Roads and Maritime Services/Sydney Airport Corporation Limited

Sydney Gateway Road Project

Environmental Impact Statement/ Preliminary Draft Major Development Plan

Technical Working Paper 4

Air Quality

November 2019

Sydney Gateway Road Project
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Contents

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.
AWS	automatic weather station
B	
BAM	Beta Attenuation Monitor, a type of instrument used for measuring airborne particulate matter
B(a)P	benzo(a)pyrene
BTEX	benzene, toluene, ethylbenzene and xylenes
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
Cartesian grid	A grid of points with an equal spacing of 10 metres in the x and y directions
CO	carbon monoxide
CO_2	carbon dioxide
CSIRO	Commonwealth Scientific and Industrial Research Organisation
D	
DEC	(NSW) Department of Environment and Conservation
DECCW	(NSW) Department of Environment, Climate Change and Water
Defra	(UK) Department for Environment, Food and Rural Affairs
DSEWPC	Former (Commonwealth) Department of Sustainability, Environment, Water, Population and Communities
Domain (model)	Modelled area in space

Term	Definition
E	
EIS	Environmental Impact Statement
Emission factor	A quantity which expresses the mass of a pollutant emitted per unit of activity. For road transport, the unit of activity is usually either distance (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)
EU	European Union
G	
GHG	greenhouse gas
GRAL	Graz Lagrangian Model – dispersion model for vehicle emissions on complex road networks
GRAMM	Graz Mesoscale Model – meteorological model required for the GRAL dispersion model
GVM	gross vehicle mass
H	
HC	hydrocarbons
HCV	heavy commercial vehicle (interchangeable with HGV)
HDV	heavy-duty vehicle, which includes heavy goods vehicles, buses and coaches
HGV	heavy goods vehicle (truck)
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
LIDAR	Light Detection And Ranging
N	
NEPC	National Environment Protection Council
NEPM	National Environment Protection Measure
NH_3	ammonia

Term	Definition
NHMRC	National Health and Medical Research Council
NMVOC	non-methane volatile organic compound
NO	nitric oxide
NO_2	nitrogen dioxide
NO_X	oxides of nitrogen
NPI	National Pollutant Inventory
NSW	New South Wales
NSW EPA	(NSW) Environment Protection Authority
NSW Health	NSW Department of Health
O	
O_3	ozone
OEH	(NSW) Office of Environment and Heritage
P	
PAH(s)	polycyclic aromatic hydrocarbon(s)
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
R	
Road links	Sections of the road network included in the traffic model
Roads and Maritime	(NSW) Roads and Maritime Services. For the purpose of presentation, the shortened form 'RMS' is used in some figures and tables of the report.
RWR	Residential, workplace and recreational (RWR). This term refers to all discrete receptor locations included in this air quality assessment, and mainly covers residential and commercial land uses.
S	
SEARs	Secretary's Environmental Assessment Requirements
SMPM	Strategic Motorway Project Model

Term	Definition
SO_2	sulfur dioxide
SO_X	sulfur oxides
T	
TEOM	Tapered Element Oscillating Microbalance, a type of instrument used for measuring airborne particulate matter
THC	total hydrocarbons
TRAQ	Tool for Roadside Air Quality, an air pollution screening tool developed by Roads and Maritime
TSP	total suspended particulate (matter)
U	
UFP	ultrafine particles (particles with a diameter of less than 0.1 µm)
UK	United Kingdom
UN	United Nations
USEPA	United States Environmental Protection Agency
V	
VKT	vehicle-kilometres travelled
VOCs	volatile organic compounds
W	
WHO	World Health Organization
Other	
µm	micrometre
$\mu g/m^3$	micrograms per cubic metre

1 Introduction

1.1 Overview

1.1.1 Sydney Gateway and the project

Sydney Kingsford Smith Airport (Sydney Airport) and Port Botany are two of Australia's most important infrastructure assets, providing essential domestic and international connectivity for people and goods. Together they form a strategic centre, which is set to grow significantly over the next 20 years. To support this growth, employees, residents, visitors and businesses need reliable access to the airport and port, and efficient connections to Sydney's other strategic centres.

The NSW and Australian governments are making major investments in the transport network to achieve this vision. New road and freight rail options are being investigated to cater for the forecast growth in passengers and freight through Sydney Airport and Port Botany. Part of this solution is Sydney Gateway, which comprises the following road and rail projects:

- Sydney Gateway road project (the subject of this assessment)
- Botany Rail Duplication

Sydney Gateway will expand and improve the road and freight rail networks to Sydney Airport and Port Botany to keep Sydney moving and growing. The Sydney Gateway road project forms part of the NSW Government's long-term strategy to invest in an integrated transport network and make journeys easier, safer and faster.

Roads and Maritime and Sydney Airport Corporation propose the Sydney Gateway road project (the project). The project comprises new direct high capacity road connections linking the Sydney motorway network at St Peters interchange with Sydney Airport's terminals and beyond. It involves constructing and operating new and upgraded sections of road connecting to the airport terminals, four new bridges over Alexandra Canal, and other operational infrastructure and road connections.

The project and its location is shown on Figure 1-1.

