Appendix

H

Appendix H

Air quality

January 2020

Roads and Maritime Services

Western Harbour Tunnel and Warringah Freeway Upgrade

Technical working paper: Air quality

January 2020

Prepared for

Roads and Maritime

Prepared by

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Glossary of terms and abbreviations

Term	Definition
A	
AAQ NEPM	National Environment Protection (Ambient Air Quality) Measure
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.
BaP	Benzo(a)pyrene
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
DPF	diesel particulate filter
DSEWPC	(Commonwealth) Department of Sustainability, Environment, Water, Population and Communities
E	
EC	elemental carbon
EIA	environmental impact assessment
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).

Term	Definition
Emission rate	A quantity which expresses the mass of a pollutant emitted per unit of time (eg 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
NO_X	oxides of nitrogen
NPI	National Pollutant Inventory
NSW	New South Wales
NSW EPA	(NSW) Environment Protection Authority
O	
O_3	Ozone
OC	organic carbon

Term	Definition
OEH	The former (NSW) Office of Environment and Heritage (now part of the Department of Planning, Industry and Environment)
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
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
SMPO	Sydney Motorways Project Office
SO_2	sulfur dioxide
SO_X	sulfur oxides
SPI	St Peters interchange
T	
TAPM	The Air Pollution Model
TEOM	Tapered Element Oscillating Microbalance, a type of instrument used for measuring airborne particulate matter
TfNSW	Transport for NSW
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

Term	Definition
W	
WHO	World Health Organization
WHTBL	Western Harbour Tunnel and Beaches Link
Other	
$\mu g/m^3$	micrograms per cubic metre

Executive summary

E.1 The project

NSW Roads and Maritime Services (Roads and Maritime) is seeking approval under Division 5.2, Part 5 of the *Environmental Planning and Assessment Act 1979* (EP&A Act) to construct and operate the Western Harbour Tunnel and Warringah Freeway Upgrade (the project), which would comprise two main components:

- A new crossing of Sydney Harbour involving twin tolled motorway tunnels connecting the WestConnex M4-M5 Link at Rozelle and the existing Warringah Freeway at North Sydney (the Western Harbour Tunnel)
- Upgrade and integration works along the existing Warringah Freeway, including allowance for connections to the Beaches Link and Gore Hill Freeway Connection project (the Warringah Freeway Upgrade).

E.2 The purpose of this report

This report has been prepared to support the environmental impact statement for the project. The environmental impact statement has been prepared to accompany the application for approval of the project and address the requirements of the air quality section of the Secretary's environmental assessment requirements for the project, issued on 15 December 2017. 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.

E.3 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 settlement the risk of health effects due to an increase in human exposure, and harm to ecological receptors. Above-ground construction activities would take place at a number of separate locations.

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 potential odour impacts from dredged material during construction showed the predicted odour levels are likely to be well below odour assessment criteria.

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

E.4 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 2027 and 2037
- Worst case traffic scenarios. These simulations addressed the most onerous traffic conditions for the ventilation system to manage air quality, and included capacity traffic at speeds of between 20 and 80 kilometres per hour, vehicle breakdown, and free-flowing traffic at maximum capacity.
- Travel route scenarios. All the possible routes within the Western Harbour Tunnel and Beaches Link tunnels were identified for each direction of travel, and route-average NO_2 concentrations were assessed against the corresponding in-tunnel criterion.

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 acceptable limits for all scenarios.

E.5 Operational impacts – local air quality (expected traffic)

E.5.1 Scenarios

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

- Expected traffic scenarios. These included:
  - ‘Base case’. 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
  - ‘Do minimum 2027’. This scenario represented conditions in the opening year of the project, but without the project
  - ‘Do something 2027’. As ‘Do minimum 2027’, but with the Western Harbour Tunnel and Warringah Freeway Upgrade also completed
  - ‘Do something cumulative 2027’. As ‘Do something 2027’, but with Sydney Gateway, Beaches Link, Gore Hill Freeway Connection and F6 Extension – Stage 1 also completed
  - ‘Do minimum 2037’. As ‘Do minimum 2027’, but for 10 years after project opening and without the project
  - ‘Do something 2037’. As ‘Do something 2027’, but for 10 years after project opening
  - ‘Do something cumulative 2037’. As ‘Do something cumulative 2027’, but with all stages of the F6 Extension 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.

E.5.2 Methodology and conclusions

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 tunnel portals (Sydney Harbour Tunnel and Eastern Distributor only)
- 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, 11 separate tunnel ventilation outlets were included in the assessment. This included outlets associated with the project as well as existing or future projects (M4-M5 Link, Cross City Tunnel and Lane Cove Tunnel). The outlets associated with existing or future projects were included to assess potential cumulative impacts only.

Emission modelling – existing tunnel portals

For two tunnels in the model domain – Sydney Harbour Tunnel and the Eastern Distributor tunnel – emissions from portals are permitted. The traffic in these tunnels, and hence emissions from the portals, were affected by the project. It was assumed that the emissions from the traffic in each tunnel would be released from the portals at all times (ie there would be no emissions from the tunnel ventilation outlets). This is a worst case assumption as these sources are at ground level. Emission rates were estimated using a model in conjunction with a simplified tunnel geometry and traffic data from the SMPM. Air flows from the tunnel portals in all scenarios were based on recently observed diurnal profiles.

Emission modelling – surface roads

The road network (including tunnels) had between 5867 and 5972 individual road links, depending on the scenario. Data on traffic volume, composition and speed were taken from SMPM. The vehicle fleet composition would change over time as cleaner vehicles enter the fleet; however, the fleet forecast for this assessment is considered to be conservative in that it does not account for alternate-fuel and low-emission vehicle technologies (eg electric vehicles, hybrids).

Comparing the ‘Do something 2027’ scenario with the ‘Do minimum 2027’ scenario, emissions of CO increased by around three per cent. There was little change in emissions of NO_X, PM_{10}, $PM_{2.5}$ and total hydrocarbons (THC). In 2037, emissions of all pollutants decreased by less than one per cent, with the exception of CO which increased by around three per cent. For the ‘Do something cumulative 2027’ scenario, emissions of CO increased relative to the ‘Do minimum 2027’ scenario by around five per cent, emissions of NO_X, PM_{10} and $PM_{2.5}$ increased by 0.8 to 1.3 per cent, and emissions of THC decreased by three per cent. Again, in ‘Do something cumulative 2037’ the emissions of all pollutants increased with the exception of THC which remained unchanged.

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 (30 x 30 kilometres) covered the full project. 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:

- Forty two ‘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 1500 metres either side of the Western Harbour Tunnel and Beaches Link program of works 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.
- A maximum of 35490 ‘residential, workplace and recreational (RWR) receptors’. These were all discrete receptor locations along the Western Harbour Tunnel and Beaches Link program of works 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.

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.

E.6 Operational impacts – local air quality (expected traffic, elevated receptors)

Concentrations at four elevated receptor heights (10, 20, 30 and 45 metres) were considered for annual mean and 24-hour $PM_{2.5}$ at all RWR receptor locations. Existing buildings are not at all of these heights at all RWR receptor locations.

For existing buildings at the heights considered in the assessment, the changes in annual mean $PM_{2.5}$ concentrations were less than 1.7 µg/m^3. Changes in maximum 24-hour average $PM_{2.5}$ concentrations at these existing buildings are less than 2 µg/m^3.

For potential future development, the changes in annual mean $PM_{2.5}$ concentrations at heights of up to 30 metres above ground level are below 1.7 µg/m^3. Above this height, and within 300 metres of the ventilation outlets, the changes in annual mean $PM_{2.5}$ concentrations can exceed 1.7 µg/m^3. For potential future development, the changes in maximum 24-hour $PM_{2.5}$ concentrations at heights of up to 20 metres above ground level are very low, but increase to 9 µg/m^3 at 45 metres.

The results indicate that:

- There are no adverse impacts predicted at any existing buildings at any height
- There are no adverse impacts predicted at any existing or future buildings up to a height of 20 metres
- There are impacts predicted for potential future buildings above 20 metres in height within 300 metres of the outlets, but this would not necessarily preclude such development. Further consideration at rezoning or development application stage would be required.

However, within 300 metres of the Warringah Freeway outlet, current planning controls for permissible habitable structures restrict buildings to below 20 metres. There are no restrictions to building heights within 300 metres of the Rozelle Interchange outlet.

From this, land use considerations would be required to manage any interaction between the project and future development for buildings above 20 metres and within 300 metres of the ventilation outlet.

E.7 Operational impacts – local air quality (regulatory worst case)

The regulatory worst case assessed the maximum theoretical increase in ambient air quality due to the ventilation outlets operating continuously at the proposed emission limits. The concentrations from the ventilation outlets in the regulatory worst case scenarios were higher than those for the expected traffic scenarios. 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. Exceedances of the criterion due to the ventilation outlets are highly unlikely
- For PM_{10} the annual mean and maximum 24-hour metrics the ventilation outlet contributions were four per cent and 14 per cent of the respective criteria. Any exceedances of the criteria are dominated by background concentrations
- The ventilation outlet contribution would be more important for $PM_{2.5}$, with the maximum contributions equating to 11 per cent and 28 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 ventilation 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. In some cases, the ventilation outlet contributions appeared to be substantial; however, as the background, surface road and tunnel portal contributions (and total NO_X) increase, there is a pronounced reduction in the ventilation outlet contribution to NO_2. The analysis showed that the 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. Exceedances of the criteria due to the ventilation outlets alone would therefore be unlikely
- 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 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.

E.8 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.

E.9 Management of impacts

E.9.1 Construction impacts

Levels of risk for potential impacts were identified based on the proximity and sensitivity of nearby receptors and the magnitude of dust generating activities near those receptors. A range of measures for the management of these risks, to reduce these potential impacts, has been provided in the report. Most of the recommended measures are routinely employed as standard practice on construction sites.

E.9.2 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:

- Minimising gradients as far as reasonably practicable
- Large tunnel cross-sectional area to reduce the pollutant concentration for a given emission into the tunnel volume, and to permit greater volumetric air throughput. The tunnels would have a width of varying between nine to 12.5 metres and, with a vertical clearance of about 5.3 metres, which would be higher than most previous tunnels
- Increased height to reduce the risk of incidents involving high vehicles blocking the tunnel and disrupting traffic. This would reduce the risk of higher pollutant concentrations associated with flow breakdown.

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

1.1 Overview

The Greater Sydney Commission's Greater Sydney Region Plan – A Metropolis of Three Cities (Greater Sydney Commission, 2018) proposes a vision of three cities where most residents have convenient and easy access to jobs, education and health facilities and services. In addition to this plan, and to accommodate for Sydney's future growth the NSW Government is implementing the Future Transport Strategy 2056 (Transport for NSW, 2018), a plan that sets the 40 year vision, directions and outcomes framework for customer mobility in NSW. The Western Harbour Tunnel and Beaches Link program of works is proposed to provide additional road network capacity across Sydney Harbour and to improve transport connectivity with Sydney's northern beaches. The Western Harbour Tunnel and Beaches Link program of works include:

- The Western Harbour Tunnel and Warringah Freeway Upgrade project comprises a new tolled motorway tunnel connection across Sydney Harbour, and an upgrade of the Warringah Freeway to integrate the new motorway infrastructure with the existing road network and to connect to the Beaches Link and Gore Hill Freeway Connection project
- The Beaches Link and Gore Hill Freeway Connection project which comprises a new tolled motorway tunnel connection across Middle Harbour from the Warringah Freeway and Gore Hill Freeway to Balgowlah and Killarney Heights and including the surface upgrade of Wakehurst Parkway to Frenchs Forest and upgrade and integration works to connect to the Gore Hill Freeway at Artarmon.

A combined delivery of the Western Harbour Tunnel and Beaches Link program of works would unlock a range of benefits for freight, public transport and private vehicle users. It would support faster travel times for journeys between the Northern Beaches and south and west of Sydney Harbour. Delivering the program of works would also improve the resilience of the motorway network, given that each project provides an alternative to heavily congested harbour crossings.

1.2 The project

Roads and Maritime Services (Roads and Maritime) is seeking approval under Division 5.2, Part 5 of the *Environmental Planning and Assessment Act 1979* (EP&A Act) to construct and operate the Western Harbour Tunnel and Warringah Freeway Upgrade (the project), which would comprise two main components:

- A new crossing of Sydney Harbour involving twin tolled motorway tunnels connecting the M4-M5 Link at Rozelle and the existing Warringah Freeway at North Sydney (the Western Harbour Tunnel)
- Upgrade and integration works along the existing Warringah Freeway, including allowance for connections to the Beaches Link and Gore Hill Freeway Connection project (the Warringah Freeway Upgrade).

Key features of the Western Harbour Tunnel component of the project are shown in Figure 1-1 and would include:

- Twin mainline tunnels about 6.5 kilometres long and each accommodating three lanes of traffic in each direction, connecting the stub tunnels from the M4-M5 Link at Rozelle to the Warringah Freeway and to the Beaches Link mainline tunnels at Cammeray. The crossing of Sydney Harbour between Birchgrove and Waverton would involve a dual three lane, immersed tube tunnels
- Connections to the stub tunnels at the M4-M5 Link project in Rozelle and to the mainline tunnels at Cammeray (for a future connection to the Beaches Link and Gore Hill Freeway Connection project)
- Surface connections at Rozelle, North Sydney and Cammeray, including direct connections to and from the Warringah Freeway (including integration with the Warringah Freeway Upgrade), an off ramp to Falcon Street and an on ramp from Berry Street at North Sydney

- A ventilation outlet and motorway facilities (fitout and commissioning only) at the Rozelle Interchange
- A ventilation outlet and motorway facilities at the Warringah Freeway
- Operational facilities including a motorway control centre at Waltham Street, within the Artarmon industrial area and tunnel support facilities at the Warringah Freeway in Cammeray
- Other operational infrastructure including groundwater and tunnel drainage management and treatment systems, signage, tolling infrastructure, fire and life safety systems, lighting, emergency evacuation and emergency smoke extraction infrastructure, CCTV and other traffic management systems.

Key features of the Warringah Freeway Upgrade component of the project are shown in Figure 1-2 and would include:

- Upgrade and reconfiguration of the Warringah Freeway from immediately north of the Sydney Harbour Bridge through to Willoughby Road at Naremburn
- Upgrades to interchanges at Falcon Street in Cammeray and High Street in North Sydney
- New and upgraded pedestrian and cyclist infrastructure
- Connection of the Warringah Freeway to the portals for the Western Harbour Tunnel mainline tunnels and the Beaches Link tunnels via on and off ramps, which would consist of a combination of trough and cut and cover structures
- Upgrades to existing roads around the Warringah Freeway to integrate the project with the surrounding road network
- Upgrades and modifications to bus infrastructure, including relocation of the existing bus layover along the Warringah Freeway
- Other operational infrastructure, including surface drainage and utility infrastructure, signage, tolling, lighting, CCTV and other traffic management systems.

A detailed description of the project is provided in Chapter 5 (Project description) and construction of the project is described in Chapter 6 (Construction works) of the environmental impact statement. The project alignment at the Rozelle Interchange shown in Figure 1-1 and Figure 1-3 reflects the arrangement presented in the environmental impact statement for the M4-M5 Link, and as amended by the proposed modifications. The project would be constructed in accordance with the finalised M4-M5 Link detailed design (refer to Section 2.1.1 of Chapter 2 (Assessment process) of the environmental impact statement for further details).

The project does not include ongoing motorway maintenance activities during operation or future use of residual land occupied or affected by project construction activities, but not required for operational infrastructure. These would be subject to separate planning and processes at the relevant times.

Subject to the project obtaining planning approval, construction is anticipated to commence in 2020 and is expected to take around six years to complete.

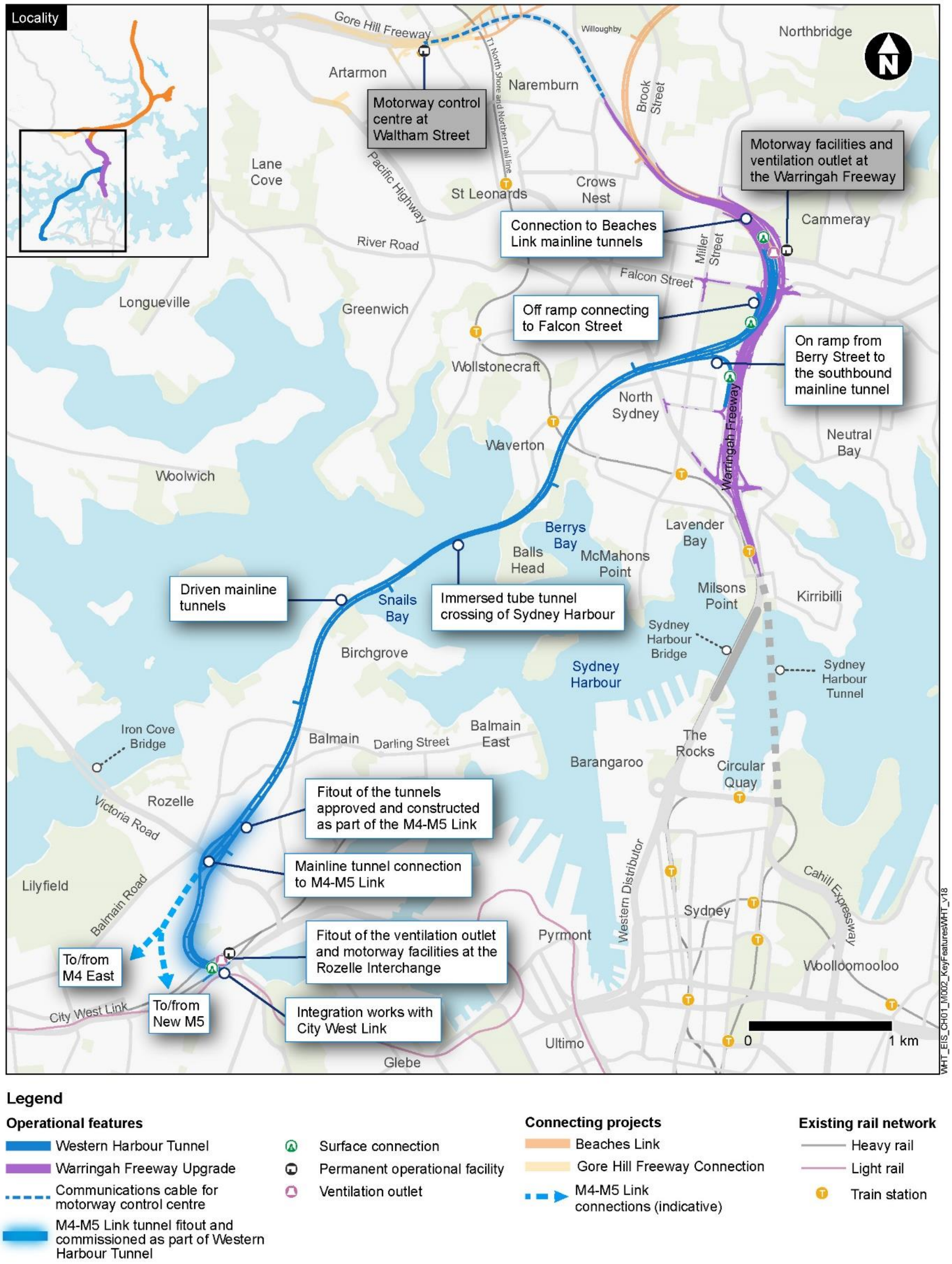

Figure 1-1 Key features of the Western Harbour Tunnel component of the project

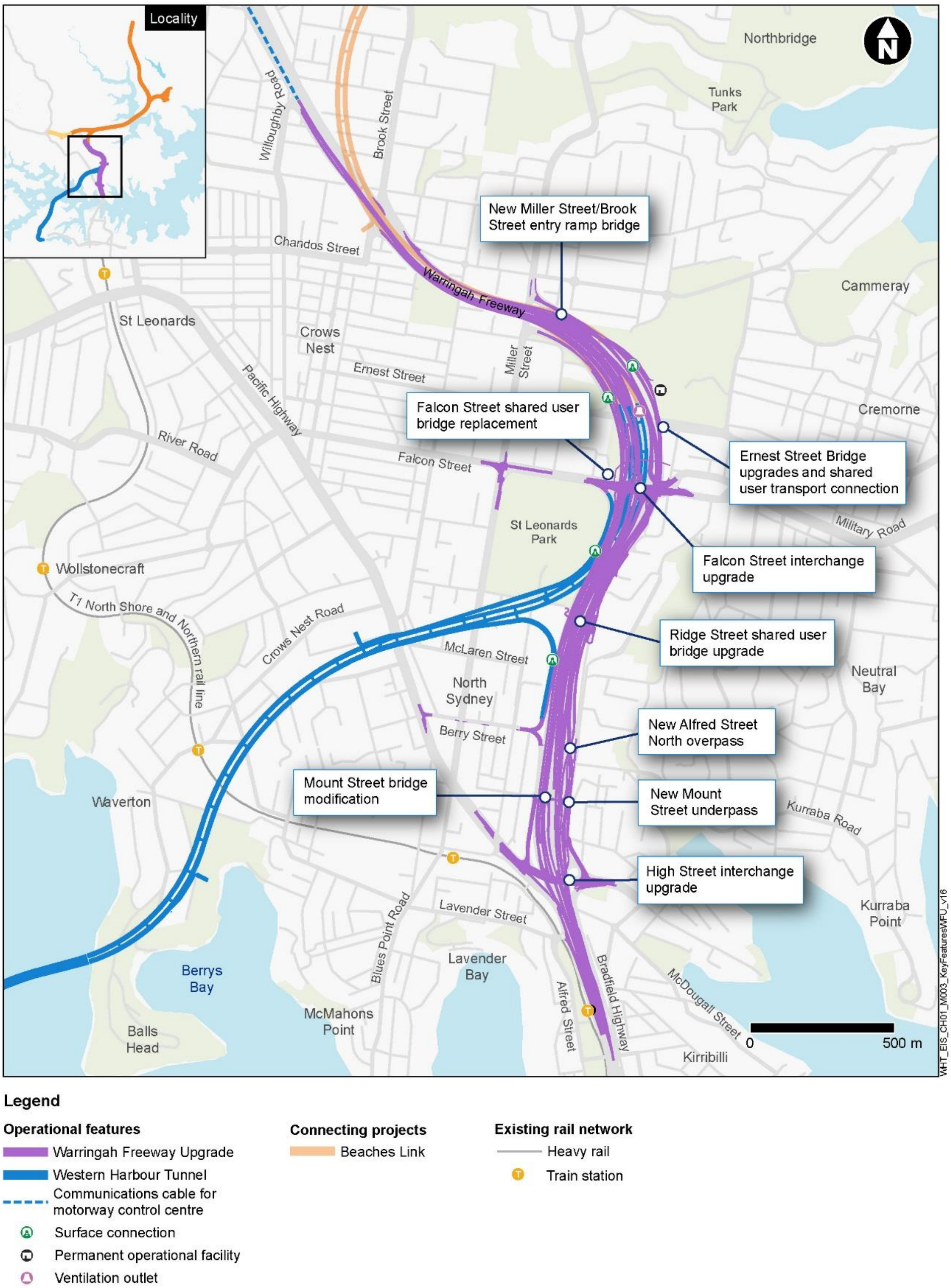

Figure 1-2 Key features of the Warringah Freeway Upgrade component of the project

1.3 Key construction activities

The area required to construct the project is referred to as the construction footprint. The majority of the construction footprint would be located underground within the tunnels. However, surface areas would be required to support tunnelling activities and to construct the tunnel connections, tunnel portals and operational ancillary facilities.

Key construction activities would include:

- Early works and site establishment, with typical activities being property acquisition, utilities protection, adjustments and relocations, installation of site fencing, environmental controls (including noise attenuation) and traffic management controls, vegetation clearing, earthworks and demolition of structures, establishment of construction support sites including acoustic sheds and associated access decline acoustic enclosures (where required), temporary relocation of swing moorings within Berrys Bay, and relocation of the historic vessels
- Construction of Western Harbour Tunnel, with typical activities being excavation of tunnel construction accesses, construction of driven tunnels, cut and cover and trough structures and construction of cofferdams, dredging activities in preparation for the installation of immersed tube tunnels, casting and installation of immersed tube tunnels and civil finishing and tunnel fitout
- Construction of operational facilities comprising of a motorway control centre at Artarmon, motorway and tunnel support facilities and ventilation outlets at Cammeray, construction and fitout of the project operational facilities that form part of the M4-M5 Link Rozelle East Motorway Operations Complex, a wastewater treatment plant at Rozelle and the installation of motorway tolling infrastructure
- Construction of the Warringah Freeway Upgrade, with typical activities being earthworks, bridgeworks, construction of retaining walls, stormwater drainage, pavement works and linemarking and the installation of road furniture, lighting, signage and noise barriers
- Testing of plant and equipment, and commissioning of the project, backfill of access declines, removal of construction support sites, landscaping and rehabilitation of disturbed areas and removal of environmental and traffic controls.

Temporary construction support sites would be required as part of the project (refer to Figure 1-3), and would include tunnelling and tunnel support sites, civil surface sites, cofferdams, mooring sites, wharf and berthing facilities, laydown areas, parking and workforce amenities. Construction support sites for Western Harbour Tunnelwould include:

- Rozelle Rail Yards (WHT1)
- Victoria Road (WHT2)
- White Bay (WHT3)
- Yurulbin Point (WHT4)
- Sydney Harbour south cofferdam (WHT5)
- Sydney Harbour south cofferdam (WHT6)
- Berrys Bay (WHT7)
- Berry Street north (WHT8)
- Ridge Street north (WHT9)
- Cammeray Golf Course (WHT10)
- Waltham Street (WHT11).

During the construction of the Warringah Freeway Upgrade, smaller construction support sites would be required to support the construction works (as shown on Figure 1-3). These include:

- Blue Street (WFU1)
- High Street south (WFU2)

- High Street north (WFU3)
- Arthur Street east (WFU4)
- Berry Street east (WFU5)
- Ridge Street east (WFU6)
- Merlin Street (WFU7)
- Cammeray Golf Course (WFU8)
- Rosalind Street east (WFU9).

A detailed description of construction works for the project is provided in Chapter 6 (Construction work) of the environmental impact statement.

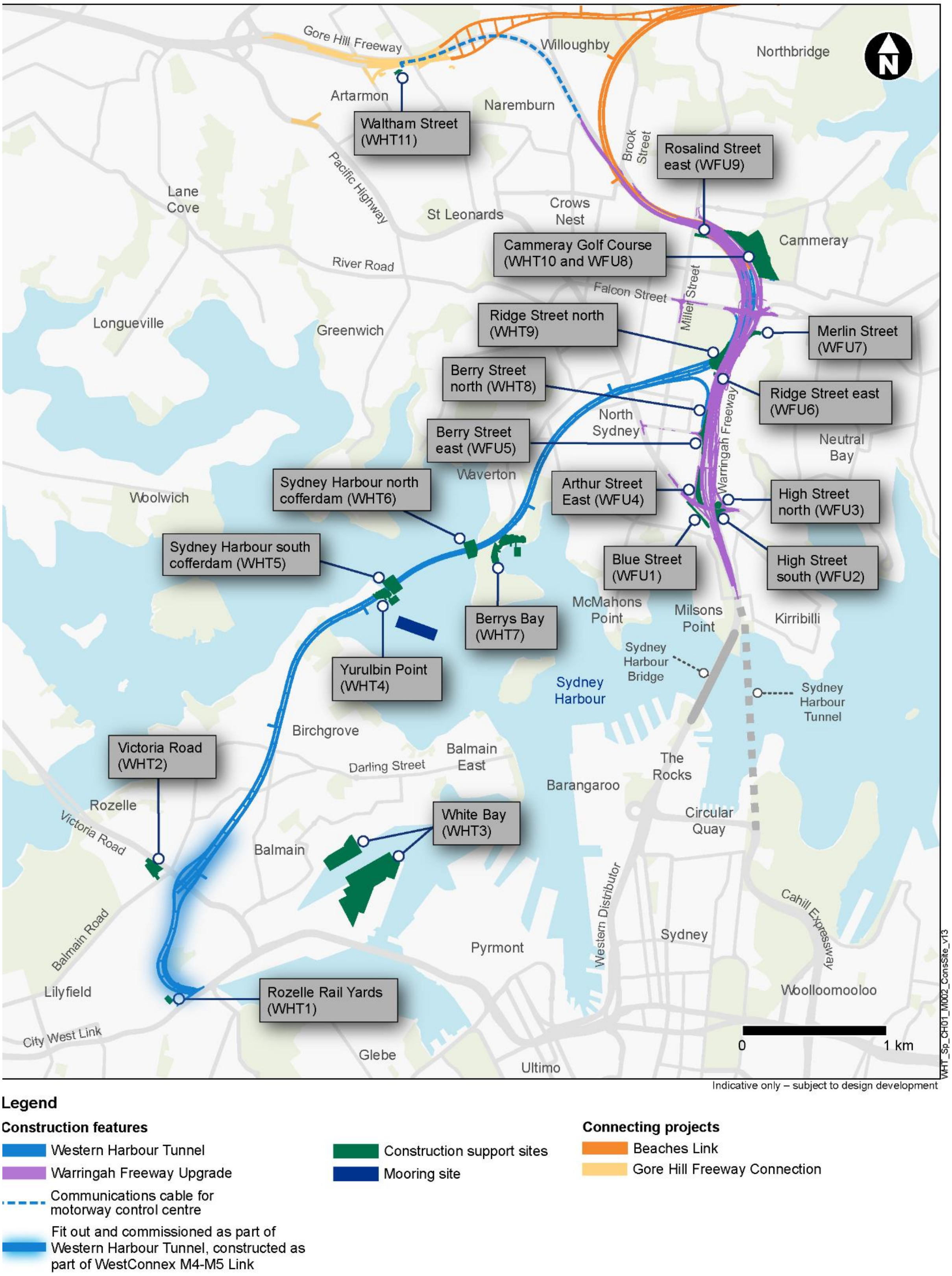

Figure 1-3 Overview of construction sites

1.4 Project location

The project would be located within the Inner West, North Sydney and Willoughby local government areas, connecting Rozelle in the south with Naremburn in the north.

Commencing at the Rozelle Interchange, the mainline tunnels would pass under Balmain and Birchgrove, then cross Sydney Harbour between Birchgrove and Balls Head. The tunnels would then continue under Waverton and North Sydney, linking directly to the Warringah Freeway to the north of the existing Ernest Street bridge.

The motorway control centre would be located at Waltham Street, Artarmon, with a trenched communications cable connecting the motorway control centre to the Western Harbour tunnel along the Gore Hill Freeway and Warringah Freeway road reserves.

The Warringah Freeway Upgrade would be carried out on the Warringah Freeway from around Fitzroy Street at Milsons Point to around Willoughby Road at Naremburn. Upgrade works would include improvements to bridges across the Warringah Freeway, and upgrades to surrounding roads.

1.5 Purpose of this report

This report has been prepared to support the environmental impact statement for the project and to address the environmental assessment requirements of the Secretary of the Department of Planning. Infrastructure and Environment (Planning and Assessment) (formerly Department of Planning and Environment) ('the Secretary's environmental assessment requirements').

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 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 construction is assessed in the report and a comprehensive range of management measures is recommended
  - The potential for local ambient air quality impacts during operation is assessed in detail, and the report demonstrates that the proposed ventilation system would be effective at maintaining ambient air quality. Regional air quality is also considered.

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 impacts associated with air quality (refer to Chapter 13 (Human health) and Technical working paper: Health impact assessment (EnRiskS, 2020) of the environmental impact statement)
- Greenhouse gas emissions (assessed in Chapter 26 (Climate change risk and adaptation) of the environmental impact statement).

1.6 Secretary's environmental assessment requirements

Table 1-1 displays the sections of the Secretary's environmental assessment requirements that are specific to air quality, and also provides a cross-reference to the sections of this report which address these requirements. The covering letter for the Secretary's environmental assessment requirements for the project contains an additional requirement, as described in Table 1-2.

Table 1-1 Secretary's environmental assessment requirements – Air quality

Secretary's environmental assessment requirement	Where 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.	Section 9 (management of impacts)
1. The Proponent must carry out an air quality impact assessment (AQIA) for construction and operation of the project in accordance with the current guidelines.	Section 7 (construction impacts) Section 8 (operational impacts)
• Approved Methods for the Modelling and Assessment of Air Pollutants in New South Wales (NSW EPA, 2016)	Section 8 (operational impacts)
• 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)	Section 7 (construction impacts)
• In-Tunnel Air Quality (Nitrogen Dioxide) Policy (ACTAQ, 2016)	Annexure K (ventilation report)
• Optimisation of the Application of GRAL[2] in the Australian Context (Pacific Environment, 2017).	A brief summary of the GRAL optimisation study is provided in Section 8.4.4

[2] GRAL = Graz Lagrangian Model

Secretary's environmental assessment requirement	Where addressed
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*;	Section 4.4.5 (tunnel ventilation outlets)
(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;	Section 3 (air quality issues) Section 8 (operational impacts)
(c) a review of vehicle emission trends and an assessment that uses or sources best available information on vehicle emission factors;	Section 6.6 (existing environment – air pollutant emissions) Annexure C (emission model description for surface roads Annexure K (ventilation report)
(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 (eg BTEX) including consideration of short and long term exposure periods;	Section 8 (operational impacts)
(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 network;	Section 8 (operational impacts)
(f) a qualitative assessment of the redistribution of ambient air quality impacts compared with existing conditions, due to the predicted changes in traffic volumes;	Section 8 (operational impacts), and specifically Section 8.4.12
(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;	Annexure K (ventilation report)
(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 (ie ventilation outlets and air inlets) including details of proposed air quality monitoring (including frequency and criteria);	Section 9 (management of impacts)
(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 M4 East project, New M5 project and the In-Tunnel Air Quality (Nitrogen Dioxide) Policy;	Section 5 (assessment criteria) Section 8 (operational impacts) Annexure K (ventilation report)
(j) details of any emergency ventilation systems, such as air intake/exhaust outlets, including protocols for the operation of these systems in emergency situation, potential emission of air pollutants and their dispersal, and safety procedures;	Section 9 (management of impacts)
(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;	Section 9 (management of impacts)
(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 proposal, particularly in relation to ancillary facilities (such as concrete	Section 7 (construction impacts) Section 9 (management of impacts)

Secretary’s environmental assessment requirement	Where addressed
batching plants), dredge and tunnel spoil handling and storage at Glebe Island and White Bay, the use of mobile plant, stockpiles and the processing and movement of spoil; and	
(m) a cumulative assessment of the in-tunnel, local and regional air quality due to the operation of the project and due to the operation of and potential continuous travel through motorway tunnels and surface roads.	Section 8 (operational impacts) Annexure K (ventilation report)

Table 1-2 Secretary’s environmental assessment requirements covering letter requirement

Secretary’s environmental assessment requirement covering letter	Where addressed
Prior to the lodgement of the EIS, the proponent shall provide the Department with the details of the model(s) used in the assessment of air quality, including assumptions and inputs considered. The proponent shall also perform sensitivity analysis of the modelled results to key inputs (eg diesel/petrol splits, traffic speeds, etc.) and model additional scenarios and design requirements.	The models used are described in Section 7 (construction impacts), Section 8 (operational impacts) and Annexure K (ventilation report). Sensitivity analyses are presented in Section 8.4.16.

1.7 Structure of this report

The remainder of the report is structured as follows:

- **Section 2** describes specific aspects of the project design relating to in-tunnel and ambient air quality
- **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 road 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 road 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 WestConnex 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
- 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.

2 Specific aspects of the project design relating to in-tunnel and ambient air quality

2.1 Overview

The project's ventilation system has been designed to:

- Safeguard the health and amenity of motorists using the tunnels during normal operation and emergency conditions
- Meet the current in-tunnel, ventilation outlet and ambient air quality criteria relevant to the project
- 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 tunnels or the achievement of applicable air quality criteria.

The tunnel ventilation system would comprise ventilation outlets 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 outlets.

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

2.2 Tunnel ventilation outlets, motorway facilities and portals

Eleven ventilation outlets (labelled A to K) for existing and proposed tunnels in the dispersion modelling domain were included in the air quality assessment. These ventilation outlets are summarised in Table 2-1. Outlets F and G (shaded in the table) would form part of the project. Further details of the project ventilation outlets and motorway facilities are provided in Chapter 5 (Project description) of the environmental impact statement. The remaining ventilation outlets were included to assess potential cumulative impacts only.

The locations of the 11 ventilation outlets are provided in Section 8.2.2, and details of the ventilation outlets that were of specific interest to this air quality assessment are provided in Annexure G. The control of air flows through the project tunnels and ventilation outlets is described in Annexure K.

For two tunnels in the GRAL[3] domain – Sydney Harbour Tunnel and the Eastern Distributor tunnel – emissions from portals currently occur. For each of these two tunnels, it was assumed that the emissions from the traffic in the tunnel would be released from the portals at all times (ie there would be no emissions from the tunnel ventilation outlets). This is a worst case assumption as these sources are at ground level.

2.3 Interface with adjacent tunnels

The Western Harbour Tunnel would provide a direct aerodynamic connection to the WestConnex M4-M5 Link as well as the future Beaches Link. The operation of each tunnel would be coordinated with adjacent tunnels within the network to ensure safe and effective ventilation is maintained under all circumstances.

[3] GRAL = Graz Lagrangian Model

Operation of the ventilation systems for the Western Harbour Tunnel, Beaches Link and the WestConnex M4-M5 Link would be largely independent of each other. This would be achieved through the operation of a complete air exchange at each tunnel interface underground in which air from the upstream tunnel carriageway would be extracted and replenished with a suitable volume of fresh air to the downstream tunnel, under all traffic conditions.

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

Ventilation Outlet	Project	Location	Function of the ventilation outlet
Existing ventilation outlets and motorway facilities (included in all scenarios)			
Outlet A	Lane Cove Tunnel	Marden Street, Artarmon	Removal and management of emissions from eastbound[(a)] traffic in the Lane Cove Tunnel.
Outlet B	Cross City Tunnel	Between the Western Distributor viaducts in Darling Harbour, west of Harbour Street, Sydney	Removal and management of emissions from all traffic in the Cross City Tunnel.
Ventilation outlets and motorway facilities for the M4-M5 Link (included in Do minimum scenarios)			
Outlet C	M4-M5 Link, Iron Cove Link	Rozelle (mid)[(b)], within the Rozelle Rail Yards	Removal and management of emissions from the traffic in the M4-M5 Link and southbound tunnel of the Iron Cove Link.
Outlet D	M4-M5 Link, Iron Cove Link	Rozelle (west)[(b)], within the Rozelle Rail Yards	
Outlet E	Iron Cove Link	Rozelle, near Iron Cove Bridge, over the exit portal to Victoria Road	Removal and management of emissions from traffic in the northbound tunnel of the Iron Cove Link.
Ventilation outlets and motorway facilities for the Western Harbour Tunnel			
Outlet F[(c)]	Western Harbour Tunnel (Rozelle ventilation outlet and motorway facility)	Rozelle (east)[(b)], located within the Rozelle Rail Yards	Removal and management of emissions from traffic in the southbound tunnel and ramps. Supply of fresh air to the southbound tunnel connecting to the M4-M5 Link.
Outlet G	Western Harbour Tunnel (Warringah Freeway ventilation outlet and motorway facility)	Cammeray, located within Warringah Freeway near Ernest Street, separate to the motorway facility	Removal and management of emissions from traffic in the northbound tunnel and connected ramps. Supply of fresh air to the northbound tunnel connecting to the future Beaches Link.
Ventilation outlets and motorway facilities for Beaches Link			
Outlet H	Beaches Link (Warringah Freeway ventilation outlet and motorway facility)	Cammeray, located within Warringah Freeway near Ernest Street, separate to the motorway facility	Removal and management of emissions from traffic in the southbound tunnel and connected ramps. Supply of fresh air into the southbound tunnel connecting to the Western Harbour Tunnel.
Outlet I	Beaches Link (Gore Hill Freeway ventilation outlet and motorway facility)	Gore Hill, located at Punch Street, Artarmon	Removal and management of emissions from traffic in the southbound tunnel and ramps connecting with the Gore Hill Freeway.

Ventilation Outlet	Project	Location	Function of the ventilation outlet
Outlet J	Beaches Link (Wakehurst Parkway ventilation outlet and motorway facility)	Wakehurst Parkway, located within Wakehurst Parkway, over the tunnel portal	Removal and management of tunnel air from the northbound tunnel and ramps connecting with the Wakehurst Parkway.
Outlet K	Beaches Link (Burnt Bridge Creek Deviation ventilation outlet and motorway facility	Balgowlah, located east of Burnt Bridge Creek Deviation, Balgowlah	Removal and management of emissions from traffic in the northbound tunnel and ramps connecting with the Burnt Bridge Creek Deviation.

(a) The ventilation outlet for the westbound Lane Cove Tunnel traffic is outside the GRAL domain.

(b) The motorway facility in the Rozelle Rail Yards has three ventilation outlets (termed here ‘west’, ‘mid’, ‘east’).

(c) This ventilation outlet would be constructed as part of the M4-M5 Link but would not operate until the opening of the Western Harbour Tunnel, if approved.

2.4 Operating modes

2.4.1 Ventilation operations

The tunnel ventilation system would operate in two modes:

- 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 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 emissions 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 project tunnels, 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.

2.4.2 Normal traffic conditions

Under normal traffic conditions (ie when traffic flow within the project tunnels is travelling at the posted speed limit of 80 kilometres per hour), the tunnels would be longitudinally ventilated. Fresh air would be drawn into the 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 as described in Annexure K with no portal emissions. At the ventilation outlets and motorway facility offtake points, tunnel air would be drawn upwards into the ventilation outlets by large fans prior to discharge to the atmosphere. The locations and heights of the ventilation outlets are provided in

Annexure G. The air would then be discharged from each ventilation outlet to the atmosphere at velocities that would achieve effective dispersion of the tunnel air.

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

2.4.3 Low speed traffic conditions

Where low speed conditions persist within the project tunnels (ie 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) may be applied to manage the incident and restore as far as practicable free flowing traffic conditions. 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 the exit portals) to provide the fresh air demand required to meet the relevant air quality criteria.

2.4.4 Emergency conditions

During a major incident, when traffic is stopped in the project tunnels, the jet fans would be used to increase the air flow to protect vehicle occupants and emergency services personnel from a build-up of vehicle 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 Chapter 5 (Project description) of the environmental impact statement.

2.5 Iterative approach to design

The design of the project has been carried out using an iterative approach, with changes being made to various aspects – such as ventilation outlet and motorway facility locations – 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 Western Harbour Tunnel

3.1 Overview of section

This section:

- Summarises the main aspects of traffic-related emissions and air pollution, including the air quality issues that are associated specifically with road tunnels
- Provides contextual information on topics such as the main traffic pollutants and their effects, the processes affecting air pollution, and air pollution in and around tunnels
- Identifies the key air quality 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 health, refer to Appendix F of the environmental impact statement, Technical working paper: Health impact assessment). Traffic pollution also has impacts on wider geographical scales.

3.2.2 Pollutants

Many different air pollutants are associated with 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.

3.2.3 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 (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 depends on particle size, composition and density (PIARC, 2019).

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, all urban tunnels over one kilometre in length since the M5 East tunnels have been designed in such a way that portal emissions are avoided. In line with this approach, the Western Harbour Tunnel has been designed so that there would be no emissions from the tunnel portals during normal operations.

Ventilation outlet emissions

Tunnel portal emissions are avoided through the extraction and emission of tunnel air via elevated ventilation outlets, which 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 ventilation outlet increases. A combination of the design height of the ventilation 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 avoid portal emissions, 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 including:

- 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.

Studies suggest that the greatest impacts from a ventilation outlet occur some distance from the ventilation outlet. Impacts are also largely restricted to locations which are downwind of the ventilation outlet in the most frequent local wind directions, and there may be effectively zero impact in many directions. However, ventilation 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 road 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, both inside and outside the tunnel.

3.3 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 Transport for NSW, Ministry of Health, Department of Planning, Industry and Environment 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 (Pacific Environment, 2017b). These reports were consulted as part of the assessment for the project.

3.4 NSW tunnel ventilation initiative

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

In addition, for new motorway tunnels that are at the environmental impact statement stage, such as the Western Harbour Tunnel, additional checks would be required including:

- The ACTAQ will coordinate a scientific review of the project’s air emissions from ventilation outlets
- The NSW Chief Health Officer will release a statement on the potential health impacts of emissions from the 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.

3.5 Summary of key air quality considerations

To summarise the previous sections, the key air quality considerations for the project are likely to be:

- 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 Western Harbour Tunnel users, but also to the cumulative exposure of users of multiple Sydney tunnels, and notably WestConnex and Beaches Link
- Understanding the ambient air quality impacts of the 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 as a result of the project
  - Potential deterioration in air quality alongside new and upgraded/widened surface roads forming part of the project
  - Potential deterioration in air quality alongside existing roads which would have an increase in traffic volume as a result of the project
  - Potential deterioration in air quality in the vicinity of the 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
- Construction impacts of the project.

This report details the assessment of the potential impacts of the project on air quality (both adverse and beneficial) and also informs the detailed design of the tunnel ventilation system, including the location, design and operation of the ventilation 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 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 (HDVs), and their timetable for adoption in the ADRs, are listed on the Australian Government website[4], 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.

[4] https://infrastructure.gov.au/vehicles/environment/emission/index.aspx

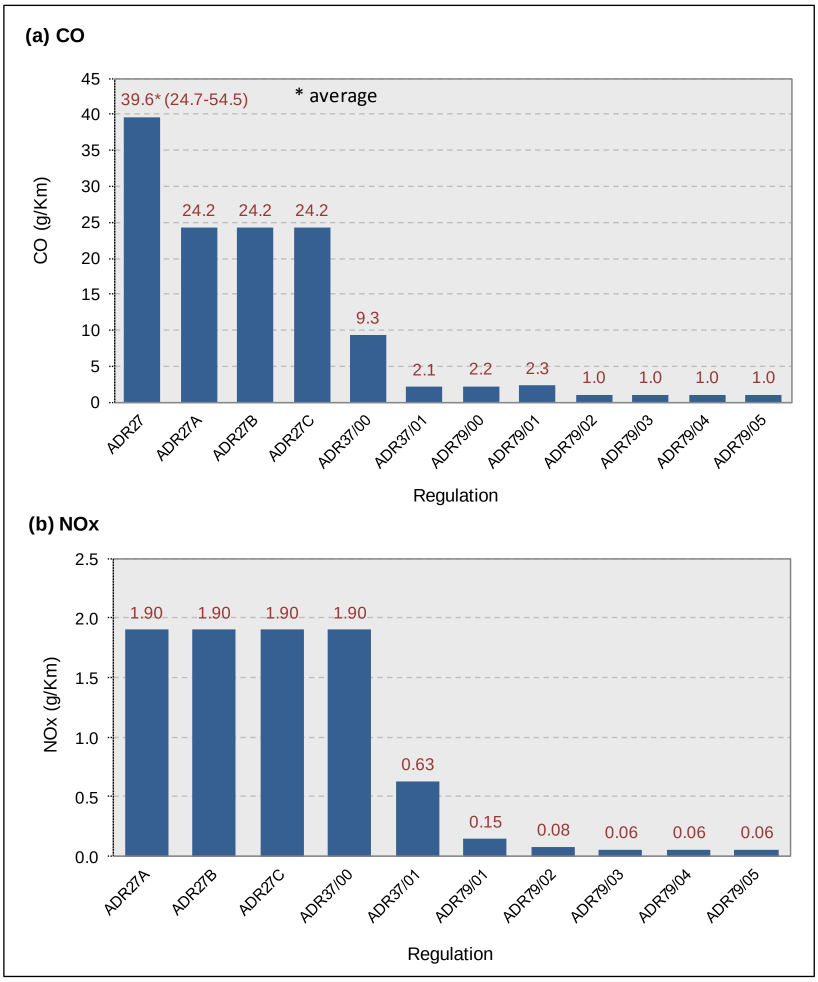

Figure 4-1 Exhaust emission limits for CO and NOx applicable to new petrol cars in Australia

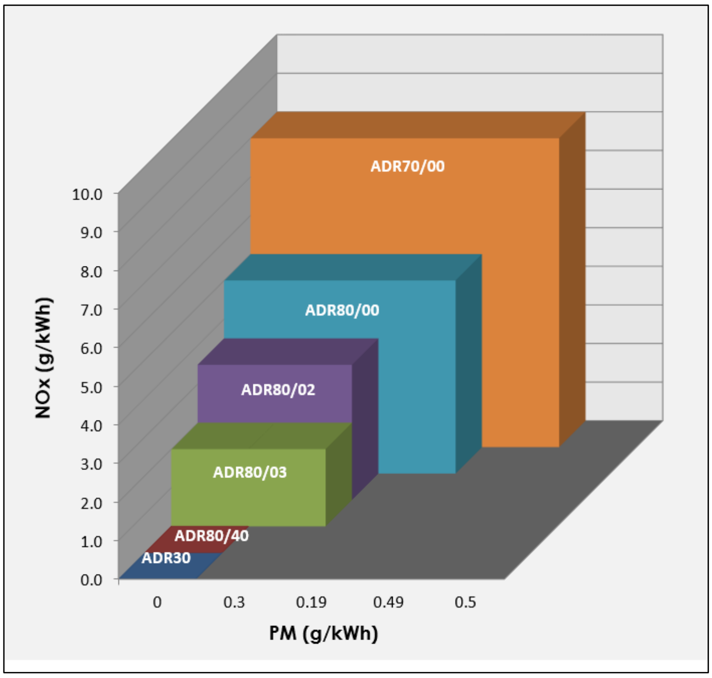

Figure 4-2 Exhaust emission limits for NOx and PM applicable to HDVs in Australia

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 liquefied petroleum gas (LPG) conversions.

Between 2004 and 2012, the NSW Government ran a diesel vehicle retrofit program which involved retrofitting engines with pollution-reduction devices, primarily to reduce PM emissions. Under the program, the NSW Government assisted truck operators to fit 591 heavy diesel vehicles with retrofit devices[6].

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 HDVs; 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 air quality limits

4.4.1 Gaseous pollutants

An understanding of in-tunnel air quality is required for three main reasons:

- To design and control ventilation systems
- To manage in-tunnel exposure to vehicle emissions
- To manage external air quality.

For many road tunnels, the ventilation requirements have been determined according to guidelines from the World Road Association (PIARC, 2019), 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 on the in-tunnel CO concentration, given that:

- CO emissions have historically been dominated by road transport

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[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.

[6] http://www.rms.nsw.gov.au/about/environment/air/diesel-retrofit.html

- 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 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 (eg 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 will 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. This compares favourably with international guidelines.

4.4.2 Visibility and particular matter

Another important consideration for tunnel ventilation design is visibility. Consideration of visibility criteria in the design of the tunnel ventilation system is required due to the need for visibility levels that exceed the minimum vehicle stopping distance at the design speed (PIARC, 2019). Visibility is reduced by the scattering and absorption of light by particulate matter 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 depends on 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 alternate 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, so visibility cannot reliably be used as a criterion for health risk (NHMRC, 2008).

The nature of particulate matter emitted by road vehicles is changing with time. Diesel exhaust particles have normally been taken as the reference for visibility. Non-exhaust particulate matter 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 managing air quality during normal operating conditions, 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 three in-tunnel pollutants that are assessed are NO_2, CO and 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.

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 M4 East New M5 M4-M5 Link	200[(a)]	87[(b)]	50[(b)]	0.5[(b)]	0.005[(c)]

(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)

The ventilation system for the project was designed to ensure air quality within the tunnel would be maintained at or below the design criteria shown in Table 4-2, independent of the M4-M5 Link and Beaches Link.

Table 4-2 In-tunnel air quality limits for the ventilation design

Pollutant/Parameter	Averaging period	Concentration limit	Units measured
CO	3-minute	200	ppm
CO	15-minute	87	ppm
CO	30-minute	50	ppm
NO_2	15-minute	0.5	ppm
Visibility	N/A	0.005	m^{-1}

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

In February 2016, the NSW Government ACTAQ 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 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 the same requirements would apply to the project.

For the Western Harbour Tunnel component of the project 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, and the calculation of this is outlined in 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 applied to the discharges from the ventilation outlets. The limits specified for the NorthConnex, M4 East and New M5 projects are shown in Table 4-3 and have been adopted as design criteria for the project that would not be exceeded. The Secretary's environmental assessment requirements for the project 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 discharge concentration limits, these are designed primarily for industrial activities and the limit values are much higher than those applied to road tunnels in Sydney[7].

Table 4-3 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

(a) Stated as 1.0 in the conditions of approval for NorthConnex.

Sources: NSW Government (2015, 2016a, 2016b)

4.5 Ambient air quality standards and criteria

Ambient air quality standards are a major consideration during road tunnel 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 (eg 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

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[7] Refer to for example, Schedule 4 of the *Protection of the Environment Operations (Clean Air) Regulation 2010*, which specifies standards 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.

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, flora or fauna.

The health effects of criteria pollutants and some specific air toxics are summarised in Annexure A, and further information on standards and impact assessment criteria is provided below.

NB: The actual impact assessment criteria that are applicable to the project are summarised in Section 5.4.3.

4.5.1 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):

- CO
- NO_2
- Sulfur dioxide (SO_2)
- Lead (Pb)
- Photochemical oxidants as O_3
- PM 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 PM 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 sites which are broadly representative of population exposure. The use of any NEPM air quality criteria for the assessment of projects and developments is outside the scope of the NEPM itself, and is decided by the jurisdictions.

The Australian States and Territories manage emissions and air quality in relation to source type (eg 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. 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[8] and averaging periods for specific pollutants that are taken

[8] In this 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.

from several sources, including the AAQ NEPM. The metrics, criteria and goals set out for criteria pollutants in the NSW Approved Methods are provided in Annexure B.

4.5.2 Air toxics

In recognition of the potential health issues 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.

The NSW Approved Methods specify air quality impact assessment criteria and odour assessment criteria for many other substances (mostly hydrocarbons), including air toxics, which are too numerous to reproduce here. The Secretary's environmental assessment requirements 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 for the project
- Reviews recent air quality assessments for major road projects in Australia and New Zealand to inform the methodology and to ensure that the assessment was conducted in line with Australian and international best practice
- Describes the general approaches that were used to assess the impacts of the project on air quality, including:
  - Construction
  - Operation – emissions
  - Operation – in-tunnel air quality
  - Operation – ambient air quality (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
- The *Approved Methods for the Modelling and Assessment of Air Pollutants in NSW* (NSW EPA, 2016)
- *Air Quality in and Around Traffic Tunnels* (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 on the environment (PIARC, 2008)
  - Road tunnels: vehicle emissions and air demand for ventilation (PIARC, 2012)
  - Road tunnels: vehicle emissions and air demand for ventilation (PIARC, 2019)
- 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* (Pacific Environment, 2017b).

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
- Ministry of Health
- NSW Chief Scientist and Engineer
- ACTAQ.

5.4 General assessment approach for the project

5.4.1 Construction assessment

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

- Annoyance due to dust deposition (eg settlement of surfaces at residences) and visible dust plumes
- Elevated PM_{10} concentrations due to on-site dust-generating activities
- Increased concentrations of airborne particulate matter 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, or the removal of contaminated soils. These issues need to be considered on a site-by-site basis. Very high levels of settlement can also damage plants and affect the health and diversity of ecosystems (IAQM, 2014).

Particulate matter emissions can occur during the preparation of the land (eg 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 carried out, 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, particulate matter levels can increase at some distance from the construction site (IAQM, 2014).

The risk of particulate matter 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 conducted
- 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 particulate matter
- The adequacy of the mitigation measures applied to reduce or eliminate particulate matter.

It is difficult to quantify/model particulate matter 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 carried out. Any effects of construction on airborne particulate matter 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[9], risk-based approach was used for the project assessment, and the impacts of construction were not specifically modelled. The approach has 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 particulate matter impacts during construction using the IAQM procedure is presented in Section 7.1.

There is also the potential for odour impacts due to emissions from dredged material being brought to shore for either treatment or transfer to landfill. This quantitative assessment is presented in Section 7.2 and involves a dispersion modelling study using estimated odour emission rates from a similar operation. Limitations to the odour assessment include the use of emission estimations rather than site-specific measurements. Assumptions are also made regarding the size of exposed areas undergoing treatment and the time-periods over which these are exposed.

5.4.2 Operational assessment – in-tunnel air quality

The tunnel ventilation method adopted for the project is a longitudinal ventilation system, where fresh air is typically introduced into the tunnels via the entry portals, extracted prior to the exit portals and discharged to atmosphere via the ventilation outlets. Airflow through the tunnel is the so-called 'piston effect', which can be supplemented by jet fan operation at lower traffic speeds, if required. In order to avoid portal emissions, motorway facilities located adjacent to exit portals capture and exhaust the tunnel air from ventilation outlets at elevated heights above ground level.

For in-tunnel air quality, the modelling incorporated the project and all linked projects (WestConnex and Beaches Link tunnels), to provide representative aerodynamic and pollution boundary conditions at the project interfaces.

In-tunnel traffic, air flow, pollution levels, and temperature for the project were modelled using the IDA Tunnel software[10]. The criteria, scenarios, data and detailed method that were used in the tunnel ventilation simulation are provided in full in Annexure K.

The performance of the tunnel ventilation system was analysed for a variety of expected traffic conditions, as well as for worst case variable speed scenarios and breakdowns. The following paragraphs summarise the traffic and ventilation scenarios that were assessed.

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[9] The phrase 'semi-quantitative' as been used as some aspects of the assessment are quantified (eg prevailing PM_{10} concentrations) whereas others are based more on judgement (eg receptor sensitivity) or coarse classifications.
[10] http://www.equa.se/en/tunnel/ida-tunnel/road-tunnels

Expected traffic (24-hour) scenarios

The expected traffic scenarios are described in Section 5.4.3. These scenarios represented the 24-hour operation of the project ventilation system under day-to-day conditions of expected traffic demand in 2027 and 2037. 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 ventilation outlet emissions for use in the ambient air quality assessment. In 'cumulative' scenarios, emissions from other tunnel projects were also considered.

Worst case traffic scenarios

These simulations demonstrated the most onerous traffic conditions for the ventilation system. The first set of these was based on capacity traffic conditions at speeds of between 20 and 80 kilometres per hour. These represent an upper bound on daily operations for the ventilation system, regardless of year of operation. Other scenarios examined the effects of congestion due to vehicle breakdown in the tunnel. It was assumed that a breakdown would cause a complete blockage of a specific ramp, or exit, causing traffic to take other routes. The most conservative case of a breakdown scenario has been assessed to be a breakdown on the northbound tunnel prior to the exit to the Warringah Freeway Upgrade, or the tunnel-to-tunnel connection with Beaches Link, requiring all northbound traffic to exit via the Falcon Street off ramp at North Sydney.

Travel route scenarios

An additional series of calculations dealt with a worst case trip scenario for in-tunnel exposure to NO_2. All the possible routes within the Western Harbour Tunnel, and ending at the Western Harbour Tunnel to Beaches Link connection, and all the possible routes all the way from/to Beaches Link Balgowlah and Wakehurst Parkway, were identified. These were then assessed against the in-tunnel criterion for NO_2 (0.5 ppm). The details of the mathematical formulae and models used are provided in Annexure K. Provided that each project satisfies the air quality criteria, the average through the entire network would remain at, or below, 0.5 ppm under all traffic conditions.

5.4.3 Operational assessment – local air quality

The operational local ambient air quality assessment was based on 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 (Graz Lagrangian 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 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 solid red boundary in Figure 5-1. The domain covered a substantial part of Sydney, extending 30 kilometres in the east–west (x) direction and 30 kilometres in the north–south (y) direction.

The GRAL domain for dispersion modelling is shown by the grey dashed boundary in Figure 5-1. Every dispersion model run was carried out for this domain, which extended 11.6 kilometres in the x direction and 16.7 kilometres in the y direction. The domain extended well beyond the project itself to allow for the traffic interactions between the project, Beaches Link, Gore Hill Freeway Connection and the WestConnex M4-M5 Link project, as well as changes along affected surface roads.

Having relatively large GRAMM and GRAL domains also increased the number of meteorological and air quality monitoring stations that could be included for model evaluation purposes.

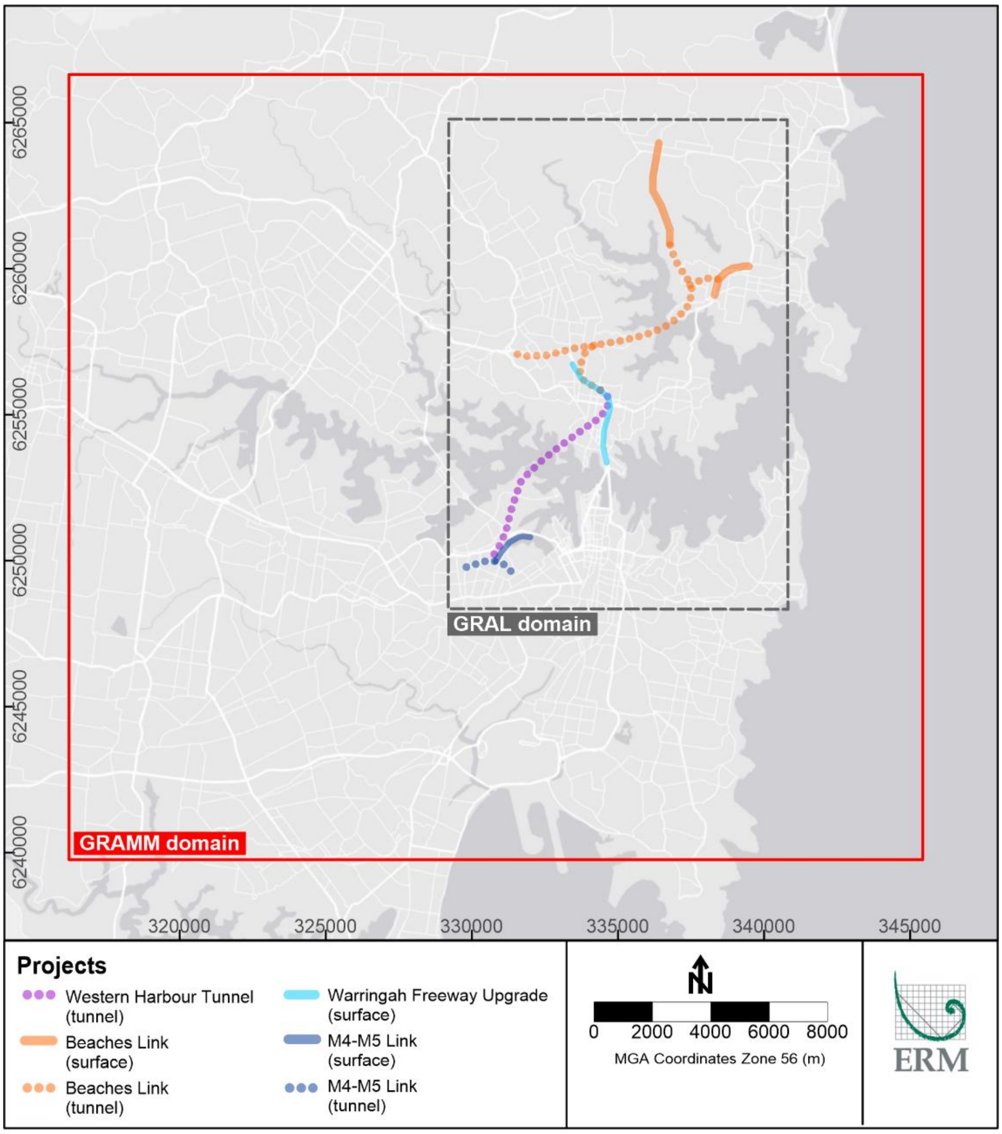

Figure 5-1 Modelling domains for GRAMM and GRAL (grid system MGA94)

Modelling scenarios

Two types of scenario were considered for ambient air quality:

- Expected traffic scenarios
- Regulatory worst case scenarios.

These scenarios are described below.

Expected traffic scenarios

The seven expected traffic scenarios included in the operational air quality assessment are summarised in Table 5-1. The scenarios were based on traffic volumes, distribution of traffic across the road network and average traffic speeds forecast by the strategic traffic model (Strategic Motorway Project Model, or SMPM). They also took into account future changes over time in the composition and performance of the vehicle fleet. 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 human health impact assessment for the project.

Table 5-1 Expected traffic scenarios for the operational assessment

Scenario code	Scenario description	Notes	Roads/projects included						
			Existing network	Full WestConnex	Sydney Gateway	Western Harbour Tunnel and Beaches Link projects			
						Western Harbour Tunnel / Warringah Freeway Upgrade	Beaches Link / Gore Hill Freeway Connection	F6 Extension (Stage 1)	F6 Extension (full)
2016-BY	'Base case'[(a)]	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.	✓	-	-	-	-	-	-
2027-DM	'Do minimum 2027'	This scenario represented conditions in the opening year of the project (2027), 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.	✓	✓	-	-	-	-	-
2027-DS(WHT)	'Do something 2027' (with the project)	As 'Do minimum 2027', but with the Western Harbour Tunnel and Warringah Freeway Upgrade also completed.	✓	✓	-	✓	-	-	-
2027-DSC	'Do something cumulative 2027'	As 'Do something 2027', but with Sydney Gateway, Beaches Link, Gore Hill Freeway Connection and F6 Extension – Stage 1 also completed.	✓	✓	✓	✓	✓	✓	-
2037-DM	'Do minimum 2037'	As 'Do minimum 2027', 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.	✓	✓	-	-	-	-	-
2037-DS(WHT)	'Do something 2037' (with the project)	As 'Do something 2027', but for 10 years after project opening.	✓	✓	-	✓	-	-	-
2037-DSC	'Do something cumulative 2037'	As 'Do something cumulative 2027', but with all stages of the F6 Extension also completed.	✓	✓	✓	✓	✓	✓	✓

(a) The base (calibration) year in the 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.

Regulatory worst case scenarios

The objective of these scenarios was to present the maximum theoretical increase in ambient air quality due to the ventilation outlets operating continuously at the proposed emissions limits. The scenarios assessed emissions from the ventilation outlets only, with emissions continuously at the proposed emissions limits for all 8760 hours of the year. This is analogous to both the project and the Beaches Link tunnels operating under breakdown scenarios continuously for a full-year. The regulatory worst case represents a theoretical upper bound that would never occur for periods longer that a few hours.

The regulatory worst case scenarios included in the assessment varied by pollutant, as shown in Table 5-2. The regulatory worst case scenarios were analogous to the 'with project' scenarios in the expected traffic case. Modelling for ventilation outlets in all scenarios showed that for annual mean $PM_{2.5}$ (the key metric in terms of health) the RWC-2027-DSC scenario resulted in the highest predicted concentrations at receptors, and therefore only this scenario was used for the pollutants that were not dependent on atmospheric chemistry in the vicinity of roads (ie 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 regulatory worst case scenarios 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 project tunnels.

Table 5-2 Regulatory worst case scenarios

Scenario	Pollutant				
	CO	NO_2	PM_{10}	$PM_{2.5}$	THC
RWC-2027-DS(WHT)	-	✓	-	-	-
RWC-2027-DSC	✓	✓	✓	✓	✓
RWC-2037-DS(WHT)	-	✓	-	-	-
RWC-2037-DSC	-	✓	-	-	-

Ambient air quality metrics used in the assessment

The assessment has been carried out in accordance with all relevant guidelines regarding national and international best practice. The assessment also goes through a rigorous external peer review process.

Impacts have been assessed against the appropriate air quality criteria, set by the NSW EPA in the Approved Methods. Some of these criteria are among the most stringent worldwide (see Annexure B). For example, the annual average $PM_{2.5}$ criterion used, and on which the health metrics are based, is the lowest in world, including the World Health Organisation, and supports the best practice approach used throughout the assessment.

Air quality criteria

Air quality in the study area domain was assessed in relation to the most relevant pollutants, and the criteria from the NSW Approved Methods and AAQ NEPM. The pollutants and criteria are summarised in Table 5-3. The long-term goals for $PM_{2.5}$ in the AAQ NEPM were considered but not formally used in the assessment of impacts, and these are shown in italics in the table.

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.

Change in annual mean $PM_{2.5}$

The Technical working paper: Health impact assessment 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 human health impact assessment considers a comprehensive range of health endpoints, the key metric that emerged during the assessment of the NorthConnex, M4 East and New M5 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 to the change in the annual mean $PM_{2.5}$ concentration ($\Delta PM_{2.5}$) (eg Pacific Environment, 2017). 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:

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

Where, for the project study area:

R = additional risk

β = slope coefficient for the percentage 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 (eg annual mortality rate) (1026 per 100,000 for mortality all causes ≥ 30 years) (Golder Associates, 2013)

This equation can be rewritten as:

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

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

$$\Delta PM_{2.5} = \frac{0.0001}{0.0058 \times 0.00976} = 1.7\ \mu g/m^3$$

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):

- 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 1300 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[11]. 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
- 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)
- Total suspended particulate (TSP). TSP 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
- O_3. Because of its secondary and regional nature, O_3 cannot practicably be considered in a local air quality assessment. Emissions of O_3 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. O_3 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 O_3 concentration. This non-linearity makes it difficult to develop management scenarios for O_3 control (DECCW, 2010). O_3 was, however, considered in the regional air quality assessment (refer to Section 5.4.4)
- 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.

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

In recent years, a considerable amount of attention has focused 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[12]:

- *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[13]. 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 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)
- *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
- *Tunnel portal concentration*. This is the contribution from the portals of existing tunnels for which portal emissions are permitted (Sydney Harbour Tunnel and Eastern Distributor tunnel). The tunnel portal contribution was determined using GRAL.
- *Ventilation outlet concentration*. This is the contribution from all tunnel ventilation outlets, again determined using GRAL.

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

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 case and the future years as a result of improved emission controls. However, there is the potential for such reductions to be offset by traffic growth. In the example shown, the project has the effect of decreasing total traffic (surface road and ventilation outlet) emissions in the vicinity of the receptor. As the background is assumed to be constant with time (refer to Figure 5-2), the total concentration with the project in 2027 and 2037 is smaller than the total concentration without the project.

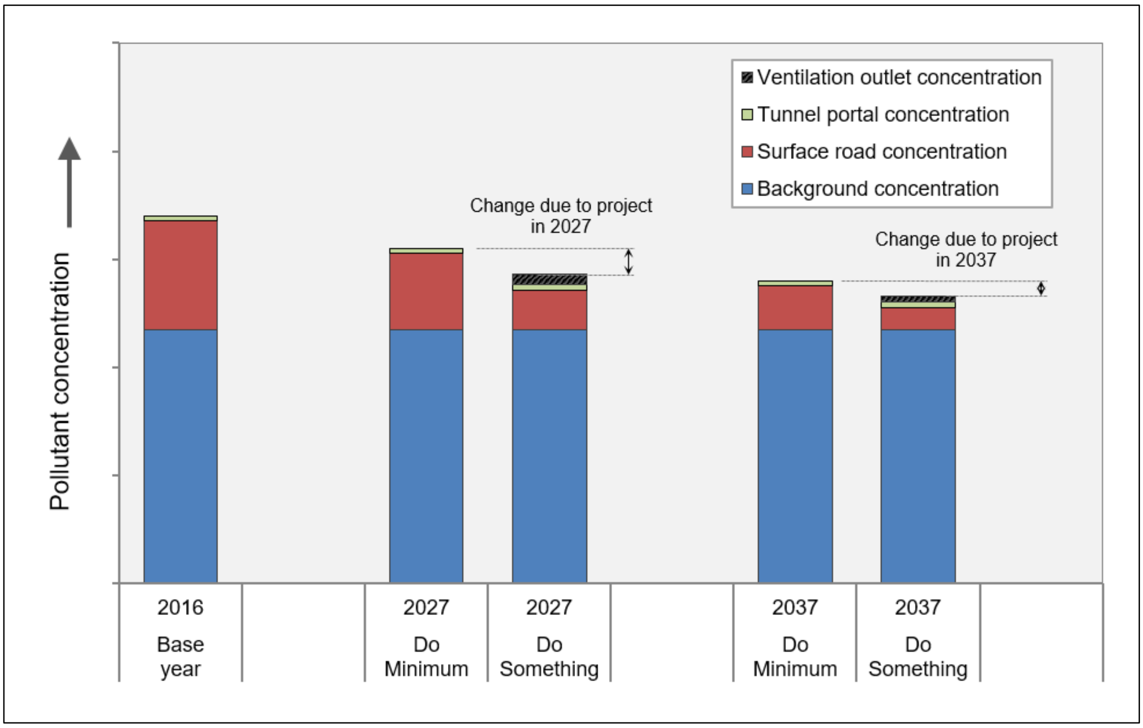

Figure 5-2 Contributions to total pollutant concentrations (example) (portals include Sydney Harbour Tunnel and Eastern Distributor only)

The following results are presented in the report:

- The *total* pollutant concentration from all contributions (background, surface roads, portals and ventilation outlets)
- The *change* in the total pollutant concentration with the project. Given the non-threshold nature of some air pollutants (notably particulate matter), 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. At any given location the change may be either an increase or a decrease, depending on, among other things, how traffic is redistributed on the network as a result of 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 are 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 more than 1.9 million grid locations across the GRAL domain
- Pollutant concentrations (and changes) in the vicinity of the project ventilation outlets (as contour plots).

5.4.4 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 O_3 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 O_3 concentrations in the broader Sydney region.

5.4.5 Operational assessment – odour

The Secretary's environmental assessment requirements for the project 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.

5.5 Treatment of uncertainty

5.5.1 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 (eg 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.

