Transport for NSW

Beaches Link and Gore Hill Freeway Connection

Appendix H

Air quality

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Beaches Link and Gore Hill Freeway Connection

Technical working paper: Air quality

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ERM

Contents

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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	
DAWE	Australian Government Department of Agriculture, Water and the Environment
DEC	The former (NSW) Department of Environment and Conservation (now part of DPIE (EES) or NSW EPA)
DECCW	The former (NSW) Department of Environment, Climate Change and Water (now part of DPIE (EES) or NSW EPA)
Defra	(UK) Department for Environment, Food and Rural Affairs
DERM	(Queensland) Department of Environment and Resource Management
DPF	diesel particulate filter
DPIE	NSW Department of Planning, Industry and Environment
DPIE (EES)	NSW Department of Planning, Industry and Environment (Environment, Energy and Science)

Term	Definition
DSEWPC	The former (Australian Government) Department of Sustainability, Environment, Water, Population and Communities (now DAWE)
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 (ie g/km) or fuel consumed (ie g/litre).
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; refers to the area encompassing the Sydney, Newcastle, and Wollongong regions
GRAL	Graz Lagrangian Model
GRAMM	Graz Mesoscale Model
GVM	gross vehicle mass
H	
HCV	heavy commercial vehicle (interchangeable with HGV)
HDV	heavy-duty vehicle, which includes heavy goods vehicles, buses and coaches
HGV	heavy goods vehicle (truck)
HVAS	high volume air sampler
I	
IAQM	(UK) Institute of Air Quality Management
L	
LCT	Lane Cove tunnel
LCV	light commercial vehicle
LDV	light-duty vehicle, which includes cars and light commercial vehicles
N	
NEPC	National Environment Protection Council
NEPM	National Environment Protection Measure
NH_3	Ammonia
NHMRC	National Health and Medical Research Council
NIWA	National Institute of Water and Atmospheric Research (New Zealand)
NMVOC	non-methane volatile organic compound
NO	nitric oxide
NO_2	nitrogen dioxide

Term	Definition
NO_X	oxides of nitrogen
NPI	National Pollutant Inventory
NSW	New South Wales
NSW EPA	(NSW) Environment Protection Authority
O	
O_3	ozone
OC	organic carbon
OEH	The former (NSW) Office of Environment and Heritage (now part of the DPIE (EES))
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
RMS	The former (NSW) Roads and Maritime Services (now part of Transport for NSW)
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	The former Sydney Motorways Project Office (now part of Transport for NSW)
SO_2	sulfur dioxide
SO_X	sulfur oxides
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; the proponent
THC	total hydrocarbons
TRAQ	Tool for Roadside Air Quality, an air pollution screening tool developed by Transport for NSW

Term	Definition
TSP	total suspended particulate (matter)
U	
UFP	ultrafine particles (particles with a diameter of less than 0.1 µm)
UK	United Kingdom
UN	United Nations
USA	United States of America
USEPA	United States Environmental Protection Agency
V	
VKT	vehicle-kilometres travelled
VOCs	volatile organic compounds
W	
WHO	World Health Organization
WHTBL	Western Harbour Tunnel and Beaches Link
Other	
$\mu g/m^3$	micrograms per cubic metre

Executive summary

E.1 The project

Transport for NSW is seeking approval under Part 5, Division 5.2 of the *Environmental Planning and Assessment Act 1979* (EP&A Act) to construct and operate the Beaches Link and Gore Hill Freeway Connection (the project), which would comprise two components:

- Twin tolled motorway tunnels connecting the Warringah Freeway at Cammeray and the Gore Hill Freeway at Artarmon to the Burnt Bridge Creek Deviation at Balgowlah and Wakehurst Parkway at Killarney Heights, and an upgrade of Wakehurst Parkway (the Beaches Link)
- Connection and integration works along the existing Gore Hill Freeway at Artarmon (the Gore Hill Freeway Connection).

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 20 April 2020. 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.

With regard to odour, the area to the west of Flat Rock Drive and east of Willoughby Road at Willoughby was used extensively as a municipal landfill prior to redevelopment as recreation facilities. The Flat Rock Drive construction support site (BL2) is a tunnel support site and would have access decline to the tunnels underground. A gabion wall at the eastern extent of the site and filling is proposed to create a flat area for the construction support site and minimise the need to excavate. There is some potential that landfill gases might be present in the soils underneath the site from any putrescible waste present, or that might have migrated from the landfilled areas to the west. If present, excavations on site could

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

release these landfill gases. However, as the site will be designed to minimise excavations, potentially limiting the release of significant volumes of landfill gases that might be present.

E.4 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 assessment

E.5.1 Scenarios

Three 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 (includes full WestConnex)
    - ‘Do something 2027’. As ‘Do minimum 2027’, but with the Beaches Link and Gore Hill Freeway Connection (including Warringah Freeway Upgrade) also completed
    - ‘Do something cumulative 2027’. As ‘Do something 2027’, but with Sydney Gateway, Western Harbour Tunnel and Warringah Freeway Upgrade and M6 Motorway – 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 M6 Motorway also completed

- Regulatory worst case scenario. This assessed emissions from the ventilation outlets only, with pollutant concentrations fixed at the regulatory limits. The scenario represented the theoretical maximum change in air quality for all potential traffic operations in the tunnel, including unconstrained and worst case traffic conditions from an emissions perspective, as well as vehicle breakdown situations.

- Sensitivity scenario. This assessed emissions from the ventilation outlets only, with pollutant concentrations lower than regulatory worst case, but higher than those for the expected traffic case. Emissions varied throughout the day (as with expected traffic), but peaked at the regulatory worst case limit. This is therefore a hybrid scenario, representing a highly conservative expected traffic case.

E.5.2 Methodology

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

- Emissions from the traffic on the surface road network, including any new roads associated with the project (or projects in the cumulative scenarios)

- Emissions from existing 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 Western Harbour Tunnel and Beaches Link projects as well as existing or future projects (WestConnex 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 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:

- 42 '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 1.5 kilometres 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 35,484 '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 – ground level

E.6.1 Expected traffic

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
- For PM, exceedances were driven by the elevated background concentrations
- 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 Beaches Link and Gore Hill Freeway Connection project there were predicted to be noticeable decreases in pollutant concentrations along Military Road, Spit Road, Manly Road and Warringah Road, reflecting reductions in traffic of between 23 per cent and 38 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 and, to a lesser extent, the portals of Sydney Harbour Tunnel. There were increases in concentration along Sydney Harbour Bridge and Wakehurst Parkway. In the case of the latter there was a 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.
  - In the cumulative scenarios there were predicted to be some additional changes as a result of the Western Harbour Tunnel. These included reductions in concentration along the Western Distributor, Sydney Harbour Bridge and Warringah Freeway.

E.6.2 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} for the annual mean and maximum 24-hour metrics the ventilation outlet contributions were four per cent and 16 per cent of the respective criteria. Any exceedances of the criteria are be 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 31 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.6.3 Sensitivity scenario

- The impacts for the sensitivity scenario lie between the expected traffic and regulatory worst case scenarios, 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 regulatory worst case concentrations, were slightly higher for the maximum 24-hour average concentrations than for the annual average concentrations

E.7 Operational impacts – elevated receptors

E.7.1 Expected traffic

Concentrations at four elevated receptor heights (10, 20, 30 and 45 metres) were considered for $PM_{2.5}$, PM_{10}, NO_2 and air toxics for receptors within 300 metres of the ventilation outlets. 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 results showed the following:

- For the annual average PM_{10} and $PM_{2.5}$ concentrations, there are no predicted exceedances at any modelled height of the NSW EPA impact assessment criteria
- For the maximum 24-hour average PM_{10} concentrations, there is one predicted exceedances of the NSW EPA impact assessment criterion at 45 metres when considering all RWR receptors, irrespective of building that exist at those heights and when considering the maximum ventilation outlet contribution. When considering RWR receptors that do exist at each modelled height, there are no predicted exceedances of the NSW EPA impact assessment criterion of 50 µg/m^3 at any height
- For the maximum 24-hour average $PM_{2.5}$ concentrations, there is one predicted exceedances of the NSW EPA impact assessment criterion at 45 metres when considering all RWR receptors, irrespective of building that exist at those heights and when considering the maximum ventilation outlet contribution. When considering RWR receptors that do exist at each modelled height, there are no predicted exceedances of the NSW EPA impact assessment criterion of 25 µg/m^3 at any height
- For the annual average and maximum 1-hour average NO_2 concentrations, there are no predicted exceedances at any modelled height of the NSW EPA impact assessment criterion

- For the maximum 1-hour average benzene, PAHs, formaldehyde, 1,3-butadiene and ethylbenzene concentrations, there are no predicted exceedances at any modelled height of the NSW EPA impact assessment criteria.

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 30 metres
- There are impacts predicted for potential future buildings above 30 metres in height within 300 metres of the Gore Hill Freeway ventilation outlet, but this would not necessarily preclude such development. Further consideration at rezoning or development application stage would be required.

Within 300 metres of the Warringah Freeway outlet, current planning controls for permissible habitable structures restrict buildings to below 20 metres.

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.7.2 Regulatory worst case

When considering the maximum ventilation outlet contribution, the findings are as follows:

- For the annual average PM_{10} concentrations, there are no predicted exceedances at any modelled height of the NSW EPA impact assessment criterion.
- For the maximum 24-hour average PM_{10} concentrations, there are predicted exceedances of the NSW EPA impact assessment criterion of 50 µg/m^3 at 20 metres, 30 metres and 45 metres when considering all RWR receptor locations, irrespective of buildings that exist at those heights and when considering the maximum ventilation outlet contribution. When considering RWR receptors that do exist at each modelled height, there is one predicted exceedance of the NSW EPA impact assessment criterion of 50 µg/m^3 at 30 metres at receptor RWR-12249, located near to the Warringah Freeway Ventilation Outlet (Outlet H). At this location, the contribution from the ventilation outlets is approximately 25 per cent of the total contribution.
- For the annual average $PM_{2.5}$ concentrations, there are predicted exceedances of the NSW EPA impact assessment criterion of 8 µg/m^3 at 10 metres, 20 metres, 30 metres and 45 metres when considering all RWR receptor locations, irrespective of buildings that exist at those heights and when considering the maximum ventilation outlet contribution. When considering RWR receptors that do exist at each modelled height, there are no predicted exceedance of the NSW EPA impact assessment criterion of 8 µg/m^3.
- For the maximum 24-hour average $PM_{2.5}$ concentrations, there are exceedances of the NSW EPA impact assessment criterion of 25 µg/m^3 at 20 metres, 30 metres and 45 metres when considering all RWR receptor locations, irrespective of buildings that exist at those heights and when considering the maximum ventilation outlet contribution. When considering RWR receptors that do exist at each modelled height, there is one predicted exceedance of the NSW EPA impact assessment criterion of 25 µg/m^3 at 30 metres at receptor RWR-12249, located near to the Warringah Freeway Ventilation Outlet (Outlet H). At this location, the contribution from the ventilation outlets is approximately 43 per cent of the total contribution.
- For the annual average NO_2 and maximum 1-hour average concentrations, there are no predicted exceedances at any modelled height of the NSW EPA impact assessment criterion.
- For the maximum 1-hour average benzene, PAHs, 1,3-butadiene and ethylbenzene concentrations, there are no predicted exceedances at any modelled height of the NSW EPA impact assessment criteria.
- For the maximum 1-hour average formaldehyde concentrations, there is one predicted exceedance of the NSW EPA impact assessment criterion of 20 µg/m^3 at 45 metres at RWR-17555, located

near to the Gore Hill Freeway Ventilation Outlet (Outlet I) when considering all RWR locations, irrespective of buildings that exist at those heights.

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 dust 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.

With regard to odour at the Flat Rock Drive construction support site, further investigations are recommended to confirm the presence and extent of any potentially odorous materials or gases in the areas that would be excavated as part of the project. If present, excavations should be kept to a minimum in affected locations, and other management measures developed and implemented, so as to minimise the potential for the release of landfill gases.

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), 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 Middle 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 which 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 the Gore Hill Freeway to Balgowlah and Killarney Heights and including the surface upgrade of the Wakehurst Parkway from Seaforth 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 areas south, west and north-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 existing harbour crossings.

1.2 The project

Transport for NSW is seeking approval under Part 5, Division 5.2 of the *Environmental Planning and Assessment Act 1979* to construct and operate the Beaches Link and Gore Hill Freeway Connection project, which would comprise two components:

- Twin tolled motorway tunnels connecting the Warringah Freeway at Cammeray and the Gore Hill Freeway at Artarmon to the Burnt Bridge Creek Deviation at Balgowlah and the Wakehurst Parkway at Killarney Heights, and an upgrade of the Wakehurst Parkway (the Beaches Link)
- Connection and integration works along the existing Gore Hill Freeway and surrounding roads at Artarmon (the Gore Hill Freeway Connection).

A detailed description of these two components is provided in Section 1.3.

1.3 Key features of the project

Key features of the Beaches Link component of the project are shown in Figure 1-1 and would include:

- Twin mainline tunnels about 5.6 kilometres long and each accommodating three lanes of traffic in each direction, together with entry and exit ramp tunnels to connections at the surface. The crossing of Middle Harbour between Northbridge and Seaforth would involve three lane, twin immersed tube tunnels
- Connection to the stub tunnels constructed at Cammeray as part of the Western Harbour Tunnel and Warringah Freeway Upgrade project
- Twin two lane ramp tunnels:

  - Eastbound and westbound connections between the mainline tunnel under Seaforth and the surface at the Burnt Bridge Creek Deviation, Balgowlah (about 1.2 kilometres in length)
  - Northbound and southbound connections between the mainline tunnel under Seaforth and the surface at the Wakehurst Parkway, Killarney Heights (about 2.8 kilometres in length)
  - Eastbound and westbound connections between the mainline tunnel under Northbridge and the surface at the Gore Hill Freeway and Reserve Road, Artarmon (about 2.1 kilometres in length).
- An access road connection at Balgowlah between the Burnt Bridge Creek Deviation and Sydney Road including the modification of the intersection at Maretimo Street and Sydney Road, Balgowlah
- Upgrade and integration works along the Wakehurst Parkway, at Seaforth, Killarney Heights and Frenchs Forest, through to Frenchs Forest Road East
- New open space and recreation facilities at Balgowlah
- New and upgraded pedestrian and cyclist infrastructure
- Ventilation outlets and motorway facilities at the Warringah Freeway in Cammeray, the Gore Hill Freeway in Artarmon, the Burnt Bridge Creek Deviation in Balgowlah and the Wakehurst Parkway in Killarney Heights
- Operational facilities, including a motorway control centre at the Gore Hill Freeway in Artarmon, and tunnel support facilities at the Gore Hill Freeway in Artarmon and the Wakehurst Parkway in Frenchs Forest
- Other operational infrastructure including groundwater and tunnel drainage management and treatment systems, surface drainage, signage, tolling infrastructure, fire and life safety systems, roadside furniture, lighting, emergency evacuation and emergency smoke extraction infrastructure, Closed Circuit Television (CCTV) and other traffic management systems.

Key features of the Gore Hill Freeway Connection component of the project are shown in Figure 1-2 and would include:

- Upgrade and reconfiguration of the Gore Hill Freeway between the T1 North Shore & Western Line and T9 Northern Line and the Pacific Highway
- Modifications to the Reserve Road and Hampden Road bridges
- Widening of Reserve Road between the Gore Hill Freeway and Dickson Avenue
- Modification of the Dickson Avenue and Reserve Road intersection to allow for the Beaches Link off ramp
- Upgrades to existing roads around the Gore Hill Freeway to integrate the project with the surrounding road network
- Upgrade of the Dickson Avenue and Pacific Highway intersection
- New and upgraded pedestrian and cyclist infrastructure
- Other operational infrastructure, including surface drainage and utility infrastructure, signage and lighting, CCTV and other traffic management systems.

A detailed description of the project is provided in Chapter 5 (Project description) of the environmental impact statement.

Subject to obtaining planning approval, construction of the project is anticipated to commence in 2023 and is expected to take around five to six years to complete.

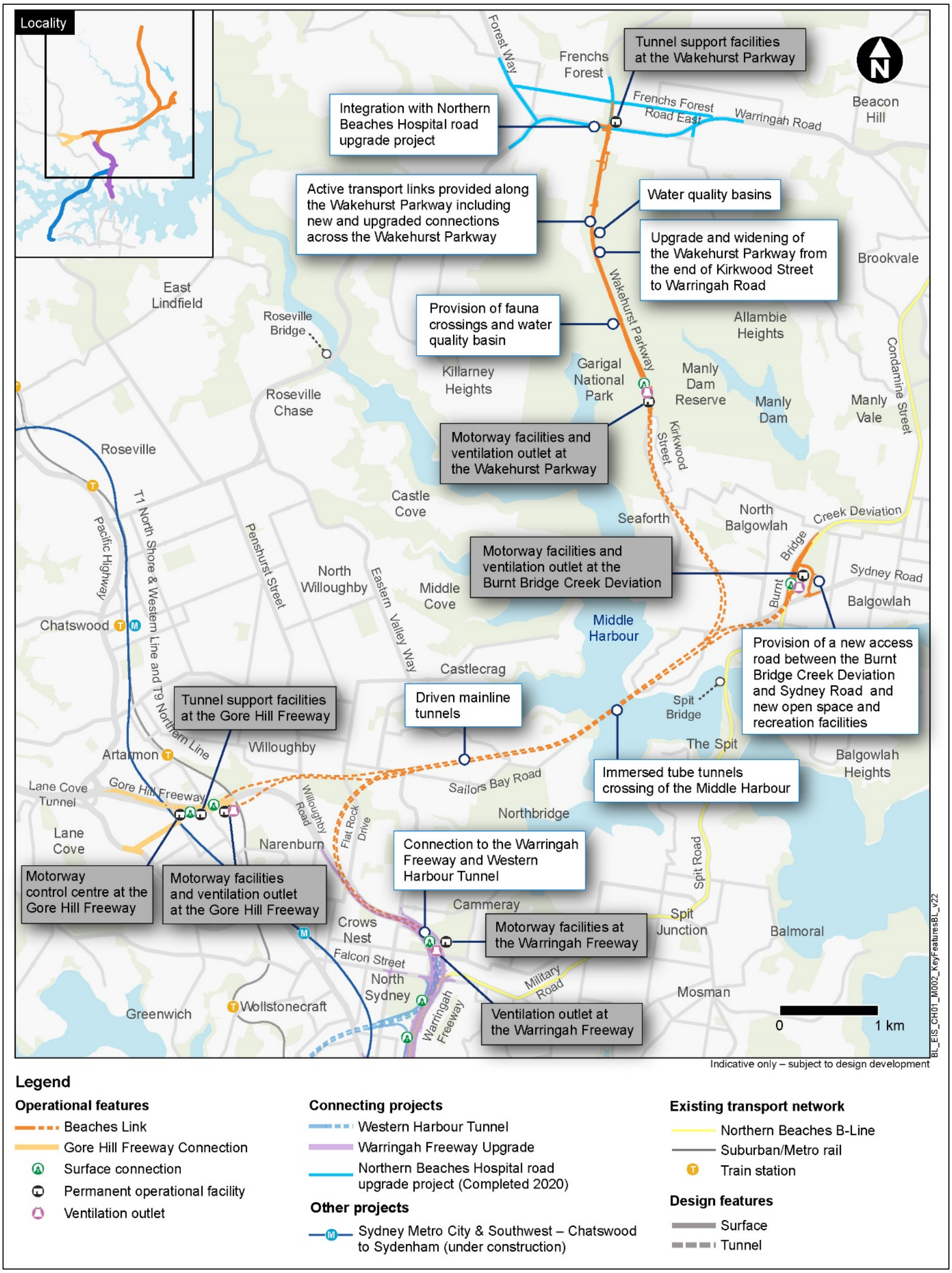

Figure 1-1 **Key features of the Beaches Link component of the project**

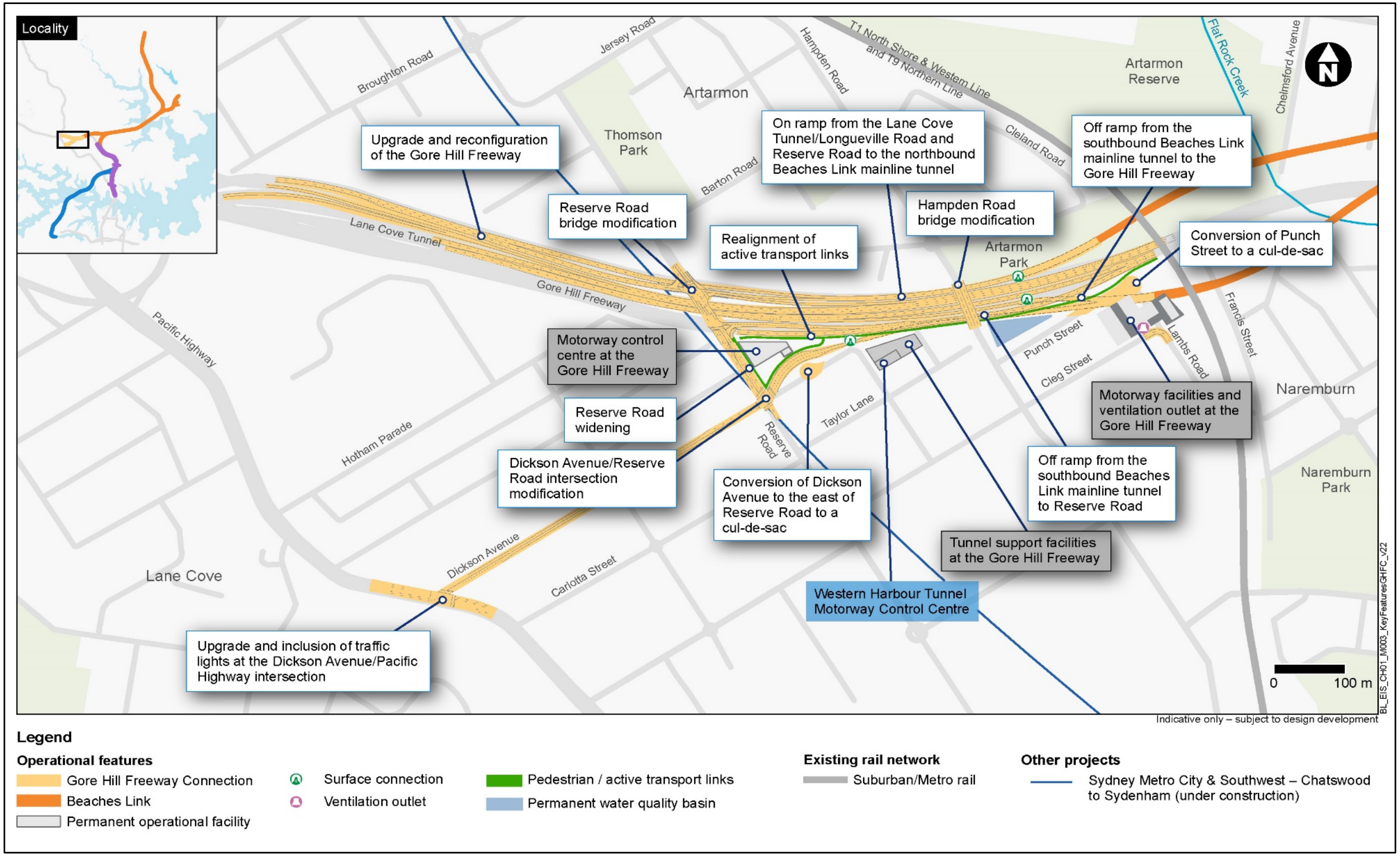

Figure 1-2 Key features of the Gore Hill Freeway Connection component of the project

1.4 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 mainline and ramp tunnels. However, surface areas would also be required to support tunnelling activities and to construct the tunnel connections, tunnel portals, surface road upgrades and operational facilities.

Key construction activities would include:

- Early works and site establishment, with typical activities being property acquisition and condition surveys, utilities installation, protection, adjustments and relocations, installation of site fencing, environmental controls (including noise attenuation and erosion and sediment control), traffic management controls, vegetation clearing, earthworks, demolition of structures, building construction support sites including acoustic sheds and associated access decline acoustic enclosures (where required), construction of minor access roads and the provision of property access, temporary relocation of pedestrian and cycle paths and bus stops, temporary relocation of swing moorings and/or provision of alternative facilities (mooring or marina berth) within Middle Harbour
- Construction of the Beaches Link, with typical activities being excavation of tunnel construction access declines, construction of driven tunnels, cut and cover and trough structures, construction of surface upgrade works, construction of cofferdams, dredging and immersed tube tunnel piled support 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:
  - A motorway control centre at the Gore Hill Freeway in Artarmon
  - Tunnel support facilities at the Gore Hill Freeway in Artarmon and at the Wakehurst Parkway in Frenchs Forest
  - Motorway facilities and ventilation outlets at the Warringah Freeway in Cammeray (fitout only of the Beaches Link ventilation outlet at the Warringah Freeway (being constructed by the Western Harbour Tunnel and Warringah Freeway Upgrade project), the Gore Hill Freeway in Artarmon, the Burnt Bridge Creek Deviation in Balgowlah and the Wakehurst Parkway in Killarney Heights
  - A wastewater treatment plant at the Gore Hill Freeway in Artarmon
  - Installation of motorway tolling infrastructure
- Staged construction of the Gore Hill Freeway Connection at Artarmon and upgrade and integration works at Balgowlah and along the Wakehurst Parkway with typical activities being earthworks, bridgeworks, construction of retaining walls, stormwater drainage, pavement works and linemarking and the installation of roadside 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 would include:

- Cammeray Golf Course (BL1)
- Flat Rock Drive (BL2)
- Punch Street (BL3)

- Dickson Avenue (BL4)
- Barton Road (BL5)
- Gore Hill Freeway median (BL6)
- Middle Harbour south cofferdam (BL7)
- Middle Harbour north cofferdam (BL8)
- Spit West Reserve (BL9)
- Balgowlah Golf Course (BL10)
- Kitchener Street (BL11)
- Wakehurst Parkway south (BL12)
- Wakehurst Parkway east (BL13)
- Wakehurst Parkway north (BL14).

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

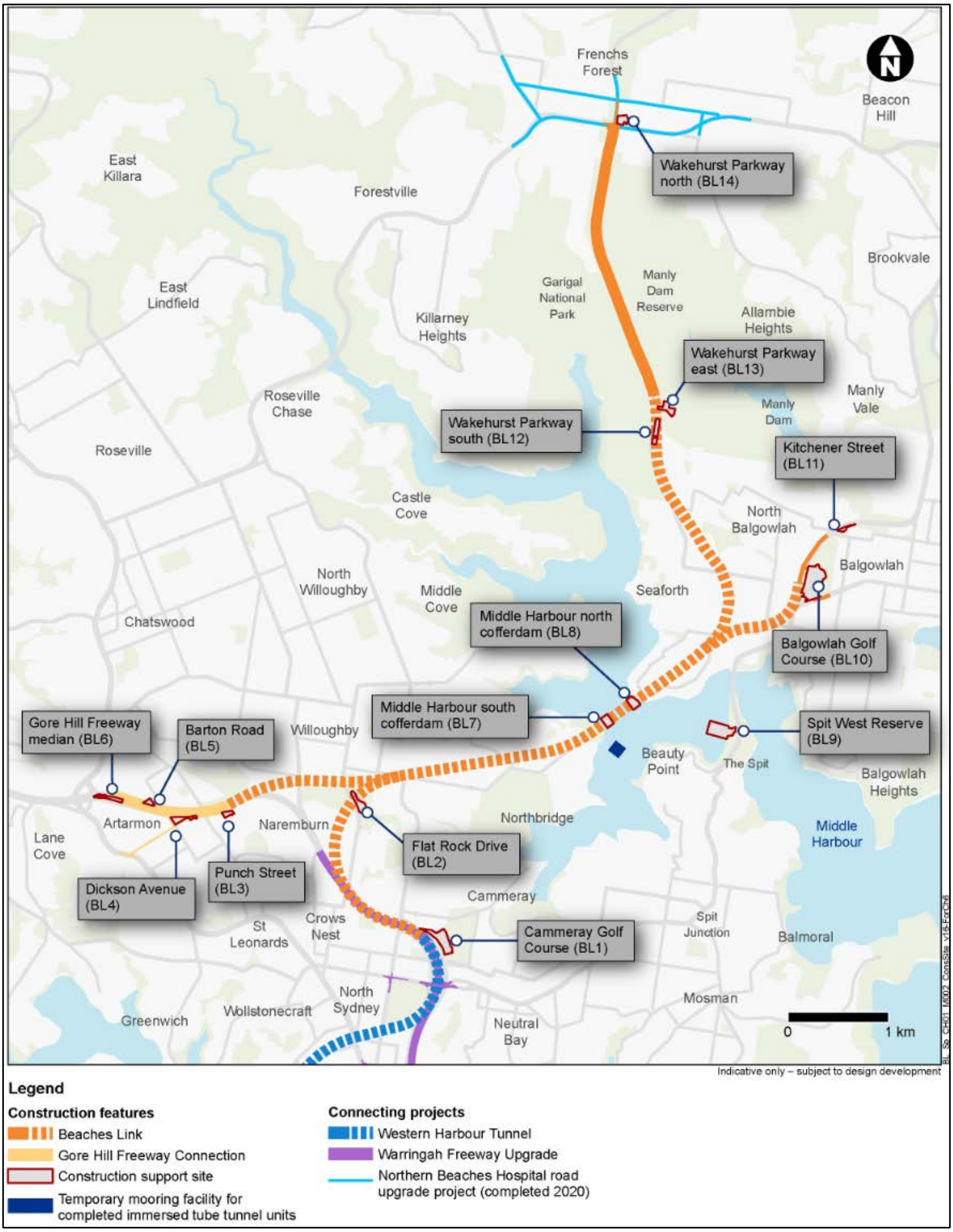

Figure 1-3 Overview of construction sites

1.5 Project location

The project would be located within the North Sydney, Willoughby, Mosman and Northern Beaches local government areas, connecting Cammeray in the south with Killarney Heights, Frenchs Forest and Balgowlah in the north. The project would also connect to both the Gore Hill Freeway and Reserve Road in Artarmon in the west.

Commencing at the Warringah Freeway at Cammeray, the mainline tunnels would pass under Naremburn and Northbridge, then cross Middle Harbour between Northbridge and Seaforth. The mainline tunnels would then split under Seaforth into two ramp tunnels and continue north to the Wakehurst Parkway at Killarney Heights and north-east to Balgowlah, linking directly to the Burnt Bridge Creek Deviation to the south of the existing Kitchener Street bridge.

The mainline tunnels would also have on and off ramps from under Northbridge connecting to the Gore Hill Freeway and Reserve Road east of the existing Lane Cove Tunnel. Surface works would also be carried out at the Gore Hill Freeway in Artarmon, Burnt Bridge Creek Deviation at Balgowlah and along the Wakehurst Parkway between Seaforth and Frenchs Forest to connect the project to the existing arterial and local road networks.

1.6 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 (‘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 changes in ambient air quality due to the tunnel project. 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 Appendix I (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).

1.7 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 6.4.3

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[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 5.6 (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 8.4.6
(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 6 (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)
	Section 7 (construction impacts)

Secretary's environmental assessment requirement	Where addressed
(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 batching plants), dredge and tunnel spoil handling and storage, the use of mobile plant, stockpiles and the processing and movement of spoil; and	Section 9 (management of impacts)
(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 8.4.11.

1.8 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** 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 6** 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 7** describes the assessment of the construction impacts associated with dust emissions of the project using a semi-quantitative risk-based approach. Potential odour issues are considered qualitatively
- **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. The potential impacts at elevated receptors are also considered in this section

- **Section 9** provides a review of air quality mitigation measures, and recommendations on measures to manage potential impacts of the project. This section deals with both the construction and the operation of the project
- **Section 10** provide a high level summary of the assessment
- Annexures which address various technical aspects of the air quality assessment. In particular, the report on the ventilation requirements for the project is provided in Annexure K.

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. Warringah Freeway Ventilation Outlet (Outlet H), Gore Hill Freeway Ventilation Outlet (Outlet I), Wakehurst Parkway Ventilation Outlet (Outlet J) and Burnt Bridge Creek Deviation Ventilation Outlet (Outlet K) (shaded in the table) would form part of the Beaches Link 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

Beaches Link would provide a direct aerodynamic connection to the future Western Harbour Tunnel, which would be connected to the WestConnex M4-M5 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.

Operation of the ventilation systems for Beaches Link, the Western Harbour Tunnel and the WestConnex M4-M5 Link would be largely independent of each other. This would be achieved through

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[3] GRAL = Graz Lagrangian Model

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 WestConnex M4-M5 Link (included in 'Do minimum' scenarios)			
Outlet C	WestConnex M4-M5 Link, Iron Cove Link	Rozelle (mid)(b), within the Rozelle Rail Yards	Removal and management of emissions from the traffic in the WestConnex M4-M5 Link and southbound tunnel of the Iron Cove Link.
Outlet D	WestConnex 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 WestConnex 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
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 WestConnex 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 will be introduced through ventilation supply facilities at functional tunnel interfaces. Additional fresh air would also 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 upstream of 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 sensitivity 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 avoid and/or minimise potential impacts.

3 Air quality considerations for Beaches Link

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 I (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 Beaches Link 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 Services, 2015). The air quality assessment informs the ventilation outlet design and operating conditions to ensure that existing 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 considered 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, carry out air quality monitoring and make the monitoring results available to the community via a dedicated website.

In addition, for new motorway tunnels that are at the environmental impact statement stage, such as the Beaches Link, 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 Beaches Link users, but also to the cumulative exposure of users of multiple Sydney tunnels, and notably WestConnex and the Western Harbour Tunnel
- 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.

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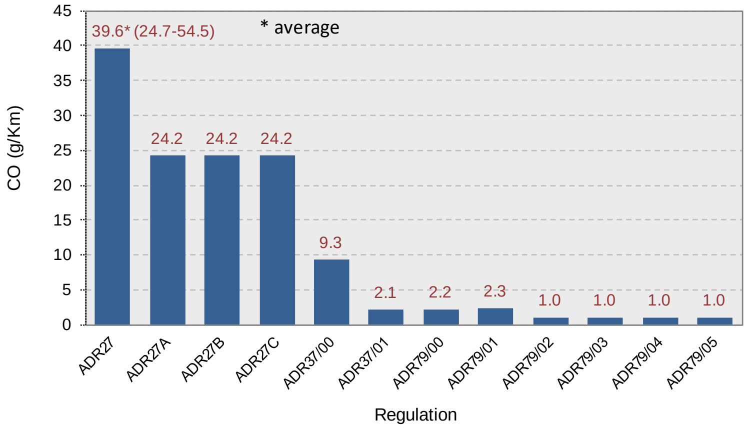
[4] https://infrastructure.gov.au/vehicles/environment/emission/index.aspx

(a) CO



(b) NOx

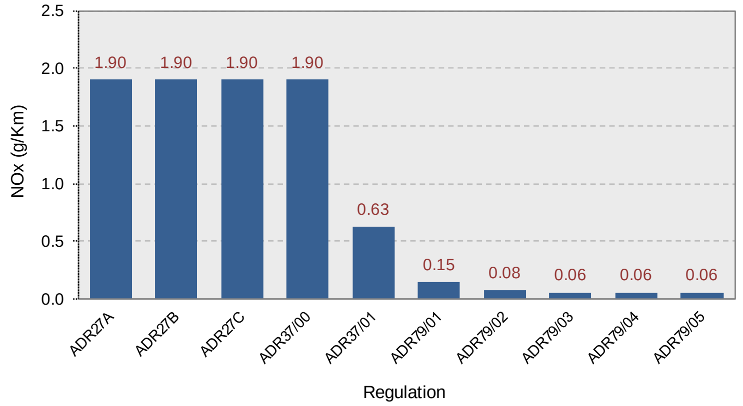


Figure 4-1 Exhaust emission limits for CO and NO_X applicable to new petrol cars in Australia

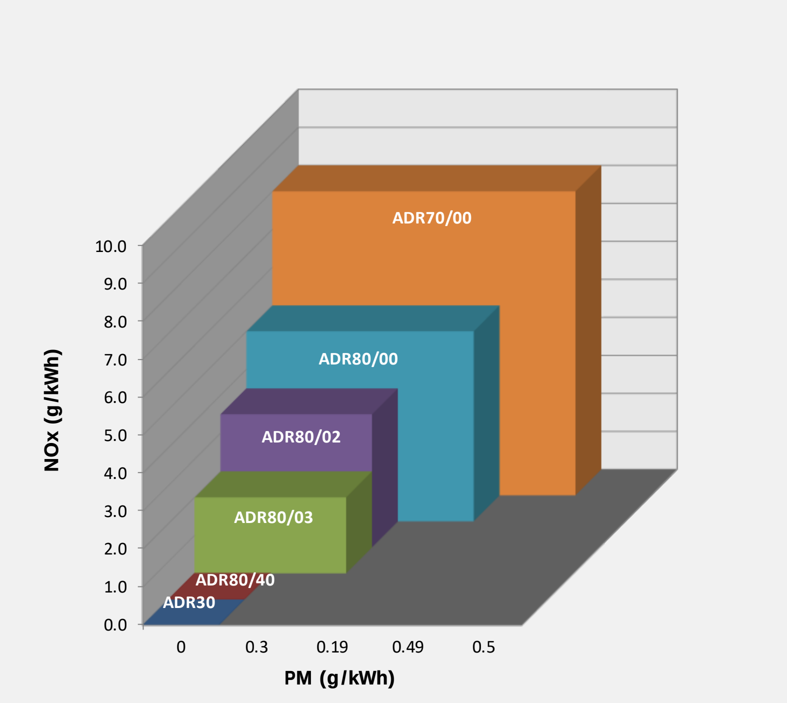


Figure 4-2 Exhaust emission limits for NO_X and PM applicable to HDVs in Australia

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 parts per million (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
- CO is the only traffic-related pollutant with a short-term (15-minute) World Health Organization (WHO) health-based guideline

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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 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	200(a)	87(b)	50(b)	0.5(b)	0.005(c)
WestConnex M4					
WestConnex M8					
WestConnex M4-M5 Link					

(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 Western Harbour Tunnel.

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, WestConnex M4 and WestConnex M8 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 Beaches Link 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, WestConnex M4 and WestConnex M8 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 regulation specifies 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 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 6.4.3.

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[7] See 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.

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 AAQ NEPM is a national monitoring and reporting protocol. The AAQ NEPM standards are applicable to urban background monitoring sites which are broadly representative of population exposure. The use of any AAQ NEPM air quality criteria for the assessment of projects and developments is outside the scope of the AAQ 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 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

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[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.

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 Existing environment

5.1 Overview of section

This section describes the existing air quality environment and conditions in the Graz Mesoscale Model (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 6.

5.2 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 GRAL modelling. Figure 5-1 shows the terrain immediately surrounding the project, based on the five-metre resolution data. The vertical scale is clearly exaggerated.

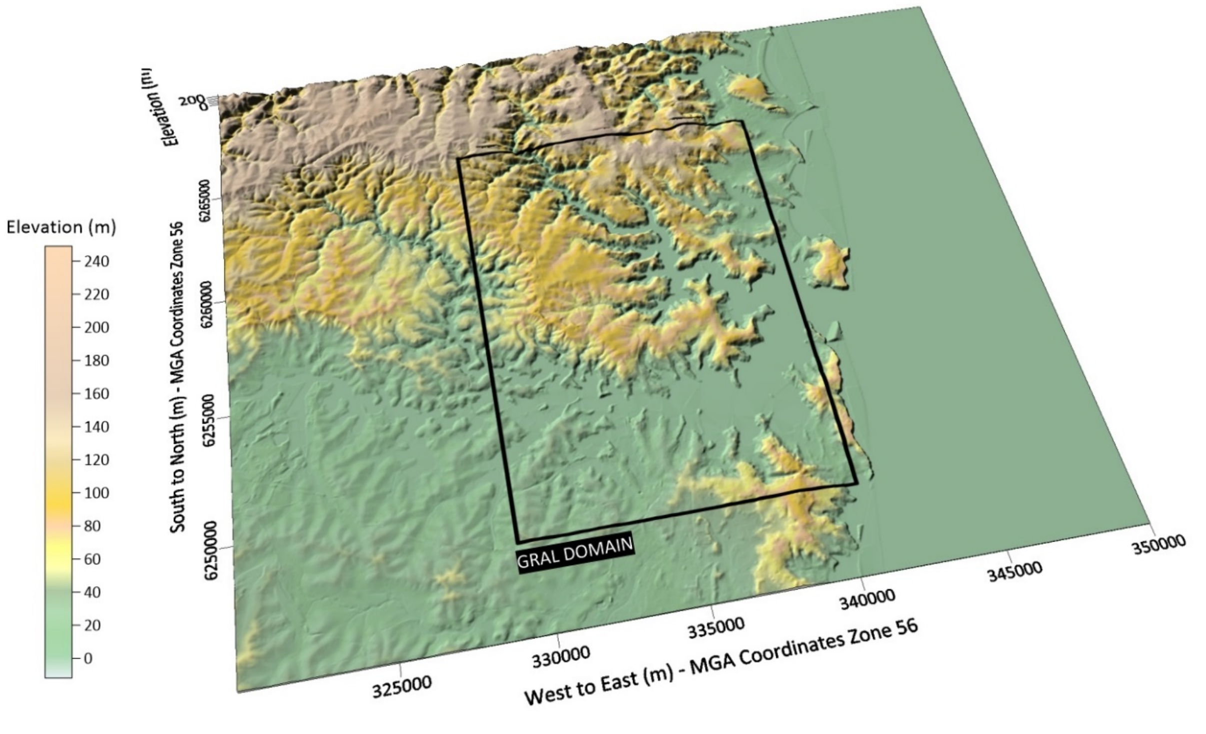


Figure 5-1 **Terrain in the GRAL domain (grid system MGA94)**

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 75 metres Australian Height Datum (AHD) at the southern end at the Warringah Freeway to an elevation of around 240 metres at Frenchs Forest at the northern end.

5.3 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, Middle Harbour and Northern Beaches suburbs.

5.4 Climate

Table 5-1 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 5-1 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

5.5 Meteorology

As noted in Annexure B, meteorology is an important factor affecting the dispersion of air pollution. Eleven meteorological stations in the GRAMM domain were considered for modelling, and their locations are shown on Figure 5-2. 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 Department of Planning, Industry and Environment (formerly Office of Environment and Heritage (OEH)):
  - 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.

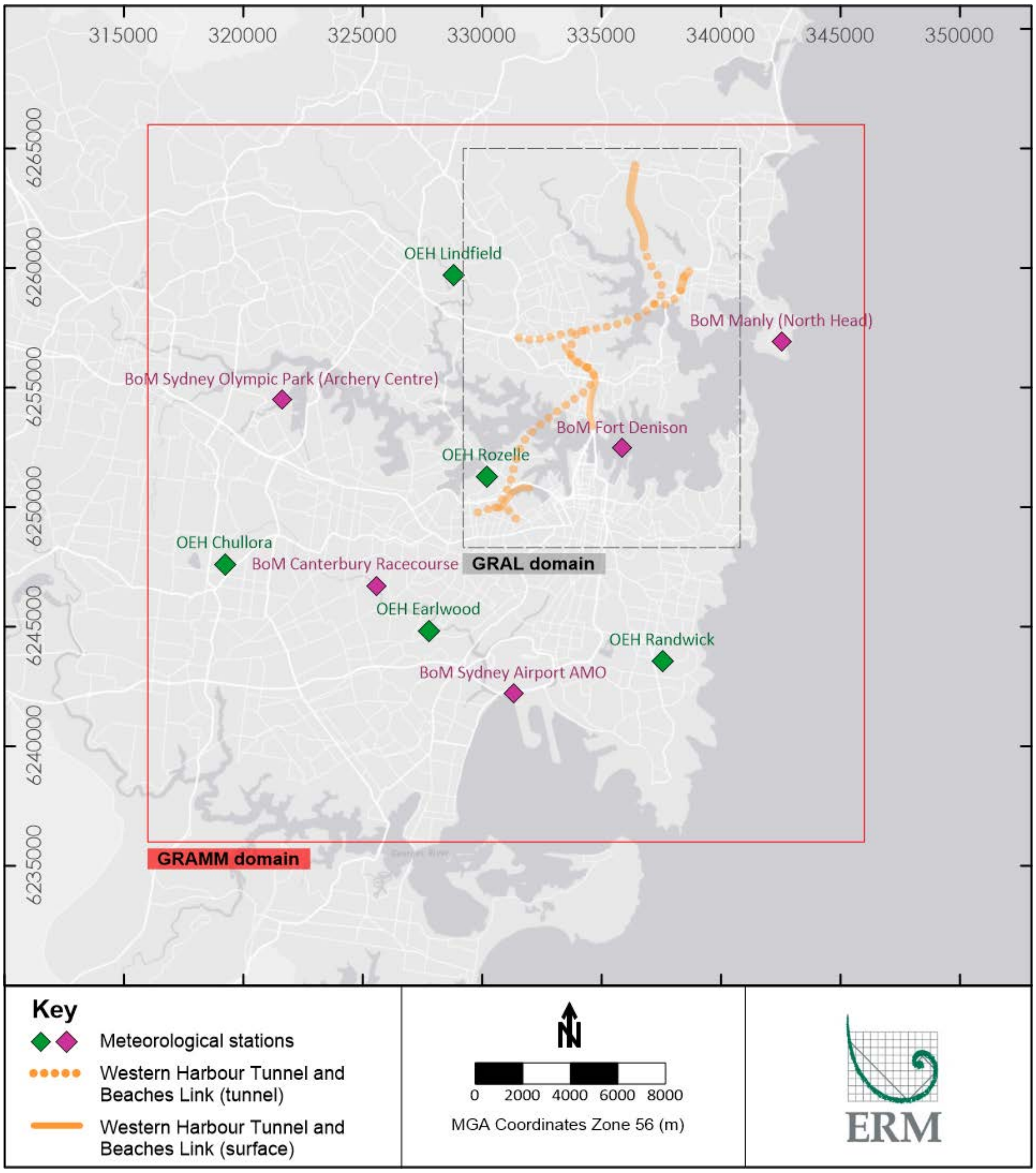
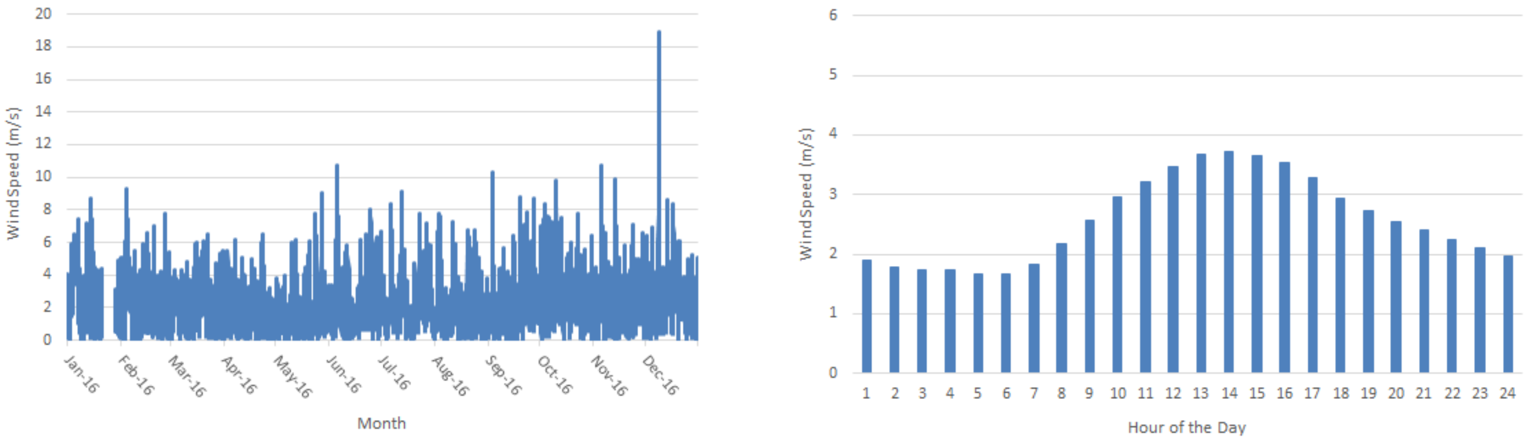


Figure 5-2 **Meteorological stations in the model domains (grid system MGA94)**

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 6.4.3. 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 explained in Section 6.4.3.

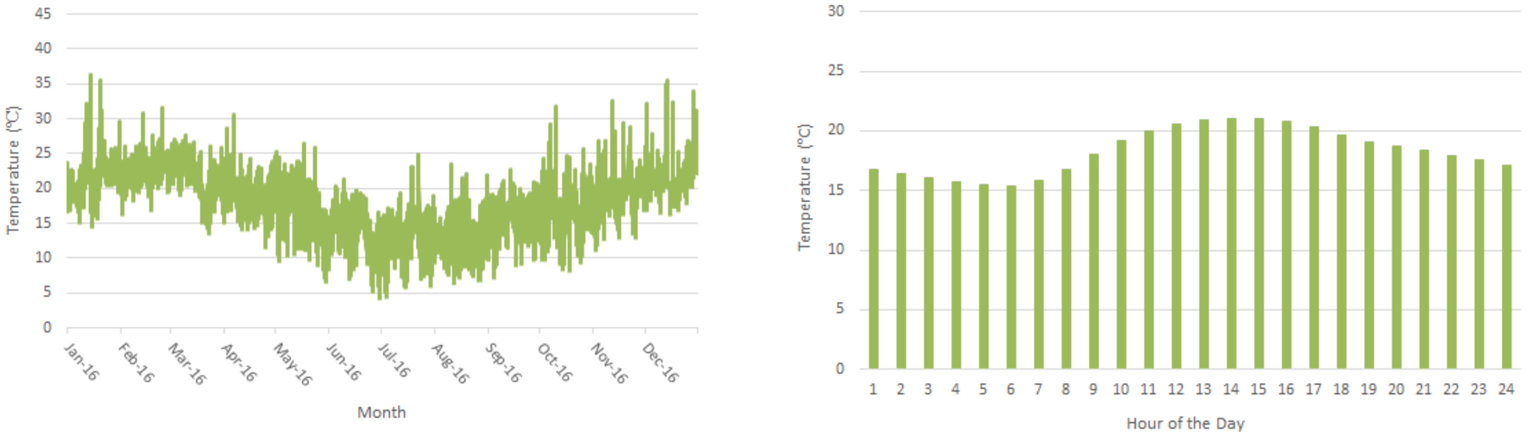
At Randwick, the wind speed and wind direction patterns over the eight-year period between 2009 and 2016 were generally consistent; the annual average wind speed ranged from 1.9 metres per second to 2.6 metres per second. It is worth noting that the station was surrounded by trees until 2010 when they 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 5-3 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.

The selection of the meteorological year is linked to the selection of the ambient air quality monitoring (background) year, and also the base year for available traffic data. The base year for the air quality assessment was therefore taken to be 2016. As this assessment process began in 2017 and one of the first tasks completed was to assemble the meteorological data to be used and compile GRAMM, this was the most appropriate choice. At that time, the most recent year was 2016. The year 2016 was also used for the Western Harbour Tunnel assessment and so using this year also allowed for consistency between the two assessments.



(a) Wind speed

(b) Average diurnal variation in wind speed



(c) Temperature by hour of the year

(d) Average diurnal variation in temperature

Figure 5-3 **Annual and diurnal plots of wind speed and temperature for Randwick (2016)**

5.6 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[9] 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[10] and are presented here. Emissions were considered for the most recent historical year (2016) and for the future years.

Figure 5-4 shows that road transport, including cars, light duty vehicles, heavy duty vehicles, busses and other transport such as motorcycles, 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 5-5 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 5-6. Petrol passenger vehicles (mainly cars) accounted for a large proportion of the vehicle kilometres travelled (VKT) in Sydney[11]. 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.. Non-exhaust processes, such as brake wear, tyre wear, road surface wear and resuspension of particulate matter from the road surfaces, were the largest source of road transport PM_{10} (71 per cent) and $PM_{2.5}$ (57 per cent), whereas exhaust emissions from petrol passenger vehicles were only a minor source of road transport PM_{10} (three per cent) and $PM_{2.5}$ (four 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 5-7. 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

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

[10] 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.

[11] 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).

growing contribution of non-exhaust particles. SO_2 emissions are proportional to fuel sulfur content, and this is assumed to remain constant in the inventory. The inventory also provides emissions of specific organic compounds, based on speciation profiles of petrol and diesel fuels.

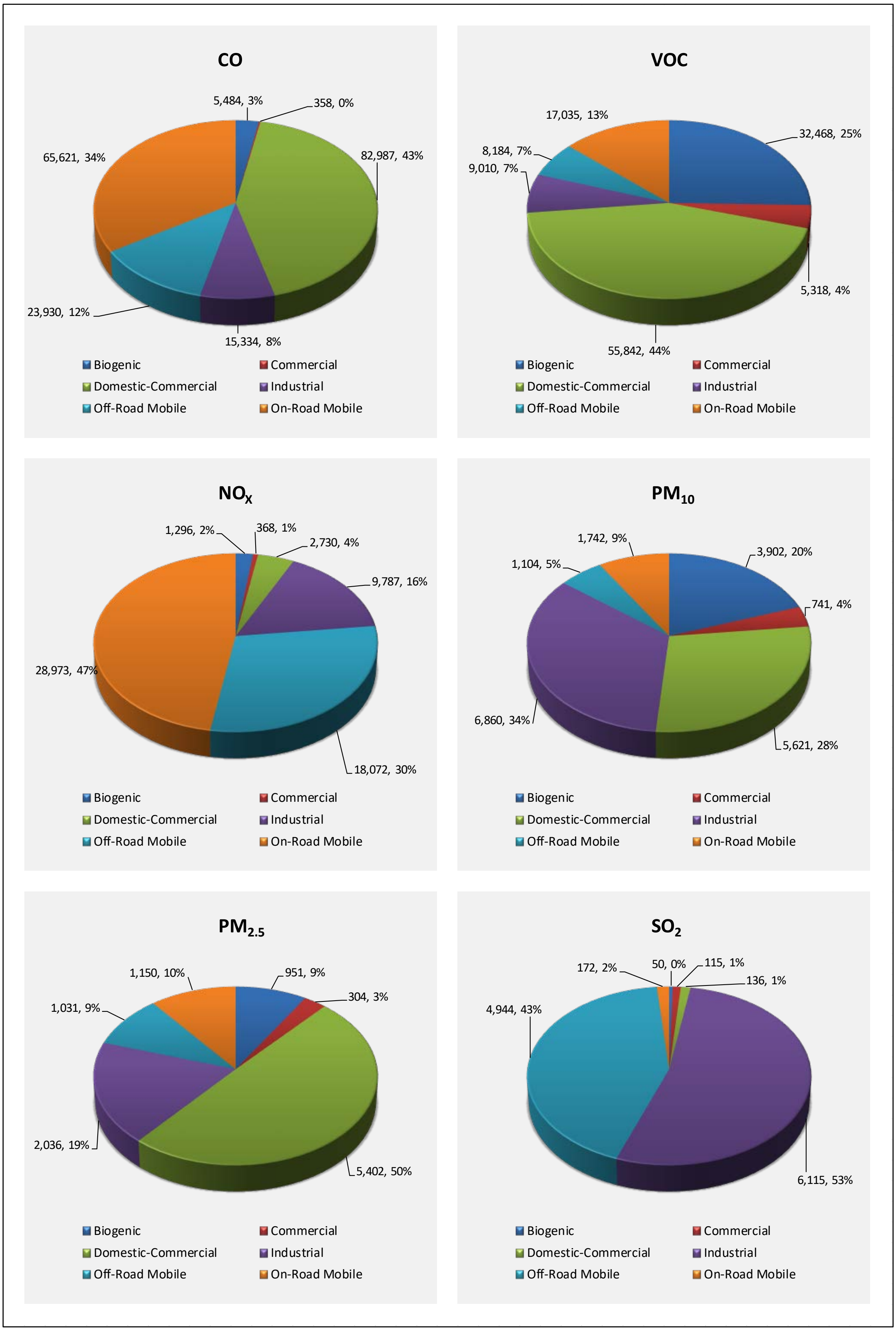

Figure 5-4 Sectoral emissions in Sydney, 2016 (tonnes per year and percentage of total)

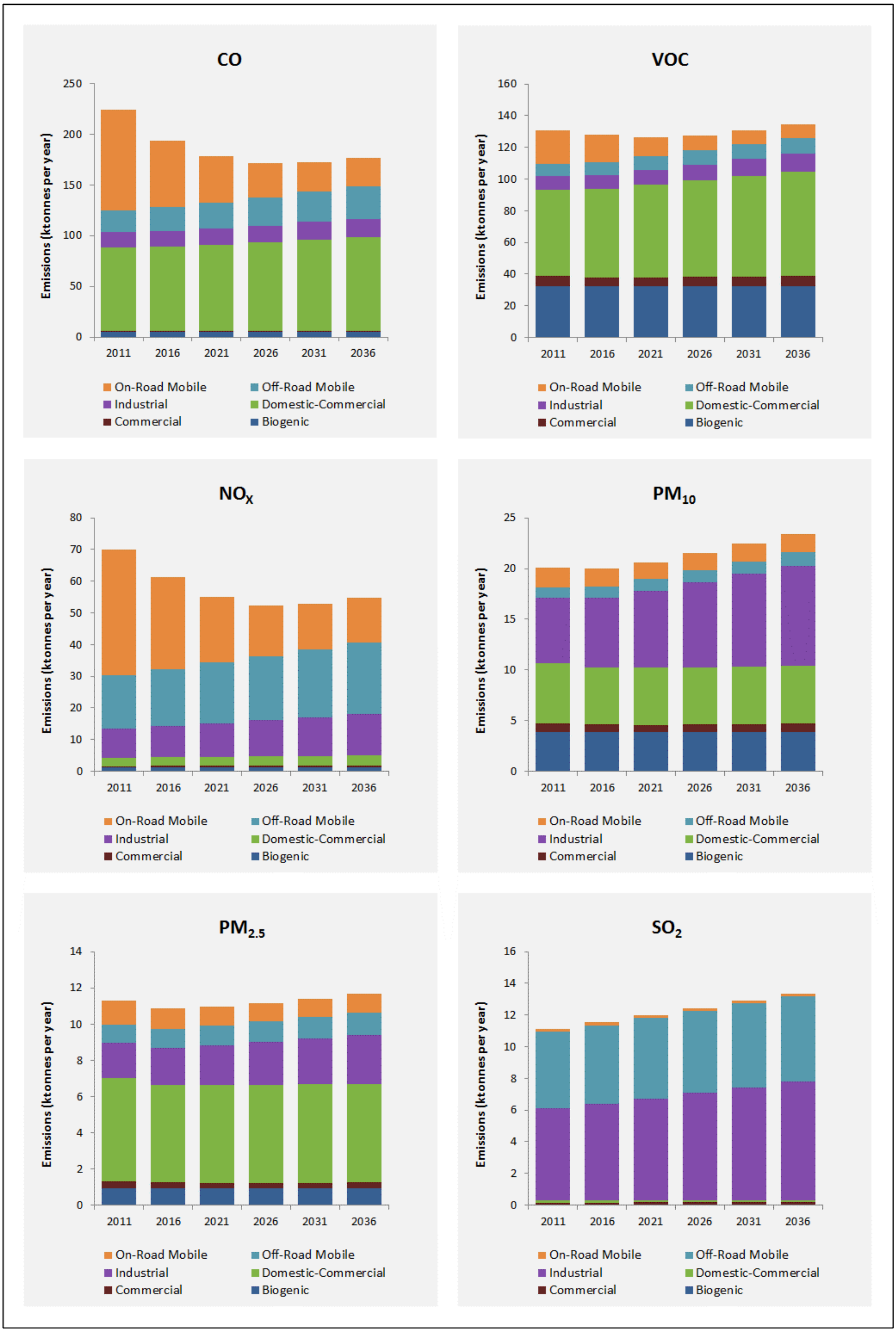

Figure 5-5 **Projections of sectoral emissions – Sydney, 2011-2036**

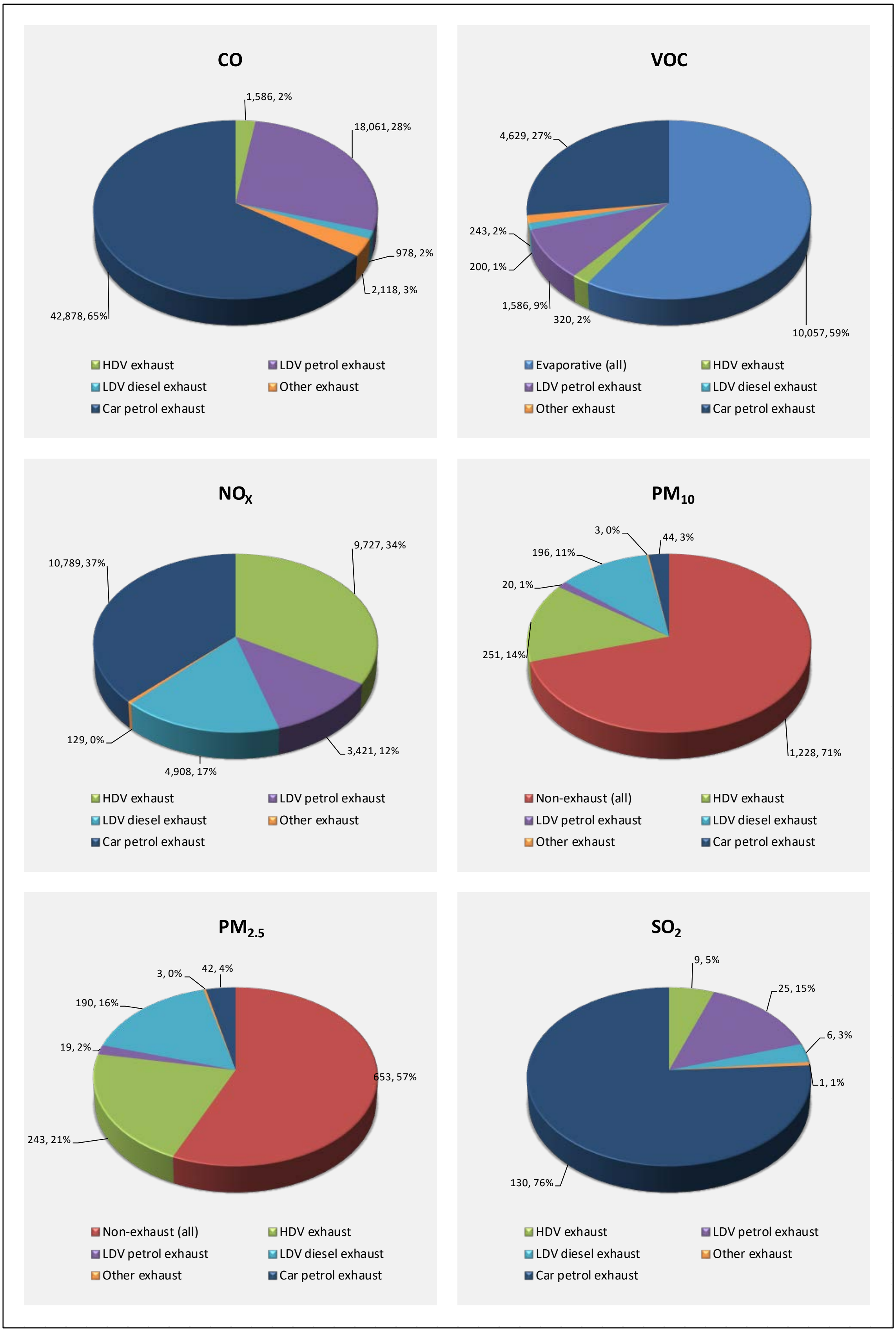

Figure 5-6 **Breakdown of road transport emissions – Sydney, 2016 (tonnes per year and percentage of total)**

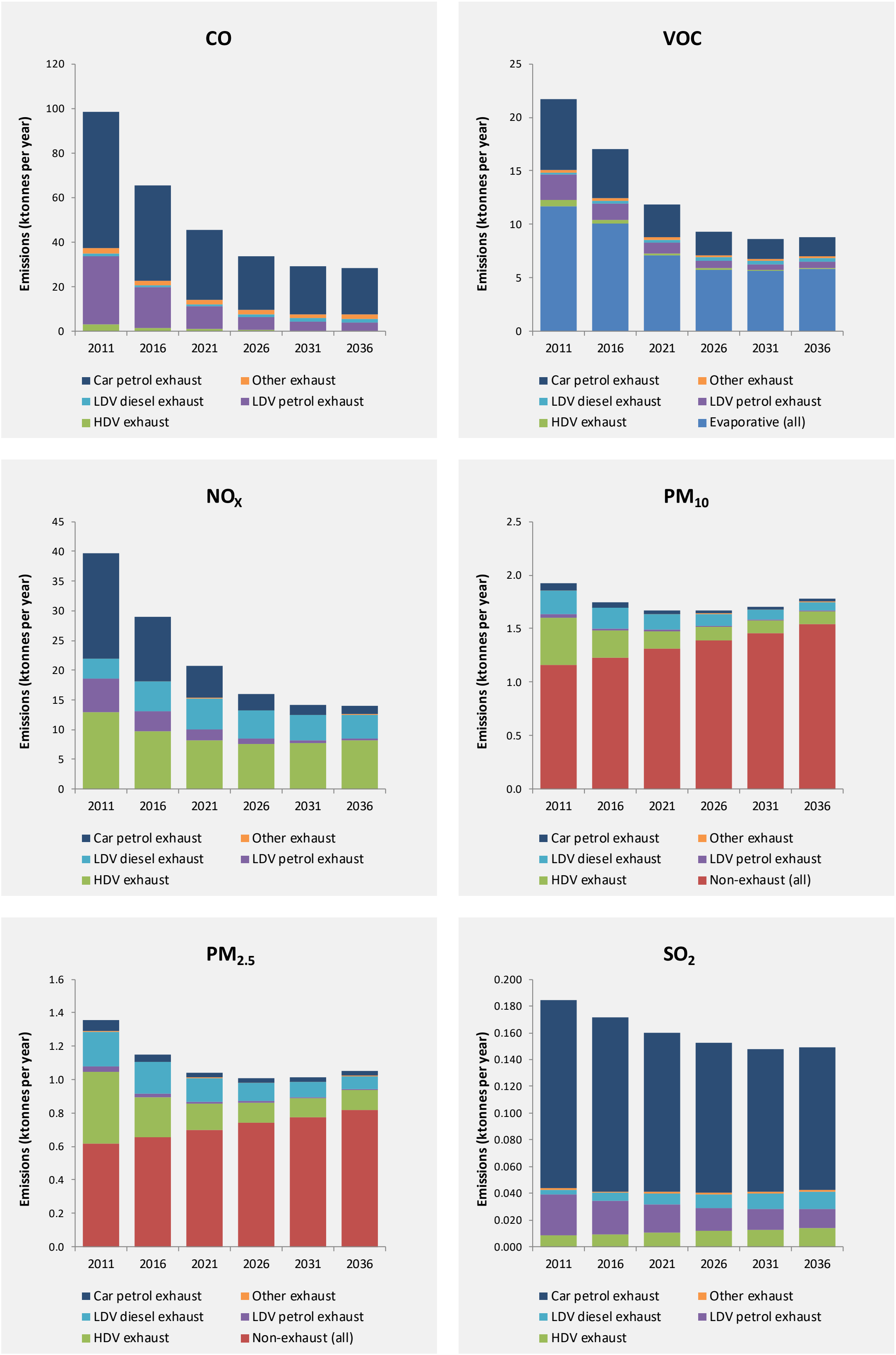

Figure 5-7 **Projections of road transport emissions – Sydney, 2011-2036**

5.7 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[12,13] 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.

5.8 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.

5.8.1 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).

5.8.2 Data from monitoring stations in the study area

A detailed analysis of the historical trends in Sydney's air quality (2004–2019), 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 and Transport for NSW:

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

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

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

  - F1, M1.

Consideration was also given to the shorter-term data from other Transport for NSW (eg NorthConnex and WestConnex) air quality monitoring stations.

The results for specific air quality metrics during the period 2004-2019 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 2019. 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
  - With the exception of 2019, there were general downward trends in maximum concentrations, and these were statistically significant at most stations
- Annual mean NO_2
  - Concentrations at all stations were well below the air quality criterion of 62 µg/m^3 and ranged between around 15 and 25 µg/m^3 (depending on the station) in recent years. Values at the 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 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 80-140 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 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 have shown an upward trend, and this was statistically significant at several stations. This is largely due to the values increasing from 2017 with drought conditions worsening and then severe bushfire activity in 2018 and 2019. In recent years, the annual mean concentration at many stations has been above 20 µg/m^3
- Maximum 24-hour PM_{10}
  - Maximum 24-hour PM_{10} concentrations are extremely variable but have exhibited an upward trend since 2018, due to extended drought conditions and widespread bushfires. Based on the previous 13 years of data, these most recent years are anomalous
- 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 beyond 2013 were 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. The large increase in 2019 was, again, due to the severe bushfire activity in the second half of the year

- Maximum 24-hour $PM_{2.5}$
  - There has been no systematic trend in the maximum 24-hour $PM_{2.5}$ concentration. The maximum 24-hour concentrations over a year are often 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. Significant events such as dust storms and bushfires will result in maximum levels well above these criteria.

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

While the data from 2016 was used to determine background concentrations for the assessment, to coincide with the base year traffic modelling among other things, it is noted that this does not result in significantly different values than it a later year was used.

Table 5-2 shows a comparison of the background concentrations assumed for the assessment, based on 2016 data, compared with data collected subsequently in 2018. The comparison shows that levels in 2018 were consistent than those in 2016.

Table 5-2 Comparison of background concentrations for 2016 and 2018

Pollutant	Averaging period	Units	Measurement year	
			2016	2018
CO	1-hour	mg/m^3	3.13	1.25
NO_X	1-hour	µg/m^3	603.8	554.1
	Annual *	µg/m^3	54.7	34.5
PM_{10}	24-hour	µg/m^3	48.0	43.8
	Annual *	µg/m^3	21.2	21.6
$PM_{2.5}$	24-hour	µg/m^3	22.1	19.2
	Annual *	µg/m^3	9.1	7.4

* Spatially varying maps were used to determine the background value for specific receptors, but this table presents the annual average for the monitoring sites used in the synthetic profiles for easier comparison

5.8.3 Project-specific air quality monitoring

Three project-specific monitoring stations for Beaches Link and the Western Harbour tunnel program of works were established by Transport for NSW in 2017. The locations of the stations are shown in Annexure D. 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 Transport for NSW stations in Sydney
- Establish the representativeness of the data from these stations that were used to characterise air quality in the Beaches Link and Western Harbour tunnel 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 Department of Planning, Industry and Environment 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 stations and WHTBL data would not have had a material impact on the outcomes of the assessment for this pollutant.

For NO_X, NO_2, 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 May 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.

6 Overview of assessment methodology

6.1 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.

6.2 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).

6.3 Consultation with government agencies and committees

Transport for NSW 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.

6.4 General assessment approach for the project

6.4.1 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 of particulate matter emissions 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[14], 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.

6.4.2 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 and ventilation supply facilities along the tunnel, 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 the Western Harbour Tunnel), 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[15]. 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.

Expected traffic (24-hour) scenarios

The expected traffic scenarios are described in Section 6.4.3. 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

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[14] 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.

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

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 southbound exit to the Warringah Freeway, requiring all southbound traffic to exit via the Gore Hill Freeway or via the tunnel-to-tunnel connection with Western Harbour Tunnel.

