.5 and Annexure K
(b) the identification of all potential sources of air pollution including details of the location, configuration and design of all potential sources including ventilation systems and tunnel portals;	Air quality considerations are outlined in section 3 and potential sources of air pollution for the project are identified in section 8
(c) a review of vehicle emission trends and an assessment that uses or sources best available information on vehicle emission factors;	Vehicle emission trends and vehicle emissions factors are outlined in section 6.6, Annexure C and Annexure K
(d) an assessment of impacts (including human health impacts) from potential emissions of PM_{10}, $PM_{2.5}$, CO, NO_2 and other nitrogen oxides and volatile organic compounds (e.g. BTEX) including consideration of short and long-term exposure periods;	Potential impacts from the dispersal of air pollutants are considered in section 8
(e) 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, ramps and interchanges and the alternative surface road routes;	Potential impacts from the dispersal of air pollutants are considered in section 8
(f) a qualitative assessment of the redistribution of ambient air quality impacts compared with existing conditions, due to the predicted changes in traffic volumes;	Ambient air quality impacts are assessed in section 8.
(g) assessment of worst case scenarios for in-tunnel and ambient air quality, including a range of potential ventilation scenarios and 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;	An assessment of worst case scenarios for in-tunnel and ambient air quality is provided in the ventilation report at Annexure K

Requirement of SEARs (air quality)	Section where requirement is addressed
(h) 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 outlets and air inlets) including details of proposed air quality monitoring (including frequency and criteria);	Measures to manage potential air quality impacts are outlined in section 9. Section 9.2.3 outlines design provisions to reduce pollutant emissions and concentrations within the tunnel
(i) a demonstration of 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 New M5 Motorway project and the In-Tunnel Air Quality (Nitrogen Dioxide) Policy;	An assessment of air emissions against relevant criteria is provided in section 5, section 8 and Annexure K
(j) details of any emergency ventilation systems, such as air intake/exhaust outlets, including protocols for the operation of these systems in emergency situations, potential emission of air pollutants and their dispersal, and safety procedures;	Measures to manage potential air quality impacts are outlined in section 9. Section 9.2.3 outlines design provisions to reduce pollutant emissions and concentrations within the tunnel
(k) details of in-tunnel air quality control measures considered, including air filtration, and justification of the proposed measures or for the exclusion of other measures;	Measures to manage potential air quality impacts are outlined in section 9. Section 9.2.3 outlines design provisions to reduce pollutant emissions and concentrations within the tunnel
(l) a description and assessment of the impacts of potential emissions sources relating to construction, including details of the proposed mitigation measures to prevent the generation and emission of dust (particulate matter and TSP) and air pollutants (including odours) during the construction of the project, particularly in relation to ancillary facilities (such as concrete batching plants), tunnel spoil handling and cut and cover earthworks, the use of mobile plant, stockpiles and the processing and movement of spoil; and	Measures to manage potential air quality impacts are outlined in section 9
(m) a cumulative assessment of the in-tunnel, local and regional air quality impacts due to the operation of the project and due to the operation of and potential continuous travel through existing and committed future motorway tunnels and surface roads.	Potential cumulative air quality impacts are assessed in section 8 and Annexure K

1.5 Structure of this report

The remainder of the report is structured as follows:

- **Section 2** describes the project, including its construction and the main elements of the proposed ventilation strategy
- **Section 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
- **Section 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
- **Section 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 methods that were used for assessing the impacts of project construction and operation, and the scenarios that were evaluated
- **Section 6** describes the existing environment in the area of Sydney affected by the project, with specific reference to terrain, meteorology, emissions and ambient air quality
- **Section 7** describes the assessment of the construction impacts of the project using a semi-quantitative risk-based approach
- **Section 8** describes the assessment of the operational impacts of the project, including the cumulative impacts with the M4 East, New M5 Motorway and M4-M5 Link projects, as well as other associated projects. The section deals with emission modelling, in-tunnel air quality, and dispersion modelling for ambient air quality
- **Section 9** provides a review of air quality mitigation measures, and recommendations on measures to manage any impacts of the project. This section deals with both the construction and the operation of the project
- **Section 10** summarises the assessment
- Annexures which address various technical aspects of the air quality assessment. In particular, the report on the ventilation requirements for the project is provided in **Annexure K.**

At the start of each section the most important aspects that are covered are briefly summarised.

2 The project

2.1 Project features

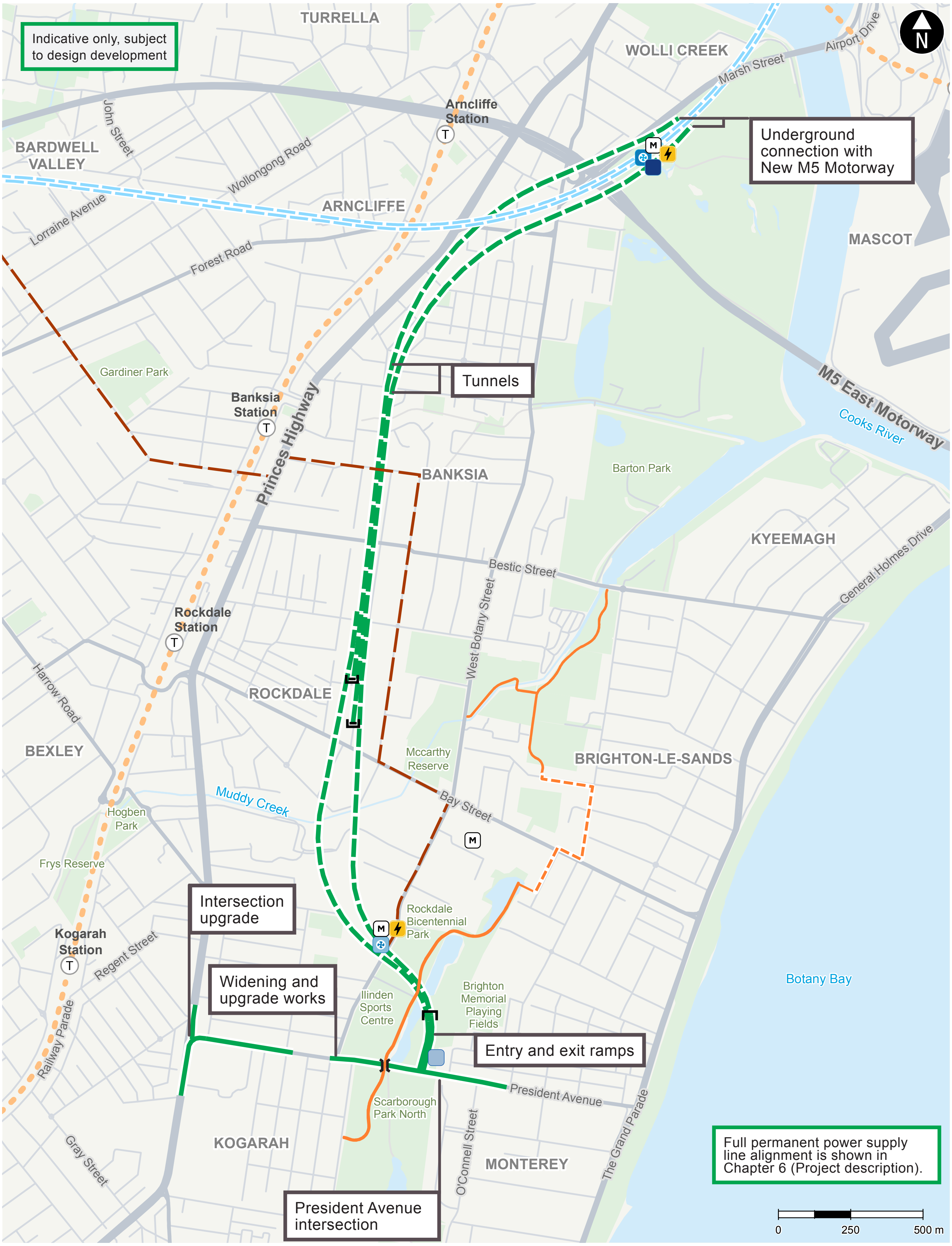
The project would comprise a new multi-lane underground road link between the New M5 Motorway and a surface intersection at President Avenue, Kogarah.

Key components of the project would include:

- Twin mainline tunnels. Each mainline tunnel would be around 2.5 kilometres in length, sized for three lanes of traffic, and line marked for two lanes as part of the project
- A tunnel-to-tunnel connection to the New M5 Motorway southern extension stub tunnels, including line marking of the New M5 Motorway tunnels from St Peters interchange to the New M5 Motorway stub-tunnels
- Entry and exit ramp tunnels about 1.5 kilometres long (making the tunnel four kilometres in length overall) and a tunnel portal connecting the mainline tunnels to the President Avenue intersection
- An intersection with President Avenue including entry and exit ramps and the widening and raising of President Avenue
- Upgrade of the President Avenue / Princes Highway intersection to improve intersection capacity
- Shared cycle and pedestrian pathways connecting Bestic Street, Brighton-Le-Sands to Civic Avenue, Kogarah (including an on-road cycleways)
- Three motorway operation complexes:
  - Arncliffe, including a water treatment plant, substation and fitout (mechanical and electrical) of a ventilation facility currently being constructed as part of the New M5 Motorway project
  - Rockdale (north), including a motorway control centre, deluge tanks, a workshop and an office
  - Rockdale (south), including a ventilation facility, substation and power supply.
- Reinstatement of Rockdale Bicentennial Park and recreational facilities
- In-tunnel ventilation systems including jet fans and ventilation ducts connecting to the ventilation facilities
- Drainage infrastructure to collect surface water and groundwater inflows for treatment
- Ancillary infrastructure for electronic tolling, traffic control and signage (both static and electronic signage)
- Emergency access and evacuation facilities (including pedestrian and vehicular cross and long passages); and fire and life safety systems
- New service utilities, and modifications and connections to existing service utilities
- A proposed permanent power supply connection from the Ausgrid Canterbury subtransmission substation, to Rockdale Motorway Operations Complex south.

The project does not include ongoing motorway maintenance activities during operation or future upgrades to other intersections in the vicinity during operation. These works are permitted under separate existing approvals and are subject to separate assessment and approval in accordance with the EP&A Act.

The key features of the project are shown on **Figure 2-1**.



LEGEND

- The project in tunnel
- The project on surface
- On-road cycleway
- Shared cycle and pedestrian pathways
- President Avenue shared cycle and pedestrian bridge
- Tunnel stub
- Tunnel portal
- Water quality basin
- Water treatment facility
- Rockdale ventilation facility
- Motorway operations complex
- Substation
- Permanent power supply line
- New M5 Tunnel
- Arncliffe ventilation facility*
- * Under construction as part of the New M5 Motorway project
- Road
- Waterway
- Railway line
- Railway station
- Parks and recreation

Figure 2-1 Project features

2.2 Construction

2.2.1 Construction activities

The proposed construction activities for the project would include:

- Preparatory investigations
- Site establishment and enabling work
- Tunnelling
- Surface earthworks and structures
- Construction of motorway operations complexes
- Drainage and construction of operational water management infrastructure
- Construction of the permanent power supply connection
- Road pavement works
- Finishing works.
- These activities would generally be undertaken within the following construction ancillary facilities:
- Arncliffe construction ancillary facility (C1) at Arncliffe, within the Kogarah Golf Course currently being used for construction of the New M5 Motorway
- Rockdale construction ancillary facility (C2) at Rockdale, within a Roads and Maritime depot at West Botany Street
- President Avenue construction ancillary facility (C3) at Rockdale, north and south of President Avenue within Rockdale Bicentennial Park and part of Scarborough Park North, and a site west of West Botany Street
- Shared cycle and pedestrian pathways construction ancillary facilities (C4 and C5) at Brighton-le-Sands, within the recreation area between West Botany Street and Francis Avenue, near Muddy Creek
- Princes Highway construction ancillary facility (C6), on the north-east corner of the President Avenue and Princes Highway intersection.

2.2.2 Construction boundary

The area required for project construction is referred to as the ‘construction boundary’. This comprises the surface construction works area, and construction ancillary facilities (refer to **Figure 2-2**). Utility works to support the project would occur within and outside the construction boundary (refer to **Chapter 7** (Construction) of the EIS).

In addition to these works, the underground construction boundary (including mainline tunnel construction and temporary access tunnels) is also shown on **Figure 2-2**.

C1

- Tunnelling and spoil handling
- Construction of MOC1 (Water treatment plant, substation)
- Fitout, testing and commissioning of tunnels and MOC 1

C2

- Construction of the decline tunnel
- Tunnelling and spoil handling
- Pavement works for internal access road
- Construction of MOC2
-

  enable ongoing/future use for maintenance activities

C3

- Demolition of buildings and vegetation clearing and removal
- Relocation of utilities
- Temporary stockpiling of spoil and

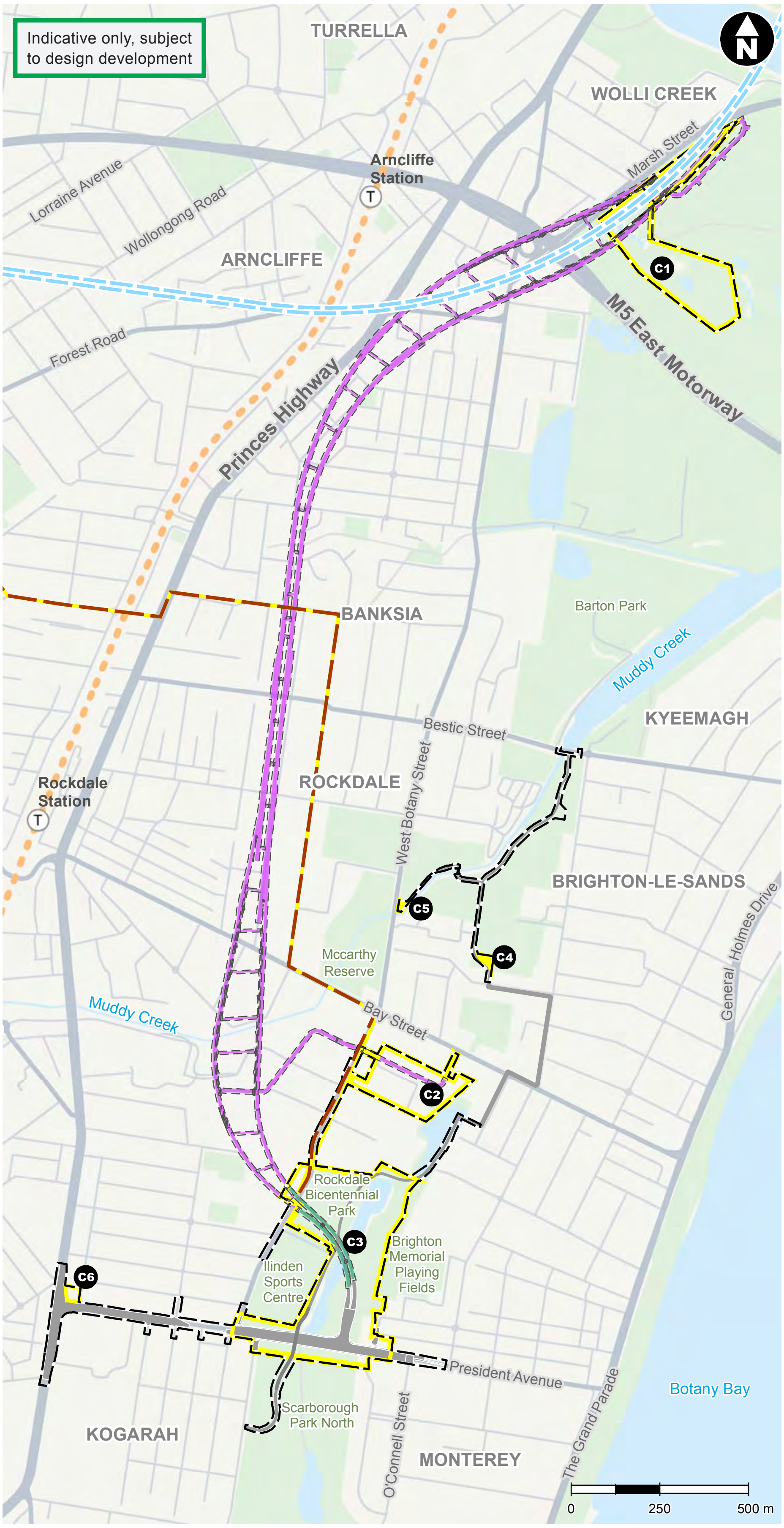
- Management of any contaminated land, including acid sulphate soils
- Construction of cut-and-cover structures
- Construction of MOC3 (Rockdale ventilation facility and substation)
- President Avenue intersection upgrade works
- Construction of shared pedestrian and cyclist path and overpass

C4/C5

- Site establishment
- Vegetation clearing and removal, topsoil stripping areas and land-form shaping
- Temporary stockpiling of materials
- Construction of the shared pedestrian and cyclist path
- Finishing works including lighting, line marking and signage installation

C6

- Property adjustment and demolition
- Relocation of utilities, stormwater infrastructure, underground storage tanks and substation
- Laydown and parking of construction vehicles and equipment
- Reinstatement of site



LEGEND

- Surface works
- Construction boundary
- Cut-and-cover structures
- Underground construction
- Construction ancillary facility
- Permanent power supply line
- Permanent power supply construction route
- New M5 Tunnel
- Road
- Waterway
- Railway line
- Railway station
- Parks and recreation

Figure 2-2 Construction boundary and construction ancillary facilities

2.2.3 Construction program

The project would be constructed over a period expected to be around four years, including commissioning which would occur concurrently with the final stages of construction (refer to **Figure** 2-3). The project is expected to be completed towards the end of 2024.

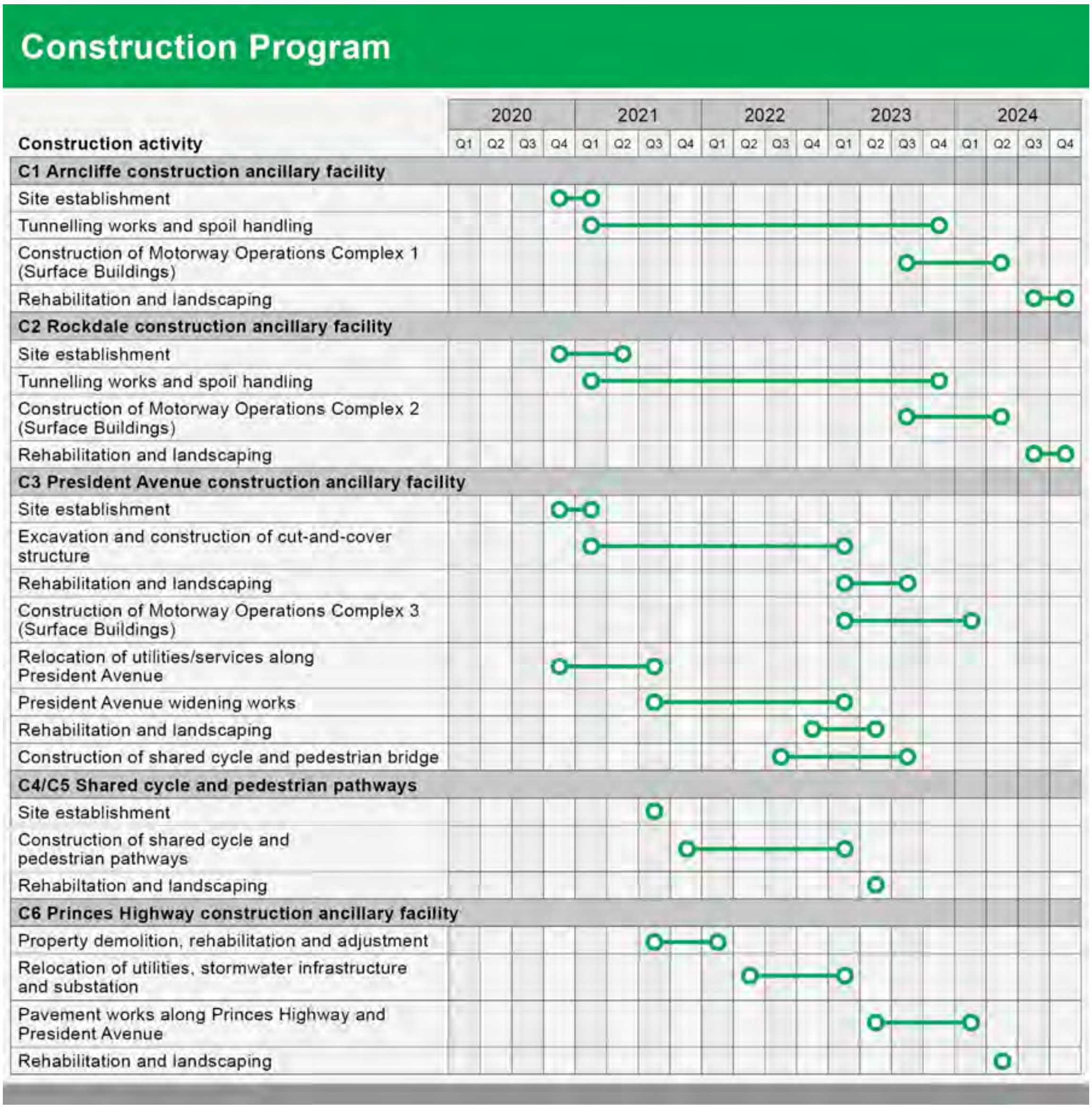


Figure 2-3 Indicative construction program

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

2.3.1 Overview

The project's ventilation system has been designed to:

- Safeguard the health and amenity of motorists using the mainline tunnels during normal operation and emergency conditions
- Meet the current in-tunnel, ventilation outlet and ambient air quality criteria relevant to the project (**section 4.4.4**)
- Operate automatically to manage air quality
- Meet the requirements of the Australian Government's Civil Aviation Safety Authority with respect to emissions to the atmosphere and potential aviation hazards
- Minimise the consumption of energy and other resources where doing so would not compromise the health and amenity of motorists using the mainline 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 ventilation facilities and jet fans. 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 only via ventilation facilities.

2.3.2 Tunnel ventilation facilities and outlets

The ventilation facilities – and, more importantly in terms of ambient air quality, the associated air outlets – are summarised in **Table 2-1**. Some facilities had more than one outlet.

Table 2-1 Tunnel ventilation facilities and outlets included in the assessment

Outlet	Project	Facility location	Function of outlet
Existing ventilation facility			
Outlet A	M5 East	Turrella	Single point of release of air from M5 East tunnel.
Ventilation facilities under construction for the New M5 Motorway			
Outlet B	New M5 Motorway	Arncliffe	Exhaust from the first section of eastbound traffic of the New M5 Motorway tunnel (Kingsgrove to Arncliffe)[a].
Outlet C	New M5 Motorway	St Peters Interchange	Exhaust from the second section of the eastbound New M5 Motorway tunnel (Arncliffe to St Peters).
Proposed ventilation facility for the M4-M5 Link			
Outlet D	M4-M5 Link	St Peters Interchange	Exhaust from the eastbound traffic to the M4-M5 Link (Arncliffe to St Peters)[b].
Proposed ventilation facilities for the F6 Extension Stage 1 (subject of this EIS)			
Outlet E[c]	F6 Extension Stage 1	Arncliffe	Exhaust from the northbound F6 Extension Stage 1 tunnel (Kogarah to Arncliffe).
Outlet F	F6 Extension Stage 1	Rockdale	Exhaust from the southbound tunnel of the F6 Extension Stage 1.

Outlet	Project	Facility location	Function of outlet
Proposed ventilation facilities for the F6 Extension Section B			
Outlet G	F6 Extension Section B	Rockdale	Exhaust from the northbound tunnel of the F6 Extension Section B.

(a) This facility will also provide the fresh air supply for the second section of the eastbound New M5 Motorway tunnel (Arncliffe to St Peters).

(b) The facility will also provide the fresh air supply to the northbound M4-M5 Link (St Peters to Rozelle).

(c) This facility is being constructed as part of New M5 Motorway, and would not operate until the opening of the proposed F6 Extension Stage 1, if the project is approved.

In total, 7 separate tunnel ventilation outlets (A to G) were included in the assessment. For outlets B, C, D and E, four exhaust sub-outlets would be provided to improve dispersion of the exhaust air and assist in meeting the Civil Aviation Safety Authority and Sydney Airport's requirements. The ventilation outlets that would be specific to the F6 Extension Stage 1 are E and F. The remaining outlets (A, B, C, D and G) were included to assess potential cumulative impacts only.

Further details of the ventilation facilities, including the locations and surrounding environments, are provided in **Chapter 6** (Project description) of the EIS.

The control of air flows through the tunnels and ventilation outlets is described in **Annexure K**. Cross-references to the relevant sections and figures in **Annexure K** are provided in **Table 2-2**. Details of the ventilation outlets that were of specific interest to the air quality assessment are provided in **Annexure G**.

Table 2-2 References to air flow diagrams for tunnel ventilation outlets

Ventilation outlet	Air flow diagrams (Annexure K)
A	Not applicable
B	Figure 3.1
C	Figure 3.3
D	Figure 3.3
E	Figure 3.1
F	Figure 3.2
G	Figure 3.2

2.3.3 Operating modes

Ventilation operations

- Normal traffic conditions, including worst case and low speed traffic
- Major incident (emergency) conditions including major accident and fire scenarios.

In-tunnel air quality, traffic volumes and average traffic speeds through the project tunnels would be constantly monitored by operators in the Motorway Control Centre and decisions about the operation of the project's ventilation system made 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 by the use of jet fans within the tunnel, and potential introduction of additional fresh air into the tunnels through the ventilation supply facilities
- 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 with no portal emissions. At the ventilation facility offtake points, tunnel air would be drawn upwards into ventilation facilities by large fans prior to discharge to the atmosphere. The locations and heights of the various ventilation outlets are provided in **Annexure G**. 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.

Portal emissions are prevented by using the ventilation system to draw the air back against the flow of traffic at the exit ramps and directing the air through the exhaust outlets.

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 reducing speed limits, ramp 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 using jet fans, which would operate by moving air in the same direction that the traffic is flowing (except at exit portals) to provide the fresh air demand required to meet the relevant air quality criteria.

Emergency conditions

During a major incident, when traffic is stopped in the tunnel, the jet fans would be used to increase the air flow to protect vehicle occupants and emergency services personnel from a build-up of emissions. Drivers would be requested, via the public address system, to turn off vehicle engines to reduce emissions if there is an extended delay while the incident is cleared.

In the case of a fire, the incident carriageway would be closed to incoming traffic and traffic downstream of the fire would exit the tunnel. Jet fans would be used to propel the smoke downstream to the nearest ventilation outlet, or exit portal(s), depending on the location of the fire. This would prevent smoke flowing backwards from the fire source over any vehicles that are stationary behind the fire and jet fans upstream of the fire. Further details of the smoke control system are provided in **section 6.11.5** of the EIS.

2.3.4 Iterative approach to design

The design of the proposed F6 Extension Stage 1 project has been undertaken using an iterative approach, with changes being made to various aspects – such as ventilation outlet locations and dimensions – and testing to ensure that impacts on in-tunnel and ambient air quality have been adequately managed to meet air quality goals and criteria. The design on which this report is based has been developed using this approach, to minimise potential impacts.

3 Air quality considerations for the F6 Extension Stage 1 project

3.1 Overview of section

This section:

- Summarises the main aspects of traffic-related emissions and air pollution, including the air quality issues that relate specifically with road tunnels
- Provides contextual information on topics such as the main traffic pollutants, the processes affecting air pollution, and air pollution in and around tunnels
- Identifies the key air quality considerations 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 local effects on amenity, ecosystems, cultural heritage and health (for the latter, see **Appendix F** (Human health technical report)). Traffic pollution also has impacts on wider geographical scales.

Health effects account for the majority of the cost to society of air pollution. When considering mortality alone (i.e. ignoring short-term illness and hospital admissions), the health cost of air pollution in Australia is estimated to be in the order of $11.1 billion to $24.3 billion annually (Begg et al., 2007; Access Economics, 2008). Road transport is a significant contributor; the health cost of emissions from road transport in Australia has been estimated to be $2.7 billion per year (BTRE, 2005). The Organisation for Economic Co-operation and Development (OECD) has estimated that about half of the economic cost of air pollution in its member countries is specifically attributable to road transport, and in Australia in 2010 this equated to around ($2.9 billion) (OECD, 2014). However, more work is needed to provide a robust estimate of the road transport share.

3.2.2 Pollutants

Many different air pollutants are emitted by road vehicles. Pollutants that are emitted directly into the air are termed 'primary' pollutants. With regard to local air quality and health, as well as the quantity emitted, the most significant 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, particularly when there is a 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 specific pollutants and metrics that were addressed in this assessment are identified in **section 5.5.3**.

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, and the formation processes for traffic-derived pollutants are explained in **Annexure A**. The processes that lead to emissions of primary pollutants from vehicles are:

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

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

- The volume, composition and operation (e.g. speed) 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 also summarised in **Annexure A**.

The main direct impacts of primary traffic 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 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 combinations of 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). 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.

NB: The calculation of integrated exposure 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 typically 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 also reflected in the regulation of ambient air quality, and has been used in this assessment.

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, would increase the risk of effects (National Health and Medical Research Council (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 a significant 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 (Permanent International Association of Road Congresses (PIARC), 2012).

Portal emissions

In most road tunnels around the world emissions are released from the portals. One of the potential advantages of tunnels is the opportunity to site portals so that emissions in sensitive areas are avoided. However, this can often be challenging in densely populated urban settings (Longley, 2014b). In Sydney, several urban tunnels have therefore been designed in such a way that portal emissions are avoided. In line with this approach, the F6 Extension Stage 1 project would also be designed so that there are no emissions from the tunnel portals during normal operations.

Ventilation outlet emissions

Tunnel portal emissions are avoided through the extraction of air via elevated ventilation outlets, and these provide an effective means of dispersing the polluted air from a tunnel.

Ventilation outlets work by taking advantage of the turbulent mixing in the atmosphere, and the fact that wind speed generally increases with height (Longley, 2014a). The concentrations of pollutants at locations of potential exposure are determined by the emission rates of the pollutants and the effectiveness of the ventilation system at harnessing the dispersive capacity of the atmosphere. The concentrations of pollutants at ground level are progressively reduced as the height of the outlet increases. A combination of the design height of the outlet and the amount of fresh air that is mixed with the polluted 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, (PIARC, 2008). The temperature of the air leaving tunnel ventilation outlets is also 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 would be carried through to the ventilation outlets.

To achieve zero emissions from a portal, the polluted air from the section of tunnel between a ventilation outlet and the portal must be extracted from the ventilation outlet. This requires that the air in the tunnel section is drawn back against air flow induced by vehicle aerodynamic drag (the so-called ‘piston effect’). 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 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 regardless of traffic or pollutant levels in the tunnel.

Ventilation outlets can also be deliberately sited away from dense residential areas to address community concern about the impact. However, this can considerably increase the construction, maintenance and running costs of a tunnel for no significant gain in air quality, and such designs are very rare outside Australia (Longley, 2014a).

Studies suggest that the greatest impacts from an outlet occur some distance from the outlet, and also largely restricted to directions which are downwind of the outlet in the most frequent local wind directions, and there may be effectively zero impact in many directions. However, outlets are designed so that even these peak concentrations do not lead to any significant or measurable impact on the local community, as predicted by modelling and frequently confirmed by monitoring *(*Longley, 2014a*).* Nevertheless, 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; Roads and Maritime, 2015). 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 opening of the Eastern Distributor tunnel in 1999, the major road tunnels constructed in Sydney have all been designed to avoid portal emissions[2], and the tunnel air is discharged from elevated ventilation outlets. This approach was initially required by the Conditions of Approval for the M5 East tunnel as a precautionary measure to protect residents around the tunnel portals, and was subsequently retained for the Cross City Tunnel and Lane Cove Tunnel (LCT). It also applies to the recently approved NorthConnex, M4 East, New M5 Motorway and M4-M5 Link tunnels.

The M5 East Tunnel (4 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). On the other hand, ambient air quality continues to be monitored at five locations in the vicinity of the ventilation outlet for the M5 East Tunnel and, 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; Roads and Maritime, 2015).

Conversely, for the Cross City Tunnel (2.1 kilometre long) there was a significant overestimation of the traffic volume at opening. This has been attributed to toll avoidance and a reversal of surface road changes designed to encourage tunnel use. 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 (3.6 kilometres long) 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 about road tunnels in Sydney, and the scale of projects such as NorthConnex and 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), NSW Department of Planning and Environment (DP&E), the NSW Office of Environment and Heritage (OEH) and NSW Environment Protection Authority (NSW EPA). The main role of ACTAQ is to provide the NSW Government with an understanding of the scientific and engineering issues concerning tunnel ventilation design and operation based on NSW, national and international experience. Between 2014 and 2016 ACTAQ released a number of reports on motor vehicle emissions, air quality and tunnels, and in 2017 ACTAQ published a study designed to optimise GRAL in the Australian context (Manansala et al., 2017). These reports were consulted as part of the assessment for the project.

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[2] This approach is not unique to Sydney. For example, each of Brisbane's road tunnels (North South Bypass Tunnel, Airport Link and Northern Link) has been designed to operate without portal emissions (SMPO, 2013).

3.5 NSW tunnel ventilation initiative

Reforms announced by the NSW Government on the 17 February 2018 will mean that the ventilation outlets of all current and future operating motorway tunnels in NSW will be regulated by NSW EPA. The EPA will require tunnel operators to meet air quality limits and undertake air quality monitoring.

In addition, for new motorway tunnels that are at the Environmental Impact Statement stage, such as F6 Extension Stage 1, additional checks will be required prior to planning determination, including:

- The Advisory Committee on Tunnel Air Quality (ACTAQ) will coordinate a scientific review of a project's air emissions from ventilation outlets
- The NSW Chief Health Officer will release a statement on the potential health impacts of emissions from tunnel ventilation outlets.

To facilitate these checks, the parts of this assessment that deal specifically with the operational impacts of tunnel ventilation outlets are provided in the following section of this report:

- The tunnel ventilation outlet parameters are given in **Annexure G**
- The results for the ventilation outlets only are given in **Annexure J**
- The tunnel ventilation report is given in **Annexure K**.

3.6 Summary of key air quality considerations

To summarise the previous sections, the key air quality considerations 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 F6 Extension Stage 1 tunnel users, but also to the cumulative exposure of users of multiple Sydney tunnels, and notably the M4 East, New M5 Motorway, M4-M5 Link, Western Harbour Tunnel and Beaches Link
- 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 would have a decrease in traffic volume
  - Potential deterioration in air quality alongside new and upgraded/widened surface roads
  - Potential deterioration in air quality alongside existing roads which would have an increase in traffic volume
  - Potential deterioration in air quality in the vicinity of tunnel ventilation outlets
  - The combined impacts of multiple road infrastructure projects in Sydney
- Accurate modelling of air quality to inform tunnel ventilation design and management
- Public understanding of air quality and the magnitude of any project impacts
- The impacts of the construction of the project.

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

4 Regulation of emissions, air pollution and exposure

4.1 Overview of section

A number of legislative instruments and guidelines apply to air pollution from road transport in general, and road tunnels specifically. This section:

- 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 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 **Annexure B**.

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 Australian Design Rules (ADRs). The specific emission limits that 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 website[3], and further information is provided in **Annexure B**. Some examples, showing the reduction in the allowable emissions with time, are shown in **Figure 4-1** and **Figure 4-2** (based on the information on the website).

The evaporation of fuel from petrol vehicles constitutes a significant 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 **Annexure B**.

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 properly quantify non-exhaust emissions and assess their health relevance. The EU Particle Measurement Programme is evaluating the options for the measurement of non-exhaust particles[4]. Although there is an intention to develop standardised methodologies, there is currently no plan to regulate non-exhaust PM in Europe.

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

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

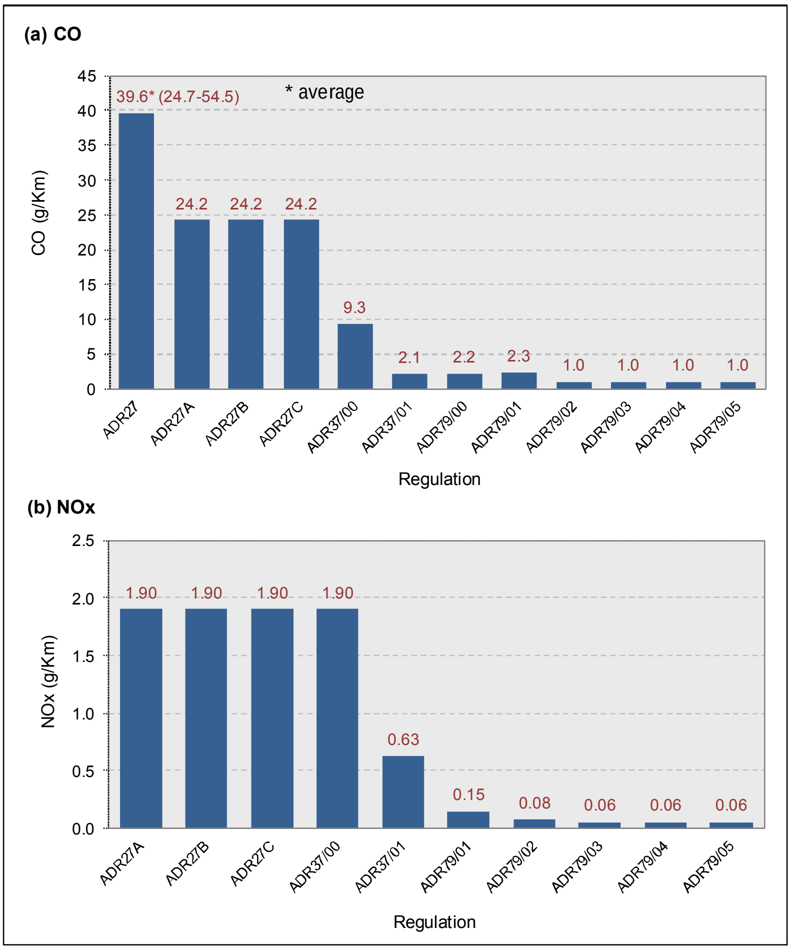

Figure 4-1 Exhaust emission limits for CO and NO_X applicable to new petrol cars in Australia

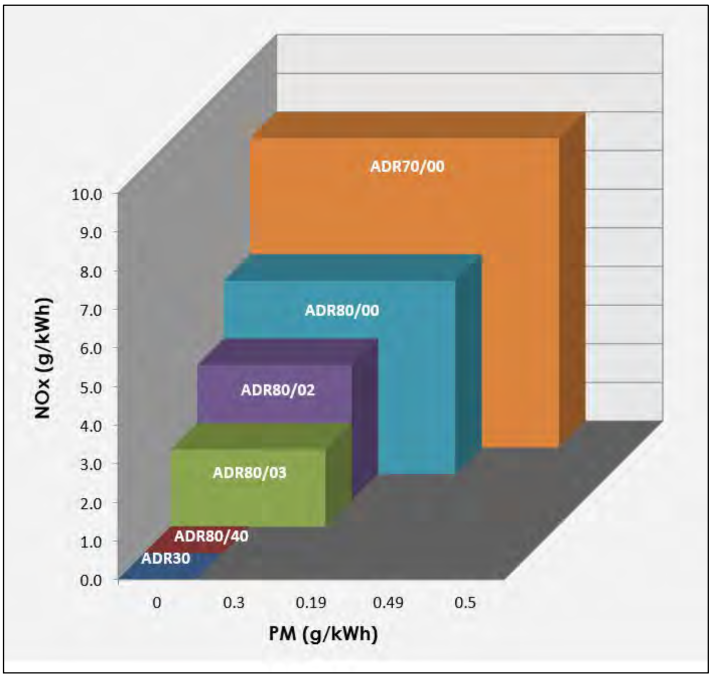

Figure 4-2 Exhaust emission limits for NO_X and PM applicable to heavy-duty vehicles in Australia

4.2.2 Checks on in-service vehicles

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

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[5] are for modified vehicles and LPG conversions.

The OEH has, in conjunction with the then NSW Roads and Traffic 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 was launched in 2006 in response to community concern about the large numbers of smoky heavy vehicles using the tunnel. The Plan 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 (refer to **section 9.2.2**). A subsequent review of the AQIP led to the implementation of a stronger suite of measures in the 2012 Air Quality Improvement Program. 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* (Commonwealth).

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
- To manage in-tunnel exposure to air pollution
- To manage external air pollution.

[5] 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.

For many tunnels, the ventilation requirements have been determined according to guidelines from the World Road Association (PIARC, 2012), and the relevant criteria are presented in **Annexure B**. The fresh air 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) World Health Organization (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 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 CO 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 using NO_2 concentrations for tunnel ventilation design. This is partly in response to health concerns relating to short-term exposure to NO_2 (e.g. Svartengren et al., 2000), and partly to ensure compliance with ambient air quality standards outside the tunnel. This shift in emphasis is also supported by evidence of the increase in primary NO_2 emissions from road vehicles (Carslaw and Beevers, 2004; Carslaw, 2005).

A policy paper on in-tunnel NO_2 was produced by ACTAQ (2016). This stated that all new road tunnels over one kilometre in length shall be designed and operated so that the tunnel-average NO_2 concentration is less than 0.5 ppm measured using a rolling 15-minute average.

4.4.2 Visibility and PM

Another important consideration for tunnel ventilation design is the need to ensure that in-tunnel visibility exceeds 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 the 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 established 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 characteristics that are different from those of 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 NFPA-502 (NFPA, 2017).

4.4.4 Limit values

The tunnel ventilation system would be designed and operated so that the in-tunnel air quality limits are not exceeded.

The three in-tunnel pollutants that are assessed are nitrogen dioxide (NO_2), carbon monoxide (CO) and particulate matter (PM) which is measured as an optical extinction coefficient. The operational in-tunnel limits for CO and NO_2 in several Sydney road tunnels are shown in **Table 4-1**, and the limits used for tunnels in other countries are summarised in **Annexure B**.

With the current pollution limits, and for the assessment years of the F6 Extension Stage 1 project, NO_2 would be the pollutant that determines the required air flows and drives the design of ventilation for in-tunnel pollution.

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

Tunnel	CO concentration (ppm, rolling average)			NO_2 concentration (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
NorthConnex WestConnex M4 East WestConnex New M5 Motorway WestConnex M4-M5 Link	200[(a)]	87[(b)]	50[(b)]	0.5[(b)]	0.005[(c)]

Notes:

(a) In-tunnel single point exposure limit
(b) In-tunnel average limit along tunnel length
(c) In-tunnel limit at any location along tunnel length, rolling 15-minute average

Sources: NHMRC (2008), Longley (2014c), PIARC (visibility), NSW Government (2015, 2016a, 2016b)

In February 2016, the NSW Government issued a document entitled 'In-Tunnel Air Quality (Nitrogen Dioxide) Policy' (ACTAQ, 2016). That document further consolidated the approach taken earlier for the NorthConnex, M4 East and New M5 Motorway projects. The policy wording requires tunnels to be '*designed and operated so that the tunnel average nitrogen dioxide (NO_2) concentration is less than 0.5 ppm as a rolling 15 minute average*'. It is expected that this wording will be the same for the proposed F6 Extension Stage 1.

For the F6 Extension Stage 1 and the associated integrated analysis of other tunnel projects, the 'tunnel average' has been interpreted as a 'route average', being the 'length-weighted average pollutant concentration over a portal-to-portal route through the system'. Tunnel average NO_2 has been assessed for every possible route through the system under all circumstances, and the calculation of this is outlined in **section 7.4** of **Annexure K**. The path with the highest average NO_2 concentration is reported.

With the predicted maximum CO levels falling well below the 'tunnel average' requirement, the complexity of evaluating 'tunnel average' CO criteria has been simplified and assessed as an in-tunnel maximum criterion throughout the project.

4.4.5 Tunnel ventilation outlets

For tunnels in Sydney, limits are also imposed on the discharges from the ventilation outlets. The limits specified for the NorthConnex, M4 East and New M5 Motorway projects are shown in **Table 4.2**. The SEARs for the F6 Extension Stage 1 refer to the *Protection of the Environment Operations Act 1997* (NSW) and the Protection of the Environment Operations (Clean Air) Regulation 2010. Although the Regulations specify in-stack concentration limits, these are designed primarily for industrial activities and the limit values are much higher than those imposed for road tunnels in Sydney[6].

[6] See for example, Schedule 4 of the Protection of the Environment Operations (Clean Air) Regulation 2010, which specifies standards of in-stack concentration for general activities and plant. These standards have values of at least 50 mg/m^3 for total particles, at least 350 mg/m^3 for NO_X, and at least 125 mg/m^3 for CO.

Table 4-2 Concentration limits for the NorthConnex and WestConnex 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)	4.0[(a)]	Rolling 1 hour	Dry, 273 K, 101.3 kPa

Notes:
(d) (a) Stated as 1.0 in the Conditions of Approval for NorthConnex.
(e) Sources: NSW Government (2015, 2016a, 2016b)

4.5 Tunnel portal emission restrictions

As noted in **section 3.3**, a key operating restriction for tunnels in Sydney is the requirement for there to be no emissions of air pollutants from the portals. To avoid portal emissions, the polluted air from within 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 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 specified 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.

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

4.6.1 Criteria pollutants

In 1998 Australia adopted a *National Environment Protection (Ambient Air Quality) Measure* (AAQ NEPM) that established national standards for six criteria pollutants (NEPC, 1998):

- 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 AAQ NEPM was extended in 2003 to include advisory reporting standards for PM with an aerodynamic diameter of less than 2.5 µm ($PM_{2.5}$) (NEPC, 2003). The standards for particles were further amended in February 2016, with the main changes being as follows (NEPC, 2016):

- The advisory reporting standards for $PM_{2.5}$ were converted to formal standards
- A new annual average PM_{10} standard of 25 µg/m^3 was established
- An aim to move to annual average and 24-hour $PM_{2.5}$ standards of 7 µg/m^3 and 20 µg/m^3 by 2025 was included
- A nationally consistent approach to reporting population exposure to $PM_{2.5}$ was initiated
- The existing five-day allowed exceedance form of the 24-hour $PM_{2.5}$ and PM_{10} standards was replaced with an exceptional event rule.

The NEPM is a national monitoring and reporting protocol. The NEPM standards are applicable to urban background monitoring stations 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 would take into account the new NEPM standards, but they may not necessarily take exactly the same form. Nevertheless, the project would be designed so that any increases in $PM_{2.5}$ concentrations due to emissions from the ventilation outlets are minimal.

The Australian States and Territories manage emissions and air quality in relation to particular 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 EPA, 2016) (NSW Approved Methods) sets out the approaches and criteria to be used. 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[7] 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 provided in **Annexure B**.

4.6.2 Air toxics

In recognition of the potential health problems arising from the exposure to air toxics, the *National Environment Protection (Air Toxics) Measure* (Air Toxics NEPM) (NEPC, 2011a) 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 the protection of human health.

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[7] 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.

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 investigation levels in the Air Toxics NEPM and the impact assessment criteria in the NSW Approved Methods for priority air toxics and BTEX compounds are given in **Annexure B**.

5 Overview of assessment methodology

5.1 Overview of section

This section:

- Identifies the key guidelines and policies that were relevant to the air quality assessment
- 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 approaches that were used to assess the impacts of the project on air quality for:
  - Construction
  - Operation – emissions
  - Operation – in-tunnel air quality
  - Operation – ambient air quality (local and regional)
- Defines the scenarios that were assessed
- Explains why certain pollutants and metrics were included in the air quality assessment, and why others were excluded, and identifies the relevant criteria
- 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 (NSW EPA, 2012a). 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 EPA, 2016)
- 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
- Approved Methods for the Sampling and Analysis of Air Pollutants in NSW (DEC, 2007)
- Technical Framework - Assessment and Management of Odour from Stationary Sources in NSW (DEC, 2006)
- In-Tunnel Air Quality (Nitrogen Dioxide) Policy (ACTAQ, 2016)
- Optimisation of the Application of GRAL in the Australian Context (Manansala et al., 2017).

5.3 Consultation with government agencies and committees

Roads and Maritime consulted the following government agencies and bodies during the development and production of the methodology and the air quality assessment report:

- NSW EPA
- NSW Health
- NSW Chief Scientist & Engineer
- 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 F6 Extension Stage 1 assessment. The review included details of the pollutants considered, the sources of emission factors, the dispersion models applied, and the approaches used to assess construction impacts. The findings are summarised below:

- 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
- Several studies have used international emission factors e.g. PIARC), and weighted these according to the local fleet, rather than using emission factors that are specific to Australian/NZ. Local vehicle emission factors have been used in some cases e.g. NSW GMR 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[8] or CALMET[9], in combination with dispersion models such as CALPUFF for tunnel ventilation outlets and CALINE[10]-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[11], GRAL[12] 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, while larger scale projects like WestConnex have looked at tens of thousands
- The impacts of project construction have generally been assessed qualitatively, and in some cases estimated using emissions factors.

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[8] TAPM = The Air Pollution Model

[9] CALMET is a meteorological model that is a component of CALPUFF modelling system

[10] CALINE = California Line Source Dispersion Model

[11] Tool for Roadside Air Quality (TRAQ), an air pollution screening tool developed by Roads and Maritime

[12] GRAL = Graz Lagrangian Model

5.5 General approach for F6 Extension Stage 1

5.5.1 Construction assessment

The main air pollution and amenity considerations at demolition/construction sites are:

- Annoyance due to dust deposition (e.g. soiling of surfaces at residences) and visible dust plumes
- Elevated PM_{10} concentrations due to on-site dust-generating activities
- Increased concentrations of airborne particles and NO_2 due to exhaust emissions from on-site diesel-powered vehicles and construction equipment. 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 would not need to be quantitatively assessed.

There are other potential impacts of demolition and construction, 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. Very high levels of soiling can also damage plants and affect the health and diversity of ecosystems (IAQM, 2014).

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 levels can increase 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:

- The nature and duration of the activities being undertaken
- 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 quantify dust emissions from construction activities reliably. 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. Alternatives to modelling have therefore been developed for the assessment of potential construction dust impacts.

A semi-quantitative[13], risk-based approach was used for the F6 Extension – Stage 1 assessment, and the impacts of construction were not specifically modelled. The approach followed the guidance published by the United Kingdom (UK) Institute of Air Quality Management (IAQM, 2014), the aim of which is to identify risks and to recommend appropriate mitigation measures. The assessment of construction impacts using the IAQM procedure is presented in **section 7**.

[13] The phrase ‘semi-quantitative’ as been used as some aspects of the assessment are quantified (e.g. prevailing PM_{10} concentrations) whereas others are based more on judgement (e.g. receptor sensitivity) or coarse classifications.

5.5.2 Operational assessment – in-tunnel air quality

Overview

For in-tunnel air quality the modelling incorporated the F6 Extension Stage 1 project and all WestConnex projects, to provide representative aerodynamic and pollution boundary conditions at the interface between M4-M5 Link and New M5 Motorway. WestConnex was modelled as defined in the M4-M5 Link EIS, and incorporated connections to Western Harbour Tunnel. To reduce the overall complexity of the models, the system was sub-divided into two distinct models which were aerodynamically separated from each other and did not involve underground traffic connections:

- Southbound direction (WestConnex M4 to M5 direction)
- Northbound direction (WestConnex M5 to M4 direction).

Future stages of F6 Extension were included for the purpose of estimating emissions capture at the northbound interface between Stage 1 and futures stages (Outlet G) for the expected traffic operations. The future stages of the F6 Extension have not been analysed for design purposes.

The in-tunnel air quality modelling supplemented that conducted for the M4-M5 Link EIS, reviewing alternative plant operating philosophy for the coordinated operation of the integrated tunnel network including WestConnex and F6 Extension, incorporating revised tunnel geometry for the project and traffic demand for differing years of operation.

In-tunnel traffic, air flow, pollution levels, and temperature for the project were modelled using the IDA Tunnel software[14]. The criteria, scenarios, data and detailed method that were used in the tunnel ventilation simulation are provided in full in **Annexure K**. The modelling scenarios for expected traffic were the same as those used in the ambient air quality modelling (refer to **section 5.5.3** for the definition of these). The regulatory demand and worst case traffic scenarios were specific to traffic conditions within the tunnel.

Expected traffic (24-hour) scenarios

These scenarios represented the 24-hour operation of the tunnel ventilation system under day-to-day conditions of expected traffic demand in 2026 and 2036. For the expected traffic cases, the ventilation operation is based on producing the reasonable worst-case outlet emissions for the project outlets and for outlets directly affected by the project. The purpose of this is to provide the highest outlet emissions reasonably expected within the ambient air quality modelling domain, rather than providing the most efficient ventilation operation across the interconnected network.

Vehicle emissions were based on the design fleets in the corresponding years, with the results being presented for both in-tunnel air quality and for outlet emissions for use in the ambient air quality assessment. In the cumulative scenario, emissions from adjacent tunnel projects were also considered.

Worst case traffic scenarios

Several scenarios were devised to assess ‘worst case’ traffic conditions for the ventilation system. These scenarios were based on simplified boundary traffic conditions at 20 km/h, 60 km/h and 80 km/h that encompassed:

- Congestion (down to 20 km/h on average)
- Ramp metering
- Breakdown or minor incident
- Accident closing a tube
- Free-flowing traffic at maximum capacity

Travel route scenarios

An additional series of calculations dealt with a worst case trip scenario for in-tunnel exposure to NO_2. The approach is described in **section 7.4** of **Annexure K**.

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

All possible travel routes through the project and the adjoining tunnels were identified for each direction of travel, and these were assessed against the in-tunnel criterion for NO_2. For routes that will ultimately incorporate parts of WestConnex, the route average NO_2 was calculated as beginning or ending at the respective interface. As each portion of the entire trip met the in-tunnel NO_2 criterion on its own, the average of the entire route from origin portal to destination portal also met the criterion.

5.5.3 Operational assessment – local air quality

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

Definition of modelling domains

Separate domains were required for the meteorological modelling and dispersion modelling, and these domains are shown relative to the project and all modelled tunnel ventilation outlets in **Figure 5-1**.

The GRAMM domain (also referred to as the ‘study area’ in places) for the modelling of meteorology is shown by the red boundary in **Figure 5-1**. The domain covered a substantial part of Sydney, extending 18 kilometres in the east–west (x) direction and 15 kilometres in the north–south (y) direction.

The F6 Extension Stage 1 GRAL domain for dispersion modelling is shown by the dashed grey boundary in **Figure 5-1**. Every dispersion model run was undertaken for this domain, which extended 9.0 kilometres in the x direction and 11.6 kilometres in the y direction. The domain extended well beyond the project itself to allow for the traffic interactions between the F6 Extension Stage 1 and other projects (M4-M5 Link, New M5 Motorway and Sydney Gateway), as well as effects on all affected roads. Having relatively large GRAMM and GRAL domain also increased the number of meteorological and air quality monitoring stations that could be included for model set-up and evaluation purposes.

Modelling scenarios

Two types of scenario were considered for ambient air quality:

- Expected traffic scenarios
- Regulatory worst case scenarios.

These scenarios are described below.

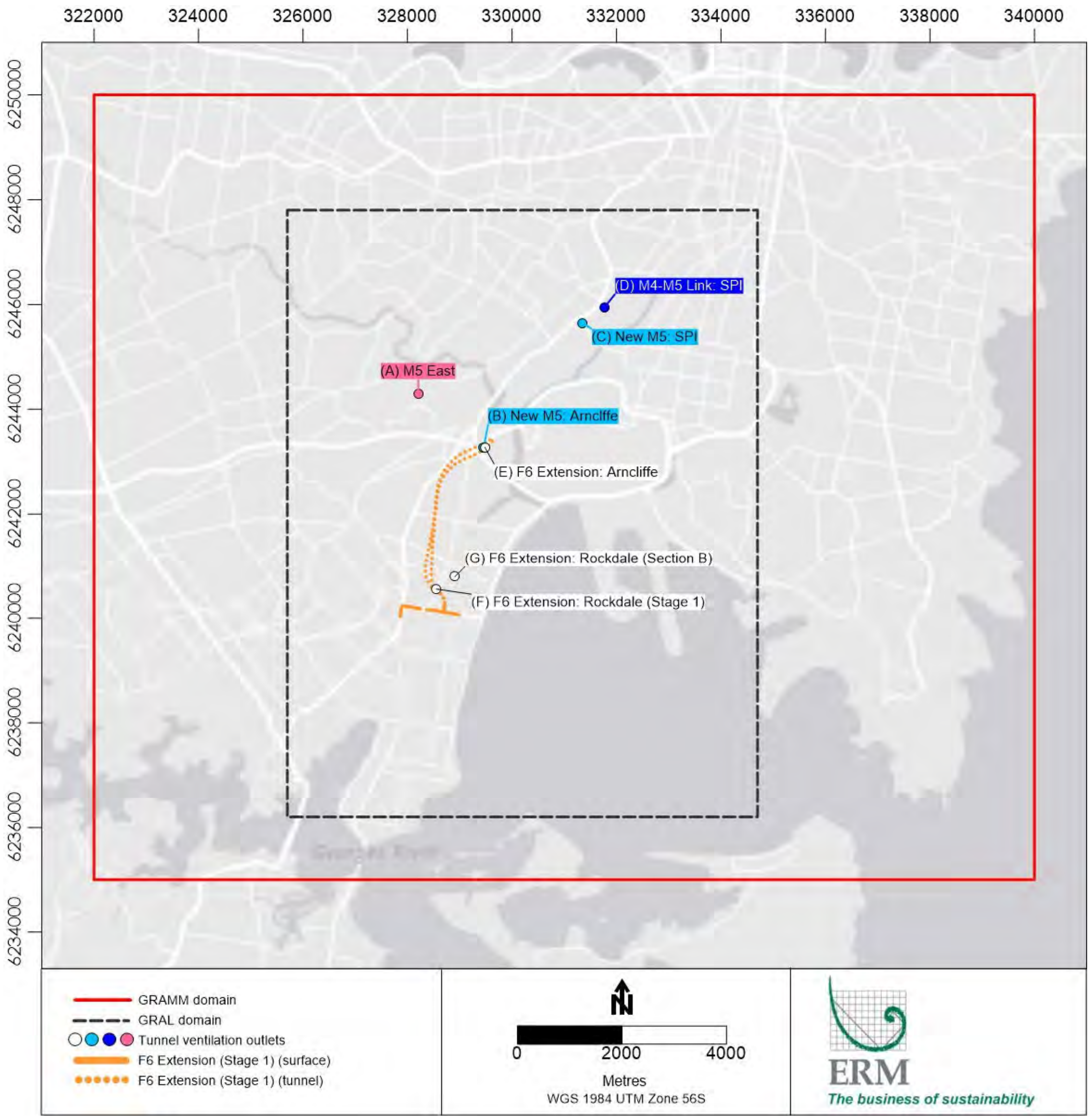

Figure 5-1 Modelling domains for GRAMM and GRAL (grid system MGA94)

Expected traffic scenarios

The six expected traffic scenarios included in the operational air quality assessment are summarised in **Table 5-1**. 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 and speed, as represented in the traffic model that was used for the assessment (Strategic Motorway Project Model - SMPM). 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. The results from the modelling of these scenarios were also used in the health risk assessment for the project.

Table 5-1 Expected traffic scenarios for the operational assessment

Scenario	Scenario description	Notes	Roads/projects included							
			Existing network	F6 Extension projects		Other projects				
				Stage 1	Future Stages	WestConnex[a]	King St Gateway	Sydney Gateway	Western Harbour Tunnel	Beaches Link
2016-BY	2016 – Base Year [b] (existing conditions)	This scenario represented the current road network with no new projects/upgrades, and was used to establish existing conditions. The main purpose was to enable the dispersion modelling methodology to be verified against actual air quality monitoring data [c].	✓	-	-	-	-	-	-	-
2026-DM	2026 – Do Minimum (no F6 Extension)	This scenario represented conditions in the opening year of the project (2026), but without the project. It is referred to as 'Do Minimum' as it assumed that some improvements would be made to the broader transport network to improve capacity and cater for traffic growth.	✓	-	-	✓	✓	✓	-	-
2026-DS	2026 – Do Something (with F6 Extension	As 2026 Do Minimum, but with F6 Extension – Stage 1 also completed.	✓	✓	-	✓	✓	✓	-	-
2036-DM	2036 – Do Minimum (no F6 Extension)	As 2026 Do Minimum, but for 10 years after project opening and without the project. This took into account changes in traffic and the emission behaviour of the fleet with time.	✓	-	-	✓	✓	✓	-	-
2036-DS	2036 – Do Something (with F6 Extension	As 2026 Do Something, but for 10 years after project opening.	✓	✓		✓	✓	✓	-	-
2036-DSC [d]	2036 – Do Something Cumulative (with full F6	As 2036 Do Something, but with all stages of the F6 Extension, Western Harbour Tunnel and Beaches Link also completed.	✓	✓	✓	✓	✓	✓	✓	✓

Notes

(a) Included WestConnex Stages 1, 2 and 3.

(b) The base (calibration) year in SMPM was 2014. In the 2016-BY scenario the traffic data for 2014 were used in conjunction with fleet data and emission factors for 2016.

(c) A similar approach is used in other countries. For example, the inclusion of a base year for model evaluation is included in the Design Manual for Roads and Bridges (http://www.standardsforhighways.co.uk/ha/standards/dmrb/vol11/section3/ha20707.pdf) in the UK. The effects of the project relative to the base year are not considered, as this would confound changes in the emission performance of the fleet, and general growth in traffic, with the effects of the project itself.

(d) Note that there was no 2026 Do Something Cumulative scenario as there were no other projects that would be open in that year in addition to those included in the 2026 Do Something scenario.

Regulatory worst case (RWC) scenarios

The objective of these scenarios was to demonstrate that compliance with the concentration limits for the tunnel ventilation outlets would deliver acceptable ambient air quality. The scenarios assessed emissions from the ventilation outlets only, with concentrations fixed at the limits. This represented the theoretical maximum change 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. Assuming that concentration limits are applied to the ventilation outlets, the results of the analysis would 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 due to changing traffic volume and tunnel fan operation.

The RWC scenarios included in the assessment varied by pollutant, as shown in **Table 5-2**. The RWC scenarios were analogous to the 'with-project' scenarios in the expected traffic case. Tests showed that for annual mean $PM_{2.5}$ the RWC-2036-DSC scenario resulted in the highest predicted concentrations at receptors, and therefore only this scenario was used for the 'inert' pollutants (i.e. CO, PM_{10}, $PM_{2.5}$ and THC). For NO_2 the influence of atmospheric chemistry, and hence total NO_X from all sources, had to be considered. This meant that all four RWC had to be examined for NO_2, as the background and road traffic contributions to NO_X were also required.

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.

Table 5-2 Regulatory worst case scenarios

Scenario	Pollutant				
	CO	NO_2	PM_{10}	$PM_{2.5}$	THC
• RWC-2026-DS	-	✓	-	-	-
• RWC-2036-DS	-	✓	-	-	-
• RWC-2036-DSC	✓	✓	✓	✓	✓

Ambient air quality criteria used in the assessment

Air quality in the F6 Extension Stage 1 domain was assessed in relation to the most relevant pollutants and the criteria from the NSW Approved Methods. These pollutants and criteria are summarised in **Table 5-3**. The long-term goals for $PM_{2.5}$ in the AAQ NEPM were also considered in the assessment of impacts, and these goals are shown in italics in the Table. However, any assessment against these goals would not have been very meaningful because the measured background concentrations of $PM_{2.5}$ were already above the goals. This is also one reason why the change in the annual mean $PM_{2.5}$ concentration was also considered (see below).

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. In this assessment, this concept has been extended to include all potentially affected receptor locations outside the construction footprint
- 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 that are consistent with the standards, and compared with the relevant standards.

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.

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

Pollutant/metric	Concentration	Averaging period	Source
Criteria pollutants			
CO	30 mg/m^3	1 hour	NSW EPA (2016)
	10 mg/m^3	8 hours (rolling)	NSW EPA (2016)
NO_2	246 µg/m^3	1 hour	NSW EPA (2016)
	62 µg/m^3	1 year	NSW EPA (2016)
PM_{10}	50 µg/m^3	24 hours	NSW EPA (2016)
	25 µg/m^3	1 year	NSW EPA (2016)
$PM_{2.5}$	25 µg/m^3	24 hours	NSW EPA (2016)
	20 µg/m^3 (goal by 2025)	24 hours	NEPC (2016)
	8 µg/m^3	1 year	NSW EPA (2016)
	7 µg/m^3 (goal by 2025)	1 year	NEPC (2016)
Air toxics(a)			
Benzene	0.029 mg/m^3	1 hour	NSW EPA (2016)
PAHs (as b(a)p)	0.0004 mg/m^3	1 hour	NSW EPA (2016)
Formaldehyde	0.02 mg/m^3	1 hour	NSW EPA (2016)
1,3-butadiene	0.04 mg/m^3	1 hour	NSW EPA (2016)
Ethylbenzene	8 mg/m^3	1 hour	NSW EPA (2016)

(a) These compounds were taken to be representative of the much wider range of air toxics associated with motor vehicles.

The human health risk assessment (**Appendix F** (Human health technical report)) has adopted a risk level in excess of 10^{-4} (one chance in 10,000) as a point where risk is considered to be unacceptable. Although the health assessment considers a comprehensive range of health endpoints, the key metric that emerged during the assessment of the NorthConnex and WestConnex projects was the increase of risk in all-cause mortality for ages 30 and over. An increase in risk of all-cause mortality is related directly to the change in the annual mean $PM_{2.5}$ concentration ($\Delta PM_{2.5}$) (Boulter et al., 2015; Manansala et al., 2015). A risk of one in 10,000 equates to a value for $\Delta PM_{2.5}$ that varies depending on the baseline mortality, and is calculated as follows:

$$R = \boldsymbol{\beta} \times \boldsymbol{\Delta} PM_{2.5} \times B$$

Where, for the project study area:

R = additional risk

β = slope coefficient for the % change in response to a 1 µg/m^3 change in exposure (β =0.0058 for $PM_{2.5}$ all-cause mortality ≥ 30 years) (Krewski et al., 2009)

$\Delta PM_{2.5}$ = change in concentration in µg/m^3 at the point of exposure

B = baseline incidence of a given health effect per person (e.g. annual mortality rate) (976.6 per 100,000 for mortality all causes ≥ 30 years) (Golder Associates, 2013)

This equation can be rewritten as:

$$\boldsymbol{\Delta} PM_{2.5} = R \; / \; (\boldsymbol{\beta} \times B)$$

For the project, the value of $\Delta PM_{2.5}$ for a risk of one in 10,000 is:

$$\Delta PM_{2.5} = \frac{0.0001}{0.0058 \times 0.00976} = 1.8 \text{ µg/m}^3$$

Pollutants and metrics excluded from the assessment

The following pollutants/metrics were not considered to be relevant to the local 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[15]. 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) (DECCW, 2010). Since 2002 the lead content of petrol has been limited to 0.005 grams per 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 $PM_{2.5}$). Although it is possible that a fraction of non-exhaust particles is greater than 10 µm in diameter, this is not well quantified

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

- 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 (DECCW, 2010). Ozone was, however, considered in the regional air quality assessment (refer to **section 5.5.4**)
- 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. Although 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
- 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 $PM_{2.5}$.

Sources contributing to ambient concentrations

The concentration of a given pollutant at a given location/receptor has contributions from various different sources. The following terms for these sources have been used in this assessment[16]:

- *Background concentration*. This is the contribution 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. In the assessment, background concentrations were based on measurements from air quality monitoring stations at urban background locations[17]. The approaches used to determine long-term and short-term background concentrations are explained in **Annexure D**. Background concentrations were assumed to remain unchanged in future years, given that trends over the last decade have generally shown them to be quite stable (or slightly decreasing). For all pollutants except NO_2, as the background concentration was the same with and without the project. A different method was required for NO_2 to account for the atmospheric chemistry in the roadside environment (refer to **Annexure E**).

[16] These terms are relevant to both annual mean and short-term (e.g. 1-hour mean or 24-hour mean) ambient air quality criteria.
[17] As defined in Australian Standard AS/NZS 3580.1.1:2007.

- *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). In the assessment, surface road concentrations were estimated using a dispersion model (GRAL). The modelling of the road network gave non-zero concentrations at the locations of air quality monitoring stations, which introduced a small element of conservatism into the approach.
- *Ventilation outlet concentration*. This is the contribution from all tunnel ventilation outlets, again determined using GRAL.

Presentation of results

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 would typically decrease between the base year and the future years as a result of improved emission controls[18]. 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 2026 and 2036 is smaller than the total concentration without the project.