5.5.2 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 on a sub-area of the GRAL domain of about two to three kilometres square around the Warringah Freeway ventilation outlet. Only the ventilation outlet contribution, and only annual mean $PM_{2.5}$ and maximum 24-hour $PM_{2.5}$, were included in the tests. A sub-set of 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

The covering letter from the Secretary's environmental assessment requirements calls for a 'sensitivity analysis of the modelled results to key inputs (eg diesel/petrol splits, traffic speeds, etc.) and model additional scenarios and design requirements'.

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 would 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 (2019) emissions factors applied in this assessment were considered to be representative of real-world driving conditions within tunnels, with some elements of conservatism (eg road gradient effects, and non-exhaust particulate matter).

While the tunnel ventilation assessment provided in Annexure K[14] 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 outlets and motorway facilities would be acceptable, even in the most unlikely of circumstances.

In the sensitivity analysis, for each ventilation outlet the daily $PM_{2.5}$ emission profiles in the 2027-DSC scenario for expected traffic were proportionally scaled up until the corresponding emission limit (i.e. regulatory worst case assumption) was reached for at least one hour each day.

A visualisation of this approach is shown for the $PM_{2.5}$ emissions for the Beaches Link Warringah Freeway ventilation outlet (H) in Figure 5-3. This shows how the 2027-DSC scenario has been scaled such that the maximum 1-hour $PM_{2.5}$ emission rate is at parity with the regulatory worst case (RWC) emission scenario assumption, for that hour. The average mass emission rate for the 24-hour period under the two emission profiles have then been compared to provide a scaling factor between 2027-DSC predictions and those under the sensitivity test.

[14] The tunnel ventilation assessment provided in Annexure K also includes a sensitivity analysis around the use of emission standards. In particular, the analysis addresses the possibility of Euro 6 emissions not being implemented by 2027. The analysis showed that the mass emission rates of NO_X and NO_2 were estimated to be between 12 – 26% higher if Euro 6 was not implemented. The analysis also found that emissions of PM and CO would remain unchanged. As the scaling factor used for the sensitivity analysis described in this air quality assessment is based on PM, it would also remain unchanged with or without the implementation of Euro 6.

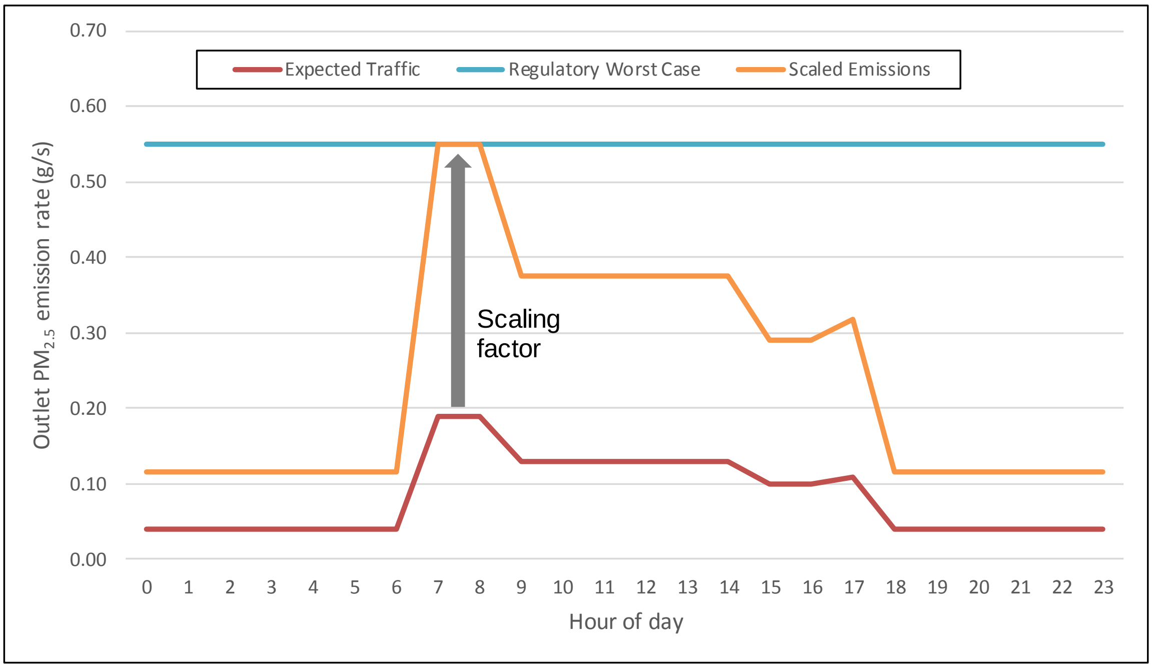

Figure 5-3 Calculation of sensitivity scaling factor over the course of a day for $PM_{2.5}$ (Outlet H, 2027-DSC scenario)

The scaling factor is slightly different for each ventilation outlet as the mass emission rates are dependent on variables such as in-stack concentration and volumetric flow rates. A summary of the derived $PM_{2.5}$ scaling factors for all ventilation outlets is provided in Table 5-4, with the value of 2.8 for Outlet H shaded.

Table 5-4 $PM_{2.5}$ scaling factors for all ventilation outlets

Ventilation Outlet	Name	Scaling Factor
F	WHT: Rozelle (West)	5.0
G	WHT: Warringah Freeway	4.1
H	**BL: Warringah Freeway**	**2.8**
I	BL: Gore Hill Freeway	4.0
J	BL: Wakehurst Parkway	2.9
K	BL: Burnt Bridge Creek Deviation	3.1

A scaling factor based on the outlet with the highest expected traffic concentrations is considered a reasonable upper bound to be applied across the network. It is considered highly unlikely that all outlets would be operating at the emission limit simultaneously. The analysis is considered to be conservative as it describes a three-fold increase in emission estimations over the expected traffic case. In the case of 24-hour averages, the diurnal pattern coincides with worst-case dispersion meteorology, while in the case of annual averages it assumes this exaggerated profile occurs every day of the year. Any predicted health risks derived using the sensitivity test values should, therefore, be assessed in this context.

The ten most impacted RWR receptors were chosen around each outlet and the scaling factor was then applied to the expected traffic results at those relevant receptors. This was done separately for annual mean and maximum 24-hour average as the receptors would be different for the different averaging periods. The magnitude of the change in annual mean and maximum 24-hour ground-level concentrations of $PM_{2.5}$ were then determined.

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. Twenty-five-metre resolution terrain data were used in the GRAMM modelling and five-metre data for the GRAL modelling. Figure 6-1 shows the terrain immediately surrounding the project, based on the five-metre resolution data. The vertical scale is clearly exaggerated.

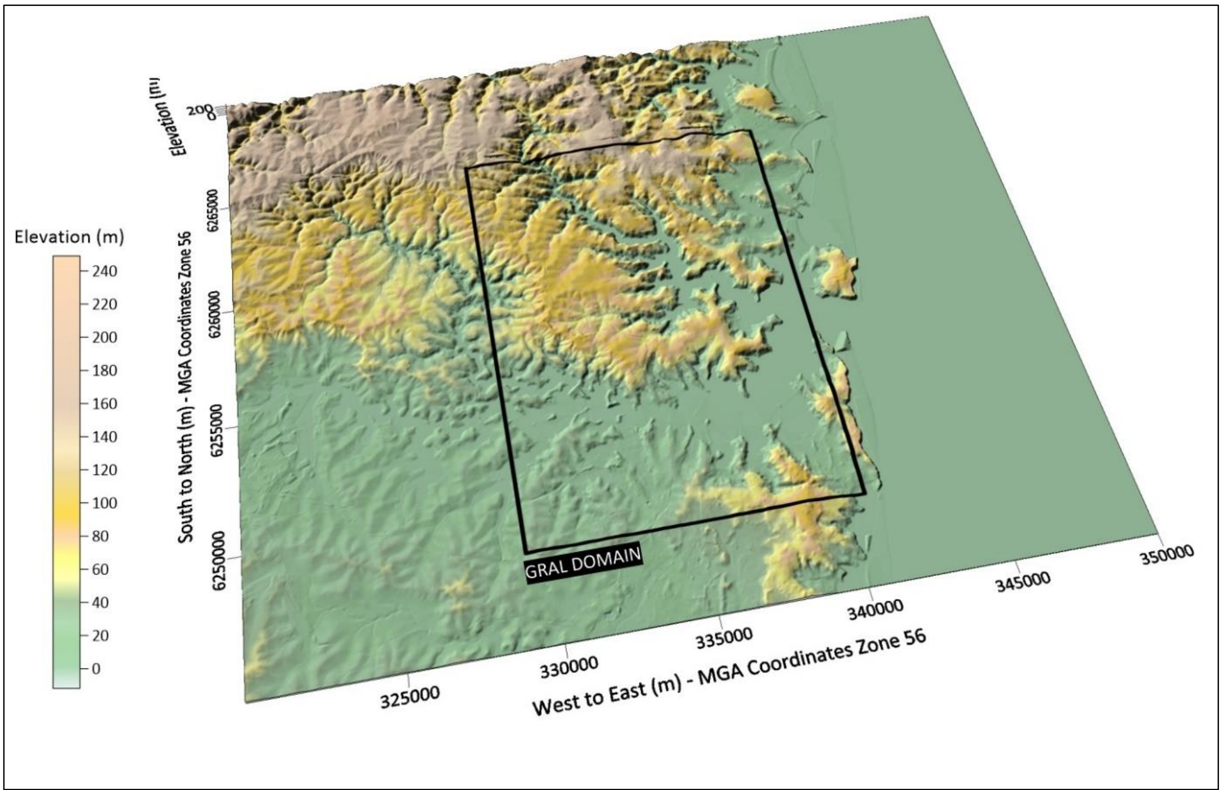

Figure 6-1 Terrain in the GRAL domain (grid system MGA94)

The terrain within the GRAL domain is predominantly flat towards the southern end in and around the Sydney CBD. Elevation increases to the north of Sydney Harbour towards northern Sydney and for most of the northern part of the GRAL domain. The terrain along the project corridor varies from an elevation of around 20 metres Australian Height Datum (AHD) at the southern end at the Rozelle Interchange to an elevation of around 75 metres at Warringah Freeway, at the northern end.

6.3 Land use

Land use within the GRAL domain consists primarily of urban areas, with pockets of recreational reserves and waterbodies throughout the domain predominantly around Sydney Harbour and the northern suburbs.

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 (Observatory Hill) (site number 066062), which is located near to the centre of the GRAMM domain and broadly representative of the area. The annual average daily maximum and minimum temperatures are 21.8°C and 13.8°C, respectively. On average, January is the hottest month with an average daily maximum temperature of 26.0°C. July is the coldest month, with an average daily minimum temperature of 8.1°C. The wettest month is April, with 128.5 millimetres falling over nine rain days. The average annual rainfall is 1215.7 millimetres over an average of 99 rain days per year.

Table 6-1 Long-term average climate summary for Sydney (Observatory Hill)

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Mean daily maximum temperature (ºC)												
26.0	25.8	24.8	22.5	19.5	17.0	16.4	17.9	20.1	22.2	23.7	25.2	21.8
Mean daily minimum temperature (ºC)												
18.8	18.8	17.6	14.7	11.6	9.3	8.1	9.0	11.1	13.6	15.7	17.6	13.8
Mean monthly rainfall (mm)												
101.7	117.5	130.8	128.5	118.6	133.2	96.6	80.7	67.9	76.4	83.6	77.5	1215.7
Mean rain days per month (number)												
8.6	9.0	9.8	9.0	8.6	8.7	7.5	7.2	7.2	7.9	8.4	8.0	99.9

Source: BoM (2018) Climate averages for Station: 066064; Commenced: 1858 – last record April 2018; Latitude: 33.86°S; Longitude: 151.21 °E

6.5 Meteorology

As noted in Annexure B, meteorology is an important factor affecting the dispersion of air pollution. Seven meteorological stations in the GRAMM domain were considered for modelling, and their locations are shown on Figure 6-2. Data relevant to the dispersion modelling such as wind speed, wind direction, temperature and cloud cover were obtained from these stations:

- Meteorological stations operated by the former Office of Environment and Heritage (OEH) (now the Department of Planning, Industry and Environment):
  - Chullora
  - Earlwood
  - Randwick
  - Rozelle

– Lindfield

- BoM meteorological stations:
  - Canterbury Racecourse (AWS)
  - Fort Denison
  - Manly (North Head)
  - Sydney Airport
  - Sydney Olympic Park (Archery Centre)
  - Wedding Cake West.

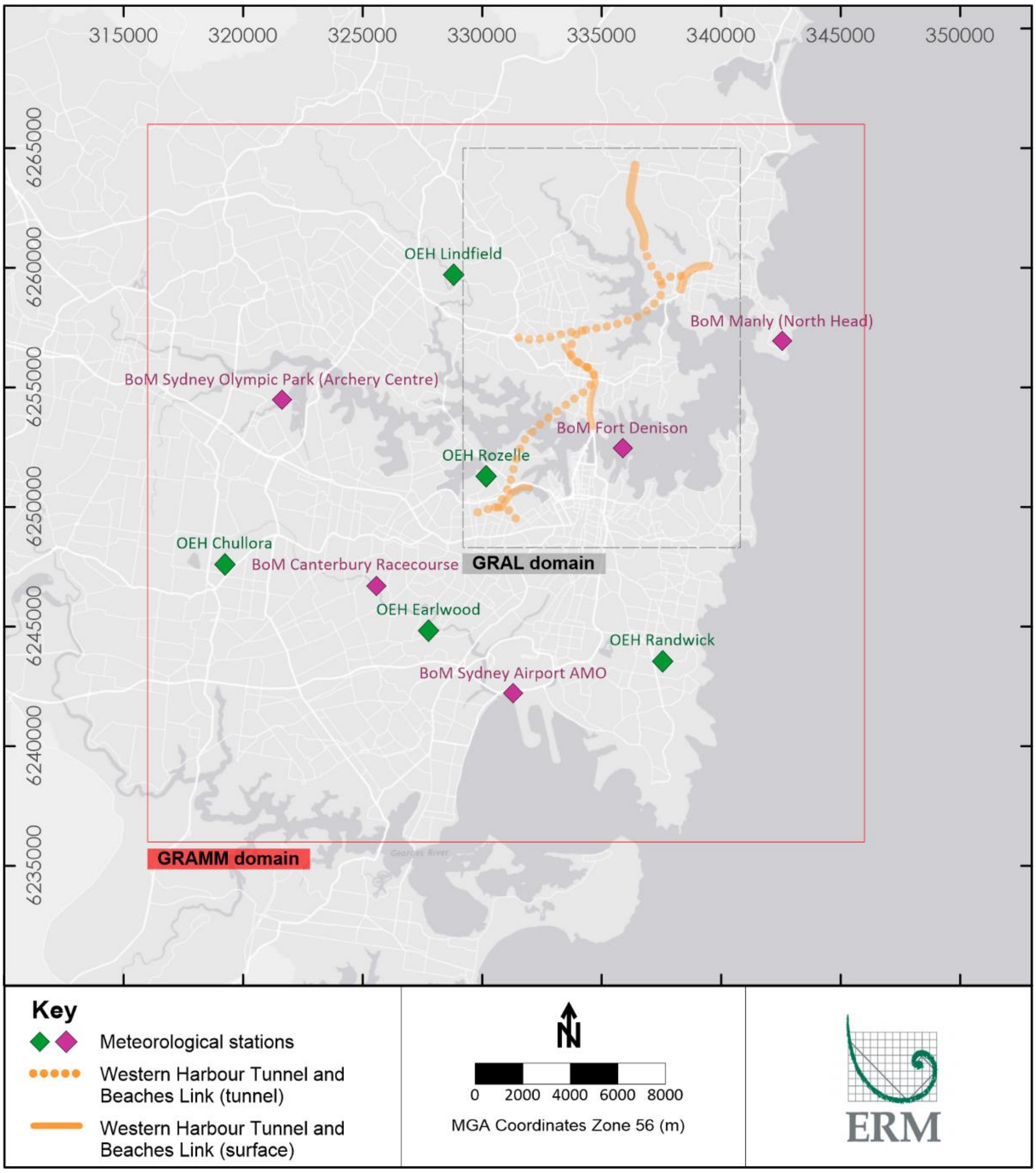

Figure 6-2 Meteorological stations in the model domains (grid system MGA94)

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 Randwick, Rozelle, BoM Fort Denison and BoM Manly (North Head) stations in 2016 were chosen as reference meteorological data for modelling. The rationale for this selection is also summarised in Annexure F. The meteorological modelling method in GRAMM that was applied to this project is known as ‘Match-to-Observations’ (MtO), and this is explained in Section 8.4.2. The method allowed different weighting factors to be applied to meteorological stations, depending on the desired level of influence required in the modelling. The meteorological data analysis showed that the Randwick station was the most representative of the project corridor, and this station was therefore given the highest weighting. Rozelle, BoM Fort Denison and BoM Manly (North Head) were given lower weightings, which is again explained in Section 8.4.2.

At Randwick, the wind speed and wind direction patterns over the eight-year period between 2009 and 2016 were fairly 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 less than 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.

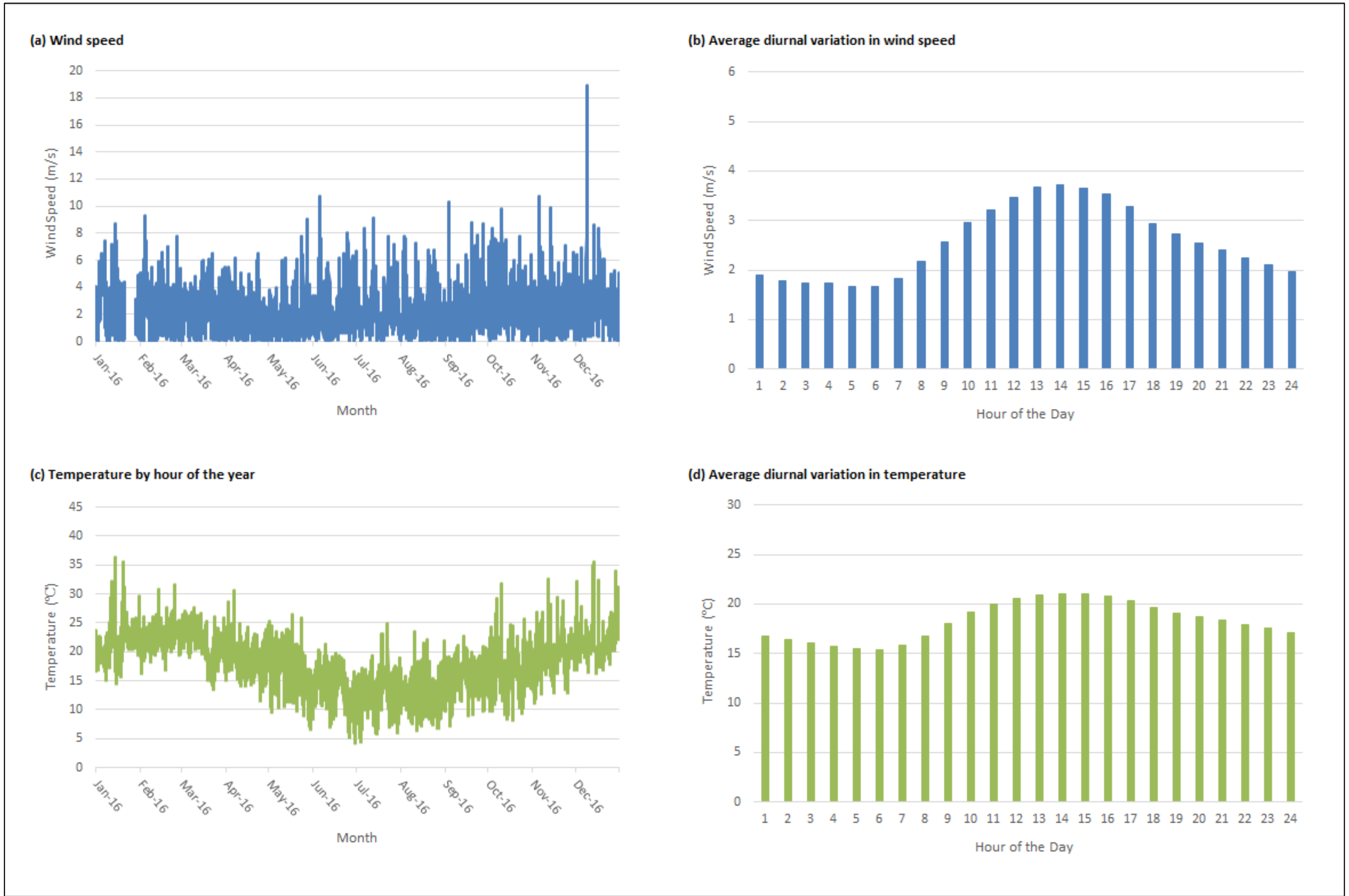

Figure 6-3 Annual and diurnal plots of wind speed and temperature for Randwick (2016)

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[15] that is compiled periodically by the 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 the NSW EPA[16] 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} (nine 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 particulate matter 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, would have contributed significantly to ambient particulate matter 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[17]. Exhaust emissions from these vehicles were responsible for 65 per cent of CO from road transport in Sydney in 2016, 37 per cent of NO_X, and 71 per cent of SO_2. They were a minor source of PM_{10} (three per cent) and $PM_{2.5}$ (four 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 NO_X and particulate matter 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,

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

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

[17] 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).

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.

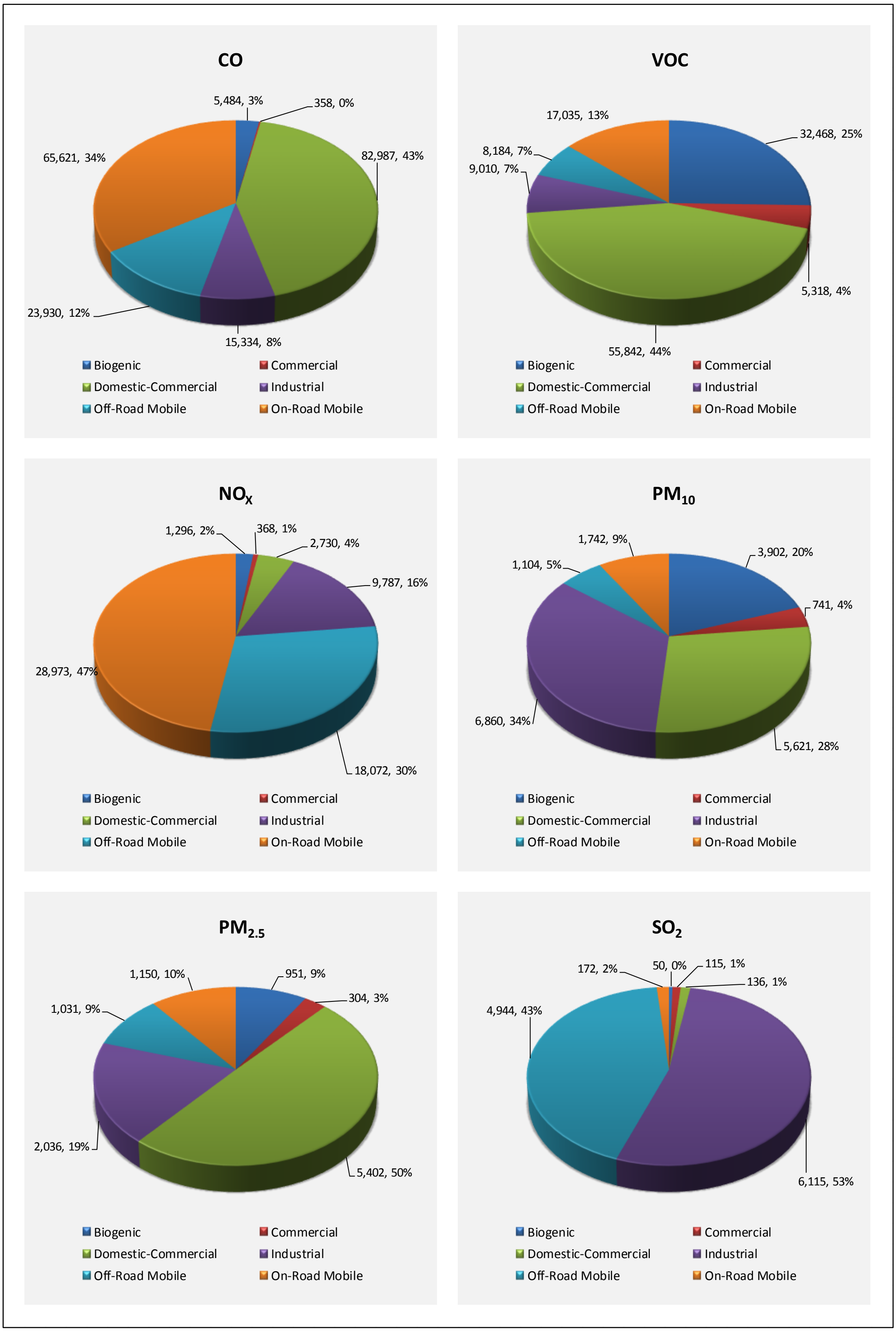

Figure 6-4 Sectoral emissions in Sydney, 2016 (tonnes per year and percentage of total)

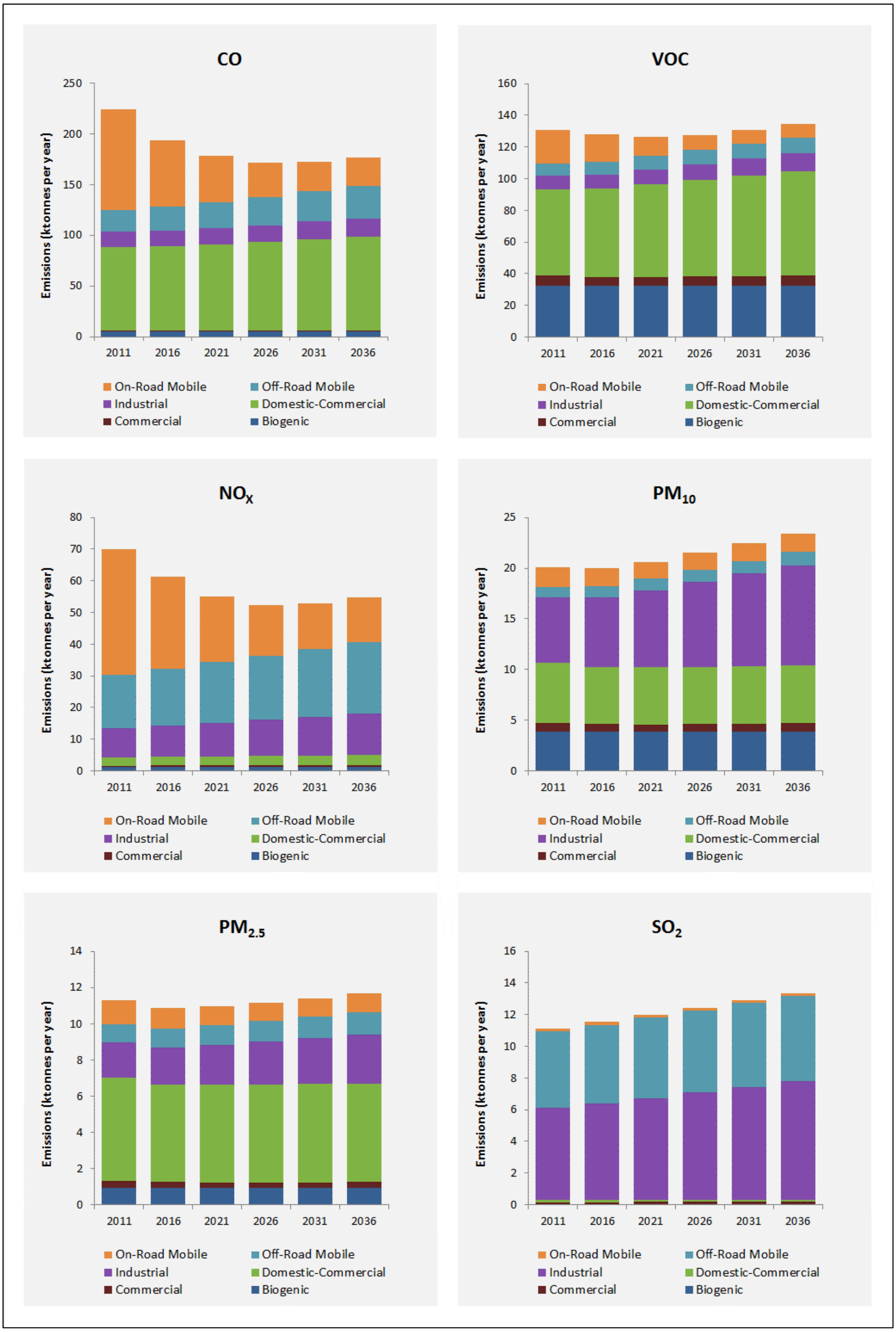

Figure 6-5 Projections of sectoral emissions – Sydney, 2011-2036

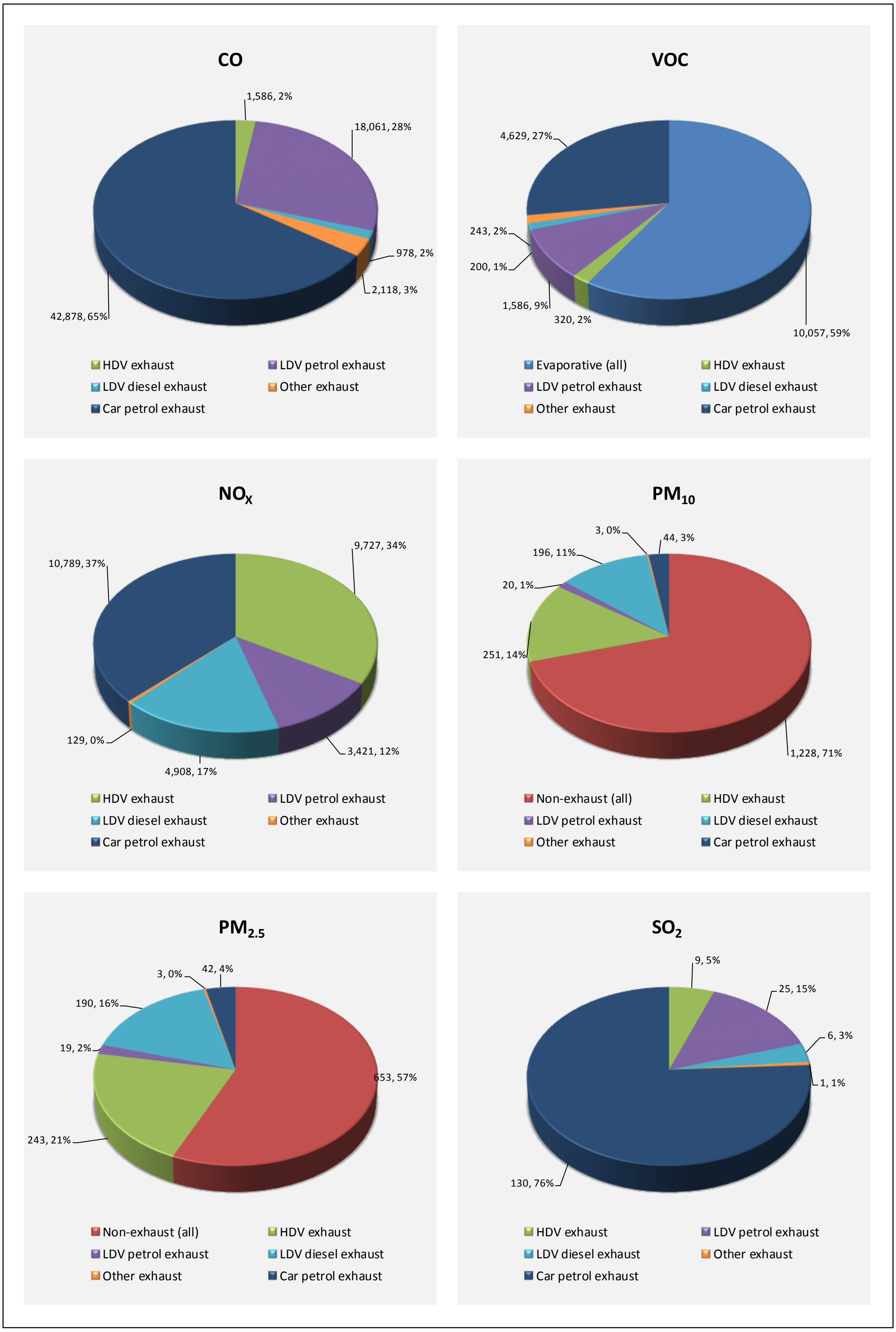

Figure 6-6 Breakdown of road transport emissions – Sydney, 2016 (tonnes per year and percentage of total)

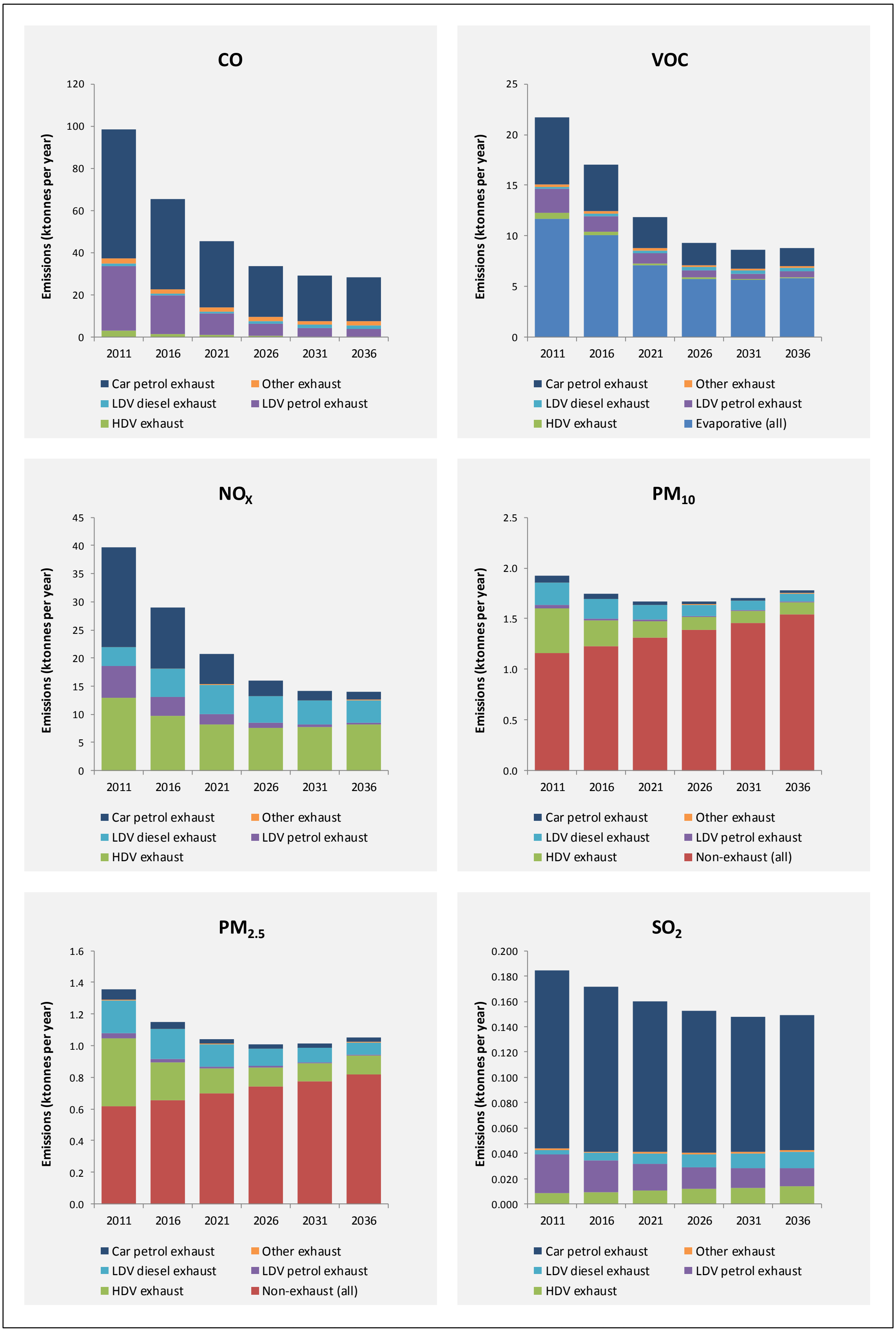

Figure 6-7 Projections of road transport emissions – Sydney, 2011-2036

6.7 In-tunnel air quality

Air quality is monitored continuously in 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[18,19], 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 derive emissions rates from existing ventilation outlets to support the ambient air quality assessment.

6.8 Ambient air quality

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 concentrations 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 concentrations of NO_2, SO_2 and CO continue to be below national standards, concentrations of O_3 and particulate matter (PM_{10} and $PM_{2.5}$) still exceed the standards on occasion.

Concentrations of O_3 and particulate matter 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 (2004–2018), 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 the Department of Planning, Industry and Environment (formerly Office of Environment and Heritage) and Roads and Maritime:

- Department of Planning, Industry and Environment (urban background)
  - Chullora, Earlwood, Randwick, Rozelle, Lindfield, Liverpool, Prospect
- Roads and Maritime (M5 East urban background)
  - CBMS, T1, U1, X1

[18] http://www.lanecovemotorways.com.au/downloads.htm.
[19] http://www.crosscity.com.au/AirQuality.htm.

- Roads and Maritime (M5 East roadside)
  - F1, M1.

Consideration was also given to the shorter-term data from other Roads and Maritime (eg NorthConnex) and Sydney Motorway Corporation (WestConnex) air quality monitoring stations.

The results for specific air quality metrics during the period 2004–2018 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 fairly stable at all stations between 2004 and 2018. In 2016 the maximum 1-hour concentrations were typically between around 2–3 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 15–25 µg/m^3 (depending on the station) in recent years. Values at the Department of Planning, Industry and Environment 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 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 fairly stable in the longer term. The values across all stations typically range between 80–120 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 Department of Planning, Industry and Environment 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 17–19 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 Department of Planning, Industry and Environment 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 (refer to Annexure D).

6.8.3 Project-specific air quality monitoring

Three project-specific monitoring stations for Western Harbour Tunnel and Beaches Link program of works were established by Roads and Maritime in 2017. The locations of the stations are shown in Annexure E. One of these was at a background location, and the other two were at locations near busy roads. 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 project-specific monitoring stations were used to:

- Supplement the existing Department of Planning, Industry and Environment 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 Western Harbour Tunnel and Beaches Link modelling domains
- Provide a time series of air quality data in the vicinity of the project.

The data from the stations are presented in Annexure D.

For background air quality, the data from the WHTBL:01 station were compared with the range of measurements at the Department of Planning, Industry and Environment stations. Only the Department of Planning, Industry and Environment stations closest to the project (ie Chullora, Earlwood, Lindfield, Macquarie Park, Randwick and Rozelle) were included in the evaluation. The Liverpool and Prospect stations, which were much further to the west, were excluded.

Average CO concentrations at WHTBL:01 were towards the upper end of the range at the OEH 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 Department of Planning, Industry and Environment and WHTBL data would not have had a material impact on the outcomes of the assessment for this pollutant.

For NO_X, NO_2 and PM_{10}, the measurements at the WHTBL:01 background were generally towards the lower end of the range of values at the Department of Planning, Industry and Environment stations. This has already been noted earlier with the respect to the concentration gradients in Sydney. Based on the limited dataset at WHTBL:01, it seems that the use of the Department of Planning, Industry and Environment stations could result in conservative maximum concentrations of these pollutants in the air quality assessment, at least in the northern part of the GRAL domain. For example, between October 2017 and January 2019 the highest 1-hour average NO_X concentration at an Department of Planning, Industry and Environment station used in the synthetic profile (Rozelle) was 554 µg/m^3, compared with 140 µg/m^3 at the WHTBL:01 station.

O_3 concentrations at WHTBL:01 were higher than those at the Department of Planning, Industry and Environment stations, which is unsurprising given the relatively low NO_X at this station. NO_X, NO_2 and O_3 are linked by chemical reactions in the atmosphere, and concentrations of NO_X and O_3 typically have an inverse relationship (refer to Section A.3.3 of Annexure A).

The statistics for the near-road project monitoring stations (eg NO_X) indicated that station WHTBL:03 was more strongly influenced by road traffic emissions that station WHTBL:02.

Project specific monitoring has been carried out for the purposes of providing information for this assessment. Further compliance monitoring may be required as a condition of approval and may recommence at that time if required.

7 Assessment of construction impacts

This section considers:

- Potential dust impacts associated with construction (Section 7.1)
- Potential odour impacts associated with the treatment and stockpiling of dredged material for disposal at the White Bay constructions support site (WHT3) (Section 7.2).

The use of on-site diesel-powered vehicles, generators and construction equipment, and the handling and/or on-site storage of fuel and other chemicals, may result in localised increased concentrations of airborne particles, CO, NO_X, SO_2 and VOCs. Minor emissions from these sources would be localised and would be adequately managed with standard environmental management measures. These sources have not been quantitatively assessed because emissions from these sources would not significantly affect local air quality at the nearest sensitive receptors. Emissions of fine particles in particular would not be significant relative to existing levels near busy roads.

There is the potential for dust emissions to contain contaminants mobilised through the disturbance of contaminated soils, and other hazardous materials (such as asbestos fibres or organic matter) mobilised through the demolition of buildings and other structures. These issues would need to be considered on a site-by-site basis, and would be adequately managed through standard air quality environmental management measures. In the event of encountering unexpected finds of contamination during construction, work would cease until the need for further assessment, remediation or other actions have been identified and carried out. Further assessment and management of contamination, if required, would be carried out in accordance with the *Contaminated Land Management Act 1997* and is described further in Technical working paper: Contamination. While the consequences of finding contaminants can be significant, this would depend on the type, magnitude and location of the contamination and whether or not it is in a form able to be transported in the atmosphere. The relevant mitigation measures would be deployed and reduce this risk of impact.

If blasting for the project is required, it would be carried out underground and there would be no direct emissions from blasting to the external air. Blasting would be managed to ensure safe working conditions for both workers and sensitive receptors, and standard practice implemented to keep any potential emissions to ambient air to a minimum.

There is also the potential for crystalline silica emissions to occur during tunnel excavation due to the high temperature caused at the excavation face. This risk would be managed to ensure safe working conditions for workers and in accordance with relevant NSW and Australian guidelines. This would effectively manage any potential impact to ambient air quality. Crystalline silica is not considered further in this assessment.

7.1 Dust impacts

7.1.1 Overview

This section deals with the potential dust impacts of the construction phase of the project. The construction activities for the project are described in Section 1.3.

This section:

- Identifies the construction footprint and assessment zones
- Describes the assessment procedure, which was based on the guidance published by the UK Institute of Air Quality Management, *Guidance on the assessment of dust from demolition and construction* (IAQM, 2014). The IAQM guidance is designed primarily for use in the UK, although it may be applied elsewhere. 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 reduce potential impacts
- Discusses the significance of the identified risks.

The levels of risk identified in this section apply prior to mitigation. The purpose of the assessment is to identify high risk areas, based on their sensitivity and the level of activity, and then to provide mitigation measures to reduce this risk. These measures are outlined in Section 9.1.

Overall construction dust is therefore 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 would be ‘not significant’.

7.1.2 Construction footprint and assessment zones

The total above ground area required to facilitate the construction of the project is referred to as the construction footprint. The construction footprint includes all surface works associated with the project, including:

- Surface works in the vicinity of Rozelle Interchange
- Surface areas required to support tunnelling activities and to construct the tunnel connections and tunnel portals for the Western Harbour Tunnel
- The Warringah Freeway Upgrade
- Operational ancillary facilities
- Construction support sites.

The construction footprint has been divided into construction assessment zones for the purposes of this assessment (refer to Table 7-1). The assessment zones are depicted in Figure 7-1 and represent a grouping of discrete areas within the construction footprint that are in close proximity to each other (within 350 metres for the purposes of the assessment method).

Table 7-1 Construction assessment zones

Assessment Zone	Construction support sites within each assessment zone	Construction works at surface	Indicative construction period
Zone 1	WHT1	Construction works associated with the Rozelle Interchange connection. Fitout of operational infrastructure for Western Harbour Tunnel, including the Rozelle ventilation outlet.	Q2 2023 to Q1 2026
Zone 2	WHT2	No construction works beyond activities associated with WHT2.	Q3 2021 to Q3 2025
Zone 3	WHT3	No construction works beyond activities associated with WHT2.	Q2 2021 to Q3 2025
Zone 4	WHT4, WHT5, WHT6, WHT7	Construction activities associated with WHT4 and WHT7 and construction of the harbour crossing (including dredging and handling of dredged material).	Q2 2021 to Q4 2025 (collectively)

Assessment Zone	Construction support sites within each assessment zone	Construction works at surface	Indicative construction period
Zone 5	WHT8, WHT9, WHT10, WHT11 WFU1, WFU2, WFU3, WFU4, WFU5, WFU6, WFU7, WFU8, WFU9	Construction works associated with Western Harbour Tunnel component of the project. Construction works associated with the upgrade and reconfiguration of the Warringah Freeway. Construction works associated with the motorway control centre. Collectively, this would include tunnel dive structures and construction of tunnel portals and ramps, construction of operational ancillary infrastructure, upgrades to interchanges, alterations or upgrades to the surrounding road network, and adjustments to other infrastructure (eg active transport, utilities).	Q4 2020 to Q4 2025 (collectively)

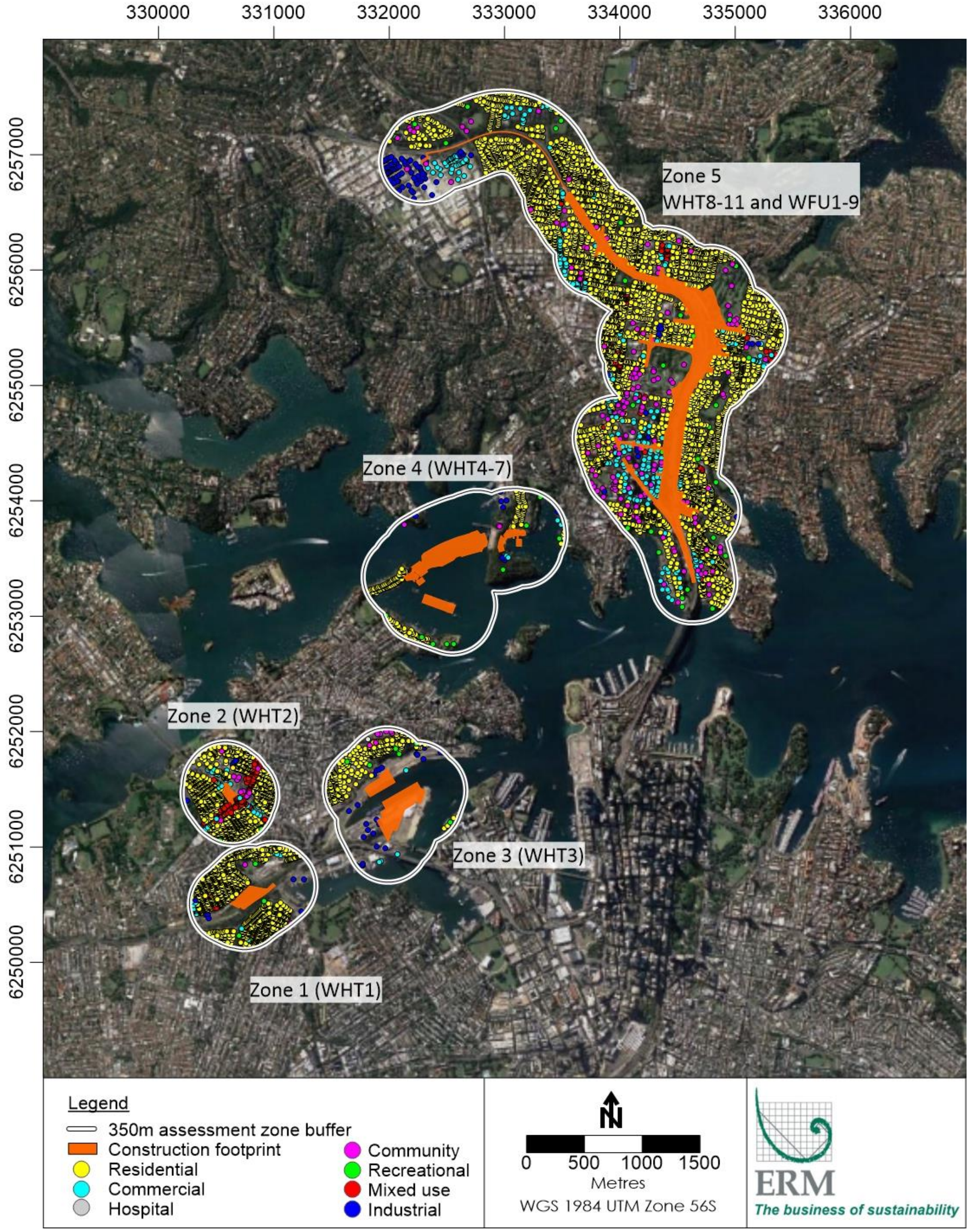

Figure 7-1 **Construction assessment zones**

7.1.3 Assessment procedure

The IAQM procedure for assessing risk from construction dust is summarised in Figure 7-2. Key steps in the assessment process are detailed in the following sections. This assessment considers three separate types of dust impacts:

- Annoyance due to dust settlement
- The risk of health effects due to an increase in exposure to particulate matter (PM_{10})
- Harm to ecological receptors.

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.

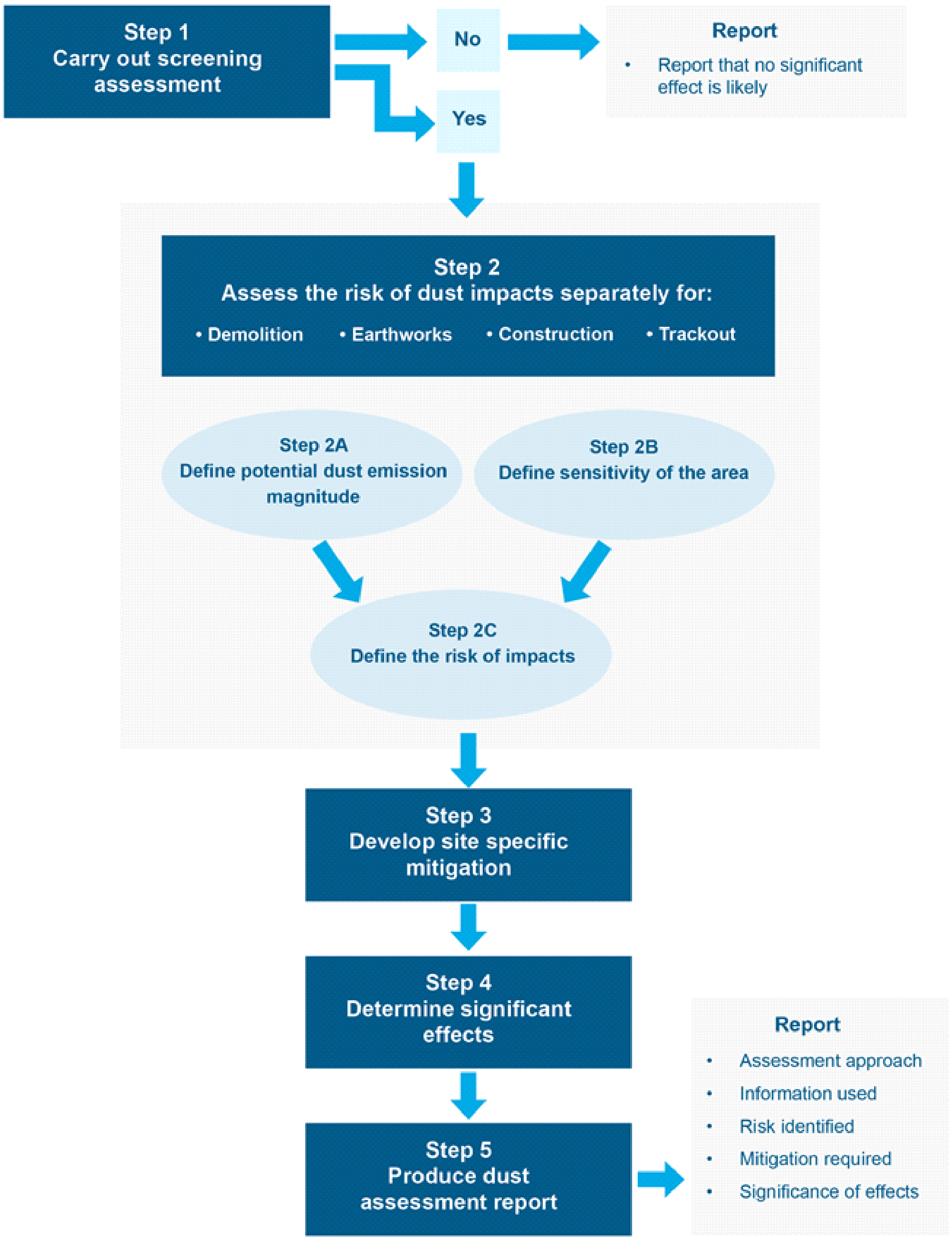

Figure 7-2 Steps in the risk assessment of construction dust (IAQM, 2014)

7.1.4 Step 1: Screening

Step 1 involved screening to determine whether or not any further assessment was required. A construction dust assessment is normally required where:

- There are human receptors within 350 metres of the assessment zone boundary and/or within 50 metres of the route(s) used by construction vehicles on the public road that are up to 500 metres from the construction assessment zone 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 that are up to 500 metres from the construction assessment 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 settlement, 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 (eg museums and galleries), vehicle showrooms, food manufacturers, electronics manufacturers, amenity areas and horticultural operations (eg soft-fruit production).

An 'ecological receptor' refers to any sensitive habitat affected by dust settlement. This includes the direct impacts on vegetation or aquatic ecosystems of dust deposition, and the indirect impacts on fauna (eg on foraging habitats) (IAQM, 2014).

As depicted in Figure 7-1, there are multiple human receptors within 350 metres of the construction assessment zones. This has triggered the need for further assessment (Step 2).

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 zone and each of the four types of activities (demolition, earthworks, construction, and track-out). Risk categories were assigned to the assessment zones based on two factors:

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

These factors are combined in Step 2C to provide an estimate of the risk of dust impacts, prior to mitigation. Risks were categorised as low, medium or high for each of the four separate potential activities. Where there was risk of an impact, then site-specific mitigation measures were considered 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 provided in Table 7-2.

The categorisation of the construction assessment zones for the project is summarised in Table 7-3. This assessment is based on the description of activities in Chapter 6 (Construction work) of the environmental impact statement. With respect to Zone 1, demolition activities haven't been considered on the basis that site preparation works at the Rozelle Rail Yards are completed as part of the WestConnex M4-M5 Link.

Table 7-2 Criteria for assessing the potential scale of emissions

Type of activity	Potential emission magnitude		
	Large	Medium	Small
Demolition	Volume >50000 m^3, potentially dusty construction material (e.g. concrete), on-site crushing and screening, demolition activities >20 m above ground level.	Volume 20000–50000 m^3, potentially dusty construction material, demolition activities 10–20 m above ground level.	Volume <20000 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 >10000 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 >100000 tonnes.	Site area 2500–10000 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 20000–100000 tonnes.	Site area <2500 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 <20000 tonnes, earthworks during wetter months.
Construction	Total building volume >100000 m^3, piling, on site concrete batching; sandblasting	Building volume 25000–100000 m^3, potentially dusty construction material (e.g. concrete), piling, on site concrete batching.	Total building volume <25000 m^3, construction material with low potential for dust release (e.g. metal cladding or timber).
Track-out	>50 HDVs (>3.5 tonnes) outward movements in any one day, potentially dusty surface material (e.g. high clay content), unpaved road length >100 m.	10–50 HDVs (>3.5 tonnes) outward movements in any one day, moderately dusty surface material (e.g. high clay content), unpaved road length 50–100 m.	<10 HDVs (>3.5 tonnes) outward movements in any one day, surface material with low potential for dust release, unpaved road length <50 m.

Note: Demolition is defined as 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 surfacing any excavated material, soil stripping, ground levelling, excavation and landscaping. Earthworks would primarily involve excavating material, haulage, rock breaking, tipping and stockpiling.
Construction is any activity that involves the provision of new structures, modification or refurbishment. A structure would include a residential dwelling, office building, retail outlet and road.
Track-out involves the potential transport of dust and dirt by HDVs from the work sites onto the public road network, where it may potentially be deposited and then re-suspended by other vehicles.

Table 7-3 Categorisation of assessment zones for each type of activity

	Site category by assessment zone				
	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5
Demolition	N/A	Medium	N/A	Small	Large
Earthworks	Medium	Medium	Medium	Medium	Large
Construction	Medium	Small	N/A	Small	Large
Track-out	Medium	Medium	Medium	Medium	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.

Sensitivity of area to dust settlement effects on people and property

The criteria for determining the sensitivity of an area to dust settlement impacts are provided 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. To maintain conservatism, all other sensitive receptor locations were considered as having equal sensitivity to residential locations. The types of receptors shown in Figure 7-1 are predominantly residential, so in consideration of the IAQM guidance, the receptor sensitivity was assumed to be 'high' for all types.

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

Receptor sensitivity	Number of receptors	Distance from assessment zone boundary (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 within each distance was estimated from land-use zoning of the area. 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 varying distances.

For this project, the numbers of receptors per building (or location) assumed are shown in Table 7-5. The numbers of receptors for each assessment zone and activity, and the resulting sensitivities, are provided in Table 7-6.

Based on the receptor sensitivity and the numbers of receptors within certain distances from construction activities, the sensitivity for all areas and all activities was determined to be 'high'.

Table 7-5 Number of receptors assumed for each location type

Land-use category	Number of receptors
Commercial Local Centre	5 5
Mixed Use	3
Aged Care Childcare Community Education Medical Place of Worship	100 30 20 100 10 10
Industrial	10
General Residential Low Density Residential Medium Density residential High Density Residential	3 3 5 50
Recreational	20
Hospital	1000

Table 7-6 Results of sensitivity to dust settlement effects

Zone	Activity	Receptor sensitivity	Number of receptors by distance from assessment zone boundary (m)				Sensitivity of area
			<20	20–50	50–100	100–350	
Zone 1 (WHT1)	Demolition	N/A	N/A	N/A	N/A	N/A	N/A
	Earthworks	High	0	113	228	3066	High
	Construction	High	0	113	228	3066	High
	Track-out	High	0	113	N/A	N/A	High
Zone 2 (WHT2)	Demolition	High	36	171	523	3739	High
	Earthworks	High	36	171	523	3739	High
	Construction	High	36	171	523	3739	High
	Track-out	High	36	171	N/A	N/A	High
Zone 3 (WHT3)	Demolition	N/A	N/A	N/A	N/A	N/A	N/A
	Earthworks	High	20	30	46	2800	High
	Construction	N/A	N/A	N/A	N/A	N/A	N/A
	Track-out	High	20	30	N/A	N/A	High
Zone 4 (WHT4,5,6,7)	Demolition	High	9	82	155	1057	Medium
	Earthworks	High	9	82	155	1057	Medium
	Construction	High	9	82	155	1057	Medium
	Track-out	High	9	82	N/A	N/A	Medium
Zone 5 (WHT8-11, WFU1-9)	Demolition	High	5894	8637	10,635	32,155	High
	Earthworks	High	5894	8637	10,635	32,155	High
	Construction	High	5894	8637	10,635	32,155	High
	Track-out	High	5894	8637	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 provided in Table 7-7. Air quality monitoring data from different monitoring stations was used to establish an annual average background PM_{10} concentration of 16.5 µg/m^3 (refer to 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 7-8.

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

Receptor sensitivity	Annual mean PM_{10} concentration ($\mu g/m^3$) [(a)]	Number of receptors	Distance from assessment zone boundary (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 PM_{10} standards (25 $\mu g/m^3$ and 40 $\mu g/m^3$ respectively).

Table 7-8 Results for sensitivity of area to health impacts

Zone	Activity	Receptor sensitivity	Annual mean PM_{10} conc. ($\mu g/m^3$)	Number of receptors by distance from assessment zone boundary (m) <20	20-50	50-100	100-200	200-350	Sensitivity of area
Zone 1 (WHT1)	Demolition	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Earthworks	High	15-17.5	0	113	228	730	2336	High
	Construction	High	15-17.5	0	113	228	730	2336	High
	Track-out	High	15-17.5	0	113	N/A	N/A	N/A	High
Zone 2 (WHT2)	Demolition	High	15-17.5	36	171	523	1184	2555	High
	Earthworks	High	15-17.5	36	171	523	1184	2555	High
	Construction	High	15-17.5	36	171	523	1184	2555	High
	Track-out	High	15-17.5	36	171	N/A	N/A	N/A	High
Zone 3 (WHT3)	Demolition	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Earthworks	High	15-17.5	20	30	46	315	2485	High
	Construction	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Track-out	High	15-17.5	20	30	N/A	N/A	N/A	High

Zone	Activity	Receptor sensitivity	Annual mean PM_{10} conc.	Number of receptors by distance from assessment zone boundary (m)					Sensitivity of area
Zone 4 (WHT 4,5,6,7)	Demolition	High	15-17.5	9	82	155	135	922	Medium
	Earthworks	High	15-17.5	9	82	155	135	922	Medium
	Construction	High	15-17.5	9	82	155	135	922	Medium
	Track-out	High	15-17.5	9	82	N/A	N/A	N/A	Medium
Zone 5 (WHT8-11 WFU1-9)	Demolition	High	15-17.5	5894	8637	10,635	14,015	18,140	High
	Earthworks	High	15-17.5	5894	8637	10,635	14,015	18,140	High
	Construction	High	15-17.5	5894	8637	10,635	14,015	18,140	High
	Track-out	High	15-17.5	5894	8637	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 from construction dust are provided in Table 7-9. Based on the IAQM guidance, the receptor sensitivity was assumed to be ‘high’ for ecologically sensitive areas, which were defined as areas that contained native vegetation or habitat values (as identified in Technical working paper: Biodiversity Development Assessment Report (Arcadis, 2020) for the project). Areas containing potential for ecological significance within 20 metres of the construction footprint of Zone 5 include Anzac Park. Sensitive ecological areas such as Balls Head Reserve were located within Zone 4. The results are shown in Table 7-10. Receptors within these zones were determined to have a ‘high’ sensitivity to ecological impacts, that is, within 20 metres of the construction footprint.

Table 7-9 Criteria for sensitivity of area to ecological impacts

Receptor sensitivity	Distance from assessment zone boundary (metres)	
	<20	**20–50**
High	High	Medium
Medium	Medium	Low
Low	Low	Low

Table 7-10 Results of sensitivity to ecological impacts

Zone	Activity	Receptor sensitivity	Distance from zone boundary (metres)	Sensitivity of area
Zone 4 (WHT 4,5,6,7)	Demolition	High	<20	High
	Earthworks	High	<20	High
	Construction	High	<20	High
	Track-out	High	<20	High
Zone 5 (WHT8-11, WFU1-9)	Demolition	High	<20	High
	Earthworks	High	<20	High
	Construction	High	<20	High
	Track-out	High	<20	High

Step 2C: Risk of dust impacts

The risk of potential dust impacts, without mitigation, was determined by combining the scale of potential emissions (Step 2A) with the sensitivity of the surrounding area (Step 2B). The risk matrix for Step 2C is provided in Table 7-11.

Table 7-11 Risk categories

Type of activity	Sensitivity of area (from Step 2B)	Potential emission magnitude (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 for the project is summarised in Table 7-12. It is noted that these risks are based on assumptions prior to mitigation. The purpose of this assessment is to provide mitigation measures to reduce this risk (which are identified in in Section 9.1). As the level of risk varies in accordance with zone and activity, those activities that were determined to be of high and medium risk have been identified as follows:

- Zone 1: Medium risk for earthworks, construction and track-out for dust settlement and human health
- Zone 2: Medium risk for demolition, earthworks and track-out for dust settlement and human health
- Zone 3: Medium risk for earthworks and track-out for dust settlement and human health
- Zone 4: Medium risk for earthworks for dust settlement and human health
- Zone 5: High risk for all activities for dust settlement, human health and ecological sensitivity.

Table 7-12 Summary of risk assessment for each zone

Zone	Activity	Step 2A: Potential for dust emissions	Step 2B: Sensitivity of area			Step 2C: Risk of dust impacts		
			Dust settlement	Human health	Ecological	Dust settlement	Human health	Ecological
Zone 1 (WHT1)	Demolition	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Earthworks	Medium	High	Medium	N/A	Medium risk	Medium risk	N/A
	Construction	Medium	High	Medium	N/A	Medium risk	Medium risk	N/A
	Track-out	Medium	High	Medium	N/A	Medium risk	Low risk	N/A
Zone 2 (WHT2)	Demolition	Medium	High	High	N/A	Medium risk	Medium risk	N/A
	Earthworks	Medium	High	High	N/A	Medium risk	Medium risk	N/A
	Construction	Small	High	High	N/A	Low risk	Low risk	N/A
	Track-out	Medium	High	High	N/A	Medium risk	Medium risk	N/A
Zone 3 (WHT3)	Demolition	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Earthworks	Medium	High	High	N/A	Medium risk	Medium risk	N/A
	Construction	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Track-out	Medium	High	High	N/A	Medium risk	Medium risk	N/A
Zone 4 (WHT4,5,6,7)	Demolition	Small	Medium	Medium	High	Low risk	Low risk	Medium risk
	Earthworks	Medium	Medium	Medium	High	Medium risk	Medium risk	Medium risk
	Construction	Small	Medium	Medium	High	Low risk	Low risk	Low risk
	Track-out	Medium	Medium	Medium	High	Low risk	Low risk	Medium risk
Zone 5 (WHT8-11, WFU1-9)	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

N/A = not applicable

7.1.6 Step 3: Mitigation

Step 3 involved identifying potential mitigation measures that could be applied to minimise the risk of dust impacts 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. Identified mitigation measures are discussed in Section 9.1.

7.1.7 Step 4: Significance of risks

Once the risk of dust impacts had been determined in Step 2C, and the appropriate dust mitigation measures identified in Step 3, the final step was to determine whether there are significant residual effects arising from the development and construction phase of a proposed development.

For all activities, the aim should be to prevent significant effects on receptors through the use of effective mitigation in construction environmental management documentation. Experience shows that this is normally possible; however, even with a rigorous management strategy in place, conditions on site are changeable (due to changes in activities and/or weather conditions), and mitigation measures may be less effective under some conditions. There is therefore, a risk of short term impact, but these may not necessarily be frequent or persistent.

Overall construction dust is therefore 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 would be 'not significant'.

The construction activities at Rozelle Rail Yards have been included in this assessment. However, the majority of the main dust generating works would already have been completed as part of the WestConnex M4-M5 Link works so only the remaining works are included.

The area around the Warringah Freeway Upgrade is also an area where two significant infrastructure projects coincide. In this case, there may be cumulative impacts from construction works associated with the proposed Beaches Link project; however, the main dust generating works would not overlap. Recommended mitigation measures would reduce this risk.

In summary, any cumulative effects would be in close proximity to the dust generating works and are not likely to be experienced further afield.

7.2 Odour impacts

7.2.1 Overview

As part of the harbour tunnelling activities for the project, a significant amount of dredged material would need to be excavated from beneath the water. This would be done using mechanical dredging, bringing potentially odorous material to the surface. Roads and Maritime has submitted an application to the Commonwealth Department of the Environment and Energy for an offshore disposal permit for disposal of suitable dredged material. Offshore disposal would be beneficial as it would avoid unnecessary disposal of spoil to landfill and would reduce the impacts of construction vehicle movements on the local road network.

While on the barges in the vicinity of the dredging activity or while in transit to the offshore disposal location, dredged material would be covered with water which would significantly reduce any odour emissions. Any odour impacts from this material would be low, given it would remain wet and located at some distance from any sensitive receptor.

For dredged material that is unsuitable for offshore disposal, the material would be transported by barge to the White Bay construction support site (WHT3) for treatment, if required (eg addition of lime or polymers), prior to delivery by trucks to an appropriately licenced waste management facility.

The treatment of this material for dewatering, for mitigation of odour generation, and for neutralisation of acid sulfate soils would be carried out either on the barges or onshore. Treated material could be either directly loaded from the barges into sealed and covered trucks or temporarily stockpiled in a controlled onshore containment area for subsequent rehandling into trucks.

As this has the potential to generate odour impacts, an assessment on the potential odour impacts has been carried out.

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.

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

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

The NSW Approved Methods include ground-level concentration criteria for complex mixtures of odorous air pollutants. These have been refined by the 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 would be a wide range of responses in the population exposed to the odour. In a densely populated area there would therefore be a greater risk that some individuals within the community would find the odour unacceptable than in a sparsely populated area.

Table 7-13 lists the odour criteria to be exceeded not more than one per cent of the time for different population sizes. The most stringent of the impact assessment criterion of 2 odour units (OU) at the 99^{th} percentile has been applied to the assessment of the exposed dredging material.

Table 7-13 Criteria for the assessment of odour (NSW EPA, 2016)

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

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

To determine more rigorously the ratio between a one-second peak concentration and a three-minute (or longer) average concentrations (referred to as the peak-to-mean ratio) that might be predicted by a Gaussian dispersion model, the EPA commissioned a study by Katestone Scientific Pty Ltd (1995, 1998). This study recommended peak-to-mean ratios for a range of variables such as source type, receptor distance, stability class, and stack height (for point sources). The Approved Methods take account of the peak-to-mean factor in the criteria shown in Table 7-13.

7.2.3 Modelling methodology

Dispersion modelling was carried out to inform a quantitative assessment of the potential odour impacts resulting from dredging activities. This involved various model inputs, including local meteorology and emission rates from potential odour 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[20] and CALMET/CALPUFF[21].

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 on 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.

Estimates of odour emission rates were taken from measurements made for similar dredging operations. The assumption is made that the total treatment area would be exposed with odorous material for every day of the year which generates conservatism in the assessment. The following sections provide more detail on these inputs with results provided in Section 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 both the Western Harbour Tunnel and Beaches Link program of works. 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.

[20] TAPM = The Air Pollution Model

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

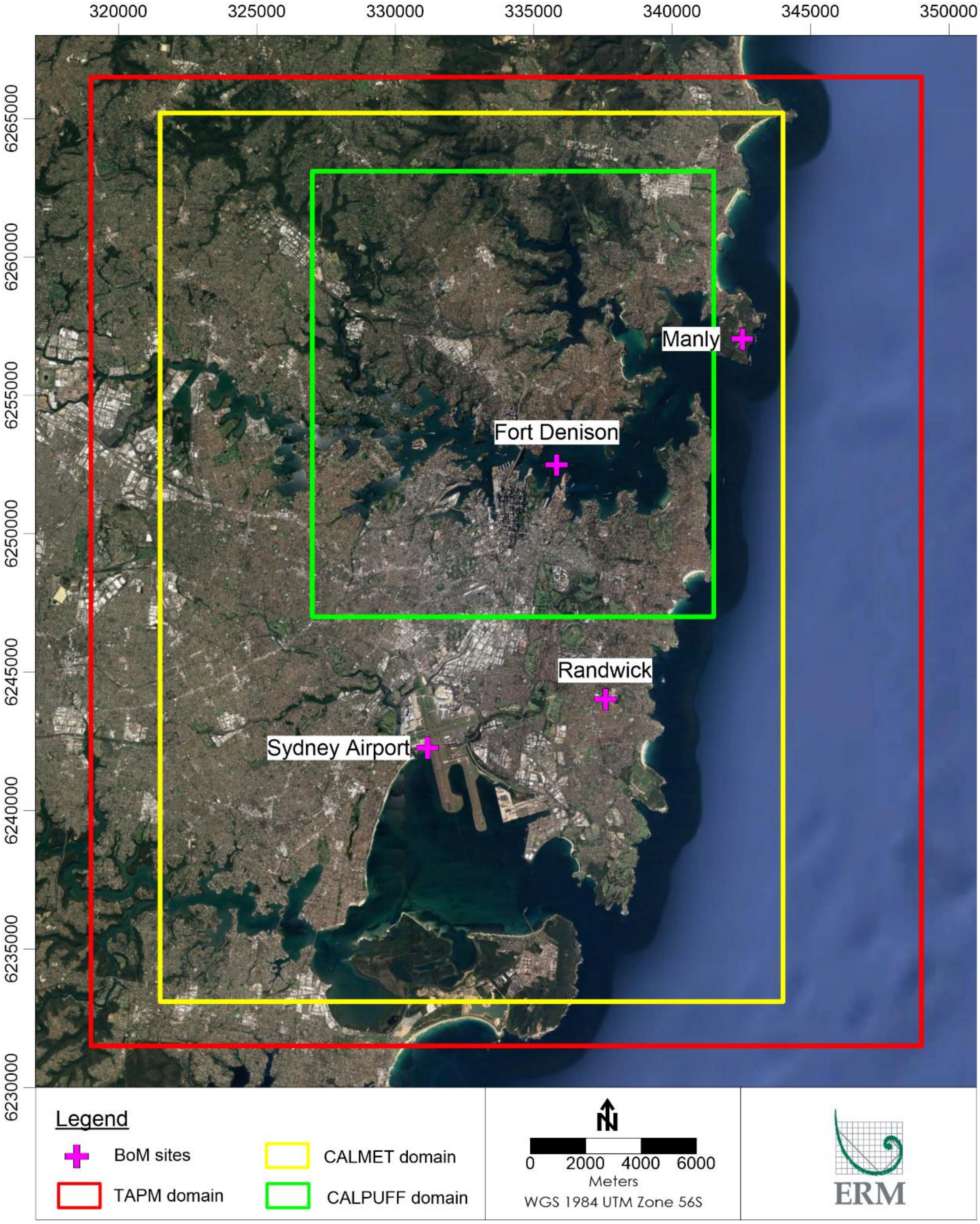

Figure 7-3 Meteorological and dispersion modelling domains for odour assessment

Emission sources

To obtain site-specific odour emission rates, odour samples were taken from dredged material from within Sydney Harbour near Birchgrove.