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 Beaches Link tunnels, and ending at the Western Harbour Tunnel to Beaches Link connection at the Warringah Freeway, and all the possible routes all the way from/to Beaches Link connection to Burnt Bridge Creek Deviation at Balgowlah and Wakehurst Parkway at Killarney Heights 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.

6.4.3 Operational assessment – local air quality

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).

The operational ambient local 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 details of the methodology.

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.

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 in Figure 6-1. 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.

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.

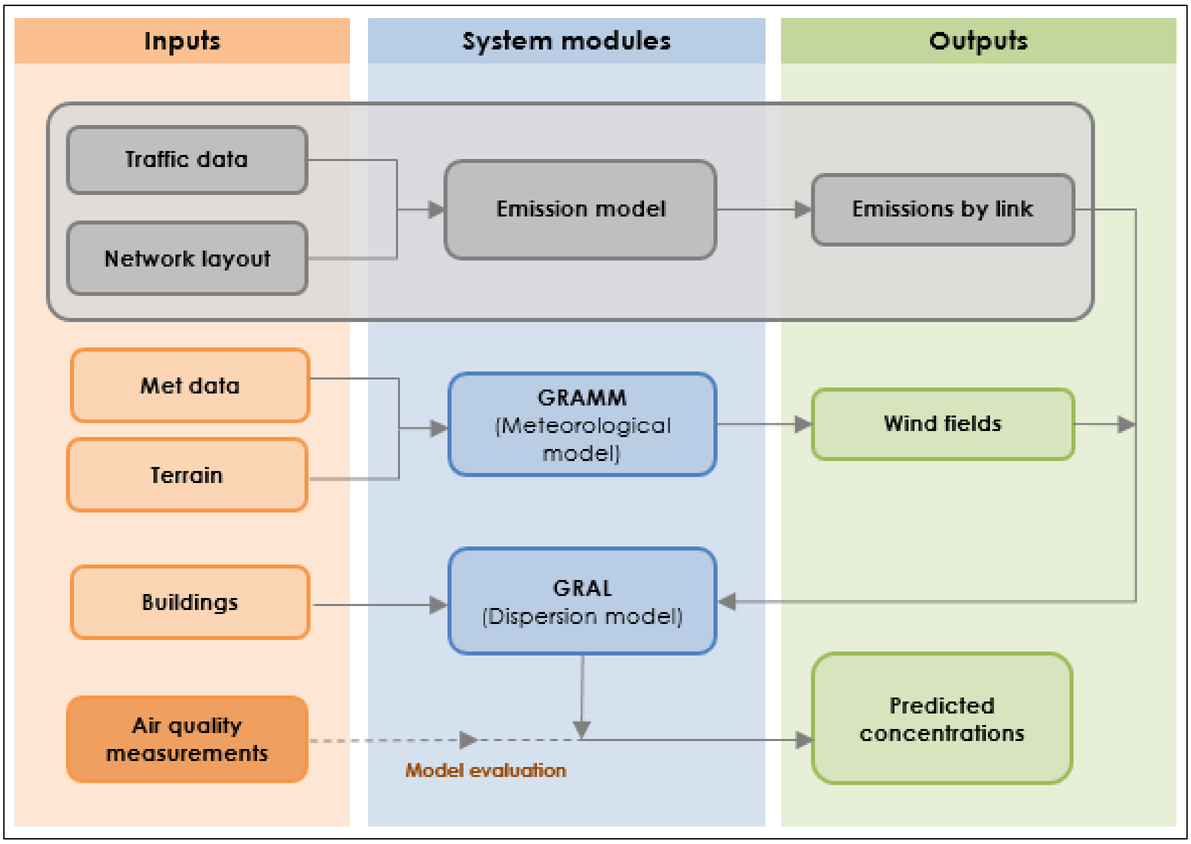

Figure 6-1 Overview of the GRAMM/GRAL modelling system

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 6-2.

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 6-2. 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 6-2. 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 beyond the project itself to allow for the traffic interactions between the project, the Western Harbour Tunnel, the Warringah Freeway Upgrade 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.

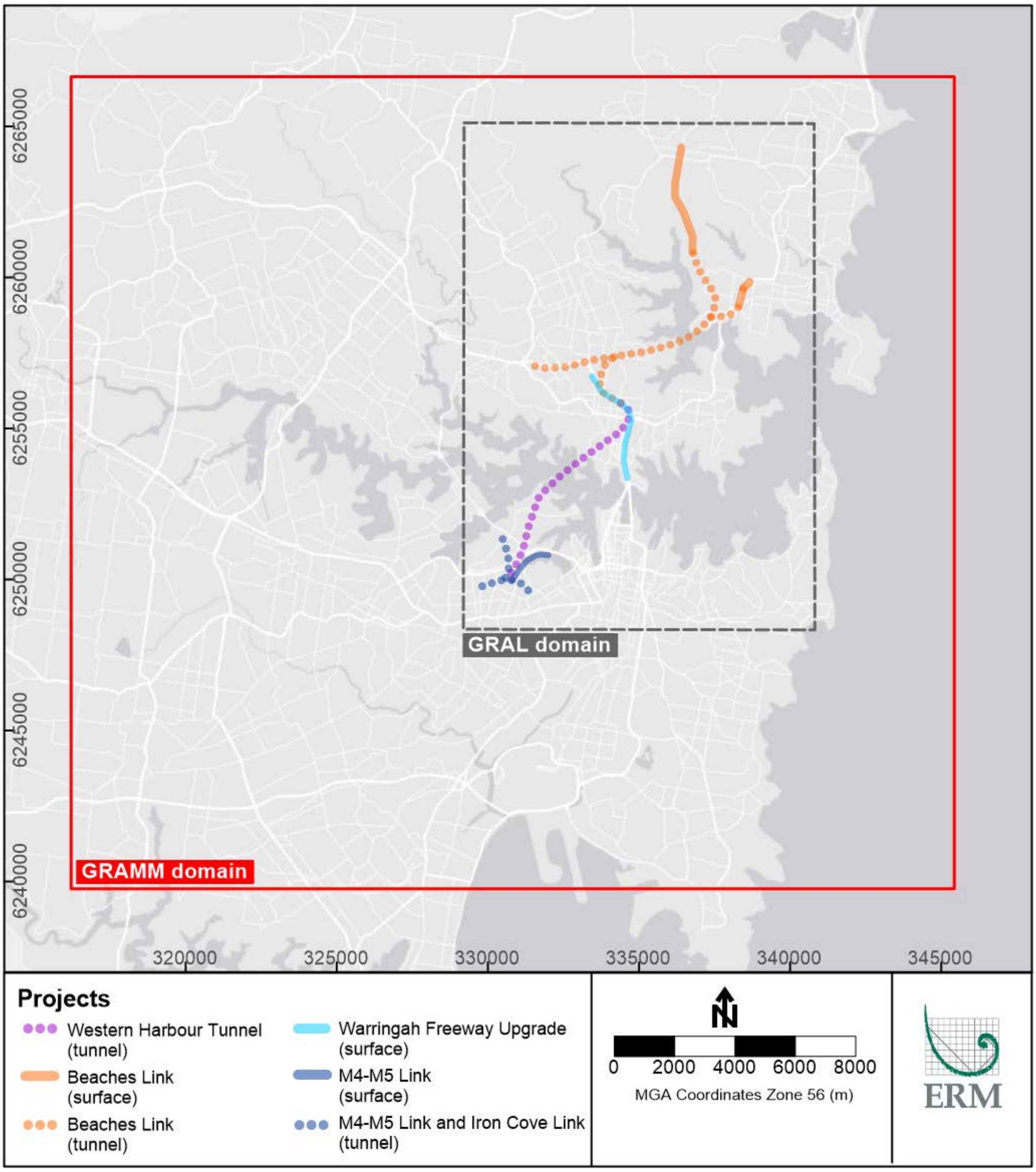

Figure 6-2 Modelling domains for GRAMM and GRAL (grid system MGA94)

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 MtO 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.

GRAMM configuration

GRAMM domain set-up

The GRAMM domain (refer to Figure 6-2) 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 6-1 presents the meteorological and topographical parameters that were selected in GRAMM.

Table 6-1 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) Rozelle (operated by the Department of Planning, Industry and Environment) 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 2016 – 31 December 2016
Meteorological parameters	Wind speed (m/s), Wind direction (°), stability class (1-7)
Number of wind speed classes	10
Wind speed classes (m/s)	0-0.5, 0.5-1.5, 1.5-2.5, 2.5-3.5, 3.5-4.5, 4.5-5.5, 5.5-6.5, 6.5-7.5, 7.5-9 >9
Number of wind speed sectors	36
Sector size (degrees)	10
Anemometer height above ground (m)	10
Concentration grids and general GRAMM input	
GRAMM domain in UTM (m)	N = 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 5.2, 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 75 metres Australian Height Datum (AHD) at the southern end at the Warringah Freeway to an elevation of around 240 metres at Frenchs Forest 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 5.2, 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 6-3 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.

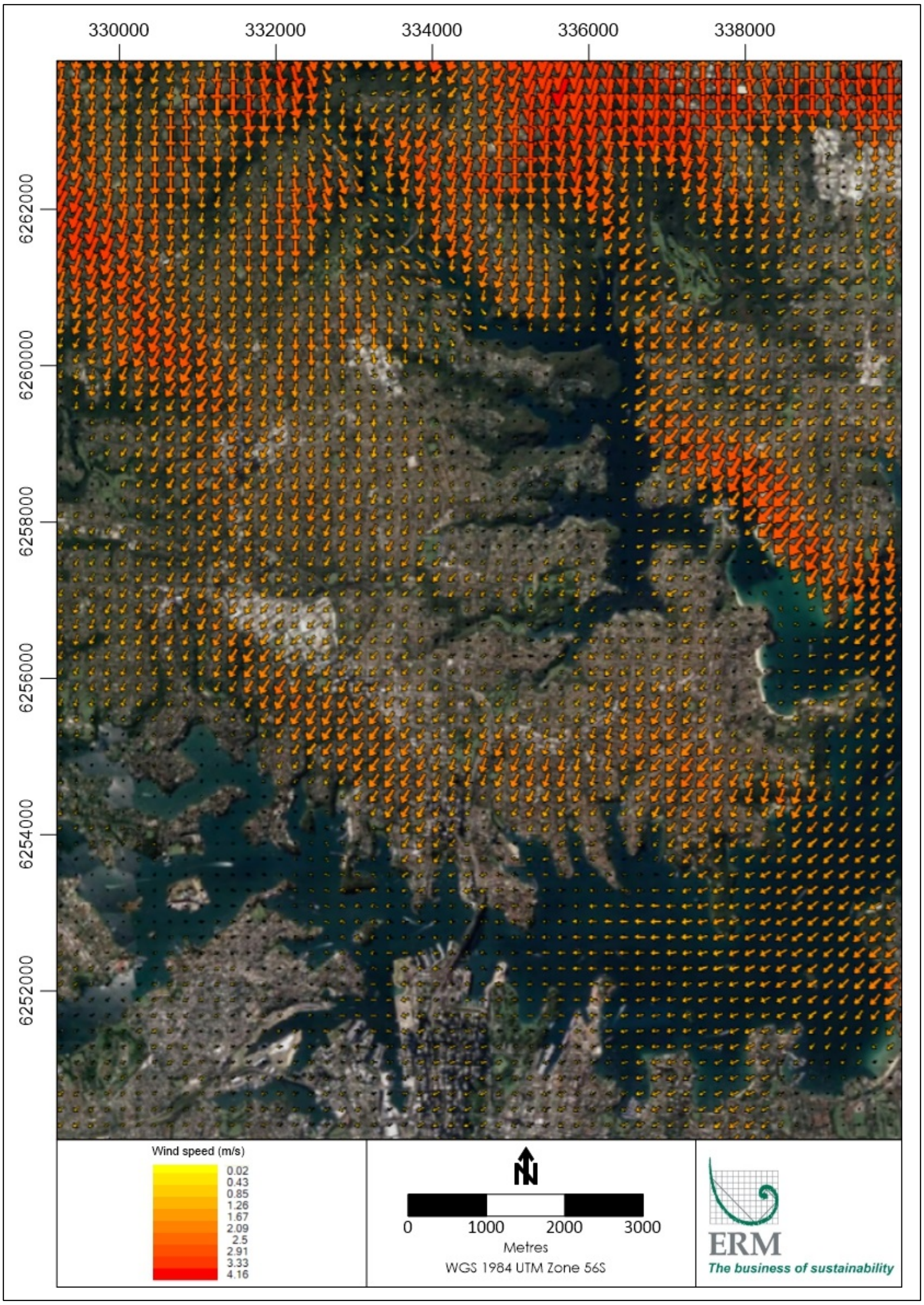

Figure 6-3 **Example of a wind field across the GRAMM domain (grid system MGA94)**

GRAMM Match-to-Observations function

The GRAMM Match-to-Observations (MtO) function was used to refine the order of the predicted wind fields to provide a better match to the observations the 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 weighting factors were applied for this study are shown in Table 6-2.

Table 6-2 MtO weighting factors

Site	Suggested MtO 'weighting factor'	Suggested MtO 'direction factor'
Rozelle	0.2	0.05
Randwick	1	1
Manly	0.2	0.2
Fort Denison	0.2	0.2

Evaluation of meteorological model

Wind speed and wind direction values were extracted for each of the meteorological stations shown on Figure 5-2, 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.

Modelling scenarios

Expected traffic scenarios and regulatory worst case (RWC) scenarios were both considered for ambient air quality. These are described below.

Expected traffic scenarios

The seven expected traffic scenarios included in the operational air quality assessment are summarised in Table 6-3. 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). The scenarios also took into account future changes over time in the composition and performance of the vehicle fleet. The objective of these scenarios was to evaluate the expected impacts of the operation of the project on 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 6-3 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		M6 Motorway projects	
						Western Harbour Tunnel / Warringah Freeway Upgrade	Beaches Link / Gore Hill Freeway Connection	M6 Motorway (Stage 1)	M6 Motorway (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(BL)	'Do something 2027' (with the project)	As 'Do minimum 2027', but with the project as well as Warringah Freeway completed.	✓	✓	-	Warringah Freeway Upgrade only	✓	-	-
2027-DSC	'Do something cumulative 2027'	As 'Do something 2027', but with Sydney Gateway, Western Harbour Tunnel, Warringah Freeway Upgrade and M6 Motorway - Stage 1 also completed.	✓	✓	✓	✓	✓	✓	-
2037-DM	'Do minimum 2037'	As 'Do minimum 2037', 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(BL)	'Do something 2037' (with the project)	As 'Do something 2037', but for 10 years after project opening.	✓	✓	-	Warringah Freeway Upgrade only	✓	-	-
2037-DSC	'Do something cumulative 2037'	As 'Do something cumulative 2037', but with all stages of the M6 Motorway 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 scenario

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 scenario presented in the analysis was 2037-DSC and assessed CO, NO_X, PM_{10}, $PM_{2.5}$ and THC 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 Western Harbour Tunnel operating under breakdown scenarios continuously for a full-year. The regulatory worst case (RWC) represents a theoretical upper bound that would never occur for periods longer than a few hours. As RWC emissions are only relevant for the ventilation outlets, these were then combined with expected traffic results from the surface roads and portals to estimate the total potential RWC impact.

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 6-4. 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 6-4 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 Appendix I (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, WestConnex M4 and WestConnex M8 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:

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

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:

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

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[16]. 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)

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

- Total suspended particulates (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 6.4.4)
- 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.

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[17]:

- *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[18]. 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,

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[17] These terms are relevant to both annual mean and short-term (eg 1-hour mean or 24-hour mean) ambient air quality criteria.

[18] As defined in Australian Standard AS/NZS 3580.1.1:2007.

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.

Presentation of results

An example of the different contributions at a receptor for different scenarios is shown in Figure 6-4. 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 6-4), the total concentration with the project in 2027 and 2037 is smaller than the total concentration without the project.

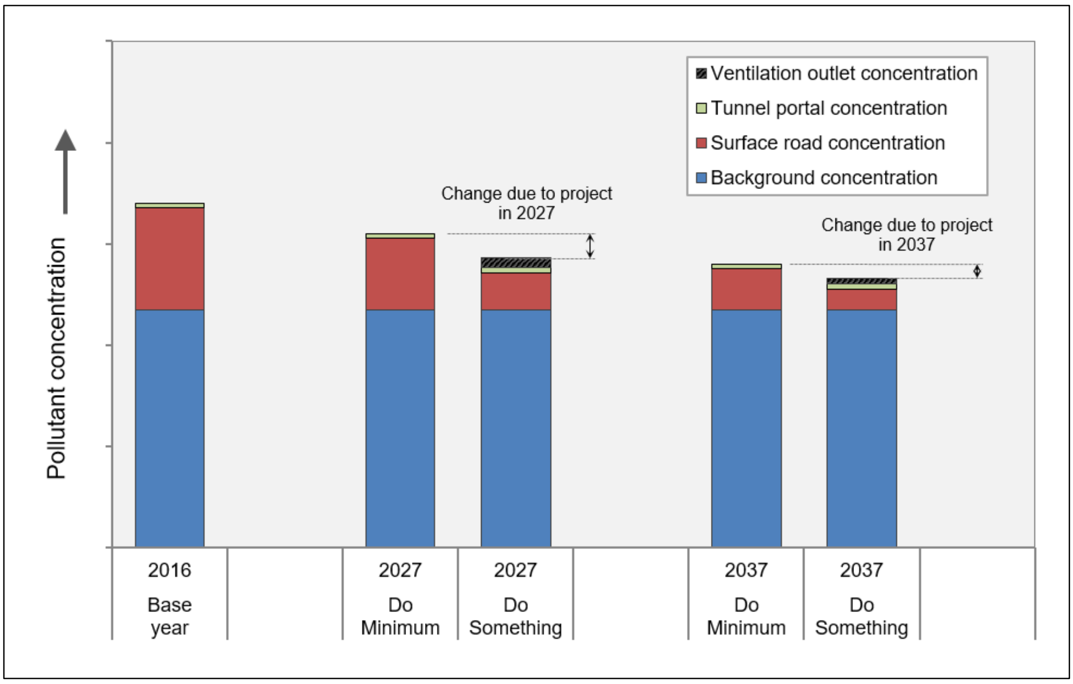

Figure 6-4 Contributions to total pollutant concentrations (example) (portals include Sydney Harbour Tunnel and Eastern Distributor only)

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 8.4.1
- 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).

6.4.4 Operational assessment – regional air quality

The potential impacts of the project on air quality more widely across the across the Greater 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 developed the *Tiered Procedure for Estimating Ground Level Ozone Impacts from Stationary Sources* (ENVIRON, 2011) to estimate ground-level O_3. 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.

6.4.5 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 NSW Approved Methods (toluene, xylenes, and acetaldehyde). These pollutants were taken to be representative of other odorous pollutants from motor vehicles.

6.5 Treatment of uncertainty

6.5.1 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.

6.5.2 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'. Annexure C provides a detailed analysis of the emissions modelling which includes these key inputs and a number of others, such as road gradients, hot running and cold start emissions, as well as non-exhaust PM.

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 (eg 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). The assumption for this assessment is that the uptake of Euro VI vehicles will not occur until after 2027, and so ventilation outlet emissions do not include these until 2037.

While the tunnel ventilation assessment provided in Annexure K[19] is considered to be conservative and encapsulates all feasible traffic scenarios, a sensitivity analysis was conducted to evaluate potential changes in air quality and health risks due to the operation of ventilation outlets and motorway facilities under even in the most unlikely of circumstances.

In the sensitivity analysis, for each ventilation outlet the daily $PM_{2.5}$ emission profiles in the 2037-DSC scenario for expected traffic were proportionally scaled up until the corresponding emission limit (ie 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 (Outlet H) in Figure 6-5. This shows how the 2037-DSC scenario has been

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[19] 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 2037. 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.

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 2037-DSC predictions and those under the sensitivity test.

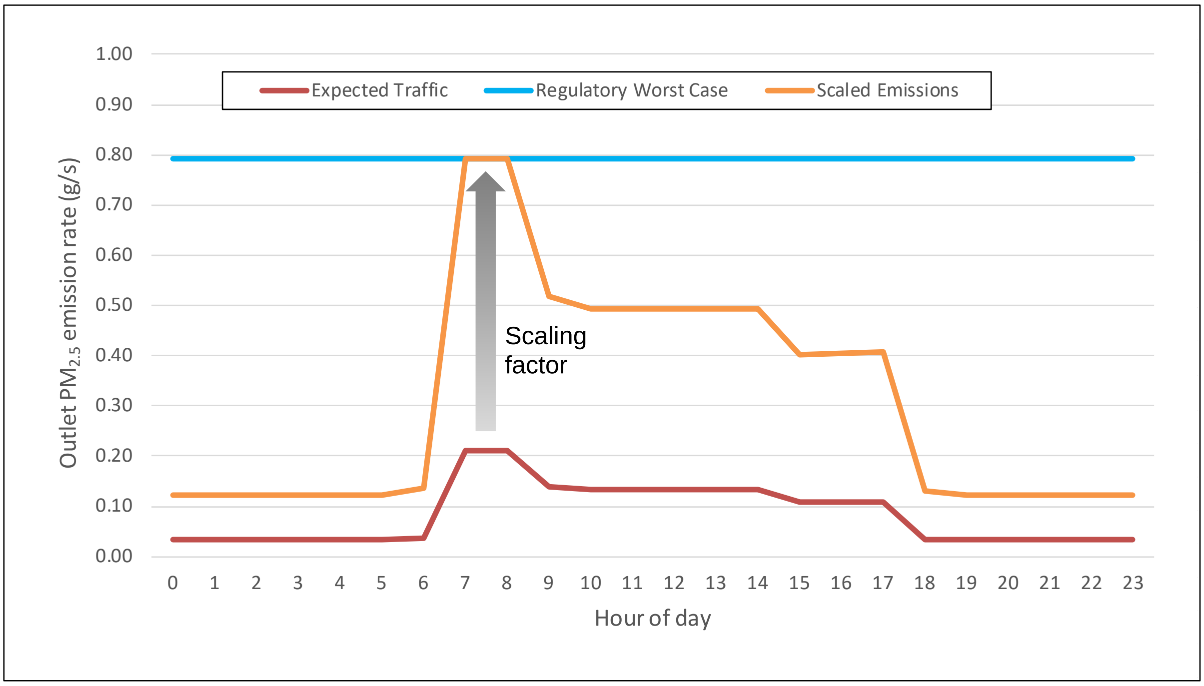

Figure 6-5 **Calculation of sensitivity scaling factor over the course of a day for $PM_{2.5}$ (Warringah Freeway Ventilation Outlet H, 2037-DSC scenario)**

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 6-5, with the value of 3.7 for the Warringah Freeway Ventilation Outlet (Outlet H) shaded.

Table 6-5 **$PM_{2.5}$ scaling factors for all ventilation outlets**

Ventilation Outlet	Name	Scaling Factor
F	WHT: Rozelle (West)	5.3
G	WHT: Warringah Freeway	4.3
H	**BL: Warringah Freeway**	**3.7**
I	BL: Gore Hill Freeway	5.6
J	BL: Wakehurst Parkway	4.1
K	BL: Burnt Bridge Creek Deviation	5.0

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 more than 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.

7 Assessment of construction impacts

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 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 managed through standard air quality environmental management measures. In the event of encountering unexpected finds of contamination during construction, work should 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, should be carried out in accordance with the *Contaminated Land Management Act 1997* (NSW) and is described further in Technical working paper: Contamination. While the consequences of finding contaminants can be significant, the risk 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 should be deployed and reduce this risk of impact.

Controlled surface-based blasting may be used for cross passage excavation and bench removal in mainline and ramp tunnels, and excavation and surface works along Wakehurst Parkway. It is anticipated that sections of Wakehurst Parkway might also be excavated using controlled blasting during bulk earthworks as an alternative to ripping or hammering of rock so as to minimise the duration of this activity and potential noise and amenity impacts. 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 temperatures caused at the excavation face. This risk should 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 1.4.

This section:

- Identifies the construction footprint and assessment zones for the purposes of the air quality assessment
- 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 unlikely to represent a serious ongoing problem if risks are managed well. 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 adequate or 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 areas required to support tunnelling activities and to construct the tunnel connections and tunnel portals. This includes connections to the Warringah Freeway, Gore Hill Freeway, Burnt Bridge Creek Deviation and Wakehurst Parkway
- The Gore Hill Freeway Connection
- Surface works at Balgowlah, Seaforth, Killarney Heights and Frenchs Forest
- Construction of 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(a)
Zone 1	BL3, BL4, BL5, BL6	Construction works associated with Beaches Link component of the project. Construction works associated with the upgrade and realignment of the Gore Hill Freeway. Collectively, this would include (but not limited to) tunnel decline structures and construction of tunnel portals and ramps, construction of operational ancillary infrastructure and adjustments to other infrastructure (eg shared user transport infrastructure).	Q1 2023 – Q2 2027
Zone 2	BL1, BL2	Construction works associated with Beaches Link tunnel decline structures and tunnel portals at Cammeray Golf Course (BL1) and Flat Rock Drive (BL2), and connections to Warringah Freeway, including fitout of the ventilation outlet and motorway facility.	Q11 2023 – Q4 2027
Zone 3	BL7, BL8, BL9	Construction of the harbour crossing (including cofferdam excavation, dredging and handling of dredged material).	Q1 2023 – Q2 2027
Zone 4	BL10, BL11	Construction works associated with connections and integration of Beaches Link to the surrounding road network at Balgowlah. This includes (but is not limited to) construction of portals and the new access road, modifications to existing surface roads (including Burnt Bridge Creek Deviation), construction of the Burnt Bridge Creek Deviation ventilation outlet and motorway facility and construction of the new open space and recreation facilities at Balgowlah	Q1 2023 – Q4 2028
Zone 5	BL12, BL13, BL14	Construction works associated with connections and integration of Beaches Link with Wakehurst Parkway at Seaforth and Killarney Heights. This includes (but is not limited to) surface road works associated with the realignment and upgrade of Wakehurst Parkway and minor changes to intersections, as well as the construction of the Wakehurst Parkway ventilation outlet and motorway facility.	Q1 2023 – Q4 2027

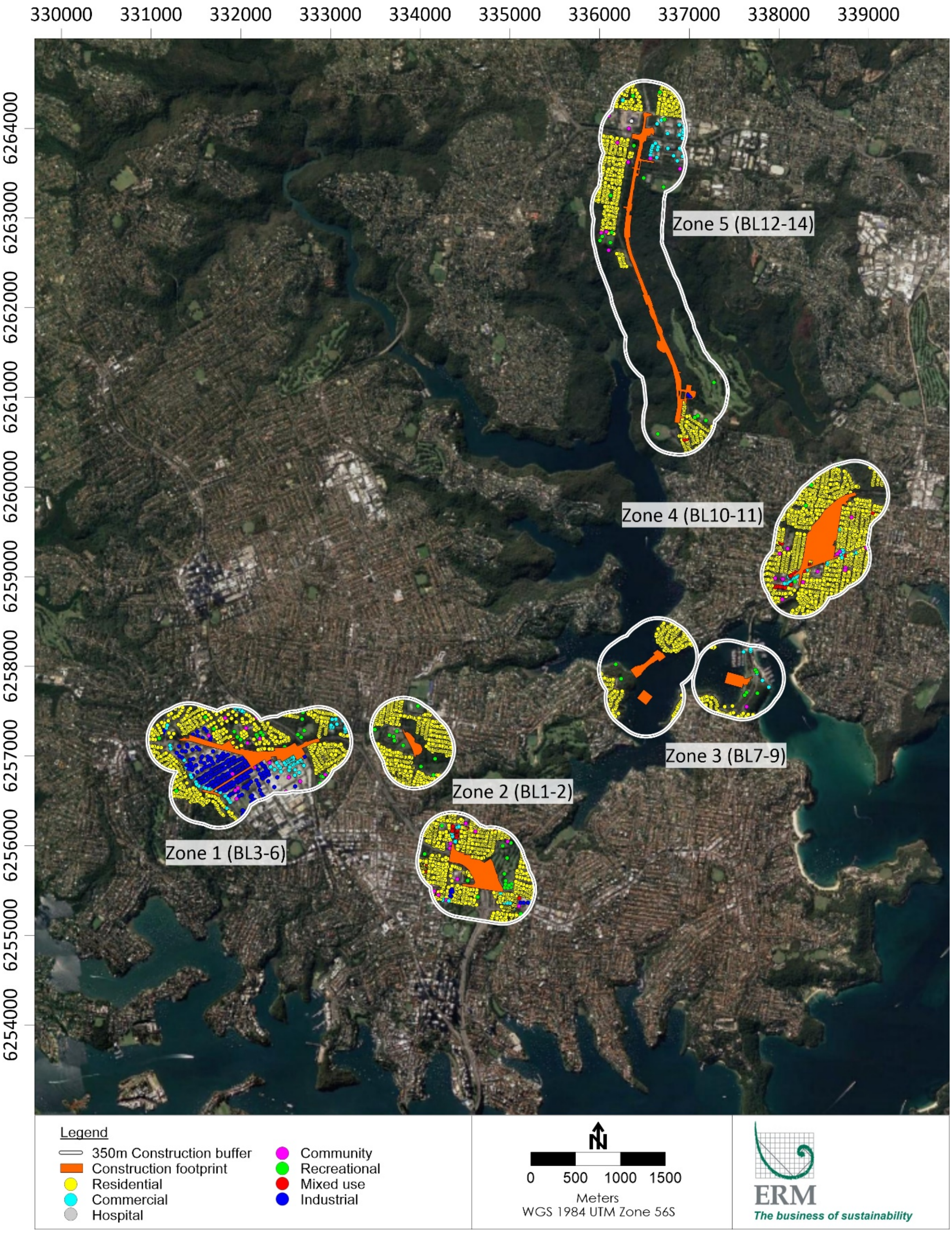

Figure 7-1 **Construction assessment zones**

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.

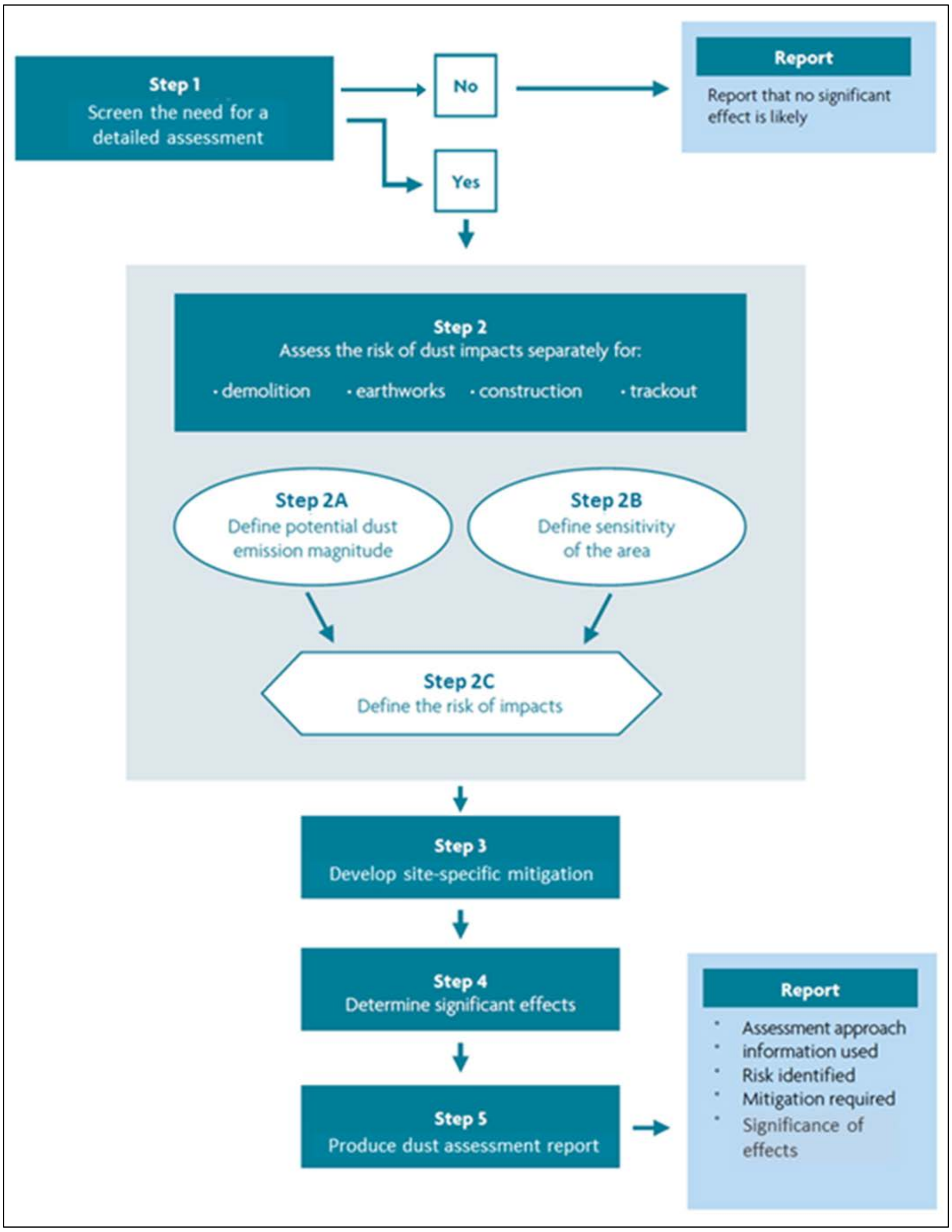

Figure 7-2 Steps in the risk assessment of construction dust (IAQM, 2014)

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. The majority of construction assessment Zone 2 would have already undergone significant disturbance during the construction of the Western Harbour Tunnel and Warringah Freeway Upgrade. The construction activities assessed here therefore assumes that much of the works have already been completed as part of that project.

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 (eg 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 (eg metal cladding, timber), demolition activities <10 m above ground and during wetter months.
Earthworks	Site area >10000 m^2, potentially dusty soil type (eg 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 (eg 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 (eg 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 (eg concrete), piling, on site concrete batching.	Total building volume <25000 m^3, construction material with low potential for dust release (eg metal cladding or timber).
Track-out	>50 HDVs (>3.5 tonnes) outward movements in any one day, potentially dusty surface material (eg high clay content), unpaved road length >100 m.	10–50 HDVs (>3.5 tonnes) outward movements in any one day, moderately dusty surface material (eg 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.

Notes:
- 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 heavy-duty vehicles (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	Large	Small	N/A	Medium	Small
Earthworks	Large	Medium	Small	Large	Large
Construction	Large	Medium	Small	Large	Large
Track-out	Large	Medium	Medium	Large	Large

Step 2B: Sensitivity of area

The sensitivity of the area takes into account the specific sensitivities of local receptors, the proximity and number of the receptors, and the local background PM_{10} concentration.

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 7-2 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 Hotel	5 5 200
Mixed Use	3
Aged Care Childcare Community Education Medical Place of Worship	100 30 20 500 10 10
Industrial	10
General Residential Low Density Residential Medium Density residential High Density Residential	3 2 5 50
Recreational	20
Hospital	1000
Other	5

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 (BL3,4,5,6)	Demolition	High	465	830	1,440	5,825	High
	Earthworks	High	465	830	1,440	5,825	High
	Construction	High	465	830	1,440	5,825	High
	Track-out	High	465	830	N/A	N/A	High
Zone 2 (BL1,2)	Demolition	High	335	385	1,353	8,651	High
	Earthworks	High	335	385	1,353	8,651	High
	Construction	High	335	385	1,353	8,651	High
	Track-out	High	335	385	N/A	N/A	High
Zone 3 (BL7,8,9)	Demolition	N/A	N/A	N/A	N/A	N/A	N/A
	Earthworks	High	0	10	160	1,410	Medium
	Construction	High	0	10	160	1,410	Medium
	Track-out	High	0	10	N/A	N/A	Low
Zone 4 (BL10,11)	Demolition	High	552	706	1,556	6,763	High
	Earthworks	High	552	706	1,556	6,763	High
	Construction	High	552	706	1,556	6,763	High
	Track-out	High	552	706	N/A	N/A	High
Zone 5 (BL12,13,14)	Demolition	High	70	135	390	4,921	High
	Earthworks	High	70	135	390	4,921	High
	Construction	High	70	135	390	4,921	High
	Track-out	High	70	135	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.	Number of receptors by distance from assessment zone boundary (m)					Sensitivity of area
				<20	20-50	50-100	100-200	200-350	
Zone 1 (BL3,4,5,6)	Demolition	High	15-17.5	465	830	1,440	2,960	2,865	High
	Earthworks	High	15-17.5	465	830	1,440	2,960	2,865	High
	Construction	High	15-17.5	465	830	1,440	2,960	2,865	High
	Track-out	High	15-17.5	465	830	N/A	N/A	N/A	High
Zone 2 (BL1,2)	Demolition	High	15-17.5	355	385	1,353	2,408	6,243	High
	Earthworks	High	15-17.5	355	385	1,353	2,408	6,243	High
	Construction	High	15-17.5	355	385	1,353	2,408	6,243	High
	Track-out	High	15-17.5	355	385	N/A	N/A	N/A	High
Zone 3 (BL7,8,9)	Demolition	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Low
	Earthworks	High	15-17.5	0	10	160	280	1,130	Low
	Construction	High	15-17.5	0	10	160	280	1,130	Low
	Track-out	High	15-17.5	0	10	N/A	N/A	N/A	Low
Zone 4 (BL10,11)	Demolition	High	15-17.5	552	706	1,556	3,200	3,563	High
	Earthworks	High	15-17.5	552	706	1,556	3,200	3,563	High
	Construction	High	15-17.5	552	706	1,556	3,200	3,563	High
	Track-out	High	15-17.5	552	706	N/A	N/A	N/A	High
Zone 5 (BL12,13,14)	Demolition	High	15-17.5	70	135	390	2,206	2,715	High
	Earthworks	High	15-17.5	70	135	390	2,206	2,715	High
	Construction	High	15-17.5	70	135	390	2,206	2,715	High
	Track-out	High	15-17.5	70	135	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 Appendix S (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 are in all zones. 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 1 (BL3,4,5,6)	Demolition	High	<20	High
	Earthworks	High	<20	High
	Construction	High	<20	High
	Track-out	High	<20	High
Zone 2 (BL1,2)	Demolition	High	<20	High
	Earthworks	High	<20	High
	Construction	High	<20	High
	Track-out	High	<20	High
Zone 3 (BL7,8,9)	Demolition	High	N/A	N/A
	Earthworks	High	<20	High
	Construction	High	<20	High
	Track-out	High	<20	High
Zone 4 (BL10,11)	Demolition	High	<20	High
	Earthworks	High	<20	High
	Construction	High	<20	High
	Track-out	High	<20	High
Zone 5 (BL12,13,14)	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

Type of activity	Sensitivity of area (from Step 2B)	Potential emission magnitude (from Step 2A)		
		Large	Medium	Small
	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: High risk for all activities for dust soiling, human health and ecological.
- Zone 2: Medium risk for all activities for dust soiling, human health and ecological.
- Zone 3: Low risk for all activities for dust soiling. Negligible for the earthworks and construction activities and low risk for the track-out activity for human health and ecological. Low risk for the earthworks and construction activities and medium risk for the track-out activity for human health and ecological. Demolition activity is not undertaken in Zone 3.
- Zone 4: Medium risk for demolition and high risk for all other activities for dust soiling, human health and ecological.
- Zone 5: High risk for all activities, except demolition, for dust soiling, human health and ecological.

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 soiling	Human health	Ecological	Dust soiling	Human health	Ecological
Zone 1 (BL3,4,5,6)	Demolition	Large	High	High	High	High Risk	High Risk	High Risk
	Earthworks	Large	High	High	High	High Risk	High Risk	High Risk
	Construction	Large	High	High	High	High Risk	High Risk	High Risk
	Track-out	Large	High	High	High	High Risk	High Risk	High Risk
Zone 2 (BL1,2)	Demolition	Small	High	High	High	Medium Risk	Medium Risk	Medium Risk
	Earthworks	Medium	High	High	High	Medium Risk	Medium Risk	Medium Risk
	Construction	Medium	High	High	High	Medium Risk	Medium Risk	Medium Risk
	Track-out	Medium	High	High	High	Medium Risk	Medium Risk	Medium Risk
Zone 3 (BL7,8,9)	Demolition	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Earthworks	Small	Medium	Low	High	Low Risk	Negligible	Low Risk
	Construction	Small	Medium	Low	High	Low Risk	Negligible	Low risk
	Track-out	Medium	Low	Low	High	Low Risk	Low Risk	Medium Risk
Zone 4 (BL10,11)	Demolition	Medium	High	High	High	Medium Risk	Medium Risk	Medium 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

Zone	Activity	Step 2A: Potential for dust emissions	Step 2B: Sensitivity of area			Step 2C: Risk of dust impacts		
			Dust soiling	Human health	Ecological	Dust soiling	Human health	Ecological
Zone 5 (BL12,13,14)	Demolition	Small	High	High	High	Medium Risk	Medium Risk	Medium Risk
	Earthworks	Large	High	High	High	High Risk	High Risk	High Risk
	Construction	Large	High	High	High	High Risk	High Risk	High Risk
	Track-out	Large	High	High	High	High Risk	High Risk	High Risk

(a) N/A = not applicable

7.1.6 Step 3: Mitigation

Step 3 involved 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 majority of assessment Zone 2 would have already undergone significant disturbance during the construction of the Western Harbour Tunnel and Warringah Freeway Upgrade. The construction activities assessed here therefore assumes that much of the main dust generating works will have already been completed as part of that project. There may be a low risk of cumulative impacts from construction works associated with the proposed Western Harbour Tunnel and Warringah Freeway Upgrade project. Recommended mitigation measures will reduce this risk (Section 9).

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 Excavated material from Middle Harbour

As part of the harbour construction activities for the project, a large amount of material would be dredged from the bed of the harbour. Dredged material has the potential to generate odour once exposed to air or while being processed. The potential impacts to surrounding sensitive receivers would be dependent on the:

- Characteristics of the material
- Amount of material undergoing treatment at any one time

- Treatment, handling and storage method
- Proximity and density of surrounding sensitive receivers.

Dredged material on the barges would be loaded as saturated material and remain covered with water which would reduce any odour emissions. Any potential odour impacts from the dredged material during barge transport would be negligible to low, given it would remain saturated, overflow from the barge would not be permitted and transport routes would be at some distance from any sensitive receivers.

For dredged material that is unsuitable for offshore disposal, the material would be transported by barge to a land-based load-out facility, most likely outside Middle Harbour. Additives such as lime and polymers would be mixed into dredged material in the barge at the load out facility to make it dry enough to load into a truck (spadable). This would also limit the potential for odour emission. The dredged material would then be loaded directly into sealed trucks before being transported for disposal at a licensed facility.

The location of the load-out facility for the dredged material would be determined during further design and construction planning. If the dredged material requires stockpiling or processing on land at the load-out facility, an odour assessment would be carried out to determine the potential for odour impacts at sensitive receivers in the vicinity, and identify any monitoring and management requirements.

7.2.2 Excavation at Flat Rock Creek reserve

Flat Rock Drive construction support site (BL2) is a tunnel support site and would have an access decline to the tunnels underground. The area to the west of Flat Rock Drive and east of Willoughby Road at Willoughby was used extensively as a municipal landfill prior to redevelopment as recreation facilities. Following the construction of Flat Rock Drive in 1968, and prior to 1971, areas to the east were filled with material comprising of putrescible waste. Since that time the majority of fill has been non-putrescible, predominantly consisting of building debris and so the material most likely to be encountered during excavation in this area would the more recent non-putrescible waste. A geotechnical investigation carried out within the footprint of the proposed construction support site identified clayey material with some building debris, but did not encounter any putrescible municipal waste.

A gabion wall at the eastern extent of the site and filling is proposed to create a flat area for the construction support site and minimise the need to excavate. The main excavations that would be required at the site would be piling to support an acoustic shed, piling to create the walls of the proposed tunnel access decline and excavation of the tunnel access decline. The location of the decline has been chosen to minimise the amount of excavation required to reach bedrock. Excavations associated with the project at the Flat Rock Drive construction support site (BL2), therefore, have limited potential to encounter putrescible landfilled waste that could generate odour.

There is some potential that landfill gases might be present in the soils underneath the Flat Rock Drive construction support site (BL2) from any putrescible waste present, or that might have migrated from the landfilled areas to the west. Excavations on site could release these landfill gases (if present). However, as the construction support site has been designed to minimise excavations, the potential for the release of significant volumes of landfill gases (if present) is limited.

While no landfill gas investigations have been carried out at the proposed construction support site, geotechnical investigations have been carried out generally in the area, including west of Flat Rock Drive in the vicinity of Willoughby Leisure Centre. While no specific landfill gas monitoring was carried out as part of those investigations, routine gas detection did not identify significant amounts of methane, which is a key landfill gas. This anecdotal evidence does not indicate a significant landfill gas issue associated with the former landfill.

As there is a low potential for significant amounts of putrescible waste materials and landfill gases to be present beneath the proposed Flat Rock Drive construction support site (BL2) site, the potential for significant odour issues during excavation is very low. As such, a quantitative assessment of potential odour issues is not warranted at this time. Prior to excavations at the construction support site, further investigations should be carried out to determine the potential to encounter odorous materials and gases. If present, it is likely that any potential odour issues could be adequately managed with routine measures such as minimising the amount of exposed waste, sealing excavated surfaces as the excavations progress and temporarily covering excavated waste materials. The specific measures would, however, be best developed by the construction contractor based on the results of the investigations and details of the proposed construction methodology. Refer to Section 9.1 for recommended mitigation and management measures.

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
- Dispersion modelling, including
  - Model configuration
  - Results for community receptors (CR), residential, workplace and recreational (RWR) receptors and the whole model domain (contours)
  - Predicted changes to local air quality due to the project
  - Elevated receptors
  - Regulatory worst case emissions from outlet
- 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. Warringah Freeway Ventilation Outlet (Outlet H), Gore Hill Freeway Ventilation Outlet (Outlet I), Wakehurst Parkway Ventilation Outlet (Outlet J) and Burnt Bridge Creek Deviation Ventilation Outlet (Outlet K) 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.

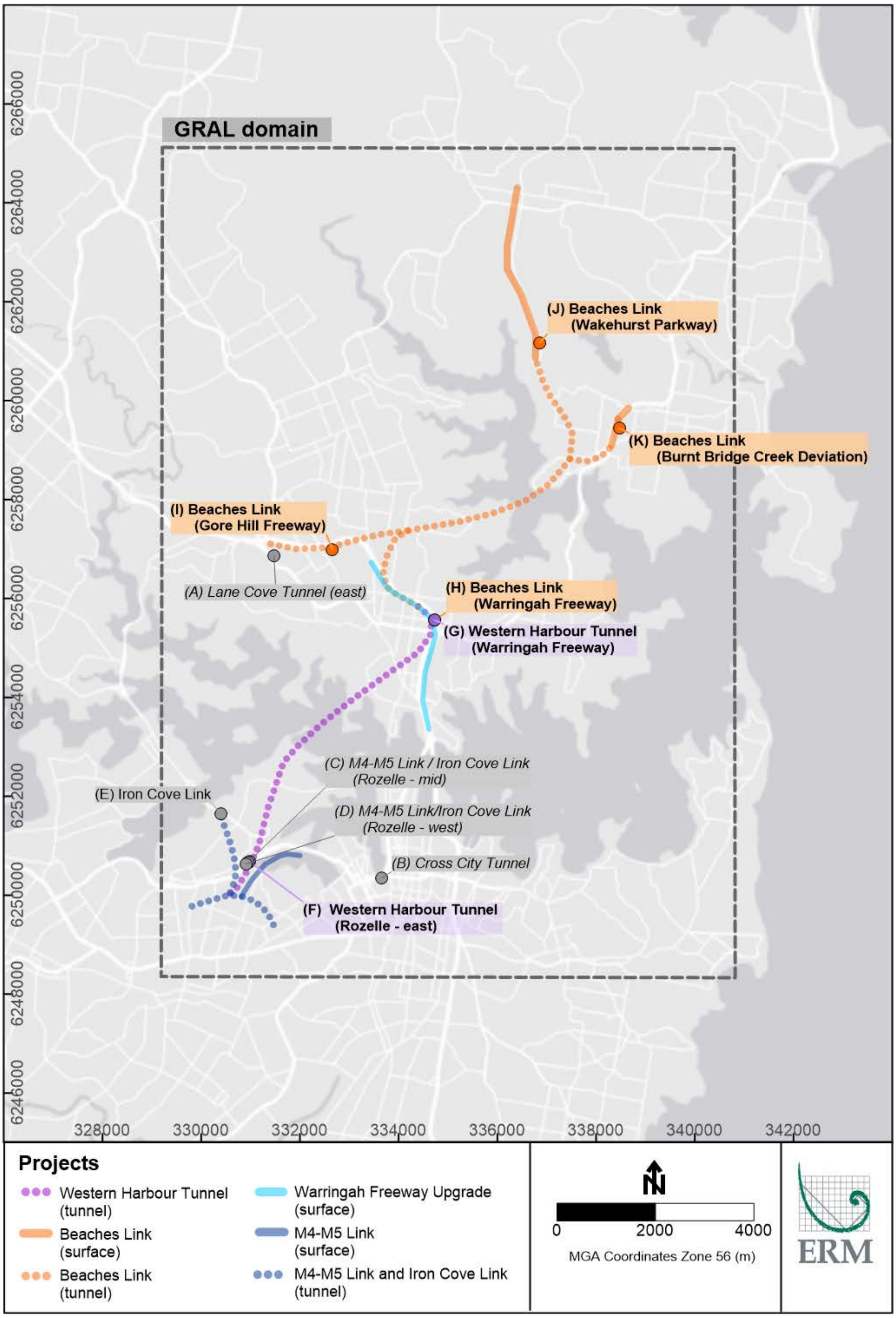

Figure 8-1 **Locations of all tunnel ventilation outlets included in the assessment (grid system MGA94)**

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 8.4.1). 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 Transport for NSW. 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 WestConnex M4-M5 Link environmental impact statement (Pacific Environment, 2017). Given that the future years for the WestConnex 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 Beaches Link and Western Harbour Tunnel 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 in Figure 8-2. The traffic in Sydney Harbour Tunnel and the Eastern Distributor tunnel, and hence 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 therefore 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.

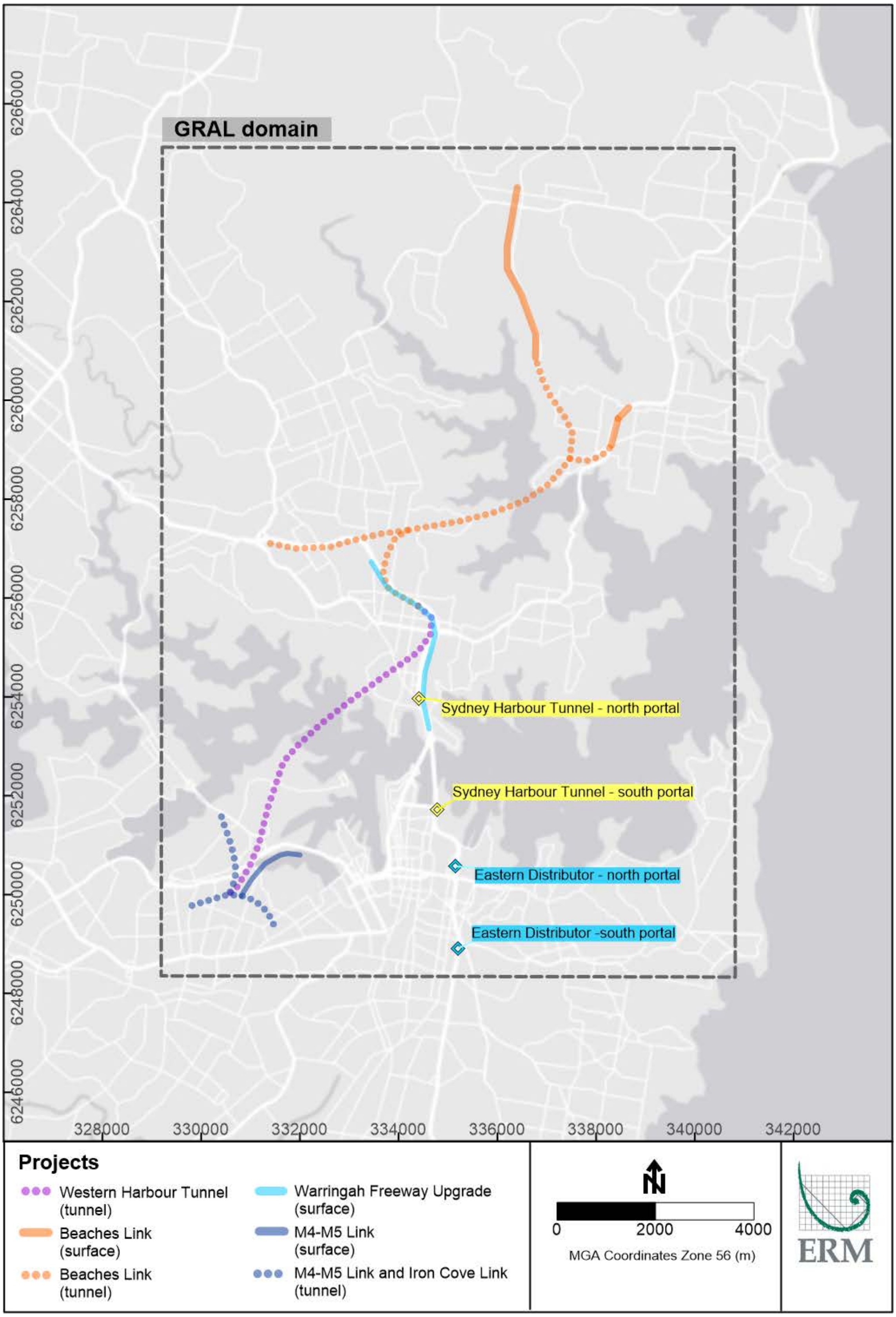

Figure 8-2 Locations of all tunnel portals included in the assessment (grid system MGA94)

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 NSW 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 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 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 Beaches 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 Transport for NSW's air quality screening model TRAQ[20]. 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.

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[20] Tool for Roadside Air Quality (TRAQ), an air pollution screening tool developed by Transport for NSW

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[21] 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)[22]. 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 Beaches 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 are 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 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.

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

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

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.

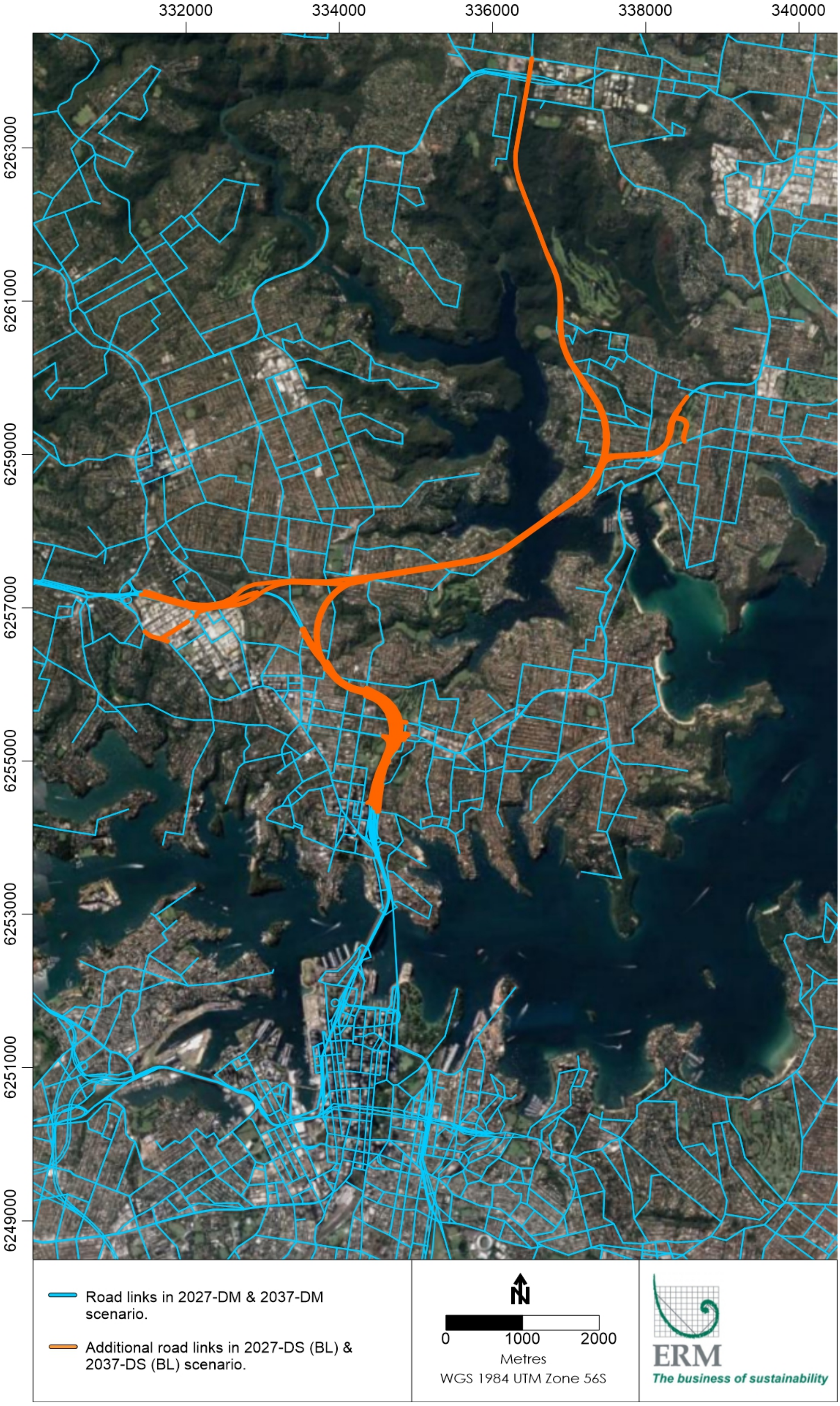

Figure 8-3 Road links in the 'Do minimum' scenarios, and additional links in the 2027-DS(BL) and 2037-DS(BL) scenarios (grid system MGA94)

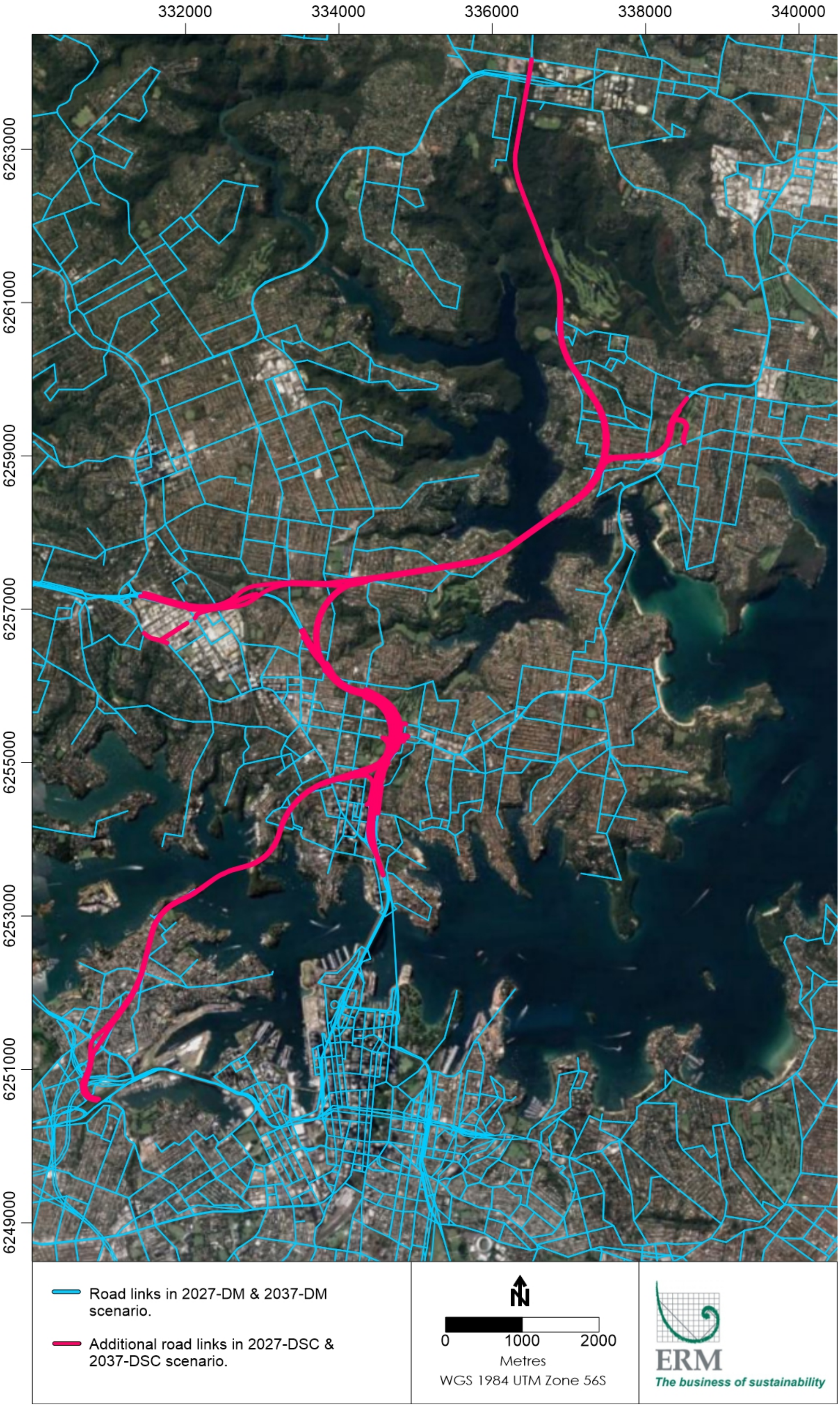

Figure 8-4 Road links in the 'Do minimum' scenarios, and additional links in the 2027-DSC and 2037-DSC scenarios (grid system MGA94)

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(BL)	'Do something 2027' (with project with Warringah Freeway Upgrade)	5934
2027-DSC	'Do something cumulative 2027' (with project, Western Harbour Tunnel and Warringah Freeway Upgrade)	5972
2037-DM	'Do minimum 2037' (without project)	5915
2037-DS(BL)	'Do something 2037' (with project with Warringah Freeway Upgrade)	5934
2037-DSC	'Do something cumulative 2037' (with project, Western Harbour Tunnel and Warringah Freeway Upgrade)	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 Road	9.0	21.1
Spit Road	9.2	18.2
Military Road	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.

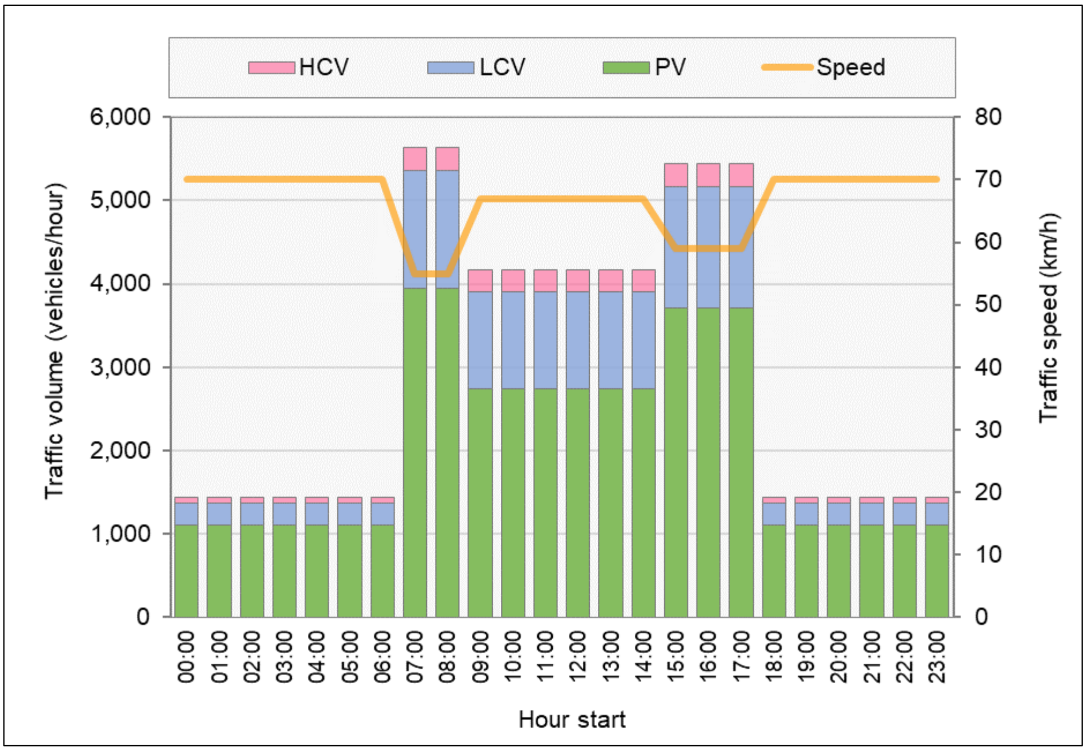

Figure 8-5 Example traffic model output (link 10358-10359, motorway, 2027-DSC scenario)

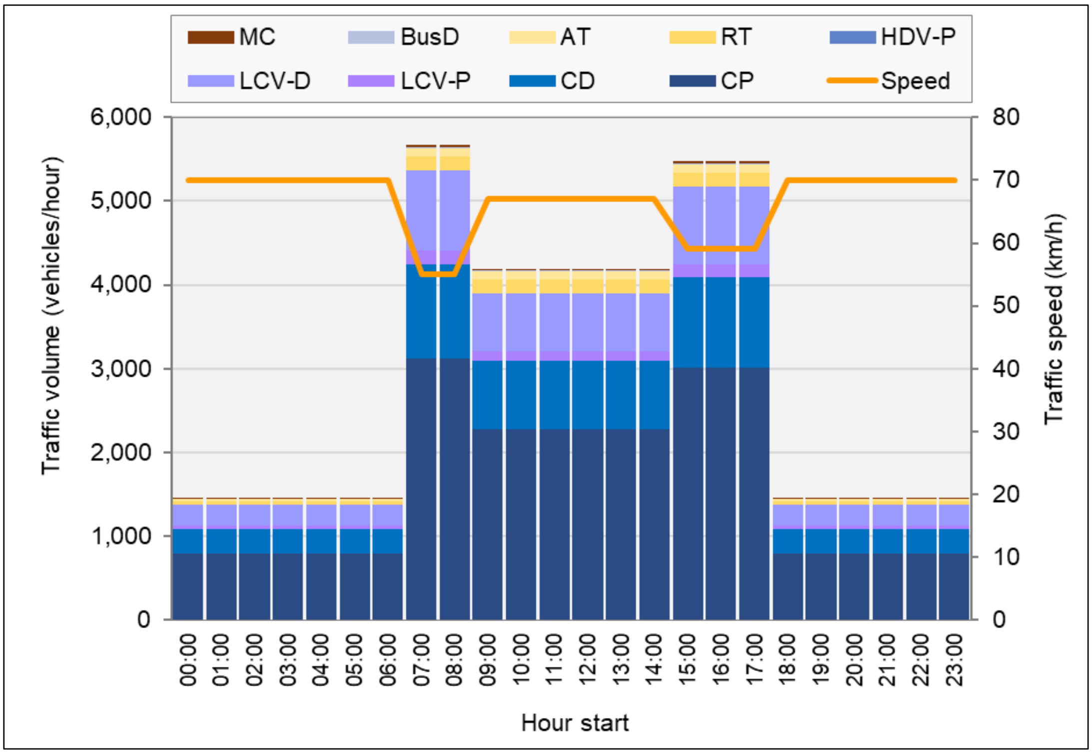

Figure 8-6 Example emission model input (link 10358-10359, motorway, 2027-DSC scenario)

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 in Figure 8-7. The predicted emission reductions due to advances in emissions technology incorporated in the model are clearly seen in the future years. 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 8-8 respectively.

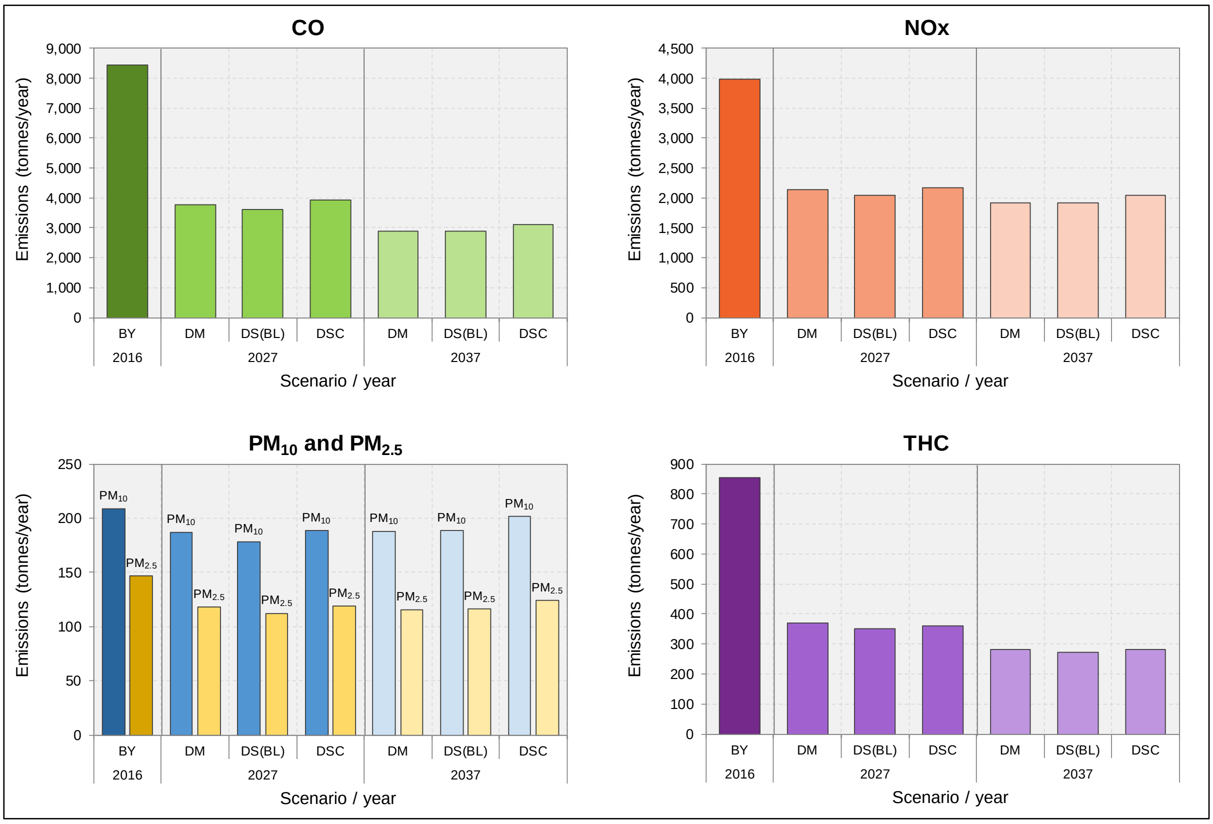

Figure 8-7 **Total traffic emissions in the GRAL domain**

Table 8-8 **Total traffic emissions in the GRAL domain**

Scenario code	Total daily VKT[(a)] (million vehicle-km)	Total emissions (tonnes/year) CO	NO_X	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(BL)	11.5	3616	2043	178	112	351
2027-DSC	12.5	3942	2175	188	119	359
2037-DM	12.3	2882	1919	188	116	281
2037-DS(BL)	12.5	2876	1921	189	116	274
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	NO_X	PM_{10}	$PM_{2.5}$	THC
Underlying changes in emissions with time[(a)]					
2027-DM vs 2016-BY	-4681	-1835	-21.7	-28.9	-485
2037-DM vs 2016-BY	-5566	-2062	-20.6	-30.9	-575
Changes due to the project in a given year					
2027-DS(BL) vs 2027-DM	-150.0	- 102.8	- 8.7	- 5.4	-19.2
2027-DSC vs 2027-DM	+176.0	+28.5	+1.5	+1.2	-11.1
2037-DS(BL) vs 2037-DM	- 5.5	+2.2	+0.4	+0.4	-7.1
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 Beaches Link GRAL domain

Scenario comparison	Change in total emissions (%)				
	CO	NO_X	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(BL) vs 2027-DM	-4.0%	-4.8%	-4.6%	-4.6%	-5.2%
2027-DSC vs 2027-DM	+4.7%	+1.3%	+0.8%	+1.0%	-3.0%
2037-DS(BL) vs 2037-DM	-0.2%	+0.1%	+0.2%	+0.3%	-2.5%
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 WestConnex M4 and WestConnex M8 projects. The 2016-BY scenario does not.