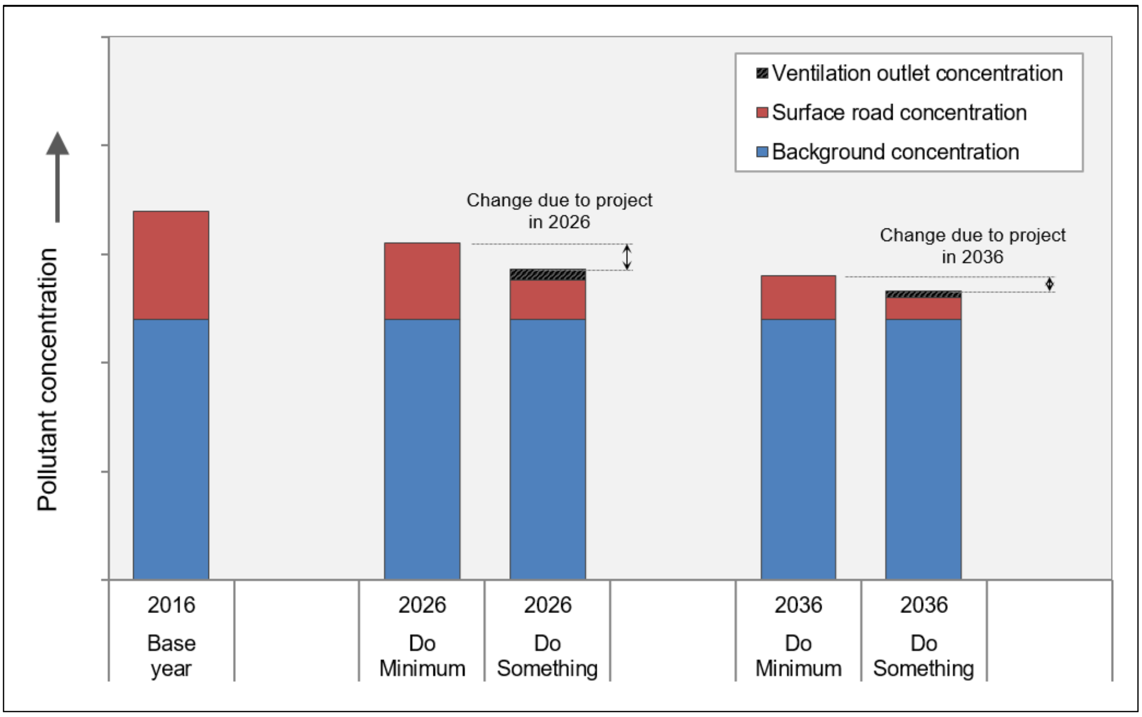

Figure 5-2 Contributions to total pollutant concentrations (example)

[18] In this figure the base year scenario is included for illustrative purposes, and the dispersion model predictions for this scenario are not presented in the report, apart from where they are used for model validation. The effects of the project on air quality are considered relative to the Do Minimum scenario in each assessment year (2026 and 2036).

The following results are presented in the report:

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

The results have been presented as:

- Pollutant concentrations (and changes) at discrete receptors (in charts and tables) at receptor locations along the project corridor where people are likely to be present for some period of the day. The actual receptors included in the assessment are described in **section 8.4.7**
- Pollutant concentrations (and changes in concentration) across the entire GRAL modelling domain as contour plots. 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 around one million grid locations across the GRAL domain
- Pollutant concentrations (and changes) in the vicinity of the project tunnel ventilation outlets (as contour plots).

5.5.4 Operational assessment – regional air quality

The potential impacts of the project on air quality more widely across the across the Sydney region were assessed through consideration of the changes in emissions across the road network (as a proxy). The regional air quality impacts of a project can also be framed in terms of its capacity to influence ozone production. NSW EPA has recently developed a Tiered Procedure for Estimating Ground Level Ozone Impacts from Stationary Sources (ENVIRON, 2011). Although this procedure does not relate specifically to road projects, it was applied here to give an indication of the likely significance of the project's effect on ozone concentrations in the broader Sydney region.

5.5.5 Operational assessment – odour

The project SEARs require the consideration of potential odour. 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 1-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 into an equivalent change for three of the odorous pollutants identified in the Approved Methods (toluene, xylenes, and acetaldehyde). These pollutants were taken to be representative of other odorous pollutants from motor vehicles.

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. This approach:

- Allows 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)

- Provides 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 community and stakeholder concerns 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 would 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 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). Excessive conservatism in modelling can also lead to potential improvements in air quality being overestimated.

5.6.2 Key assumptions

The key assumptions underpinning the assessment of operational impacts have been summarised in **section 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

Ventilation outlet parameters

A number of sensitivity tests were conducted to investigate the effects of varying key ventilation outlet parameters in the operational assessment, and to test whether these would materially affect the outcomes and conclusions of the assessment. The sensitivity tests were conducted for the following parameters:

- 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 F6 Extension domain of about two to three kilometres around the project ventilation outlets. 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 sensitive receptors was evaluated. The predicted concentrations were indicative, as the aim of the sensitivity tests was to assess the proportional sensitivity of the model to specific input parameters.

Traffic and emissions

There are a number of assumptions which may influence the performance and operation of the ventilation system. Some assumptions can influence the ventilation system more than others, and these include:

- Traffic forecasts. The expected traffic may not eventuate, or the tunnel may prove more popular than expected. So the ventilation system is designed for all feasible traffic scenarios.
- Fleet composition. The composition will vary from location to location, and with time as cleaner vehicles enter the fleet. However, the fleet forecast for ventilation design is considered to be conservative in that it does not account for alternative-fuel and low-emission vehicle technologies (e.g. electric vehicles, hybrids).
- Emissions factors. There are uncertainties in the emission factors for some recent diesel vehicle technologies, including future Euro 6 and Euro VI vehicles in Australia. However, the PIARC (2012) emissions factors applied in this assessment were considered to be representative of real-world driving conditions within tunnels, with some elements of conservatism (e.g. road gradient effects, and non-exhaust particulate matter).

While the tunnel ventilation assessment provided in **Annexure K** is considered to be conservative and encapsulates all feasible traffic scenarios, a sensitivity analysis was conducted to demonstrate that the changes in air quality and health risks due to the operation of ventilation facilities would be acceptable, even in the most unlikely of circumstances.

In the sensitivity analysis, for each ventilation outlet the daily $PM_{2.5}$ and NO_X emission profiles in the 2036-DSC scenario for expected traffic were scaled up until the corresponding emission limit was reached for least one hour each day. For both $PM_{2.5}$ and NO_X a scaling factor of 3.7 was used. The impacts of this change on annual mean ground-level concentrations of $PM_{2.5}$ and NO_2 were then determined.

This sensitivity analysis is considered to be extremely unlikely and near impossible to experience in reality. Any predicted air quality impacts or health risks predicted as a result of this sensitivity analysis should be assessed in this context.

6 Existing environment

6.1 Overview of section

This section describes the existing environment and conditions in the GRAMM domain, and covers the following aspects:

- Terrain
- Land use
- Climate
- Meteorology
- Air pollutant emissions, with an emphasis on road traffic
- In-tunnel air quality
- Ambient air quality.

The meteorological inputs and background pollutant concentrations required for the operational air quality assessment are described in **section 8**.

6.2 Terrain

Terrain data for Sydney were obtained from the Geoscience Australia Elevation Information System (ELVIS) website. 25-metre resolution terrain data were used in the GRAMM modelling and 5-metre data used in the GRAL modelling. **Figure 6-1** shows the terrain immediately surrounding the F6 Extension Stage 1 project, based on the 5-metre resolution data. The vertical scale is clearly exaggerated.

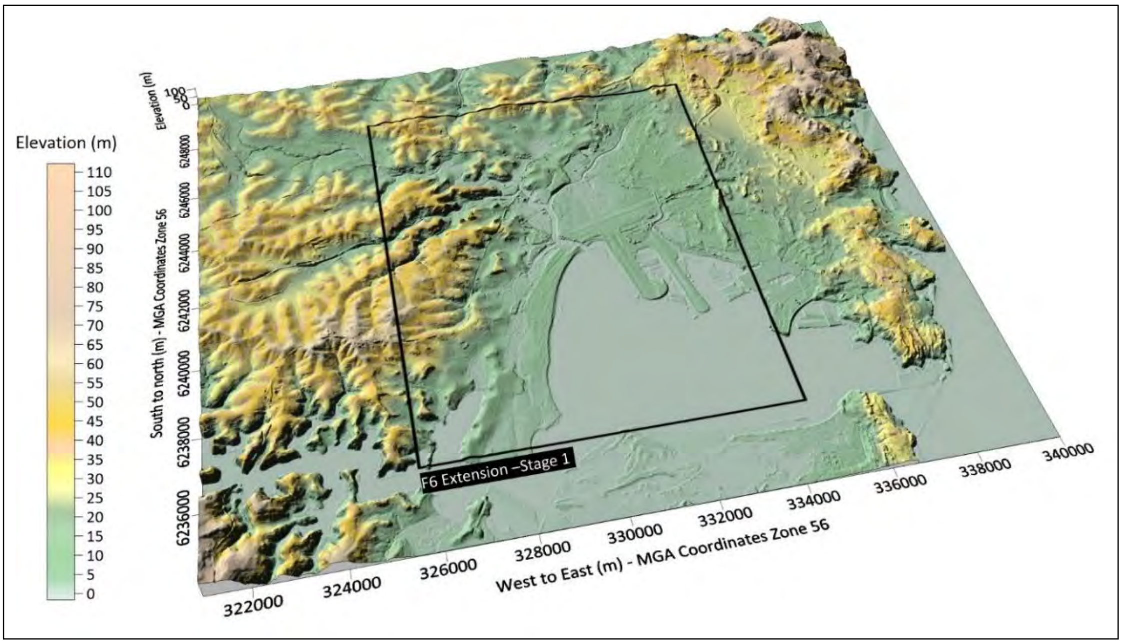

Figure 6-1 Terrain in the GRAL domain (grid system MGA94)

The terrain within the GRAL domain is predominantly flat, but the elevation increases to the north of the Airport area towards Alexandria and to the west towards Kingsgrove. The terrain along the project corridor varies from an elevation of around 2 metres Australian Height Datum (AHD) at the southern end at President Avenue to an elevation of around 10 metres at St Peters, at the northern end. To the east of the project and the south of the Airport is Botany Bay which covers a large portion of the southern area of the GRAL domain. The general uniformity of the terrain, and the lack of major geographical obstacles to wind flow, should support good dispersion and air flow throughout the GRAL domain.

6.3 Land use

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

6.4 Climate

Table 6-1 presents the long-term average temperature and rainfall data for the Bureau of Meteorology (BoM) weather station at Sydney Airport (site 066037), which is located near to the centre of the GRAL domain and is broadly representative of the area. The annual average daily maximum and minimum temperatures are 22.3°C and 13.5°C, respectively. On average, January is the hottest month with an average daily maximum temperature of 26.6°C. July is the coldest month, with an average daily minimum temperature of 7.3°C. The wettest month is March, with 117 millimetres falling over five rain days. The average annual rainfall is 1,083 millimetres over an average of 104 rain days per year.

Table 6-1 Long-term average climate summary for Sydney Airport AMO

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Mean daily maximum temperature (ºC)												
26.6	26.5	25.3	22.9	20.1	17.6	17.1	18.4	20.7	22.7	24.1	25.9	22.3
Mean daily minimum temperature (ºC)												
18.9	19.1	17.6	14.3	11.0	8.7	7.3	8.2	10.5	13.3	15.5	17.6	13.5
Mean monthly rainfall (mm)												
94.6	111.4	117.1	108.8	96.9	124.2	68.6	76.8	59.7	69.7	80.4	73.6	1083.4
Mean rain days per month (number)												
6.8	5.5	7.7	8.8	9.3	9.1	12.0	13.2	11.0	8.2	6.4	6.5	104.5

Source: BoM (2018) Climate averages for Station: 066037; Commenced: 1929 – last record January 2018; Latitude: 33.99°S; Longitude: 151.17 °E

6.5 Meteorology

As noted in **Annexure F**, meteorology is an important factor affecting the dispersion of air pollution. Six meteorological stations in the GRAMM domain 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 from these stations:

- OEH meteorological stations:
  - Randwick
  - Earlwood
- BoM meteorological stations:
  - Canterbury Racecourse AWS
  - Sydney Airport AMO
  - Kurnell AWS
  - Little Bay (The Coast Golf Club).

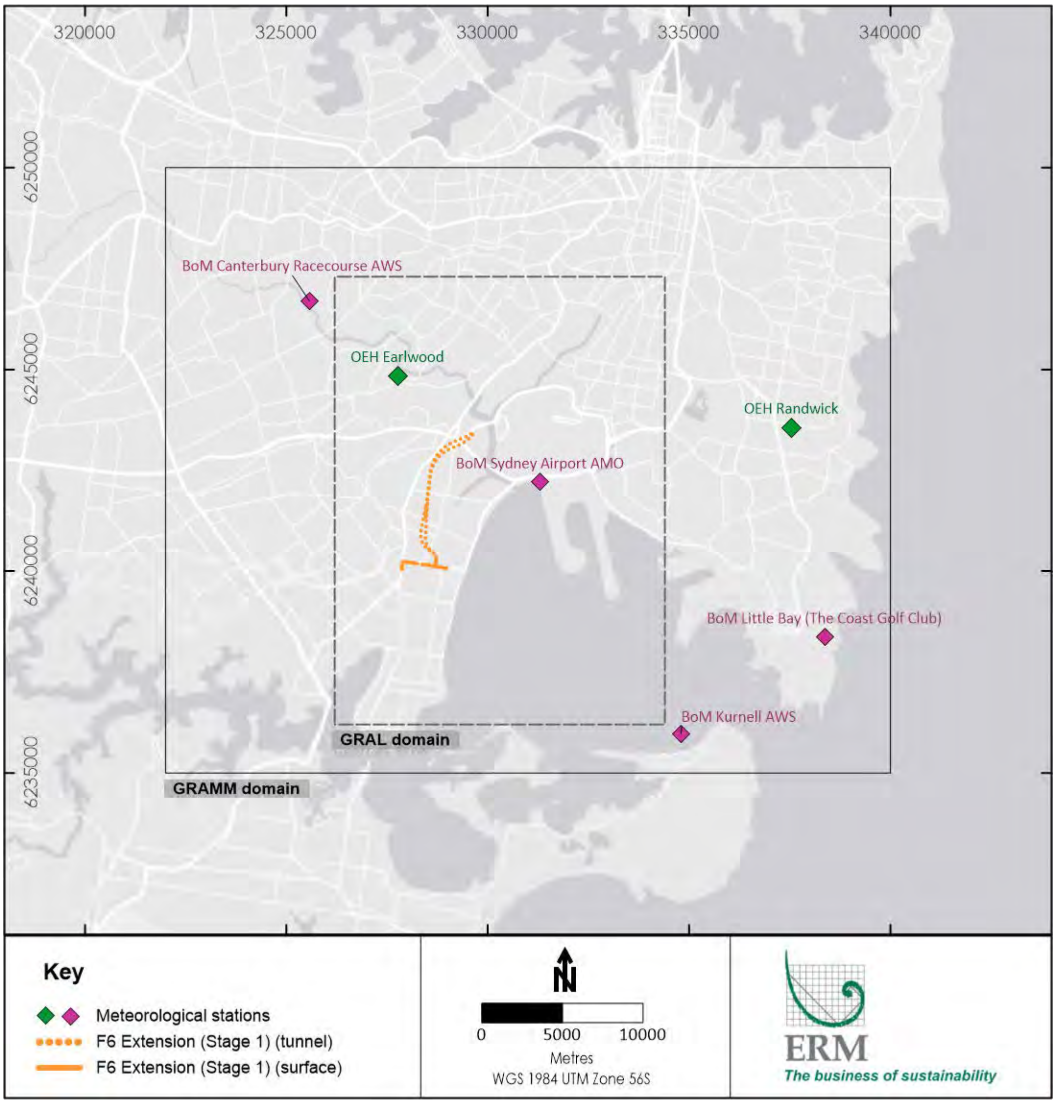

Figure 6-2 Meteorological stations in the model domains (grid system MGA94)

A detailed analysis of the meteorological data from the weather stations within the GRAMM domain is presented in **Annexure F**. Based on this analysis and other considerations, the measurements from the OEH Randwick and OEH Earlwood stations in 2016 were chosen as the reference meteorological data for modelling with varying influence. OEH Randwick was considered the most representative of the GRAL domain and specifically the project corridor. The rationale for this selection is also summarised in **Annexure F**.

At Randwick the wind speed and wind direction patterns over the eight-year period between 2009 and 2016 were quite consistent; the annual average wind speed ranged from 1.9 metres per second to 2.6 metres per second. It is worth noting that the station was surrounded by trees until 2010 when they were removed. The annual average wind speeds between 2011 and 2016 were 2.4 to 2.6 m/s. The annual percentage of calms (wind speeds <0.5 metres per second) ranged from 9.1 to 10.7 per cent between 2011 and 2016. **Figure 6-3** shows annual and diurnal plots of wind speed and temperature from the Randwick station for 2016. 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 lower wind speeds and temperatures at night and in the early morning.

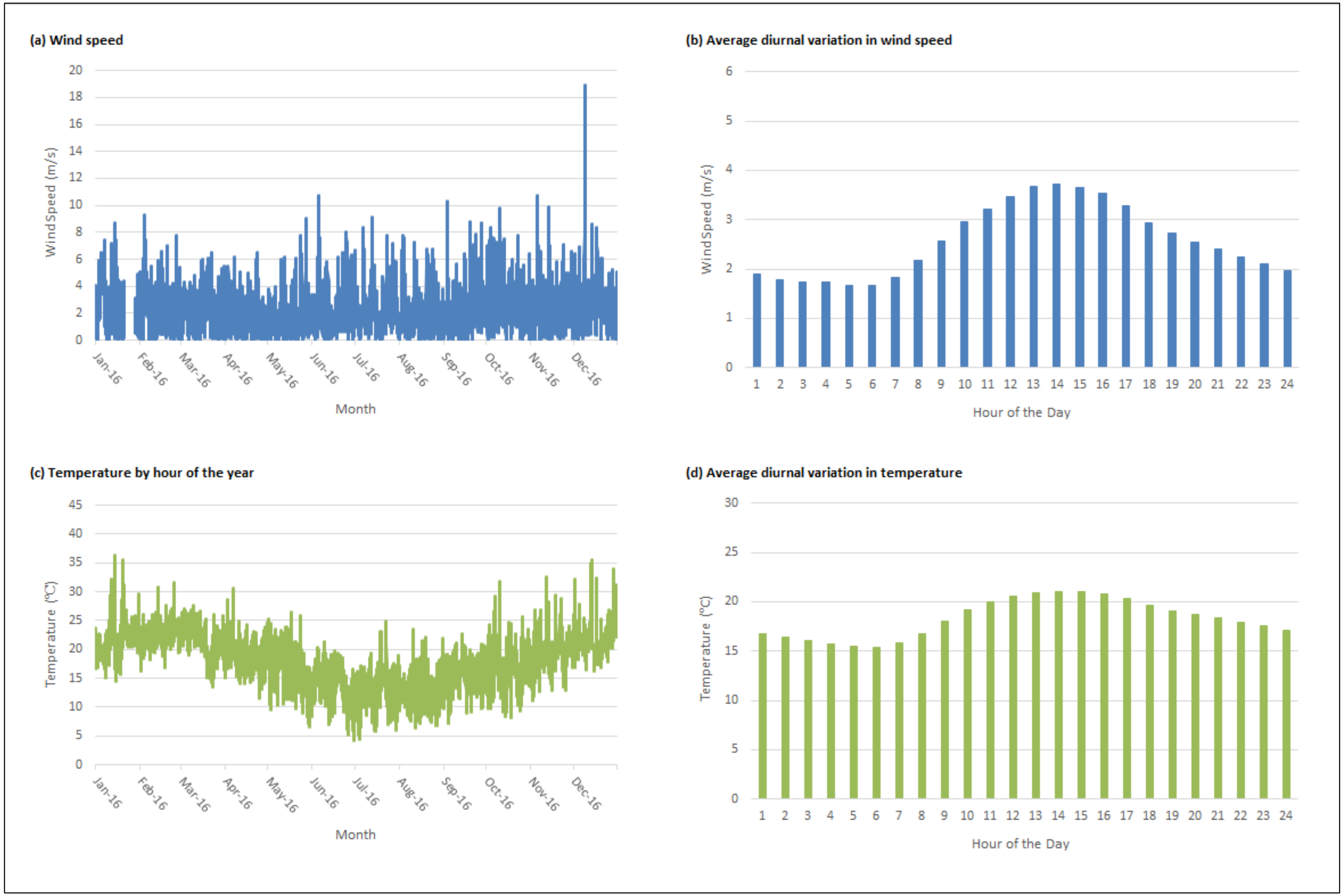

Figure 6-3 Annual and diurnal plots of wind speed and temperature for the OEH Randwick station (2016)

6.6 Air pollutant 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 would start to rise again, as increases in annual vehicle activity would 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 (2016) and for the future years.

Figure 6-4 shows that road transport was the second largest sectoral contributor to emissions of CO (34 per cent) and the largest contributor to NO_X (47 per cent) in Sydney during 2016. It was also responsible for a significant proportion of emissions of VOCs (13 per cent), PM_{10} (9 per cent) and $PM_{2.5}$ (10 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, will have contributed significantly to ambient 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 6-5** 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 would have only a minor impact on total emissions.

The breakdown of emissions in 2016 from the road transport sector by process and vehicle type is presented in **Figure 6-6**. 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 65 per cent of CO from road transport in Sydney in 2016, 37 per cent of NOx, and 71 per cent of SO_2. They were a minor source of PM_{10} (3 per cent) and $PM_{2.5}$ (4 per cent). Non-exhaust processes were the largest source of road transport PM_{10} (71 per cent) and $PM_{2.5}$ (57 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 would increase in line with projected traffic growth. Heavy-duty diesel vehicles are disproportionate contributors to 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 6-7**. There are projected to be substantial reductions in emissions of CO, VOCs, and NO_X between 2011 and 2036. There would 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).

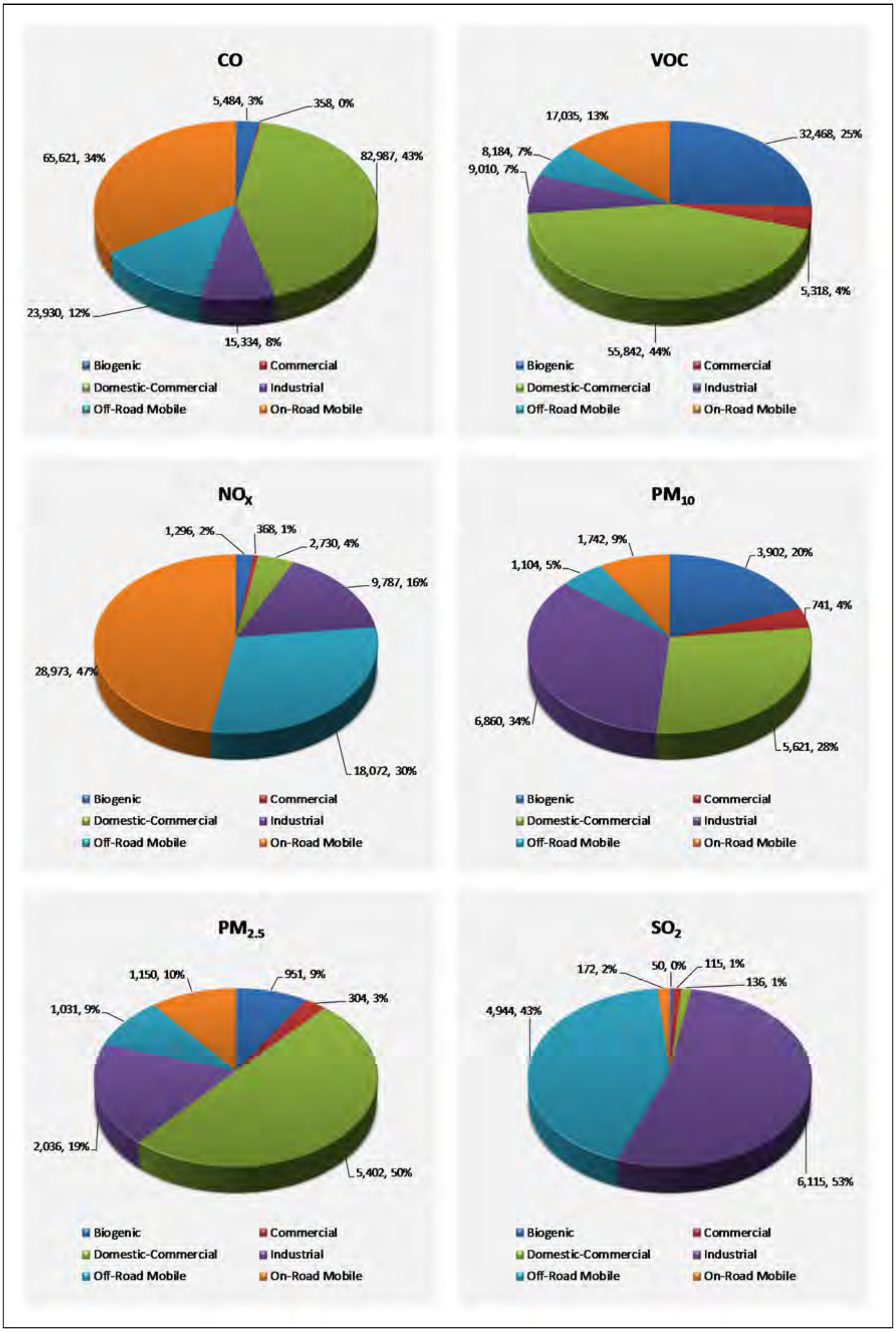

Figure 6-4 Sectoral emissions in Sydney, 2016 (tonnes per year and percentage of total)

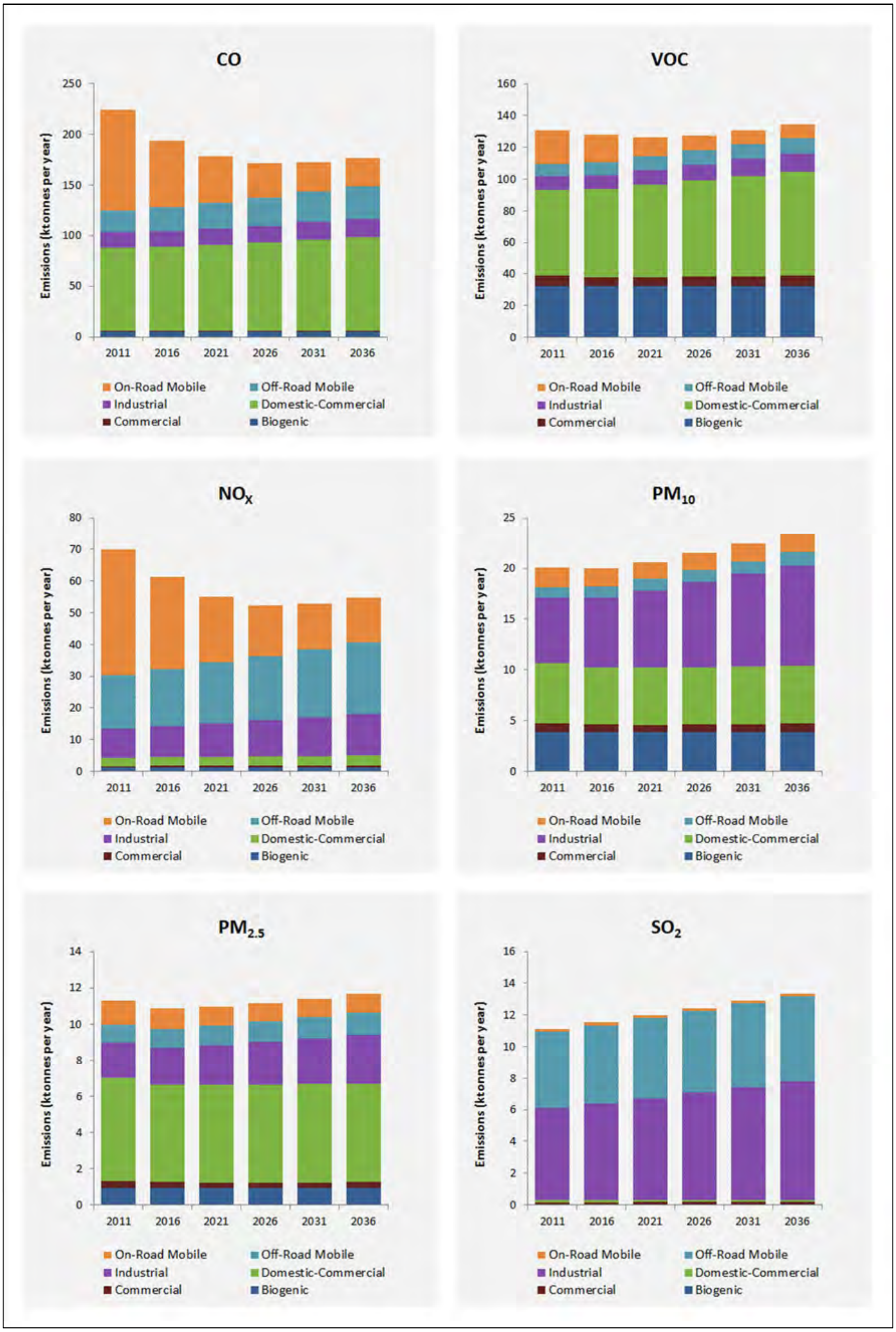

Figure 6-5 Projections of sectoral emissions – Sydney, 2011-2036

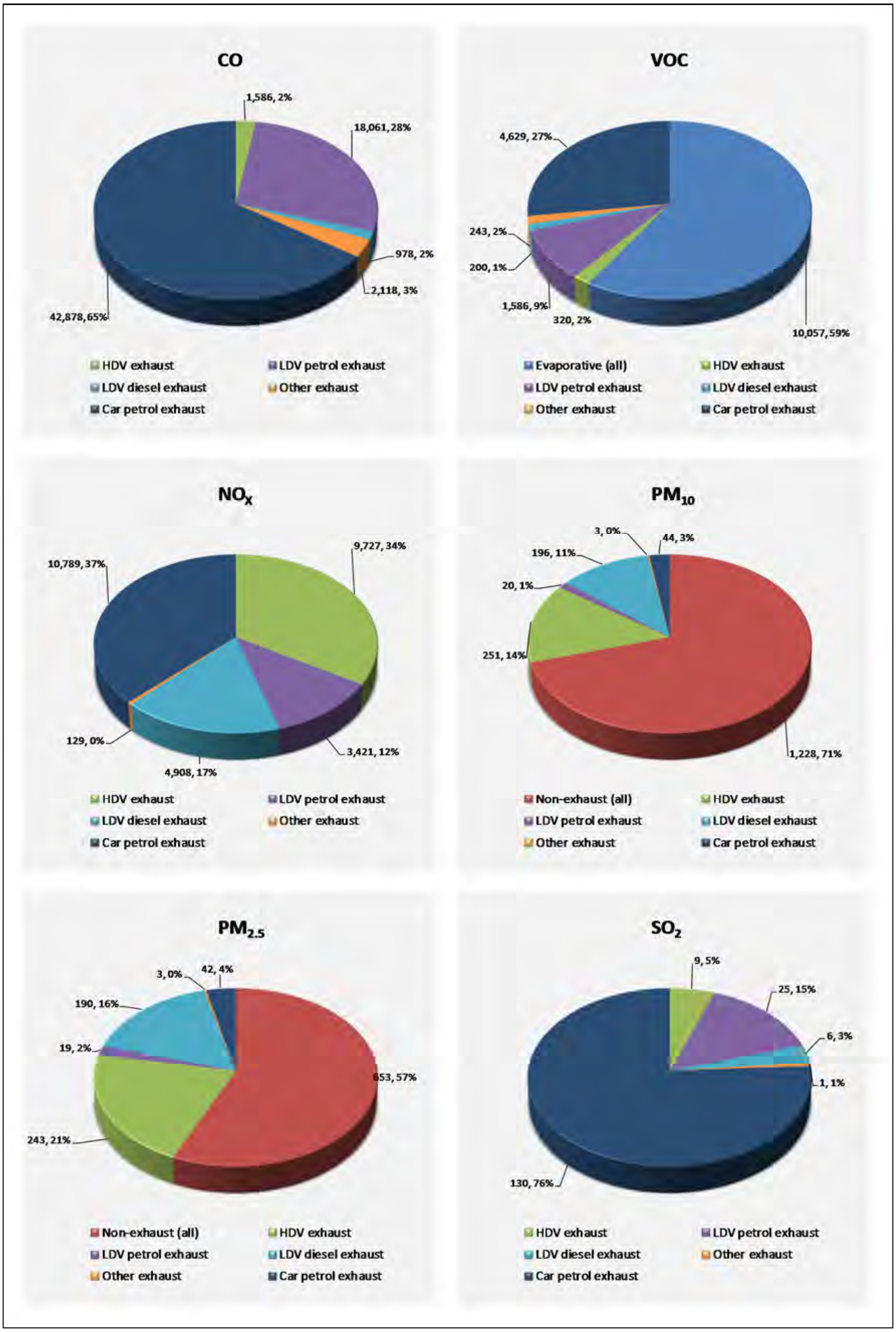

Figure 6-6 Breakdown of road transport emissions – Sydney, 2016 (tonnes per year and percentage of total)

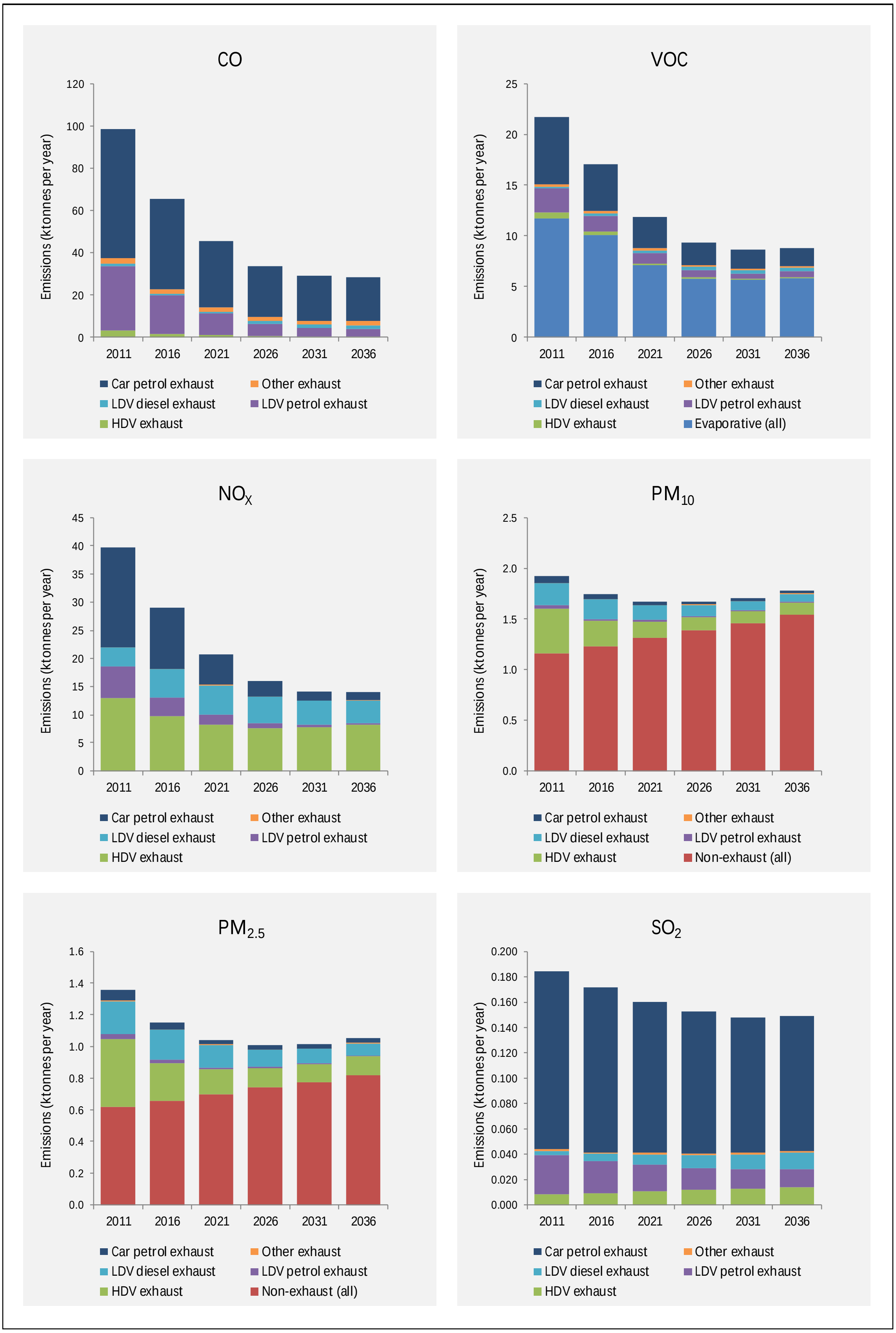

Figure 6-7 Projections of road transport emissions – Sydney, 2011-2036

6.7 In-tunnel air quality

Air quality is monitored continuously in all of 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. Some of the data are available on the websites of the tunnel operators[22,23], but the instruments typically only have a coarse resolution which is adequate for ventilation control but not for detailed scientific assessment. 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 these measurements have been used to support the ambient air quality assessment.

6.8 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 the monitoring stations in the study area.

6.8.1 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 (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 (OEH, 2015).

6.8.2 Data from monitoring stations in the study area

A detailed analysis of the historical trends in Sydney's air quality (2004–2016), and the current situation, is provided in **Annexure D**. The analysis was based on hourly data from the following long-term monitoring stations operated by OEH and Roads and Maritime:

- OEH stations (urban background)
  - Chullora, Earlwood, Randwick, Rozelle, Lindfield, Liverpool, Prospect
- Roads and Maritime (M5 East urban background)
  - CBMS, T1, U1, X1
- Roads and Maritime (M5 East roadside)
  - F1, M1.

Consideration was also given to the shorter-term data from other Roads and Maritime air quality monitoring stations.

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

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

The results for specific air quality metrics during the period 2004-2016 can be summarised as follows:

- Maximum 1-hour and rolling 8-hour mean CO
  - All values were well below the air quality criteria of 30 mg/m^3 (1-hour) and 10 mg/m^3 (8-hour), and quite stable at all stations between 2004 and 2016. In 2016 the maximum 1-hour concentrations were typically between around 2 and 3 mg/m^3, and the maximum 8-hour concentrations were around 2 mg/m^3
  - There were general downward trends in maximum concentrations, and these were statistically significant at most stations
- Annual mean NO_2
  - Concentrations at all stations were well below the air quality criterion of 62 µg/m^3, and ranged between around 15 and 25 µg/m^3 (depending on the station) in recent years. Values at the OEH stations exhibited a systematic, and generally significant, downward trend overall. However, in recent years the concentrations at some stations appear to have stabilised
  - The long-term average NO_2 concentrations at the Roads and Maritime roadside stations (F1 and M1) were 34–37 µg/m^3, and hence around 10–20 µg/m^3 higher than those at the background stations. Even so, the concentrations at the roadside stations were also well below the criterion
- Maximum 1-hour NO_2
  - Although variable from year to year, maximum NO_2 concentrations have been quite stable in the longer term. The values across all stations typically range between 80 and 120 µg/m^3, and continue to be well below the criterion of 246 µg/m^3
  - The maximum 1-hour mean NO_2 concentrations at the Roads and Maritime roadside stations in 2016 were 144-165 µg/m^3. These values were higher than the highest maximum values for the background stations
- Annual mean PM_{10}
  - Concentrations at the OEH stations showed a downward trend, and this was statistically significant at several stations. In recent years the annual mean concentration at these stations has been between 17 µg/m^3 and 19 µg/m^3, except at Lindfield where the concentration is substantially lower (around 14 µg/m^3). The concentrations at the Roads and Maritime background stations appear to have stabilised at around 15 µg/m^3. These values can be compared with air quality criterion of 30 µg/m^3 and the standard of 25 µg/m^3 in the recently varied NEPM
- Maximum 24-hour PM_{10}
  - Maximum 24-hour PM_{10} concentrations exhibited a slight downward trend overall, but there was a large amount of variation from year to year. In 2016 the concentrations at the various stations were clustered around 40 µg/m^3
- Annual mean $PM_{2.5}$
  - $PM_{2.5}$ has only been measured over several years at three OEH stations in the study area. Concentrations at Chullora and Earlwood showed a similar pattern, with a systematic reduction between 2004 and 2012 being followed by a substantial increase in 2013. 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 2016 were already very close to or above the standard in the AAQ NEPM of 8 µg/m^3, and above the long-term goal of 7 µg/m^3
- Maximum 24-hour $PM_{2.5}$
  - 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 standard in the AAQ NEPM of 25 µg/m^3, and were generally above the long-term goal of 20 µg/m^3.

The data from these stations were also used to define appropriate background concentrations of pollutants for the project assessment (see **Annexure D**).

6.8.3 Project-specific air quality monitoring

Two project-specific monitoring stations were established for the F6 Extension by Roads and Maritime in late 2017. One of these (station F6:01) was at a background location, and the other at a roadside location. Given the date of deployment, the time period covered was too short for these to be included in the development of background concentrations and model evaluation. However, the data from the stations for December 2017 to June 2018 are presented in **Annexure D**.

The F6 Extension stations were designed to:

- Supplement the existing OEH and Roads and Maritime stations in Sydney
- Establish the representativeness of the data from these stations that were used to characterise air quality in the F6 Extension modelling domain
- Provide a time series of air quality data in the vicinity of the project.

For background air quality, the data from the F6:01 station have been compared with the range of measurements at OEH/SMC stations, and these comparisons are shown in **Annexure D**.

- It is worth noting that background stations are located so as to characterise regional air quality, and therefore the data ought to show similar patterns from station to station, albeit with some variation in absolute concentrations. The data from roadside stations are, on the other hand, dependent on additional factors - such as the type of road (level in hierarchy), the level of traffic, and the distance between the road and the monitoring station - and are inherently more variable.

Given that the various monitoring stations are at a range of locations across Sydney, differences in concentration are to be expected. It is therefore more helpful to consider the general patterns in the data than features of specific stations.

Average CO concentrations at the F6:01 station were broadly comparable to those at the OEH/SMC stations. It is worth observing that all the measured 1-hour CO concentrations were well below the corresponding criterion of 30 mg/m^3, and any differences between the OEH and F6 Extension data would not have had a material impact on the outcomes of the assessment for this pollutant.

For NO_X, NO_2 and O_3 the average measurements at the F6:01 station were comparable to those at the OEH/SMC sites, and showed broadly similar patterns in terms of peak concentrations. However, for NO_X not all of the concentration peaks in the OEH/SMC data were apparent in the F6:01 data. This suggests that the the use of the OEH/SMC stations could have resulted in rather conservative maximum concentrations of NO_2 in the air quality assessment.

The average PM_{10} and $PM_{2.5}$ measurements at the F6:01 station were very similar to those at the OEH stations. Various peaks in the OEH/SMC data were not apparent in the data for the F6:01 station, which again suggests that the maximum concentrations in the air quality assessment would be conservative.

7 Assessment of construction impacts

7.1 Dust impacts

7.1.1 Overview of section

This section deals with the potential impacts of the construction phase of the project. The construction activities for the project were described in **section 2.2.1**. The section:

- Identifies the construction footprint and scenarios
- Describes the assessment procedure, which was based upon the guidance published by the UK Institute of Air Quality Management (IAQM, 2014). 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 Sydney, taking into account factors such as the assessment criteria for ambient PM_{10} concentrations
- Identifies the measures that are recommended to manage any potential impacts of construction (these are listed in **section 9.1**)
- Discusses the significance of the identified risks.

7.1.2 Construction footprint and scenarios

The total above-ground area required to facilitate the construction of the project is referred to as the 'construction footprint', and an overview of this was provided in **Figure 2-2**. The above-ground construction activities would take place at a number of separate locations, and these have been grouped into two distinct zones as shown in **Table 7-1**.

The power line has not been included in either of the construction zones. This line will be underground for its entire length, either by trenching or, where required, under-boring to avoid sensitive features. Where the power line crosses waterways or railways, conduits will be attached to existing bridges. The trench will require very minor earth works, which would be backfilled at the end of each day. It will not be a significant source of dust and is not included in this assessment of construction.

Table 7-1 F6 Extension Stage 1 construction compounds

Compound	Description	Indicative construction period
Zone 1	C1	Q4 2020 to Q2 2023
Zone 2	C2,3,4,5,6	Q4 2020 to Q4 2023

7.1.3 Assessment procedure

The IAQM procedure for assessing risk from construction dust[24] is summarised in **Figure 7-1**.

If an initial screening step shows that an assessment is required, construction activities are 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. 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. Covers the processes of soil stripping, ground levelling, excavation and landscaping. Earthworks would primarily involve excavating material, haulage, tipping and stockpiling
- Construction. Any activity that involves the provision of new structures, modification or refurbishment. Structures would include a residential dwelling, office building, retail outlet or road
- Track-out. This involves the transport of dust and dirt by heavy-duty vehicles (HDVs) from the work sites onto the public road network, where it may be deposited and then re-suspended by other vehicles.

[24] It was assumed that exhaust emissions from on-site plant and site traffic would be unlikely to have a significant impact on local air quality.

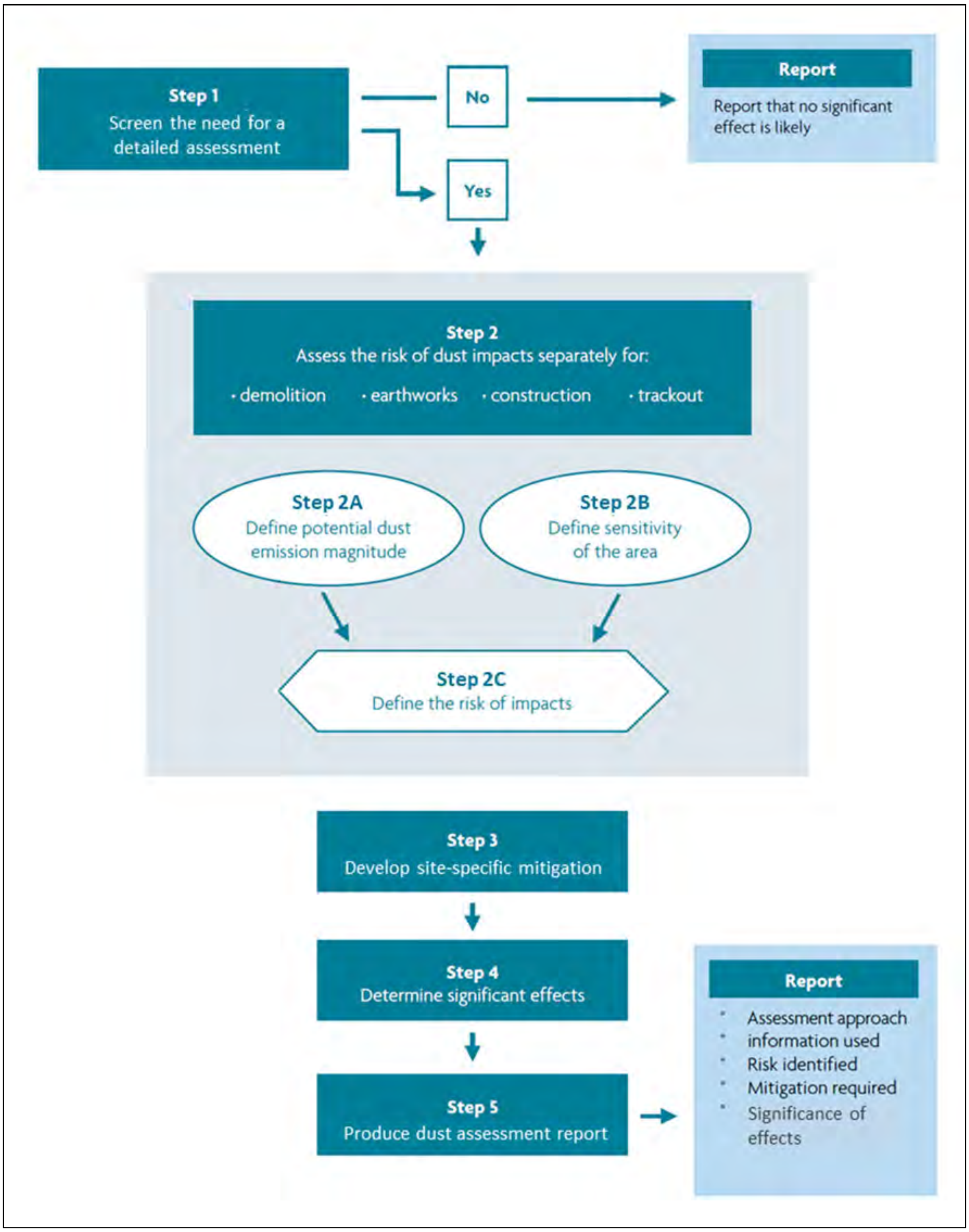

Figure 7-1 Steps in an assessment of construction dust (IAQM, 2014)

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 would be no significant effect.

The assessment steps, as they were applied to the project, are summarised in the following sections. Professional judgement was required at some stages, and where the justification for assumptions could not be fully informed by data a precautionary approach was adopted.

For some construction excavation activities there can be associated odour issues. In the case of this project this may include the disturbance of sulfurous material as it is exposed to the atmosphere. These issues have been considered in detail in section **section 7.2**.

For some major construction excavation activities (such as landfill sites for the New M5 Motorway project) can cause potential odour issues during excavation. For the F6 Extension Stage 1 project, there is a section of cut-and-cover activity that may disturb odorous material and so a separate odour assessment has been undertaken to address this risk. This can be found in **section 7.2**.

7.1.4 Step 1: Screening

Step 1 involved a screening assessment. A construction dust assessment is normally 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 that is relevant to air quality standards and goals. Annoyance effects would 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. 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 proposed construction work compounds were examined in combination. It can be seen from **Figure 7-2** that there were multiple off-site human receptors within 350 metres of the boundaries of the project construction sites. The areas potentially affected by construction dust also contained areas of ecological significance, and these were therefore included in the assessment.

7.1.5 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 would be required in proportion to the level of risk.

Step 2A: Potential for dust emissions

The criteria for assessing the potential scale of dust emissions based on the scale and nature of the works are shown in **Table 7.2**. The appropriate categories for each zone were determined based on these criteria and the types of activity proposed within the zone and are shown in **Table 7-3**.

Figure 7-2 Screening assessment – receptors near the construction of the F6 Extension Stage 1 project

Table 7-2 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 20,000–50,000 m^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 would 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 (>3.5 t) outward movements in any one day, potentially dusty surface material (e.g. high clay content), unpaved road length >100 m.	10–50 HDV (>3.5 t) outward movements in any one day, moderately dusty surface material (e.g. high clay content), unpaved road length 50–100 m.	<10 HDV (>3.5 t) outward movements in any one day, surface material with low potential for dust release, unpaved road length <50 m.

Table 7-3 Results of categorisation of compound for each type of activity

Type of activity	Site category by Zone	
	Zone 1 (C1)	Zone 2 (C2,3,4,5)
Demolition	N/A	Large
Earthworks	Large	Large
Construction	Small	Large
Track-out	Large	Large

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 impacts are shown in **Table 7-4**. 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 that is relevant to the air quality criterion for PM_{10} (in the case of the 24-hour criterion a relevant location would be one where individuals may be exposed for eight hours or more in a day). The main example of this would be a residential property. All non-residential sensitive receptor locations were considered as having equal sensitivity to residential locations for the purposes of this assessment. In view of the types of receptor shown in **Figure 7-2**, being predominantly residences in addition to community centres, and in consideration of the IAQM guidance, the receptor sensitivity was assumed to be 'high'.

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

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 land-use zoning 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 that are not dwellings, professional judgement should be used to determine the number of human receptors. In the case of the F6 Extension Stage 1 the following numbers of receptors per building were assumed:

- Commercial:
  - Commercial = 5
- Mixed use:
  - Mixed Use = 3
- Community:
  - Aged Care = 100
  - Childcare = 30
  - Community = 20
  - Further Education = 500
  - Medical = 10
  - School = 10
- Industrial:
  - Industrial = 10
- Residential:
  - Residential = 5
- Recreation:
  - Recreation = 20
- Special Purpose:
  - Hospital = 1000.

The numbers of receptors for each compound and activity, and the resulting outcomes, are shown in **Table 7-5**. Based on the receptor sensitivity and the numbers of receptors within certain distances from activities, the sensitivity for all areas and all activities was determined to be 'high'.

Table 7-5 Results of sensitivity to dust soiling effects

Zone	Activity	Receptor sensitivity	Number of receptors by distance from source (m)				Sensitivity of area
			<20	20–50	50–100	100–350	
Zone 1 (C1)	Demolition	N/A	N/A	N/A	N/A	N/A	N/A
	Earthworks	High	0	25	149	1339	Medium
	Construction	High	0	25	149	1339	Medium
	Track-out	High	0	25	N/A	N/A	Medium
Zone 2 (C2,3,4, 5 & 6)	Demolition	High	1256	1014	3875	18353	High
	Earthworks	High	1256	1014	3875	18353	High
	Construction	High	1256	1014	3875	18353	High
	Track-out	High	1256	1014	N/A	N/A	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 7-6**. Air quality monitoring data from monitoring stations in the vicinity were used to establish an annual average PM_{10} concentration of 19 µg/m^3 (see **Annexure E**). Based on the IAQM guidance the receptor sensitivity was assumed to be 'high'. The numbers of receptors for each zone and activity, and the resulting outcomes, are shown in **Table 7-7**.

Table 7-6 Criteria for sensitivity of area to health impacts

Receptor sensitivity	Annual mean PM_{10} conc. (µg/m^3)[(a)]	Number of receptors	Distance from source (m)				
			<20	<50	<100	<200	<350
High	>20	>100	High	High	High	Medium	Low
		10–100	High	High	Medium	Low	Low
		1–10	High	Medium	Low	Low	Low
	17.5 – 20	>100	High	High	Medium	Low	Low
		10–100	High	Medium	Low	Low	Low
		1–10	High	Medium	Low	Low	Low
	15 – 17.5	>100	High	Medium	Low	Low	Low
		10–100	High	Medium	Low	Low	Low
		1–10	Medium	Low	Low	Low	Low
	<15	>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 for Sydney, according to the ratio of NSW and UK annual mean standards (30 µg/m^3 and 40 µg/m^3 respectively).

Table 7-7 Results for sensitivity of area to health impacts

Zone	Activity	Receptor sensitivity	Annual mean PM_{10} conc. (µg/m^3)	Number of receptors by distance from source (m)					Sensitivity of area
				<20	20-50	50-100	100-200	200-350	
Zone 1 (C1)	Demolition	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Earthworks	High	17.5-20	0	25	149	424	915	Medium
	Construction	High	17.5-20	0	25	149	424	915	Medium
	Track-out	High	17.5-20	0	25	N/A	N/A	N/A	Medium
Zone 2 (C2,3,4,5, 6)	Demolition	High	17.5-20	1256	1014	3875	7169	11184	High
	Earthworks	High	17.5-20	1256	1014	3875	7169	11184	High
	Construction	High	17.5-20	1256	1014	3875	7169	11184	High
	Track-out	High	17.5-20	1256	1014	N/A	N/A	N/A	High

Sensitivity of area to ecological impacts

The criteria for determining the sensitivity of an area to ecological impacts of construction dust are shown in **Table 7-8**. Based on the IAQM guidance the receptor sensitivity was assumed to be 'high' for ecologically sensitive areas such as threatened flora and fauna. Areas containing potential for ecological significance within 20 metres of the construction disturbance footprint were found in Zones 1 and 2. The results are shown in **Table 7-9**.

Table 7-8 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 7-9 Results of sensitivity to ecological impacts

Zone	Activity	Receptor sensitivity	Distance from source (metres)	Sensitivity of area
Zone 1 (C1)	Demolition	High	<20	High
	Earthworks	High	<20	High
	Construction	High	<20	High
	Track-out	High	<20	High
Zone 2 (C2,3,4,5,6)	Demolition	High	<20	High
	Earthworks	High	<20	High
	Construction	High	<20	High
	Track-out	High	<20	High

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 7-10**.

Table 7-10 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

The final results for the Step 2C risk assessment are provided in **Table 7-11**, combining the scale of the activity and the sensitivity of the area. As the level of risk varies in accordance with zone and activity, those activities that were determined to be of high risk have been identified as follows:

- Zone 1: High risk for earthworks and track-out for ecological
- Zone 2: High risk for dust soiling, human health and ecological for all type of activities.

Table 7-11 Summary of risk assessment for the construction of the F6 Extension Stage 1

Zone	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
Zone 1 (C1)	Demolition	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Earthworks	Large	Medium	Medium	High	Medium Risk	Medium Risk	High Risk
	Construction	Small	Medium	Medium	High	Low Risk	Low Risk	Low Risk
	Track-out	Large	Medium	Medium	High	Medium Risk	Medium Risk	High Risk
Zone 2 (C2,3,4,5,6)	Demolition	Large	High	High	High	High Risk	High Risk	High Risk
	Earthworks	Large	High	High	High	High Risk	High Risk	High Risk
	Construction	Large	High	High	High	High Risk	High Risk	High Risk
	Track-out	Large	High	High	High	High Risk	High Risk	High Risk

(a) N/A = not applicable

7.1.6 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 9.1**.

7.1.7 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 significant residual 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 would 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 would 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'.

7.2 Odour impacts

7.2.1 Overview

As part of the construction program the cut and cover area to the north of President Avenue will require excavation. There is potential for impacts from odour during this process as contaminated acid sulfate soils will be exposed to the air. This has the potential to release the odorous hydrogen sulfide gas (H_2S) into the atmosphere impacting nearby receptors.

This section provides an assessment of H_2S emissions and resulting ground level concentrations predicted using atmospheric dispersion modelling.

7.2.2 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:

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

For most odours, when determining offensiveness the context in which an odour is perceived is also relevant. However some odours, for example the smell of hydrogen sulfide (H_2S) as relevant for this study, are likely to be judged offensive regardless of the context in which they occur.

The NSW Approved Methods include ground-level concentration criteria for complex mixtures of odorous air pollutants and also particular odorous gases such as H_2S. 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 7-12 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. With regard to H_2S, the relevant odorous pollutant for this assessment, odour units (OU) are converted to micrograms per cubic metre (µg/m^3) as a function of population density, using the following equation from the Approved Methods:

Impact assessment criterion (µg/m^3) = ($\log_{10}$ (population) – 4.5) / (– 0.87)

Table 7-12 also presents these equivalent H_2S criteria for the corresponding odour values. The most stringent of the impact assessment criterion of 1.38 µg/m^3 at the 99th percentile has been applied to the assessment.

Table 7-12 Criteria for the assessment of odour and hydrogen sulfide (NSW EPA, 2016)

Population of affected community	Complex mixtures of odour (OU)	Hydrogen sulfide (µg/m^3)
≤ ~2	7	4.83
~10	6	4.14
~30	5	3.45
~125	4	2.76
~500	3	2.07
Urban (≥ ~2000)	2	1.38

Note: these criteria apply to the 99th percentile 1-hour average

7.2.3 Modelling methodology

In order to conduct a quantitative assessment of the potential odour impacts resulting from dredging activities, a dispersion modelling study has been undertaken. Dispersion modelling involves various model inputs, including local meteorology and emission rates from potential sources. Given the coastal nature of this study and also the terrain in some parts of the model domain, the air dispersion modelling conducted for this assessment is based on an advanced modelling system using the models TAPM and CALMET/CALPUFF.

The modelling system works as follows:

- TAPM is a prognostic meteorological model that generates gridded three-dimensional meteorological data for each hour of the model run period.
- CALMET, the meteorological pre-processor for the dispersion model CALPUFF, calculates fine resolution three-dimensional meteorological data based upon observed ground and upper level meteorological data, as well as observed or modelled upper air data generated, for example, by TAPM.
- CALPUFF then calculates the dispersion of plumes within this three-dimensional meteorological field.

Sections 7.2.4 and 7.2.5 provide more detail on these inputs with results provided in section 7.2.6.

7.2.4 Local meteorology

Meteorological data from a number of BoM stations during 2016 were used for this assessment. A three-dimensional CALMET file (for use as input for the CALPUFF model) was generated for a domain which covered the F6 Extension Stage 1 project. The four stations within the domain were Manly, Fort Denison, Randwick and Sydney Airport. Only cloud cover and cloud height data were used from Sydney Airport. Wind speed, direction, temperature and other parameters were used from all other sites. **Figure 7-3** shows the locations of these stations and also the TAPM, CALMET and CALPUFF domains for modelling purposes.

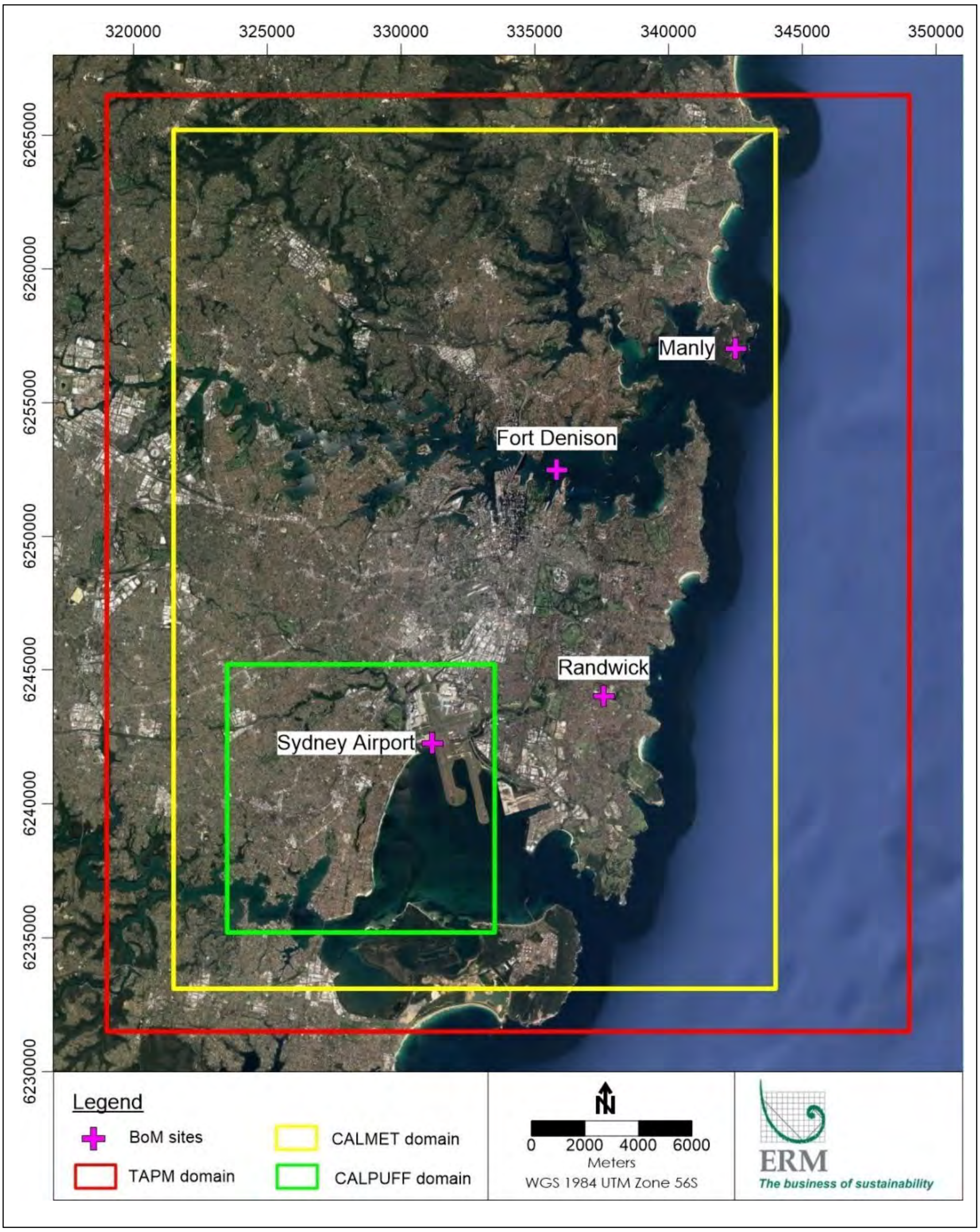

Figure 7-3 Meteorological and dispersion modelling domains for odour assessment

7.2.5 Emission sources

The source of odour for this project is the release of hydrogen sulfide gas when the excavation activities disturb an historical landfill site. This is in the area north of President Avenue and west of West Botany Street.

In the absence of site specific H_2S emission rates, flux values from a CSIRO study that measured sulfur gas emissions in coastal acid sulfate soils in eastern Australia, have been used (**CSIRO, 2011**). The maximum value, plus the standard error of the mean, has been used for this assessment, 2.01±2.19 ng/m^2/s (4.20 ng/m^2/s).

This maximum H_2S flux was assumed to occur for every hour of the year and across the total exposed area of 7,000 m^2. Assuming a peak-to-mean ratio of 2.5, is shown in **Table 7-13**. Dispersion modelling results are presented in **section 7.2.6**.

Table 7-13 Odour emission rates for each odour source

Source	Emission rate (ng/m^2/s)	Total area (m^2)	Peak-to-mean ratio	Total odour emission rate (ng/s)
Excavation area at Rockdale Bicentennial Park	4.2	2,500	2.5	26,250
Excavation are near creek on Pres Ave.	4.2	4,500	2.5	47,250
Acid sulfate treatment area	4.2	10,000	2.5	105,000

7.2.6 Modelling results

This section provides the predicted H_2S concentrations due to proposed construction activities, stockpiling and treatment north of President Avenue. The results, presented in **Figure 7-4** show that the predicted 99th percentile H_2S concentrations at the nearest receptors are well below the criterion of 1.38 µg/m^3 and likely to be below the level of detection.

It is assumed that these areas will be exposed for all hours of the year, which may be the case for the treatment area, but unlikely for the excavation areas.

It is recommended that onsite odour measurements be carried out once operations begin so that site-specific odour emission rates can be determined. These can be used to re-model the area, or alternatively, site odour audits could be carried out to determine the actual impacts at the nearest receptors.

Figure 7-4 Predicted 99th percentile H_2S concentration due to exposure of acid sulfate material ($\mu g/m^3$)

8 Assessment of operational impacts

8.1 Overview of section

This section details 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 both tunnel ventilation outlets and surface roads, and considered the cumulative impacts of these and background pollutant concentrations. The section describes the following:

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

8.2 Emissions

8.2.1 Introduction

For each scenario (expected traffic) a spatial emissions inventory was developed for road traffic sources in the F6 Extension Stage 1 GRAL domain. The following components were treated separately:

- Emissions from existing and proposed tunnel ventilation outlets
- 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.

The assessment was conducted assuming no emissions from any tunnel portals; that is, all emissions from the traffic in tunnels were assumed to be released to the atmosphere via ventilation outlets.

8.2.2 Tunnel ventilation outlets

Method

Overview

Emissions were determined for seven different tunnel ventilation outlets, the locations of which are shown in **Figure 8-1**. All ventilation outlets for tunnels in the domain were included.

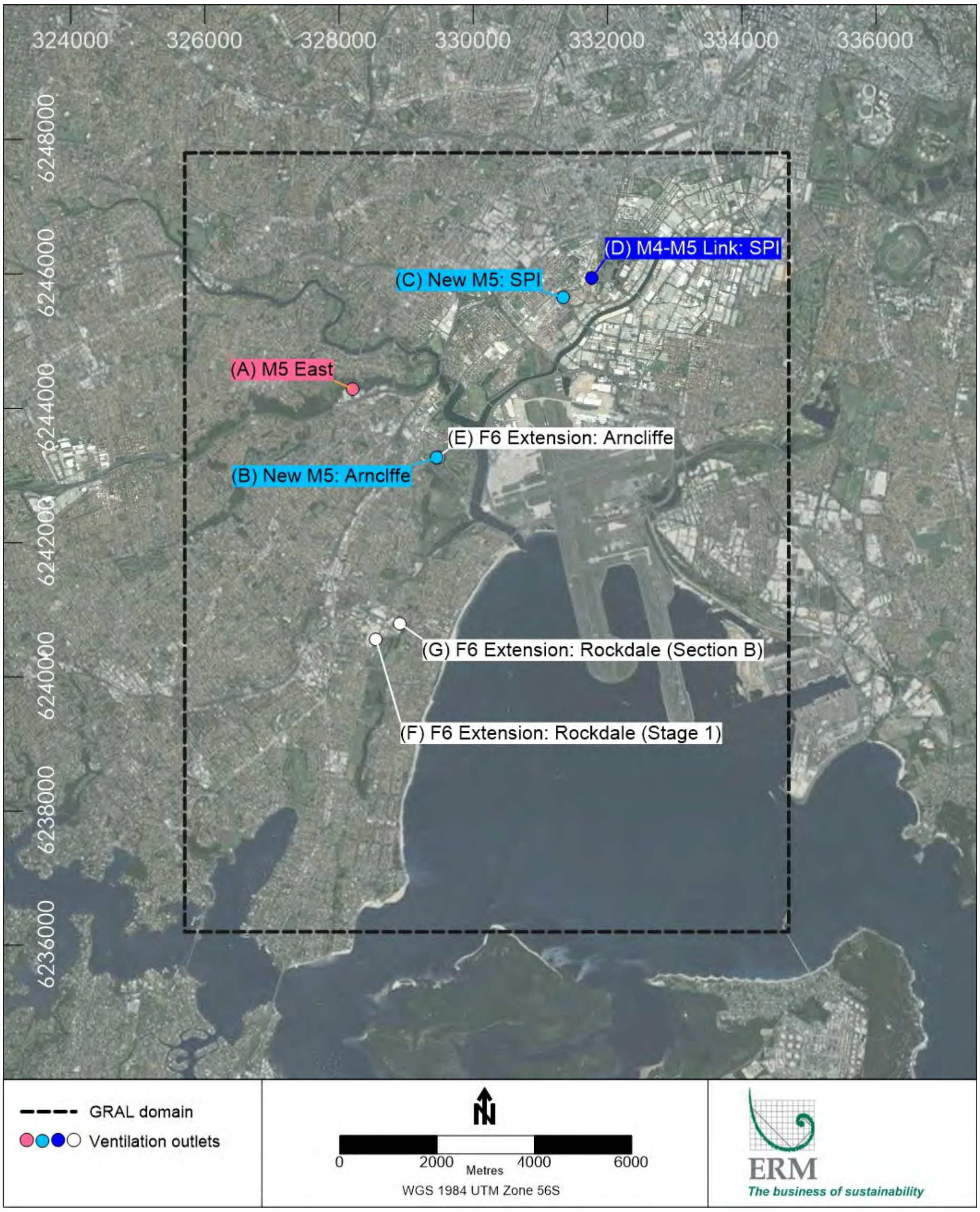

Figure 8-1 Locations of all tunnel ventilation outlets included in the assessment (grid system MGA94)

The ventilation facilities and outlets were summarised in **Table 2-1**, and are listed below.