Odour samples were taken for freshly extracted and undisturbed sediment, freshly extracted and disturbed sediment and a disturbed sample that was allowed to settle and dry after extraction. This enabled a range of different potential odour emissions.

Sampling was carried out using an isolation flux hood and analysed using the Australian Standard for odour measurement *'Determination of odour concentration by dynamic olfactometry'* (AS/NZS 4323.3:2001). Once odour concentrations for each sample were determined, a specific odour emission rate could be calculated for use in the dispersion modelling. These specific odour emission rates were very low at both sites, so the maximum value was used for dispersion modelling. This rate was 0.028 ou.$m^3/m^2/s$.

At the White Bay construction support site (WHT 3), a total area of about 1000 square metres would be used to stockpile and treat dredged material that is unsuitable for offshore disposal. This would be a combination of areas on land or on barges. Following treatment, material would be transferred to sealed trucks for delivery to landfill.

The total odour emission rate for the whole area of 1000 square metres, assuming a peak-to-mean ratio of 2.5 (discussed in Section 7.2.2), is shown in Table 7-14. Dispersion modelling results are presented in Section 7.2.4.

Table 7-14 Odour emission rates for each odour source

Source	Specific odour emission rate (OU.$m^3/m^2/s$)	Total area (m^2)	Peak-to-mean ratio	Total odour emission rate (OU.m^3/s)
Dredged material	0.028	1000	2.5	70

7.2.4 Results

This section provides the predicted odour concentrations due to proposed dredging activities, stockpiling and treatment at White Bay. The results presented in Figure 7-4 show that the predicted 99th percentile odour concentrations at all sensitive receptors are well below the 2 OU criterion and also well below the theoretical level of detection of 1 OU.

The dispersion modelling has assumed that the whole 1000 square metre area is exposed continuously. The assumption has also been made that all material is undergoing treatment on land and not on barges. This is unlikely to happen in practice, as it is expected that there would be some treatment occurring on barges, and hence further away from receptors.

Figure 7-4 Predicted 99th percentile odour concentration due to treatment of dredging material (OU)

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 GRAL domain. The following components were treated separately to take in to account all potential changes in traffic emissions on the network:

- Emissions from existing and proposed tunnel ventilation outlets for tunnels where portal emissions are, or would not be, permitted
- Emissions from the portals of existing tunnels, where these are currently permitted
- 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.

8.2.2 Tunnel ventilation outlets

A noted in Section 2.2, 11 ventilation outlets for existing and proposed tunnels in the GRAL domain were included in the modelling. The locations of the ventilation outlets (labelled A to K) are shown on Figure 8-1. Outlets F and G would be specific to the project. The remaining ventilation outlets were included to assess potential cumulative impacts only. Details of the ventilation outlets that were of specific interest to the air quality assessment are provided in Annexure G.

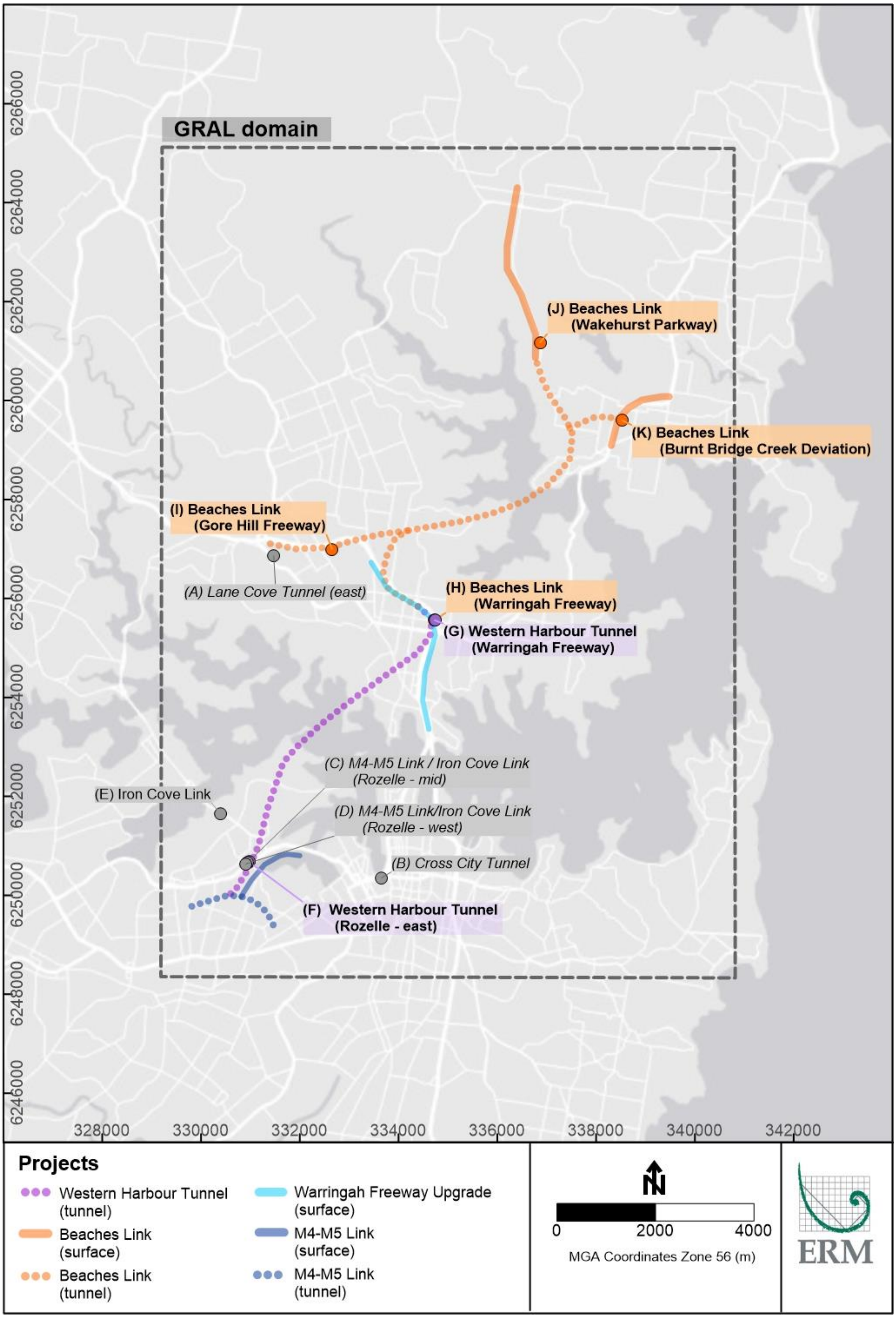

Figure 8-1 Locations of all tunnel ventilation outlets included in the assessment (grid system MGA94)

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 therefore had to be calculated for each ventilation 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 tunnels and the proposed tunnels are summarised below.

Existing facilities for Lane Cove Tunnel and Cross City Tunnel

Emissions of CO, NO_X, VOCs, PM_{10} and $PM_{2.5}$ were calculated for the eastern ventilation outlet of the Lane Cove Tunnel (Outlet A) and the ventilation outlet of the Cross City Tunnel (outlet B). It was assumed that there would be no portal emissions from these tunnels at any time of day.

For the 2016-BY scenario, emissions were calculated using hourly in-stack concentration and air flow measurements for 2016 supplied by Roads and Maritime. Emission scaling factors for the future year scenarios were developed using the NSW EPA emission model, the SMPM outputs (traffic volume speed and composition), and a basic geometry (road gradient and length by section) for each tunnel.

The pollutants measured in each tunnel ventilation outlet were CO, NO_X, PM_{10} and $PM_{2.5}$. THC emissions were calculated using a method similar to that described below for the project ventilation outlets.

Air flows for all scenarios were based on the in-stack measurements from 2016, simplified as source groups for use in GRAL.

Proposed facilities for WestConnex M4-M5 Link and Iron Cove Link

The emissions and air flows from these ventilation outlets (C, D and E) were taken from the air quality report for the M4-M5 Link environmental impact statement (Pacific Environment, 2017). Given that the future years for the M4-M5 Link environmental impact statement (2023 and 2033) were earlier than those for the project assessment years (2027 and 2037), it is likely that this assumption would be conservative.

Proposed facilities for Western Harbour Tunnel and Beaches Link program of works

The method for determining emissions from the project 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 PM_{10} and THC emissions

Pollutant emission ratio	Value by year	
	2027	2037
$PM_{10}:PM_{2.5}$	1.447	1.505
$THC:NO_X$	0.068	0.064

The diurnal profiles of ventilation 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 ventilation outlets, consistent with the assumptions in GRAL, are also provided in Annexure G.

8.2.3 Tunnel portals

For two tunnels in the GRAL domain – Sydney Harbour Tunnel and the Eastern Distributor tunnel – emissions from portals are permitted. The locations of these portals are shown on Figure 8-2. The traffic in the Sydney Harbour Tunnel and the Eastern Distributor tunnel and emissions from the portals, were affected by the project. For these tunnel portals, several assumptions were made which would have tended to result in conservative estimates of emissions. For example, in both cases it was assumed that all emissions from the traffic in the tunnel would be released from the portals at all times (ie there would be no emissions from the tunnel ventilation outlets). Detailed direct measurements of portal emissions were not available, and so emission rates for all scenarios were estimated using the NSW EPA model (also likely to be conservative) in conjunction with a simplified tunnel geometry and traffic data from the SMPM. Air flows from the tunnel portals in all scenarios were based on recently observed diurnal profiles, and these were therefore decoupled from the emission estimates.

The temperature difference between the tunnel air and the ambient air was assumed to be negligible. In other words, the temperature of the air leaving the portals was assumed to be the same as the ambient temperature. This was likely to be a conservative assumption, as it would underestimate the thermal buoyancy of the tunnel air.

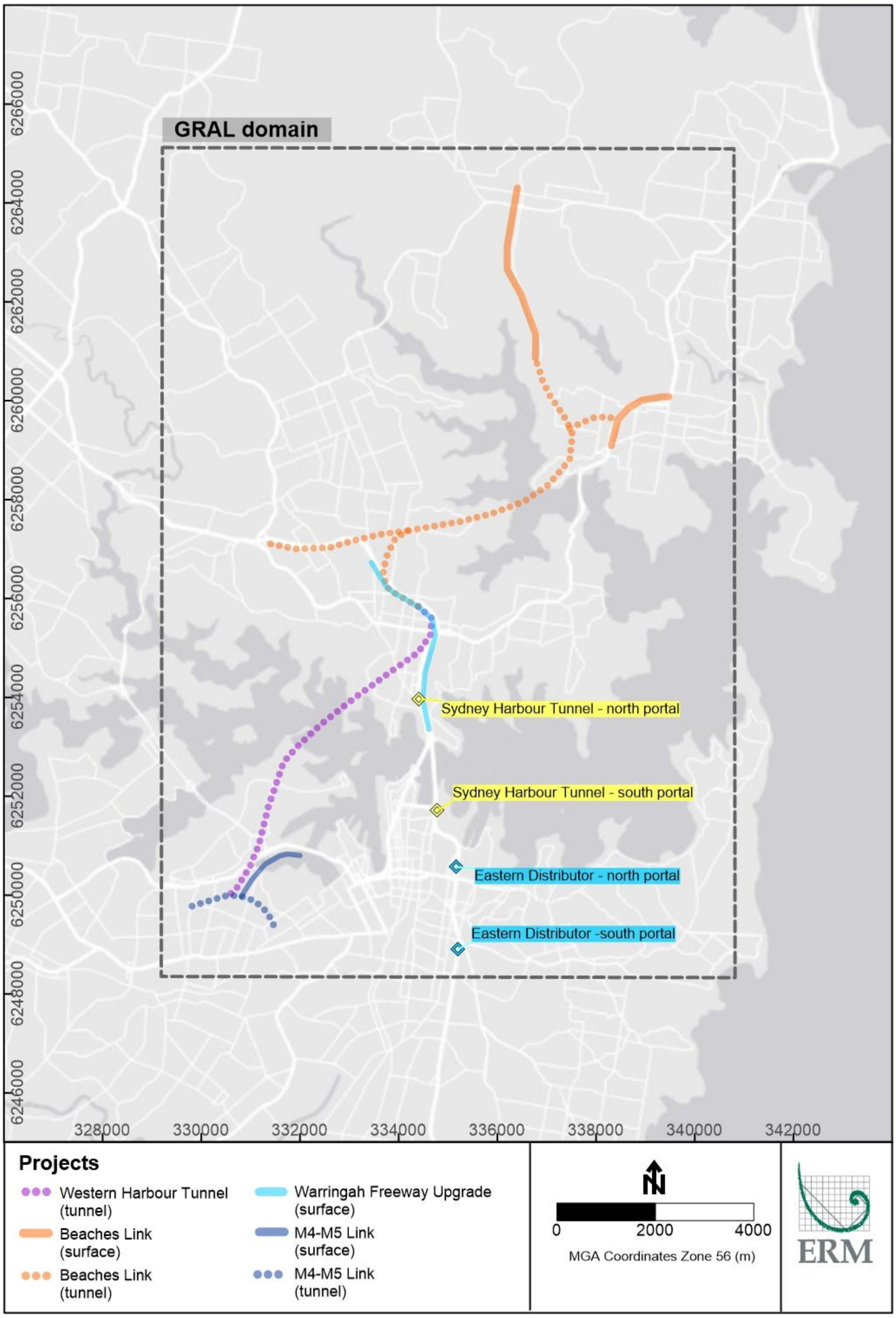

Figure 8-2 Locations of all tunnel portals included in the assessment (grid system MGA94)

8.2.4 Surface roads

Model selection

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

- Good availability and accessibility (eg readily able to accommodate future updates)
- A high level of detail and robustness (ie 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 (ie 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 (eg 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 M4-M5 Link, 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[22]. In January 2015 the NSW EPA provided ERM (then 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.

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

A more detailed description of the model used, including an evaluation, is provided in Annexure C.

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[23] to enable emissions from each sector of activity to be calculated. For road vehicles, Environment Australia (2000) provides the emissions estimation techniques for the relevant NPI substances, as well as guidance on the spatial allocation of emissions. The NPI manual for road vehicles is now well out of date, and 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 (refer below) (Smit, 2014)
- COPERT Australia. This is a commercial model for calculating emissions from traffic on surface roads (Smit and Ntziachristos, 2012; 2013)[24]. The model has been developed to a high standard. It follows a similar structure to that of the COPERT 5 model that is widely used in Europe. COPERT Australia covers all the main vehicle classes and driving conditions in Australia, and is based on a database of emission tests that is similar to that used in the NSW inventory model. However, the model was not evaluated in detail as part of the M4-M5 Link 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

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 of Sydney, were 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 the 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 population and employment projections released by former Department of Planning and Environment in 2017. SMPM version 1.0, which includes induced traffic demand, was used for this environmental impact statement.

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

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

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

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.

Time periods

The SMPM models an average weekday during a school term.

The model included 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 carried out 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 on the following figures. 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 8-3 shows the additional links in the 2027-DS and 2037-DS scenarios
- Figure 8-4 shows the additional links in the 2027-DSC and 2037-DSC scenarios

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

The road network (including tunnels) had between 5867 and 5972 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 the 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.

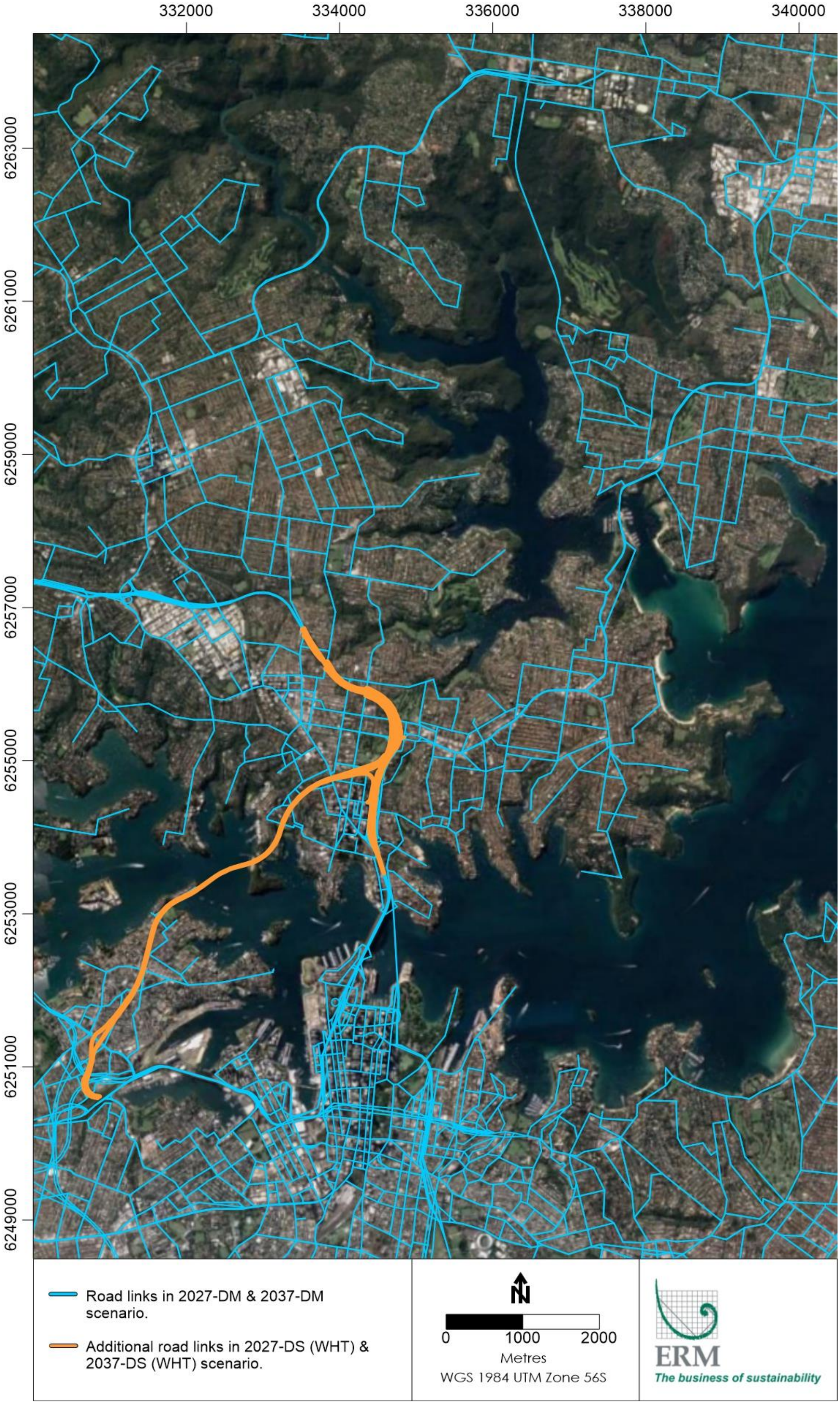


Figure 8-3 Road links in the Do minimum scenarios, and additional links in the 2027-DS(WHT) and 2037-DS(WHT) scenarios (grid system MGA94)

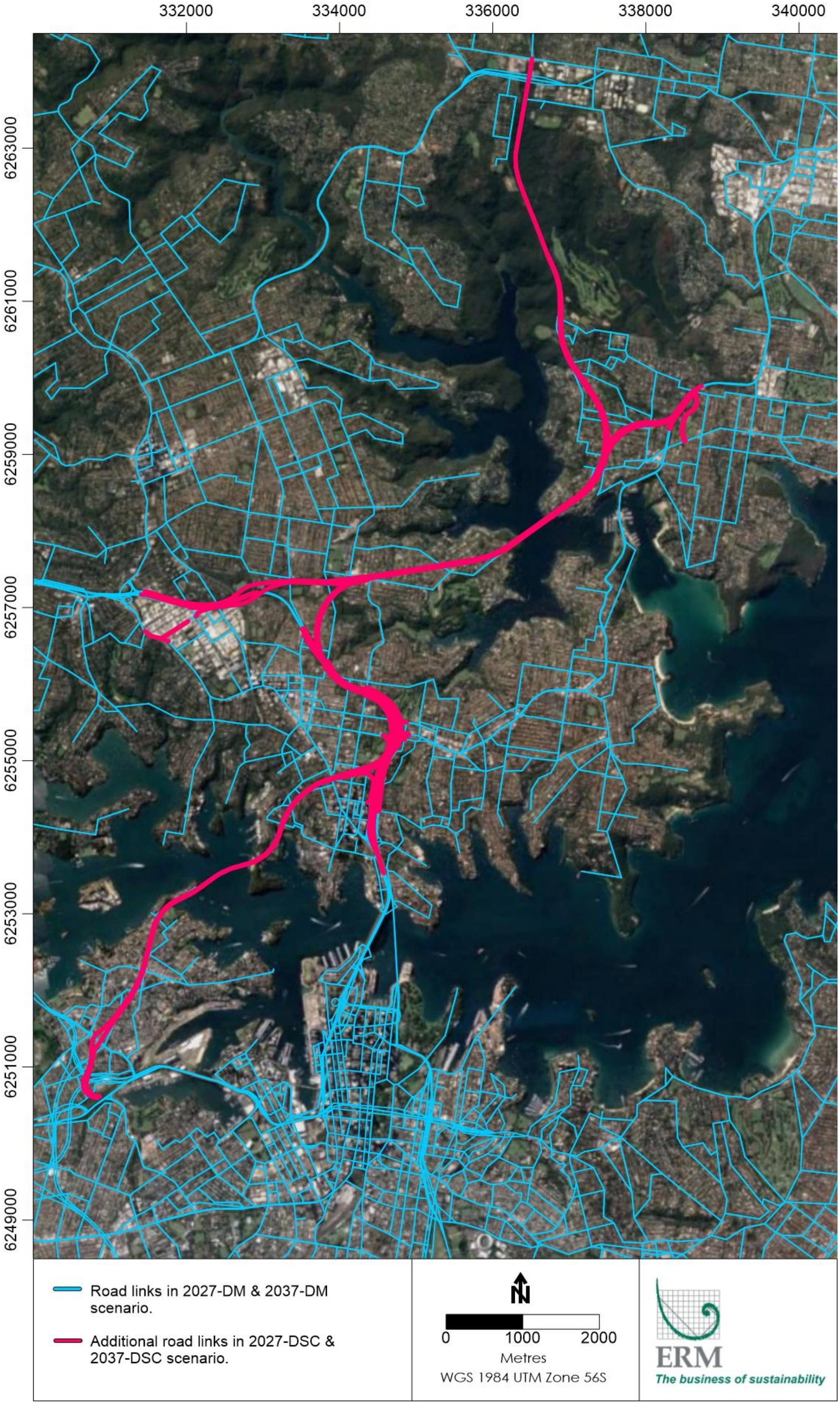


Figure 8-4 Road links in the Do minimum scenarios, and additional links in the 2027-DSC and 2037-DSC scenarios (grid system MGA94)

Table 8-2 Number of road links by scenario

Scenario code	Scenario description	Number of road links included (GRAL domain)
2016-BY	'Base case' (existing conditions)	5867
2027-DM	'Do minimum 2027' (without project)	5915
2027-DS(WHT)	'Do something 2027' (with project)	5934
2027-DSC	'Do something cumulative 2027' (with project, Beaches Link and Gore Hill Freeway Connection and F6 Extension – Stage 1)	5972
2037-DM	'Do minimum 2037' (without project)	5915
2037-DS(WHT)	'Do something 2037' (with project)	5934
2037-DSC	'Do something cumulative 2037' (with project, Beaches Link and Gore Hill Freeway Connection and F6 Extension)	5972

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 the SMPM road types to NSW EPA road types

Road type in the 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 2017.

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 for the air quality modelling 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 (eg 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 WestConnex projects.

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)
Wakehurst Parkway (to Frenchs Forest Road (west/east))	4.0	8.1
Warringah Rd	9.0	21.1
Spit Rd	9.2	18.2
Military Rd	8.2	16.8
Sydney Harbour Bridge	7.7	16.5

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	3.9	7.0
Collector	3.6	7.3
Sub-Arterial	4.6	9.4
Arterial	7.4	15.4
Regional arterial	9.1	18.3
Highway	N/A	N/A
Motorway	10.1	21.3
Motorway ramp	7.1	N/A

Road gradient

The average gradient of each road link in the GRAL domain was estimated using high-resolution terrain data derived from LIDAR surveys. For each node point in the traffic model output, the elevation above sea level was determined. The average gradient of each link ($\Delta z/\Delta x$) was then estimated based on the difference in the height (Δz) of the start node and the end node and the approximate length of the link (Δx) from the traffic model. The upper and lower limits of 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 the 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 the 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.

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

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

The sub-division was based on a default traffic mix for each road type in the GMR inventory, as shown in Table 8-7. The default traffic mix for each road type took into account the projected fuel split (ie 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.

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[(a)]	MC
Residential	2016	70.4	9.7	6.3	8.9	0.0	2.8	0.8	0.6	0.5
	2027	58.1	21.1	2.2	13.3	0.0	3.2	1.0	0.6	0.5
	2037	46.9	31.8	0.6	15.0	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
	2027	55.7	20.2	2.4	15.0	0.0	4.3	1.3	0.5	0.5
	2037	44.9	30.4	0.7	16.9	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
	2027	53.8	19.5	2.6	16.0	0.0	5.4	1.9	0.4	0.5
	2037	43.2	29.2	0.7	18.1	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
	2027	53.8	19.5	2.6	16.0	0.0	5.4	1.9	0.4	0.5
	2037	43.2	29.2	0.7	18.1	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
	2027	46.8	17.0	2.3	14.4	0.0	12.0	6.8	0.3	0.4
	2037	37.0	25.1	0.7	16.1	0.0	13.1	7.3	0.2	0.4

(a) Only used for routes for which the actual numbers of buses were not considered.

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

- The proportions of LCVs in the traffic model outputs were 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 HDVs. 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. This relatively simple approach was adopted because of the large number of surface road links.
- HCVs from the traffic model were redistributed according to the split for HD-P, RT and AT in Table 8-7
- For most links, relatively small numbers of buses and motorcycles were added to the traffic model output, again based on the proportions in Table 8-7. However, for four main thoroughfares in the model domain bus timetables and route maps in 2018 were analysed to determine actual numbers of buses. These were:
  - Military Road/Spit Road, between Sydney Road and Warringah Freeway
  - Wakehurst Parkway, between Clontarf Street and Warringah Road
  - Warringah Road, between Starkey Street and Harbord Road
  - Warringah Freeway, between Military Road and Wynyard Station.

  To maintain consistency with the SMPM, bus timetables were used to estimate volumes for each of the four time periods, morning (07:00-09:00), inter-peak (09:00-15:00), afternoon (15:00-18:00) and night-time (18:00-07:00). Bus numbers in future years were assumed to remain at 2018 levels.

An example of the SMPM output for one link is shown on Figure 8-5, and the transformation of the data for this link into a suitable format for the NSW EPA emission model is shown on Figure 8-6.

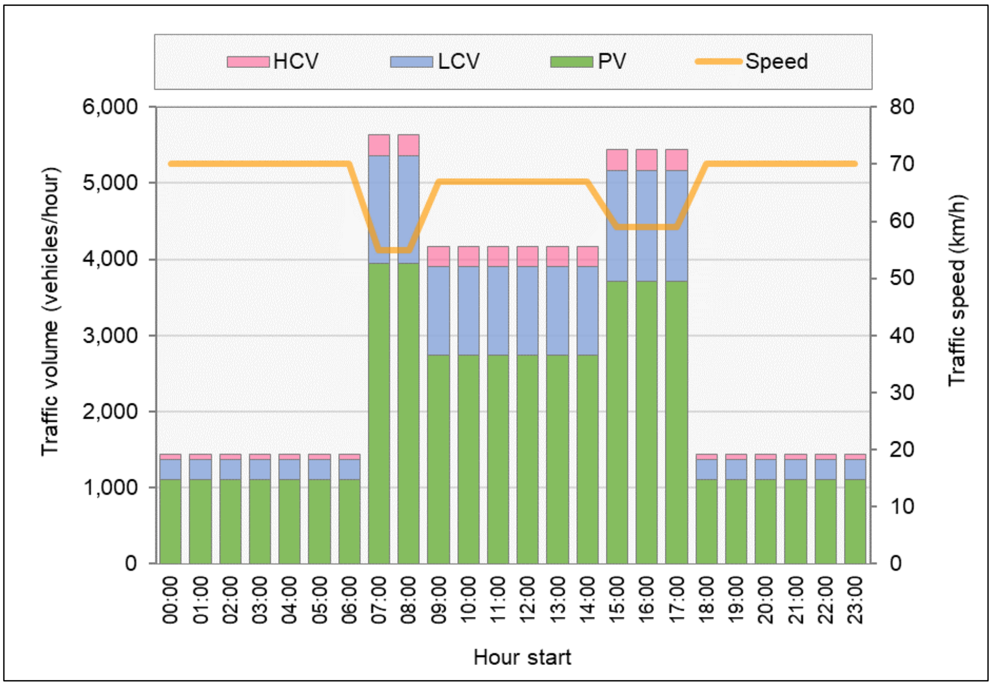


Figure 8-5 **Example traffic model output (link 10358-10359, motorway, 2027-DSC scenario)**

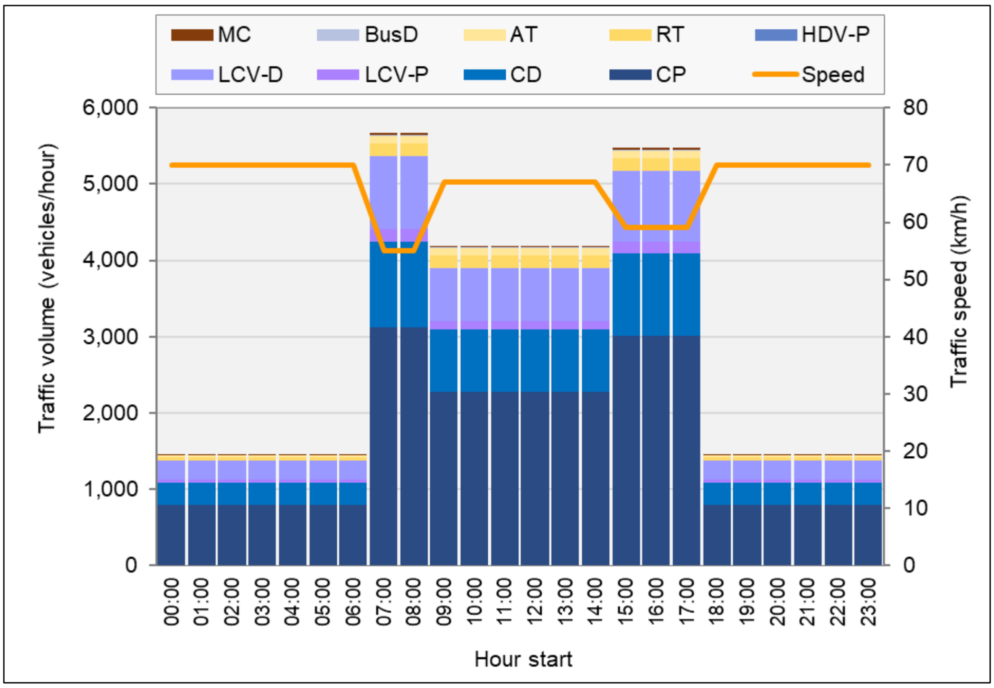


Figure 8-6 **Example emission model input (link 10358-10359, motorway, 2027-DSC scenario)**

Results

Expected traffic scenarios

As emissions were determined separately for almost 6000 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. For each scenario, the total emissions in the GRAL domain, in tonnes per year, are shown graphically on Figure 8-7. The values are also presented in Table 8-8. The absolute and percentage changes in emissions between scenarios are given in Table 8-9 and Figure 8-10 respectively.

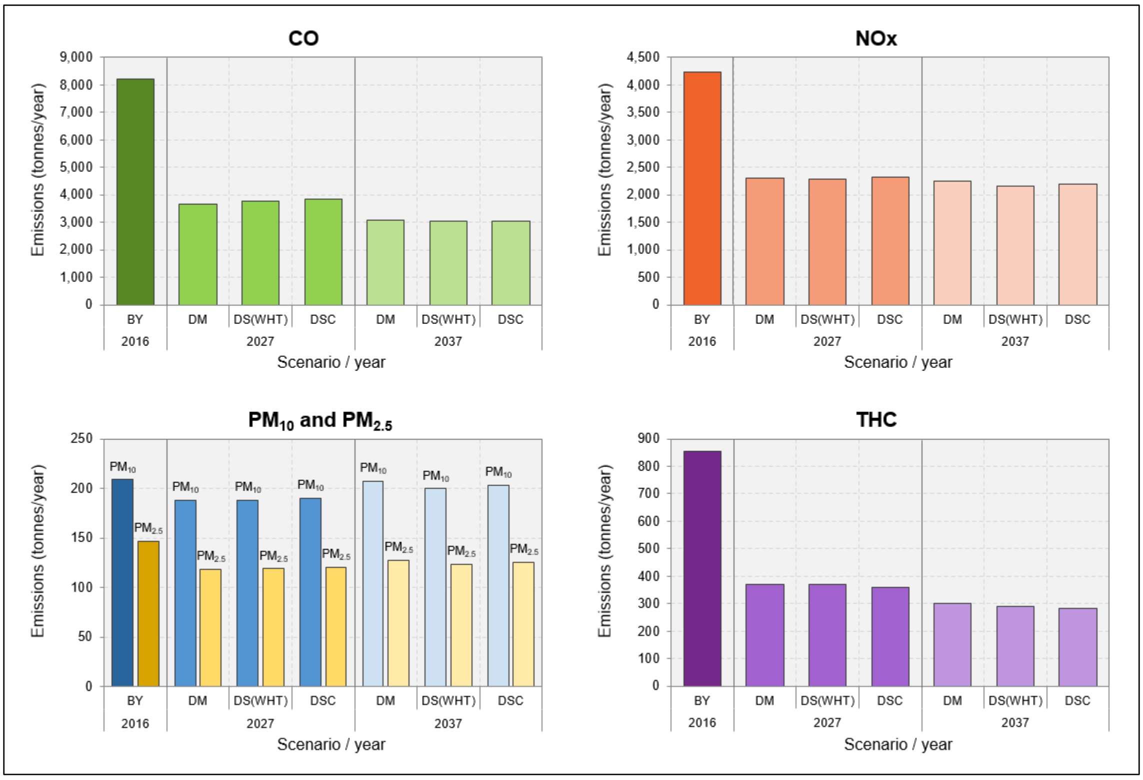


Figure 8-7 Total traffic emissions in the GRAL domain

Table 8-8 Total traffic emissions in the GRAL domain

Scenario code	Total daily VKT[(a)] (million vehicle-km)	Total emissions (tonnes/year)				
		CO	NOx	PM_{10}	$PM_{2.5}$	THC
2016-BY	10.7	8448	3981	209	147	855
2027-DM	12.0	3766	2146	187	118	371
2027-DS(WHT)	12.1	3877	2147	187	118	370
2027-DSC	12.5	3942	2175	188	119	359
2037-DM	12.3	2882	1919	188	116	281
2037-DS(WHT)	12.5	2971	1915	188	115	279
2037-DSC	13.7	3125	2044	201	124	281

(a) VKT = vehicle kilometres travelled

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)]					
2027-DM vs 2016-BY	- 4681	- 1835	- 21.7	- 28.9	- 484.9
2037-DM vs 2016-BY	- 5566	- 2062	- 20.6	- 30.9	- 574.6
Changes due to the project in a given year					
2027-DS(WHT) vs 2027-DM	+ 110.6	+ 1.4	- 0.1	0.0	- 0.7
2027-DSC vs 2027-DM	+ 176.0	+ 28.5	+ 1.5	1.2	- 11.1
2037-DS(WHT) vs 2037-DM	+ 88.8	- 4.4	- 0.4	- 0.2	- 2.1
2037-DSC vs 2037-DM	+ 243.1	+ 124.6	+ 13.3	+ 8.3	0.0

(a) NB: The 2027-DM and 2037-DM scenarios included the WestConnex projects. The 2016-BY scenario did not.

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

Scenario comparison	Change in total emissions (%)				
	CO	NOx	PM_{10}	$PM_{2.5}$	THC
Underlying changes in emissions with time[(a)]					
2027-DM vs 2016-BY	-55.4%	-46.1%	-10.4%	-19.7%	-56.7%
2037-DM vs 2016-BY	-65.9%	-51.8%	-9.9%	-21.1%	-67.2%
Changes due to the project in a given year					
2027-DS(WHT) vs 2027-DM	+2.9%	+0.1%	-0.1%	0.0%	-0.2%
2027-DSC vs 2027-DM	+4.7%	+1.3%	+0.8%	+1.0%	-3.0%
2037-DS(WHT) vs 2037-DM	+3.1%	-0.2%	-0.2%	-0.2%	-0.7%
2037-DSC vs 2037-DM	+8.4%	+6.5%	+7.1%	+7.1%	0.0%

(a) The 2027-DM and 2037-DM scenarios include the M4-East and New M5 projects. The 2015-BY scenario does not.

Comparing the ‘Do something 2027’ scenario with the ‘Do minimum 2027’ scenario, emissions of CO increased by around three per cent. There was little change in emissions of NO_X, PM_{10}, $PM_{2.5}$ and THC. In 2037, emissions of all pollutants decreased by less than one per cent, with the exception of CO which increased by around three per cent. For the ‘Do something cumulative 2027’ scenario, emissions of CO increased relative to the ‘Do minimum 2027’ scenario by around five per cent, emissions of NO_X, PM_{10} and $PM_{2.5}$ increased by 0.8 to 1.3 per cent, and emissions of THC decreased by three per cent. Again, in ‘Do something cumulative 2037’ the emissions of all pollutants increased with the exception of THC which remained unchanged.

The overall changes in emissions associated with the project in a given future scenario year (2027 or 2037) 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. Although there are some differences between the definitions of the ‘Base case’ and ‘Do minimum’ scenarios, between 2016 and 2027 the total emissions of CO, NO_X and THC from the traffic on the road network are predicted to decrease by between 46 and 57 per cent. Between 2016 and 2037 the reductions range from 52 to 67 per cent. For PM_{10} and $PM_{2.5}$, the underlying reductions are smaller.

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.

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 ventilation outlet concentration limits or, in the case of NO_2, the ventilation outlet concentration limits in conjunction with the expected traffic results and background concentration.

8.2.5 Evaluation of emission model

The NSW EPA model was evaluated using real-world air pollution measurements in the Lane Cove Tunnel, 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)
  - A possible overestimation of vehicle ages in the tunnel
- 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 (eg 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
- It 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 (GRAMM) and a dispersion model (GRAL itself). An overview of the GRAMM/GRAL modelling system is presented on Figure 8-8. 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.

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 (eg 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 8760 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.

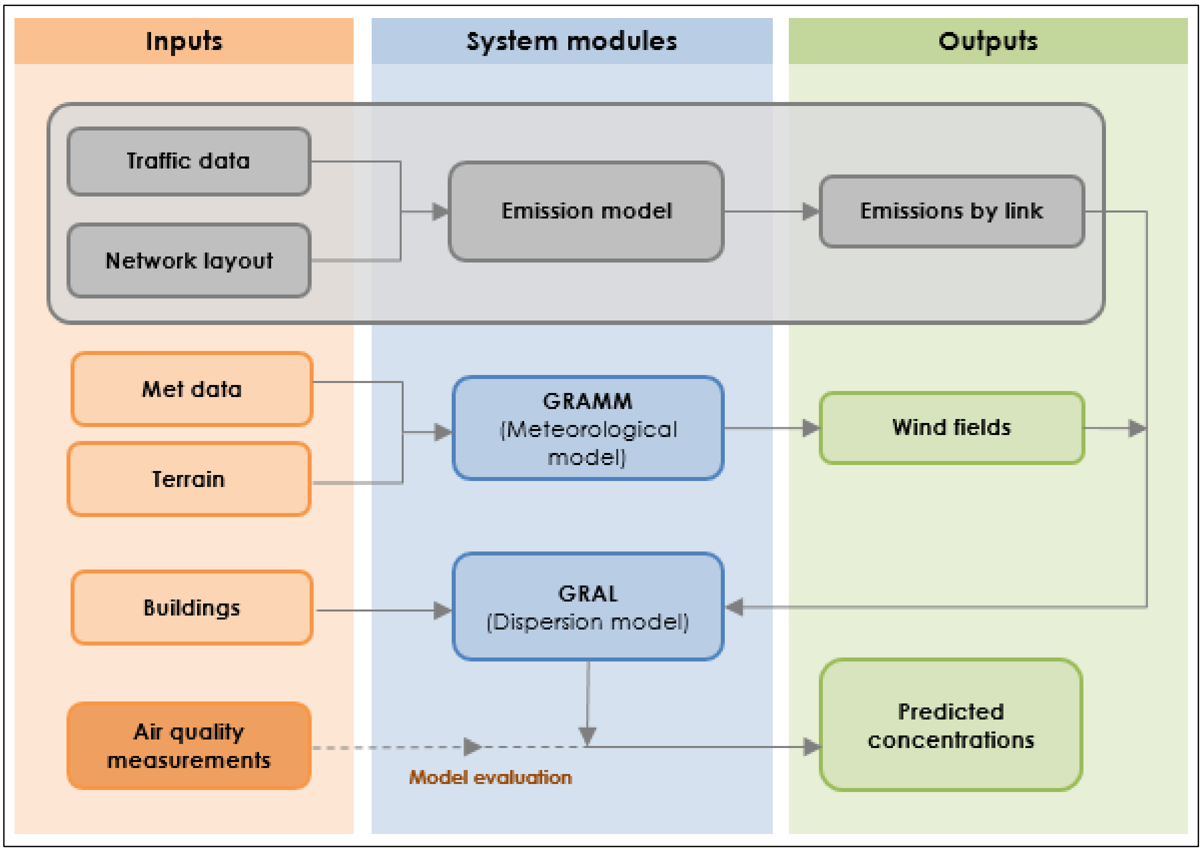


Figure 8-8 Overview of the GRAMM/GRAL modelling system

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

8.4.4 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 (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 while *average* predictions can be 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 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 MtOs 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 would be important to use the ‘MtO’ function for an appropriate (nearby, representative) meteorological station
- The results of GRAL would 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 (refer to Figure 5-1) was defined so that it covered the project, as well as the interfaces between the project and other road tunnels, with a sufficient buffer zone to minimise boundary effects in GRAL. The domain was 30 kilometres along the east–west axis and 30 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	MtO
Meteorological stations used in MtO	Randwick (operated by the Department of Planning, Industry and Environment, formerly Office of Environment and Heritage) Rozelle (operated by the Department of Planning, Industry and Environment, formerly Office of Environment and Heritage) Fort Denison (operated by BoM) Manly (North Head) (operated by BoM)
Weighting factors applied to meteorological data	Randwick: Weighting factor = 1, directional weighting factor = 1 Rozelle: Weighting factor = 0.2, directional weighting factor = 0.05 BoM Fort Denison: Weighting factor = 0.2, directional weighting factor = 0.2 BoM Manly (North Head) = Weighting factor = 0.2, directional weighting factor = 0.2
Period of meteorology	1 January 2015 – 31 December 2016
Meteorological parameters	Wind speed (m/s), Wind direction (º), stability class (1-7)
Number of wind speed classes	10
Wind speed classes (m/s)	0-0.5, 0.5-1.5, 1.5-2.5, 2.5-3.5, 3.5-4.5, 4.5-5.5, 5.5-6.5, 6.5-7.5, 7.5-9 >9
Number of wind speed sectors	36
Sector size (degrees)	10
Anemometer height above ground (m)	10
Concentration grids and general GRAMM input	
GRAMM domain in UTM (m)	N = 6236000, S = 6266000, E = 316000, W = 346000
Horizontal grid resolution (m)[(a)]	200
Vertical thickness of the first layer (m)[(b)]	10
Number of vertical layers	15
Vertical stretching factor[(c)]	1.3
Relative top level height (m)[(d)]	1683
Maximum time step (s)[(e)]	10
Modelling time (s)	3600
Relaxation velocity[(f)]	0.1
Relaxation scalars[(f)]	0.1

(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. Five metre terrain data from the same source were used to run GRAL.

The terrain within the GRAL domain is predominantly flat towards the southern end in and around Sydney city. Elevation increases to the north of Sydney Harbour towards northern Sydney and for most of the northern part of the GRAL domain. The terrain along the project corridor varies from an elevation of around 20 metres AHD at the southern end at the Rozelle Interchange to an elevation of around 75 metres at Warringah Freeway, at the northern end.

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 sites that are both reliable and representative of meteorology within the domain. As discussed in Annexure F, meteorological data from the Randwick, Rozelle, BoM Fort Denison and BoM Manly (North Head) 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 Rozelle station was deemed less representative (refer to the analysis in Annexure F). However, given its proximity to the project, meteorological data from this station was included in the GRAMM modelling but was given smaller weighting factors (0.2 for overall weighting and 0.05 for directional weighting). The BoM Fort Denison and Manly (North Head) stations were also deemed less representative of the overall GRAL domain than the Randwick site. These sites were included however, as they were deemed representative of the areas surrounding waterbodies and coastal locations in the domain. These sites were also given a lower weighting than the Randwick site; both sites were given an overall weighting factor of 0.2 and a wind direction factor of 0.2.

Cloud cover is not recorded at the Randwick, Rozelle, BoM Fort Denison or BoM Manly (North Head) sites. The stability classes (classes 1–7) required for GRAMM were therefore calculated using the temperature at 10 metres above ground level at each site and cloud content data from the BoM Sydney Airport AMO meteorological station.

Figure 8-9 provides an example of a wind field situation across the GRAMM domain. In total, 695 different wind fields were produced to represent the different conditions in each hour of the meteorological file. The wind fields are based on the GRAMM wind speeds and wind directions using the input data from the Randwick, Rozelle, BoM Fort Denison and BoM Manly (North Head) sites. In this particular example, winds are predominantly from a north and north-eastern direction, with higher wind speeds over elevated terrain to the north The terrain of the study area was not especially complex (ie 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.

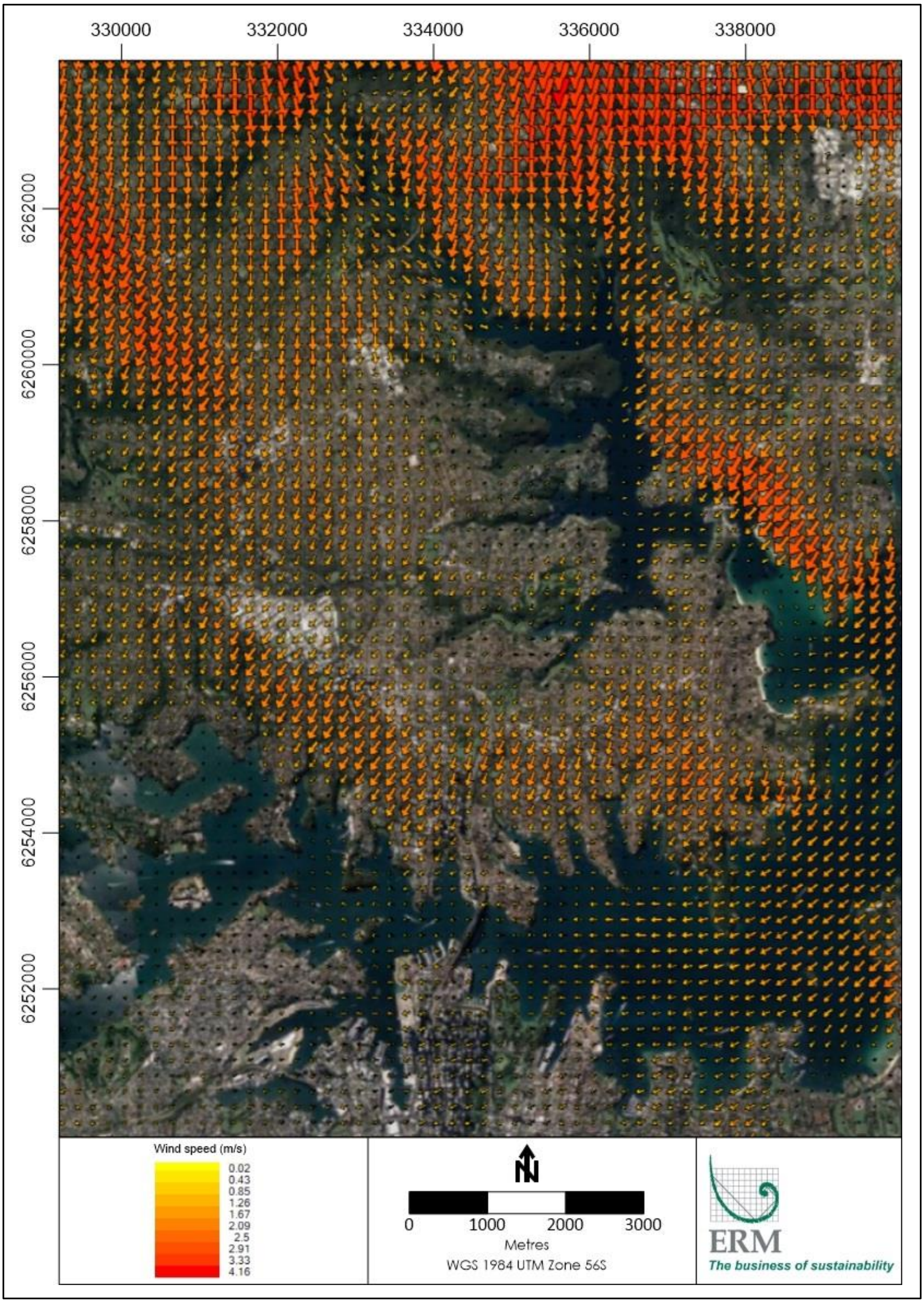


Figure 8-9 Example of a wind field across the GRAMM domain (grid system MGA94)

GRAMM Match-to-Observations function

The GRAMM MtO function was used to refine the order of the predicted wind fields to provide a better match to the observations the Randwick, Rozelle, BoM Fort Denison and BoM Manly (North Head) 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, so 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 would 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:

- Randwick
  - Overall weighting factor = 1
  - Wind direction factor = 1
- Rozelle
  - Overall weighting factor = 0.2
  - Wind direction factor = 0.05
- BoM Fort Denison
  - Overall weighting factor = 0.2
  - Wind direction factor = 0.2
- BoM Manly (North Head)
  - Overall weighting factor = 0.2
  - Wind direction factor = 0.2

8.4.6 Evaluation of meteorological model

Wind speed and wind direction values were extracted for each of the meteorological stations shown on 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 on Figure 5-1. Every dispersion model run was carried out for this domain, which extended 11.6 kilometres in the x direction and 16.7 kilometres in the y direction. GRAL was configured to provide predictions for a Cartesian grid of points with an equal spacing of 10 metres in both the x and y directions. For the GRAL domain, the total number of points in the grid was therefore around 1.9 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 5 metres) to be included in the GRAL model.

Table 8-12 presents the main parameters selected in GRAL for the model runs.

Table 8-12 GRAL configuration

Parameter	Value(s)
General	
Domain in UTM (GRAL)	N = 6265000, S = 6248300, E = 340800, W = 329200
Dispersion time (s)	3600
Number of particles per second[(a)]	400 for roads and ventilation 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 three metres 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 the size used here 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 A) would probably have been limited.

Contour plots

Contour plots showing concentrations, and changes in concentration, across the entire GRAL domain are shown in Section 8. 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 1.9 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 up to 1.5 kilometres either side of the Western Harbour Tunnel and Beaches Link program of works corridor, and generally near significantly affected roadways. This zone was sufficiently large to capture the largest impacts of the project, and the program of works. For these receptors, a detailed approach was used to calculate the total concentration of each pollutant. This involved the combination of the contemporaneous road, portal and ventilation 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, 42 community receptors were included in the assessment
- ‘Residential, workplace and recreational (RWR) receptors’. These were all discrete receptor locations along the Western Harbour Tunnel and Beaches Link program of works corridor, and mainly covered residential and commercial land uses. For these receptors, a simpler[25] statistical approach was used to combine a concentration statistic for the modelled roads, portals and ventilation outlets (eg maximum 24-hour mean PM_{10}) with an appropriate background statistic. In total, a maximum of 35490 RWR receptors were included in the assessment (this included the 42 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 Technical working paper: Health impact assessment 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 8-10 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 project (and other projects) were excluded. This included a provisional construction footprint for the Sydney Gateway project. All the project construction footprints are shown on Figure 8-10. Slightly different numbers of RWR receptors were included in each scenario to allow for the different construction footprints for project, and the Beaches Link and Gore Hill Freeway Connection project.

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

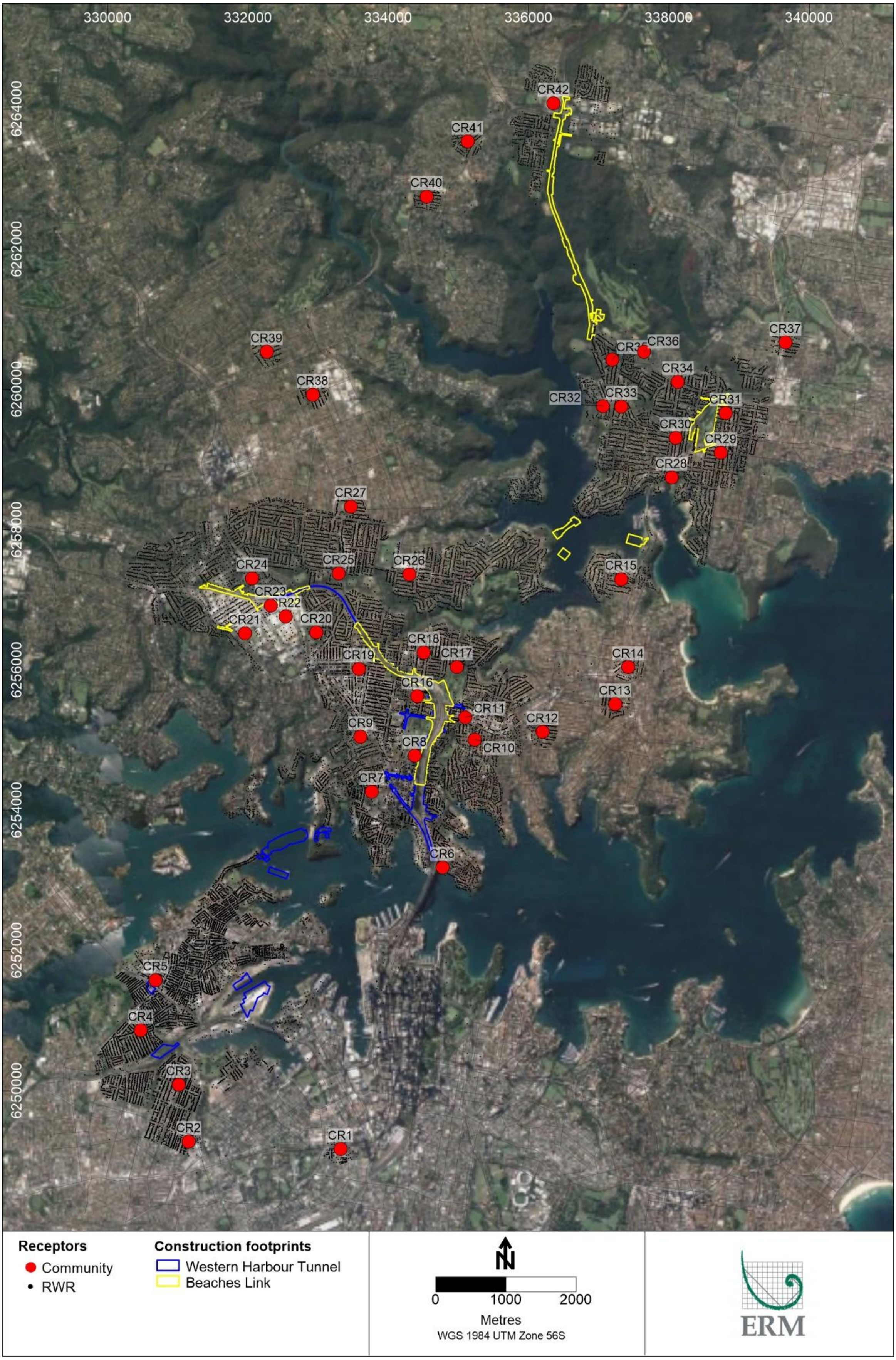


Figure 8-10 **Modelled discrete receptor locations and construction footprints**

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

Receptor code	Receptor name	Address	Suburb	Receptor location x	y
CR01	University of Notre Dame	128-140 Broadway	Chippendale	333318.6	6249169.6
CR02	Laverty Pathology	34C Taylor Street	Annandale	331153.3	6249277.9
CR03	St Basil's	252 Johnston Street	Annandale	331011.9	6250088.8
CR04	The Jimmy Little Community Centre	19 Cecily Street	Lilyfield	330469.9	6250862.3
CR05	Rozelle Public School	663 Darling Street	Rozelle	330680.9	6251579.5
CR06	St Aloysius College	47 Upper Pitt Street	Milsons Point	334770.5	6253185.2
CR07	Dancing Dingo Family Day Care	Lord Street	North Sydney	333761.0	6254266.5
CR08	Wenona School	176 Walker Street	North Sydney	334374.5	6254780.1
CR09	Mater Hospital	25 Rocklands Road	North Sydney	333604.7	6255050.1
CR10	Neutral Bay Public School	Ben Boyd Road	Neutral Bay	335234.3	6255008.8
CR11	Neutral Bay Medical Centre	116 Military Road	Neutral Bay	335099.3	6255327.3
CR12	Puddleducks Child Care Centre	17b/39 Herbert St	St Leonards	336197.3	6255120.6
CR13	Mosman Public School	27 Belmont Road	Mosman	337231.6	6255514.1
CR14	Garrison & Killarney Retirement Centre	13 Spit Road	Mosman	337419.1	6256043.2
CR15	Beauty Point Public School	17 Medusa Street	Mosman	337318.4	6257295.1
CR16	Anzac Park Public School	2 Anzac Avenue	Cammeray	334414.0	6255628.0
CR17	Ku Cammeray Preschool	Green Park, Warwick Avenue	Cammeray	334977.1	6256047.0
CR18	Cammeray Public School	Palmer Street	Cammeray	334507.3	6256250.1
CR19	Atchison Preschool	98 Atchison Street	Crows Nest	333577.5	6256018.6
CR20	Berry Cottage Childcare	9 Talus Street	Naremburn	332974.3	6256538.2
CR21	Explore & Develop Artarmon - Early Learning Centre	11/13 Campbell Street	Artarmon	331953.8	6256523.8
CR22	SBS Child Care	14 Herbert Street	Artarmon	332534.2	6256763.9
CR23	Butterflies Early Learning Childcare Centre	9 Waltham Street	Artarmon	332321.8	6256922.3
CR24	Artarmon Public School	McMillan Road	Artarmon	332058.0	6257309.9
CR25	Sue's Childcare Castlevale	2 Artarmon Road	Willoughby	333293.4	6257378.7
CR26	Northside Baptist Preschool	112 Sailors Bay Road	Northbridge	334300.6	6257366.2
CR27	Willoughby Public School	Oakville Road	Willoughby	333464.8	6258333.4

Receptor code	Receptor name	Address	Suburb	Receptor location	
				x	y
CR28	Peek A Boo Cottage	1 Magarra Place	Seaforth	338036.2	6258746.8
CR29	St Cecilia's Catholic Primary School	59 Seaview Street	Balgowlah	338740.8	6259099.4
CR30	Seaforth Public School	37 Kempbridge Avenue	Seaforth	338095.8	6259312.0
CR31	Punchinello Kindergarten	118 Wanganella Street	Balgowlah	338807.7	6259662.9
CR32	Harbour View Children’s Centre	10-12 Ross Street	Seaforth	337059.9	6259766.3
CR33	Jacaranda Creative Play Centre	25 Fromelles Avenue	Seaforth	337322.3	6259758.9
CR34	St James Medical And Cosmetics Centre	62-64 Bangaroo Street	North Balgowlah	338125.3	6260108.9
CR35	Ku Bligh Park Preschool	4A Alto Avenue	North Seaforth	337192.7	6260427.3
CR36	Balgowlah North Public School	10 Manning Street	North Balgowlah	337645.6	6260537.9
CR37	Hardi Aged Care	Condamine & Gordon Streets	Manly Vale	339661.2	6260670.6
CR38	Willoughby Retirement Village	36 Douglas Avenue	Chatswood	332921.4	6259928.6
CR39	Roseville Public School	19A Archbold Road	Roseville	332265.5	6260538.0
CR40	UnitingCare Forestville Preschool	9 Darley Street	Forestville	334546.2	6262751.2
CR41	Beehive Kindy	4 Altona Avenue	Forestville	335129.0	6263537.0
CR42	Northern Beaches Hospital	Warringah Road	Frenchs Forest	336354.5	6264081.7

Table 8-14 Summary of RWR receptor types

Receptor type	All receptors (DM scenarios)		DS(WHT) scenarios		DSC scenarios	
	Number	%	Number	%	Number	%
Aged care	31	0.09%	31	0.09%	31	0.09%
Child care/pre-school	124	0.35%	123	0.35%	123	0.35%
Commercial	946	2.67%	945	2.66%	944	2.66%
Community	175	0.49%	175	0.49%	175	0.49%
Further education	13	0.04%	13	0.04%	13	0.04%
Hospital	6	0.02%	6	0.02%	6	0.02%
Hotel	43	0.12%	43	0.12%	43	0.12%
Industrial	484	1.36%	479	1.35%	468	1.32%
Medical practice	62	0.17%	62	0.17%	62	0.17%
Mixed use	813	2.29%	811	2.29%	811	2.29%
Other[(a)]	229	0.65%	219	0.62%	218	0.61%
Park/sport/recreation	317	0.89%	316	0.89%	313	0.88%
Place of worship	76	0.21%	76	0.21%	76	0.21%
Residential	32036	90.27%	32032	90.32%	32022	90.29%
School	135	0.38%	135	0.38%	135	0.38%
Grand Total[(b)]	35490	100.00%	35466	100.00%	35440	100.00%

(a) 'Other' includes laboratories, infrastructure, construction sites, wharfs, SES facilities and non-identified locations.

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

Mesh Block centroids

The Technical working paper: Health impact assessment 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 on Figure 8-11. It should be noted that 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

The Secretary's environmental assessment requirements for the project require '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.

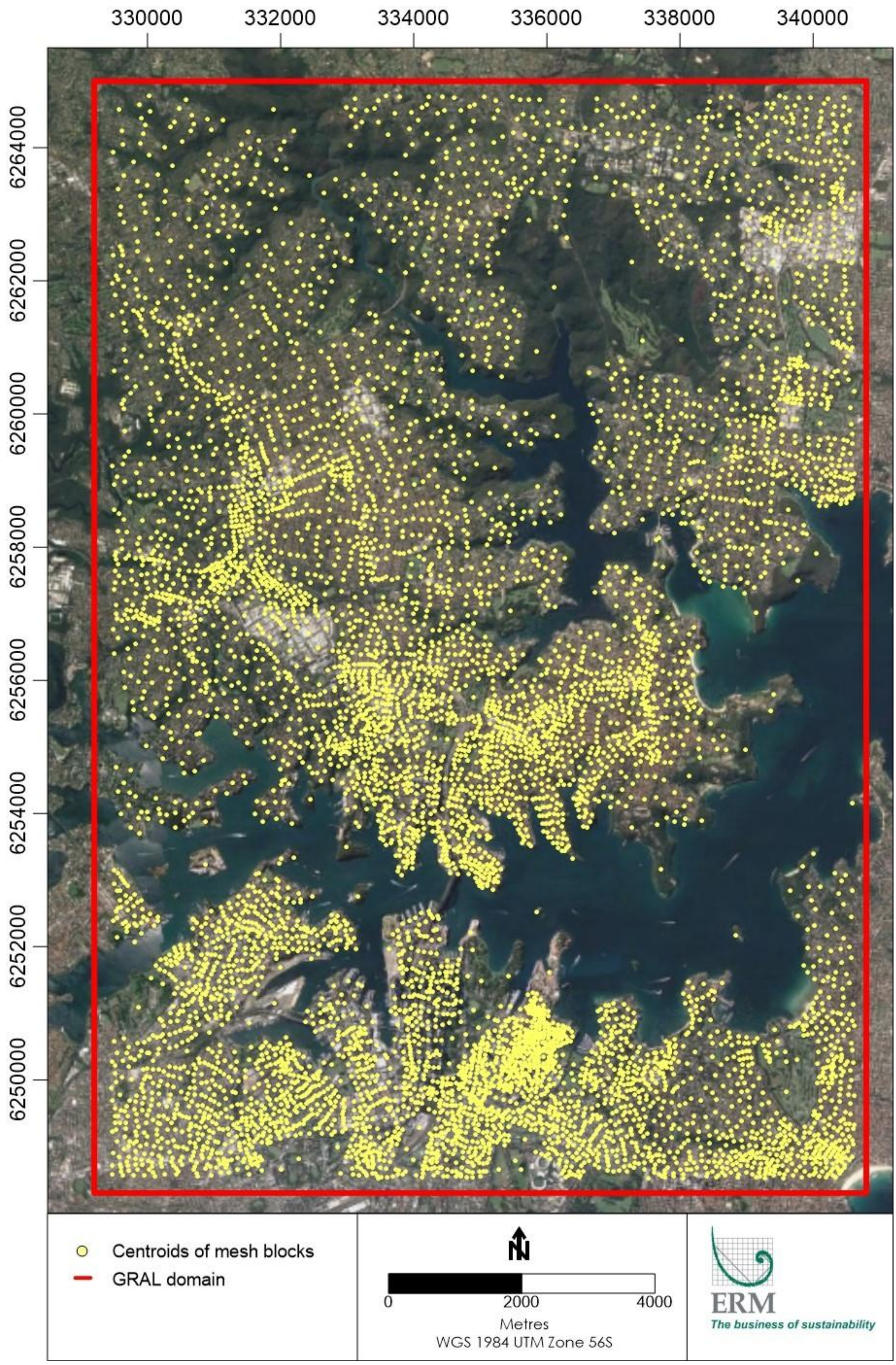


Figure 8-11 Mesh Block centroids in the GRAL domain

Elevated receptors

The main emphasis in the assessment was on ground-level concentrations (as specified in the Approved Methods). However, at a number of locations in the GRAL domain, there are existing multi-storey residential and commercial buildings, or the land zoning permits the construction of such buildings (refer to Chapter 20 (Land use and property) of the environmental impact statement). The potential impacts of the project at these elevated points are likely to be different to the impacts at ground level, and therefore these were evaluated separately. In addition, it was considered important to understand, provisionally, how future building developments (eg apartment blocks) in the domain might be restricted from an air quality perspective.

Building heights were not available for all locations in the GRAL domain, but height information was available for a sample of around 33000 buildings. The locations and heights of the buildings in the sample are shown on Figure 8-12, and the overall frequency distribution is shown on Figure 8-13.

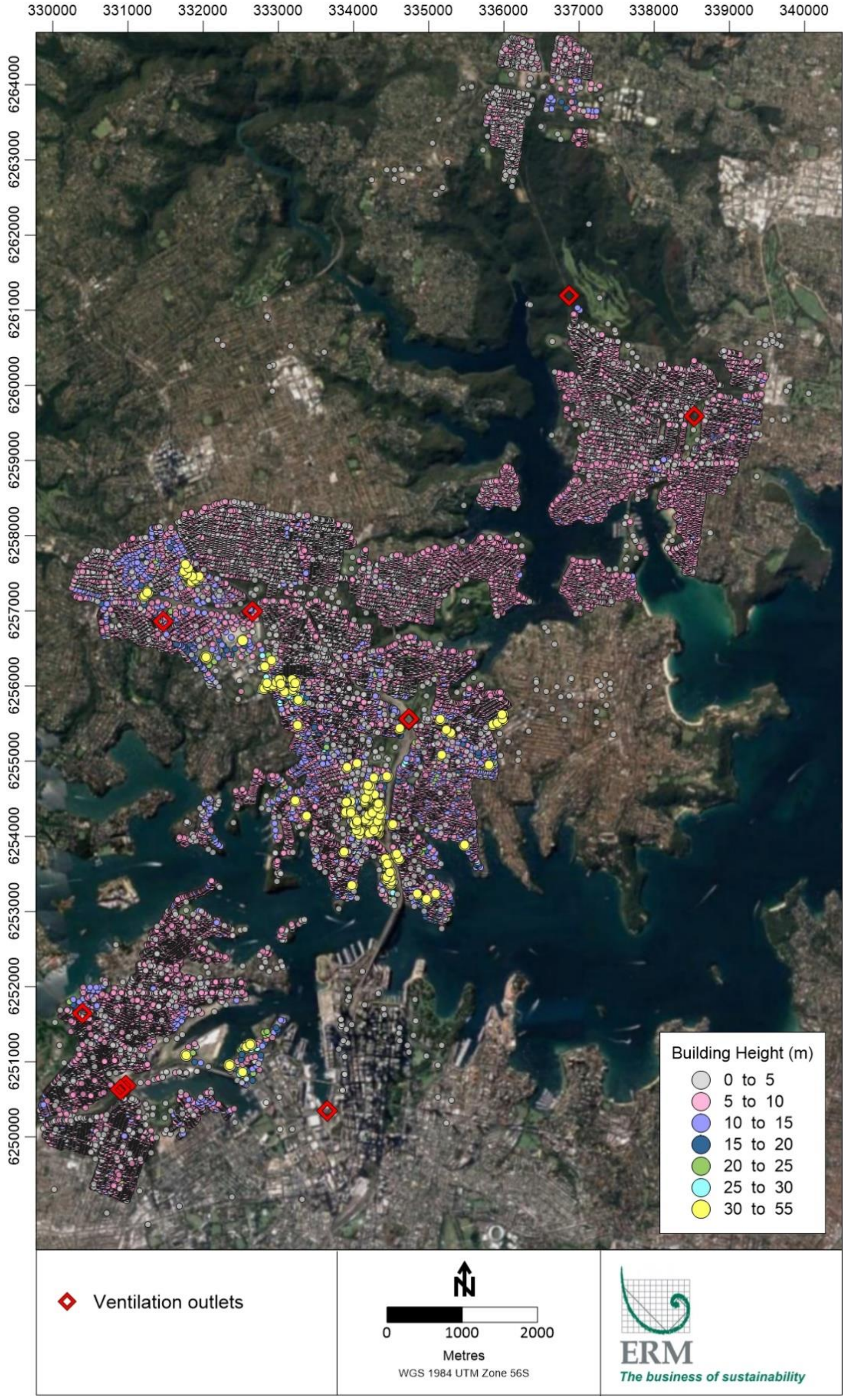


Figure 8-12 Sample of building heights in the GRAL domain (grid system MGA94)

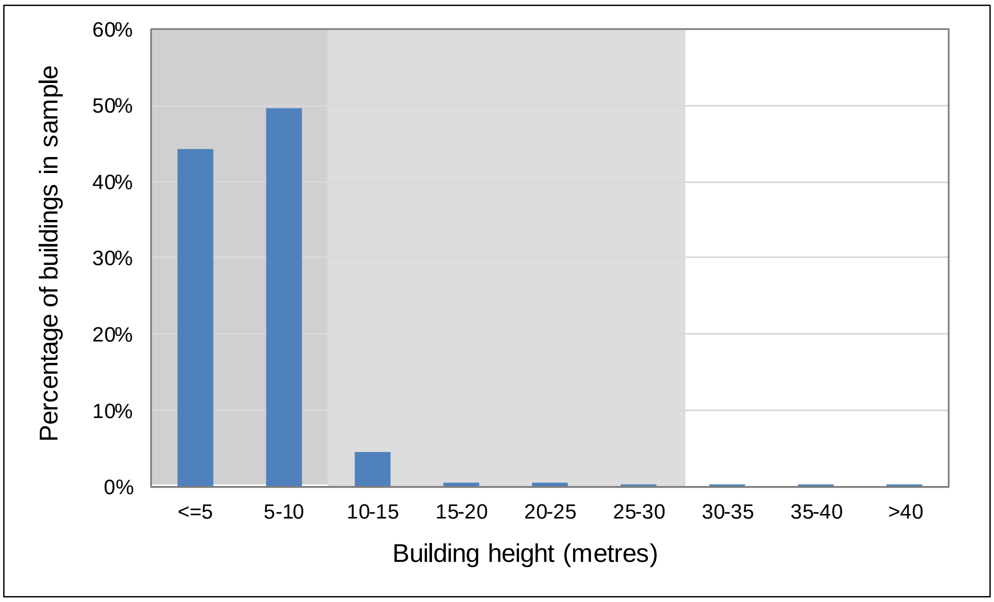


Figure 8-13 Frequency distribution of building heights

More than 90 per cent of the buildings have a height of less than 10 metres. Only a very small proportion (less than 0.5 per cent) of buildings has a height of more than 40 metres. Based on this assessment, four elevated receptor heights were selected to cover both existing buildings and future developments: 10 metres, 20 metres, 30 metres and 45 metres. For all heights, a full modelling run was completed 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 2037-DSC scenario. Background concentrations were not taken into account, as these could not be quantified at elevated locations. Only the changes in the $PM_{2.5}$ concentration are therefore presented in this 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:

- 2037-DM at a height of 10 metres above ground level
- 2037-DM at a height of 20 metres above ground level
- 2037-DM at a height of 30 metres above ground level
- 2037-DM at a height of 45 metres above ground level
- 2037-DSC at a height of 10 metres above ground level
- 2037-DSC at a height of 20 metres above ground level
- 2037-DSC at a height of 30 metres above ground level
- 2037-DSC at a height of 45 metres above ground level
- Change in annual $PM_{2.5}$ (2037-DSC minus 2037-DM) at a height of 10 metres above ground level
- Change in annual $PM_{2.5}$ (2037-DSC minus 2037-DM) at a height of 20 metres above ground level
- Change in annual $PM_{2.5}$ (2037-DSC minus 2037-DM) at a height of 30 metres above ground level
- Change in annual $PM_{2.5}$ (2037-DSC minus 2037-DM) at a height of 45 metres above ground level.