Comparing the ‘Do something 2027’ scenario with the ‘Do minimum 2027’ scenario, emissions of CO, NO_X, PM_{10}, $PM_{2.5}$ and THC decreased by around four to five per cent. In 2037, emissions of all pollutants remained relatively unchanged, with the exception of THC which decreased by 2.5 per cent.

For the ‘Do something cumulative 2027’ scenario, emissions of CO increased relative to the ‘Do minimum 2027’ scenario by 4.7 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 3.0 per cent. In the ‘Do something cumulative 2037’ scenario the emissions of all modelled 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 H 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 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 6-2. 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 8-11 presents the main parameters selected in GRAL for the model runs.

Table 8-11 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 8.4.5. 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 Beaches Link and Western harbour Tunnel 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 Beaches Link and Western Harbour Tunnel program of works corridor, and mainly covered residential and commercial land uses. For these receptors, a simpler[23] 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 35,484 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 Appendix I (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 8-8 shows the locations of the various discrete receptors.

A full list of community receptors is given in Table 8-12, and the numbers of RWR receptors are listed by category in Table 8-13. 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. All the project construction footprints are shown on Figure 8-8. Slightly different numbers of RWR receptors

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

were included in each scenario to allow for the different construction footprints for the project and the Western Harbour Tunnel and Warringah Freeway Upgrade project.

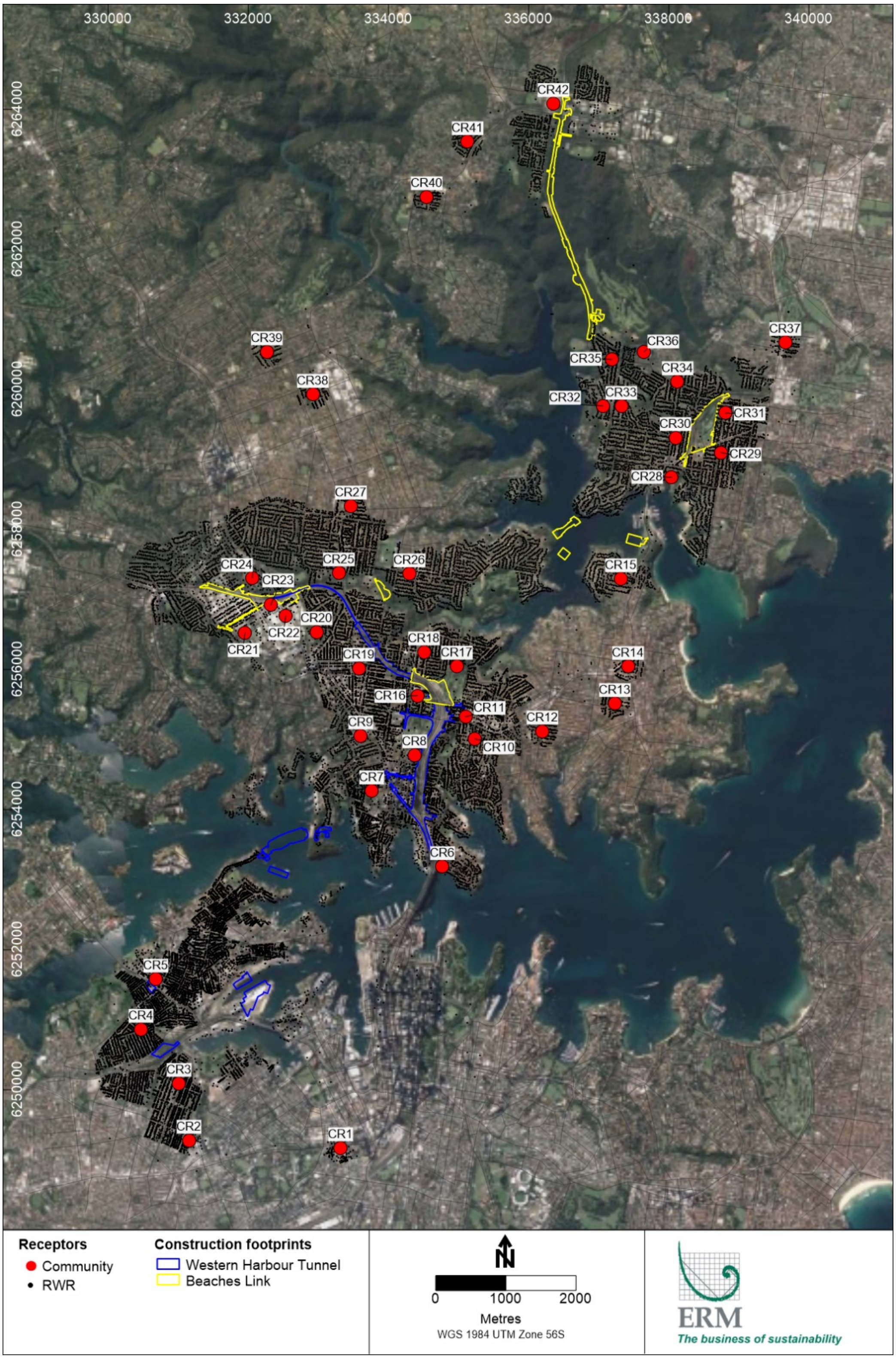

Figure 8-8 Modelled discrete receptor locations and construction footprints

Table 8-12 Full list of community receptors (grid system MGA94)

Receptor code	Receptor name	Type	Address	Suburb	Receptor location	
					x	y
CR01	University of Notre Dame	Further education	128-140 Broadway	Chippendale	333318.6	6249169.6
CR02	Laverty Pathology	Medical practice	34C Taylor Street	Annandale	331153.3	6249277.9
CR03	St Basil's	Aged care	252 Johnston Street	Annandale	331011.9	6250088.8
CR04	The Jimmy Little Community Centre	Community	19 Cecily Street	Lilyfield	330469.9	6250862.3
CR05	Rozelle Public School	School	663 Darling Street	Rozelle	330680.9	6251579.5
CR06	St Aloysius College	Further education	47 Upper Pitt Street	Milsons Point	334770.5	6253185.2
CR07	Dancing Dingo Family Day Care	Child care / pre-school	Lord Street	North Sydney	333761.0	6254266.5
CR08	Wenona School	School	176 Walker Street	North Sydney	334374.5	6254780.1
CR09	Mater Hospital	Hospital	25 Rocklands Road	North Sydney	333604.7	6255050.1
CR10	Neutral Bay Public School	School	Ben Boyd Road	Neutral Bay	335234.3	6255008.8
CR11	Neutral Bay Medical Centre	Medical practice	116 Military Road	Neutral Bay	335099.3	6255327.3
CR12	Puddleducks Child Care Centre	Child care / pre-school	17b/39 Herbert St	St Leonards	336197.3	6255120.6
CR13	Mosman Public School	School	27 Belmont Road	Mosman	337231.6	6255514.1
CR14	Garrison & Killarney Retirement Centre	Aged care	13 Spit Road	Mosman	337419.1	6256043.2
CR15	Beauty Point Public School	School	17 Medusa Street	Mosman	337318.4	6257295.1
CR16	ANZAC Park Public School	School	2 Anzac Avenue	Cammeray	334414.0	6255628.0
CR17	Ku Cammeray Preschool	Child care / pre-school	Green Park, Warwick Avenue	Cammeray	334977.1	6256047.0
CR18	Cammeray Public School	School	Palmer Street	Cammeray	334507.3	6256250.1
CR19	Atchison Preschool	Child care / pre-school	98 Atchison Street	Crows Nest	333577.5	6256018.6
CR20	Berry Cottage Childcare	Child care / pre-school	9 Talus Street	Naremburn	332974.3	6256538.2
CR21	Explore & Develop Artarmon - Early Learning Centre	Child care / pre-school	11/13 Campbell Street	Artarmon	331953.8	6256523.8
CR22	SBS Child Care	Child care / pre-school	14 Herbert Street	Artarmon	332534.2	6256763.9
CR23	Butterflies Early Learning Childcare Centre	Child care / pre-school	9 Waltham Street	Artarmon	332321.8	6256922.3
CR24	Artarmon Public School	School	McMillan Road	Artarmon	332058.0	6257309.9
CR25	Sue's Childcare Castlevale	Child care / pre-school	2 Artarmon Road	Willoughby	333293.4	6257378.7
CR26	Northside Baptist Preschool	Child care / pre-school	112 Sailors Bay Road	Northbridge	334300.6	6257366.2
CR27	Willoughby Public School	School	Oakville Road	Willoughby	333464.8	6258333.4
CR28	Peek A Boo Cottage	Child care / pre-school	1 Magarra Place	Seaforth	338036.2	6258746.8

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

Table 8-13 Summary of RWR receptor types

Receptor type	All receptors (DM scenarios)		DS(BL) 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%	471	1.33%	468	1.32%
Medical practice	62	0.17%	62	0.17%	62	0.17%
Mixed use	813	2.29%	813	2.29%	811	2.29%
Other[(a)]	229	0.65%	228	0.64%	218	0.62%
Park / sport / recreation	317	0.89%	314	0.88%	312	0.88%
Place of worship	76	0.21%	76	0.21%	76	0.21%
Residential	32,030	90.27%	32,021	90.24%	32,019	90.36%
School	135	0.38%	135	0.38%	135	0.38%
Grand Total[(b)]	35,484	100.00%	35,456	100.00%	35,436	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 Appendix I (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 8-9. 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.

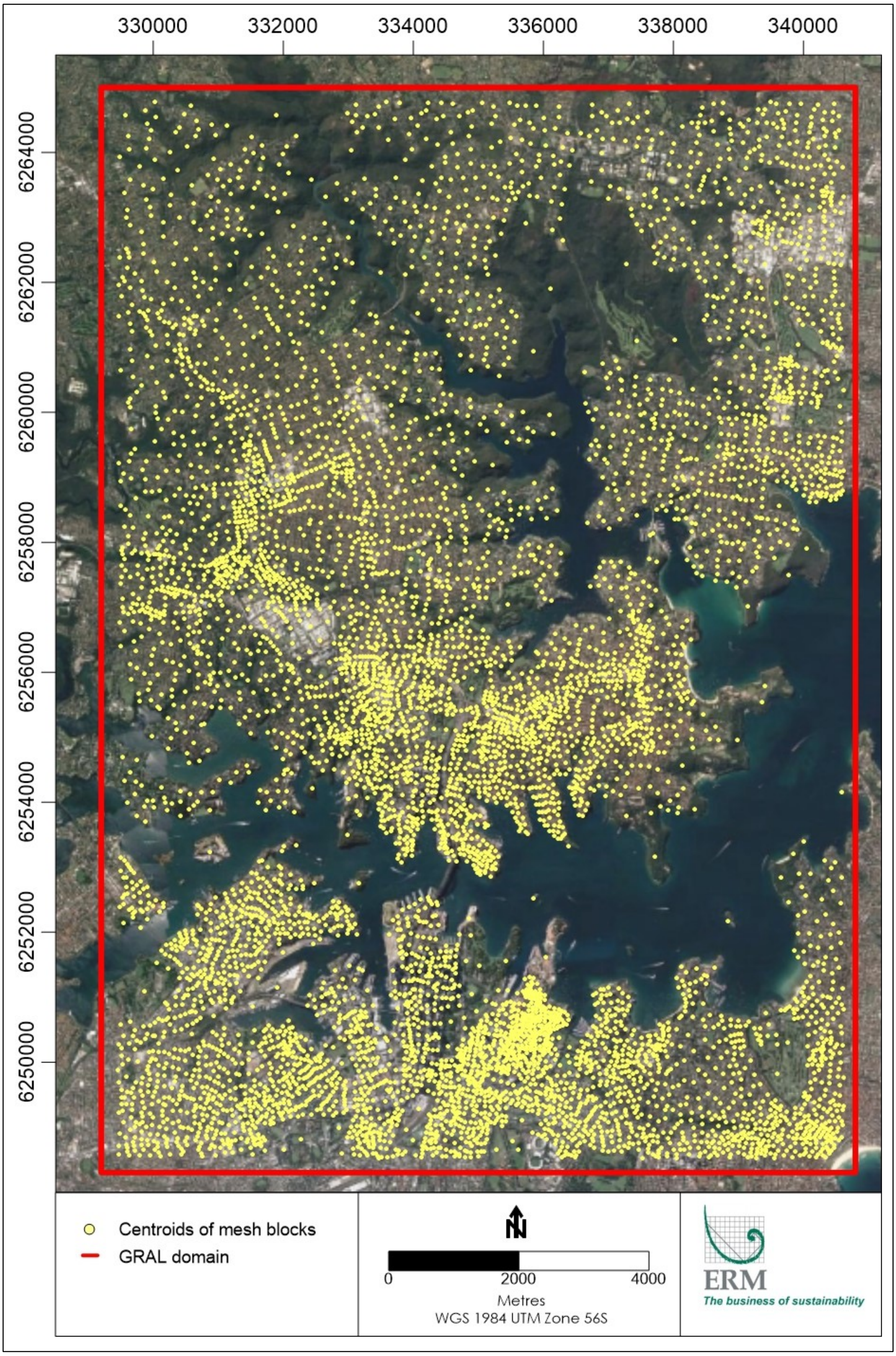

Figure 8-9 **Mesh Block centroids in the GRAL domain**

Elevated receptors

The main emphasis in the assessment was on ground-level concentrations (as specified in the NSW 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 33,000 buildings. The locations and heights of the buildings in the sample are shown on Figure 8-10, and the overall frequency distribution is shown on Figure 8-11.

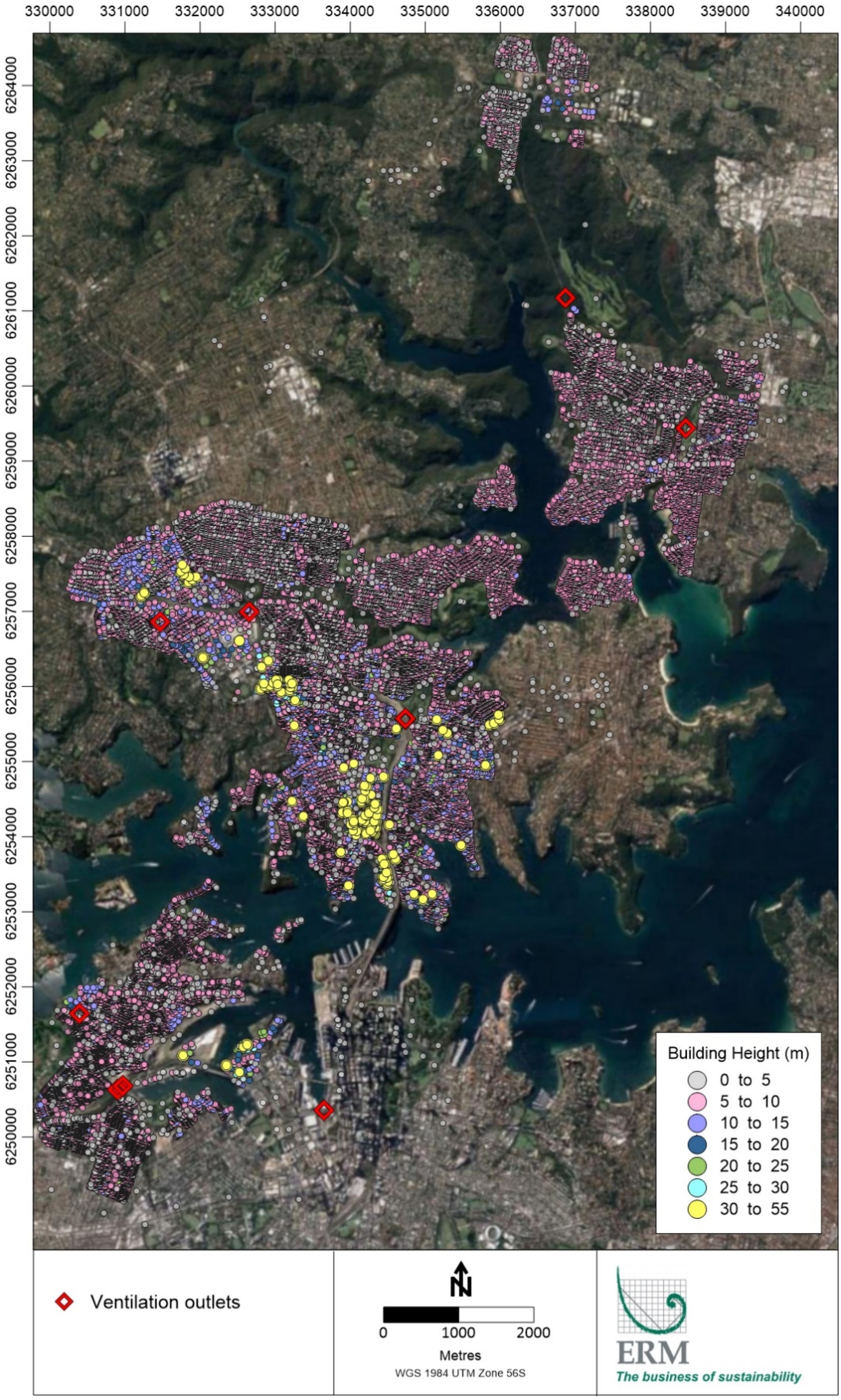

Figure 8-10 **Sample of building heights in the GRAL domain (grid system MGA94)**

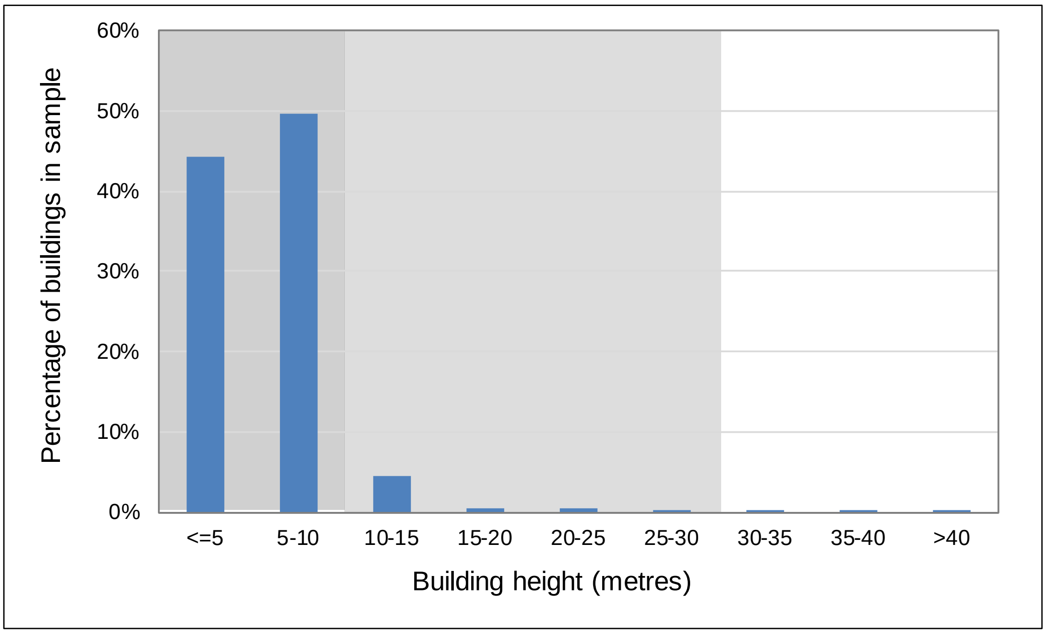

Figure 8-11 Frequency distribution of building heights

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. A detailed analysis of the impact of the project has been undertaken for elevated receptors at these heights, and is presented in Section 8.4.9.

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 8-12.

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. The air flows that were applied in GRAL for each scenario and each ventilation outlet are given in Annexure G.

The volumetric air flows for the existing 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.

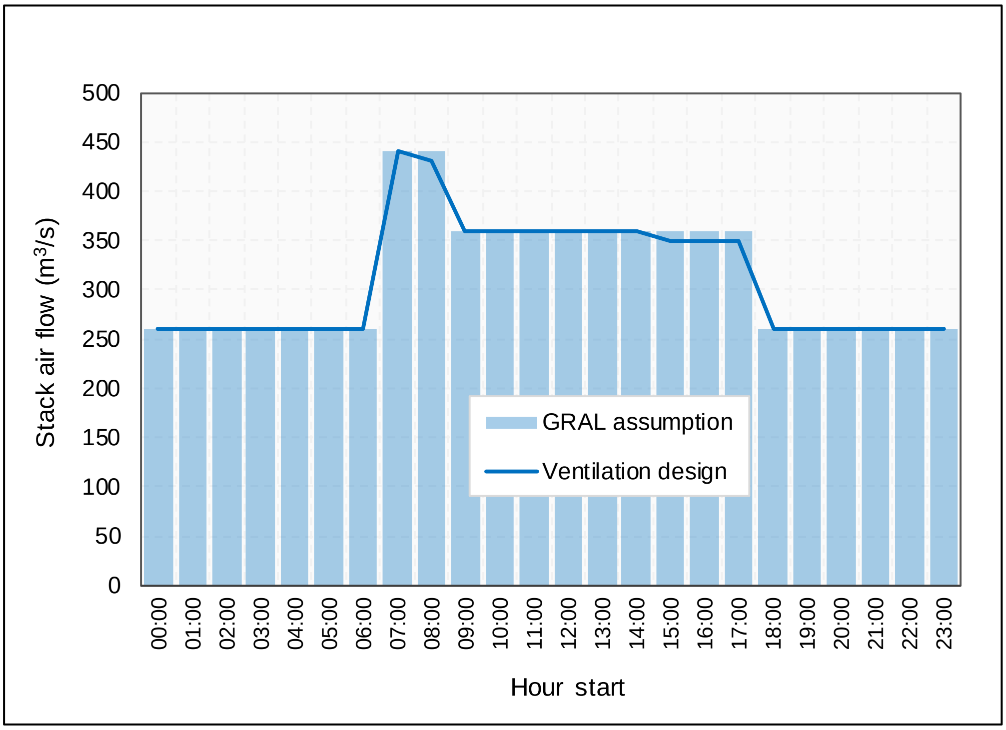

Figure 8-12 Example of ventilation air flow profile used in GRAL for Gore Hill Freeway Ventilation Outlet (Outlet I, 2037-DSC scenario)

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 supplied by Transport for NSW.

For the WestConnex M4-M5 Link and Iron Cove Link ventilation outlets, temperatures were taken from the WestConnex M4-M5 Link environmental impact statement (Pacific Environment, 2017a).

For ventilation outlets for Beaches Link and Western Harbour Tunnel 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 8-14.

Table 8-14 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.

8.4.2 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, WestConnex M4 and WestConnex M8 conditions of approval, are shown in Table 8-15. 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 8-15 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 WestConnex M4 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 WestConnex 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 25°C was therefore assumed for these scenarios.

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

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

For these pollutants the next steps were as follows:

1. The RWC 2037-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)
2. The RWC ventilation outlet contributions for the 2037-DSC scenario were then combined with the corresponding expected traffic surface road and background contributions to determine the total concentrations
3. The maximum contribution of tunnel ventilation outlets at any of the RWR receptors in the GRAL domain was also 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 for the RWC 2037-DSC
2. The ventilation outlet NO_X for the RWC 2037-DSC scenario was added to the corresponding surface road NO_X 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 the RWC 2037-DSC 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 for the RWC 2037-DSC scenario
2. Four small domains (three domains are two kilometres by two kilometres and the fourth domain is three kilometres by two kilometres) was defined around each ventilation outlet for the project. These domains are shown in Figure 8-13. The small domain for Gore Hill Freeway included the Lane Cove Tunnel (east) and the small domain for Warringah Freeway included the outlet for the Western Harbour Tunnel.
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 in Figure 8-14.
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.

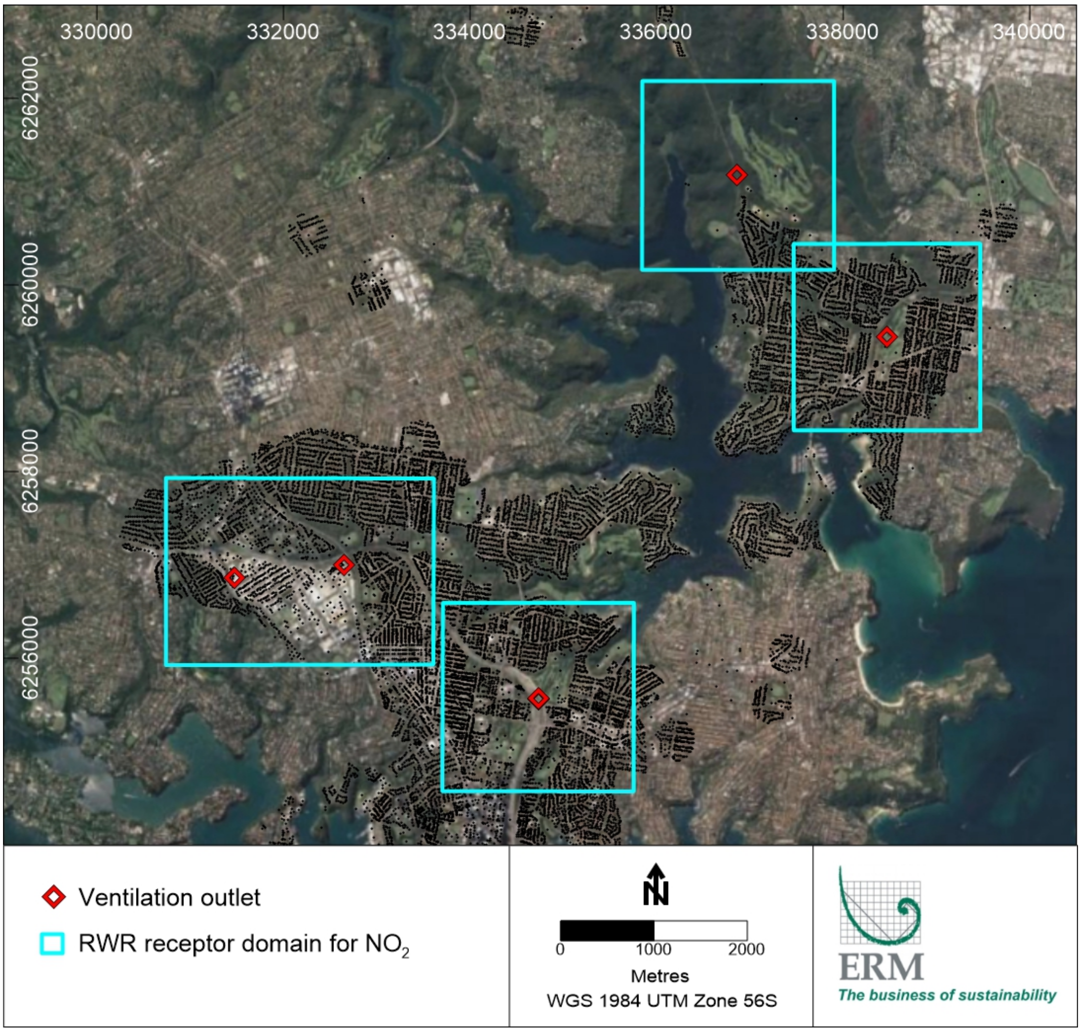

Figure 8-13 Domains around ventilation outlets for 1-hour NO_2 RWC assessment

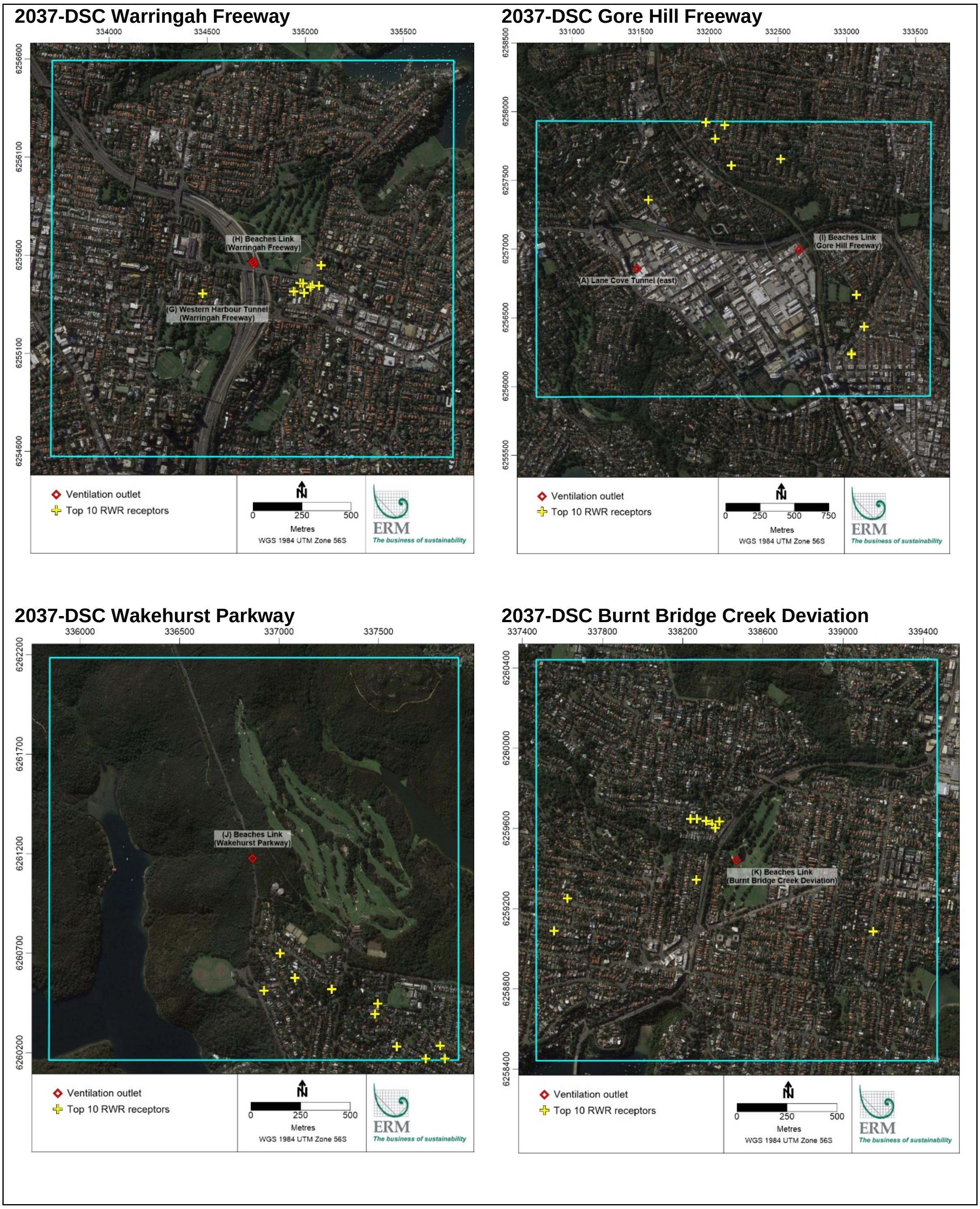

Figure 8-14 Top 10 receptors for 1-hour NO_X for 2037-DSC for each outlet

8.4.3 Calculation of total concentrations

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

For CO, NO_2, PM_{10} and $PM_{2.5}$ 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[24] 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 8-16.

Table 8-16 Methods for combining modelled (GRAL) contribution and background contribution

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

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 Beaches Link, 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.

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

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[24] With the contemporaneous approach the short-term (eg 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.

profiles for the compounds of interest were taken from the GMR emission inventory methodology (NSW EPA, 2012b), and are given in Table 8-17. 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 8-17 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 8-17 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 8-18.

Table 8-18 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 NSW Approved Methods for individual air toxics relate to incremental impacts (ie 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 NSW Approved Methods.

8.4.4 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 6.4.3), a summary of the evaluation for the WestConnex projects, and a project-specific evaluation.

For the Beaches Link, 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 in Figure 8-15. 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.

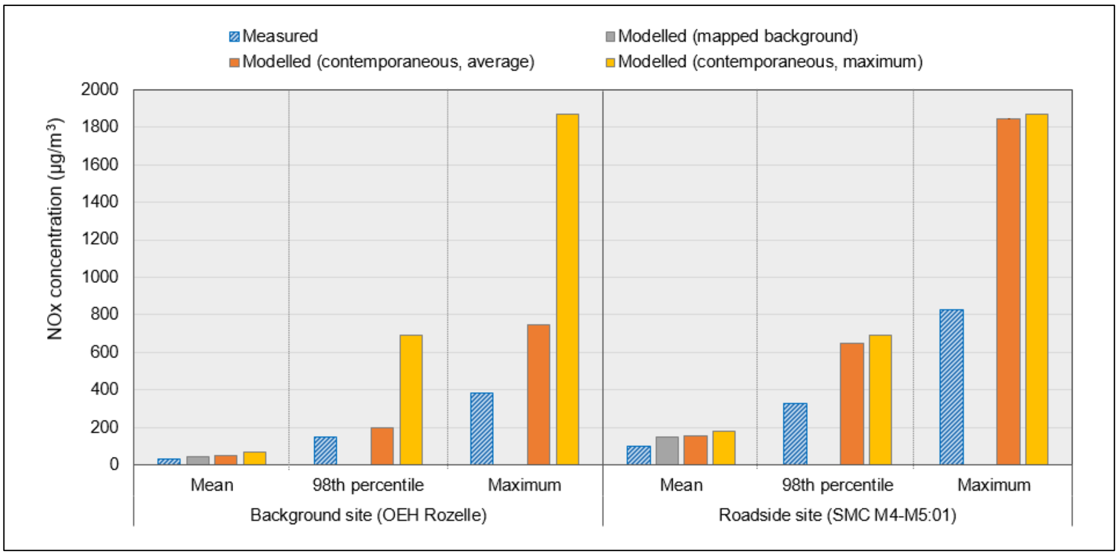


Figure 8-15 **Comparison between measured and predicted annual mean NO_X concentrations**

8.4.5 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 up to 35,484 RWR receptors (depending on the scenario):

- 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 outlets and motorway 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 Beaches Link ventilation outlets to NO_X, PM_{10} and $PM_{2.5}$ in the vicinity of each outlet (Warringah Freeway, Gore Hill Freeway, Wakehurst Parkway and Burnt Bridge Creek Deviation) 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

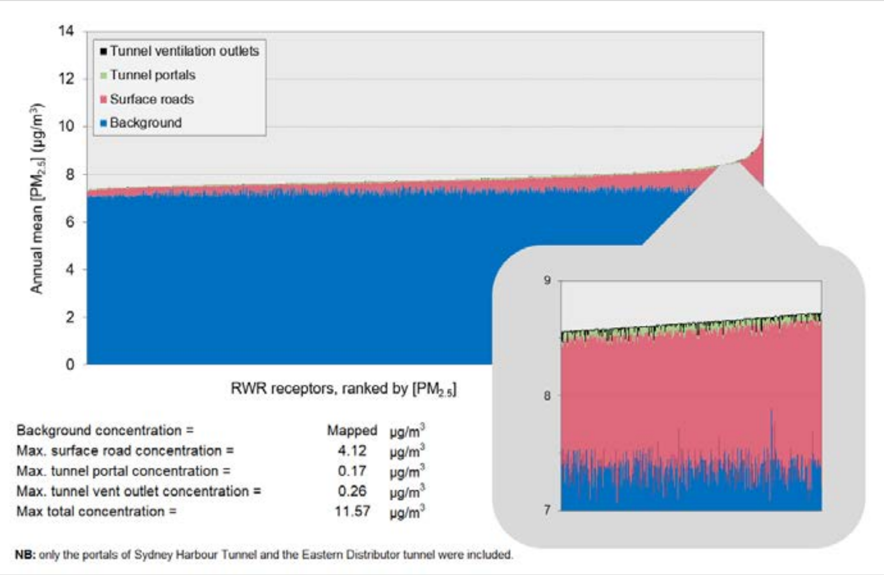
Short-term (1h and 24h) predictions for community receptors

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 35,000 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.



Background concentration = Mapped µg/m^3
Max. surface road concentration = 4.12 µg/m^3
Max. tunnel portal concentration = 0.17 µg/m^3
Max. tunnel vent outlet concentration = 0.26 µg/m^3
Max total concentration = 11.57 µg/m^3

NB: only the portals of Sydney Harbour Tunnel and the Eastern Distributor tunnel were included.

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(BL), 2027-DSC, 2037-DS(BL) and 2037-DSC) are shown in Figure 8-16. The CO concentration at each of these receptor locations was well below the NSW impact assessment criterion of 30 mg/m³. The concentrations were also well below the lowest international air quality standard identified in the literature (California, 22 mg/m³).

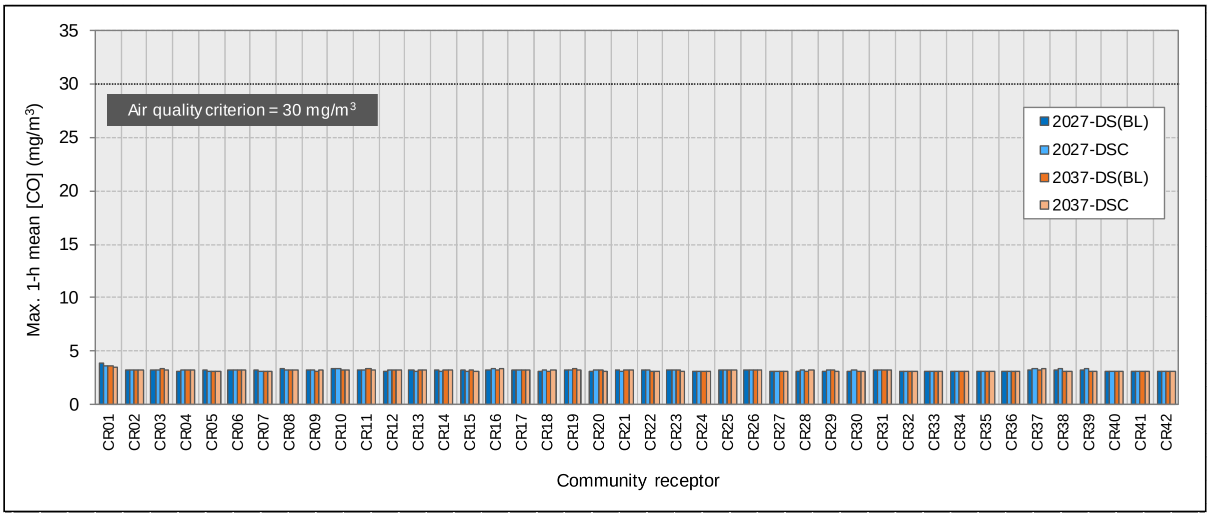


Figure 8-16 Maximum 1-hour mean CO concentration at community receptors (with-project and cumulative scenarios)

Figure 8-17 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 0.23 mg/m³, which equated to just 0.8 per cent of the impact assessment criterion of 30 mg/m³.

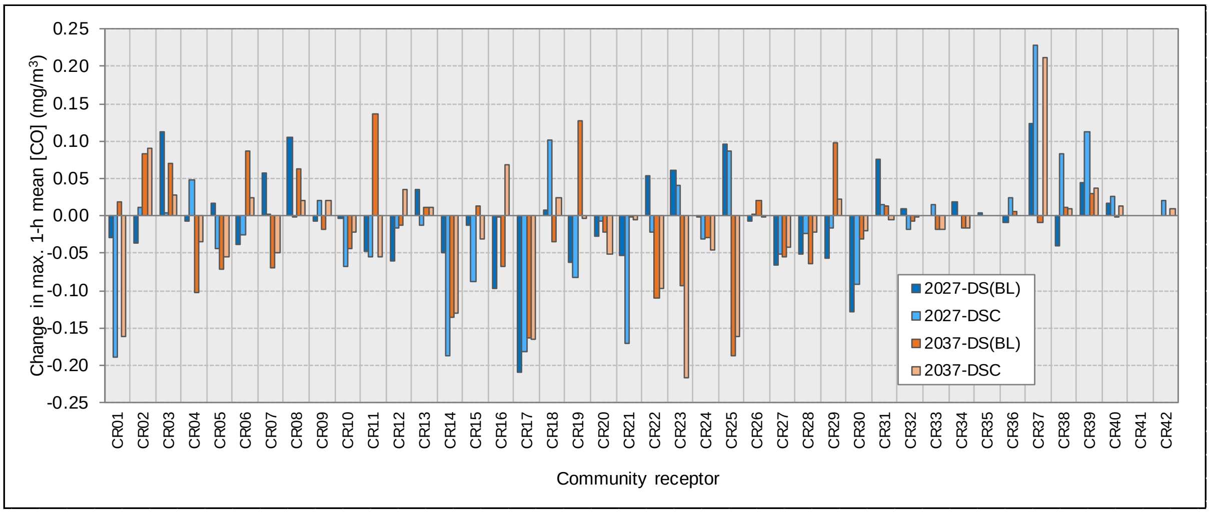


Figure 8-17 Change in maximum 1-hour mean CO concentration at community receptors (with-project and cumulative scenarios, relative to corresponding ‘Do minimum’ scenarios)

Figure 8-18 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 (1.2 mg/m^3 at receptor CR01, University of Notre Dame). 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 in Figure 8-18.

Results for RWR receptors

The maximum 1-hour CO concentrations at all the RWR receptors are shown for the with-project and cumulative scenarios in Figure 8-19. 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.

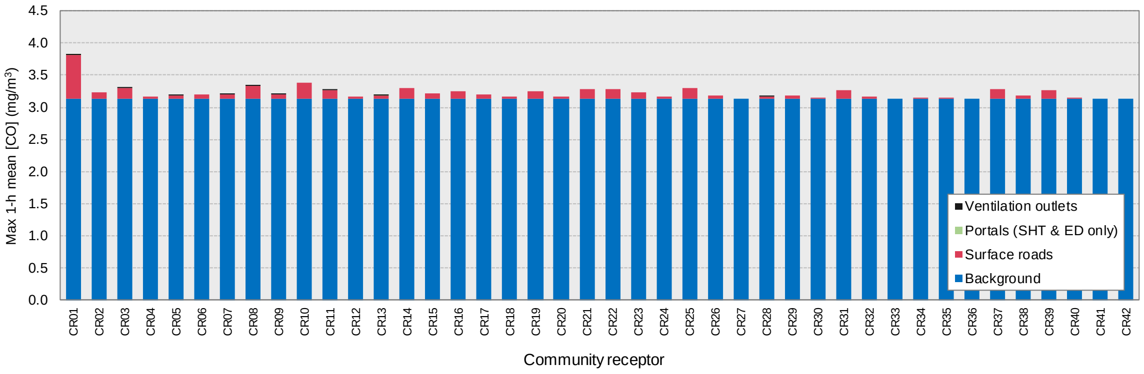
The 1-hour CO criterion for NSW was not exceeded at any of the RWR receptors in any scenario. The highest total 1-hour concentrations in any with-project or cumulative scenario was predicted to be 5.5 mg/m^3, in Rozelle. The largest contribution from ventilation outlets at any receptor was less than 0.1 mg/m^3, also in Rozelle.

The changes in the maximum 1-hour CO concentration at the RWR receptors in the with-project and cumulative scenarios are shown in Figure 8-20. There was an increase in concentration of between 38 per cent and 43 per cent of receptors with the project. However, even the largest increase in any scenario, which was 1.2 mg/m^3, was small compared with the criterion.

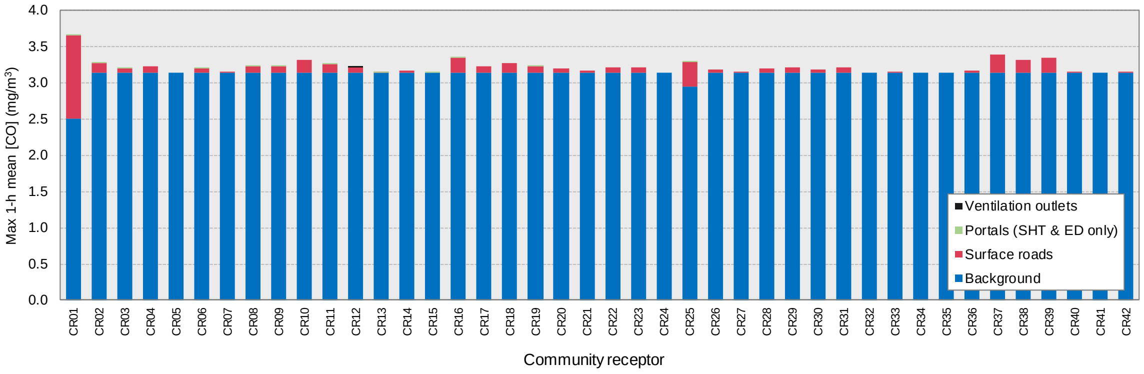
Contour plots – all sources

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.

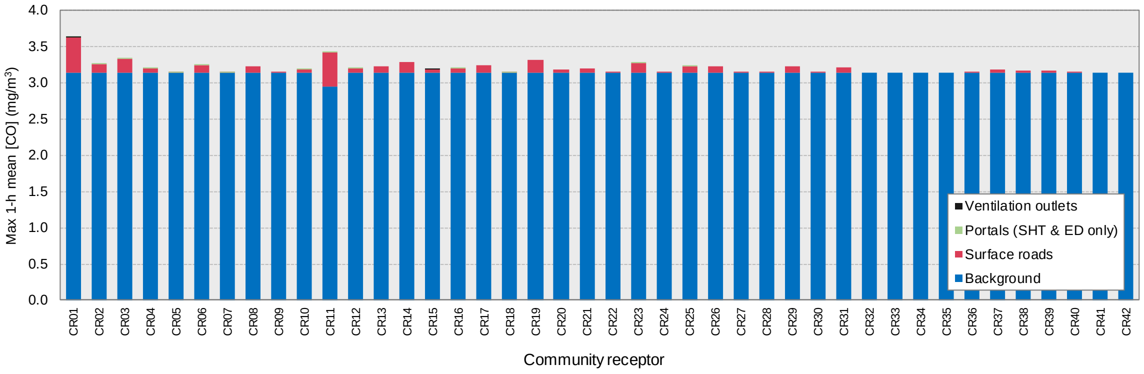
(a) 2027-DS(BL)



(b) 2027-DSC



(c) 2037-DS(BL)



(d) 2037-DSC

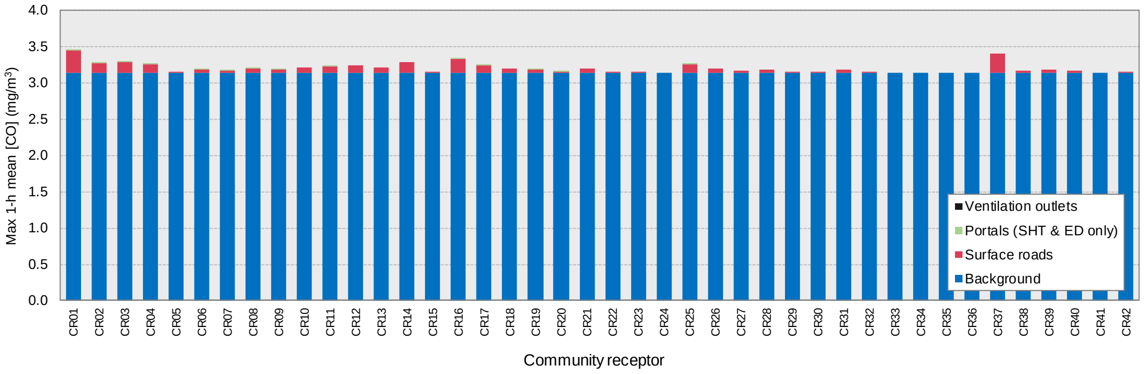


Figure 8-18 Source contributions to maximum 1-hour mean CO concentration at community receptors (with-project and cumulative scenarios) (portals include Sydney Harbour Tunnel and Eastern Distributor only)

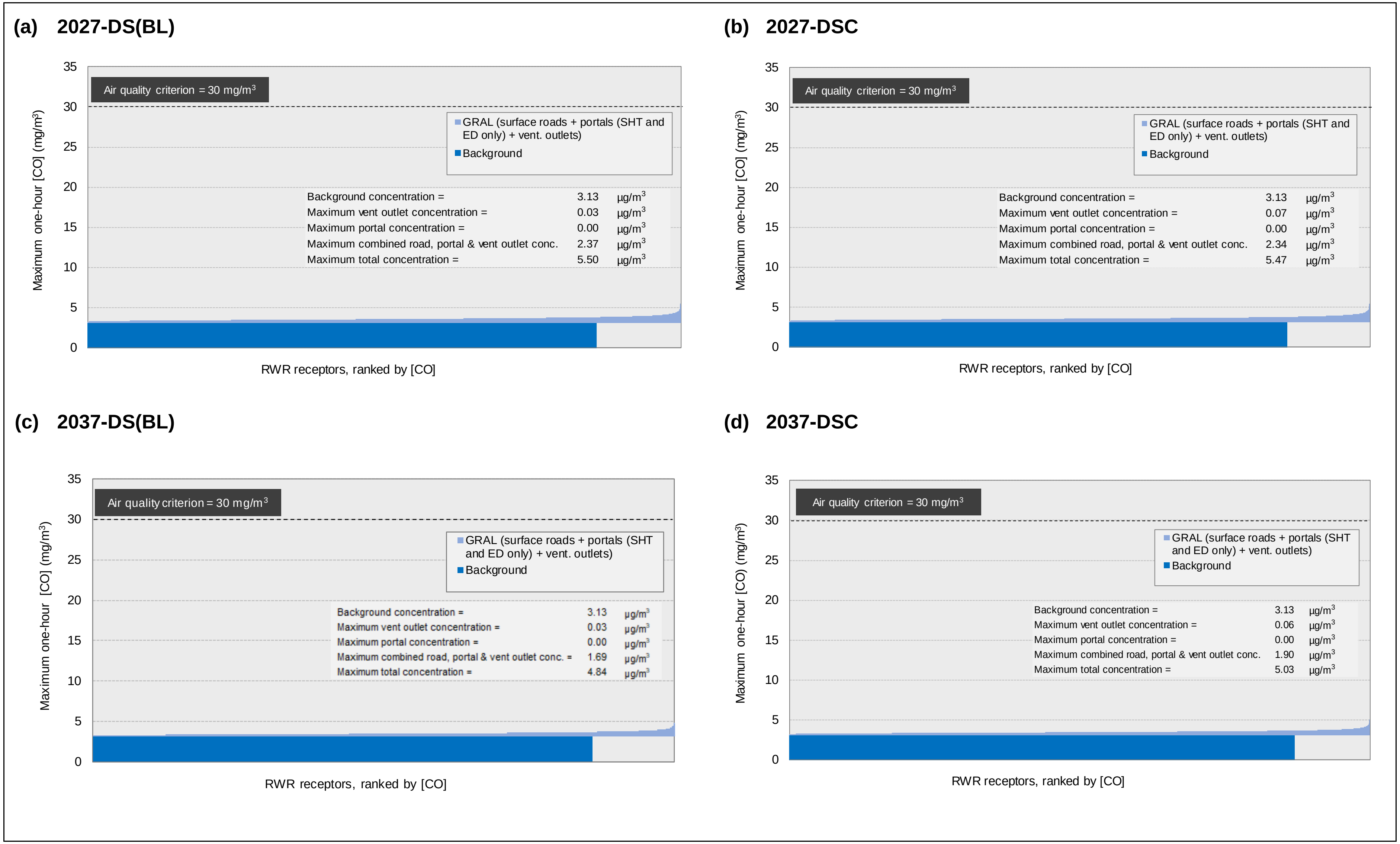


Figure 8-19 Source contributions to maximum 1-hour CO concentration at RWR receptors (with-project and cumulative scenarios) (portals include Sydney Harbour Tunnel and Eastern Distributor only)

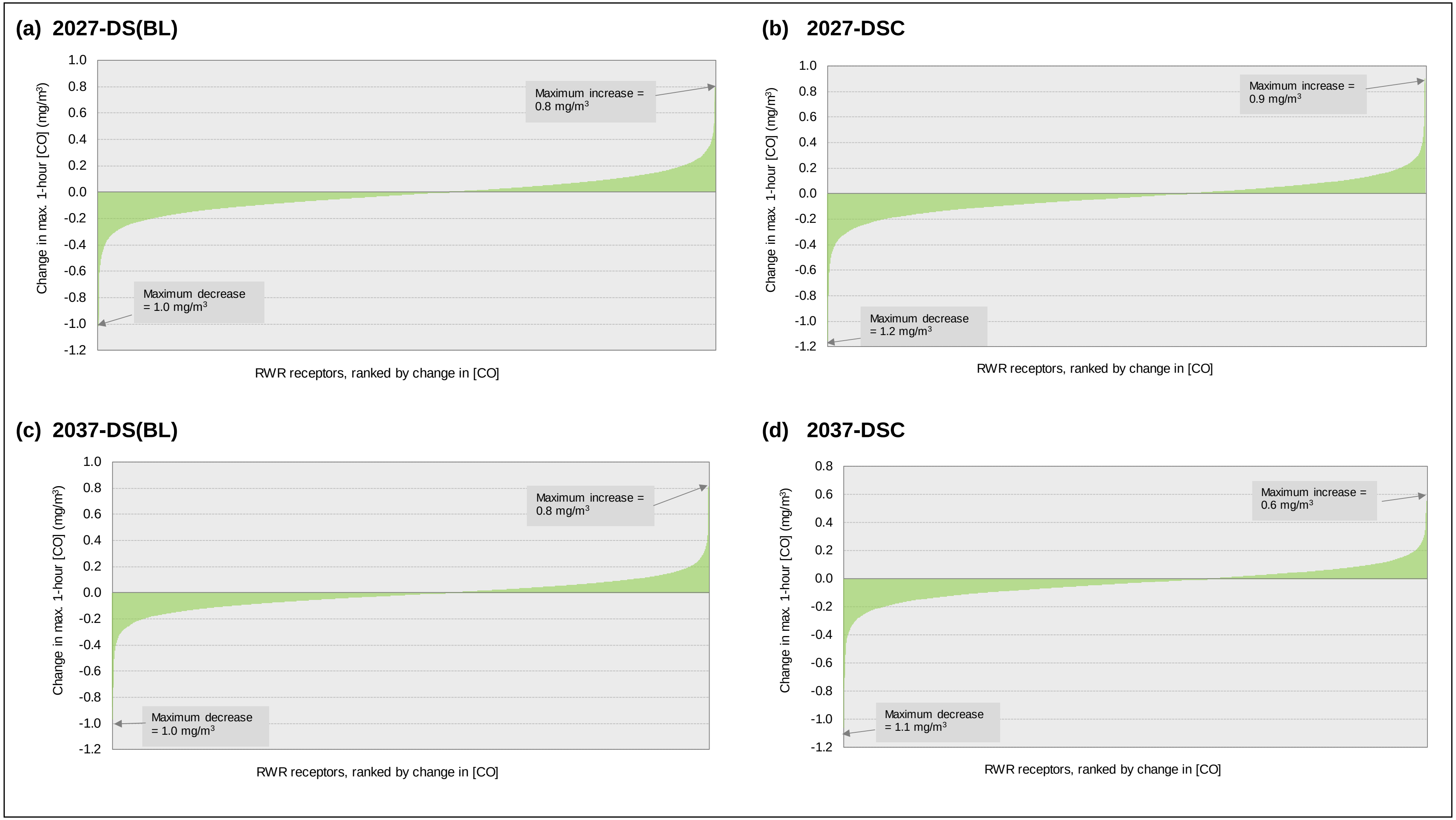


Figure 8-20 **Change in maximum 1-hour CO concentration at RWR receptors (with-project and cumulative scenarios, relative to corresponding Do minimum scenarios)**

Carbon monoxide (maximum rolling 8-hour mean)

Results for community receptors

Figure 8-21 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/m³. No lower criteria appear to be in force internationally.

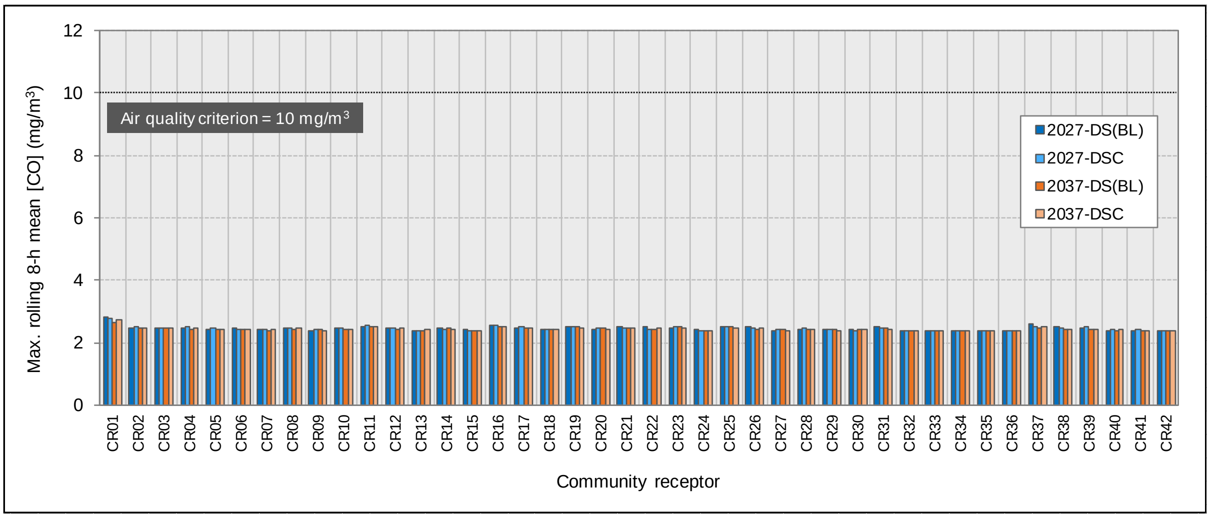


Figure 8-21 **Maximum rolling 8-hour mean CO concentration at community receptors (with-project and cumulative scenarios)**

It can be seen in Figure 8-22 that the changes in the maximum rolling 8-hour CO concentration at all the community receptors were less than 0.08 mg/m³. The largest increase with the project and in the cumulative scenarios was 0.08 mg/m³ (equating to less than one per cent of the criterion).

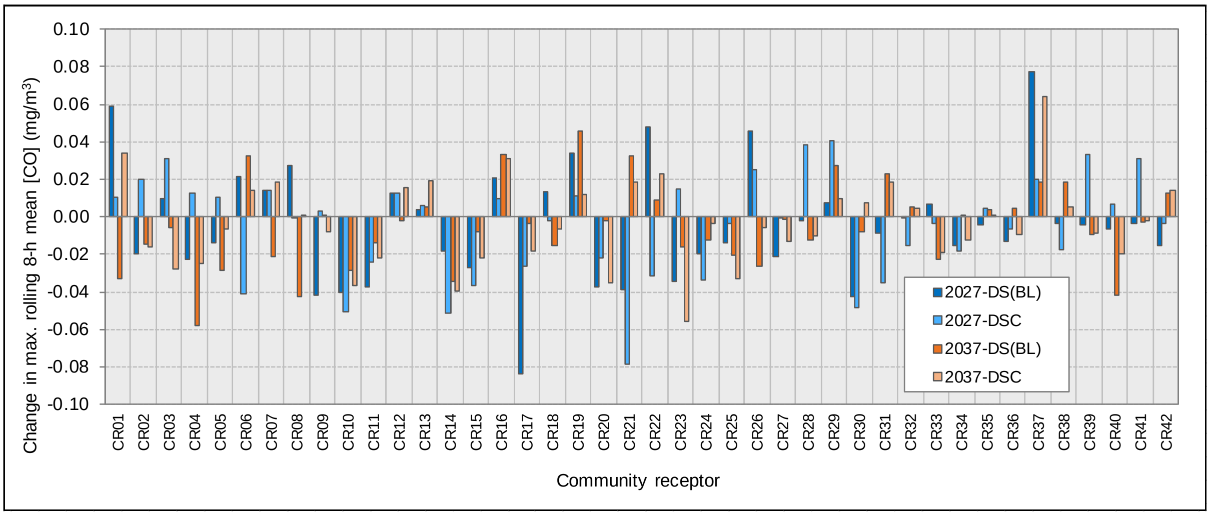


Figure 8-22 **Change in maximum rolling 8-hour mean CO concentration at community receptors (with-project and cumulative scenarios, relative to 'Do minimum' scenarios)**

The main contributor at these receptors was the background concentration (Figure 8-23). The largest surface road contribution in any with-project or cumulative scenario was 16 per cent, whereas the tunnel portal and ventilation outlet contributions were zero or negligible in all cases.

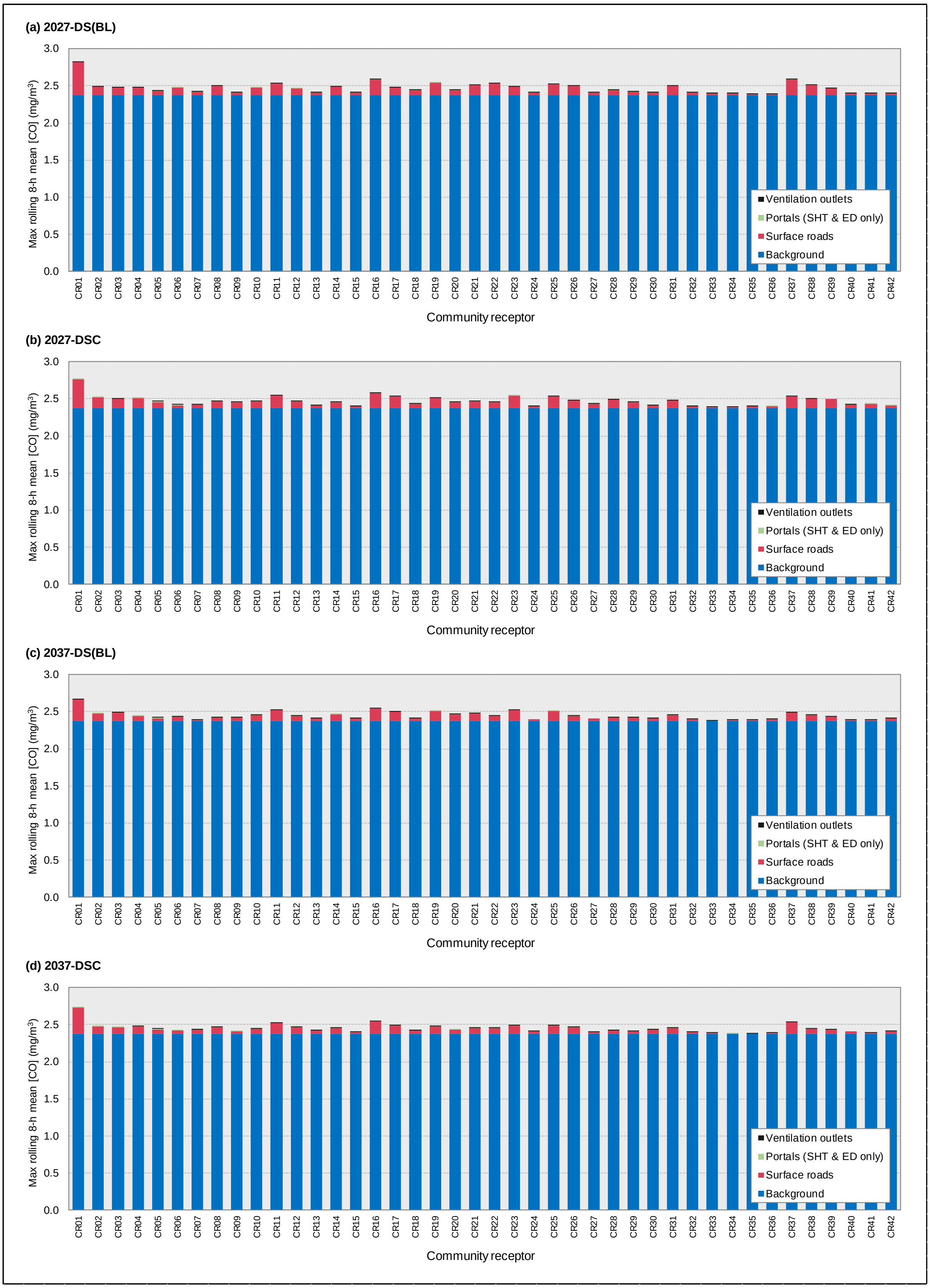


Figure 8-23 Source contributions to maximum rolling 8-hour mean CO at community receptors (with project and cumulative scenarios) (portals include Sydney Harbour Tunnel and Eastern Distributor only)

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 8-24 shows the predicted 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 well below the NSW impact assessment criterion of 62 µg/m^3.

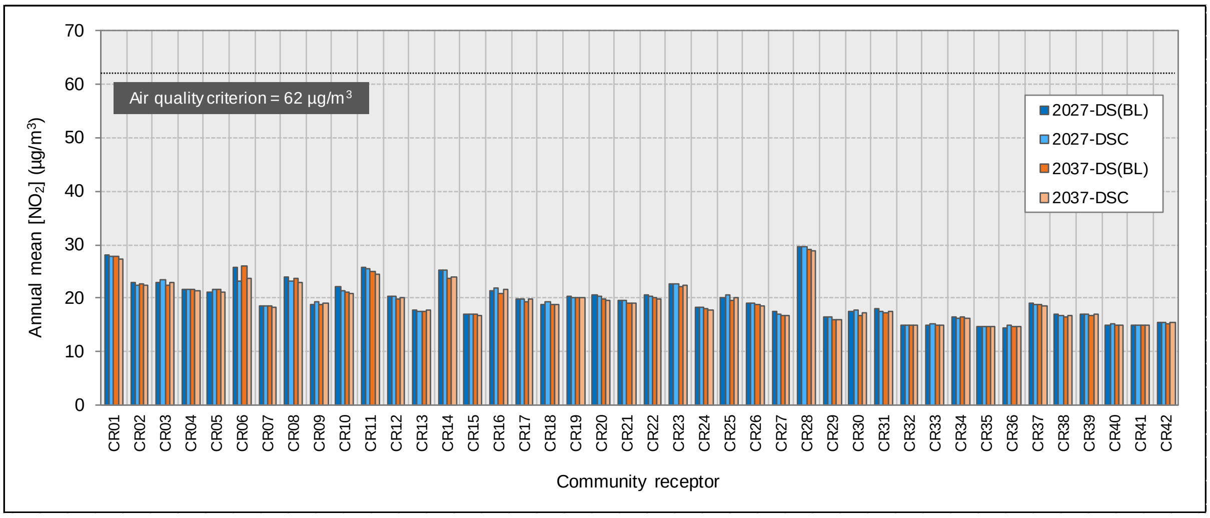


Figure 8-24 **Annual mean NO_2 concentration at community receptors (with-project and cumulative scenarios)**

Figure 8-25 shows the changes in concentration with the project. There was a small increase in the NO_2 concentration at some receptors. The largest increase with the project was around 1.3 µg/m^3, equating to less than three per cent of the criterion. There were some notable decreases in concentration in the 'Do something' and 'Do something cumulative' scenarios at some receptors. For example, at receptor CR08 (Wenona School, North Sydney) there was a predicted reduction in concentration of 0.5-1.8 µg/m^3 across the scenarios due to a substantial reduction in traffic on Warringah Freeway. There was a slightly larger reduction in concentration (1.6-2.4 µg/m^3) 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 project. As noted above, at receptor CR28 (Peek A Boo Cottage, Seaforth) there was a more substantial reduction (around 3-4 µg/m^3) in annual mean NO_2 as a result of the project for all scenarios

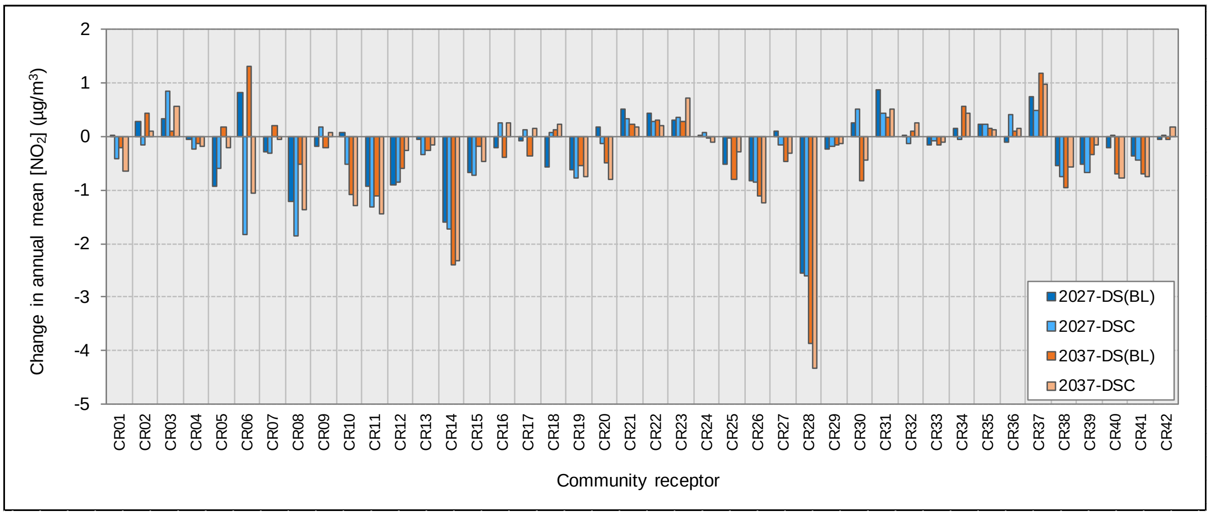


Figure 8-25 Change in annual mean NO_2 concentration at community receptors (with-project and cumulative scenarios, relative to 'Do minimum' scenarios)

Figure 8-26 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 between 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 50-55 per cent. The contributions of tunnel ventilation outlets were less than three per cent in all scenarios. The contributions of tunnel ventilation outlets were less than three per cent in all scenarios.