- Existing facility
  - Outlet A M5 East tunnel outlet at Turrella
- Facilities currently under construction for New M5 Motorway
  - Outlet B New M5 Motorway facility at Arncliffe
  - Outlet C New M5 Motorway facility at St Peters Interchange
- Facility proposed for M4-M5 link
  - Outlet D M4-M5 Link facility at St Peters Interchange
- Facilities proposed for F6 Extension Stage 1
  - Outlet E F6 Extension Stage 1 facility at Arncliffe
  - Outlet F F6 Extension Stage 1 facility at Rockdale
- Facility proposed for F6 Extension Section B
  - Outlet G F6 Extension Section B facility at Rockdale.

The ventilation outlets that would be specific to the F6 Extension Stage 1 are E and F. The remaining outlets (A, B, C, D and G) were included to assess potential cumulative impacts only. Apart from outlet A (M5 East), each ventilation outlet had four 'sub-outlets' for air.

- For the modelling of point sources in GRAL, emissions (in kilograms per hour) and exit velocities (in metres per second) were characterised as single annual average values. However, diurnal variation was modelled through the use of source groups (refer to **section 8.4.3**). For each ventilation outlet, separate source groups were defined in GRAL to reflect different air flow regimes and emission rates, and the periods of the day associated with these source groups are given in **Annexure G**. An average emission rate was calculated for each outlet and source group, and hourly 'modulation factors' (ratios, relative to the average emission rate for each source group) were used in GRAL to replicate the variation in emissions within each time period. No seasonal variation was built into the emission rates. The approaches used for the existing M5 East tunnel and the proposed tunnels are summarised below.

Existing facility for the M5 East tunnel

- The M5 East tunnel outlet was the only existing one in the F6 Extension Stage 1 GRAL domain. Emissions of NO_X, CO, PM_{10} and $PM_{2.5}$ from the outlet were calculated using hourly in-stack concentration and air flow measurements for 2016 supplied by Roads and Maritime. THC emissions were calculated using a method similar to that described below for the proposed outlets. Emission scaling factors for the future year scenarios were developed using the NSW EPA emission model and the SMPM outputs for the tunnel.

Proposed facilities for the F6 Extension Stage 1 tunnel and other projects

The method for determining emissions from the ventilation outlets is described in the tunnel ventilation report in **Annexure K**. The pollutants assessed for tunnel ventilation purposes were NO_X, NO_2, CO and $PM_{2.5}$. Emissions of PM_{10} and THC were also required for the ambient air quality assessment, and these were estimated using ratios based on calculations for a generic tunnel configuration using the NSW EPA model. The $PM_{2.5}$ emission rate from the tunnel ventilation work was multiplied by a $PM_{10}/PM_{2.5}$ ratio to determine PM_{10}. The THC emission rate was estimated using a THC/NO_X ratio. The ratios used are given in **Table 8-1**.

Table 8-1 Ratios used for estimating PM10 and THC emissions

Pollutant emission ratio	Value by year	
	2026	2036
$PM_{10}:PM_{2.5}$	1.45	1.50
$THC:NO_X$	0.07	0.06

Results

The diurnal profiles of outlet emission rates for each scenario and ventilation outlet, and the average emission factor for each source group, are given in **Annexure G**. The pollutant concentrations in the tunnel outlets, consistent with the assumptions in GRAL, are also provided in **Annexure G**.

8.2.3 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 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 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 F6 Extension, 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. In January 2015 the NSW 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.
- A more detailed description of the model used, including an evaluation, are provided in **Annexure E**.

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 website[25] to enable emissions from each sector of activity to be calculated. For road vehicles, Environment Australia (2003) 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 has not been considered further in this Report. It is worth noting, however, that a new motor vehicle emission inventory for the NPI has 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)[26]. 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 assessment, because a detailed model was already available from NSW EPA (and reflected the traffic, fuel and fleet conditions in NSW).

Input data

Sydney Strategic Motorway Planning Model (SMPM)

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 GRAL model domain, which covered an extensive area south of Sydney Harbour, was taken from the SMPM. The SMPM provided outputs on a link-by-link basis for the different scenarios and for all major roads affected by the scheme.

The SMPM provides a platform to understand changes in future weekday travel patterns under different land use, transport infrastructure and pricing scenarios

The SMPM is linked to the Strategic Travel Model (STM), which includes trip generation, trip distribution and mode choice modules, and incorporates demographic data related to land uses including population, employment and education enrolment projections. For SMPM these data were supplied by Transport for NSW's Transport Performance and Analytics (TPA) as data extracts from the STM and is based on the DP&E's 2014 population and employment projections. SMPM version 1.0, which includes induced traffic demand, was used for this EIS.

The SMPM patronage forecasting model process 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 for subsequent allocation to routes in the detailed toll choice assignment model.

A separate Toll Choice Assignment Model was developed to test the impacts of toll and infrastructure strategies and provide infrastructure project traffic forecasts. 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.

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 be considered as a range as opposed to absolute numbers.

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

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[25] http://www.npi.gov.au/reporting/industry-reporting-materials/emission-estimation-technique-manuals

[26] http://www.emisia.com/copertaustralia/General.html

Time periods

The SMPM models an average weekday during a school term.

The model includes the following time periods:

- The morning ('AM') peak period (07:00-09:00)
- The inter-peak ('IP') period (09:00-15:00)
- The afternoon ('PM') peak period (15:00-18:00)
- The night-time ('EV') period (18:00-07:00).

The SMPM outputs represent an average one-hour peak within each of these periods.

Network description

For surface roads the emission (and dispersion) modelling was undertaken for the main roads in the GRAL domain, as defined in the SMPM. The road network in the domain was defined in terms of the start node and end node of each link in the SMPM, with each direction of travel being treated separately. The SMPM output included surface roads, tunnels, and tunnel access ramps.

The road links in the domain are shown in the figures on the following pages. Each figure shows the road links in Do Minimum scenarios, as well as the additional links in the Do Something and Do Something Cumulative scenarios:

- **Figure 8-2** shows the additional links in the 2026-DS and 2036-DS scenarios
- **Figure 8-3** shows the additional links in the 2036-DSC scenario.

Both surface road links and tunnel links are included. The additional roads in each scenario are predominantly tunnels or tunnel entry/exit ramps.

Figure 8-2 Road links in the Do Minimum scenarios, and additional links in the 2026-DS and 2036-DS scenarios (grid system MGA94)

Figure 8-3 Road links in the Do Minimum scenarios, and additional links in the 2036-DSC scenario (grid system MGA94)

The road network (including tunnels) had between 2,007 and 2,131 individual links, depending on the scenario (**Table 8-2**). The tunnels were removed from the traffic files before being entered into GRAL. Emissions from these roads were allocated to the tunnel ventilation outlets, as described in **Annexure G**. In some cases, part of a link in SMPM 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.

Table 8-2 Number of road links by scenario

Scenario code	Scenario description	Number of road links included (F6 Extension Stage 1 GRAL domain)
2016-BY	2016 – Base Year (existing conditions)	2,007
2026-DM	2026 – Do Minimum (no F6 Extension Stage 1)	2,089
2026-DS	2026 – Do Something (with F6 Extension Stage 1)	2,101
2036-DM	2036 – Do Minimum (no F6 Extension Stage 1)	2,089
2036-DS	2036 – Do Something (with F6 Extension Stage 1)	2,101
2036-DSC	2036 – Do Something Cumulative (with F6 Extension Stage 1 Link and all other projects)	2,131

Road classification

In the SMPM each road link was defined in terms of its functional class. For the purpose of calculating emissions, the functional class was converted into an NSW EPA road type, as shown in **Table 8-3**. The characteristics of different road types are described in **Table C-1** of **Annexure C**. Regional arterial roads in the SMPM were treated as either commercial arterials or commercial highways in the NSW EPA emission model, depending on whether the free-flow traffic speed (taken as the evening period speed) was less than or higher than 70 kilometres per hour.

Table 8-3 Assignment of SMPM road types to NSW EPA road types

Road type in SMPM	Evening period speed (km/h)	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 twofold approach was used:

- For the roads that were considered to be the most important in terms of potential changes air quality, the specific widths were determined
- For all other roads, typical average widths were assumed for each road type.

The road widths were estimated based on samples of roads from Google Earth in March 2018.

In the traffic model, some roads had links separated by direction of travel, whereas other roads had superimposed ('stacked') links. For many major roads, the superimposed links were separated by Pacific Environment to give a better real-world spatial representation, but this was not possible for all roads. Consequently, the widths were determined separately for both roads with separated links and roads with stacked links.

The widths used in GRAL for certain specific roads are given in **Table 8-4**, and the typical road widths are given in **Table 8-5**. The specific road widths were applied to those roads that were materially influenced by the project but had widths that were different from the typical widths. It is worth mentioning that the typical road widths may appear to be unrepresentative of the road types more widely in Australia (e.g. regional arterial roads being wider than motorways). Again, this is because the values reflect the roads in the GRAL domain, and it happens to be the case that the (few) regional arterial roads in the traffic model are relatively wide. The typical road widths were also applied to any new roads associated with the F6 Extension Stage 1 project.

Table 8-4 Assumed road width by road type – specific roads in the GRAL domain

Road	Estimated road width (m)	
	Separated links (one-way traffic)	Stacked links (two-way traffic)
Princes Highway	8.0	17.0
Rocky Point Road	6.2	12.4
The Grand Parade	5.9	11.8
President Avenue	9.3	18.5

Table 8-5 Assumed road width by road type – typical roads in the GRAL domain

Road type	Estimated road width (m)	
	Separated links (one-way traffic)	Stacked links (two-way traffic)
Minor	4.9	10.2
Collector	6.2	12.7
Sub-Arterial	7.1	14.2
Arterial	6.8	12.8
Regional arterial	8.4	17.3
Highway	6.1	12.5
Motorway	10.0	20.7
Motorway ramp	5.5	N/A

Road gradient

The average gradient of each road link in the F6 Extension Stage 1 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 (Δz/Δx) 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 the 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 SMPM.

The SMPM 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 SMPM.

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

The volumes for cars, LCVs and HCVs from the strategic model were sub-divided into the nine vehicle types that are defined in the EPA model to reflect differences in emissions behaviour. These vehicle types are summarised in **Table 8-6**. The sub-division was based upon a default traffic mix for each road type in the GMR inventory, as shown in **Table 8-7**.

Table 8-6 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

Notes:

(a) Referred to as 'passenger vehicle' in the inventory

(b) LCV = light commercial vehicle

(e) 4WD = four-wheel drive

(f) SUV = sports-utility vehicle

(g) LPG = liquefied petroleum gas

Table 8-7 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	2016	70.4	9.7	6.3	8.9	0.0	2.8	0.8	0.6	0.5
	2026	59.2	20.0	2.4	13.1	0.0	3.2	0.9	0.6	0.5
	2036	48.0	30.7	0.7	14.9	0.0	3.5	1.0	0.6	0.5
Arterial	2016	67.5	9.3	7.2	10.1	0.0	3.8	1.2	0.5	0.5
	2026	56.8	19.2	2.7	14.7	0.0	4.2	1.3	0.5	0.5
	2036	46.0	29.4	0.8	16.8	0.0	4.6	1.4	0.5	0.5
Commercial arterial	2016	65.3	9.0	7.7	10.7	0.0	4.8	1.7	0.4	0.5
	2026	54.8	18.6	2.9	15.6	0.0	5.3	1.8	0.4	0.5
	2036	44.2	28.2	0.8	18.0	0.0	5.8	2.0	0.4	0.5
Commercial highway	2016	65.3	9.0	7.7	10.7	0.0	4.8	1.7	0.4	0.5
	2026	54.8	18.6	2.9	15.6	0.0	5.3	1.8	0.4	0.5
	2036	44.2	28.2	0.8	18.0	0.0	5.8	2.0	0.4	0.5
Highway/ freeway	2016	57.9	8.0	6.9	9.7	0.0	10.6	6.3	0.3	0.4
	2026	47.8	16.2	2.6	14.1	0.0	11.9	6.7	0.3	0.4
	2036	37.9	24.2	0.7	16.0	0.0	13.1	7.3	0.2	0.4

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 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.

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 SMPM the most notable of these were as follows:

- The proportions of LCVs in the traffic model outputs were very high compared with typical proportions on the road in relation to how such vehicles are defined in emission models. For example, it is likely that many of the vehicles defined as LCVs in the traffic model were, from an emissions perspective, cars, and some of them would have been more like rigid heavy-duty vehicles. The approach taken was therefore to combine PVs and LCVs from the traffic model, and redistribute these according to the relevant split (road type, year) between CP, CD, LVC-P and LCV-D from **Table 8-7**.
- HCVs from the traffic model were redistributed according to the split for HD-P, RT and AT in **Table 8-7**.
- Relatively small numbers of buses and motorcycles were added to the traffic model output, again based on the proportions in **Table 8-7**.

An example of the SMPM output for one link is shown in **Figure 8-4**, and the transformation of the data for this link into a suitable format for the NSW EPA emission model is shown in **Figure 8-5**.

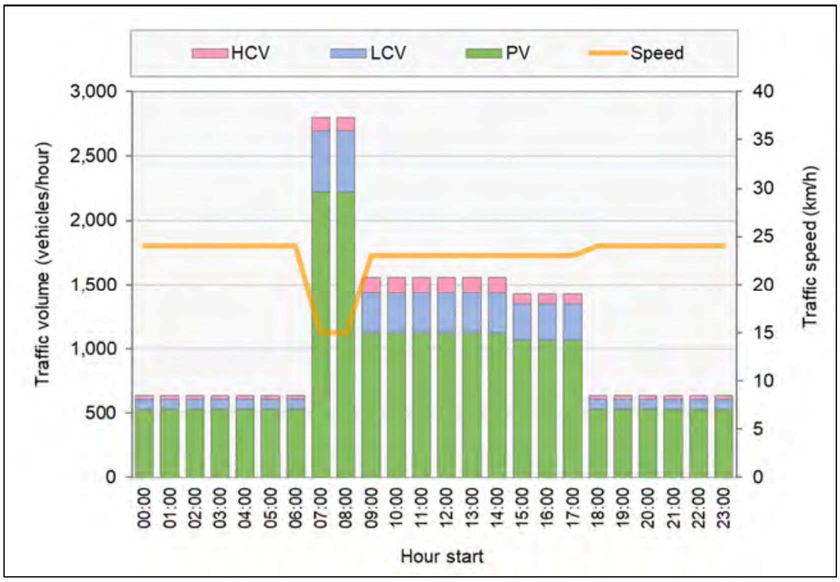


Figure 8-4 Example traffic model output (link 12239-12237, arterial road, 2026-DS scenario)

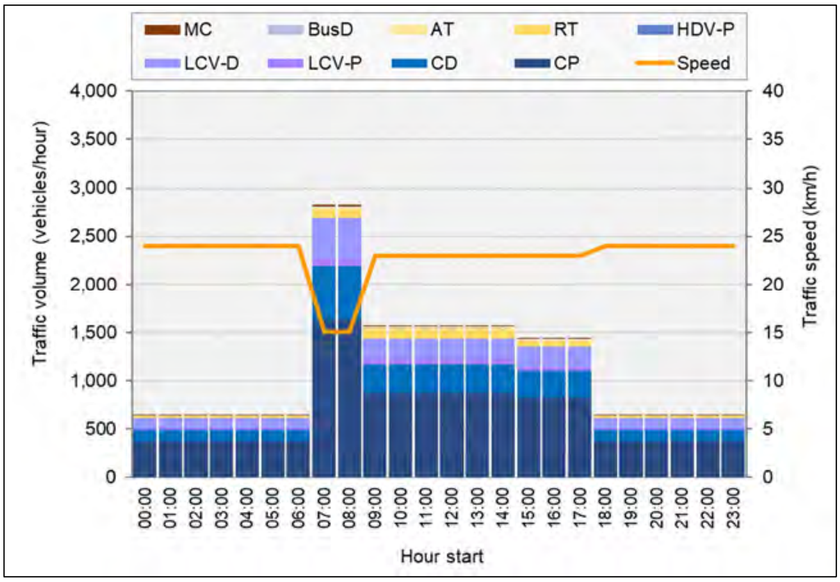


Figure 8-5 Example emission model input (link 12239-12237, arterial road, 2026-DS scenario)

Results

Expected traffic scenarios

As emissions were determined separately for more than 2,000 road links, multiple pollutants and multiple scenarios, it would not be practical to present all the results in this report. Instead, only the total emissions are for all roads (including tunnels) in the GRAL domain are presented.

The total emissions in the GRAL domain, in tonnes per year, are given for each scenario in **Table 8-8**, and are also shown graphically in **Figure 8-6**. The absolute and percentage changes in emissions between scenarios are shown in **Table 8-9** and **Table 8-10** respectively. Comparing the Do Something scenarios with the Do Minimum scenarios in 2026, emissions of all pollutants decreased by between around 2 and 3 per cent in 2026. In 2036 emissions of CO, NO_X, PM_{10} and $PM_{2.5}$ increased slightly, whereas THC emissions decreased slightly. For the cumulative scenario, emissions of CO, NO_X, PM_{10} and $PM_{2.5}$ increased by 2.5 to 3.9 per cent, whereas THC emissions decreased by 2 per cent.

The overall changes in emissions associated with the project in a given future scenario year (2026 or 2036) would be smaller than the underlying reductions in emissions from the traffic on the network between 2015 and the scenario year as a result of improvements in emission-control technology. Although there are some differences between the definitions of the Base Year and Do Minimum scenarios, it can be seen from **Table 8-10** that between 2016 and 2026 the total emissions of CO, NO_X and THC from the traffic on the road network are predicted to decrease by 50 per cent to 60 per cent, depending on the pollutant. Between 2016 and 2036 the reductions are between 55 per cent and 70 per cent. For PM_{10} and $PM_{2.5}$, the underlying reductions are smaller: around 20 per cent for PM_{10} and 30 per cent for $PM_{2.5}$. This is because there is currently no anticipated regulation of non-exhaust particles, which form a substantial fraction of the total. In the case of PM_{10}, the underlying reductions in emissions are similar to the increases associated with the project, whereas for $PM_{2.5}$ the underlying reductions are larger than the increases due to the project.

The changes in the total emissions resulting from the project can be viewed as a proxy for its regional air quality impacts. These are discussed further in **section 8.5.**

Table 8-8 Total traffic emissions in the GRAL domain

Scenario code	Scenario description	Total daily VKT[(a)] (million vehicle-km)	Total emissions (tonnes/year)				
			CO	NOx	PM_{10}	$PM_{2.5}$	THC
2016-BY	2016 – Base Year (existing conditions)	4.7	3,288	1,772	95	66	362
2026-DM	2026 – Do Minimum (no F6 Extension Stage 1)	6.1	1,919	1,161	97	61	187
2026-DS	2026 – Do Something (with F6 Extension Stage 1)	5.9	1,877	1,122	94	59	184
2036-DM	2036 – Do Minimum (no F6 Extension Stage 1)	6.4	1,450	1,083	101	62	140
2036-DS	2036 – Do Something (with F6 Extension Stage 1)	6.5	1,481	1,095	102	63	140
2036-DSC	2036 – Do Something Cumulative (with F6 Extension Stage 1 and all other projects)	6.7	1,506	1,110	104	64	138

Notes:

(a) VKT = vehicle kilometres travelled in the GRAL domain

Table 8-9 Absolute changes in total traffic emissions in the GRAL domain

Scenario comparison	Change in total emissions (tonnes/year)				
	CO	NOx	PM_{10}	$PM_{2.5}$	THC
Underlying changes in emissions with time[(a)]					
2026-DM vs 2016-BY	-1,369	-610	1.7	-5.2	-174
2036-DM vs 2016-BY	-1,838	-689	5.8	-4.2	-221
Changes due to the project in a given year					
2026-DS vs 2026-DM	-42	-39	-2.8	-1.8	-3.4
2036-DS vs 2036-DM	31	12	1.3	0.8	-0.4
2036-DSC vs 2036-DM	56	27	2.8	1.8	-2.8

Notes:

(a) The 2026-DM and 2036-DM scenarios include the WestConnex and Sydney Gateway projects. The 2016-BY scenario does not.

Table 8-10 Percentage changes in total traffic emissions in the GRAL domain

Scenario comparison	Change in total emissions (%)				
	CO	NOx	PM_{10}	$PM_{2.5}$	THC
Underlying changes in emissions with time[(a)]					
2026-DM vs 2016-BY	-41.6%	-34.4%	1.8%	-7.8%	-48.2%
2036-DM vs 2016-BY	-55.9%	-38.9%	6.1%	-6.3%	-61.2%
Changes due to the project in a given year					
2026-DS vs 2026-DM	-2.2%	-3.4%	-2.9%	-3.0%	-1.8%
2036-DS vs 2036-DM	2.2%	1.1%	1.3%	1.4%	-0.3%
2036-DSC vs 2036-DM	3.9%	2.5%	2.7%	2.9%	-2.0%

Notes:

(a) The 2026-DM and 2036-DM scenarios include the WestConnex and Sydney Gateway projects. The 2016-BY scenario does not.

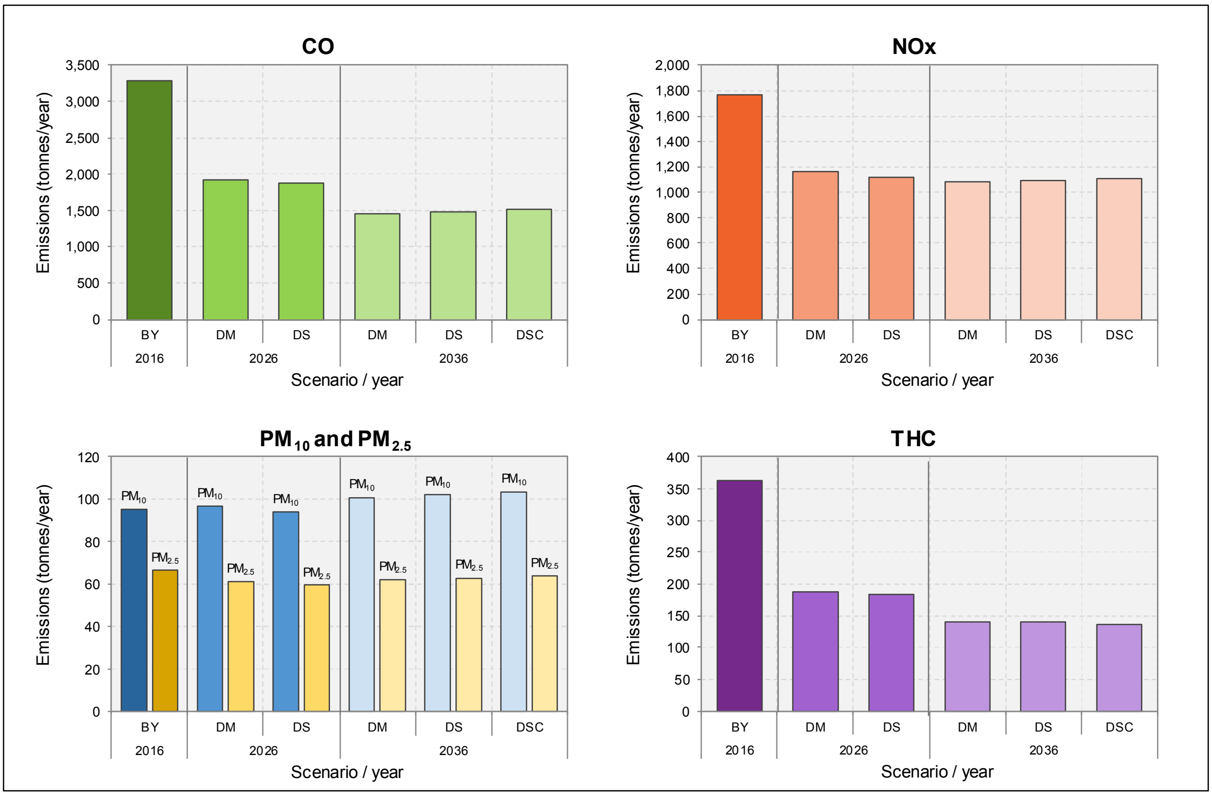


Figure 8-6 Total traffic emissions in the GRAL domain

Regulatory worst case scenarios

No additional 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 or, in the case of NO_2, the outlet concentration limits in conjunction with the expected traffic results and background concentration.

Evaluation of emission model

The NSW EPA model was evaluated using real-world air pollution measurements in the LCT, bearing in mind that the NSW EPA model is designed for application to surface roads. The findings of the model evaluation are given in **Annexure E**, and are summarised below. Additional analyses of the emission model predictions by vehicle type, and calculations of primary NO_2 emission factors, are provided in the Annexure.

- On average, the model overestimated emissions of each pollutant in the tunnel, and by a factor of between 1.7 and 3.3. This overestimation is likely to be due, at least in part, to the following:
  - The overall 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)
- There was a strong correlation between the predicted and observed emission rates for CO, NO_x, PM_{10} and $PM_{2.5}$, with an R^2 value of between 0.75 and 0.88
- Different regression slopes were obtained for the eastbound and westbound directions. Gradient effects may not be adequately reflected in the gradient adjustment approach in the model
- For LDVs the predicted emissions were higher than the observed emissions in both the eastbound and westbound tunnels
- For HDVs, emissions of CO, NO_X, PM_{10} and $PM_{2.5}$ in the eastbound (uphill) tunnel were underestimated by the model, whereas emissions of NO_2 were overestimated. In the westbound tunnel the predicted emissions were considerably higher than the observed emissions, especially for NO_2.

8.3 In-tunnel air quality

The detailed results of the simulation are provided in full in **Annexure K**. The results demonstrate that the ventilations system would ensure that air in the tunnel would meet the air quality criteria for both the expected traffic cases and the worst case traffic scenarios.

8.4 Local air quality

8.4.1 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 one metre per second) or for low-level, non-buoyant sources, is problematic for most dispersion models. To accommodate these effects, the model is configured to provide conservative estimates of pollutant concentrations at particular locations. While the models, when used appropriately and with high quality input data, can provide very good indications of the scale of pollutant concentrations and the likely locations of the maximum concentrations occurring, their outputs should not be considered to be representative of exact pollutant concentrations at any given location or point in time (AECOM, 2014b).

8.4.2 Model selection

The GRAMM/GRAL system (version 18.1) was selected for the dispersion modelling for this study for the following reasons:

- It is suitable for regulatory applications and can utilise a full year of meteorological data.
- It is a particle model and has the ability to predict concentrations under low-wind-speed conditions (less than one metre per second) better than most Gaussian models (e.g. CALINE).
- It is specifically designed for the simultaneous modelling of road transport networks, including line sources (surface roads), point sources (tunnel ventilation outlets) and other sources.
- t can characterise pollution dispersion in complex local terrain and topography, including the presence of buildings in urban areas.

8.4.3 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 8-7**. The system has in-built algorithms for calculating emission rates (the grey area of the Figure), but these were replaced by the project-specific emission rates.

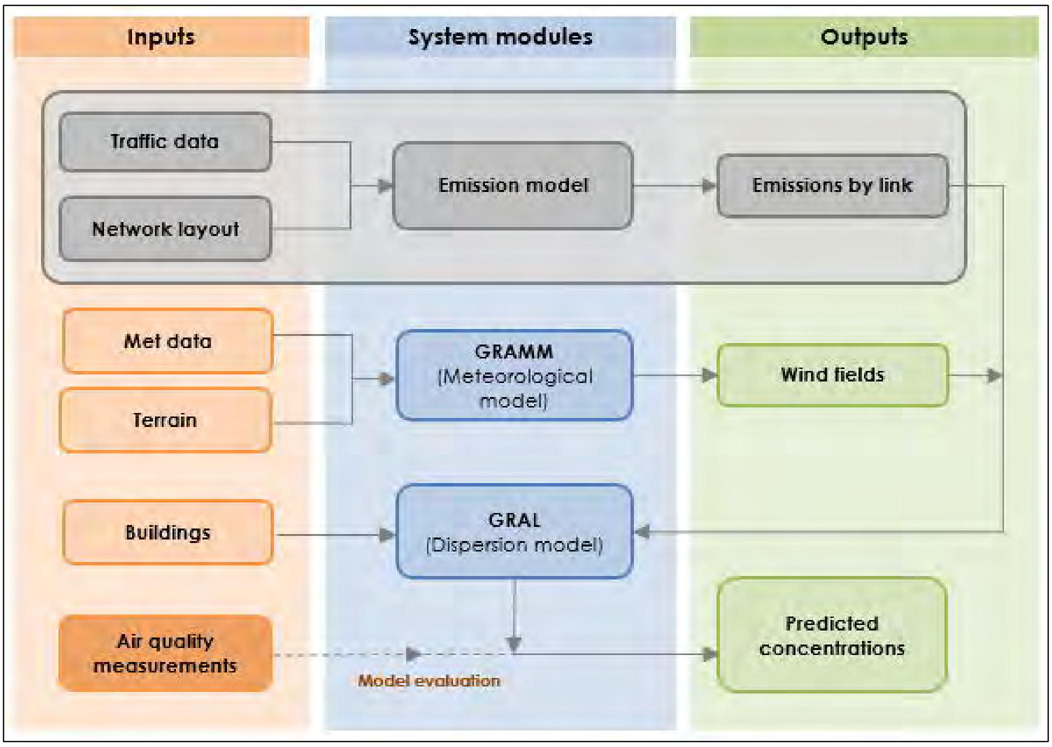


Figure 8-7 Overview of the GRAMM/GRAL modelling system

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. GRAMM uses roughness lengths, albedo, temperature conductivity, soil moisture content (an average value generated by default), soil heat capacity and emissivity in its calculations. 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, the number of traced particles (influences the statistical accuracy of results), counting grids (variable in all three directions), as well as the size of the model domain.

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

8.4.4 Model performance

- 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 and tunnel portals
- Different terrain types.
- Varying meteorological conditions (high/low wind speeds, stable/unstable atmospheric conditions, etc).

The performance of GRAMM/GRAL for surface roads has been shown to be at least as good as that of other models. In particular, a detailed evaluation of the model was conducted in Sydney by Pacific Environment (Manansala et al., 2017). The study was limited to road traffic sources of NO_X (and NO_2) in a relatively small study area around Parramatta Road with simple terrain and few large buildings. GRAMM and GRAL were compared with other models (CALMET and CAL3QHCR respectively).

With respect to meteorological modelling, it was concluded that whilst *average* predictions can be quite good at some locations, it is a challenge for both CALMET and GRAMM to predict wind speeds accurately across a domain in a situation such as the one investigated, where wind speeds varied quite considerably from location to location. The prediction of *hourly* wind speeds is very challenging for models, especially for stations not included as reference meteorology. The Match-to-Observations function in GRAMM provided an improved prediction of wind speeds compared with a set-up in which it is not used, and also compared with GRAMM using the Re-Order function.

With respect to dispersion modelling, the combination of GRAMM and GRAL captured the temporal (diurnal, seasonal and weekday) variations in NO_X well, even though there was a lot of scatter in the hourly comparisons. Overall, CAL3QHCR and GRAL gave a similar overall temporal performance at Concord Oval. GRAL generally gave a better spatial performance than CAL3QHCR. From an air quality assessment point of view, the slight over-estimation of concentrations in GRAL would be preferable to the slight underestimation in CAL3QHCR. The results of GRAL were not very sensitive to settings for grid resolution and number of particles. The inclusion of buildings and therefore wake effects, may be more important where there are many buildings within the study area and close to model sources.

The main recommendations from the study included the following:

- For the type of study area investigated, the direct use of measured meteorological data in GRAL can result in model performance that is at least as good as when GRAMM is used. Nevertheless, it would generally be advisable to run GRAMM to confirm this, and to run GRAMM for more complex situations and larger domains.
- Where GRAMM is used, then it will be important to use the 'Match-to-Observation' function for an appropriate (nearby, representative) meteorological station.
- The results of GRAL will probably not be sensitive to settings such as grid resolution and number of particles, although these should clearly be within the recommended ranges.
- The likely advantages of including buildings in a model run should be considered prior to modelling, given the implications on grid resolution (fine resolution required) and therefore computation times.
- In general, the prediction of short-term NO_2 concentrations needs to be improved to properly account for local chemical processes. Empirical methods should be further investigated. It would be useful to know, for example, how NO_2 predictions vary according to conditions.

8.4.5 GRAMM configuration

GRAMM domain and set-up

The GRAMM domain (see **Figure 5-1**) was defined so that it covered the F6 Extension Stage 1 project with a sufficient buffer zone to minimise boundary effects in GRAL. The domain was 18 kilometres along the east-west axis and 15 kilometres along the north-south axis. **Table 8-11** presents the meteorological and topographical parameters that were selected in GRAMM.

Table 8-11 GRAMM set-up parameters

Parameter	Input/value
Meteorology	
Meteorological input data method	Match-to-Observations (MtO)
Meteorological stations used in MtO	OEH Randwick OEH Earlwood
Weighting factors applied to meteorological data	Randwick: Weighting factor = 1, directional weighting factor = 1 Earlwood: Weighting factor = 0.2, directional weighting factor = 0.5
Period of meteorology	1 January 2015 – 31 December 2016
Meteorological parameters	Wind speed (m/s), Wind direction (°), 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 = 6250000, S = 6235000, E = 322000, W = 340000
Horizontal grid resolution (m)[(a)]	200
Vertical thickness of the first layer (m)[(b)]	10
Number of vertical layers	15
Vertical stretching factor[(c)]	1.4
Relative top level height (m)[(d)]	3,874
Maximum time step (s)[(e)]	10
Modelling time (s)	3,600
Relaxation velocity[(f)]	0.1
Relaxation scalars[(f)]	0.1

Notes:

(a) Defines the horizontal grid size of the flow field.

(b) Defines the cell height of the lowest layer of the flow field. Typical values are 1–2 metres.

(c) Defines how quickly cell heights increase with height above ground. For example, a factor of 1.1 means a cell is 10 per cent 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 Geoscience Australia Elevation Information System (ELVIS) website, and converted into a text file for use in GRAMM. The terrain data used in GRAMM had a resolution of 25 metres. 5 metre terrain data from the same source were used to run GRAL. The terrain in the area is predominantly flat, but increases in elevation to the north of the Airport area towards Alexandria and to the west towards Kingsgrove. The terrain along the project corridor varies from an elevation of around 2 metres Australian Height Datum (AHD) at the southern end at President Avenue to an elevation of around 10 metres at St Peters, at the northern end. To the east of the project and the south of the Airport is Botany Bay which covers a large portion of the southern area of the GRAL domain.

Although the terrain is not especially complex, a spatially-varying terrain file was used to provide an accurate reflection of the situation.

NB: All heights for buildings, ventilation outlets and dispersion modelling results are relative to the heights in the terrain file. At the node points in the terrain file the heights are equivalent to AHD heights. However, at all other locations the heights in the terrain file are interpolated. This means that there would tend to be small differences between the heights in the model and AHD heights across the domain.

Land use

A spatially-varying land use file was developed for use in the assessment. Various land use types can be specified in GRAMM, and CORINE (Coordination of Information on the Environment) land cover parameters can be imported. The land use file was based on a visual classification using aerial imagery base maps in ArcGIS. Firstly, a polygon shapefile was digitised using eight CORINE land cover classes (Continuous Urban Fabric, Discontinuous Urban Fabric, Industrial or Commercial Units, Road and Rail Networks and Associated Land, Airports, Sport and Leisure Facilities, Mixed Forests and Water Bodies). Within the GRAMM domain, the visually distinguishable areas were then classified according to these eight classes. The resulting file was converted to a 50 metre resolution ASCII raster for use within GRAMM. 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.

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. It is important to select a sites that are both reliable and representative of meteorology within the domain. As discussed in **Annexure F**, meteorological data from the OEH Randwick and OEH Earlwood sites for 2016 were selected for use in GRAMM to determine three-dimensional wind fields across the modelling domain. The Randwick station was deemed most representative of the project study area and was therefore given overall and directional weighting factors of 1. The Earlwood station was deemed less representative (see analysis in **Annexure F**) but wind directions were similar to other sites in the area and were also consistent over a number of years. Given this and its proximity to the project, meteorological data from Earlwood was included in the GRAMM modelling but was given smaller weighting factors (0.2 for overall weighting and 0.5 for directional weighting).

Cloud cover is not recorded at the OEH Randwick or OEH Earlwood sites. The stability classes (classes 1–7) required for GRAMM were therefore calculated using the temperature at 10 metres above ground level at the OEH sites and cloud content data from the BoM Sydney Airport AMO meteorological station.

Figure 8-8 provides an example of a wind field situation across the GRAMM domain. In total, 720 different wind fields were produced to represent the different conditions in each hour of the meteorological file. The wind fields are based upon the GRAMM wind speeds and wind directions using the input data from the OEH Randwick and Earlwood sites. In this particular example, winds are from a northeast 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 would be affected.

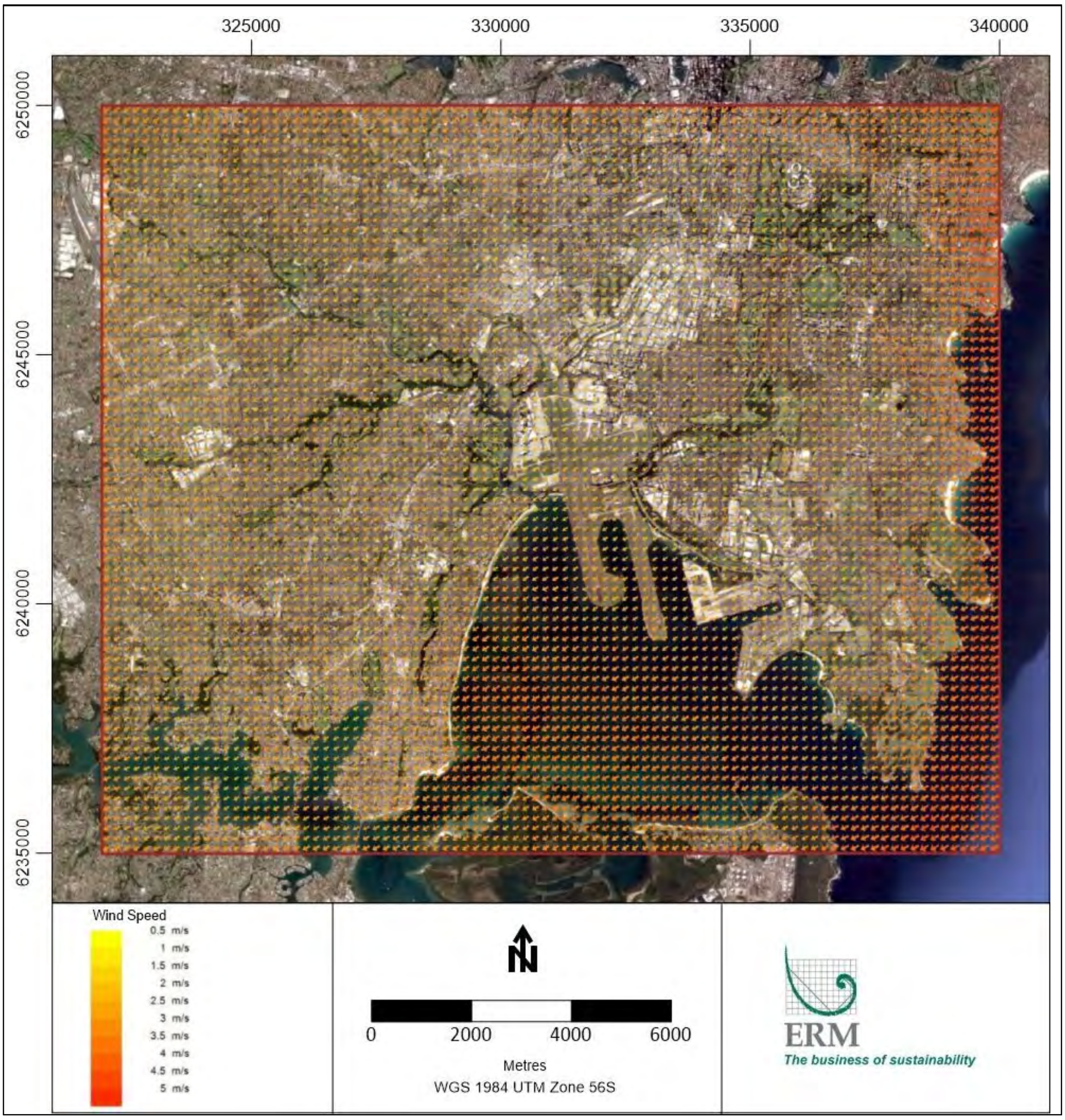


Figure 8-8 Example of a wind field across the GRAMM domain (grid system MGA94)

GRAMM Match-to-Observations function

The GRAMM 'Match-to-Observations' (MtO) function was used to refine the order of the predicted wind fields to provide a better match to the observations the OEH Randwick and Earlwood sites. The MtO function aims to match existing GRAMM wind fields to any meteorological observations inside a domain, regardless of the period of time when these measurements have been taken. The imported time series of meteorological data is synchronised automatically. Thus, it is not necessary to have each time series covering exactly the same time period. The MtO function opens up an additional modelling strategy with GRAMM. In a first step the simulations can be carried out using artificial data comprising all theoretical possible classified situations. In the second step these wind fields can be used to match any new meteorological observations inside the domain. The more flow fields are available for the fitting process, the better the results of the MtO function.

Where MtO is used for multiple reference stations the result will be a compromise. The match is optimised across all stations, and therefore the overall model performance should improve. However, for any given station the predictions may or may not improve, particularly where the meteorological data across multiple stations in a domain are dissimilar. One way of accounting for this is through the use of the weighting factors. The MtO function allows the user to apply an overall weighting factor and a specific wind direction factor. The below weighting factors were applied for this study:

- OEH Randwick
  - Overall weighting factor = 1
  - Wind direction factor = 1
- OEH Earlwood
  - Overall weighting factor = 0.2
  - Wind direction factor = 0.5.

8.4.6 Evaluation of meteorological model

Wind speed and wind direction values were extracted for each of the meteorological stations shown in **Figure 6-3**, and a statistical analysis was carried out to compare these extracted (predicted) data with the observations at each of those sites. This work is described in **Annexure F**.

8.4.7 GRAL configuration – expected traffic scenarios

The following sections describe the configuration of GRAL for the expected traffic scenarios, and cover all parameters except emissions (described earlier).

GRAL domains and main parameters

The GRAL domain was shown in Figure **5-1**. Table 8-12 presents the main parameters selected in GRAL for the model runs.

GRAL was configured to provide predictions for a Cartesian grid of points with an equal spacing of 9 metres in the x direction and 11.5 metres in the y direction. For the GRAL domain, the total number of points in the grid was around 1 million. 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.

Table 8-12 GRAL configuration

Parameter	Value(s)
General	
Domain in UTM (WestConnex GRAL)	N = 6247800, S = 6236200, E = 334700, W = 325700
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 9 kilometres by 11.5 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 (refer to **Annexure B**) would probably have been rather limited.

Contour plots

The Air Quality Assessment Report presents contour plots showing concentrations, and changes in concentration, across the entire F6 Extension Stage 1 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 around one million grid locations across the GRAL domain.

Discrete 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.

- Two types of discrete receptor location were defined for use in the assessment:
- ‘Community receptors’. These were taken to be representative of particularly sensitive locations such as schools, child care centres and hospitals within a zone around 500 to 600 metres either side of the project corridor, and generally near significantly affected roadways. This zone was sufficiently large to capture the largest impacts of the project. 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, 30 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. For these receptors, a simpler[27] statistical approach was used to combine a concentration statistic for the modelled roads and outlets (e.g. maximum 24-hour mean PM_{10}) with an appropriate background statistic. In total, 17,509 RWR receptors were included in the assessment (this included the 30 community receptors). The RWR receptors are discrete points in space - where people are likely to be present for some period of the day - 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 (**Appendix F** (Human health technical report)) 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 of short-term metrics for community receptors. The number of such receptors that could be included was dictated by the limit on the number of time series for individual receptors that could be extracted from GRAL. Due to the computational requirements of GRAL, it was not possible to include a large number of time series for community receptors.

Figure 8-9 shows the locations of the various discrete receptors.

A full list of community receptors is given in **Table 8-13**, and the numbers of RWR receptors are listed by category in **Table 8-14**. It is worth pointing out that although 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 while recognising model limitations.

Any receptors within the construction footprint for the F6 Extension project were excluded. All the project construction footprints are shown in **Figure 8-9**.

[27] The simplification only related to short-term metrics. Annual mean concentrations were equally valid for both times of receptor.

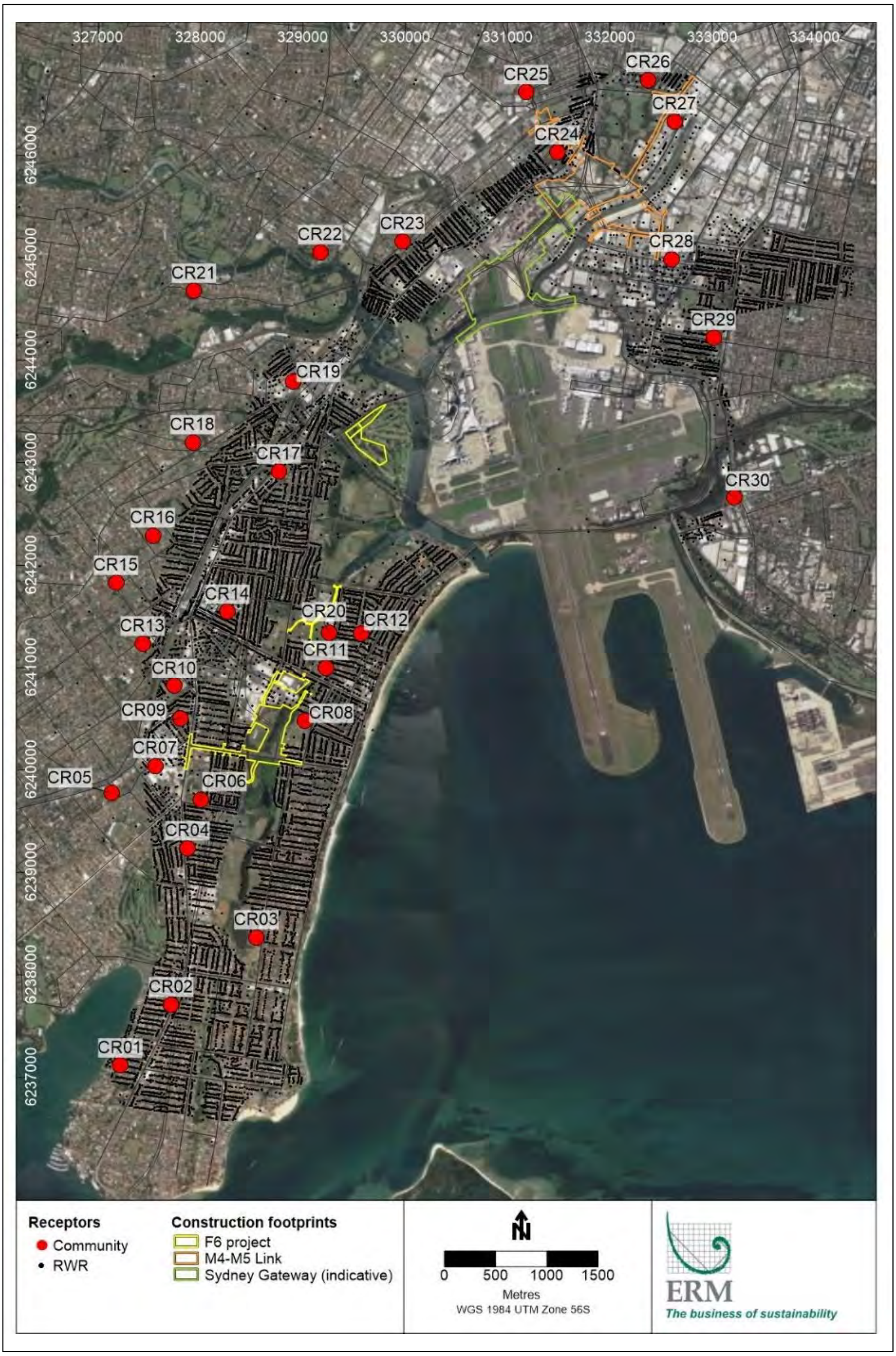


Figure 8-9 Modelled discrete receptor locations and construction footprints

Table 8-13 Full list of community receptors (grid system MGA94)

Receptor code	Receptor name	Address	Suburb	Receptor location	
				x	y
CR01	St Finbar's Primary School	21 Broughton Street	Sans Souci	327216	6237116
CR02	St George Christian School Infants	2 Hillview Street	Sans Souci	327713	6237710
CR03	Ramsgate Public School	Chuter Aveneue	Ramsgate Beach	328544	6238366
CR04	Estia Health	74-76 Rocky Point	Kogarah	327873	6239235
CR05	Wesley Hospital Kogarah	7 Blake Street	Kogarah	327128	6239775
CR06	St George School	2A Marshall Street	Kogarah	328000	6239706
CR07	St George Hospital	28A Gray Street	Kogarah	327558	6240040
CR08	Brighton-Le-Sands Public School	35 Crawford Road	Brighton-Le-Sands	329021	6240480
CR09	Kogarah Public School	24B Gladstone Street	Kogarah	327805	6240504
CR10	St George Girls High School	Victoria Street	Kogarah	327744	6240821
CR11	St Thomas More's Catholic School	Francis Avenue	Brighton-Le-Sands	329222	6240998
CR12	Jenny-Lyn Nursing Home	13 Henson Street	Brighton-Le-Sands	329568	6241338
CR13	Huntingdon Gardens Aged Care Facility	11 Connemarra Street	Bexley	327433	6241237
CR14	Rockdale Public School	4 Lord Street	Rockdale	328262	6241547
CR15	Scalabrini Village Nursing Home-Bexley	28-34 Harrow Road	Bexley	327173	6241830
CR16	Rockdale Nursing Home	22 Woodford Road	Rockdale	327533	6242293
CR17	Arncliffe Public School	168 Princes Highway	Arncliffe	328763	6242915
CR18	Athelstane Public School	2 Athelstane Avenue	Arncliffe	327922	6243201
CR19	Al Zahra College	3-5 Wollongong Road	Arncliffe	328901	6243793
CR20	Cairsfoot School	58A Francis Avenue	Brighton-Le-Sands	329255	6241343
CR21	Undercliffe Public School	143-157 Bayview	Earlwood	327936	6244679
CR22	Ferncourt Public School	74 Premier Street	Marrickville	329168	6245056
CR23	Tempe High School	Unwins Bridge Road	Tempe	329973	6245160
CR24	St Peters Public School	Church Street	St Peters	331484	6246029
CR25	St Pius' Catholic Primary School	209 Edgeware Road	Enmore	331182	6246617
CR26	Frobel Alexandria Early Learning Centre	177/219 Mitchell Road	Alexandria	332374	6246738
CR27	Little Learning School – Alexandria	95 Burrows Road	Alexandria	332630	6246331
CR28	Active Kids Mascot	18 Church Ave	Mascot	332601	6244985
CR29	Mascot Public School	207 King Street	Mascot	333010	6244221
CR30	Hippos Friends	1082 Botany Road	Botany	333216	6242662

Table 8-14 Summary of RWR receptor types

Receptor type	Number	% of total
Aged care	32	0.18%
Child care / pre-school	21	0.12%
Commercial	1,359	7.76%
Community	3	0.02%
Further education	4	0.02%
Hospital	7	0.04%
Industrial	355	2.03%
Mixed use	617	3.52%
Other	445	2.54%
Park / sport / recreation	174	0.99%
Residential	14,408	82.28%
School	84	0.48%
Total	17,509	100.00%[a]

Notes:

(a) Total of receptor types does not add up to exactly 100 per cent due to rounding.

Mesh Block centroids

The human health risk assessment (**Appendix F** (Human health technical report)) includes a population exposure assessment based on annual mean $PM_{2.5}$. A population-weighted average $PM_{2.5}$ concentration has been calculated on the basis of the smallest statistical division provided by the Australian Bureau of Statistics, termed 'Mesh Blocks'. These are small blocks that cover an area of around 30 urban residences.

For each scenario, the annual mean $PM_{2.5}$ concentration was determined for the centroid of the Mesh Blocks in the GRAL domain, and these are shown **Figure 8-10**. This information was not used in the air quality assessment, and therefore the results are not presented in this report.

Redistribution of air quality impacts

Section 2(f) of the SEARs requires 'a qualitative assessment of the redistribution of ambient air quality impacts compared with existing conditions, due to the predicted changes in traffic volumes'. The intention of this requirement is to provide assurance that those locations with relatively high concentrations in the Do Minimum scenarios do not have a large increase in concentrations in the Do Something and Do Something Cumulative scenarios. This has been addressed through the use of density plots which show the smoothed distributions of the concentrations at all RWR receptors. This analysis was conducted for annual mean and maximum 24-hour $PM_{2.5}$ only, as it was considered that these metrics would be representative for this purpose.

Figure 8-10 Mesh Block centroids in the GRAL domain

Elevated receptors

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

Building heights were not available for all locations in the GRAL domain, but height information was available for a sample of around 10,300 buildings. The locations and heights of the buildings in the sample are shown in and the overall frequency distribution is shown in **Figure 8-12.**

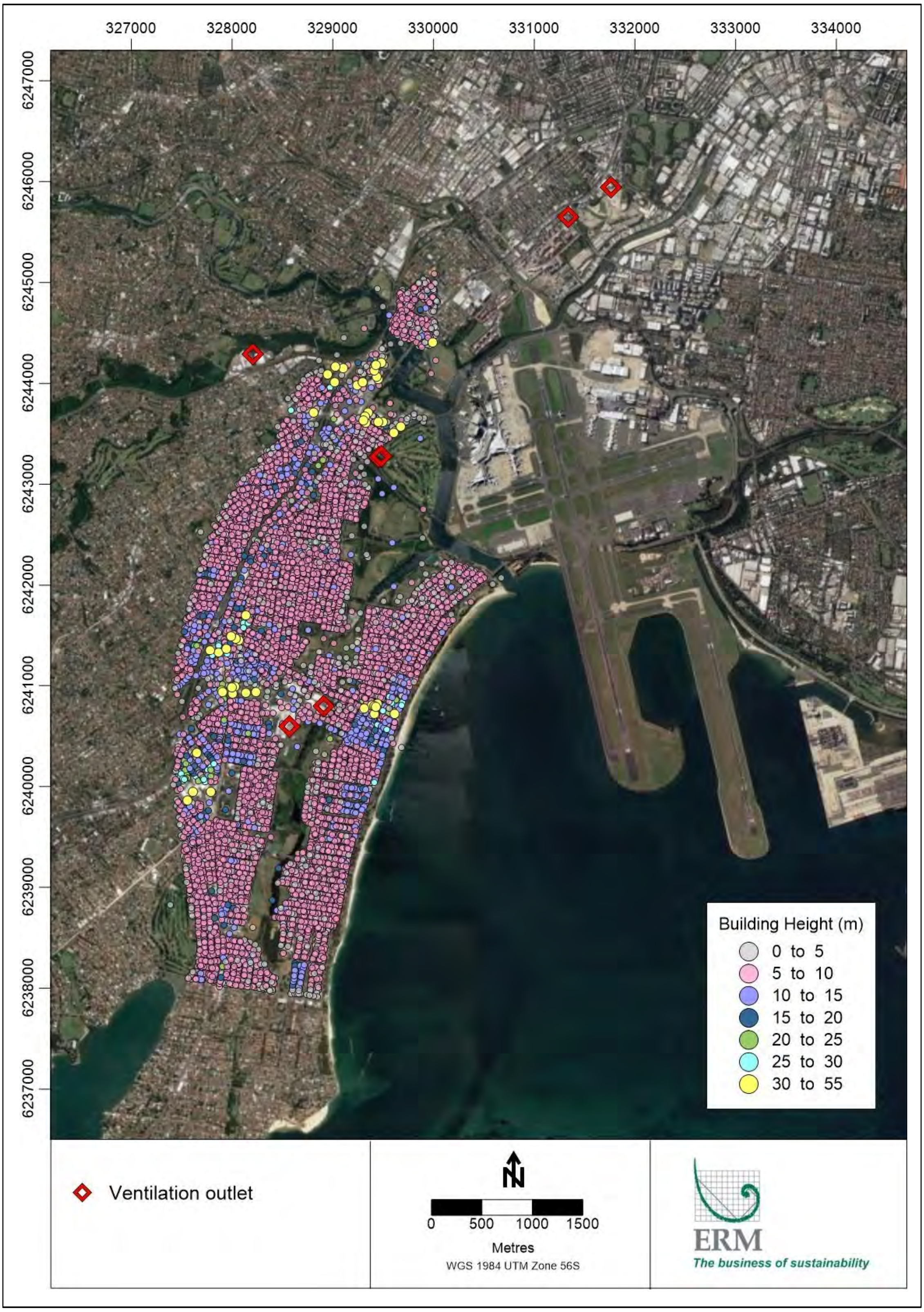


Figure 8-11 Sample of building heights in the GRAL domain (grid system MGA94

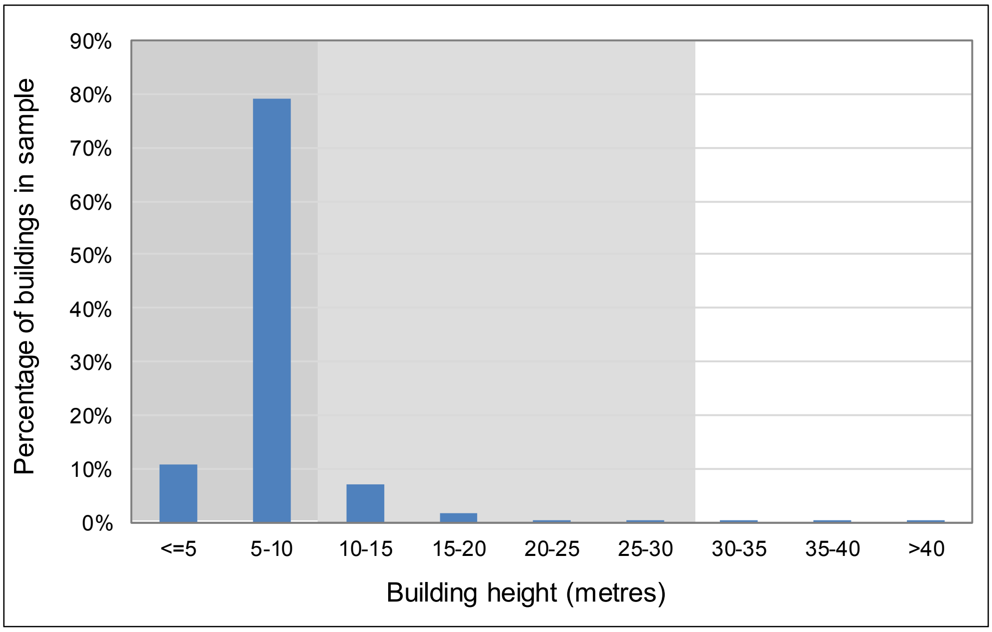


Figure 8-12 Frequency distribution of building heights

More than half (79 per cent) of the buildings had a height of less than 10 metres, and more than 99 per cent had a height of less than 30 metres. Only a very small proportion (less than 0.3 per cent) of buildings had a height of more than 40 metres. Some of the buildings in the general areas around the F6 Arncliffe and Rockdale ventilation outlets were taller than 30 metres. These included the buildings bounded by Marsh Street, Innesdale Road and Levey Street in Arncliffe, and the 18-storey Rockdale Plaza apartments. However, in the Arncliffe area the existing planning controls limited the height of buildings to around 50 metres, and the Rockdale Plaza apartment block was more than 500 metres away from the closest proposed F6 Extension Stage 1 outlet.

Based on this assessment, four additional elevated receptor heights were selected to cover both existing buildings and future developments: 10 metres, 20 metres, 30 metres and 45 metres. For all four heights a full modelling run was conducted across the GRAL domain.

Given the provisional nature of this part of the assessment, it did not cover all pollutants and averaging periods. The focus was on the changes in annual average and maximum 24-hour $PM_{2.5}$ concentrations in the 2036-DSC scenario (assumed to be the worst case scenario). Background concentrations were not taken into account, as these could not be quantified at elevated locations. This also precluded the assessment of NO_2, as NO_2 formation was calculated using total NO_X. Only the changes in the $PM_{2.5}$ concentration are therefore presented in the report.

The GRAL model was used to predict $PM_{2.5}$ concentrations associated with both surface roads and tunnel ventilation outlets. The following cases were assessed:

- 2036-DM at the height of 10 metres
- 2036-DM at the height of 20 metres
- 2036-DM at the height of 30 metres
- 2036-DM at the height of 45 metres
- 2036-DSC at the height of 10 metres
- 2036-DSC at the height of 20 metres
- 2036-DSC at the height of 30 metres
- 2036-DSC at the height of 45 metres
- Change in annual PM2.5 (2036-DSC minus 2036-DM) at the height of 10 metres
- Change in annual PM2.5 (2036-DSC minus 2036-DM) at the height of 20 metres

- Change in annual PM2.5 (2036-DSC minus 2036-DM) at the height of 30 metres
- Change in annual PM2.5 (2036-DSC minus 2036-DM) at the height of 45 metres.

Ventilation outlets

Locations and height

The locations and heights (above ground level) of the ventilation outlets included in the assessment are given in **Annexure G**.

Volumetric flow rate

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

The calculation of the volumetric air flow (in m^3/s) for each of the proposed tunnel ventilation outlets is described in **Annexure K**. The required air flow was provided for each hour of the day based on the projected traffic data for expected 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 8-13**.

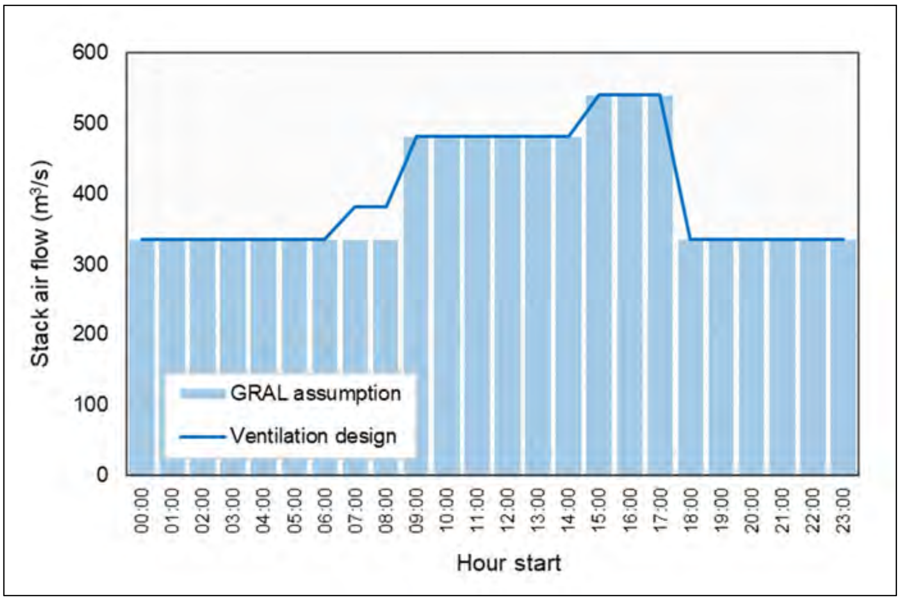


Figure 8-13 Example of ventilation air flow profile used in GRAL (F6 Extension Stage 1, Rockdale, 2026-DS)

It was necessary to simplify the ventilation profile for use in GRAL, given the large number of sources being modelled. Each ventilation profile was simplified to three phases (nominally ‘high’, ‘medium’ and ‘low’), or in some cases two phases. 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 for each scenario and each ventilation outlet are given in **Annexure G**.

The volumetric air flows for the existing M5 East outlet were determined from measurements during 2016, and a simplified diurnal profile was developed for GRAL following the approach described above for the proposed ventilation outlets. The air flows were converted to exit velocities using a cross-sectional area for the outlet of 42.3 square metres (effective circular diameter of 7.3 metres).

Effective outlet diameter and exit velocity

The diameters and exit velocities for all tunnel ventilation outlets are given in **Annexure G**.

Outlet temperature

The temperature difference between the outlet temperature and the ambient temperature is an important consideration in dispersion modelling for tunnel ventilation outlets, as it dictates the buoyancy of the exhaust air.

For simplicity and practicality in GRAL, and given the uncertainty in the tunnel temperature modelling, a single exhaust temperature for the whole year was defined for each ventilation outlet. The temperatures used for each outlet are given in **Annexure G**.

For the F6 Extension, New M5 Motorway and M4-M5 Link outlets, temperatures were estimated based on temperature differences from Lane Cove Tunnel (Cheong, 2018) and ambient temperatures from the BoM station at Sydney Airport. The calculation is shown in **Table 8-15**.

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

The uncertainty in the outlet temperature was addressed through sensitivity testing. For the sensitivity testing (applicable to all outlets), upper and lower bound temperatures that were 10°C higher and lower than a generic central estimate of 25°C were applied.

Table 8-15 Estimated annual average temperature for tunnel ventilation outlets

Period	Average temperature difference (tunnel – ambient, °C)[(a)]	Average ambient temperature (°C)[(b)]	Total (°C)
January	4	23.0	27.0
February	5	24.1	29.1
March	6	22.9	28.9
April	6	20.5	26.5
May	7	17.5	24.5
June	7	14.6	21.6
July	7	13.9	20.9
August	7	14.4	21.4
September	6	16.8	22.8
October	6	18.7	24.7
November	6	21.2	27.2
December	5	23.5	28.5
Year			25.3

Notes:

(a) From Cheong (2018), based on data for Lane Cove Tunnel

(b) Data from BoM station at Sydney Airport in 2016.

8.4.8 GRAL configuration – regulatory worst case scenarios

Overview

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

The regulatory worst case assessment involved a separate modelling exercise for the tunnel ventilation outlets only, although for NO_2 the process was more involved and required the consideration of contributions from other sources. In the case of maximum 1-hour NO_2, a second modelling step and contemporaneous assessment were required.

The concentration limits for the tunnel ventilation outlets – taken from the NorthConnex, M4 East and New M5 Motorway conditions of approval – are shown in **Table 8-16**. These were converted to mass emission rates (in kg/h) based on assumed ventilation settings, as described below.

Table 8-16 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

Notes:

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

The assumptions for the ventilation outlets are summarised in **Annexure G**.

Work undertaken for the M4 East air quality assessment showed that the predicted concentrations were not sensitive to the air flow assumption (WDA, 2015). To err on the side of caution in the F6 Extension Stage 1 regulatory worst case, a relatively low exit velocity was used for each ventilation outlet. For each ventilation outlet, the lowest exit velocity of the different source groups in GRAL from the corresponding expected traffic scenario was determined. The corresponding air flows and emissions for the regulatory worse case scenarios were calculated.

The temperature of the air from the outlets in the regulatory worst scenarios was not known, as these scenarios do not represent any real-world conditions. A 'typical' outlet temperature of 25°C was therefore assumed for these scenarios.

For the different pollutants and metrics, the next steps are described below.

Approach for CO, PM_{10}, $PM_{2.5}$ and THC

For these pollutants the next steps were as follows:

1. The worst case scenario for the tunnel ventilation outlets only was identified by modelling the outlet contribution to annual mean $PM_{2.5}$ in all three RWC scenarios (i.e. RWC-2026-DS, RWC-2036-DS and RWC-2036-DSC). The worst case scenario was determined to be RWC-2036-DSC[28].
2. The RWC-2036-DSC scenario was used to model the outlet contributions to CO (maximum 1-hour), PM_{10} (annual and maximum 24-hour), $PM_{2.5}$ (annual and maximum 24-hour) and THC (maximum 1-hour).
3. The maximum contribution of tunnel ventilation outlets at any of the 17,509 RWR receptors in the GRAL domain and in the RWC-2036-DSC scenario was determined.

Approach for annual mean NO_2

For annual mean NO_2 the next steps were:

1. The outlet contributions to annual mean NOx at all RWR receptors in the GRAL domain were determined in all four RWC scenarios.

[28] Although it was anticipated that the 2036-DSC scenario would tend to give the highest concentrations as it has the most ventilation outlets, this could not be stated definitively beforehand because of the assumption relating to exit velocities (i.e. using the lowest exit velocities from expected traffic case scenarios).

2. The outlet NOx for each RWC scenario was added to the corresponding surface road NOx and mapped background NOx, and the outlet contribution to NO_2 at each RWR receptor was calculated in the same way as in the expected traffic cases.
3. The maximum contribution of tunnel ventilation outlets to NO_2 at any of the RWR receptors in each scenario was determined.