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 so the number and output of the fans in use, would therefore vary by time of day. This would result, in turn, in hourly-varying ventilation outlet exit velocities, effective ventilation 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 on Figure 8-14.

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 source groups (nominally 'high', 'medium' and 'low'), or in some cases two source groups. 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.

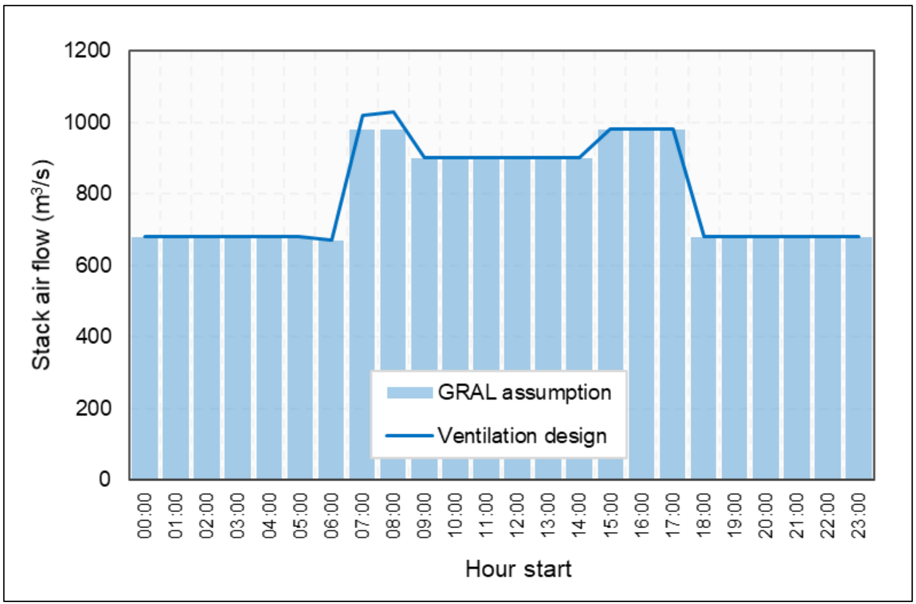


Figure 8-14 Example of ventilation air flow profile used in GRAL (outlet F, 2027-DSC scenario)

The volumetric air flows for the existing tunnel ventilation outlets (Lane Cove Tunnel and Cross City tunnel) 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 the cross-sectional area for the ventilation outlets.

Effective ventilation outlet diameter and exit velocity

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

Ventilation outlet temperature

The temperature difference between the ventilation 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 ventilation outlet are given in Annexure G.

For the existing ventilation outlets (Lane Cove Tunnel and Cross City Tunnel), ventilation outlet temperatures were based on measurements during 2016.

For the M4-M5 Link and Iron Cove Link ventilation outlets, temperatures were taken from the M4-M5 Link environmental impact statement.

For ventilation outlets for Western Harbour Tunnel and Beaches Link program of works, temperatures were estimated based on temperature differences from Lane Cove Tunnel (Cheong, 2020) and ambient temperatures from the BoM station at Sydney Airport. The calculation is shown in Table 8-15.

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

Period	Average temperature difference (tunnel – ambient, ºC)[(a)]	Average ambient temperature (ºC)[(b)]	Total (ºC)
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**

(a) From Cheong (2020), based on data for Lane Cove Tunnel.
(b) Data from BoM station at Sydney Airport in 2016.

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

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

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

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

Work carried out 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 M4-M5 Link 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 ventilation outlets in the regulatory worst scenarios was not known, as these scenarios do not represent any real-world conditions. A 'typical' ventilation outlet temperature of 25ºC was therefore assumed for these scenarios.

For the different pollutants and metrics, the next steps are described in the following section.

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 ventilation outlet contribution to annual mean $PM_{2.5}$ in all four scenarios (i.e. RWC-2027-DS(WHT), RWC-2027-DSC, RWC-2037-DS(WHT), RWC-2037-DSC). The worst case scenario was determined to be RWC-2027-DSC[26]

2. The RWC-2027-DSC scenario was used to model the ventilation 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)

[26] Although it was anticipated that the 2037-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).

3. The maximum contribution of tunnel ventilation outlets at any of the RWR receptors in the GRAL domain and in the RWC-2027-DSC scenario was determined.

Approach for annual mean NO_2

For annual mean NO_2 the next steps were:

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

2. The ventilation outlet NO_X for each RWC scenario was added to the corresponding surface road NOx and mapped background NO_X, and the ventilation 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 ventilation outlet contributions to maximum 1-hour NO_X at all RWR receptors in the GRAL domain were determined in all four RWC scenarios

2. Two small domains (two kilometres by two kilometres) were defined around each ventilation outlet for the project. These domains are shown on Figure 8-15. The small domain for Rozelle included the M4-M5 Link/Iron Cove Link facilities, and the small domain for Warringah Freeway included the outlet facility for Beaches Link

3. The RWR receptors in 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 on Figure 8-16 and Figure 8-17

4. The GRAL model was re-run for the top 10 receptors to obtain a time series for NO_X

5. A contemporaneous assessment was conducted for the top 10 receptors to combine the background contributions, GRAL surface road predictions (expected traffic) and GRAL ventilation outlet prediction (RWC) for NO_X

6. The NO_X concentration in each hour was converted to a maximum NO_2 concentration, and the background, road and ventilation outlet contributions were calculated. The overall maximum ventilation outlet contribution to NO_2 was then determined. The ventilation outlet contribution to total NO_2 was also determined for the hour with the maximum total NO_2 concentration.

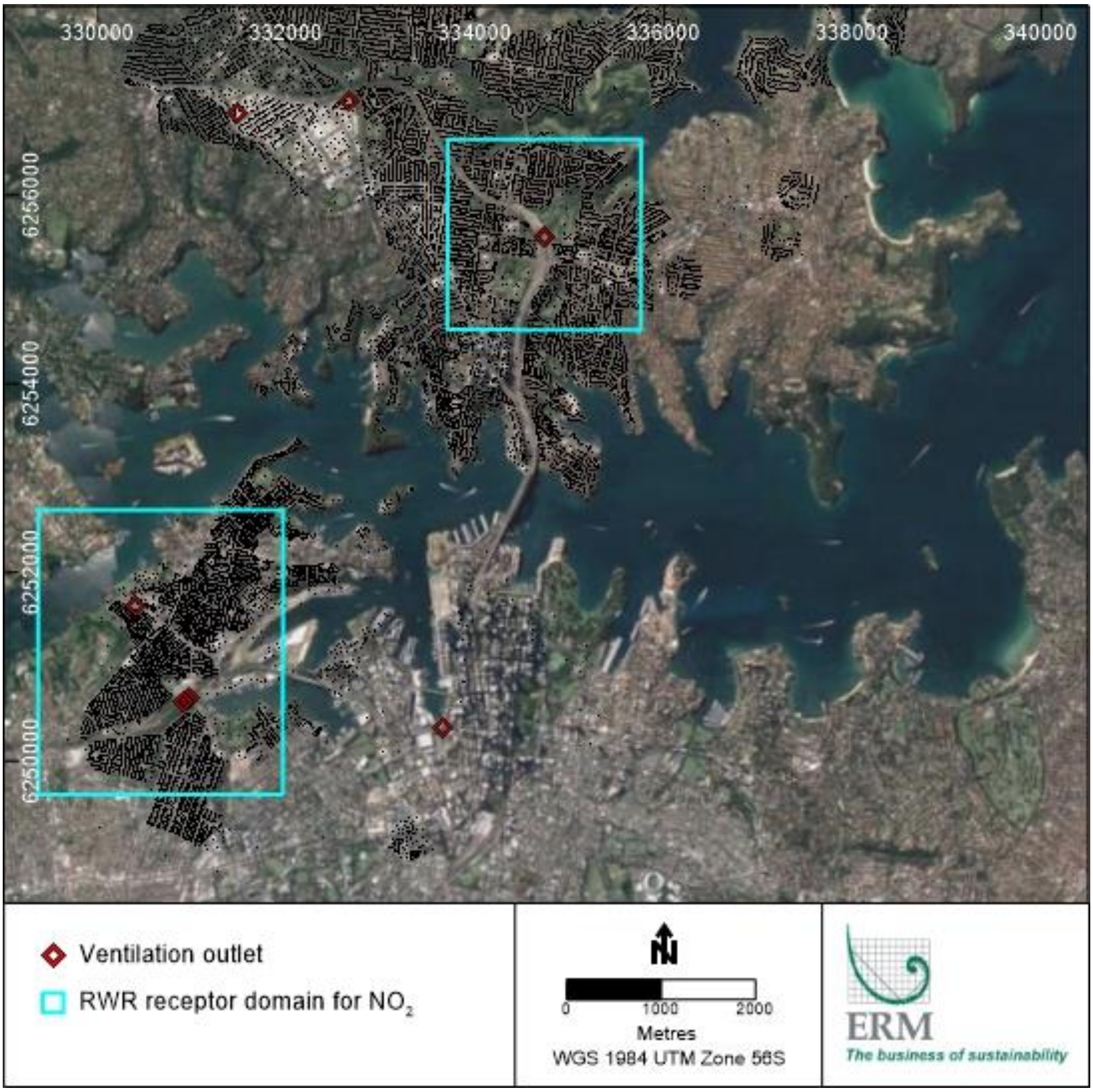


Figure 8-15 **Domains around ventilation outlets for 1-hour NO_2 RWC assessment**

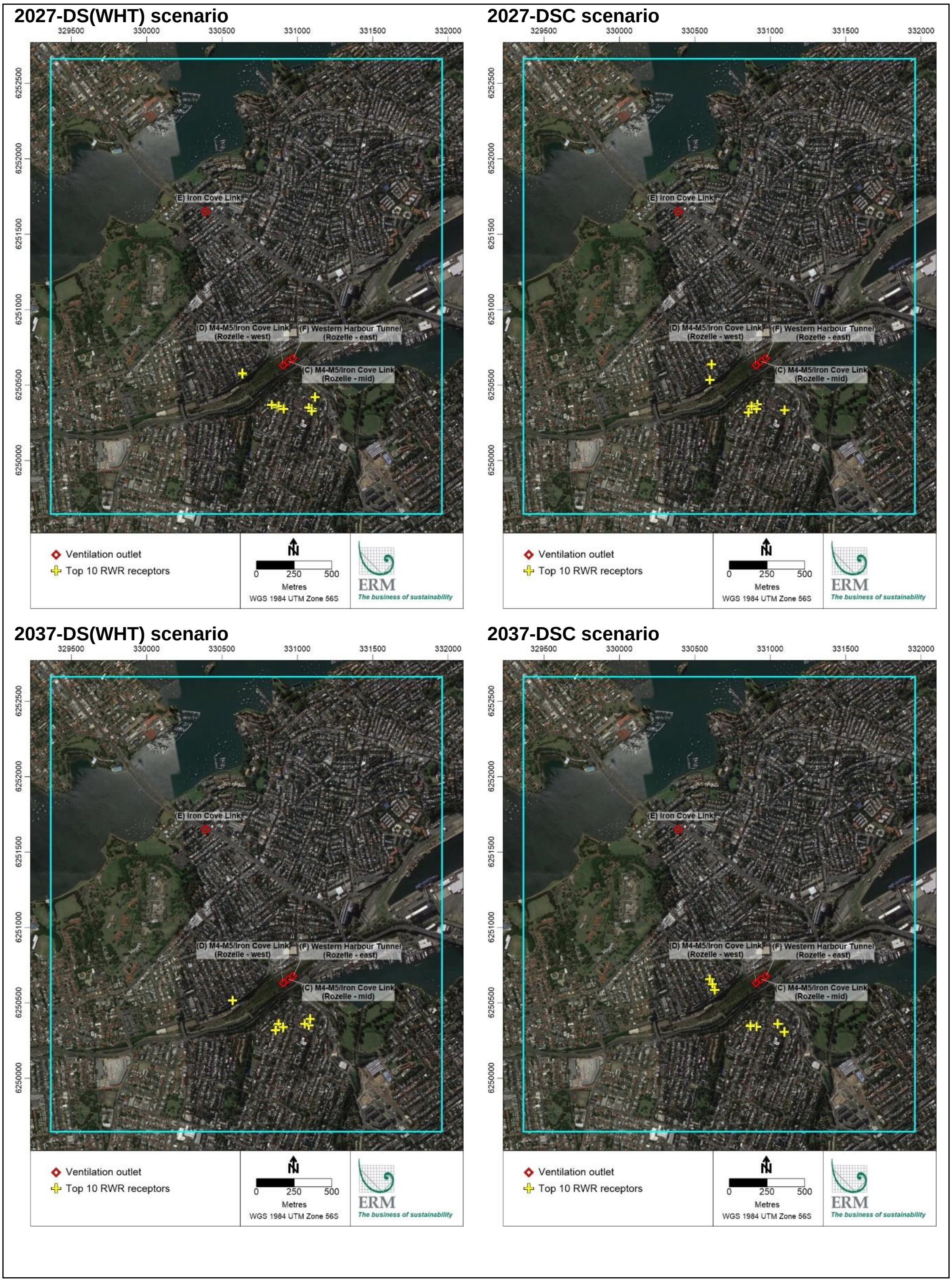


Figure 8-16 Top 10 receptors for 1-hour NO_X (Rozelle)

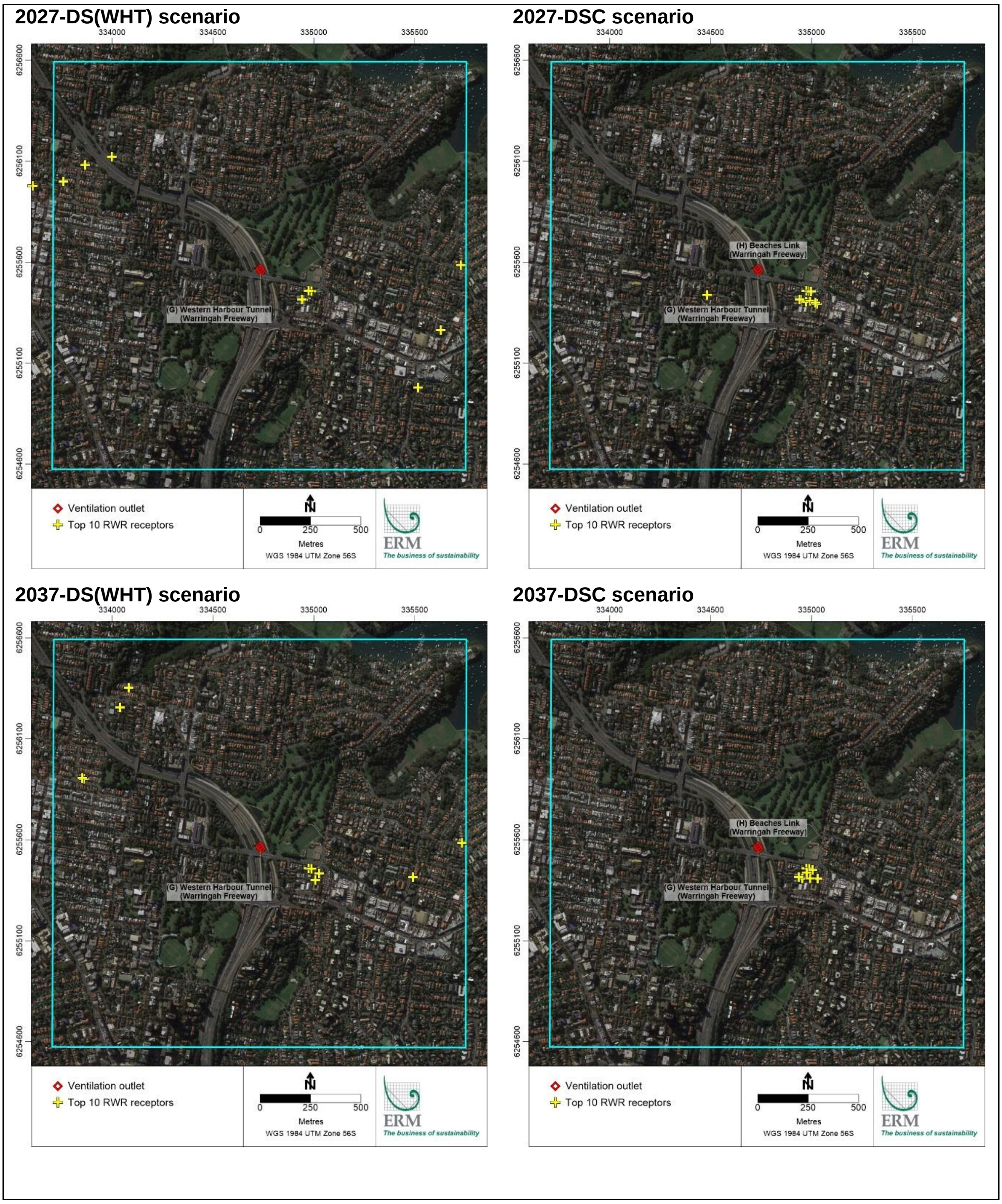


Figure 8-17 Top 10 receptors for 1-hour NO_X (Warringah Freeway)

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. A contemporaneous method[27] was used for the 42 community receptors to incorporate background concentrations. This was not possible for the large number of RWR receptors included in the assessment, and so simpler approaches were used for these. 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 98th percentile 24-hour background PM_{10} from synthetic profile
	1 year	GRAL PM_{10} added to mapped background PM_{10}	GRAL PM_{10} added to mapped background PM_{10}
$PM_{2.5}$	24 hours	24-hour GRAL $PM_{2.5}$ added to contemporaneous 24-hour background $PM_{2.5}$	Maximum 24-hour GRAL $PM_{2.5}$ added to 98th percentile 24-hour background $PM_{2.5}$ from synthetic profile
	1 year	GRAL $PM_{2.5}$ added to mapped background $PM_{2.5}$	GRAL $PM_{2.5}$ added to mapped background $PM_{2.5}$

The derivation of background concentrations is explained in Annexure D. To support the contemporaneous approach, various 'synthetic' background profiles were developed for the short-term concentration metrics for CO (1-hour mean, rolling 8-hour mean), NO_X (1-hour mean), PM_{10} (24-hour mean) and $PM_{2.5}$ (24-hour mean). For a project such as the Western Harbour Tunnel, which covers a large geographical area and features different types of land use, it was considered important to allow for spatial variation in annual mean concentrations where possible. Maps of background annual mean concentrations of the most important road transport pollutants (NO_X, PM_{10} and $PM_{2.5}$) were therefore developed for the GRAL domain. When developing these maps, the data from any non-background stations were excluded.

[27] 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.

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 LDVs (cars and LCVs) running on petrol with no ethanol (E0) and petrol with 10 per cent ethanol (E10), as well as diesel vehicles (the profiles are the same for light-duty and heavy-duty diesel vehicles).

Table 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

(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, 2027 and 2037). The weighted profiles are given in Table 8-19.

Table 8-19 Weighted THC speciation profiles for 2016, 2027 and 2037

Pollutant/metric	Weighted % of THC for traffic		
	2016	2027	2037
Benzene	4.3	3.9	3.4
PAHs (as b(a)p)	0.03	0.04	0.04
Formaldehyde	2.5	3.4	4.6
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 99.9th percentile of model predictions. However, the approach and assessment criteria in the Approved Methods cannot be readily applied to complex road projects in urban areas, as they are based on the assumption that a project represents a new source, and not a modification to an existing source. In the case of the current project, the 'impacts' are dependent in part on the emissions from the tunnel ventilation outlets but, more importantly, on how the traffic on the existing road network is affected and, at many receptors, the concentrations of air toxics actually decreased as a result of the project. A modified version of the usual approach was therefore used, whereby only the change in the maximum 1-hour concentration of each compound as a result of the project was compared with the corresponding impact assessment criterion in the Approved Methods.

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 Western Harbour Tunnel, a similar model evaluation approach to that conducted for the WestConnex projects, based on the monitoring data and model predictions for the base case (2016). However, the monitoring data available for model evaluation were limited. Only five stations were located inside the GRAL domain, and of these, only one background station (Rozelle) had full data for 2016. One roadside station (M4-M5:01, alongside the City West Link) had data for April-December 2016 so these two stations were the only ones used in the evaluation. The performance of GRAL was not investigated at the project-specific monitoring stations, as no data from these were available for 2016.

GRAL was configured to predict hourly concentrations of NO_X, NO_2, CO and PM_{10} at the two 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 particulate matter tends to be small relative to the background.

A number of different approaches were used 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 project assessment were conservative, and therefore unlikely to give an accurate impression of model accuracy.

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 on Figure 8-18. The results can be summarised as follows:

- Based on the mapped background contribution, NO_X concentrations were overestimated at both the background and roadside stations
- This overestimation of mean NO_X at the background station was around 14 µg/m^3, or 40 per cent, based on the mapped background. At the background station the bulk of the overestimation was due to GRAL
- At the roadside station, the mean NO_X concentration was overestimated by around 50 per cent based on the mapped background. The contemporaneous approaches were more conservative. The synthetic profiles also resulted in the overestimation of 98th percentile and maximum NO_X concentration by around a factor of two.

The temporal assessment of NO_X revealed the following:

- There was a pronounced overestimation of NO_X concentrations, especially at night-time and during the peak afternoon traffic periods
- The inter-peak concentrations were reasonably well reproduced, although there was still a marked overestimation during some periods
- The seasonal pattern in NO_X was reproduced well, although again there was a consistent overestimation of the monthly average concentration

- 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 gave more realistic predictions than the model with the ozone limiting method. The empirical NO_X-to-NO_2 method for determining the maximum 1-hour concentration is not well suited to the estimation of other NO_2 statistics such as means and percentiles.

Overall, the results supported the application of GRAL in the assessment, along with the empirical conversion methods for NO_2, noting that the results are 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.

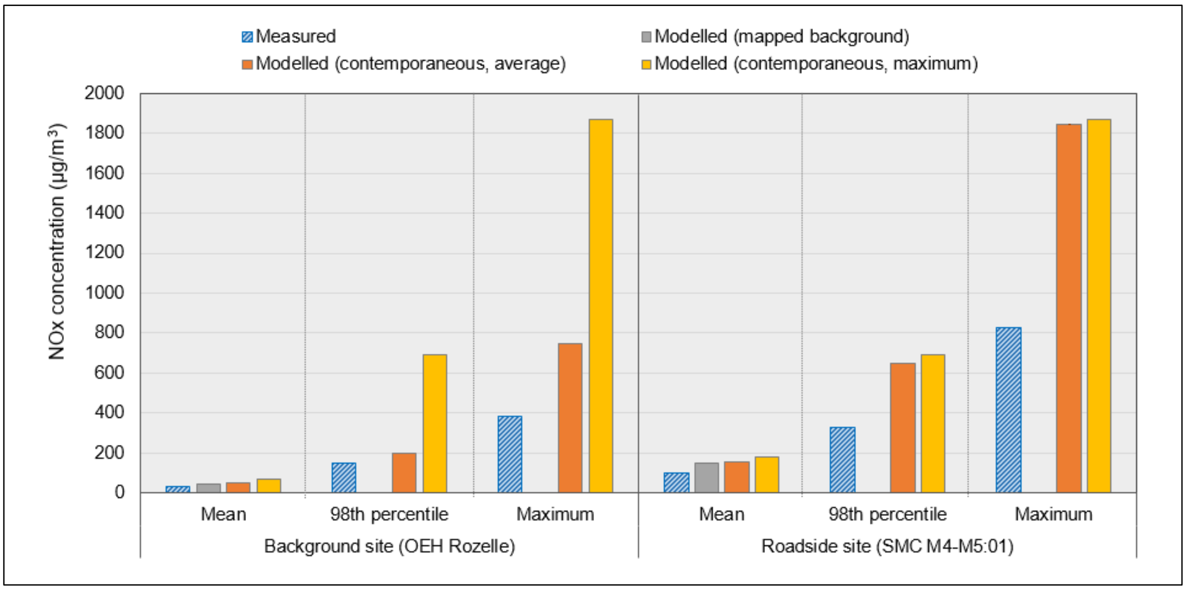


Figure 8-18 Comparison between measured and predicted annual mean NO_X concentrations

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. All results, including tabulated concentrations and contour plots, are provided in Annexure I. The pollutants and metrics are treated in turn, and in each case, the following have been determined for the 42 community and 35490 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, tunnel portals and tunnel 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 (ie 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 $PM_{2.5}$. The plots were based on 1.9 million grid points, spaced at 10 metre intervals across the domain
- As spatially mapped pollutant concentrations, and changes in concentration, for the areas around project tunnel ventilation outlet 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: In this section of the report, the results are presented in a way which shows the overall picture in terms of total pollutant concentrations and the contributions of the different sources. The results for tunnel ventilation outlets are presented in more detail in Annexure J.

NB 2: To avoid a large amount of duplication, the main report only includes the full domain contour plots for the most complex scenario in terms of changes in traffic, 2037-DSC, and the corresponding ‘Do minimum’ scenario, 2037-DM, where applicable. For all other scenarios, the contour plots are given in Annexure I.

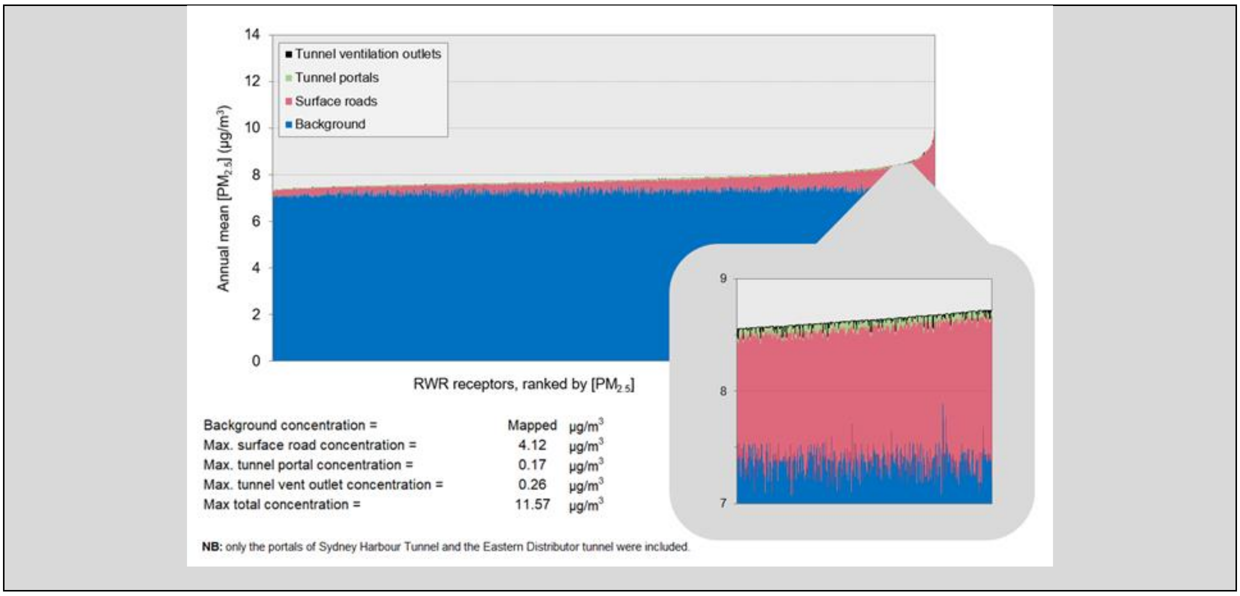
NB 3: Larger-scale contour plots showing the contributions of the Western Harbour Tunnel ventilation outlets to NO_X, PM_{10} and $PM_{2.5}$ in the vicinity of each outlet (Rozelle and Warringah Freeway) are provided in Annexure J. The presentation of these plots is slightly different to those for the 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 outlet plots (around two kilometres by two kilometres) is much smaller than that of the full GRAL domain. This allowed more local detail, with isopleths and concentration values, to be shown more clearly in the maps.

NB 4: 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 5: The ranked RWR plots are highly compressed along the x-axis, given that around 35000 receptors are included. Because 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 so the maximum contributions from each source, and the maximum total concentration are also given. An example of this compression is shown on 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

Given the historical reduction in CO emissions from petrol vehicles in recent decades, due to the effective mandating of three-way-catalysts, CO is no longer considered to be a significant health issue for road transport. The maximum 1-hour mean CO concentrations at the 42 community receptors in the with-project and cumulative scenarios (2027-DS(WHT), 2027-DSC, 2037-DS(WHT) and 2037-DSC) are shown on Figure 8-19. The CO concentration at each of these receptor locations 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).

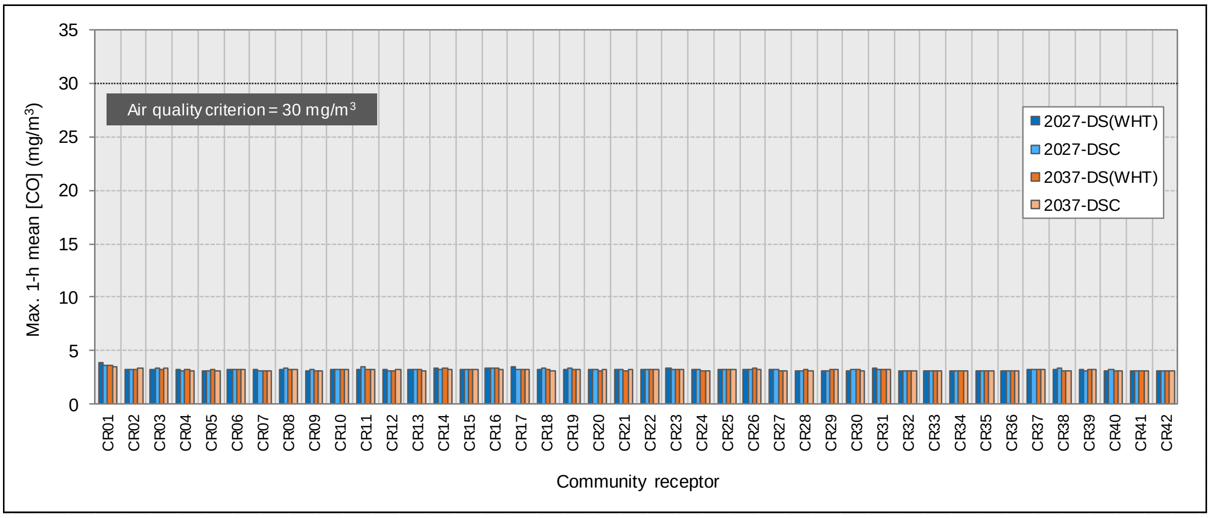


Figure 8-19 Maximum 1-hour mean CO concentration at community receptors (with-project and cumulative scenarios)

Figure 8-20 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, but these were all small in absolute terms. The largest increase at any receptor was around 0.2 mg/m^3, which equated to just 0.7 per cent of the impact assessment criterion of 30 mg/m^3.

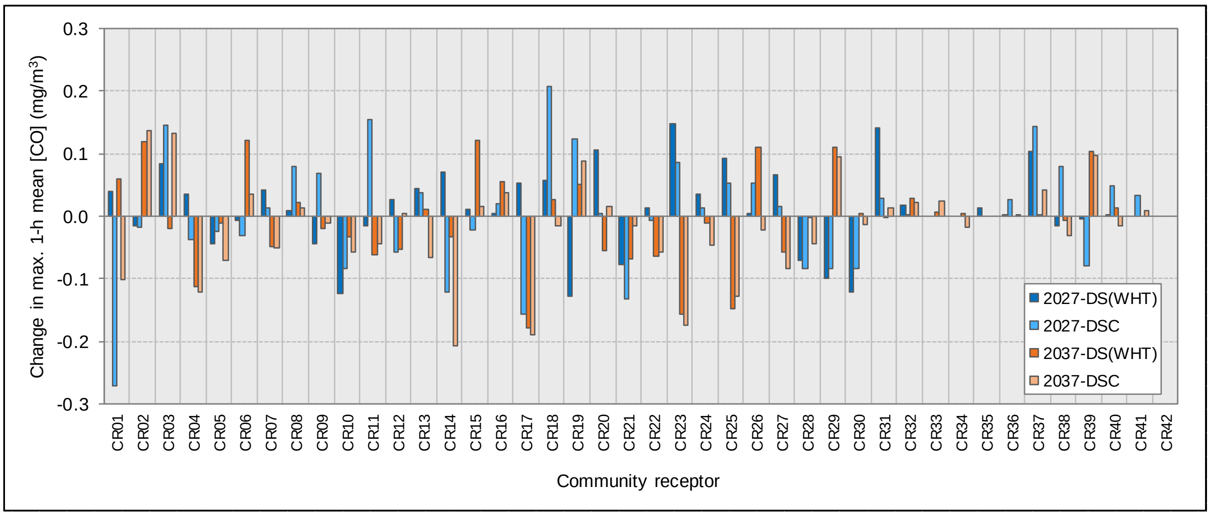


Figure 8-20 Change in maximum 1-hour mean CO concentration at community receptors (with-project and cumulative scenarios, relative to corresponding Do minimum scenarios)

Figure 8-21 presents the separate contributions of the background, surface roads, tunnel portals and ventilation outlets to the maximum total 1-hour mean CO concentrations in the with-project and cumulative scenarios. At all of the receptors, the maximum total concentration was dominated by the background. The hour of the year on which the maximum total concentration occurred was not the same for all receptors, which explains why the background concentration varied slightly. However, for most scenarios and receptors, the maximum total concentration did occur in the same hour as the maximum background CO concentration (3.13 mg/m^3). The largest non-background source was surface roads. The largest contribution of surface roads to the maximum total concentration in any of the with-project and cumulative scenarios was nevertheless small (1.1 mg/m^3 at receptor CR01). The contribution of tunnel portals and ventilation outlets to the maximum CO concentration was zero or negligible (less than 0.01 mg/m^3) for all receptors.

For any given receptor, it is possible that larger 1-hour contributions from surface roads, portals 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 totals would have been lower than that given on Figure 8-21.

Results for RWR receptors

The maximum 1-hour CO concentrations at all the RWR receptors are shown for the with-project and cumulative scenarios on Figure 8-22. The results are ranked by total CO concentration. The contributions from surface roads, portals and ventilation outlets are not shown separately, as for any short-term metric such as this, the hours during which the maxima for the different sources occurred would not necessarily coincide.

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 high concentrations.

The 1-hour CO criterion for NSW was not exceeded at any of the RWR receptors in any scenario. The highest total 1-hour concentrations in any with-project or cumulative scenario was predicted to be 5.5 mg/m^3. The largest contribution from ventilation outlets at any receptor was less than 0.1 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 on Figure 8-23. There was an increase in concentration of between 37 per cent and 49 per cent of receptors with the project; however, even the largest increase in any scenario, which was 0.9 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.

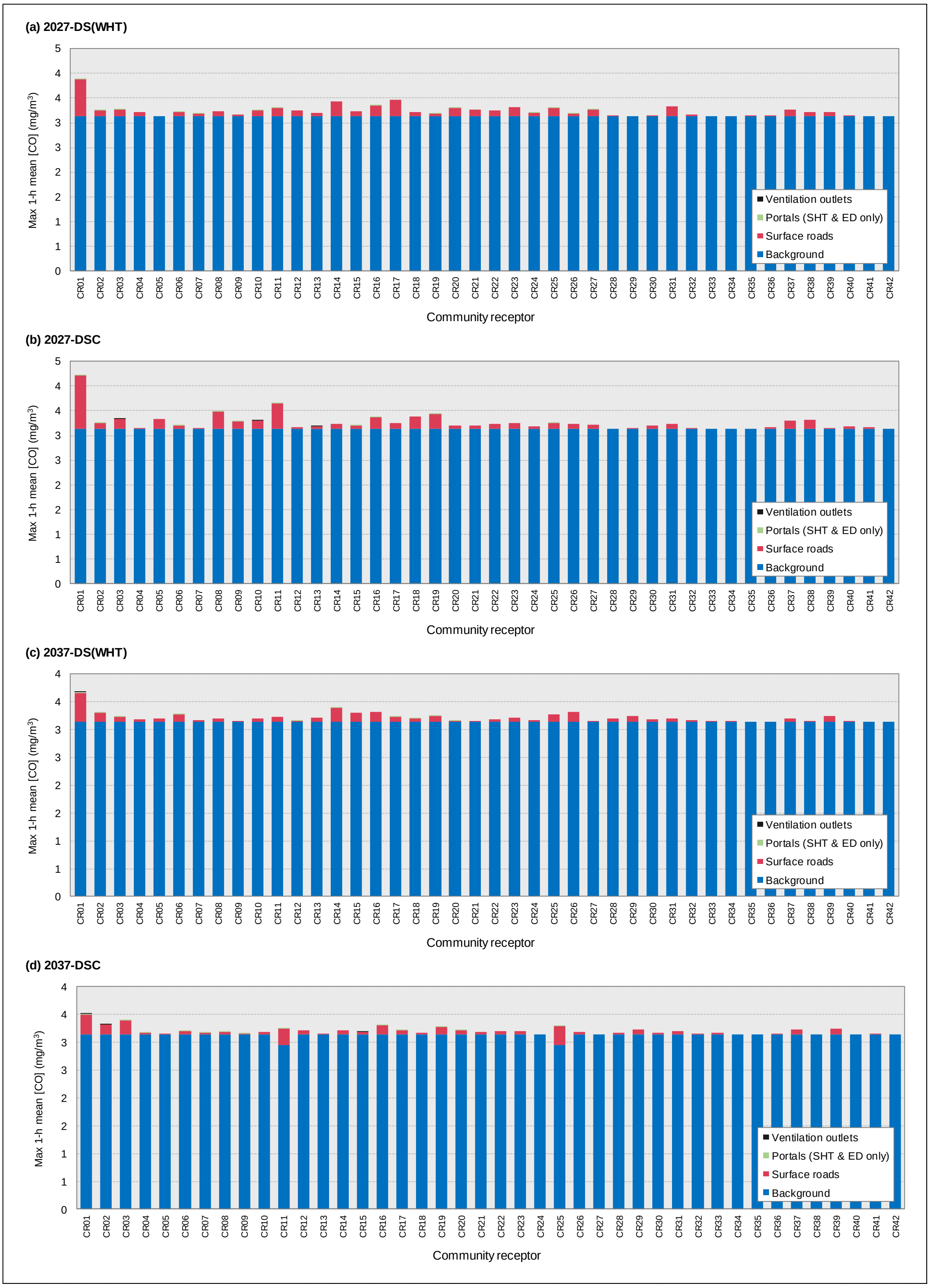


Figure 8-21 Source contributions to maximum 1-hour mean CO concentration at community receptors (with-project and cumulative scenarios) (portals include Sydney Harbour Tunnel and Eastern Distributor only)

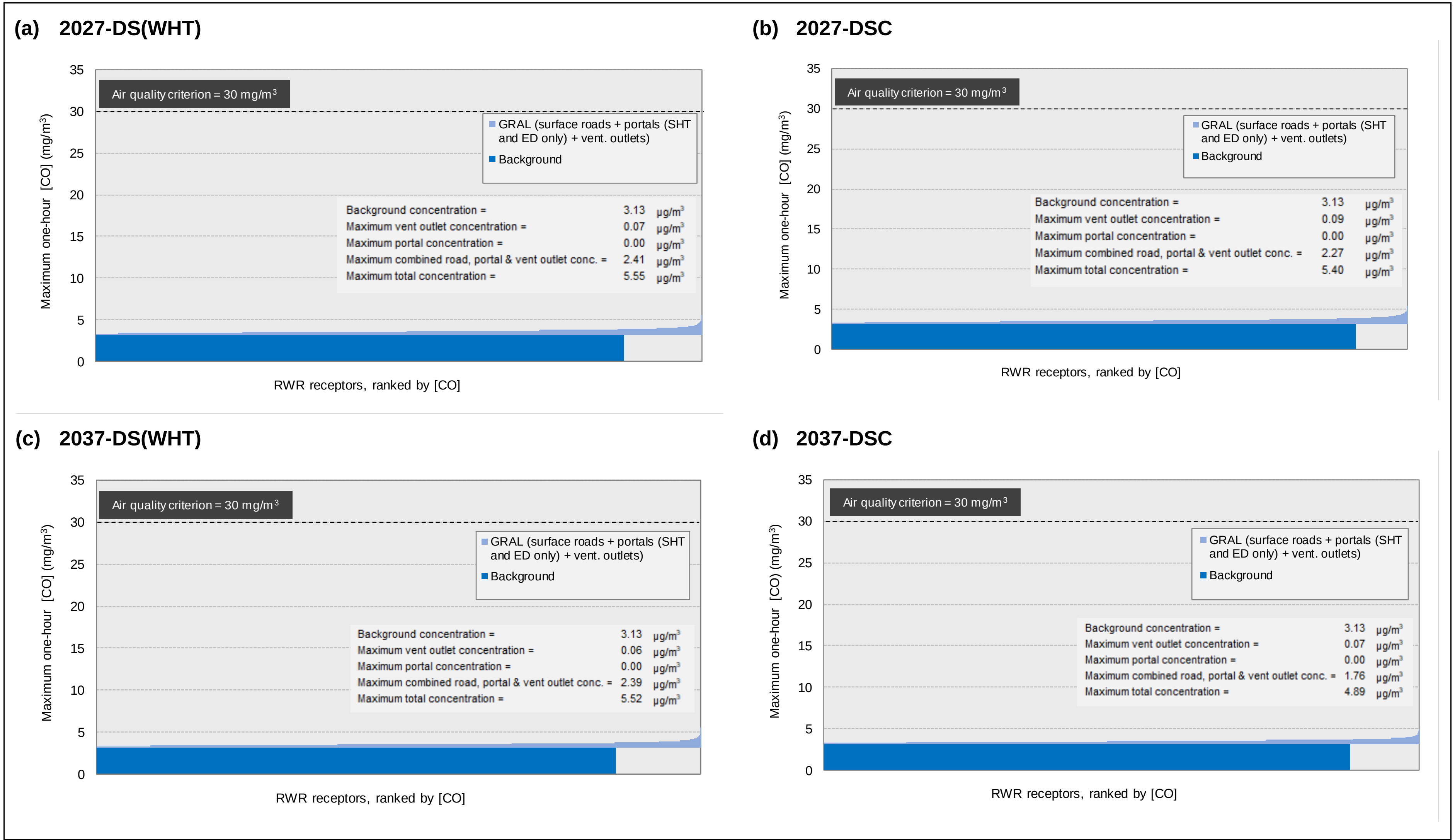


Figure 8-22 Source contributions to maximum 1-hour CO concentration at RWR receptors (with-project and cumulative scenarios) (portals include Sydney Harbour Tunnel and Eastern Distributor only)

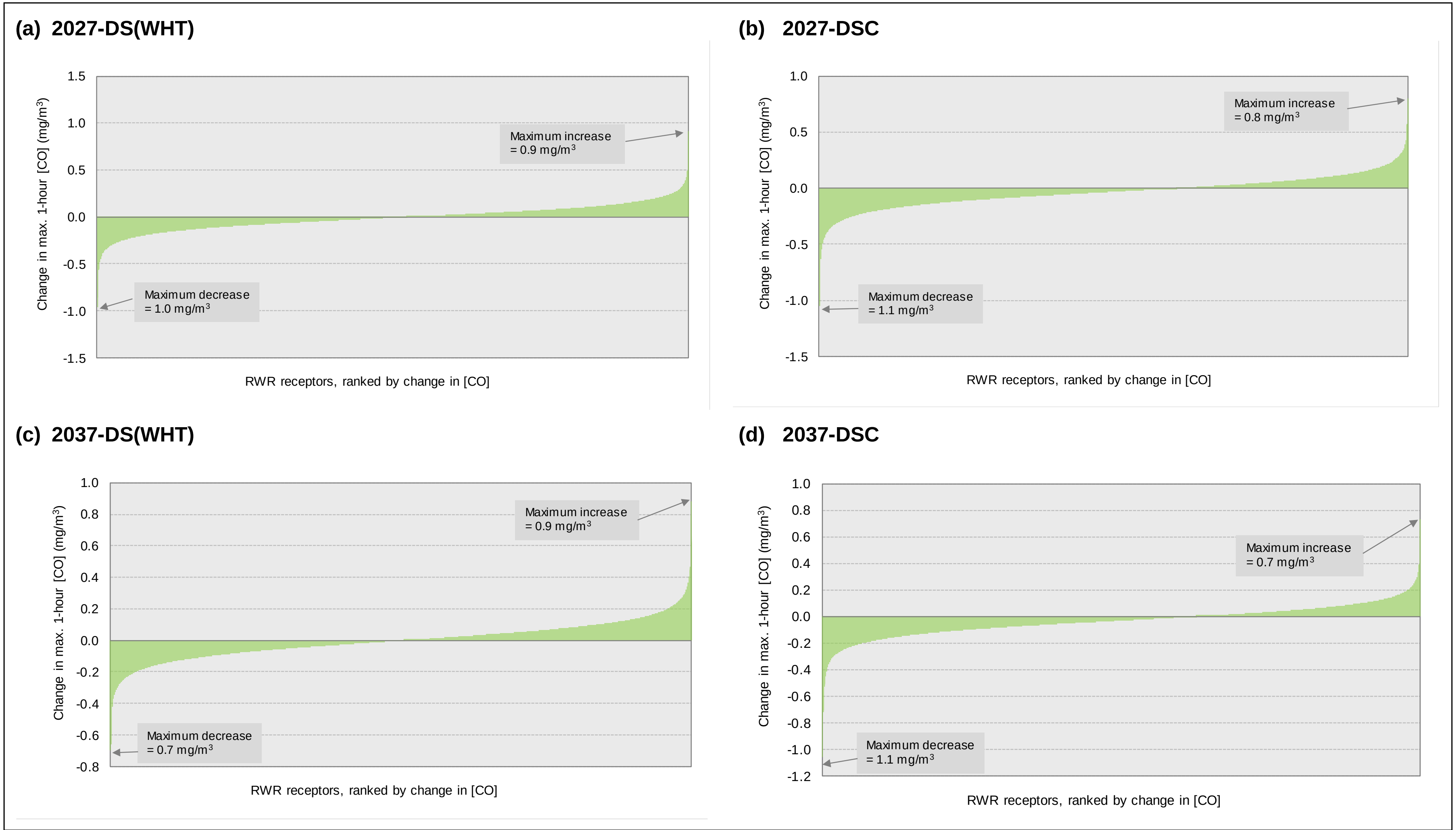


Figure 8-23 Change in maximum 1-hour CO concentration at RWR receptors (with-project and cumulative scenarios, relative to corresponding Do minimum scenarios)

Carbon monoxide (maximum rolling 8-hour mean)

Results for community receptors

Figure 8-24 shows the maximum rolling 8-hour mean CO concentrations at the community receptors with the project and in the cumulative scenarios. As with the 1-hour mean, the concentration was well below the NSW impact assessment criterion at all the receptors, which in this case is 10 mg/m^3. No lower criteria appear to be in force internationally.

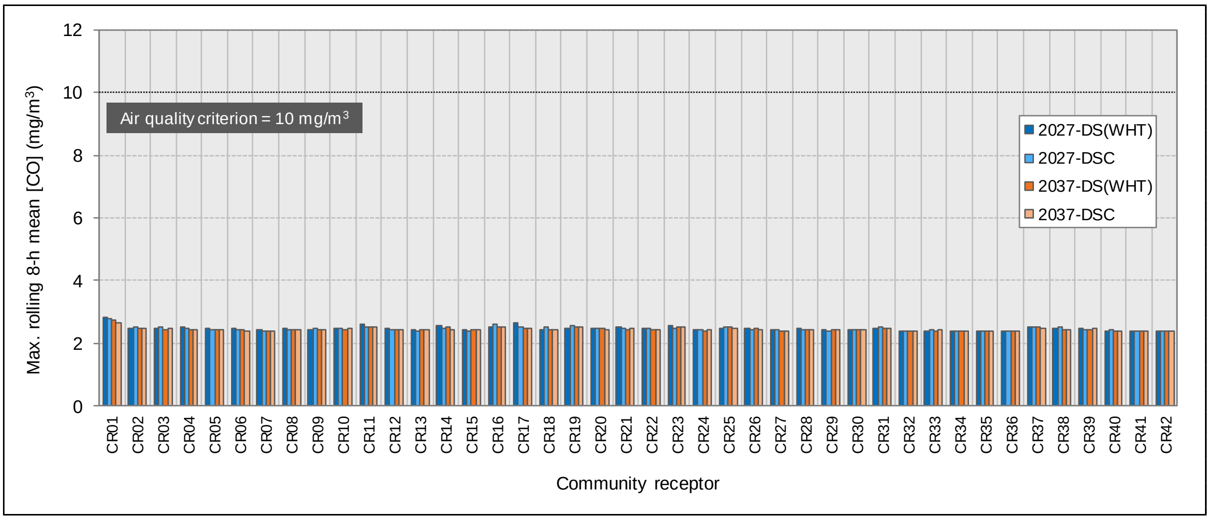


Figure 8-24 Maximum rolling 8-hour mean CO concentration at community receptors (with-project and cumulative scenarios)

It can be seen on Figure 8-25 that the changes in the maximum rolling 8-hour CO concentration at all the community receptors were less than 0.1 mg/m^3. The largest increase with the project and in the cumulative scenarios was 0.09 mg/m^3 (equating to one per cent of the criterion).

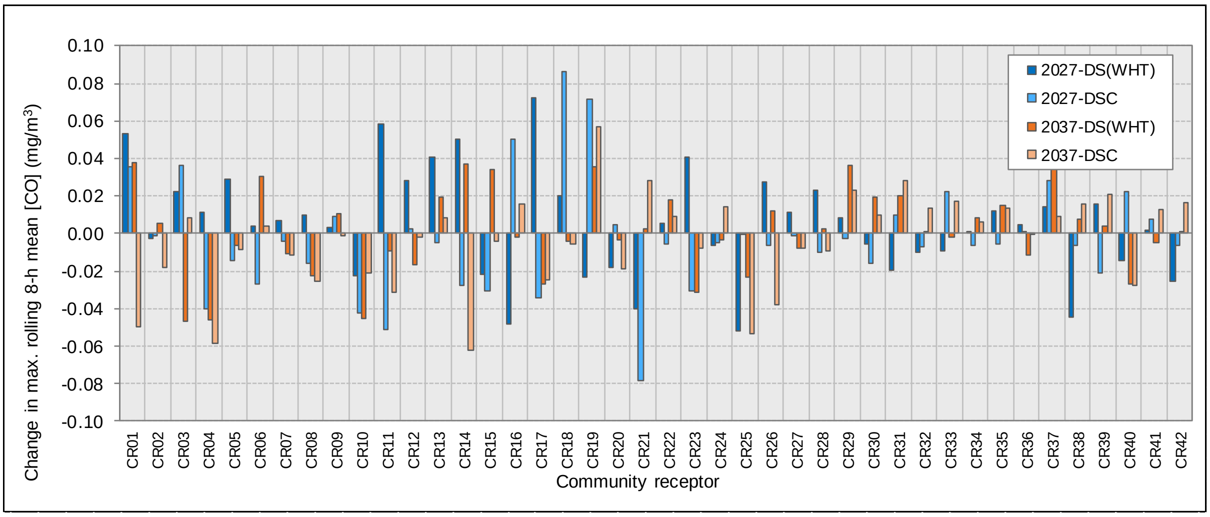


Figure 8-25 Change in maximum rolling 8-hour mean CO concentration at community receptors (with-project and cumulative scenarios, relative to Do minimum scenarios)

The main contributor at these receptors was the background concentration (Figure 8-26). The largest surface road contribution in any with-project or cumulative scenario was 16 per cent, while the tunnel portal and ventilation outlet contributions were zero or negligible in all cases.

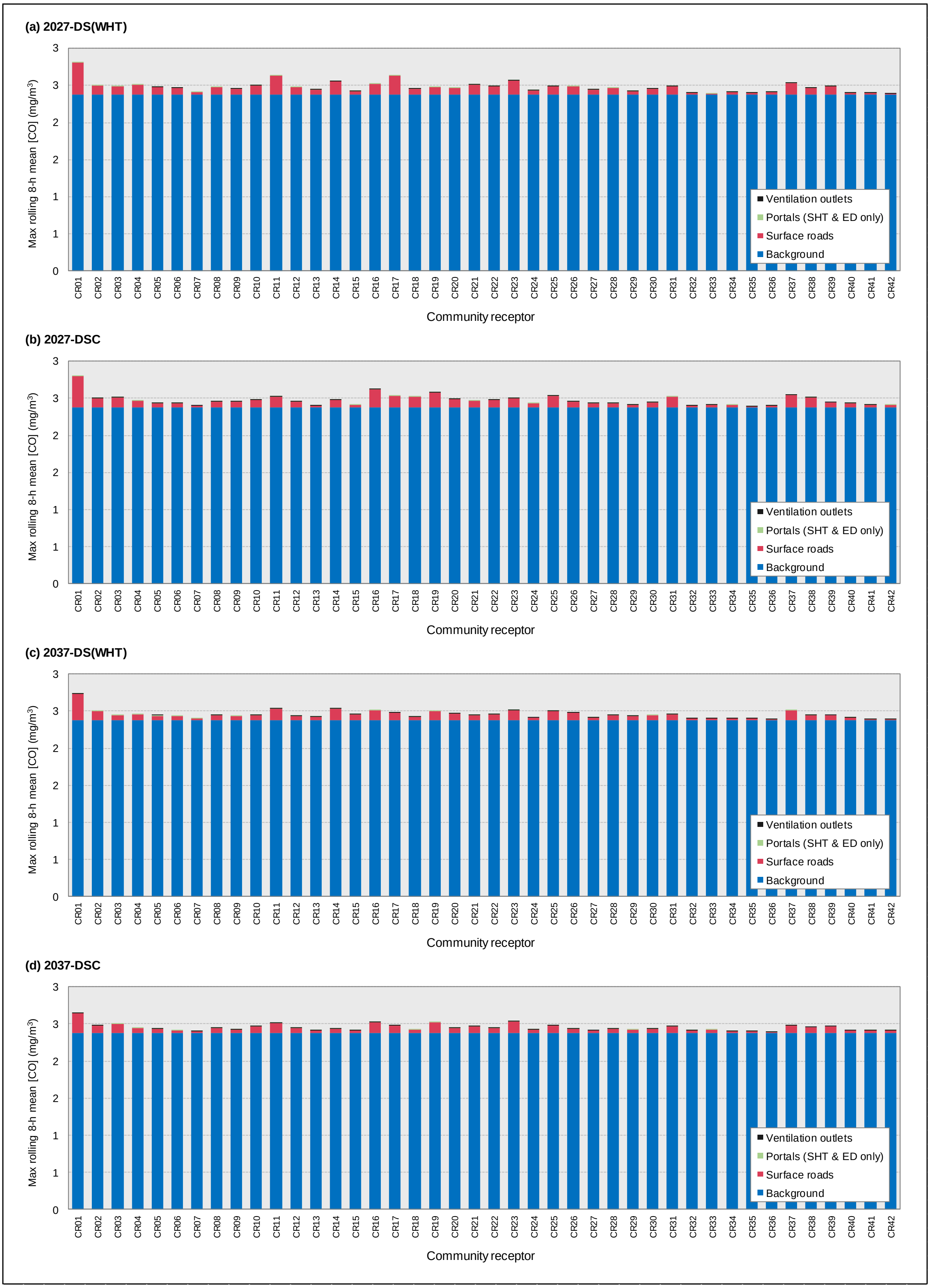


Figure 8-26 Source contributions to maximum rolling 8-hour mean CO at community receptors (with project and cumulative scenarios) (portals include Sydney Harbour Tunnel and Eastern Distributor only)

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 8-27 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 40 µg/m^3 (the air quality standard adopted in the EU) and therefore well below the NSW impact assessment criterion of 62 µg/m^3. Receptor CR28 (Peek A Boo Cottage, Seaforth) exceeded 30 µg/m^3 for 2027-DS(WHT), 2037-DS(WHT) and 2037-DSC. This receptor was located close to the heavily trafficked Manly Road (65,000 vehicles per day), and already had a relatively high NO_2 concentration in the Do minimum scenarios (32.3 µg/m^3 for 2027-DM and 33.1 µg/m^3 for 2037-DM).

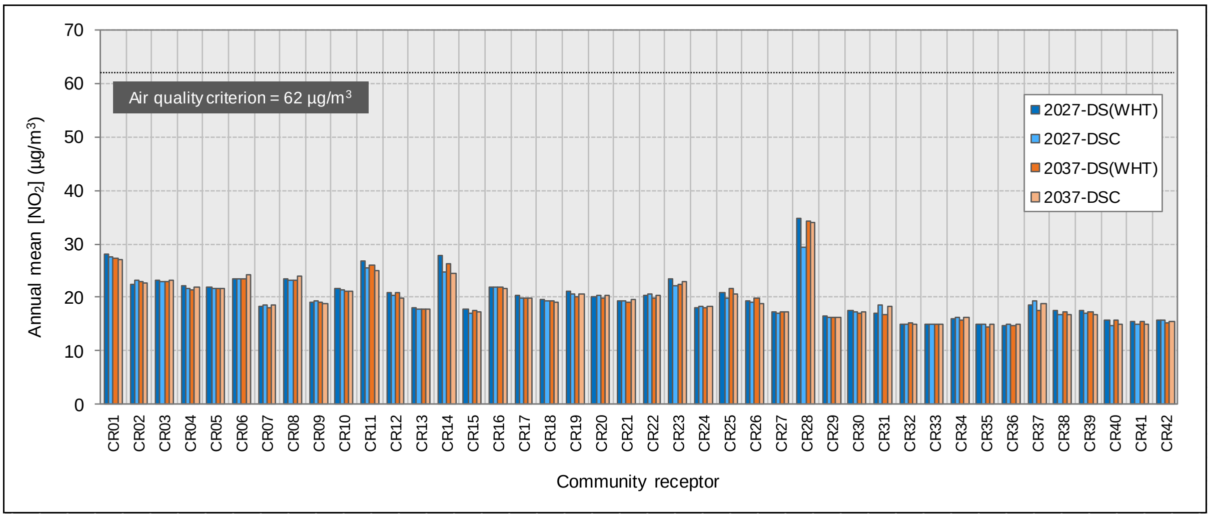


Figure 8-27 Annual mean NO_2 concentration at community receptors (with-project and cumulative scenarios)

Figure 8-28 shows the changes in concentration with the project. There was a small increase (less than 1.5 µg/m^3) in the NO_2 concentration at some receptors. The largest increase with the project was around 2.5 µg/m^3, equating to four per cent of the criterion. There were some notable decreases in concentration in the Do something and cumulative scenarios at some receptors. For example, at receptor CR08 (Wenona School, North Sydney) there was a predicted reduction in concentration of around 1-2 µg/m^3 in all scenarios due to the change in traffic volumes on the surface road network. There was a similar reduction in concentration at receptor CR14 (Garrison & Killarney Retirement Centre, Mosman) in the cumulative scenarios, due to a reduction in traffic on Spit Road as a result of the Beaches Link and Gore Hill Freeway Connection project. As noted above, although there was a slight increase in concentration at receptor CR28 (Peek A Boo Cottage, Seaforth) with the project, there was a reduction (around 3 µg/m^3) in the 2027 cumulative scenario as a result of the Beaches Link and Gore Hill Freeway Connection project.

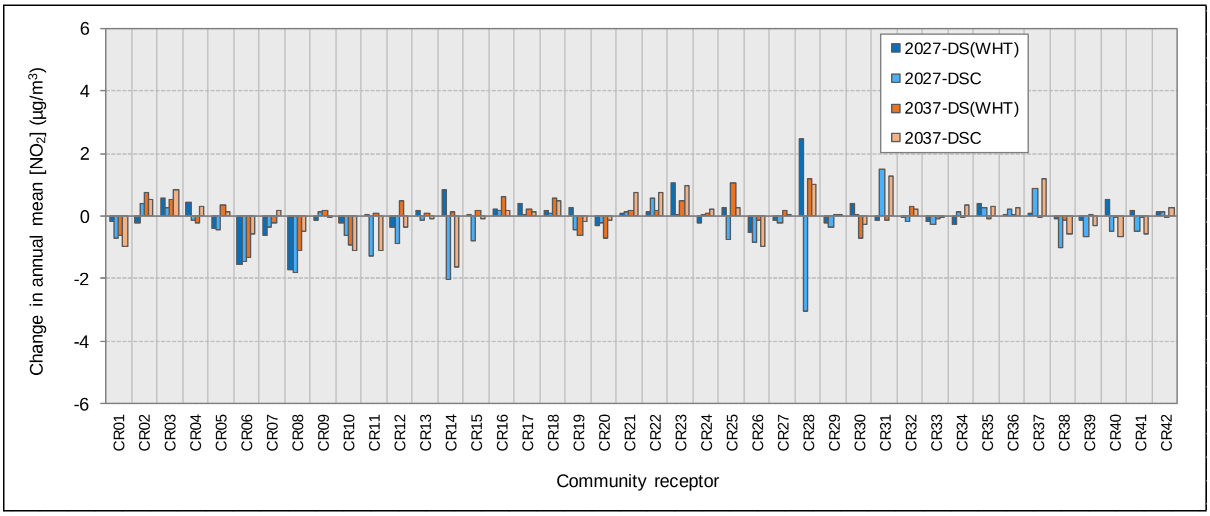


Figure 8-28 Change in annual mean NO_2 concentration at community receptors (with-project and cumulative scenarios, relative to Do minimum scenarios)

Figure 8-29 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 portal NO_X concentrations was converted to NO_2

Step D: The sum of the background, road, portal and ventilation outlet NO_X concentrations was converted to NO_2.

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

The results indicate that the background component at the community receptors is likely to be responsible for, on average, around 80-90 per cent of the predicted total annual mean NO_2, with most of the remainder being due to surface roads. At most receptors, surface roads were responsible for around 10 per cent and 30 per cent of the total, but at some receptors close to busy roads there was a more substantial surface road contribution. This was the most noticeable for receptor CR28 (Peek A Boo Cottage, Seaforth), which had a surface road contribution of around 50-60 per cent. The contributions of tunnel ventilation outlets were less than three per cent in all scenarios. There was negligible contribution from tunnel portals at the community receptors.

Figure 8-29 **Source contributions to annual mean NO_2 concentration at community receptors (with-project and cumulative scenarios) (portals include Sydney Harbour Tunnel and Eastern Distributor only)**

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 8-30. Concentrations at the vast majority (more than 97 per cent) of receptors were between around 13 $\mu g/m^3$ and 25 $\mu g/m^3$. The annual mean NO_2 criterion for NSW of 62 $\mu g/m^3$ was not exceeded at any of the receptors in any scenario. For all scenarios, NO_2 concentrations were below the EU limit value of 40 $\mu g/m^3$.

The maximum contribution of tunnel ventilation outlets for any scenario and receptor was 0.6 $\mu g/m^3$, whereas the maximum surface road contribution was 22 $\mu g/m^3$. Given that annual mean 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 (relative to the Do minimum scenarios) are shown, ranked by the change in concentration, in Figure 8-31. There was predicted to be an increase in the annual mean NO_2 concentration at between 40 per cent and 52 per cent of receptors, depending on the scenario. However, at many receptors the changes in concentration were very small. The increase in concentration was greater than 1 $\mu g/m^3$ for only around 0.8 per cent of receptors. Conversely, there was a reduction in annual mean NO_2 at between around 47 per cent and 60 per cent of receptors. The majority of the increases for the Western Harbour Tunnel scenarios were located along the Warringah Freeway Upgrade, Falcon Street and Gore Hill Freeway. There were also some increases in Rozelle along Victoria Road. In addition to these locations, the cumulative scenarios saw a small number of increases over 1 $\mu g/m^3$ at Manly Road and The Spit.

Contour plots – all sources

The contour plot of annual mean total NO_2 concentrations across the GRAL domain in the 2037-DM scenario (ie all sources without the project) is provided in Figure 8-32, and an equivalent plot for the 2037-DSC scenario (ie all sources in the cumulative scenario) is shown in Figure 8-33. The figures also show main surface roads and the locations of tunnel ventilation outlets.

The plots are based on 1.9 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.

It should be noted that some of the roads in the model are presented as being on the surface, whereas in reality, they are elevated. The main examples of this are Sydney Harbour Bridge and Anzac Bridge. It was not considered necessary to represent these roads more accurately given that they were some distance from sensitive receptor locations (moreover, decreases in concentration were predicted along these roads).

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 the Western Distributor, the Bradfield Highway and Warringah Freeway. It is noticeable that the tunnel ventilation outlets have little impact on total annual mean NO_2 concentrations.

The contour plot in Figure 8-34 shows the changes in annual mean NO_2 concentration in the 2037-DSC 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 2 $\mu g/m^3$ (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.

Further discussion of the general spatial redistribution of pollutant concentrations across the domain was qualitatively similar for all pollutants, and these are discussed further in Section 8.4.12.