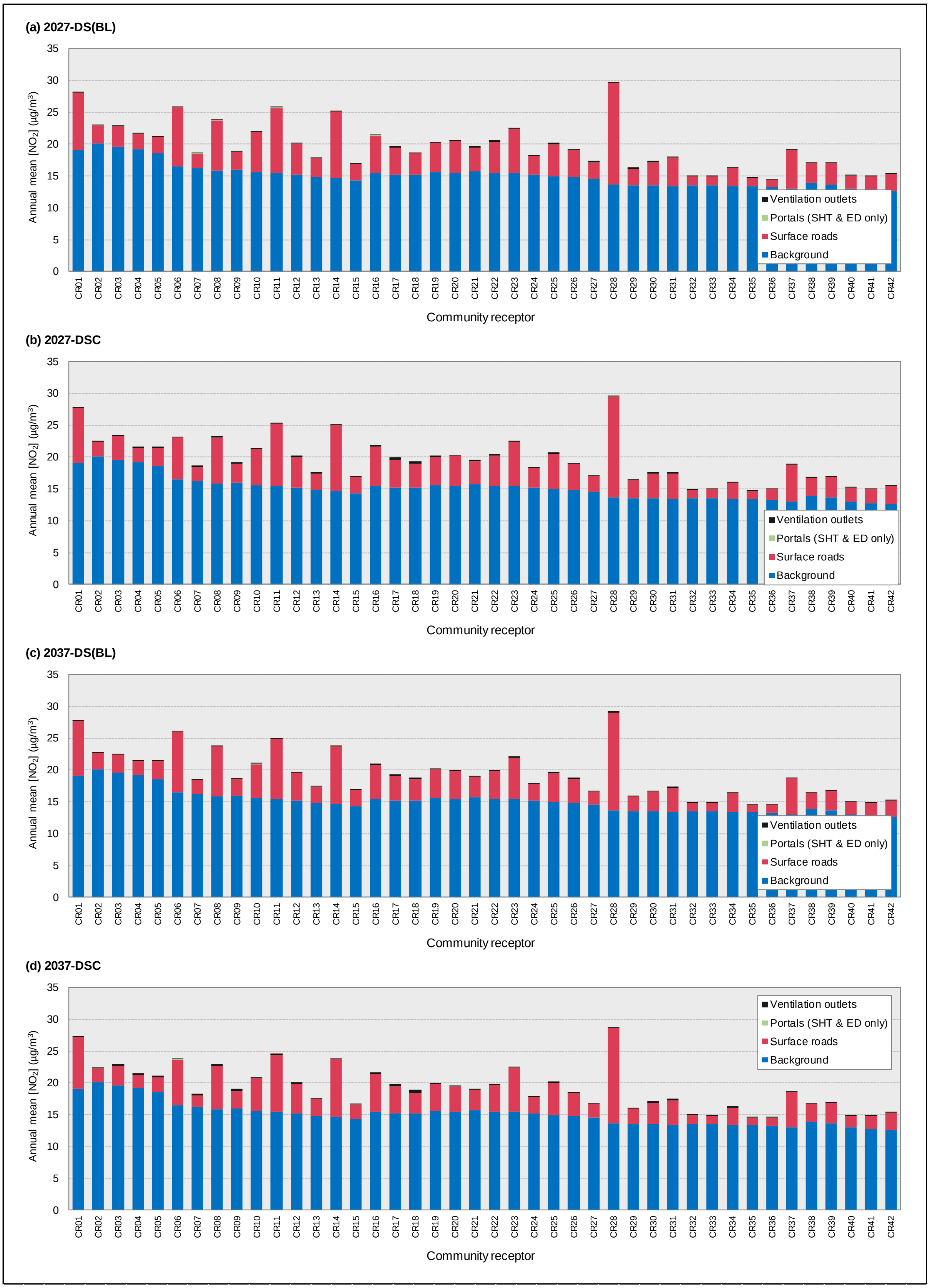


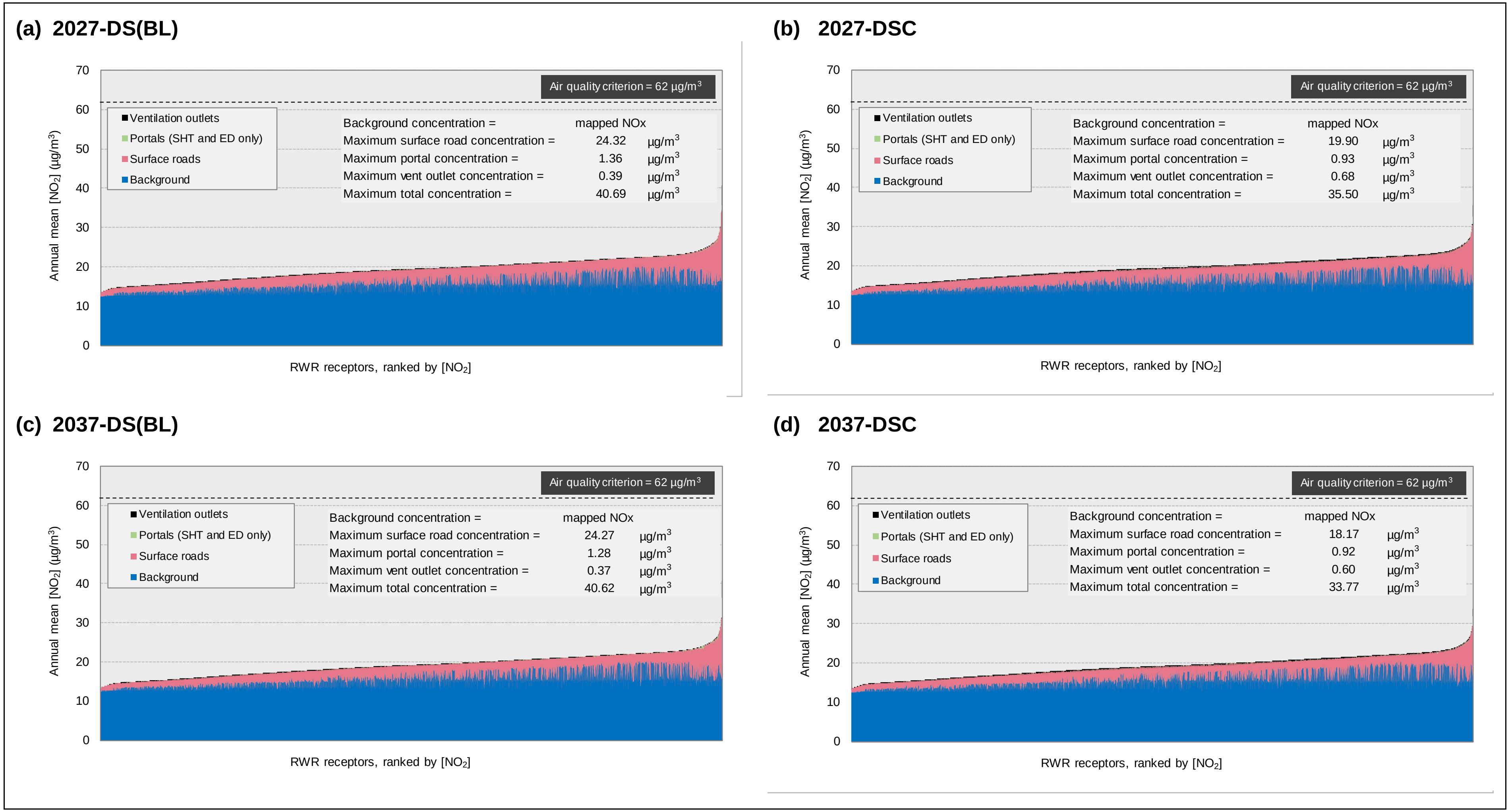
Figure 8-26 Source contributions to annual mean NO_2 concentration at community receptors (with-project and cumulative scenarios) (portals include Sydney Harbour Tunnel and Eastern Distributor only)

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 8-27. Concentrations at the vast majority (more than 97 per cent) of receptors were between around 13 µg/m^3 and 25 µg/m^3. The annual mean NO_2 criterion for NSW of 62 µg/m^3 was not exceeded at any of the receptors in any scenario. At all but one of the receptors in the 2027-DS(BL) and 2037-DS(BL) scenarios, NO_2 concentrations were also below the EU limit value of 40 µg/m^3, which is the most stringent NO_2 criterion worldwide (see Annexure B).

The maximum contribution of tunnel ventilation outlets for any scenario and receptor was around 0.7 µg/m^3, whereas the maximum surface road contribution was 24.3 µg/m^3. Given that annual mean NO_2 concentrations at the majority of receptors were well below the NSW criterion, the potential contribution of the ventilation outlets is 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 8-28. There was predicted to be an increase in the annual mean NO_2 concentration at between 37 per cent and 44 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 µg/m^3 for only around 0.6 per cent of receptors. Conversely, there was a reduction in annual mean NO_2 at between around 56 per cent and 63 per cent of receptors. The majority of the increases for the 2027-DS(BL) scenario were located along the Warringah Freeway but further to the south and closer to the Harbour Bridge. There were also some increases over 1 µg/m^3 at Manly Road and The Spit in this scenario. In 2037, the increases were mostly located along the Warringah Freeway Upgrade and closer to the Gore Hill Freeway. There were some increases in Rozelle along Victoria Road which increased in number in the cumulative scenarios. There are also predicted increases in concentration along Wakehurst Parkway; however, these are limited to within the road corridor and do not extend out to the nearby RWRs.



(a) 2027-DS(BL)

(b) 2027-DSC

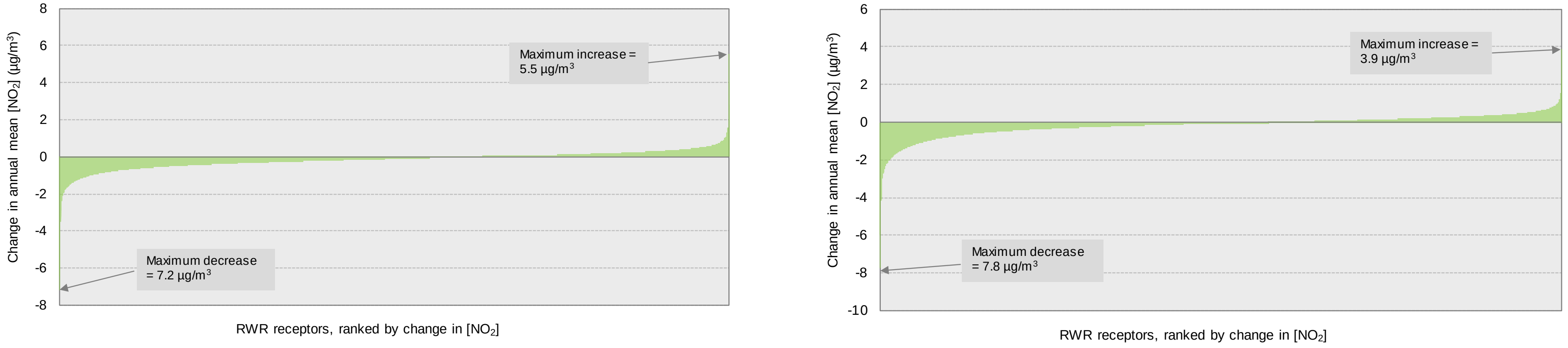
(c) 2037-DS(BL)

(d) 2037-DSC

Figure 8-27 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)

(a) 2027-DS(BL)

(b) 2027-DSC



(c) 2037-DS(BL)

(d) 2037-DSC

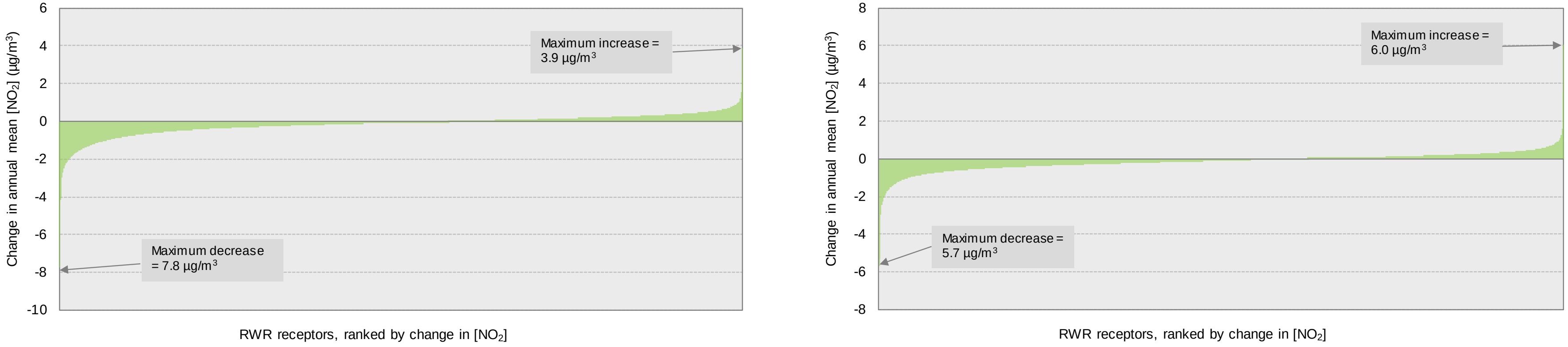


Figure 8-28 Change in annual mean NO_2 concentration at RWR receptors (with-project and cumulative scenarios, relative to corresponding ‘Do minimum’ scenarios)

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 8-29, and an equivalent plot for the 2037-DSC scenario (ie all sources in the cumulative scenario) is shown in Figure 8-30. 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 8-31 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 8.4.6.

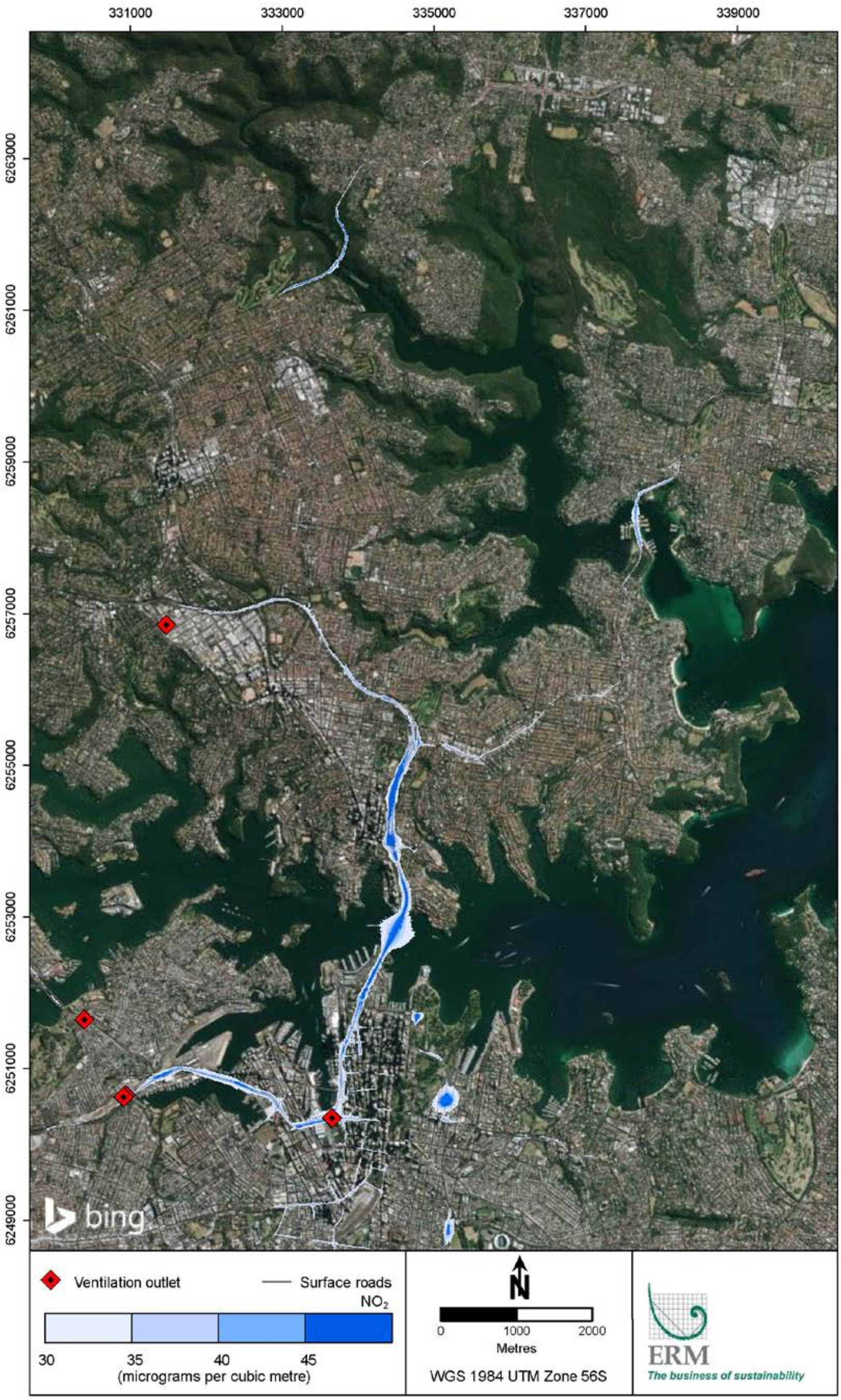


Figure 8-29 Contour plot of annual mean NO_2 concentration in the 2037 ‘Do minimum’ scenario (2037-DM)

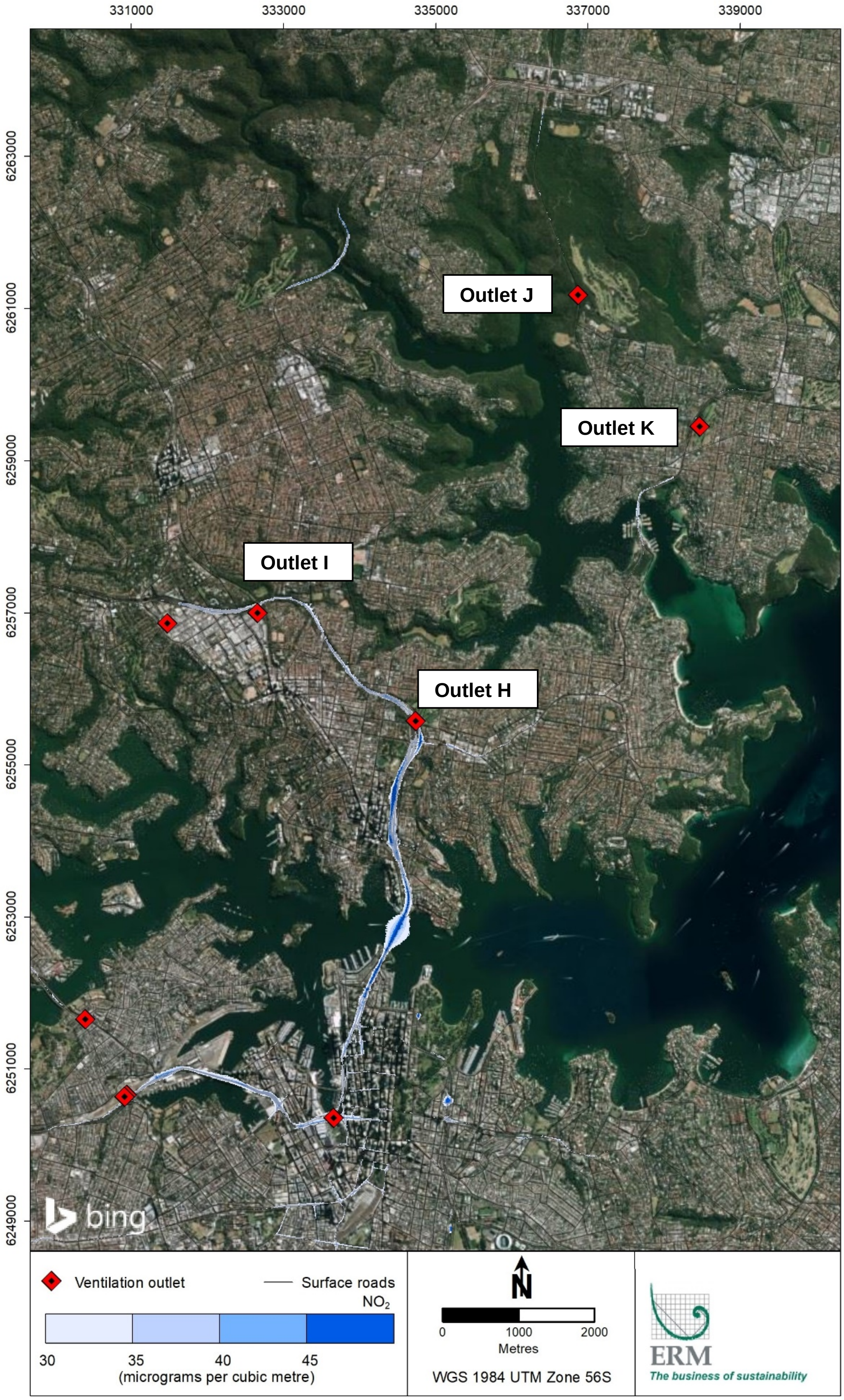


Figure 8-30 **Contour plot of annual mean NO_2 concentration in the 2037 cumulative scenario (2037-DSC)**

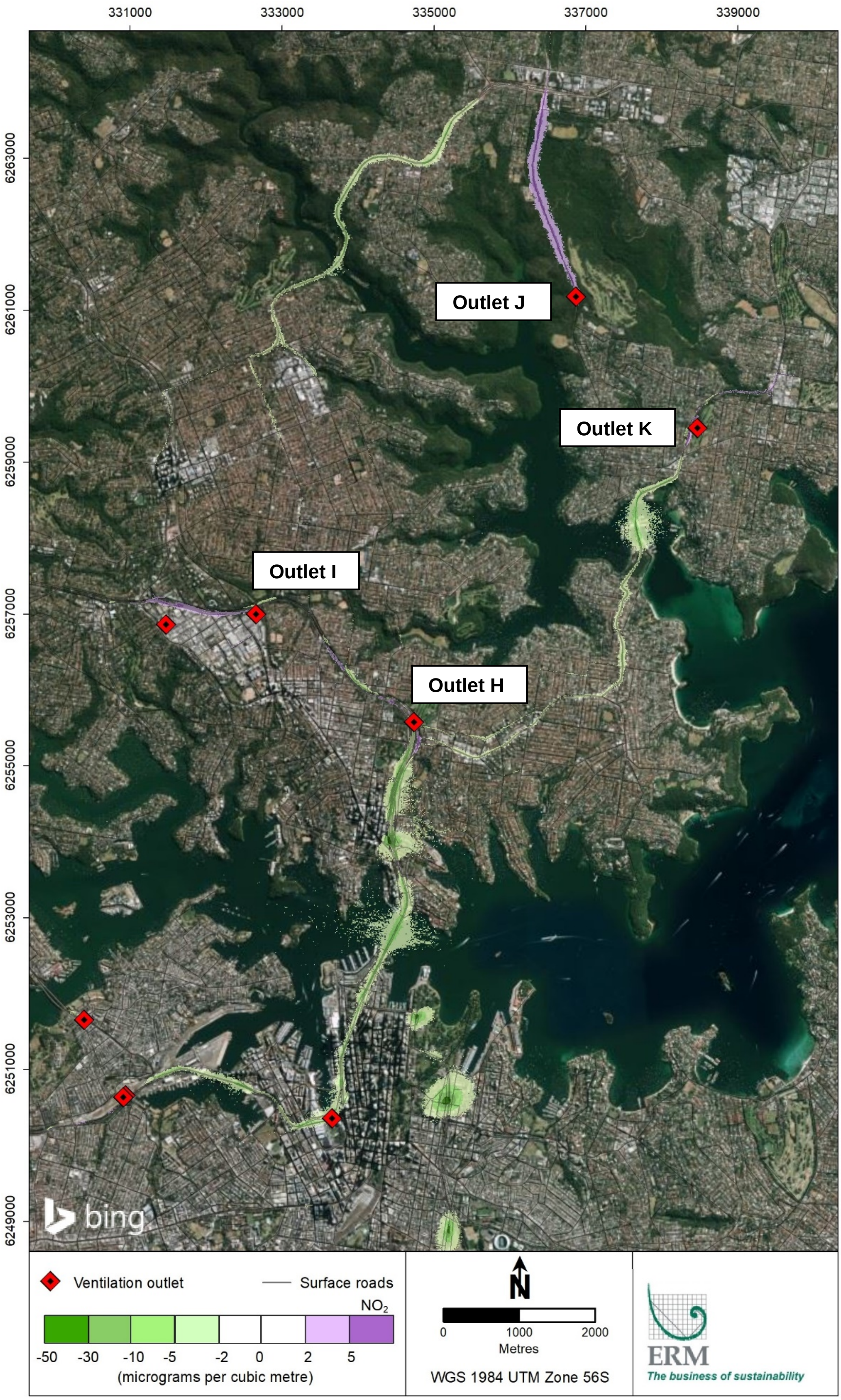


Figure 8-31 Contour plot of change in annual mean NO_2 concentration in the 2037 cumulative scenario (2037-DSC minus 2037-DM)

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 8-32. 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 more stringent limit value of 200 µg/m^3 but with nine allowed exceedances per year (Annexure B). There were fewer than nine exceedances of the New Zealand standard at all receptors in all with-project and cumulative scenarios.

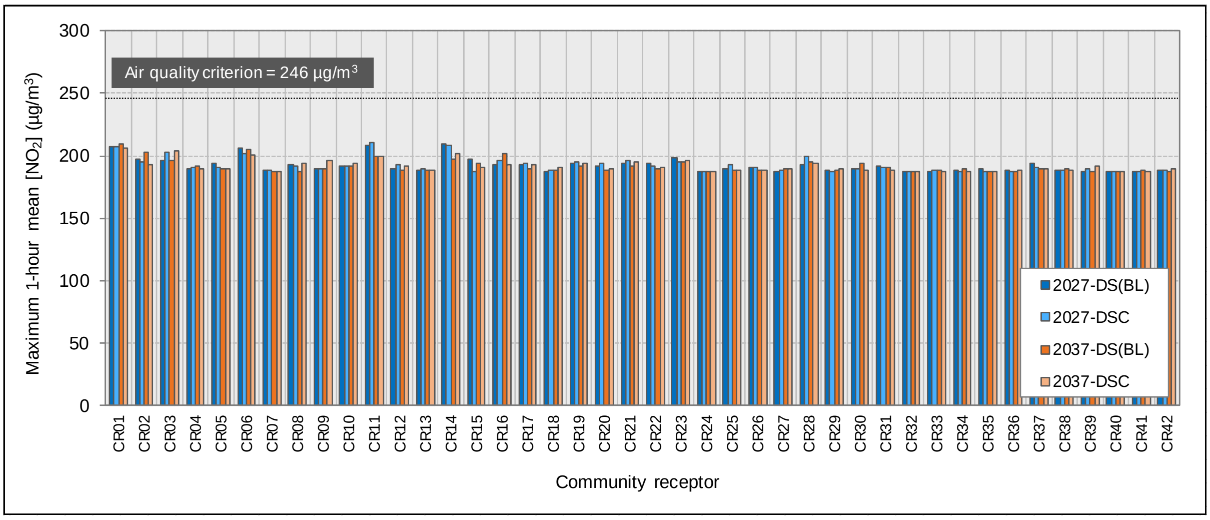


Figure 8-32 Maximum 1-hour mean NO_2 concentration at community receptors (with-project and cumulative scenarios)

The changes in the maximum 1-hour NO_2 concentration relative to the ‘Do minimum’ scenarios are shown in Figure 8-33. 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 CR11 (Neutral Bay Medical Centre), CR15 (Beauty Point Public School) and CR25 (Sue’s Childcare Castlevale).

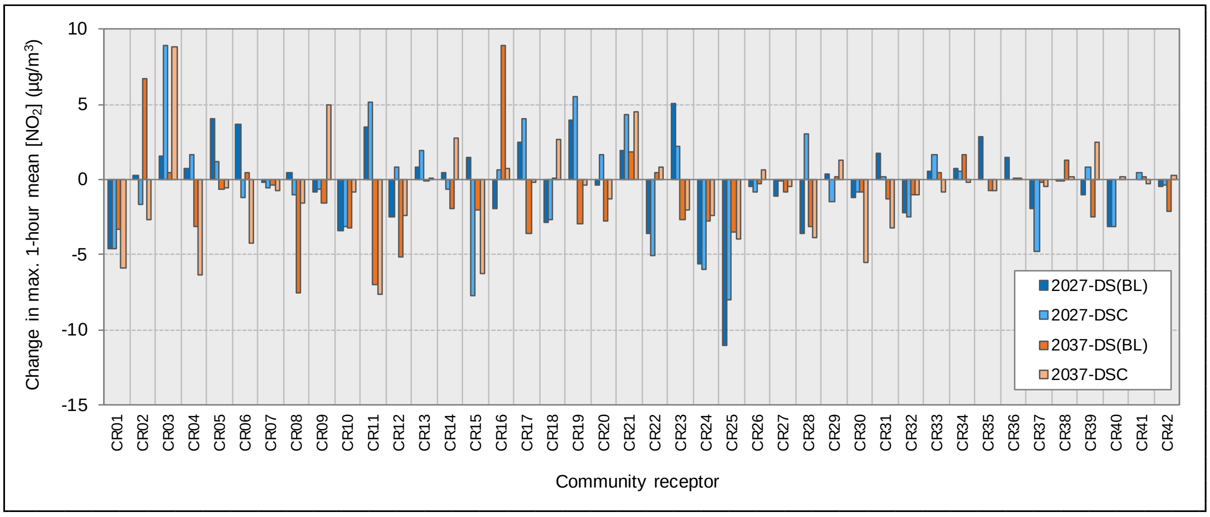


Figure 8-33 Change in maximum 1-hour mean NO_2 concentration at community receptors (with-project and cumulative scenarios, relative to ‘Do minimum’ scenarios)

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 8-34.

As with the annual mean, the background was the most important source, with generally a small contribution from surface roads. The main exceptions were CR06 (St Aloysius College) which had a large contribution from surface roads in the ‘Do-Something’ scenarios and CR11 (Neutral Bay Public School) in the 2037-DS(BL) scenario. These results show the maximum NO_2 concentrations at each receptor. Unlike other pollutants such as PM, total NO_2 is not calculated by adding two NO_2 concentrations together, but rather by adding background NO_X to project NO_X and then converting the sum to NO_2. The maximum concentration will therefore not always occur when the background it highest. In fact, the maximum cumulative NO_2 can be when the background is relatively small, but the project contribution is high, as shown in this example.

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 8-35. The contribution of surface roads and ventilation outlets are not shown separately in Figure 8-35; 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(BL) scenario, this decreased slightly to 153 receptors. 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), and this remained this same for the 2037-DS(BL) scenario. In the 2037-DSC scenario, the number decreased to 75 receptors (0.2 per cent). The majority of exceedances in all scenarios were located along Warringah Freeway (and the Warringah Freeway 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 the Western Harbour Tunnel was introduced.

The ventilation outlets individual contribution to NO_2 cannot be calculated directly for RWR receptors. 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.

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 8-36. There was predicted to be an increase in the maximum 1-hour NO_2 concentration at between 30 per cent and 43 per cent of receptors, depending on the scenario. Conversely, there was a reduction in the maximum concentration at between around 57 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 0.8 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, but further to the south and closer to the Harbour Bridge and Falcon Street. The majority of the decreases were also located along the Warringah Freeway Upgrade, Falcon Street and also along Manly Road. 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 8-37 and Figure 8-38 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 8-39. The locations with the highest concentrations and largest changes in concentration are similar to this for annual mean NO_2.

The spatial changes in pollutant concentrations are discussed further in Section 8.4.6.

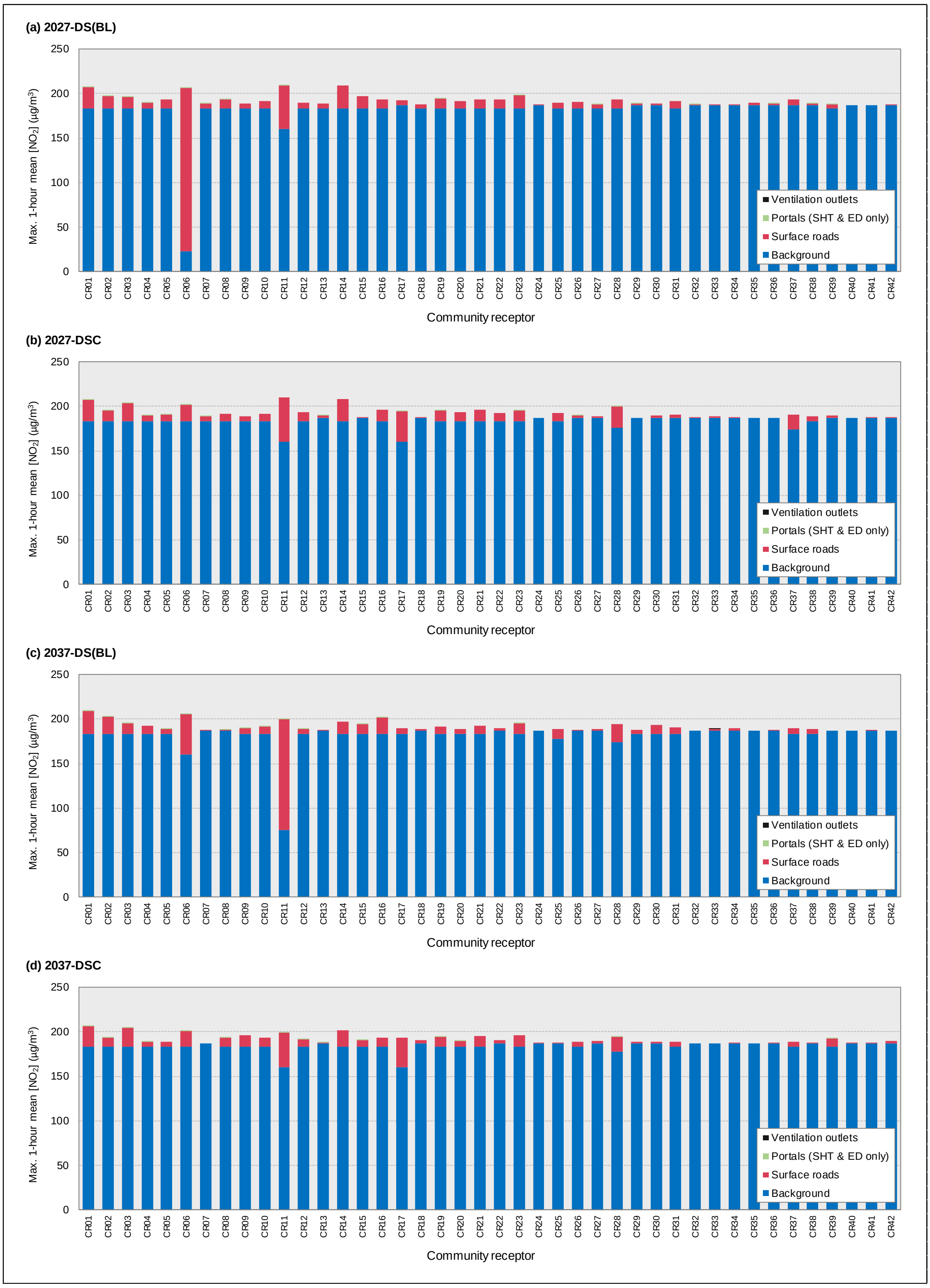


Figure 8-34 Source contributions to maximum 1-hour mean NO_2 concentration at community receptors (with-project and cumulative scenarios) (portals include Sydney Harbour Tunnel and Eastern Distributor only)

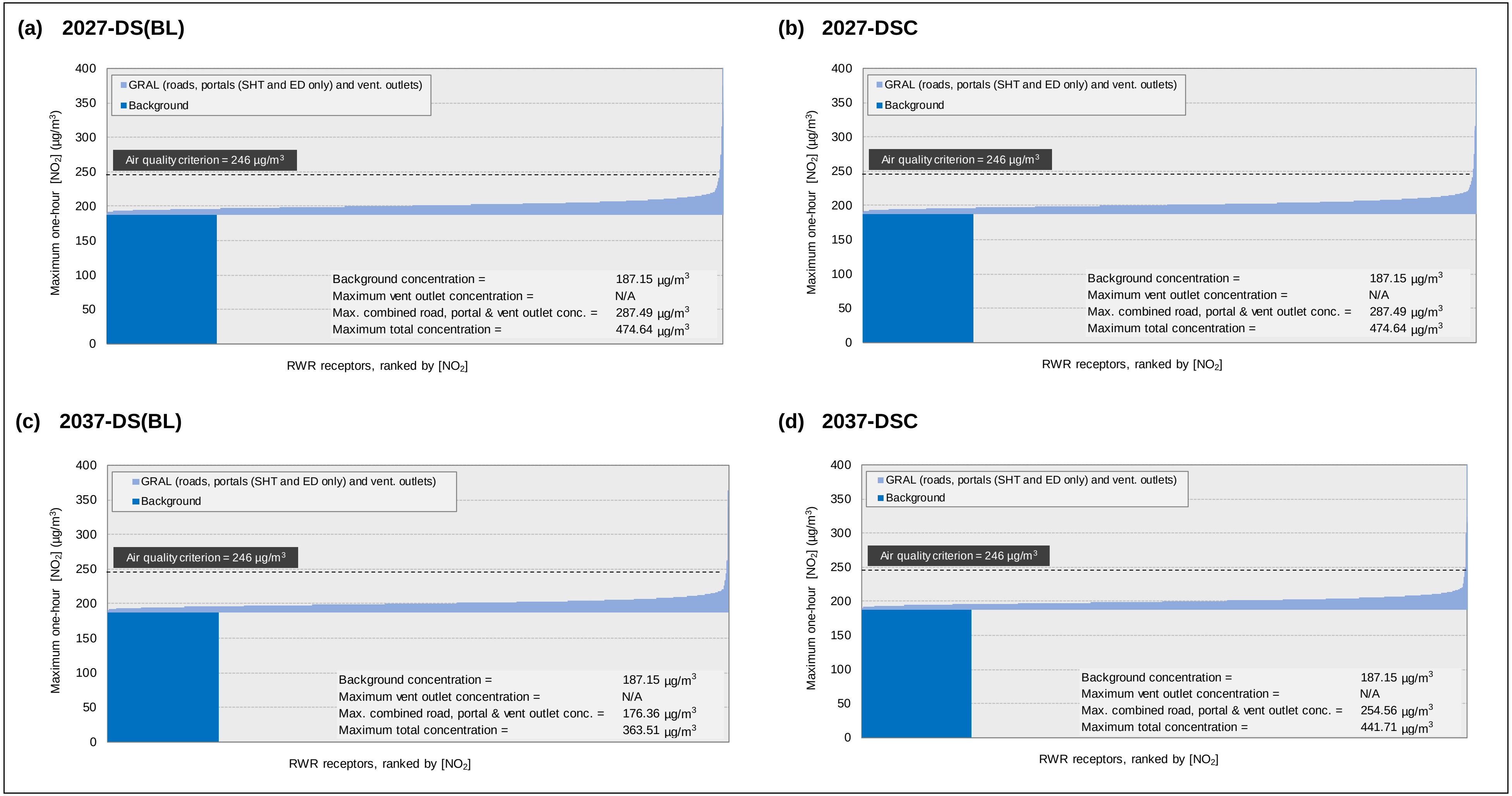
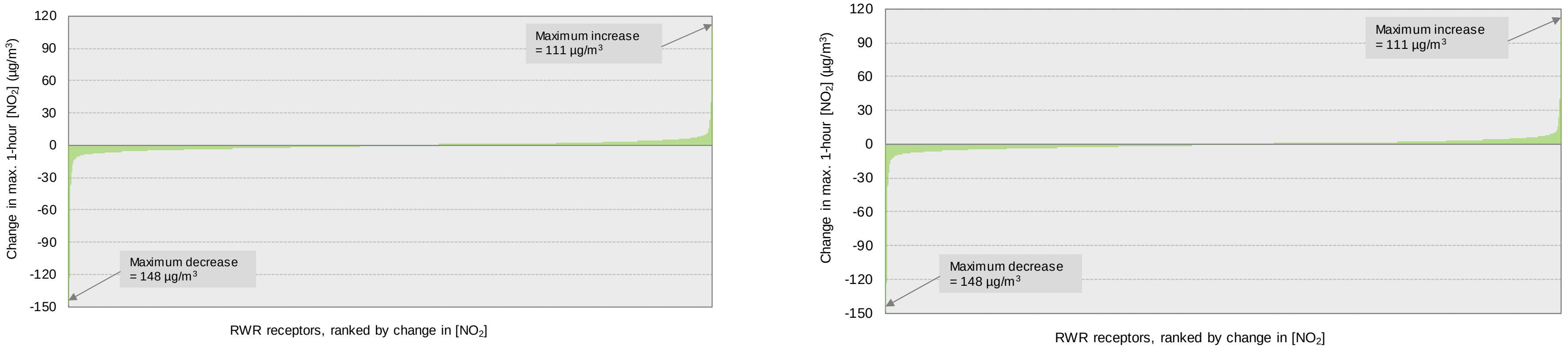
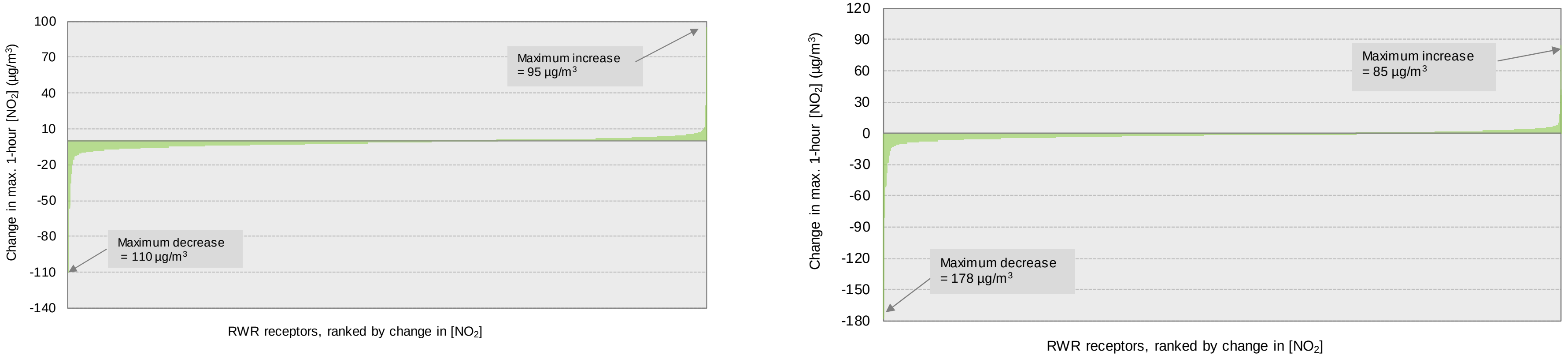


Figure 8-35 Source contributions to maximum 1-hour mean NO_2 concentration at RWR receptors (with-project and cumulative scenarios) (portals include Sydney Harbour Tunnel and Eastern Distributor only)



(a) 2027-DS(BL)

(b) 2027-DSC



(c) 2037-DS(BL)

(d) 2037-DSC

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

Figure 8-37 Contour plot of maximum 1-hour NO_2 concentration in the 2037 Do minimum scenario (2037-DM)

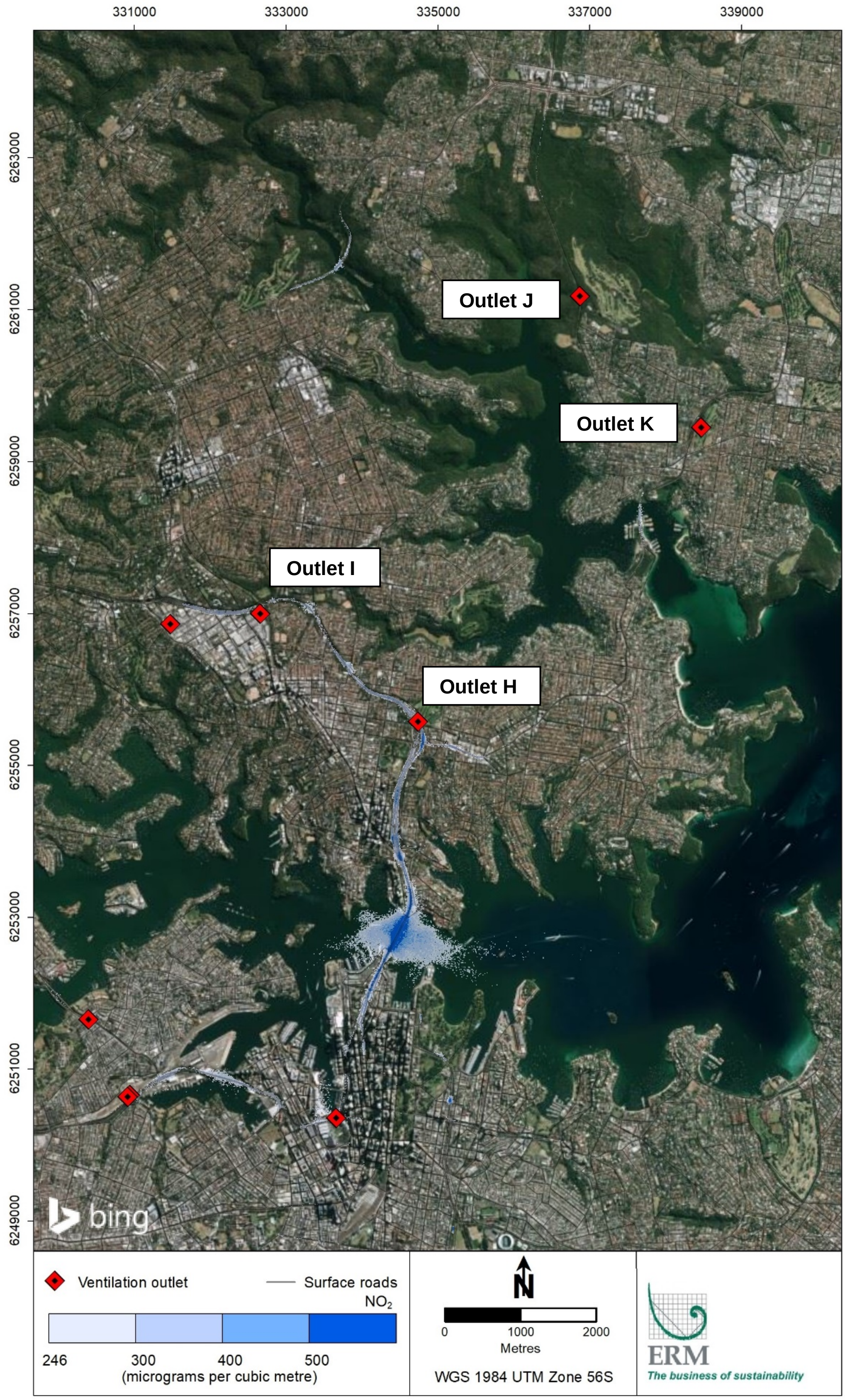


Figure 8-38 Contour plot of maximum 1-hour NO_2 concentration in the 2037 cumulative scenario (2037-DSC)

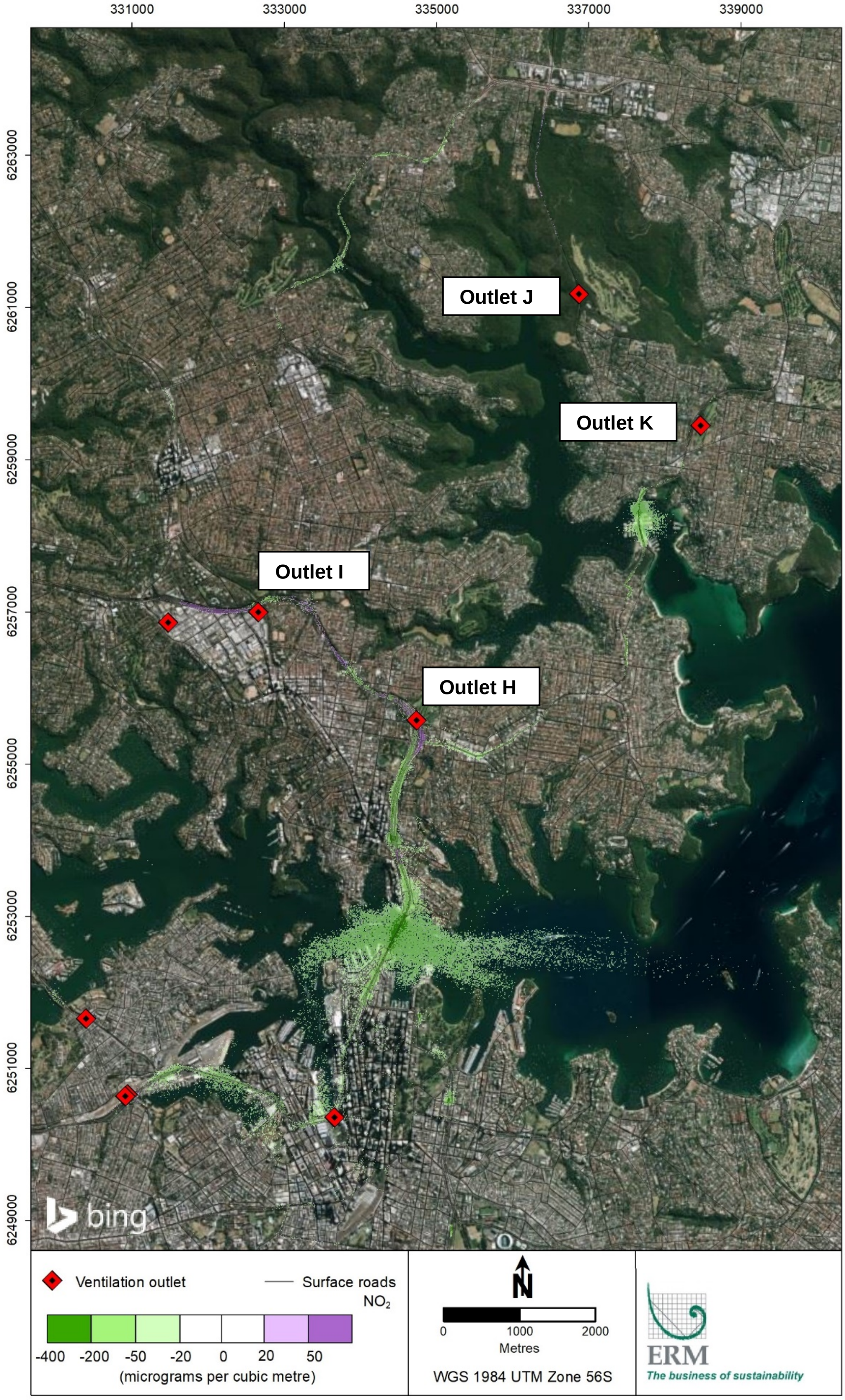


Figure 8-39 Contour plot of change in maximum 1-hour NO_2 concentration in the 2037 cumulative scenario (2037-DSC minus 2037-DM)

PM_{10} (annual mean)

Results for community receptors

The annual mean PM_{10} concentrations at community receptors are shown in Figure 8-40. These were all below the NSW impact assessment criterion of 25 µg/m^3. At all but one of the receptors the concentration was below 20 µg/m^3; receptor CR01 (University of Notre Dame, Broadway) had concentrations that were slightly above 20 µg/m^3. 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/m^3 in Scotland).

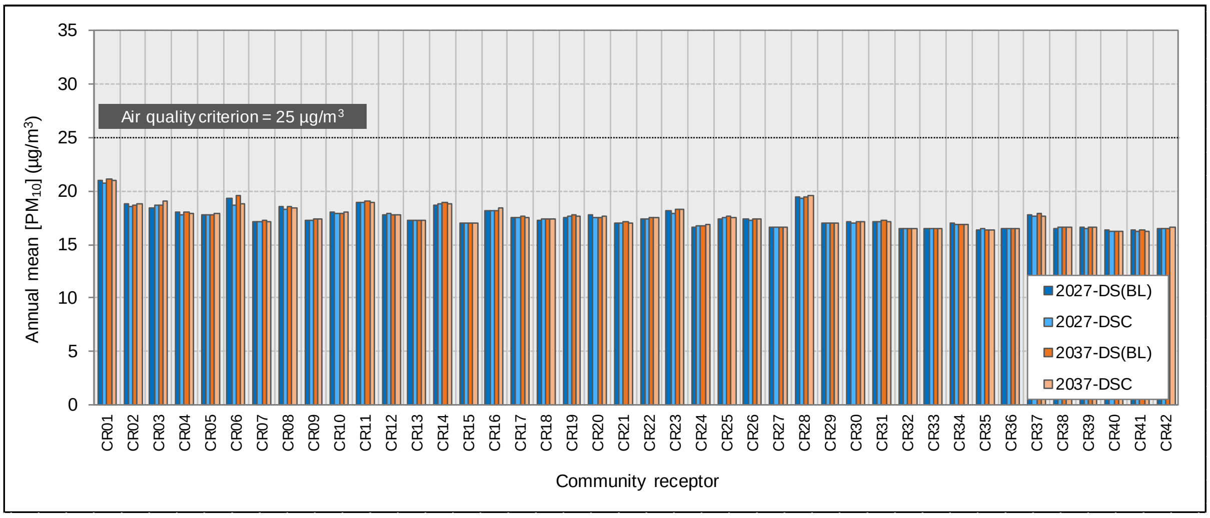


Figure 8-40 Annual mean PM_{10} concentration at community receptors (with-project and cumulative scenarios)

Figure 8-41 shows the changes in PM_{10} concentration. The largest increase was around 0.5 µg/m^3 (2 per cent of the criterion) at receptor CR03 (St Basil's Annandale), and the largest decrease around 1.5 µg/m^3 (receptor CR28: Peek A Boo Cottage, Seaforth). Concentrations decreased at most of the receptors.

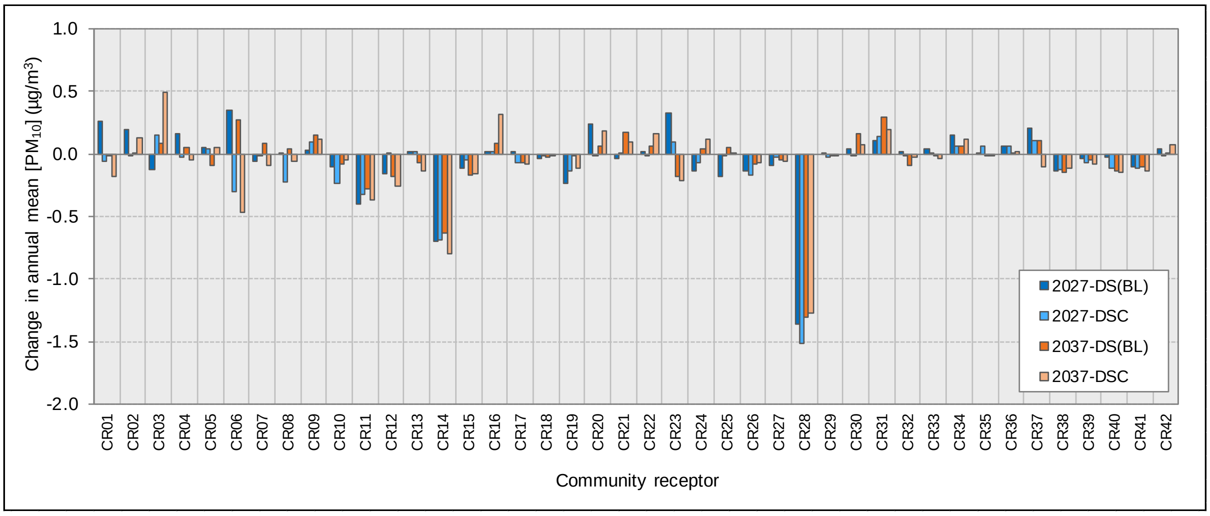
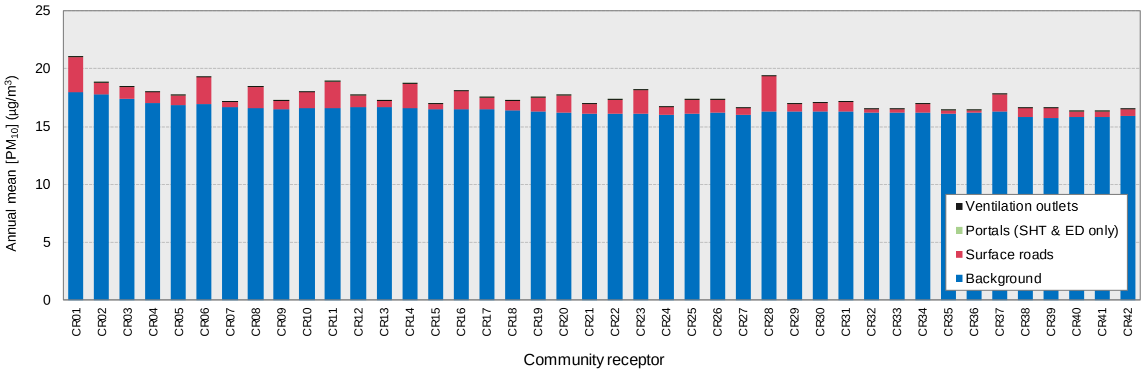


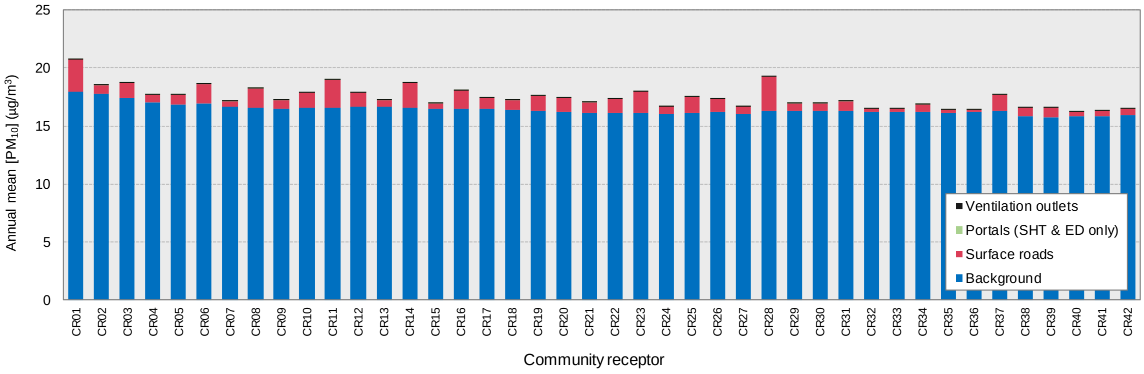
Figure 8-41 Change in annual mean PM_{10} concentration at community receptors (with-project and cumulative scenarios, relative to 'Do minimum' scenarios)

Annual mean PM_{10} concentrations in the with-project and cumulative scenarios were again dominated by the background (Figure 8-42), with a small contribution from roads at most receptors (1-3 µg/m^3) and a negligible contribution from tunnel ventilation outlets (less than around 0.2 µg/m^3).

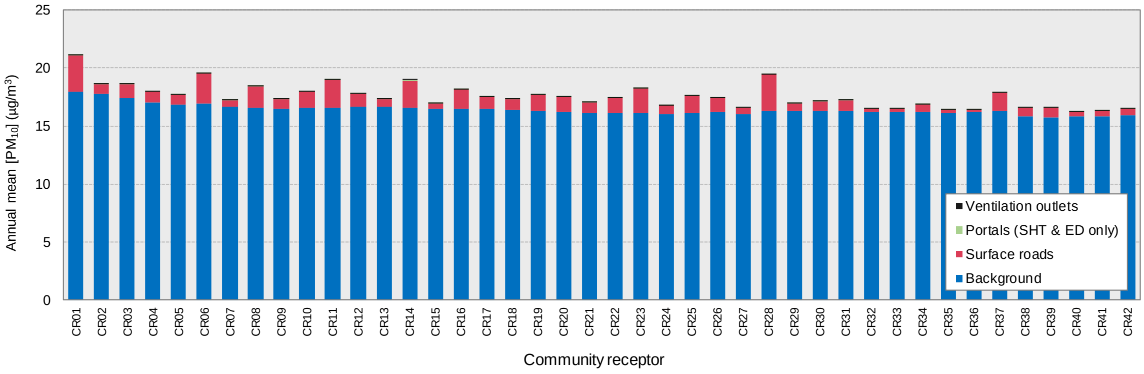
(a) 2027-DS(BL)



(b) 2027-DSC



(c) 2037-DS(BL)



(d) 2037-DSC

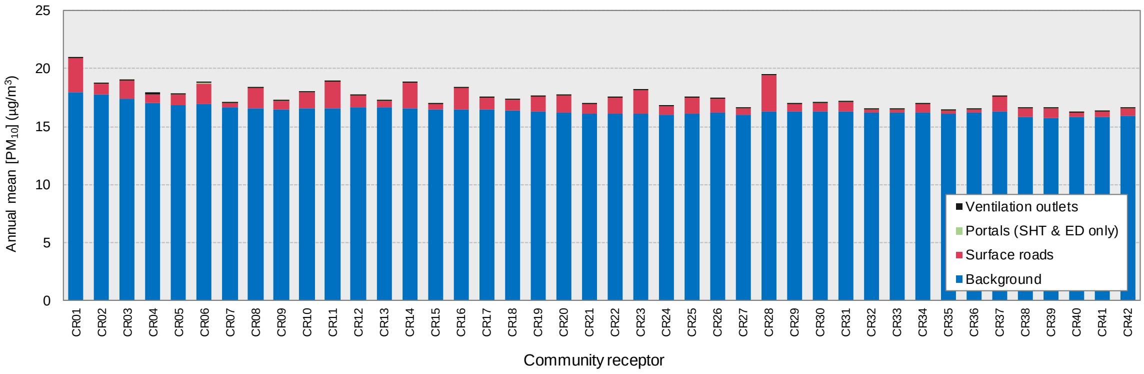


Figure 8-42 Source contributions to annual mean PM_{10} concentration at community receptors (with-project and cumulative scenarios) (portals include Sydney Harbour Tunnel and Eastern Distributor only)

Results for RWR receptors

The ranked annual mean PM_{10} concentrations at the RWR receptors are shown in Figure 8-43. The concentration at the majority of receptors was below 20 µg/m^3, and only one receptor had a concentration above the NSW assessment criterion of 25 µg/m^3. This property was a commercial property (the control centre for Sydney Harbour Tunnel), which is in the middle of the Bradfield Highway. This receptor had exceedances in the ‘Do minimum’ and ‘Do something’ scenarios (it was excluded from the cumulative scenarios, as it was inside the Western Harbour Tunnel and Warringah Freeway Upgrade construction footprint). The surface road contribution was up to 10.7 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 8-44. There was an increase in concentration at between around 39 per cent and 45 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 less than 0.1 per cent of receptors in the with-project and cumulative scenarios. The increases were mainly on the Warringah Freeway Upgrade towards the Sydney Harbour Bridge and north east of the Burnt Bridge Creek Deviation Ventilation Outlet (Outlet K) in the 2027-DS(BL) and 2037-DS(BL) scenarios. There were also some increases at Rozelle and Wakehurst Parkway in the cumulative scenarios. The predicted increases in concentration along Wakehurst Parkway are limited to within the road corridor and do not extend out to the nearby RWRs. There was a decrease in concentration at between around 55 per cent and 61 per cent of the receptors, depending on the scenario. The majority of these decreases were along Warringah Road between Roseville and Frenchs Forrest, south of Kitchener Street to The Spit and along Military Road, as well as sections of the Gore Hill Freeway between Miller Street and the Lane Cove Tunnel. There were some decreases along Eastern Valley Way.

Contour plots – all sources

The contour plots for annual mean PM_{10} in the 2027-DM and 2037-DSC scenarios are given in Figure 8-45 and Figure 8-46.

The spatial changes in pollutant concentrations are discussed further in Section 8.4.6.