Approach for maximum 1-hour NO_2

For maximum 1-hour NO_2 the next steps were:

1. The outlet contributions to maximum 1-hour NOx at all RWR receptors in the GRAL domain were determined in all four RWC scenarios
2. A small domain (two kilometres by two kilometres) was defined around each ventilation facility area for the F6 Extension. These domains are shown in **Figure 8-14**
3. The small domain for Arncliffe included both the New M5 Motorway and F6 Extension Stage 1 facilities, and the small domain for SPI included both the New M5 Motorway and M4-M5 Link facilities
4. The RWR receptors in the each small domain were ranked in terms of the largest ventilation outlet contributions to 1-hour NO_X, and the 'top 10' receptors were identified. These receptors are shown in **Figure 8-15** and **Figure 8-16**
5. The GRAL model was re-run for the top 10 receptors to obtain a time series for NO_X
6. A contemporaneous assessment was conducted for the top 10 receptors to combine the background contributions, GRAL surface road predictions (expected traffic) and GRAL outlet prediction (RWC) for NO_X
7. The NO_X concentration in each hour was converted to a maximum NO_2 concentration, and the background, road and outlet contributions were calculated. The overall maximum outlet contribution to NO_2 was then determined. The outlet contribution to total NO_2 was also determined for the hour with the maximum total NO_2 concentration.

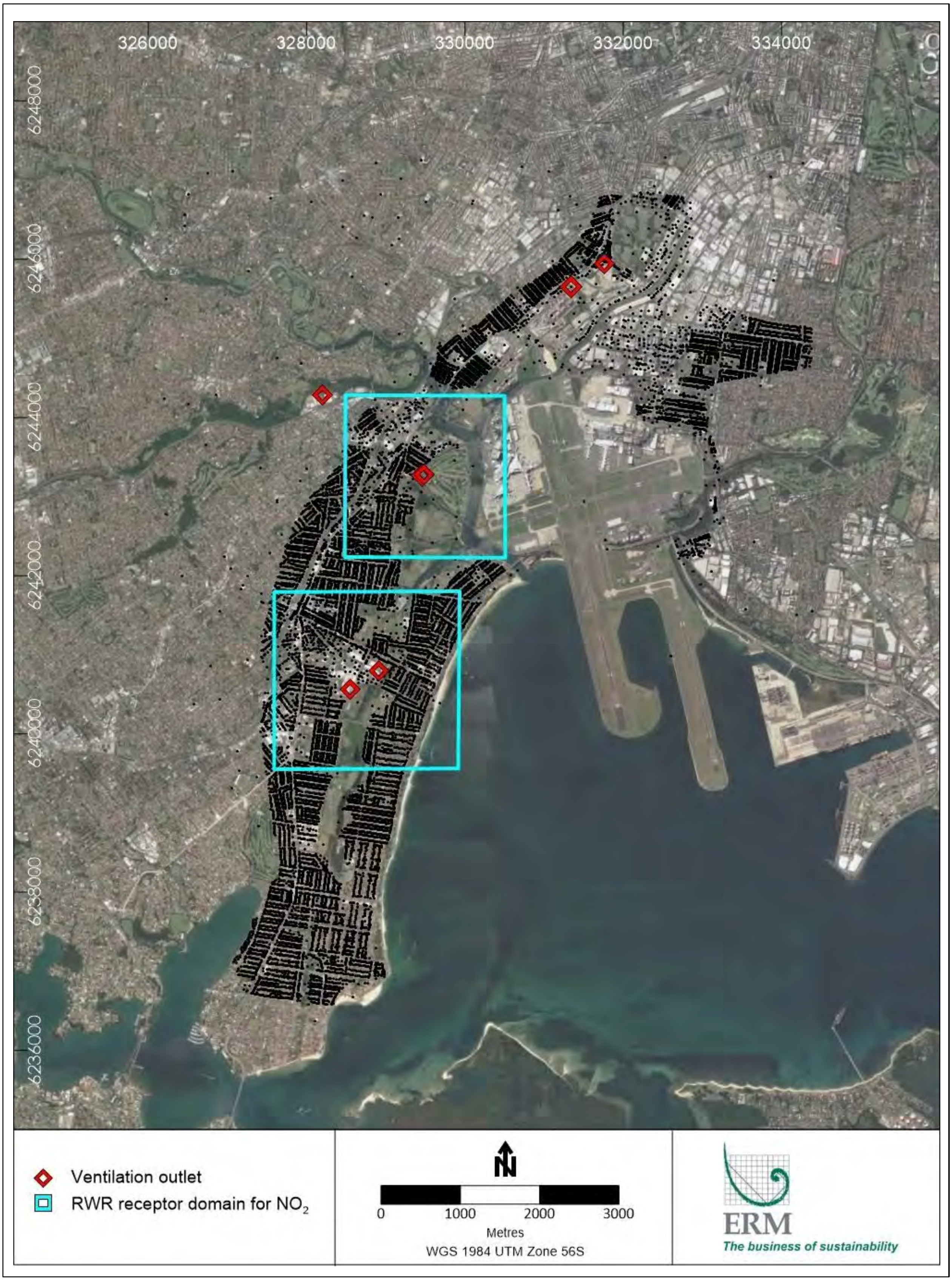


Figure 8-14 Domains around ventilation outlets for 1-hour NO_2 RWC assessment

2026-DS scenario

2036-DS scenario

2036-DSC scenario

Figure 8-15 Top 10 receptors for 1-hour NO_X (Arncliffe ventilation outlet)

Figure 8-16 Top 10 receptors for 1-hour NO_X (Rockdale ventilation outlets)

8.4.9 Calculation of total concentrations

CO, NO_2, PM_{10} and $PM_{2.5}$

For these pollutants the total concentrations were required for comparison with the applicable air quality criteria. This required a variety of different methods because of the range of metrics in the criteria, as well as the nature of the information that could be extracted from GRAL for the two types of receptor. For the 30 community receptors a contemporaneous method[29] was used to incorporate background concentrations, but this was not possible for the large number of RWR receptors included in the assessment, and therefore simpler approaches were required for these.

The derivation of background concentrations is explained in **Annexure D**. The approaches used for determining the total concentration of each pollutant for the community and RWR receptors are summarised in **Table 8-17**.

Table 8-17 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 maximum 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 maximum 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 maximum 24-hour background $PM_{2.5}$ from synthetic profile
	1 year	GRAL $PM_{2.5}$ added to mapped background $PM_{2.5}$	GRAL $PM_{2.5}$ added to mapped background $PM_{2.5}$

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 8-18**. NSW 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).

[29] With the contemporaneous approach the short-term (e.g. 1-hour) mean concentration from GRAL was added to the corresponding background concentration for every period of the year. The maximum total short-term concentration during the year was then determined.

Table 8-18 THC speciation profiles by fuel type (NSW EPA, 2012b; Environment Australia, 2003)

Pollutant/metric	% of THC (where THC=VOC)			
	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) [a]	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
Ethylbenzene	1.65	1.63	0.18	0.18

Notes:

(a) NSW EPA assumes 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 of 4.6 per cent from Environment Australia (2003).

The NSW 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** 8-18 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 (2016, 2026 and 2036). The weighted profiles are given in **Table 8-19**.

Table 8-19 Weighted THC speciation profiles for 2016, 2026 and 2036

Pollutant/metric	Weighted % of THC for traffic		
	2016	2026	2036
Benzene	4.3	4.0	3.5
PAHs (as b(a)p)	0.03	0.04	0.04
Formaldehyde	2.5	3.3	4.5
1,3-butadiene	1.1	1.1	0.9
Ethylbenzene	1.5	1.3	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 99.9^{th} 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.

8.4.10 Evaluation of dispersion model

The evaluation of the GRAMM-GRAL system performance is described in Annexure H. This includes a summary of the GRAL optimisation study (the findings of which were also summarised in **section 8.4.4**), a summary of the evaluation for the WestConnex projects, and a project-specific evaluation.

For the F6 Extension, a similar project-specific model evaluation approach to that conducted for the WestConnex projects, based on the monitoring data and model predictions for the 2016 base year. In total, 13 stations were located inside the GRAL domain. Of these, seven had data for all months of 2016 and four had partial data. The 11 stations with data for 2016 were therefore the only ones used in the evaluation. The performance of GRAL was not investigated at the two project-specific monitoring stations, as no data from these were available for the 2016 base year.

GRAL was configured to predict hourly concentrations of NO_X, NO_2, CO and PM_{10} at the 11 stations. For PM_{10}, daily average concentrations were also calculated. The emphasis was on NO_X and NO_2, as the road traffic increment for CO and PM tends to be small relative to the background.

A number of different approaches were to account for the background contribution to the predicted concentrations, and to compare the effects of different assumptions. This is because the approaches for calculating short-term concentrations in the F6 Extension Stage 1 assessment were designed to be quite conservative.

In order to cover different characteristics of the data, three statistical metrics were used: the annual mean concentration, the maximum short-term concentration (one hour or 24-hour, depending on the pollutant), and the 98th percentile short-term concentration.

An example of the results – for NO_X - is shown in **Figure 8-17**. The results can be summarised as follows:

- At the background stations annual mean NO_X concentrations were overestimated, as would be expected. This overestimation of mean NO_X at the background stations was around 7-23 µg/m^3, or 15-48 per cent, based on the mapped background. The bulk of the overestimation was due mainly to the GRAL prediction. The 98th percentile and maximum concentrations were overestimated by up to around 60 per cent using the 'maximum' synthetic background profile, as in the assessment.
- At the near-road stations the mean NO_X concentration was overestimated by up to 90 per cent based on the mapped background. The synthetic background profiles also resulted in the overestimation of 98th percentile and maximum NO_X concentrations. It is worth noting that, for some of the near-road stations included in the assessment, the measured NO_X increment above the background was not very pronounced.
- The temporal assessment of NO_X at four near-road stations revealed the following:
- The average diurnal pattern was reasonably well reproduced at the one station (Canal Road). At the other three stations there were some pronounced differences between the predictions and the observations. For example, there was a marked overestimation of NO_X concentrations at these stations during the night-time period. The inter-peak concentrations were reasonably well reproduced, although there was still a marked overestimation at the Princes Highway station.
- The seasonal pattern in NO_X was well reproduced, although there was a consistent overestimation of the monthly average concentration at three of the four stations (again, the pattern at the Canal Road station matched closely to the observations).
- At some stations the overestimation was larger at the weekend 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.
- For annual mean and maximum 1-hour NO_2 the model with the empirical NO_X-to-NO_2 conversion methods was compared with the model with ozone limiting method, with the following results:
- At the background stations, the predicted mean NO_2 concentrations based on the background maps for NO_X were slightly higher (5-20 per cent) than the measured values. When the OLM was used to determine NO_2 for each hour of the year, the predicted mean concentration was generally higher than that obtained using the mapped background. For the background stations the empirical method and the OLM gave broadly similar maximum concentrations.

- For the near-road stations, the mapped background approach and empirical conversion method resulted in mean NO_2 predictions that were quite close to the measurements (ranging from a 7 per cent under-prediction to a 30 per cent over-prediction). The OLM gave substantially higher mean predictions at three of the four stations. For the maximum NO_2 concentration at the near-road stations, the empirical conversion methods gave results that were reasonably close to the measurements.

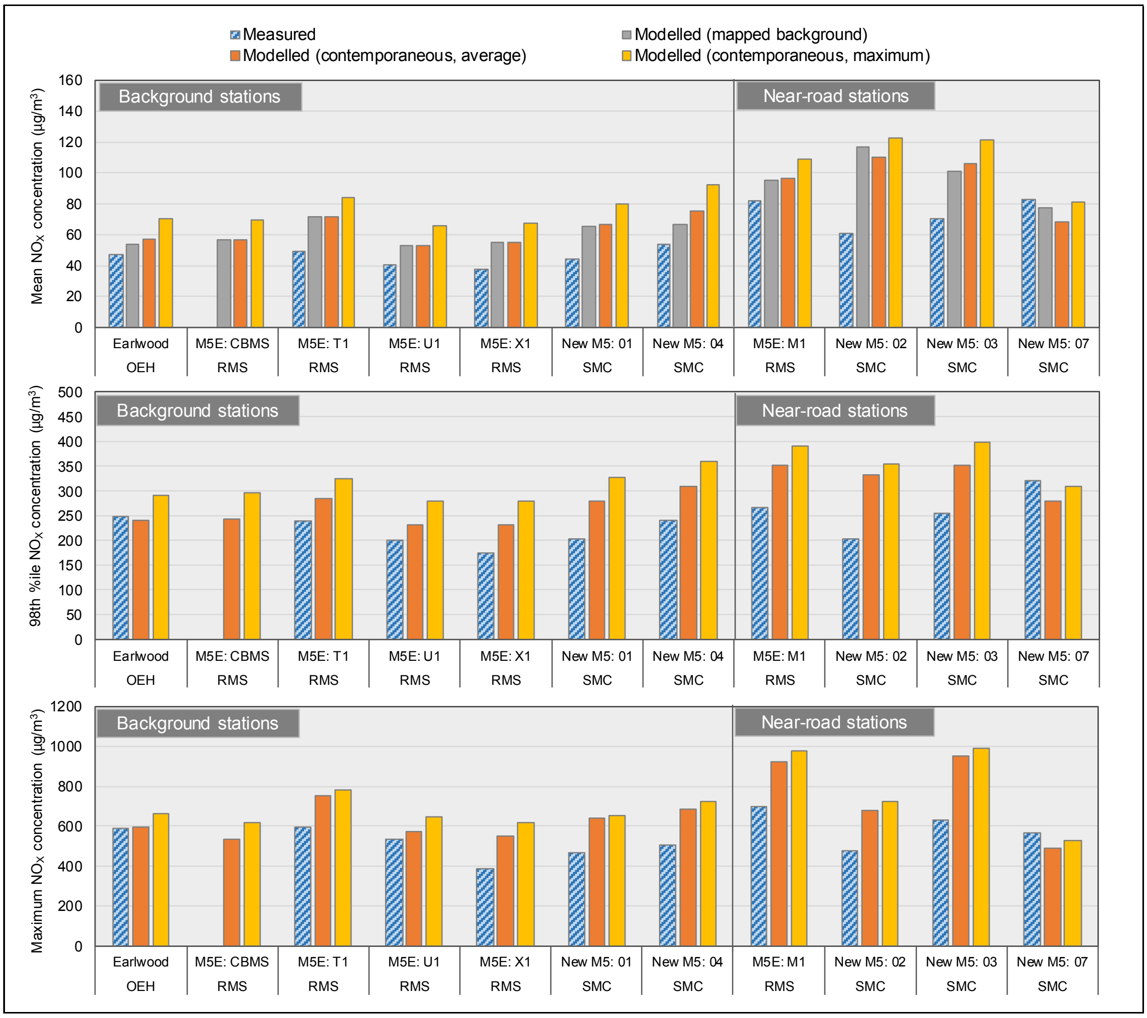


Figure 8-17 Comparison between measured and predicted annual mean NO_X concentrations

Overall, the results supported the application of GRAL in the assessment, along with the empirical conversion methods for NO_2, noting that the results tend to be quite conservative. The results suggest that the estimated concentrations ought to be conservative for most of the modelling domain, introducing a clear margin of safety into the assessment.

8.4.11 Results for expected traffic scenarios: ground-level concentrations

Overview

The predicted ground-level concentrations for the expected traffic scenarios are presented, by pollutant, in the following sections of the report. The overall results for all pollutant sources, including tabulated concentrations and contour plots, are provided in **Annexure I**. The results for ventilation outlets only are presented in **Annexure J**.

The pollutants and metrics are treated in turn, and in each case the following have been determined for the 30 community and 17,509 RWR receptors:

- The total ground-level concentration for comparison against the NSW impact assessment criteria and international air quality standards
- The change in the total ground-level concentration. This was calculated as the difference in concentration between the 'Do Something' and 'Do Minimum' scenarios
- The contributions of the background, surface road and ventilation outlet sources to the total ground-level concentration.

The results are presented in the following ways:

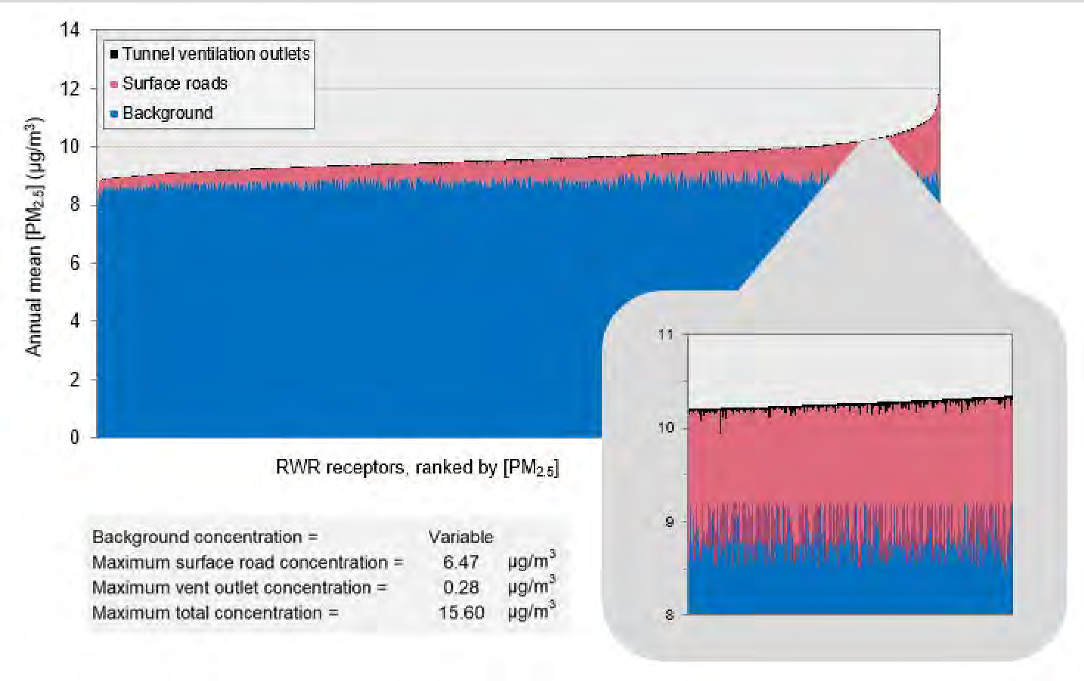
- As pollutant concentrations at discrete receptors, using:
  - Bar charts for total concentration, and changes in concentration, at the community receptors
  - Ranked bar charts for total concentration, and changes in concentration, at the RWR receptors
- As spatially mapped pollutant concentrations (i.e. contour plots) across the GRAL domain, and also changes in concentration across the domain. These have only been provided for the most important pollutants: NO_2, PM_{10} and $PM_{2.5}$
- As spatially mapped pollutant concentrations, and changes in concentration, for the areas around project tunnel ventilation facilities. Again, these are only provided for NO_X, PM_{10} and $PM_{2.5}$.

Some important points to consider when viewing these results are identified below.

- **NB 1**: To avoid a large amount of duplication, the main report only includes the contour plots for the 2036-DS scenario, and the corresponding Do Minimum scenario, 2036-DM, where applicable. For all other scenarios, the contour plots are given in **Annexure I**.
- **NB 2:** The larger-scale contour plots showing the contributions of the project ventilation outlets to NO_X, PM_{10} and $PM_{2.5}$ in the vicinity of each facility (Arncliffe and Rockdale) are provided in **Annexure J**. The presentation of these plots is slightly different to those for the full GRAL domain. The plots for the full domain are designed to show changes in air pollution across a wide area. The geographical area covered by each of the ventilation facility plots (around 2 kilometres by 2 kilometres) is much smaller than that of the full GRAL domain. This allowed local detail to be shown more clearly in the maps.
- **NB 3:** It is well known that the accuracy of dispersion model predictions decreases as the averaging period of the predictions decreases. In addition, the reliability of predictions based on a detailed contemporaneous approach for incorporating background should be greater than that of predictions based on a simpler statistical approach. Consequently, not all the model predictions in this assessment should be viewed with the same level of confidence, but rather according to the following hierarchy:
- Annual mean predictions for community and RWR receptors
- Short-term (1h and 24h) predictions for community receptors
- Short-term (24h) predictions for RWR receptors
- Short-term (1h) predictions for RWR receptors

Confidence in predictions

NB 4: The ranked RWR plots are compressed along the x-axis, as more than 17,000 receptors are included. Given that the tunnel ventilation outlet contributions are generally small compared with the background and surface road contributions, they are quite difficult to see on this scale. Therefore, in each plot the maximum contributions from each source, and the maximum total concentration, are also given. An example of this compression is shown in the figure below. The inset shows the results for a sub-set of 500 RWR receptors, with the ventilation outlet contribution being more clearly depicted.



Carbon monoxide (maximum 1-hour mean)

Results for community receptors

The maximum 1-hour mean CO concentrations at the 30 community receptors in the with-project and cumulative scenarios (2026-DS, 2036-DS and 2036-DSC) are shown in **Figure 8-18**. 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).

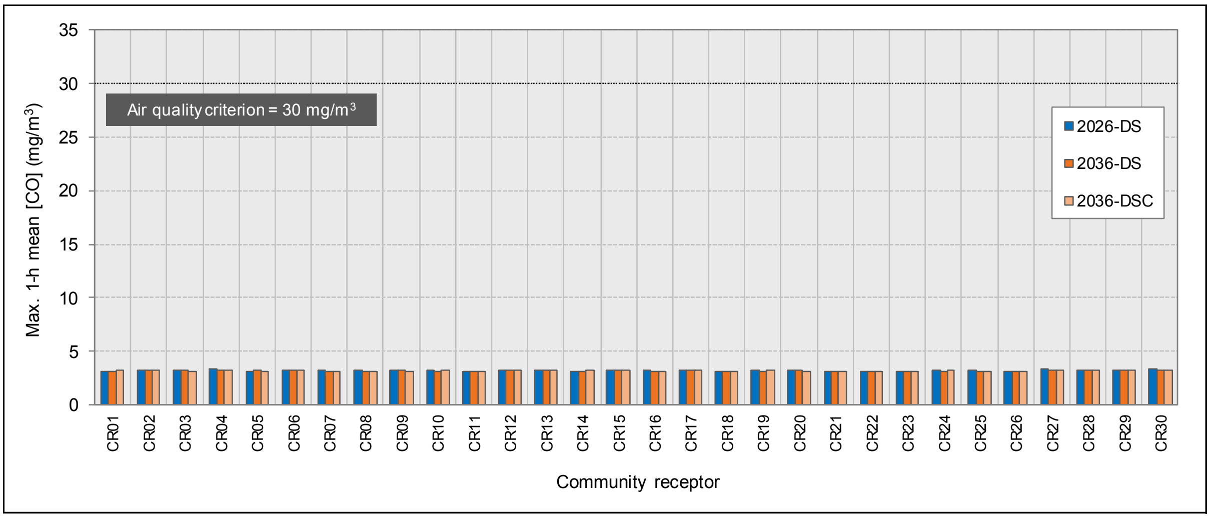


Figure 8-18 Maximum 1-hour mean CO concentration at community receptors (with-project and cumulative scenarios)

Figure 8-19 demonstrates the changes in the maximum 1-hour CO concentration in the Do Something scenarios relative to the Do Minimum scenarios at the community receptors. There was a mixture of increases and decreases in concentration at the receptors. The largest increase at any receptor was around 0.1 mg/m^3, which equated to just 0.3 per cent of the impact assessment criterion of 30 mg/m^3.

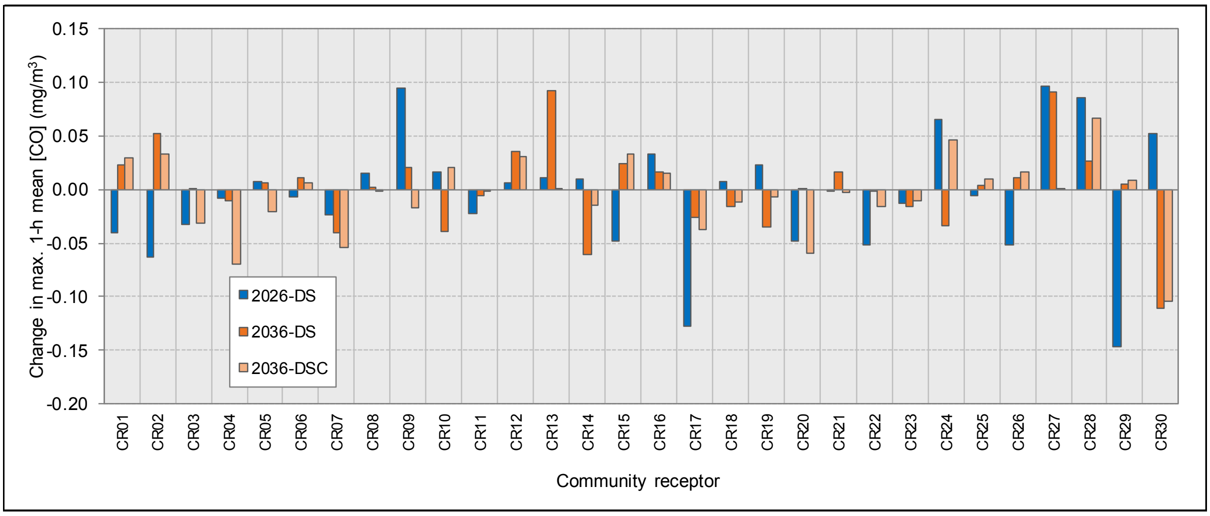


Figure 8-19 Change in maximum 1-hour mean CO concentration at community receptors (with-project and cumulative scenarios, relative to corresponding Do Minimum scenarios)

Figure 8-20 presents the separate contributions of the background, surface roads and ventilation outlets to the maximum 1-hour mean CO concentrations in the with-project and cumulative scenarios. At all receptors the maximum concentration was dominated by the background. The hour of the year was the same for almost all receptors, as it coincided with the highest background concentration during the year. The contribution of tunnel ventilation outlets to the maximum CO concentration was zero or negligible for all receptors. In other words, at all receptors, the concentration due to emissions from the ventilation outlets was very low during the hour of the year when the maximum total concentration occurred. For any given receptor, it is possible that larger 1-hour contributions from roads and ventilation outlets could have occurred during other hours of the year. However, these contributions would have been added to a lower background, and the overall total would have been lower than that given in **Figure 8-20**.

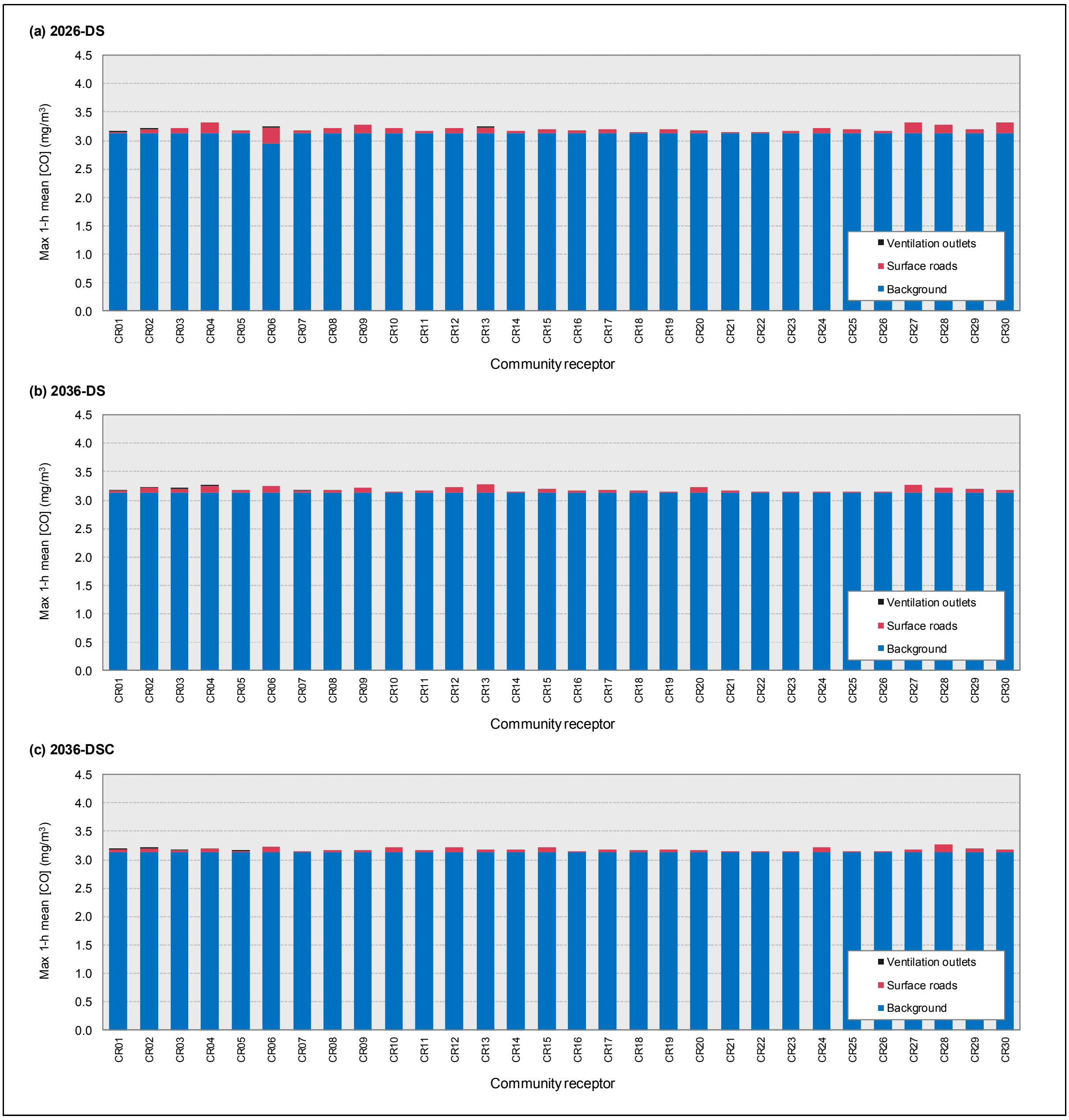


Figure 8-20 Source contributions to maximum 1-hour mean CO concentration at community receptors (with-project and cumulative scenarios)

Results for RWR receptors

The maximum 1-hour CO concentrations at the RWR receptors are shown for the with-project and cumulative scenarios in **Figure 8-21**. The values are ranked by total CO concentration. The contributions from surface roads and ventilation outlets are not shown separately, as for any short-term metric such as this the hours when the maxima for the different sources occurred were not known.

A typical feature of these ranked plots, which also extends to other pollutants, is that most of the receptors in the domain tend to have a fairly low concentration, but a very small proportion of receptors have higher concentrations.

The 1-hour CO criterion for NSW was not exceeded at any of the RWR receptors in any scenario. The highest 1-hour concentrations in any with-project or cumulative scenario was predicted to be 5.3 mg/m^3. The largest contribution from ventilation outlets at any receptor – which was determined from a separate model extraction - was less than 0.08 mg/m^3.

The changes in the maximum 1-hour CO concentration at the RWR receptors in the with-project and cumulative scenarios are shown in **Figure 8-22**. There was an increase in concentration of between 26 per cent and 44 per cent of receptors with the project. However, even the largest increase in any scenario, which was 0.5 mg/m^3, was small compared with the criterion.

Contour plots – all sources

Given that CO is not a critical pollutant for the assessment of the project's impacts on ambient air quality, contour plots for maximum 1-hour concentrations were not developed.

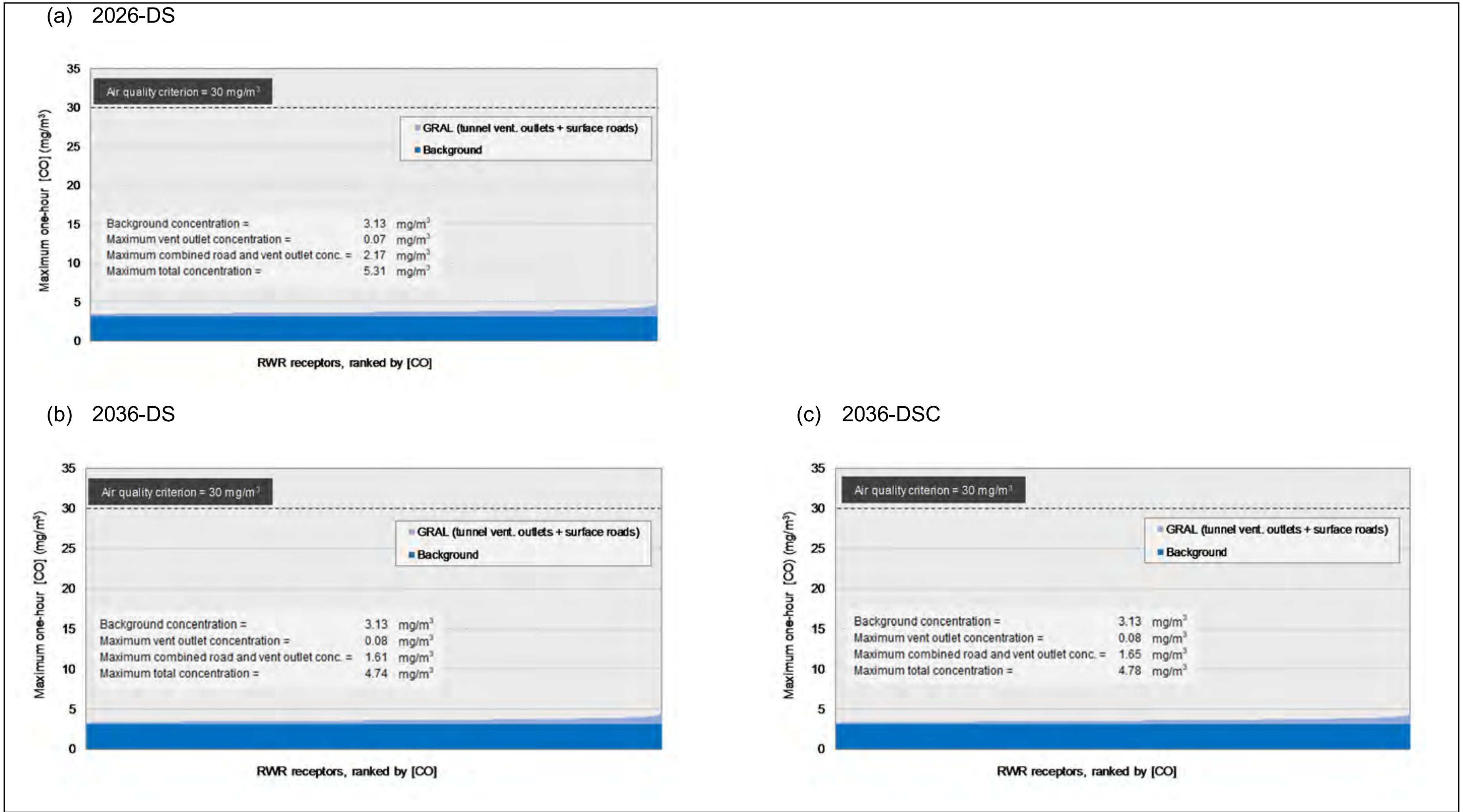


Figure 8-21 Source contributions to maximum 1-hour CO concentration at RWR receptors (with-project and cumulative scenarios)

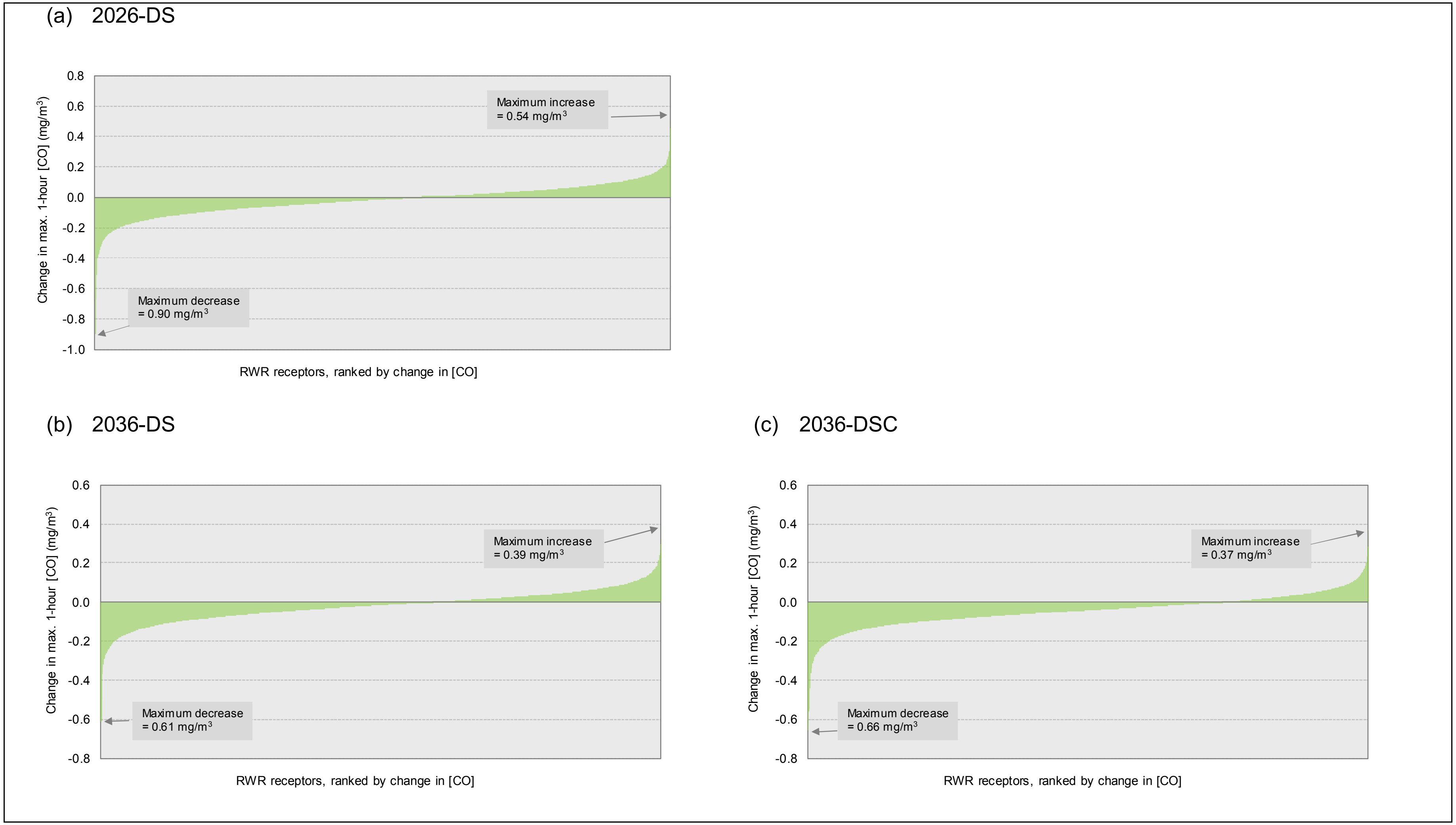


Figure 8-22 Change in maximum 1-hour CO concentration at RWR receptors (with-project and cumulative scenarios, minus corresponding Do Minimum scenarios)

Carbon monoxide (maximum rolling 8-hour mean)

Results for community receptors

Figure 8-23 shows the maximum rolling 8-hour mean CO concentrations at the community receptors with the project and in the cumulative scenario. 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. The background was therefore 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.

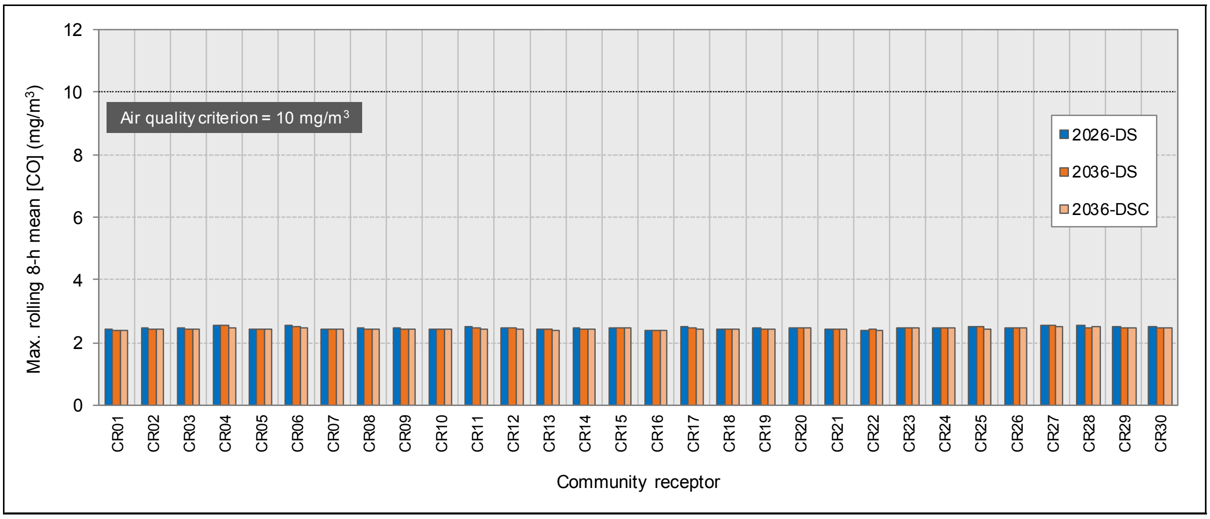


Figure 8-23 Maximum rolling 8-hour mean CO concentration at community receptors (with-project and cumulative scenarios)

It can be seen in **Figure 8-24** that the changes in the maximum rolling 8-hour CO concentration at all the community receptors were mostly less than 0.04 mg/m^3. The largest increase with the project and in the cumulative scenario was around 0.06 mg/m^3 (equating to 0.6 per cent of the criterion).

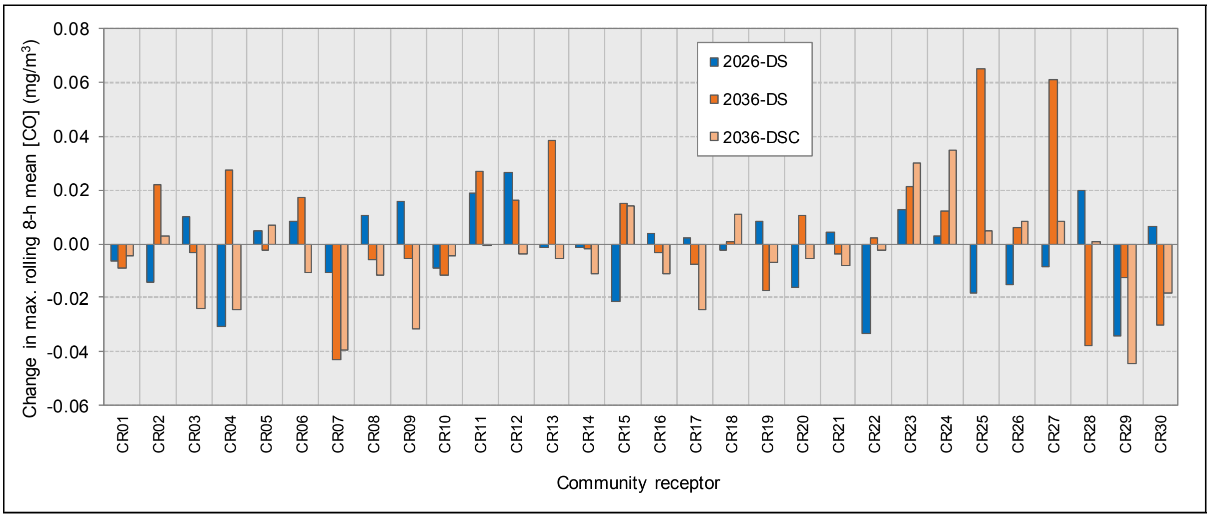


Figure 8-24 Change in maximum rolling 8-hour mean CO concentration at community receptors (with-project and cumulative scenarios, minus Do Minimum scenarios)

The main contributor at these receptors was the background concentration (**Figure 8-25**). The maximum surface road contribution in any with-project or cumulative scenario was 8 per cent, whereas the tunnel ventilation outlet contribution was zero or negligible in all cases.

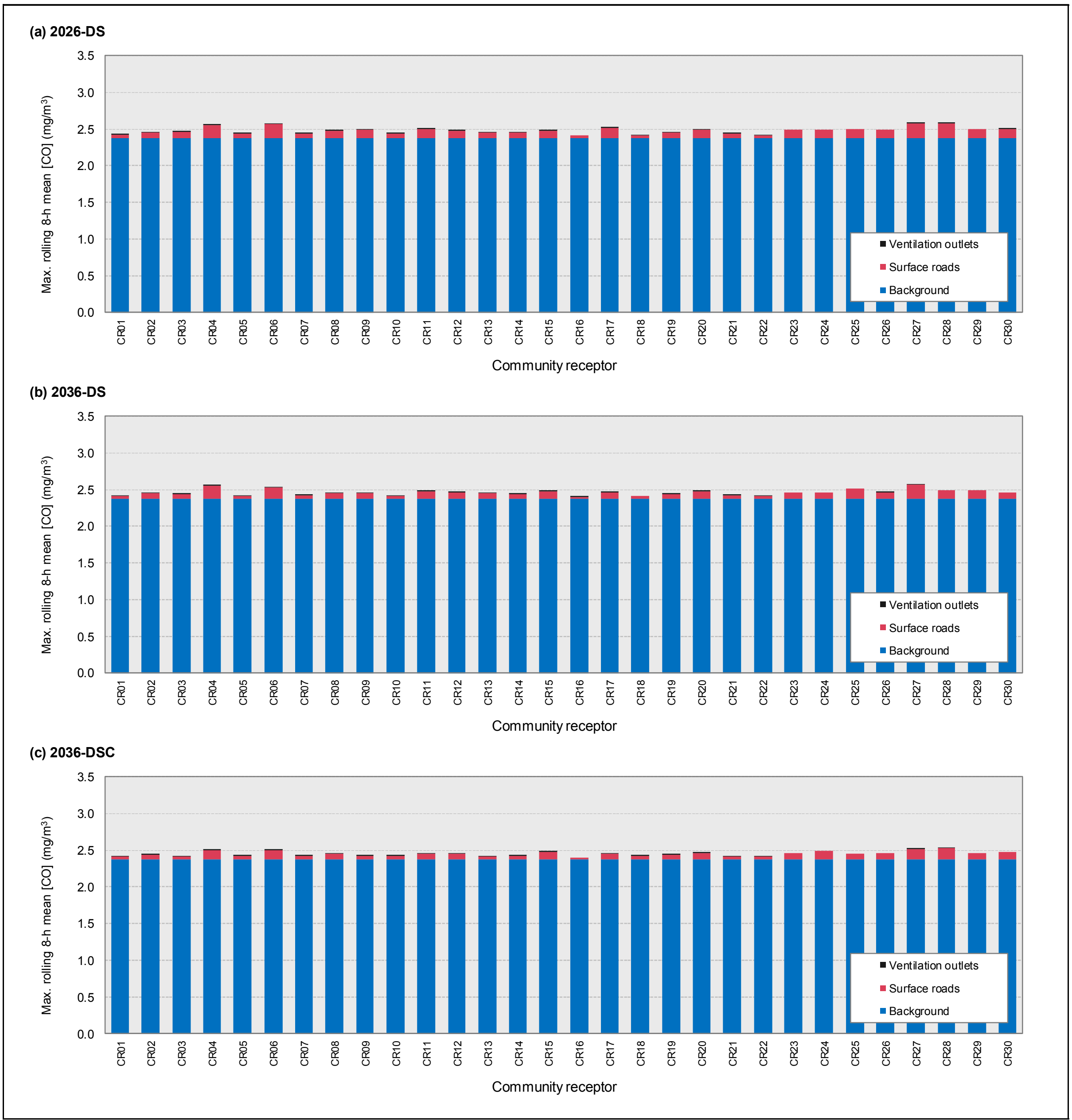


Figure 8-25 Source contributions to maximum rolling 8-hour mean CO at community receptors (2026-DS)

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.

Contour plots – all sources

Given that CO is not a critical pollutant for the assessment of the project's impacts on ambient air quality, contour plots for maximum 8-hour concentrations were not developed.

Nitrogen dioxide (annual mean)

Results for community receptors

Figure 8-26 shows the annual mean NO_2 concentrations for the with-project and cumulative scenarios at the community receptors. At all these locations the concentration was below 30 µg/m^3, and therefore well below the NSW impact assessment criterion of 62 µg/m^3. The concentrations at receptors were also well below the lower air quality standards have been adopted elsewhere (e.g. 40 µg/m^3 in the EU).

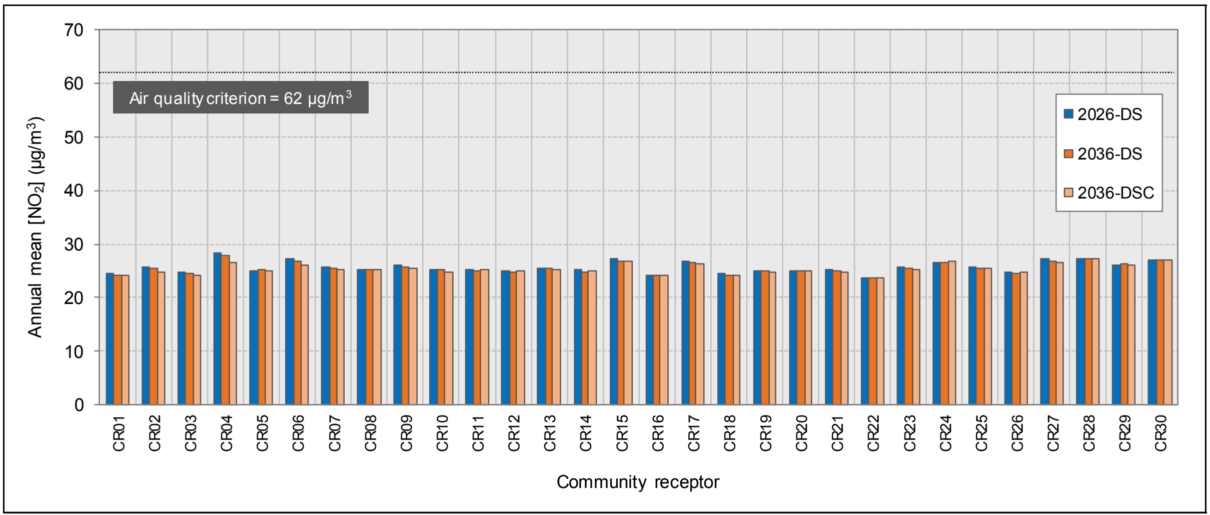


Figure 8-26 Annual mean NO_2 concentration at community receptors (with-project and cumulative scenarios)

Figure 8-27 shows the changes in concentration with the project. There was a small increase in the NO_2 concentration at some receptors. The largest increase with the project was around 0.4 µg/m^3 at receptor CR06 (St George School, Kogarah), equating to less than one per cent of the criterion. At most receptors, there were reductions in NO_2, the largest of which – between around 0.6 and 0.8 µg/m^3 – were predicted to occur at receptors CR02 (St George Christian School Infants, Sans Souci) and CR04 (Estia Health, Kogarah).

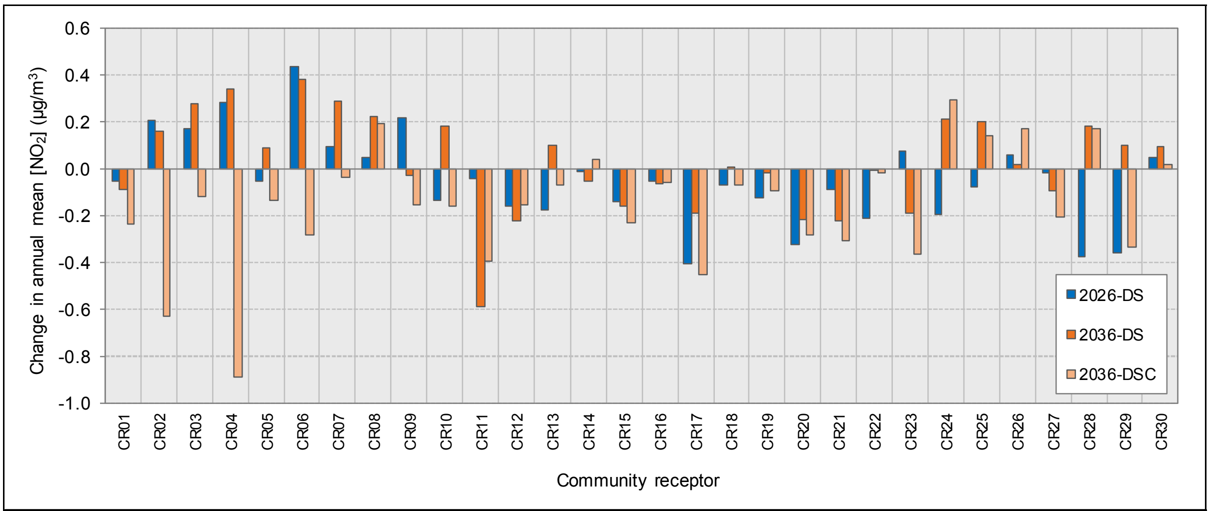


Figure 8-27 Change in annual mean NO_2 concentration at community receptors (with-project and cumulative scenarios, minus Do Minimum scenarios)

Figure 8-28 gives the source contributions to total annual mean NO_2 concentrations in the with-project and cumulative scenarios. These source contributions were estimated using a ‘cumulative’ approach involving the following steps:

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

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

Step 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 component at these receptors is likely to responsible for, on average, almost 90 per cent of the predicted annual mean NO_2, with most of the remainder being due to mainly surface roads. For the with-project and cumulative scenarios, surface roads were responsible for between around 5 per cent and 23 per cent of the total, depending on the scenario and receptor. The contribution of tunnel ventilation outlets was less than 1.4 per cent in all scenarios.

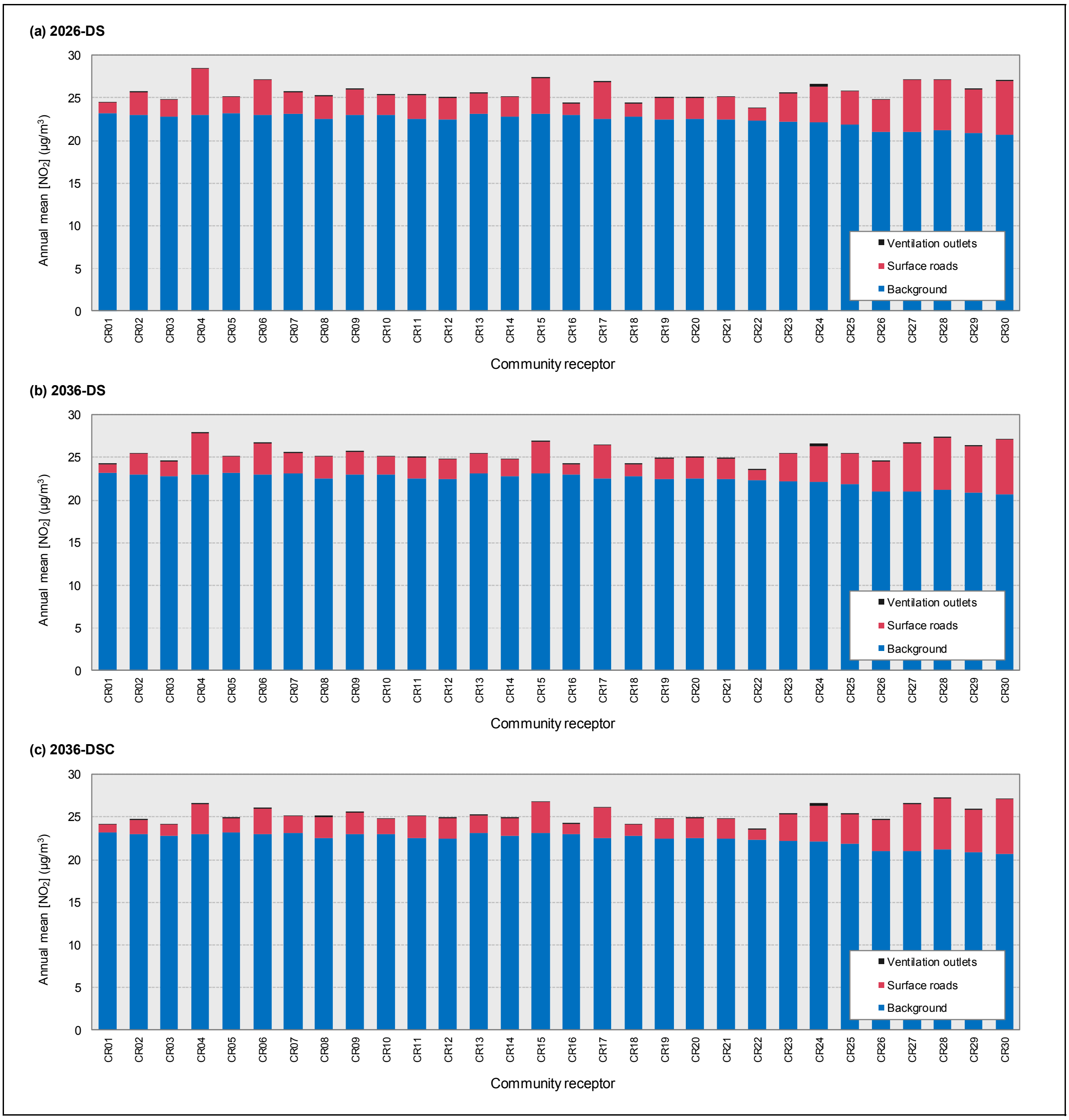


Figure 8-28 Source contributions to annual mean NO_2 concentration at community receptors (with-project and cumulative scenarios)

Results for RWR receptors

The annual mean NO_2 concentrations at the RWR receptors in the with-project and cumulative scenarios are shown, with a ranking by total concentration, in **Figure 8-29**. Concentrations at the vast majority (more than 98 per cent) of receptors were between around 20 µg/m^3 and 30 µg/m^3.

The annual mean NO_2 criterion for NSW of 62 µg/m^3 was not exceeded at any of the receptors in any scenario. At all but two receptors, NO_2 concentrations were also below the EU limit value of 40 µg/m^3. The highest concentrations with the project and in the cumulative scenario were predicted to be around 43 µg/m^3.

The maximum contribution of tunnel ventilation outlets for any scenario and receptor was 0.5 µg/m^3, whereas the maximum surface road contribution was 21 µg/m^3. Given that NO_2 concentrations at the majority of receptors were well below the NSW criterion, the contribution of the ventilation outlets was not a material concern.

The changes in the annual mean NO_2 concentration at the RWR receptors in the with-project and cumulative scenarios (minus the Do Minimum scenarios) are shown, ranked by the change in concentration, in **Figure 8-30**. There was predicted to be an increase in the annual mean NO_2 concentration at around 40 per cent of receptors in the Do Something scenarios, and 16 per cent in the 2036 cumulative scenario.

Whilst the largest increases in annual NO_2 were around 1.6 µg/m^3, the increase was greater than 0.5 µg/m^3 for no more than 3 per cent of receptors.

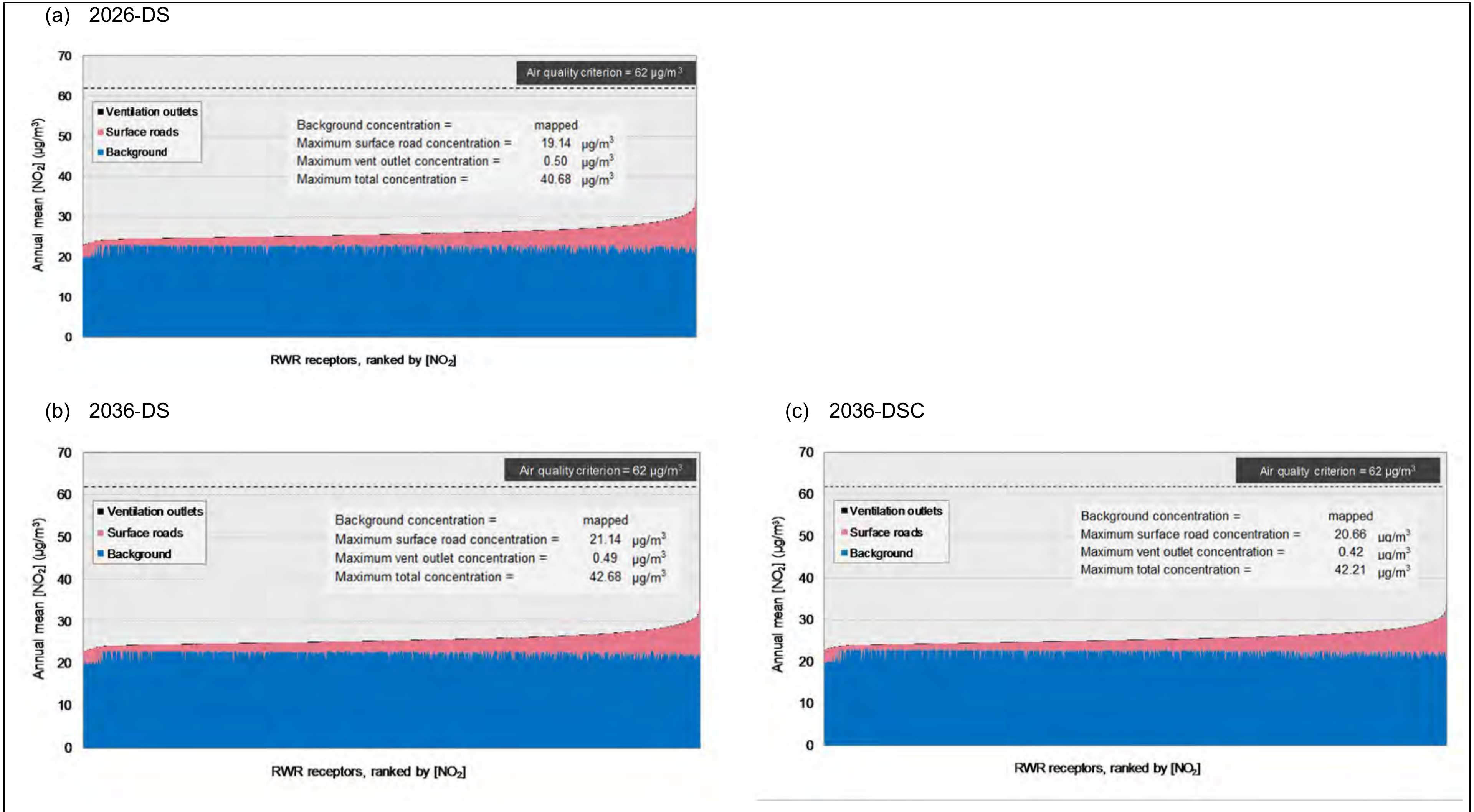


Figure 8-29 Source contributions to annual mean NO_2 concentration at RWR receptors (with-project and cumulative scenarios)

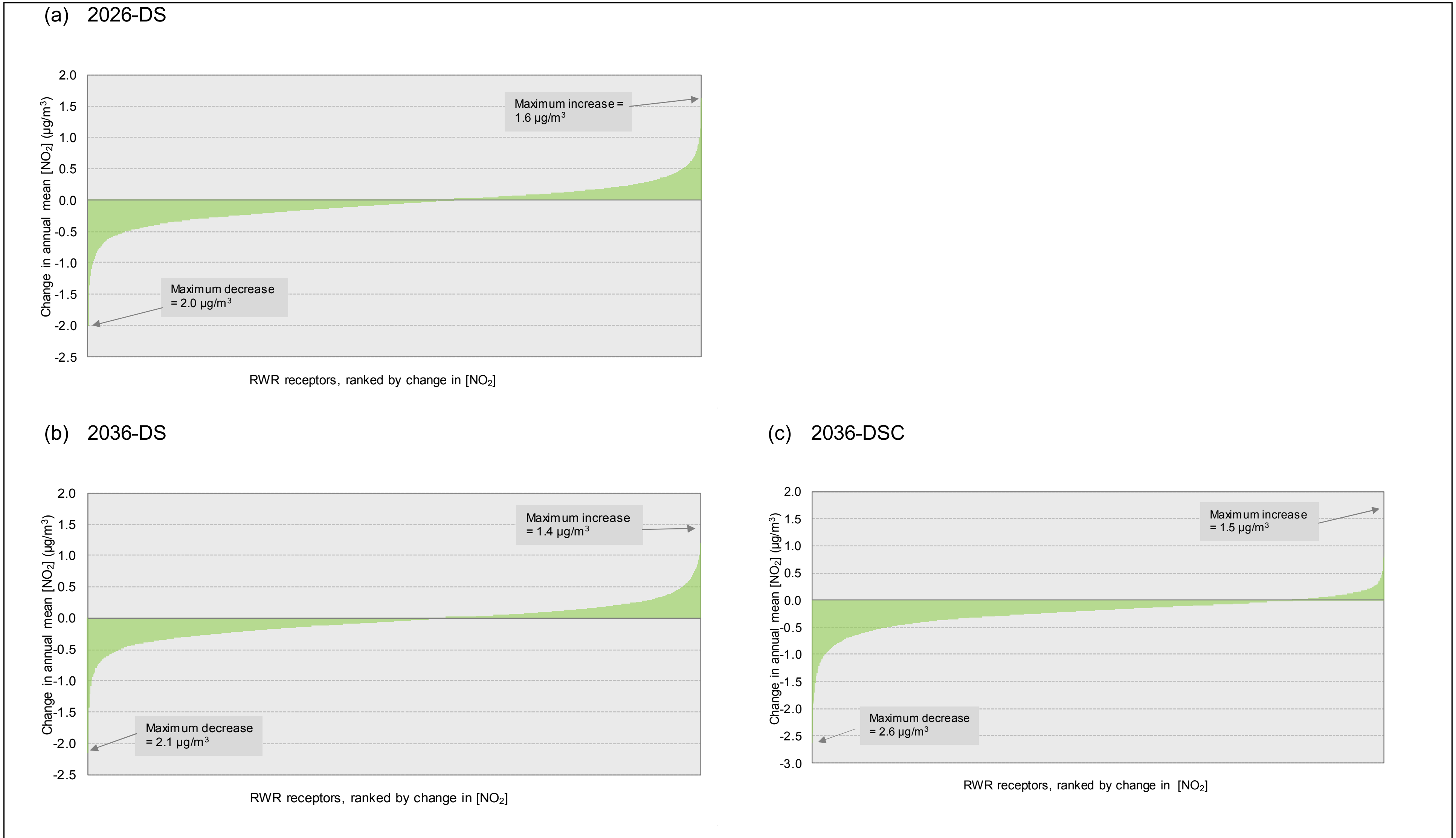


Figure 8-30 Change in annual mean NO_2 concentration at RWR receptors (with-project and cumulative scenarios, minus corresponding Do Minimum scenarios)

Contour plots – all sources

The contour plot of annual mean total NO_2 concentrations across the GRAL domain in the 2036-DM scenario (i.e. all sources without the project) is provided in **Figure 8-31**, and an equivalent plot for the 2036-DS scenario (i.e. all sources with the project) is shown in **Figure 8-32**. The Figures also show main surface roads and the locations of tunnel ventilation outlets.

The plots are based on one million grid points, regularly spaced at 10 metre intervals across the domain. Consequently, 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. The highest total concentrations are found along the most heavily trafficked roads in the GRAL domain, such as General Holmes Drive and Southern Cross Drive. It is noticeable that tunnel ventilation outlets had little impact on total annual mean NO_2 concentrations.

The contour plot in **Figure 8-33** shows the changes in annual mean NO_2 concentration in the 2036-DS scenario. The green shading represents a decrease in concentration with the projects included in the cumulative scenario, and the purple shading an increase in concentration. Any changes in NO_2 of less than 1 µg/m^3 (and hence the changes at a large proportion of RWR receptors) are not shown. This explains the observation that increases in concentration were predicted for up to half of all receptors, whereas the contour plot showing the change in NO_2 would suggests that there would be considerably more receptors with decreases than increases, especially close to the roads affected by the project.

The spatial changes in pollutant concentrations were qualitatively similar for all pollutants, and these are discussed further at the end of this section.