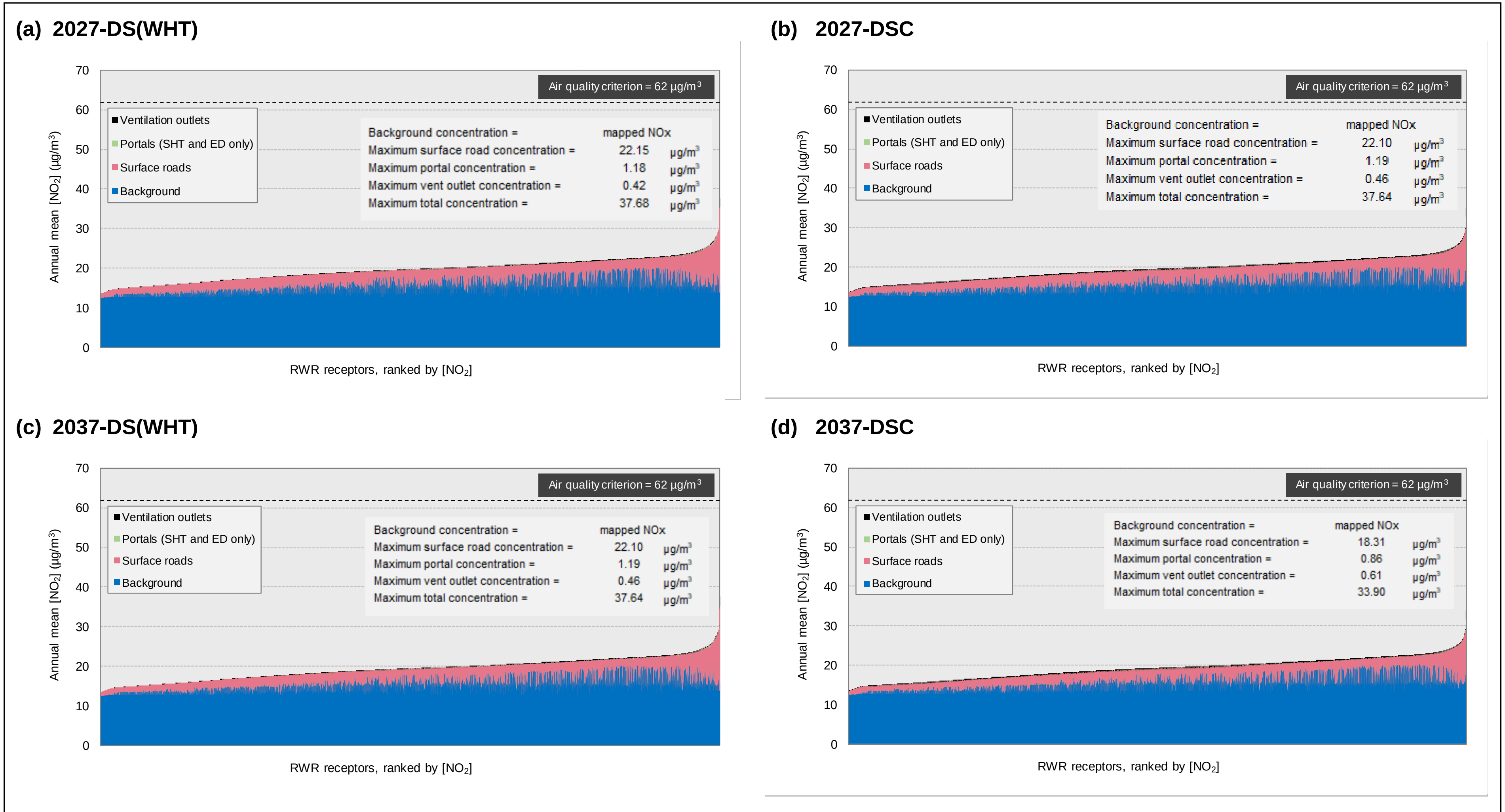


Figure 8-30 Source contributions to annual mean NO_2 concentration at RWR receptors (with-project and cumulative scenarios) (portals include Sydney Harbour Tunnel and Eastern Distributor only)

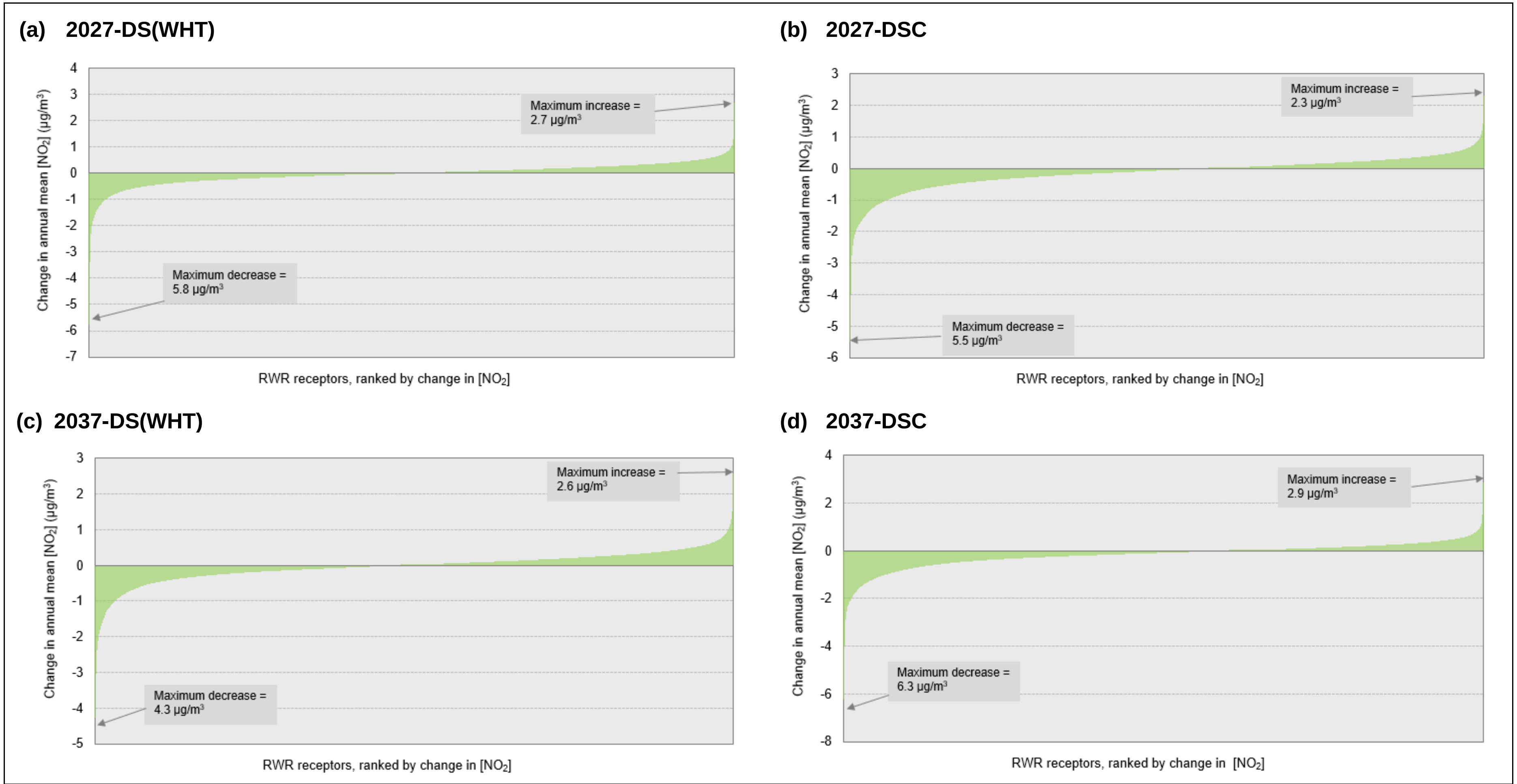


Figure 8-31 Change in annual mean NO_2 concentration at RWR receptors (with-project and cumulative scenarios, relative to corresponding Do minimum scenarios)

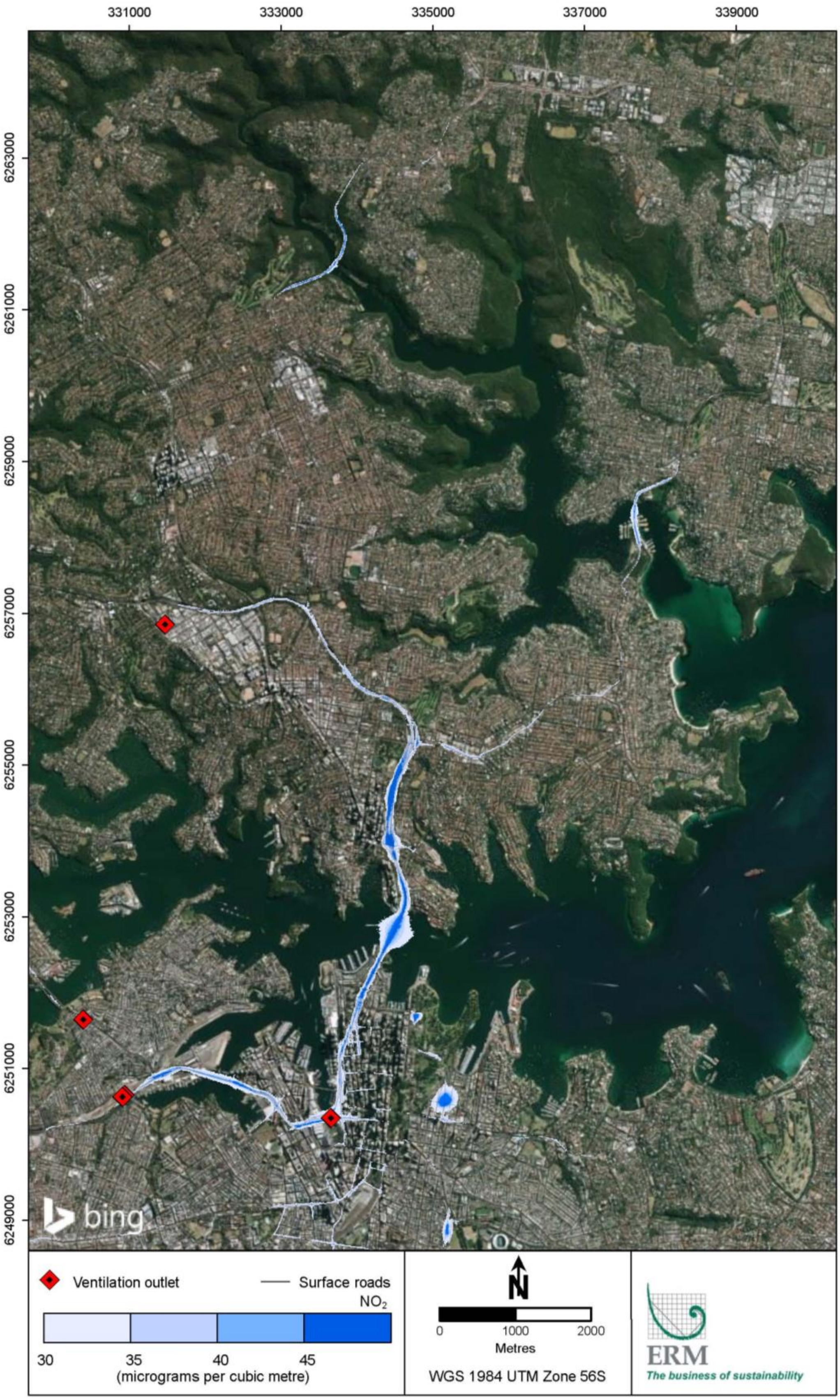


Figure 8-32 Contour plot of annual mean NO_2 concentration in the 2037 Do minimum scenario (2037-DM)

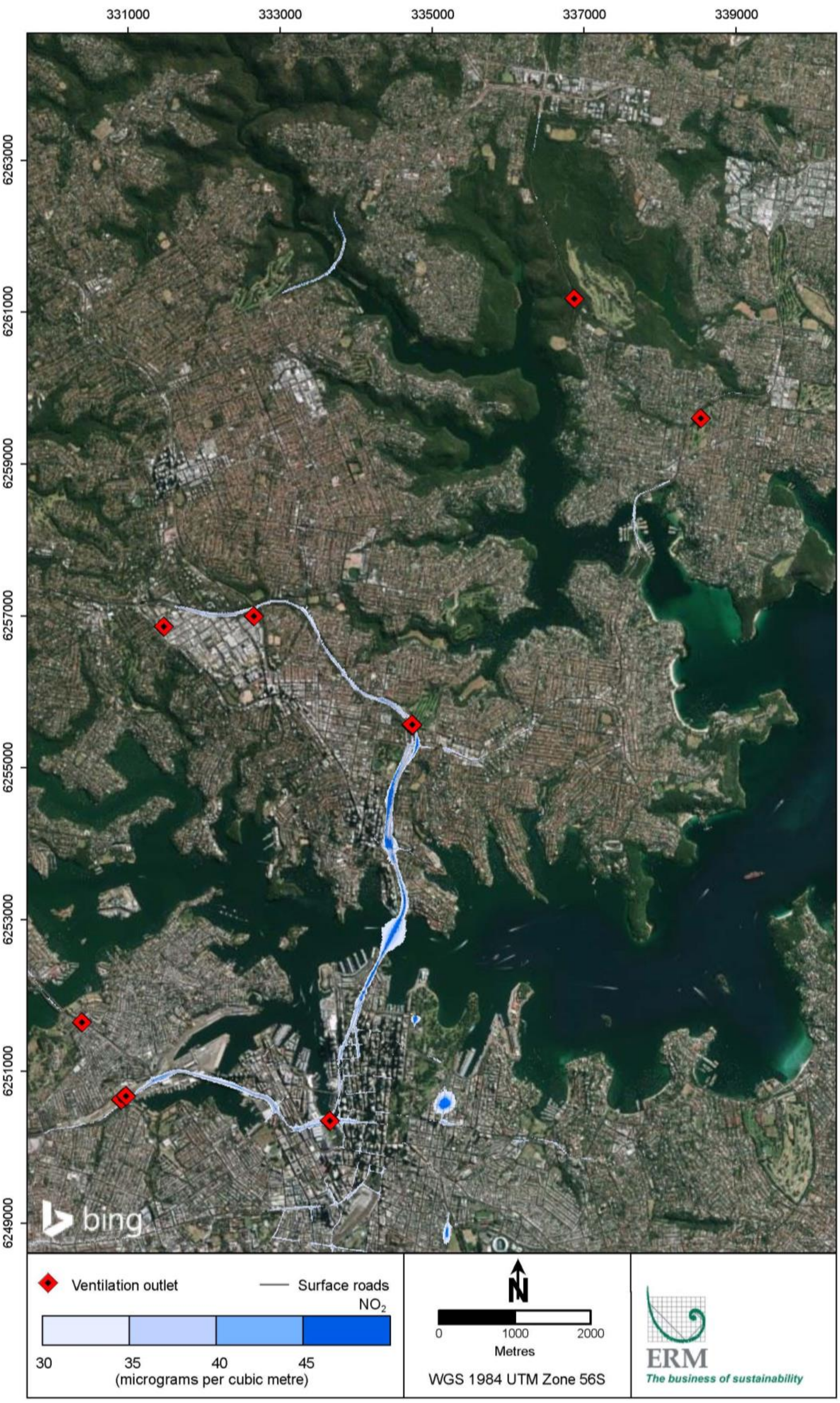


Figure 8-33 Contour plot of annual mean NO_2 concentration in the 2037 cumulative scenario (2037-DSC)

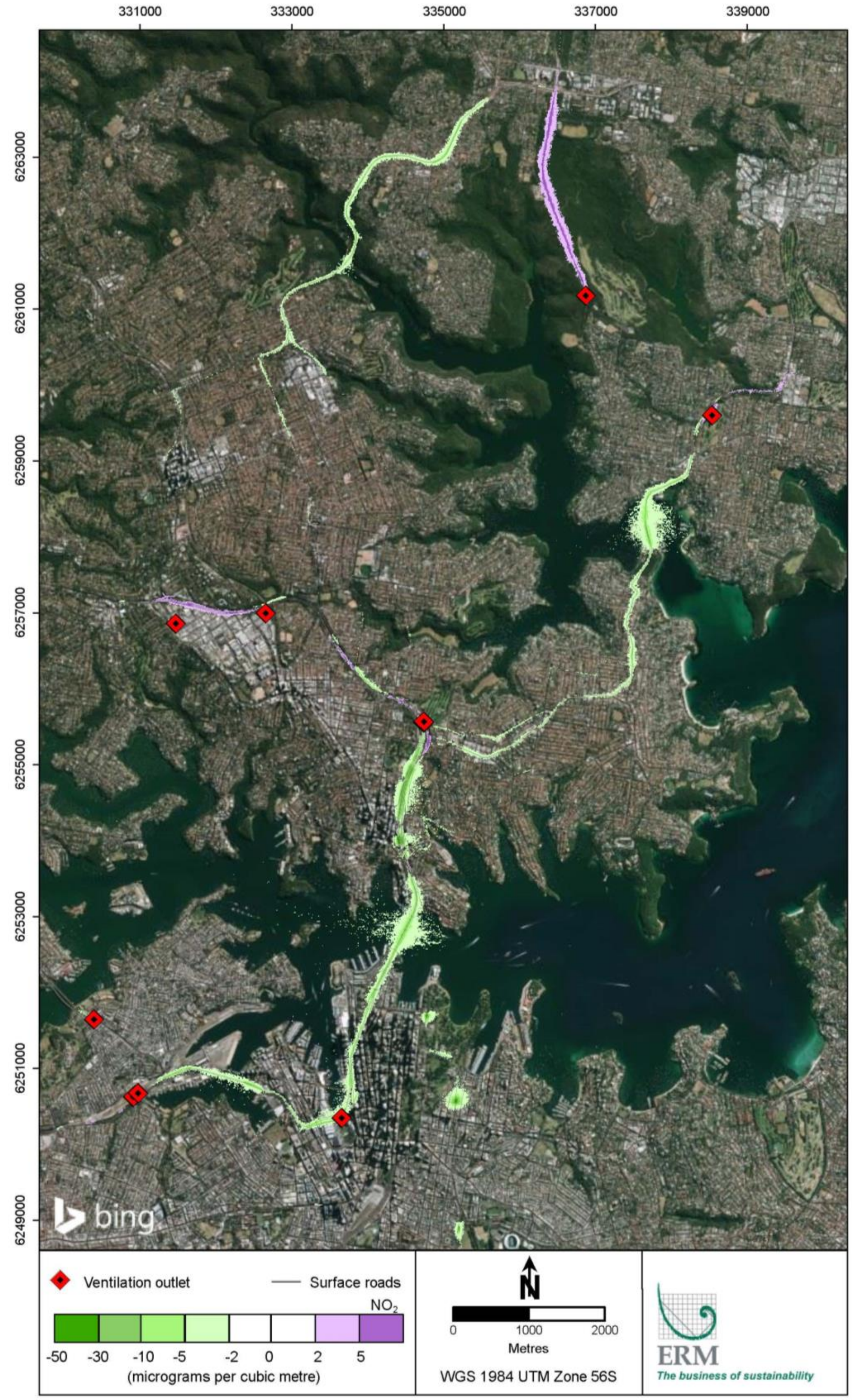


Figure 8-34 Contour plot of change in annual mean NO_2 concentration in the 2037 cumulative scenario (2037-DSC minus 2037-DM)

Nitrogen dioxide (maximum 1-hour mean)

Results for community receptors

The maximum 1-hour NO_2 concentrations at the 42 community receptors in the with-project and cumulative scenarios are shown in Figure 8-35. At all receptor locations the maximum concentration was below the NSW impact assessment criterion of 246 µg/m^3, and in most cases below 200 µg/m^3. Lower air quality standards than the one in NSW are in force in other countries. For example, New Zealand has a limit value of 200 µg/m^3 but with nine allowed exceedances per year. There were fewer than nine exceedances of the New Zealand standard at all receptors in all with-project and cumulative scenarios.

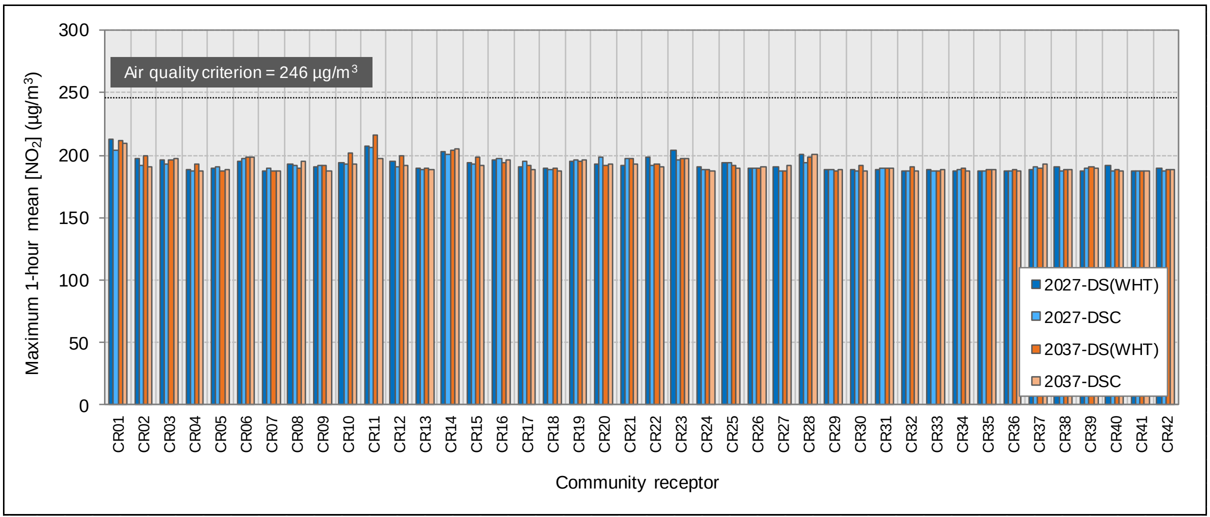


Figure 8-35 Maximum 1-hour mean NO_2 concentration at community receptors (with-project and cumulative scenarios)

The changes in the maximum 1-hour NO_2 concentration relative to the Do minimum scenarios are shown in Figure 8-36. Again, there was a mixture of small (relative to the NSW criterion) increases and decreases. There were some notable increases in the maximum concentration at a small number of receptors, but as observed above these did not result in any exceedances of the NSW criterion. There were notable reductions in the maximum NO_2 concentration at receptors CR06 and CR24.

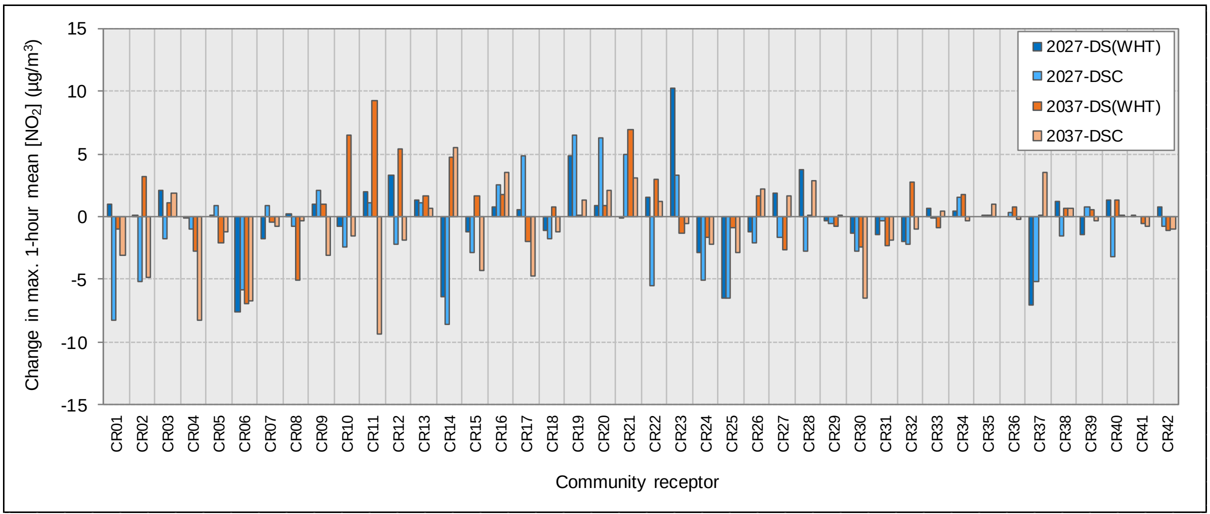


Figure 8-36 Change in maximum 1-hour mean NO_2 concentration at community receptors (with-project and cumulative scenarios, relative to Do minimum scenarios)

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, portal and ventilation 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 8-37.

Figure 8-37 Source contributions to maximum 1-hour mean NO_2 concentration at community receptors (with-project and cumulative scenarios) (portals include Sydney Harbour Tunnel and Eastern Distributor only)

As with the annual mean, the background was the most important source, with generally a small contribution from surface roads. The main exception was again receptor CR28, at which there was a relative large contribution (around 50 per cent) from surface roads in the with-project scenarios. 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, portals and ventilation outlets could have occurred during other hours of the year, but the total concentration would have been lower.

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 8-38. The contribution of surface roads and ventilation outlets are not shown separately in Figure 8-38; 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 some predicted exceedances of the NSW 1-hour NO_2 criterion (246 µg/m^3), both with and without the project. In the 2027-DM scenario the maximum concentration exceeded the NSW criterion at 201 receptors (0.6 per cent of all receptors), but with the introduction of the project in the 2027-DS(WHT) scenario, this decreased to 183 receptors (0.5 per cent). In the 2027-DSC scenario, the number decreased further (88 receptors, 0.2 per cent). In the 2037-DM scenario, there were exceedances at 234 receptors (0.7 per cent), decreasing to 170 receptors (0.5 per cent) in the 2037-DS(WHT) scenario. In the 2037-DSC scenario, the number decreased to 86 receptors (0.2 per cent). The majority of exceedances in all scenarios were located along Warringah Freeway (and the Upgrade in future years). There were also a small number of exceedances close to Victoria Road in Rozelle and along Manly Road at The Spit. These exceedances reduced even further in the cumulative scenarios when Beaches Link was introduced.

The ventilation outlets individual contribution to NO_2 cannot be calculated directly. However, given the maximum contribution of tunnel ventilation outlets to NO_X at any receptor was 60 µg/m^3 in the 2037-DSC scenario and this did not coincide with maximum contributions from surface roads, this would not lead to an exceedance of the NSW 1-hour NO_2 criterion.

Compliance with the New Zealand limit value of 200 µg/m^3 with nine allowed exceedances per year could not be determined for the RWR receptors, as time series were not available.

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 8-39. There was predicted to be an increase in the maximum 1-hour NO_2 concentration at between 30 per cent and 44 per cent of receptors, depending on the scenario. Conversely, there was a reduction in the maximum concentration at between around 56 per cent and 70 per cent of receptors. At the majority of receptors the change was relatively small; at more than 99 per cent of receptors the change in concentration (either an increase or a decrease) was less than 20 µg/m^3. Up to 0.7 per cent of receptors had a change in concentration (increase or decrease) of more than 20 µg/m^3 in the with-project and cumulative scenarios. The majority of the increases were located along the Warringah Freeway Upgrade, Falcon Street and Gore Hill Freeway. The majority of the decreases were also located along the Warringah Freeway Upgrade but further to the south and closer to the Harbour Bridge and also along Military Road to the east of the Upgrade. There were also some decreases in Rozelle along Victoria Road.

Contour plots – all sources

Contour plots of maximum 1-hour NO_2 concentrations in the 2037-DM and 2037-DSC scenarios are provided in Figure 8-40 and Figure 8-41 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 2037 cumulative scenario is given in Figure 8-42. The locations with the highest concentrations and largest changes in concentration are similar to this for annual mean NO_2.

The general spatial changes in pollutant concentrations are discussed further in Section 8.4.12.

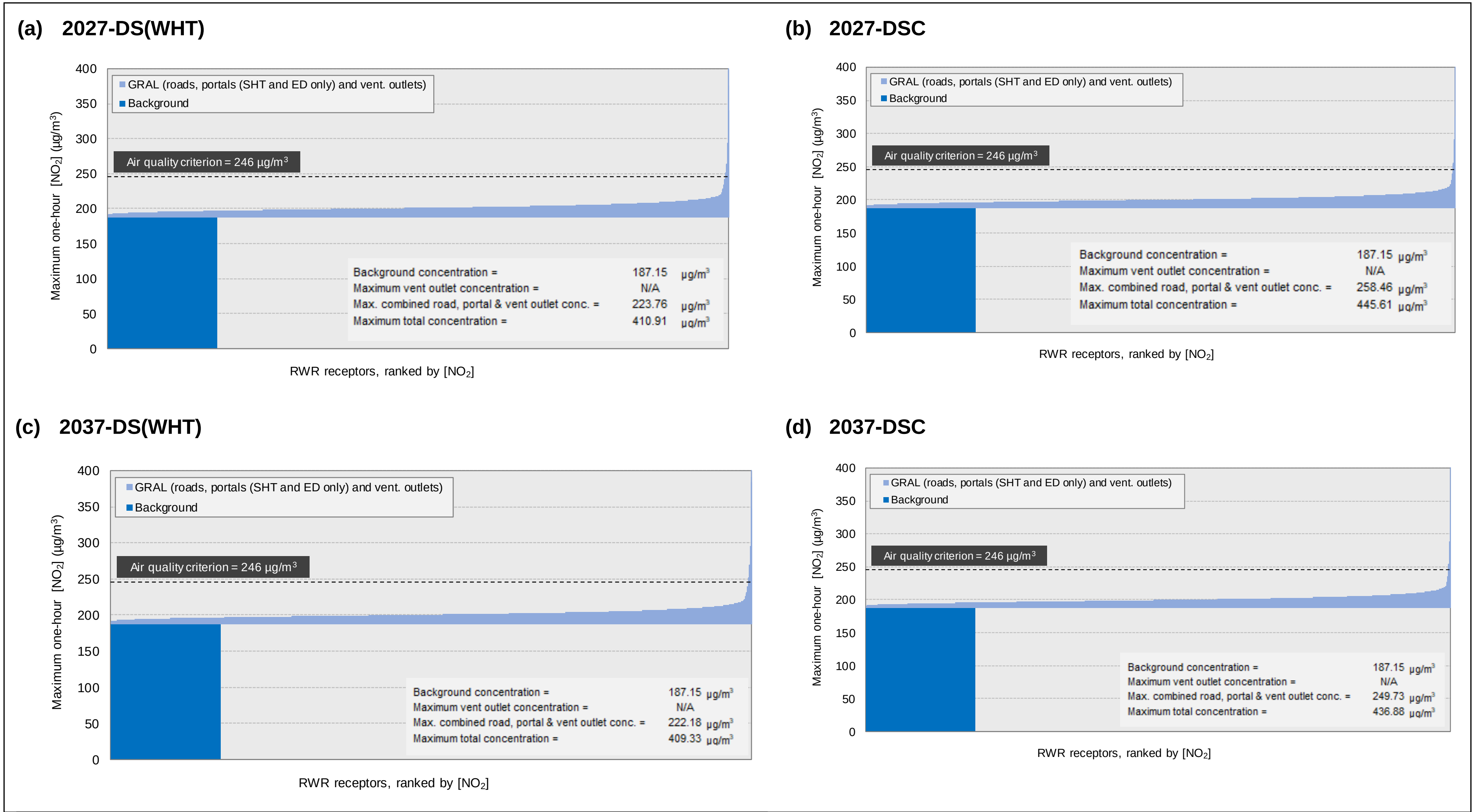


Figure 8-38 Source contributions to maximum 1-hour mean NO_2 concentration at RWR receptors (with-project and cumulative scenarios) (portals include Sydney Harbour Tunnel and Eastern Distributor only)

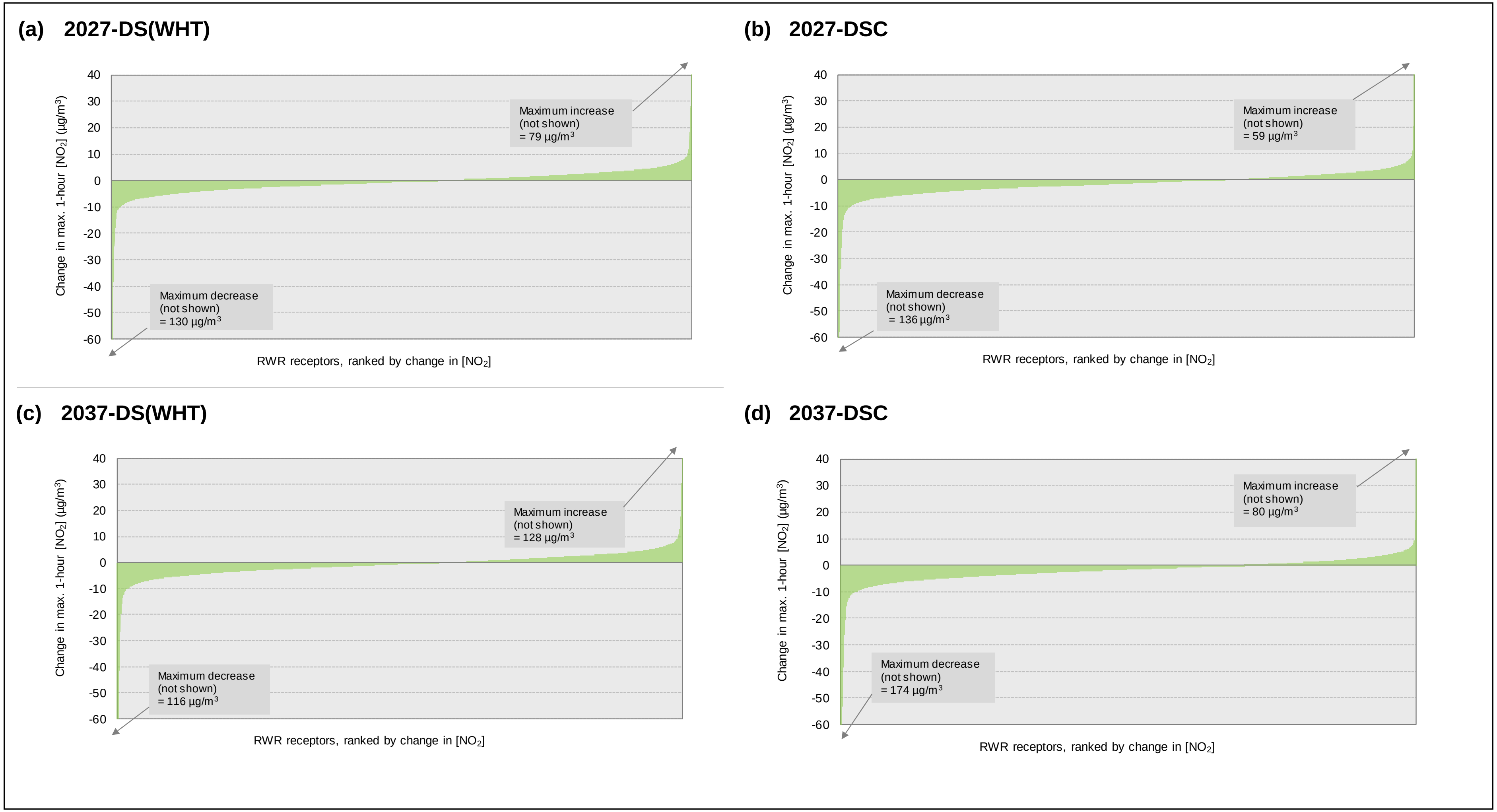


Figure 8-39 Change in maximum 1-hour mean NO_2 concentration at RWR receptors (with-project and cumulative scenarios, relative to Do minimum scenarios)

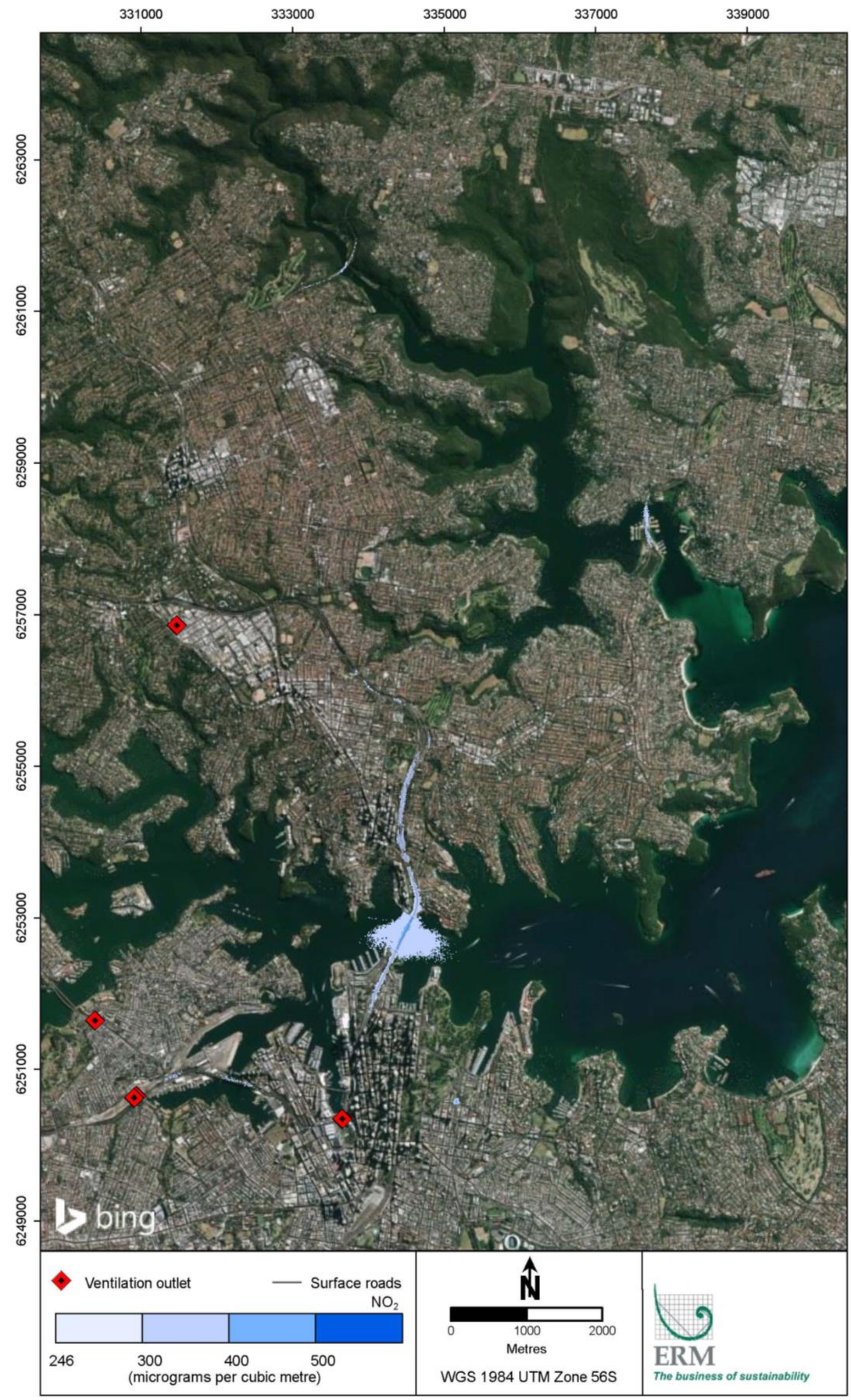


Figure 8-40 Contour plot of maximum 1-hour NO_2 concentration in the 2037 Do minimum scenario (2037-DM)

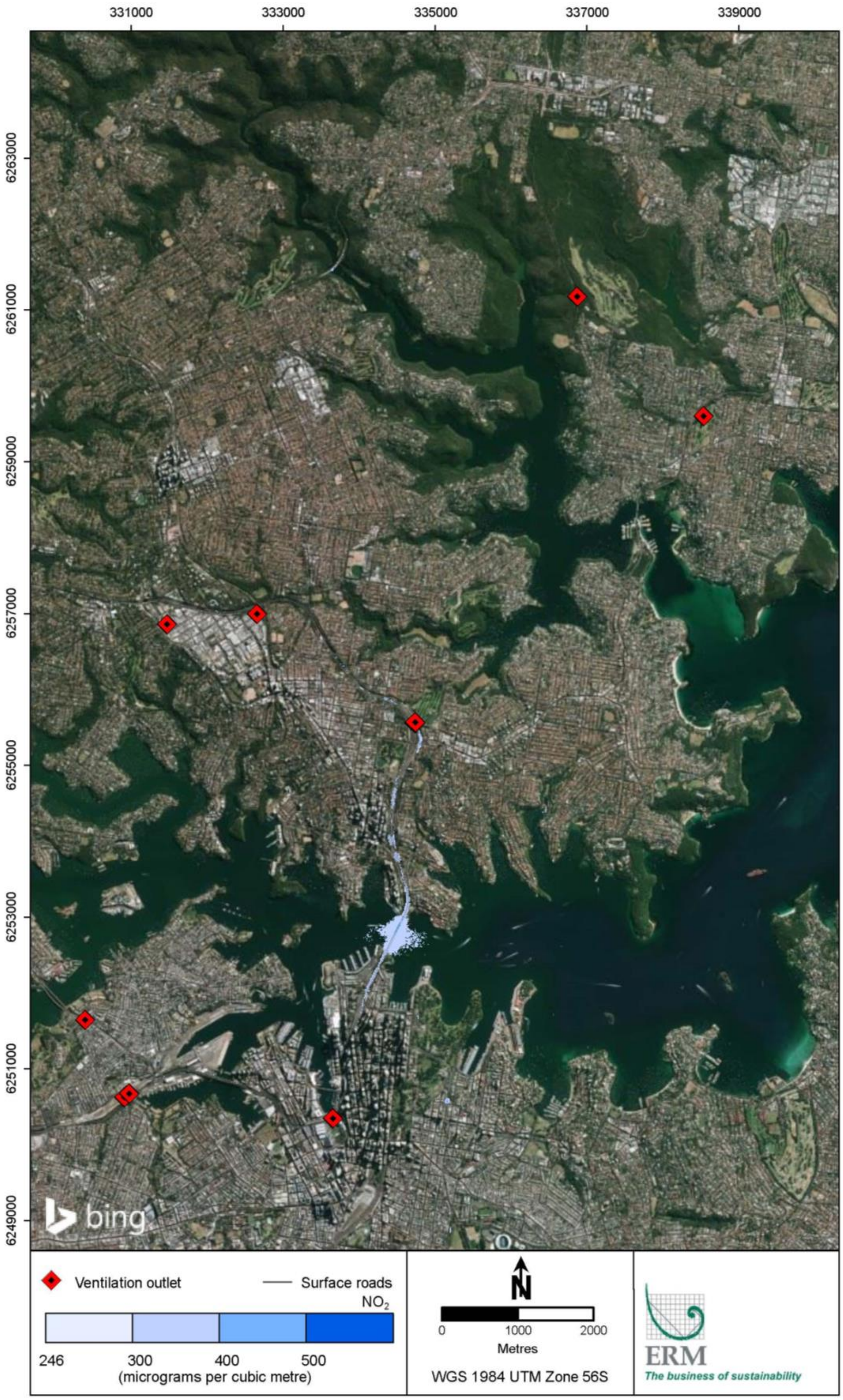


Figure 8-41 Contour plot of maximum 1-hour NO_2 concentration in the 2037 cumulative scenario (2037-DSC)

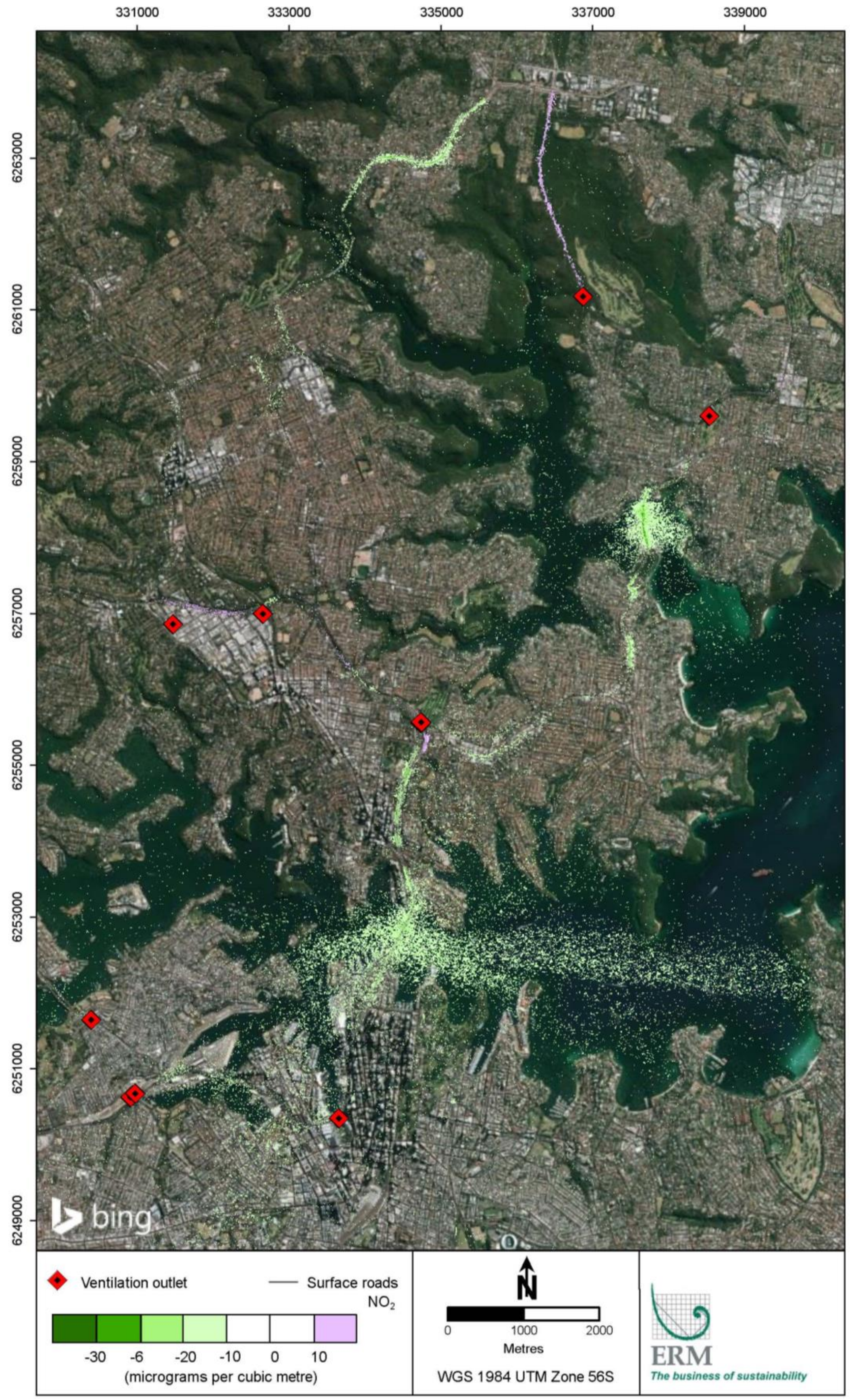


Figure 8-42 Contour plot of change in maximum 1-hour NO_2 concentration in the 2037 cumulative scenario (2037-DSC minus 2037-DM)

PM_{10} (annual mean)

Results for community receptors

The annual mean PM_{10} concentrations at community receptors are shown in Figure 8-43. These were all below the NSW impact assessment criterion of 25 µg/m³. At all but two of the receptors the concentration was below 20 µg/m³; receptors CR01 (University of Notre Dame, Broadway) and CR28 (Peek A Boo Cottage, Seaforth) had concentrations that were slightly above 20 µg/m³. PM_{10} concentrations at these receptors – several of which are near busy roads in Sydney – were only slightly above the lowest PM_{10} standards in force in other countries (18 µg/m³ in Scotland).

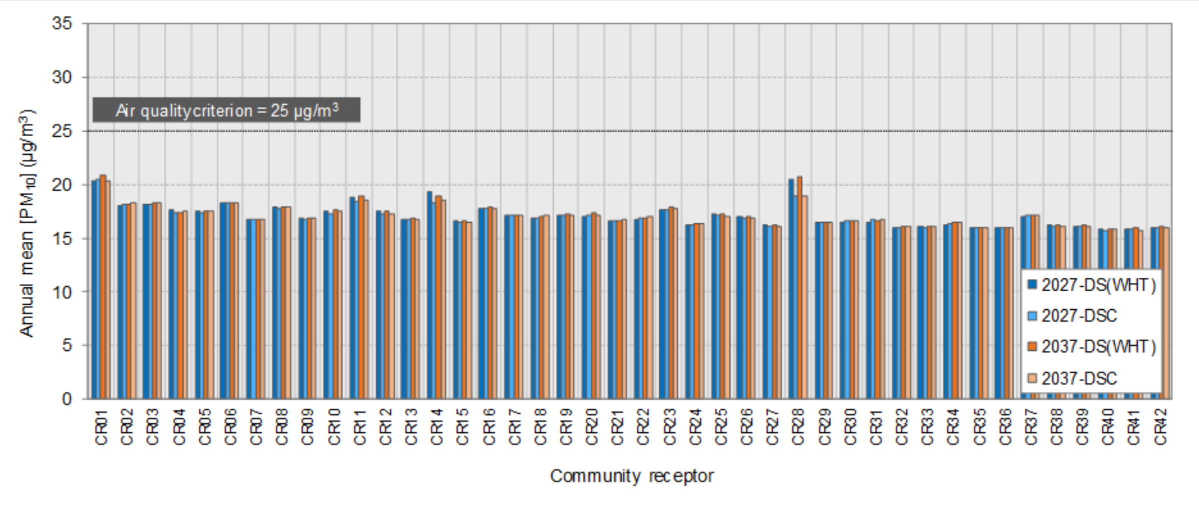


Figure 8-43 Annual mean PM_{10} concentration at community receptors (with-project and cumulative scenarios)

Figure 8-44 shows the changes in PM_{10} concentration. The largest increase was around 0.45 µg/m³ (1.8 per cent of the criterion) at receptor CR28 (Peek A Boo Cottage, Seaforth), and the largest decrease around 1.45 µg/m³. Concentrations decreased at most of the receptors.

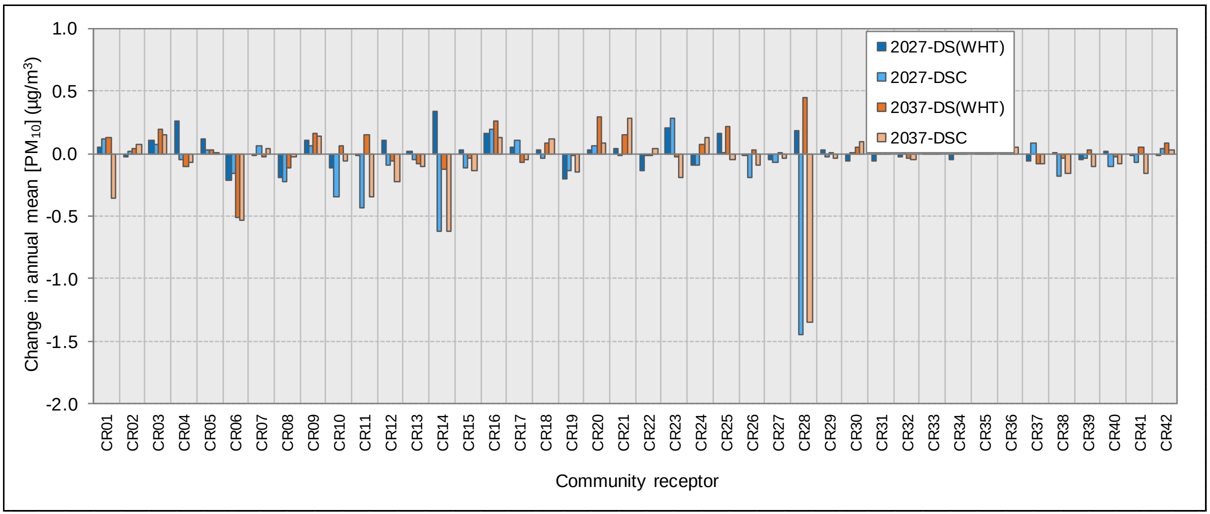


Figure 8-44 Change in annual mean PM_{10} concentration at community receptors (with-project and cumulative scenarios, relative to Do minimum scenarios)

Annual mean PM_{10} concentrations in the with-project and cumulative scenarios were again dominated by the background (Figure 8-45), with a small contribution from roads at most receptors (1-5 µg/m³) and a negligible contribution from tunnel ventilation outlets (less than around 0.2 µg/m³).

Figure 8-45 Source contributions to annual mean PM_{10} concentration at community receptors (with-project and cumulative scenarios) (portals include Sydney Harbour Tunnel and Eastern Distributor only)

Results for RWR receptors

The ranked annual mean PM_{10} concentrations at the RWR receptors are shown in Figure 8-46. The concentration at the majority of receptors was below 20 µg/m^3, and no receptors had a concentration 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 23.5 µg/m^3. The surface road contribution was up to 6.6 µg/m^3, with an average of 0.8–0.9 µg/m^3. The largest contribution from tunnel ventilation outlets was 0.3 µg/m^3 in the 2037-DSC scenario.

The changes in the annual mean PM_{10} concentration at the RWR receptors are shown, ranked by change in concentration, in Figure 8-47. There was an increase in concentration at 43-52 per cent of the receptors, depending on the scenario. At the majority of receptors the change was negligible, and where there was an increase this was greater than 0.5 µg/m^3 at up to 0.08 per cent of receptors in the with-project and cumulative scenarios. The increases were mainly in Rozelle and Artarmon. There was a decrease in concentration at 48-57 per cent of the receptors, depending on the scenario. The majority of these decreases were along Warringah Freeway (and the Warringah Freeway Upgrade), along Manly Road at The Spit and in Rozelle mainly along Victoria Road.

Contour plots – all sources

The contour plots for annual mean PM_{10} in the 2027-DM and 2037-DSC scenarios are given in Figure 8-48 and Figure 8-49.

The spatial changes in pollutant concentrations are discussed further in Section 8.4.12.

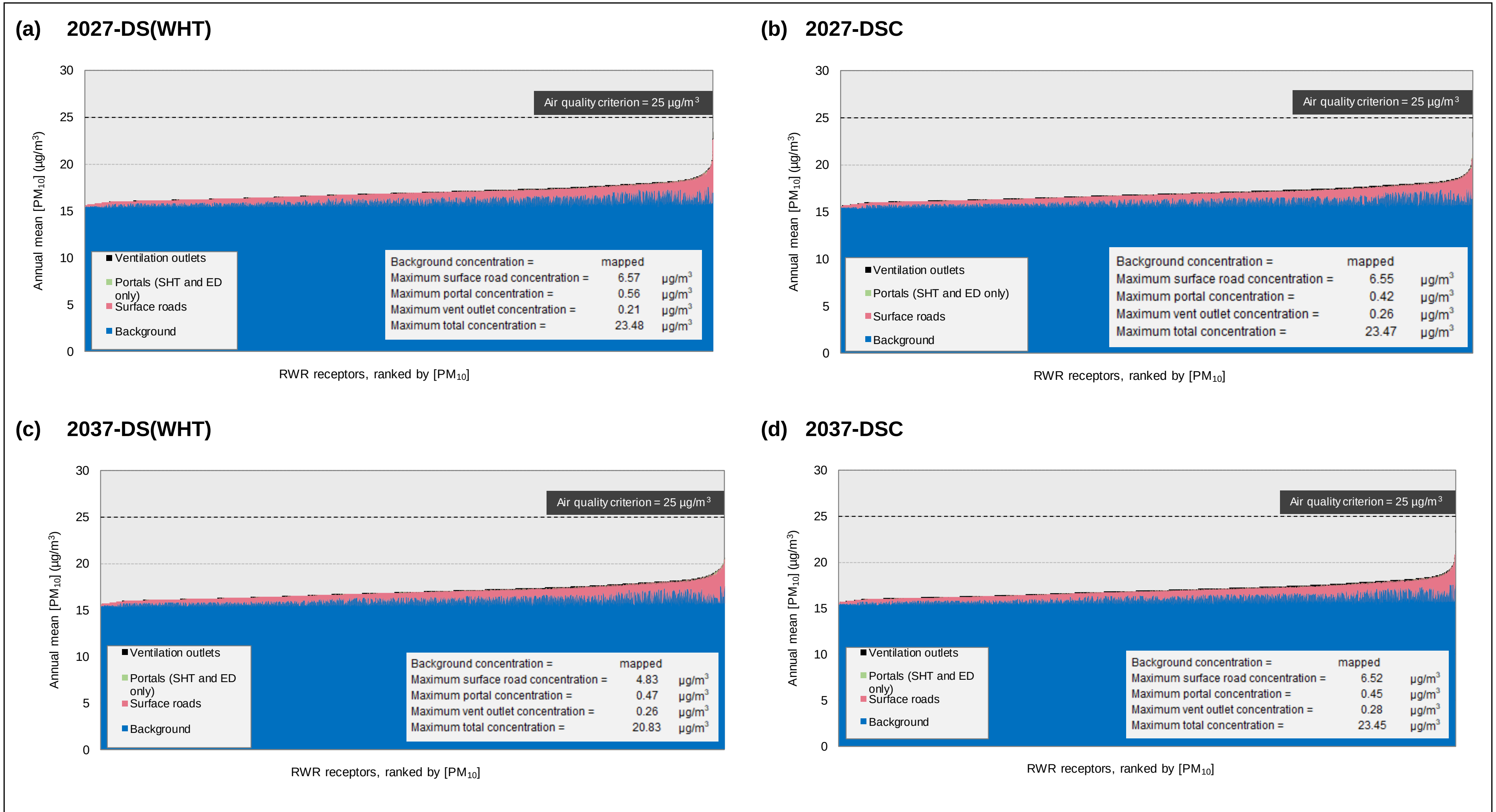


Figure 8-46 Source contributions to annual mean PM_{10} concentration at RWR receptors (with-project and cumulative scenarios) (portals include Sydney Harbour Tunnel and Eastern Distributor only)

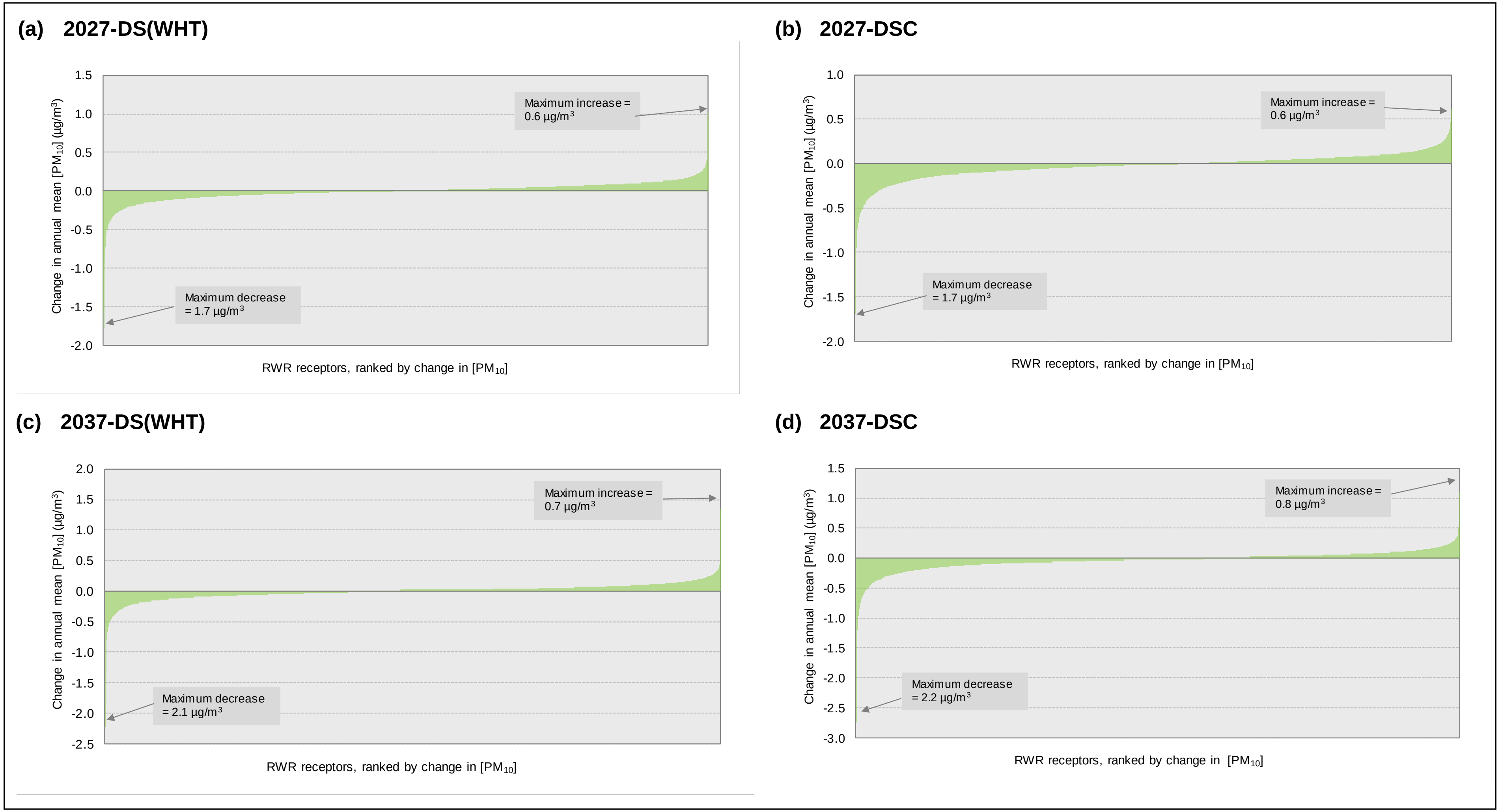


Figure 8-47 Changes in annual mean PM_{10} concentration at RWR receptors (with-project and cumulative scenarios, relative to Do minimum scenarios)

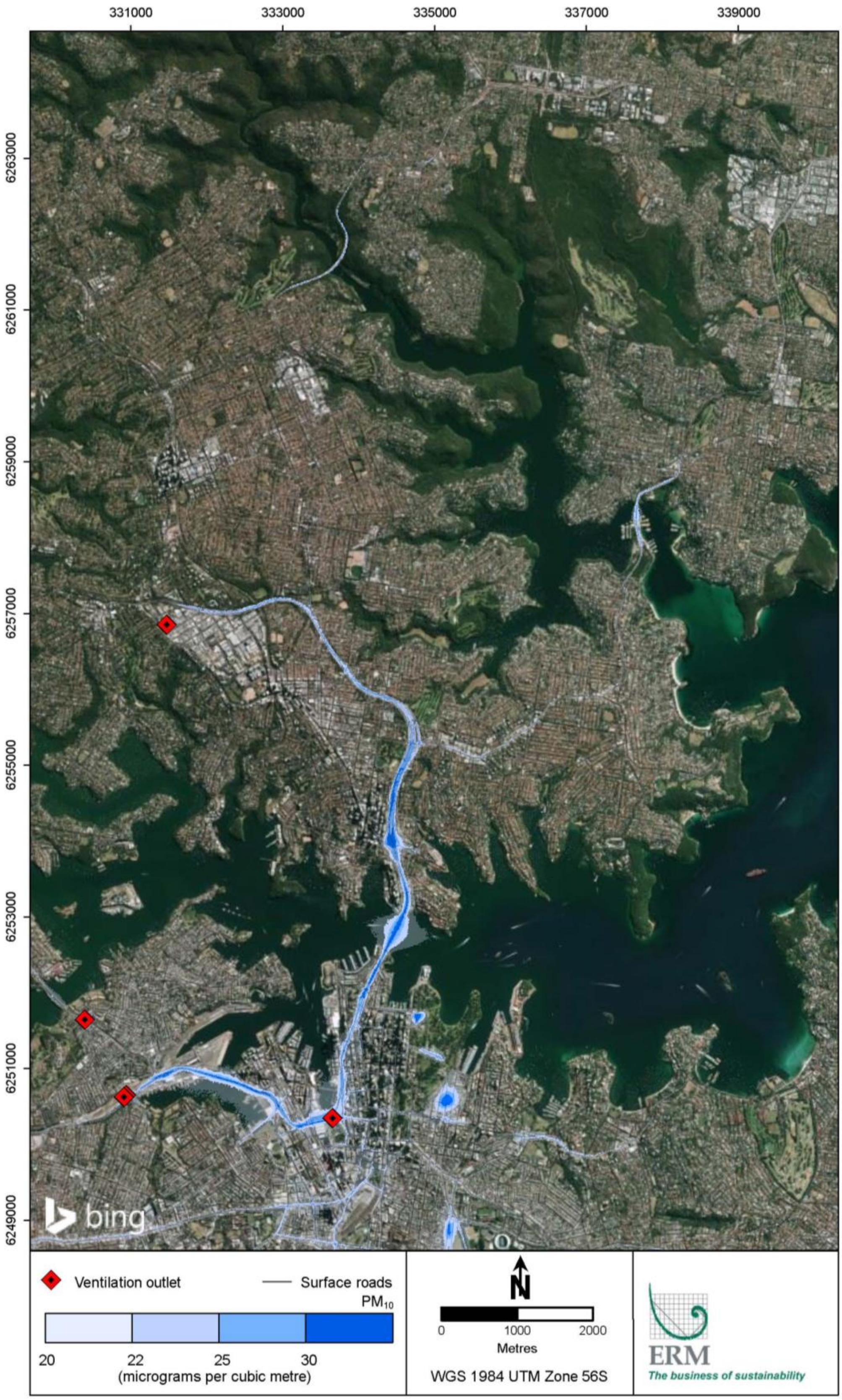


Figure 8-48 Contour plot of annual mean PM_{10} concentration in the 2037 Do minimum scenario (2037-DM)

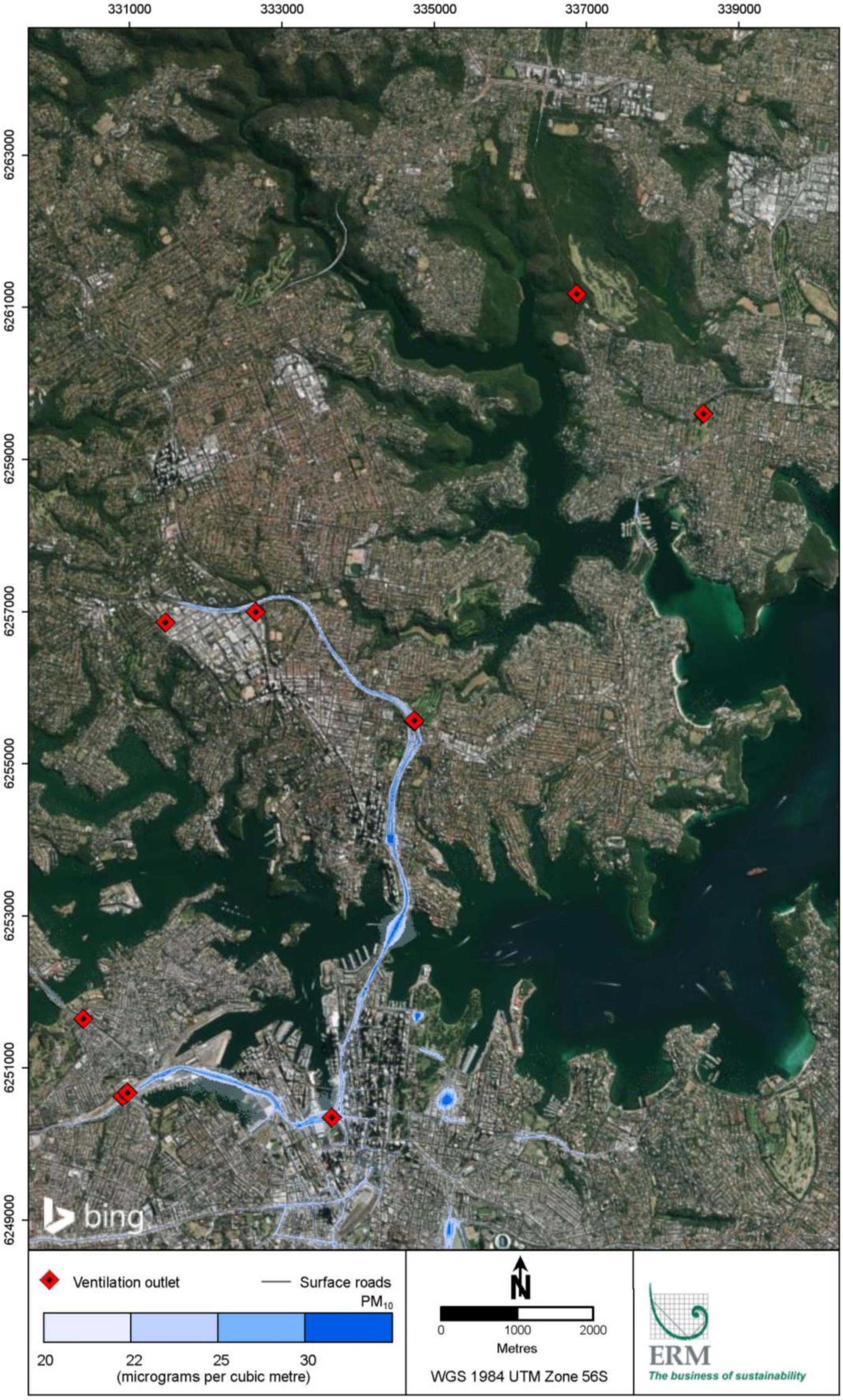


Figure 8-49 Contour plot of annual mean PM_{10} concentration in the 2037 cumulative scenario (2037-DSC)

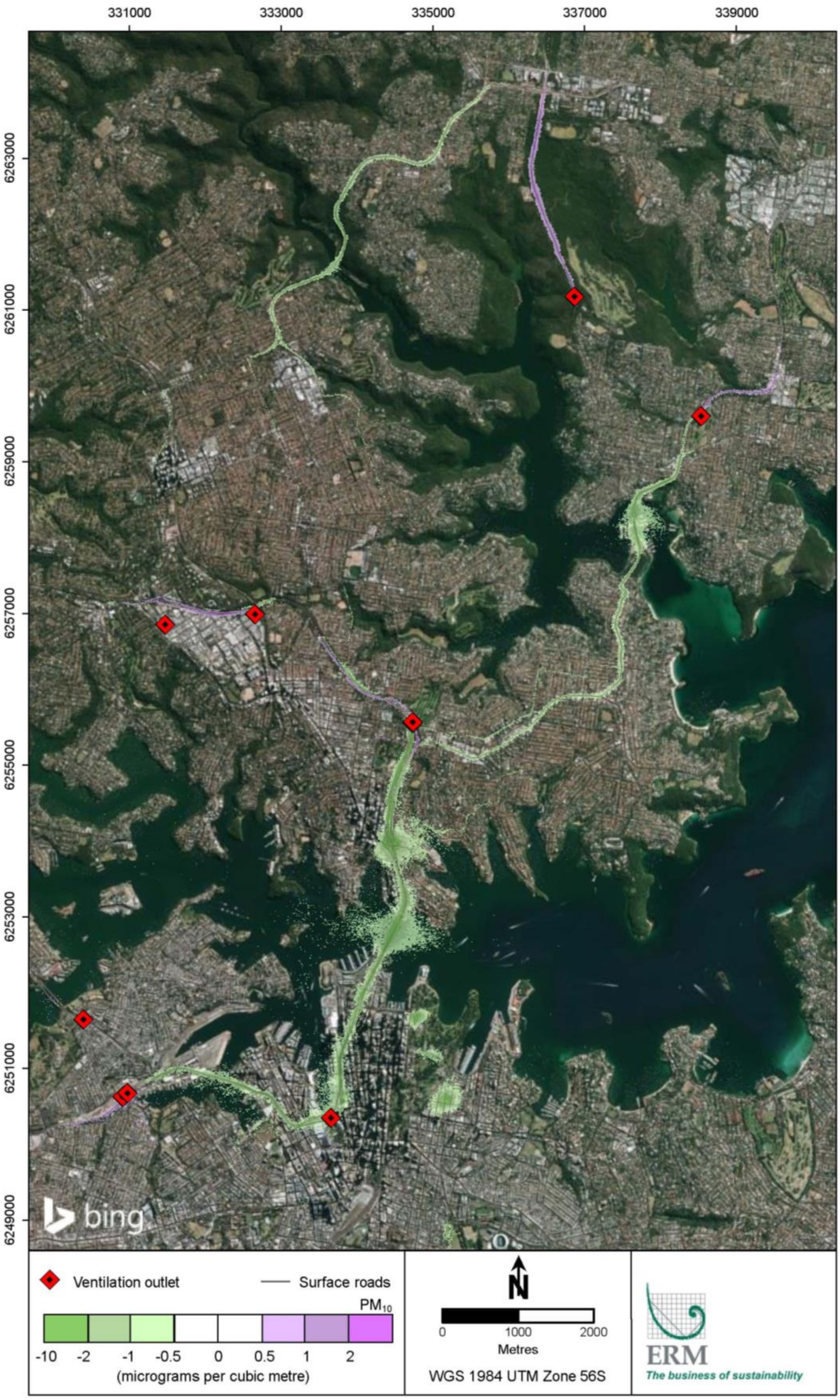


Figure 8-50 Contour plot of change in annual mean PM_{10} concentration in the 2037 cumulative scenario (2037-DSC minus 2037-DM)

PM_{10} (maximum 24-hour mean)

Results for community receptors

Figure 8-51 presents the maximum 24-hour mean PM_{10} concentrations at the community receptors. At all locations, and in all scenarios, the maximum concentration was above the NSW impact assessment criterion of 50 µg/m^3, which is also the most stringent standard in force internationally. The maximum concentration exceeded the criteria due to elevated background concentrations which occur during extreme events such as dust storms, bushfires and hazard reduction burns. The two highest 24-hour PM_{10} average concentrations recorded in 2016 were 121 µg/m^3 and 126 µg/m^3, recorded on consecutive days during a hazard reduction burn that affected much of Sydney in May. There were only five other days in 2016 which recorded greater than 50 µg/m^3.

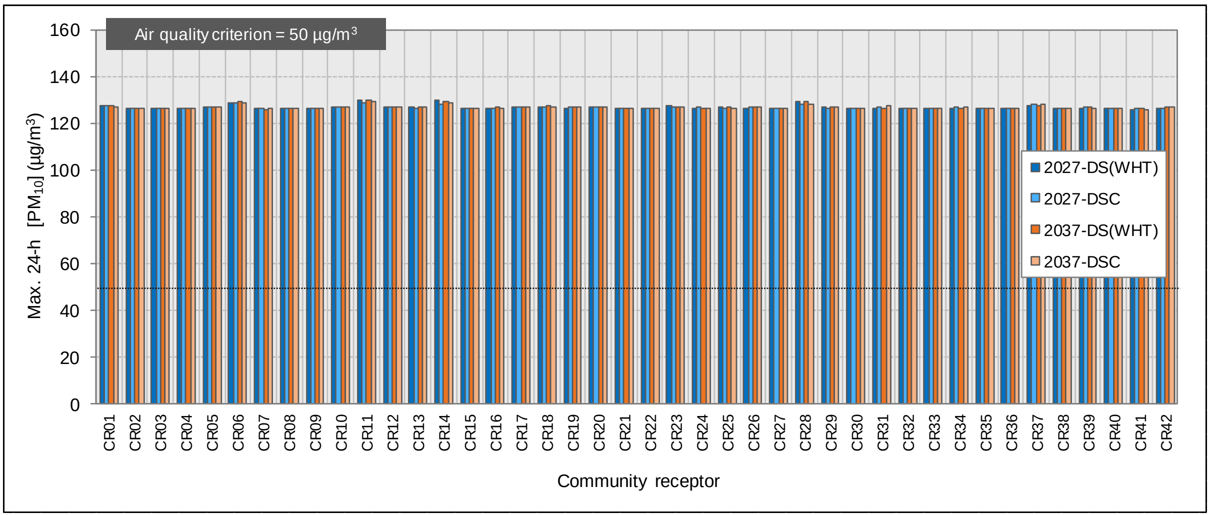


Figure 8-51 Maximum 24-hour mean PM_{10} concentration at community receptors (with-project and cumulative scenarios)

Figure 8-52 shows the changes in concentration in the with-project and cumulative scenarios relative to the Do minimum scenarios for the community receptors. The changes were mixed; there were no systematic changes by year or by scenario. At several receptors there was an increase in concentration, but this was less than 1 µg/m^3.

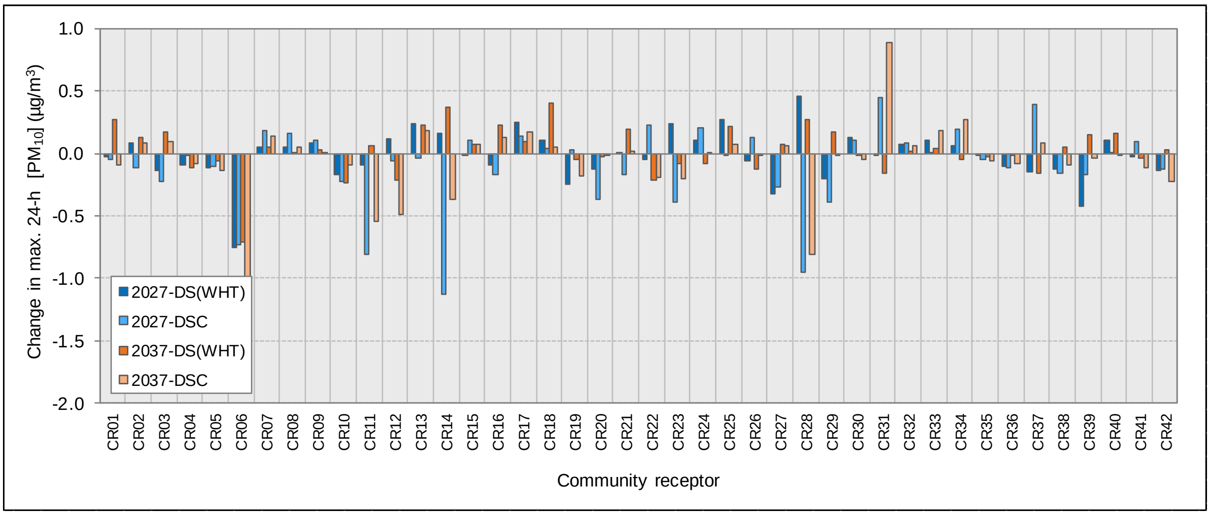


Figure 8-52 Change in maximum 24-hour mean PM_{10} concentration at community receptors (with-project and cumulative scenarios, relative to Do minimum scenarios)

Figure 8-53 demonstrates that the background was the largest contributor to peak 24-hour PM_{10} concentrations. At most community receptors the maximum total 24-hour concentration occurred on one day of the year (24 May), coinciding with the highest 24-hour background concentration in the synthetic PM_{10} profile (126.2 µg/m^3). The surface road contribution to the maximum 24-hour PM_{10} concentration at each community receptor was relatively small, less than 4 µg/m^3.

In the 2027-DS(WHT) and 2037-DS(WHT) scenarios the tunnel ventilation outlet contribution at all community receptors was negligible, with the largest value being slightly greater than 0.1 µg/m^3. The ventilation outlet contributions were slightly higher in some cases in the cumulative scenarios, although they generally remained small (less than 0.2 µg/m^3). However, one receptor (CR31, Punchinello Kindergarten) had a higher ventilation outlet contribution of around 0.6-0.75 µg/m^3 in the cumulative scenarios although this still only equated to around 1.5 per cent of the air quality criterion of 50 µg/m^3.

Results for RWR receptors

The ranked maximum 24-hour mean PM_{10} concentrations at the RWR receptors are shown in Figure 8-54. The results for the RWR receptors were highly dependent on the assumption for the background concentration. This was assumed to be the 98th percentile 24-hour concentrations in the synthetic background profile (i.e. 48.04 µg/m^3), and many of the receptors in the with-project and cumulative scenarios (60 to 67 per cent) was above the NSW impact assessment criterion of 50 µg/m^3. For further discussion of the background concentrations, see Annexure D.

The number of receptors with a concentration above the criterion decreased slightly as a result of the project, such as from 23,065 in the 2027-DM scenario to 22,509 in the 2027-DS(WHT) scenario and 21,239 in the 2027-DSC scenario. The corresponding numbers of receptors in the 2037 scenarios were 24,341, 23,841 and 22,501.

The contributions of surface roads, portals and ventilation outlets were not additive. For the with-project and cumulative scenarios, the maximum contribution of tunnel ventilation outlets at any receptor was between 1.3 µg/m^3 and 1.6 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 8-55. There was an increase in concentration at between 36 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 4.4 µg/m^3, and the largest predicted decrease was 7.8 µg/m^3. Where there was an increase, this was greater than 0.5 µg/m^3 (one per cent of the criterion) at less than ten per cent of receptors. The increases over 0.5 µg/m^3 were scattered fairly evenly along the main parts of the project and a larger number along the northern end of the Warringah Freeway Upgrade and at the Gore Hill Freeway.

Contour plots – all sources

The contour plots for maximum 24-hour average PM_{10} in the 2037-DM and 2037-DSC scenarios are given in Figure 8-56 and Figure 8-57. The changes in maximum 24-hour PM_{10} are shown in Figure 8-58.