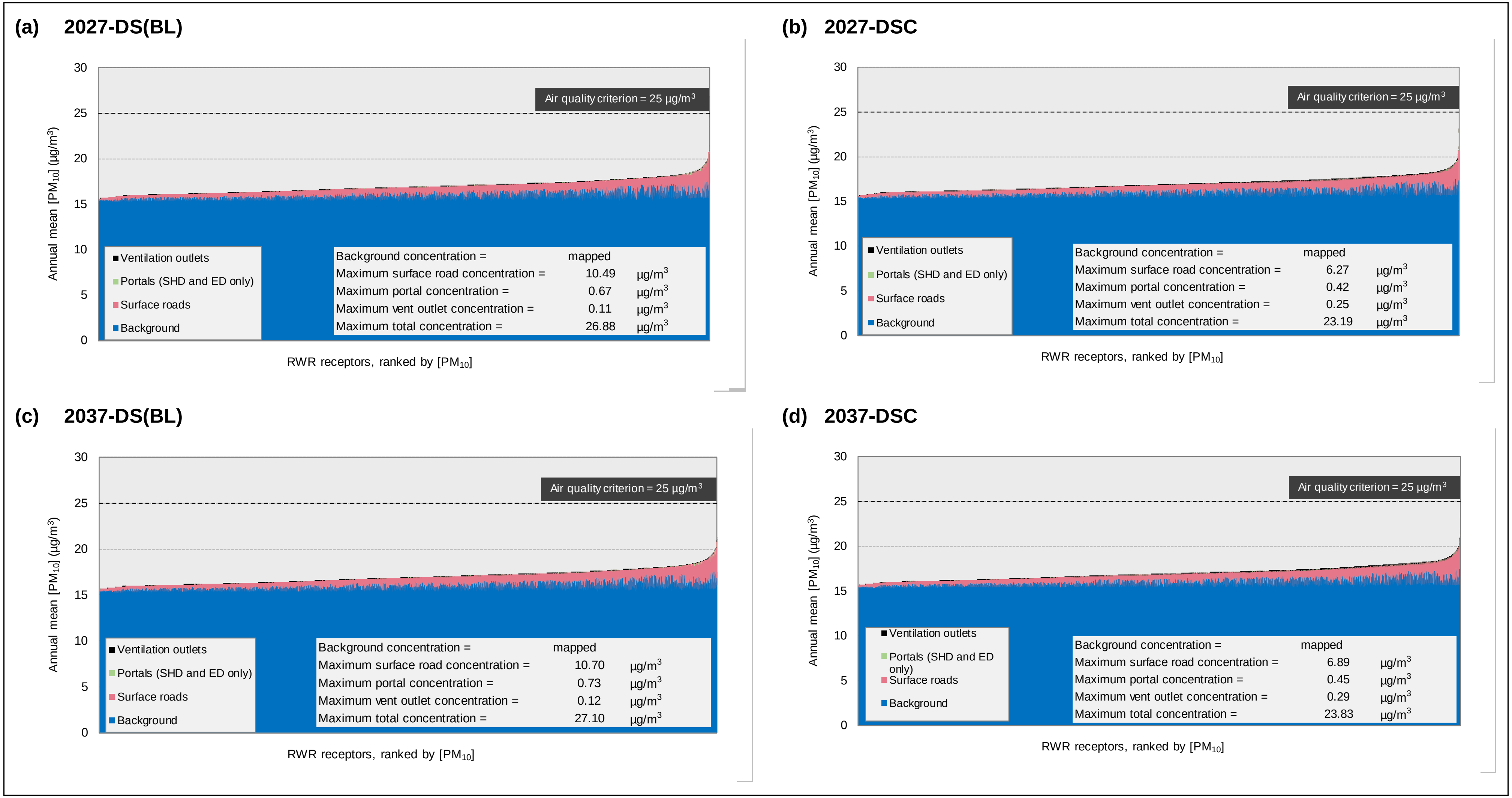


Figure 8-43 **Source contributions to annual mean PM_{10} concentration at RWR receptors (with-project and cumulative scenarios) (portals include Sydney Harbour Tunnel and Eastern Distributor only)**

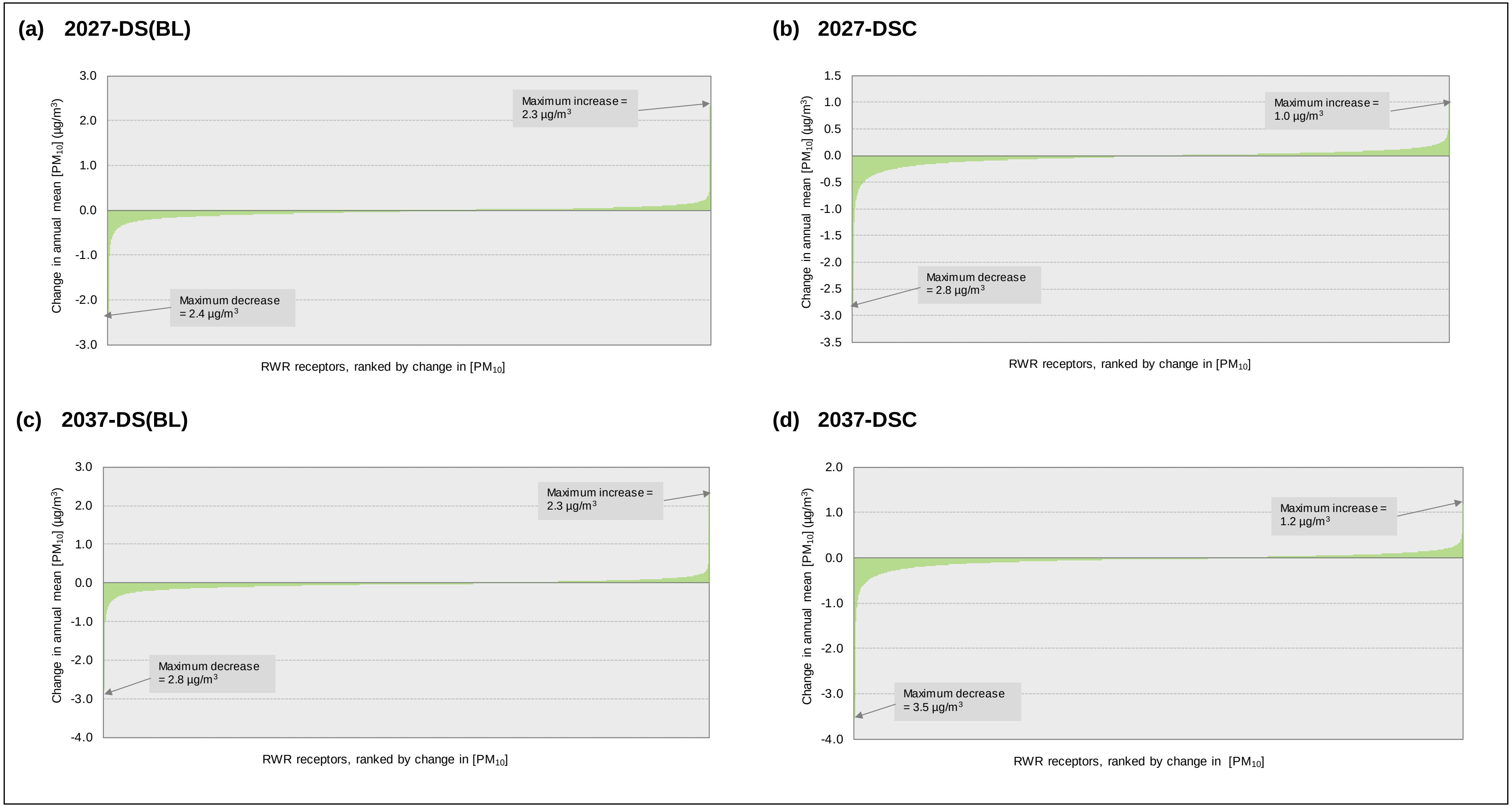


Figure 8-44 Changes in annual mean PM_{10} concentration at RWR receptors (with-project and cumulative scenarios, relative to 'Do minimum' scenarios)

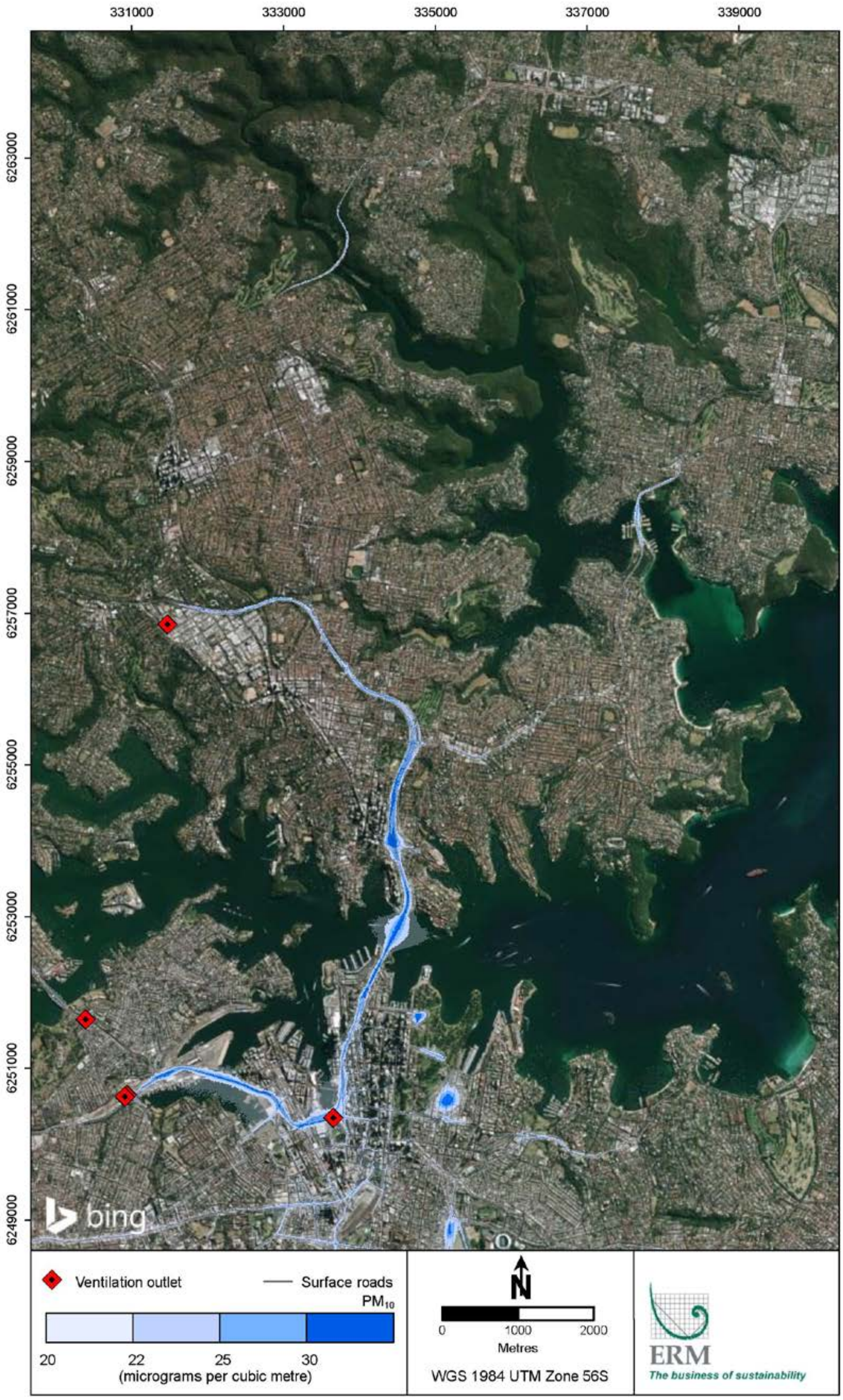


Figure 8-45 Contour plot of annual mean PM_{10} concentration in the 2037 Do minimum scenario (2037-DM)

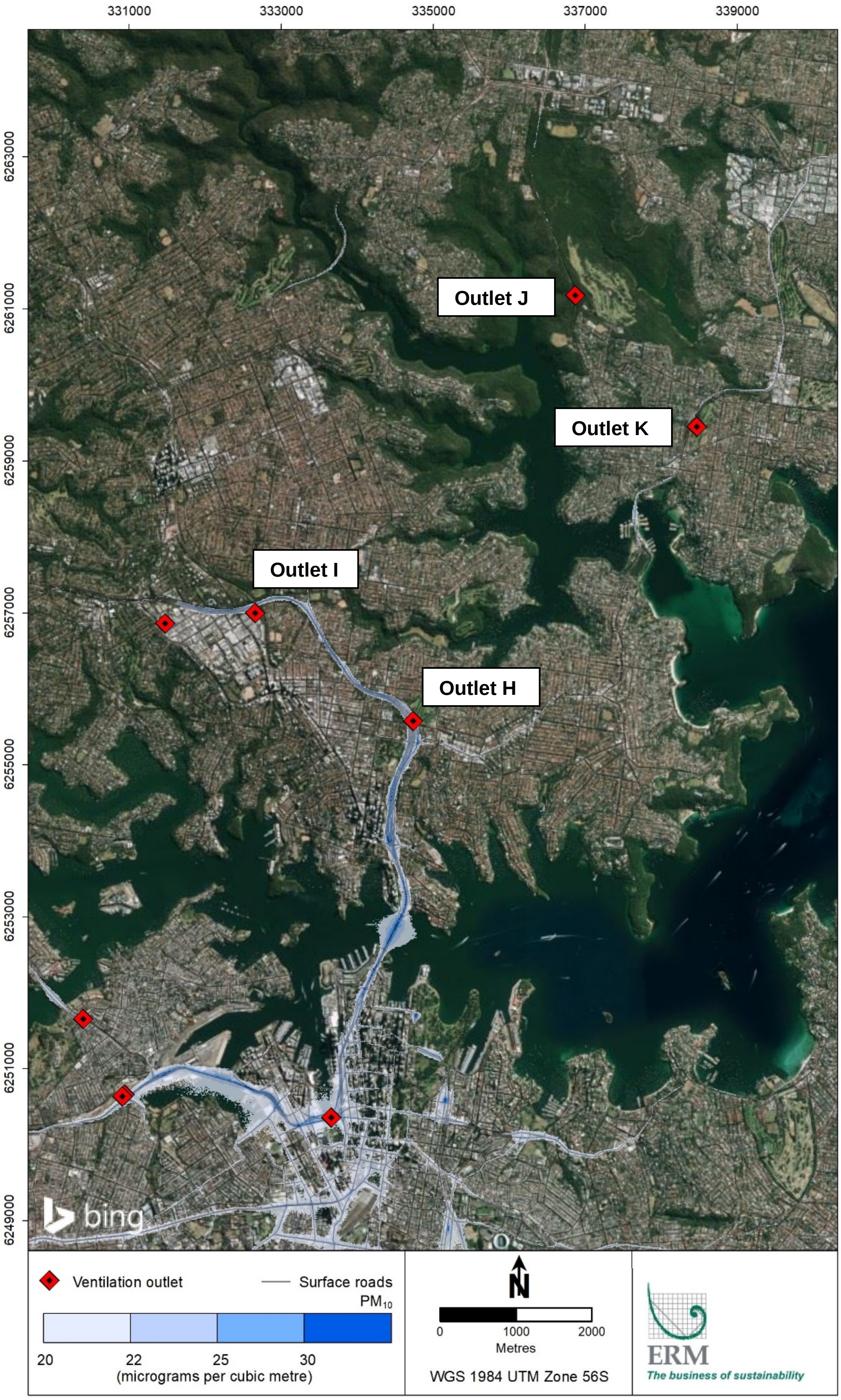


Figure 8-46 **Contour plot of annual mean PM_{10} concentration in the 2037 cumulative scenario (2037-DSC)**

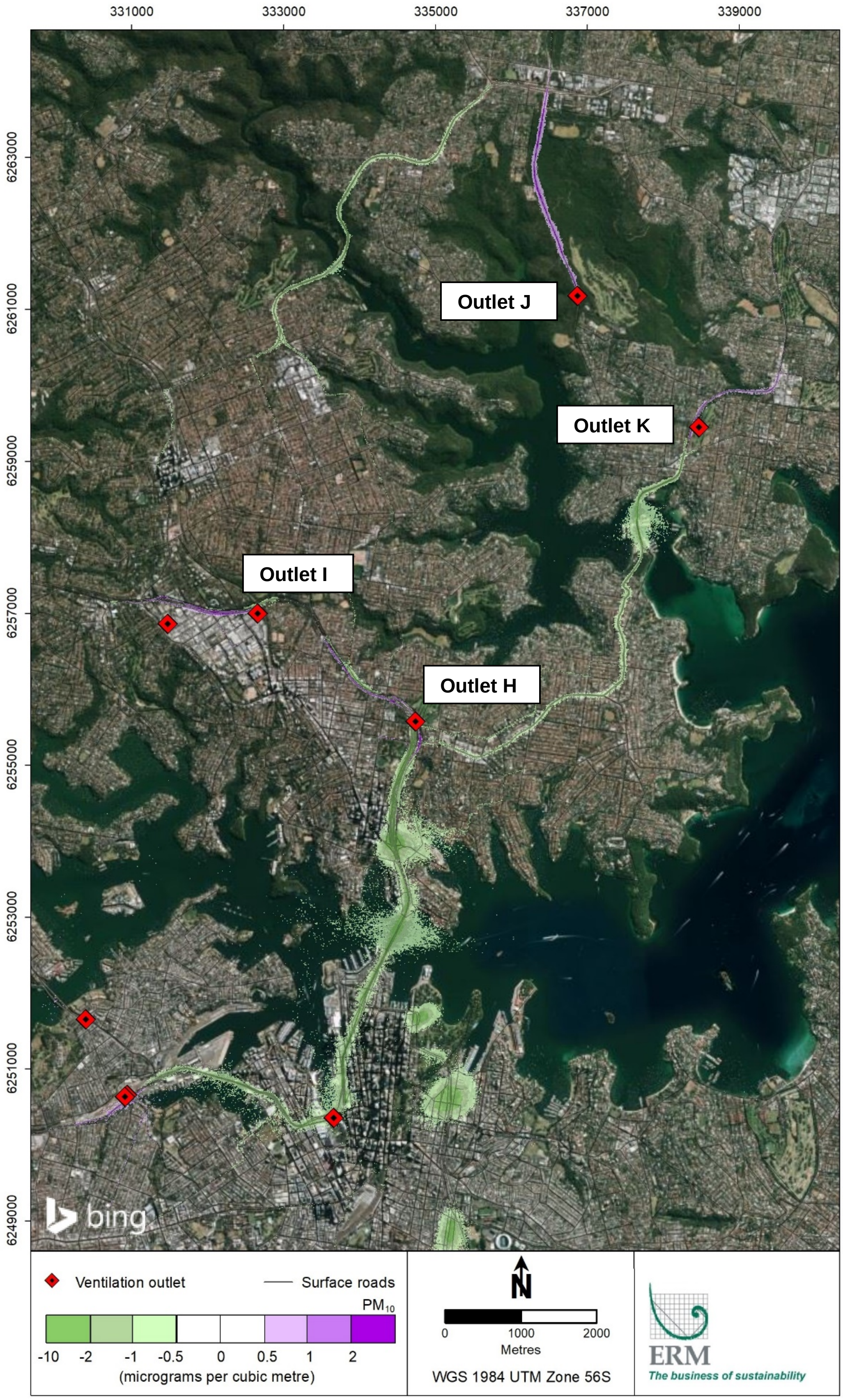


Figure 8-47 Contour plot of change in annual mean PM_{10} concentration in the 2037 cumulative scenario (2037-DSC minus 2037-DM)

PM_{10} (maximum 24-hour mean)

Results for community receptors

Figure 8-48 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.

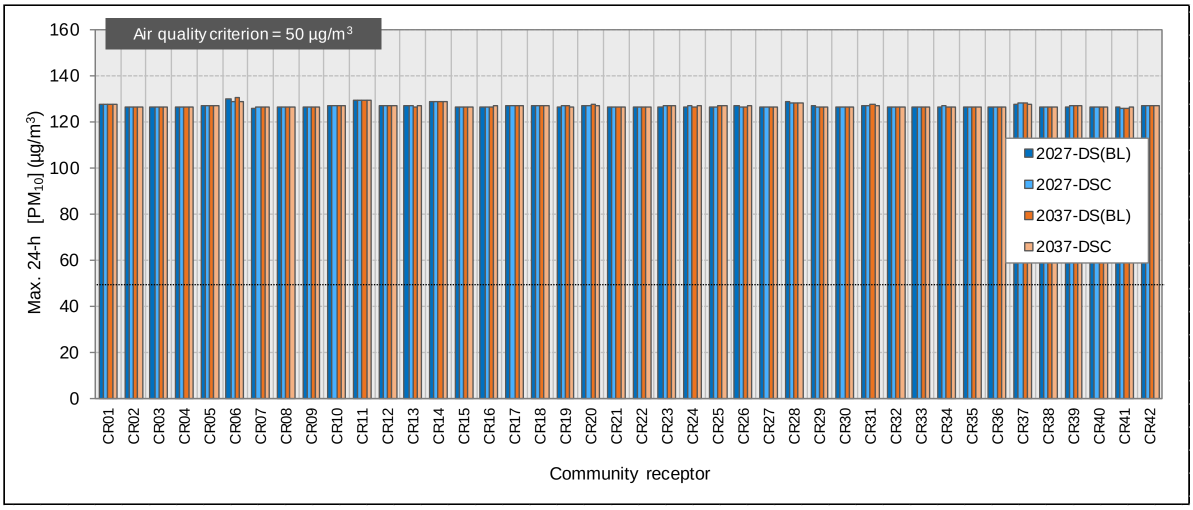


Figure 8-48 Maximum 24-hour mean PM_{10} concentration at community receptors using the contemporaneous background (with-project and cumulative scenarios)

While including the bushfire affected days in the contemporaneous approach clearly illustrates that it is the background driving the exceedances, an alternative approach is also presented using the 98th percentile for the background level, as was done for the RWR receptors. These results are shown in Figure 8-51 and present a more realistic scenario with an occasional exceedance at some receptors, still due to elevated background levels. The 98th percentile background concentration in this case is 48.0 µg/m^3, which by definition is exceeded on approximately 8 days of the year.

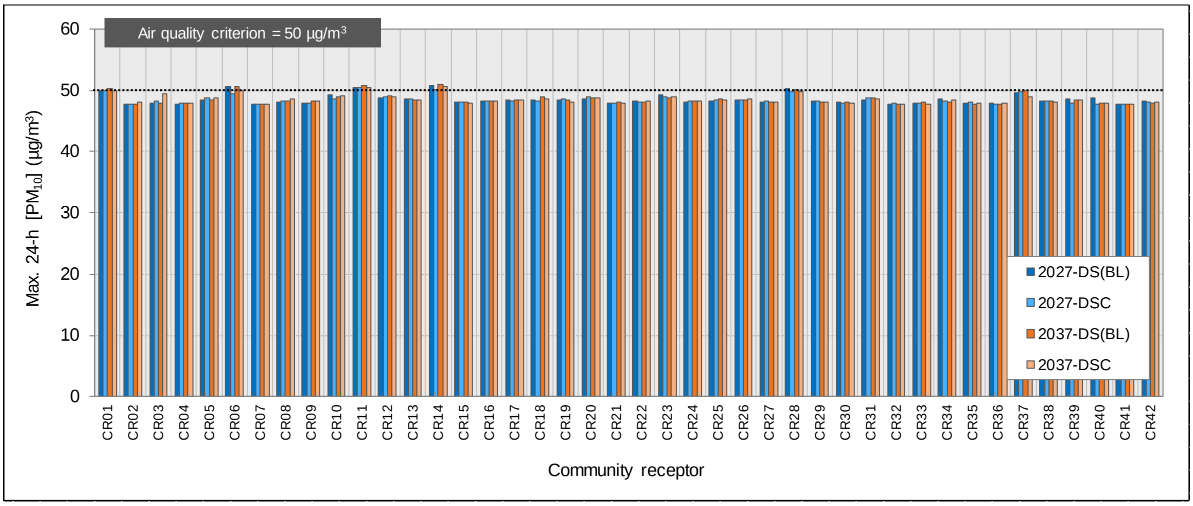


Figure 8-49 Maximum 24-hour mean PM_{10} concentration at community receptors using the 98th percentile approach (with-project and cumulative scenarios)

Figure 8-50 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/m³.

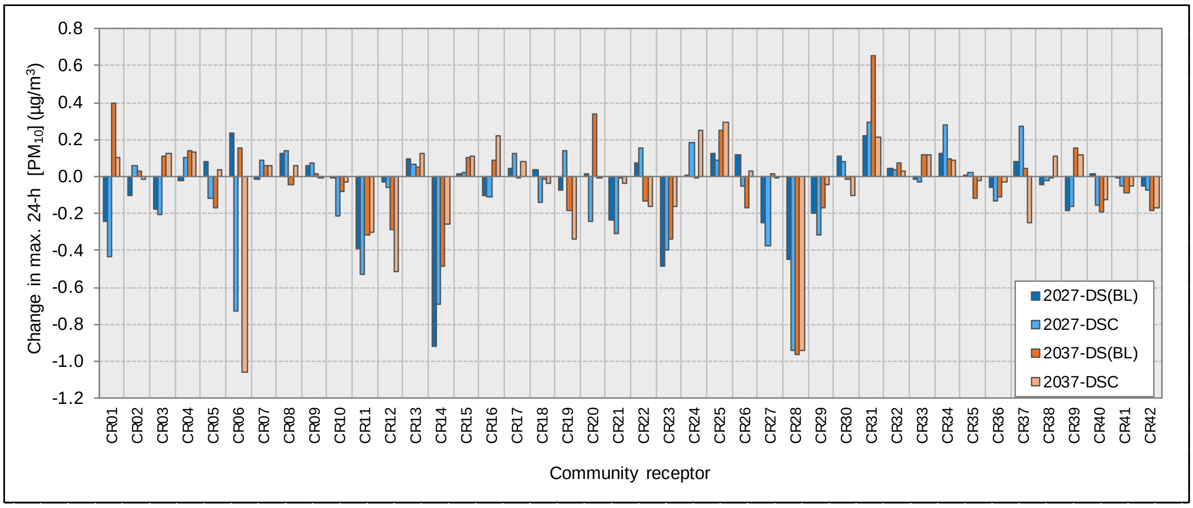


Figure 8-50 Change in maximum 24-hour mean PM_{10} concentration at community receptors (with-project and cumulative scenarios, relative to ‘Do minimum’ scenarios)

Figure 8-51 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/m³). The surface road contribution to the maximum 24-hour PM_{10} concentration at each community receptor was relatively small, generally less than 4 µg/m³. The main exception to this was receptor CR06 (St Aloysius College) (up to 4.2 µg/m³).

As was shown above, these results are presented again in Figure 8-52 but using the 98th percentile background concentration to exclude the effects of events such as bushfires that generate extremely high background concentrations.

In all scenarios the tunnel ventilation outlet contribution at all community receptors was generally negligible. The ventilation outlet contributions were less than 0.3 µg/m³.

Results for RWR receptors

The ranked maximum 24-hour mean PM_{10} concentrations at the RWR receptors are shown in Figure 8-53. The results for the RWR receptors were highly dependent on the assumption for the background concentration. This was assumed to be the 98th percentile of the maximum 24-hour concentration in the synthetic background profile (ie 48 µg/m³), and many of the receptors in the with-project and cumulative scenarios (around 63 per cent) were above the NSW impact assessment criterion of 50 µg/m³. For further discussion of the background concentrations, see Annexure D.

The number of receptors with a concentration above the criterion reduced as a result of the project, such as from 23,065 in the 2027-DM scenario to 21,795 in the 2027-DS(BL) scenario and then decreased to 21,083 in the 2027-DSC scenario. The corresponding numbers of receptors in the 2037 scenarios were 24,341, 23,236 and 22,507.

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 0.7 µg/m³ and 1.8 µg/m³.

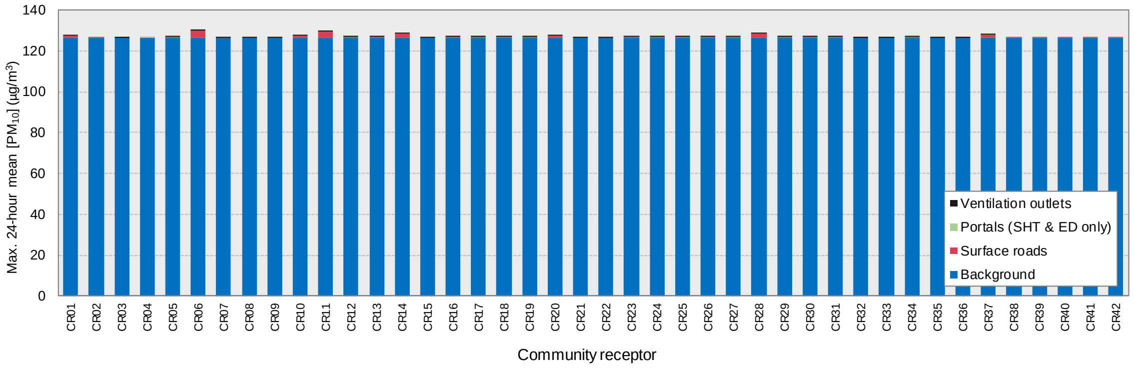
The changes in the maximum 24-hour mean PM_{10} concentration with the project and in the cumulative scenarios are ranked by change in concentration in Figure 8-54. There was an increase in concentration at between 36 and 41 per cent of the receptors, depending on the scenario. The largest predicted increase in concentration at any receptor as a result of the project was 6.1 µg/m³, and the largest predicted decrease was 9.8 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 10 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, Gore Hill Freeway, Manly Road and Rozelle. There are predicted increases in concentration along Wakehurst Parkway; however, these are limited to within the road corridor and do not extend out to the nearby RWRs.

Contour plots – all sources

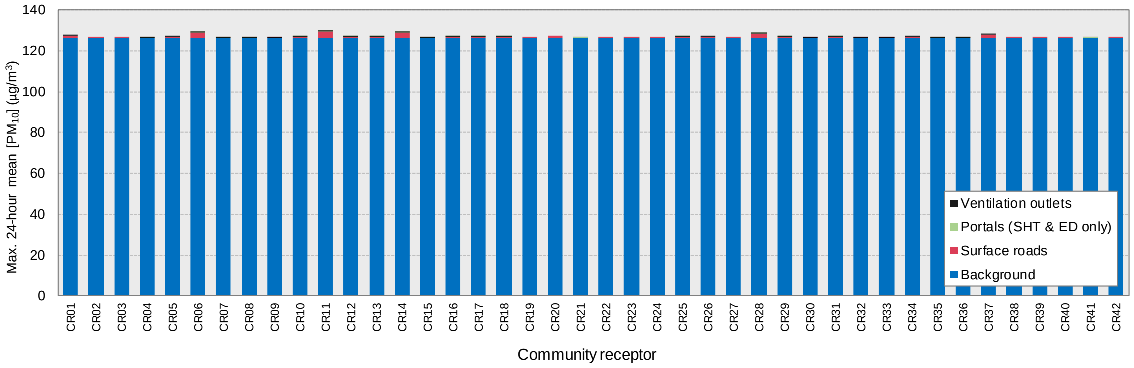
The contour plots for maximum 24-hour average PM_{10} in the 2037-DM and 2037-DSC scenarios are given in Figure 8-55 and Figure 8-56. The changes in maximum 24-hour PM_{10} are shown in Figure 8-57.

The spatial changes in pollutant concentrations are discussed further in Section 8.4.6.

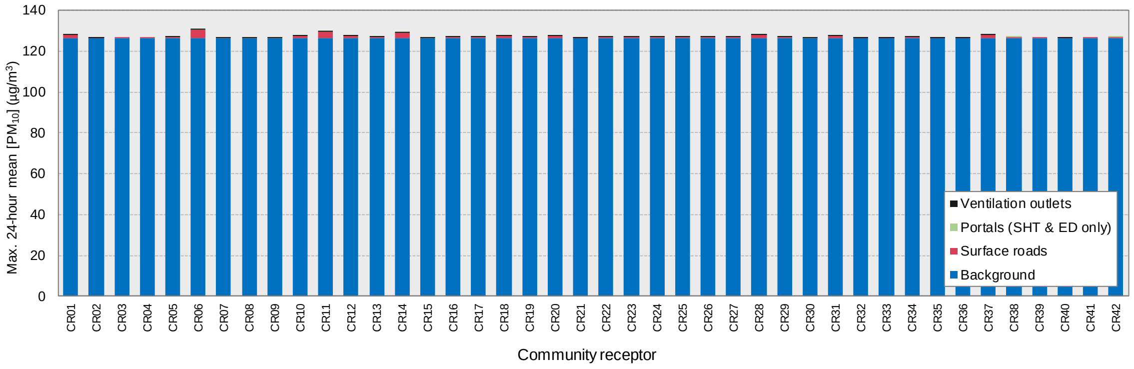
(a) 2027-DS(BL)



(b) 2027-DSC



(c) 2037-DS(BL)



(d) 2037-DSC

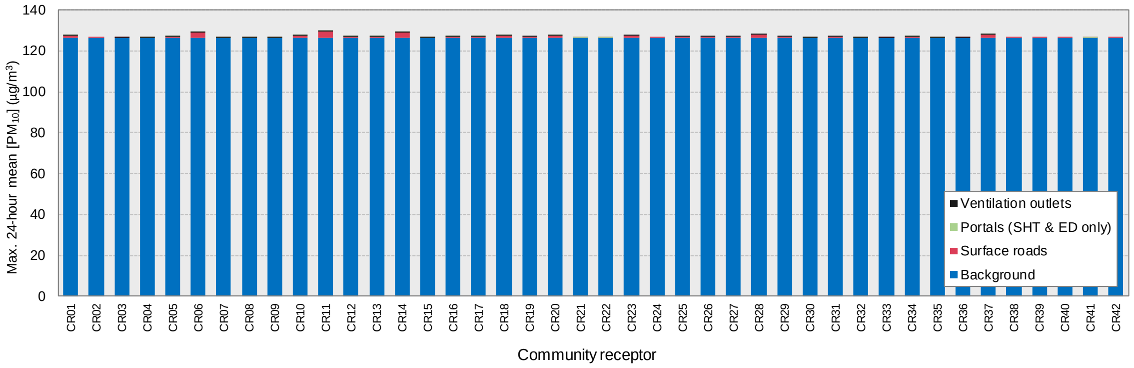


Figure 8-51 Source contributions to maximum 24-hour mean PM_{10} concentration at community receptors using the contemporaneous background (with-project and cumulative scenarios) (portals include Sydney Harbour Tunnel and Eastern Distributor only)

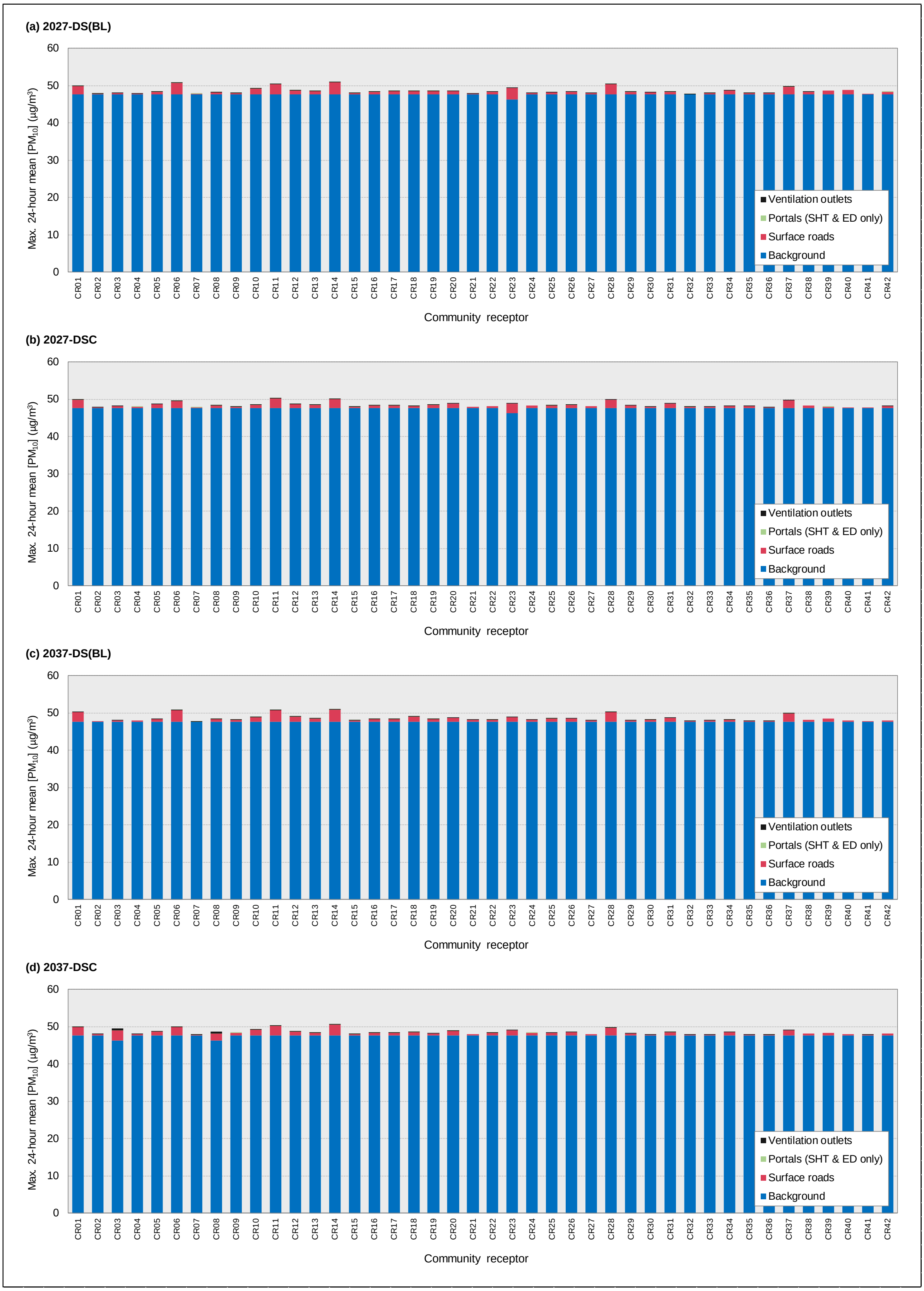


Figure 8-52 Source contributions to maximum 24-hour mean PM_{10} concentration at community receptors using the 98th percentile background (with-project and cumulative scenarios) (portals include Sydney Harbour Tunnel and Eastern Distributor only)

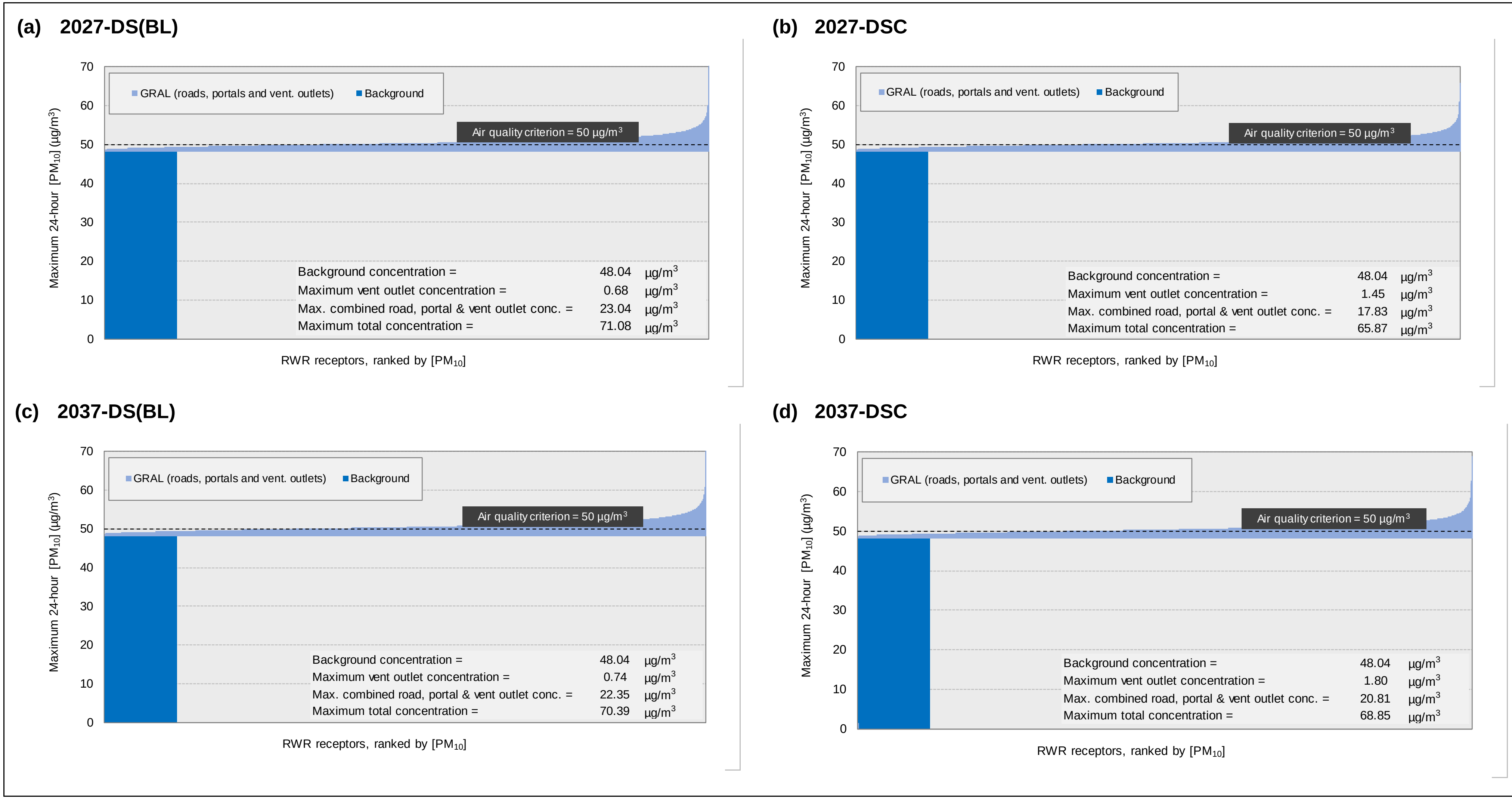


Figure 8-53 **Source contributions to maximum 24-hour mean PM_{10} concentration at RWR receptors (with-project and cumulative scenarios) (portals include Sydney Harbour Tunnel and Eastern Distributor only)**

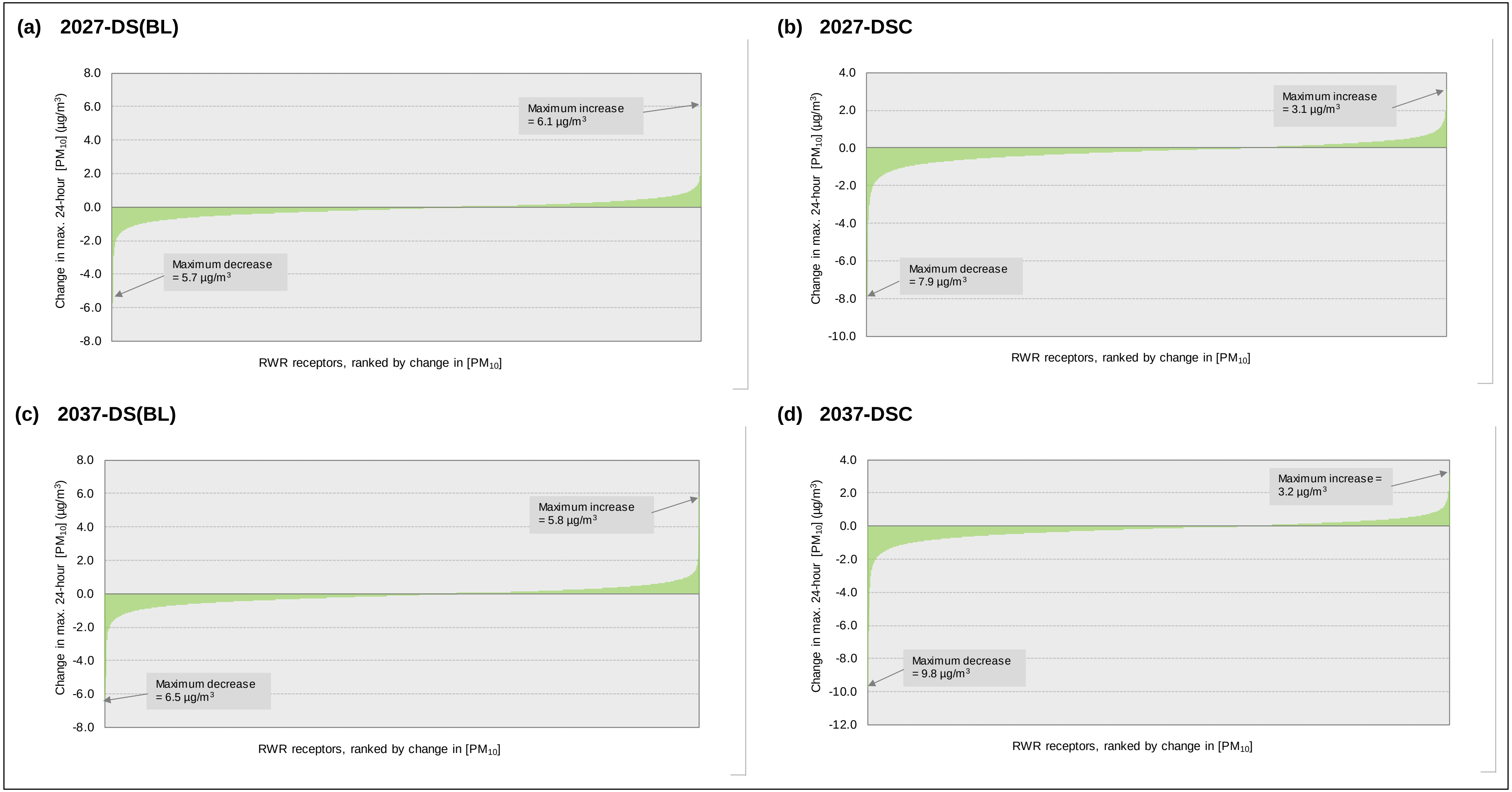


Figure 8-54 **Change in maximum 24-hour mean PM_{10} concentration at RWR receptors (with-project and cumulative scenarios, relative to ‘Do minimum’ scenarios)**

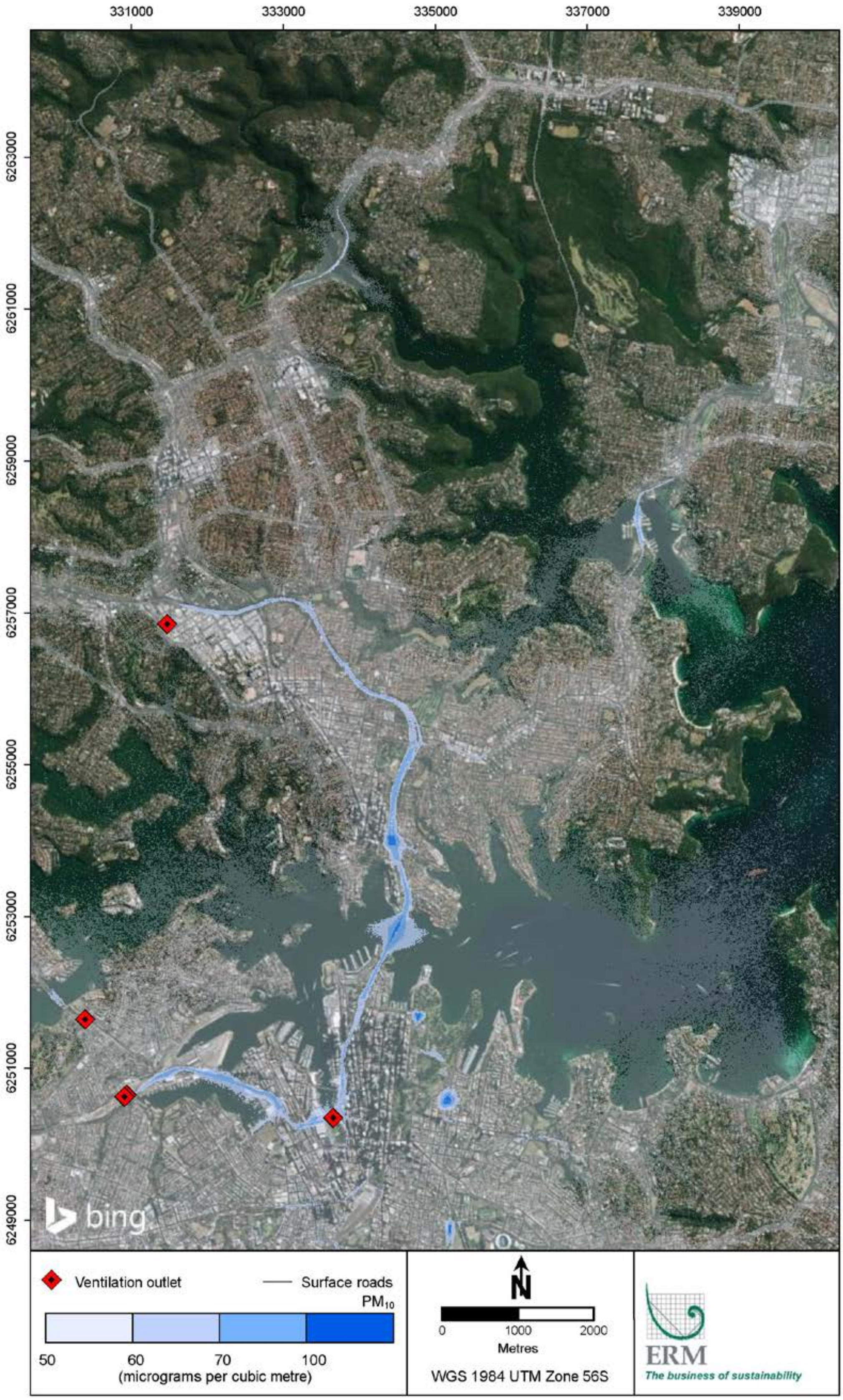


Figure 8-55 Contour plot of maximum 24-hour average PM_{10} concentration in the 2037 Do minimum scenario (2037-DM)

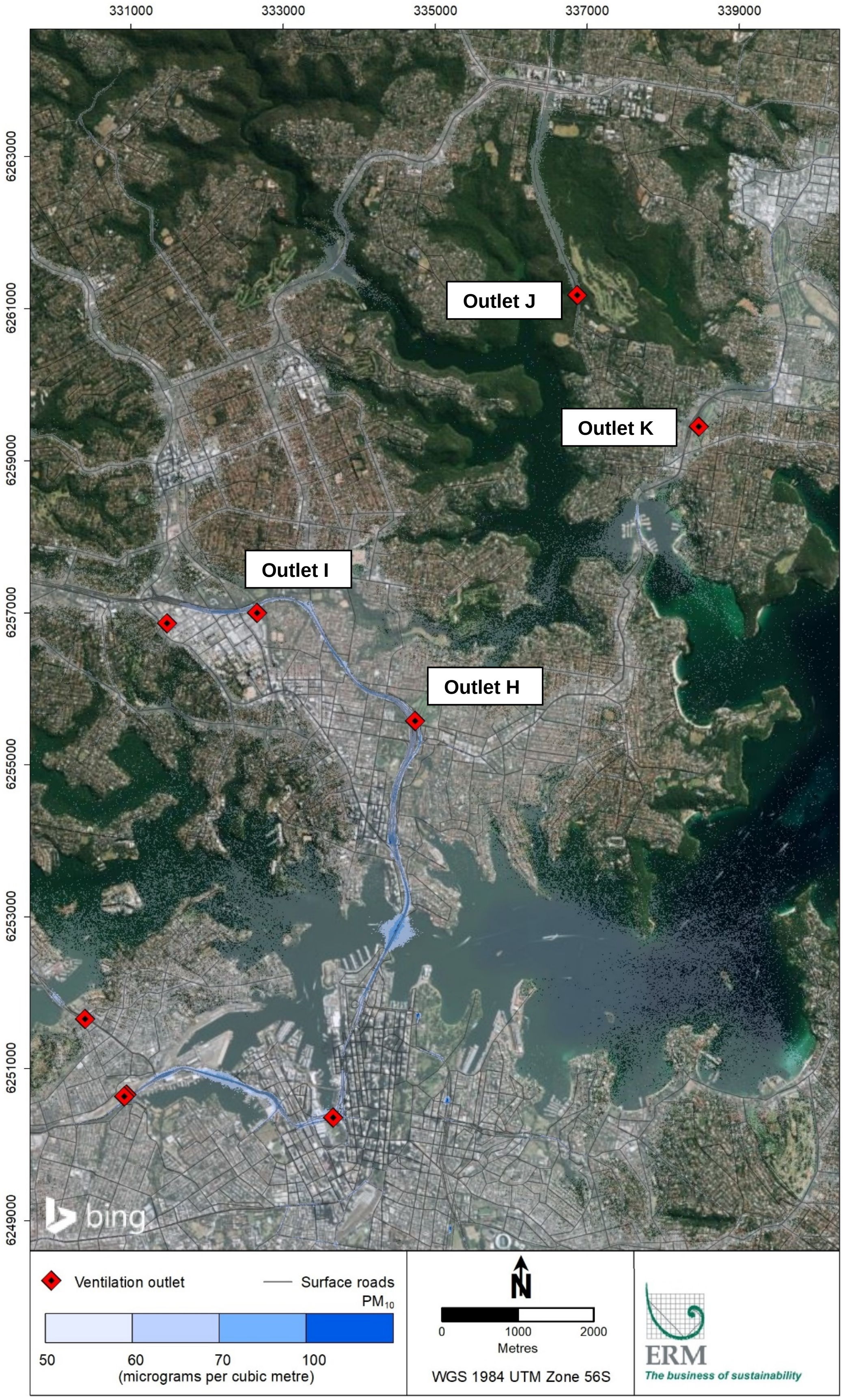


Figure 8-56 Contour plot of maximum 24-hour average PM_{10} concentration in the 2037 cumulative scenario (2037-DSC)

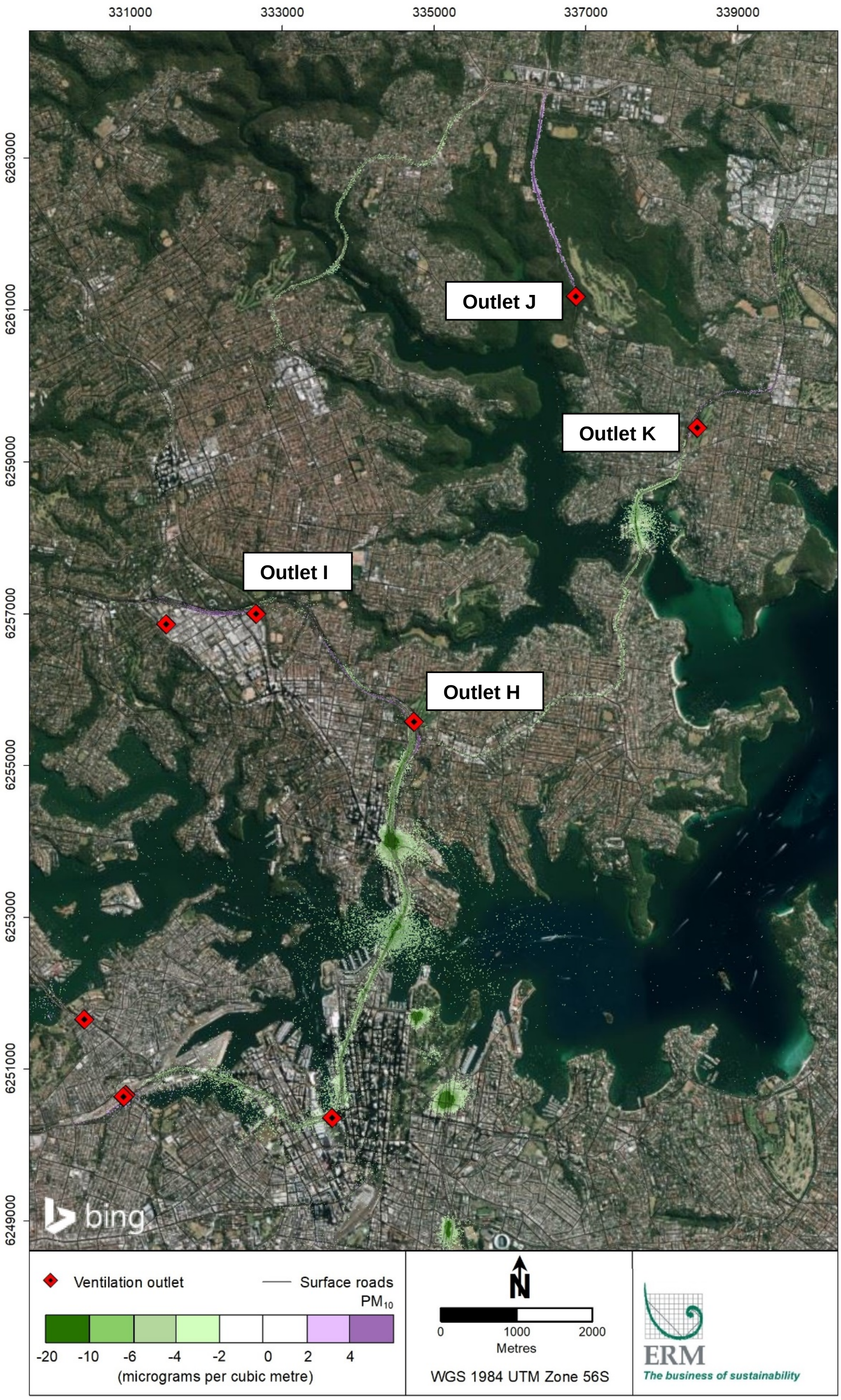


Figure 8-57 **Contour plot of change in maximum 24-hour mean PM$_{10}$ concentration in the 2037 cumulative scenario (2037-DSC minus 2037-DM)**

$PM_{2.5}$ (annual mean)

Results for community receptors

Figure 8-58 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/m³) 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/m³. Internationally, there are no standards lower than 8 µg/m³ for annual mean $PM_{2.5}$. The next lowest standard internationally is 12 µg/m³ (California and Scotland).

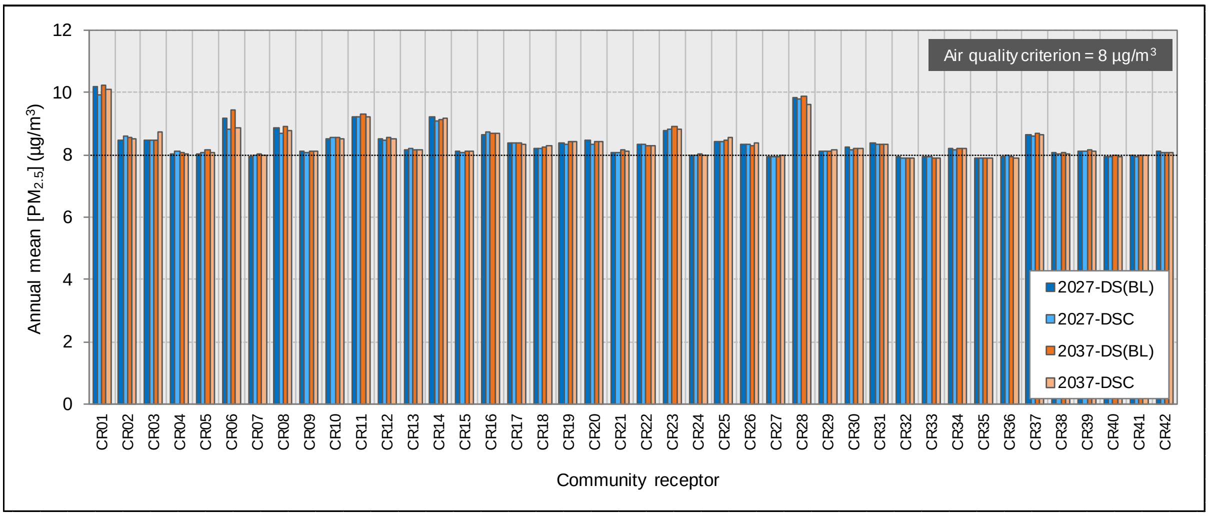


Figure 8-58 Annual mean $PM_{2.5}$ concentration at community receptors (with-project and cumulative scenarios)

Figure 8-59 presents the changes in annual mean $PM_{2.5}$ with the project and in the cumulative scenarios at the community receptors. Any increases were less than 0.3 µg/m³; the largest increase (0.3 µg/m³ at receptor CR03 (St Basil's Annandale) in the 2037-DSC scenario) equated to less than four per cent of the air quality criterion. There was a substantial reduction in concentration (up to 1.1 µg/m³) at receptor CR28 (Peek A Boo Cottage, Seaforth) with the project.

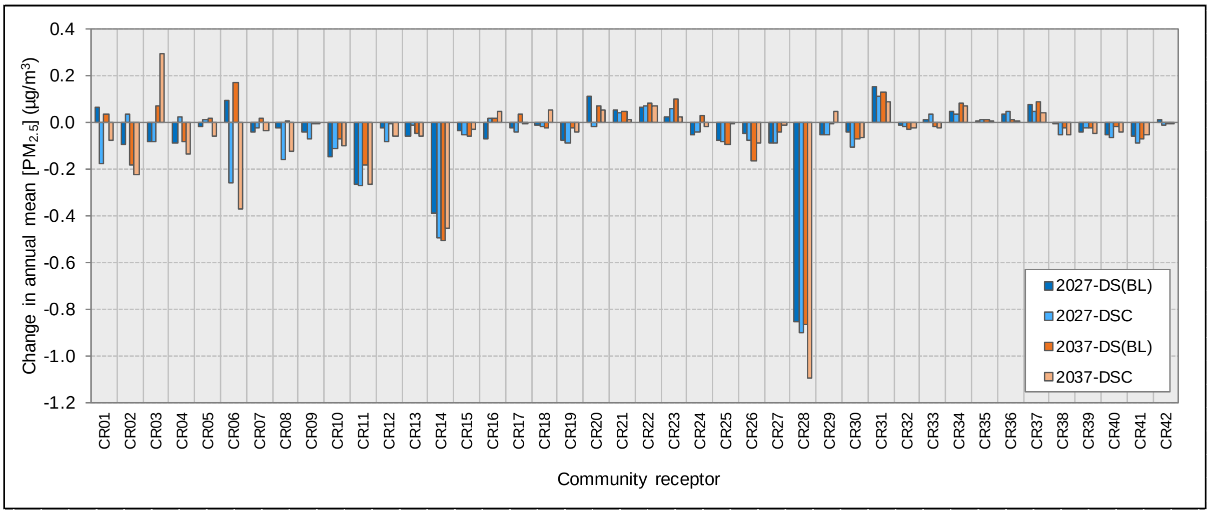


Figure 8-59 Change in annual mean $PM_{2.5}$ concentration at community receptors (with-project and cumulative scenarios, relative to 'Do minimum' scenarios)

Figure 8-60 shows that concentrations were again dominated by the background contribution. The surface road contribution was between 0.1 µg/m³ and 2.1 µg/m³. The largest contribution from tunnel ventilation outlets at any receptor was just 0.1 µg/m³.

Figure 8-60 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 8-61, including the contributions of background, surface roads, portals and ventilation outlets. The highest concentration at any receptor was 14.5 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 17 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 6.7 µg/m^3. The largest contribution from tunnel ventilation outlets in these scenarios was 0.18 µg/m^3, at Rozelle.

The change in the annual mean $PM_{2.5}$ concentration at the RWR receptors in the with-project and cumulative scenarios are ranked in Figure 8-62. There was an increase in concentration at between 39 per cent and 43 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 1.6 µg/m^3, in Kirribilli at the northern end of the Sydney Harbour Bridge. The largest predicted decrease was 2.3 µg/m^3, at North Sydney near Little Alfred Street. Where there was an increase, this was greater than 0.1 µg/m^3 at less than five per cent of receptors for all scenarios. The increases were mainly along the Warringah Freeway Upgrade, north east of the Burnt Bridge Creek Deviation ventilation outlet, along Wakehurst Parkway and particularly near the Sydney Harbour Bridge and Cammeray. The predicted increases in concentration along Wakehurst Parkway are limited to within the road corridor and do not extend out to the nearby RWRs. There were also increases at Gore Hill Freeway, Manly Road and Rozelle.

As noted in Section 6.4.3, 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 6.4.3. 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 8-63 (2037-DM) and Figure 8-64 (2037-DSC). The contour plot for the associated change in concentration in this cumulative scenario is shown in Figure 8-65.

The spatial changes in pollutant concentrations are discussed further in Section 8.4.6.

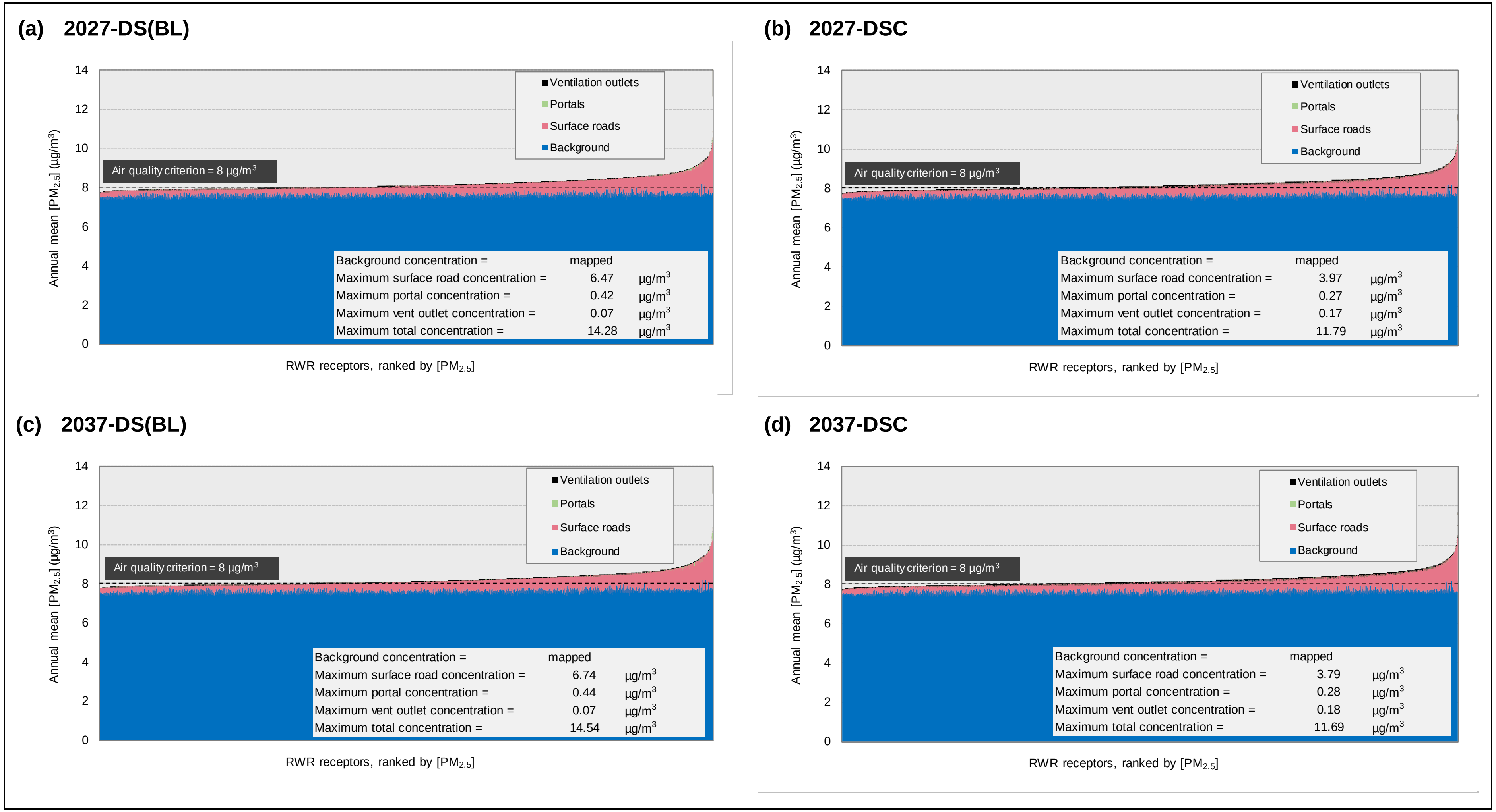
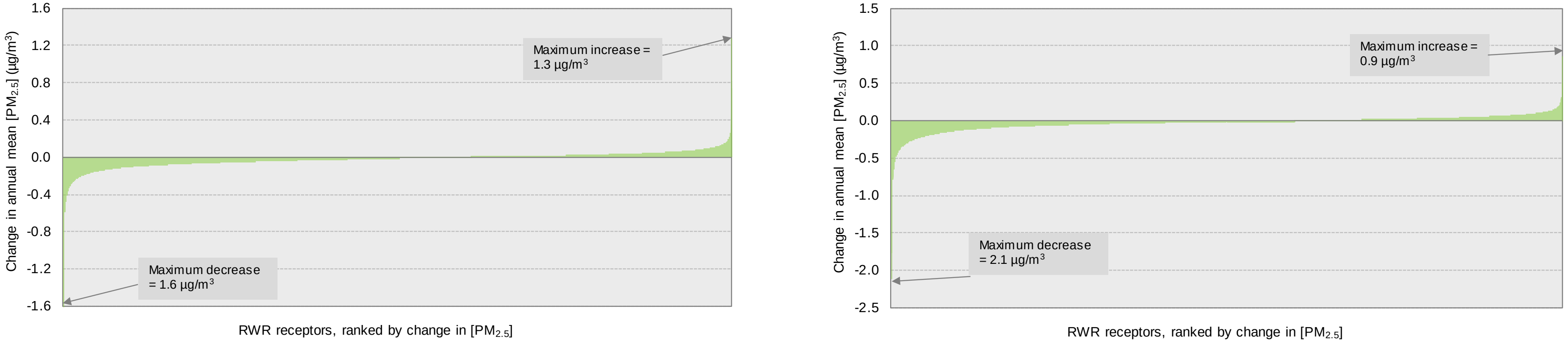


Figure 8-61 Source contributions to annual mean $PM_{2.5}$ concentration at RWR receptors (with-project and cumulative scenarios) (portals include Sydney Harbour Tunnel and Eastern Distributor only)

(a) 2027-DS(BL) **(b) 2027-DSC**



(c) 2037-DS(BL) **(d) 2037-DSC**

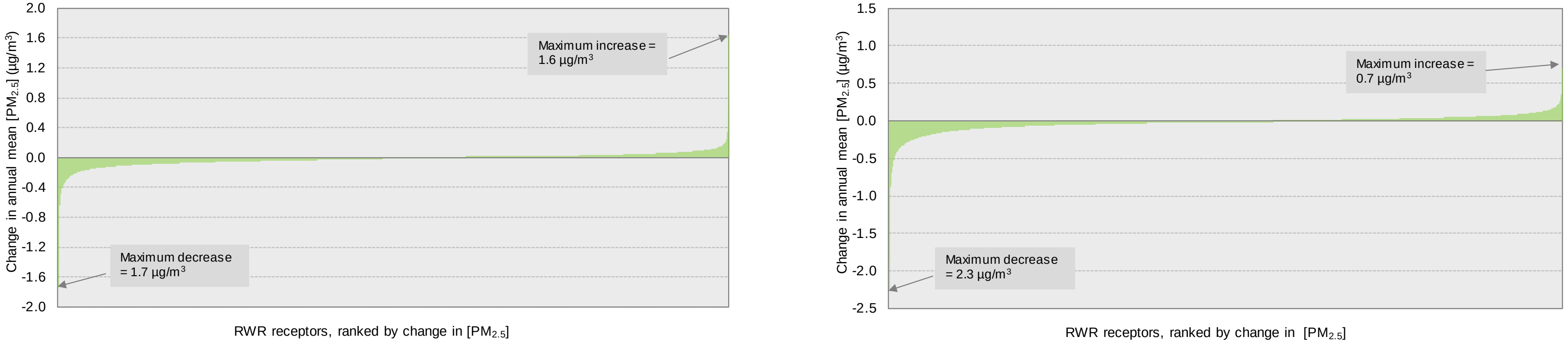


Figure 8-62 Change in annual mean $PM_{2.5}$ concentration at RWR receptors (with-project and cumulative scenarios, relative to 'Do minimum' scenarios)

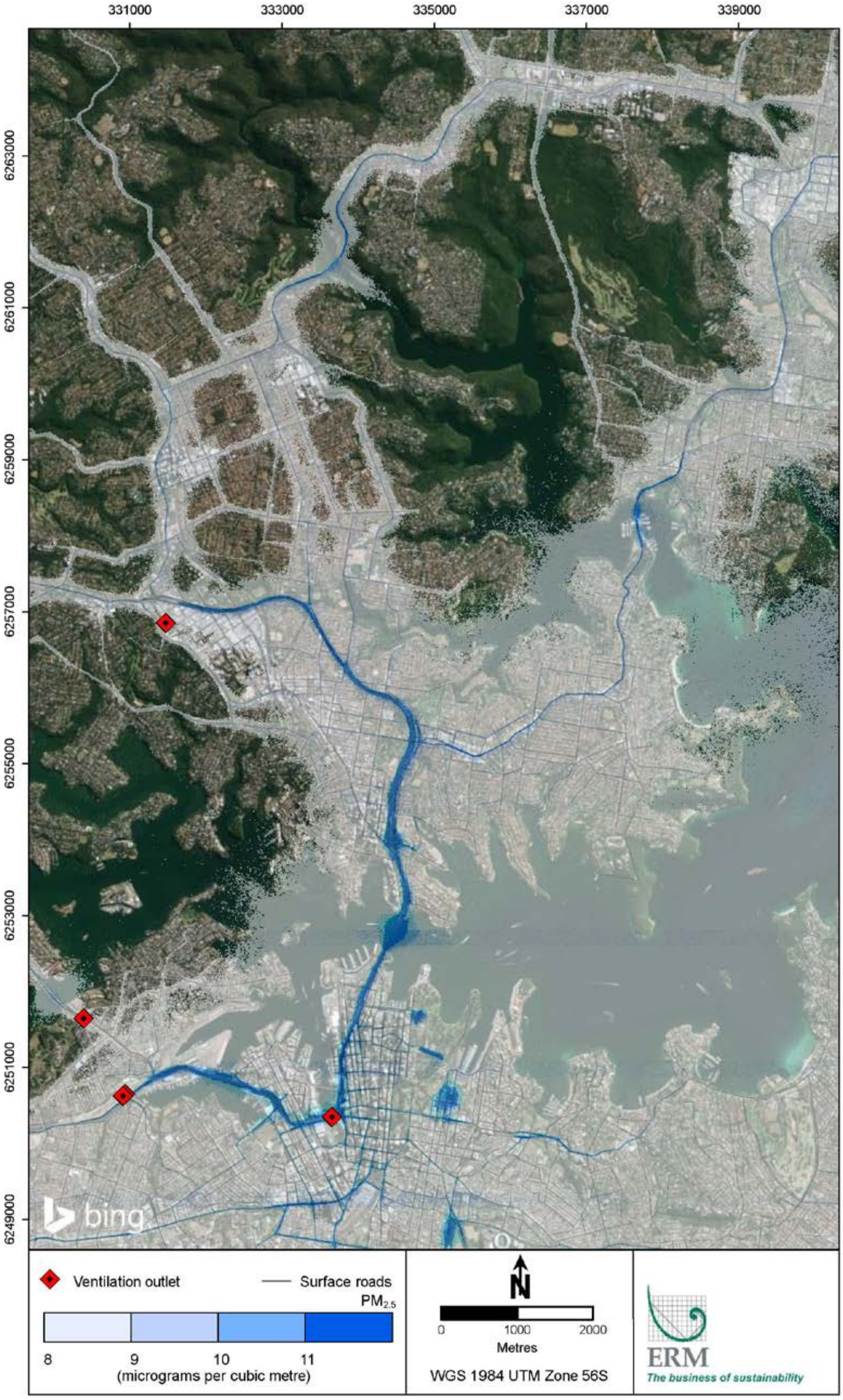


Figure 8-63 Contour plot of annual mean $PM_{2.5}$ concentration in the 2037 Do minimum scenario (2037-DM)

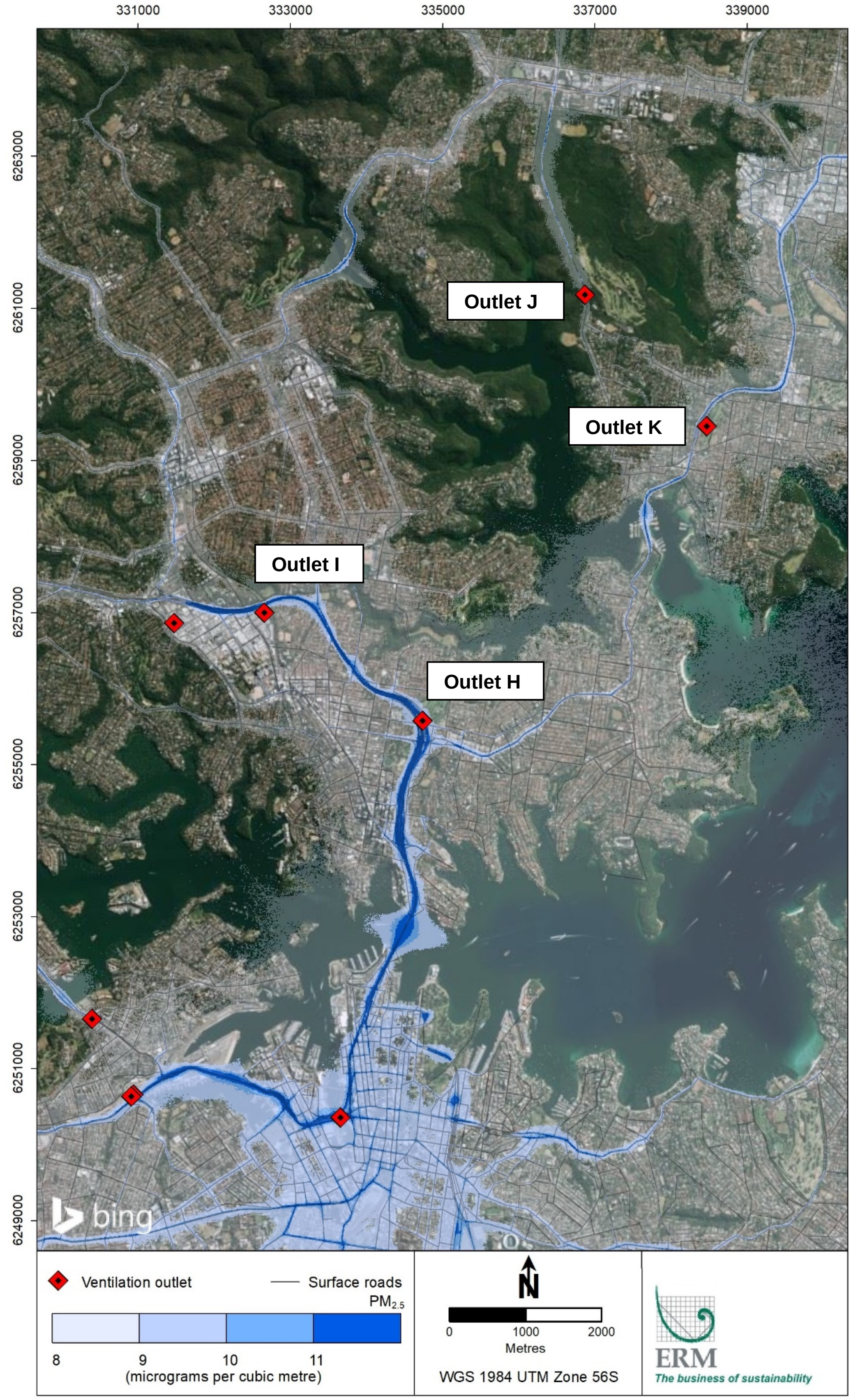


Figure 8-64 Contour plot of annual mean $PM_{2.5}$ concentration in the 2037 cumulative scenario (2037-DSC)

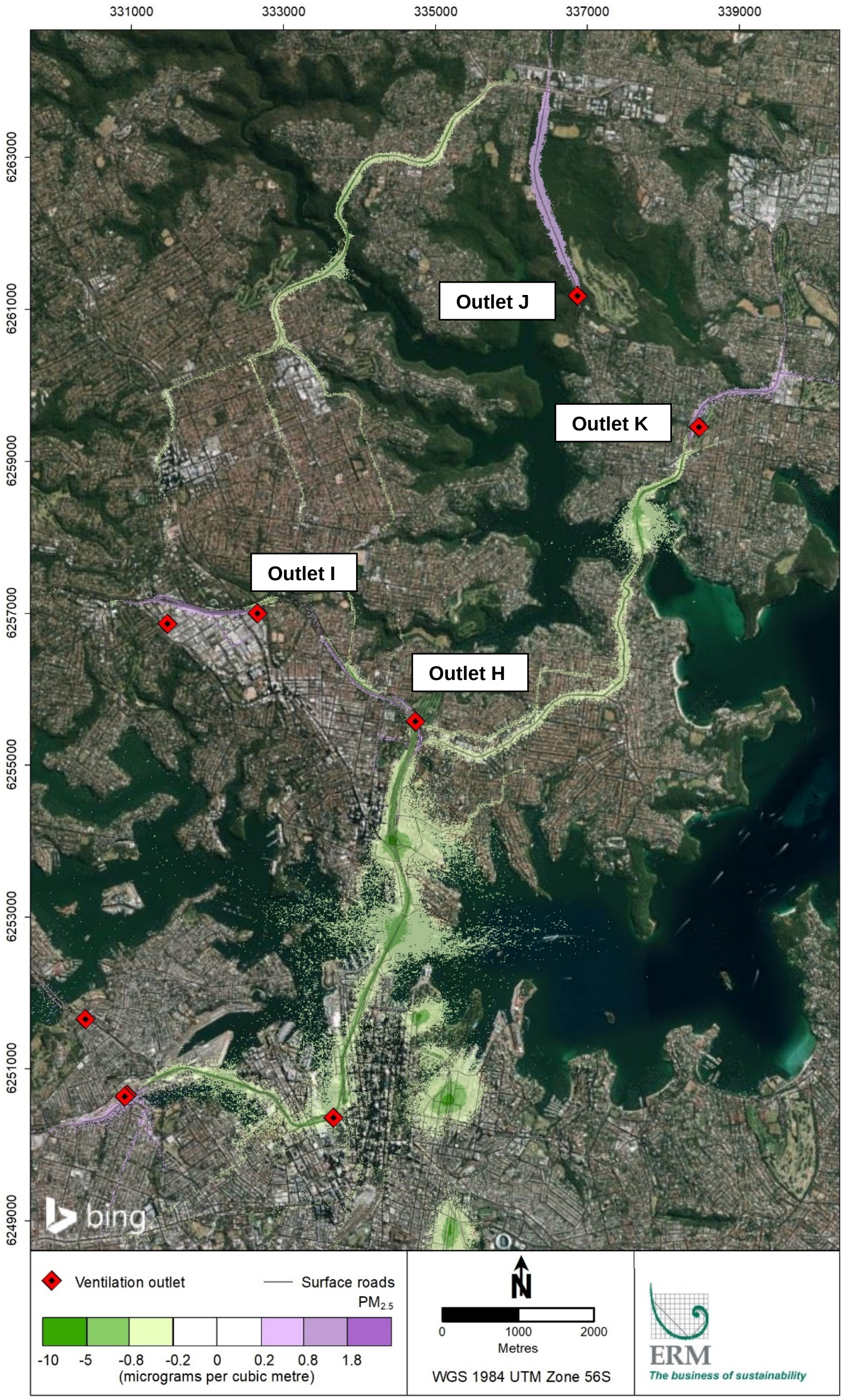


Figure 8-65 Contour plot of change in annual mean $PM_{2.5}$ concentration in the 2037 cumulative scenario (2037-DSC minus 2037-DM)

$PM_{2.5}$ (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 8-66. 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.