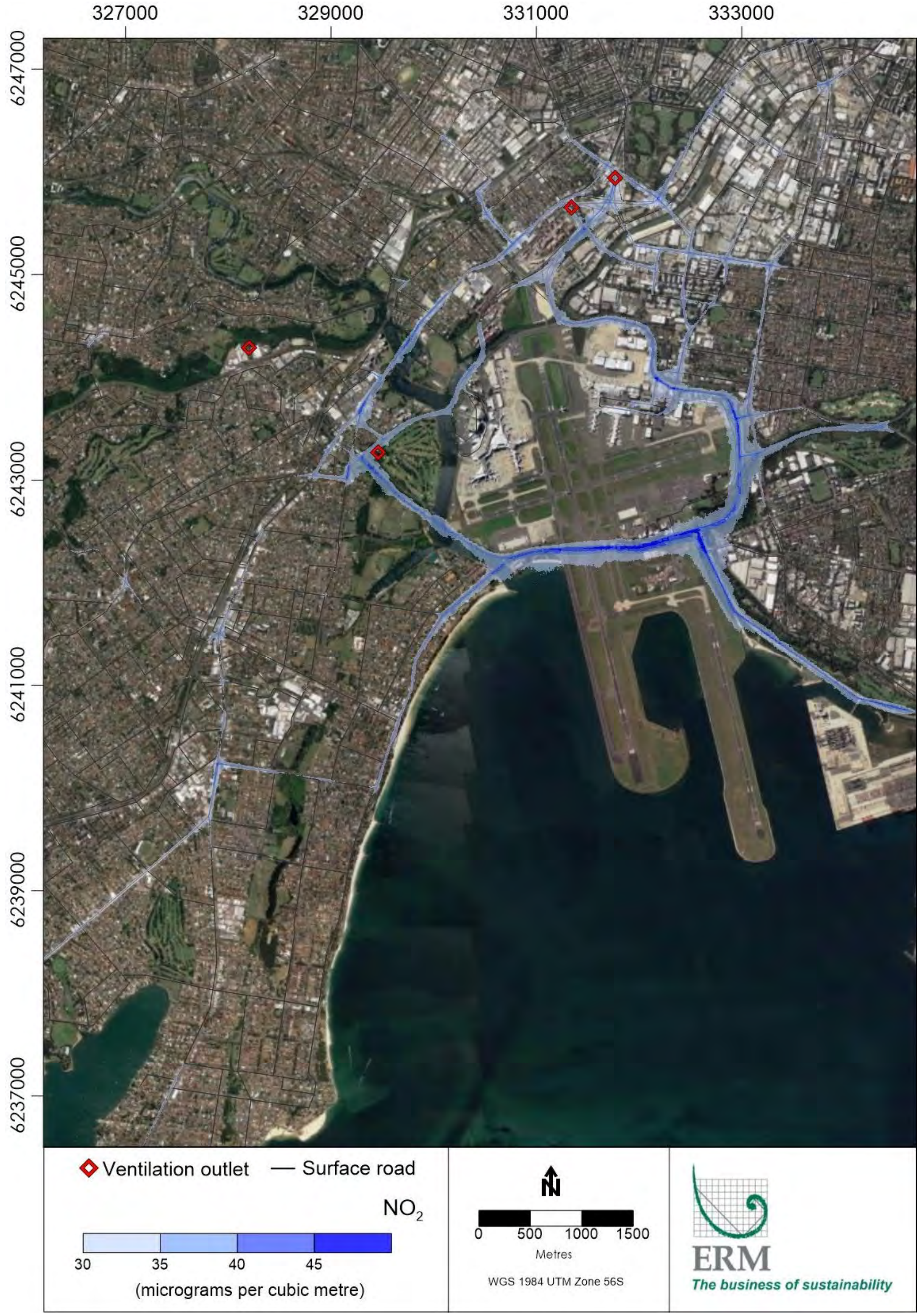


Figure 8-31 Contour plot of annual mean NO_2 concentration in the 2036 Do Minimum scenario (2036-DM)

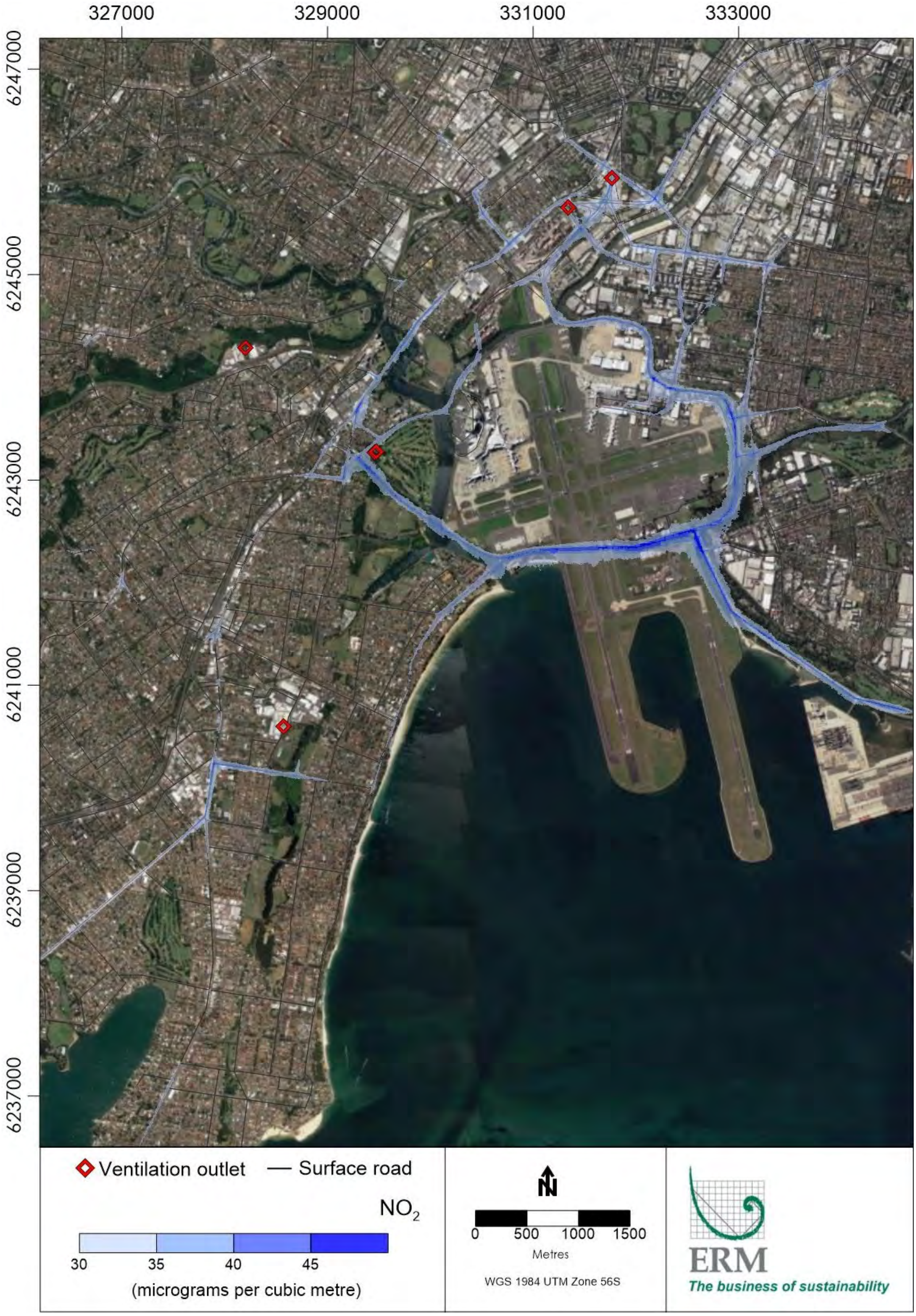


Figure 8-32 Contour plot of annual mean NO_2 concentration in the 2036 Do Something scenario (2036-DS)

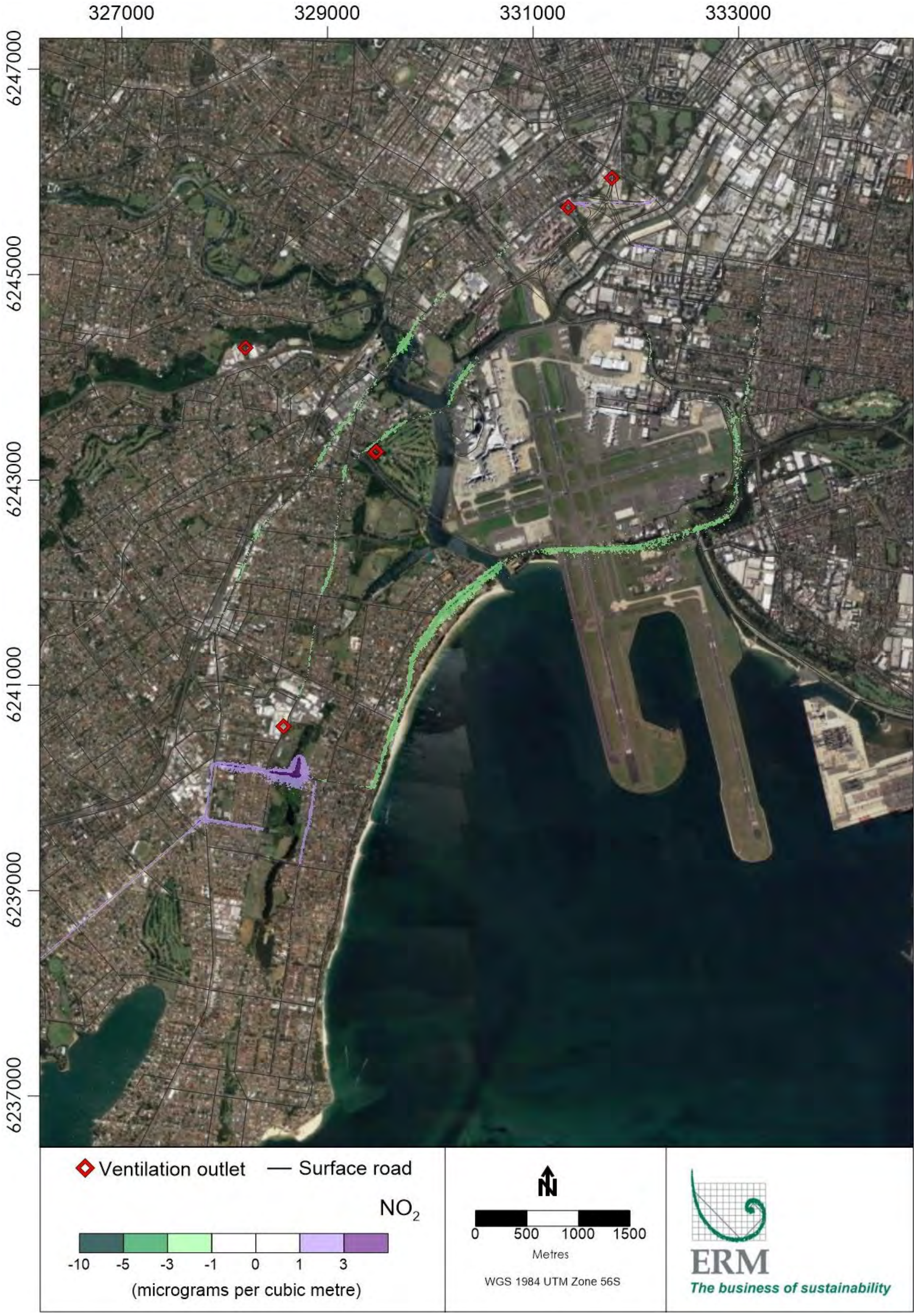


Figure 8-33 Contour plot of change in annual mean NO_2 concentration in the 2036 Do Something scenario (2036-DS minus 2036-DM)

Nitrogen dioxide (maximum 1-hour mean)

Results for community receptors

The maximum 1-hour NO_2 concentrations at the 30 community receptors in the with-project and cumulative scenarios are shown in **Figure 8-34**. At all receptor locations the maximum concentration was below the NSW impact assessment criterion of 246 µg/m^3.

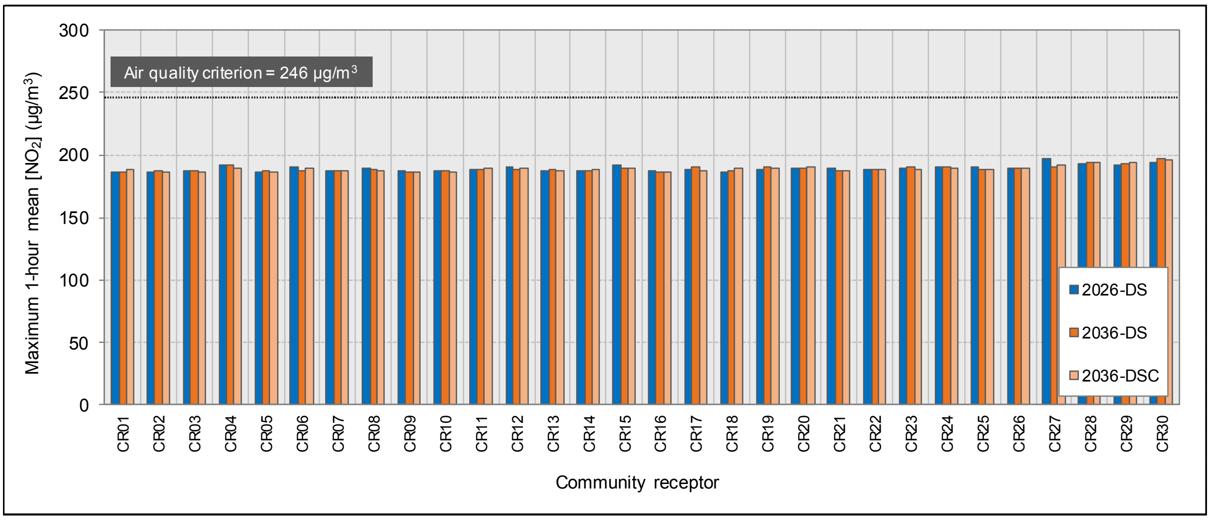


Figure 8-34 Maximum 1-hour mean NO_2 concentration at community receptors (with-project and cumulative scenarios)

The changes in the maximum 1-hour NO_2 concentration minus the Do Minimum scenarios are shown in **Figure 8-35**. Again, there was a mixture of small (relative to the NSW criterion) increases and decreases. As observed above, the increases did not result in any exceedances of the NSW criterion.

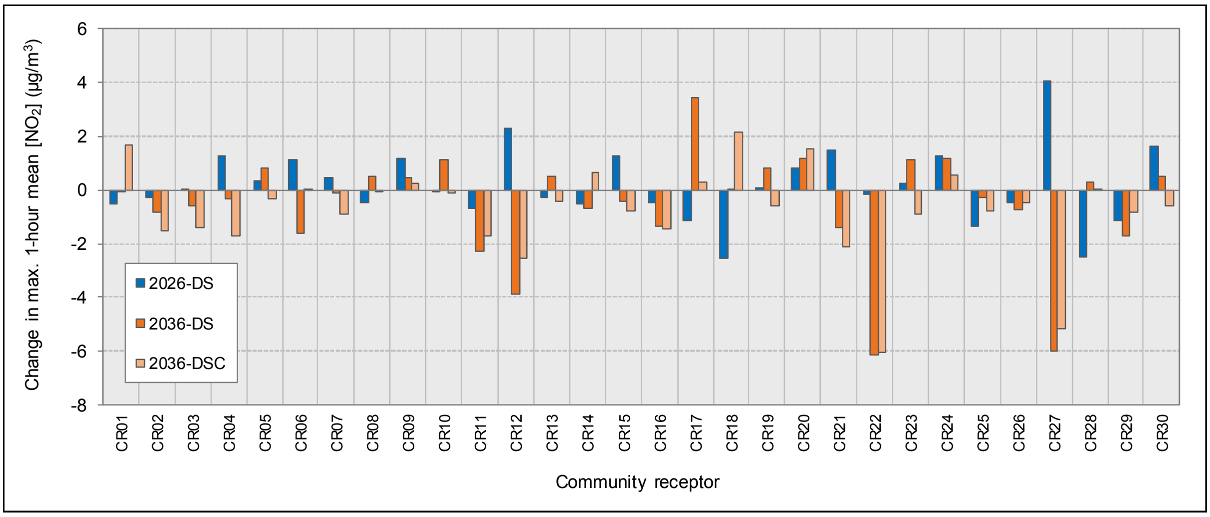


Figure 8-35 Change in maximum 1-hour mean NO_2 concentration at community receptors (with-project and cumulative scenarios, minus Do Minimum scenarios)

To calculate the contributions of different sources to maximum 1-hour NO_2, it was firstly necessary to identify the hour in which the maximum NO_X value occurred, and then determine the modelled surface road and outlet contributions 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 8-36**. As with the annual mean, the background was the most important source, with generally a small contribution from surface roads. The tunnel ventilation outlet contribution to the maximum NO_2 concentration was either zero or negligible. As with 1-hour mean CO, larger 1-hour contributions from roads and outlets could have occurred during other hours of the year, but the total concentration would have been lower.

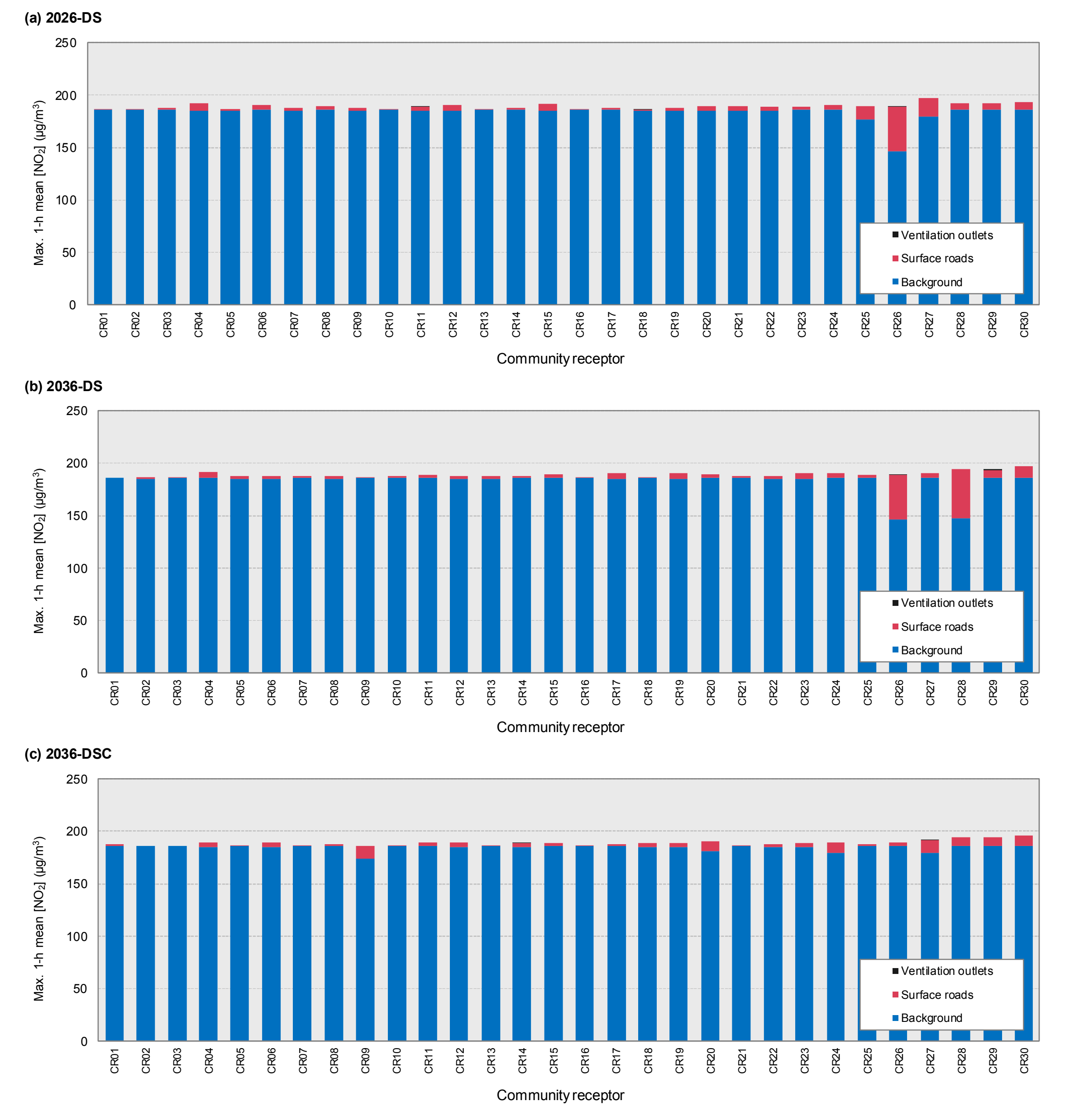


Figure 8-36 Source contributions to maximum 1-hour mean NO_2 concentration at community receptors (with-project and cumulative scenarios)

Results for RWR receptors

The maximum 1-hour mean NO_2 concentrations at the RWR receptors in the with-project contributions and cumulative scenarios are shown, with a ranking by total concentration, in **Figure 8-37**. The contribution of surface roads and ventilation outlets are not shown separately in **Figure 8-37**; as in the case of 1-hour CO and other short-term metrics, the hours when the maxima for the different sources occurred were not known.

There were small numbers of predicted exceedances of the NSW 1-hour NO_2 criterion (246 µg/m^3), both with and without the project. In the 2026-DM scenario the maximum concentration exceeded the NSW criterion at 12 receptors (0.1 per cent of all receptors), and with the introduction of the project in the 2026-DS scenario, this decreased to 10 receptors. In 2036 the number decreased from 12 to 7 receptors. In the 2036-DSC scenario, the number of receptors with an exceedance was decreased to 6.

Although the ventilation outlet contributions to NO_2 could not be calculated, the maximum contribution of tunnel outlets to NO_X at any receptor in the with-project and cumulative scenarios was 54 µg/m^3 in the 2036-DS scenario. This would equate to a very small NO_2 contribution relative to the air quality assessment criterion.

The changes in the maximum 1-hour mean NO_2 concentration at the RWR receptors in the with-project and cumulative scenarios are shown, ranked by change in concentration as a result of the project, in **Figure 8-38**. There was predicted to be an increase in the annual mean NO_2 concentration at around 40 per cent of receptors in the Do Something scenarios, and 24 per cent in the 2036 cumulative scenario. At the majority of receptors the change was relatively small in all scenarios; at around 95 per cent of receptors the change in concentration (either an increase or a decrease) was less than 5 µg/m^3. The changes at a small number of receptors (up to 5.3 per cent in the cumulative case) were substantially larger (up to 42 µg/m^3). However, as noted earlier, these changes did not result in any exceedances of air quality standards.

Contour plots – all sources

Contour plots of maximum 1-hour NO_2 concentrations in the 2036-DM and 2036-DSC scenarios are provided in **Figure 8-39** and **Figure 8-40** respectively. It is important to note that these plots do not represent a particular time period; each point in the plot is a maximum value for any hour of the year. The contour plot for the change in the maximum 1-hour NO_2 concentration with in the 2026 cumulative scenario is given in **Figure 8-41**. The locations with the highest concentrations and largest changes in concentration are similar to this for annual mean NO_2.

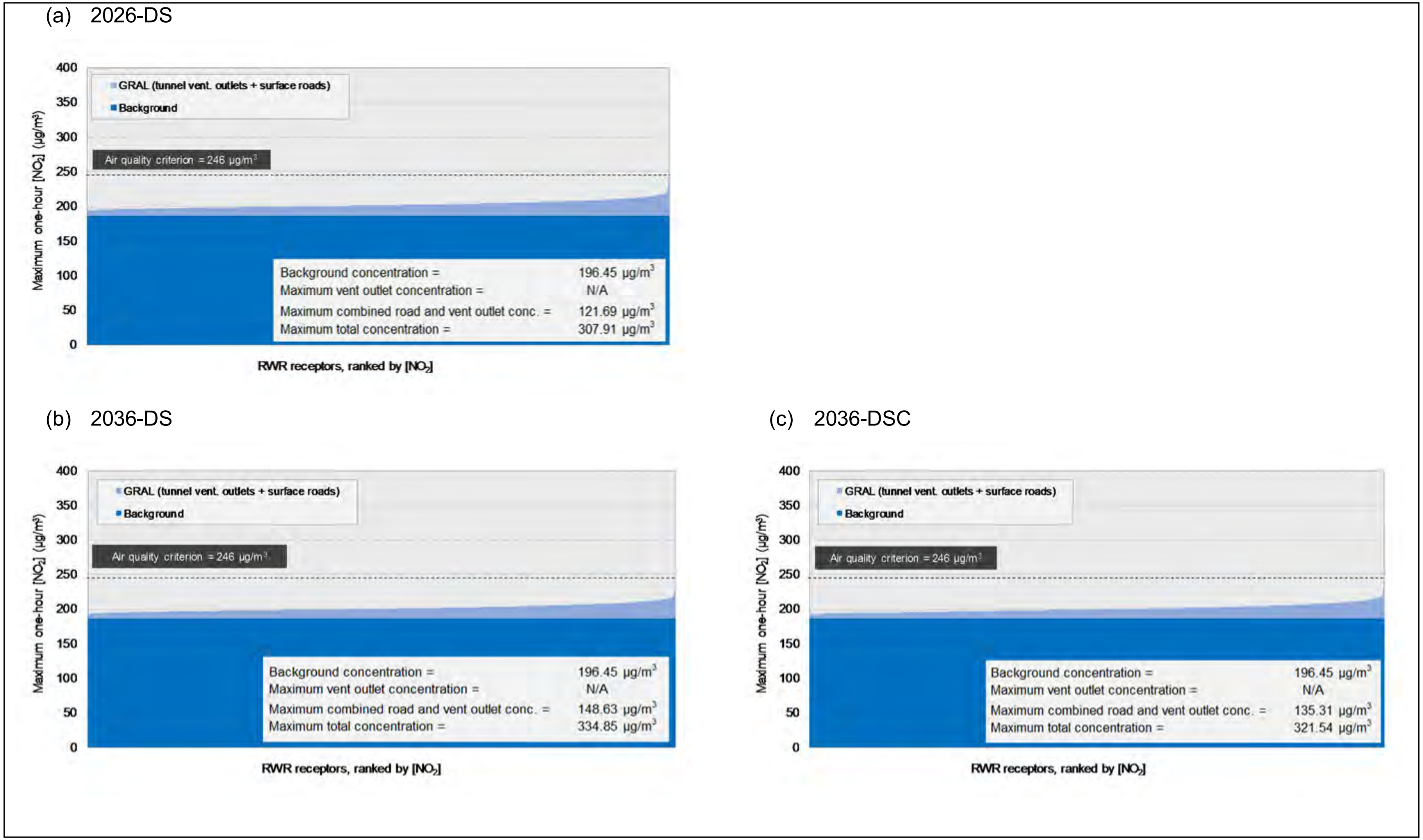


Figure 8-37 Source contributions to maximum 1-hour mean NO_2 concentration at RWR receptors (with-project and cumulative scenarios)

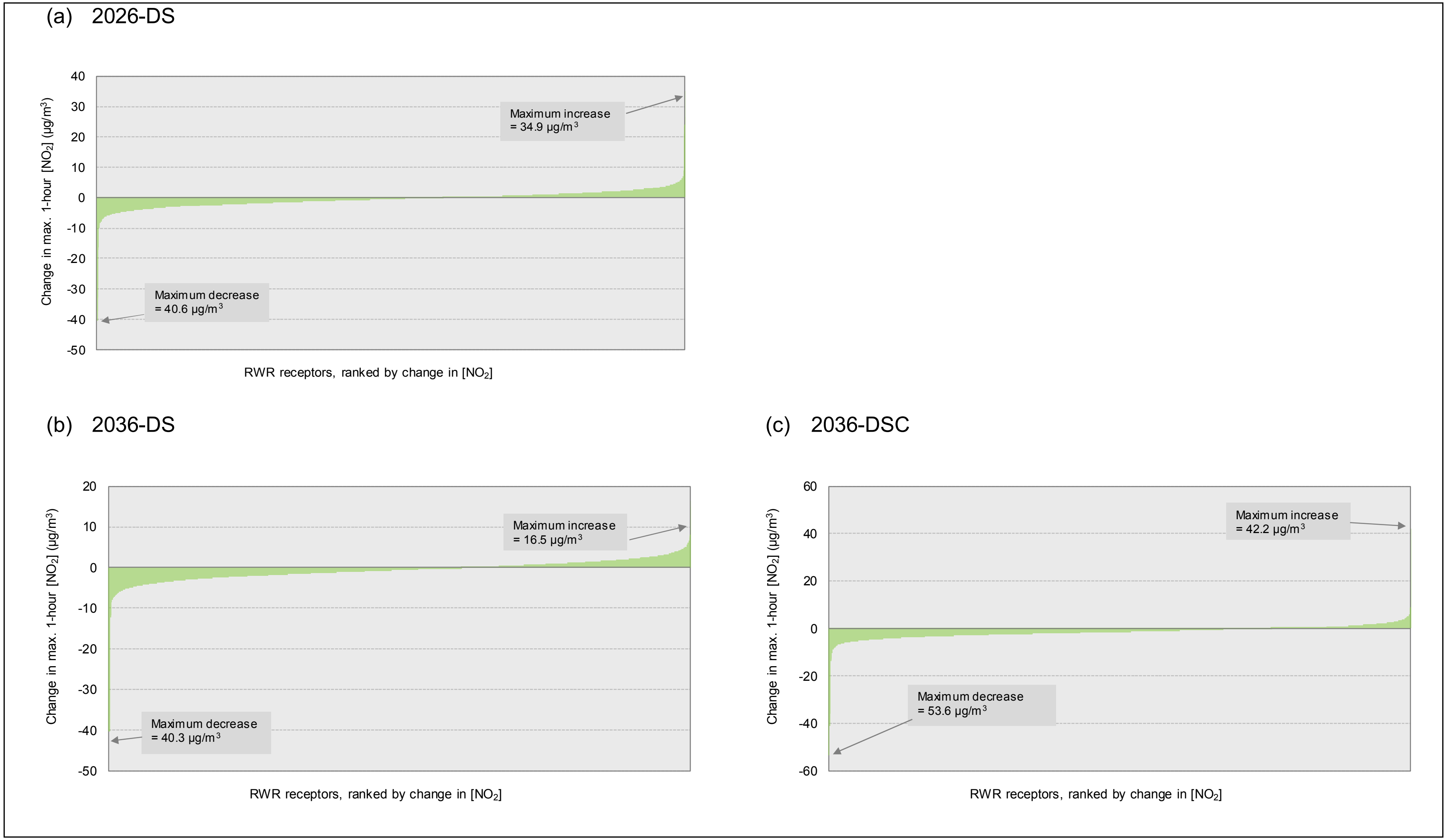


Figure 8-38 Change in maximum 1-hour mean NO_2 concentration at RWR receptors (with-project and cumulative scenarios, minus Do Minimum scenarios)

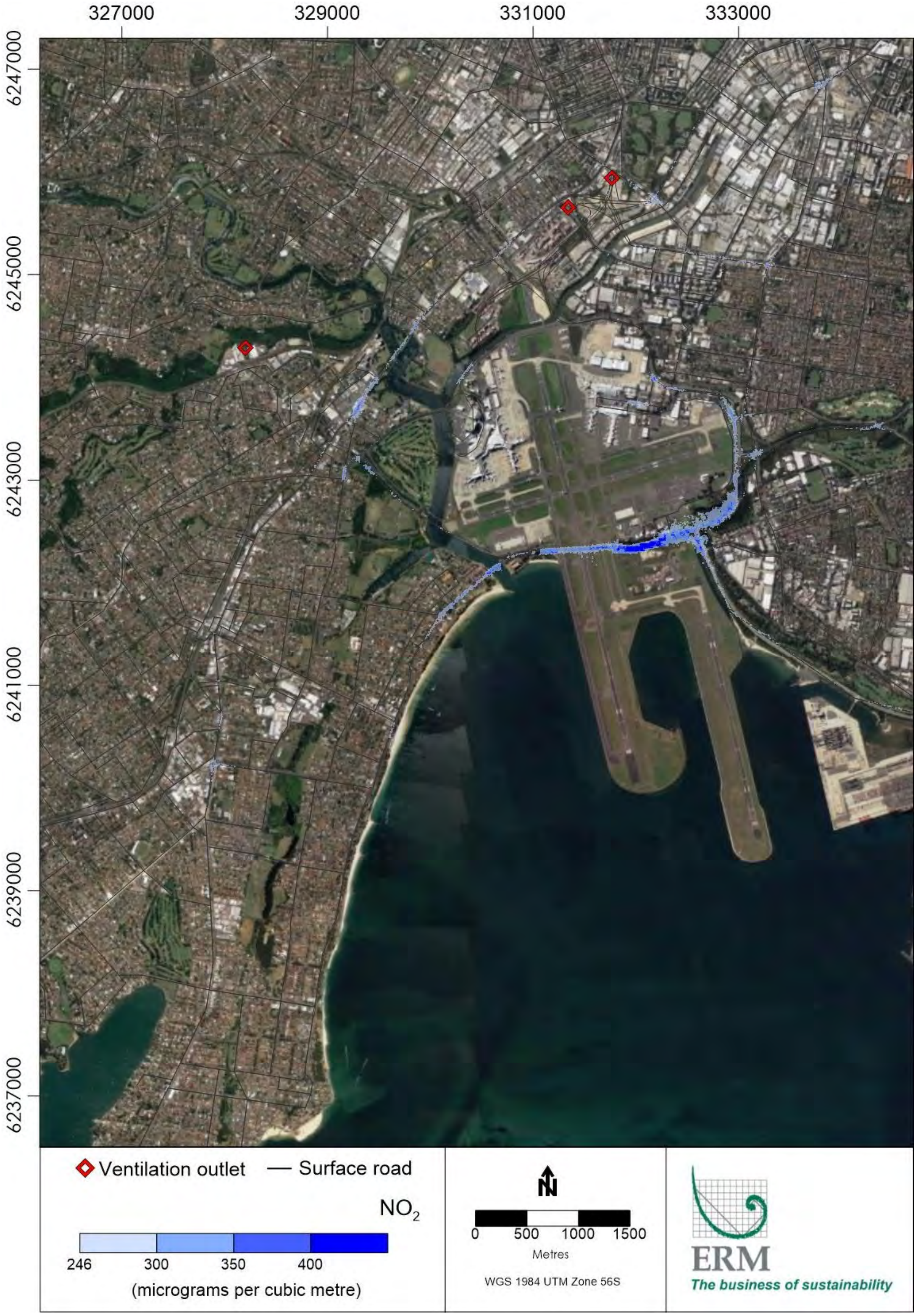


Figure 8-39 Contour plot of maximum 1-hour NO_2 concentration in the 2036 Do Minimum scenario (2036-DM)

Figure 8-40 Contour plot of maximum 1-hour NO_2 concentration in the 2036 Do Something scenario (2036-DS)

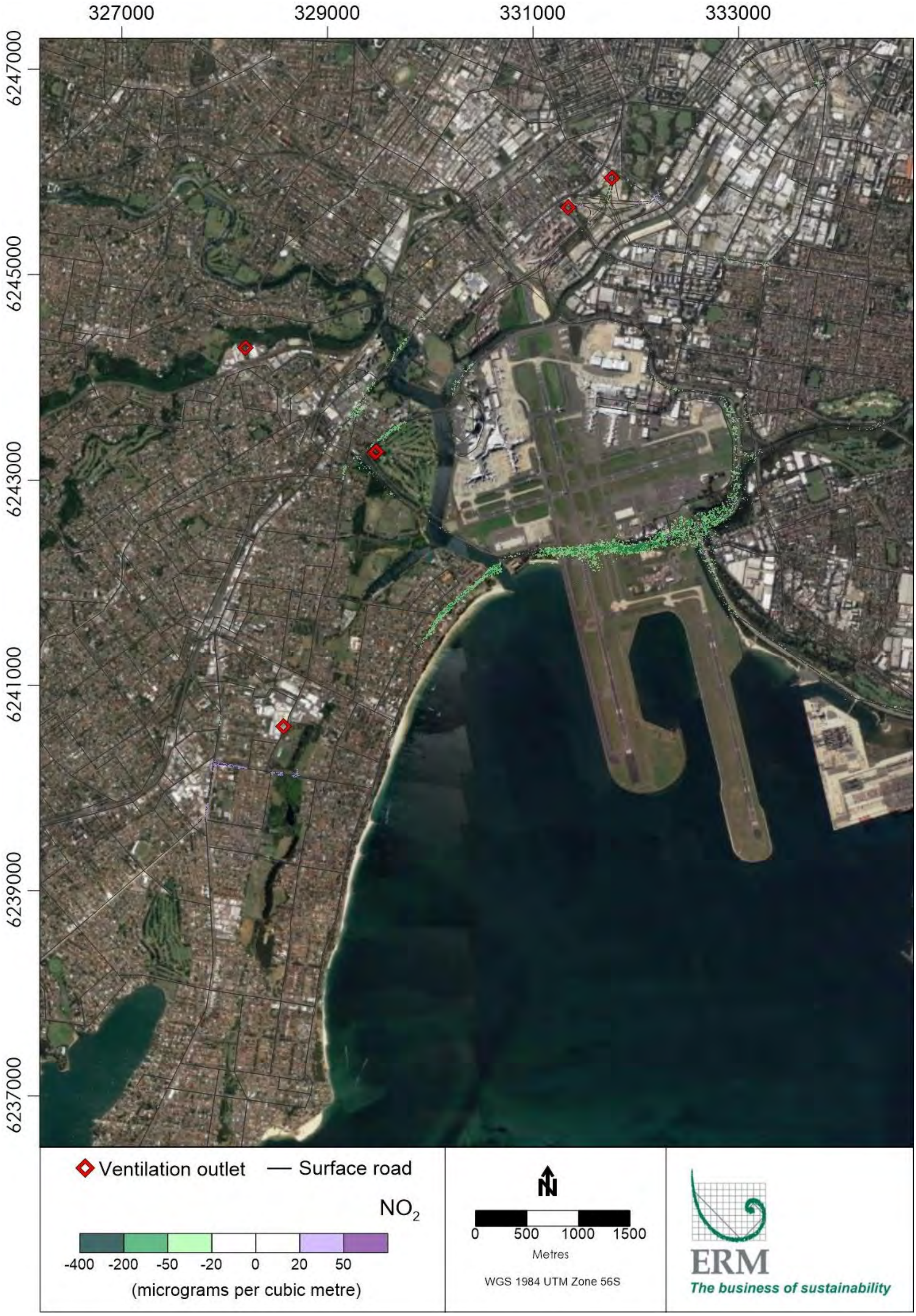


Figure 8-41 Contour plot of change in maximum 1-hour NO_2 concentration in the 2036 Do Something scenario (2036-DS minus 2036-DM)

PM_{10} (annual mean)

Results for community receptors

The annual mean PM_{10} concentrations community receptors are shown in **Figure 8-42**. These were all below the NSW impact assessment criterion of 25 µg/m^3. At most the receptors the concentration was close to 20 µg/m^3, and therefore only slightly above the lowest PM_{10} standards in force in other countries (18 µg/m^3 in Scotland).

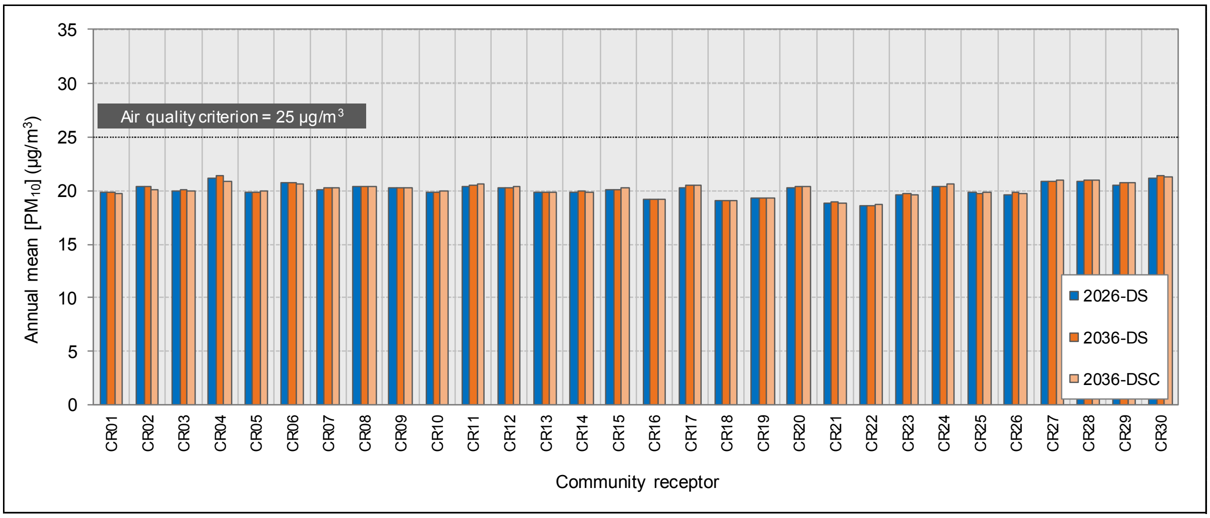


Figure 8-42 Annual mean PM_{10} concentration at community receptors (with-project and cumulative scenarios)

Figure 8-43 shows the changes in PM_{10} concentration. The largest increase was around 0.2 µg/m^3 (less than one per cent of the criterion) at receptor CR27 (Little Learning School, Alexandria), and the largest decrease was around 0.25 µg/m^3.

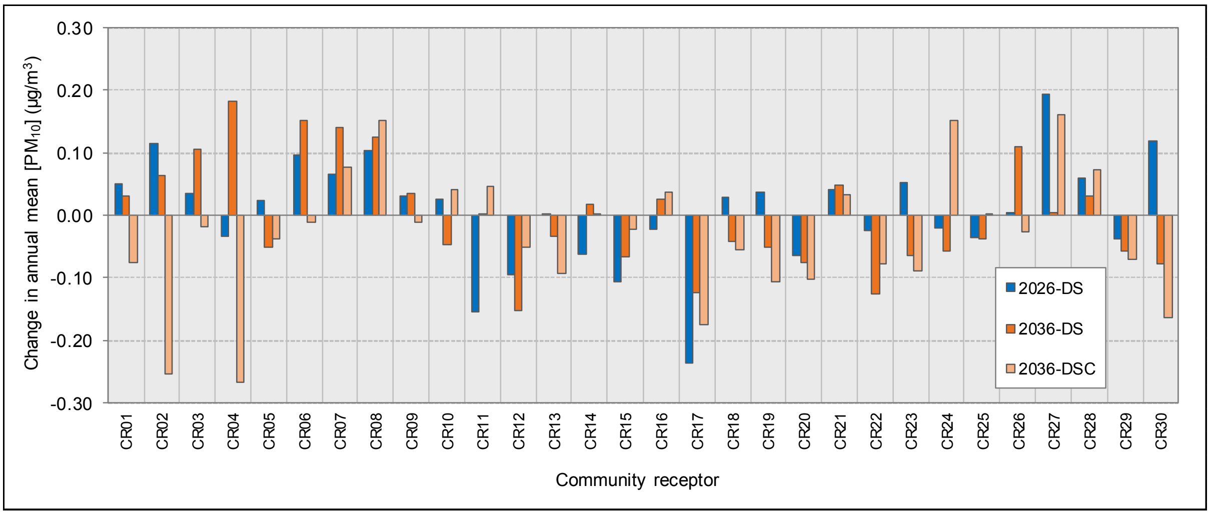


Figure 8-43 Change in annual mean PM_{10} concentration at community receptors (with-project and cumulative scenarios, minus Do Minimum scenarios)

Concentrations in the with-project and cumulative scenarios were again dominated by the background (**Figure 8-44**), with a small contribution from roads (0.4-2.6 µg/m^3) and a negligible contribution from tunnel ventilation outlets (generally less than 0.1 µg/m^3, with a maximum of 0.28 µg/m^3 at receptor CR24 in the 2036-DSC scenario).

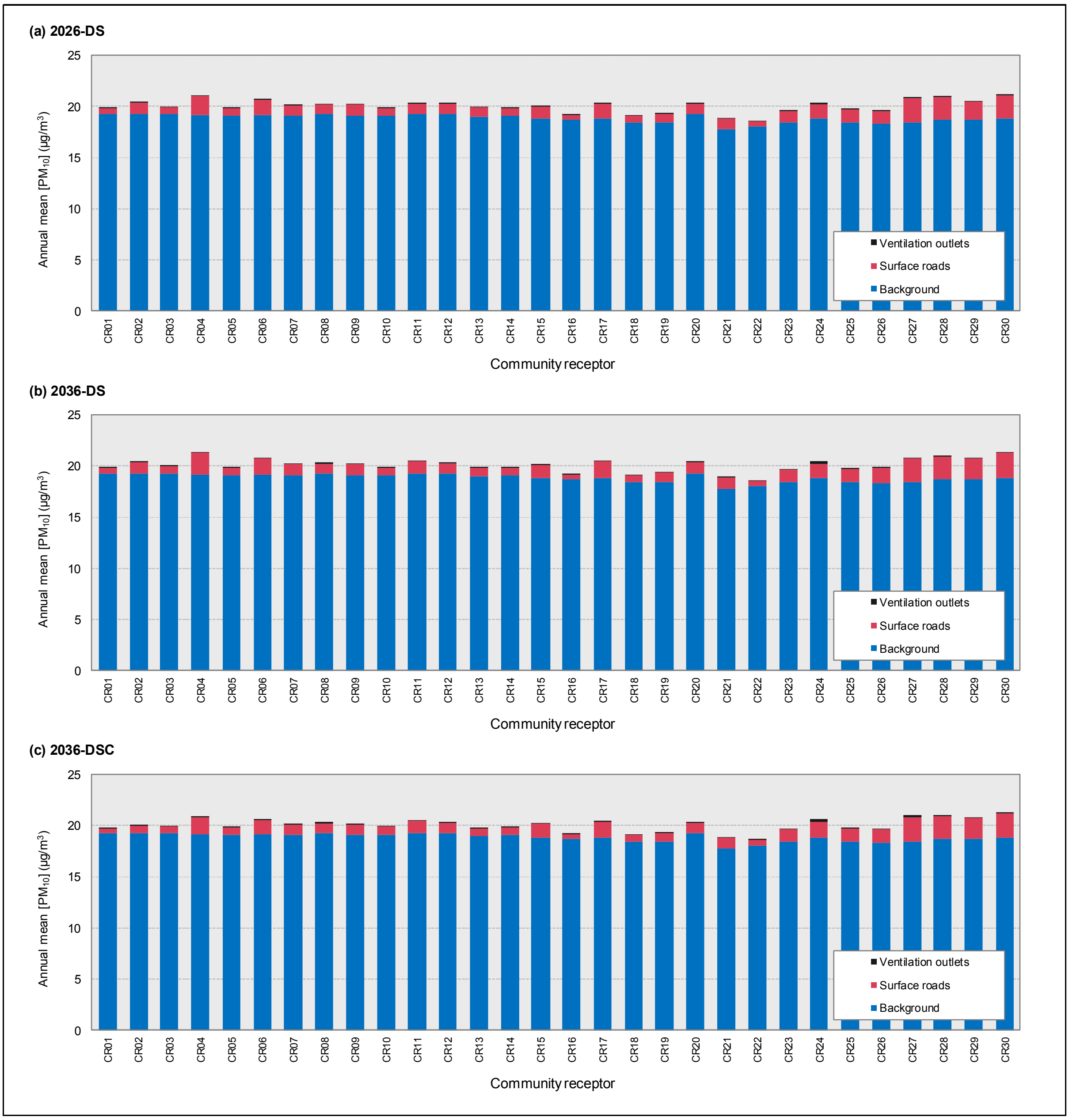


Figure 8-44 Source contributions to annual mean PM_{10} concentration at community receptors (with-project and cumulative scenarios)

Results for RWR receptors

The ranked annual mean PM_{10} concentrations at the RWR receptors in the with-project and cumulative scenarios are shown in **Figure 8-45**. The concentration at the majority of receptors was below 20 µg/m^3, with only three receptors having a concentration just above the NSW assessment criterion of 25 µg/m^3. The highest predicted concentration at any receptor in a with-project or cumulative scenario was 30.9 µg/m^3. The surface road contribution was between 0.2 µg/m^3 and 11.9 µg/m^3, with an average of 1.3 µg/m^3. The largest contribution from tunnel ventilation outlets was 0.50 µg/m^3 in the 2036-DSC scenario.

The changes in the annual mean PM_{10} concentration at the RWR receptors are shown, ranked by change in concentration, in **Figure 8-46**. There was an increase in concentration at 30-48 per cent of the receptors, depending on the scenario. At the majority of receptors the change was relatively small, and where there was an increase, this was greater than 0.25 µg/m^3 (one per cent of the criterion) at less than 2 per cent of receptors.

Contour plots – all sources

The contour plots for annual mean PM_{10} in the 2026-DM and 2026-DS scenarios are given in **Figure 8-47** and **Figure 8-48**. As in the case of NO_2, elevated concentrations are evident along the major road corridors. The contour plot for the change in concentration in the cumulative scenario in (**Figure 8-49**) also shows complex spatial changes that are similar to those for NO_2.

The spatial changes in pollutant concentrations are discussed further at the end of this section.

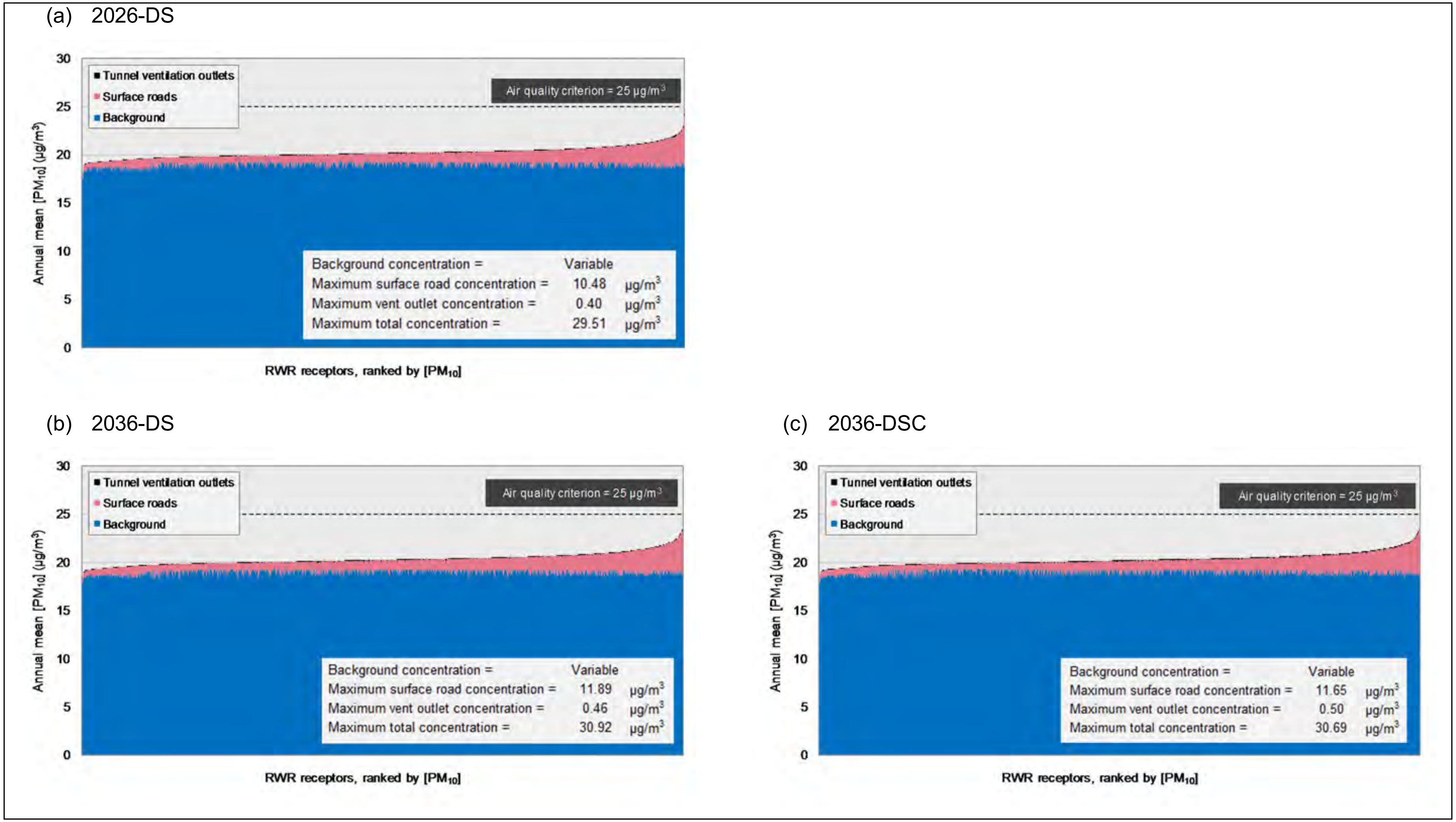


Figure 8-45 Source contributions to annual mean PM_{10} concentration at RWR receptors (with-project and cumulative scenarios)

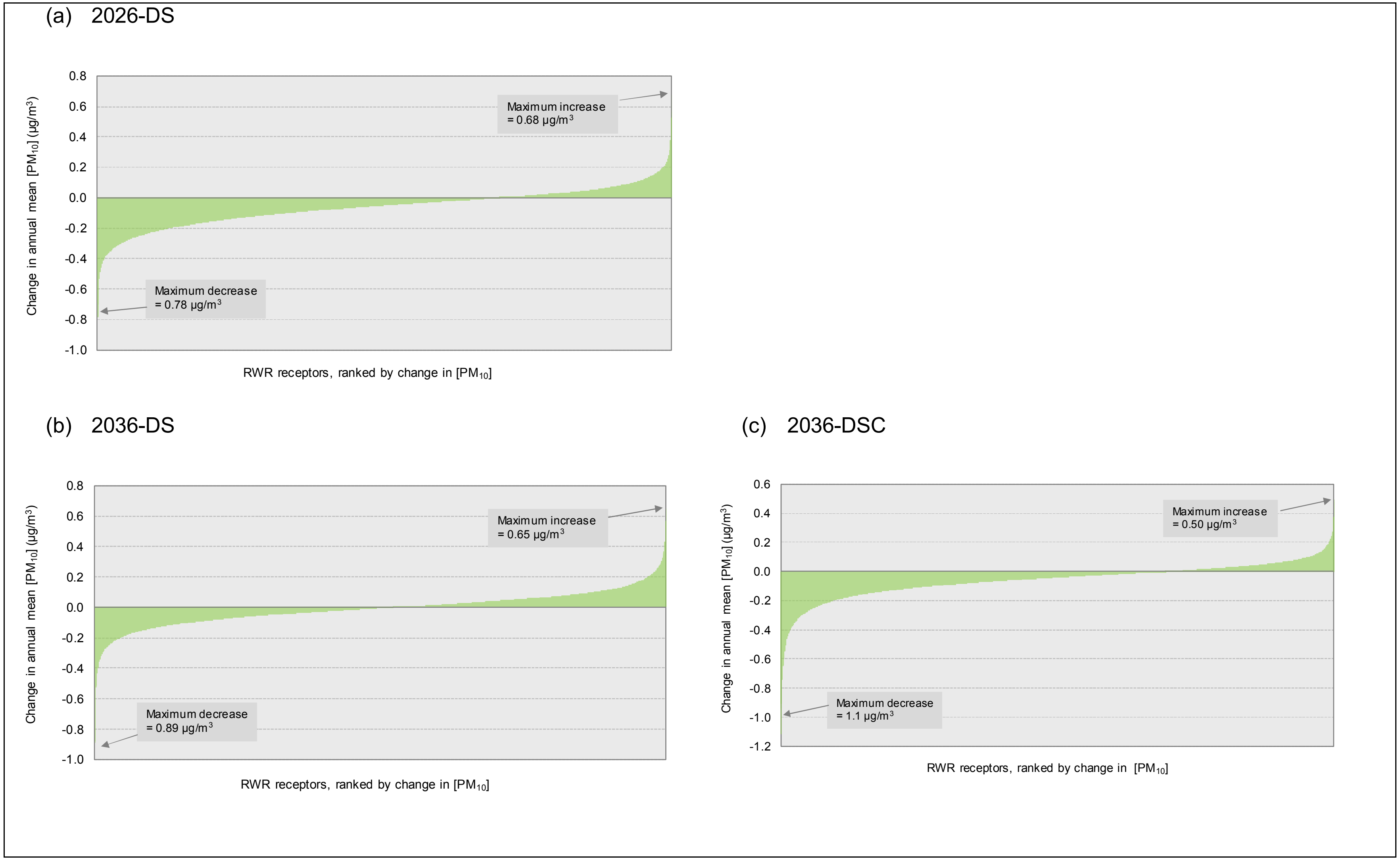


Figure 8-46 Changes in annual mean PM_{10} concentration at RWR receptors (with-project and cumulative scenarios, minus Do Minimum scenarios)

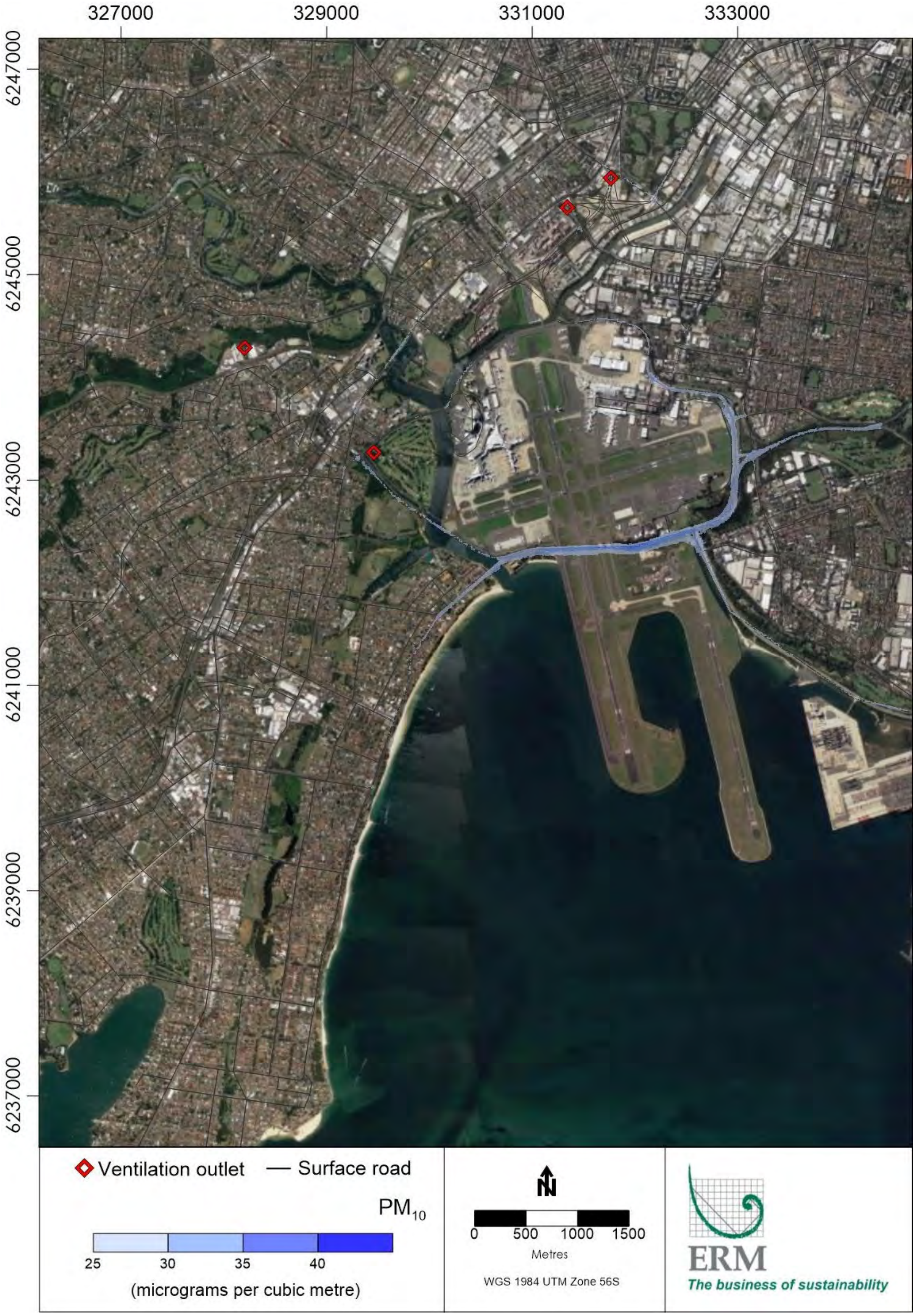


Figure 8-47 Contour plot of annual mean PM_{10} concentration in the 2036 Do Minimum scenario (2036-DM)

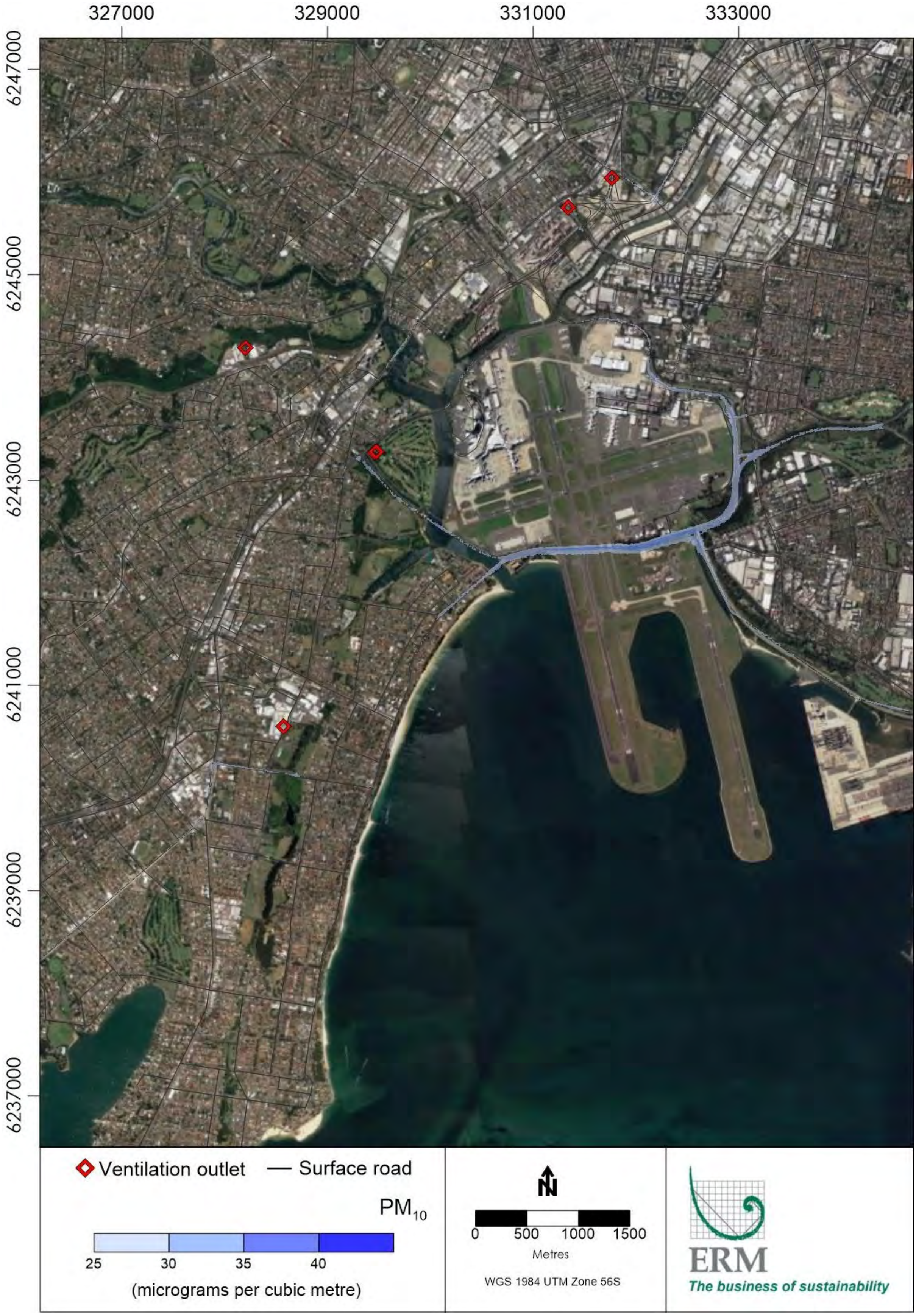


Figure 8-48 Contour plot of annual mean PM_{10} concentration in the 2036 Do Something scenario (2036-DS)

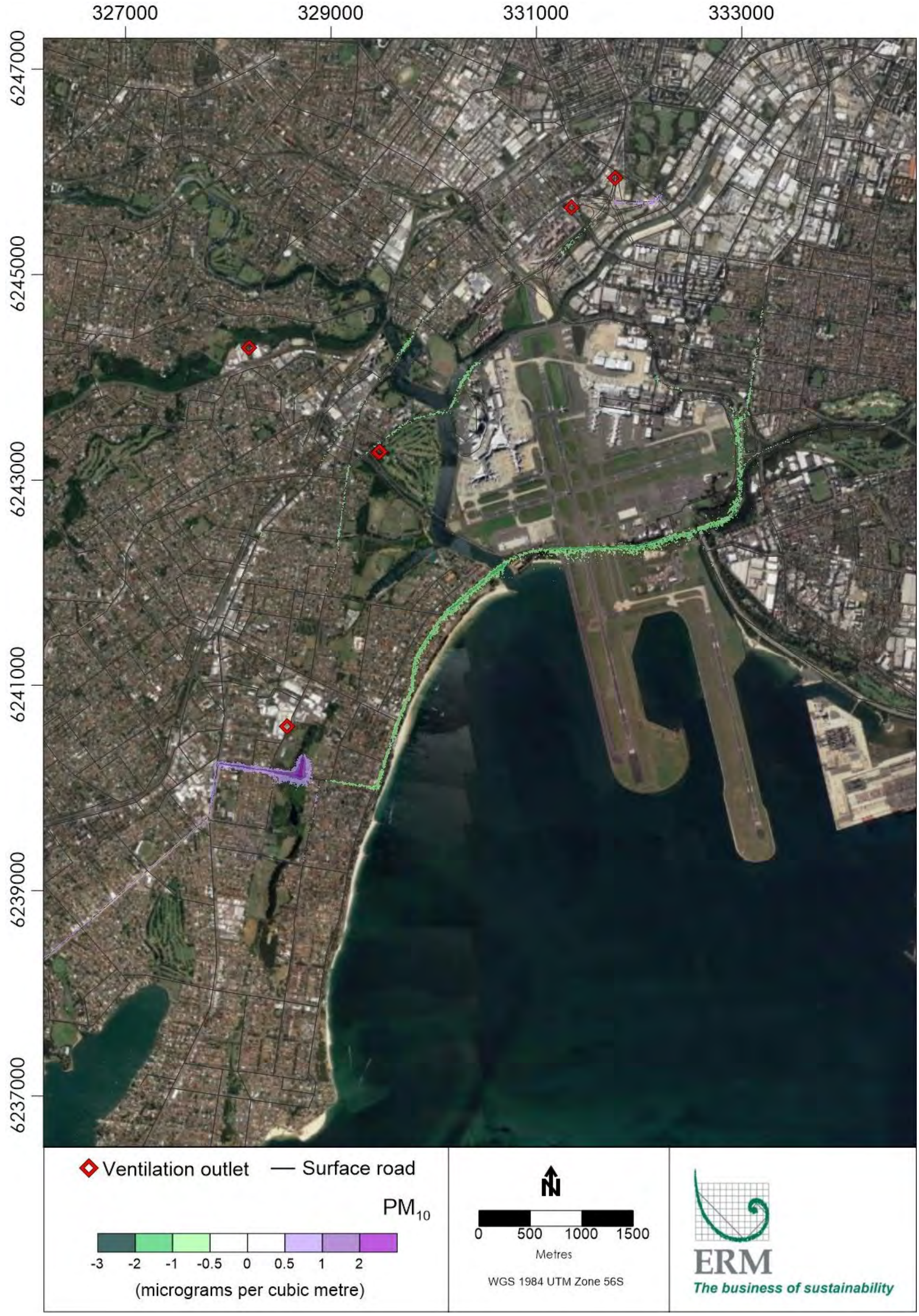


Figure 8-49 Contour plot of change in annual mean PM_{10} concentration in the 2036 Do Something scenario (2036-DS minus 2036-DM)

PM_{10} (maximum 24-hour mean)

Results for community receptors

Figure 8-50 presents the maximum 24-hour mean PM_{10} concentrations at the community receptors. At all locations, and in all scenarios, the concentration was below the NSW impact assessment criterion of 50 µg/m^3, which is also the most stringent standard in force internationally.

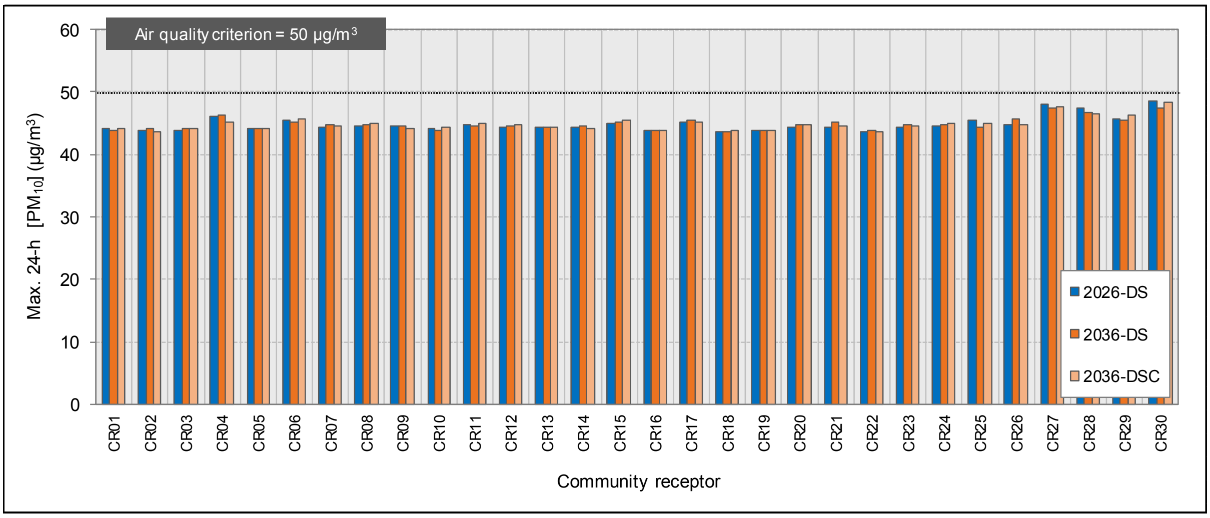


Figure 8-50 Maximum 24-hour mean PM_{10} concentration at community receptors (with-project and cumulative scenarios)

Figure 8-51 shows the changes in concentration in the Do Something scenarios minus the Do Minimum scenarios for the community receptors. There were no systematic changes by year or by scenario. At most receptors, the change was less than 1 µg/m^3, and at all receptors it was less than 2 µg/m^3. The largest increase was 1.8 µg/m^3 at receptor CR30 (Hippos Friends, Botany) in the 2026-DS scenario.