The spatial changes in pollutant concentrations are discussed further in Section 8.4.12.

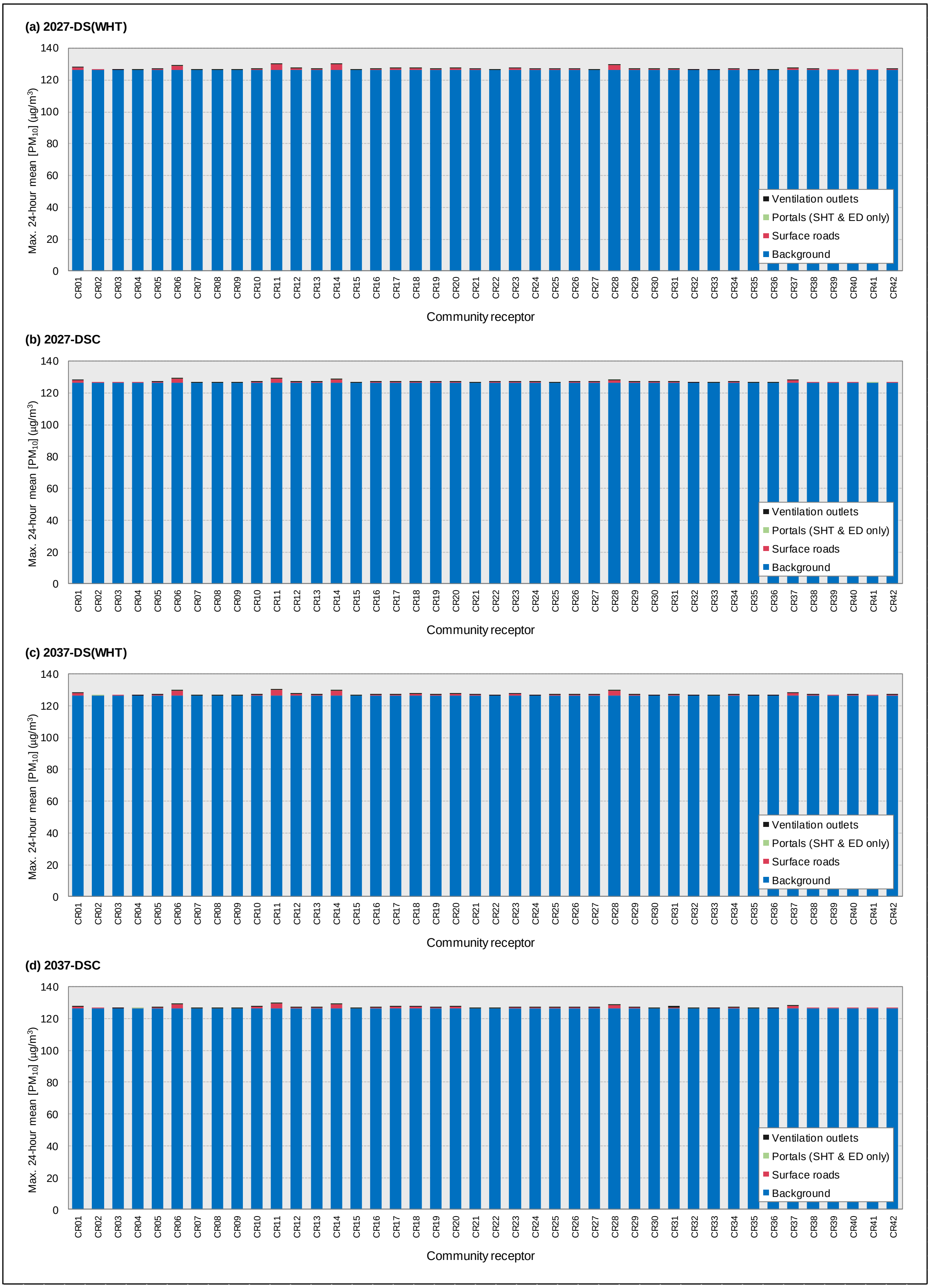


Figure 8-53 Source contributions to maximum 24-hour mean PM_{10} concentration at community receptors (with-project and cumulative scenarios) (portals include Sydney Harbour Tunnel and Eastern Distributor only)

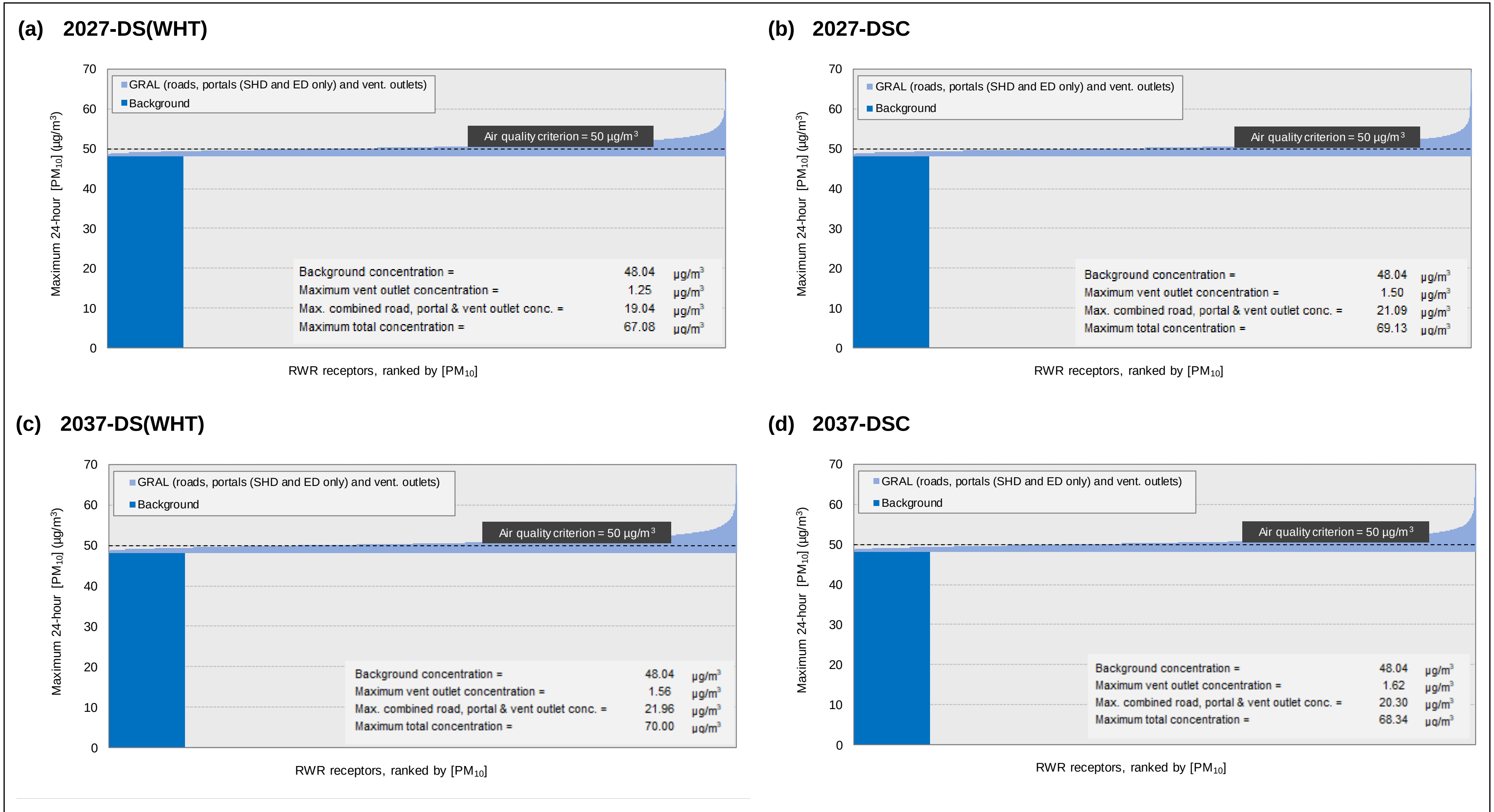


Figure 8-54 Source contributions to maximum 24-hour mean PM_{10} concentration at RWR receptors (with-project and cumulative scenarios) (portals include Sydney Harbour Tunnel and Eastern Distributor only)

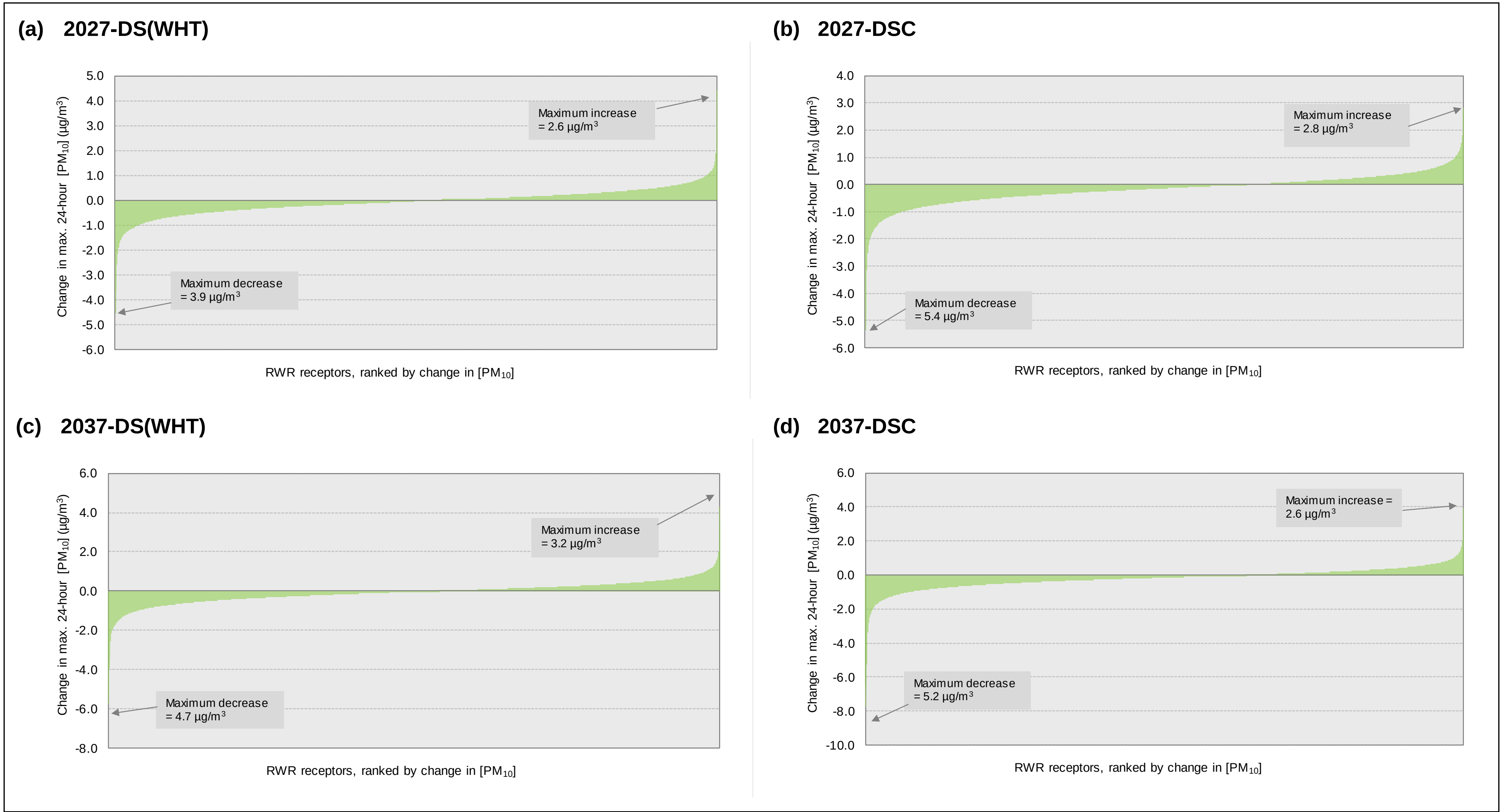


Figure 8-55 Change in maximum 24-hour mean PM_{10} concentration at RWR receptors (with-project and cumulative scenarios, relative to Do minimum scenarios)

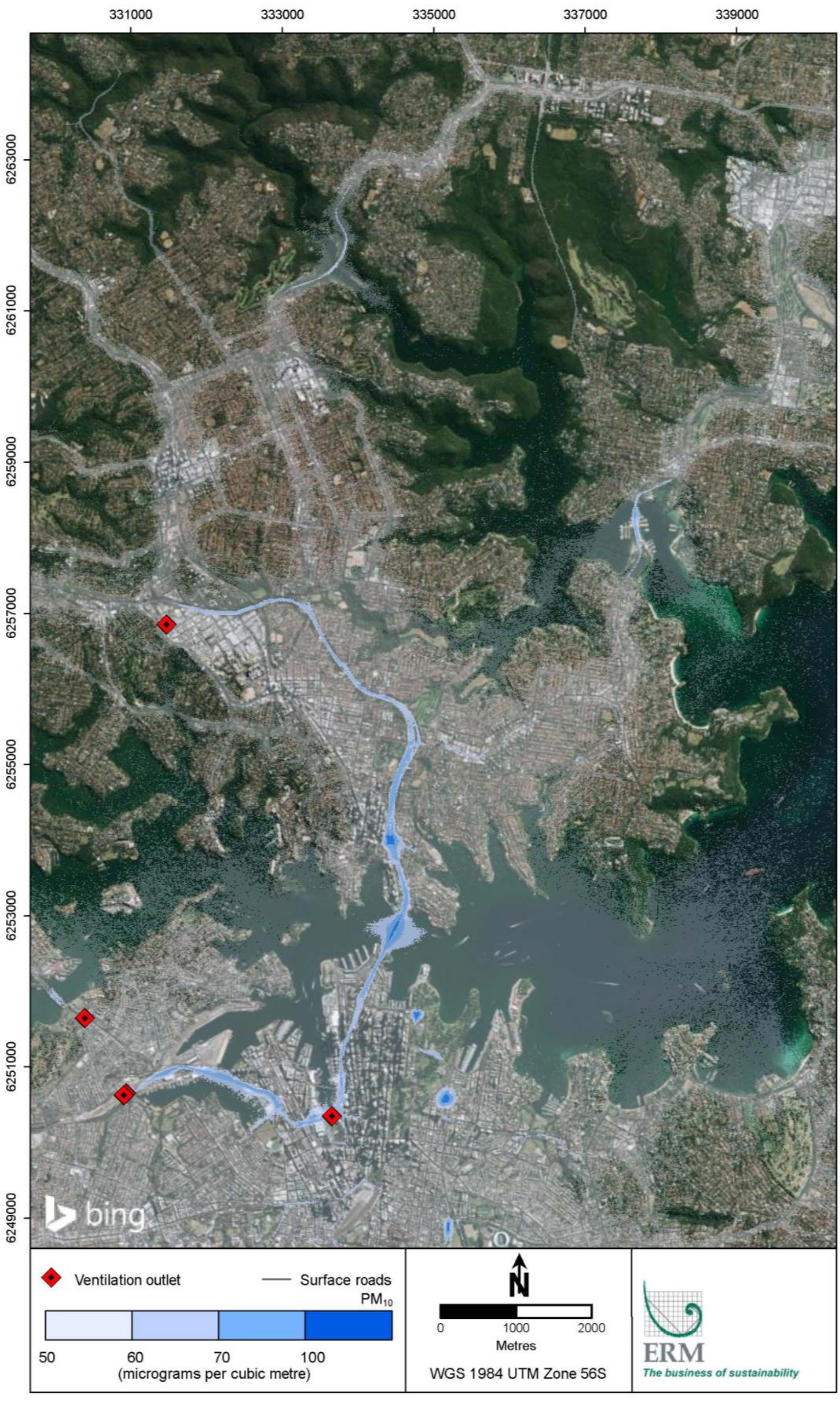


Figure 8-56 Contour plot of maximum 24-hour average PM_{10} concentration in the 2037 Do minimum scenario (2037-DM)

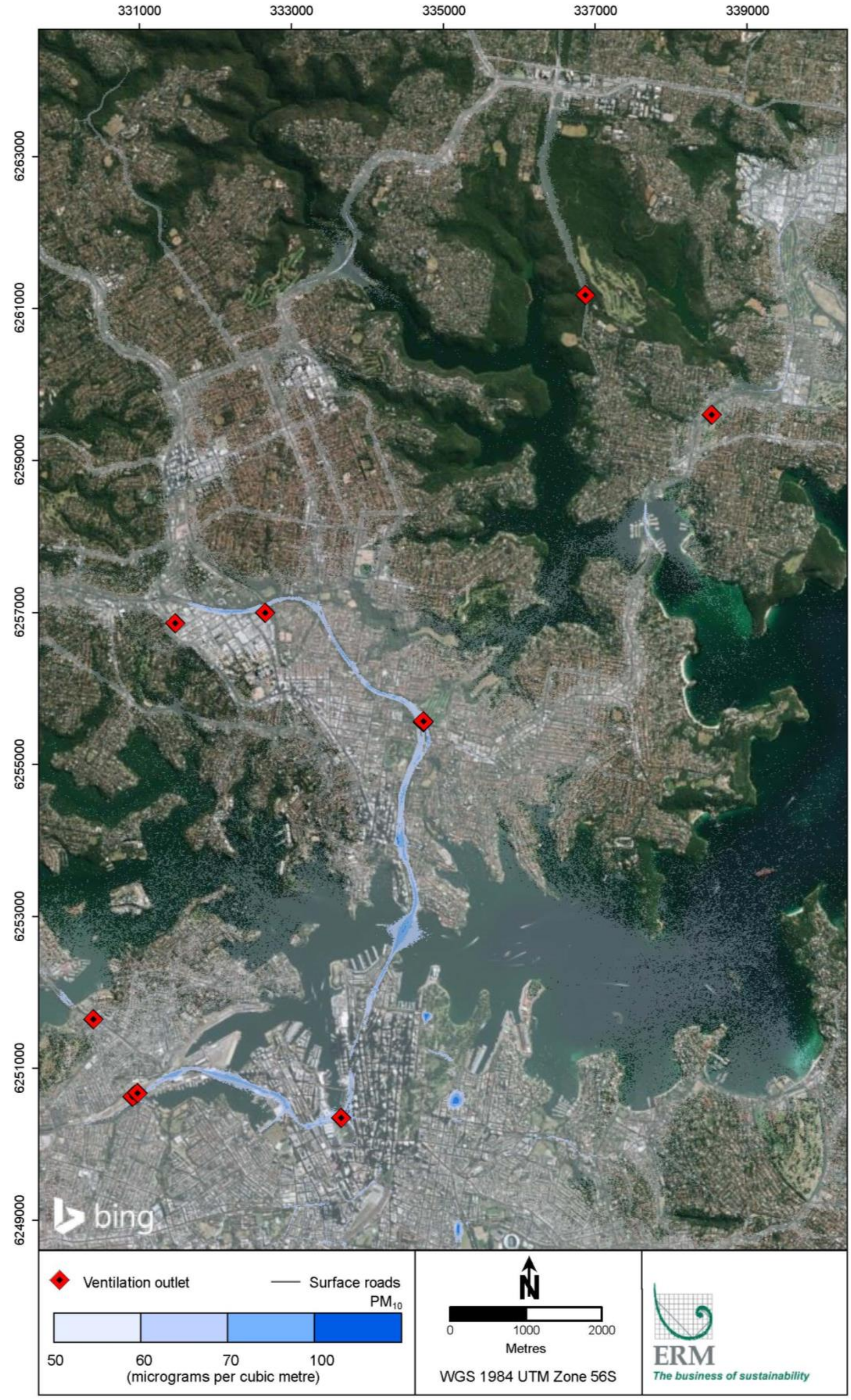


Figure 8-57 Contour plot of maximum 24-hour average PM_{10} concentration in the 2037 cumulative scenario (2037-DSC)

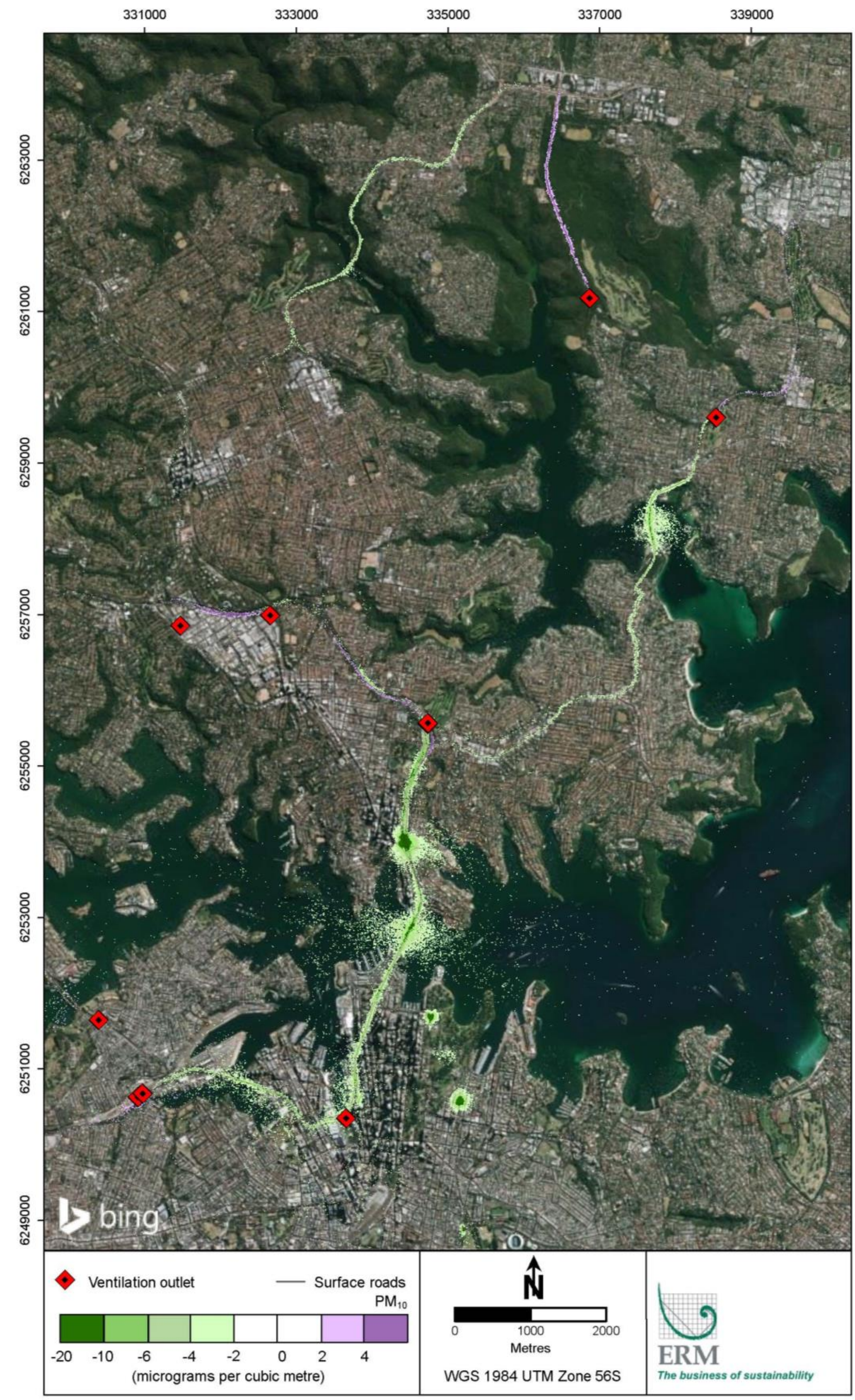


Figure 8-58 Contour plot of change in maximum 24-hour mean PM_{10} concentration in the 2037 cumulative scenario (2037-DSC minus 2037-DM)

$PM_{2.5}$ (annual mean)

Results for community receptors

Figure 8-59 presents the annual mean $PM_{2.5}$ concentrations at the community receptors. Given that the mapped background concentration at some community receptors (up to 7.9 µg/m^3) was already very close to the air quality criterion, it is unsurprising that there were some exceedances. These exceedances also occurred in the Do minimum scenarios. Clearly, there would also be exceedances of the NSW target of 7 µg/m^3. Internationally, there are no standards lower than 8 µg/m^3 for annual mean $PM_{2.5}$. The next lowest standard internationally is 12 µg/m^3 (California, Scotland).

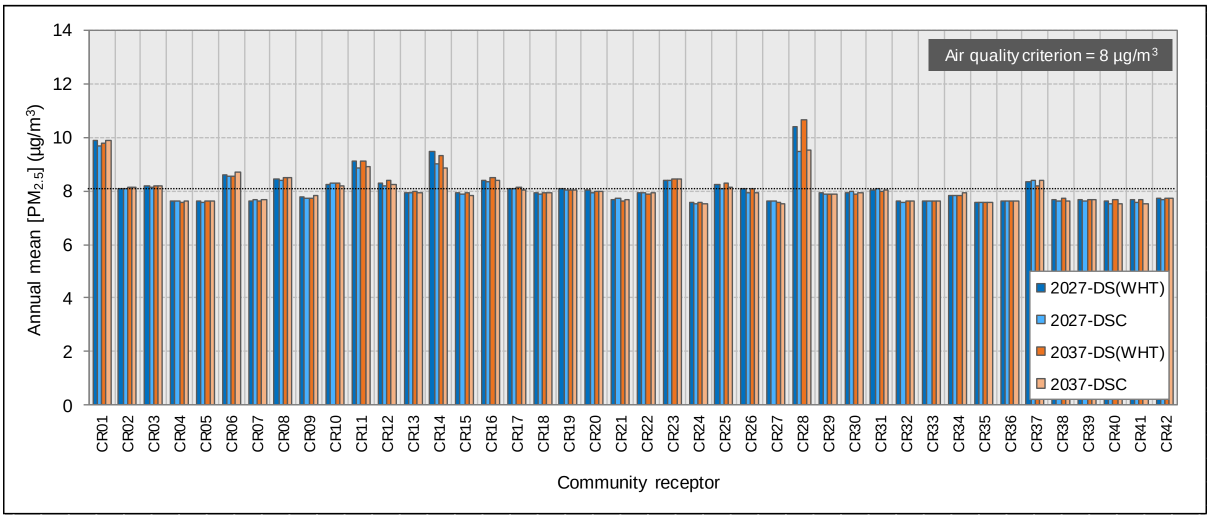


Figure 8-59 Annual mean $PM_{2.5}$ concentration at community receptors (with-project and cumulative scenarios)

Figure 8-60 presents the changes in annual mean $PM_{2.5}$ with the project and in the cumulative scenarios at the community receptors. Any increases were generally less than 0.2 µg/m^3; the largest increase (0.19 µg/m^3 at receptor CR16 and CR28 in the 2037-DS(WHT) scenario) equated to less than 2.5 per cent of the air quality criterion.

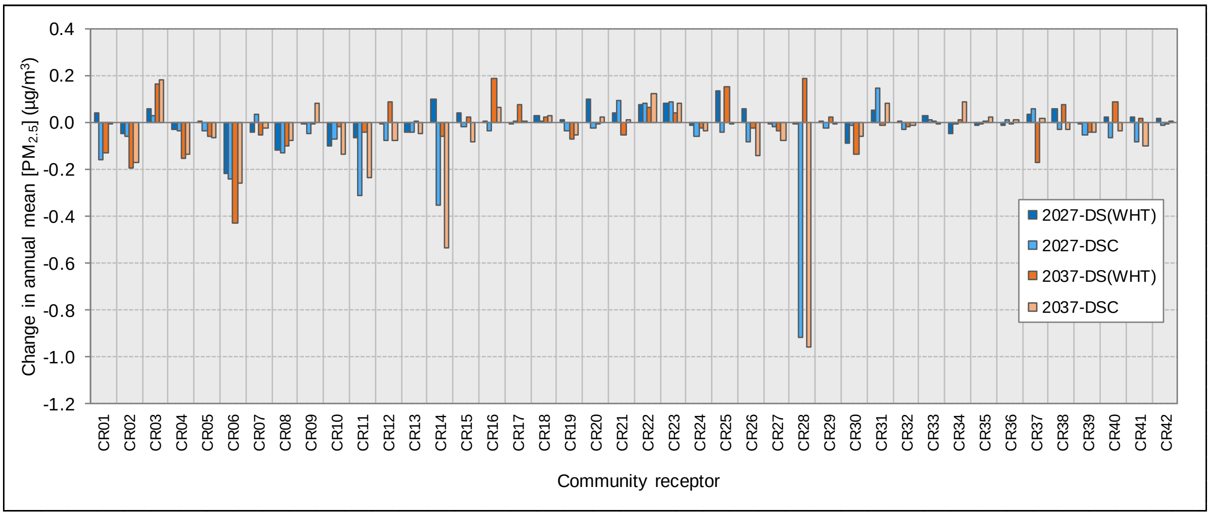


Figure 8-60 Change in annual mean $PM_{2.5}$ concentration at community receptors (with-project and cumulative scenarios, relative to Do minimum scenarios)

Figure 8-61 shows that concentrations were again dominated by the background contribution. The surface road contribution was between 0.2 µg/m^3 and 3.2 µg/m^3. The largest contribution from tunnel ventilation outlets at any receptor was just 0.10 µg/m^3.

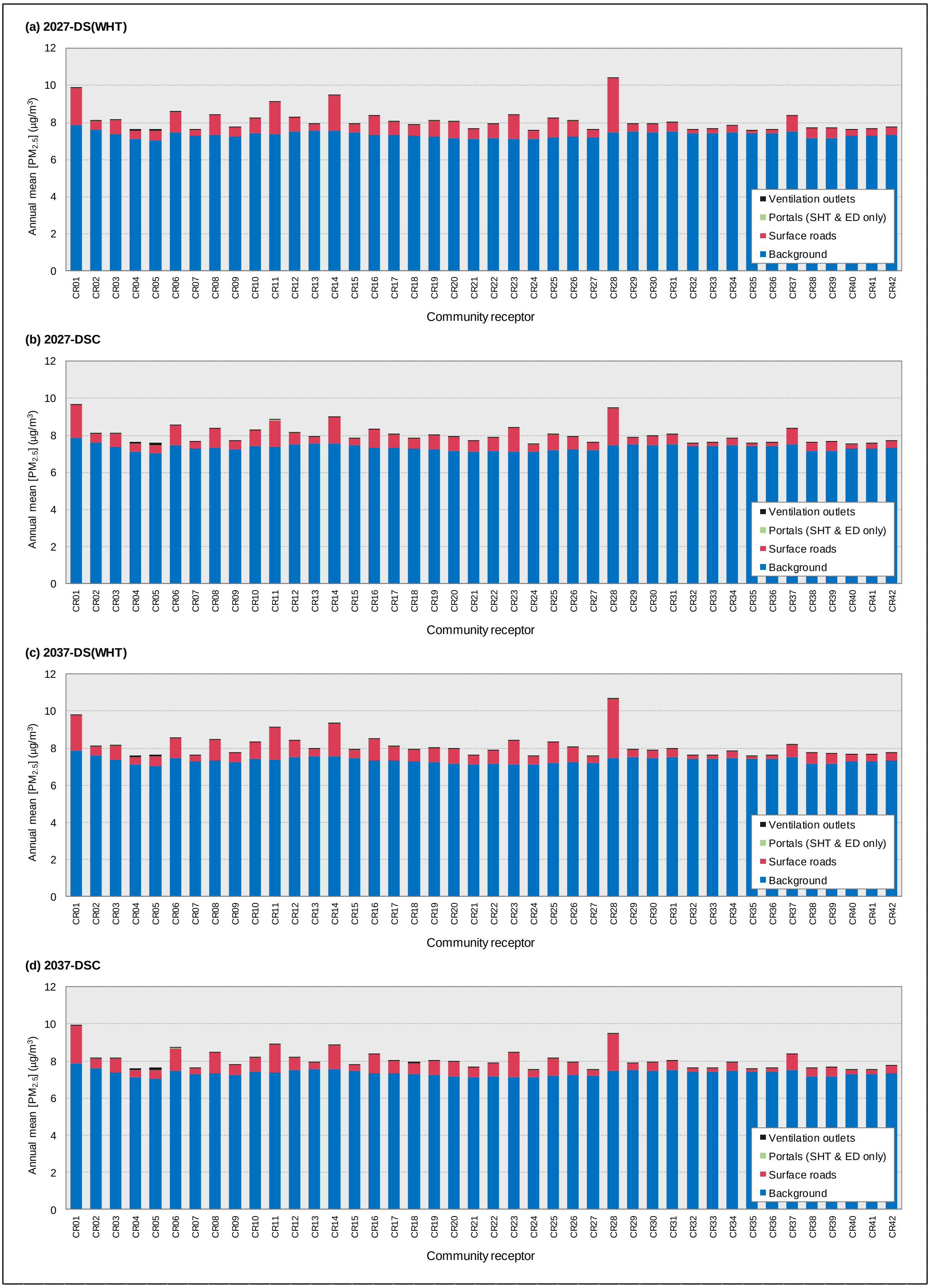


Figure 8-61 Source contributions to annual mean $PM_{2.5}$ concentration at community receptors (with-project and cumulative scenarios) (portals include Sydney Harbour Tunnel and Eastern Distributor only)

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 8-62, including the contributions of background, surface roads, portals and ventilation outlets. The highest concentration at any receptor was 11.9 µg/m^3 but, as with other pollutants and metrics, the highest values were only predicted for a small proportion of receptors. For example, in all with-project and cumulative scenarios no more than 10 receptors had a concentration above 11 µg/m^3. In the with-project and cumulative scenarios, the largest surface road contribution at any receptor was 4.1 µg/m^3. The largest contribution from tunnel ventilation outlets in these scenarios was 0.18 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 8-63. There was an increase in concentration at between 41 per cent and 77 per cent of the receptors, depending on the scenario. However, at most receptors the changes were very small. The largest predicted increase in concentration at any receptor as a result of the project was 0.6 µg/m^3, and the largest predicted decrease was 2.1 µg/m^3. Where there was an increase, this was greater than 0.1 µg/m^3 at four to five per cent of receptors depending on the scenario, with the exception of 2027-DSC which was 23 per cent of receptors. The increases were mainly in Rozelle and Gore Hill Freeway and with a small number of additional increases of 0.1 µg/m^3 at Manly Road at The Spit in the cumulative scenarios.

As noted in Section 5.4.3, 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 project, the acceptable value of $\Delta PM_{2.5}$ was determined to be 1.7 µg/m^3, as described in section 5.4.3. 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 8-64 (2037-DM) and Figure 8-65 (2037-DSC). The contour plot for the associated change in concentration in this cumulative scenario is shown in Figure 8-66.

The spatial changes in pollutant concentrations are discussed further in Section 8.4.12.

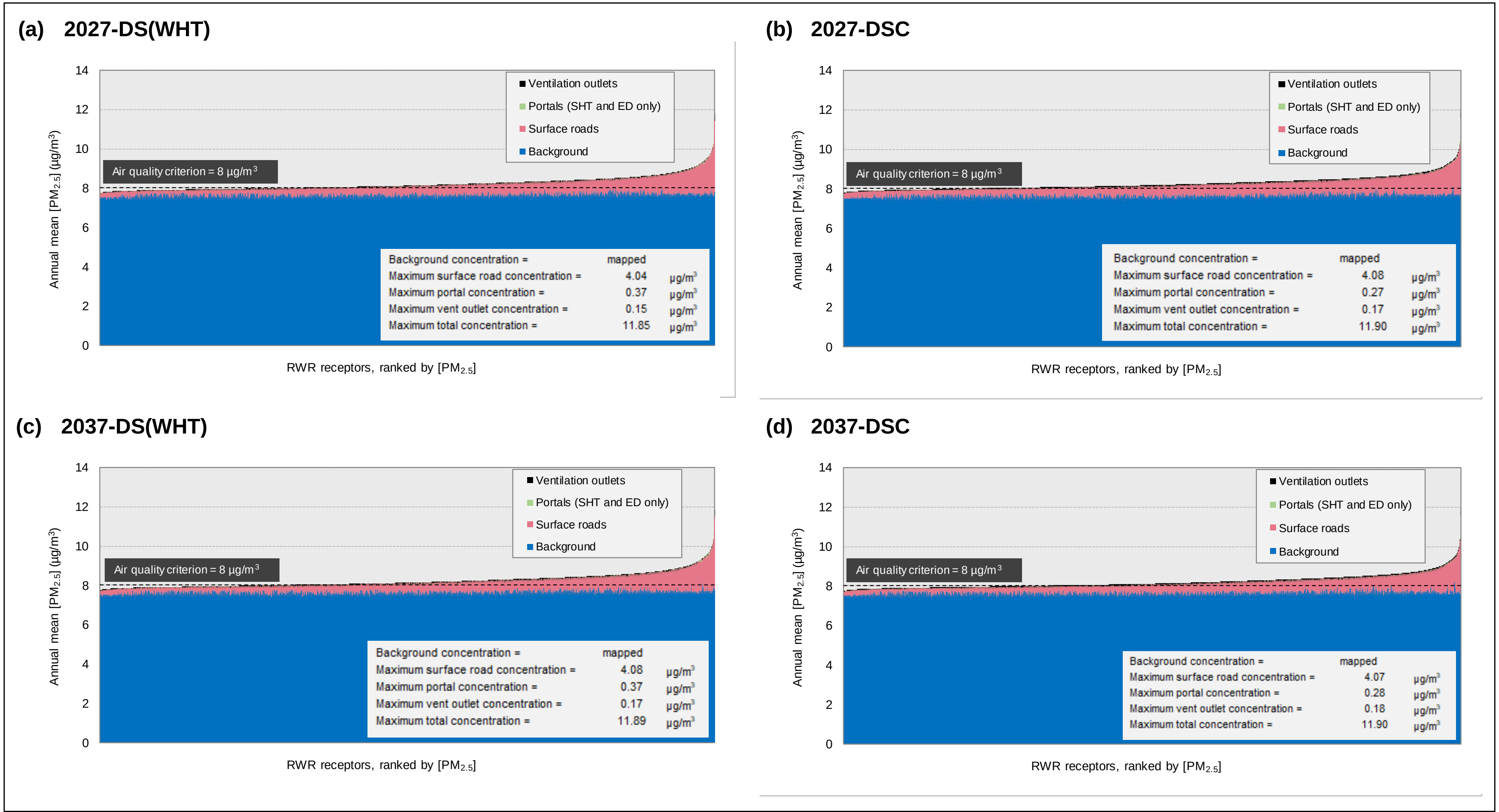


Figure 8-62 Source contributions to annual mean $PM_{2.5}$ concentration at RWR receptors (with-project and cumulative scenarios) (portals include Sydney Harbour Tunnel and Eastern Distributor only)

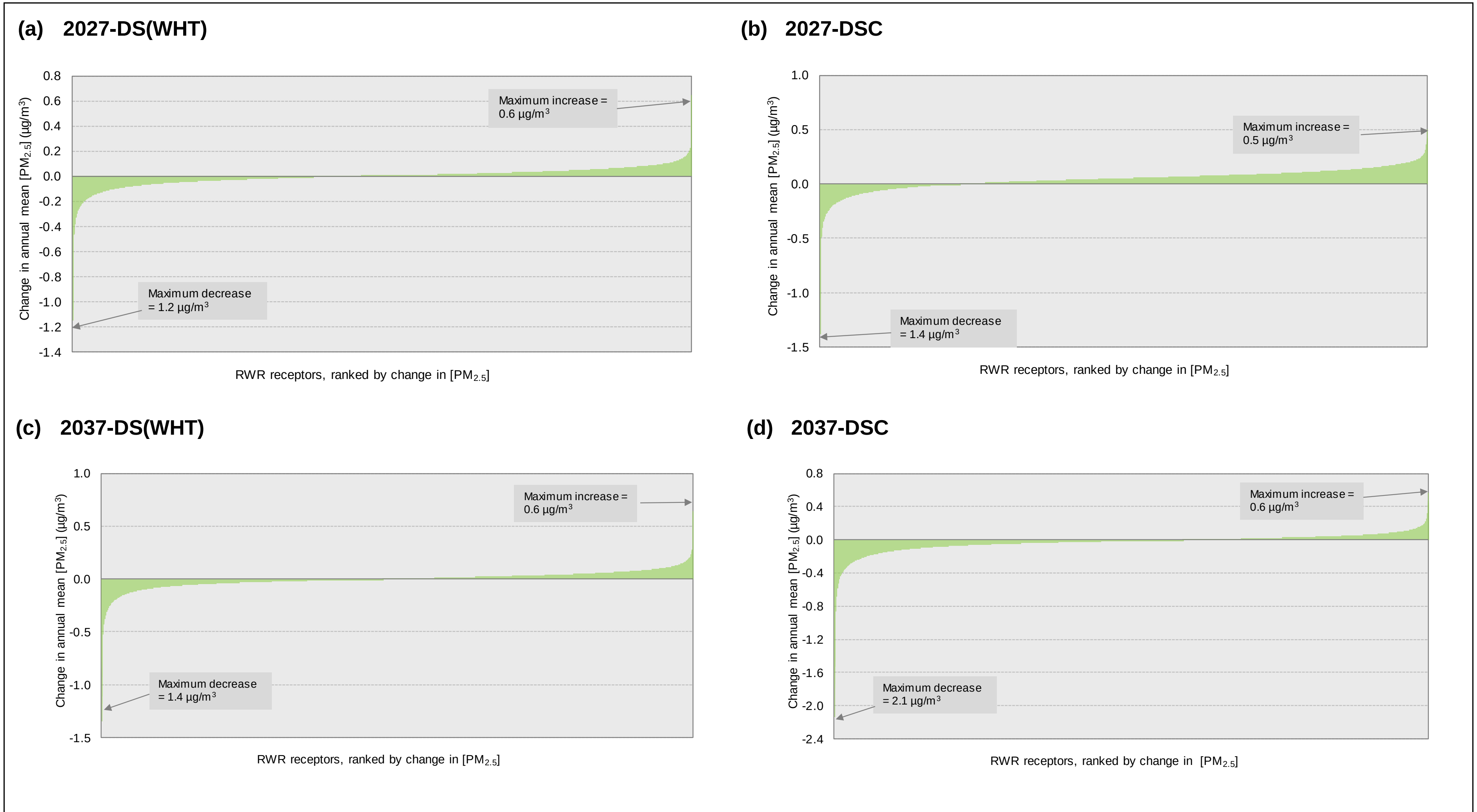


Figure 8-63 Change in annual mean $PM_{2.5}$ concentration at RWR receptors (with-project and cumulative scenarios, relative to Do minimum scenarios)

Figure 8-64 Contour plot of annual mean $PM_{2.5}$ concentration in the 2037 Do minimum scenario (2037-DM)

Figure 8-65 Contour plot of annual mean $PM_{2.5}$ concentration in the 2037 cumulative scenario (2037-DSC)

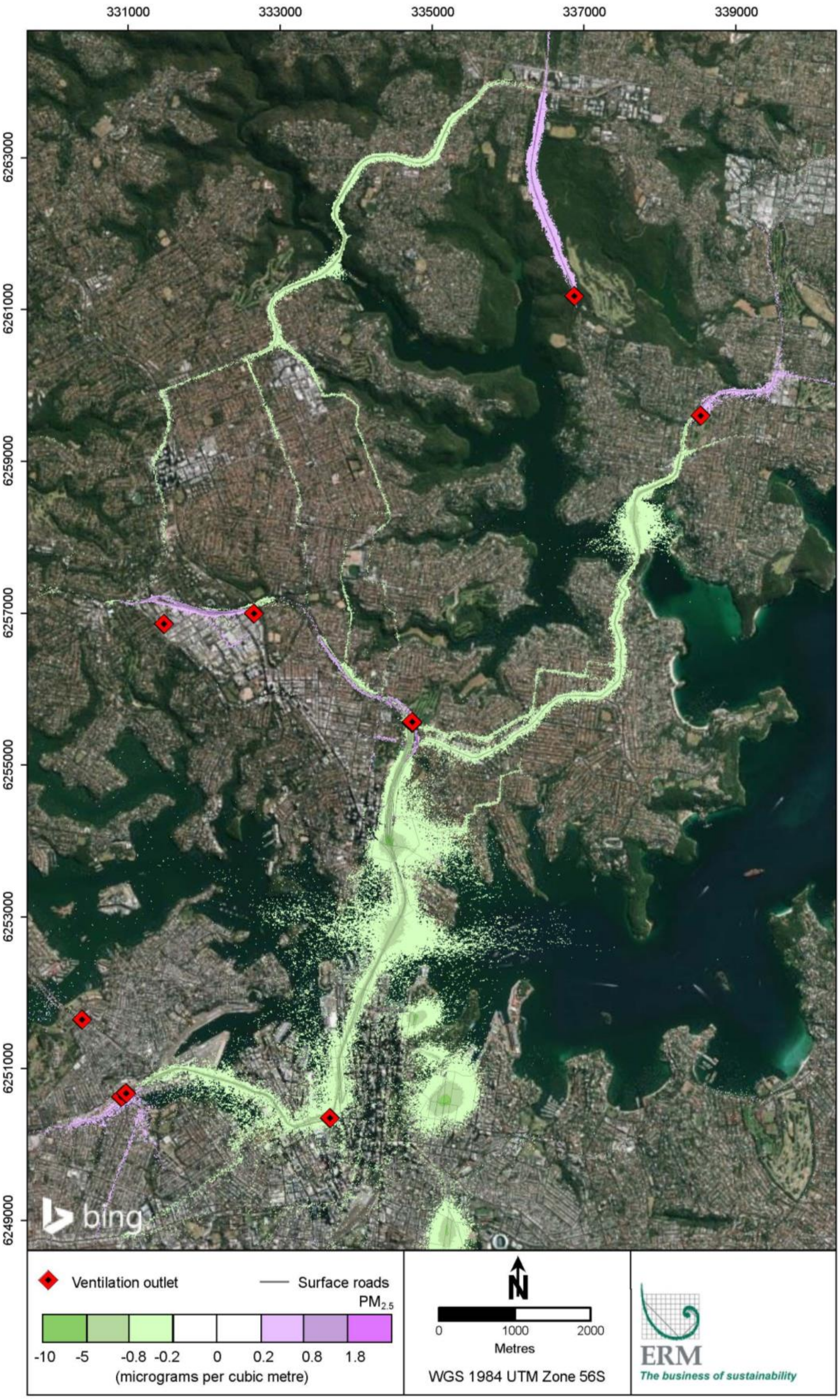


Figure 8-66 Contour plot of change in annual mean $PM_{2.5}$ concentration in the 2037 cumulative scenario (2037-DSC minus 2037-DM)

$PM_{2.5}$ (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 8-67. At all receptor locations, the maximum concentration was above the NSW impact assessment criterion of 25 µg/m^3, as 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. For example, the highest 24-hour background concentration at these receptors was already around 49.4 µg/m^3.

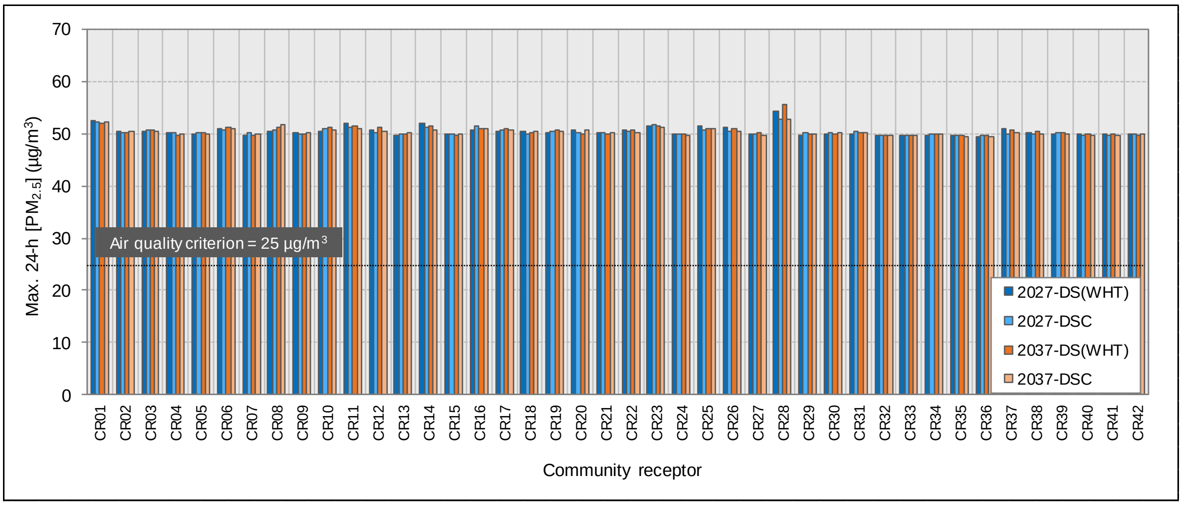


Figure 8-67 Maximum 24-hour $PM_{2.5}$ concentration at community receptors (with-project and cumulative scenarios)

Figure 8-68 presents the changes in maximum 24-hour $PM_{2.5}$ with the project and in the cumulative scenarios at the community receptors. Most of the increases in concentration were less than 1 µg/m^3. The largest increase (2.1 µg/m^3 at receptor CR28 in the 2037-DS(WHT) scenario) equated to eight per cent of the air quality criterion.

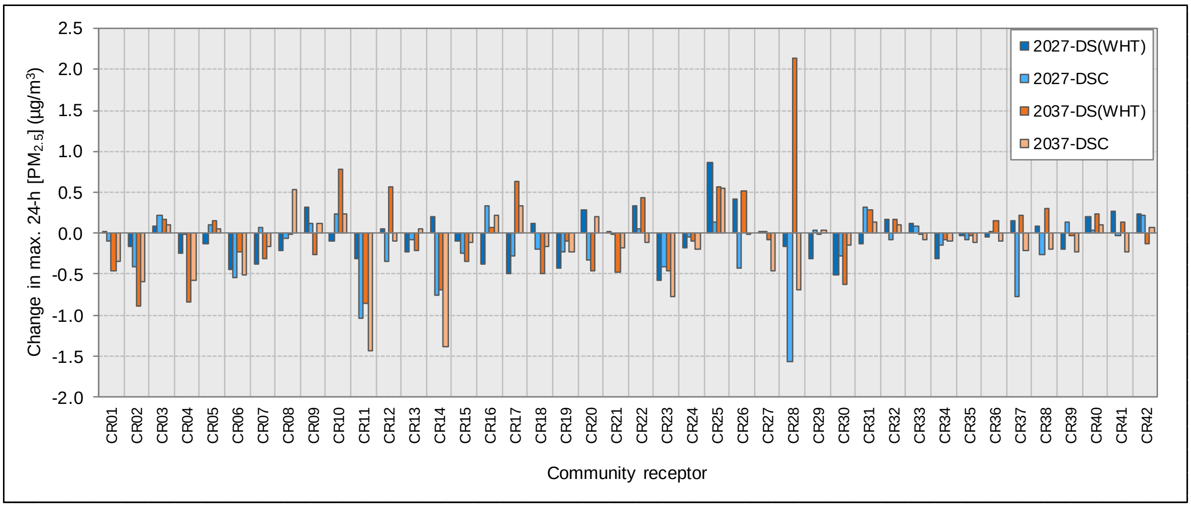


Figure 8-68 Change in maximum 24-hour $PM_{2.5}$ concentration at community receptors (with-project and cumulative scenarios, relative to Do minimum scenarios)

The combined non-background contributions to the maximum 24-hour $PM_{2.5}$ concentration at the community receptors were relatively small, as shown in Figure 8-69. On the days when the maximum total concentration occurred, the tunnel ventilation outlet contributions alone were small in all cases. At all community receptors, the maximum total 24-hour concentration occurred on one day which coincided with the highest 24-hour background concentration in the synthetic $PM_{2.5}$ profile (49.4 $\mu g/m^3$).

In the 'Do something' scenarios (ie with the operation of the project), the ventilation outlet contribution at all community receivers is predicted to be negligible, with the largest value being slightly greater than 0.05 $\mu g/m^3$. The outlet contributions are predicted to be slightly higher in the 'Do something cumulative' scenarios, although they would still be small, with the maximum outlet contribution of around 0.4 per cent of the air quality criterion at Mater Hospital – CR09 (0.07 – 0.1 µg/m3). The maximum outlet contribution at all other community receivers would be less than 0.5 per cent of the air quality criterion (less than 0.1 $\mu g/m^3$).

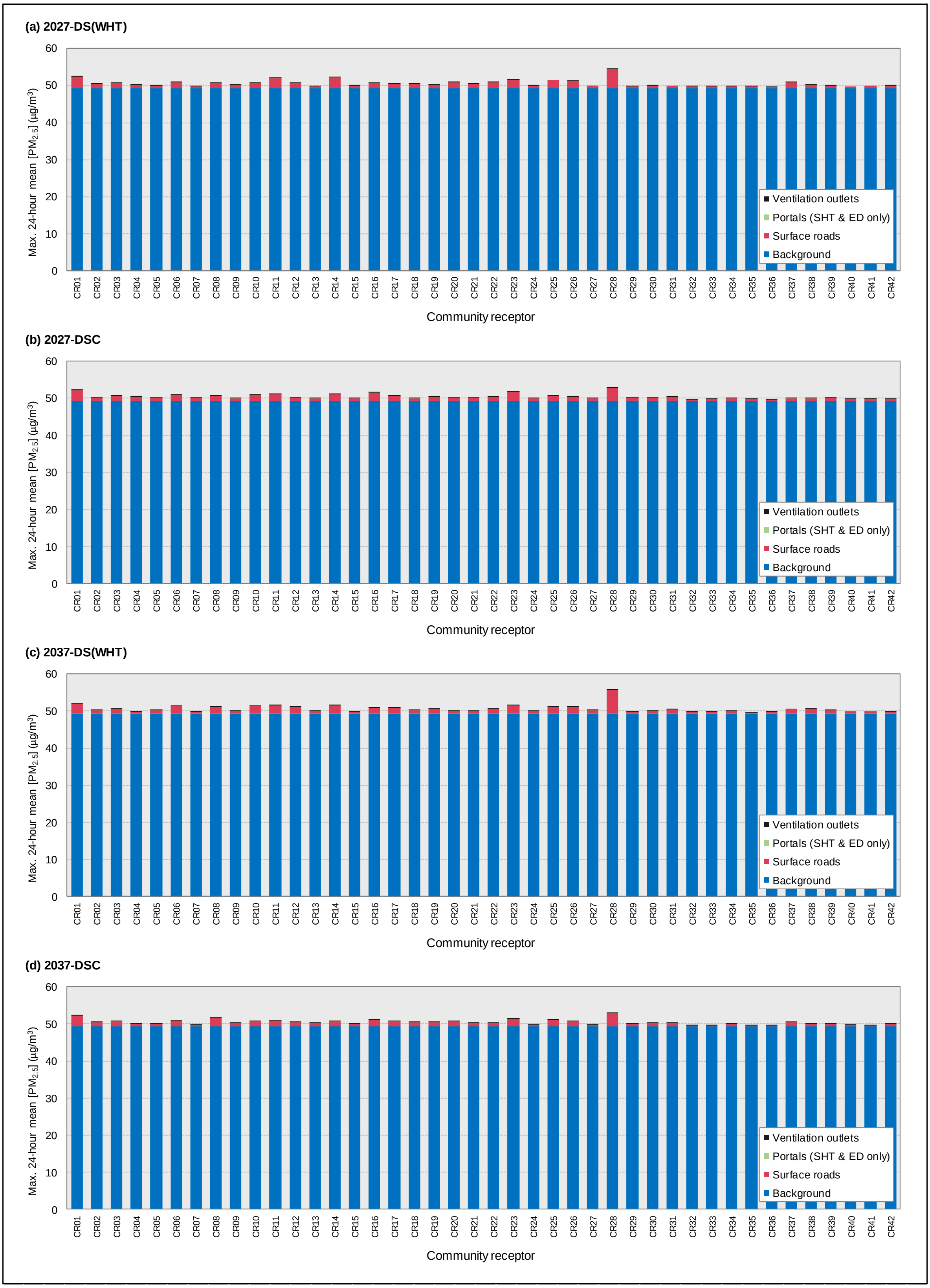


Figure 8-69 Source contributions to maximum 24-hour mean $PM_{2.5}$ concentration at community receptors (with-project and cumulative scenarios) (portals include Sydney Harbour Tunnel and Eastern Distributor only)

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 8-70.

Given the relatively high background concentration (22.1 µg/m^3), the concentration at a number of receptors was above the NSW impact assessment criterion of 25 µg/m^3 although this decreased slightly with the project. For example, the proportion of exceedances decreased from 8.6 per cent in the 2027-DM scenario to 7.5 per cent in the 2027-DS(WHT) scenario and 6.9 per cent in the 2027-DSC scenario. The proportions were slightly higher in 2037 (9.3 per cent for 2037-DM, 8.3 per cent for 2037-DS(WHT) and 6.4 per cent for 2037-DSC). As with PM_{10}, the contributions of surface roads and ventilation outlets are not shown separately as these were not additive. The maximum contribution of tunnel ventilation outlets at any RWR receptor was 1.0 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 8-71. There was an increase in concentration at between 36 per cent and 50 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 2.2 µg/m^3 (2027-DS(WHT) scenario), and the largest predicted decrease was 6.3 µg/m^3 (2037-DSC). For most of the receptors the change in concentration was small; where there was an increase in concentration, this was greater than 1 µg/m^3 at only around 0.2 to 0.7 per cent of receptors.

Contour plots – all sources

The contour plots for maximum 24-hour $PM_{2.5}$ in the 2037-DM and 2037-DSC scenarios are given in Figure 8-72 and Figure 8-73 respectively. The changes with the project and in the cumulative scenarios are shown in Figure 8-74.

The spatial changes in pollutant concentrations are discussed further in Section 8.4.12.

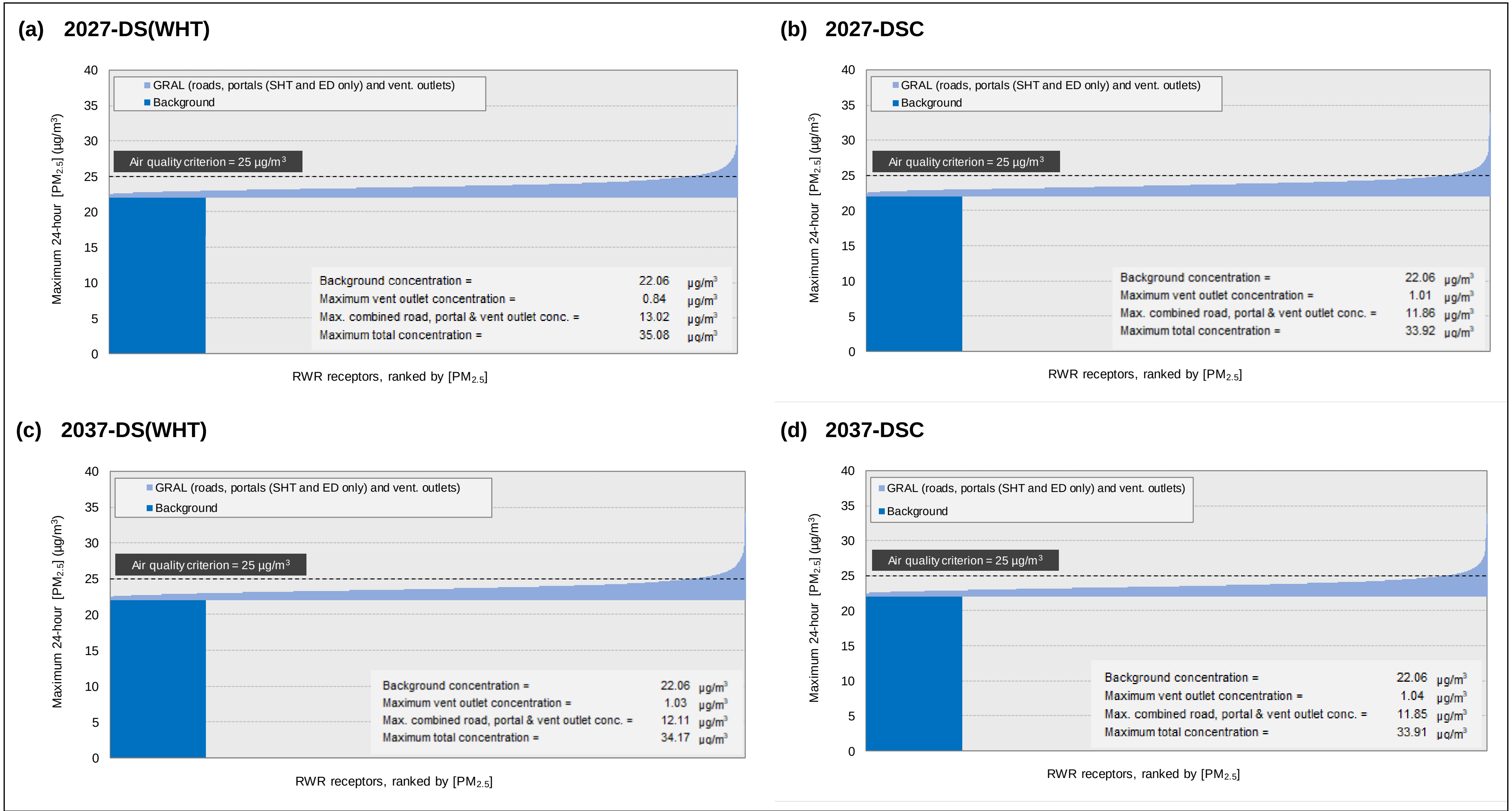


Figure 8-70 Source contributions to maximum 24-hour mean $PM_{2.5}$ concentration at RWR receptors (with-project and cumulative scenarios) (portals include Sydney Harbour Tunnel and Eastern Distributor only)

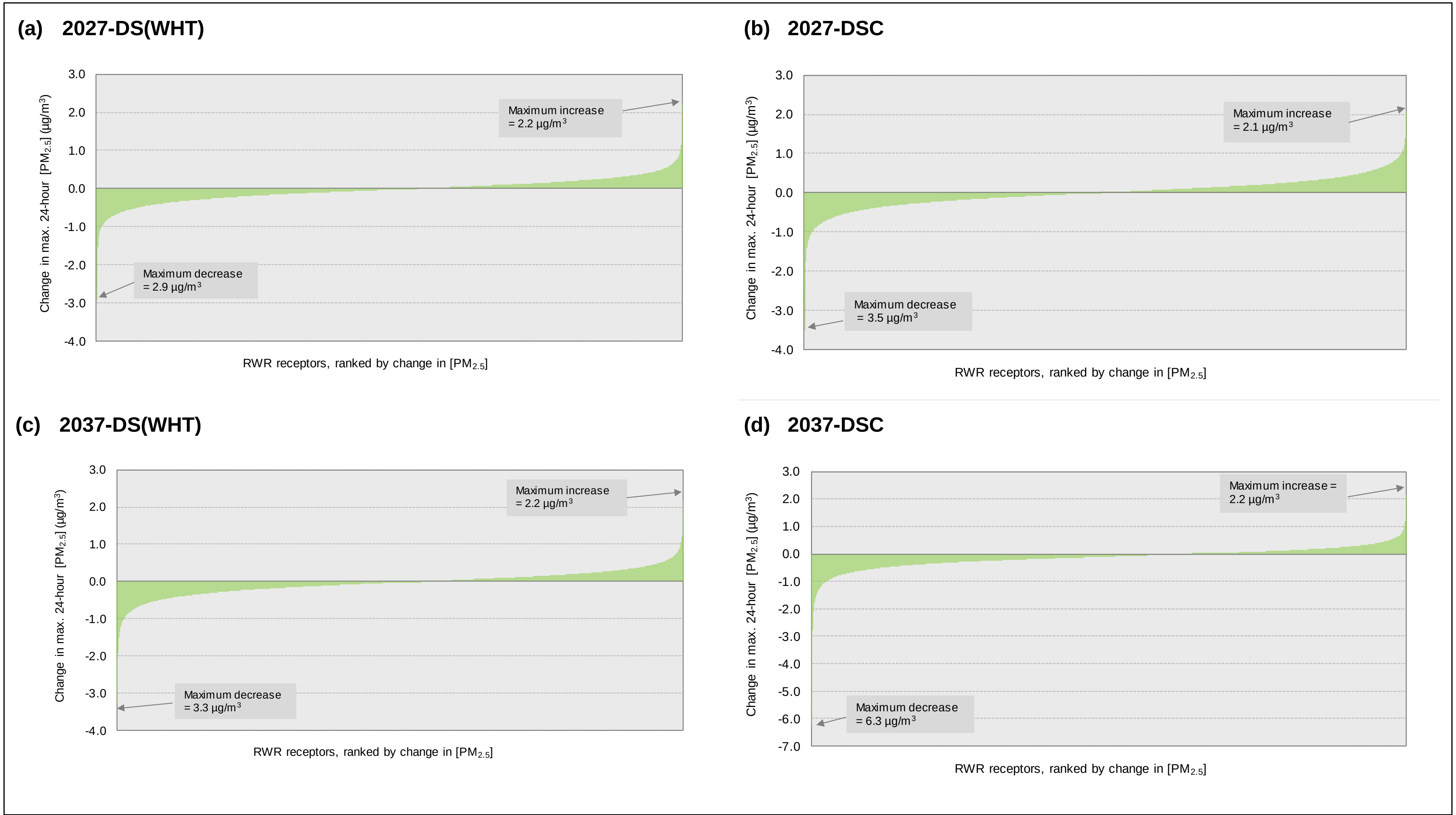


Figure 8-71 Change in maximum 24-hour mean $PM_{2.5}$ concentration at RWR receptors (with-project and cumulative scenarios, relative to Do minimum scenarios)

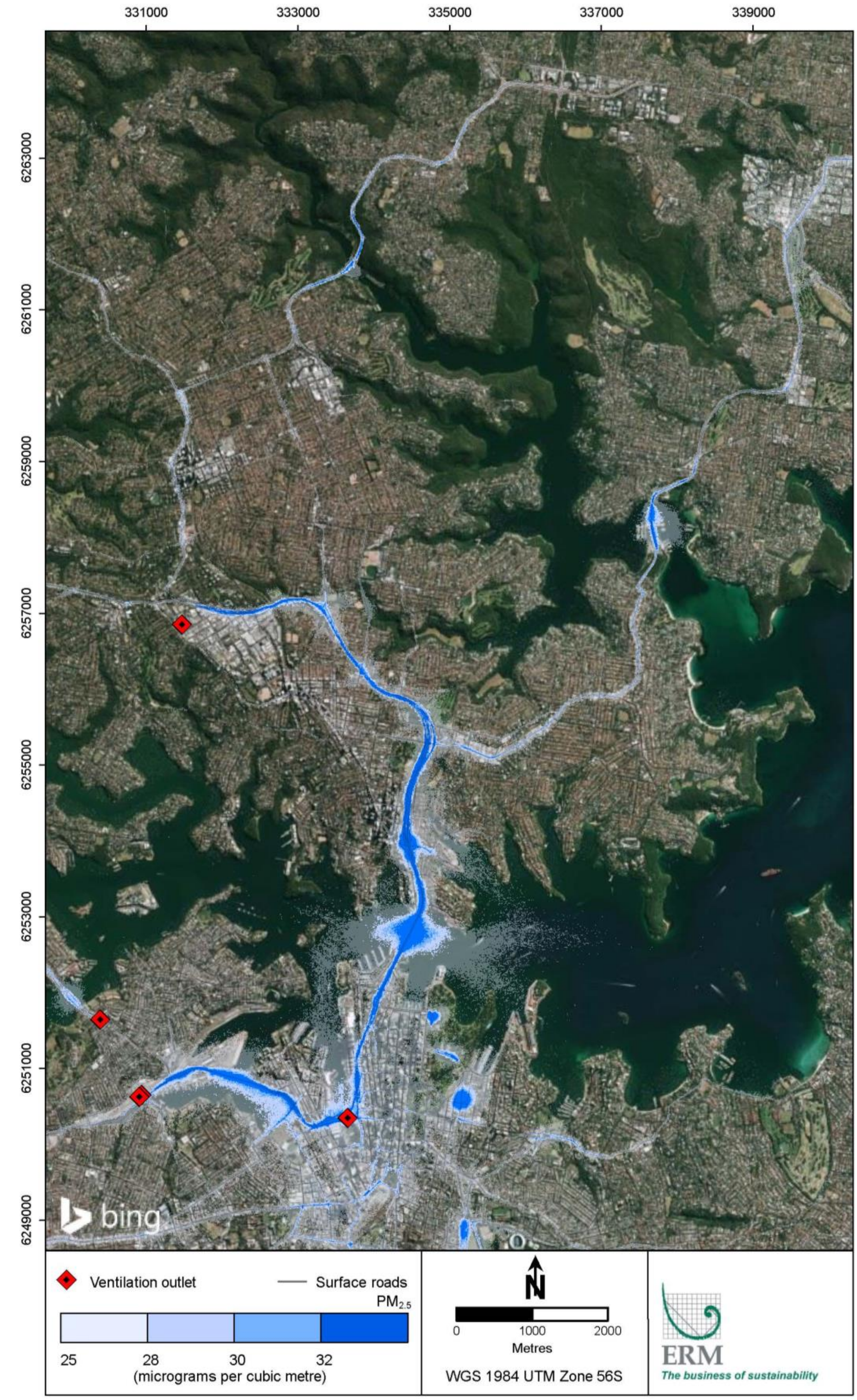


Figure 8-72 **Contour plot of maximum 24-hour average $PM_{2.5}$ concentration in the 2037 Do minimum scenario (2037-DM)**

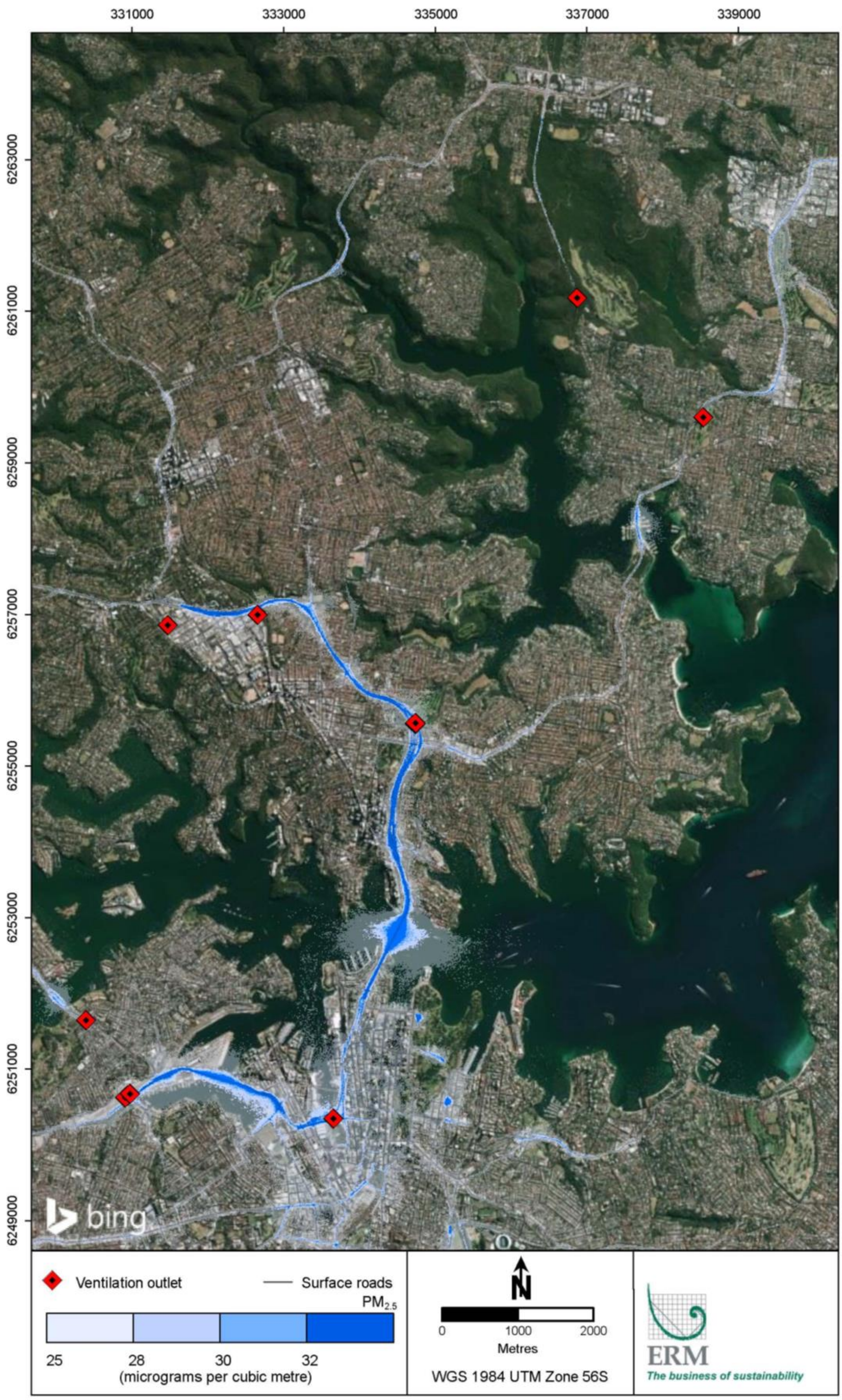


Figure 8-73 Contour plot of maximum 24-hour average $PM_{2.5}$ concentration in the 2037 cumulative scenario (2037-DSC)

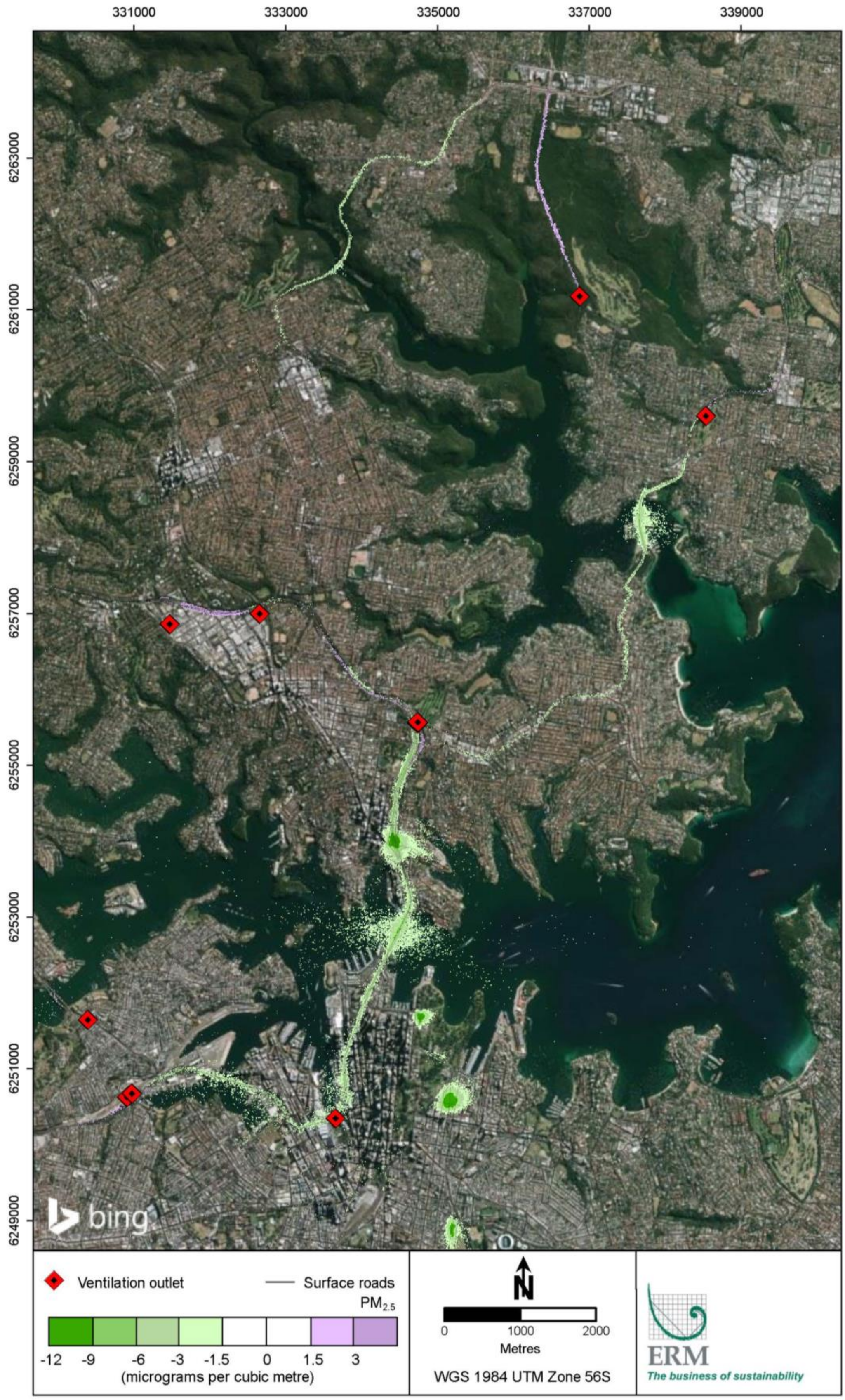


Figure 8-74 **Contour plot of change in maximum 24-hour $PM_{2.5}$ concentration in the 2037 cumulative scenario (2037-DSC minus 2037-DM)**

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 on Figure 8-75, 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 on Figure 8-76, Figure 8-77, Figure 8-78, and Figure 8-79 respectively. For each compound, where there was an increase in the concentration, this was well below the NSW impact assessment criterion.