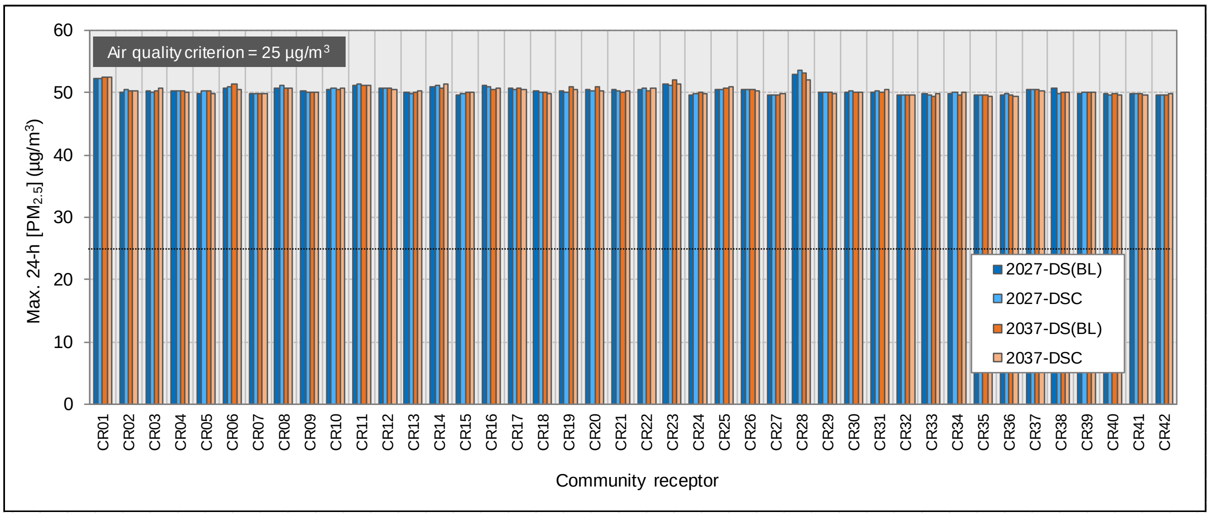


Figure 8-66 Maximum 24-hour $PM_{2.5}$ concentration at community receptors using the contemporaneous background (with-project and cumulative scenarios)

While including the bushfire affected days in the contemporaneous approach clearly illustrates that it is the background driving the exceedances, an alternative approach is also presented using the 98th percentile for the background level, as was done for the RWR receptors. These results are shown in Figure 8-51 and present a more realistic scenario with an occasional exceedance at some receptors, still due to elevated background levels. The 98th percentile background concentration in this case is 22.1 µg/m^3.

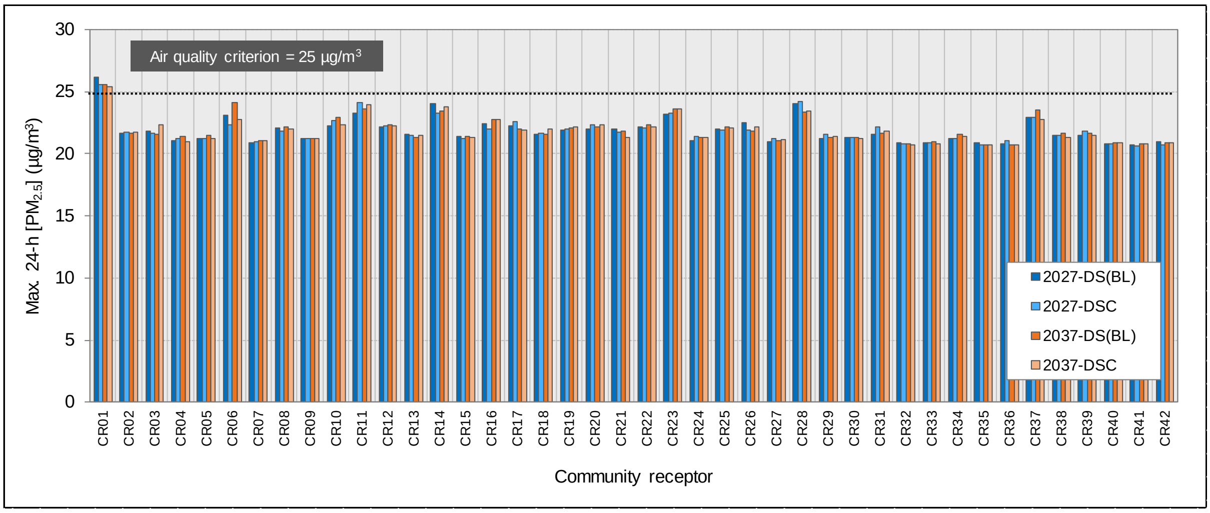


Figure 8-67 Maximum 24-hour mean $PM_{2.5}$ concentration at community receptors using the 98th percentile approach (with-project and cumulative scenarios)

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. All of the increases in concentration were less than 1 µg/m^3. The largest increase (0.54 µg/m^3 at receptor CR25 Sue's Childcare Castlevale in the 2037-DSC) scenario) equated to less than two per cent of the air quality criterion.

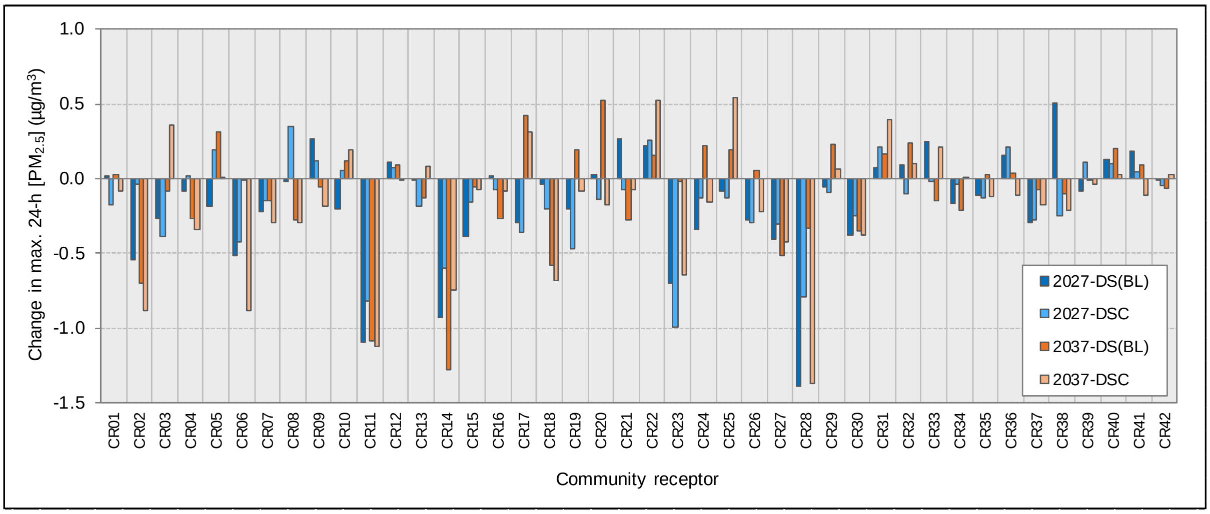
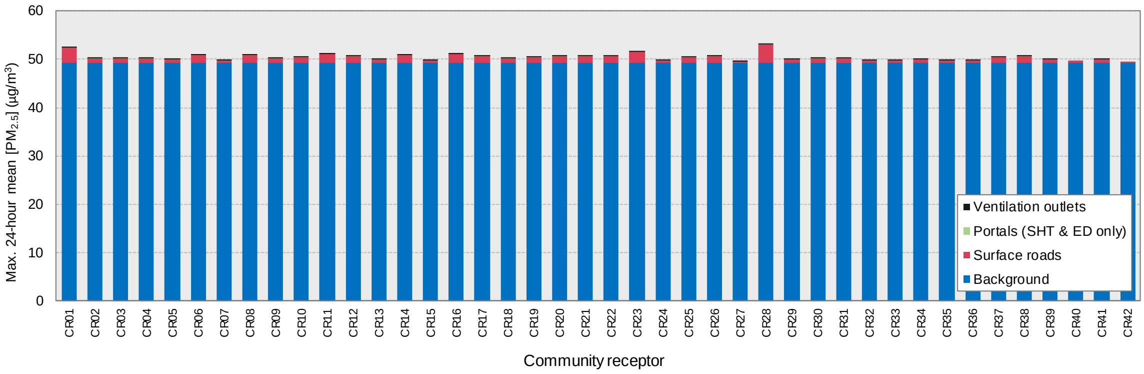


Figure 8-68 Change in maximum 24-hour $PM_{2.5}$ concentration at community receptors (with-project and cumulative scenarios, relative to Do minimum scenarios)

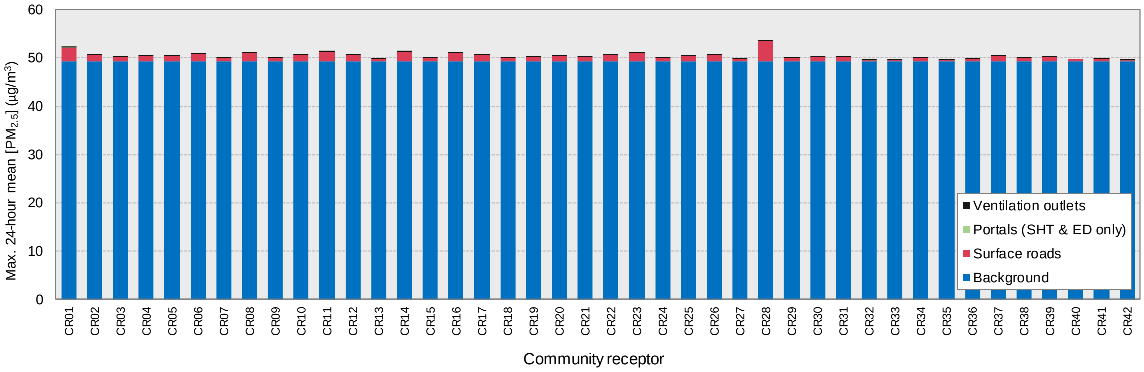
The combined non-background contributions to the maximum 24-hour $PM_{2.5}$ concentration at the community receptors were relatively small, as shown in Figure 8-69. On the days when the maximum total concentration occurred, the tunnel ventilation outlet contributions alone were small in all cases (less than 0.2 µg/m^3). At all community receptors, the maximum total 24-hour concentration occurred on one day which coincided with the highest 24-hour background concentrations in the synthetic $PM_{2.5}$ profile (49.4 µg/m^3).

As was shown above, these results are presented again in Figure 8-70 but using the 98th percentile background concentration.

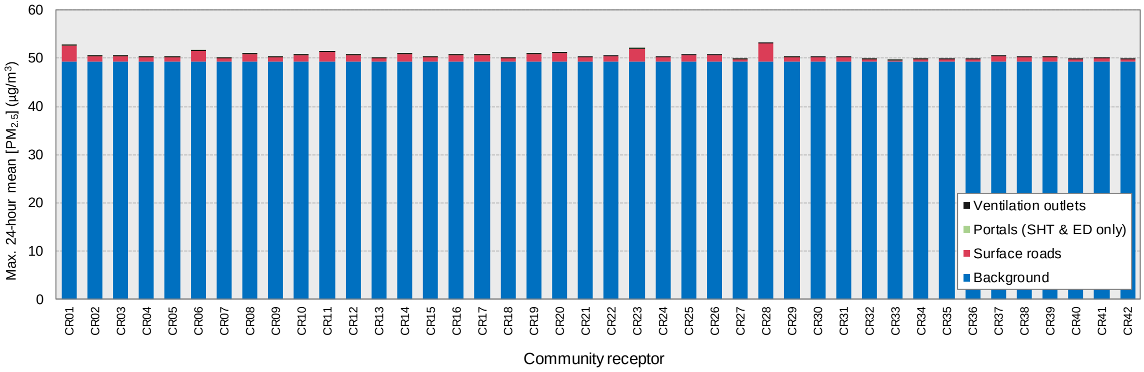
(a) 2027-DS(BL)



(b) 2027-DSC



(c) 2037-DS(BL)



(d) 2037-DSC

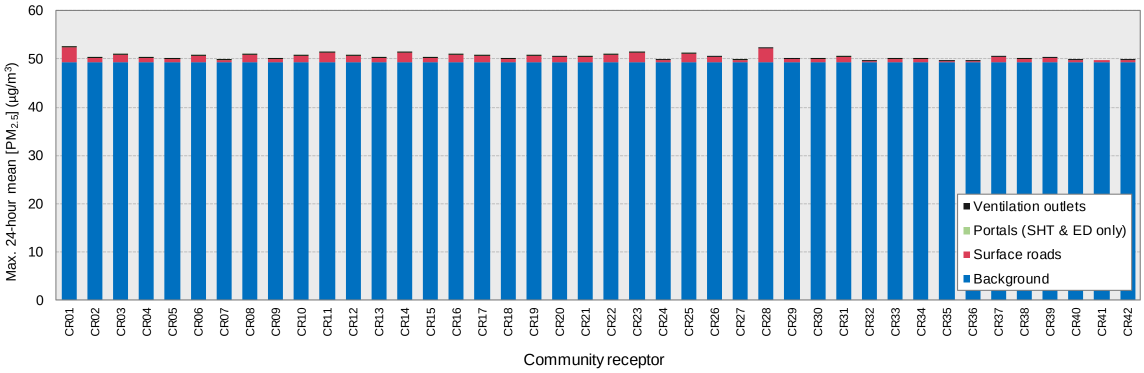


Figure 8-69 Source contributions to maximum 24-hour mean $PM_{2.5}$ concentration at community receptors using the contemporaneous background (with-project and cumulative scenarios) (portals include Sydney Harbour Tunnel and Eastern Distributor only)

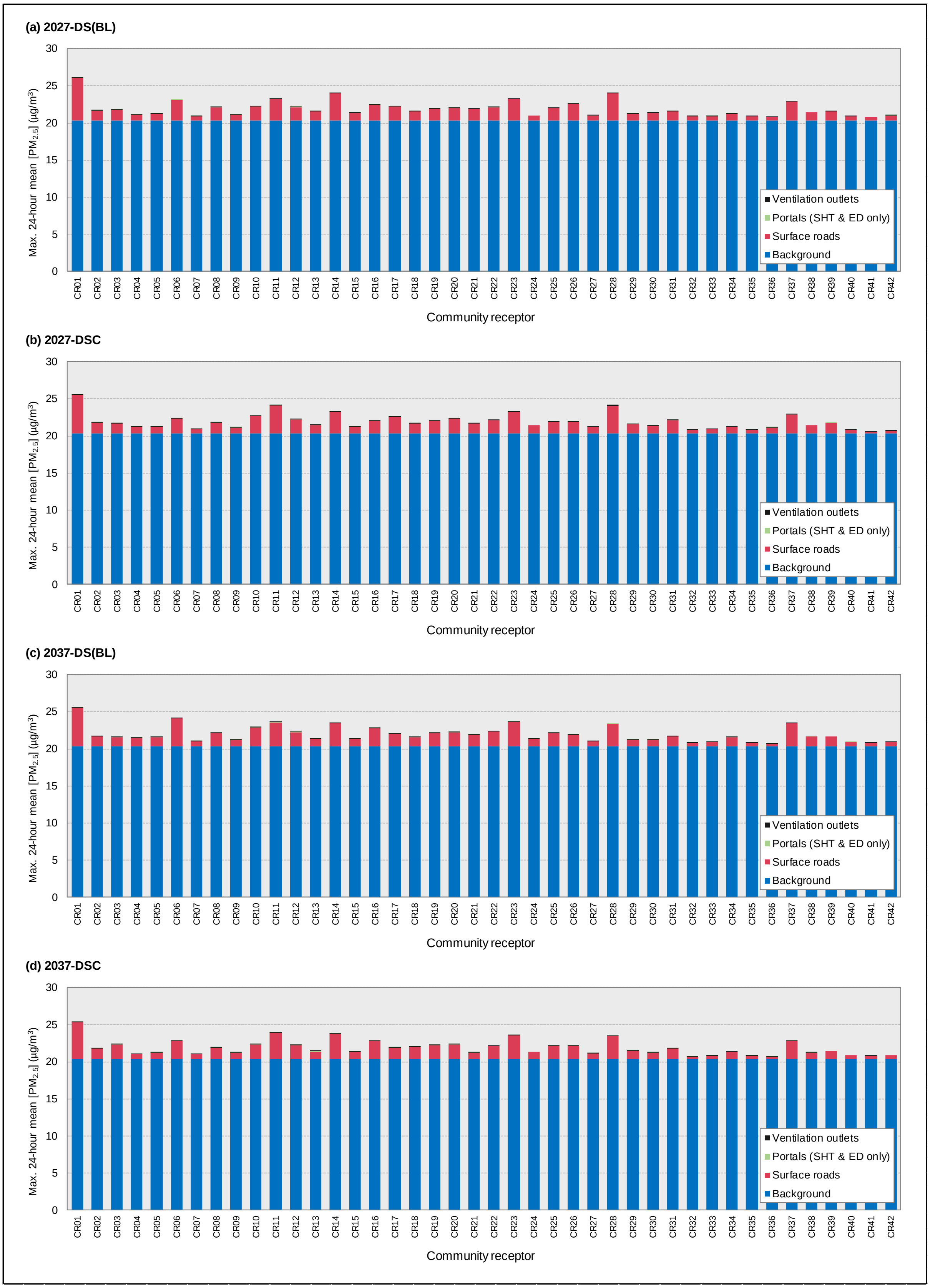


Figure 8-70 Source contributions to maximum 24-hour mean $PM_{2.5}$ concentration at community receptors using the 98th percentile background (with-project and cumulative scenarios) (portals include Sydney Harbour Tunnel and Eastern Distributor only)

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 8-71.

Given the relatively high background concentration (98th percentile of 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 7.1 per cent in the 2027-DS(BL) scenario and 5.9 per cent in the 2027-DSC scenario. The proportions were slightly higher in 2037 (9.3 per cent for 2037-DM, 7.7 per cent for 2037-DS(BL) and 6.6 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 1.1 µg/m^3, at Rozelle.

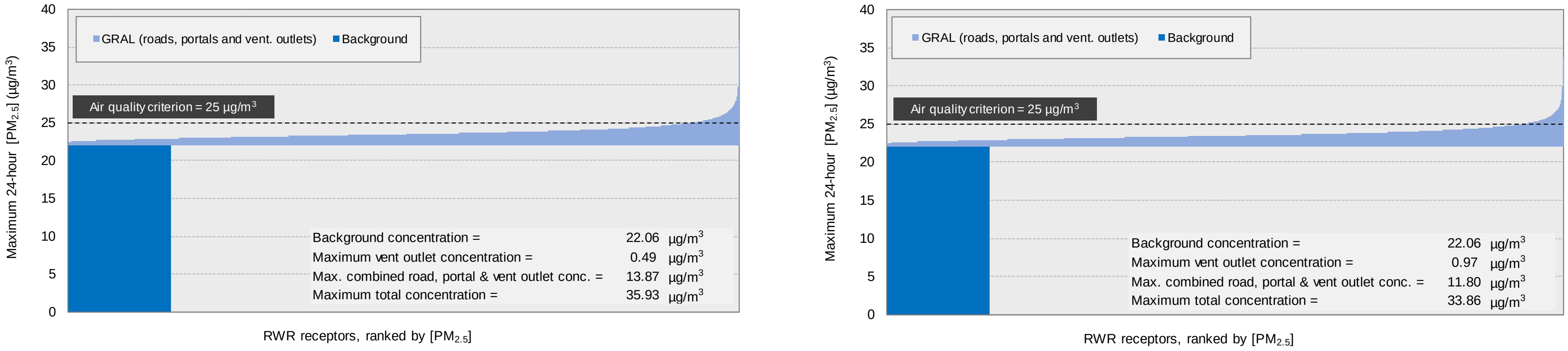
The changes in the maximum 24-hour mean $PM_{2.5}$ concentration at the RWR receptors in the with-project and cumulative scenarios are ranked in Figure 8-72. There was an increase in concentration at between 34 per cent and 41 per cent of the receptors, depending on the scenario. The largest predicted increase in concentration at any receptor as a result of the project was 4.2 µg/m^3, near Mowbray Road West in Lane Cove North and the largest predicted decrease was 6.3 µg/m^3 at North Sydney near Little Alfred Street. 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 0.1-0.4 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 8-73 and Figure 8-74 respectively. The changes with the project and in the cumulative scenarios are shown in Figure 8-75.

The spatial changes in pollutant concentrations are discussed further in Section 8.4.6.

(a) 2027-DS(BL) **(b) 2027-DSC**



(c) 2037-DS(BL) **(d) 2037-DSC**

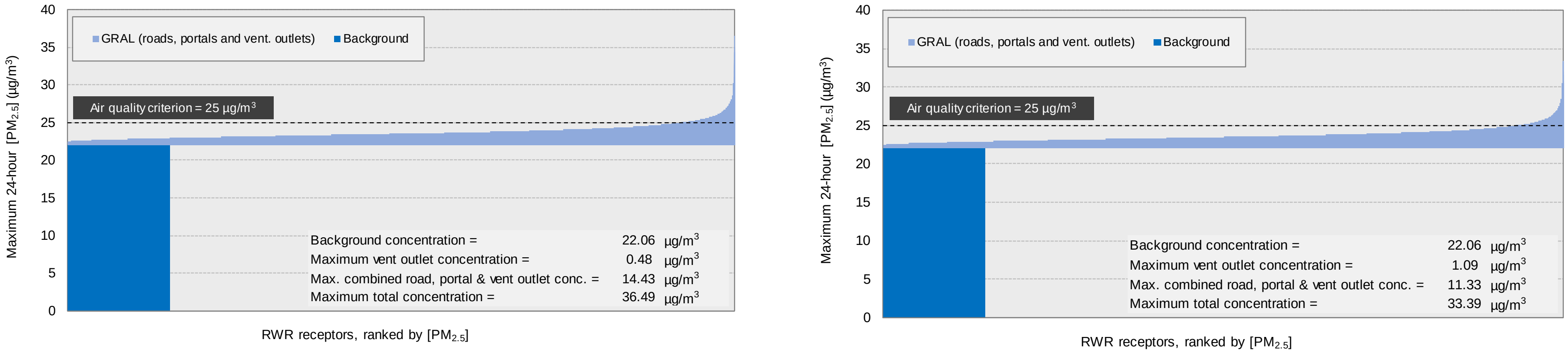


Figure 8-71 **Source contributions to maximum 24-hour mean $PM_{2.5}$ concentration at RWR receptors (with-project and cumulative scenarios) (portals include Sydney Harbour Tunnel and Eastern Distributor only)**

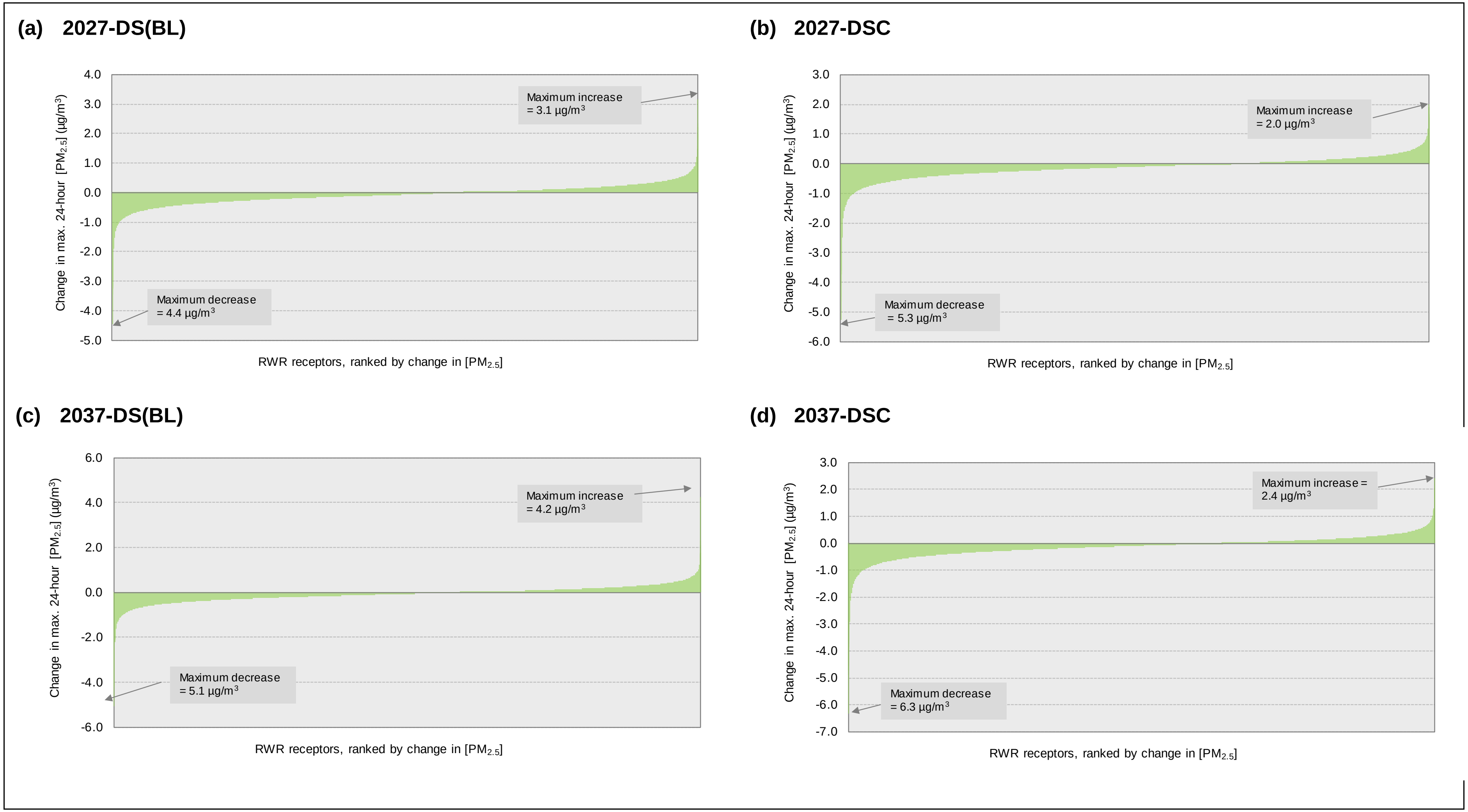


Figure 8-72 Change in maximum 24-hour mean $PM_{2.5}$ concentration at RWR receptors (with-project and cumulative scenarios, relative to 'Do minimum' scenarios)

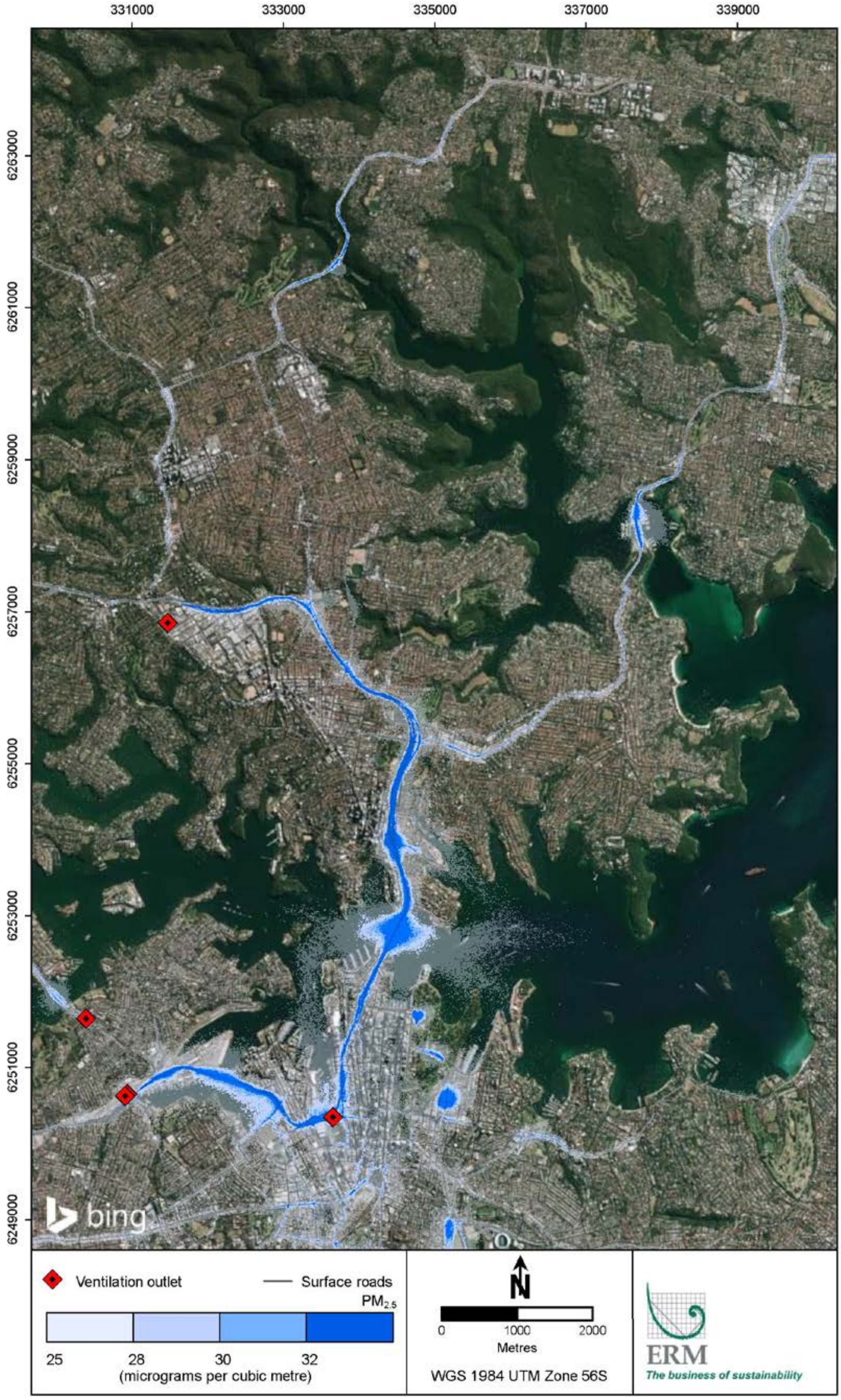


Figure 8-73 Contour plot of maximum 24-hour average $PM_{2.5}$ concentration in the 2037 Do minimum scenario (2037-DM)

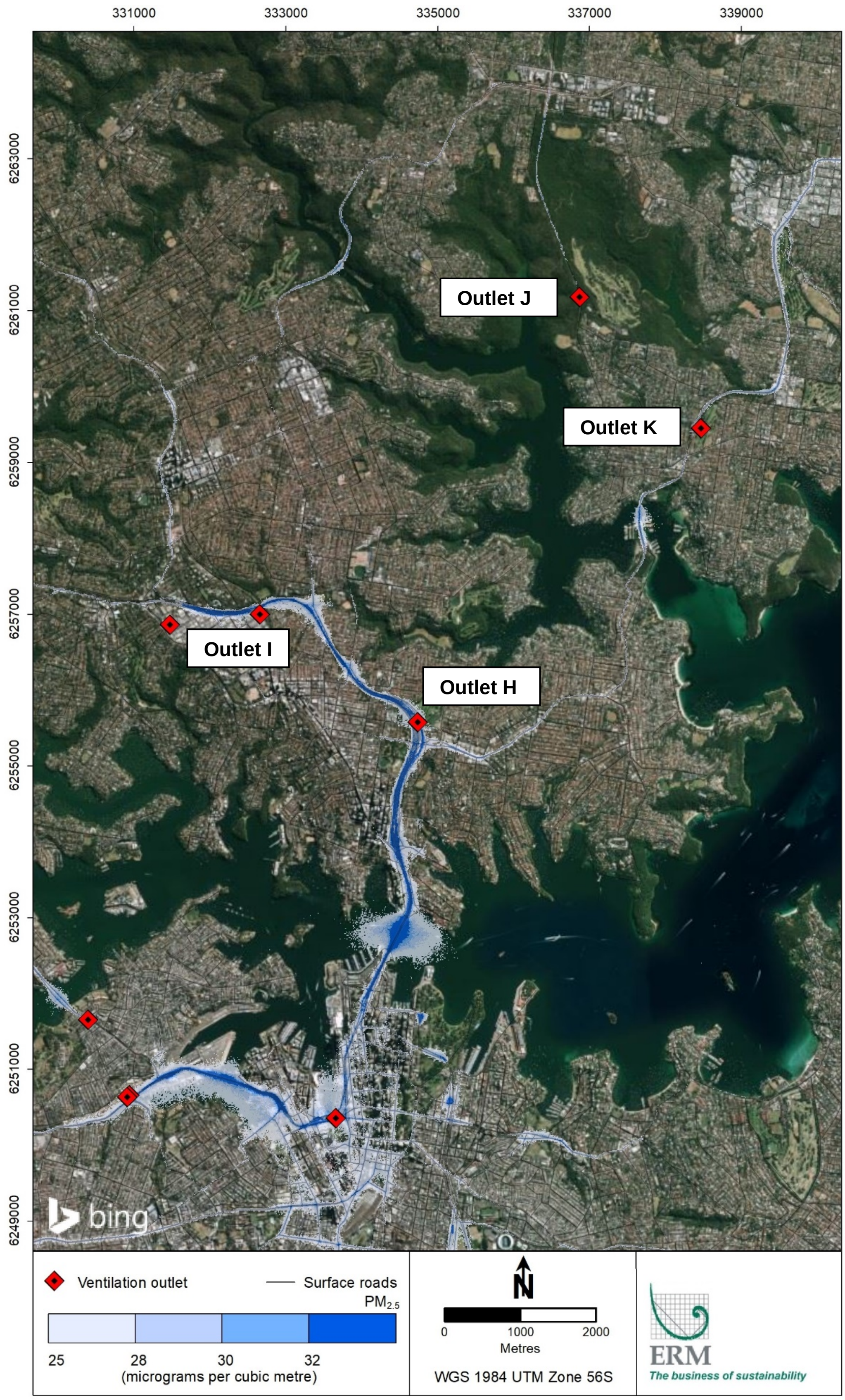


Figure 8-74 Contour plot of maximum 24-hour average $PM_{2.5}$ concentration in the 2037 cumulative scenario (2037-DSC)

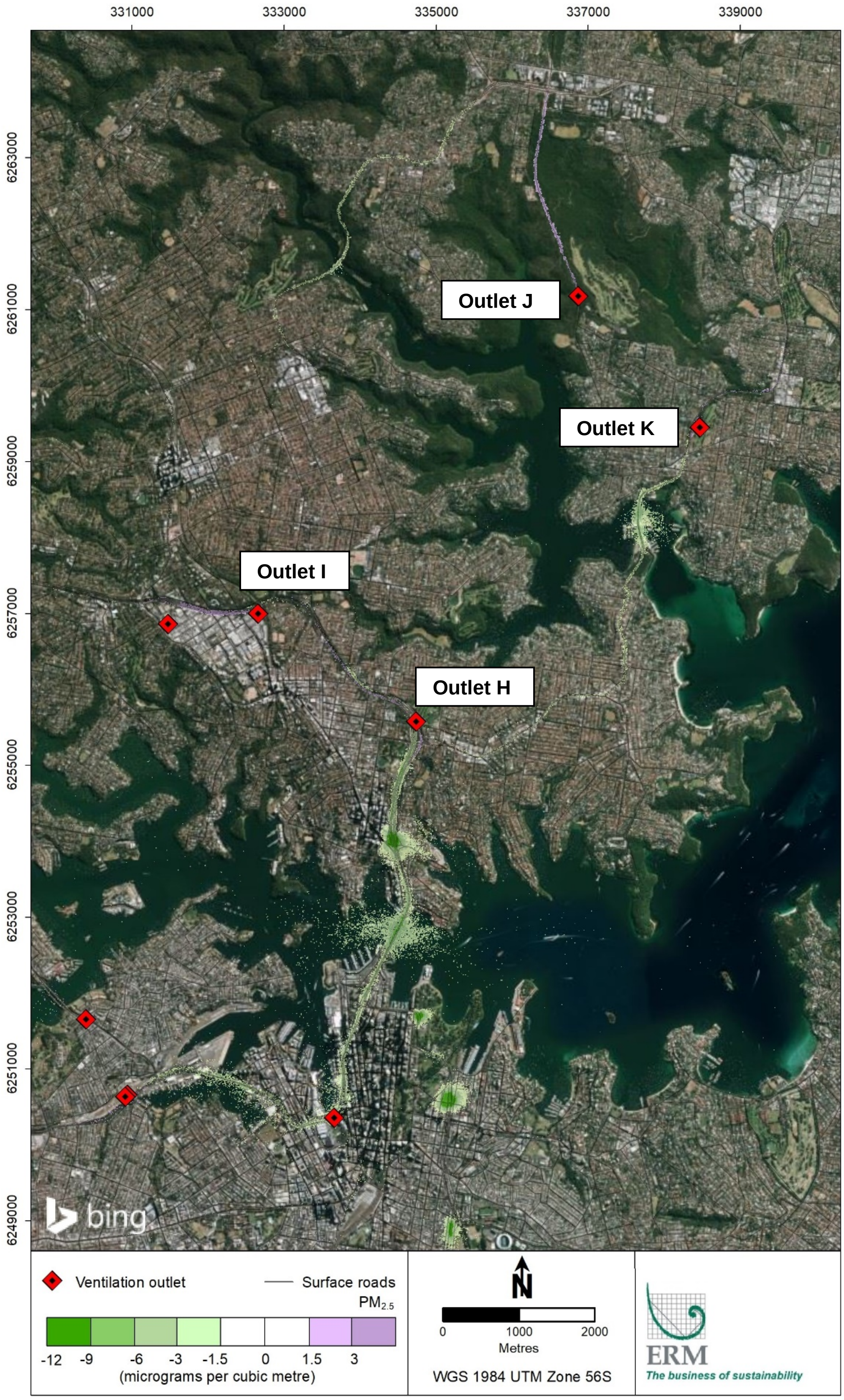


Figure 8-75 **Contour plot of change in maximum 24-hour $PM_{2.5}$ concentration in the 2037 cumulative scenario (2037-DSC minus 2037-DM)**

Air toxics

Five air toxics, benzene, PAHs (as benzo[a]pyrene (BaP)), formaldehyde, 1,3-butadiene and ethylbenzene, were considered in the assessment. These compounds were taken to be representative of the much wider range of air toxics associated with motor vehicles, and they have commonly been assessed for road projects. The changes in the maximum 1-hour benzene concentration at the community receptors as a result of the project are shown in Figure 8-76, where they are compared with the NSW impact assessment criterion from the Approved Methods. These changes took into account emissions from both surface roads and tunnel ventilation outlets. It can be seen from the figure that there where there was an increase in the concentration, this was well below the assessment criterion. The changes in the maximum 1-hour BaP, formaldehyde, 1,3-butadiene and ethylbenzene concentration are presented in Figure 8-77, Figure 8-78, Figure 8-79, and 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 3.7 µg/m^3, but the total concentration of 8.7 µg/m^3 still remains well below the criterion of 29 µg/m^3.

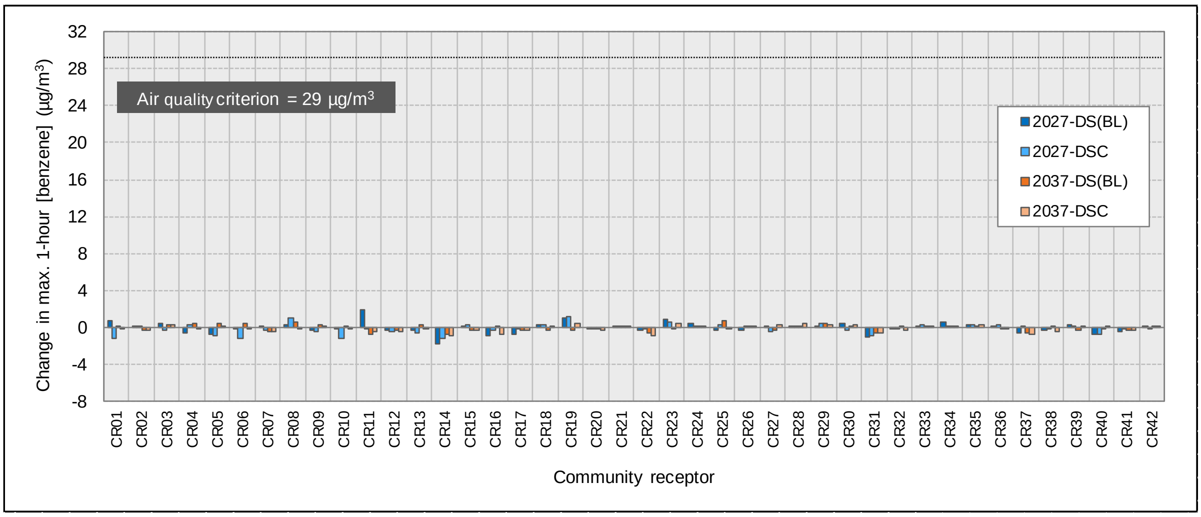


Figure 8-76 Change in maximum 1-hour mean benzene concentration at community receptors (with-project and cumulative scenarios)

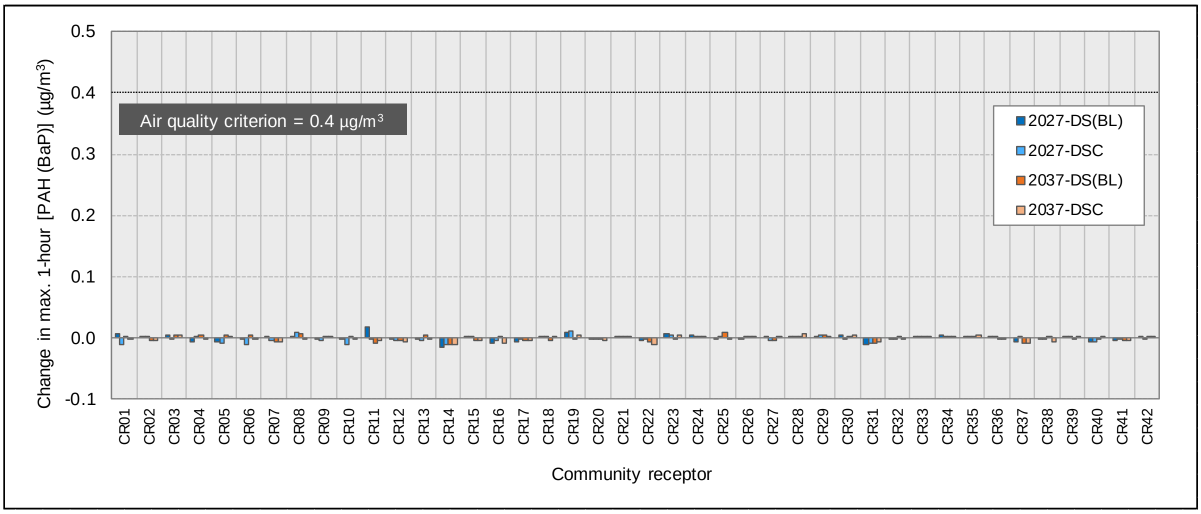


Figure 8-77 Change in maximum 1-hour mean b(a)p concentration at community receptors (with-project and cumulative scenarios)

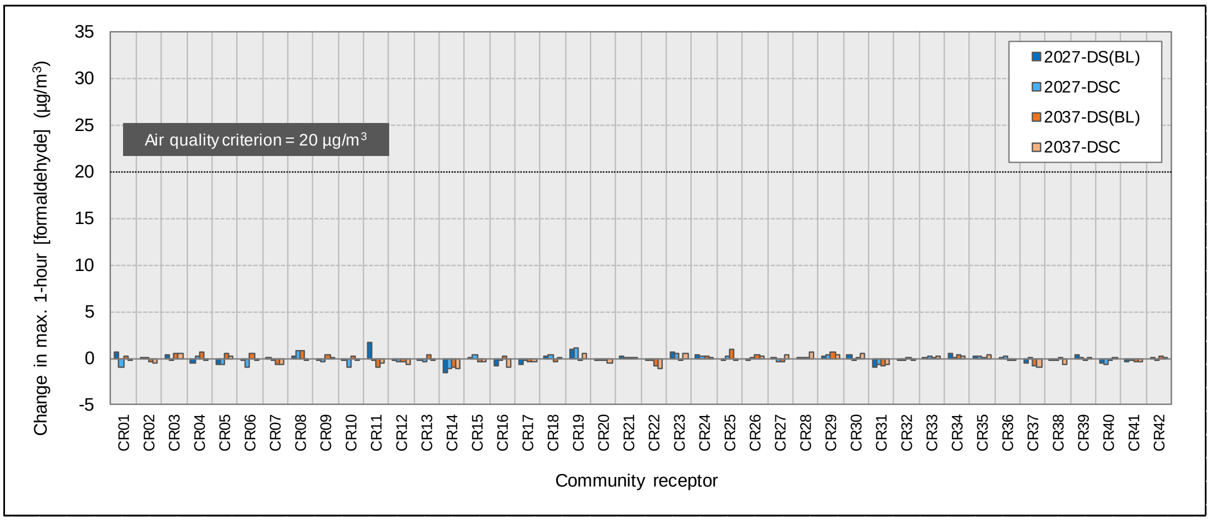


Figure 8-78 Change in maximum 1-hour mean formaldehyde concentration at community receptors (with-project and cumulative scenarios)

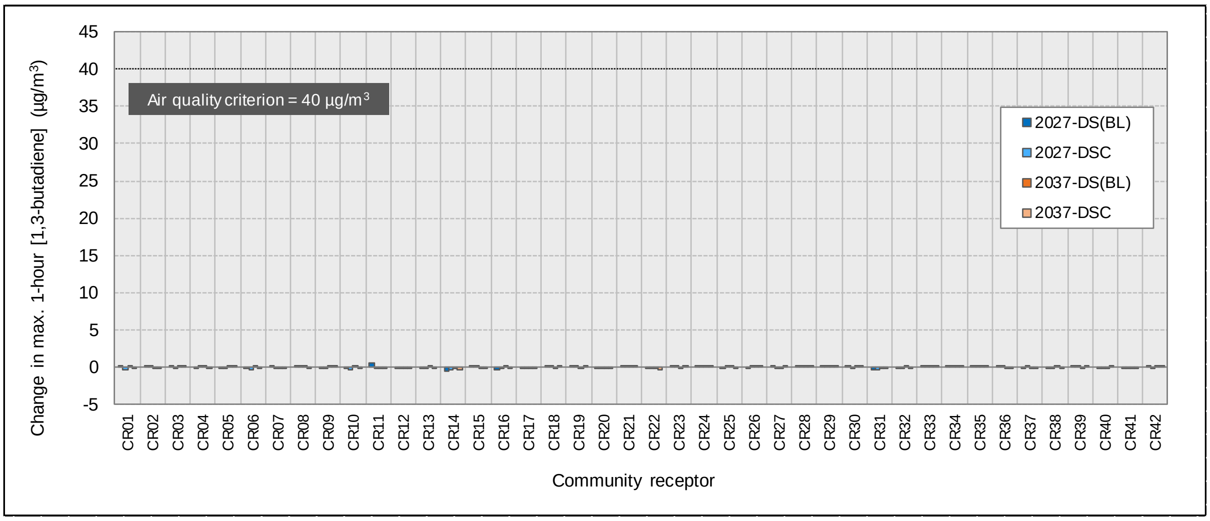


Figure 8-79 Change in maximum 1-hour mean 1,3-butadiene concentration at community receptors (with-project and cumulative scenarios)

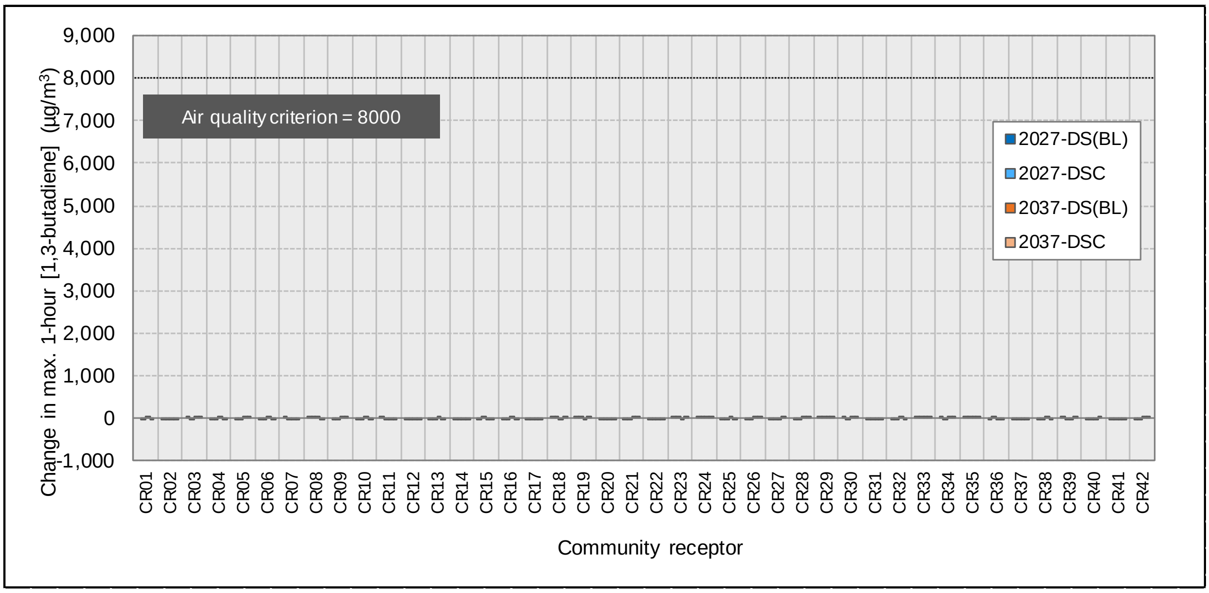


Figure 8-80 Change in maximum 1-hour mean ethylbenzene concentration at community receptors (with-project and cumulative scenarios)

8.4.6 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 risk. 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 8-19 summarises the average weekday two-way traffic on some affected roads in all scenarios, and Table 8-20 gives the changes between scenarios.

Table 8-19 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(BL)	2027-DSC	2037-DM	2037-DS(BL)	2037-DSC
ANZAC Bridge	176,292	176,425	159,435	185,214	185,696	166,552
Western Distributor, near Erskine Street	108,816	111,759	66,892	117,552	121,318	73,750
Sydney Harbour Bridge	203,452	214,061	166,494	220,514	231,959	183,838
Warringah Freeway, near North Sydney Oval	277,916	286,494	231,354	296,689	309,246	251,501
Gore Hill Freeway, near Artarmon Reserve	138,315	134,156	138,111	148,859	145,875	154,880
Eastern Distributor tunnel (northbound)	45,623	45,817	33,788	50,585	50,640	38,744
Military Road, near Spofforth Street	66,391	48,914	47,814	70,002	52,254	50,561
Manly Road, near Avona Crescent	71,545	41,660	43,413	76,851	49,247	46,937
Wakehurst Parkway, near Yarraman Avenue	20,989	48,325	50,567	23,692	53,611	56,635
Warringah Road, near Bangalla Place	82,949	62,024	61,507	87,038	66,566	65,764

Table 8-20 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	133	0.1%	-16,857	-10%	482	0.3%	-16,662	-10%
Western Distributor, near Erskine Street	2,943	2.7%	-41,924	-39%	3,766	3.2%	-43,802	-37%
Sydney Harbour Bridge	10,609	5.2%	-36,958	-18%	11,445	5.2%	-36,676	-17%
Warringah Freeway, near North Sydney Oval	8,578	3.1%	-46,562	-17%	12,557	4.2%	-45,188	-15%
Gore Hill Freeway, near Artarmon Reserve	-4,159	-3.0%	-204	-0.1%	-2,968	-2.0%	6,021	4.0%
Eastern Distributor tunnel (northbound)	194	0.4%	-11,835	-26%	55	0.1%	-11,841	-23%
Military Road, near Spofforth Street	-17,477	-26%	-18,577	-28%	-17,748	-25%	-19,441	-28%
Manly Road, near Avona Crescent	-29,885	-42%	-28,132	-39%	-27,604	-36%	-29,914	-39%
Wakehurst Parkway, near Yarraman Avenue	27,336	130%	29,578	141%	29,919	126%	32,943	139%
Warringah Road, near Bangalla Place	-20,925	-25%	-21,442	-26%	-20,472	-24%	-21,274	-24%

The contour plot for the change in annual mean $PM_{2.5}$ in the 2027-DS(BL) scenario (relative to 2027-DM) is shown in Figure I-43 of Annexure I. With the Beaches Link project there were noticeable decreases in $PM_{2.5}$ concentrations along Military Road, Spit Road, Manly Road and Warringah Road. Table 8-29 shows that there were reductions in traffic of between 23 per cent and 38 per cent on these roads. There was also a marked reduction in concentration in the vicinity of the exit portal of the northbound Eastern Distributor tunnel and, to a lesser extent, the portals of the Sydney Harbour Tunnel. There were increases in $PM_{2.5}$ concentration along Sydney Harbour Bridge and the Wakehurst Parkway between Warringah Road and Kirkwood Street. In the case of the latter there was a substantial increase in traffic (around 140 per cent) associated with Beaches Link. However, a large section of Wakehurst Parkway that is affected crosses bushland between Kirkwood Street and Ararat Reserve, where there are no sensitive receptors close to the road. There were broadly similar changes in the 2037-DS(BL) scenario (Figure I-48). As discussed in previous sections, the predicted increases in concentration along Wakehurst Parkway are limited to within the road corridor and do not extend out to the nearby RWRs

For the cumulative scenarios (2027-DSC and 2037-DSC) there were some additional changes as a result of the Western Harbour Tunnel project (refer to Figures I-45 and I-50 of Annexure I). These included reductions in concentration along the Western Distributor, Sydney Harbour Bridge and Warringah Freeway. Again, the reductions in traffic on some of these roads are given in Table 8-20.

It is also worth noting that at some locations the changes in concentration were made greater due to the 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 in Figure 8-81 to Figure 8-84, and those for maximum 24-hour $PM_{2.5}$ are presented in Figure 8-85 to Figure 8-88. 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 average $PM_{2.5}$ plots that there was generally 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.

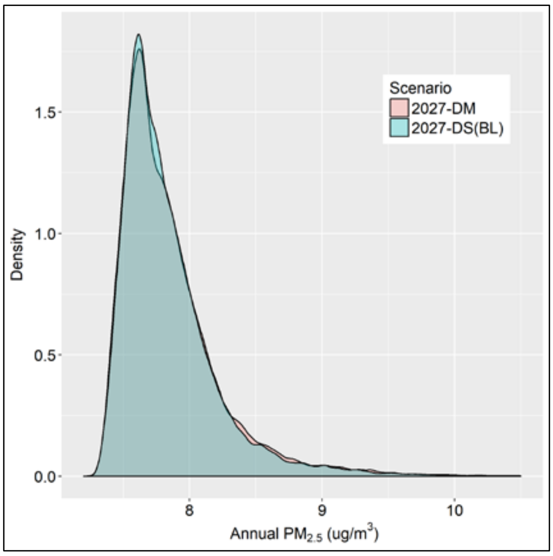


Figure 8-81 Density plot for annual mean $PM_{2.5}$ (2027-DM and 2027-DS(BL))

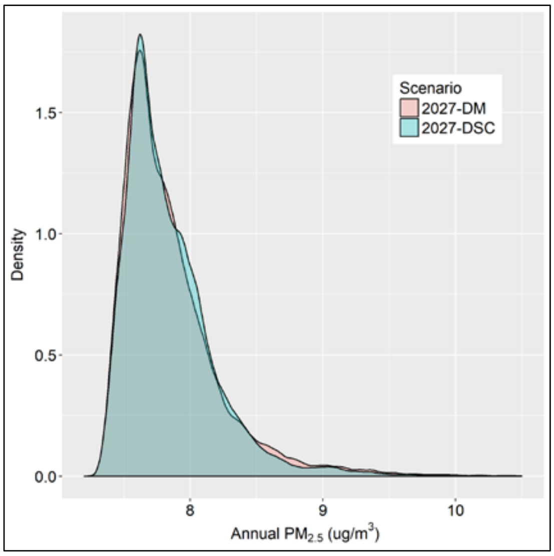


Figure 8-82 Density plot for annual mean $PM_{2.5}$ (2027-DM and 2027-DSC)

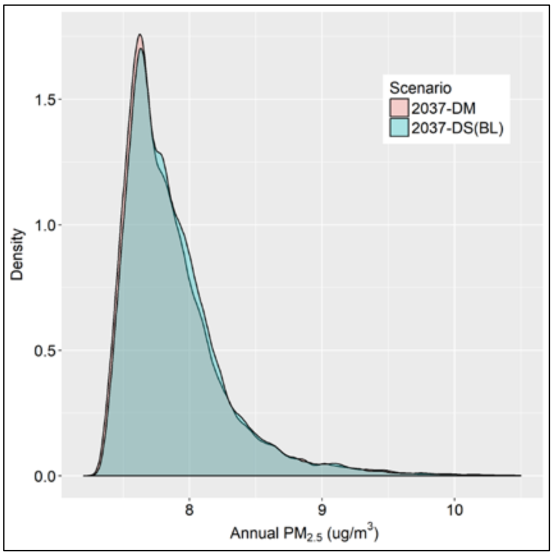


Figure 8-83 Density plot for annual mean $PM_{2.5}$ (2037-DM and 2037-DS(BL))

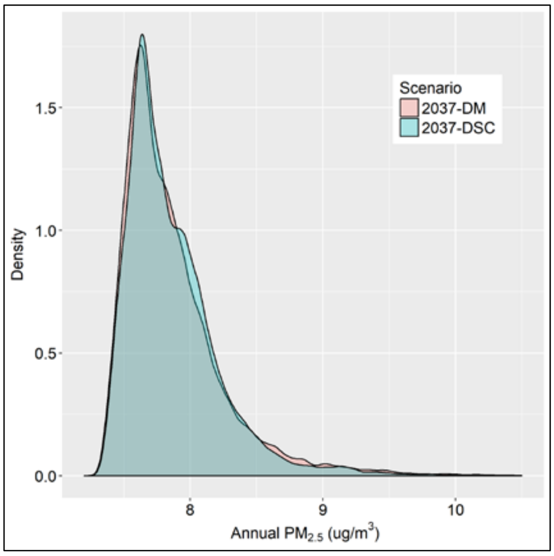


Figure 8-84 Density plot for annual mean $PM_{2.5}$ (2037-DM and 2037-DSC)

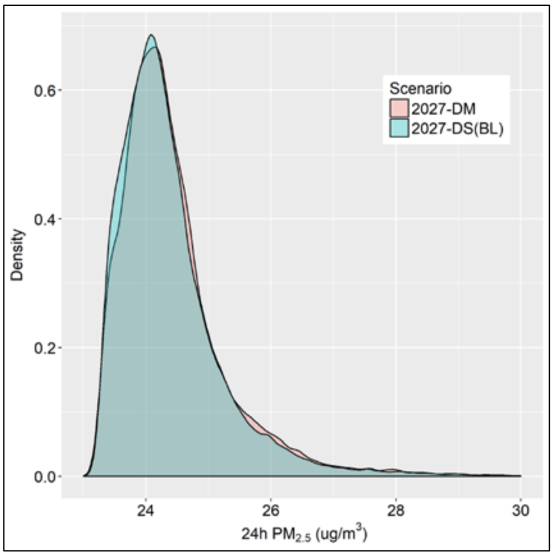


Figure 8-85 Density plot for maximum 24-hour $PM_{2.5}$ (2027-DM and 2027-DS(BL))

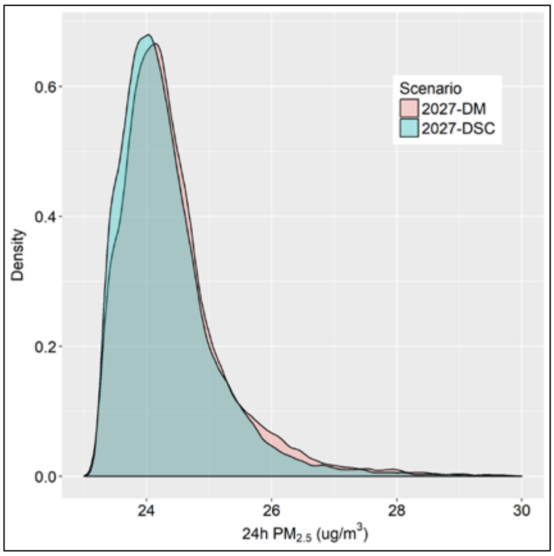


Figure 8-86 Density plot for for maximum 24-hour $PM_{2.5}$ (2027-DM and 2027-DSC)

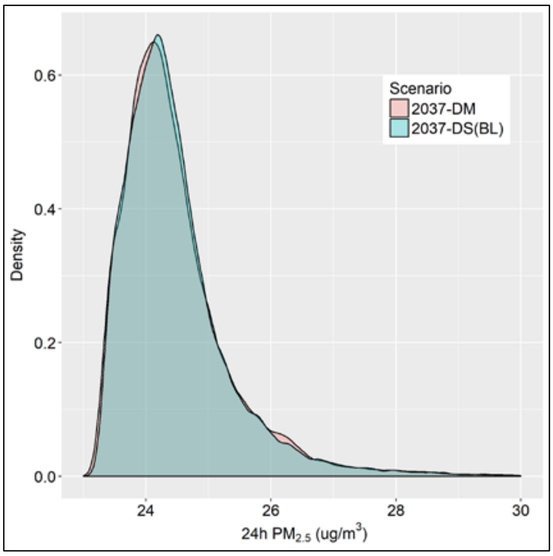


Figure 8-87 Density plot for for maximum 24-hour $PM_{2.5}$ (2037-DM and 2037-DS(BL))

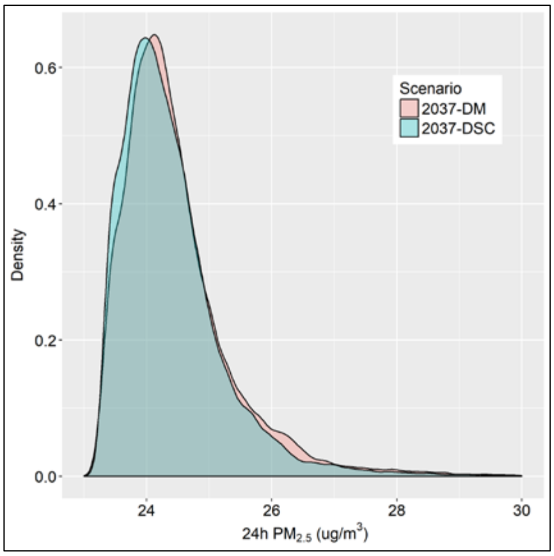


Figure 8-88 Density plot for for maximum 24-hour $PM_{2.5}$ (2037-DM and 2037-DSC)

8.4.7 Additional exceedances for annual average $PM_{2.5}$

This section presents a brief analysis of the occurrence of additional exceedances of annual average $PM_{2.5}$, due to the project. This is determined by comparing BL Do-Something (DS(BL)) or Do-Something-Cumulative (DSC) scenario results for 2027 and 2037 with the Do-Minimum (DM) scenario results for the same years. In other words, there are many locations where there are estimated exceedances of the annual $PM_{2.5}$ criterion, which are unrelated to the project and largely due to the elevated background levels already present in an urban atmosphere. These receptors will show an exceedance in the DM-2027 and DM-2037 scenarios, that is, without the project. This exercise identifies those receptors which were not predicted to exceed the criterion in the DM scenarios, but then do as a result of the project.

Table 8-21 presents the number of additional annual average $PM_{2.5}$ exceedances for each of the project scenarios.

Table 8-21 **Number of additional annual average $PM_{2.5}$ exceedances for each of the project scenarios**

Scenario	Number of additional exceedances
2027-DS(BL)	188
2027-DSC	204
2037-DS(BL)	167
2037-DSC	201

For each of the additional exceedances for each of the project scenarios the maximum concentration by total concentration and by ventilation outlet contribution has been calculated. Table 8-22 to Table 8-25 presents the annual average $PM_{2.5}$ concentrations for each project scenario for RWR receptors which the maximum total concentration and the maximum ventilation outlet contribution.

Table 8-22 **Annual average $PM_{2.5}$ concentrations for 2027-DS(BL) for maximum total concentration and maximum ventilation outlet contribution**

Maximum by total or ventilation outlet contribution	Receptor ID	2027-DM Total Concentration (µg/m^3)	2027-DS(BL) Total Concentration (µg/m^3)	2027-DS(BL) Ventilation Outlet Contribution (µg/m^3)
By total	RWR-08425	7.94	8.20	0.02
By ventilation outlet	RWR-29079	7.97	8.05	0.06

For RWR receptor RWR-08425, the ventilation outlet contribution is only 0.2 per cent of the total concentration. For RWR receptor RWR-29079, the ventilation outlet contribution is only 0.7 per cent of the total concentration.

Table 8-23 **Annual average $PM_{2.5}$ concentrations for 2027-DSC for maximum total concentration and maximum ventilation outlet contribution**

Maximum by total or ventilation outlet contribution	Receptor ID	2027-DM Total Concentration (µg/m^3)	2027-DSC Total Concentration (µg/m^3)	2027-DSC Ventilation Outlet Contribution (µg/m^3)
By total	RWR-28733	7.99	8.17	0.09
By ventilation outlet	RWR-27311	7.99	8.12	0.10

For RWR receptor RWR-28733, the ventilation outlet contribution is only 1.1 per cent of the total concentration. For RWR receptor RWR-27311, the ventilation outlet contribution is only 1.3 per cent of the total concentration.

Table 8-24 **Annual average $PM_{2.5}$ concentrations for 2037-DS(BL) for maximum total concentration and maximum ventilation outlet contribution**

Maximum by total or ventilation outlet contribution	Receptor ID	2037-DM Total Concentration (µg/m^3)	2037-DS(BL) Total Concentration (µg/m^3)	2037-DS(BL) Ventilation Outlet Contribution (µg/m^3)
By total	RWR-11759	7.98	8.29	0.02
By ventilation outlet	RWR-28166	8.00	8.05	0.06

For RWR receptor RWR-11759, the ventilation outlet contribution is only 0.2 per cent of the total concentration. For RWR receptor RWR-28166, the ventilation outlet contribution is only 0.7 per cent of the total concentration.

Table 8-25 Annual average $PM_{2.5}$ concentrations for 2037-DSC for maximum total concentration and maximum ventilation outlet contribution

Maximum by total or ventilation outlet contribution	Receptor ID	2037-DM Total Concentration (µg/m³)	2037-DSC Total Concentration (µg/m³)	2037-DSC Ventilation Outlet Contribution (µg/m³)
By total	RWR-11759	7.98	8.24	0.03
By ventilation outlet	RWR-27220	7.99	8.15	0.12

For RWR receptor RWR-11759, the ventilation outlet contribution is only 0.4 per cent of the total concentration. For RWR receptor RWR-27220, the ventilation outlet contribution is only 1.5 per cent of the total concentration.

In summary, the maximum ventilation outlet contribution as a percentage of the total concentration is 1.5 per cent. The maximum change for the any of the RWR receptors with an additional exceedance is only 0.31 µg/m³.