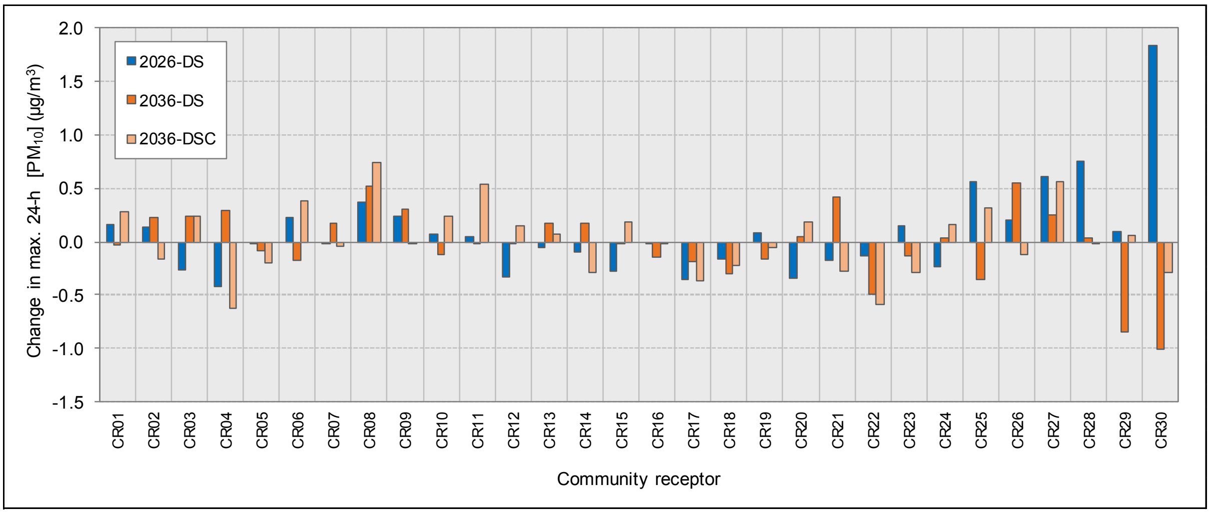


Figure 8-51 Change in maximum 24-hour mean PM_{10} concentration at community receptors (with-project and cumulative scenarios, minus Do Minimum scenarios)

Figure 8-52 demonstrates that the surface road contribution to the maximum 24-hour PM_{10} concentration at each community receptor was less than 5 µg/m^3. At almost all community receptors, the maximum total 24-hour concentration occurred on one day of the year, and coincided with the highest 24-hour background concentration in the synthetic PM_{10} profile (43.6 µg/m^3). The tunnel ventilation outlet contribution at the community receptors was negligible, being less than 0.6 µg/m^3 in all cases.

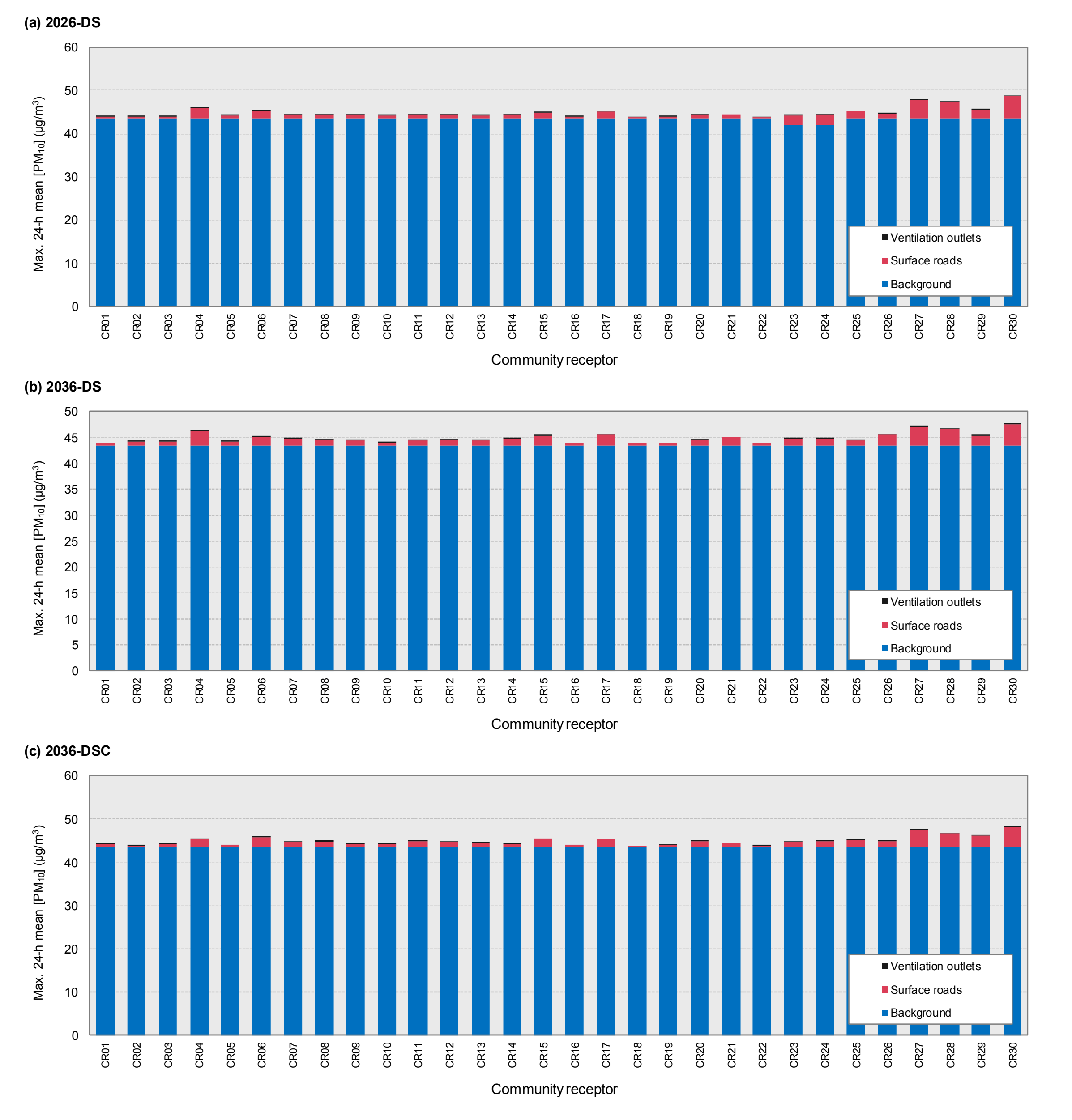


Figure 8-52 Source contributions to maximum 24-hour mean PM_{10} concentration at community receptors (with-project and cumulative scenarios)

Results for RWR receptors

The ranked maximum 24-hour mean PM_{10} concentrations at the RWR receptors are shown in **Figure 8-53**. The results for the RWR receptors were highly dependent on the assumption for the background concentration. Because this was assumed to be the maximum concentration in the synthetic background profile (i.e. 43.6 μg/m^3), the total concentration in the with-project and cumulative scenarios was above the NSW impact assessment criterion of 50μg/m^3 at between 8 and 10 per cent of receptors.

The proportion of receptors with a concentration above the criterion decreased slightly as a result of the project, such as from 9 per cent in the 2026-DM scenario to 8 per cent in the 2026-DS scenario. The contributions of surface roads and ventilation outlets were not additive. The maximum contribution of tunnel ventilation outlets at any receptor in a with-project or cumulative scenario was between 2.0 μg/m^3 to 2.5 μg/m^3.

The changes in the maximum 24-hour mean PM_{10} concentration with the project and in the cumulative scenarios are ranked – by change in concentration – in **Figure 8-54**. There was an increase in concentration at between 28 and 45 per cent of the receptors, depending on the scenario. The largest predicted increase in concentration at any receptor as a result of the project (including the cumulative scenario) was 3.6 μg/m^3, and the largest predicted decrease was also 3.6 μg/m^3. Where there was an increase, this was greater than 0.5 μg/m^3 (one per cent of the criterion) at 4-8 per cent of receptors depending on the scenario.

Contour plots – all sources

The contour plots for maximum 24-hour average PM_{10} in the 2036-DM and 2036-DS scenarios are given in **Figure 8-55** and **Figure 8-56**. The spatial changes in maximum 24-hour PM_{10} are shown in **Figure 8-57**.

The spatial changes in pollutant concentrations are discussed further at the end of this section.

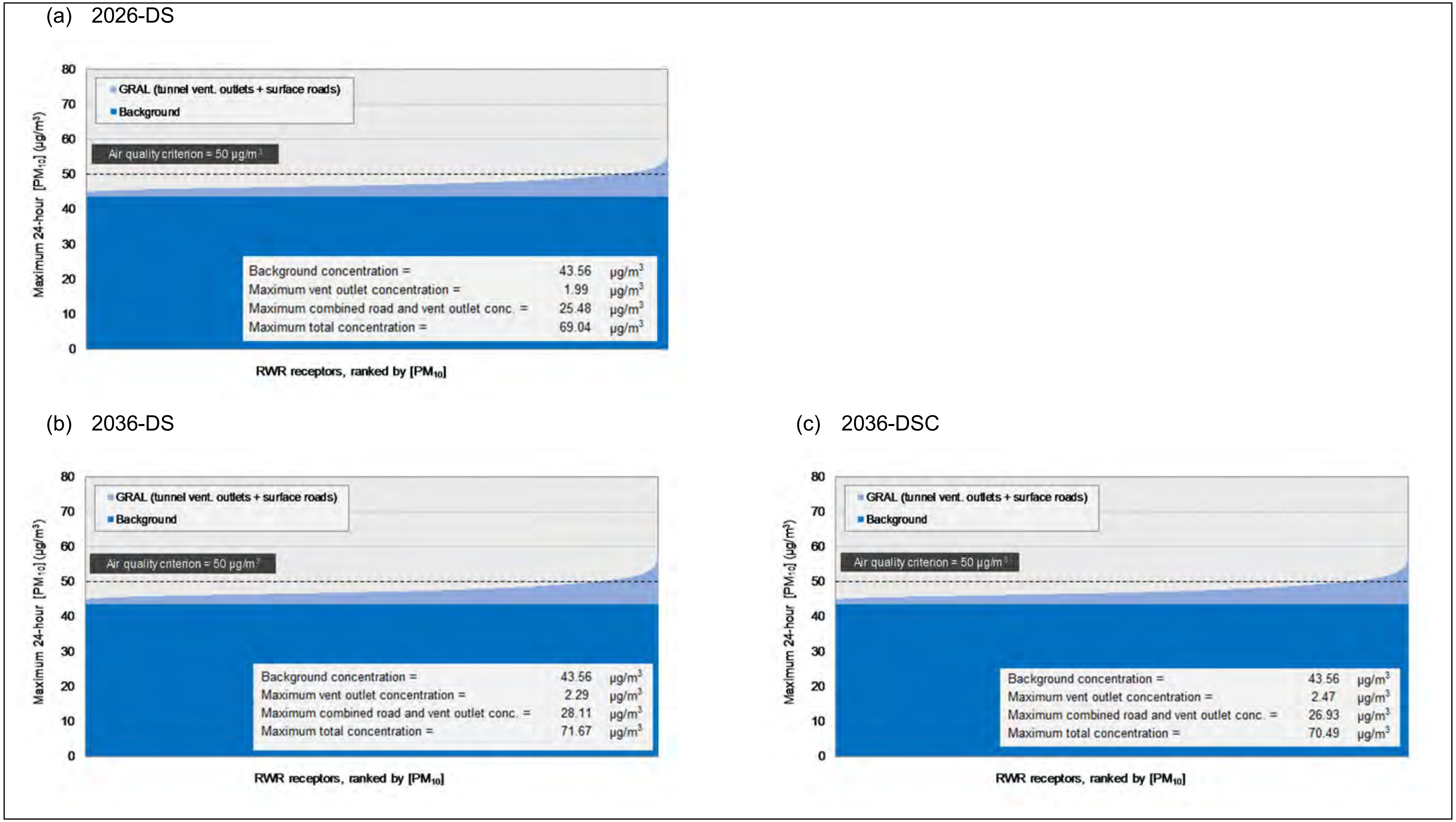


Figure 8-53 Source contributions to maximum 24-hour mean PM_{10} concentration at RWR receptors (with-project and cumulative scenarios)

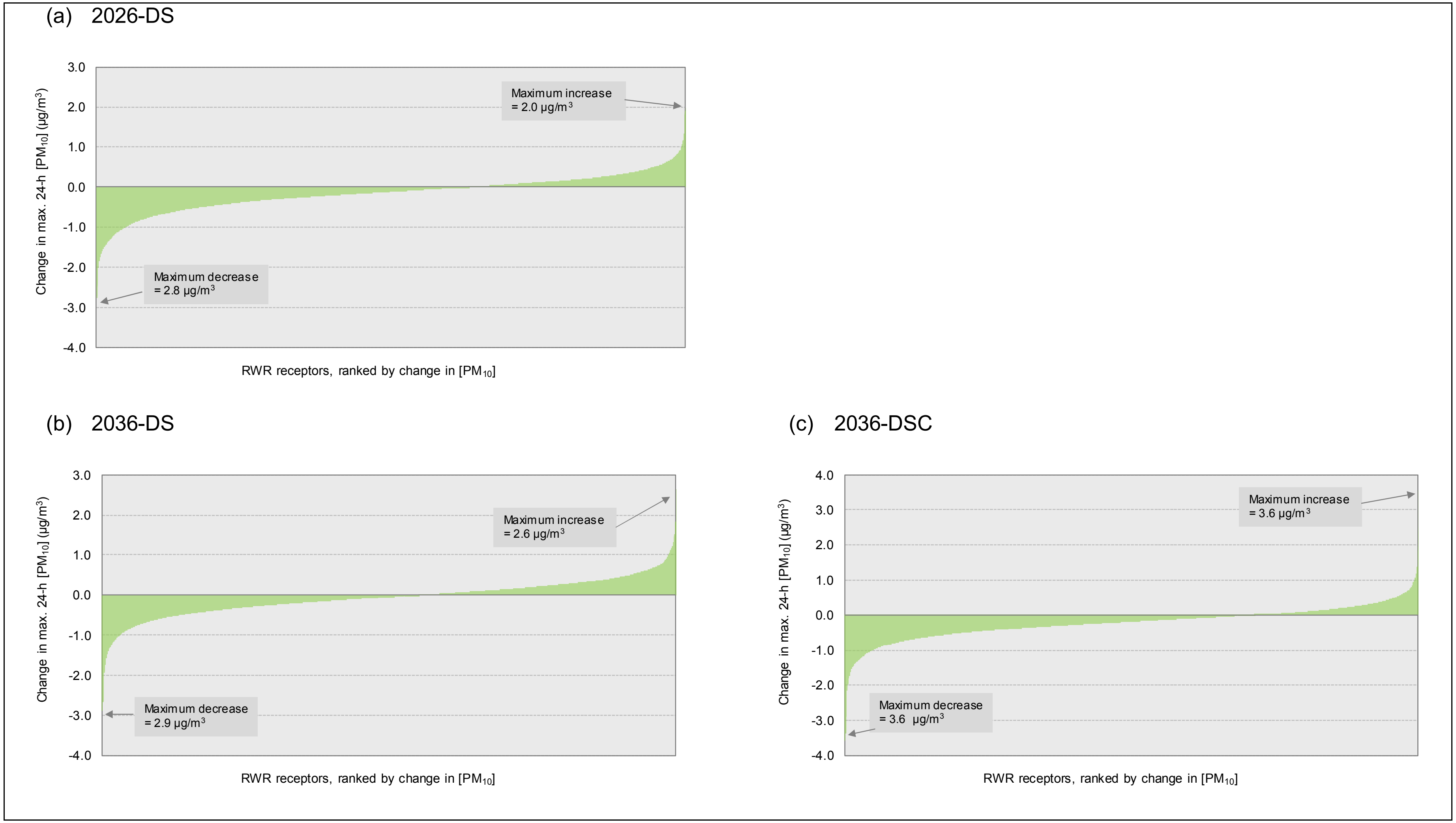


Figure 8-54 Change in maximum 24-hour mean PM_{10} concentration at RWR receptors (with-project and cumulative scenarios, minus Do Minimum scenarios)

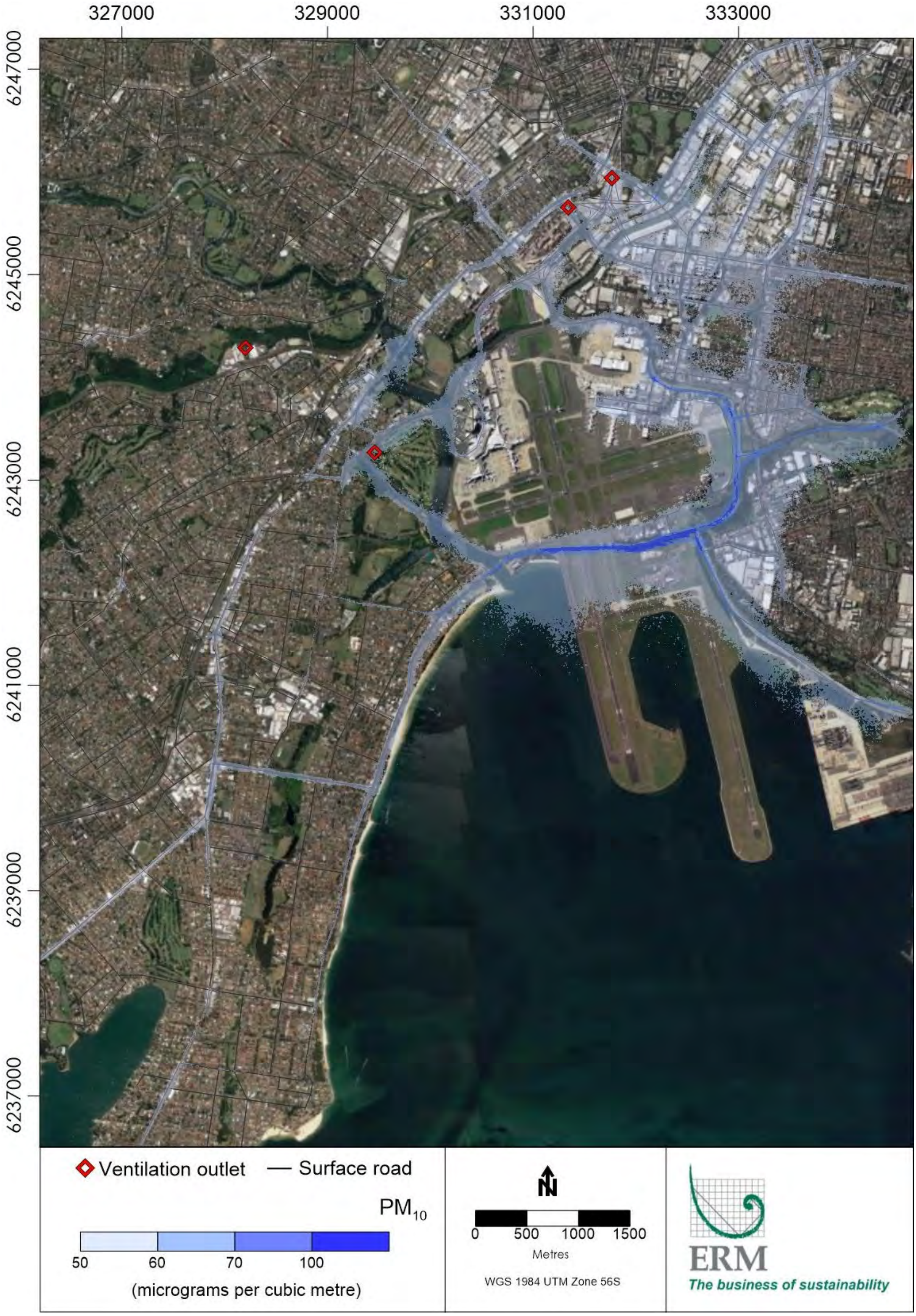


Figure 8-55 Contour plot of maximum 24-hour average PM_{10} concentration in the 2036 Do Minimum scenario (2036-DM)

Figure 8-56 Contour plot of maximum 24-hour average PM_{10} concentration in the 2036 Do Something scenario (2036-DS)

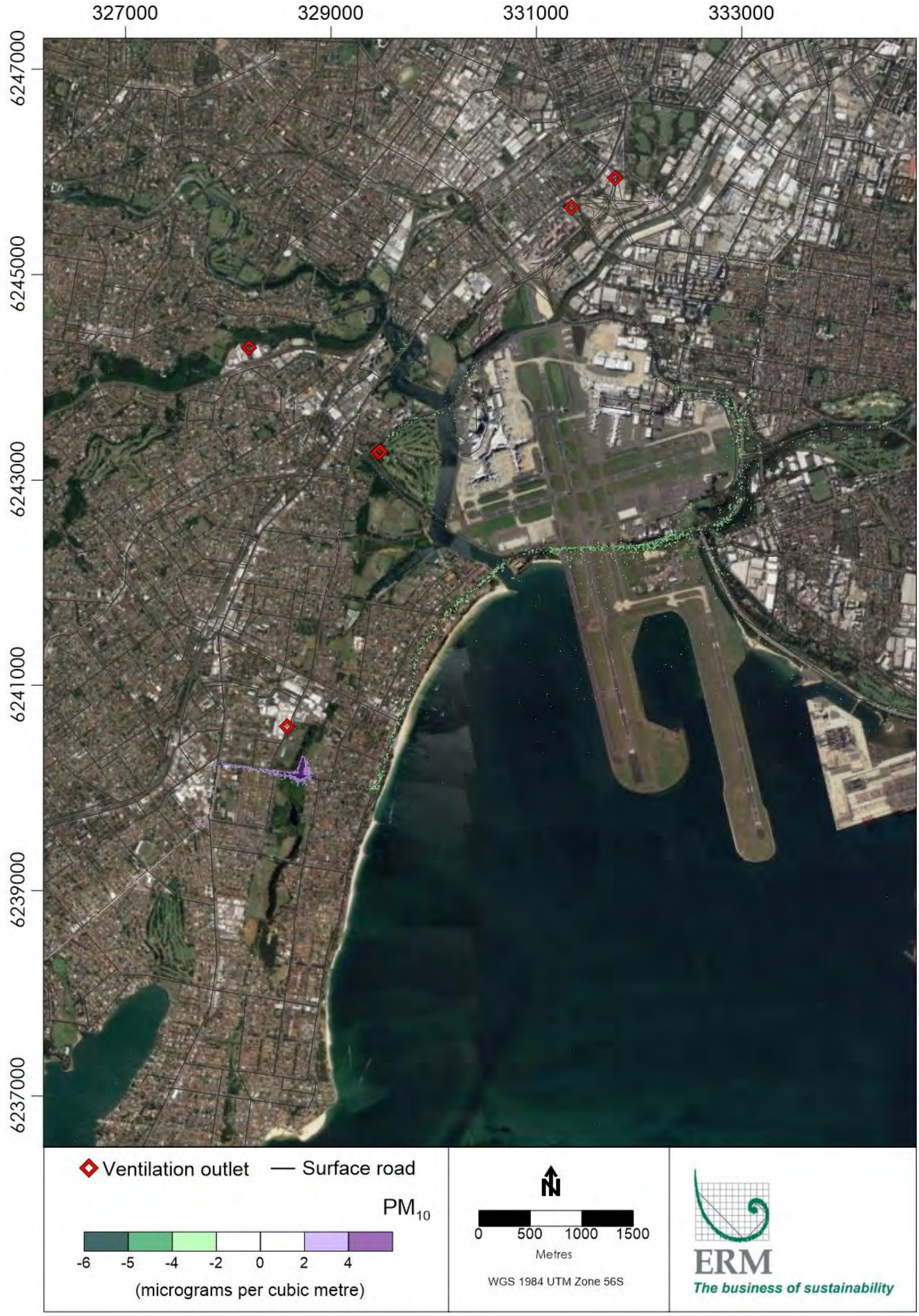


Figure 8-57 Contour plot of change in maximum 24-hour mean PM_{10} concentration in the 2036 Do Something scenario (2036-DS minus 2036-DM)

$PM_{2.5}$ (annual mean)

Results for community receptors

Figure 8-58 presents the annual mean $PM_{2.5}$ concentrations at the community receptors. The results are based on a mapped background concentration with values at these locations of between 8.0 and 9.2 µg/m^3, and therefore the Figure shows exceedances of the NSW criterion of 8 µg/m^3 at all receptors. Clearly, there would also be exceedances of the AAQ NEPM long-term 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).

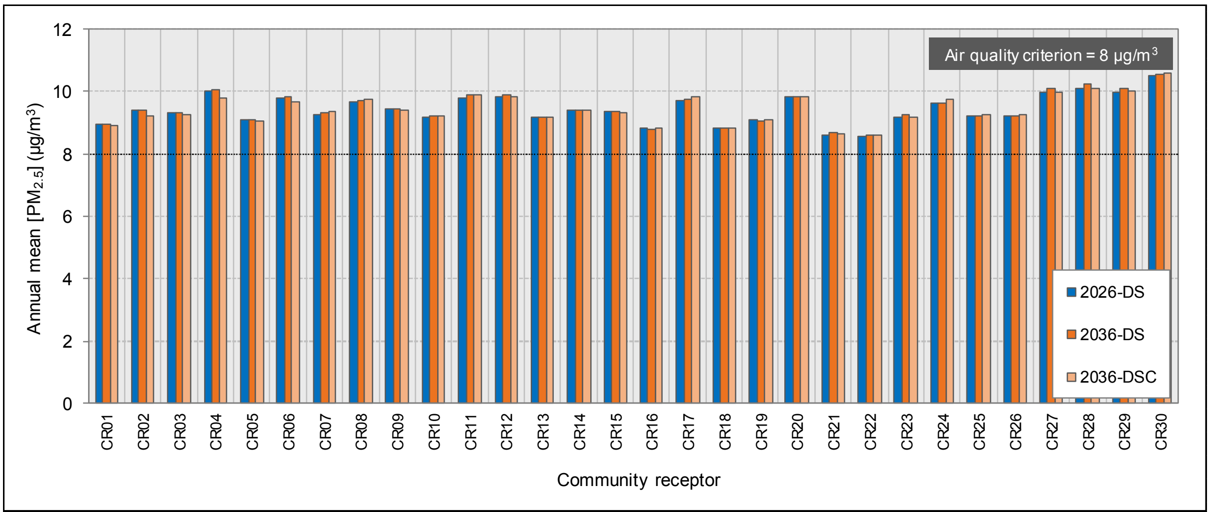


Figure 8-58 Annual mean $PM_{2.5}$ concentration at community receptors (with-project and cumulative scenarios)

Figure 8-59 presents the changes in annual mean $PM_{2.5}$ with the project and in the cumulative scenario at the community receptors. Any increases in concentration at these locations were less than 0.2 µg/m^3; the largest increase (0.17 µg/m^3 at receptor CR06 in the 2026-DS scenario) equated to two per cent of the air quality criterion.

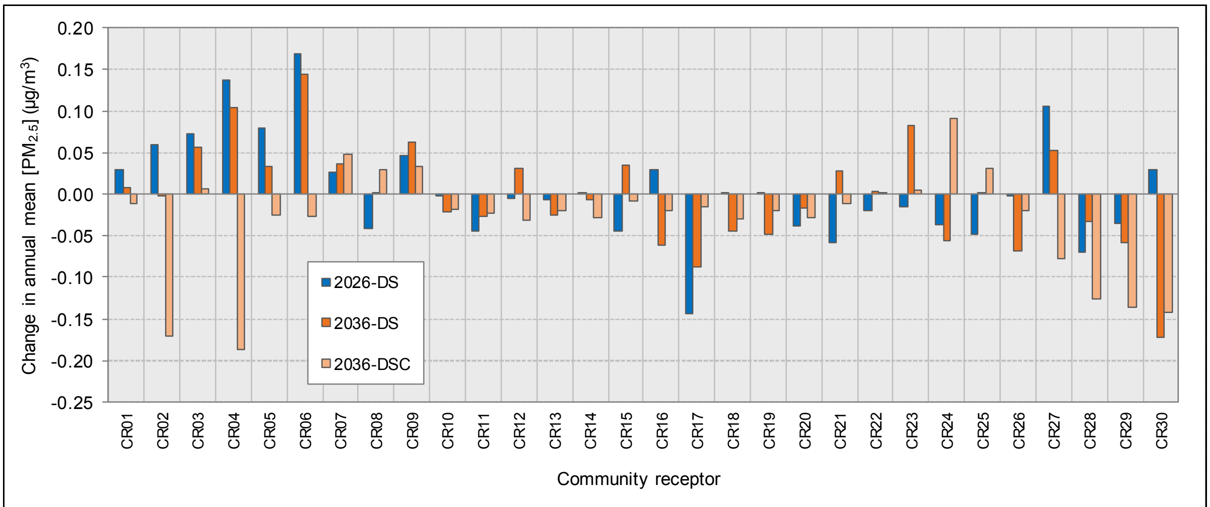


Figure 8-59 Change in annual mean $PM_{2.5}$ concentration at community receptors (with-project and cumulative scenarios, minus Do Minimum scenarios)

Figure 8-60 shows that concentrations were again dominated by the background contribution. The surface road contribution was between 0.3 µg/m^3 and 1.7 µg/m^3. The largest contribution from tunnel ventilation outlets at any receptor was just 0.18 µg/m^3.

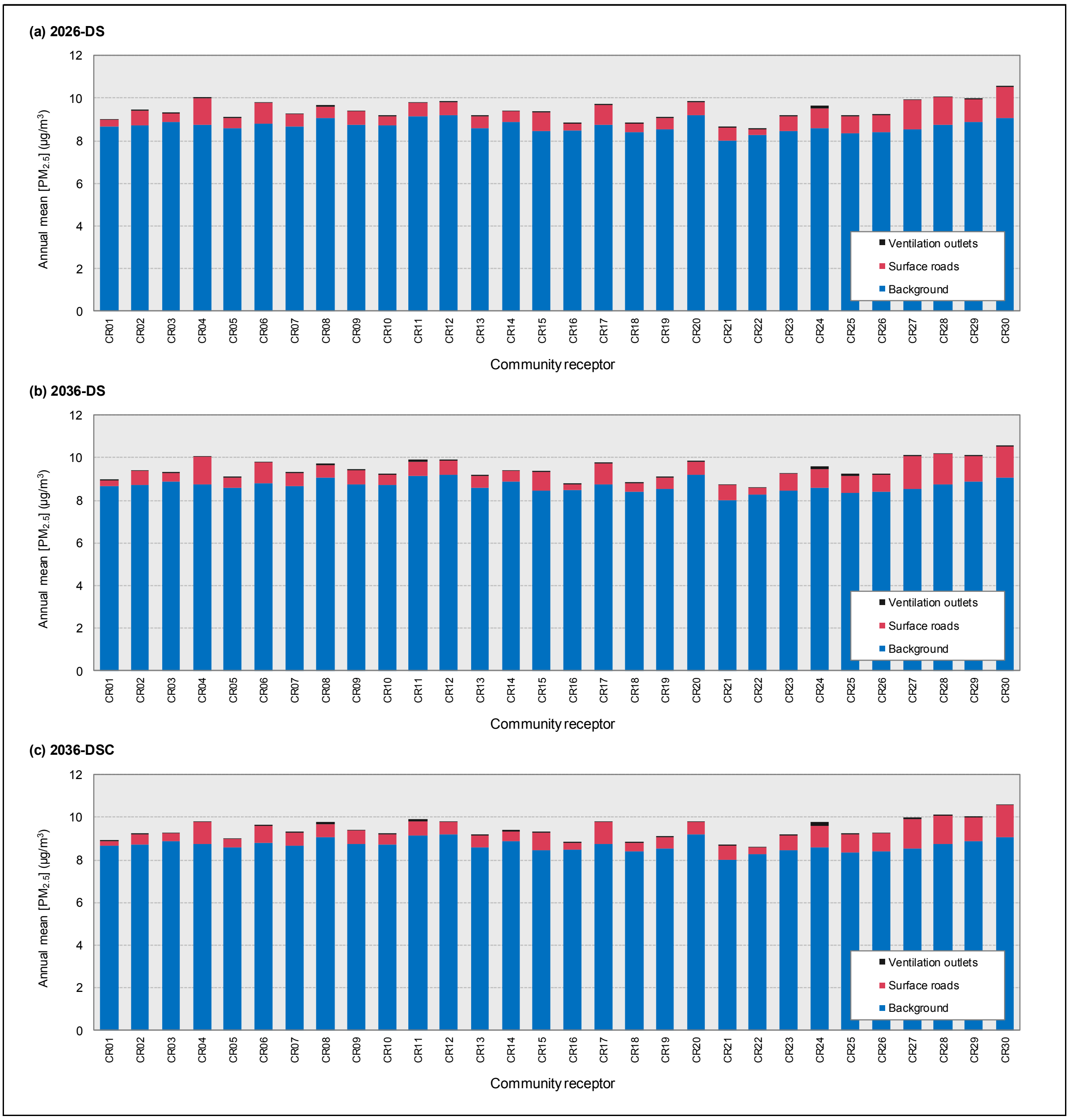


Figure 8-60 Source contributions to annual mean $PM_{2.5}$ concentration at community receptors (with-project and cumulative scenarios)

Results for RWR receptors

The ranked annual mean $PM_{2.5}$ concentrations at the RWR receptors in the with-project and cumulative scenarios are shown in **Figure 8-61**, including the contributions of surface roads and ventilation outlets. As the background concentration was already above the NSW criterion of 8 µg/m^3 at all but 29 of the 17,509 RWR receptors, the total concentration at almost all receptors was also above this value. The highest concentration at any receptor was 16.3 µg/m^3 but, as with other pollutants and metrics, the highest values were only predicted for a very small proportion of receptors. In the with-project and cumulative scenarios, the largest surface road contribution at any receptor was 7.1 µg/m^3. The largest contribution from tunnel ventilation outlets in these scenarios was 0.34 µg/m^3.

The change in the annual mean $PM_{2.5}$ concentration at the RWR receptors in the with-project and cumulative scenarios are ranked in **Figure 8-62**. There was an increase in concentration at between 31 per cent and 46 per cent of the receptors, depending on the scenario. The largest predicted increase in concentration at any receptor as a result of the project was 0.44 µg/m^3, and the largest predicted decrease was 1.0 µg/m^3. Where there was an increase, this was greater than 0.1 µg/m^3 at around 4 per cent of receptors in the with-project scenarios (1.3 per cent in the cumulative scenario).

As noted in **section 5.5.3**, the increase in annual mean $PM_{2.5}$ at sensitive receptors with the project ($\Delta PM_{2.5}$) is a key metric for assessing the risk to human health. For the F6 Extension Stage 1 project, the acceptable value of $\Delta PM_{2.5}$ was determined to be 1.8 µg/m^3. No receptors had a predicted change in $PM_{2.5}$ above this value.

Contour plots – all sources

The contour plots for total annual mean $PM_{2.5}$ are given in **Figure 8-63** (2036-DM) and **Figure 8-64** (2036-DS). The contour plot for the associated change in concentration in this scenario is shown in **Figure 8-65**.

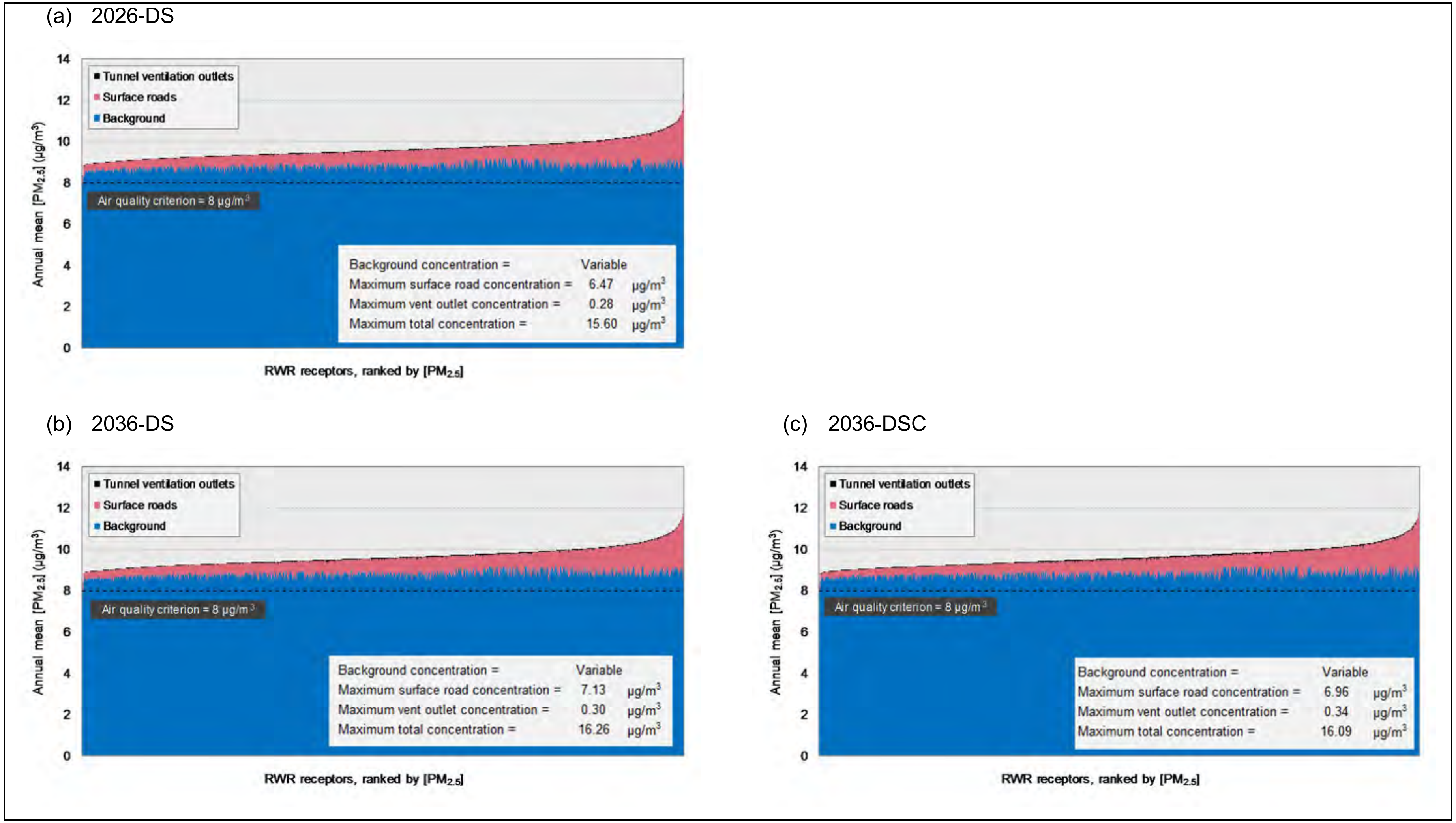


Figure 8-61 Source contributions to annual mean $PM_{2.5}$ concentration at RWR receptors (with-project and cumulative scenarios)

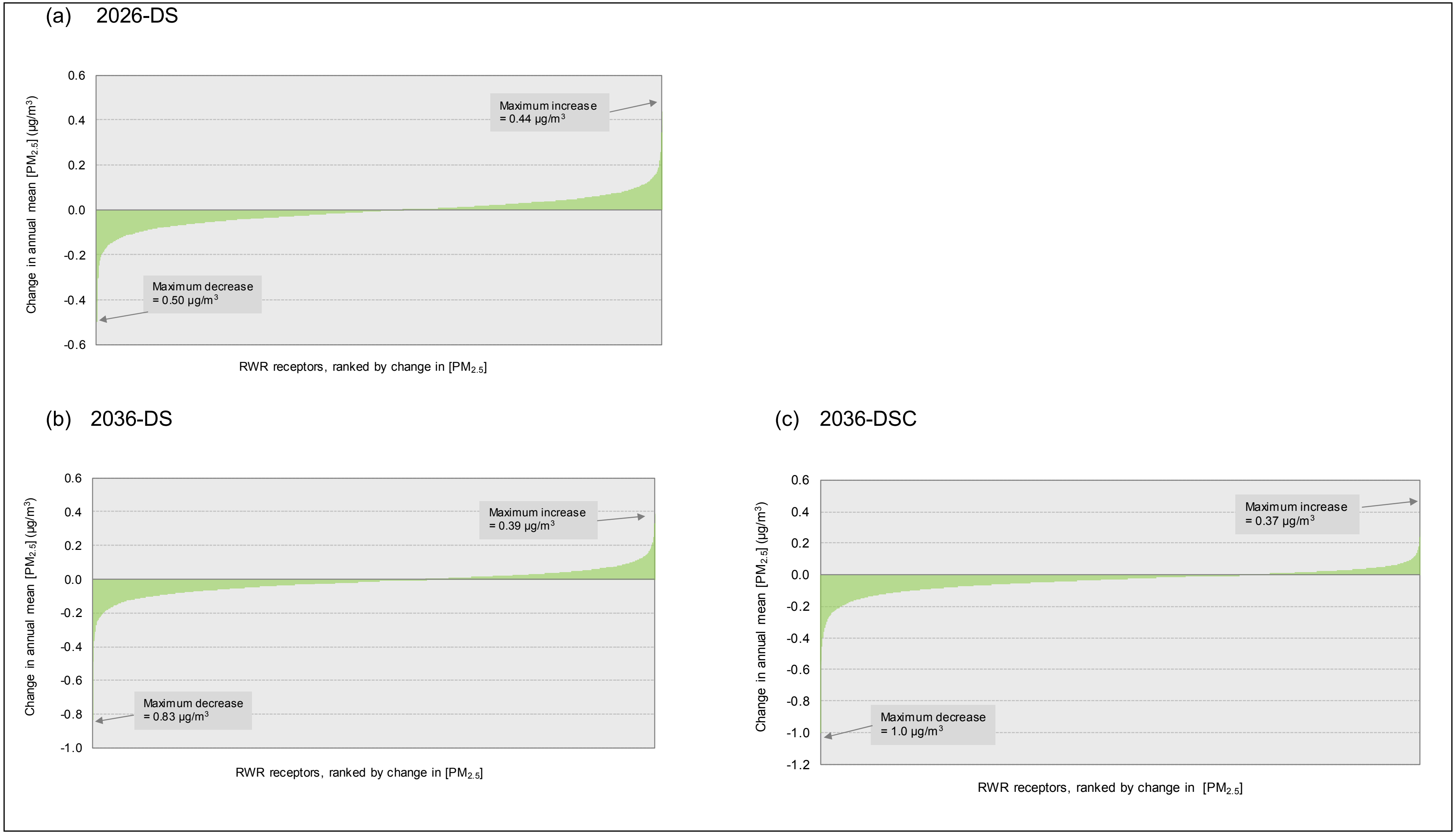


Figure 8-62 Change in annual mean $PM_{2.5}$ concentration at RWR receptors (with-project and cumulative scenarios, minus Do Minimum scenarios)

Figure 8-63 Contour plot of annual mean $PM_{2.5}$ concentration in the 2036 Do Minimum scenario (2036-DM)

Figure 8-64 Contour plot of annual mean $PM_{2.5}$ concentration in the 2036 Do Something scenario (2036-DS)

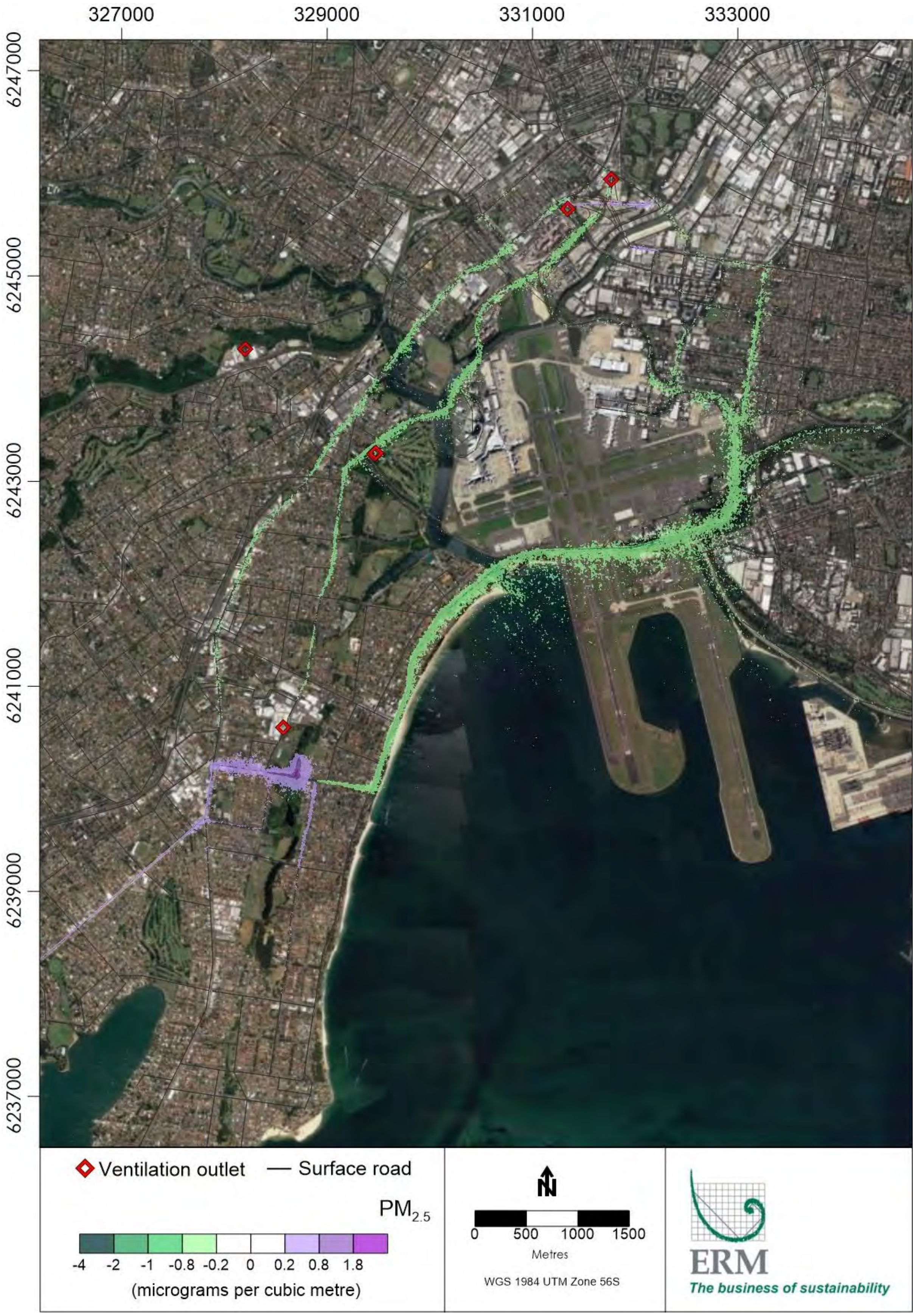


Figure 8-65 Contour plot of change in annual mean $PM_{2.5}$ concentration in the 2036 Do Something scenario (2036-DS minus 2036-DM)

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

Results for community receptors

The maximum 24-hour mean $PM_{2.5}$ concentrations at the community receptors with the project and in the cumulative scenarios are presented in **Figure 8-66**. At four receptors the maximum concentration was above the NSW impact assessment criterion of 25 µg/m^3, although exceedances were already predicted without the project. Internationally, there are no standards lower than 25 µg/m^3 for 24-hour $PM_{2.5}$. However, the AAQ NEPM includes a long-term goal of 20 µg/m^3, and the results suggest that this would be difficult to achieve in the study area at present.

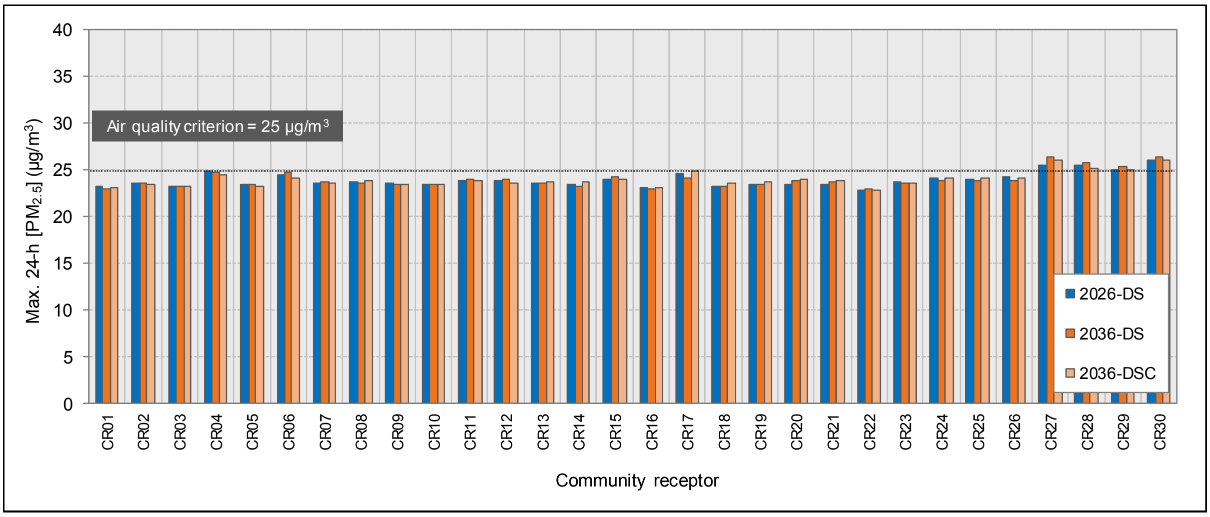


Figure 8-66 Maximum 24-hour $PM_{2.5}$ concentration at community receptors (with-project and cumulative scenarios)

Figure 8-67 presents the changes in maximum 24-hour $PM_{2.5}$ with the project and in the cumulative scenarios at the community receptors. Any increases in concentration were less than 1 µg/m^3. The largest increase (0.8 µg/m^3 at receptor CR06 in the 2036-DS scenario) equated to 3 per cent of the air quality criterion.

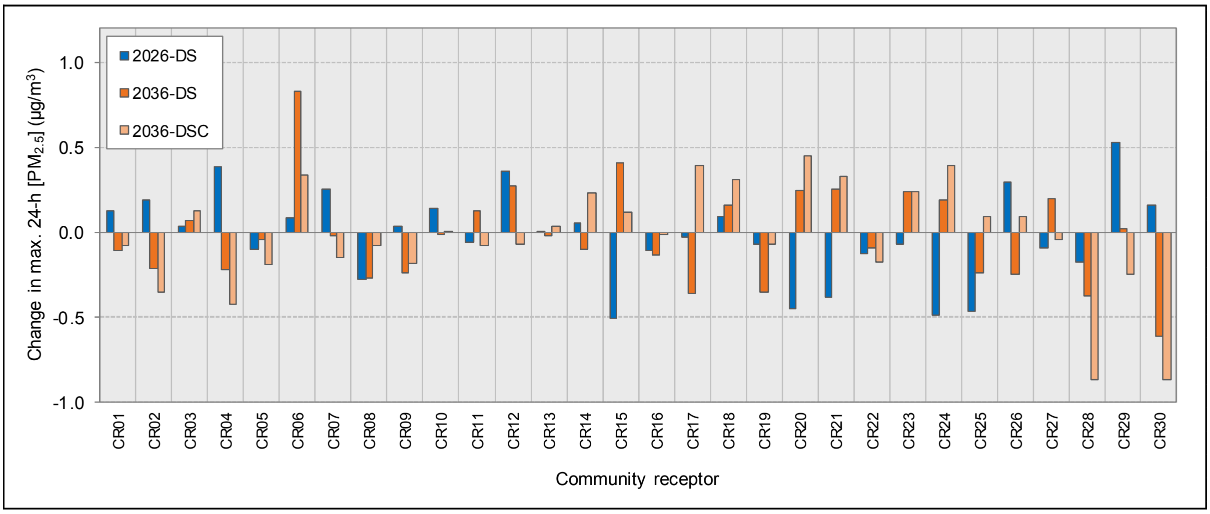


Figure 8-67 Change in maximum 24-hour $PM_{2.5}$ concentration at community receptors (with-project and cumulative scenarios, minus Do Minimum scenarios)

The combined road/outlet contributions to the maximum 24-hour $PM_{2.5}$ concentration at the community receptors were relatively small, as shown in **Figure 8-68**. The tunnel ventilation outlet contributions alone were negligible in all cases (less than or equal to 0.1 µg/m^3).

At all community receptors, the maximum total 24-hour concentration occurred on the same date, and coincided with the highest 24-hour background concentrations in the synthetic $PM_{2.5}$ profile (22.6 µg/m^3).

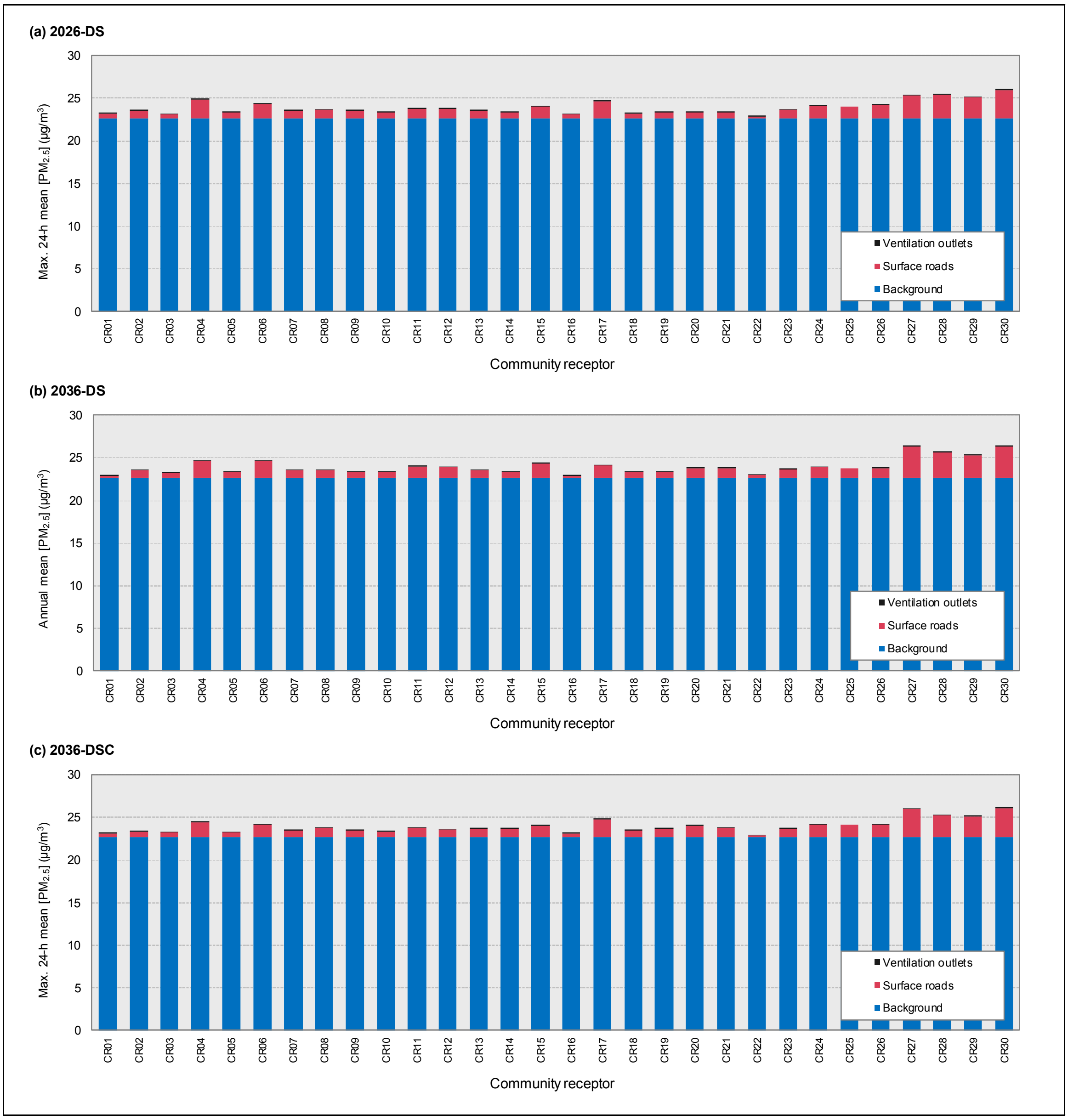


Figure 8-68 Source contributions to maximum 24-hour mean $PM_{2.5}$ concentration at community receptors (with-project and cumulative scenarios)

Results for RWR receptors

The ranked maximum 24-hour mean $PM_{2.5}$ concentrations at the RWR receptors in the with-project and cumulative scenarios are shown in **Figure 8-69**. Given the high background concentration, the total concentration at up to 35 per cent of receptors in a with-project scenario was above the NSW impact assessment criterion of 25 µg/m^3. It is noted that exceedances of the impact assessment criterion decreased as a result of the project. In the without-project scenarios the maximum number of receptors over the criterion was 39 per cent. As with 24-hour 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 was 1.6 µg/m^3.

The changes in the maximum 24-hour mean $PM_{2.5}$ concentration at the RWR receptors in the with-project and cumulative scenarios are ranked in **Figure 8-70**. In the with-project scenarios there was an increase in concentration at around 45 per cent of the receptors (27 per cent in the cumulative scenario). The largest predicted increase in concentration at any receptor as a result of the project was 1.5 µg/m^3 (2026-DS scenario), and the largest predicted decrease was 3.7 µg/m^3. For most of the receptors the change in concentration was small; where there was an increase in concentration, this was greater than 0.5 µg/m^3 at only around 1-2 per cent of receptors.

Contour plots – all sources

The contour plots for maximum 24-hour $PM_{2.5}$ in the 2036-DM and 2036-DS scenarios are given in **Figure 8-71** and **Figure 8-72** respectively. The changes with the project and in the cumulative scenarios are shown in **Figure 8-73**.

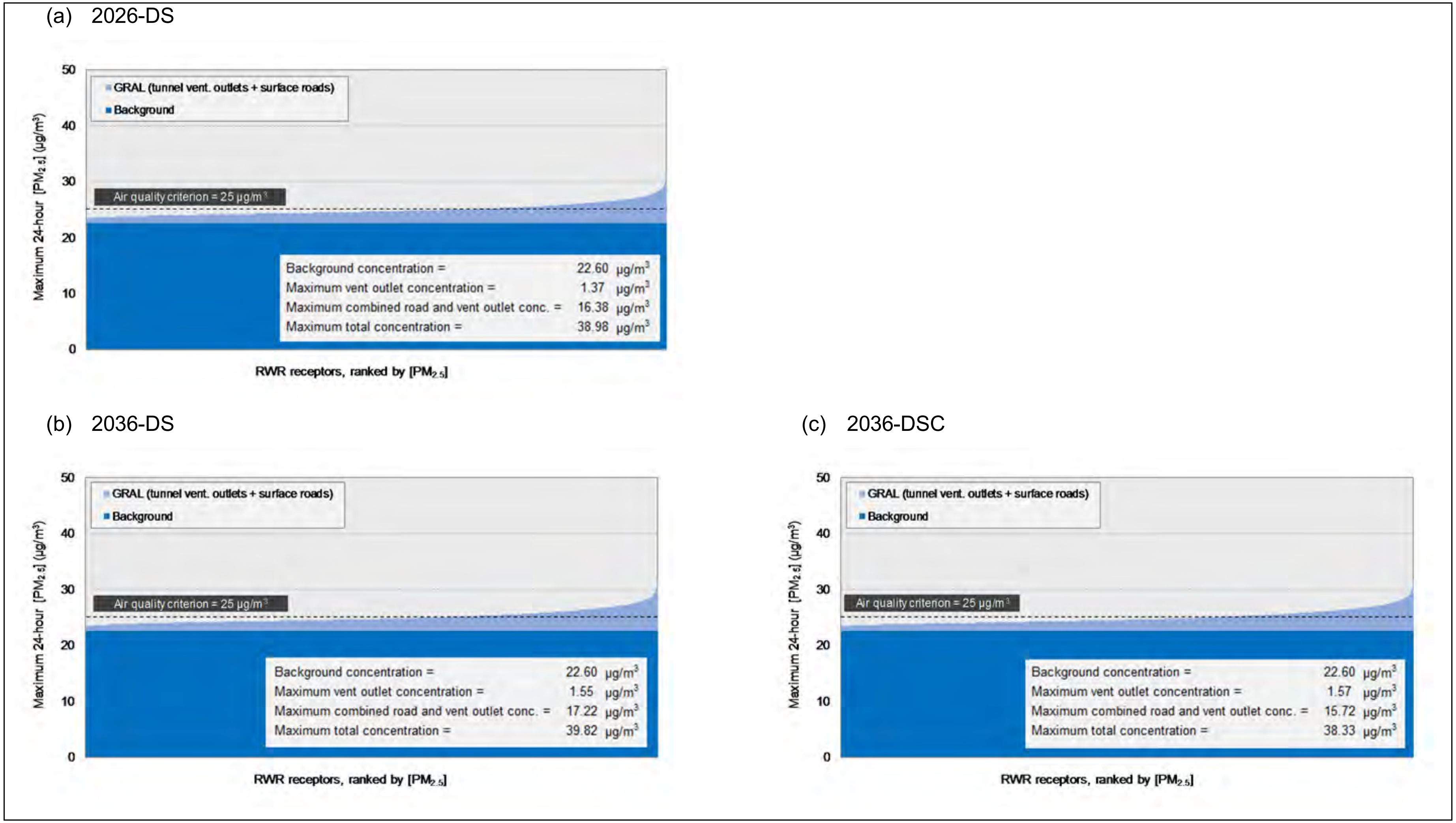


Figure 8-69 Source contributions to maximum 24-hour mean $PM_{2.5}$ concentration at RWR receptors (with-project and cumulative scenarios)

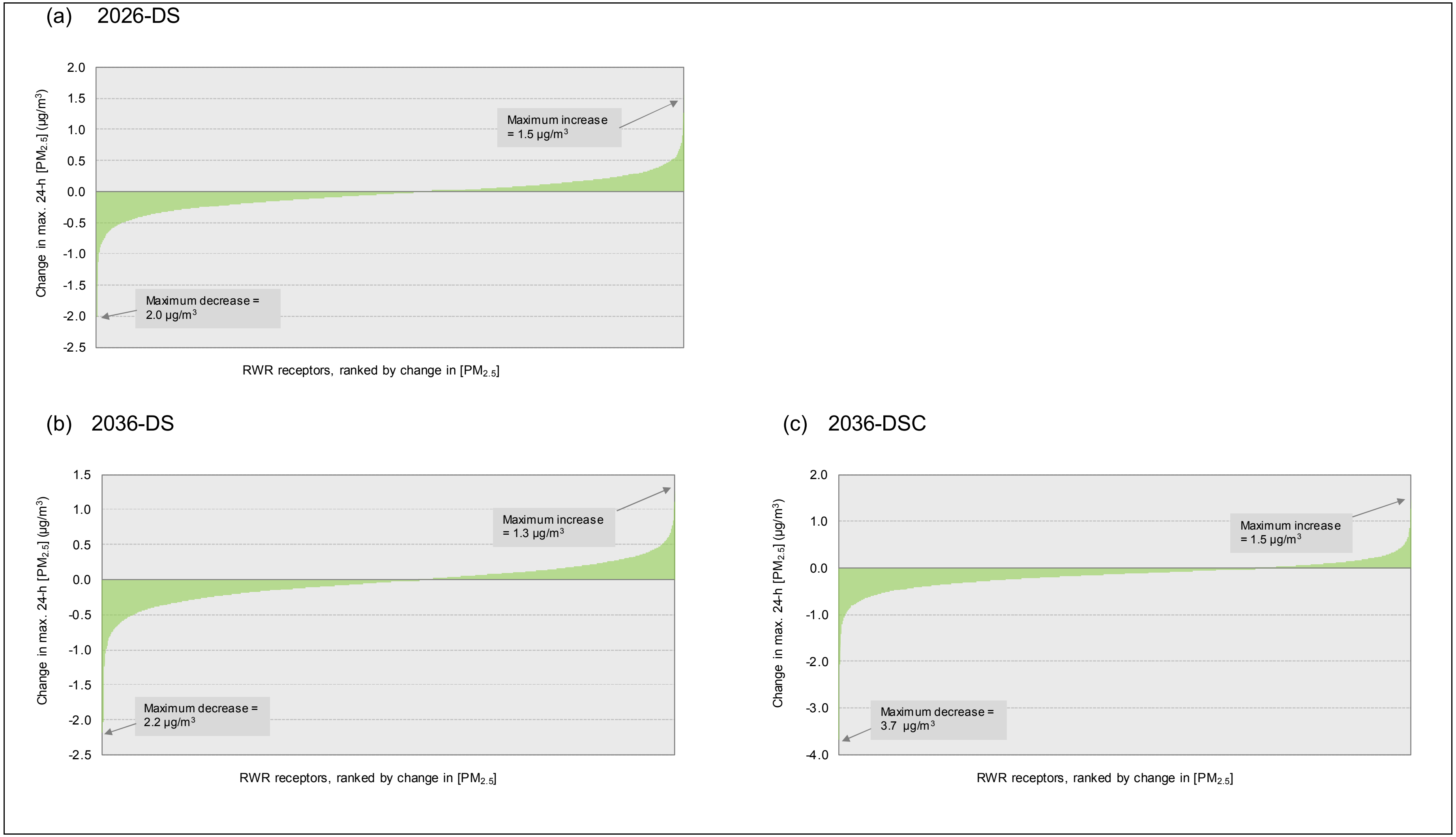


Figure 8-70 Change in maximum 24-hour mean $PM_{2.5}$ concentration at RWR receptors (with-project and cumulative scenarios, minus Do Minimum scenarios)

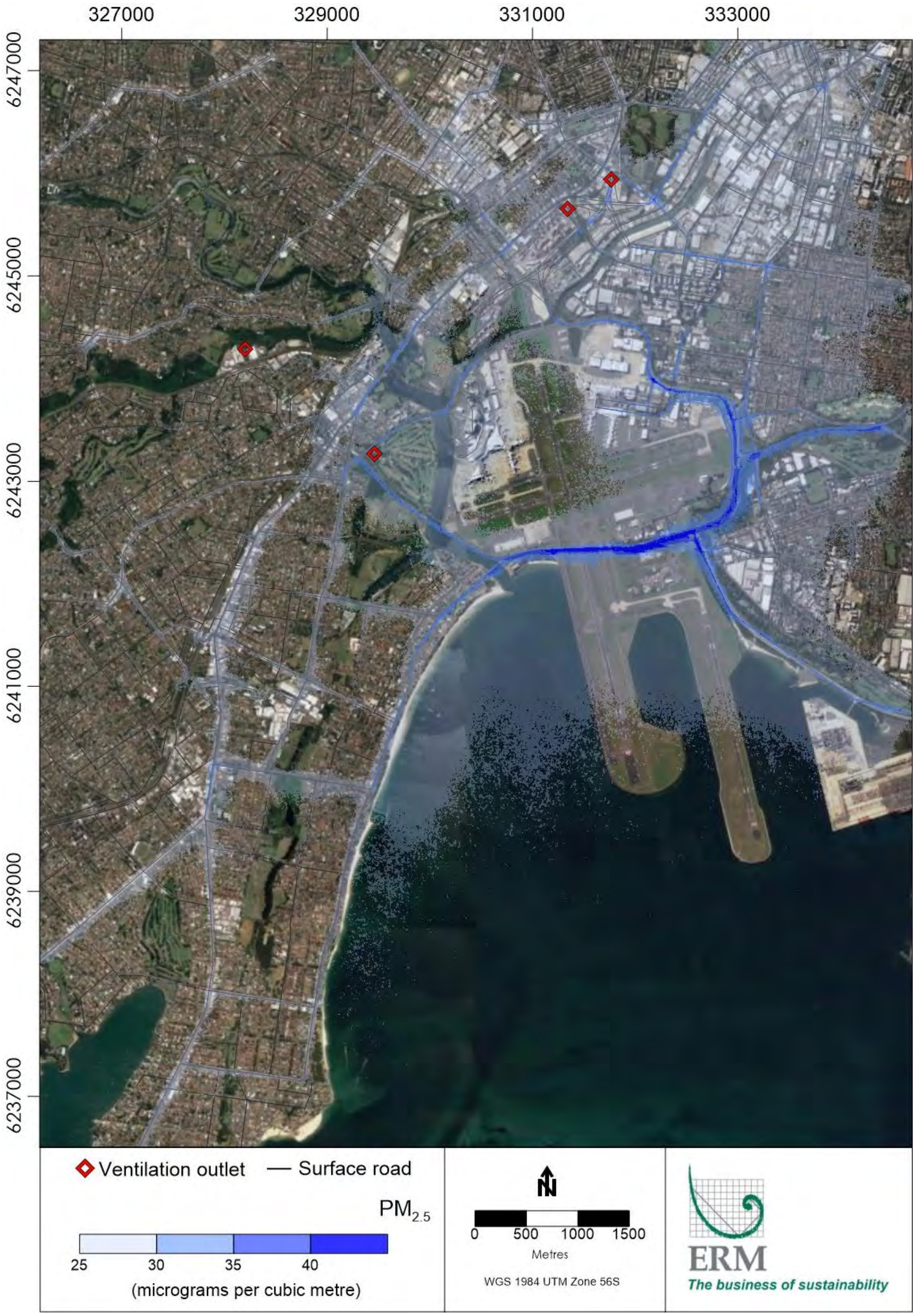


Figure 8-71 Contour plot of maximum 24-hour average $PM_{2.5}$ concentration in the 2036 Do Minimum scenario (2036-DM)

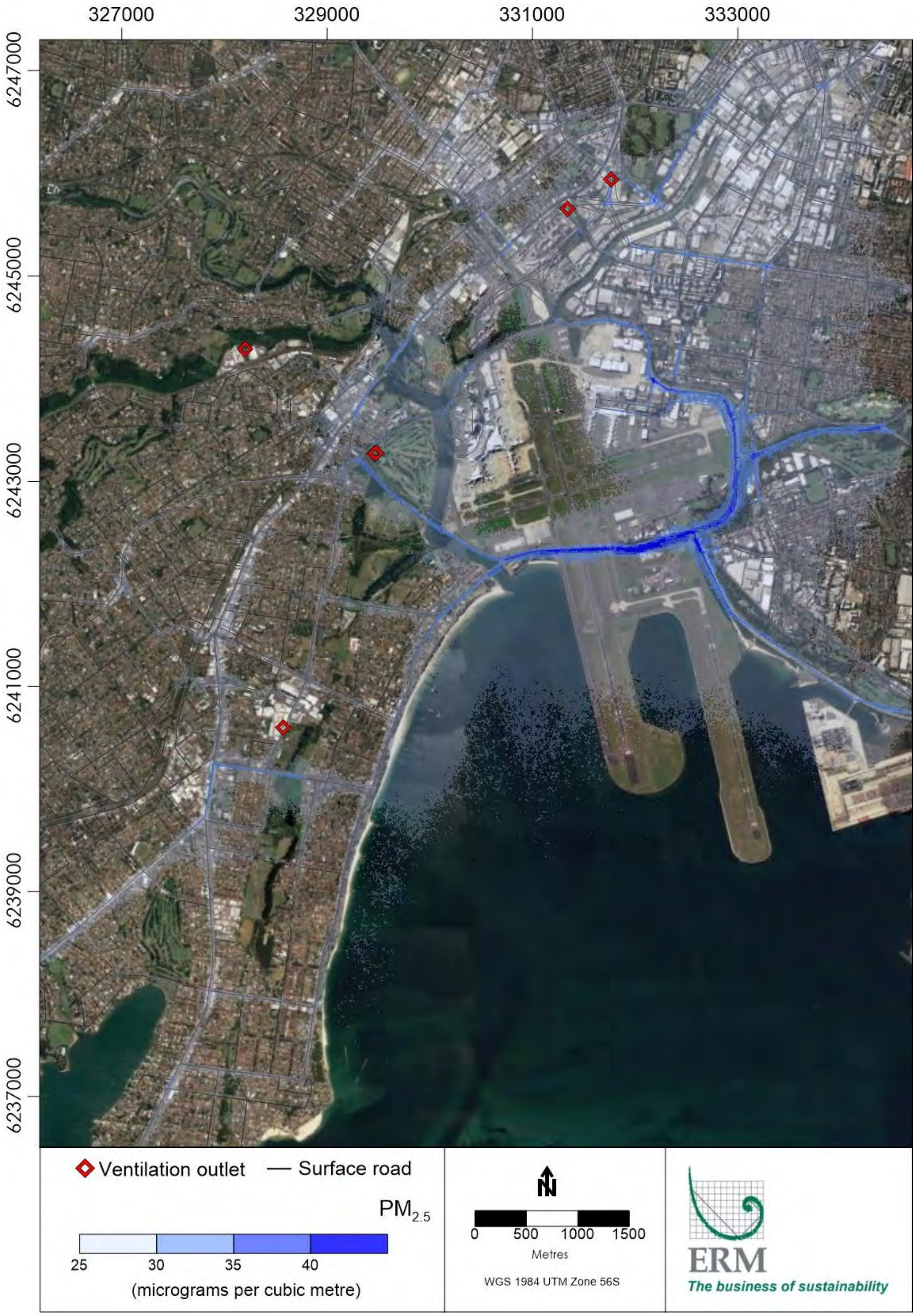


Figure 8-72 Contour plot of maximum 24-hour average $PM_{2.5}$ concentration in the 2036 Do Something scenario (2036-DS)

Figure 8-73 Contour plot of change in maximum 24-hour $PM_{2.5}$ concentration in the 2036 Do Something scenario (2036-DS minus 2036-DM)

Air toxics

Five air toxics - benzene, PAHs (as BaP), formaldehyde, 1,3-butadiene and ethylbenzene – 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 of the project are shown in **Figure 8-74**, 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, 1,3-butadiene and ethylbenzene concentration are presented in **Figure 8-75**, **Figure 8-76**, **Figure 8-77** and **Figure 8-78** 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.