The increases (and decreases) for the most affected RWR receptors are higher for those that are in closer proximity to the surface roads, but in all cases and for all five air toxics total predicted concentrations are well below their respective criteria. For example, the largest increase in benzene concentration at any RWR receptor for a cumulative scenario is 3.6 µg/m^3, but the total concentration of 8.0 µg/m^3 still remains well below the criterion of 29 µg/m^3.

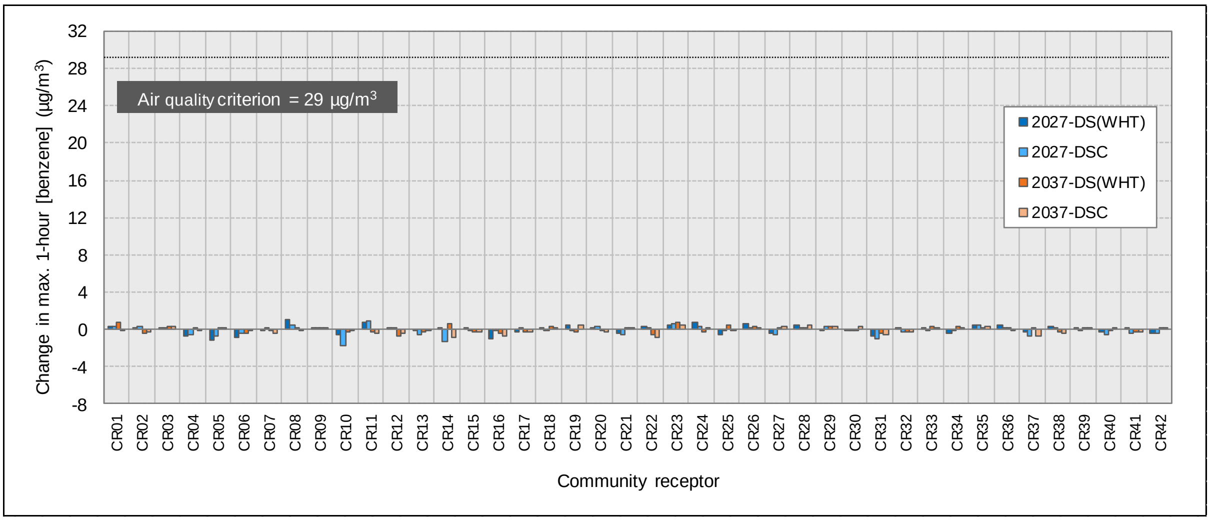


Figure 8-75 Change in maximum 1-hour mean benzene concentration at community receptors (with-project and cumulative scenarios)

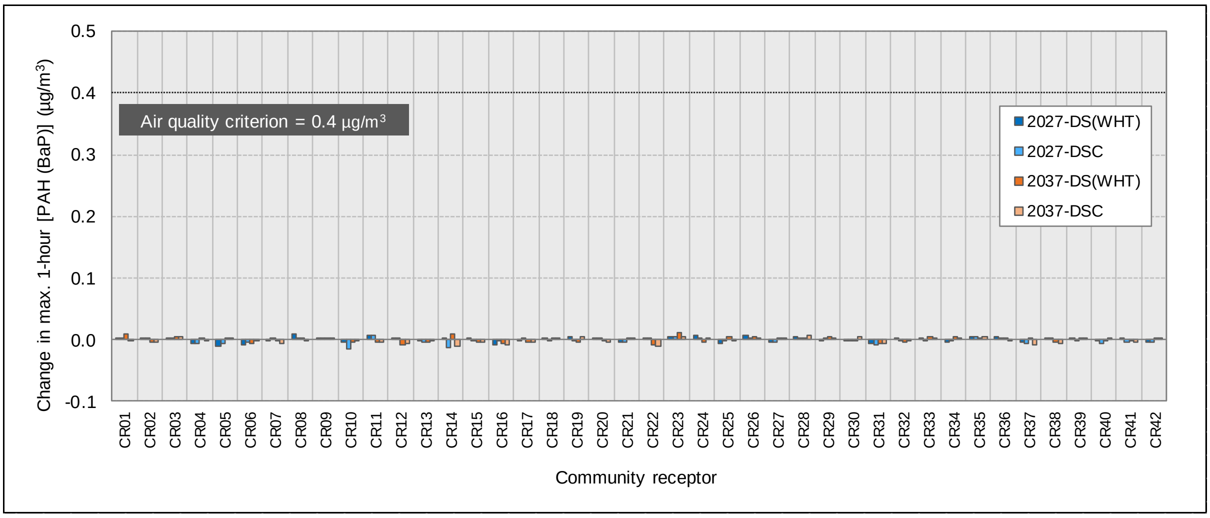


Figure 8-76 **Change in maximum 1-hour mean b(a)p concentration at community receptors (with-project and cumulative scenarios)**

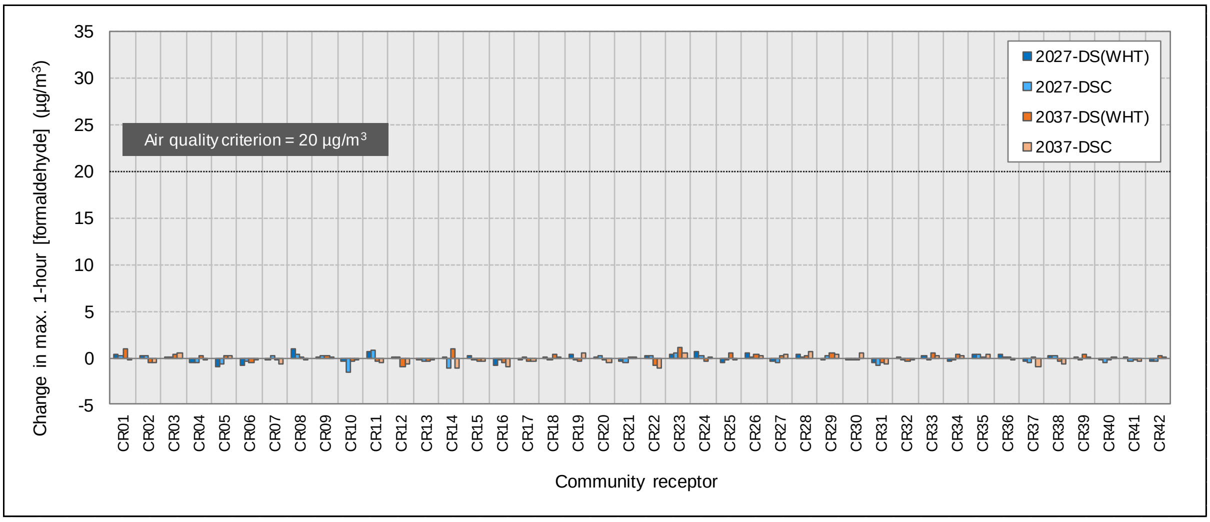


Figure 8-77 **Change in maximum 1-hour mean formaldehyde concentration at community receptors (with-project and cumulative scenarios)**

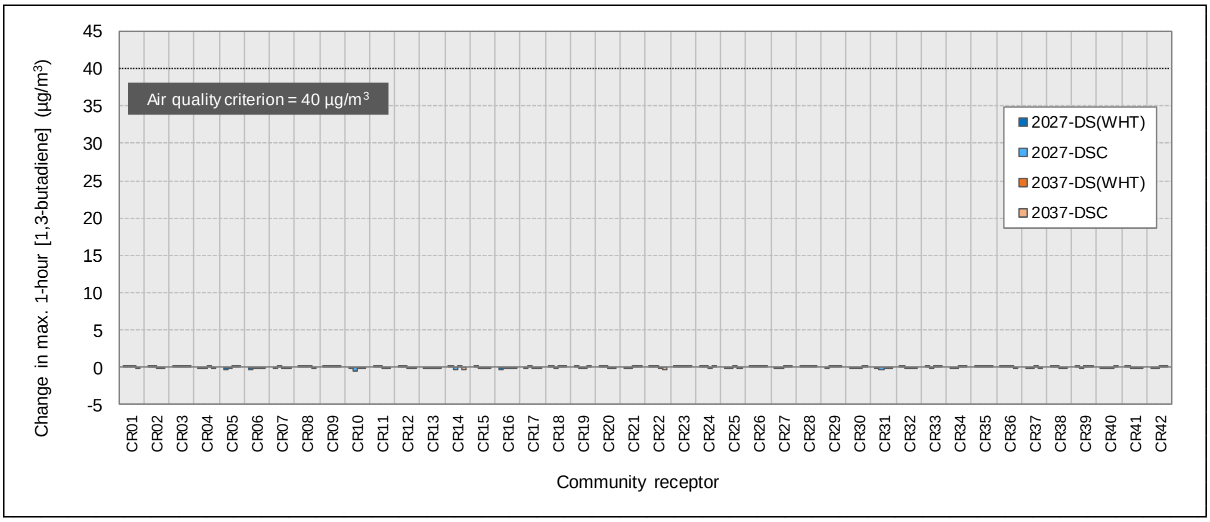


Figure 8-78 Change in maximum 1-hour mean 1,3-butadiene concentration at community receptors (with-project and cumulative scenarios)

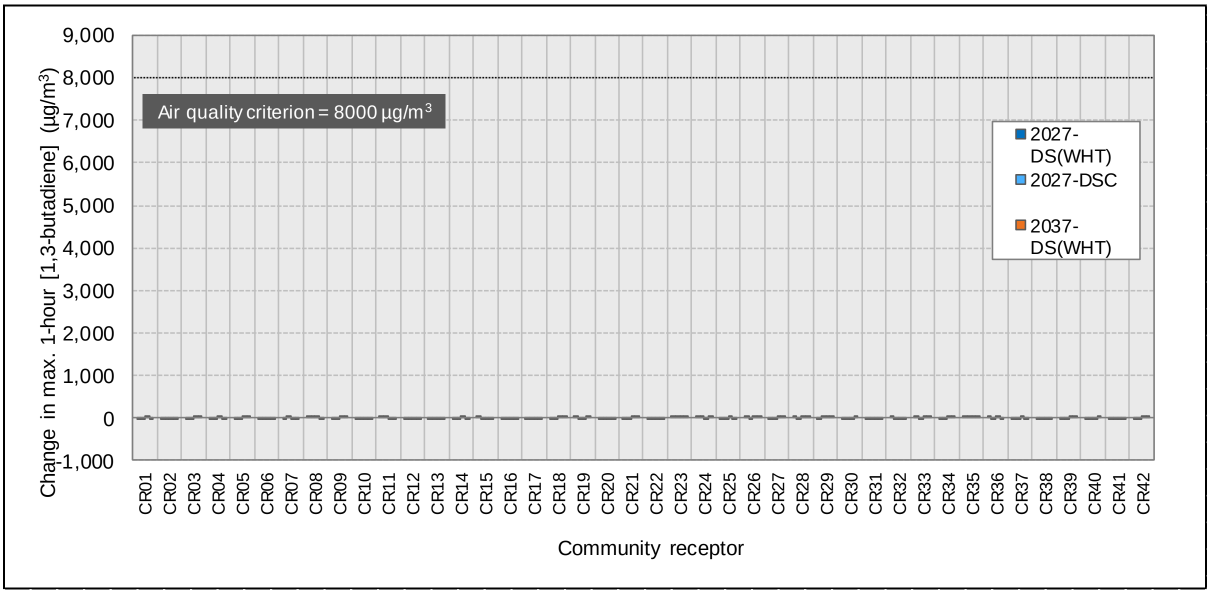


Figure 8-79 Change in maximum 1-hour mean ethylbenzene concentration at community receptors (with-project and cumulative scenarios)

8.4.12 Redistribution of air quality impacts

Spatial changes in air quality

In the previous section of the report, the spatial changes in air quality were presented in the form of contour plots (2037-DSC 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 human health risks; 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 project, and increases on other roads. These changes broadly reflected the effects of the project on traffic in the 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)					
	2027-DM	2027-DS(WHT)	2027-DSC	2037-DM	2037-DS(WHT)	2037-DSC
Anzac Bridge	176,292	160,434	159,435	185,214	167,495	166,552
Western Distributor, near Erskine Street	108,816	68,377	66,892	117,552	74,372	73,750
Sydney Harbour Bridge	203,452	167,954	166,494	220,514	183,811	183,838
Warringah Freeway, near North Sydney Oval	277,916	234,125	231,354	296,689	249,880	251,501
Gore Hill Freeway, near Artarmon Reserve	138,315	140,674	138,111	148,859	153,485	154,880
Eastern Distributor tunnel (northbound)	45,623	42,381	33,788	50,585	46,899	38,744
Military Road, near Spofforth Street	66,391	65,534	47,814	70,002	70,020	50,561
Manly Road, near Avona Crescent	71,545	71,798	43,413	76,851	77,546	46,937
Wakehurst Parkway, near Yarraman Avenue	20,989	21,066	50,567	23,692	24,091	56,635
Warringah Road, near Bangalla Place	82,949	82,949	61,507	87,038	87,746	65,764

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/%)							
	2027-DS minus 2027-DM		2027-DSC minus 2027-DM		2037-DS minus 2037-DM		2037-DSC minus 2037-DM	
Anzac Bridge	-15,858	-9.0%	-16,857	-9.6%	-17,719	-9.6%	-18,662	-10.1%
Western Distributor, near Erskine Street	-40,439	-37.2%	-41,924	-38.5%	-43,180	-36.7%	-43,802	-37.3%
Sydney Harbour Bridge	-35,498	-17.4%	-36,958	-18.2%	-36,703	-16.6%	-36,676	-16.6%
Warringah Freeway, near North Sydney Oval	-43,791	-15.8%	-46,562	-16.8%	-46,809	-15.8%	-45,188	-15.2%
Gore Hill Freeway, near Artarmon Reserve	2359	1.7%	-204	-0.1%	4626	3.1%	6021	4.0%
Eastern Distributor tunnel (northbound)	-3242	-7.1%	-11,835	-25.9%	-3686	-7.3%	-11,841	-23.4%
Military Road, near Spofforth Street	-857	-1.3%	-18,577	-28.0%	18	0.0%	-19,441	-27.8%
Manly Road, near Avona Crescent	253	0.4%	-28,132	-39.3%	695	0.9%	-29,914	-38.9%
Wakehurst Parkway, near Yarraman Avenue	77	0.4%	29,578	140.9%	399	1.7%	32,943	139.0%
Warringah Road, near Bangalla Place	0	0.0%	-21,442	-25.8%	708	0.8%	-21,274	-24.4%

The contour plot for the change in annual mean $PM_{2.5}$ in the 2027-DS(WHT) scenario (relative to 2027-DM) is shown on Figure I-43 of Annexure I. With the Western Harbour Tunnel there were noticeable decreases in $PM_{2.5}$ concentrations along the Western Distributor, Sydney Harbour Bridge and Warringah Freeway. Table 8-21 shows that there were reductions in traffic of between 16 per cent and 37 per cent on these roads. There was also a marked reduction in concentration in the vicinity of the portal of the northbound Eastern Distributor tunnel and, to a lesser extent, the portals of the Sydney Harbour Tunnel. There were broadly similar changes in the 2037-DS(WHT) scenario (Figure I-48).

For the cumulative scenarios (2027-DSC and 2037-DSC) there were some additional changes as a result of the Beaches Link project (refer to Figures I-45 and I-50 of Annexure I). These included reductions in concentration along Military Road, Spit Road, Manly Road and Warringah Road. Again, the reductions in traffic on some of these roads are given in Table 8-21. There was an increase in concentration along Wakehurst Parkway as a result of the substantial increase in traffic (around 140 per cent) associated with Beaches Link and Gore Hill Freeway Connection project. However, the section of Wakehurst Parkway that is affected crosses bushland, and there are no sensitive receptors close to the road.

It is also worth noting that at some locations the changes in concentration were made greater due to a significant impact of road gradient on emissions. An example of this is Manly Road north of The Spit.

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 on Figure 8-80 to Figure 8-83, and those for maximum 24-hour $PM_{2.5}$ are presented on Figure 8-84 to Figure 8-87. 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 particular, there was no significant increase in concentration at receptor locations which already had a relatively high concentration in the ‘Do minimum’ cases.

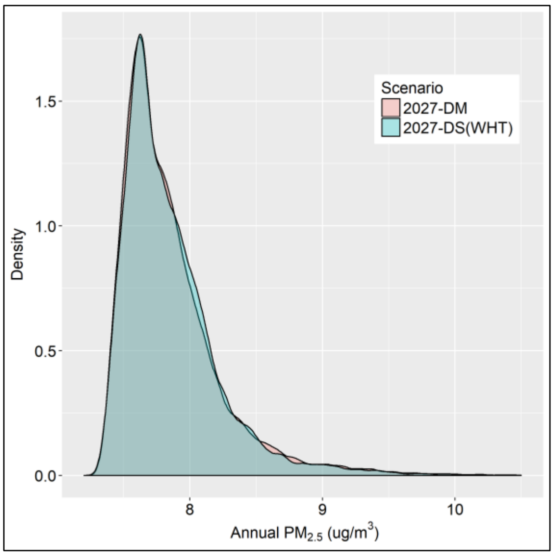


Figure 8-80 Density plot for annual mean $PM_{2.5}$ (2027-DM and 2027-DS(WHT))

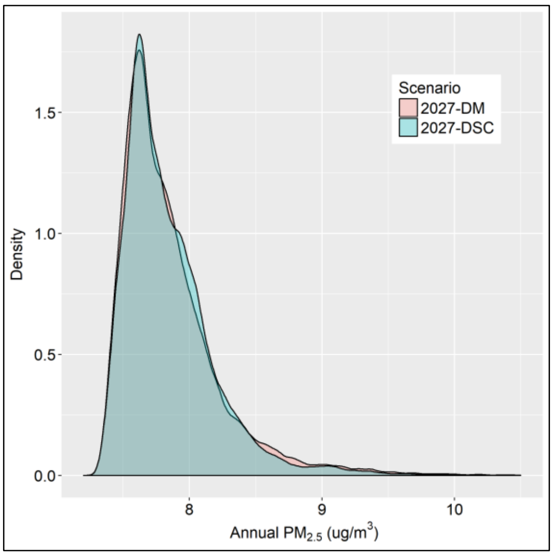


Figure 8-81 Density plot for annual mean $PM_{2.5}$ (2027-DM and 2027-DSC)

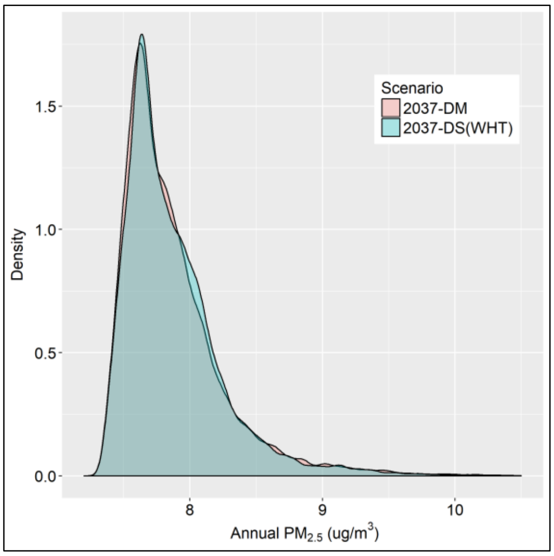


Figure 8-82 Density plot for annual mean $PM_{2.5}$ (2037-DM and 2037-DS(WHT))

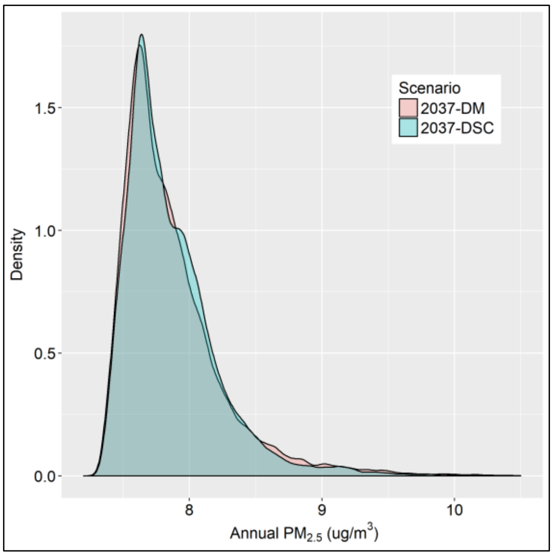


Figure 8-83 Density plot for annual mean $PM_{2.5}$ (2037-DM and 2037-DSC)

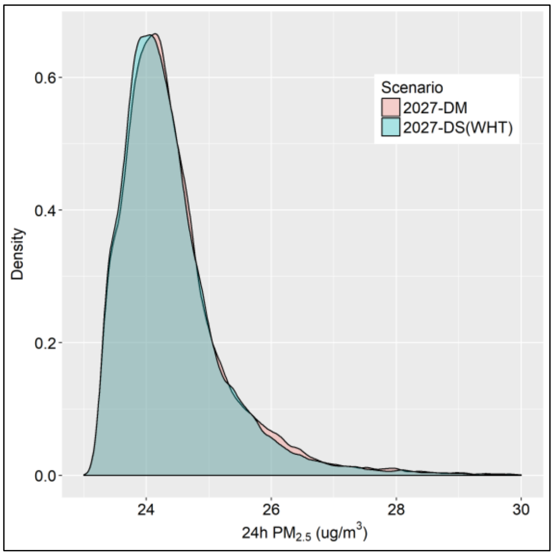


Figure 8-84 Density plot for maximum 24-hour $PM_{2.5}$ (2027-DM and 2027-DS(WHT))

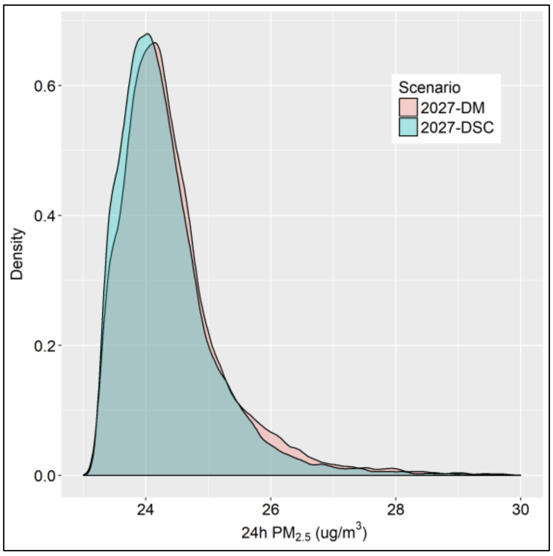


Figure 8-85 Density plot for for maximum 24-hour $PM_{2.5}$ (2027-DM and 2027-DSC)

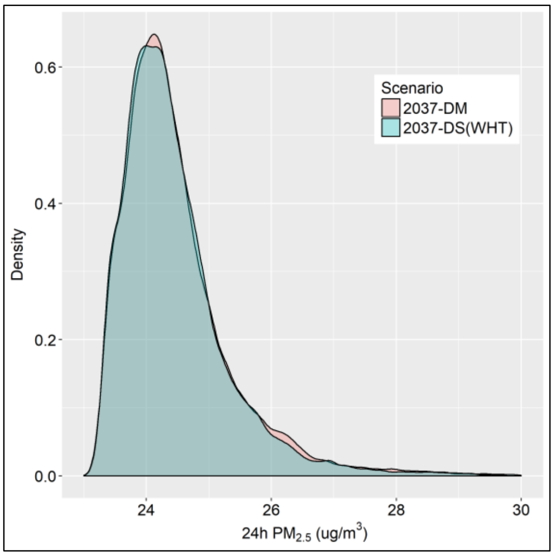


Figure 8-86 Density plot for for maximum 24-hour $PM_{2.5}$ (2037-DM and 2037-DS(WHT))

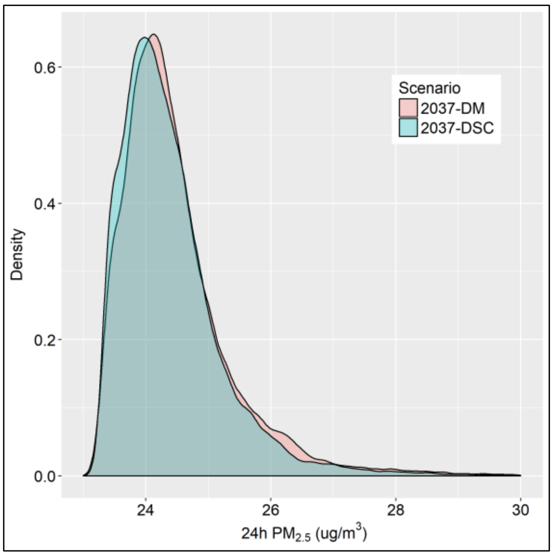


Figure 8-87 Density plot for for maximum 24-hour $PM_{2.5}$ (2037-DM and 2037-DSC)

8.4.13 Results for expected traffic scenarios (elevated receptors)

Annual mean $PM_{2.5}$

Figure 8-88, Figure 8-89 and Figure 8-90 present contour plots for the changes in annual mean $PM_{2.5}$ concentration in the 2037-DSC scenario, and for receptor heights of 10 metres, 20 metres, 30 metres and 45 metres above ground level, respectively. Existing buildings are not at all of these heights at all RWR receptor locations (eg at a RWR receptor location, an existing building may be up to 10 metres in height, but was assessed at all four selected heights). The contour plots can be compared with the changes in ground-level annual mean concentration for the same scenario (refer to Figure 8-66). Statistics relating to the changes in annual mean concentration at all RWR receptor locations (whether there is an existing building at that location at each height or not) and at RWR receptor locations with an existing building at that height in the GRAL domain are also provided in Table 8-22 below. The shaded columns are the statistics relating to existing buildings.

Table 8-22 Changes in annual mean $PM_{2.5}$ concentration at elevated receptor locations (RWR receptor locations, 2037-DSC compared with 2037-DM)

Height	Maximum increase in concentration at all RWR receptor locations[(a)] (µg/m^3)	Number of RWR receptor locations with an increase of more than 0.1 (µg/m^3)	Maximum increase in concentrations at RWR receptor locations[(b)] (µg/m^3)	Number of RWR receptor locations with an increase of more than 0.1 (µg/m^3)
Ground level	0.58	1554 (4.4%)	0.58	1554
10 metres	0.37	998 (2.8%)	0.18	25
20 metres	0.24	590 (1.7%)	0.09	0
30 metres	0.48	447 (1.3%)	0.13	2
45 metres	2.06	499 (1.4%)	0.05	0

(a) Assumes at RWR receptor locations that buildings exist at all heights, irrespective of existing building heights at those locations
(b) Only includes existing buildings that exist at each height

The reduced influence of surface roads and portals at a receptor height of 10 metres compared with ground level can be seen in Figure 8-88. However, because the influence of surface roads and portals in the 'Do minimum' case at 10 metres was also reduced, the spatial distributions of changes in annual average $PM_{2.5}$ concentration at 10 metres and ground level were similar. For example, where there was an increase in annual mean $PM_{2.5}$ at the height of 10 metres, this was greater than 0.1 µg/m^3 at 2.8 per cent of RWR locations, when compared with 4.4 per cent at ground level. The largest changes in concentration at 10 metres were slightly smaller than those at ground level. The largest increase at the height of 10 metres for the RWR receptor locations was 0.37 µg/m^3, which can be compared with the maximum increase for any ground-level receptor in the 2037-DSC scenario of 0.58 µg/m^3.

Figure 8-89 and Figure 8-90 show that the situation was different at receptor heights of 20 metres, 30 metres and 45 metres. At these heights, the changes in annual mean $PM_{2.5}$ associated with surface roads appeared to be negligible at all locations, but changes (improvements) around the Sydney Harbour Tunnel and Eastern Distributor portals are still noticeable. The largest increases at RWR receptor locations at 20 metres, 30 metres and 45 metres were between 0.24, 0.48 and 2.06 µg/m^3.

Further consideration has been given to existing buildings that currently exist at each of the specific heights modelled (shaded columns). At heights of 10 metres, there are only 25 existing buildings that show an increase in annual mean $PM_{2.5}$ concentration of more than 0.1 µg/m^3. At heights of 20 metres and 45 metres, there are no existing buildings that show an increase in annual mean $PM_{2.5}$ concentrations of greater than 0.1 µg/m^3. At a height of 30 metres, there are two existing buildings that show an increase in annual mean $PM_{2.5}$ concentrations of greater than 0.1 µg/m^3. No existing buildings at those heights are predicted to exceed 1.7 µg/m^3, with the maximum predicted increase being 0.18 µg/m^3.

Maximum 24-hour $PM_{2.5}$

Figure 8-92, Figure 8-93 and Figure 8-94 show the contour plots showing the changes in maximum 24-hour $PM_{2.5}$ concentration in the 2037-DSC scenario at receptor heights of 10 metres, 20 metres, 30 metres and 45 metres, respectively. These plots can be compared with the changes in ground-level concentration for the same scenario (refer to Figure 8-74). As mentioned in the previous section, existing buildings do not exist at all of these heights at all RWR receptor locations. Statistics relating to the changes in maximum 24-hour mean concentration at all RWR receptor locations (whether there is an existing building at that location at each height or not) and at RWR receptor locations within an existing building at that height in the GRAL domain are also provided in Table 8-23. The shaded columns are the statistics relating to existing buildings.

Table 8-23 Changes in maximum 24-hour $PM_{2.5}$ concentration at elevated receptors (RWR receptors, 2037-DSC compared with 2037-DM)

Height	Maximum increase in concentration at all RWR receptor locations[a] (µg/m^3)	Number of RWR receptor locations with an increase of more than 0.5 (µg/m^3)	Maximum increase in concentrations at RWR receptor locations[b] (µg/m^3)	Number of RWR receptor locations with an increase of more than 0.5 (µg/m^3)
Ground level	2.20	919 (2.6%)	2.20	919
10 metres	2.07	253 (0.7%)	1.61	43
20 metres	1.46	575 (1.6%)	0.44	0
30 metres	8.67	537 (1.5%)	1.01	2
45 metres	9.02	620 (1.8%)	0.36	0

(a) Assumes at RWR receptor locations that buildings exist at all heights, irrespective of existing building heights at those locations
(b) Only includes existing buildings that exist at each height

At modelled RWR receptor location heights of 10 metres and 20 metres, the maximum increase in concentration were slightly lower than at ground level but, as with the annual mean, the spatial distributions of changes were similar. At the height of 30 metres and 45 metres, the largest increases in the maximum 24-hour $PM_{2.5}$ concentrations were in the vicinity of the proposed ventilation outlets, and these largest increases were greater than those at 20 metres, 10 metres and ground level.

The largest increase in maximum 24-hour $PM_{2.5}$ concentrations at any RWR receptor location was around 9 µg/m^3 (18 per cent of the assessment criterion) which occurred at a height of 45 metres above ground. At a height of 30 metres above ground, the largest increase was around 8.7 µg/m^3. It can be seen that there is a large increase in concentration from 20 metres above ground to 30 metres above ground. This is not unexpected given that maximum outlet contributions are likely to be at or above the height of that outlet. The increase in the maximum concentration from 30 metres to 45 metres is less pronounced. The horizontal extent of the increases at height has been considered at both 30 metres and 45 metres due to the large predicted increases in concentration, when compared against the predicted concentration at 20 metres. At a height of both 30 metres and 45 metres at any RWR receptor location, the increase in concentration was less than 1 µg/m^3 at distances from the outlets of greater than 300 metres.

Further consideration has been given to RWR receptor locations within an existing building at each of the specific heights modelled (shaded columns). At heights of 10 metres, there are 43 RWR receptor locations that show an increase in the maximum 24-hour $PM_{2.5}$ concentration of more than 0.5 µg/m^3. At heights of 20 metres and 45 metres, there are no existing buildings at RWR receptor locations that show an increase in the maximum 24-hour $PM_{2.5}$ concentration of greater than 0.5 µg/m^3. At a height of 30 metres, there are two existing buildings that show an increase in the maximum 24-hour $PM_{2.5}$ concentration of greater than 0.5 µg/m^3.

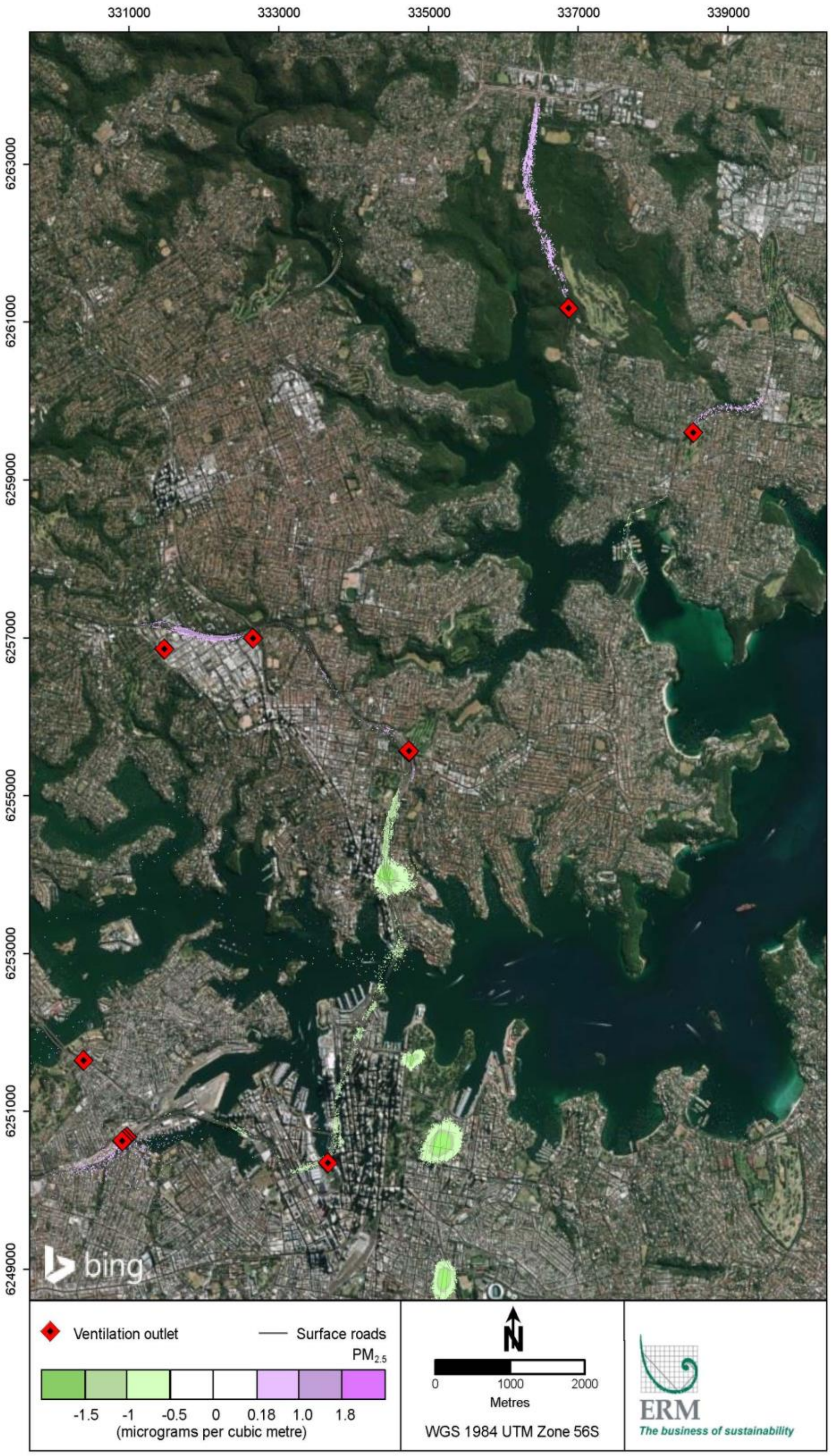


Figure 8-88 Contour plot of change in annual mean $PM_{2.5}$ concentration (2037-DSC minus 2037-DM, 10 metre RWR receptor location height)

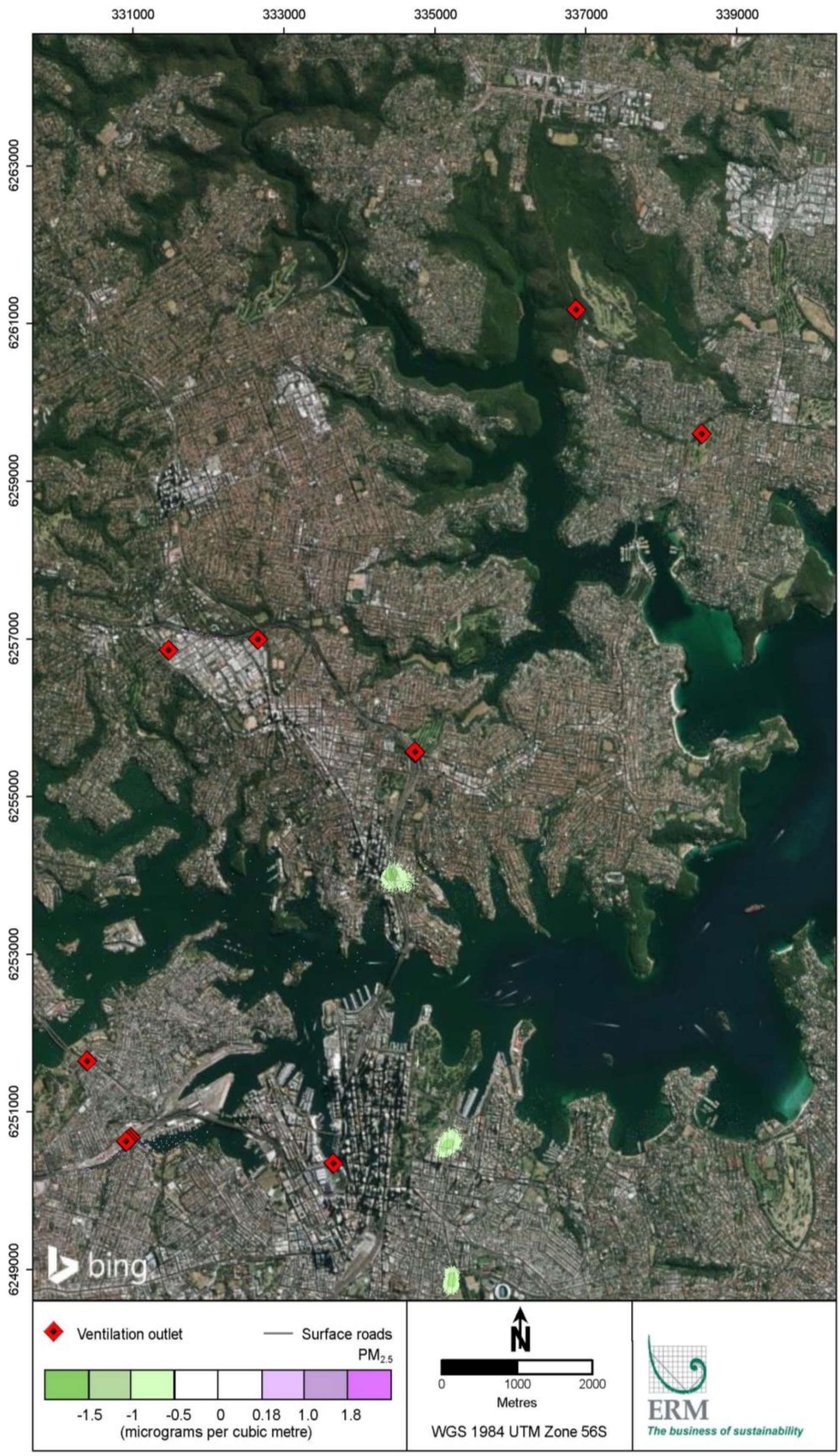


Figure 8-89 Contour plot of change in annual mean $PM_{2.5}$ concentration (2037-DSC minus 2037-DM, 20 metre RWR receptor location height)

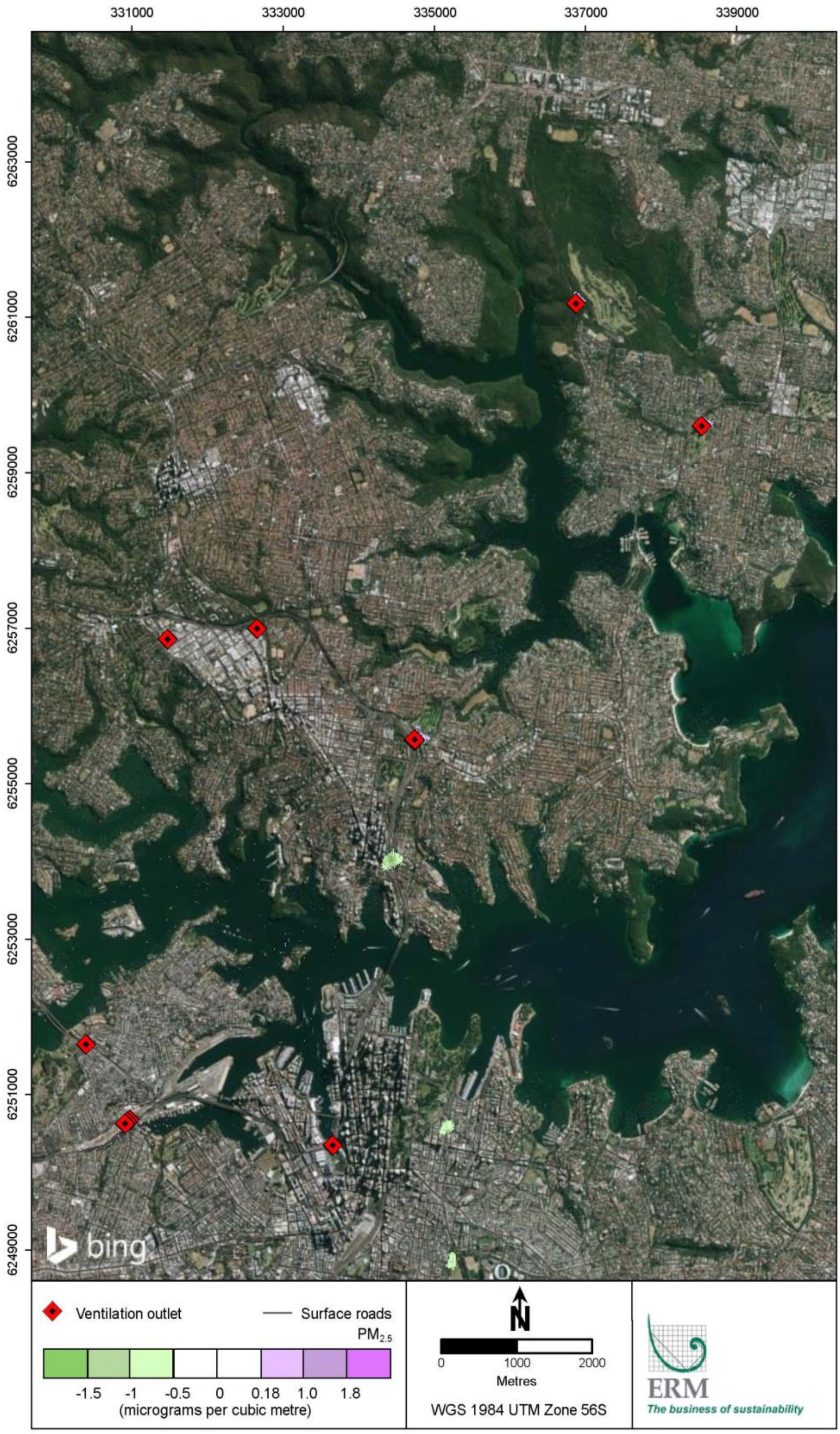


Figure 8-90 **Contour plot of change in annual mean $PM_{2.5}$ concentration (2037-DSC minus 2037-DM, 30 metre RWR receptor location height)**

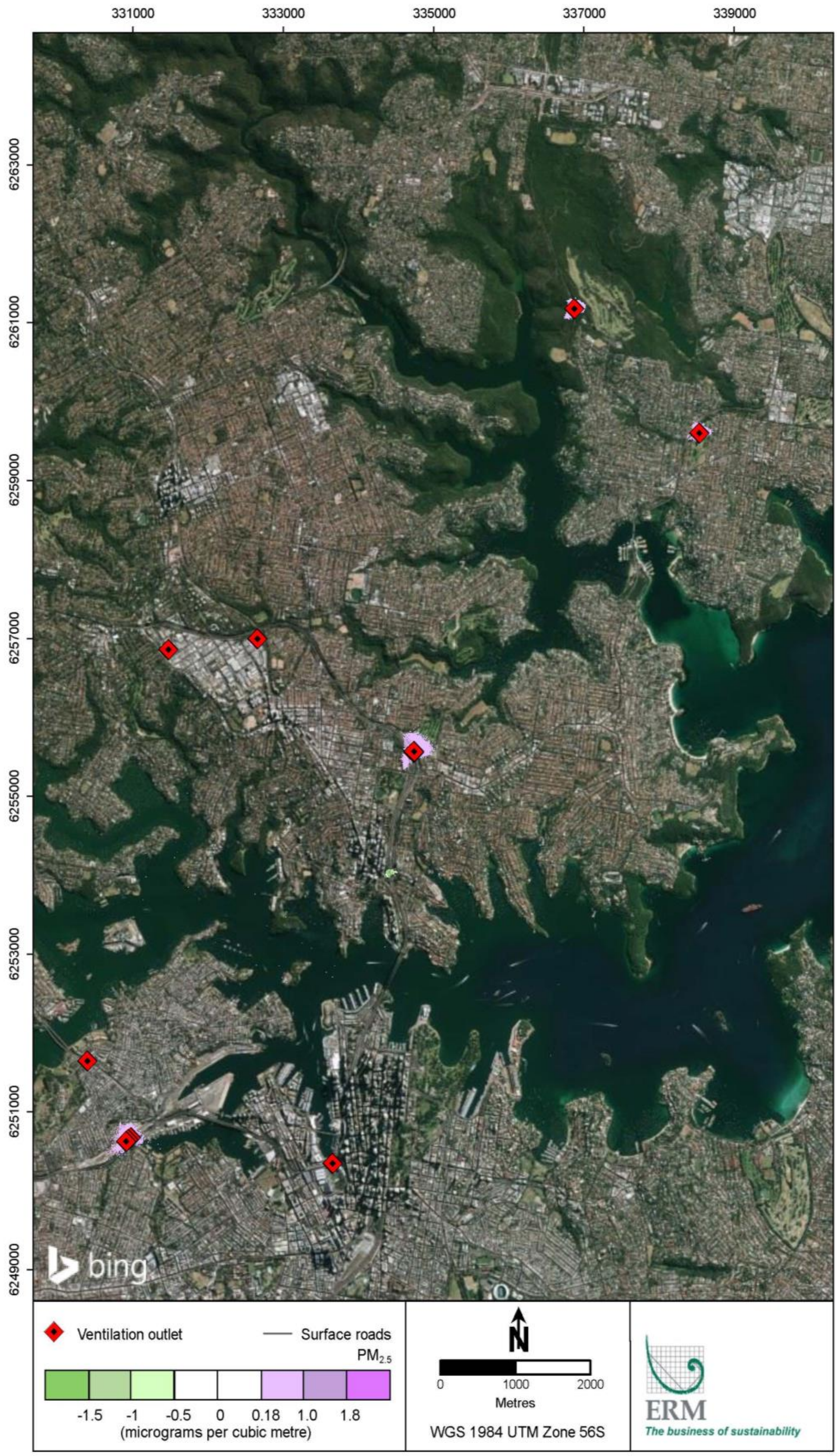


Figure 8-91 Contour plot of change in annual mean $PM_{2.5}$ concentration (2037-DSC minus 2037-DM, 45 metre RWR receptor location height)

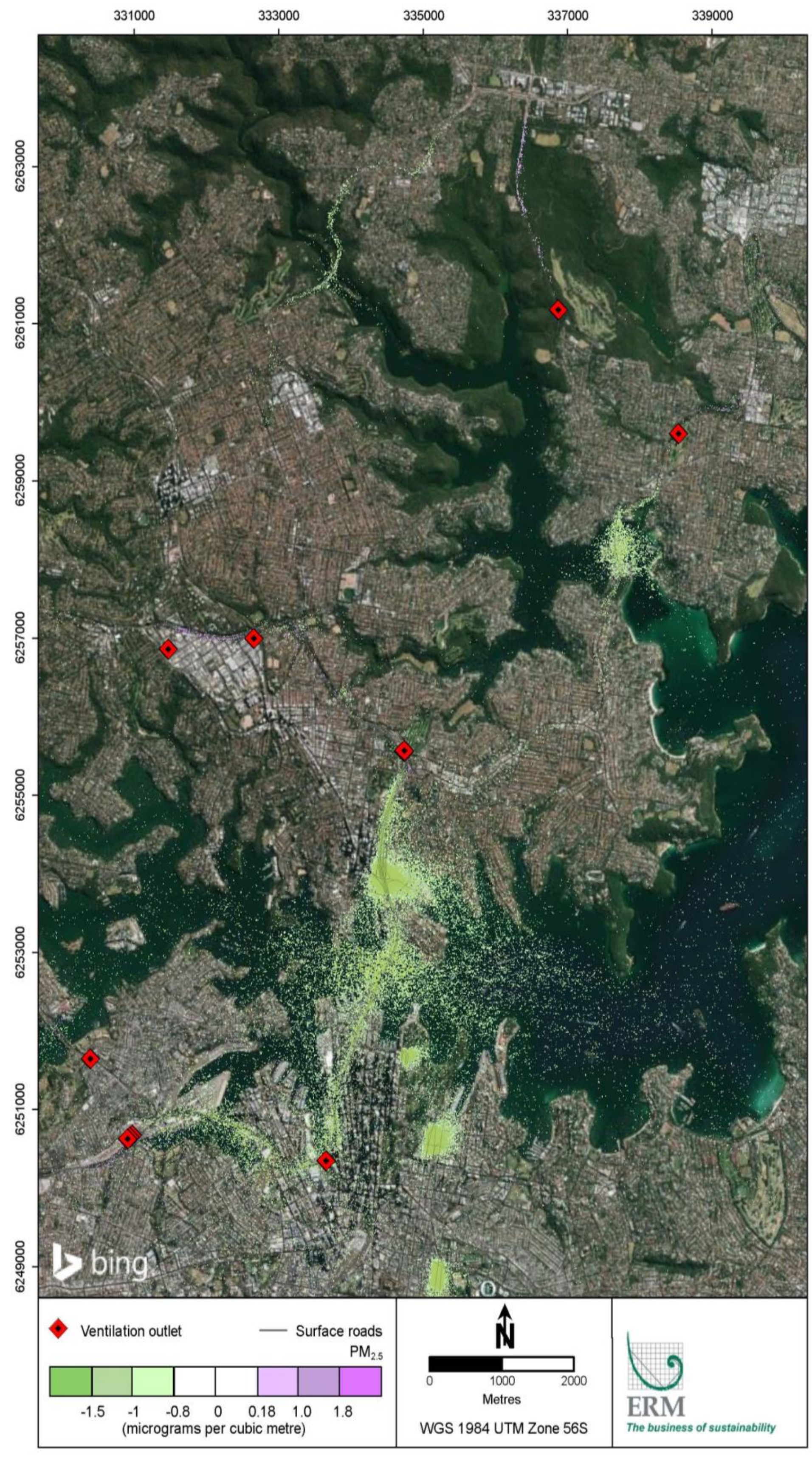


Figure 8-92 **Contour plot for change in maximum 24-hour $PM_{2.5}$ concentration (2037-DSC minus 2037-DM, 10 metre RWR receptor location height)**

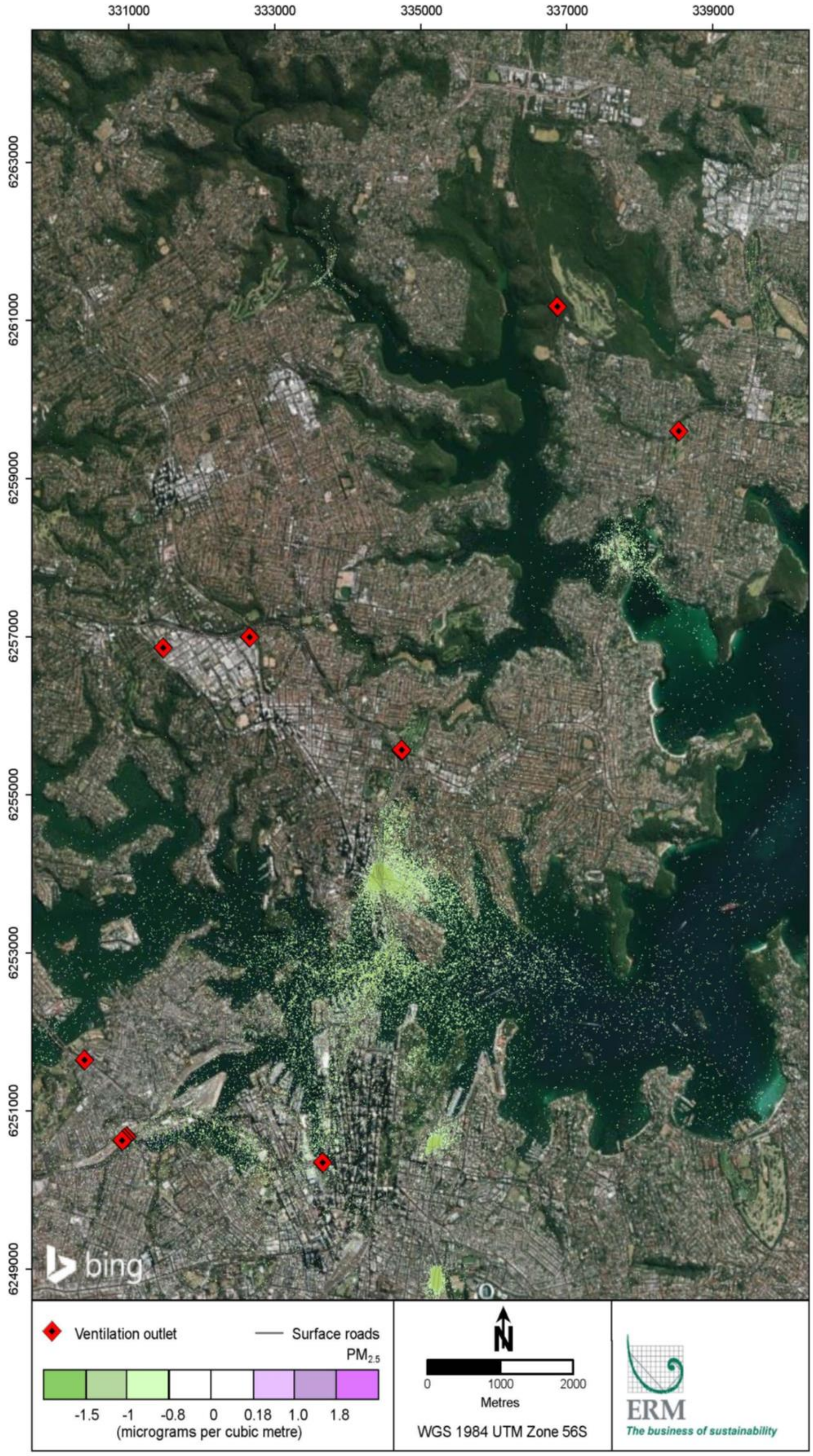


Figure 8-93 Contour plot for change in maximum 24-hour $PM_{2.5}$ concentration (2037-DSC minus 2037-DM, 20 metre RWR receptor location height

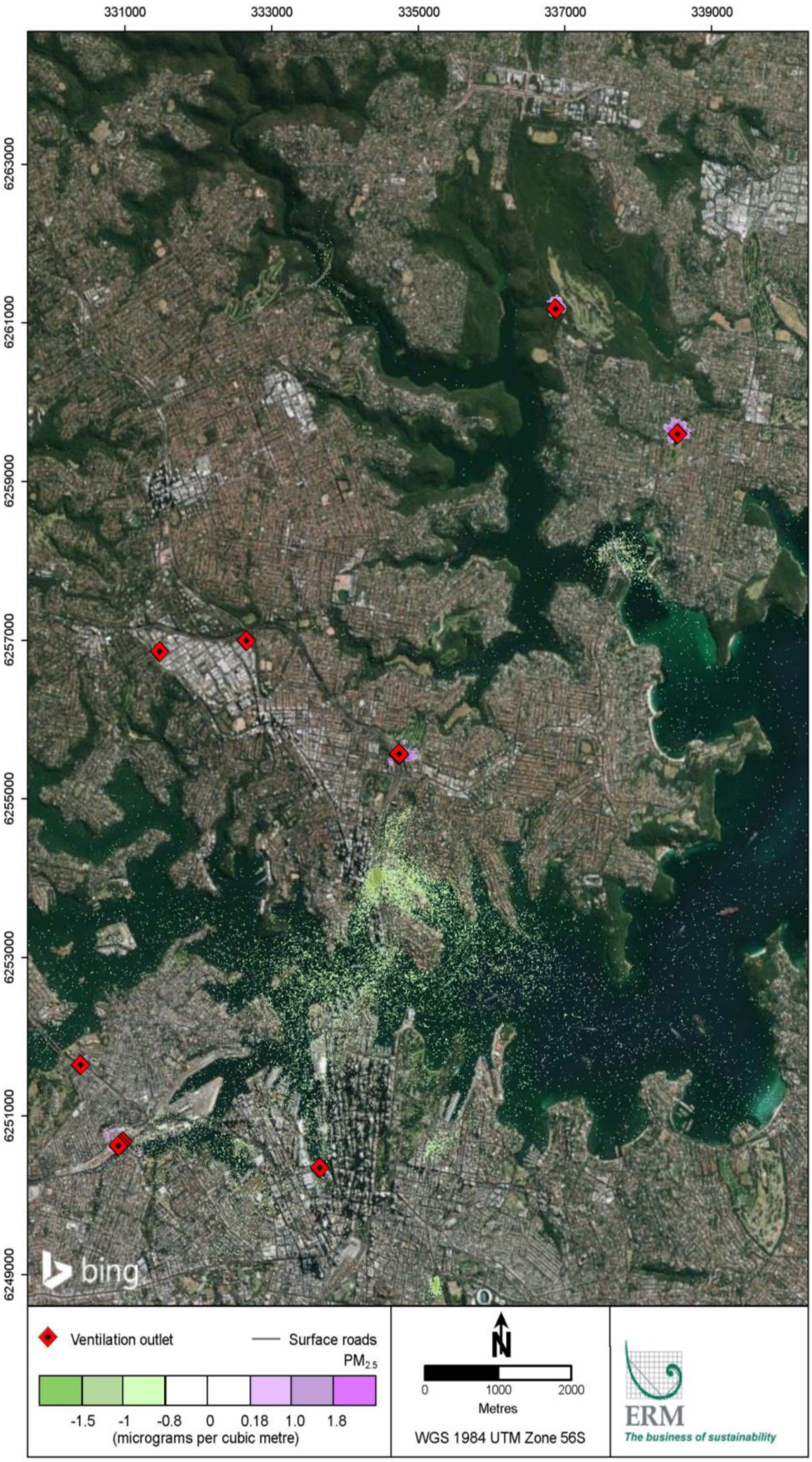


Figure 8-94 Contour plot for change in maximum 24-hour $PM_{2.5}$ concentration (2037-DSC minus 2037-DM, 30 metre RWR receptor location height

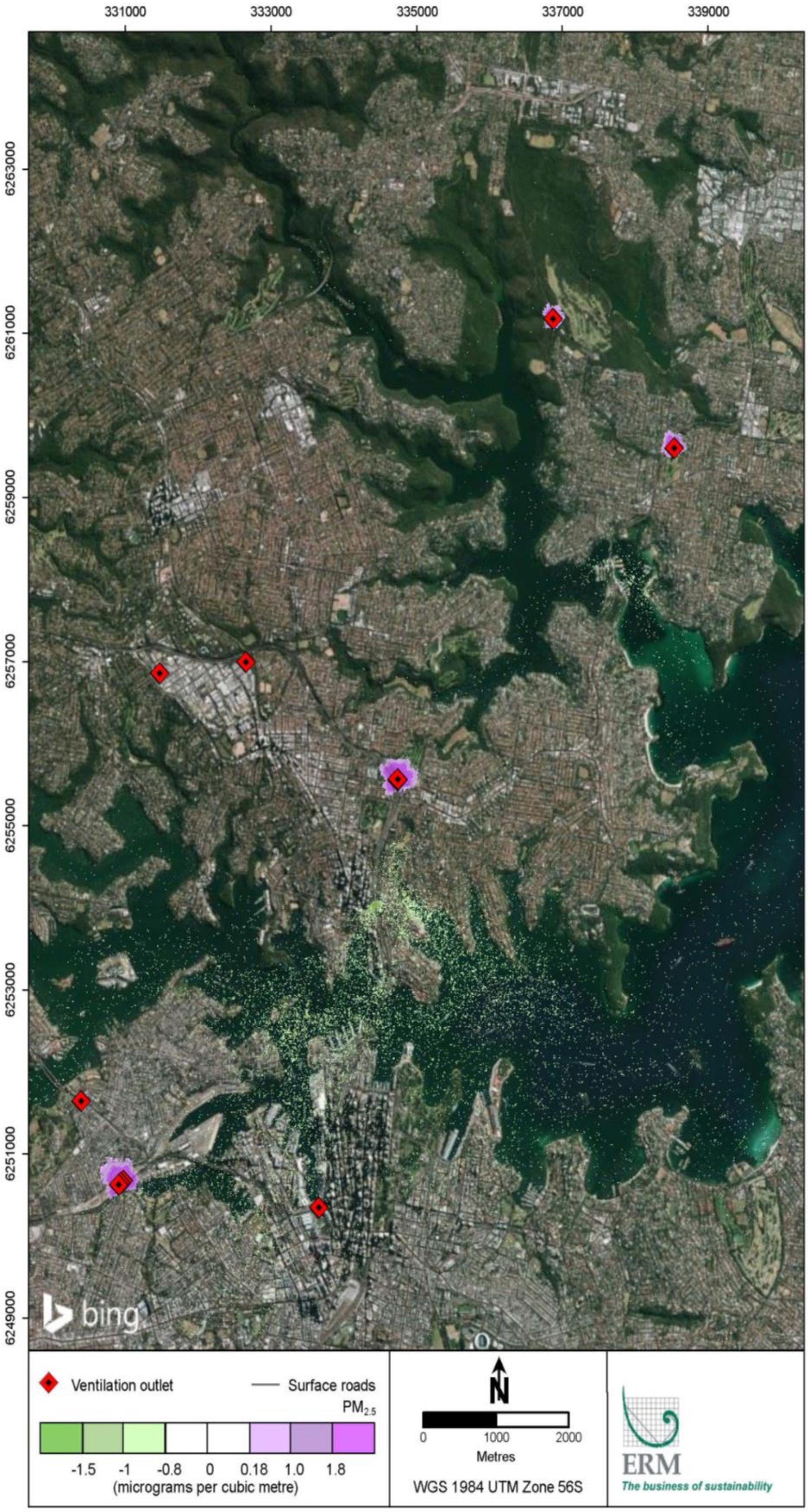


Figure 8-95 **Contour plot for change in maximum 24-hour $PM_{2.5}$ concentration (2037-DSC minus 2037-DM, 45 metre RWR receptor location height**

Summary

The implications of these results can be summarised as follows:

- There are no predicted adverse impacts at any existing buildings at any height
- There are no predicted adverse impacts at any existing or future buildings up to a height of 20 metres
- There are predicted impacts for potential future buildings above 20 metres in height within 300 metres of the ventilation outlets, but this would not necessarily preclude such development. Further consideration at rezoning or development application stage would be required
- There are no restrictions to building heights within 300 metres of the Rozelle Interchange outlet. Within 300 metres of the Warringah Freeway outlet, current planning controls for permissible habitable structures restrict buildings to below 20 metres
- Land use considerations would be required to manage any interaction between the project and future development for buildings with habitable structures above 20 metres and within 300 metres of the ventilation outlet
- Roads and Maritime would assist Inner West Council, North Sydney Council and the Department of Planning, Industry and Environment (as appropriate) in determining relevant land use considerations applicable to future development in the immediate vicinity of ventilation outlets for inclusion in Local Environmental Plans or Development Control Plans, where required, to manage interactions between the project and future development. This may include procedures for identifying the requirement for consultation with Roads and Maritime for proposed rezoning or development applications.

8.4.14 Results for regulatory worst case scenario

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 particulate matter

The results for CO, PM_{10} and $PM_{2.5}$ in the regulatory worst case scenario (RWC-2027-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). The results were the same 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-2027-DSC)		Expected traffic scenarios (all receptors)			
		All receptors	Sensitive receptors	2027-DS(WHT)	2027-DSC	2037-DS(WHT)	2037-DSC
CO (one hour)	(mg/m^3)	0.60	0.60	0.07	0.09	0.06	0.07
PM_{10} (annual)	($\mu g/m^3$)	0.89	0.89	0.21	0.26	0.26	0.28
PM_{10} (24-h)	($\mu g/m^3$)	7.07	7.07	1.25	1.50	1.56	1.62
$PM_{2.5}$ (annual)[(a)]	($\mu g/m^3$)	0.89	0.89	0.15	0.17	0.17	0.18
$PM_{2.5}$ (24-h)[(a)]	($\mu g/m^3$)	7.07	7.07	0.84	0.98	1.02	1.10

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

The concentrations in the regulatory worst case scenario were 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 ventilation outlet contribution in the regulatory worst case scenario (0.60 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 have been small. For the annual mean and maximum 24-hour metrics the ventilation outlet contributions were four per cent and 14 per cent of the respective criteria. This would be material 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 11 per cent and 28 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). The results were the same, or very similar, in both cases. The maximum ventilation 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)			
	2027-DS(WHT)	2027-DSC	2037-DS(WHT)	2037-DSC
Regulatory worst case scenarios				
All RWR receptors				
NO_X (annual mean)	15.47	15.99	15.51	16.46
NO_2 (annual mean)	4.80	4.96	4.81	5.27
All sensitive RWR receptors				
NO_X (annual mean)	15.47	15.99	15.51	15.77
NO_2 (annual mean)	4.80	4.96	4.81	5.05
Expected traffic scenarios				
All RWR receptors				
NO_X (annual mean)	1.51	1.79	1.59	1.82
NO_2 (annual mean)	0.42	0.46	0.46	0.616

Maximum 1-hour

The results of the more detailed assessment for NO_2 at the project ventilation outlets in the with-project and cumulative scenarios are shown, by scenario and ventilation outlet, on Figure 8-96 to Figure 8-103*.* 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 so the total NO_2 concentrations are well below the criterion.

For some receptors, the same maximum ventilation 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 can be misinterpreted, because as the background, surface road and portal contributions (and hence total NO_X) increase, there is a pronounced reduction in the contribution from the ventilation 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 ventilation 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 O_3 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.