8.4.8 Results for regulatory worst case scenario (ground-level concentrations)

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-2037-DSC only) are given in Table 8-26. 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 8-26 Results of regulatory worst case assessment (RWR receptors) – CO and PM

		Maximum ventilation outlet contribution at any receptor					
Pollutant and Period	Units	Regulatory worst case scenario (RWC-2037-DSC)		Expected traffic scenarios (all receptors)			
		All receptors	Sensitive receptors	2027-DS(BL)	2027-DSC	2037-DS(BL)	2037-DSC
CO (one hour)	(mg/m³)	0.65	0.65	0.03	0.06	0.03	0.06
PM_{10} (annual)	(µg/m³)	0.90	0.90	0.11	0.25	0.12	0.29
PM_{10} (24-h)	(µg/m³)	7.85	7.85	0.68	1.45	0.74	1.80
$PM_{2.5}$ (annual)(a)	(µg/m³)	0.90	0.90	0.07	0.17	0.07	0.18
$PM_{2.5}$ (24-h)(a)	(µg/m³)	7.85	7.85	0.49	0.97	0.48	1.09

(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 (0.65 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 predicted maximum contribution of the ventilation outlets is generally small. For the annual mean and maximum 24-hour metrics the ventilation outlet contributions were four per cent and 16 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 31 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 the regulatory worst case scenario (RWC-2037-DSC) 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, 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 8-27 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) 2037-DSC)
Regulatory worst case scenarios	
All RWR receptors	
NO_X (annual mean)	16.5
NO_2 (annual mean)	5.2
All sensitive RWR receptors	
NO_X (annual mean)	16.5
NO_2 (annual mean)	5.2
Expected traffic scenarios	
All RWR receptors	
NO_X (annual mean)	1.8
NO_2 (annual mean)	0.6

Maximum 1-hour

The results of the more detailed assessment for NO_2 contributions from the project ventilation outlets from the regulatory worst case scenario (RWC-2037-DSC) are shown, by ventilation outlet, in Figure 8-89 to Figure 8-92. The results are also summarised in Table 8-28.

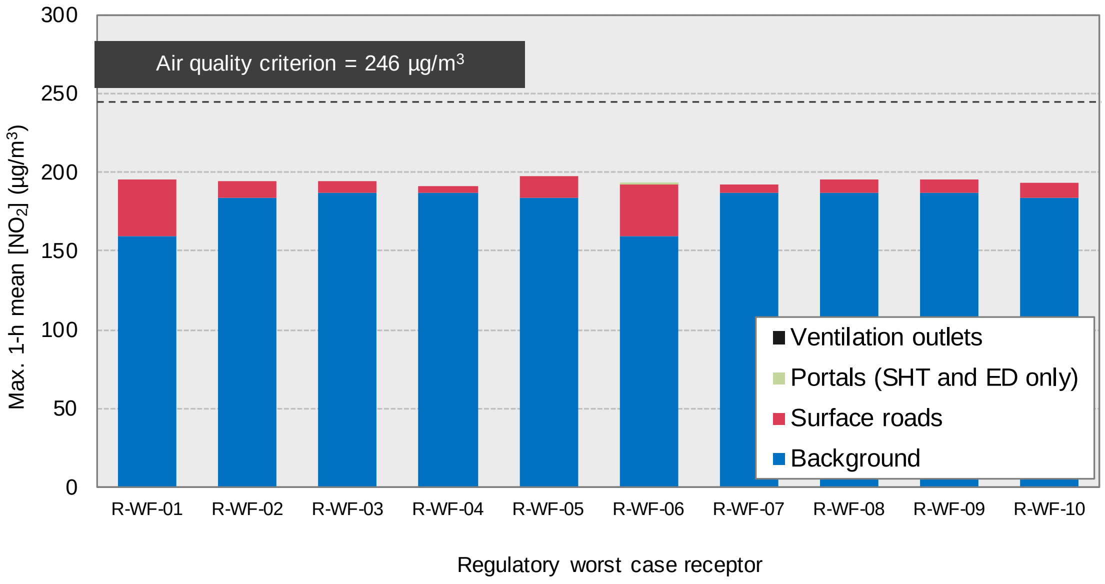
In each figure:

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

For some receptors, the same maximum 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 ventilation outlet contribution occurs when other contributions are low, such that overall NO_2 concentrations are well below the criterion or even the current maximum.

(a) Maximum total NO_2 concentrations



(b) NO_2 concentrations for maximum outlet contributions

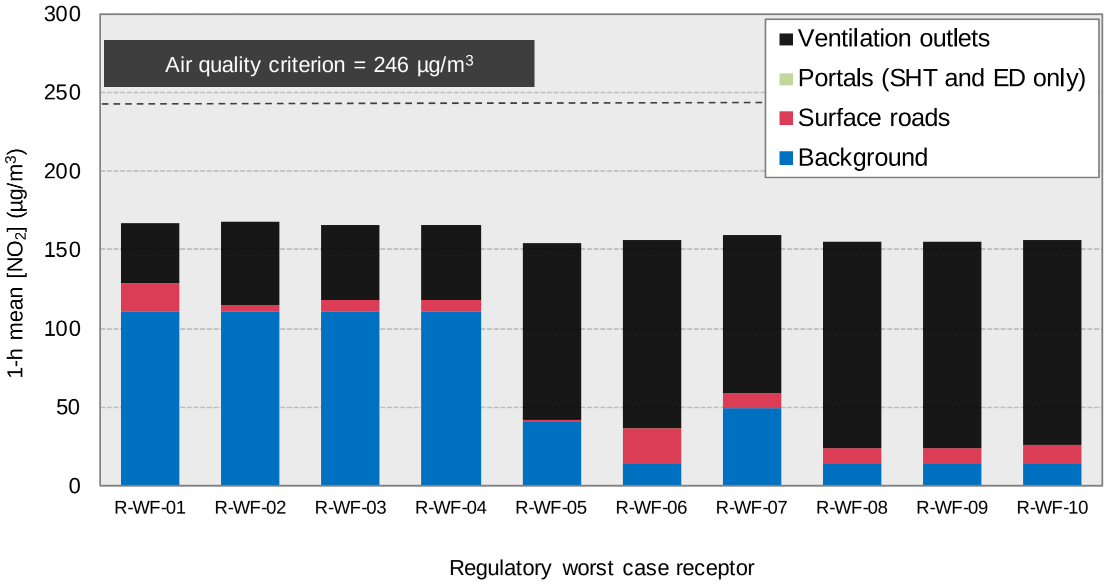
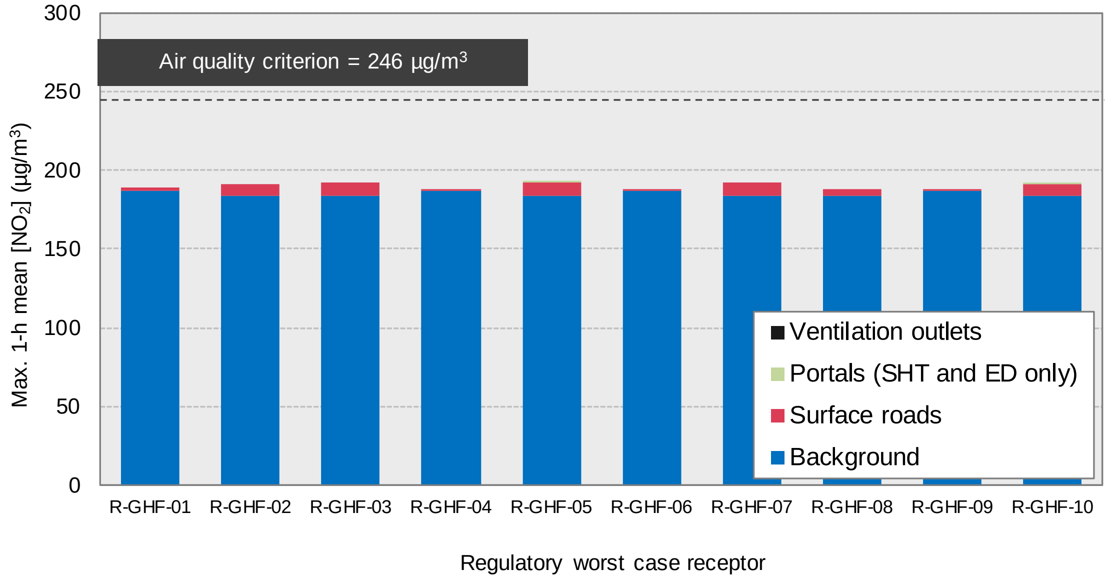


Figure 8-89 **Regulatory worst case: 1-hour mean NO_2 concentrations (2037-DSC, Warringah Freeway ventilation outlet, Outlet H)**

(a) Maximum total NO_2 concentrations



(b) NO_2 concentrations for maximum outlet contributions

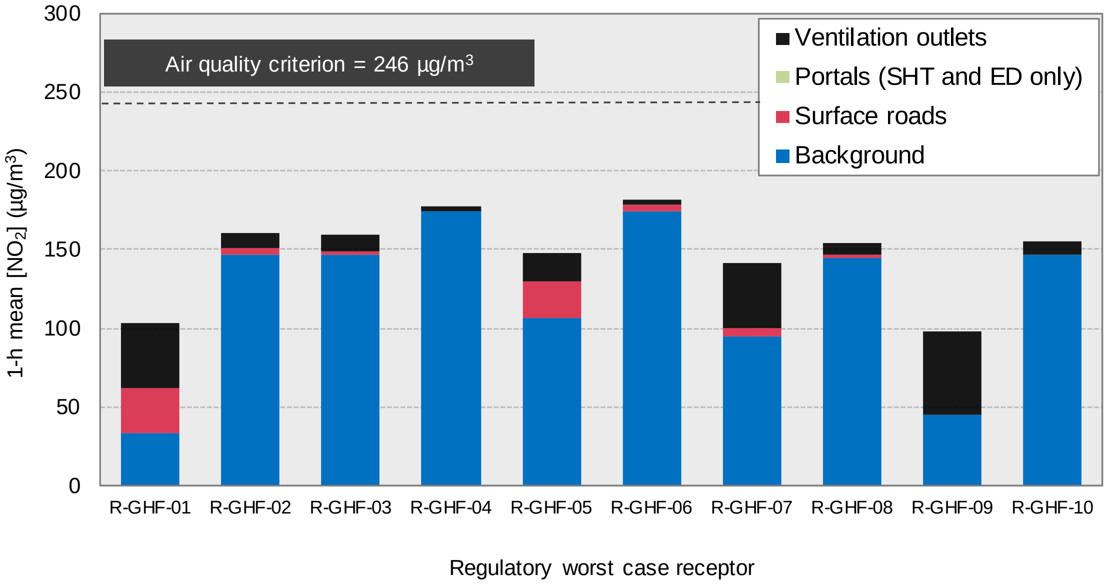
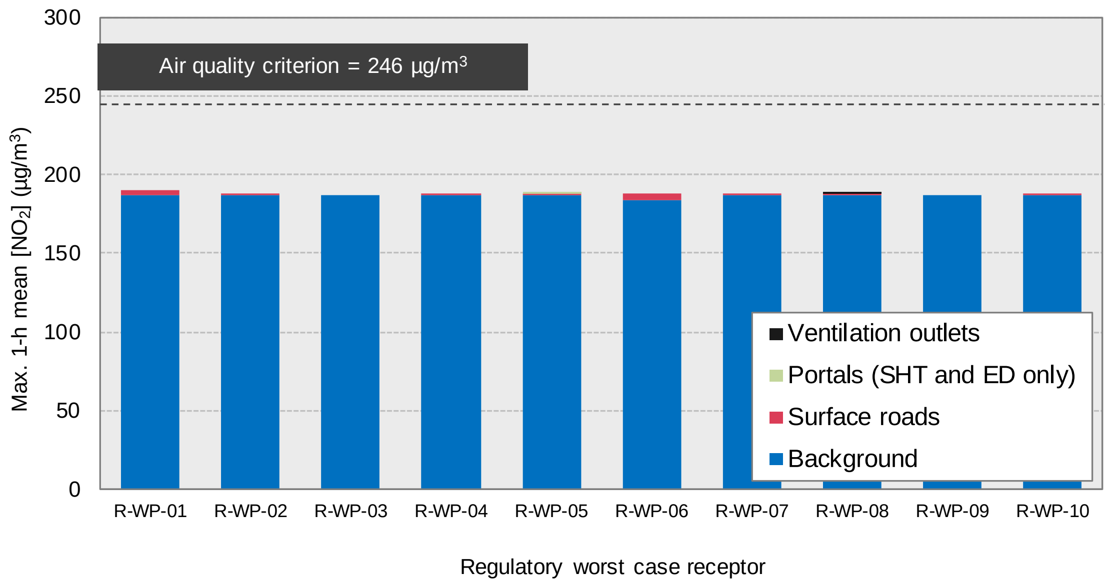


Figure 8-90 **Regulatory worst case: 1-hour mean NO_2 concentrations (2037-DSC, Gore Hill Freeway ventilation outlet, Outlet I)**

(a) Maximum total NO_2 concentrations



(b) NO_2 concentrations for maximum outlet contributions

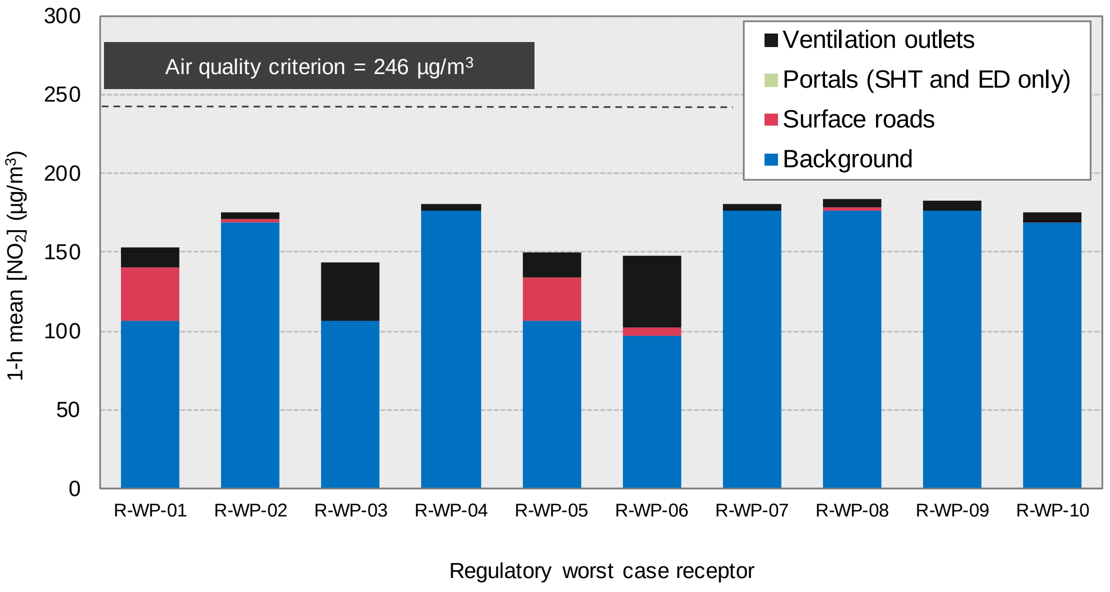
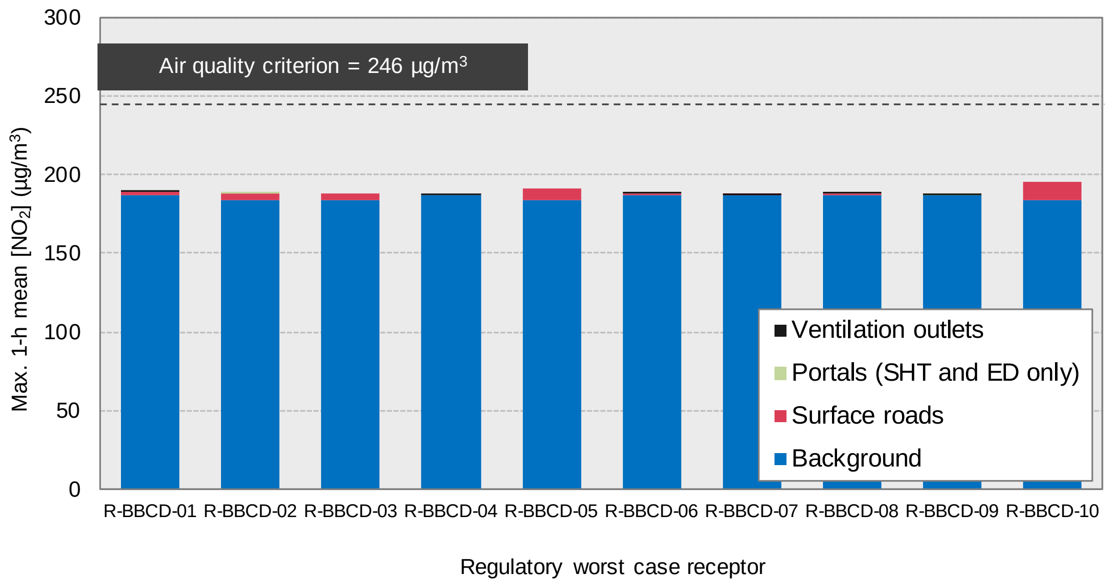


Figure 8-91 **Regulatory worst case: 1-hour mean NO_2 concentrations (2037-DSC, Wakehurst Parkway ventilation outlet, Outlet J)**

(a) Maximum total NO_2 concentrations



(b) NO_2 concentrations for maximum outlet contributions

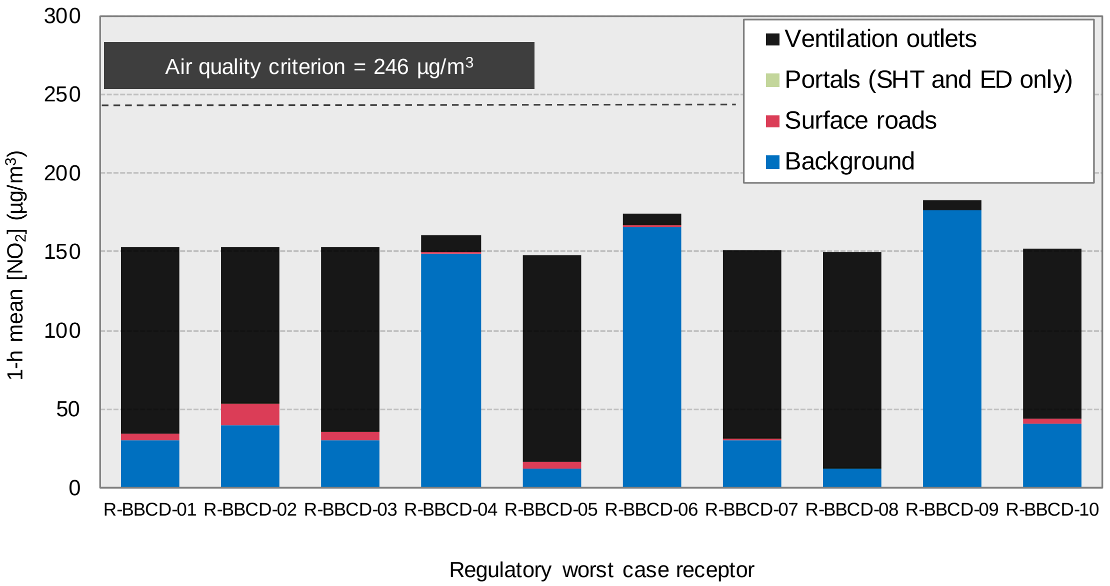


Figure 8-92 **Regulatory worst case: 1-hour mean NO_2 concentrations (2037-DSC, Burnt Bridge Creek Deviation ventilation outlet, Outlet K)**

Table 8-28 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) 2037-DSC
Outlet H: Warringah Freeway	
NO_2 (one hour) [when maximum total NO_2 occurs]	0.3
NO_2 (one hour) [when maximum ventilation outlet contribution to NO_2 occurs]	45.1
Outlet I: Gore Hill Freeway	
NO_2 (one hour) [when maximum total NO_2 occurs]	1.0
NO_2 (one hour) [when maximum ventilation outlet contribution to NO_2 occurs]	137.2
Outlet J: Wakehurst Parkway	
NO_2 (one hour) [when maximum total NO_2 occurs]	0.0
NO_2 (one hour) [when maximum ventilation outlet contribution to NO_2 occurs]	53.4
Outlet K: Burnt Bridge Creek Deviation	
NO_2 (one hour) [when maximum total NO_2 occurs]	0.0
NO_2 (one hour) [when maximum ventilation outlet contribution to NO_2 occurs]	131.4

THC and air toxics

The maximum ventilation outlet concentrations for the five specific air toxics considered in the regulatory worst case assessment (scenario RWC-2037-DSC only) were determined using the THC predictions in conjunction with the speciation profiles stated in Table 8-18. The results are given in Table 8-29. 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 8-29 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-2037-DSC)	Impact assessment criterion (µg/m^3)
THC (annual)	(µg/m^3)	3.4	-
THC (1 hour)	(µg/m^3)	65.9	-
Benzene (1 hour)	(µg/m^3)	2.24	*29*
PAH (BaP) (1 hour)	(µg/m^3)	0.03	*0.4*
Formaldehyde (1 hour)	(µg/m^3)	3.04	*20*
1,3-butadiene (1 hour)	(µg/m^3)	0.61	*40*
Ethylbenzene (1 hour)	(µg/m^3)	0.73	*8000*

Table 8-30 shows that, even if the maximum ventilation outlet contribution is added to the maximum increase in concentration in the 2037-DSC scenario (which implies some double counting), the results are still comfortably below the impact assessment criteria.

Table 8-30 Results of regulatory worst case assessment (RWR receptors) – air toxics (ventilation outlets plus traffic, 2037-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)	(µg/m^3)	65.9			-
Benzene (1 hour)	(µg/m^3)	2.24	5.5	7.71	*29*
PAH (BaP) (1 hour)	(µg/m^3)	0.03	0.07	0.10	*0.4*
Formaldehyde (1 hour)	(µg/m^3)	3.04	7.4	10.45	*20*
1,3-butadiene (1 hour)	(µg/m^3)	0.61	1.5	2.11	*40*
Ethylbenzene (1 hour)	(µg/m^3)	0.73	1.77	2.50	*8000*

8.4.9 Results for elevated receptors

Overview

This section presents results from the modelling of all pollutants at elevated receptors, for the expected traffic cases and the regulatory worst case (RWC) at heights of 10 metres, 20 metres, 30 metres and 45 metres above ground level. The aim is to provide an evaluation of impacts at elevated receptors within 300 metres of the Beaches Link ventilation outlets. The following information will be presented for PM_{10}, $PM_{2.5}$ and NO_2 for expected traffic and regulatory worst case:

- Incremental (ventilation outlet) concentrations
- Background concentrations
- Total (cumulative) concentrations

For air toxics, only incremental (ventilation outlet) concentrations will be presented.

This section also quantifies the percentage of exceedances for the expected traffic scenario, both with and without the project.

A summary of the modelling for the expected traffic cases is provided below:

- Scenarios: 2037-DSC and 2037-DM
- Pollutants: PM_{10}, $PM_{2.5}$, NO_X and air toxics
- Sources: ventilation outlets, portals and surface roads

The modelling for the RWC includes the following:

- Scenario: 2037-DSC
- Pollutants: PM_{10}, $PM_{2.5}$, NO_X and air toxics
- Sources: ventilation outlets

To summarise, this response presents the following:

- Selection of sensitive receptors for reporting
- Methodology for establishing background concentrations at height. Separate methodologies are provided for PM_{10}, $PM_{2.5}$ and NO_X/NO_2.

- Expected traffic modelling results for 2037-DSC scenario. This includes presentation of incremental (ventilation outlet) concentrations, background concentrations and total (cumulative) concentrations at selected RWR receptors and comparison with NSW EPA impact assessment criteria. Results are provided for predicted concentrations at heights of 10 metres, 20 metres, 30 metres and 45 metres above ground level. This section also quantifies the percentage of exceedances for the expected traffic scenario, both with and without the project.
- RWC modelling results for 2037-DSC scenario. This section includes presentation of incremental (ventilation outlet) concentrations, background concentrations and total (cumulative) concentrations at selected RWR receptors and comparison with NSW EPA impact assessment criteria. Results are provided for maximum predicted concentrations at heights of 10 metres, 20 metres, 30 metres and 45 metres above ground level.

Receptors

This analysis focuses on RWR receptors within 300 metres of the Beaches Link ventilation outlets. There are 128 RWR receptors around the Warringah Freeway Ventilation Outlet (Outlet H) , 136 RWR receptors around the Gore Hill Freeway Ventilation Outlet (Outlet I, 8 RWR receptors around the Wakehurst Parkway Ventilation Outlet (Outlet J) and 164 RWR receptors around the Burnt Bridge Creek Deviation Ventilation Outlet (Outlet K). It should be noted that there is one existing receptor within 300 metres of the Warringah Freeway Ventilation Outlet (Outlet H) that is greater than 30 metres in height, and there are no existing receptors within 300 metres of the Gore Hill Freeway Ventilation Outlet (Outlet I), the Wakehurst Parkway Ventilation Outlet (Outlet J) and the Burnt Bridge Creek Deviation Ventilation Outlet (Outlet K) that are greater than 30 metres in height.

Figure 8-93, Figure 8-94, Figure 8-95 and Figure 8-96 shows the RWR receptors located within 300 metres of the Warringah Freeway Ventilation Outlet (Outlet H), the Gore Hill Freeway Ventilation Outlet (Outlet I), the Wakehurst Parkway Ventilation Outlet (Outlet J) and the Burnt Bridge Creek Deviation Ventilation Outlet (Outlet K), respectively.

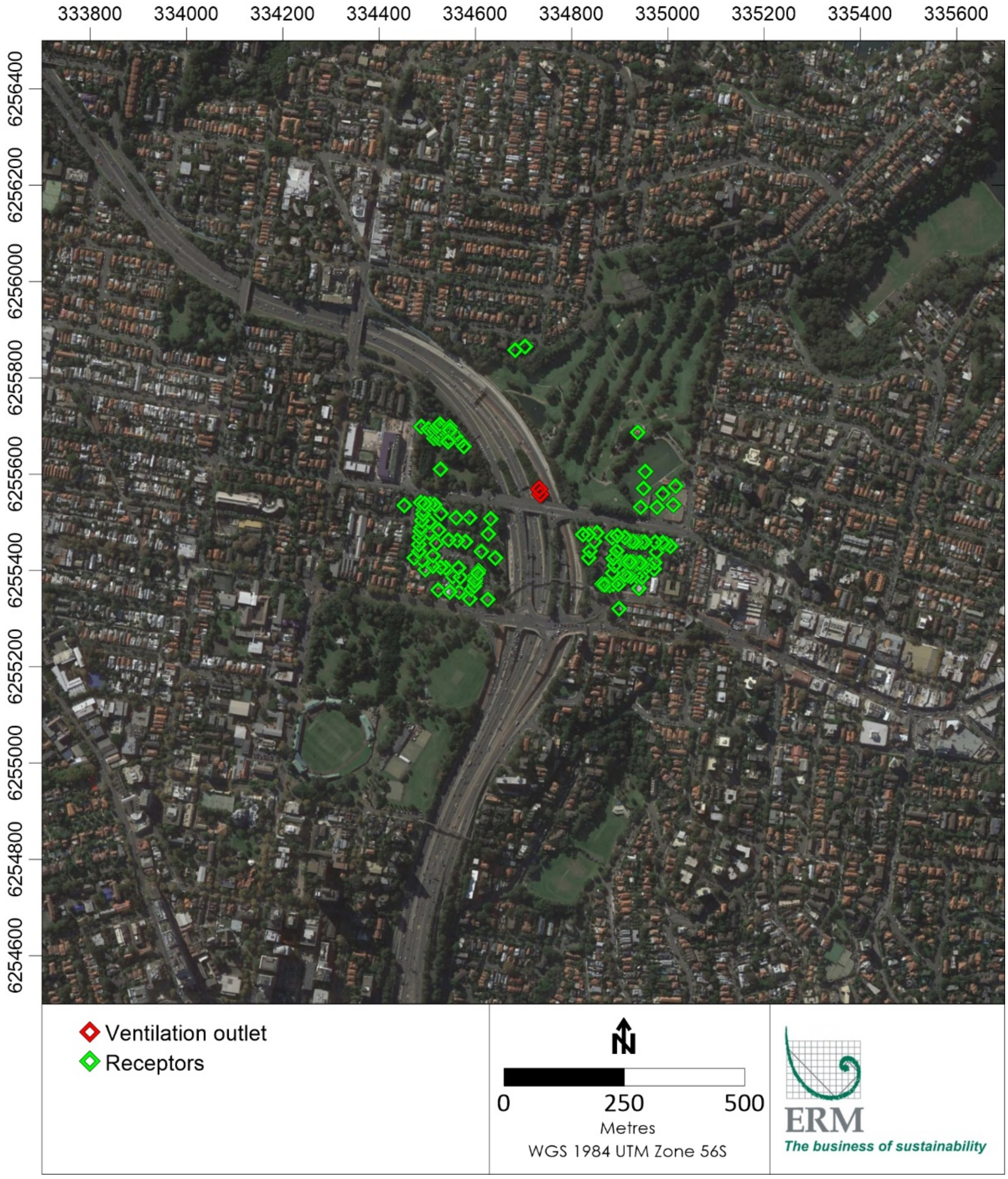


Figure 8-93 **RWR receptors located within 300 metres of Warringah Freeway Ventilation Outlet (Outlet H)**

Figure 8-94 RWR receptors located within 300 metres of Gore Hill Freeway Ventilation Outlet (Outlet I)

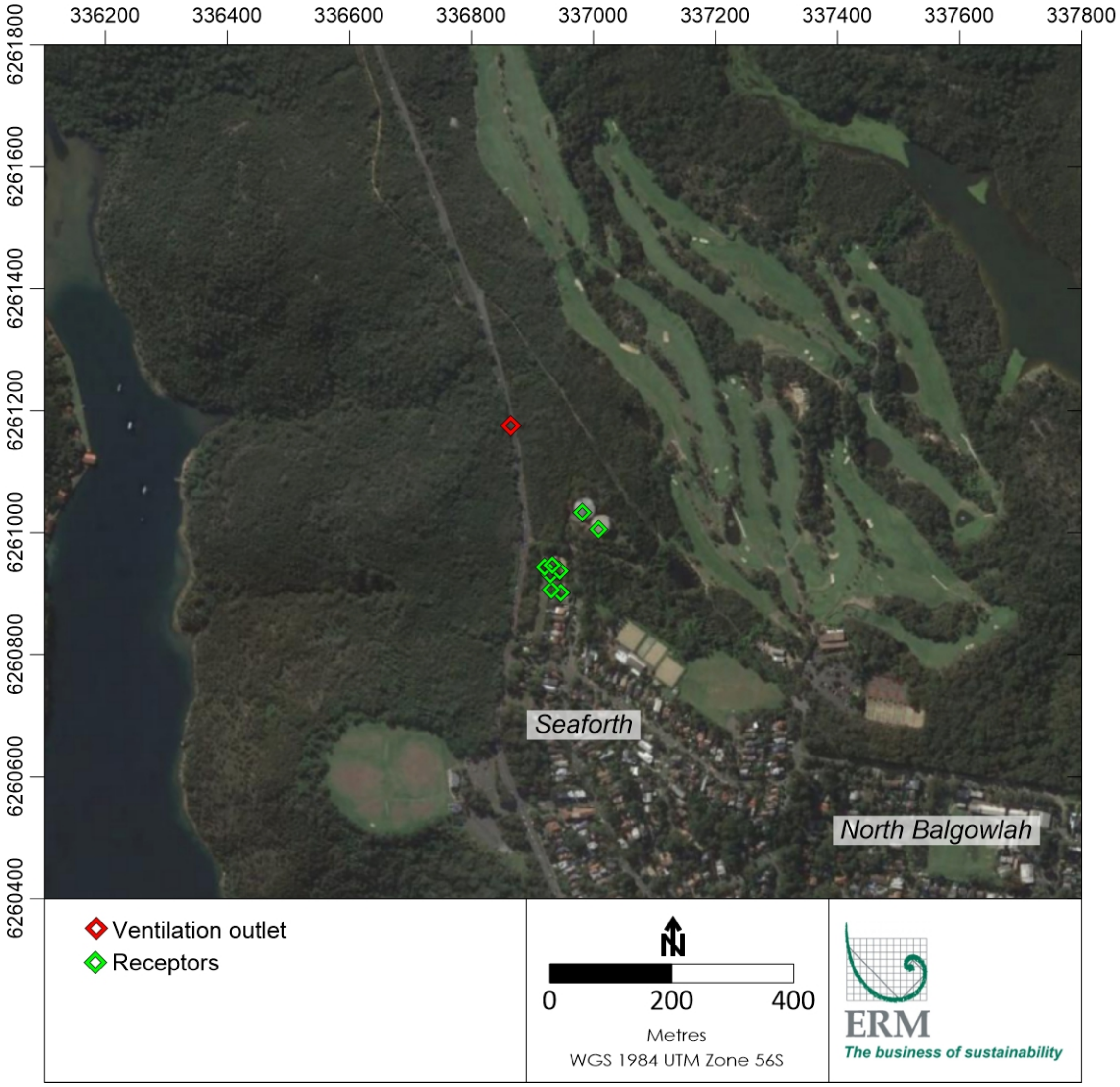


Figure 8-95 RWR receptors located within 300 metres of Wakehurst Parkway Ventilation Outlet (Outlet J)

Figure 8-96 **RWR receptors located within 300 metres of Burnt Bridge Creek Deviation Ventilation Outlet (Outlet K)**

Results have been processed for all RWR receptors within 300 metres of the Beaches Link ventilation outlets and results are presented for those most impacted. For the expected traffic and RWC modelling, the receptors were chosen based on the following process:

1. The maximum ventilation outlet concentration at RWR receptor locations within 300 metres of the ventilation outlet at each modelled height (10 metres, 20 metres, 30 metres and 45 metres). This assumes that at RWR receptor locations that buildings exist at all heights, irrespective of the actual heights of existing buildings at those locations – described as 'maximum all locations'

2. The maximum ventilation outlet concentration at RWR receptor locations within 300 metres of the ventilation outlet at each modelled height (10 metres, 20 metres, 30 metres and 45 metres). This only includes buildings that currently exist at each height – described as ‘maximum existing’.

Receptors may not currently exist at all of the heights modelled. For example, a 10 metre building may exist at a particular location, and this location is modelled for all four heights. However, only the 10 metre prediction is relevant at that location as the building does not reach heights of 20 metres, 30 metres or 45 metres.

Establishing background concentrations at height

There is considerable uncertainty in estimating background concentrations at height. For the purposes of this assessment, separate methodologies for establishing background concentrations at heights have been prepared for particulate matter (PM_{10} and $PM_{2.5}$) and NO_X. For air toxics, only incremental (ventilation outlet) concentrations are being presented and therefore no methodology for calculating background concentrations is presented here.

The purpose of determining the background concentrations is to combine with Project contributions to determine total concentrations. The total concentrations can then be compared with the NSW EPA impact assessment criterion, as per the Approved Methods.

Particulate matter (PM_{10} and $PM_{2.5}$)

For annual average PM_{10} and $PM_{2.5}$, the methodology is as follows:

- Extract ground level surface road contribution for the expected traffic 2037-DSC scenario at RWR receptors for PM_{10} and $PM_{2.5}$
- Subtract the surface road contribution from the background (spatially varying for annual mean) to get the ‘residual’ ground level background. It has been assumed that this background will be consistent at all heights (ground level, 10 metres, 20 metres, 30 metres and 45 metres).

For maximum 24-hour average PM_{10} and $PM_{2.5}$, the methodology is as follows:

- Extract ground level surface road contribution for the expected traffic 2037-DSC scenario at all RWR receptors for PM_{10} and $PM_{2.5}$
- Determine the 98th percentile for the ground level surface roads contribution for receptors within 50 metres of the roads (that it, those receptors most impacts by surface road emissions)
- Subtract the 98th percentile for the ground level surface roads contribution from the background (48.04 $\mu g/m^3$ for PM_{10} and 22.06 $\mu g/m^3$ for $PM_{2.5}$) to get the ‘residual’ ground level background. It will be assumed that this background will be consistent at all heights (ground level, 10 metres, 20 metres, 30 metres and 45 metres).

NO_X/NO_2

For NO_X/NO_2, the methodology is as follows:

- Extract total project contribution for the expected traffic 2037-DSC scenario at each modelled height for each of the RWR receptors for NO_X (annual average)
- Extract ventilation outlet contribution for the expected traffic 2037-DSC scenario at each modelled height for each of the RWR receptors for NO_X (annual average)
- Subtract the ventilation outlet contribution from the total project contribution to determine the surface roads contribution for NO_X at each height
- Calculate the average reduction in NO_X concentration at RWR receptors within 50 metres of modelled surface roads between each modelled height and ground level (e.g. 10 metres and ground level, 20 metres and ground level, 30 metres and ground level, 45 metres and ground level). This generates an average vertical profile

- Calculate the revised NO_X background concentration by applying the vertical reduction profile to the background concentration from the AQTWP (e.g. ground level background = 603.8 µg/m^3, reduction at 10 metres = 19 per cent, revised background at 10 metres = 489.1 µg/m^3).

Assumptions and limitations

General

- For short-term averaging periods, it has been determined that surface road contributions are total contributions minus ventilation outlet contributions.
- To establish a profile, only receptors that are located within 50 metres of modelled surface roads were considered. A distance of 50 metres was chosen as beyond this there is a drop-off in pollutant concentrations preventing a clear profile from being established.

Specific for NO_X/NO_2

- The annual average NO_X concentration profile for receptors within 50 metres of modelled surface roads has been established comparing ground level concentrations (from surface roads only) with the concentrations at the heights modelled (10 metres, 20 metres, 30 metres and 45 metres). The surface roads contribution reduced by the following amounts:
    - 10 metres – 19 per cent reduction in ground level NO_X concentrations
    - 20 metres – 32 per cent reduction in ground level NO_X concentrations
    - 30 metres – 41 per cent reduction in ground level NO_X concentrations
    - 45 metres – 52 per cent reduction in ground level NO_X concentrations
- The annual average NO_X surface road concentration profile has been applied to the background 1-hour average and annual average concentrations.

Elevated receptor modelling results – expected traffic

This section presents the following for PM_{10}, $PM_{2.5}$ and NO_X /NO_2:

- Incremental (ventilation outlet) contribution
- Background (surface road and other non-surface road contributions)
- Total concentrations (ventilation outlet plus background)
- Comparison to NSW criterion

For air toxics, only the incremental (ventilation outlet) contribution has been presented.

The results in the following sections are presented based on the maximum ventilation outlet contribution.

PM_{10} concentrations

Table 8-31, Table 8-32, Table 8-33 and Table 8-34 present the annual average PM_{10} concentrations for selected RWR receptors within 300 metres of the Warringah Freeway Ventilation Outlet (Outlet H), Gore Hill Freeway Ventilation Outlet (Outlet I), Wakehurst Parkway Ventilation Outlet (Outlet J) and Burnt Bridge Creek Deviation Ventilation Outlet (Outlet K) at four modelled heights.

Table 8-31 Annual average and maximum 24-hour average PM_{10} concentrations for selected RWR receptors within 300 metres of Warringah Freeway Ventilation Outlet (Outlet H)

Receptor height (m)	Maximum all or existing	Receptor ID	PM_{10} concentration (µg/m^3)			
			Incremental	Background	Total	Criterion
Annual average PM_{10}						
10 m	All[(a)]	RWR-13729	0.1	15.6	15.7	25
	Existing[(b)]	RWR-13729	0.1	15.6	15.7	25
20 m	All	RWR-12236	0.1	14.7	14.7	25
	Existing	RWR-12518	0.1	15.3	15.4	25
30 m	All	RWR-33249	0.3	15.4	15.7	25
	Existing	RWR-12249	0.2	14.9	15.2	25
45 m	All	RWR-12516	0.7	13.9	14.7	25
	Existing	-	-	-	-	-
Maximum 24-hour average PM_{10}						
10 m	All[(a)]	RWR-33248	1.0	43.9	44.9	50
	Existing[(b)]	RWR-11931	0.8	43.4	44.2	50
20 m	All	RWR-33249	1.8	41.4	43.2	50
	Existing	RWR-12249	1.5	42.4	43.9	50
30 m	All	RWR-12516	5.4	41.4	46.9	50
	Existing	RWR-12249	3.1	41.5	44.6	50
45 m	All	RWR-32899	6.0	41.5	47.6	50
	Existing	-	-	-	-	-

(a) Assumes at RWR receptor locations that buildings exist at all heights, irrespective of existing building heights at those locations
(b) Only includes buildings that exist at each height
Numbers in **bold** represent an exceedance of the criterion
Incremental = ventilation outlet contribution
Background = surface road and non-surface road contributions
Total concentration = incremental ventilation outlet contribution + background

Table 8-32 Annual average and maximum 24-hour average PM_{10} concentrations for selected RWR receptors within 300 metres of Gore Hill Freeway Ventilation Outlet (Outlet I)

Receptor height (m)	Maximum all or existing	Receptor ID	PM_{10} concentration (µg/m³)			
			Incremental	Background	Total	Criterion
Annual average PM_{10}						
10 m	All[(a)]	RWR-17639	0.1	15.4	15.5	25
	Existing[(b)]	RWR-17181	0.1	15.2	15.2	25
20 m	All	RWR-17662	0.1	15.2	15.3	25
	Existing	-	-	-	-	-
30 m	All	RWR-17646	0.3	15.2	15.6	25
	Existing	-	-	-	-	-
45 m	All	RWR-17555	1.3	14.8	16.1	25
	Existing	-	-	-	-	-
Maximum 24-hour average PM_{10}						
10 m	All[(a)]	RWR-18285	0.4	42.7	43.1	50
	Existing[(b)]	RWR-17181	0.2	44.3	44.5	50
20 m	All	RWR-17526	1.1	43.0	44.1	50
	Existing	-	-	-	-	-
30 m	All	RWR-17646	4.3	41.4	45.7	50
	Existing	-	-	-	-	-
45 m	All	RWR-17555	15.5	40.6	**56.1**	50
	Existing	-	-	-	-	-

(a) Assumes at RWR receptor locations that buildings exist at all heights, irrespective of existing building heights at those locations
(b) Only includes buildings that exist at each height
Numbers in **bold** represent an exceedance of the criterion
Incremental = ventilation outlet contribution
Background = surface road and non-surface road contributions
Total concentration = incremental ventilation outlet contribution + background

Table 8-33 Annual average and maximum 24-hour average PM_{10} concentrations for selected RWR receptors within 300 metres of Wakehurst Parkway Ventilation Outlet (Outlet J)

Receptor height (m)	Maximum all or existing	Receptor ID	PM_{10} concentration (µg/m^3)			
			Incremental	Background	Total	Criterion
Annual average PM_{10}						
10 m	All(a)	RWR-03624	<0.1	15.5	15.5	25
	Existing(b)	RWR-04647	<0.1	15.5	15.6	25
20 m	All	RWR-03624	<0.1	15.4	15.5	25
	Existing	-	-	-	-	-
30 m	All	RWR-03628	<0.1	15.4	15.4	25
	Existing	-	-	-	-	-
45 m	All	RWR-04647	0.1	15.4	15.5	25
	Existing	-	-	-	-	-
Maximum 24-hour average PM_{10}						
10 m	All(a)	RWR-03624	0.2	41.4	41.6	50
	Existing(b)	RWR-04646	0.1	41.3	41.4	50
20 m	All	RWR-03623	0.2	41.3	41.5	50
	Existing	-	-	-	-	-
30 m	All	RWR-03628	0.4	41.1	41.5	50
	Existing	-	-	-	-	-
45 m	All	RWR-04647	0.8	40.9	41.7	50
	Existing	-	-	-	-	-

(a) Assumes at RWR receptor locations that buildings exist at all heights, irrespective of existing building heights at those locations
(b) Only includes buildings that exist at each height
Numbers in **bold** represent an exceedance of the criterion
Incremental = ventilation outlet contribution
Background = surface road and non-surface road contributions
Total concentration = incremental ventilation outlet contribution + background

Table 8-34 Annual average and maximum 24-hour average PM_{10} concentrations for selected RWR receptors within 300 metres of Burnt Bridge Creek Deviation Ventilation Outlet (Outlet K)

Receptor height (m)	Maximum all or existing	Receptor ID	PM_{10} concentration (µg/m³) Incremental	Background	Total	Criterion
Annual average PM_{10}						
10 m	All[(a)]	RWR-01304	0.1	15.7	15.7	25
	Existing[(b)]	RWR-01569	<0.1	15.7	15.8	25
20 m	All	RWR-01270	0.1	15.5	15.7	25
	Existing	-	-	-	-	-
30 m	All	RWR-01270	0.2	15.5	15.6	25
	Existing	-	-	-	-	-
45 m	All	RWR-00895	0.2	14.8	15.0	25
	Existing	-	-	-	-	-
Maximum 24-hour average PM_{10}						
10 m	All[(a)]	RWR-01319	0.9	41.8	42.6	50
	Existing[(b)]	RWR-01569	0.5	41.8	42.3	50
20 m	All	RWR-01400	1.9	40.6	42.5	50
	Existing	-	-	-	-	-
30 m	All	RWR-01400	3.1	40.6	43.7	50
	Existing	-	-	-	-	-
45 m	All	RWR-01400	2.3	40.6	43.0	50
	Existing	-	-	-	-	-

(a) Assumes at RWR receptor locations that buildings exist at all heights, irrespective of existing building heights at those locations
(b) Only includes buildings that exist at each height
Numbers in **bold** represent an exceedance of the criterion
Incremental = ventilation outlet contribution
Background = surface road and non-surface road contributions
Total concentration = incremental ventilation outlet contribution + background

For the annual average PM_{10} concentrations, there are no predicted exceedances at any modelled height of the NSW EPA impact assessment criterion of 25 µg/m³, when considering the maximum ventilation outlet contribution.

For the maximum 24-hour average PM_{10} concentrations, there is one predicted exceedance of the NSW EPA impact assessment criterion of 50 µg/m³ at 45 metres when considering all RWR receptors, irrespective of buildings that exist at those heights and when considering the maximum ventilation outlet contribution. When considering RWR receptors that do exist at each modelled height, there are no predicted exceedances of the NSW EPA impact assessment criterion of 50 µg/m³ at any height.

$PM_{2.5}$ concentrations

Table 8-35, Table 8-36, Table 8-37 and Table 8-38present the annual average $PM_{2.5}$ concentrations for selected RWR receptors within 300 metres of the Warringah Freeway Ventilation Outlet (Outlet H), Gore Hill Freeway Ventilation Outlet (Outlet I), Wakehurst Parkway Ventilation Outlet (Outlet J) and Burnt Bridge Creek Deviation Ventilation Outlet (Outlet K) at four modelled heights.

Table 8-35 Annual average and maximum 24-hour average $PM_{2.5}$ concentrations for selected RWR receptors within 300 metres of Warringah Freeway Ventilation Outlet (Outlet H)

Receptor height (m)	Maximum all or existing	Receptor ID	$PM_{2.5}$ concentration (µg/m³)			
			Incremental	Background	Total	Criterion
Annual average $PM_{2.5}$						
10 m	All[(a)]	RWR-33537	0.1	7.5	7.6	8
	Existing[(b)]	RWR-13729	0.1	7.5	7.6	8
20 m	All	RWR-33249	0.1	7.4	7.5	8
	Existing	RWR-12249	0.1	7.3	7.4	8
30 m	All	RWR-33249	0.2	7.3	7.5	8
	Existing	RWR-12249	0.1	7.1	7.2	8
45 m	All	RWR-12516	0.5	6.5	7.0	8
	Existing	-	-	-	-	-
Maximum 24-hour average $PM_{2.5}$						
10 m	All[(a)]	RWR-33248	0.7	18.9	19.6	25
	Existing[(b)]	RWR-11931	0.5	19.5	20.0	25
20 m	All	RWR-33249	1.2	18.3	19.5	25
	Existing	RWR-12249	1.0	18.3	19.4	25
30 m	All	RWR-12516	3.7	18.0	21.7	25
	Existing	RWR-12249	2.2	18.2	20.3	25
45 m	All	RWR-32899	4.0	18.1	22.1	25
	Existing	-	-	-	-	-

(a) Assumes at RWR receptor locations that buildings exist at all heights, irrespective of existing building heights at those locations
(b) Only includes buildings that exist at each height
Numbers in **bold** represent an exceedance of the criterion
Incremental = ventilation outlet contribution
Background = surface road and non-surface road contributions
Total concentration = incremental ventilation outlet contribution + background

Table 8-36 Annual average and maximum 24-hour average $PM_{2.5}$ concentrations for selected RWR receptors within 300 metres of Gore Hill Freeway Ventilation Outlet (Outlet I)

Receptor height (m)	Maximum all or existing	Receptor ID	$PM_{2.5}$ concentration (µg/m^3)			
			Incremental	Background	Total	Criterion
Annual average $PM_{2.5}$						
10 m	All[a]	RWR-17475	<0.1	7.5	7.5	8
	Existing[b]	RWR-17181	<0.1	7.4	7.4	8
20 m	All	RWR-17662	0.1	7.4	7.4	8
	Existing	-	-	-	-	-
30 m	All	RWR-17646	0.2	7.2	7.5	8
	Existing	-	-	-	-	-
45 m	All	RWR-17555	0.9	7.0	7.8	8
	Existing	-	-	-	-	-
Maximum 24-hour average $PM_{2.5}$						
10 m	All[a]	RWR-18285	0.3	19.7	19.9	25
	Existing[b]	RWR-17181	0.2	20.6	20.8	25
20 m	All	RWR-17526	0.7	18.6	19.3	25
	Existing	-	-	-	-	-
30 m	All	RWR-17646	3.0	18.0	21.0	25
	Existing	-	-	-	-	-
45 m	All	RWR-17555	10.4	17.6	**28.0**	25
	Existing	-	-	-	-	-

(a) Assumes at RWR receptor locations that buildings exist at all heights, irrespective of existing building heights at those locations
(b) Only includes buildings that exist at each height
Numbers in **bold** represent an exceedance of the criterion
Incremental = ventilation outlet contribution
Background = surface road and non-surface road contributions
Total concentration = incremental ventilation outlet contribution + background

Table 8-37 Annual average and maximum 24-hour average $PM_{2.5}$ concentrations for selected RWR receptors within 300 metres of Wakehurst Parkway Ventilation Outlet (Outlet J)

Receptor height (m)	Maximum all or existing	Receptor ID	$PM_{2.5}$ concentration (µg/m^3)			
			Incremental	Background	Total	Criterion
Annual average $PM_{2.5}$						
10 m	All[(a)]	RWR-03624	<0.1	7.6	7.7	8
	Existing[(b)]	RWR-04646	<0.1	7.7	7.7	8
20 m	All	RWR-03624	<0.1	7.6	7.6	8
	Existing	-	-	-	-	-
30 m	All	RWR-03628	<0.1	7.6	7.6	8
	Existing	-	-	-	-	-
45 m	All	RWR-04647	<0.1	7.6	7.6	8
	Existing	-	-	-	-	-
Maximum 24-hour average $PM_{2.5}$						
10 m	All[(a)]	RWR-03624	0.1	18.3	18.5	25
	Existing[(b)]	RWR-04646	0.1	18.0	18.1	25
20 m	All	RWR-03625	0.2	18.0	18.2	25
	Existing	-	-	-	-	-
30 m	All	RWR-04647	0.2	17.9	18.1	25
	Existing	-	-	-	-	-
45 m	All	RWR-04647	0.5	17.7	18.2	25
	Existing	-	-	-	-	-

(a) Assumes at RWR receptor locations that buildings exist at all heights, irrespective of existing building heights at those locations
(b) Only includes buildings that exist at each height
Numbers in **bold** represent an exceedance of the criterion
Incremental = ventilation outlet contribution
Background = surface road and non-surface road contributions
Total concentration = incremental ventilation outlet contribution + background

Table 8-38 Annual average and maximum 24-hour average $PM_{2.5}$ concentrations for selected RWR receptors within 300 metres of Burnt Bridge Creek Deviation Ventilation Outlet (Outlet K)

Receptor height (m)	Maximum all or existing	Receptor ID	$PM_{2.5}$ concentration (µg/m^3)			
			Incremental	Background	Total	Criterion
Annual average $PM_{2.5}$						
10 m	All[(a)]	RWR-01242	0.1	7.7	7.8	8
	Existing[(b)]	RWR-01569	<0.1	7.7	7.7	8
20 m	All	RWR-01270	0.1	7.7	7.8	8
	Existing	-	-	-	-	-
30 m	All	RWR-01270	0.1	7.6	7.7	8
	Existing	-	-	-	-	-
45 m	All	RWR-00967	0.1	7.3	7.4	8
	Existing	-	-	-	-	-
Maximum 24-hour average $PM_{2.5}$						
10 m	All[(a)]	RWR-01226	0.6	18.4	19.0	25
	Existing[(b)]	RWR-01569	0.4	18.4	18.8	25
20 m	All	RWR-01400	1.3	17.6	18.8	25
	Existing	-	-	-	-	-
30 m	All	RWR-01400	2.0	17.6	19.6	25
	Existing	-	-	-	-	-
45 m	All	RWR-01400	1.5	17.6	19.0	25
	Existing	-	-	-	-	-

(a) Assumes at RWR receptor locations that buildings exist at all heights, irrespective of existing building heights at those locations
(b) Only includes buildings that exist at each height
Numbers in **bold** represent an exceedance of the criterion
Incremental = ventilation outlet contribution
Background = surface road and non-surface road contributions
Total concentration = incremental ventilation outlet contribution + background

For the annual average $PM_{2.5}$ concentrations, there are no predicted exceedances at any modelled height of the NSW EPA impact assessment criterion of 8 µg/m^3, when considering the maximum ventilation outlet contribution.

For the maximum 24-hour average $PM_{2.5}$ concentrations, there is one predicted exceedance of the NSW EPA impact assessment criterion of 25 µg/m^3 at 45 metres when considering all RWR receptors, irrespective of building that exist at those heights and when considering the maximum ventilation outlet contribution. When considering RWR receptors that do exist at each modelled height, there are no predicted exceedances of the NSW EPA impact assessment criterion of 25 µg/m^3 at any height.

NO_2 concentrations

Table 8-39, Table 8-40, Table 8-41 and Table 8-42 present the annual average NO_2 concentrations for selected RWR receptors within 300 metres of the Warringah Freeway Ventilation Outlet (Outlet H), Gore Hill Freeway Ventilation Outlet (Outlet I), Wakehurst Parkway Ventilation Outlet (Outlet J) and Burnt Bridge Creek Deviation Ventilation Outlet (Outlet K) at four modelled heights

Table 8-39 Annual average and maximum 1-hour average NO_2 concentrations for selected RWR receptors within 300 metres of Warringah Freeway Ventilation Outlet (Outlet H)

Receptor height (m)	Maximum all or existing	Receptor ID	NO_X and NO_2 concentrations (µg/m^3)				
			Incremental NO_X	Background NO_X	Total NOx	Total NO_2	Criterion
Annual average NO_X / NO_2							
10 m	All[(a)]	RWR-33248	1.5	30.8	32.3	18.7	62
	Existing[(b)]	RWR-13729	1.4	35.5	36.9	20.2	62
20 m	All	RWR-33249	2.2	25.5	27.7	17.0	62
	Existing	RWR-12249	1.5	28.1	29.6	17.7	62
30 m	All	RWR-33249	3.8	21.3	25.1	15.9	62
	Existing	RWR-12249	2.8	23.2	26.0	16.3	62
45 m	All	RWR-12516	9.1	18.1	27.2	16.8	62
	Existing	-	-	-	-	-	-
Maximum 1-hour average NO_X / NO_2							
10 m	All[(a)]	RWR-12274	52	938	989	207	246
	Existing[(b)]	RWR-13729	37	909	946	205	246
20 m	All	RWR-12026	84	787	871	201	246
	Existing	RWR-12249	60	758	818	199	246
30 m	All	RWR-12414	193	803	996	207	246
	Existing	RWR-12249	115	648	764	196	246
45 m	All	RWR-12414	366	564	930	204	246
	Existing	-	-	-	-	-	-

(a) Assumes at RWR receptor locations that buildings exist at all heights, irrespective of existing building heights at those locations
(b) Only includes buildings that exist at each height
Numbers in **bold** represent an exceedance of the criterion
Incremental = ventilation outlet contribution
Background = surface road and non-surface road contributions
Total NO_X = incremental ventilation outlet contribution + background
Total NO_2 = Total NO_X converted to NO_2

Table 8-40 Annual average and maximum 1-hour average NO_2 concentrations for selected RWR receptors within 300 metres of Gore Hill Freeway Ventilation Outlet (Outlet I)

Receptor height (m)	Maximum all or existing	Receptor ID	NO_X and NO_2 concentrations (µg/m³)				
			Incremental NO_X	Background NO_X	Total NO_X	Total NO_2	Criterion
Annual average NO_X / NO_2							
10 m	All[(a)]	RWR-17271	0.84	27.9	28.7	17.4	62
	Existing[(b)]	RWR-17181	0.67	32.2	32.9	18.9	62
20 m	All	RWR-17662	1.07	25.2	26.3	16.4	62
	Existing	-	-	-	-	-	-
30 m	All	RWR-17646	4.15	22.0	26.1	16.4	62
	Existing	-	-	-	-	-	-
45 m	All	RWR-17555	15.85	17.7	33.6	19.1	62
	Existing	-	-	-	-	-	-
Maximum 1-hour average NO_X / NO_2							
10 m	All[(a)]	RWR-17200	16	705	720	194	246
	Existing[(b)]	RWR-17181	11	771	782	197	246
20 m	All	RWR-17526	32	671	703	193	246
	Existing	-	-	-	-	-	-
30 m	All	RWR-17555	251	379	630	189	246
	Existing	-	-	-	-	-	-
45 m	All	RWR-17555	692	290	982	206	246
	Existing	-	-	-	-	-	-

(a) Assumes at RWR receptor locations that buildings exist at all heights, irrespective of existing building heights at those locations
(b) Only includes buildings that exist at each height
Numbers in **bold** represent an exceedance of the criterion
Incremental = ventilation outlet contribution
Background = surface road and non-surface road contributions
Total NO_X = incremental ventilation outlet contribution + background
Total NO_2 = Total NO_X converted to NO_2

Table 8-41 Annual average and maximum 1-hour average NO_2 concentrations for selected RWR receptors within 300 metres of Wakehurst Parkway Ventilation Outlet (Outlet J)

Receptor height (m)	Maximum all or existing	Receptor ID	NO_X and NO_2 concentrations (µg/m^3)				
			Incremental NO_X	Background NO_X	Total NOx	Total NO_2	Criterion
Annual average NO_X / NO_2							
10 m	All[(a)]	RWR-03625	0.52	18.1	18.6	13.0	62
	Existing[(b)]	RWR-04647	0.32	18.2	18.6	13.0	62
20 m	All	RWR-03625	0.51	15.2	15.7	11.5	62
	Existing	-	-	-	-	-	-
30 m	All	RWR-03625	0.59	13.4	14.0	10.5	62
	Existing	-	-	-	-	-	-
45 m	All	RWR-04647	0.92	11.1	12.0	9.4	62
	Existing	-	-	-	-	-	-
Maximum 1-hour average NO_X / NO_2							
10 m	All[(a)]	RWR-03628	19	568	587	186	246
	Existing[(b)]	RWR-04646	17	627	644	190	246
20 m	All	RWR-03628	23	486	508	181	246
	Existing	-	-	-	-	-	-
30 m	All	RWR-04647	32	400	433	175	246
	Existing	-	-	-	-	-	-
45 m	All	RWR-04647	55	311	366	169	246
	Existing	-	-	-	-	-	-

(a) Assumes at RWR receptor locations that buildings exist at all heights, irrespective of existing building heights at those locations
(b) Only includes buildings that exist at each height
Numbers in **bold** represent an exceedance of the criterion
Incremental = ventilation outlet contribution
Background = surface road and non-surface road contributions
Total NO_X = incremental ventilation outlet contribution + background
Total NO_2 = Total NO_X converted to NO_2

Table 8-42 Annual average and maximum 1-hour average NO_2 concentrations for selected RWR receptors within 300 metres of Burnt Bridge Creek Deviation Ventilation Outlet (Outlet K)

Receptor height (m)	Maximum all or existing	Receptor ID	NO_X and NO_2 concentrations (µg/m^3)				
			Incremental NO_X	Background NO_X	Total NOx	Total NO_2	Criterion
Annual average NO_X / NO_2							
10 m	All[(a)]	RWR-01242	0.93	21.7	22.6	14.8	62
	Existing[(b)]	RWR-01569	0.53	21.9	22.5	14.8	62
20 m	All	RWR-01226	1.36	19.5	20.9	14.1	62
	Existing	-	-	-	-	-	-
30 m	All	RWR-01270	1.95	17.8	19.8	13.5	62
	Existing	-	-	-	-	-	-
45 m	All	RWR-00811	2.27	14.3	16.5	11.9	62
	Existing	-	-	-	-	-	-
Maximum 1-hour average NO_X / NO_2							
10 m	All[(a)]	RWR-01319	33	596	629	189	246
	Existing[(b)]	RWR-01569	26	612	638	189	246
20 m	All	RWR-01400	53	545	598	187	246
	Existing	-	-	-	-	-	-
30 m	All	RWR-01400	90	454	544	183	246
	Existing	-	-	-	-	-	-
45 m	All	RWR-01400	135	343	477	179	246
	Existing	-	-	-	-	-	-

(a) Assumes at RWR receptor locations that buildings exist at all heights, irrespective of existing building heights at those locations
(b) Only includes buildings that exist at each height
Numbers in **bold** represent an exceedance of the criterion
Incremental = ventilation outlet contribution
Background = surface road and non-surface road contributions
Total NO_X = incremental ventilation outlet contribution + background
Total NO_2 = Total NO_X converted to NO_2

For the annual average NO_2 concentrations, there are no predicted exceedances at any modelled height of the NSW EPA impact assessment criterion of 62 µg/m^3, when considering the maximum ventilation outlet contribution.

For the maximum 1-hour average NO_2 concentrations there are no predicted exceedances of the NSW EPA impact assessment criterion of 246 µg/m^3, when considering the maximum ventilation outlet contribution.

Air toxics

This section presents the maximum 1-hour average incremental air toxic concentrations for benzene, PAHs (as b(a)p), formaldehyde, 1,3-butadiene and ethylbenzene for selected RWR receptors at four modelled heights. The conversion percentage of each of the five air toxics has been applied after modelling and the values are the same as those applied in Section 8.4.5. Table 8-43, Table 8-44, Table 8-45 and Table 8-46 present the maximum 1-hour average air toxics concentrations for selected RWR receptors within 300 metres of the Warringah Freeway Ventilation Outlet (Outlet H), Gore Hill Freeway Ventilation Outlet (Outlet I), Wakehurst Parkway Ventilation Outlet (Outlet J) and Burnt Bridge Creek Deviation Ventilation Outlet (Outlet K) at four modelled heights.

Table 8-43 Maximum 1-hour average air toxics concentrations for selected RWR receptors within 300 metres of Warringah Freeway Ventilation Outlet (Outlet H)

Receptor height (m)	Maximum all or existing	Receptor ID	Incremental (ventilation outlet) contribution (µg/m^3)				
			Benzene	PEH (as b(a)p)	Formaldehyde	1,3-butadiene	Ethylbenzene
Criterion (µg/m^3)			**29**	**0.4**	**20**	**40**	**8000**
10 m	All[(a)]	RWR-12103	0.12	<0.01	0.16	0.03	0.04
	Existing[(b)]	RWR-13729	0.08	<0.01	0.11	0.02	0.03
20 m	All	RWR-12189	0.18	<0.01	0.24	0.05	0.06
	Existing	RWR-12249	0.13	<0.01	0.17	0.03	0.04
30 m	All	RWR-12414	0.42	0.01	0.58	0.12	0.14
	Existing	RWR-12249	0.23	<0.01	0.32	0.06	0.08
45 m	All	RWR-12414	0.78	0.01	1.05	0.21	0.25
	Existing	-	-	-	-	-	-

(a) Assumes at RWR receptor locations that buildings exist at all heights, irrespective of existing building heights at those locations
(b) Only includes buildings that exist at each height
Numbers in **bold** represent an exceedance of the criterion.

Table 8-44 Maximum 1-hour average air toxics concentrations for selected RWR receptors within 300 m of Gore Hill Freeway Ventilation Outlet (Outlet I)

Receptor height (m)	Maximum all or existing	Receptor ID	Incremental (ventilation outlet) contribution (µg/m^3)				
			Benzene	PEH (as b(a)p)	Formaldehyde	1,3-butadiene	Ethylbenzene
Criterion (µg/m^3)			**29**	**0.4**	**20**	**40**	**8000**
10 m	All[(a)]	RWR-17132	0.03	<0.01	0.04	0.01	0.01
	Existing[(b)]	RWR-17181	0.02	<0.01	0.03	0.01	0.01
20 m	All	RWR-17526	0.07	<0.01	0.09	0.02	0.02
	Existing	-	-	-	-	-	-
30 m	All	RWR-17555	0.53	0.01	0.72	0.15	0.17
	Existing	-	-	-	-	-	-
45 m	All	RWR-17555	1.47	0.02	1.99	0.40	0.47
	Existing	-	-	-	-	-	-

(a) Assumes at RWR receptor locations that buildings exist at all heights, irrespective of existing building heights at those locations
(b) Only includes buildings that exist at each height
Numbers in **bold** represent an exceedance of the criterion.

Table 8-45 Maximum 1-hour average air toxics concentrations for selected RWR receptors within 300 m of Wakehurst Parkway Ventilation Outlet (Outlet J)

Receptor height (m)	Maximum all or existing	Receptor ID	Incremental (ventilation outlet) contribution (µg/m^3)				
			Benzene	PEH (as b(a)p)	Formaldehyde	1,3-butadiene	Ethylbenzene
Criterion (µg/m^3)			**29**	**0.4**	**20**	**40**	**8000**
10 m	All(a)	RWR-03628	0.04	<0.01	0.06	0.01	0.01
	Existing(b)	RWR-04647	0.02	<0.01	0.03	0.01	0.01
20 m	All	RWR-03628	0.05	<0.01	0.06	0.01	0.02
	Existing	-	-	-	-	-	-
30 m	All	RWR-04647	0.07	<0.01	0.10	0.02	0.02
	Existing	-	-	-	-	-	-
45 m	All	RWR-04647	0.12	<0.01	0.16	0.03	0.04
	Existing	-	-	-	-	-	-

(a) Assumes at RWR receptor locations that buildings exist at all heights, irrespective of existing building heights at those locations
(b) Only includes buildings that exist at each height
Numbers in **bold** represent an exceedance of the criterion.

Table 8-46 Maximum 1-hour average air toxics concentrations for selected RWR receptors within 300 m of Burnt Bridge Creek Deviation Ventilation Outlet (Outlet K)

Receptor height (m)	Maximum all or existing	Receptor ID	Incremental (ventilation outlet) contribution (µg/m^3)				
			Benzene	PEH (as b(a)p)	Formaldehyde	1,3-butadiene	Ethylbenzene
Criterion (µg/m^3)			**29**	**0.4**	**20**	**40**	**8000**
10 m	All(a)	RWR-33605	0.07	<0.01	0.09	0.02	0.02
	Existing(b)	RWR-01569	0.05	<0.01	0.07	0.01	0.02
20 m	All	RWR-01400	0.12	<0.01	0.17	0.03	0.04
	Existing	-	-	-	-	-	-
30 m	All	RWR-01396	0.20	<0.01	0.27	0.05	0.06
	Existing	-	-	-	-	-	-
45 m	All	RWR-01400	0.32	<0.01	0.43	0.09	0.10
	Existing	-	-	-	-	-	-

(a) Assumes at RWR receptor locations that buildings exist at all heights, irrespective of existing building heights at those locations
(b) Only includes buildings that exist at each height
Numbers in **bold** represent an exceedance of the criterion.

For the maximum 1-hour average benzene concentrations, there are no predicted exceedances at any modelled height of the NSW EPA impact assessment criterion of 29 µg/m^3, when considering the maximum ventilation outlet contribution.

For the maximum 1-hour average PAHs concentrations, there are no predicted exceedances at any modelled height of the NSW EPA impact assessment criterion of 0.4 µg/m^3, when considering the maximum ventilation outlet contribution.

For the maximum 1-hour average formaldehyde concentrations, there are no predicted exceedances at any modelled height of the NSW EPA impact assessment criterion of 20 µg/m^3, when considering the maximum ventilation outlet contribution.

For the maximum 1-hour average 1,3-butadiene concentrations, there are no predicted exceedances at any modelled height of the NSW EPA impact assessment criterion of 40 µg/m^3, when considering the maximum ventilation outlet contribution.

For the maximum 1-hour average ethylbenzene concentrations, there are no predicted exceedances at any modelled height of the NSW EPA impact assessment criterion of 8000 µg/m^3, when considering the maximum ventilation outlet contribution.

Quantification of exceedances

The above sections have considered total concentrations based on the maximum contribution from the Beaches Link ventilation outlets. The discussion below considers all 436 receptors around the Beaches Link ventilation outlets.

For the annual average PM_{10} concentrations, there are no predicted exceedances at any modelled height of the NSW EPA impact assessment criterion of 25 µg/m^3.

For maximum 24-hour PM_{10} concentrations, there is only one predicted exceedance of the maximum 24-hour average PM_{10} NSW EPA impact assessment criterion of 50 µg/m^3. For 2037-DM, this receptor is exceeding the criterion at ground level. This receptor does not exist at the heights modelled.

For the annual average $PM_{2.5}$ concentrations, there are no predicted exceedances at any modelled height of the NSW EPA impact assessment criterion of 8 µg/m^3.

For the maximum 24-hour average $PM_{2.5}$ concentrations, there is only one predicted exceedance of the maximum 24-hour NSW EPA impact assessment criterion of 25 µg/m^3. For 2037-DM, this receptor is meeting the criterion at ground level and has a predicted concentration of 25 µg/m^3. This receptor does not exist at the heights modelled.

For the annual average NO_2 concentrations, there are no predicted exceedances at any modelled height of the NSW EPA impact assessment criterion of 62 µg/m^3.

For the maximum 1-hour average NO_2 concentrations, there are no predicted exceedances at any modelled height of the NSW EPA impact assessment criterion of 246 µg/m^3.

Elevated receptor modelling results – regulatory worst case (RWC)

This section presents the total concentrations for 2037-DSC scenario for RWC for all pollutants modelled for comparison with NSW EPA impact assessment criterion.

PM_{10} concentrations

Table 8-47, Table 8-48, Table 8-49 and Table 8-50 present the annual average PM_{10} concentrations for selected RWR receptors within 300 metres of Warringah Freeway Ventilation Outlet (Outlet H), Gore Hill Freeway Ventilation Outlet (Outlet I), Wakehurst Parkway Ventilation Outlet (Outlet J) and Burnt Bridge Creek Deviation Ventilation Outlet (Outlet K) at four modelled heights, for regulatory worst case outlet emissions.