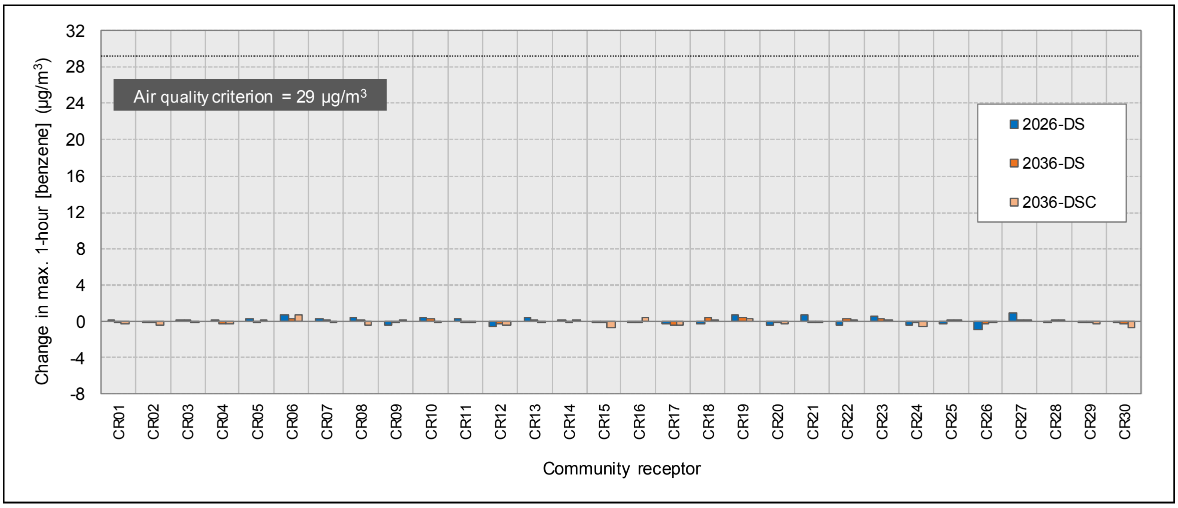


Figure 8-74 Change in maximum 1-hour mean benzene concentration at community receptors (with-project and cumulative scenarios)

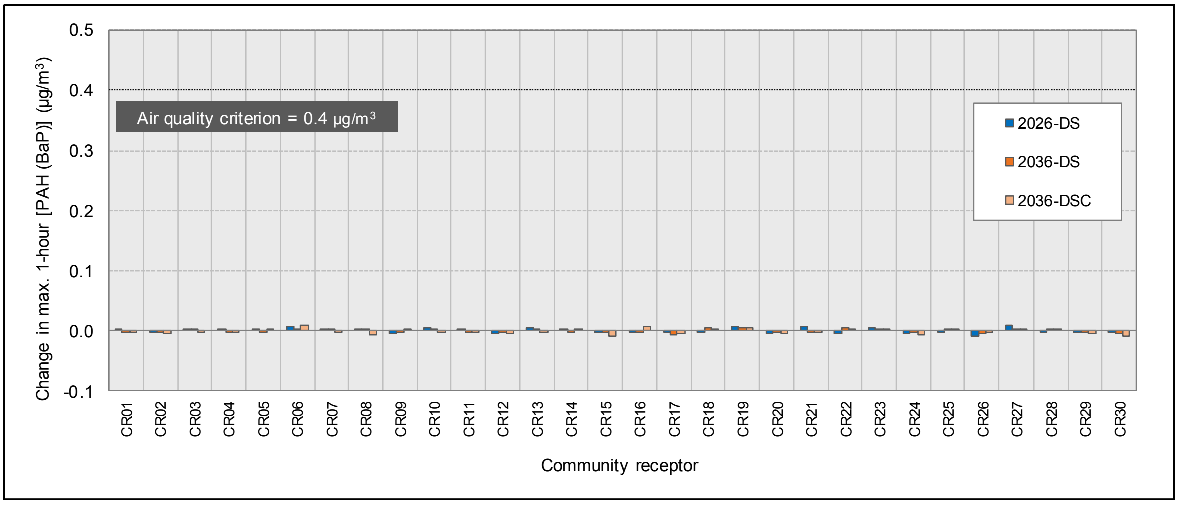


Figure 8-75 Change in maximum 1-hour mean b(a)p concentration at community receptors (with-project and cumulative scenarios)

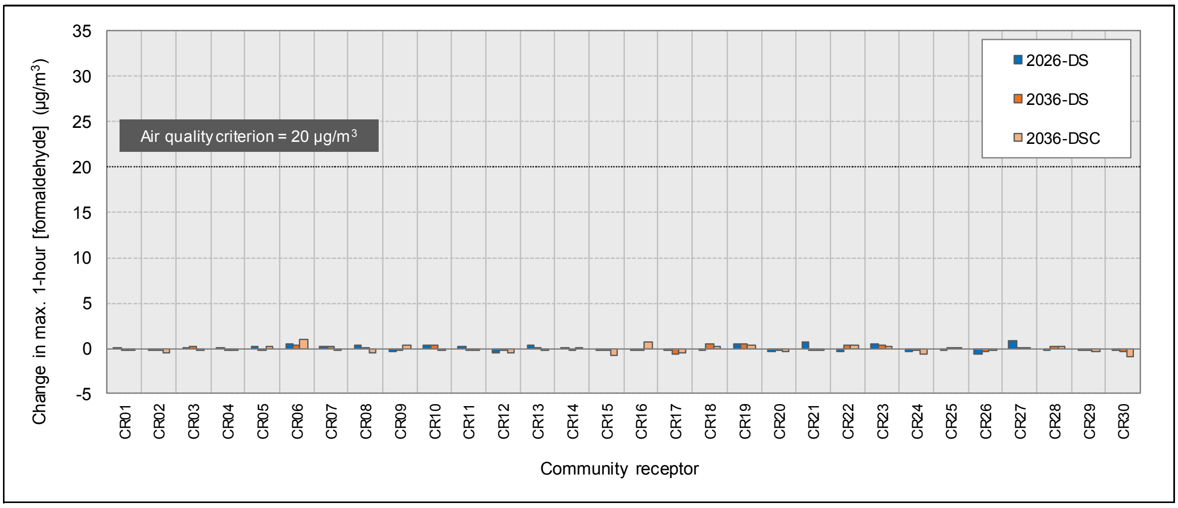


Figure 8-76 Change in maximum 1-hour mean formaldehyde concentration at community receptors (with-project and cumulative scenarios)

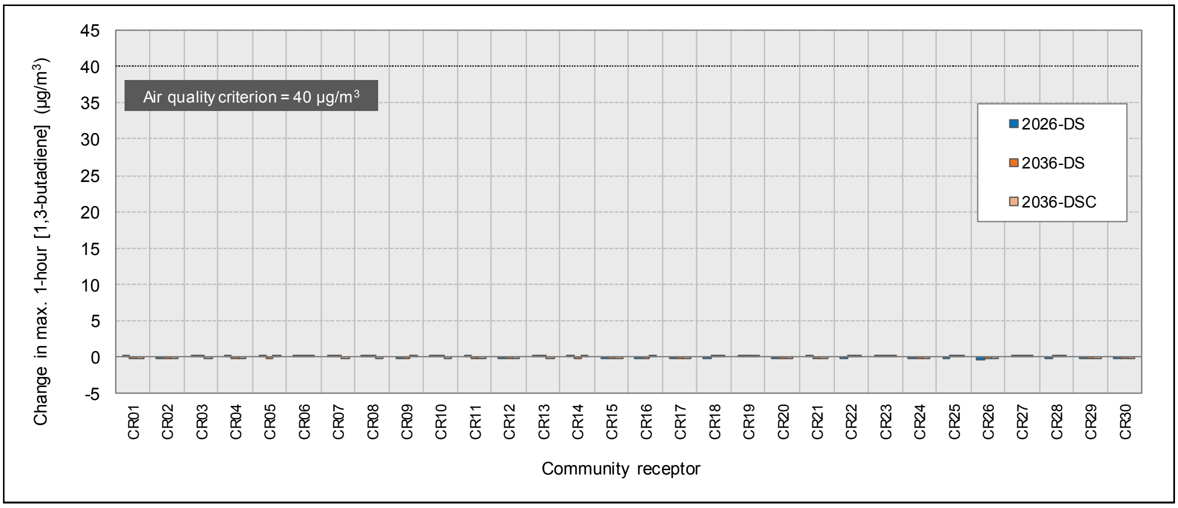


Figure 8-77 Change in maximum 1-hour mean 1,3-butadiene concentration at community receptors (with-project and cumulative scenarios)

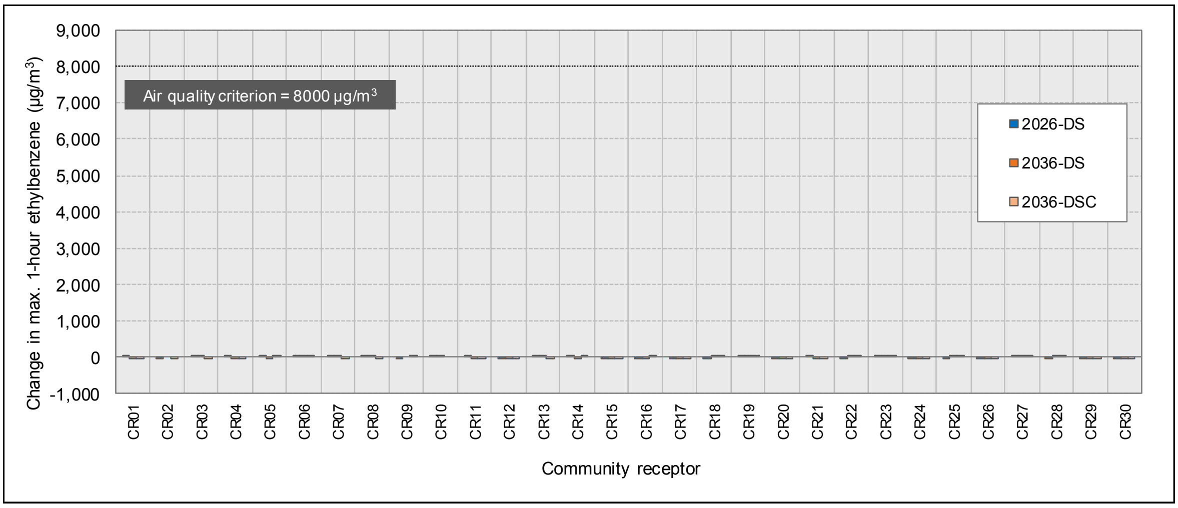


Figure 8-78 Change in maximum 1-hour mean ethylbenzene concentration at community receptors (with-project and cumulative scenarios)

Redistribution of air quality impacts

Spatial distribution of air pollutants

In the previous section of the report, the spatial changes in air quality were presented in the form of contour plots (2036-DS scenario only). The corresponding contour plots for all scenarios are provided in **Annexure I**. The spatial changes in pollutant concentrations are summarised below. The discussion refers to annual mean $PM_{2.5}$, given its importance in terms of health. However, the spatial changes were qualitatively similar for all pollutants, and therefore the discussion is more widely relevant.

There were predicted to be marked reductions in concentration along some major roads as a result of the F6 Extension Stage 1 project, and increases on other roads. These changes broadly reflected the effects of the project on traffic in SMPM, also taking into account factors such as road gradient and meteorology. **Table 8-20** summarises the average weekday two-way traffic on some affected roads in all scenarios, and **Table 8-21** gives the changes between scenarios.

Table 8-20 Average weekday two-way traffic volume on selected roads

Road	Average weekday two-way traffic volume by scenario (vehicles per day)				
	2026-DM	2026-DS	2036-DM	2036-DS	2036-DSC
Joyce Drive	61,705	59,342	70,346	68,011	64,616
Botany Road	32,481	29,103	36,949	32,643	32,262
Southern Cross Drive	118,357	115,518	125,973	123,360	113,302
General Holmes Drive, south of Sydney Airport	169,359	160,568	182,593	172,478	167,460
General Holmes Drive, near Bestic Street	112,399	103,130	119,349	109,362	106,195
The Grand Parade, north of President Avenue	81,797	71,055	85,970	72,868	71,458
President Ave, east of F6 Extension Stage 1	43,440	34,030	45,220	33,282	40,754
President Ave, west of F6 Extension Stage 1	54,702	65,690	56,258	68,945	63,692
Sandringham Street	21,786	22,043	24,725	25,291	13,593
Rocky Point Road	33,460	34,648	40,333	37,624	25,936
Princes Highway, north of junction with Rocky Point Road	77,252	82,028	80,517	85,147	75,870
Princes Highway, south of junction with Rocky Point Road	34,576	33,861	43,700	39,085	38,877
Marsh Street	52,386	45,963	57,406	50,261	50,627

Table 8-21 Changes in average weekday two-way traffic volume on selected roads

Road	Change in average weekday two-way traffic volume by scenario (vehicles per day/%)					
	2026-DS minus 2026-DM		2036-DS minus 2036-DM		2036-DSC minus 2036-DM	
Joyce Drive	-2,363	-4%	-2,335	-3%	-5,730	-8%
Botany Road	-3,378	-10%	-4,306	-12%	-4,687	-13%
Southern Cross Drive	-2,839	-2%	-2,613	-2%	-[illegible]	-10%
General Holmes Drive, south of Sydney Airport	-8,791	-5%	-[illegible]	-6%	-[illegible]	-8%
General Holmes Drive, near Bestic Street	-9,269	-8%	-9,987	-8%	-[illegible]	-11%
The Grand Parade, north of President Avenue	-[illegible]	-13%	-[illegible]	-15%	-[illegible]	-17%
President Ave, east of F6 Extension Stage 1	-9,410	-22%	-[illegible]	-26%	-4,466	-10%
President Ave, west of F6 Extension Stage 1	10,988	+20%	12,687	+23%	7,434	+13%
Sandringham Street	257	+1%	566	+2%	-[illegible]	-45%
Rocky Point Road	1,188	+4%	-2,709	-7%	-[illegible]	-36%
Princes Highway, north of junction with Rocky Point Road	4,776	+6%	4,630	+6%	-4,647	-6%
Princes Highway, south of junction with Rocky Point Road	-715	-2%	-4,615	-11%	-4,823	-11%
Marsh Street	-6,423	-12%	-7,145	-12%	-6,779	-12%

The contour plot for the change in annual mean $PM_{2.5}$ in the 2026-DS scenario (relative to 2026-DM) is shown in **Figure 8-65**. With the F6 Extension Stage 1 there were noticeable decreases in $PM_{2.5}$ along several roads, including Botany Street, Southern Cross Drive, General Holmes Drive, The Grand Parade to the North of President Avenue, President Avenue to the east of the F6 Extension Stage 1 project, and March Street. **Table 8-21** shows that there were reductions in traffic of between 2 per cent and 22 per cent on these roads. There were increases in concentration along President Avenue to the west of the F6 Extension Stage 1 project and Princes Highway to the south of the junction with Rocky Point Road. These were associated with increases in traffic volume on these roads. Similar spatial changes to these were also predicted for the 2036-DS scenario.

For the cumulative scenario (2026-DSC) there were some additional changes associated with the introduction of the full F6 Extension (see **Figure I-24**). These included reductions in $PM_{2.5}$ concentration along The Grand Parade to the south of President Avenue, Sandringham Street and Rocky Point Road. In addition, the increase in concentration on Princes Highway in the Do Something scenarios was converted to a reduction in concentration in the cumulative scenario. Again, the changes in traffic on these roads are given in **Table 8-21**.

Concentration distribution

The redistribution of air quality impacts across the GRAL domain as a result of the project was also addressed through the use of density plots which show the smoothed distributions of the concentrations at all RWR receptors. This analysis was conducted for annual mean and maximum 24-hour $PM_{2.5}$ only, as it was considered that these metrics would be representative for this purpose.

The results for annual mean $PM_{2.5}$ are shown in **Figure 8-79** to **Figure 8-81**, and those for maximum 24-hour $PM_{2.5}$ are presented in **Figure 8-82** to **Figure 8-84**. In each plot the Do-Something (or cumulative) scenario is compared with the corresponding Do Minimum scenario. In all cases, the distributions with and without the project were very similar. In other words, there was no marked redistribution of air quality impacts, although it can be seen from the 24-hour plots that there was a slight shift towards lower concentrations in the 2036-DSC scenario. It is worth noting that there was no significant increase in concentration at receptor locations which already had a relatively high concentration in the Do Minimum cases.

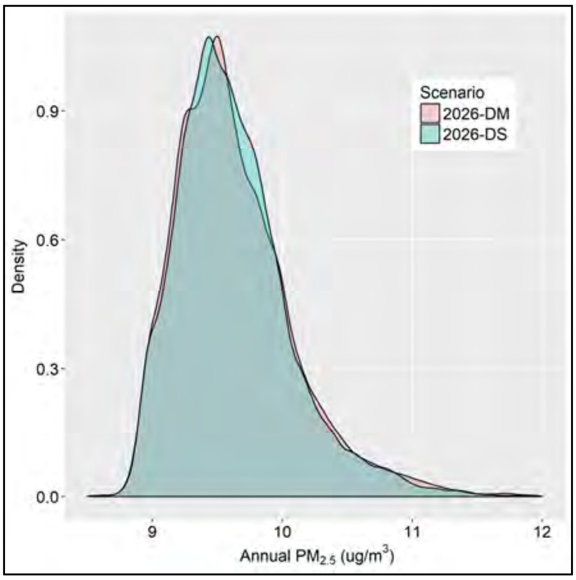


Figure 8-79 Density plot for annual mean $PM_{2.5}$ (2026-DM and 2026-DS)

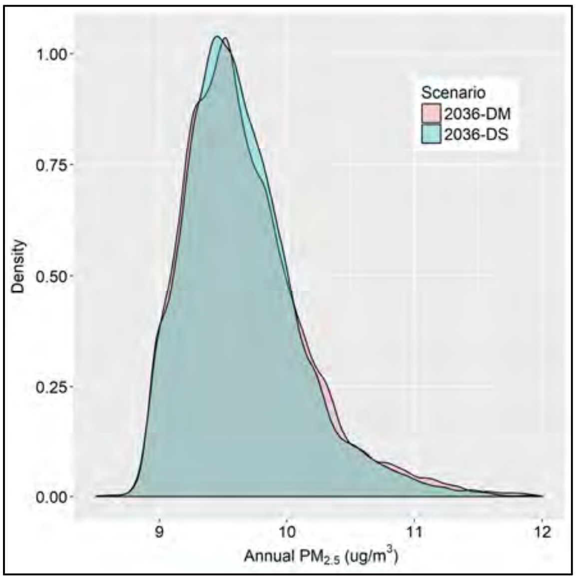


Figure 8-80 Density plot for annual mean $PM_{2.5}$ (2036-DM and 2036-DS)

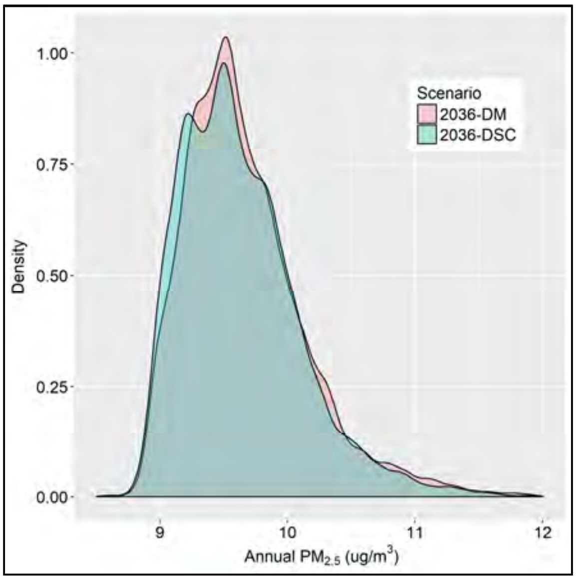


Figure 8-81 Density plot for annual mean $PM_{2.5}$ (2036-DM and 2036-DSC

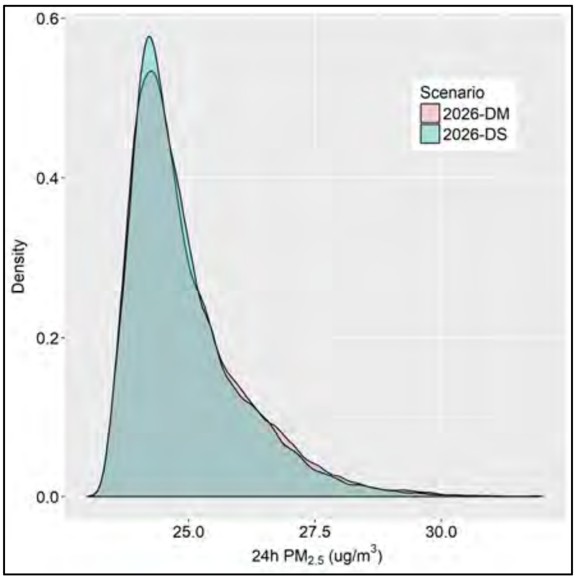


Figure 8-82 Density plot for maximum 24-hour $PM_{2.5}$ (2026-DM and 2026-DS)

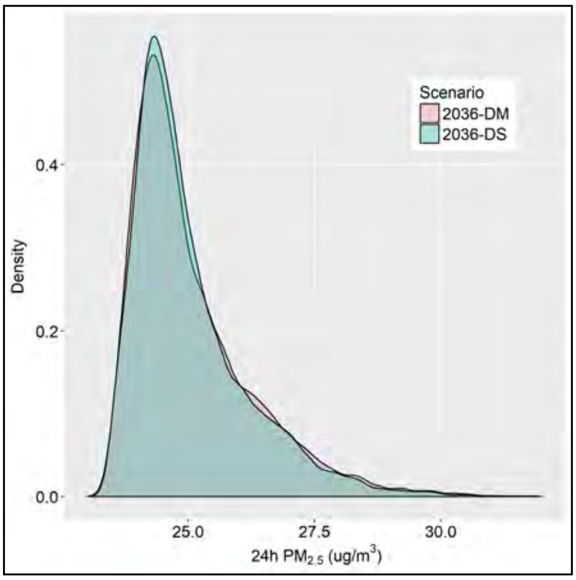


Figure 8-83 Density plot for for maximum 24-hour $PM_{2.5}$ (2036-DM and 2036-DS)

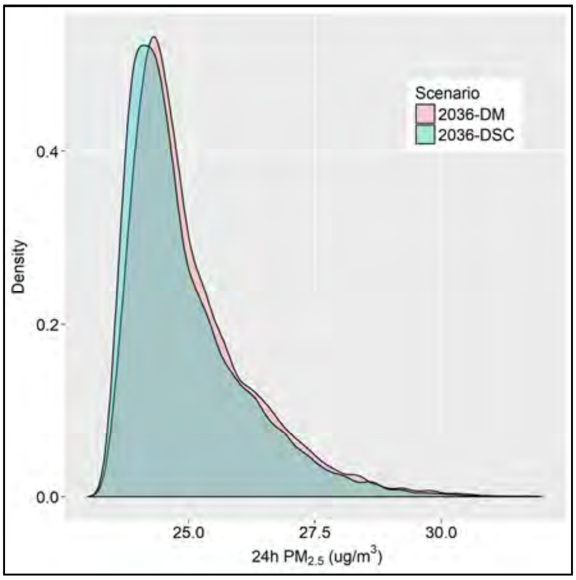


Figure 8-84 Density plot for for maximum 24-hour $PM_{2.5}$ (2036-DM and 2036-DSC)

8.4.12 Results for expected traffic scenarios: elevated receptors

Elevated receptors were considered in the assessment for two main reasons:

- To determine the potential impacts of the project at *existing* multi-storey residential and commercial buildings, based on the RWR receptor locations
- To understand, provisionally, how *future* building developments (e.g. apartment blocks) in the domain might be restricted from an air pollution perspective.

Concentrations at four elevated receptor heights (10, 20, 30 and 45 metres) were considered for both annual mean and 24-hour $PM_{2.5}$.

Existing receptor locations

Annual mean $PM_{2.5}$

Figure 8-85, **Figure 8-86**, **Figure 8-87** and **Figure 8-88** present contour plots for the changes in annual mean $PM_{2.5}$ in the 2036-DSC scenario, and for heights of 10, 20, 30 and 45 metres, respectively. These plots can be compared with the changes in concentration for the same scenario at ground level (Annexure I, Figure I-39). The reduced influence of surface roads at a height of 10 metres compared with ground level can be seen in **Figure 8-85** (note that the influence of surface roads in the Do Minimum scenario at 10 metres was also reduced). **Figure 8-86** and **Figure 8-87** show that at heights of 20 metres, 30 metres and 45 metres the surface road contribution was further reduced. At the height of 30 metres the tunnel ventilation outlet contribution became more noticeable, although the largest changes in annual mean $PM_{2.5}$ across the GRAL domain were still lower than those at ground level (see below). At the height of 45 metres the outlet contribution was very clear.

Statistics relating to the largest increases in annual mean $PM_{2.5}$ at the RWR receptor locations are provided in **Table 8-22**. For the 10, 20, 30 and 45 metre results, it was not necessarily the case that there were existing buildings at these heights at the RWR receptor locations.

The largest increases in concentration at heights of 10, 20 and 30 metres were smaller than those at ground level. For example, the largest increase at a height of 10 metres was 0.23 µg/m^3, compared with 0.45 µg/m^3 at ground level. The situation at a height of 45 metres was different. At this height, the maximum increase at any receptor location (1.58 µg/m^3) was markedly higher than at ground level.

Although the available information on building height was approximate (and incomplete), it can be seen from the last column of **Table 8-22** that none of the receptor locations with an increase in annual mean $PM_{2.5}$ of more than 0.1 µg/m^3 had a building height of more than 20 metres.

Table 8-22 Changes in annual mean $PM_{2.5}$ concentration at elevated receptors (RWR receptors, 2036-DSC compared with 2036-DM)

Height of modelled concentrations	Maximum increase in concentration at any RWR receptor (µg/m^3)	Number of RWR receptors with an increase of more than 0.1 µg/m^3	Number RWR receptors with an increase of more than 0.1 µg/m^3 and a building above model
Ground level	0.45	250 (1.4%)	All
10 metres	0.23	197 (1.1%)	24
20 metres	0.23	218 (1.3%)	0
30 metres	0.30	345 (2.0%)	0
45 metres	1.58	519 (3.0%)	0

These results indicate that, for all RWR receptor locations, and assuming no further construction at those locations, the changes in annual mean $PM_{2.5}$ concentration at heights of up to 45 metres above ground level are acceptable (i.e. lower than at ground level, and/or below the criterion for $\Delta PM_{2.5}$ of 1.8 µg/m^3).

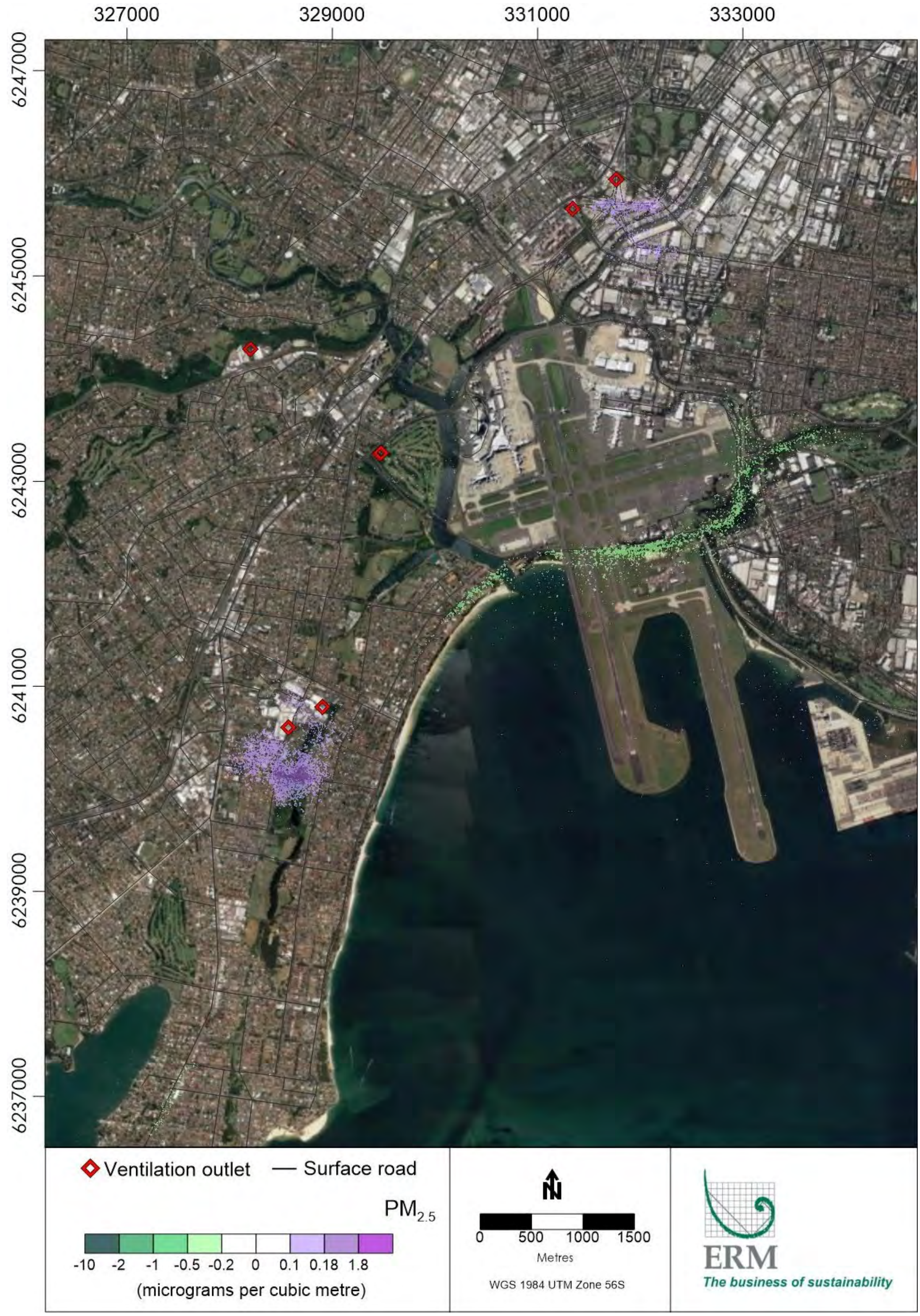


Figure 8-85 Contour plot of change in annual mean $PM_{2.5}$ concentration (2036-DSC minus 2036-DM, 10 metre receptor height)

Figure 8-86 Contour plot of change in annual mean $PM_{2.5}$ concentration (2036-DSC minus 2036-DM, 20 metre receptor height)

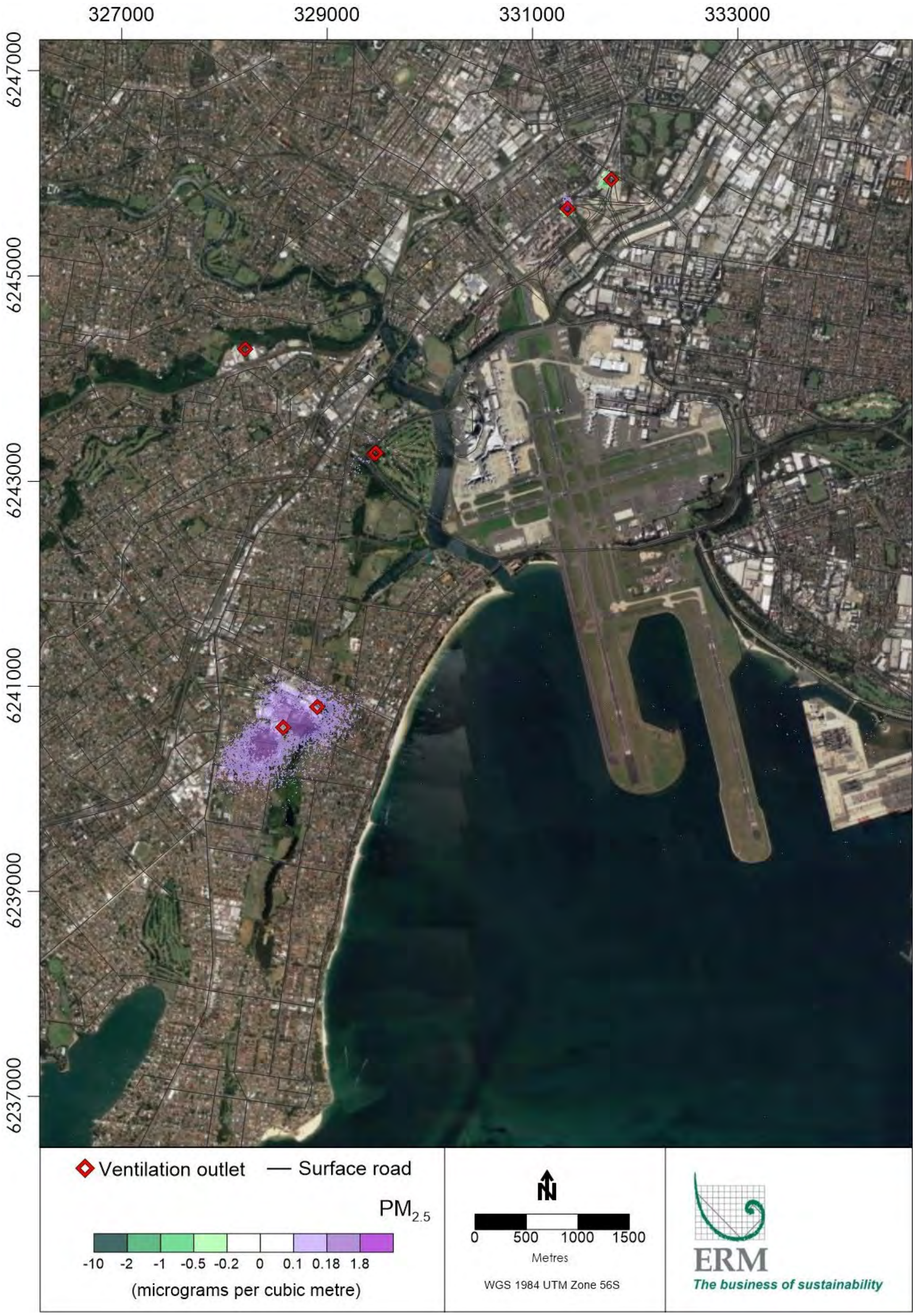


Figure 8-87 Contour plot of change in annual mean $PM_{2.5}$ concentration (2036-DSC minus 2036-DM, 30 metre receptor height)

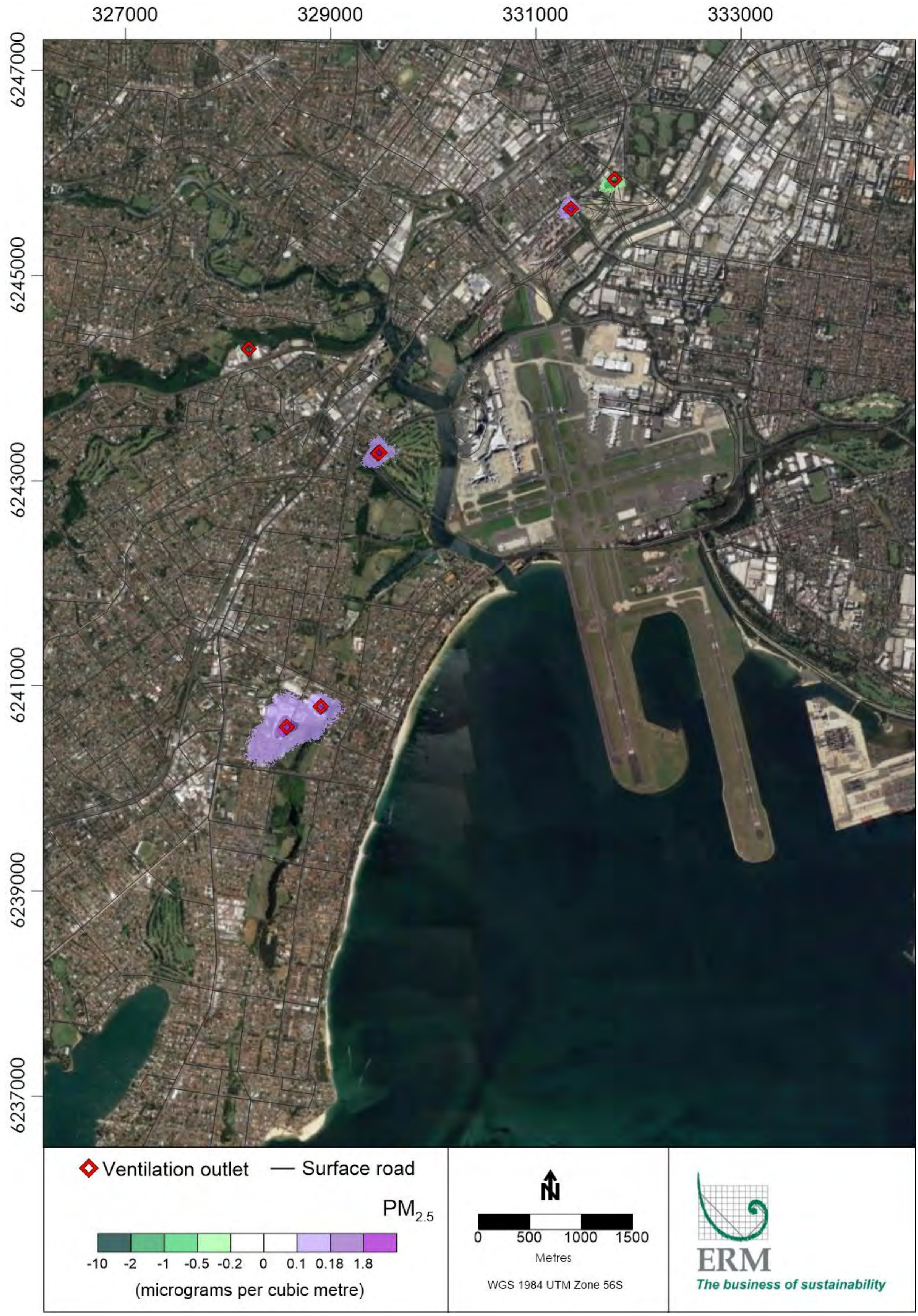


Figure 8-88 Contour plot of change in annual mean $PM_{2.5}$ concentration (2036-DSC minus 2036-DM, 45 metre receptor height)

Maximum 24-hour $PM_{2.5}$

Figure 8-89, **Figure 8-90**, **Figure 8-91** and **Figure 8-92** show the contour plots for the changes in maximum 24-hour $PM_{2.5}$ concentration in the 2036-DSC scenario at heights of 10, 20, 30 and 45 metres, respectively. These plots can be compared with the changes in ground-level concentration for the same scenario (Annexure I, Figure I-47). The patterns in the contour plots for 24-hour $PM_{2.5}$ were broadly in line with those for annual mean $PM_{2.5}$, with the surface road influence diminishing with height and the ventilation outlet influence becoming more distinct.

Statistics relating to the largest increases in the maximum 24-hour $PM_{2.5}$ concentration at the RWR receptor locations are also provided in **Table 8-23**. As mentioned in the previous section, it is not necessarily the case that there would be existing buildings with heights of 10, 20, 30 or 45 metres at the RWR receptor locations. The largest increase at the height of 10 metres was 1.40 µg/m^3, which can be compared with the maximum increase at ground-level of 1.47 µg/m^3. The largest increase in concentration decreased further at a height of 20 metres, but began to increase again at a height of 30 metres, and had increased markedly by a height of 45 metres. For the receptor with the largest increase in maximum 24-hour $PM_{2.5}$ (around 15 µg/m^3) at a height of 45 metres, the location was in the middle of a low-rise industrial area on West Botany Street.

The last column of **Table 8-23** suggests that none of the receptors with an increase in maximum 24-hour $PM_{2.5}$ of more than 0.5 µg/m^3 had a building height of more than 10 metres. However, in this case it should be added that there were significant gaps in the building height data for the subset of RWR receptors with a change in concentration of more than 0.5 µg/m^3.

Table 8-23 Changes in maximum 24-hour $PM_{2.5}$ concentration at elevated receptors (RWR receptors, 2036-DSC compared with 2036-DM)

Height of modelled concentrations	Maximum increase in concentration at any RWR receptor (µg/m^3)	Number of RWR receptors with an increase of more than 0.5 µg/m^3	Number RWR receptors with an increase of more than 0.5 µg/m^3 and a building above model output height
Ground level	1.47	216 (1.2%)	All
10 metres	1.40	129 (0.7%)	0
20 metres	1.09	88 (0.5%)	0
30 metres	1.22	109 (0.6%)	0
45 metres	15.36	220 (1.3%)	0

These results indicate that, for all existing receptor locations, and assuming no further construction at those locations, the changes in maximum 24-hour $PM_{2.5}$ concentration are likely to be acceptable up to a height of 30 metres (i.e. they are lower than at ground level). At a height of 45 metres the largest increases in concentration are considerably higher than at ground level, but even so at the relevant locations there are no existing or proposed buildings above this height.

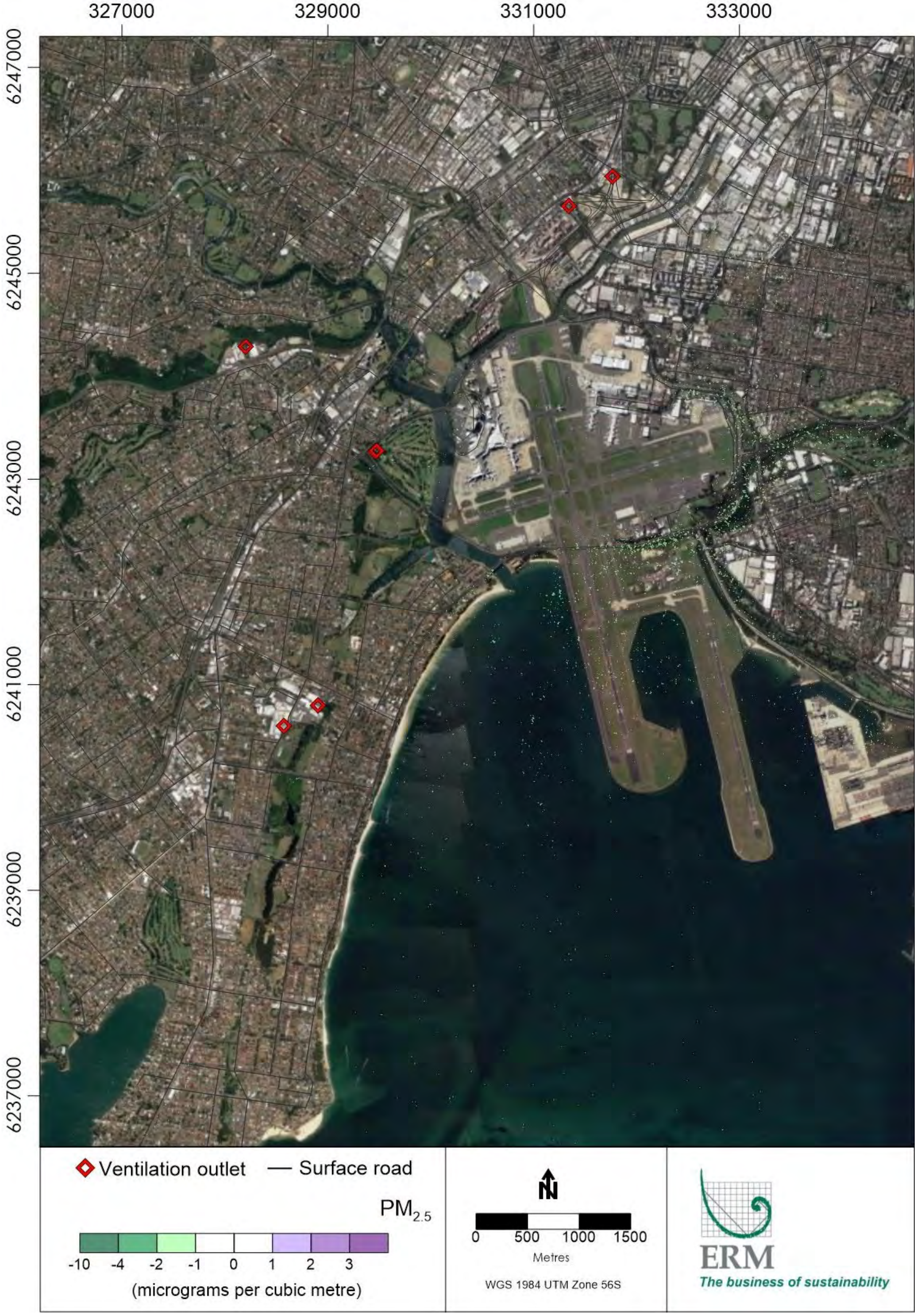


Figure 8-89 Contour plot for change in maximum 24-hour $PM_{2.5}$ concentration (2036-DSC minus 2036-DM, 10 metre receptor height)

Figure 8-90 Contour plot for change in maximum 24-hour $PM_{2.5}$ concentration (2036-DSC minus 2036-DM, 20 metre receptor height

Figure 8-91 Contour plot for change in maximum 24-hour $PM_{2.5}$ concentration (2036-DSC minus 2036-DM, 30 metre receptor height

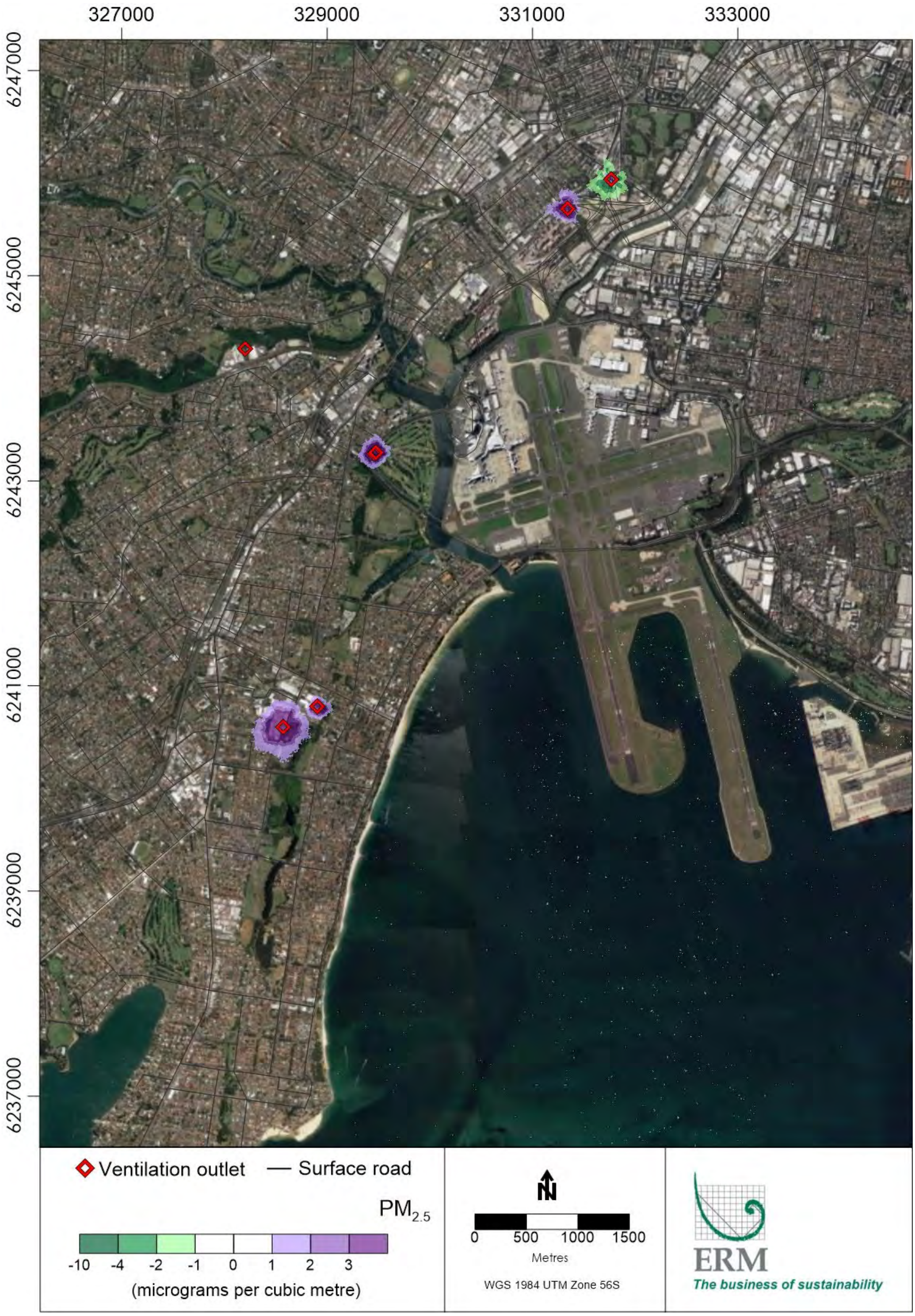


Figure 8-92 Contour plot for change in maximum 24-hour $PM_{2.5}$ concentration (2036-DSC minus 2036-DM, 45 metre receptor height

Implications for future developments

The results for both annual mean and 24-hour $PM_{2.5}$ do not seem to impose any significant restrictions on future developments in the GRAL domain up to a height of 30 metres above ground level. This statement only applies to the RWR receptor locations included in the modelling, although these should be broadly representative of other similar locations. However, planning controls should be developed in the vicinity of the ventilation outlets to ensure that future developments at heights of 30 metres or higher are not adversely impacted by the ventilation outlets. Development of planning controls would be supported by detailed modelling addressing all relevant pollutants and averaging periods.

8.4.13 Results for regulatory worst case scenarios

The following sections highlight the results of this scenario for the receptors with the largest impacts. As noted in the methodology, a more detailed approach was required for NO_2 than for the other pollutants.

CO and PM

The results for CO, PM_{10} and $PM_{2.5}$ in the regulatory worst case scenario (RWC-2036-DSC only) are given in **Table 8-24**. The Table shows the maximum contribution of tunnel ventilation outlets at any of the RWR receptors in this scenario, as well as the maximum contribution at any sensitive receptor (residence, schools, hospitals, etc). However, the results were similar in both cases.

Table 8-24 Results of regulatory worst case assessment (RWR receptors) – CO and PM

Pollutant and Period	Units	Maximum ventilation outlet contribution at any receptor				
		Regulatory worst case scenario (RWC-2036-DSC)		Expected traffic scenarios (all receptors)		
		All receptors	Sensitive receptors	2026-DS	2036-DS	2036-DSC
CO (one hour)	(mg/m^3)	0.76	0.73	0.07	0.08	0.08
PM_{10} (annual)	($\mu g/m^3$)	1.79	1.24	0.40	0.46	0.50
PM_{10} (24-h)	($\mu g/m^3$)	9.96	9.56	1.99	2.29	2.47
$PM_{2.5}$ (annual)[(a)]	($\mu g/m^3$)	1.79	1.24	0.28	0.30	0.34
$PM_{2.5}$ (24-h)[(a)]	($\mu g/m^3$)	9.96	9.56	1.37	1.55	1.57

(a) The same emission rates were used for PM_{10} and $PM_{2.5}$.

The concentrations in the regulatory worst case scenario 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 1-hour CO concentration was negligible, especially taking into account the fact that CO concentrations are well below the NSW impact assessment criterion. For example, the maximum 1-hour outlet contribution in the regulatory worst case scenario (0.76 mg/m^3) was a very small fraction of the criterion (30 mg/m^3). The maximum background 1-hour CO concentration (3.13 mg/m^3) was also well below the criterion. Exceedances of the criterion are therefore highly unlikely to occur.
- For PM_{10} the maximum contribution of the ventilation outlets would be small. For the annual mean and maximum 24-hour metrics the outlet contributions were 7 per cent and 20 per cent of the respective criteria. This would be significant for some receptors, but any exceedances of the criteria would be dominated by background concentrations.
- The ventilation outlet contribution would be most important for $PM_{2.5}$, with the maximum contributions equating to 22 per cent and 40 per cent of the annual mean and 24-hour criteria respectively. Again, any exceedances of the criteria would be dominated by background concentrations.

NO_X and NO_2

Annual mean

The results for NO_X and NO_2 in all regulatory worst case scenarios are given in **Table 8-25**. The Table shows the maximum contribution of tunnel ventilation outlets at any of the RWR receptors in each scenario, as well as the maximum contribution at any sensitive receptor (residence, schools, hospitals, etc). However, the results were similar in both cases. The maximum outlet concentrations in the regulatory worst case were an order of magnitude higher than those in the expected traffic case, although total annual mean NO_2 concentrations would still remain below the NSW air quality criterion.

Table 8-25 Results of regulatory worst case assessment (RWR receptors) – annual mean NO_X and NO_2

Receptor type and pollutant metric	Maximum ventilation outlet contribution by scenario (µg/m^3)		
	2026-DS	2036-DS	2036-DSC
Regulatory worst case scenarios			
All RWR receptors			
NOx (annual mean)	30.46	31.08	32.39
NO_2 (annual mean)	5.74	5.75	5.92
All sensitive RWR receptors			
NOx (annual mean)	21.13	21.45	22.54
NO_2 (annual mean)	4.39	4.48	4.68
Expected traffic scenarios			
All RWR receptors			
NOx (annual mean)	2.40	2.39	2.06
NO_2 (annual mean)	0.50	0.49	0.42

Maximum 1-hour

The results of the more detailed assessment for NO_2 at the project ventilation facilities in the with-project and cumulative scenarios are shown, by scenario and outlet, in **Figure 8-93** to **Figure 8-98**. The results are also summarised in **Table 8-26**..

In each figure:

- The first plot (a) shows the different source contributions when the maximum 1-hour NO_2 concentration occurs during the year. During these periods the tunnel ventilation contributions are zero or close to zero
- The second plot (b) shows the NO_2 concentrations when the maximum ventilation outlet concentrations occur; under these circumstances, the background, surface road and portal concentrations tend to be lower than in plot (a), and therefore the total NO_2 concentrations are well below the criterion.

For some receptors, the same maximum outlet concentration occurred in more than one hour of the year. Where this was the case the hour having the largest total NO_X concentration has been presented.

In some cases the ventilation outlet contributions appear to be substantial. This is deceptive, as the background, surface road and portal contributions (and hence total NOx) increase, there is a pronounced reduction in the contribution of the outlets to NO_2. In other words, as the total NO_2 concentration tends towards the 'maximum' situation in plot (a) of each figure, the outlet contribution to NO_2 decreases dramatically, indicated by the black 'ventilation outlet' contribution being imperceptible in the plots. This is because as the concentration of NO increases the amount of ozone available for NO_2 production decreases. Plot (b) of each figure shows that the maximum outlet contribution occurs when other contributions are low, such that overall NO_2 concentrations are well below the criterion or even the current maximum.