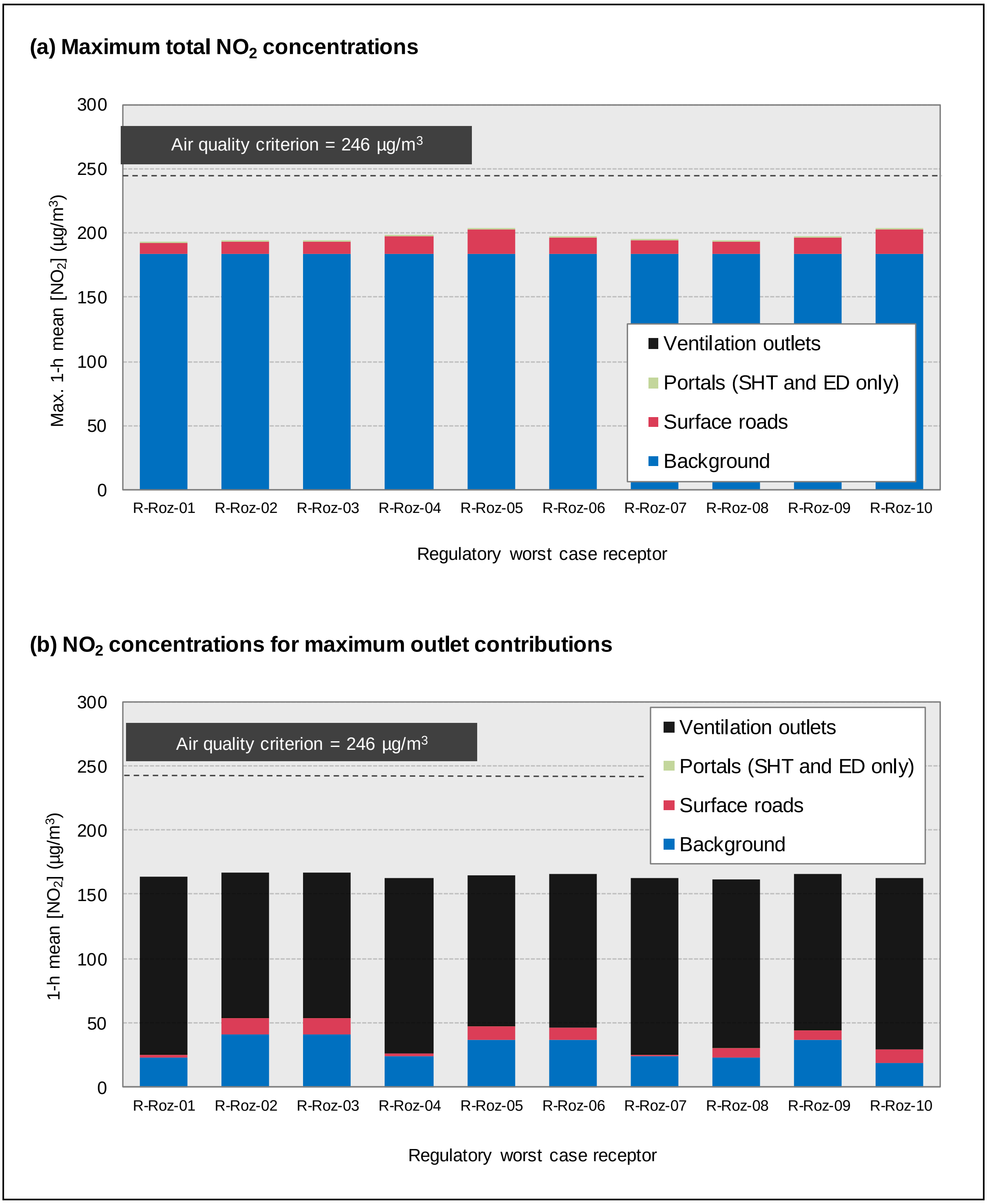


Figure 8-96 Regulatory worst case: 1-hour mean NO_2 concentrations (2027-DS(WHT), Rozelle ventilation outlets)

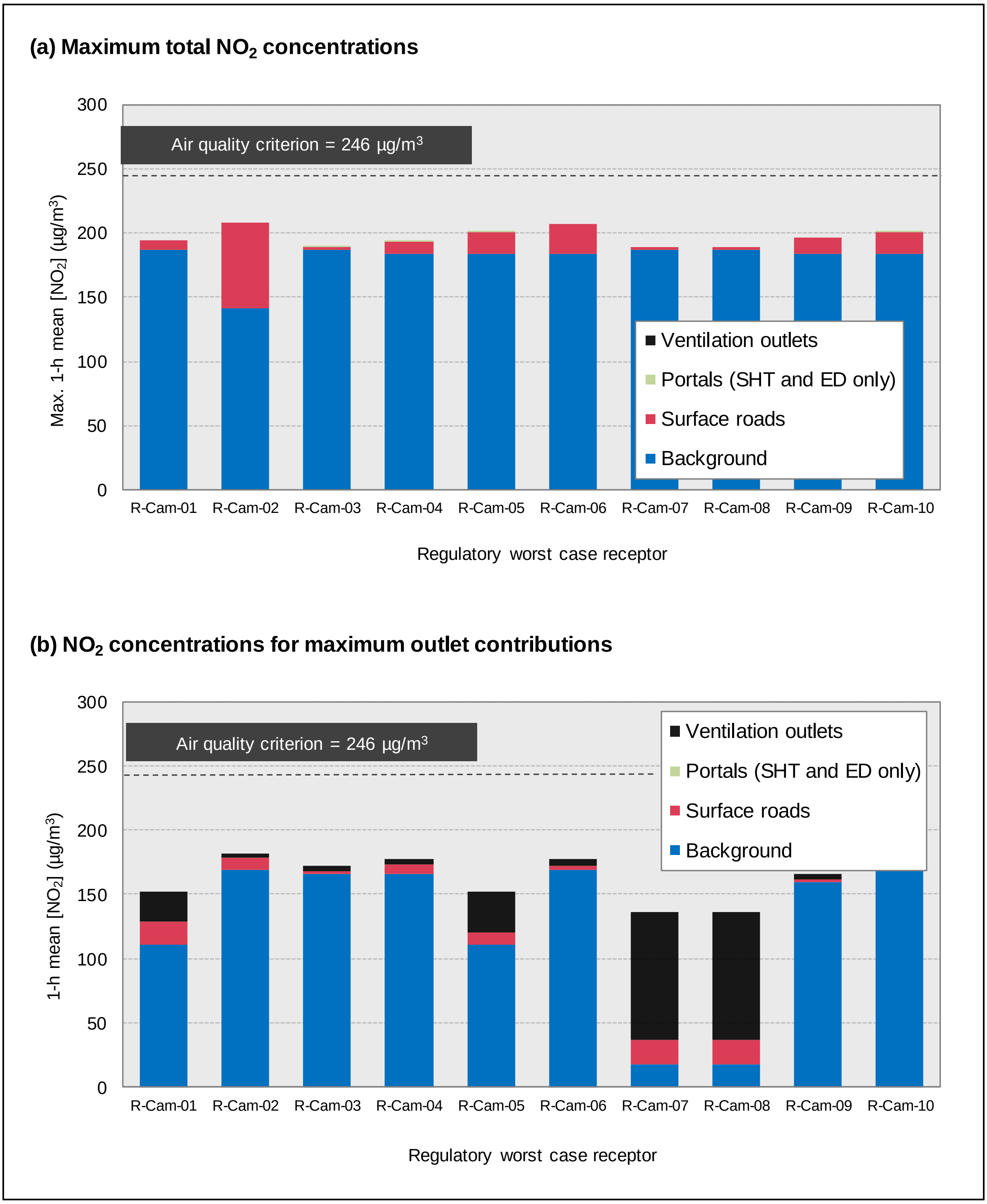


Figure 8-97 Regulatory worst case: 1-hour mean NO_2 concentrations (2027-DS(WHT), Warringah Freeway ventilation outlets)

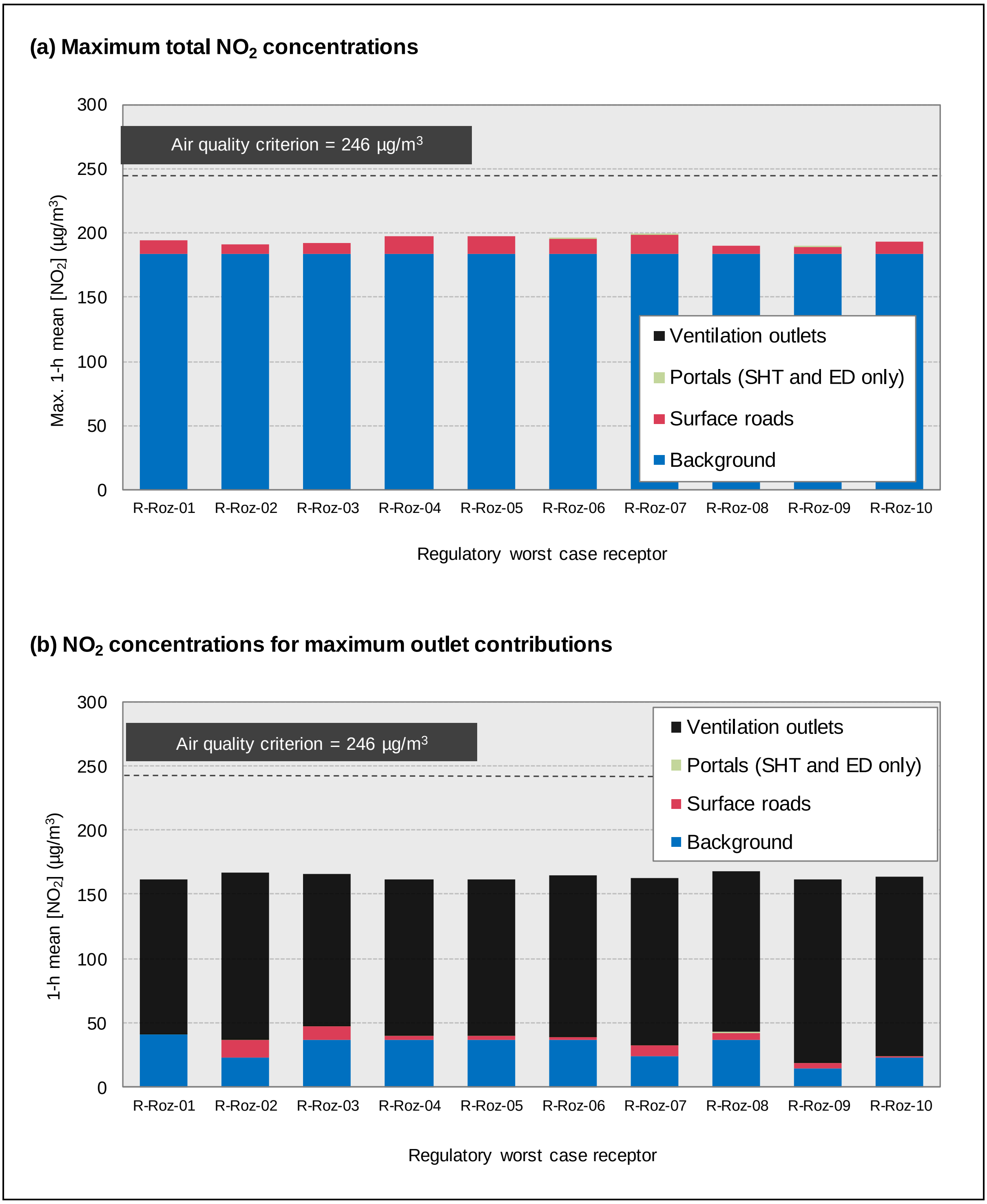


Figure 8-98 Regulatory worst case: 1-hour mean NO_2 concentrations (2027-DSC, Rozelle ventilation outlets)

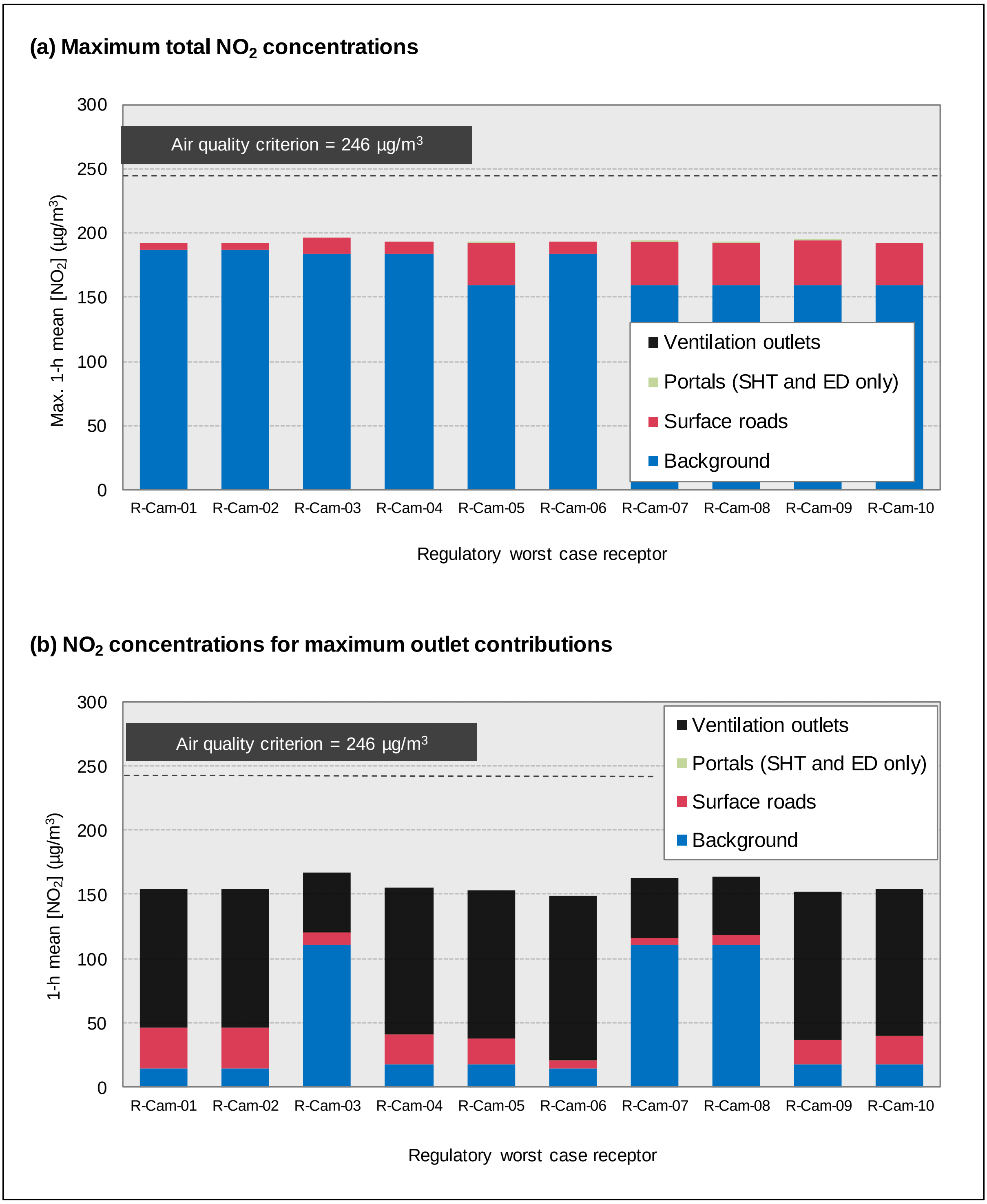


Figure 8-99 **Regulatory worst case: 1-hour mean NO_2 concentrations (2027-DSC, Warringah Freeway ventilation outlets)**

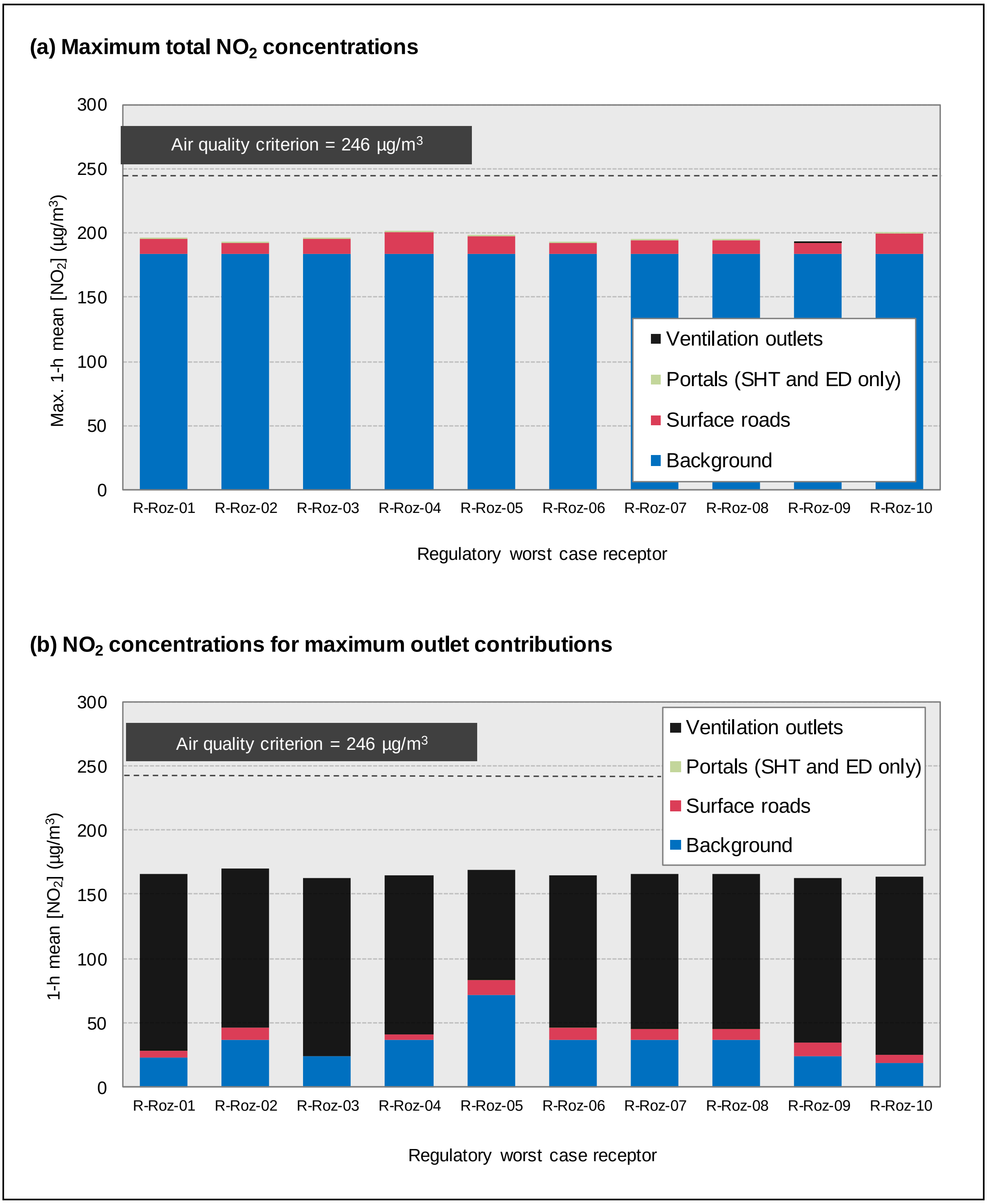


Figure 8-100 Regulatory worst case: 1-hour mean NO_2 concentrations (2037-DS(WHT), Rozelle ventilation outlets)

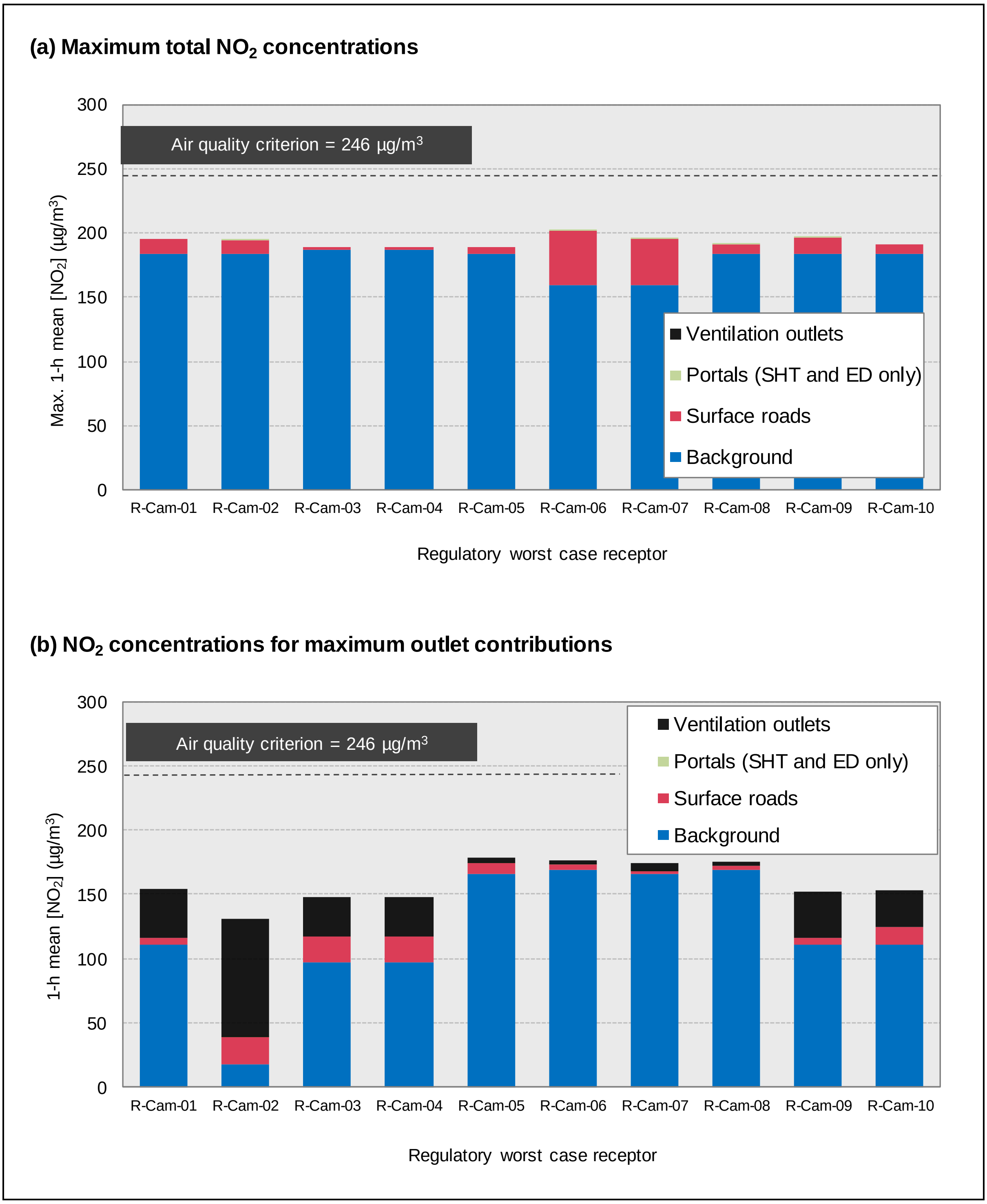


Figure 8-101 Regulatory worst case: 1-hour mean NO_2 concentrations (2037-DS(WHT), Warringah Freeway ventilation outlets)

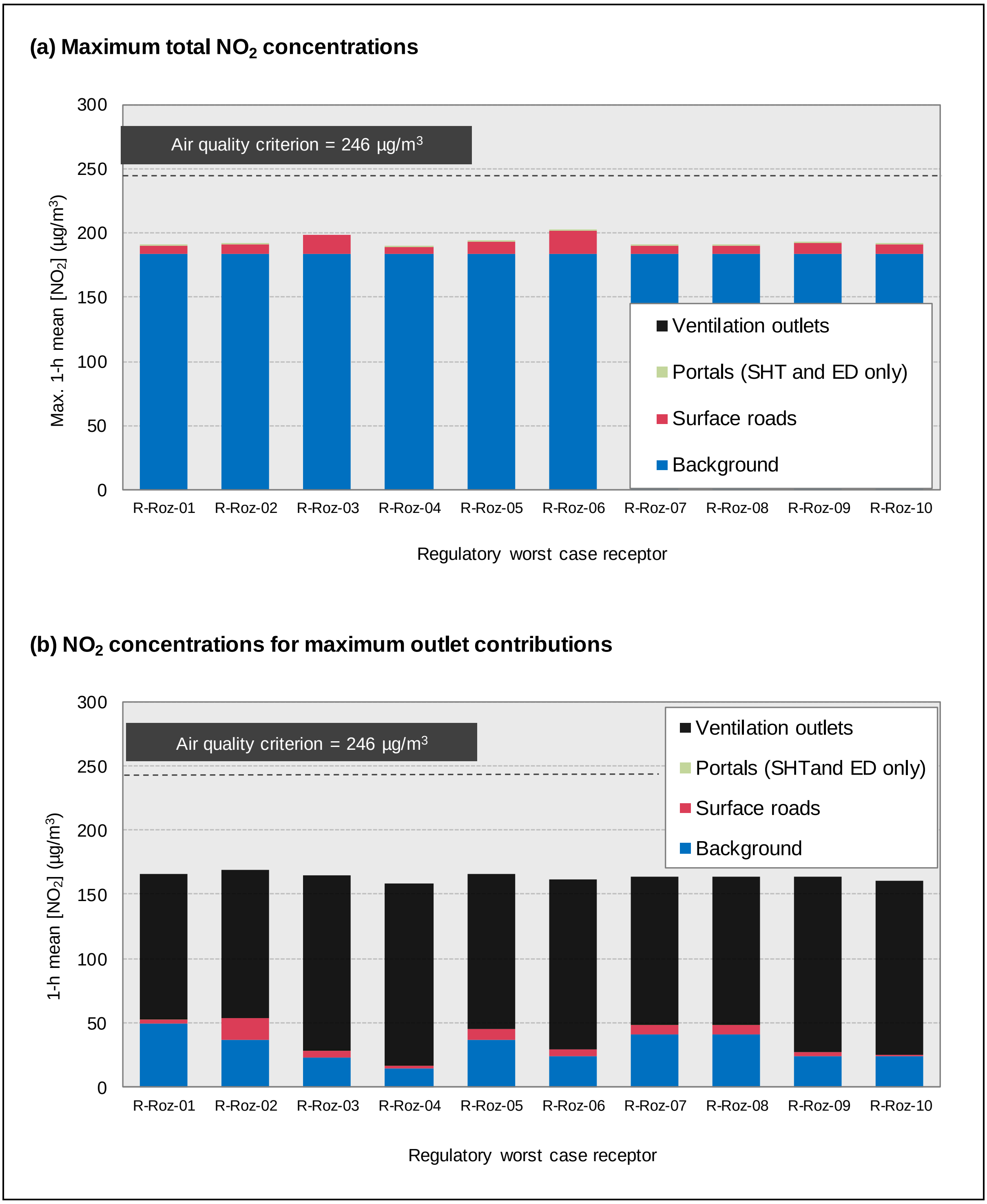


Figure 8-102 Regulatory worst case: 1-hour mean NO_2 concentrations (2037-DSC, Rozelle ventilation outlets)

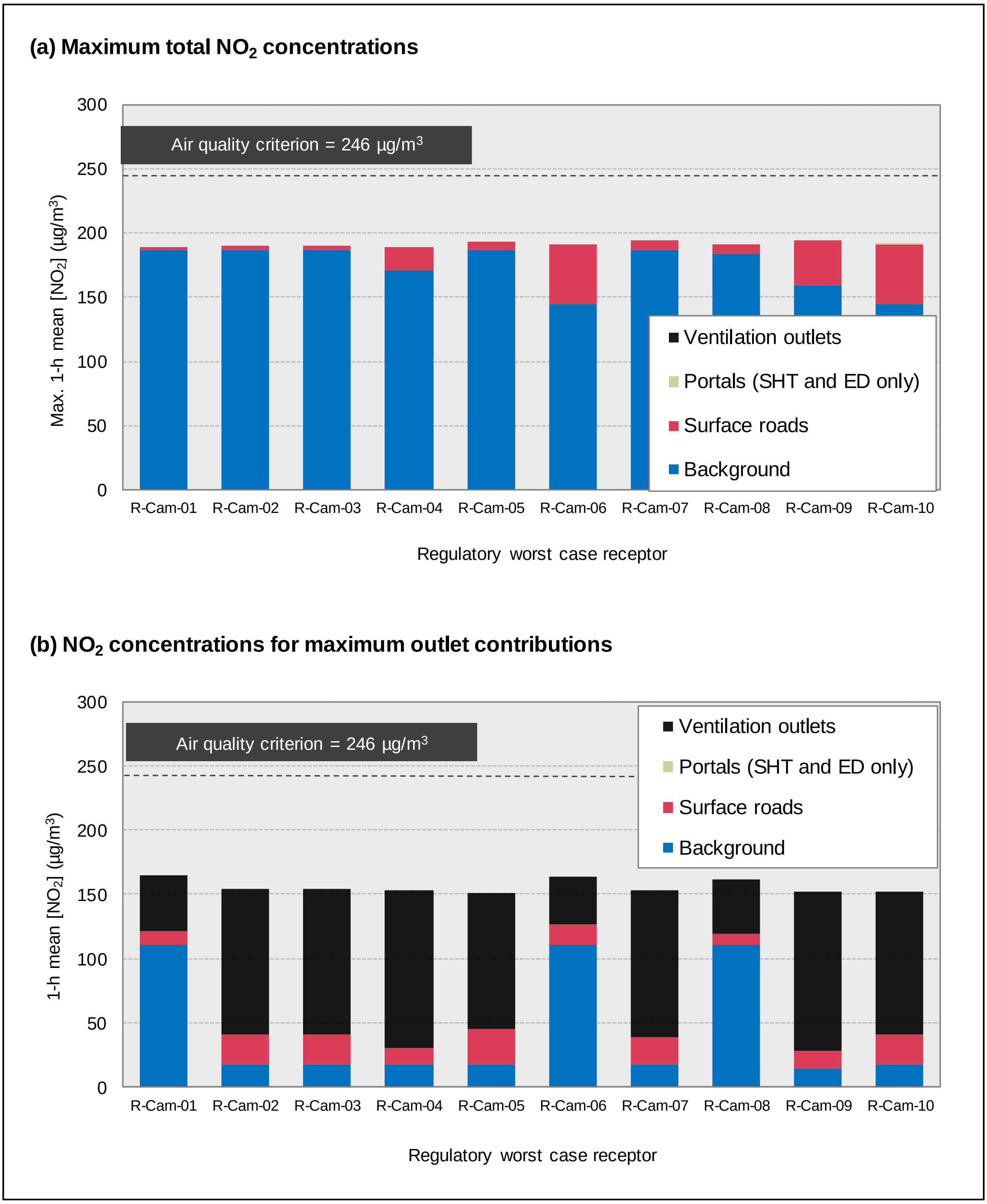


Figure 8-103 Regulatory worst case: 1-hour mean NO_2 concentrations (2037-DSC, Warringah Freeway ventilation outlets)

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

Ventilation outlet and metric	Maximum ventilation outlet contribution across 'top 10' receptors (µg/m^3)			
	2027-DS(WHT)	2027-DSC	2037-DS(WHT)	2037-DSC
Outlet F: Rozelle				
NO_2 (one hour) [when maximum total NO_2 occurs]	0.0	0.0	0.0	0.0
NO_2 (one hour) [when maximum ventilation outlet contribution to NO_2 occurs]	138.6	142.5	139.0	141.7
Outlet G: Warringah Freeway				
NO_2 (one hour) [when maximum total NO_2 occurs]	0.0	0.0	0.0	0.0
NO_2 (one hour) [when maximum ventilation outlet contribution to NO_2 occurs]	99.0	128.5	91.8	124.0

THC and air toxics

The maximum ventilation outlet concentrations for the five specific air toxics considered in the regulatory worst case assessment (scenario RWC-2027-DSC only) were determined using the THC predictions in conjunction with the speciation profiles stated in Table 8-19. 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 ventilation outlet contributions to the specific air toxics are well below the impact assessment criteria in the Approved Methods.

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

Pollutant and period	Units	Maximum ventilation outlet contribution at any receptor	
		Regulatory worst case scenario (RWC-2027-DSC)	Impact assessment criterion (µg/m^3)
THC (annual)	(µg/m^3)	3.24	-
THC (one hour)	(µg/m^3)	60.69	-
Benzene (1 hour)	(µg/m^3)	2.39	*29*
PAH (BaP) (1 hour)	(µg/m^3)	0.022	*0.4*
Formaldehyde (1 hour)	(µg/m^3)	2.07	*20*
1,3-butadiene (1 hour)	(µg/m^3)	0.64	*40*
Ethylbenzene (1 hour)	(µg/m^3)	0.79	*8000*

Table 8-28 shows that, even if the maximum ventilation outlet contribution is added to the maximum increase in concentration in the 2027-DSC scenario (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, 2027-DSC)

Pollutant and period	Units	Maximum ventilation outlet contribution at any receptor	Maximum increase due to project (ventilation outlet + expected traffic)	Sum	Impact assessment criteria
THC (1 hour)	($\mu g/m^3$)	60.69	-	-	-
Benzene (1 hour)	($\mu g/m^3$)	2.39	8.00	10.39	*29*
PAH (BaP) (1 hour)	($\mu g/m^3$)	0.022	0.070	0.090	*0.4*
Formaldehyde (1 hour)	($\mu g/m^3$)	2.07	6.93	9.00	*20*
1,3-butadiene (1 hour)	($\mu g/m^3$)	0.64	2.14	2.78	*40*
Ethylbenzene (1 hour)	($\mu g/m^3$)	0.79	2.65	3.43	*8000*

8.4.15 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 discussed in this section. This discussion is provided to clarify the level of uncertainty and conservatism in the assessment, and consequently the total conservatism in the predicted air quality impacts of the project.

Table 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 the Department of Planning, Industry and Environment (formerly Office of Environment and Heritage), Roads and Maritime and SMC air quality monitoring stations in the study area.	The monitoring stations were considered to reflect background air quality in the study area accurately.
		Pollutant concentrations at background monitoring stations in 2016 were assumed to be representative of background concentrations in 2027 and 2037.	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 stations. The GRAL model actually gave non-zero (but generally small) values at the locations of the background monitoring stations.	Total predicted concentrations (GRAL + background) would generally be overestimated across the GRAL domain. The annual mean GRAL predictions at the Rozelle background station in 2016 were: • CO 0.03 mg/m^3 • NO_X 14.5 µg/m^3 • PM_{10} 1.03 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 Department of Planning, Industry and Environment (formerly Office of Environment and Heritage) and Roads and Maritime monitoring stations in 2016 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.

Topic and sub-topic		Method and assumptions	Implications for conservatism
1.4	Community receptors *NO_X, 1-hour mean*	Hourly monitoring data several Department of Planning, Industry and Environment (formerly Office of Environment and Heritage)and Roads and Maritime monitoring stations in 2016 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 Department of Planning, Industry and Environment (formerly Office of Environment and Heritage) and Roads and Maritime monitoring stations in 2016 were combined, and the highest monitored concentration in each hour was selected as the background value for that hour.	This resulted in an average concentration that was higher than the average for any individual station, and a distribution of concentrations that was shifted towards higher values than for any individual station.
1.7	Community and RWR receptors *$PM_{2.5}$, 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. However, there were relatively few measurement stations for $PM_{2.5}$.
1.8	Community receptors *$PM_{2.5}$, 24-hour mean*	24-hour monitoring data from three Department of Planning, Industry and Environment (formerly Office of Environment and Heritage) monitoring stations in 2016 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 the 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.

Topic and sub-topic		Method and assumptions	Implications for conservatism
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 Lane Cove Tunnel (and probably more widely for tunnels in Sydney during normal operation), the NSW EPA emission factors overestimate real-world emissions (refer below).
3.2	CO emission factors	NSW EPA model	Lane Cove Tunnel 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	Lane Cove Tunnel 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	Lane Cove Tunnel 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	Lane Cove Tunnel 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 Lane Cove Tunnel analysis.
4	Emission model (tunnels)		
The assumptions concerning in-tunnel emissions are provided in Annexure K.			
5	Dispersion modelling (general)		
5.1	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 five-metre data used in the GRAL modelling.	The terrain data were assumed to reflect the study area accurately.
5.2	Meteorology	Data from the Department of Planning, Industry and Environment (formerly Office of Environment and Heritage) Randwick meteorological station were chosen as the input to GRAMM for modelling, with match-to-observations at other stations.	The site was considered to be representative of the meteorology in the domain.

Topic and sub-topic		Method and assumptions	Implications for conservatism
6	Dispersion modelling (ventilation outlets)		
6.1	Portal emissions	Portal emissions were modelled for the Sydney Harbour Tunnel and the Eastern Distributor tunnel.	It was assumed that there would be full portal emissions at all times of day, with emissions being calculated using traffic volumes from the SMPM and emission factors from the NSW EPA model. Measure air flows in the tunnel were used to characterise exit velocities. It was considered that, overall, this combination would give a conservative estimate of the concentrations around the tunnel portals.
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 project showed that the total predicted concentrations are not likely to be very sensitive to ventilation outlet height, based on a sensitivity range of 20 to 40 metres.
6.2	Ventilation outlet exit diameter	The dispersion modelling involved either time-varying or fixed ventilation outlet diameters, depending on the ventilation 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	Ventilation Outlet temperature	An annual average ventilation 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 project showed that the total predicted concentrations are not likely to be very sensitive to ventilation outlet temperature, based on a sensitivity range of 15 – 35ºC.

Topic and sub-topic		Method and assumptions	Implications for conservatism
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.
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 RWR receptors. The maximum 1-hour mean NO_X value predicted by GRAL was added to the 98th percentile NO_X value for the background in the synthetic profile for 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.

8.4.16 Sensitivity tests – ventilation 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 (ie background and surface road contributions were excluded), and for maximum 1-hour $PM_{2.5}$, 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 (eg CO, NO_X, and PM_{10}).

The tests were mainly conducted for a sub-area of the Western Harbour Tunnel GRAL domain of around two kilometres x two kilometres around the Warringah Freeway ventilation outlets (Outlet G for project and Outlet H for Beaches Link), as shown on Figure 8-104.

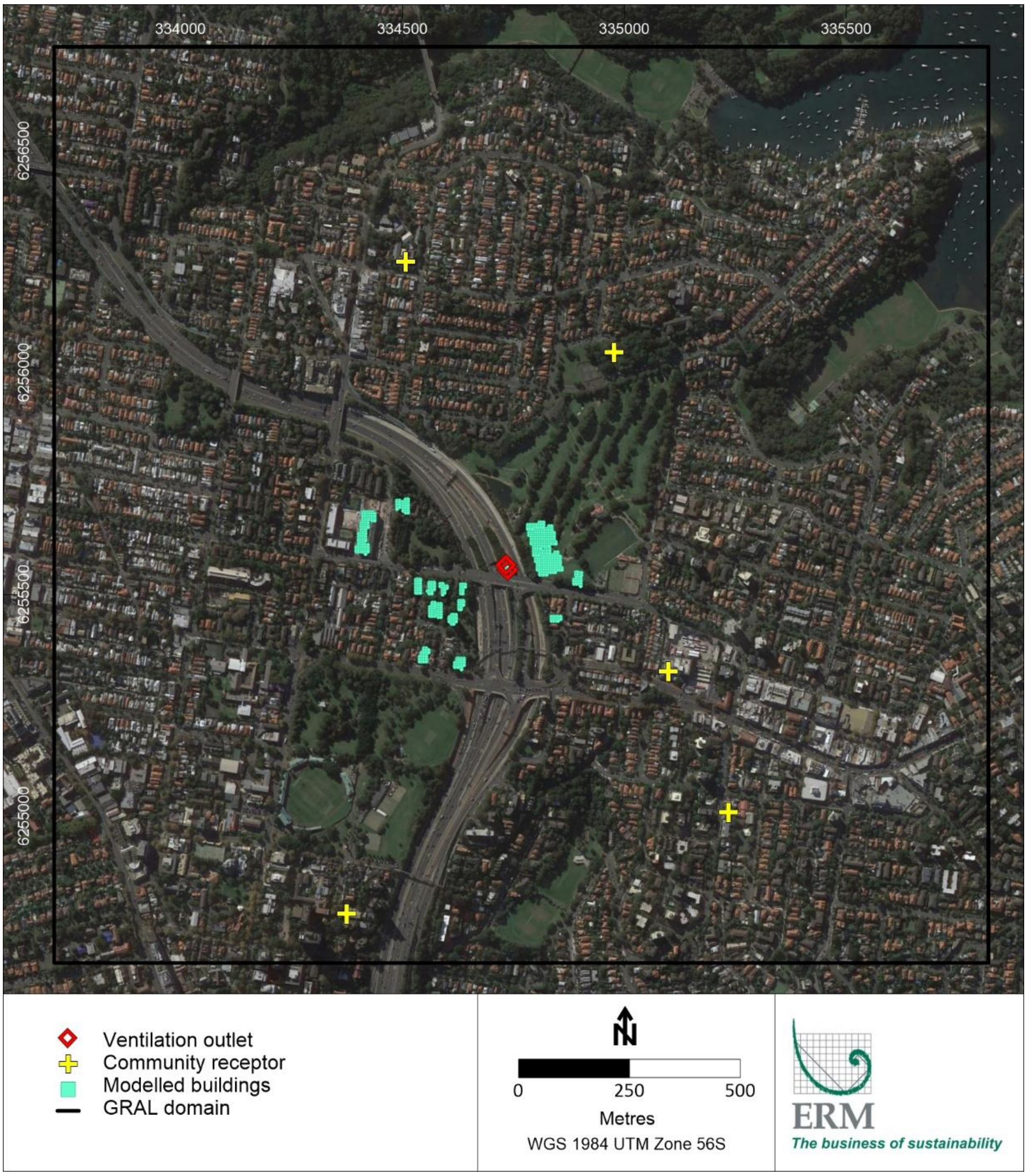


Figure 8-104 Domain and buildings for Warringah Freeway ventilation outlets sensitivity tests

Model predictions were considered for five community receptors located within the Warringah Freeway domain, as listed in Table 8-30.

Table 8-30 Community receptors included in the sensitivity tests

ID	Location
CR08	Wenona School
CR10	Neutral Bay Public School
CR11	Neutral Bay Medical Centre
CR17	KU Cammeray Preschool
CR18	Cammeray Public 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 25ºC. The effects of defining ventilation outlet temperatures 10ºC below and above this value were then investigated. In temperature test TT01, the ventilation outlet temperature was set to 15ºC, and in temperature test TT03, the ventilation outlet temperature was set to 35ºC.

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 ventilation outlet temperature of 15ºC, the predicted $PM_{2.5}$ concentrations were higher at almost all locations and averaging periods 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 40 per cent. The predicted ventilation outlet concentrations remained well below the air quality criteria for $PM_{2.5}$.

For the ventilation outlet temperature of 35ºC, the predicted $PM_{2.5}$ concentrations were lower at almost all locations and averaging periods than those in the central estimate because of increased thermal plume buoyancy. The largest decrease at any community receptor was 32 per cent.

Table 8-31 Results of sensitivity tests for ventilation 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 Average	Max 1h	Max 24h	Annual Average	Max 1h	Max 24h	Annual Average
		Impact Assessment Criteria								
		N/A	*25*	*8*	N/A	*25*	*8*	N/A	*25*	*8*
CR08	Wenona School	0.720	0.235	0.031	0.660	0.196	0.023	0.659	0.200	0.019
CR10	Neutral Bay Public School	1.001	0.277	0.013	1.022	0.217	0.010	0.921	0.170	0.007
CR11	Neutral Bay Medical Centre	1.296	0.394	0.026	1.180	0.329	0.021	0.835	0.238	0.014
CR17	KU Cammeray Preschool	1.604	0.525	0.044	1.539	0.446	0.036	1.349	0.418	0.032
CR18	Cammeray Public School	1.299	0.523	0.044	1.096	0.543	0.041	1.066	0.465	0.032

Table 8-32 Results of sensitivity tests for ventilation 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
CR08	Wenona School	9%	20%	31%		0%	2%	-18%
CR10	Neutral Bay Public School	-2%	28%	40%		-10%	-21%	-22%
CR11	Neutral Bay Medical Centre	10%	20%	24%		-29%	-28%	-32%
CR17	KU Cammeray Preschool	4%	18%	24%		-12%	-6%	-12%
CR18	Cammeray Public School	18%	-4%	8%		-3%	-14%	-20%

*No values presented for 25°C as the percentage change is compared against this central estimate.

Ventilation outlet height

For the ventilation outlet heights, the central estimate (for test HT02) was taken to be 30 metres (the ventilation outlet height used in the expected traffic case modelling). In height test HT01, the height was set to 20 metres, and in height test HT03, the height was set to 40 metres. This was considered to be a realistic potential range for the ventilation 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 ventilation outlet height of 20 metres, the predicted $PM_{2.5}$ concentrations were systematically higher at all locations 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 50 per cent. As with the temperature tests, the predicted ventilation outlet concentrations remained well below the air quality criteria for $PM_{2.5}$.

For the ventilation outlet height of 40 metres, the predicted $PM_{2.5}$ concentrations were systematically lower than those in the central estimate. The largest decrease at any community receptor was 30 per cent.

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

ID	Name	HT01 (20 metres)			HT02 (30 metres)			HT03 (40 metres)		
		$PM_{2.5}$ (µg/m³)								
		Max 1h	Max 24h	Annual Average	Max 1h	Max 24h	Annual Average	Max 1h	Max 24h	Annual Average
		Impact Assessment Criteria								
		N/A	*25*	8	N/A	*25*	*8*	N/A	*25*	*8*
CR08	Wenona School	1.150	0.287	0.030	1.039	0.279	0.029	1.001	0.212	0.025
CR10	Neutral Bay Public School	1.534	0.370	0.013	1.362	0.300	0.013	1.207	0.255	0.012
CR11	Neutral Bay Medical Centre	2.265	0.586	0.034	1.736	0.414	0.027	1.214	0.292	0.020
CR17	KU Cammeray Preschool	2.515	0.796	0.061	1.779	0.551	0.046	1.469	0.393	0.036
CR18	Cammeray Public School	2.218	0.865	0.060	1.604	0.576	0.050	1.174	0.421	0.042

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

ID	Name	**Change in $PM_{2.5}$ relative to central estimate (%)**						
		HT01 (20 metres)			HT02 (30 metres)*	HT03 (40 metres)		
		Max 1h	Max 24h	Annual		Max 1h	Max 24h	Annual
CR08	Wenona School	11%	3%	2%		-4%	-24%	-14%
CR10	Neutral Bay Public School	13%	23%	4%		-11%	-15%	-7%
CR11	Neutral Bay Medical Centre	30%	41%	25%		-30%	-30%	-26%
CR17	KU Cammeray Preschool	41%	44%	31%		-17%	-29%	-23%
CR18	Cammeray Public School	38%	50%	22%		-27%	-27%	-16%

*No values presented for 30 metres as the percentage change is compared against this central estimate.

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 8.4.7 of this report). The sensitivity of the inclusion of buildings to predicted concentrations was therefore assessed.

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 18 per cent, and a maximum decrease of 20 per cent.

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

ID	Name	$PM_{2.5}$ (µg/m^3)								
		BT01 (with buildings)			BT02 (without buildings)			*Change with buildings compared to without buildings (%)*		
		Max 1h	Max 24h	Annual Average	Max 1h	Max 24h	Annual Average	Max 1h	Max 24h	Annual Average
		Impact Assessment Criteria								
		N/A	*25*	8	N/A	*25*	*8*	N/A	*25*	*8*
CR8	Wenona School	1.728	0.366	0.046	1.551	0.409	0.055	*10%*	*-12%*	*-20%*
CR10	Neutral Bay Public School	1.783	0.421	0.027	1.912	0.415	0.027	*-7%*	*1%*	*0%*
CR11	Neutral Bay Medical Centre	3.436	0.595	0.051	3.320	0.595	0.047	*3%*	*0%*	*8%*
CR17	KU Cammeray Preschool	2.690	0.750	0.078	2.585	0.820	0.073	*4%*	*-9%*	*6%*
CR18	Cammeray Public School	2.398	0.810	0.081	1.973	0.758	0.070	*18%*	*6%*	*14%*

Interpretation

In the ventilation outlet temperature tests, even with a significant change in temperature relative to the central estimate, the predicted ventilation 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.

While the building tests were not comprehensive, they also indicated (again, given the small absolute ventilation 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.

8.4.17 Sensitivity tests – traffic and emissions

Results for this sensitivity test outlined in Section 5.5.2 have been presented for the ten most impacted RWR receptors surrounding each ventilation outlet, separately for annual mean and maximum 24-hour average $PM_{2.5}$, for the regulatory worst case (RWC) scenario. The locations of the individual receptors around the ventilation outlets are presented in Annexure L.

Figure 8-105 presents the annual mean $PM_{2.5}$ results for the three scenarios, that is, expected traffic (ET), the sensitivity test (with the scaling factors applied) and the RWC for the ten most impacted RWR receptors around each of the project-related ventilation outlets (for cumulative scenarios). These are presented on a single figure for ease of comparison. The results for all scenarios (ET, sensitivity and RWC) are to a significant number of decimal places and for ease of reporting have been rounded to two decimal places in the tables in Annexure L. The sensitivity as a percentage of RWC has been calculated using the original results and presented to the nearest whole number.

Figure 8-106 and Figure 8-107 presents this same information, for the two project-related ventilation outlets individually (outlets F and G).

Results for the maximum 24-hour average $PM_{2.5}$, as well as tabulated results for both averaging periods, are presented in Annexure L.

The following commentary is provided for the sensitivity test outcomes:

- The impacts for the sensitivity scenario lie between the expected traffic (ET) and RWC scenario, as anticipated, but to varying degrees depending on the averaging time and the nearest ventilation outlet
- The sensitivity scenario concentrations, as a percentage of the RWC concentrations, were slightly higher for annual average $PM_{2.5}$ concentrations than for the maximum 24-hour average $PM_{2.5}$ concentrations
- For annual average $PM_{2.5}$, the sensitivity scenario concentrations, as a percentage of RWC concentrations, were highest at receptors surrounding the Rozelle Interchange ventilation outlet. At RWR-25739 and RWR-25735 the results for the sensitivity scenario were 53 per cent of the RWC values
- For maximum 24-hour average $PM_{2.5}$, the sensitivity scenario concentrations as a percentage of RWC impacts were slightly higher at receptors surrounding the Rozelle Interchange ventilation outlet, with a maximum of 41 per cent at RWR-26836, RWR-26922 and RWR-26930.

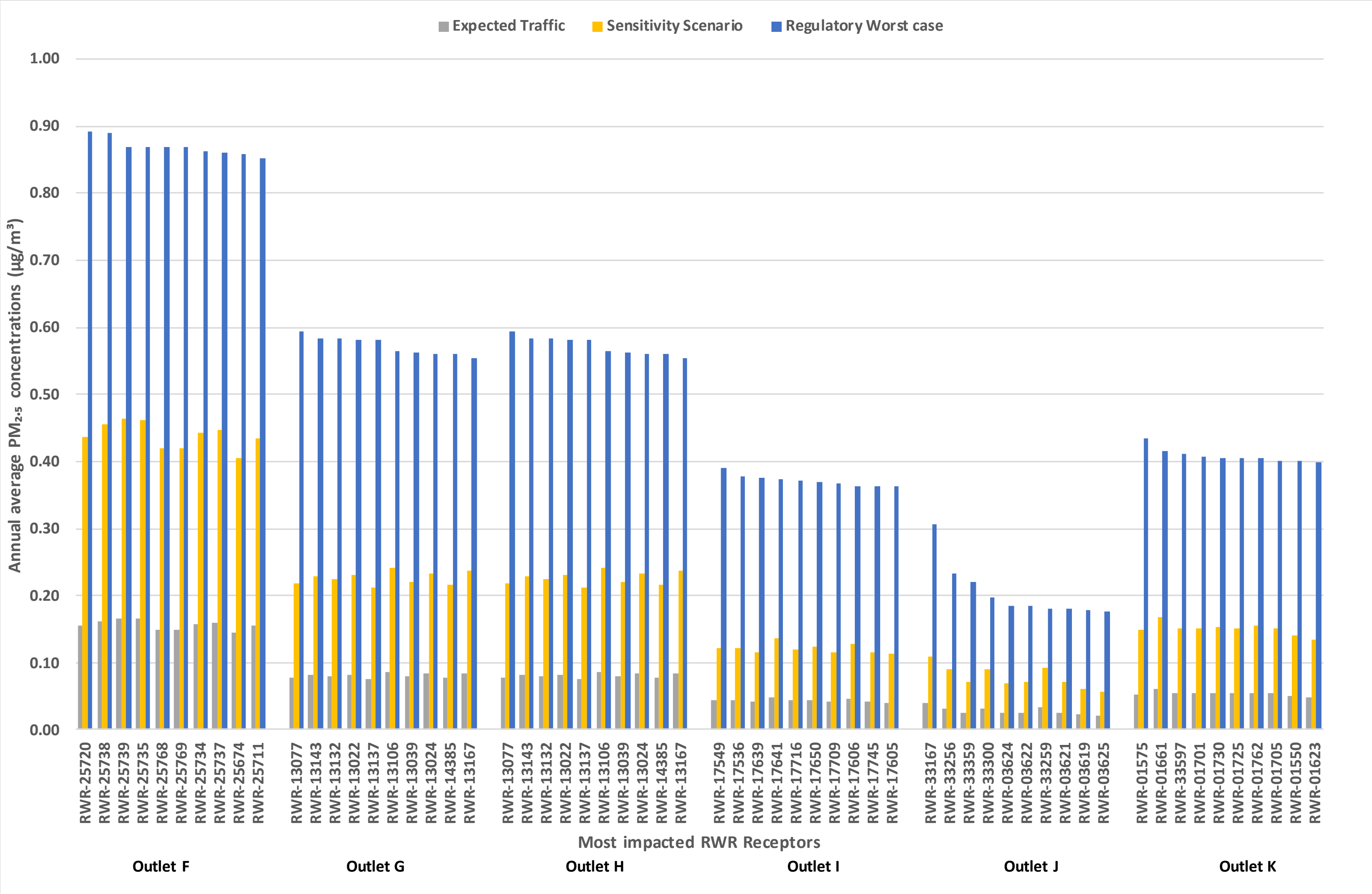


Figure 8-105 Annual average $PM_{2.5}$ concentrations for the sensitivity scenario compared against ET and RWC for the ten most impacted surrounding each of the project-related ventilation outlets

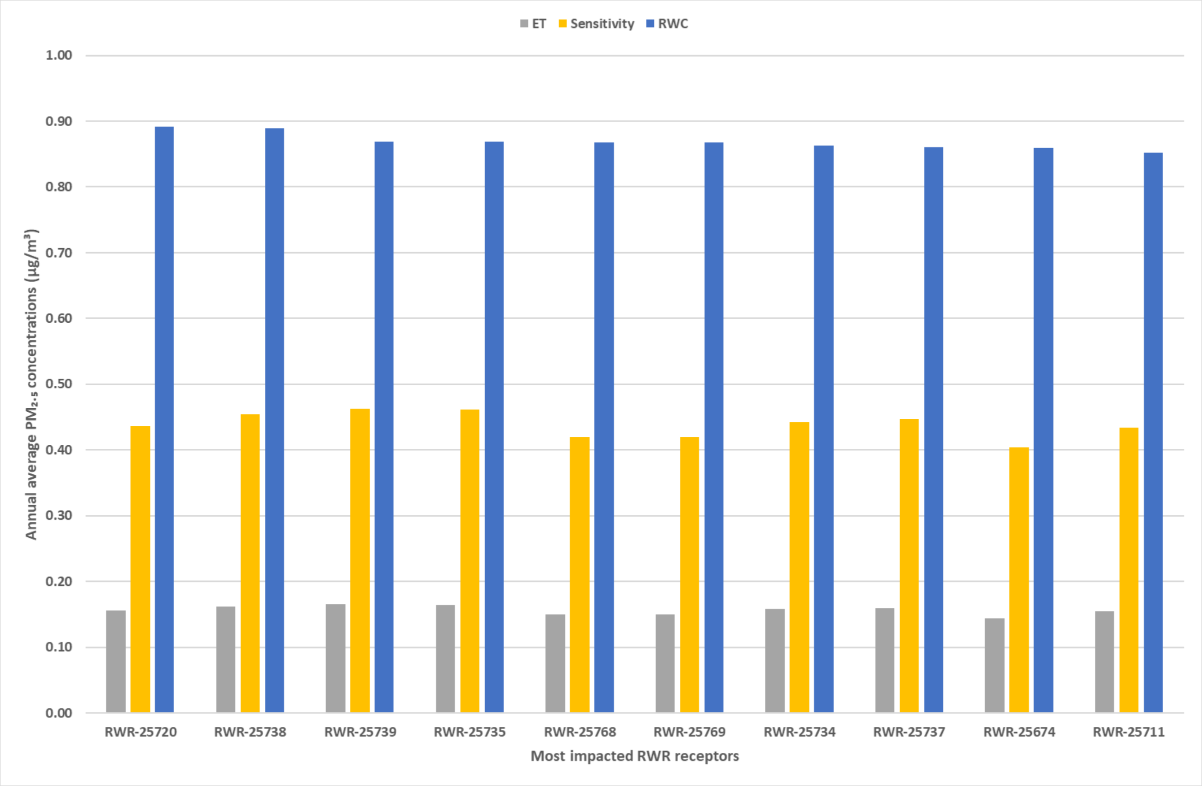


Figure 8-106 Annual average $PM_{2.5}$ concentrations for the sensitivity scenario compared against ET and RWC for the ten most impacted surrounding the Western Harbour Tunnel Rozelle Interchange ventilation outlet (F)

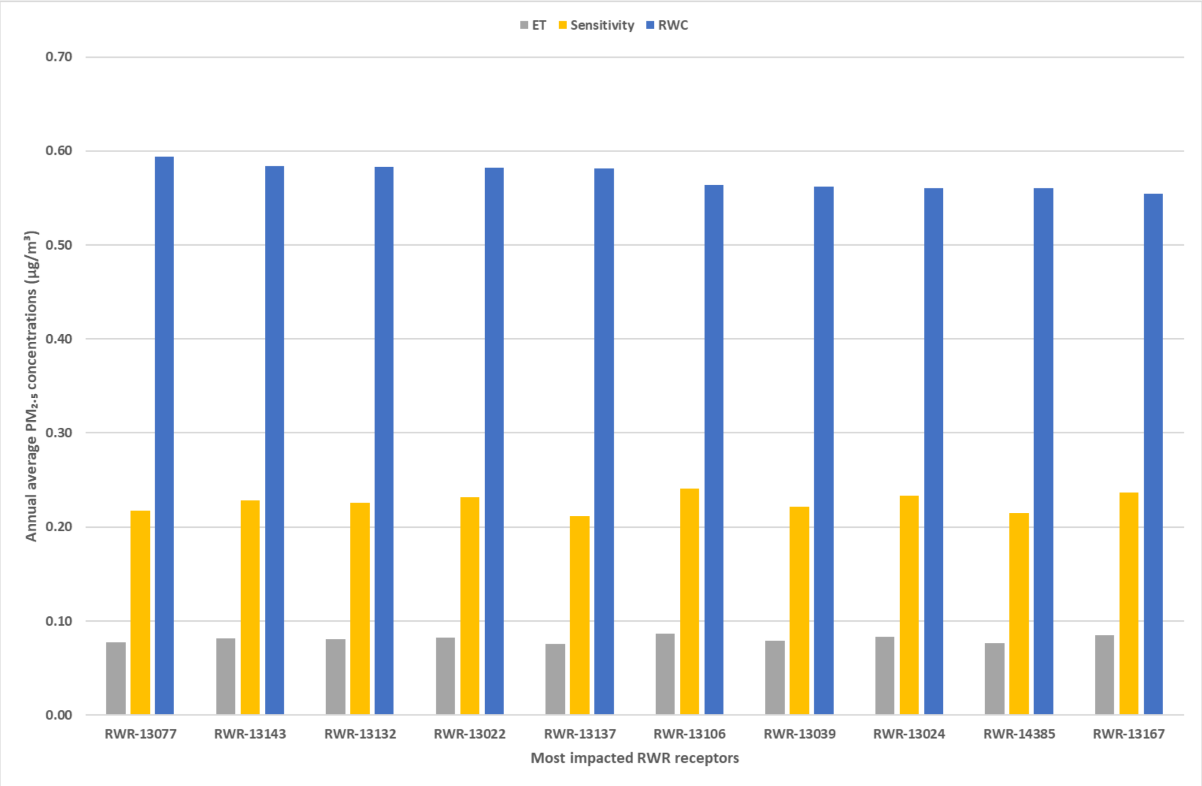


Figure 8-107 Annual average $PM_{2.5}$ concentrations for the sensitivity scenario compared against ET and RWC for the ten most impacted surrounding the Western Harbour Tunnel Warringah Freeway ventilation outlet (G)

8.5 Regional air quality

For the traffic on the roads in the GRAL domain, the absolute changes in total annual emission rates due to the project were given in Table 8-9. 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 the NO_X emission rate due to the project in a given assessment year (2027 or 2037) ranged from an increase of around one tonne per year to a decrease of around four tonnes per year, and in the 'Do something cumulative' scenarios, ranged from an increase of around 29 tonnes to 125 tonnes per year.. These values equated to very small proportions of anthropogenic NO_X emission rate in the entire Sydney airshed in 2016 (around 53700 tonnes per year)
- Any increases in the NOx emission rate due to the project in a given assessment year (2027 or 2037) were much smaller than the underlying reduction in the emission rate between 2016 and 2037. This underlying reduction was around 2000 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 O_3 'attainment' or 'non-attainment' area, based on measurements from Department of Planning, Industry and Environment (formerly Office of Environment and Heritage) monitoring stations over the past five years and criteria specified in the procedure. Following this approach, the project was identified as being in an O_3 non-attainment area, although it should be noted that there are few long-term monitoring stations 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 per year for new sources, above which a detailed modelling assessment for O_3 may be required. Some lower thresholds are also specified for modified sources and for the scale of O_3 non-attainment.

The results in Table 8-9 show that, the largest increase in NO_X emissions (125 tonnes per year in the 2037-DSC) was above the 90 tonnes per year threshold for assessment. Further assessment was therefore undertaken using the NSW EPA Level 1 screening tool. Table 8-36 presents the outputs from these calculations, showing the project does not exceed the screening impact level of 0.5 ppb, and no further consideration is required.

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

Table 8-36 Summary of Level 1 screening tool for ozone

Scenario	Increase in NO_X emissions (tonnes/year)	Maximum 1-hour incremental (ppb)	Maximum 4-hour incremental (ppb)
2037-DSC	125	0.2	0.1

8.6 Odour

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.

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 8-37. 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 8-37 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)
2027-DS(WHT)	68.9	4.9	4.1	1.1
2027-DSC	51.0	3.6	3.0	0.8
2037-DS(WHT)	61.3	3.6	3.0	1.2
2037-DSC	42.3	2.5	2.1	0.8
Odour criterion (µg/m^3)		360	190	42

9 Management of impacts

9.1 Management of construction impacts

Dust

Details of the construction assessment are outlined in Section 7.1. Step 3 of the construction assessment involved determining mitigation measures for each of the four activities in Step 2. This was based on the risk of dust impacts identified in Step 2C and the outcomes are shown in Table 9-1. All mitigation measures are highly recommended. Most of the recommended measures are routinely employed as 'good practice' on construction sites.

Construction environmental management documentation would 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[28]. 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 Recommended mitigation measures for construction dust

	Mitigation measure
1	Standard construction air quality mitigation and management measures would be detailed in construction management documentation and implemented during construction, such as: • Reasonable and feasible dust suppression and/or management measures, including the use of water carts, dust sweepers, sprinklers, dust screens, site exit controls (eg wheel washing systems and rumble grids), stabilisation of exposed areas or stockpiles, and surface treatments • Selection of construction equipment and/or materials handling techniques that minimise the potential for dust generation • Management measures to minimise dust generation during the transfer, handling and on site storage of spoil and construction materials (such as sand, aggregates or fine materials) (eg the covering of vehicle loads) • Adjustment or management of dust generating activities during unfavourable weather conditions, where possible • Minimisation of exposed areas during construction • Internal project communication protocols to ensure dust-generating activities in the same area are coordinated and mitigated to manage cumulative dust impacts of the project • Site inspections will be carried out to monitor compliance with implemented measures.
2	Dust and air quality complaints will be managed in accordance with the overarching complaints handling process for the project. Appropriate corrective actions would be taken to reduce emissions in a timely manner.
3	Liaison and coordination measures will be put in place with the proponents of other major construction projects within 500 metres of the project, to minimise and manage potential cumulative construction dust impacts. Measures may include scheduling of construction activities and construction deliveries, coordinated monitoring and data sharing, cooperation in the event of cumulative dust complaints, and coordination of engagement with potentially affected receivers.

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

Odour

The dispersion modelling results for odour from dredging were shown in Section 7.2. Predictions were well below both the level of detection and the most stringent odour criterion and it is unlikely that any mitigation would be required.

9.2 Management of operational impacts

9.2.1 Overview

The Secretary's environmental assessment requirements 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 is 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. Traffic management can also be used to improve traffic flows, which results in reduced overall emissions.

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. Ventilation, and the dispersion of pollutants, is overwhelmingly the most popular and effective 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 ventilation 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 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, where 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, where 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, 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).

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

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 ventilation 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, is reinjected into the tunnel and then eventually discharged by the existing ventilation 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).

In November 2018, the ACTAQ published a technical paper which reviewed options for treating road tunnel emissions (ACTAQ, 2018). The review concluded that:

- Decisions on how to best manage tunnel air can only be made at the project level. Health-based air quality standards must be a priority; however, engineering and economic factors also need to be taken into account
- Air filtration systems in tunnels are rare around the world. They have high infrastructure, operating and maintenance costs
- Although filtration for particulates or NO_2 is technically feasible, the available technologies will not lower concentrations of other air pollutants
- Alternatives such as portal air extraction (ie no portal emissions) and dispersion via ventilation outlets may achieve the same outcomes as filtration at a lower cost.

This assessment has demonstrated that the design of the ventilation outlets would achieve the same (or better) outcomes as installing filtration – that is, the contribution of tunnel ventilation outlets to pollutant concentrations would be negligible for all receptors.

Emission controls and other measures

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

- Traffic management. Traffic management would 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 influence driver behaviour in tunnels
- Cleaning the tunnel regularly to avoid high concentrations of small particles (PIARC, 2008).

9.2.3 Summary

Section 9.2.2 provided a review of the measures that are available for improving tunnel-related air quality. The measures that will be adopted for the project are summarised below.

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

- Minimal gradients as far as reasonably practicable
- Large tunnel cross-sectional area to reduce the pollutant concentration for a given emission into the tunnel volume, and to permit greater volumetric air throughput. The tunnels would have a width of varying between nine to 12.5 metres and, with a vertical clearance of about 5.3 metres, which would be higher than most previous tunnels
- Increased height to reduce the risk of incidents involving high vehicles blocking the tunnel and disrupting traffic. This would reduce the risk of higher pollutant concentrations associated with flow breakdown.

With regard to the ventilation design and control:

- The ventilation system has been designed and would be operated so that it would achieve some of the most stringent standards in the world for in-tunnel air quality, and would be effective at maintaining local air quality.
- The design of the ventilation system will ensure zero portal emissions. This would involve using jet fans to draw air back into the tunnel at the exit portals, to be emitted via the ventilation outlets.
- 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 would be developed to manage breakdown, congested and emergency situations.

10 Summary and conclusions

This report has presented an assessment of the construction and operational activities for the Western Harbour Tunnel 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 guidance 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 settlement, the risk of health effects due to an increase in exposure to PM_{10}, and harm to ecological receptors.

For the project, above-ground construction activities would take place at a number of separate locations, which 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, without mitigation. Consequently, a range of management measures have 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 standard practice on NSW construction sites. 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 would be ‘not significant’.

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 project 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 Local 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 substantial 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 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. For example:
  - With the Western Harbour Tunnel, there were predicted to be marked decreases in pollutant concentrations along the Western Distributor, Sydney Harbour Bridge and Warringah Freeway, reflecting reductions in traffic of between 16 per cent and 37 per cent on these roads. There was also a marked reduction in concentration in the vicinity of the northern portal of the Eastern Distributor tunnel (associated with a 26 per cent reduction in traffic) and, to a lesser extent, the portals of Sydney Harbour Tunnel.
  - In the cumulative scenarios, there were predicted to be some additional changes as a result of the Beaches Link project. These included reductions in concentration along Military Road, Spit Road, Manly Road and Warringah Road. There was an increase in concentration along Wakehurst Parkway as a result of the substantial increase in traffic (around 140 per cent) associated with Beaches Link. However, the section of Wakehurst Parkway that is affected crosses bushland, and there are no sensitive receptors close to the road.

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 37 and 49 per cent of RWR receptors, although even the largest increase (0.9 mg/m^3) was an order of magnitude below the criterion
- The largest contribution from ventilation outlets at any receptor was less than 0.1 mg/m^3.

Carbon monoxide (maximum rolling 8-hour mean)

- As with the 1-hour mean, the concentration was well below the NSW impact assessment criterion at all receptors, which in this case is 10 $\mu g/m^3$. No lower criteria appear to be in force internationally. Any increases in concentration with the project were again negligible.

Nitrogen dioxide (annual mean)

- The NO_2 concentration was well below the NSW impact assessment criterion of 62 $\mu g/m^3$ at all RWR 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 97 per cent) of receptors were between around 13 $\mu g/m^3$ and 25 $\mu g/m^3$
- The maximum contribution of tunnel ventilation outlets for any scenario and receptor was 0.6 $\mu g/m^3$, while the maximum surface road contribution was 22 $\mu g/m^3$. 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 between 40 per cent and 52 per cent of receptors, depending on the scenario. The increase in concentration was greater than 1 µg/m^3 for just 0.8 per cent of receptors.

Nitrogen dioxide (maximum 1-hour mean)

- The maximum 1-hour NO_2 concentration was below the NSW impact assessment criterion of 246 µg/m^3 at all community receptor locations investigated in detail
- At the RWR receptors, there were some predicted exceedances of the NSW 1-hour NO_2 criterion (246 µg/m^3), both with and without the project. The number of receptors with exceedances decreased with the project and in the cumulative scenarios
- There was predicted to be an increase in the maximum 1-hour NO_2 concentration at between 30 per cent and 44 per cent of RWR receptors, depending on the scenario. At the majority of receptors the change was relatively small; at more than 99 per cent of receptors the change in concentration (either an increase or a decrease) was less than 20 µg/m^3. Some of the changes at receptors were much larger (up to 128 µg/m^3)
- The maximum contribution of tunnel ventilation outlets to NO_X at any receptor in the with-project or cumulative scenarios was 60 µg/m^3. This would equate to a very small NO_2 contribution relative to the air quality assessment criterion.

PM_{10} (annual mean)

- The annual mean PM_{10} concentration at all RWR receptors was below the NSW impact assessment criterion of 25 µg/m^3
- The surface road contribution was less than 7 µg/m^3, with an average of 0.8–0.9 µg/m^3. The largest contribution from tunnel ventilation outlets at any receptor was 0.3 µg/m^3
- There was an increase in concentration at 43–52 per cent of the receptors with the project and in the cumulative scenarios, depending on the scenario. At the majority of receptors the change was relatively small, and where there was an increase, this was greater than 0.5 µg/m^3 at only a very small proportion of receptors.

PM_{10} (maximum 24-hour mean)

- The maximum concentration was above the NSW impact assessment criterion of 50 µg/m^3 at all community receptor locations, which is also the most stringent standard in force internationally. The maximum concentration exceeded the criteria due to elevated background concentrations which occur during extreme events such as dust storms, bushfires and hazard reduction burns
- The results for the RWR receptors were highly dependent on the assumption for the background concentration. Because this was high (48.0 µg/m^3), the total concentration at the majority of receptors in the with-project and cumulative scenarios was above the NSW impact assessment criterion of 50 µg/m^3. 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 RWR receptor was 1.3 µg/m^3 to 1.6 µg/m^3, depending on the scenario
- There was an increase in concentration at 36–46 per cent of receptors with the project and in the cumulative scenarios, 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 less than 10 per cent of receptors.

$PM_{2.5}$ (annual mean)

- Given that the mapped background concentration for annual mean $PM_{2.5}$ at some community receptors (up to 7.9 µg/m^3) was already very close to the air quality criterion of 8 µg/m^3, it is unsurprising that there were some predicted exceedances. These exceedances also occurred in the ‘Do minimum’ scenarios.
- The highest concentration at any RWR receptor was 11.9 µg/m^3. In the with-project and cumulative scenarios, the largest surface road contribution was 4.1 µg/m^3, and the largest contribution from tunnel ventilation outlets in these scenarios was 0.18 µg/m^3

- There was an increase in concentration at between 41 per cent and 77 per cent of receptors, depending on the scenario. The largest predicted increase in concentration at any receptor as a result of the project was 0.6 µg/m^3. Where there was an increase, this was greater than 0.1 µg/m^3 at around four to five per cent of receptors
- No RWR receptor had a value for $\Delta PM_{2.5}$ that was above the acceptable value 1.7 µg/m^3.

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

- The maximum concentrations at a number of RWR receptors with the project and in the cumulative scenarios were above the NSW impact criterion of 25 µg/m^3 although, given the high background (22.1 µg/m^3), 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
- The maximum contribution of tunnel ventilation outlets at any RWR receptor with the project and in the cumulative scenarios was 1.0 µg/m^3
- The largest predicted increase in concentration at any receptor as a result of the project was 2.2 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 1 µg/m^3 at up to only 0.7 per cent of receptors.

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 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 four elevated RWR receptor location heights (10, 20, 30 and 45 metres) were considered for annual mean and 24-hour $PM_{2.5}$. Existing buildings are not at all of these heights at all RWR receptor locations. The influence of surface roads was clearly reduced at the elevated levels compared with at ground level, and was negligible beyond 30 metres.

The implications of these results can be summarised as follows:

- There are no adverse impacts at any existing buildings at any height
- There are no adverse impacts at any existing or future buildings up to a height of 20 metres
- There are potential impacts for future buildings above 20 metres in height within 300 metres of the ventilation outlets, but this would not necessarily preclude such development. Further consideration at rezoning or development application stage would be required
- There are no restrictions to building heights within 300 metres of the Rozelle Interchange outlet. Within 300 metres of the Warringah Freeway outlet, current planning controls for permissible habitable structures restrict buildings to below 20 metres
- Land use considerations would be required to manage any interaction between the project and future development for buildings with habitable structures above 20 metres and within 300 metres of the ventilation outlet
- Roads and Maritime would assist Inner West Council, North Sydney Council and the Department of Planning, Industry and Environment (as appropriate) in determining relevant land use considerations applicable to future development in the immediate vicinity of ventilation outlets for inclusion in Local Environmental Plans or Development Control Plans, where required, to manage interactions between the project and future development. This may include procedures for identifying the requirement for consultation with Roads and Maritime for proposed rezoning or development applications.

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 ventilation outlet contribution in the regulatory worst case scenario (0.6 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
- For PM_{10} the maximum contribution of the ventilation outlets would have been small. For the annual mean and maximum 24-hour metrics, the ventilation outlet contributions were four per cent and 14 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 11 per cent and 28 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 ventilation 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. While in some cases the ventilation outlet contributions appeared to be substantial, this is deceptive. As the background and surface road contributions (and hence total NO_X) increase, there is a pronounced reduction in the contribution of the ventilation outlets to NO_2. The analysis showed that maximum ventilation 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, while 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 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.

10.4 Management of impacts

10.4.1 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 standard practice on construction sites.

10.4.2 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 would be adopted for the project are summarised below.

Tunnel design

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

- Minimal gradients as far as reasonably practicable
- Large tunnel cross-sectional area to reduce the pollutant concentration for a given emission into the tunnel volume, and to permit greater volumetric air throughput. The tunnels would have a width of varying between nine to 12.5 metres and, with a vertical clearance of about 5.3 metres, which would be higher than most previous tunnels
- Increased height to reduce the risk of incidents involving high vehicles blocking the tunnel and disrupting 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 would achieve some of the most stringent standards in the world for in-tunnel air quality, and would be effective at maintaining local air quality. The design of the ventilation system would 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 would be developed to manage breakdown, congested and emergency situations.

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