Table 8-47 Annual average and maximum 24-hour average PM_{10} concentrations for selected RWR receptors within 300 metres of Warringah Freeway Ventilation Outlet (Outlet H) (regulatory worst case)

Receptor height (m)	Maximum all or existing	Receptor ID	PM_{10} concentration (µg/m^3)			
			Incremental	Background	Total	Criterion
Annual average PM_{10}						
10 m	All[(a)]	RWR-13726	0.5	15.7	16.2	25
	Existing[(b)]	RWR-13729	0.5	15.6	16.1	25
20 m	All	RWR-33249	0.8	15.6	16.4	25
	Existing	RWR-12249	0.5	15.2	15.7	25
30 m	All	RWR-33249	1.3	15.4	16.7	25
	Existing	RWR-12249	0.9	14.9	15.8	25
45 m	All	RWR-12516	2.6	13.9	16.5	25
	Existing	-	-	-	-	-
Maximum 24-hour average PM_{10}						
10 m	All[(a)]	RWR-33248	3.8	43.9	47.7	50
	Existing[(b)]	RWR-13729	3.4	45.2	48.6	50
20 m	All	RWR-33249	7.8	41.4	49.2	50
	Existing	RWR-12249	6.5	42.4	48.9	50
30 m	All	RWR-12516	21.5	41.4	**62.9**	50
	Existing	RWR-12249	14.0	41.5	**55.5**	50
45 m	All	RWR-12516	32.1	41.9	**74.0**	50
	Existing	-	-	-	-	-

(a) Assumes at RWR receptor locations that buildings exist at all heights, irrespective of existing building heights at those locations
(b) Only includes buildings that exist at each height
Numbers in **bold** represent an exceedance of the criterion
Incremental = ventilation outlet contribution
Background = surface road and non-surface road contributions
Total concentration = incremental ventilation outlet contribution + background

Table 8-48 Annual average and maximum 24-hour average PM_{10} concentrations for selected RWR receptors within 300 metres of Gore Hill Freeway Ventilation Outlet (Outlet I) (regulatory worst case)

Receptor height (m)	Maximum all or existing	Receptor ID	PM_{10} concentration (µg/m³)			
			Incremental	Background	Total	Criterion
Annual average PM_{10}						
10 m	All[(a)]	RWR-17639	0.4	15.4	15.8	25
	Existing[(b)]	RWR-17181	0.3	15.2	15.5	25
20 m	All	RWR-17628	0.5	15.2	15.7	25
	Existing	-	-	-	-	-
30 m	All	RWR-17646	1.3	15.2	16.5	25
	Existing	-	-	-	-	-
45 m	All	RWR-17555	6.4	14.8	21.2	25
	Existing	-	-	-	-	-
Maximum 24-hour average PM_{10}						
10 m	All[(a)]	RWR-18448	2.1	42.7	44.8	50
	Existing[(b)]	RWR-17181	1.5	44.3	45.8	50
20 m	All	RWR-17526	5.7	43.0	48.7	50
	Existing	-	-	-	-	-
30 m	All	RWR-17564	21.2	41.5	**62.7**	50
	Existing	-	-	-	-	-
45 m	All	RWR-17555	59.4	40.6	**100.0**	50
	Existing	-	-	-	-	-

(a) Assumes at RWR receptor locations that buildings exist at all heights, irrespective of existing building heights at those locations
(b) Only includes buildings that exist at each height
Numbers in **bold** represent an exceedance of the criterion
Incremental = ventilation outlet contribution
Background = surface road and non-surface road contributions
Total concentration = incremental ventilation outlet contribution + background

Table 8-49 Annual average and maximum 24-hour average PM_{10} concentrations for selected RWR receptors within 300 metres of Wakehurst Parkway Ventilation Outlet (Outlet J) (regulatory worst case)

Receptor height (m)	Maximum all or existing	Receptor ID	PM_{10} concentration (µg/m^3)			
			Incremental	Background	Total	Criterion
Annual average PM_{10}						
10 m	All[(a)]	RWR-03624	0.2	15.5	15.6	25
	Existing[(b)]	RWR-04647	0.1	15.5	15.7	25
20 m	All	RWR-03624	0.2	15.4	15.6	25
	Existing	-	-	-	-	-
30 m	All	RWR-03628	0.2	15.4	15.6	25
	Existing	-	-	-	-	-
45 m	All	RWR-04647	0.3	15.4	15.7	25
	Existing	-	-	-	-	-
Maximum 24-hour average PM_{10}						
10 m	All[(a)]	RWR-03624	0.7	41.4	42.1	50
	Existing[(b)]	RWR-04646	0.5	41.3	41.8	50
20 m	All	RWR-03624	0.9	41.4	42.3	50
	Existing	-	-	-	-	-
30 m	All	RWR-04647	1.2	40.9	42.1	50
	Existing	-	-	-	-	-
45 m	All	RWR-04647	2.1	40.9	43.0	50
	Existing	-	-	-	-	-

(a) Assumes at RWR receptor locations that buildings exist at all heights, irrespective of existing building heights at those locations
(b) Only includes buildings that exist at each height
Numbers in **bold** represent an exceedance of the criterion
Incremental = ventilation outlet contribution
Background = surface road and non-surface road contributions
Total concentration = incremental ventilation outlet contribution + background

Table 8-50 Annual average and maximum 24-hour average PM_{10} concentrations for selected RWR receptors within 300 metres of Burnt Bridge Creek Deviation Ventilation Outlet (Outlet K) (regulatory worst case)

Receptor height (m)	Maximum all or existing	Receptor ID	PM_{10} concentration (µg/m³) Incremental	Background	Total	Criterion
Annual average PM_{10}						
10 m	All[(a)]	RWR-01242	0.4	15.6	16.0	25
	Existing[(b)]	RWR-01569	0.2	15.7	15.9	25
20 m	All	RWR-01270	0.6	15.5	16.2	25
	Existing	-	-	-	-	-
30 m	All	RWR-01226	0.9	15.5	16.4	25
	Existing	-	-	-	-	-
45 m	All	RWR-01226	1.1	15.4	16.5	25
	Existing	-	-	-	-	-
Maximum 24-hour average PM_{10}						
10 m	All[(a)]	RWR-01242	4.4	41.5	45.9	50
	Existing[(b)]	RWR-01569	2.3	41.8	44.1	50
20 m	All	RWR-01574	9.4	40.9	**50.3**	50
	Existing	-	-	-	-	-
30 m	All	RWR-01400	19.7	40.6	**60.3**	50
	Existing	-	-	-	-	-
45 m	All	RWR-01364	15.7	40.6	**56.3**	50
	Existing	-	-	-	-	-

(a) Assumes at RWR receptor locations that buildings exist at all heights, irrespective of existing building heights at those locations
(b) Only includes buildings that exist at each height
Numbers in **bold** represent an exceedance of the criterion
Incremental = ventilation outlet contribution
Background = surface road and non-surface road contributions
Total concentration = incremental ventilation outlet contribution + background

For the annual average PM_{10} concentrations, there are no predicted exceedances at any modelled height of the NSW EPA impact assessment criterion of 25 µg/m³, when considering the maximum ventilation outlet contribution.

For the maximum 24-hour average PM_{10} concentrations, there are exceedances of the NSW EPA impact assessment criterion of 50 µg/m³ at 20 metres, 30 metres and 45 metres when considering all RWR receptor locations, irrespective of buildings that exist at those heights and when considering the maximum ventilation outlet contribution. When considering RWR receptors that do exist at each modelled height, there is one predicted exceedance of the NSW EPA impact assessment criterion of 50 µg/m³ at 30 metres at receptor RWR-12249. At this location, the contribution from the ventilation outlets is approximately 25 per cent of the total contribution. Figure 8-97 presents the location of RWR-12249 in relation to the Warringah Freeway Ventilation Outlet (Outlet H).

Figure 8-97 Location of RWR-12249 in relation to Warringah Freeway Ventilation Outlet (Outlet H)

$PM_{2.5}$ concentrations

Table 8-51, Table 8-52, Table 8-53 and Table 8-54 present the annual average $PM_{2.5}$ concentrations for selected RWR receptors within 300 metres of Warringah Freeway Ventilation Outlet (Outlet H), Gore Hill Freeway Ventilation Outlet (Outlet I), Wakehurst Parkway Ventilation Outlet (Outlet J) and Burnt Bridge Creek Deviation Ventilation Outlet (Outlet K) at four modelled heights.

Table 8-51 Annual average and maximum 24-hour average $PM_{2.5}$ concentrations for selected RWR receptors within 300 metres of Warringah Freeway Ventilation Outlet (Outlet H) (regulatory worst case)

Receptor height (m)	Maximum all or existing	Receptor ID	$PM_{2.5}$ concentration (µg/m^3)			
			Incremental	Background	Total	Criterion
Annual average $PM_{2.5}$						
10 m	All[(a)]	RWR-12414	0.2	7.1	7.4	8
	Existing[(b)]	RWR-32900	0.3	6.9	7.2	8
20 m	All	RWR-33249	0.8	7.4	**8.2**	8
	Existing	RWR-12249	0.5	7.3	7.8	8
30 m	All	RWR-33249	1.3	7.3	**8.6**	8
	Existing	RWR-12249	0.9	7.1	7.9	8
45 m	All	RWR-12516	2.6	6.5	**9.0**	8
	Existing	-	-	-	-	-
Maximum 24-hour average $PM_{2.5}$						
10 m	All[(a)]	RWR-33248	3.8	18.9	22.7	25
	Existing[(b)]	RWR-13729	3.4	20.8	24.2	25
20 m	All	RWR-33249	7.8	18.3	**26.1**	25
	Existing	RWR-12249	6.5	18.3	24.8	25
30 m	All	RWR-12516	21.5	18.0	**39.5**	25
	Existing	RWR-12249	14.0	18.2	**32.1**	25
45 m	All	RWR-12516	32.1	18.4	**50.5**	25
	Existing	-	-	-	-	-

(a) Assumes at RWR receptor locations that buildings exist at all heights, irrespective of existing building heights at those locations
(b) Only includes buildings that exist at each height
Numbers in **bold** represent an exceedance of the criterion
Incremental = ventilation outlet contribution
Background = surface road and non-surface road contributions
Total concentration = incremental ventilation outlet contribution + background

Table 8-52 Annual average and maximum 24-hour average $PM_{2.5}$ concentrations for selected RWR receptors within 300 metres of Gore Hill Freeway Ventilation Outlet (Outlet I) (regulatory worst case)

Receptor height (m)	Maximum all or existing	Receptor ID	$PM_{2.5}$ concentration (µg/m^3)			
			Incremental	Background	Total	Criterion
Annual average $PM_{2.5}$						
10 m	All[(a)]	RWR-17639	0.4	7.5	7.9	8
	Existing[(b)]	RWR-17181	0.3	7.4	7.7	8
20 m	All	RWR-17628	0.5	7.4	7.9	8
	Existing	-	-	-	-	-
30 m	All	RWR-17646	1.3	7.2	**8.5**	8
	Existing	-	-	-	-	-
45 m	All	RWR-17555	6.4	7.0	**13.4**	8
	Existing	-	-	-	-	-
Maximum 24-hour average $PM_{2.5}$						
10 m	All[(a)]	RWR-18448	2.1	18.7	20.8	25
	Existing[(b)]	RWR-17181	1.5	20.6	22.1	25
20 m	All	RWR-17526	5.7	18.6	24.3	25
	Existing	-	-	-	-	-
30 m	All	RWR-17564	21.2	18.2	**39.3**	25
	Existing	-	-	-	-	-
45 m	All	RWR-17555	59.4	17.6	**76.9**	25
	Existing	-	-	-	-	-

(a) Assumes at RWR receptor locations that buildings exist at all heights, irrespective of existing building heights at those locations
(b) Only includes buildings that exist at each height
Numbers in **bold** represent an exceedance of the criterion
Incremental = ventilation outlet contribution
Background = surface road and non-surface road contributions
Total concentration = incremental ventilation outlet contribution + background

Table 8-53 Annual average and maximum 24-hour average $PM_{2.5}$ concentrations for selected RWR receptors within 300 metres of Wakehurst Parkway Ventilation Outlet (Outlet J) (regulatory worst case)

Receptor height (m)	Maximum all or existing	Receptor ID	$PM_{2.5}$ concentration ($\mu g/m^3$) Incremental	Background	Total	Criterion
Annual average $PM_{2.5}$						
10 m	All[(a)]	RWR-03624	0.2	7.6	7.8	8
	Existing[(b)]	RWR-04647	0.1	7.7	7.8	8
20 m	All	RWR-03624	0.2	7.6	7.8	8
	Existing	-	-	-	-	-
30 m	All	RWR-03628	0.2	7.6	7.8	8
	Existing	-	-	-	-	-
45 m	All	RWR-04647	0.3	7.6	7.9	8
	Existing	-	-	-	-	-
Maximum 24-hour average $PM_{2.5}$						
10 m	All[(a)]	RWR-03624	0.7	18.3	19.0	25
	Existing[(b)]	RWR-04646	0.5	18.0	18.4	25
20 m	All	RWR-03624	0.9	18.1	19.1	25
	Existing	-	-	-	-	-
30 m	All	RWR-04647	1.2	17.9	19.1	25
	Existing	-	-	-	-	-
45 m	All	RWR-04647	2.1	17.7	19.8	25
	Existing	-	-	-	-	-

(a) Assumes at RWR receptor locations that buildings exist at all heights, irrespective of existing building heights at those locations
(b) Only includes buildings that exist at each height
Numbers in **bold** represent an exceedance of the criterion
Incremental = ventilation outlet contribution
Background = surface road and non-surface road contributions
Total concentration = incremental ventilation outlet contribution + background

Table 8-54 Annual average and maximum 24-hour average $PM_{2.5}$ concentrations for selected RWR receptors within 300 metres of Burnt Bridge Creek Deviation Ventilation Outlet (Outlet K) (regulatory worst case)

Receptor height (m)	Maximum all or existing	Receptor ID	$PM_{2.5}$ concentration (µg/m^3)			
			Incremental	Background	Total	Criterion
Annual average $PM_{2.5}$						
10 m	All[(a)]	RWR-01242	0.4	7.7	**8.1**	8
	Existing[(b)]	RWR-01569	0.2	7.7	7.9	8
20 m	All	RWR-01270	0.6	7.7	**8.3**	8
	Existing	-	-	-	-	-
30 m	All	RWR-01226	0.9	7.6	**8.5**	8
	Existing	-	-	-	-	-
45 m	All	RWR-01226	1.1	7.6	**8.6**	8
	Existing	-	-	-	-	-
Maximum 24-hour average $PM_{2.5}$						
10 m	All[(a)]	RWR-01242	4.4	17.9	22.3	25
	Existing[(b)]	RWR-01569	2.3	18.4	20.7	25
20 m	All	RWR-01574	9.4	17.5	**26.9**	25
	Existing	-	-	-	-	-
30 m	All	RWR-01400	19.7	17.6	**37.2**	25
	Existing	-	-	-	-	-
45 m	All	RWR-01364	15.7	17.6	**33.3**	25
	Existing	-	-	-	-	-

(a) Assumes at RWR receptor locations that buildings exist at all heights, irrespective of existing building heights at those locations
(b) Only includes buildings that exist at each height
Numbers in **bold** represent an exceedance of the criterion
Incremental = ventilation outlet contribution
Background = surface road and non-surface road contributions
Total concentration = incremental ventilation outlet contribution + background

For the annual average $PM_{2.5}$ concentrations, there are predicted exceedances of the NSW EPA impact assessment criterion of 8 µg/m^3 at 10 metres, 20 metres, 30 metres and 45 metres when considering all RWR receptor locations, irrespective of buildings that exist at those heights and when considering the maximum ventilation outlet contribution. When considering RWR receptors that do exist at each modelled height, there are no predicted exceedance of the NSW EPA impact assessment criterion of 8 µg/m^3.

For the maximum 24-hour average $PM_{2.5}$ concentrations, there are exceedances of the NSW EPA impact assessment criterion of 25 µg/m^3 at 20 metres, 30 metres and 45 metres when considering all RWR receptor locations, irrespective of buildings that exist at those heights and when considering the maximum ventilation outlet contribution. When considering RWR receptors that do exist at each modelled height, there is one predicted exceedance of the NSW EPA impact assessment criterion of 25 µg/m^3 at 30 metres at receptor RWR-12249. At this location, the contribution from the ventilation outlets is approximately 43 per cent of the total contribution. The location of this receptor is shown in Figure 8-97.

NO_2 concentrations

Table 8-55, Table 8-56, Table 8-57 and Table 8-58 present the annual average NO_2 concentrations for selected RWR receptors within 300 metres of Warringah Freeway Ventilation Outlet (Outlet H), Gore

Hill Freeway Ventilation Outlet (Outlet I), Wakehurst Parkway Ventilation Outlet (Outlet J) and Burnt Bridge Creek Deviation Ventilation Outlet (Outlet K) at four modelled heights.

Table 8-55 Annual average and maximum 1-hour average NO_2 concentrations for selected RWR receptors within 300 metres of the Warringah Freeway Ventilation Outlet (Outlet H) (regulatory worst case)

Receptor height (m)	Maximum all or existing	Receptor ID	NO_X and NO_2 concentrations (µg/m^3)				
			Incremental NO_X	Background NO_X	Total NO_X	Total NO_2	Criterion
Annual average NO_X / NO_2							
10 m	All[(a)]	RWR-13729	9.9	35.5	45.4	22.8	62
	Existing[(b)]	RWR-13729	9.9	35.5	45.4	22.8	62
20 m	All	RWR-33249	13.4	25.5	38.9	20.9	62
	Existing	RWR-12249	8.2	28.1	36.3	20.0	62
30 m	All	RWR-33249	23.3	21.3	44.7	22.5	62
	Existing	RWR-12249	15.0	23.2	38.2	20.6	62
45 m	All	RWR-12516	46.9	18.1	65.0	27.5	62
	Existing	-	-	-	-	-	-
Maximum 1-hour average NO_X / NO_2							
10 m	All[(a)]	RWR-12146	201	840	1040	209	246
	Existing[(b)]	RWR-11931	201	787	988	207	246
20 m	All	RWR-12189	319	722	1040	209	246
	Existing	RWR-12249	238	637	875	202	246
30 m	All	RWR-12414	193	476	669	191	246
	Existing	RWR-12249	115	472	588	186	246
45 m	All	RWR-12414	366	290	656	190	246
	Existing	-	-	-	-	-	-

(a) Assumes at RWR receptor locations that buildings exist at all heights, irrespective of existing building heights at those locations
(b) Only includes buildings that exist at each height
Numbers in **bold** represent an exceedance of the criterion
Incremental = ventilation outlet contribution
Background = surface road and non-surface road contributions
Total NO_X = incremental ventilation outlet contribution + background
Total NO_2 = Total NO_X converted to NO_2

Table 8-56 Annual average and maximum 1-hour average NO_2 concentrations for selected RWR receptors within 300 metres of the Gore Hill Freeway Ventilation Outlet (Outlet I) (regulatory worst case)

Receptor height (m)	Maximum all or existing	Receptor ID	NO_X and NO_2 concentrations (µg/m^3)				
			Incremental NO_X	Background NO_X	Total NOx	Total NO_2	Criterion
Annual average NO_X / NO_2							
10 m	All(a)	RWR-17319	6.98	27.5	34.5	19.4	62
	Existing(b)	RWR-17449	5.35	31.3	36.6	20.1	62
20 m	All	RWR-17706	8.54	24.4	33.0	18.9	62
	Existing	-	-	-	-	-	-
30 m	All	RWR-17646	23.99	22.0	46.0	22.9	62
	Existing	-	-	-	-	-	-
45 m	All	RWR-17555	117.83	17.7	135.6	39.8	62
	Existing	-	-	-	-	-	-
Maximum 1-hour average NO_X / NO_2							
10 m	All(a)	RWR-33392	121	769	890	202	246
	Existing(b)	RWR-17181	67	771	838	200	246
20 m	All	RWR-17526	189	554	744	195	246
	Existing	-	-	-	-	-	-
30 m	All	RWR-17555	251	356	607	187	246
	Existing	-	-	-	-	-	-
45 m	All	RWR-17555	692	356	1049	209	246
	Existing	-	-	-	-	-	-

(a) Assumes at RWR receptor locations that buildings exist at all heights, irrespective of existing building heights at those locations
(b) Only includes buildings that exist at each height
Numbers in **bold** represent an exceedance of the criterion
Incremental = ventilation outlet contribution
Background = surface road and non-surface road contributions
Total NO_X = incremental ventilation outlet contribution + background
Total NO_2 = Total NO_X converted to NO_2

Table 8-57 Annual average and maximum 1-hour average NO_2 concentrations for selected RWR receptors within 300 metres of the Wakehurst Parkway Ventilation Outlet (Outlet J) (regulatory worst case)

Receptor height (m)	Maximum all or existing	Receptor ID	NO_X and NO_2 concentrations (µg/m^3)				
			Incremental NO_X	Background NO_X	Total NO_X	Total NO_2	Criterion
Annual average NO_X / NO_2							
10 m	All[(a)]	RWR-03625	3.43	18.1	21.5	14.4	62
	Existing[(b)]	RWR-04646	2.48	18.4	20.8	14.1	62
20 m	All	RWR-03628	3.67	15.5	19.2	13.3	62
	Existing	-	-	-	-	-	-
30 m	All	RWR-03625	3.94	13.4	17.3	12.3	62
	Existing	-	-	-	-	-	-
45 m	All	RWR-03628	5.54	11.1	16.6	12.0	62
	Existing	-	-	-	-	-	-
Maximum 1-hour average NO_X / NO_2							
10 m	All[(a)]	RWR-03625	71.36	649.7	721.0	194	246
	Existing[(b)]	RWR-04647	51.26	555.0	606.3	187	246
20 m	All	RWR-03625	107.60	493.3	600.9	187	246
	Existing		-	-	-	-	-
30 m	All	RWR-04647	32.06	421.1	453.1	177	246
	Existing		-	-	-	-	-
45 m	All	RWR-04647	55.24	413.6	468.8	178	246
	Existing	-	-	-	-	-	-

(a) Assumes at RWR receptor locations that buildings exist at all heights, irrespective of existing building heights at those locations
(b) Only includes buildings that exist at each height
Numbers in **bold** represent an exceedance of the criterion
Incremental = ventilation outlet contribution
Background = surface road and non-surface road contributions
Total NO_X = incremental ventilation outlet contribution + background
Total NO_2 = Total NO_X converted to NO_2

Table 8-58 Annual average and maximum 1-hour average NO_2 concentrations for selected RWR receptors within 300 metres of the Burnt Bridge Creek Deviation Ventilation Outlet (Outlet K) (regulatory worst case)

Receptor height (m)	Maximum all or existing	Receptor ID	NO_X and NO_2 concentrations (µg/m^3)				
			Incremental NO_X	Background NO_X	Total NO_X	Total NO_2	Criterion
Annual average NO_X / NO_2							
10 m	All[(a)]	RWR-01242	7.42	21.7	29.1	17.5	62
	Existing[(b)]	RWR-01569	4.49	21.9	26.4	16.5	62
20 m	All	RWR-01270	11.33	20.0	31.4	18.3	62
	Existing	-	-	-	-	-	-
30 m	All	RWR-01270	16.30	17.8	34.1	19.3	62
	Existing	-	-	-	-	-	-
45 m	All	RWR-01226	19.94	14.9	34.9	19.6	62
	Existing	-	-	-	-	-	-
Maximum 1-hour average NO_X / NO_2							
10 m	All[(a)]	RWR-01400	184	647	831	200	246
	Existing[(b)]	RWR-01569	164	612	775	197	246
20 m	All	RWR-01400	357	488	845	200	246
	Existing	-	-	-	-	-	-
30 m	All	RWR-00467	181	581	762	196	246
	Existing	-	-	-	-	-	-
45 m	All	RWR-00485	253	385	638	189	246
	Existing	-	-	-	-	-	-

(a) Assumes at RWR receptor locations that buildings exist at all heights, irrespective of existing building heights at those locations
(b) Only includes buildings that exist at each height
Numbers in **bold** represent an exceedance of the criterion
Incremental = ventilation outlet contribution
Background = surface road and non-surface road contributions
Total NO_X = incremental ventilation outlet contribution + background
Total NO_2 = Total NO_X converted to NO_2

For the annual average NO_2 concentrations, there are no exceedances at any modelled height of the NSW EPA impact assessment criterion of 62 µg/m^3, when considering the maximum ventilation outlet contribution.

For the maximum 1-hour average NO_2 concentrations, there are no exceedances at any modelled height of the NSW EPA impact assessment criterion of 246 µg/m^3, when considering the maximum ventilation outlet contribution.

Air toxics

This section presents the maximum 1-hour average incremental air toxic concentrations for benzene, PAHs (as b(a)p), formaldehyde, 1,3-butadiene and ethylbenzene for selected RWR receptors at four modelled heights. The conversion percentage of each of the five air toxics has been applied after modelling and the values are the same as those applied previously in this assessment.

Table 8-59, Table 8-60, Table 8-61 and Table 8-62 present the maximum 1-hour average air toxics concentrations for selected RWR receptors within 300 metres of each of the four modelled heights for Warringah Freeway Ventilation Outlet (Outlet H), Gore Hill Freeway Ventilation Outlet (Outlet I), Wakehurst Parkway Ventilation Outlet (Outlet J) and Burnt Bridge Creek Deviation Ventilation Outlet (Outlet K).

For the maximum 1-hour average benzene concentrations, there are no exceedances at any modelled height of the NSW EPA impact assessment criterion of 29 µg/m³, when considering the maximum ventilation outlet contribution.

For the maximum 1-hour average PAHs concentrations, there are no exceedances at any modelled height of the NSW EPA impact assessment criterion of 0.4 µg/m³, when considering the maximum ventilation outlet contribution.

For the maximum 1-hour average formaldehyde concentrations, there is one exceedances of the NSW EPA impact assessment criterion of 20 µg/m³ at 45 metres when considering all RWR locations, irrespective of buildings that exist at those heights, when considering the maximum ventilation outlet contribution.

For the maximum 1-hour average 1,3-butadiene concentrations, there are no exceedances at any modelled height of the NSW EPA impact assessment criterion of 40 µg/m³, when considering the maximum ventilation outlet contribution.

For the maximum 1-hour average ethylbenzene concentrations, there are no exceedances at any modelled height of the NSW EPA impact assessment criterion of 8000 µg/m³, when considering the maximum ventilation outlet contribution.

Table 8-59 Maximum 1-hour average air toxics concentrations for selected RWR receptors within 300 metres of the Warringah Freeway Ventilation Outlet (Outlet H) (regulatory worst case)

Receptor height (m)	Maximum all or existing	Receptor ID	Incremental (ventilation outlet) contribution (µg/m³)				
			Benzene	PAHs (as b(a)p)	Formaldehyde	1,3-butadiene	Ethylbenzene
Criterion (µg/m³)			**29**	**0.4**	**20**	**40**	**8000**
10 m	All[(a)]	RWR-12103	1.40	0.02	1.90	0.38	0.45
	Existing[(b)]	RWR-11931	1.29	0.02	1.75	0.35	0.42
20 m	All	RWR-12325	2.06	0.03	2.79	0.56	0.67
	Existing	RWR-12249	1.69	0.02	2.29	0.46	0.55
30 m	All	RWR-12407	5.49	0.07	7.45	1.50	1.78
	Existing	RWR-12249	3.61	0.05	4.90	0.99	1.17
45 m	All	RWR-12516	12.94	0.17	17.54	3.54	4.19
	Existing	-	-	-	-	-	-

(a) Assumes at RWR receptor locations that buildings exist at all heights, irrespective of existing building heights at those locations
(b) Only includes buildings that exist at each height
Numbers in **bold** represent an exceedance of the criterion.

Table 8-60 Maximum 1-hour average air toxics concentrations for selected RWR receptors within 300 metres of the Gore Hill Freeway Ventilation Outlet (Outlet I) (regulatory worst case)

Receptor height (m)	Maximum all or existing	Receptor ID	Incremental (ventilation outlet) contribution (µg/m^3)				
			Benzene	PAHs (as b(a)p)	Formaldehyde	1,3-butadiene	Ethylbenzene
Criterion (µg/m^3)			**29**	**0.4**	**20**	**40**	**8000**
10 m	All[(a)]	RWR-18291	0.93	0.01	1.27	0.26	0.30
	Existing[(b)]	RWR-17181	0.46	0.01	0.62	0.13	0.15
20 m	All	RWR-17526	1.35	0.02	1.83	0.37	0.44
	Existing	-	-	-	-	-	-
30 m	All	RWR-17555	6.91	0.09	9.37	1.89	2.24
	Existing	-	-	-	-	-	-
45 m	All	RWR-17555	27.89	0.36	**37.82**	7.64	9.02
	Existing	-	-	-	-	-	-

(a) Assumes at RWR receptor locations that buildings exist at all heights, irrespective of existing building heights at those locations
(b) Only includes buildings that exist at each height
Numbers in **bold** represent an exceedance of the criterion.

Table 8-61 Maximum 1-hour average air toxics concentrations for selected RWR receptors within 300 metres of the Wakehurst Parkway Ventilation Outlet (Outlet J) (regulatory worst case)

Receptor height (m)	Maximum all or existing	Receptor ID	Incremental (ventilation outlet) contribution (µg/m^3)				
			Benzene	PAH (as b(a)p)	Formaldehyde	1,3-butadiene	Ethylbenzene
Criterion (µg/m^3)			**29**	**0.4**	**20**	**40**	**8000**
10 m	All[(a)]	RWR-03624	0.54	0.01	0.74	0.15	0.18
	Existing[(b)]	RWR-04647	0.47	0.01	0.64	0.13	0.15
20 m	All	RWR-03624	0.69	0.01	0.94	0.19	0.22
	Existing	-	-	-	-	-	-
30 m	All	RWR-04647	0.95	0.01	1.29	0.26	0.31
	Existing	-	-	-	-	-	-
45 m	All	RWR-04647	1.75	0.02	2.38	0.48	0.57
	Existing	-	-	-	-	-	-

(a) Assumes at RWR receptor locations that buildings exist at all heights, irrespective of existing building heights at those locations
(b) Only includes buildings that exist at each height
Numbers in **bold** represent an exceedance of the criterion.

Table 8-62 Maximum 1-hour average air toxics concentrations for selected RWR receptors within 300 metres of the Burnt Bridge Creek Ventilation Outlet (Outlet K) (regulatory worst case)

Receptor height (m)	Maximum all or existing	Receptor ID	Incremental (ventilation outlet) contribution (µg/m³)				
			Benzene	PAHs (as b(a)p)	Formaldehyde	1,3-butadiene	Ethylbenzene
Criterion (µg/m³)			**29**	**0.4**	**20**	**40**	**8000**
10 m	All[(a)]	RWR-33072	1.25	0.02	1.69	0.34	0.40
	Existing[(b)]	RWR-00508	1.03	0.01	1.39	0.28	0.33
20 m	All	RWR-01400	2.48	0.03	3.36	0.68	0.80
	Existing	-	-	-	-	-	-
30 m	All	RWR-01400	3.54	0.05	4.80	0.97	1.15
	Existing	-	-	-	-	-	-
45 m	All	RWR-01400	4.95	0.06	6.71	1.36	1.60
	Existing	-	-	-	-	-	-

(a) Assumes at RWR receptor locations that buildings exist at all heights, irrespective of existing building heights at those locations
(b) Only includes buildings that exist at each height
Numbers in **bold** represent an exceedance of the criterion.

Summary

Expected traffic

When considering the maximum ventilation outlet contribution the findings are as follows:

- For the annual average PM_{10} concentrations, there are no predicted exceedances at any modelled height of the NSW EPA impact assessment criteria.
- For the maximum 24-hour average PM_{10} concentrations, there is one predicted exceedances of the NSW EPA impact assessment criterion at 45 metres when considering all RWR receptors, irrespective of buildings that exist at those heights and when considering the maximum ventilation outlet contribution. When considering RWR receptors that do exist at each modelled height, there are no predicted exceedances of the NSW EPA impact assessment criterion of 50 µg/m³ at any height.
- For the annual average $PM_{2.5}$ concentrations, there are no predicted exceedances at any modelled height of the NSW EPA impact assessment criteria.
- For the maximum 24-hour average $PM_{2.5}$ concentrations, there is one predicted exceedances of the NSW EPA impact assessment criterion at 45 metres when considering all RWR receptors, irrespective of buildings that exist at those heights and when considering the maximum ventilation outlet contribution. When considering RWR receptors that do exist at each modelled height, there are no predicted exceedances of the NSW EPA impact assessment criterion of 25 µg/m³ at any height.
- For the annual average NO_2 concentrations, there are no predicted exceedances at any modelled height of the NSW EPA impact assessment criterion.
- For the maximum 1-hour average NO_2 concentrations, there are no predicted exceedance at any modelled height of the NSW EPA impact assessment criterion.
- For the maximum 1-hour average benzene, PAHs, formaldehyde, 1,3-butadiene and ethylbenzene concentrations, there are no predicted exceedances at any modelled height of the NSW EPA impact assessment criteria.

When considering all 436 receptors around the four ventilation outlets to provide a quantification of exceedances, the findings are as follows:

- For the annual average PM_{10} concentrations, there are no predicted exceedances at any modelled height of the NSW EPA impact assessment criteria.
- For the maximum 24-hour average PM_{10} concentrations, there is one predicted exceedance (at RWR-17555) of the NSW EPA impact assessment criterion out of 436 receptors assessed. This receptor does not exist at the heights modelled. This exceedance is an additional exceedance when compared with the 2037-DM scenario.
- For the annual average $PM_{2.5}$ concentrations, there are no predicted exceedances at any modelled height of the NSW EPA impact assessment criteria.
- For the maximum 24-hour average $PM_{2.5}$ concentrations, there is one predicted exceedance (at RWR-17555) of the NSW EPA impact assessment criterion out of 436 receptors assessed. This receptor does not exist at the heights modelled. This exceedance is an additional exceedance when compared with the 2037-DM scenario.
- For the annual average NO_2 concentrations, there are no predicted exceedances at any modelled height of the NSW EPA impact assessment criterion.
- For the maximum 1-hour average NO_2 concentrations, there are no predicted exceedances at any modelled height of the NSW EPA impact assessment criterion.
- For the maximum 1-hour average benzene, PAHs, formaldehyde, 1,3-butadiene and ethylbenzene concentrations, there are no exceedances at any modelled height of the NSW EPA impact assessment criteria.

Regulatory worst case

When considering the maximum ventilation outlet contribution the findings are as follows:

- For the annual average PM_{10} concentrations, there are no predicted exceedances at any modelled height of the NSW EPA impact assessment criterion.
- For the maximum 24-hour average PM_{10} concentrations, there are predicted exceedances of the NSW EPA impact assessment criterion of 50 $\mu g/m^3$ at 20 metres, 30 metres and 45 metres when considering all RWR receptor locations, irrespective of buildings that exist at those heights and when considering the maximum ventilation outlet contribution. When considering RWR receptors that do exist at each modelled height, there is one predicted exceedance of the NSW EPA impact assessment criterion of 50 $\mu g/m^3$ at 30 metres at receptor RWR-12249, located near to the Warringah Freeway Ventilation Outlet H (Outlet H). At this location, the contribution from the ventilation outlets is approximately 25 per cent of the total contribution.
- For the annual average $PM_{2.5}$ concentrations, there are predicted exceedances of the NSW EPA impact assessment criterion of 8 $\mu g/m^3$ at 10 metres, 20 metres, 30 metres and 45 metres when considering all RWR receptor locations, irrespective of buildings that exist at those heights and when considering the maximum ventilation outlet contribution. When considering RWR receptors that do exist at each modelled height, there are no predicted exceedance of the NSW EPA impact assessment criterion of 8 $\mu g/m^3$.
- For the maximum 24-hour average $PM_{2.5}$ concentrations, there are exceedances of the NSW EPA impact assessment criterion of 25 $\mu g/m^3$ at 20 metres, 30 metres and 45 metres when considering all RWR receptor locations, irrespective of buildings that exist at those heights and when considering the maximum ventilation outlet contribution. When considering RWR receptors that do exist at each modelled height, there is one predicted exceedance of the NSW EPA impact assessment criterion of 25 $\mu g/m^3$ at 30 metres at receptor RWR-12249, located near to the Warringah Freeway Ventilation Outlet (Outlet H). At this location, the contribution from the ventilation outlets is approximately 43 per cent of the total contribution.
- For the annual average NO_2 concentrations, there are no predicted exceedances at any modelled height of the NSW EPA impact assessment criterion.
- For the maximum 1-hour average NO_2 concentrations there are no predicted exceedances at any modelled height of the NSW EPA impact assessment criterion.

- For the maximum 1-hour average benzene, PAHs, 1,3-butadiene and ethylbenzene concentrations, there are no predicted exceedances at any modelled height of the NSW EPA impact assessment criteria.
- For the maximum 1-hour average formaldehyde concentrations, there is one predicted exceedance of the NSW EPA impact assessment criterion of 20 µg/m^3 at 45 metres at RWR-17555, located near to the Gore Hill Freeway Ventilation Outlet (Outlet I) when considering all RWR locations, irrespective of buildings that exist at those heights.

8.4.10 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 8-63 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 and Transport for NSW 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 site 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 and Transport for NSW 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.
1.4	Community receptors *NO_X, 1-hour mean*	Hourly monitoring data from several Department of Planning, Industry and Environment and Transport for NSW 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.

Topic and sub-topic		Method and assumptions	Implications for conservatism
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 and Transport for NSW 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 sites 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 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.
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.

Topic and sub-topic		Method and assumptions	Implications for conservatism
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 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.
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.

Topic and sub-topic		Method and assumptions	Implications for conservatism
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 15-35°C.
7	Post-processing (NO_2) – community receptors		
7.1	NO_X-to-NO_2 conversion, annual mean	A 'best estimate' empirical approach was used, which gave the most likely annual mean NO_2 concentration for a given annual mean NO_X concentration.	The approach used was not inherently conservative.
7.2	NO_X-to-NO_2 conversion, maximum 1-hour mean	A 'detailed' contemporaneous approach was used. This involved the use of a conservative upper bound empirical function which gave the maximum likely 1-hour mean NO_2 concentration for a given 1-hour mean NO_X concentration.	Given the wide range of possible NO_2 concentrations for a given NO_X concentration, this approach was used to estimate the maximum 1-hour mean NO_2 concentrations conservatively. The dispersion modelling evaluation showed, however, that this method was less conservative than the OLM.
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.

8.4.11 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 Beaches Link GRAL domain of around two kilometres x two kilometres around the Warringah Freeway ventilation outlets (Outlet G for Western Harbour Tunnel and Outlet H for the project), as shown on Figure 8-98.

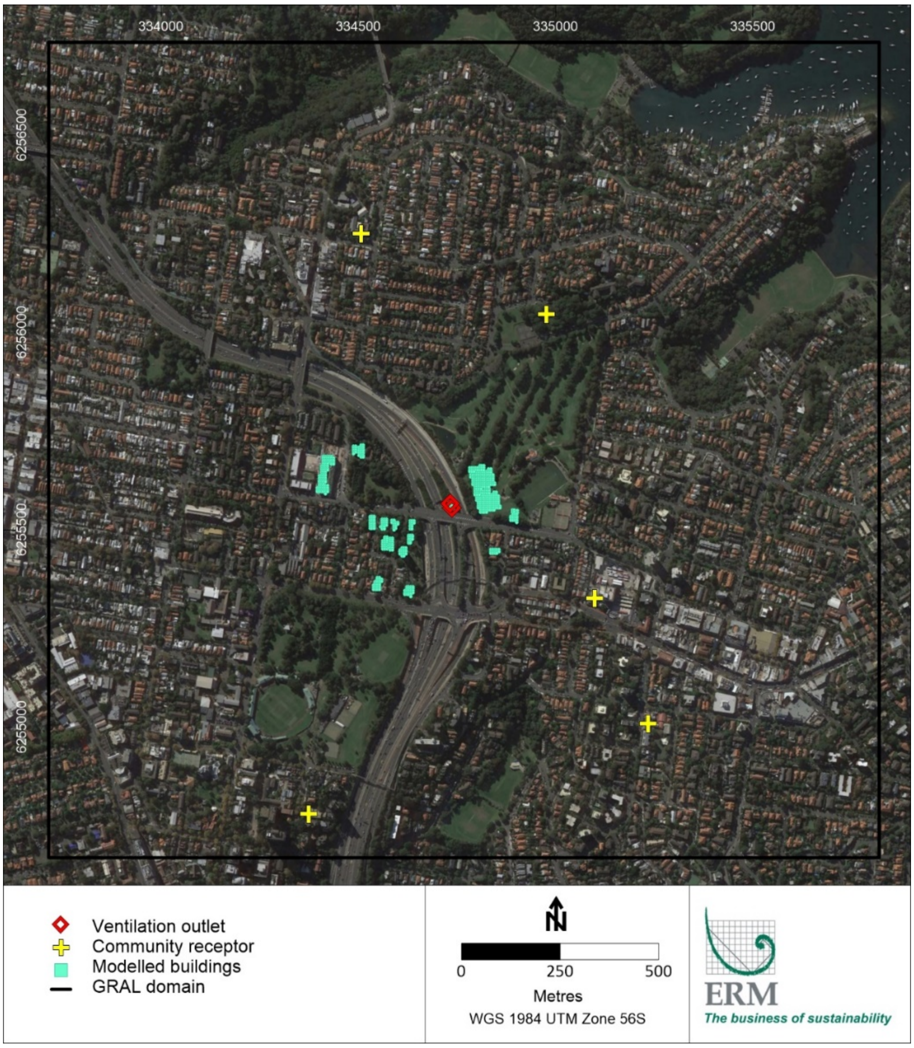


Figure 8-98 Domain and buildings for Warringah Freeway Ventilation Outlets (Outlets G and H) sensitivity tests

Model predictions were considered for five community receptors located within the Warringah Freeway domain, as listed in Table 8-64.

Table 8-64 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 10°C below and above this value were then investigated. In temperature test TT01 the ventilation outlet temperature was set to 15°C, and in temperature test TT03 the ventilation outlet temperature was set to 35°C.

Table 8-65 presents the $PM_{2.5}$ concentration results for the temperature sensitivity tests, and Table 8-66 gives the percentage changes in concentration relative to the central estimate.

For the ventilation outlet temperature of 15°C 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 contributions at ground level remained very low compared to the air quality criteria for $PM_{2.5}$ and a very small component of the total predicted $PM_{2.5}$ concentration.

For the ventilation outlet temperature of 35°C 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.

In summary, the sensitivity test shows that predicted concentrations for the ventilation outlet temperature at the central estimate of 25 ºC are generally between those at 15 ºC and 35 ºC. This gives confidence that at 25 ºC, the predicted concentrations have likely not been over-estimated or under-estimated.

Table 8-65 Results of sensitivity tests for ventilation outlet temperature – predicted $PM_{2.5}$ concentrations

ID	Name	HT01 (15°C)			HT02 (25°C)			HT03 (35°C)		
		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
CR16	Anzac Park Public School	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 8-66 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 Average				Max 1h	Max 24h	Annual average
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 8-67 presents the results of the height sensitivity tests, and the percentage changes in concentration relative to the central estimate are given in Table 8-68.

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 contributions at ground level remained well below the air quality criteria for $PM_{2.5}$ and a very small component of the total predicted $PM_{2.5}$ concentration.

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 8-67 Results of sensitivity tests for ventilation outlet height – predicted concentrations

ID	Name	HT01 (20 metres)			HT02 (30 metres)			HT03 (40 metres)		
		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
CR16	Anzac Park Public School	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 8-68 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 Average		Max 1h	Max 24h	Annual Average
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 8.4.1 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 8-69. 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.

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 $PM_{2.5}$ at ground level 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 by changes in ventilation outlet temperature. 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.

Table 8-69 Results of sensitivity tests for buildings – predicted concentrations and percentage changes

ID	Name	PM$_{2.5}$ (µg/m^3)								
		BT01 (with buildings)			BT02 (with 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*
CR08	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%*	*2%*
CR11	Neutral Bay Medical Centre	3.436	0.595	0.051	3.320	0.595	0.047	*3%*	*0%*	*7%*
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%*	*13%*

8.4.12 Sensitivity tests – traffic and emissions

Results for the sensitivity test outlined in Section 6.5.2 (the Sensitivity scenario) 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. As would be expected, the locations of the ten most impacted receptors differs depending on the averaging period.

Figure 8-99 presents the annual mean $PM_{2.5}$ results for the three scenarios, that is, expected traffic (ET), the Sensitivity scenario (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 8-100, Figure 8-101, Figure 8-102 and Figure 8-103 presents this same information, for the four project-related ventilation outlets individually (Warringah Freeway Ventilation Outlet (Outlet H), Gore Hill Freeway Ventilation Outlet (Outlet I), Wakehurst Parkway Ventilation Outlet (Outlet J) and Burnt Bridge Creek Deviation Ventilation Outlet (Outlet K)). It should be noted that while the focus is on the outlets related to the Beaches Link project, the model includes all existing and proposed ventilation outlets and so results will include contributions from all.

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 the maximum 24-hour average $PM_{2.5}$ concentrations than for the annual 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 Warringah Freeway ventilation outlet and Wakehurst Parkway ventilation outlet. At RWR-13133, RWR-13126 (both around Warringah Freeway ventilation outlet), RWR-33300, RWR-33259 (both around Wakehurst Parkway ventilation outlet) 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 Warringah Freeway ventilation outlet and Wakehurst Parkway ventilation outlet. At RWR-13132 (around Warringah Freeway ventilation outlet), RWR-33259 and RWR-33256 (both around Wakehurst Parkway ventilation outlet) the results for the sensitivity scenario were 55 per cent of the RWC values.

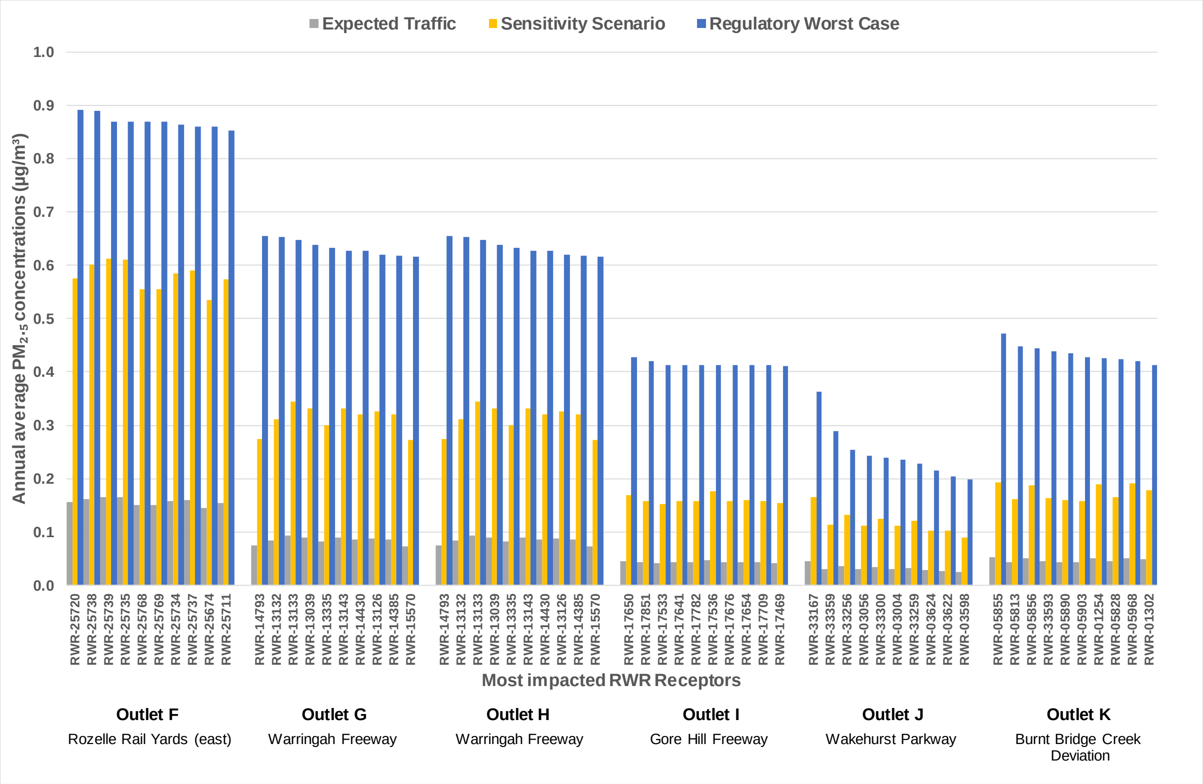


Figure 8-99 Annual average $PM_{2.5}$ concentrations for the Sensitivity scenario compared against ET and RWC for the ten most impacted receptors surrounding each of the project-related ventilation outlets

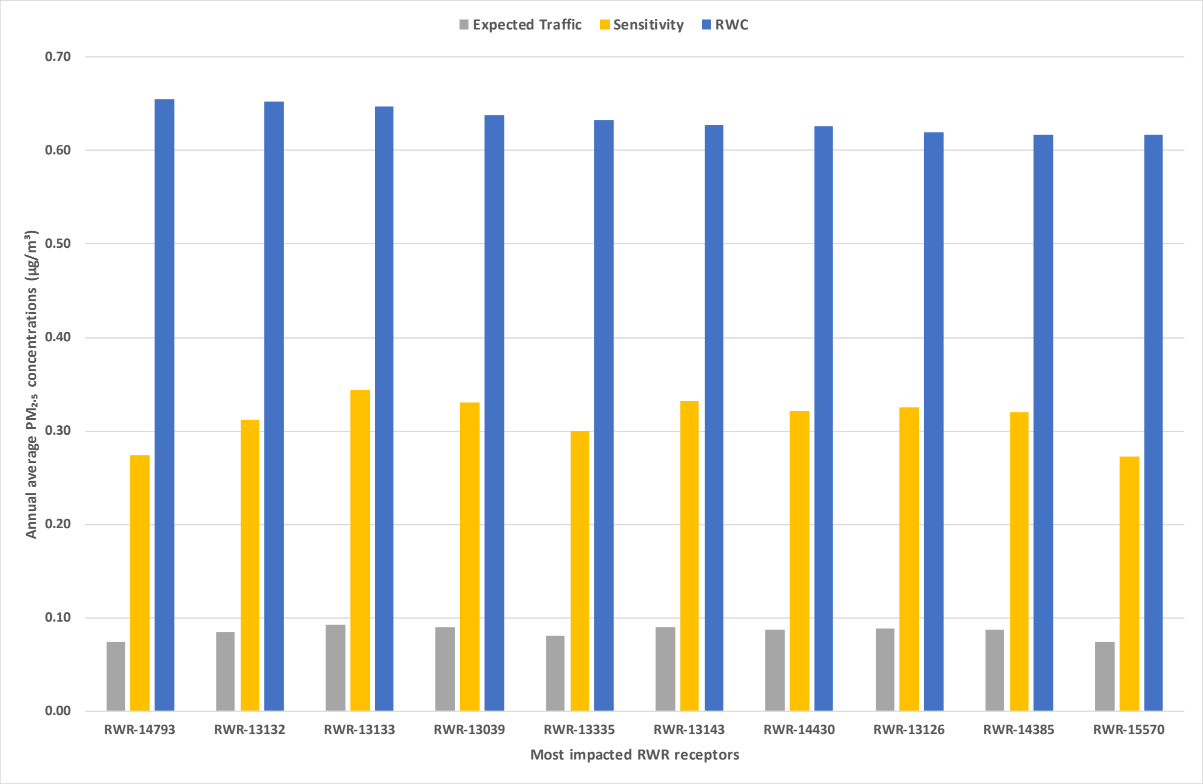


Figure 8-100 Annual average $PM_{2.5}$ concentrations for the Sensitivity scenario compared against ET and RWC for the ten most impacted receptors surrounding the Beaches Link Warringah Freeway ventilation outlet (H)

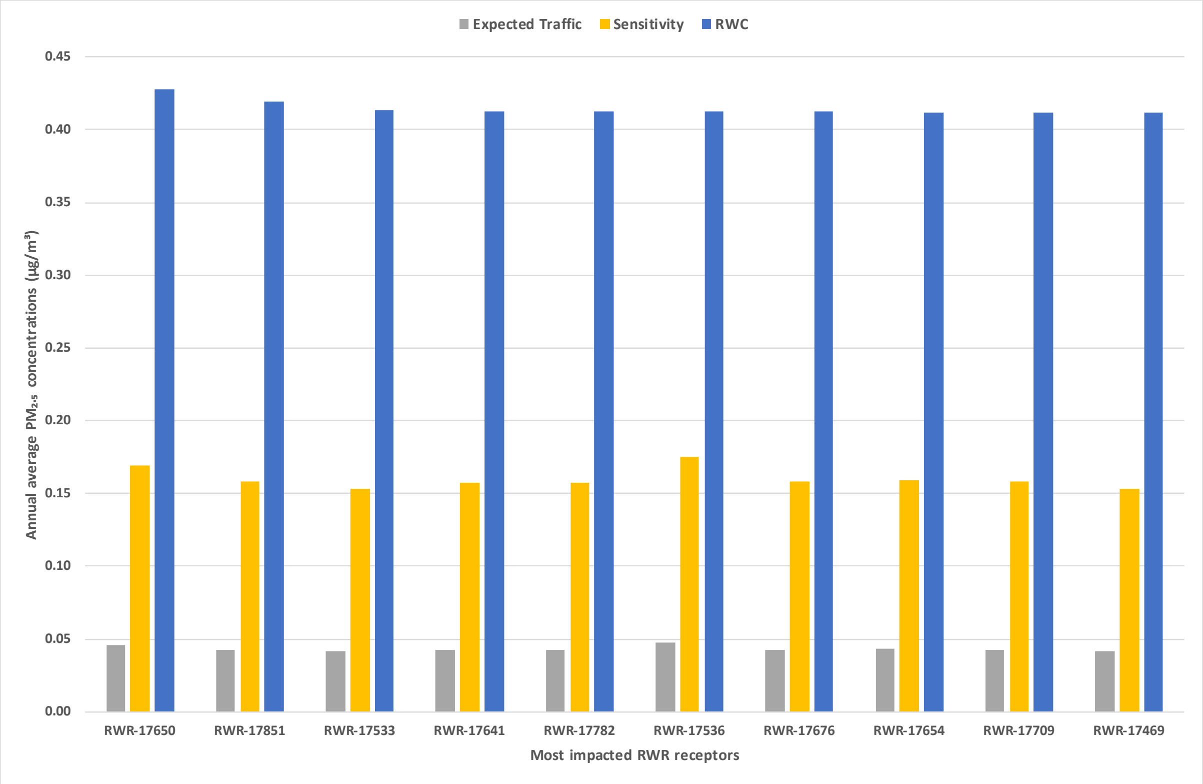


Figure 8-101 Annual average $PM_{2.5}$ concentrations for the Sensitivity scenario compared against ET and RWC for the ten most impacted receptors surrounding the Beaches Link Gore Hill Freeway ventilation outlet (I)

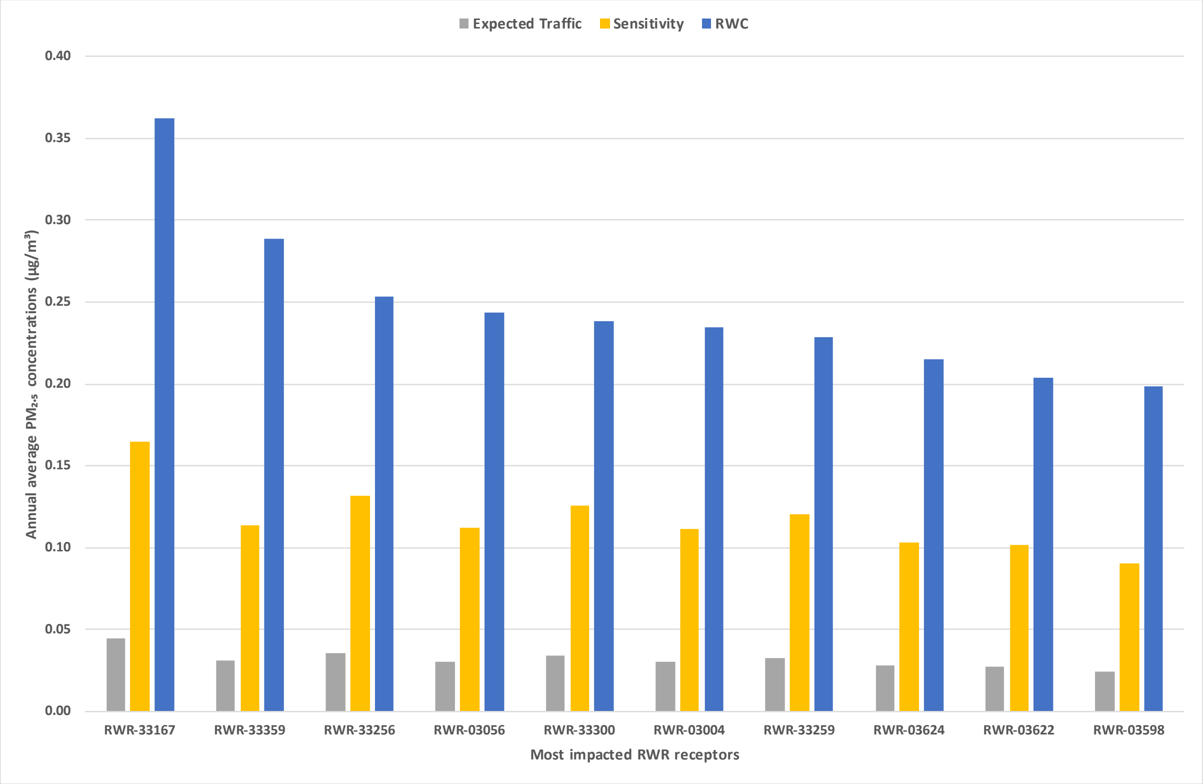


Figure 8-102 Annual average $PM_{2.5}$ concentrations for the Sensitivity scenario compared against ET and RWC for the ten most impacted receptors surrounding the Beaches Link Wakehurst Parkway ventilation outlet (J)

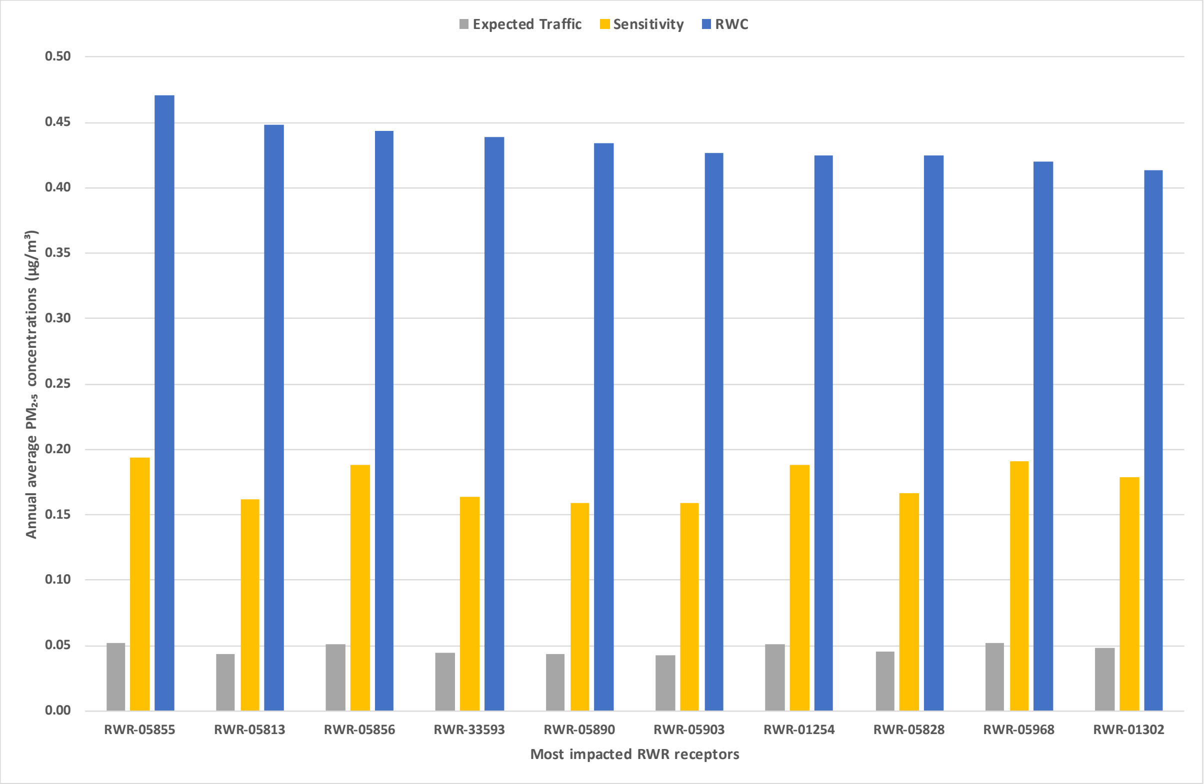


Figure 8-103 **Annual average $PM_{2.5}$ concentrations for the Sensitivity scenario compared against ET and RWC for the ten most impacted receptors surrounding the Beaches Link Burnt Bridge Creek Deviation ventilation outlet (K)**

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 Greater Sydney airshed in 2016 (around 53,700 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) to estimate ground-level O_3. 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 carried out using the NSW EPA Level 1 screening tool. Table 8-70 presents the outputs from these calculations, showing the project does not exceed the screening impact level of 0.5 parts per billion (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 8-70 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 NSW 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 NSW Approved Methods, are given in Table 8-71. 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 NSW Approved Methods.

Table 8-71 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(BL)	94.3	6.7	5.6	1.5
2027-DSC	82.2	5.9	4.8	1.3
2037-DS(BL)	65.7	3.9	3.2	1.3
2037-DSC	58.7	3.5	2.9	1.2
Odour criterion (µg/m^3)		360	190	42

9 Management of impacts

9.1 Management of construction impacts

Details of the construction assessment are outlined in Section 7.1, part of which involved determining mitigation measures. This was based on the risk of dust impacts identified in the assessment and the outcomes are shown in Table 9-1. All mitigation measures are routinely employed as standard practice on construction sites. Chapter 27 (Cumulative impacts) of the environmental impact statement provides management measures to address potential cumulative air quality impacts during construction. Mitigation measures for odour at Flat Rock Creek are also listed in Table 9-1.

Table 9-1 Recommended mitigation measures for construction dust

	Mitigation measure
Dust	
1	Include standard construction air quality mitigation and management measures in construction management documentation and implement 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 where required), 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 or handling inside acoustic sheds) • Monitoring and 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. • Carrying out site inspections to monitor compliance with implemented measures.
2	Manage dust and air quality complaints in accordance with the overarching complaints handling process for the project. Take appropriate corrective and preventative actions to reduce emissions in a timely manner.
Odour at Flat Rock Drive construction support site (BL2)	
1	Carry out site investigations during detailed construction planning to determine the potential to encounter odorous gases or materials during the proposed excavations on site. If the investigations indicate that there is potential for odorous materials to be uncovered or odorous gases to be released, investigate the potential for off-site impacts (informed by meteorological studies and modelling as required). If unacceptable off-site impacts are predicted, identify appropriate mitigation and management measures to minimise potential impacts, with consideration of the investigation results, proposed site activities and meteorological conditions, and implement the identified measures during relevant site activities. Carry out odour monitoring during relevant site activities and adjust mitigation and management measures as required to minimise potential off-site impacts.
2	Keep areas of exposed material that has the potential to generate odour to a minimum during site establishment works and while the area is uncovered. Provide temporary cover if odorous areas are to remain uncovered for more than one day.

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[25]. 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.

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 at ground level. 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:

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

- 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.

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. In newer tunnels in NSW, monitoring is also carried out for NO_2 to ensure in-tunnel limits are maintained and when additional ventilation may be required if concentrations approach these limits.

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 equivalent outcomes at a lower cost than filtration.

This assessment has demonstrated that the design of the ventilation outlets would achieve the same (or better) outcomes as installing filtration: the contribution of tunnel ventilation outlets to pollutant concentrations at ground level 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
- 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.

Although all three mechanical ventilation systems described in Section 9.2.2 could be designed to meet in-tunnel air quality criteria, a longitudinal system with elevated ventilation outlets has been selected as the preferred option for the project as it is:

- Less costly to construct and operate than transverse systems
- Able to ensure emissions are dispersed and diluted so that there is minimal or no effect on ambient air quality
- Considered to be more effective for the management of smoke in the tunnel in the event of a fire
- Able to meet the requirement to avoid portal emissions.

Accordingly the ventilation system for the project has been selected and 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. Specific to this:

- The design of the ventilation system would ensure zero portal emissions through the use of 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.

The final suite of operational measures to manage in-tunnel emissions and ambient air quality described in Section 9.2.2 would be confirmed during further design development. However, Chapter 5 (Project description) of the environmental impact statement provides further details on the proposed operational ancillary infrastructure for the project.

10 Summary and conclusions

This report has presented an assessment of the construction and operational activities for the Beaches Link and Gore Hill Freeway Connection 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 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 Beaches Link project there were predicted to be noticeable decreases in pollutant concentrations along Military Road, Spit Road, Manly Road and Warringah Road, reflecting reductions in traffic of between 23 per cent and 38 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 and, to a lesser extent, the portals of Sydney Harbour Tunnel. There were increases in concentrations along Sydney Harbour Bridge and Wakehurst Parkway. In the case of the latter there was a 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 where the increases are predicted.
  - In the cumulative scenarios there were predicted to be some additional changes as a result of the Western Harbour Tunnel. These included reductions in concentration along the Western Distributor, Sydney Harbour Bridge and Warringah Freeway.

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 µg/m^3, as well as the lowest international air quality standard identified in the literature (22 µg/m^3)
- There was an increase in CO at between 38 and 43 per cent of RWR receptors, although even the largest increase (1.2 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 µg/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 µg/m^3 at all RWR receptors. The NO_2 concentration was also below the EU limit value of 40 µg/m^3. Concentrations at the vast majority (more than 97 per cent) of receptors were between around 13 µg/m^3 and 25 µg/m^3
- The maximum contribution of tunnel ventilation outlets for any scenario and receptor was 0.7 µg/m^3, while the maximum surface road contribution was 24.3 µg/m^3. Given that NO_2 concentrations at the majority of receptors were well below the NSW criterion, the contribution of the ventilation outlets was not a material concern

- There was predicted to be an increase in the annual mean NO_2 concentration at between 37 per cent and 44 per cent of receptors, depending on the scenario. The increase in concentration was greater than 1 µg/m^3 for just 0.6 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 43 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 178 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 but one of the RWR receptors was below the NSW impact assessment criterion of 25 µg/m^3
- The surface road contribution was less than 10.7 µg/m^3, with an average of around 0.8 to 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 between 39 per cent and 45 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
- Additional analysis using the 98th percentile background concentration instead of contemporaneous background concentrations (as for the RWR receptors) resulted in significantly few exceedances at community receptors and is likely to be a more realistic representation
- 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 0.7 µg/m^3 to 1.8 µg/m^3, depending on the scenario
- There was an increase in concentration at 36 per cent to 41 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 14.5 µg/m^3. In the with-project and cumulative scenarios, the largest surface road contribution was 6.7 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 39 per cent and 43 per cent of receptors, depending on the scenario. The largest predicted increase in concentration at any receptor as a result of the project was 1.6 µg/m^3. Where there was an increase, this was greater than 0.1 µg/m^3 at around 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
- Additional analysis using the 98th percentile background concentration instead of contemporaneous background concentrations (as for the RWR receptors) resulted in significantly few exceedances at community receptors and is likely to be a more realistic representation
- The maximum contribution of tunnel ventilation outlets at any RWR receptor with the project and in the cumulative scenarios was 1.1 µg/m^3
- The largest predicted increase in concentration at any receptor as a result of the project was 4.2 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 only 0.1 per cent to 0.4 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 Regulatory worst case (ground level concentrations)

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 (0.65 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 was small. For the annual mean and maximum 24-hour metrics the ventilation outlet contributions were four per cent and 16 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 31 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. Transport for NSW should conduct ambient air quality monitoring to demonstrate that emissions from the ventilation outlets have no detectable impact on local air quality.

10.2.4 Expected traffic (elevated receptors)

Concentrations at four elevated receptor heights (10, 20, 30 and 45 metres) were considered for $PM_{2.5}$, PM_{10}, NO_2 and air toxics for receptors within 300 metres of the ventilation outlet. 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 results showed the following:

- For the annual average PM_{10} and $PM_{2.5}$ concentrations, there are no predicted exceedances at any modelled height of the NSW EPA impact assessment criteria.
- For the maximum 24-hour average PM_{10} concentrations, there is one predicted exceedances of the NSW EPA impact assessment criterion at 45 metres when considering all RWR receptors, irrespective of building that exist at those heights and when considering the maximum ventilation outlet contribution. When considering RWR receptors that do exist at each modelled height, there are no predicted exceedances of the NSW EPA impact assessment criterion of 50 µg/m^3 at any height.
- For the maximum 24-hour average $PM_{2.5}$ concentrations, there is one predicted exceedances of the NSW EPA impact assessment criterion at 45 metres when considering all RWR receptors, irrespective of building that exist at those heights and when considering the maximum ventilation outlet contribution. When considering RWR receptors that do exist at each modelled height, there are no predicted exceedances of the NSW EPA impact assessment criterion of 25 µg/m^3 at any height.

- For the annual average and maximum 1-hour average NO_2 concentrations, there are no predicted exceedances at any modelled height of the NSW EPA impact assessment criterion.
- For the maximum 1-hour average benzene, PAHs, formaldehyde, 1,3-butadiene and ethylbenzene concentrations, there are no predicted exceedances at any modelled height of the NSW EPA impact assessment criteria.

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 30 metres
- There are potential impacts for future buildings above 30 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
- 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
- Transport for NSW would assist relevant councils 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 Transport for NSW for proposed rezoning or development applications.

10.2.5 Regulatory worst case (elevated receptors)

When considering the maximum ventilation outlet contribution the findings are as follows:

- For the annual average PM_{10} concentrations, there are no predicted exceedances at any modelled height of the NSW EPA impact assessment criterion.
- For the maximum 24-hour average PM_{10} concentrations, there are predicted exceedances of the NSW EPA impact assessment criterion of 50 µg/m³ at 20 metres, 30 metres and 45 metres when considering all RWR receptor locations, irrespective of buildings that exist at those heights and when considering the maximum ventilation outlet contribution. When considering RWR receptors that do exist at each modelled height, there is one predicted exceedance of the NSW EPA impact assessment criterion of 50 µg/m³ at 30 metres at receptor RWR-12249, located near to the Warringah Freeway Ventilation Outlet (Outlet H). At this location, the contribution from the ventilation outlets is approximately 25 per cent of the total contribution.
- For the annual average $PM_{2.5}$ concentrations, there are predicted exceedances of the NSW EPA impact assessment criterion of 8 µg/m³ at 10 metres, 20 metres, 30 metres and 45 metres when considering all RWR receptor locations, irrespective of buildings that exist at those heights and when considering the maximum ventilation outlet contribution. When considering RWR receptors that do exist at each modelled height, there are no predicted exceedance of the NSW EPA impact assessment criterion of 8 µg/m³.
- For the maximum 24-hour average $PM_{2.5}$ concentrations, there are exceedances of the NSW EPA impact assessment criterion of 25 µg/m³ at 20 metres, 30 metres and 45 metres when considering all RWR receptor locations, irrespective of buildings that exist at those heights and when considering the maximum ventilation outlet contribution. When considering RWR receptors that do exist at each modelled height, there is one predicted exceedance of the NSW EPA impact assessment criterion of 25 µg/m³ at 30 metres at receptor RWR-12249, located near to the Warringah Freeway Ventilation Outlet (Outlet H). At this location, the contribution from the ventilation outlets is approximately 43 per cent of the total contribution.
- For the annual average NO_2 and maximum 1-hour average concentrations, there are no predicted exceedances at any modelled height of the NSW EPA impact assessment criterion.

- For the maximum 1-hour average benzene, PAHs, 1,3-butadiene and ethylbenzene concentrations, there are no predicted exceedances at any modelled height of the NSW EPA impact assessment criteria.
- For the maximum 1-hour average formaldehyde concentrations, there is one predicted exceedance of the NSW EPA impact assessment criterion of 20 µg/m^3 at 45 metres at RWR-17555, located near to the Gore Hill Freeway Ventilation Outlet (Outlet I) when considering all RWR locations, irrespective of buildings that exist at those heights.

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 major 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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