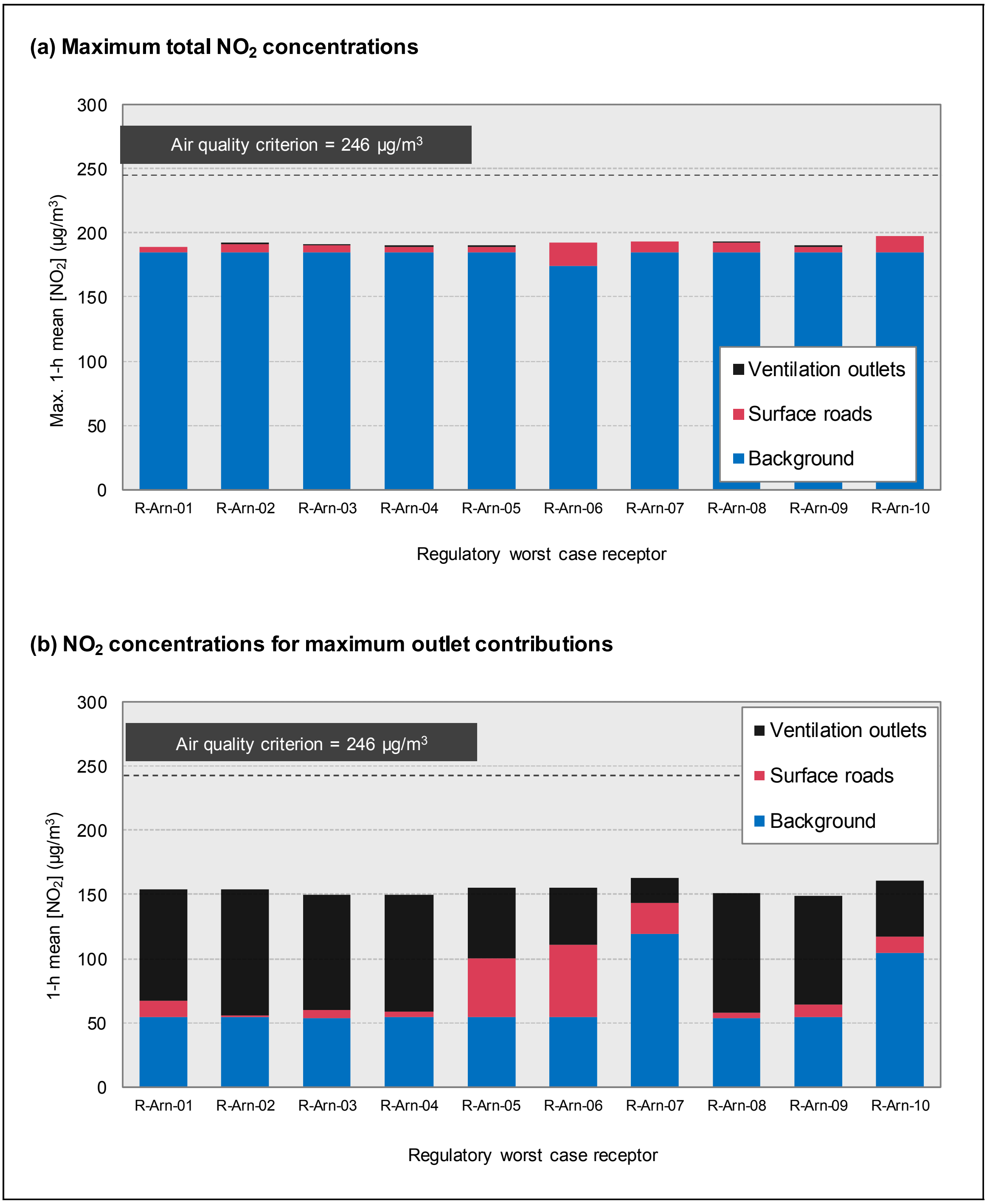


Figure 8-93 Regulatory worst case: 1-hour mean NO_2 concentrations (2026-DS, Arncliffe facilities)

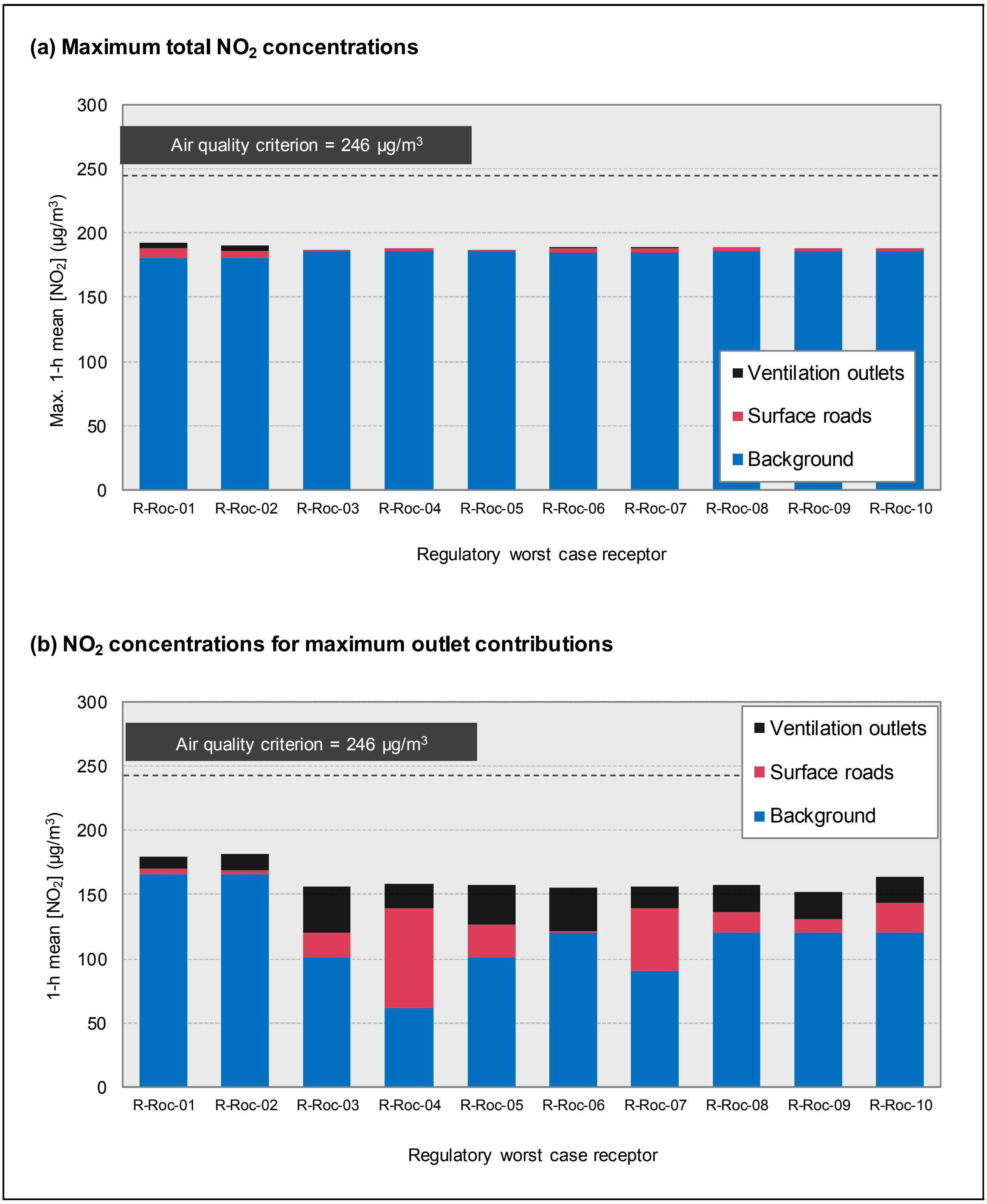


Figure 8-94 Regulatory worst case: 1-hour mean NO_2 concentrations (2026-DS, Rockdale facilities)

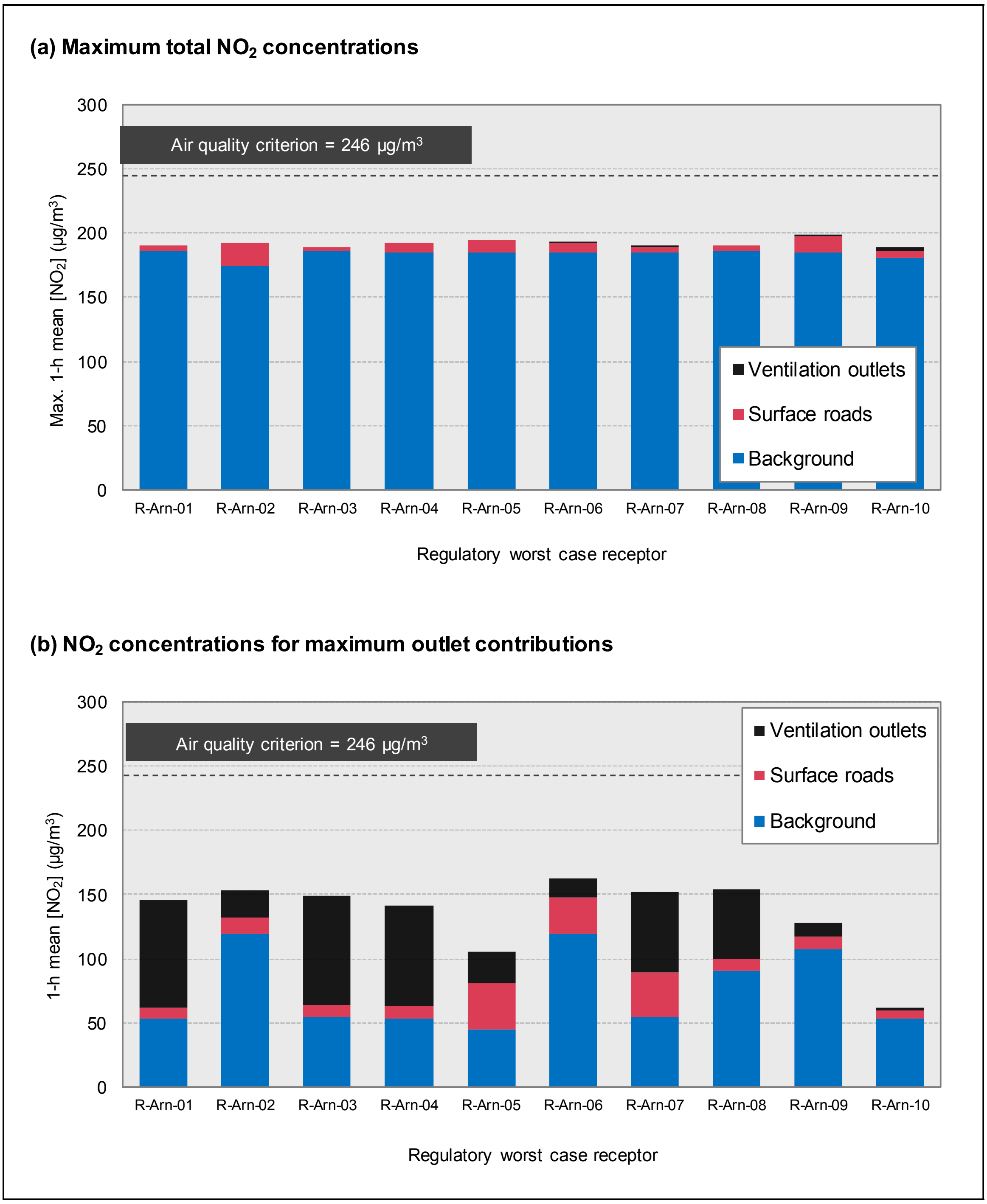


Figure 8-95 Regulatory worst case: 1-hour mean NO_2 concentrations (2036-DS, Arncliffe facilities)

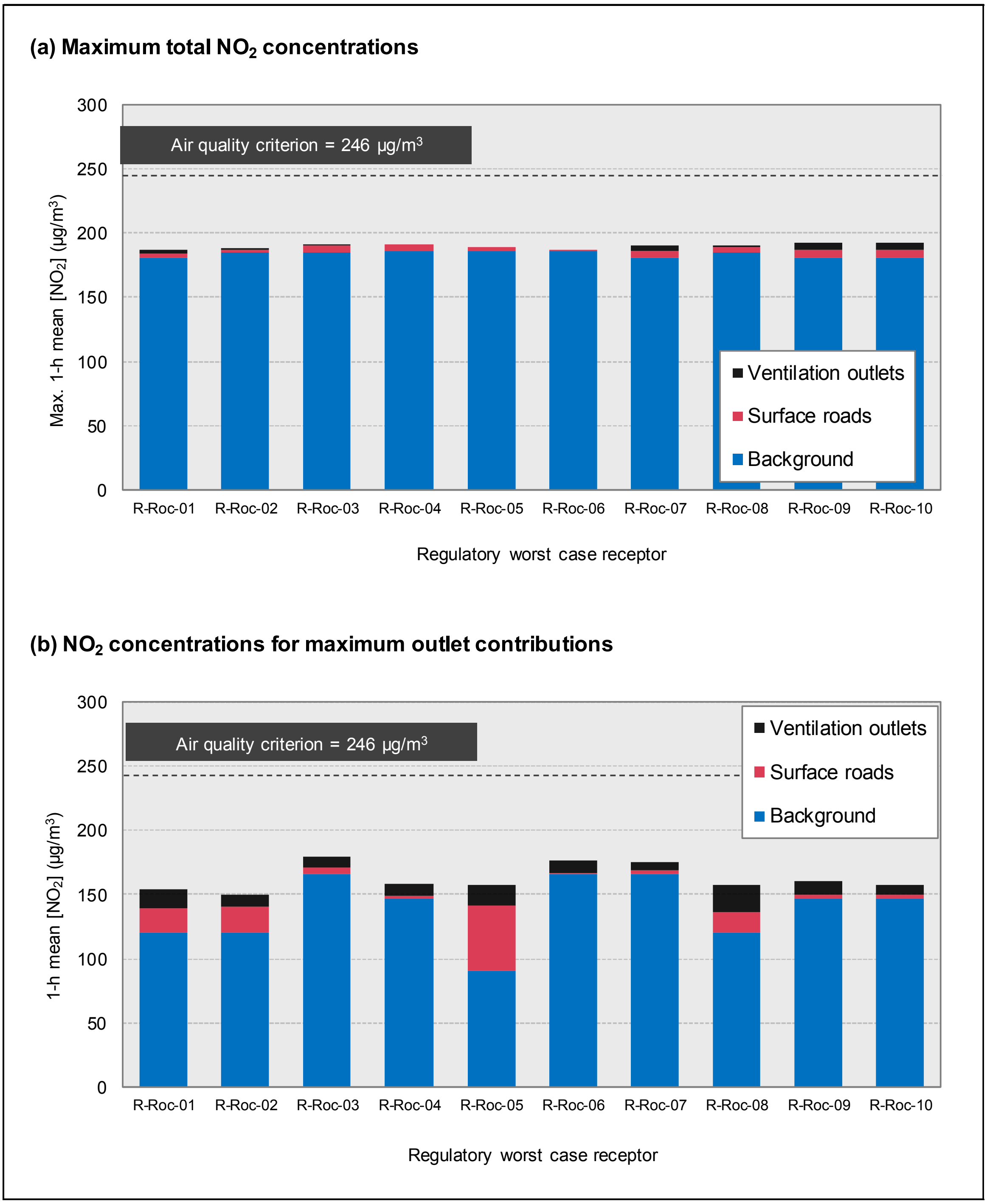


Figure 8-96 Regulatory worst case: 1-hour mean NO_2 concentrations (2036-DS, Rockdale facilities)

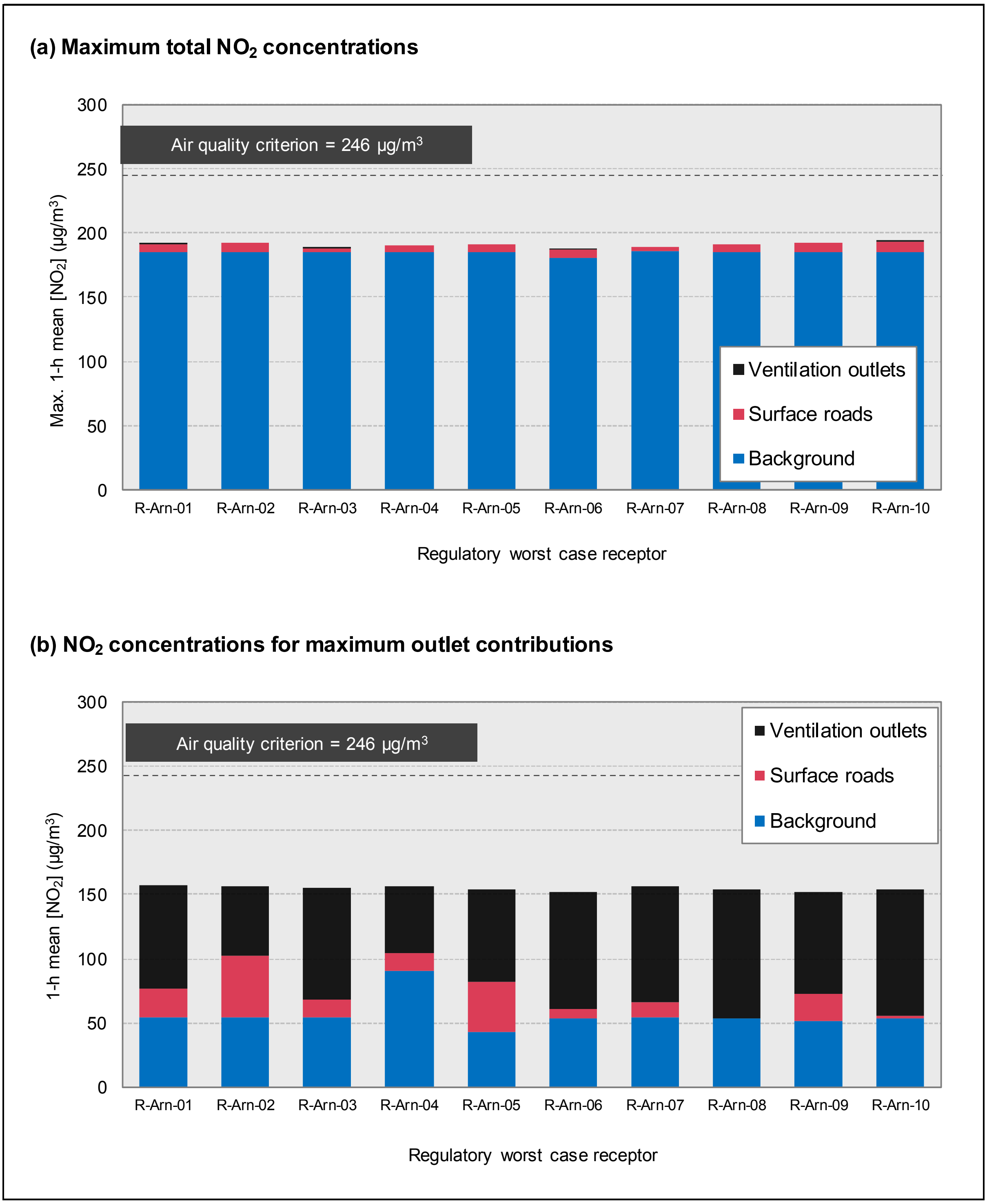


Figure 8-97 Regulatory worst case: 1-hour mean NO_2 concentrations (2036-DSC, Arncliffe facilities)

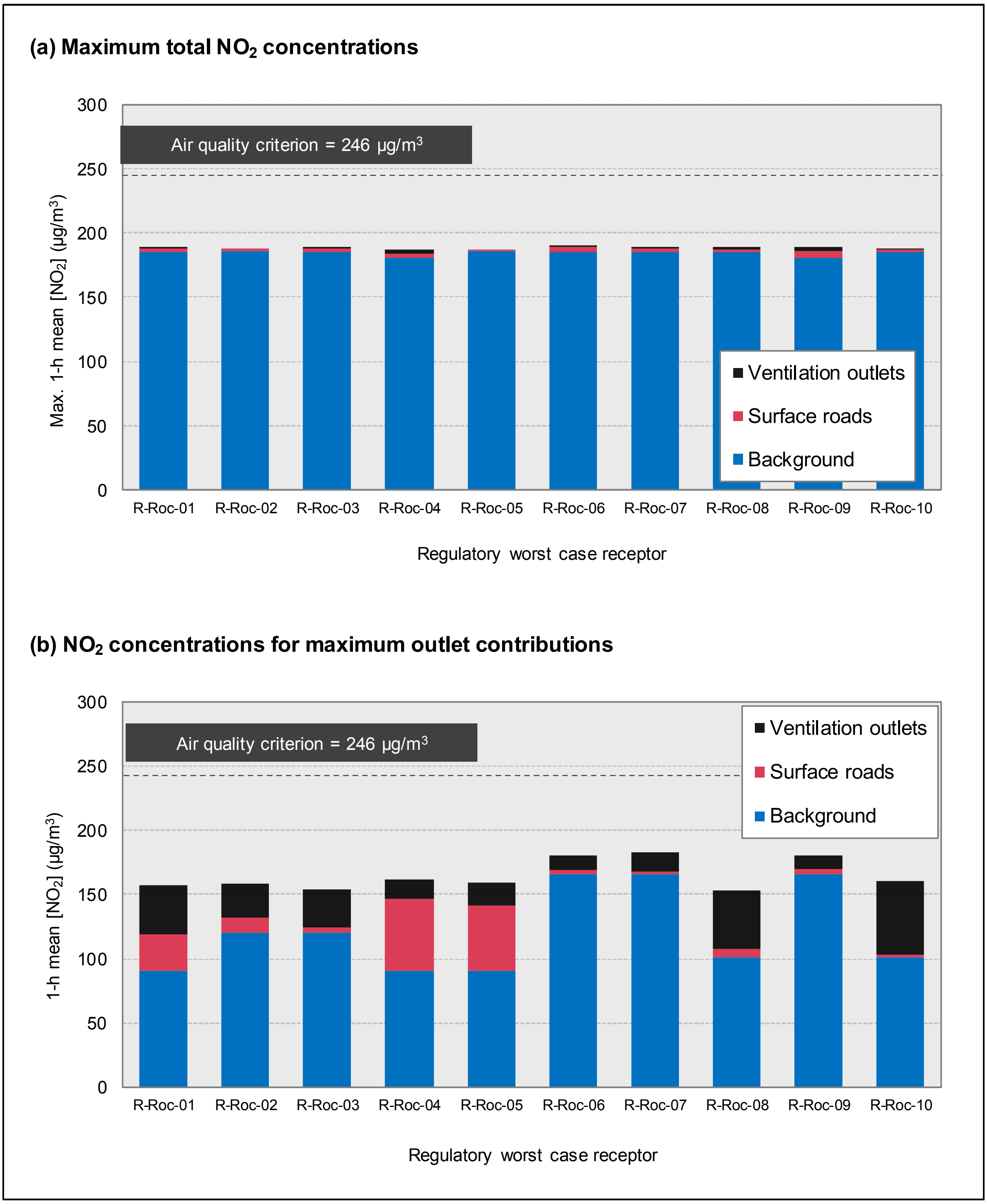


Figure 8-98 Regulatory worst case: 1-hour mean NO_2 concentrations (2036-DSC, Rockdale facilities)

Table 8-26 Results of regulatory worst case assessment ('top 10' RWR receptors) – NO_2

Outlet and metric	Maximum ventilation outlet contribution across 'top 10' receptors (µg/m³)		
	2026-DS	2036-DS	2036-DSC
Outlets B and E: New M5 Motorway and F6 Extension Stage 1 (Arncliffe)			
NO_2 (one hour) [when maximum total NO_2 occurs]	0.2	3.2	0.8
NO_2 (one hour) [when maximum outlet contribution to NO_2 occurs]	98.5	84.6	100.4
Outlets F and G: F6 Extension Stages 1 and 2 (Rockdale)[(a)]			
NO_2 (one hour) [when maximum total NO_2 occurs]	4.5	5.1	3.4
NO_2 (one hour) [when maximum outlet contribution to NO_2 occurs]	36.2	21.2	56.4

(a) F6 Extension – S Section B outlet was only included in the 2036-DSC scenario.

THC and air toxics

The maximum outlet concentrations for the four specific air toxics considered in the regulatory worst case assessment (scenario RWC-2036-DSC only) were determined using the THC predictions in conjunction with the speciation profiles stated in **Table 8-18**. The results are given in **Table 8-27**. The Table shows the maximum contribution of tunnel ventilation outlets at any of the RWR receptors in this scenario (for most of the pollutant metrics these were residential receptors). The outlet contributions to the specific air toxics are well below the impact assessment criteria in the *Approved Methods for the Modelling and Assessment of Air Pollutants in New South Wales*.

Table 8-27 Results of regulatory worst case assessment (RWR receptors) – air toxics (ventilation outlets only)

Pollutant and Period	Units	Maximum ventilation outlet contribution at any receptor	
		Regulatory worst case scenario (RWC-2036-DSC)	Impact assessment criterion (µg/m³)
THC (annual)	(µg/m³)	3.13	-
THC (1 hour)	(µg/m³)	54.92	-
Benzene (1 hour)	(µg/m³)	2.55	29
PAH (BaP) (1 hour)	(µg/m³)	0.032	0.4
Formaldehyde (1 hour)	(µg/m³)	3.32	20
1,3-butadiene (1 hour)	(µg/m³)	0.70	40
Ethylbenzene (1 hour)	(µg/m³)	0.84	8,000

Table 8-28 shows that, even if the maximum outlet contribution in the regulatory worst case scenario is added to the maximum increase in concentration in the cumulative scenario for expected traffic (which implies some double counting), the results are still comfortably below the impact assessment criteria.

Table 8-28 Results of regulatory worst case assessment (RWR receptors) – air toxics (ventilation outlets plus traffic)

Pollutant and period	Units	Maximum outlet contribution at any receptor	Maximum increase due to project (outlet + expected traffic; 2036-DSC)	Sum	Impact assessment criterion
THC (1 hour)	(µg/m³)	54.92	-	-	-
Benzene (1 hour)	(µg/m³)	2.55	1.22	3.77	29
PAH (BaP) (1 hour)	(µg/m³)	0.032	0.015	0.047	0.4
Formaldehyde (1 hour)	(µg/m³)	3.32	1.58	4.90	20
1,3-butadiene (1 hour)	(µg/m³)	0.70	0.33	1.03	40
Ethylbenzene (1 hour)	(µg/m³)	0.84	0.40	1.24	8,000

8.4.14 Key assumptions

The assumptions in the local air quality impact assessment for the project that were likely to have had the most influence on the outcomes of the assessment are presented in **Table 8-29**. 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 8-29 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 reflect background air quality in the study area accurately.
		Pollutant concentrations at background monitoring stations in 2015 were assumed to be representative of background concentrations in 2026 and 2036.	The implications of this cannot be quantified. It could be argued that concentrations in the future would decrease as emission controls improve (across all sectors of activity). However, any improvements could also be offset by increases in population and activity.
		It was assumed that there would be no contribution from the road network to the concentrations at these sites. The GRAL model actually gave non-zero (but generally small) values at the locations of the background monitoring sites.	Total predicted concentrations (GRAL + background) would generally be overestimated across the GRAL domain. The maximum annual mean GRAL predictions at background sites were: - CO 0.06 mg/m^3 - NO_X 27.5 µg/m^3 - PM_{10} 1.6 µg/m^3 This added an element of conservatism to the total concentration predictions.
1.2	Community receptors CO, rolling 8-hour mean	Hourly monitoring data from several OEH and RMS monitoring stations in 2015 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	Community and RWR receptors NO_X, annual mean	Background annual mean NO_X concentrations were mapped across the GRAL domain.	Notwithstanding the comments under item 1.1, this approach can be viewed as accurate rather than conservative.
1.4	Community receptors NO_X, 1-hour mean	Hourly monitoring data several OEH and RMS monitoring stations in 2015 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	Community and RWR receptors PM_{10}, annual mean	Background annual mean PM_{10} concentrations were mapped across the GRAL domain.	Notwithstanding the comments under item 1.1, this approach can be viewed as accurate rather than conservative.
1.6	Community receptors PM_{10}, 24-hour mean	24-hour monitoring data from several OEH and RMS monitoring stations in 2015 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.

Topic and sub-topic		Method and assumptions	Implications for conservatism
1.7	Community and RWR receptors $PM_{2.5}$, 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	Community receptors $PM_{2.5}$, 24-hour mean	24-hour monitoring data from three OEH monitoring stations in 2015 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.
1.9	RWR receptors only Short-term metrics	For 1-hour NO_X, 24-hour PM_{10} and 24-hour $PM_{2.5}$, the maximum value from the corresponding synthetic background profile was used as the background for all RWR receptors.	This would be reasonable accurate for receptors with a low road traffic contribution. For receptors with a large road traffic contribution, the total concentration would be overestimated. The approach would be very conservative for a small proportion of receptors.
2	Traffic forecasts		
2.1	Traffic volumes for tunnels and surface roads	Traffic volumes were taken from SMPM. 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 NSW EPA model is not designed to be conservative for surface roads, but the analysis presented in Annexure E indicates that for the conditions in the LCT (and probably more widely for tunnels in Sydney during normal operation), the NSW 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 (tunnels)		
The assumptions concerning in-tunnel emissions are provided in Annexure K.			
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 reflect the study area accurately.
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.	-
6.1	Ventilation outlet heights	The ventilation outlet heights were optimised to minimise the concentration increments at sensitive receptors, with a particular emphasis on annual mean $PM_{2.5}$.	A basic sensitivity analysis for the M4 East and New M5 Motorway projects showed that the total predicted concentrations are not likely to be very sensitive to ventilation outlet height, based on a sensitivity range of 25 to 35 metres.
6.2	Ventilation outlet exit diameter	The dispersion modelling involved either time-varying or fixed ventilation outlet diameters, depending on the outlet.	-
6.3	Volumetric flow rates	Volumetric flow rates were initially calculated for each hour of the day based on predicted traffic volumes.	-
6.4	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.	-
6.5	Outlet temperature	An annual average outlet temperature was used for each ventilation outlet modelled in GRAL, based on the tunnel ventilation calculations (Annexure K).	A basic sensitivity analysis for the M4 East and New M5 Motorway projects showed that the total predicted concentrations are not likely to be very sensitive to ventilation outlet temperature, based on a sensitivity range of 15 to 35^{0}C.
7	Post-processing (NO_2) – community receptors		
7.1	NO_X-to-NO_2 conversion, annual mean	A 'best estimate' empirical 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.
7.2	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 empirical 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 estimate the maximum 1-hour mean NO_2 concentrations conservatively. The dispersion modelling evaluation showed, however, that this method was less conservative than the OLM.

Topic and sub-topic		Method and assumptions	Implications for conservatism
8	Post-processing (NO_2) – RWR receptors		
8.1	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.
8.2	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 2015. 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.

8.4.15 Sensitivity tests – outlet parameters

Approach

Several sensitivity tests were conducted to investigate the effects of varying important model parameters on the predicted concentrations around project ventilation outlets. For each parameter the value used in GRAL was varied around a central estimate that was representative of the value used in the expected traffic case model scenarios.

The following model inputs were investigated:

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

The sensitivity tests were only conducted for the ventilation outlet contribution (i.e. background and surface road contributions were excluded), and for maximum 1-hour, maximum 24-hour $PM_{2.5}$ and annual mean $PM_{2.5}$. Both absolute and percentage changes in concentration were considered. The percentage changes could also be considered as being representative for other pollutants (e.g. CO, NO_X, and PM_{10}).

The tests were mainly conducted for a sub-area of the F6 Extension domain of approximately 2 km x 2 km around the Rockdale ventilation outlets, as shown in **Figure *8-99***.

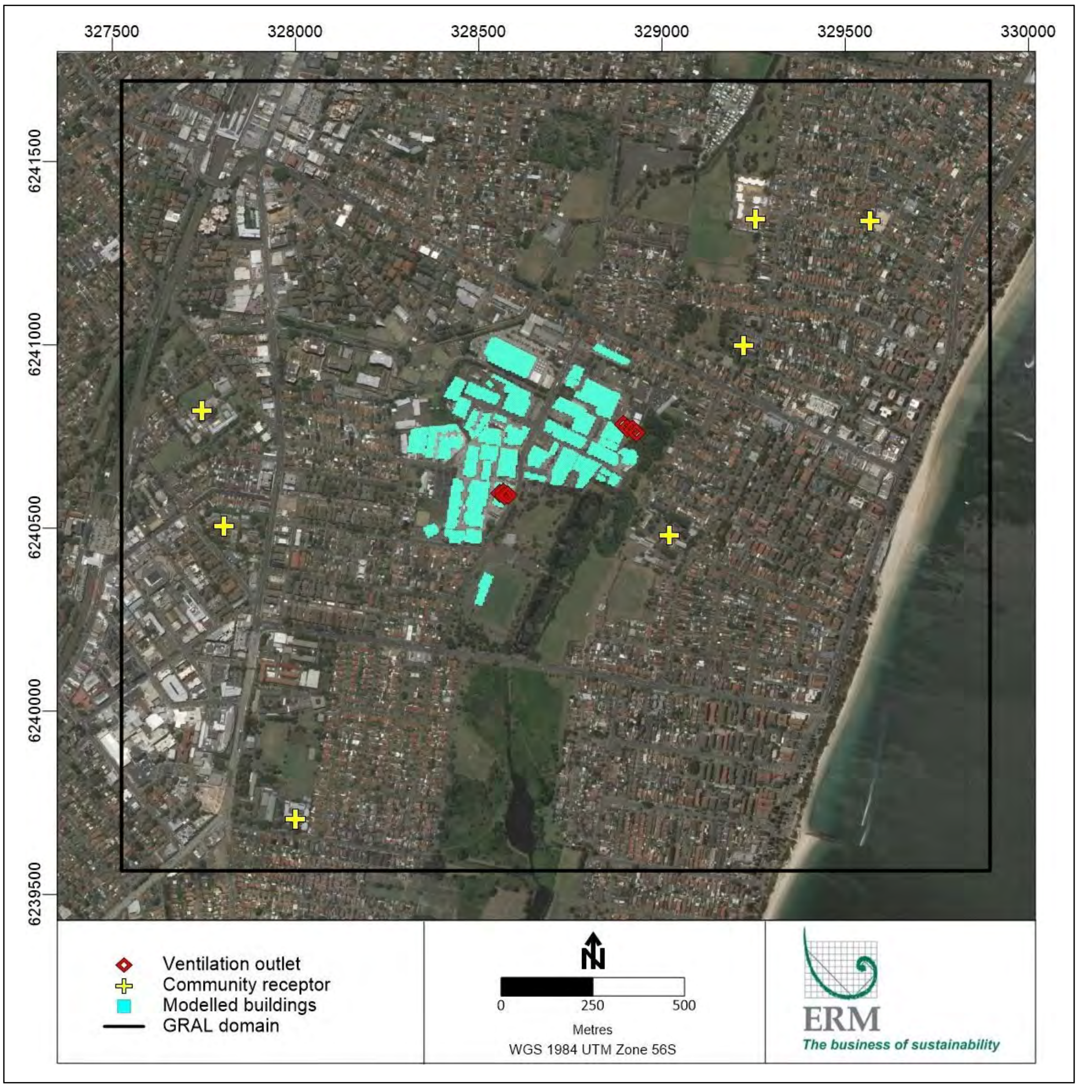


Figure 8-99 Domain and buildings for Rockdale sensitivity tests

Model predictions were considered for seven community receptors located within the Rockdale domain, as listed in **Table 8-30**.

Table 8-30 Community receptors included in sensitivity tests

ID	Location
CR06	St George School
CR08	Brighton-le-Sands Public School
CR09	Kogarah Public School
CR10	St George Girls' High School
CR11	St Thomas More's Catholic School
CR12	Jenny-Lyn Nursing Home
CR20	Cairnsfoot School

Results

Ventilation outlet temperature

In the air quality assessment a single annual average temperature was used in GRAL for each tunnel ventilation outlet. For ventilation outlet temperature the central estimate was taken to be 25˚C. The effects of defining outlet temperatures 10˚C below and above this value were then investigated. In temperature test TT01 the outlet temperature was set to 15˚C, and in temperature test TT03 the outlet temperature was set to 35˚C.

Table 8-31 presents the $PM_{2.5}$ concentration results for the temperature sensitivity tests, and **Table 8-32** gives the percentage changes in concentration relative to the central estimate.

For the outlet temperature of 15^{o}C the predicted $PM_{2.5}$ concentrations were systematically higher than those in the central estimate as a consequence of the reduced thermal buoyancy of the plume leading to poorer dispersion. Across all $PM_{2.5}$ metrics the largest increase at any community receptor was 23 per cent, and the average increase was 9 per cent. The predicted outlet concentrations remained well below the air quality criteria for $PM_{2.5}$.

For the outlet temperature of 35˚C the predicted $PM_{2.5}$ concentrations were systematically lower than those in the central estimate because of increased thermal plume buoyancy. The largest decrease at any community receptor was 19 per cent, and the average decrease was 10 per cent.

Table 8-31 Results of sensitivity tests for outlet temperature – predicted concentrations

ID	Name	HT01 (15°C)			HT02 (25°C)			HT03 (35°C)		
			$PM_{2.5}$ (µg/m³)							
		Max 1h	Max 24h	Annual Ave	Max 1h	Max 24h	Annual Ave	Max 1h	Max 24h	Annual Ave
			Impact Assessment Criteria							
		N/A	25	8	N/A	25	8	N/A	25	8
CR06	St George School	8.6	2.1	0.4	8.2	1.9	0.4	6.9	1.8	0.3
CR08	Brighton-Le-Sands Public School	17.2	3.4	0.7	14.7	3.3	0.6	11.9	3.0	0.5
CR09	Kogarah Public School	11.0	3.3	0.4	9.7	3.0	0.3	9.6	2.6	0.3
CR10	St George Girls High School	9.5	2.7	0.2	9.2	2.3	0.2	8.0	2.2	0.2
CR11	St Thomas More's Catholic School	13.0	2.7	0.4	11.4	2.5	0.4	9.7	2.5	0.3
CR12	Jenny-Lyn Nursing Home	17.3	1.3	0.2	20.0	1.2	0.2	16.2	1.2	0.2
CR20	Cairnsfoot School	29.2	2.4	0.2	28.8	2.3	0.2	28.8	2.1	0.2

Table 8-32 Results of sensitivity tests for outlet temperature – percentage changes

ID	Name	Change in $PM_{2.5}$ relative to central estimate (%)						
		HT01 (15°C)			HT02 (25°C)	HT03 (35°C)		
		Max 1h	Max 24h	Annual		Max 1h	Max 24h	Annual
CR06	St George School	5%	11%	9%		-16%	-6%	-11%
CR08	Brighton-Le-Sands Public School	17%	2%	23%		-19%	-10%	-15%
CR09	Kogarah Public School	14%	10%	10%		0%	-14%	-8%
CR10	St George Girls High School	4%	16%	6%		-13%	-4%	-11%
CR11	St Thomas More's Catholic School	14%	6%	15%		-15%	-2%	-5%
CR12	Jenny-Lyn Nursing Home	-14%	9%	9%		-19%	-1%	-4%
CR20	Cairnsfoot School	1%	4%	6%		0%	-8%	-8%

Ventilation outlet height

For the ventilation outlet heights the central estimate for (test HT02) was taken to be 35 metres (the outlet height used in the expected traffic case modelling). In height test HT01 the height was set to 25 metres, and in height test HT03 the height was set to 45 metres. This was considered to be a realistic potential range for the outlet height at this location.

Table 8-33 presents the results of the height sensitivity tests, and the percentage changes in concentration relative to the central estimate are given in **Table 8-34**.

For the outlet height of 25 metres the predicted $PM_{2.5}$ concentrations were almost all systematically higher than those in the central estimate. This is a consequence of the reduction of ambient wind speed with height in the atmosphere (which results in poorer dispersion), and the shorter distances between the source and the receptors. The largest increase at any community receptor was 43 per cent, and the average increase was 22 per cent. As with the temperature tests, the predicted outlet concentrations remained well below the air quality criteria for $PM_{2.5}$.

For the outlet height of 45 metres the predicted $PM_{2.5}$ concentrations were in most cases lower than those in the central estimate. The largest decrease at any community receptor was 30 per cent, and the average decrease was 21 per cent.

Table 8-33 Results of sensitivity tests for outlet height – predicted concentrations

ID	Name	HT01 (25 metres)			HT02 (35 metres)			HT03 (45 metres)		
			$PM_{2.5}$ (µg/m³)							
		Max 1h	Max 24h	Annual Ave	Max 1h	Max 24h	Annual Ave	Max 1h	Max 24h	Annual Ave
			Impact Assessment Criteria							
		N/A	25	8	N/A	25	8	N/A	25	8
CR06	St George School	7.8	2.1	0.4	8.8	1.8	0.4	6.6	1.5	0.3
CR08	Brighton-Le-Sands Public School	18.5	5.0	0.8	14.4	3.3	0.6	10.0	2.3	0.4
CR09	Kogarah Public School	10.6	3.2	0.4	10.2	3.0	0.4	7.3	2.3	0.3
CR10	St George Girls High School	11.0	3.0	0.3	9.6	2.5	0.2	7.5	1.7	0.2
CR11	St Thomas More's Catholic School	13.5	3.6	0.5	10.0	2.5	0.4	8.3	1.8	0.3
CR12	Jenny-Lyn Nursing Home	6.9	1.3	0.2	20.5	1.2	0.2	20.4	1.0	0.2
CR20	Cairnsfoot School	9.0	2.9	0.3	29.8	2.2	0.2	30.7	1.6	0.2

Table 8-34 Results of sensitivity tests for outlet height – percentage changes

ID	Name	Change in $PM_{2.5}$ relative to central estimate (%)						
		HT01 (25 metres)			HT02 (35 metres)	HT03 (45 metres)		
		Max 1h	Max 24h	Annual		Max 1h	Max 24h	Annual
CR06	St George School	-11%	16%	9%		-25%	-16%	-14%
CR08	Brighton-Le-Sands Public School	29%	51%	39%		-30%	-30%	-28%
CR09	Kogarah Public School	5%	7%	7%		-28%	-23%	-11%
CR10	St George Girls High School	15%	20%	14%		-22%	-30%	-13%
CR11	St Thomas More's Catholic School	34%	43%	30%		-17%	-28%	-23%
CR12	Jenny-Lyn Nursing Home	-66%	13%	13%		0%	-12%	-6%
CR20	Cairnsfoot School	-70%	33%	17%		3%	-26%	-11%

Buildings

Buildings can be included in dispersion modelling to account for building wake effects in the vicinity of ventilation outlets. However, for the project assessment buildings were excluded (the rationale for this was provided in **Section 8** of this report). The sensitivity of the inclusion of buildings to predicted concentrations was therefore assessed. The effects of stack-tip downwash were also included in this test.

The results for the buildings tests are shown in **Table 8-35**. These show that, when buildings were included, there was a maximum increase in concentrations associated with the ventilation outlet of 32 per cent, and an average increase of 20 per cent.

As with the height and temperature tests, the predicted outlet concentrations remained well below the air quality criteria for $PM_{2.5}$.

Table 8-35 Results of sensitivity tests for buildings – predicted concentrations and percentage changes

ID	Name	$PM_{2.5}$ (µg/m^3)								
		BT01 (without buildings)			BT02 (with buildings)			*Change with buildings compared to without buildings (%)*		
		Max 1h	Max 24h	Annual Ave	Max 1h	Max 24h	Annual Ave	Max 1h	Max 24h	Annual Ave
		Impact Assessment Criteria								
		N/A	*25*	8	N/A	*25*	8	N/A	*25*	8
CR06	St George School	7.5	1.8	0.3	9.2	2.1	0.4	*19%*	*14%*	*13%*
CR08	Brighton-Le-Sands Public School	12.9	3.1	0.5	16.1	4.7	0.7	*20%*	*36%*	*28%*
CR09	Kogarah Public School	9.4	2.7	0.3	13.8	3.3	0.3	*32%*	*18%*	*12%*
CR10	St George Girls High School	8.9	2.1	0.2	11.9	3.0	0.2	*25%*	*30%*	*10%*
CR11	St Thomas More's Catholic School	9.9	2.3	0.3	13.2	2.9	0.4	*25%*	*21%*	*18%*
CR12	Jenny-Lyn Nursing Home	6.3	1.1	0.2	7.8	1.3	0.2	*20%*	*12%*	*-1%*
CR20	Cairnsfoot School	7.1	2.1	0.2	8.9	2.5	0.2	*21%*	*17%*	*9%*

Interpretation

In the outlet temperature tests, even with a significant change in temperature relative to the central estimate, the predicted outlet contributions to $PM_{2.5}$ remained small in absolute terms. Consequently, the total predicted concentration (including the background, surface road and ventilation outlet contributions) is unlikely to be affected 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.

The results for the ventilation outlet height tests were broadly similar to those for the temperature sensitivity tests, and again a difference in height of the order tested is unlikely to represent a large source of uncertainty in the overall predictions.

Whilst the building tests were not comprehensive, they also indicated (again, given the small absolute outlet contribution to $PM_{2.5}$) that the exclusion of buildings is also unlikely to represent a large source of uncertainty in the overall predictions in the assessment. The total predicted concentrations, and the conclusions of the assessment, would not change significantly with the inclusion of buildings.

8.4.16 Sensitivity tests – traffic and emissions

In the traffic and emissions sensitivity the daily $PM_{2.5}$ and NO_X emission profiles for each ventilation outlet were scaled up until the corresponding emission limit was reached for least one hour each day. For both $PM_{2.5}$ and NO_X a scaling factor of 3.7 was used.

Figure 8-100 shows the results of the traffic/emission sensitivity tests for annual mean $PM_{2.5}$ at RWR receptors in the 2036-DSC scenario. The corresponding results for annual mean NO_2 are presented in **Figure 8-101**. The plots show the total concentrations for the expected traffic scenario, the sensitivity test, and the regulatory worst case scenario. The series are superimposed, with the lowest results (expected traffic) at the front, the highest results (regulatory worst case) at the back, and the sensitivity tests in between. The results are ranked by the total concentration minus the expected traffic stack contribution in order to isolate the different stack contributions. The inset shows a zoomed-in area for 500 receptors. Summary statistics for the tests are also provided in **Table 8-36** and **Table 8-37**.

The plots and the tabulated results essentially show that all assumptions for ventilation outlets resulted in relatively small contributions compared with the total. In the case of NO_2 the total predicted concentrations were not very sensitive to the assumptions for ventilation outlet emissions.

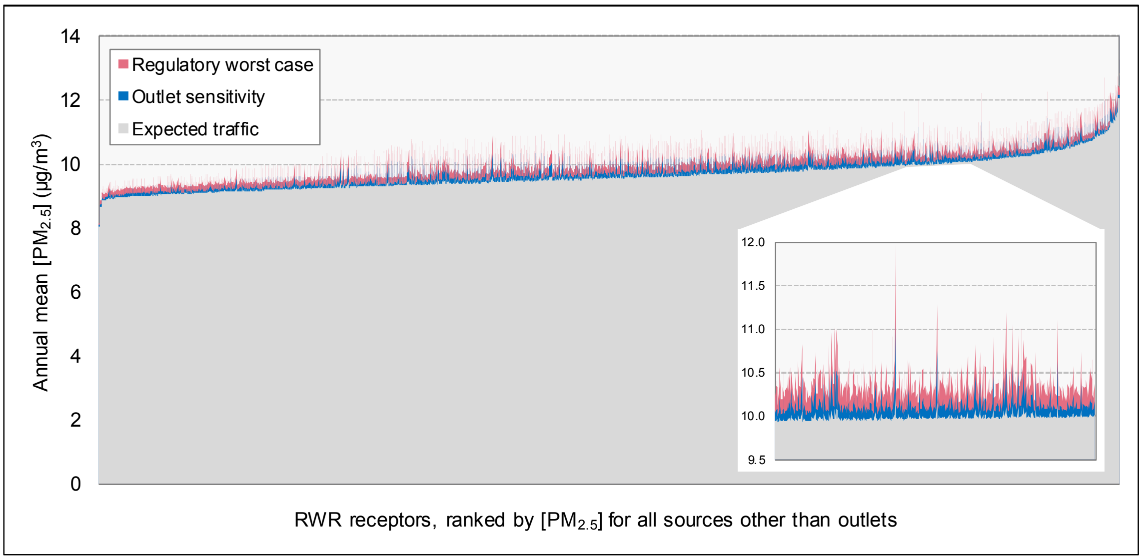


Figure 8-100 Results of traffic/emission sensitivity tests for ventilation outlets – total annual mean $PM_{2.5}$ concentration at RWR receptors (2036-DSC scenario)

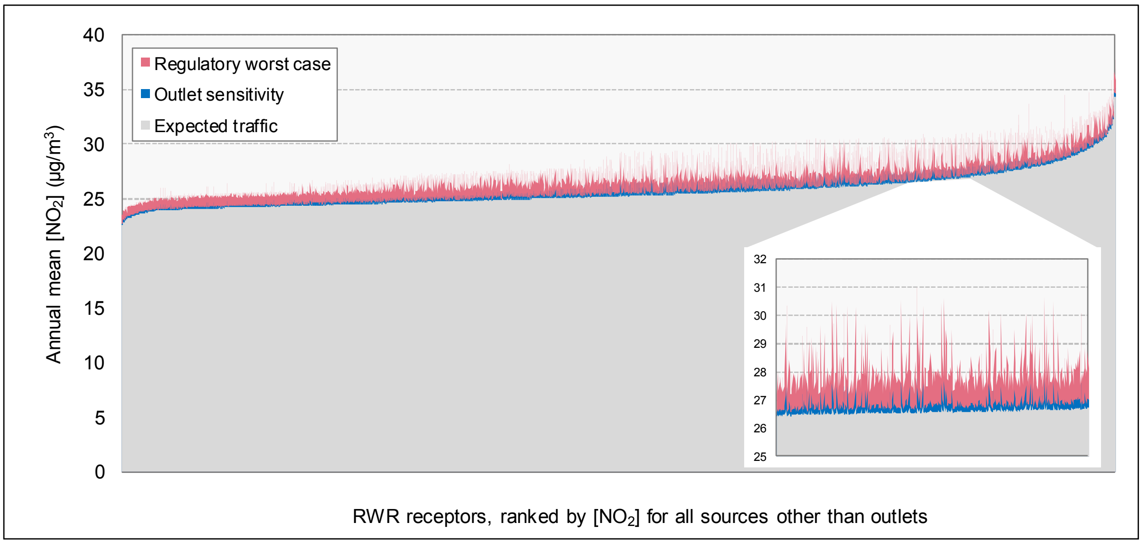


Figure 8-101 Results of traffic/emission sensitivity tests for ventilation outlets – total annual mean NO_2 concentration at RWR receptors (2036-DSC scenario)

Table 8-36 Summary statistics for traffic/emission sensitivity tests for ventilation outlets – total annual mean $PM_{2.5}$ concentration at RWR receptors (2036-DSC scenario)

Statistic	Annual mean $PM_{2.5}$ concentration (µg/m^3)		
	Expected traffic	Sensitivity test	Regulatory worst case
Ventilation outlets only			
Mean	0.05	0.18	0.35
50th percentile (median)	0.04	0.15	0.31
98th percentile	0.16	0.58	0.85
Maximum	0.34	1.25	1.79
Total			
Mean	9.6	9.8	10.0
50th percentile (median)	9.6	9.7	9.9
98th percentile	10.9	11.0	11.3
Maximum	16.1	16.2	16.4

Table 8-37 Summary statistics for traffic/emission sensitivity tests for ventilation outlets – total annual mean NO_2 concentration at RWR receptors (2036-DSC scenario)

Statistic	Annual mean NO_2 concentration (µg/m^3)		
	Expected traffic	Sensitivity test	Regulatory worst case
Ventilation outlets only			
Mean	0.09	0.32	1.45
50th percentile (median)	0.08	0.28	1.29
98th percentile	0.25	0.91	3.14
Maximum	0.42	1.51	5.92
Total			
Mean	25.6	25.8	26.9
50th percentile (median)	25.2	25.5	26.7
98th percentile	29.9	30.2	31.5
Maximum	42.2	42.3	42.9

8.5 Regional air quality

The changes in the total emissions resulting from the project were given in **Table 8-9** and **Table 8-10**. These changes can be viewed as a proxy for the project's regional air quality impacts which, on the basis of the results, are likely to be negligible. For example:

- The changes in NO_X emissions for the assessed road network in a given year ranged from a decrease of 39 tonnes per year to an increase of 27 tonnes per year. The largest increase equated to a very small proportion (around 0.05 per cent) of anthropogenic NO_X emissions in the Sydney airshed in 2016 (around 53,700 tonnes)
- The increase in NOx in a given year was much smaller than the projected reduction in emissions between 2015 and 2036 (around 690 tonnes per year).

The regional air quality impacts of a project can also be framed in terms of its capacity to influence ozone production. NSW EPA has developed a Tiered Procedure for Estimating Ground Level Ozone Impacts from Stationary Sources (ENVIRON, 2011). Although this procedure does not relate specifically to road projects, it was applied here to give an indication of the likely significance of the project's effect on ozone concentrations in the broader Sydney region.

The first step in the procedure involved the classification of the region within which the project is to be located as either an ozone 'attainment' or 'non-attainment' area, based on measurements from OEH monitoring stations over the past five years and criteria specified in the procedure. Following this approach, the project was identified as being in an ozone non-attainment area, although there are few long-term monitoring sites in the study area.

The second step involved the evaluation of the change in emissions due to the project against thresholds for NO_X and VOCs. For both attainment and non-attainment areas the procedure gives an emission threshold for NO_X and VOCs (separately) of 90 tonnes/year for new sources, above which a detailed modelling assessment for ozone may be required. Some lower thresholds are also specified for modified sources and for the scale of ozone non-attainment.

The results in **Table 8-9** show that the largest increase in NO_X emissions (27 tonnes per year in the 2036-DSC scenario) was well below the 90 tonnes/year threshold for assessment. Indeed, this was the only scenario with an increase in overall NO_X emissions. THC emissions decreased in all scenarios.

Overall, it is concluded that the regional impacts of the project would be negligible, and undetectable in ambient air quality measurements at background locations.

8.6 Odour

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 into an equivalent change for three of the odorous pollutants identified in the Approved Methods (toluene, xylenes, 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 8-38**.

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 8-38 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)
2026-DS	65.0	4.7	3.9	1.0
2036-DS	45.6	2.8	2.3	0.9
2036-DSC	41.9	2.5	2.1	0.8
Odour criterion (µg/m^3)		360	190	42

9 Management of impacts

9.1 Management of construction impacts

9.1.1 Construction dust

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 the tables below, 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 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[30]. 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 9-1 Mitigation for all sites: communication

	Mitigation measure	Zones
1	Develop and implement a stakeholder communications plan that includes community engagement before work commences on site.	Highly recommended (Zones 1 – 2)

Table 9-2 Mitigation for all sites: dust management

	Mitigation measure	Zones
2	Develop and implement a Construction Dust Management Plan (CDMP), which may include measures to control other emissions, approved by the local authority. The level of detail will depend on the risk, and should include as a minimum the highly recommended measures in this document. The desirable measures should be included as appropriate for the site.	Highly recommended (Zones 1 – 2)
Site management		
3	Regular communication with sites in close proximity to ensure that measures are in place to manage cumulative dust impacts.	Highly recommended (Zones 1 – 2)
4	Record dust and air quality complaints, identify cause(s), take appropriate measures to reduce emissions in a timely manner, and record the measures taken. Recording exceptional incidents may also help to identify causes for complaints.	Highly recommended (Zones 1 – 2)
5	Liaise 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.	Highly recommended (Zones 1-2)
Monitoring		
6	Carry out regular site inspections to monitor compliance with the CDMP and for potential dust issues. The site inspection, and issues arising, will be recorded. Increase frequency of inspections when on site activities with high potential to produce dust are being carried out during prolonged dry or windy conditions	Highly recommended (Zones 1 – 2)

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

	Mitigation measure	Zones
7	Carry out dust monitoring (deposition, flux or real-time PM_{10} continuous) at locations agreed with local authorities.	Highly recommended (Zones 1 – 2)
Preparing and maintaining the site		
8	Construction activities with the potential to generate dust will be modified or ceased during unfavourable weather conditions to reduce the potential for dust generation.	Highly recommended (Zones 1 – 2)
9	Measures to reduce potential dust generation, such as the use of water carts, sprinklers, dust screens and surface treatments, will be implemented within project sites as required.	Highly recommended (Zones 1 – 2)
10	Unsealed access roads within project sites will be maintained and managed to reduce dust generation.	Highly recommended (Zones 1 – 2)
11	Where reasonable and feasible, appropriate control methods will be implemented to minimise dust emissions from the project site.	Highly recommended (Zones 1 – 2)
12	Storage of materials that have the potential to result in dust generation will be minimised within project sites at all times.	Highly recommended (Zones 1 – 2)
Operating vehicle/machinery and sustainable travel		
13	All construction vehicles and plant will be inspected regularly and maintained to ensure that they comply with relevant emission standards.	Highly recommended (Zones 1 – 2)
14	Engine idling will be minimised when plant are stationary, and plant will be switched off when not in use to reduce emissions.	Highly recommended (Zones 1 – 2)
15	The use of mains electricity will be favoured over diesel or petrol-powered generators where practicable to reduce site emissions.	Highly recommended (Zones 1 – 2)
16	Haul roads will be treated with water carts and monitored during earthworks operations, ceasing works if necessary during high winds where dust controls are not effective.	Highly recommended (Zones 1 – 2)
17	A Sustainability Plan will be produced to manage the sustainable delivery of goods and materials.	Highly recommended (Zones 1 – 2)
Construction		
18	Suitable dust suppression and/or collection techniques will be used during cutting, grinding or sawing activities likely to generate dust in close proximity to sensitive receivers.	Highly recommended (Zones 1 – 2)
19	The potential for dust generation will be considered during the handling of loose materials. Equipment will be selected and handling protocols developed to minimise the potential for dust generation.	Highly recommended (Zones 1 – 2)
20	All vehicles loads will be covered to prevent escape of loose materials during transport.	Highly recommended (Zones 1 – 2)

Table 9-3 Mitigation specific to demolition

	Mitigation measure	Zone 1	Zone 2
21	Demolition activities will be planned and carried out to minimise the potential for dust generation.	Desirable	Highly recommended
22	Adequate dust suppression will be applied during all demolition works where required.	Desirable	
23	All potentially hazardous material will be identified and removed from buildings in an appropriate manner prior to the commencement of demolition.	Desirable	

Table 9-4 Mitigation specific to earthworks

	Mitigation measure	Zone 1	Zone 2
24	Areas of soil exposed during construction will be minimised at all times to reduce the potential for dust generation.	Highly Recommended	
25	Exposed soils will be temporarily stabilised during weather conditions conducive to dust generation and prior to extended periods of inactivity to prevent dust generation.	Highly Recommended	
26	Only small areas of cover at a time will be removed during work to minimise areas exposed to wind erosion.	Highly Recommended	

Table 9-5 Mitigation specific to construction

	Mitigation measure	Zone 1	Zone 2
27	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.	Highly Recommended	Desirable
28	Ensure fine materials (such as bulk cement and other fine powder) are delivered, stored and handled to minimise dust.	Desirable	N/A

Table 9-6 Mitigation specific to track-out of loose material onto roads

	Mitigation measure	Zone 1	Zone 2
29	Use water-assisted dust sweeper(s) on the access and local roads, to remove, as necessary, any material tracked out of the site.	Highly Recommended	
30	During establishment of project compounds, controls such as wheel washing systems and rumble grids will be installed at site exits to prevent deposition of loose material on sealed surfaces outside project sites to reduce potential dust generation.	Highly Recommended	

9.1.2 Odour

The dispersion modelling for odour, presented in **section 7.2**, shows that there are not expected to be any exceedances of the H_2S criteria at sensitive receptors. This is not to say that there will be no odour experienced at these locations, but that it is not predicted to be above the criteria for more than 1% of the time. The level of odour emission is dependent on the odour concentration of the material being excavated and the sizes of the areas left exposed.

Odorous material would be treated immediately on-site, and removed from site where necessary. Areas of odorous materials would be excavated in a staged process to allow for treatment and handling. Exposed areas of odorous material would be kept to a minimum to reduce the total emissions from the site.

On-site odour measurements would be carried out during excavation works to determine odour emission rates. Results from the monitoring would be used to inform future excavation and treatment activities on site.

9.2 Management of operational impacts

9.2.1 Overview

The SEARs for the 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.

9.2.2 Review of approaches

Tunnel design

Tunnel infrastructure will be designed in such a way that the generation of pollutant emissions by the traffic using the tunnel is minimised. The main considerations are minimising gradients and ensuring that lane capacity remains constant or increases from entry to exit point. In-tunnel air quality will be managed through monitoring and management of the ventilation systems and, where necessary, traffic management. This will require sufficient, appropriately placed monitors to calculate a journey average.

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 or stationary
- 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 releasing 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 on 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 levels of pollutants below limit values. In rare cases, traffic entry may need to be restricted by closing lanes, reducing speeds or completely closing the tunnel if air quality limits are being approached or 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 high speed (typically 30 metres per second), and rely on 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 are the only parameters measured for this purpose.

Air treatment

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 also described below.

In Australia, the issue of air treatment frequently arises during the development of new tunnel projects. 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, 2016).

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 produce 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, 2016). 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 one 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 & 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, 2016).

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 reinjected 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, 2016; AECOM, 2014b). A review of the use of the international electrostatic precipitators by country is provided below. Norway and Japan are two countries 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 (2016) 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 (2.1 kilometres) 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 (11 kilometres) 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 two kilometres, 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 (two kilometres), Kanmon (3.5 kilometres), Asukayama (0.6 kilometres), Midoribashi (3.4 kilometres) and Hanazonobashi tunnels (2.6 kilometres). The Tokyo Bay tunnel (9.6 km) is mainly equipped with ceiling-based ESPs (CETU, 2016). 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, 2016). 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, 2016). 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 (2016), 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, 2016).

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, 2016).

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, 2016).

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 construction 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 currently under construction.

Australia

An in-tunnel air treatment system – including ESP and denitrification technologies – was trialled in the Sydney M5 East tunnel, although measurement campaigns have indicated that emissions from the tunnel outlet do not have any significant impact on external air quality. The filtration system was installed 500 metres from the western portal in the westbound tunnel. A structure was built to host the ESP and NO_2 treatment systems, fans, offices and ancillary equipment. A 300 metre ventilation duct to connect the plant to the tunnel was also built. The filtered air from the tunnel, rather than being discharged directly to outside, the air is reinjected into the tunnel and then eventually discharged by the existing outlet. The end-to-end cost of this treatment project was $65 million. The high cost reflects the fact that the tunnel was not originally designed to accommodate such systems (AMOG, 2012).

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 nine metres per second 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 metres per second. At this speed, however, the efficiency drops to just over 80 per cent (Willoughby et al., 2004).

As confirmed in the CETU report, 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 & 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. Roads and Maritime (then 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 trial, 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 six 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
- The ESP was unreliable and was only available for 84 per cent of the trial period
- 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 & Associates (2004) cited the reasons given including low traffic flows, variable efficiency, the 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 (three 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. around 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 (2016), 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 a crowded city area where it is difficult to comply with the local environmental standards for NO_2 (PIARC, 2008; CETU, 2016).

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 this system.

In a review of the trial, 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 was 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 a 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 & 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 & 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, 2016).

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).

9.2.3 Summary and implications for the F6 Extension Stage 1 project

Tunnel design

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

- Minimal gradients. The mainline tunnels would have gradients of less than four per cent and the entry and exit ramp tunnels would not exceed 6.25 per cent. By comparison, the M5 East tunnel has a grade of up to eight per cent on the long western exit, which causes trucks to slow down and increase emissions. Isolated locations connecting to the existing surface road network may require short lengths of steeper grades of up to eight per cent. These grades generally match with existing conditions on local surface roads or are required to ensure appropriate ground conditions. Excessively long entry and exit ramps would be avoided
- The tunnels would 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. The mainline tunnels would have an average width of 12.5 metres and the widths of the entry and exit ramp tunnels would be 11.4 metres.
- Increased height. The height of F6 Extension Stage 1 tunnels will be around 6.5 metres with a clearance height for heavy vehicles to 5.3metres, which will reduce the risk of incidents involving high vehicles blocking the tunnel and leading to disruption of traffic. This would reduce the risk of higher pollutant concentrations associated with flow breakdown.

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 no portal emissions.

The ventilation system would be automatically controlled using real-time air flows and air quality sensor readings, 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 F6 Extension Stage 1 project, and are summarised below:

- F6 Extension Stage 1 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 F6 Extension Stage 1 tunnels 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 0.1 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.

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.

10 Summary and conclusions

This report has presented an assessment of the construction and operational activities for the F6 Extension Stage 1 project that have the potential to affect in-tunnel, local and regional air quality. The main conclusions of the air quality assessment for the project are summarised below.

10.1 Construction impacts

In the absence of specific direction for road and tunnel projects in NSW, the potential impacts of the construction phase of the project were assessed using guidance published by the UK Institute of Air Quality Management. The UK guidance was adapted for use in NSW, taking into account factors such as the assessment criteria for ambient PM_{10} concentrations.

The risks associated with construction dust emissions were assessed for four types of activity: demolition, earthworks, construction, and track-out. The assessment methodology considered three separate dust impacts: annoyance due to dust soiling, the risk of health effects due to an increase in exposure to PM_{10}, and harm to ecological receptors.

For the F6 Extension Stage 1, above-ground construction activities would take place at a number of separate locations, and these were grouped into 2 distinct zones for the purpose of the assessment.

For dust soiling impacts, the sensitivity of assessment zones and all relevant activities was determined to be ‘medium’ for Zone 1 and ‘high’ for Zone 2. For human health impacts, the sensitivity for each area and all relevant activities was determined to be ‘medium’ for Zone 1 and ‘high’ for Zone 2. For ecological impacts, the sensitivity of activities and areas was ‘high’.

Several locations and activities were determined to be of high risk. Consequently, a wide range of management measures has been recommended to mitigate the effects of construction works on local air quality at the nearest receptors. Most of the recommended measures are routinely employed as ‘good practice’ on construction sites.

10.2 Operational impacts

10.2.1 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, regulatory demand, and worst case operations scenarios.

In addition, all possible travel routes through the F6 Extension Stage 1 and the adjoining tunnels were identified for each direction of travel, and these were assessed against the in-tunnel criterion for NO_2 assessed as an average along any route through the tunnel network.

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

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

General conclusions

The following general conclusions have been drawn from this assessment:

- The predicted total concentrations of all criteria pollutants at receptors were usually dominated by the existing background contribution
- For some pollutants and metrics (such as annual mean NO_2) there was also predicted to be a significant contribution from the modelled surface road traffic
- Under expected traffic conditions, the predicted contribution of tunnel ventilation outlets to pollutant concentrations was minimal 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

- For air quality some metrics (1-hour NO_2 and 24-hour PM_{10}), exceedances of the criteria were predicted to occur both with and without the project. However, where this was the case the total numbers of receptors with exceedances decreased slightly with the project and in the cumulative scenarios
- 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.
- The spatial changes in air quality as a result of the project were quite complex, reflecting the complex changes in traffic on the network. For example:
  - With the F6 Extension Stage 1 there were noticeable decreases in $PM_{2.5}$ along several roads, including Botany Street, Southern Cross Drive, General Holmes Drive, The Grand Parade to the North of President Avenue, President Avenue to the east of the F6 Extension Stage 1 project, and March Street. These changes reflected reductions in traffic of between 2 per cent and 22 per cent on these roads. There were increases in concentration along President Avenue to the west of the F6 Extension Stage 1 project and Princes Highway to the south of the junction with Rocky Point Road.
  - For the cumulative scenario (2036-DSC) there were some additional changes associated with the introduction of the full F6 Extension (see **Figure I-24**). These included reductions in $PM_{2.5}$ concentration along The Grand Parade to the south of President Avenue, Sandringham Street and Rocky Point Road. In addition, the increase in concentration on Princes Highway in the Do Something scenarios was converted to a reduction in concentration in the cumulative scenario.
  - With respect to the overall concentration distributions, there was no marked redistribution of air quality impacts. There was no significant increase in concentration at receptor locations which already had a relatively high concentration in the Do Minimum cases.

Pollutant-specific conclusions

Carbon monoxide (maximum 1-hour mean)

- For all receptors and scenarios, the predicted maximum 1-hour CO concentration was well below the NSW impact assessment criterion of 30 $\mu g/m^3$, as well as the lowest international air quality standard identified in the literature (22 $\mu g/m^3$)
- There was an increase in CO at between 26 and 43 per cent of RWR receptors, although even the largest increases were an order of magnitude below the criterion
- The largest contribution from ventilation outlets at any receptor was less than 0.09 mg/m^3 (equating to 0.3 per cent of the criterion).

Carbon monoxide (maximum rolling 8-hour mean)

- As with the 1-hour mean, at all receptors the concentration was well below the NSW impact assessment criterion, which in this case is 10 $\mu g/m^3$. No lower criteria appear to be in force internationally
- The largest increase at any community receptor with the project or in the cumulative scenarios was around 0.06 mg/m^3 (equating to 0.6 per cent of the criterion).

Nitrogen dioxide (annual mean)

- At all receptors, the NO_2 concentration was well below the NSW impact assessment criterion of 62 $\mu g/m^3$. At all but two receptors the NO_2 concentration was also below the EU limit value of 40 $\mu g/m^3$. Concentrations at the vast majority (more than 98 per cent) of receptors were between around 20 $\mu g/m^3$ and 30 $\mu g/m^3$
- The maximum contribution of tunnel ventilation outlets for any scenario and receptor was 0.5 $\mu g/m^3$ (equating to 0.8 per cent of the criterion). The maximum surface road contribution was 21 $\mu g/m^3$. Given that NO_2 concentrations at the majority of receptors were well below the NSW criterion, the contribution of the ventilation outlets was not a material concern

- There was predicted to be an increase in the annual mean NO_2 concentration at around 40 per cent of receptors in the Do Something scenarios, and 17 per cent in the 2036 cumulative scenario. Whilst the largest increases in annual NO_2 were around 1.6 μg/m^3, the increase was greater than 0.5 μg/m^3 for no more than 3 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 a mixture of small increases and decreases, although again the increases did not result in any exceedances of the NSW criterion.
- At the RWR receptors, there were small numbers of predicted exceedances of the NSW 1-hour NO_2 criterion, both with and without the project. The number of receptors with exceedances decreased with the project, although in the cumulative scenario the number of receptors with an exceedance increased slightly.
- There was predicted to be an increase in the annual mean NO_2 concentration at around 40 per cent of receptors in the Do Something scenarios, and 24 per cent in the 2036 cumulative scenario
- At the majority of receptors the change was relatively small; at around 95 per cent of receptors the change in concentration (either an increase or a decrease) was less than 5 μg/m^3. Some of the changes at receptors were larger (up to 42 μg/m^3). However, as noted above, these changes did not result in any exceedances of air quality standards
- The maximum contribution of tunnel outlets to NO_X at any receptor in the with-project or cumulative scenarios was 54 μg/m^3 in the cumulative scenario. This would equate to a very small NO_2 contribution relative to the air quality assessment criterion.

PM_{10} (annual mean)

- The concentration at the majority of receptors was below 20 μg/m^3, with only three receptors having a concentration just above the NSW assessment criterion of 25 μg/m^3.
- The surface road contribution was less than 12 μg/m^3, with an average of 1.3 μg/m^3. The largest contribution from tunnel ventilation outlets at any receptor was 0.5 μg/m^3 (equating to 2 per cent of the criterion)
- There was an increase in concentration at 30–48 per cent of the receptors, depending on the scenario. At the majority of receptors the change was relatively small, and where there was an increase, this was greater than 0.25 μg/m^3 (one per cent of the criterion) at less than 2 per cent of receptors.

PM_{10} (maximum 24-hour mean)

- At all community receptor locations, the maximum concentration was close to the NSW impact assessment criterion of 50 μg/m^3, which is also the most stringent standard in force internationally
- The results for the RWR receptors were highly dependent on the assumption for the background concentration. Because this was quite high (43.6 μg/m^3), the total concentration in the with-project and cumulative scenarios was above the NSW impact assessment criterion of 50μg/m^3 at between 8 and 10 per cent of receptors. However, the proportion of receptors with a concentration above the criterion decreased slightly as a result of the project
- The maximum contribution of tunnel ventilation outlets at any receptor was 2.0 μg/m^3 to 2.5 μg/m^3, depending on the scenario (equating to a maximum of 5 per cent of the criterion)
- There was an increase in concentration at between 29 and 45 per cent of receptors, depending on the scenario. Where there was an increase, this was greater than 0.5 μg/m^3 (one per cent of the criterion) at 4-8 per cent of receptors, depending on the scenario.

$PM_{2.5}$ (annual mean)

- The predictions for annual mean $PM_{2.5}$ were based on a mapped background of between 8.0 and 9.2 µg/m^3, and therefore exceedances of the NSW criterion of 8 µg/m^3 were predicted at all receptors. Clearly, there would also be exceedances of the AAQ NEPM long-term target of 7 µg/m^3. Internationally, there are no standards lower than 8 µg/m^3 for annual mean $PM_{2.5}$.
- The highest concentration at any receptor was 16.3 µg/m^3. In the with-project and cumulative scenarios, the largest surface road contribution was 7.1 µg/m^3. The largest contribution from tunnel ventilation outlets in these scenarios was 0.34 µg/m^3 (equating to 4 per cent of the criterion)
- There was an increase in concentration at between 31 per cent and 46 per cent of receptors, depending on the scenario. The largest predicted increase in concentration at any receptor as a result of the project was 0.45 µg/m^3. Where there was an increase, this was greater than 0.1 µg/m^3 at around 4 per cent of receptors
- No RWR receptor had a value for $\Delta PM_{2.5}$ that was above the acceptable threshold of 1.8 µg/m^3.

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

- Given the high background concentration for 24-hour $PM_{2.5}$, the total concentration at around 40 per cent receptors was above the NSW impact assessment criterion of 25 µg/m^3, although exceedances were already predicted without the project
- The maximum contribution of tunnel outlets at receptors with the project and in the cumulative scenario was 1.6 µg/m^3 (equating to 6 per cent of the criterion)
- The largest predicted increase in concentration at any receptor as a result of the project was 1.5 µg/m^3 (2026-DS scenario). For most of the receptors the change in concentration was small; where there was an increase in concentration, this was greater than 0.5 µg/m^3 at only 1–2 per cent of receptors.

Air toxics

- Four air toxics – benzene, PAHs (as BaP), formaldehyde, 1,3-butadiene and ethylbenzene – 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.

10.2.3 Ambient air quality (expected traffic, elevated receptors)

Concentrations at the RWR receptor locations and at four additional heights (10, 20, 30 and 45 metres) were considered for annual mean and 24-hour $PM_{2.5}$. However, it was not necessarily the case that there were existing buildings at these heights at the RWR receptor locations.

For both annual mean and 24-hour $PM_{2.5}$ the patterns in the contour plots showed the surface road influence diminishing with height and the ventilation outlet influence becoming more distinct.

The largest increases in the annual mean $PM_{2.5}$ concentration at the heights of 10 metres and 20 metres were lower than at ground level. Although the maximum increase in annual mean $PM_{2.5}$ at 30 metres was larger than that at 10 metres and 20 metres (due to the increased influence of the outlets), it was still below the maximum increase at ground level. The situation at a height of 45 metres was different. At this height, the maximum increase at any receptor location (1.58 µg/m^3) was markedly higher than at ground level. However, none of the receptor locations with an increase in annual mean $PM_{2.5}$ of more than 0.1 µg/m^3 had a building height of more than 20 metres.

In the case of the maximum 24-hour $PM_{2.5}$ concentration the largest increase in concentration at the RWR receptor locations was slightly lower at a height of 10 metres than at ground level. It decreased further at a height of 20 metres, but began to increase again at a height of 30 metres and had increased markedly (to around 15 µg/m^3) by a height of 45 metres. None of the receptors with an increase in maximum 24-hour $PM_{2.5}$ of more than 0.5 µg/m^3 had a height of more than 10 metres.

The implications of these results can be summarised as follows:

- For all existing receptor locations, and assuming no further construction at those locations, the changes in annual mean $PM_{2.5}$ concentration at heights of up to 45 metres above ground level are acceptable (i.e. lower than at ground level, and/or below the criterion for $\Delta PM_{2.5}$ of 1.8 µg/m^3).
- For all existing receptor locations, and assuming no further construction at those locations, the changes in maximum 24-hour $PM_{2.5}$ concentration are likely to be acceptable up to a height of 30 metres (i.e. they are lower than at ground level). At a height of 45 metres the largest increases in concentration are considerably higher than at ground level, but at the relevant locations there are no existing or proposed buildings above this height.
- The results therefore do not seem to impose any significant additional restrictions on future developments to 45 metres height at existing RWR locations. However, planning controls should be developed in the vicinity of ventilation outlets to ensure that future developments at heights of 30 metres or higher are not adversely impacted by the ventilation outlets. Development of planning controls would be supported by detailed modelling addressing all relevant pollutants and averaging periods.

10.2.4 Ambient air quality (regulatory worst case)

The concentrations in the regulatory worst case scenario 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 1-hour CO concentration was negligible, especially taking into account the fact that CO concentrations are well below the NSW impact assessment criterion. For example, the maximum 1-hour outlet contribution in the regulatory worst case scenario (0.76 mg/m^3) was a very small fraction of the criterion (30 mg/m^3). The maximum background 1-hour CO concentration (3.13 mg/m^3) was also well below the criterion. Exceedances of the criterion due to the ventilation outlets are therefore highly unlikely to occur
- For PM_{10} the maximum contribution of the ventilation outlets would be small. For the annual mean and maximum 24-hour metrics the outlet contributions were 7 per cent and 20 per cent of the respective criteria. This would be significant for some receptors, but any exceedances of the criteria would be dominated by background concentrations.
- The ventilation outlet contribution would be most important for $PM_{2.5}$, with the maximum contributions equating to 22 per cent and 40 per cent of the annual mean and 24-hour criteria respectively. Again, any exceedances of the criteria would be dominated by background concentrations.

For annual mean NO_2, The maximum outlet concentrations in the regulatory worst case were an order of magnitude higher than those in the expected traffic case, although total concentrations would still remain below the NSW air quality criterion.

A detailed analysis was conducted for 1-hour NO_2. Although in some cases the ventilation outlet contributions appeared to be substantial, this was deceptive. As the background and surface road contributions (and hence total NOx) increased, there was a pronounced reduction in the contribution of the outlets to NO_2. The analysis showed that maximum outlet contribution occurred when other contributions were low, such that overall NO_2 concentrations were well below the criterion or even the predicted maximum.

Moreover, 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.

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 used in the regulatory worst case assessment.

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

10.3 Management of impacts

10.3.1 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 project. This should contain details of the site-specific mitigation measures to be applied.

10.3.2 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 less than four per cent
- Large main line tunnel cross-sectional area. The mainline tunnels would have widths varying between 10.5 to 16.0 metres and be higher than most previous tunnels
- Increased height to reduce the risk of incidents involving high vehicles blocking the tunnel and disrupting 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 air velocity and air quality sensor data to ensure that 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:

- 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 F6 Extension Stage 1 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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