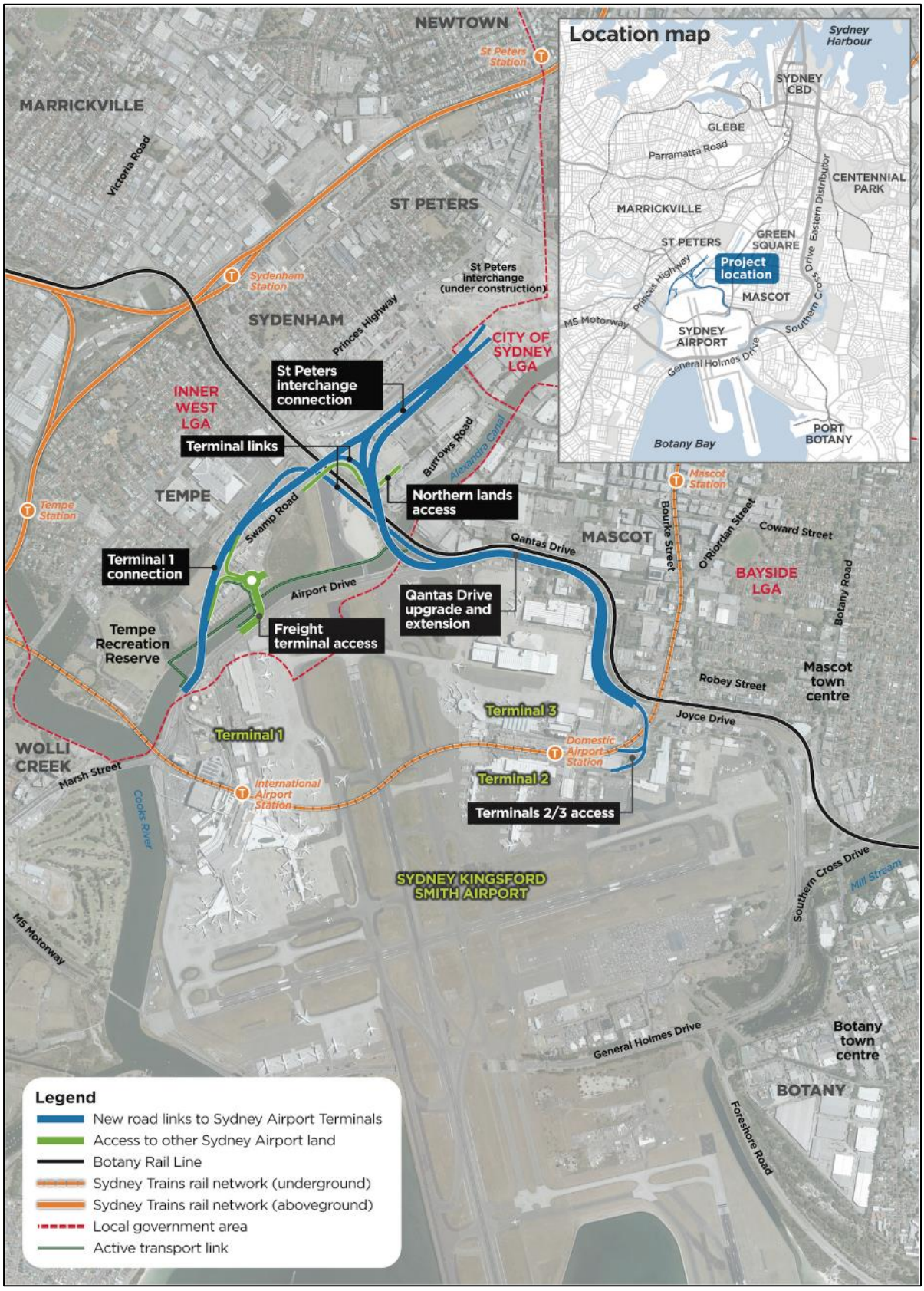


Figure 1-1 Location of the project

1.1.2 Overview of approval requirements

The project is subject to approval under NSW and Commonwealth legislation. Parts of the project located on Commonwealth-owned land leased to Sydney Airport (Sydney Airport land) are subject to the Commonwealth *Airports Act 1996* (the Airports Act). In accordance with the Airports Act, these parts of the project are major airport development. A major development plan (MDP), approved by the Australian Minister for Infrastructure, Transport and Regional Development, is required before a major airport development can be undertaken at a leased airport.

Parts of the project located on other land are State significant infrastructure in accordance with the NSW *Environmental Planning and Assessment Act 1979* (EP&A Act). As State significant infrastructure, these parts of the project require approval from the NSW Minister for Planning and Public Spaces. An environmental impact statement (EIS) is required to support the application for approval for State significant infrastructure under the EP&A Act.

A combined EIS and preliminary draft MDP is being prepared to:

- Support the application for approval of the project in accordance with NSW and Commonwealth legislative requirements
- Address the environmental assessment requirements of the Secretary of the Department of Planning and Environment (the SEARs), issued on 15 February 2019
- Address the MDP requirements defined by section 91 of the Airports Act.

This report was prepared on behalf of Roads and Maritime and Sydney Airport Corporation to support the combined EIS/preliminary draft MDP.

1.2 Purpose and scope of this report

This report describes and assesses potential air quality impacts from constructing and operating the Sydney Gateway road project. It has been prepared to assist in project design and planning and to inform regulatory agencies, councils, stakeholders and the community of potential impacts to air quality during construction and operation.

The report assesses:

- The potential for ambient air quality impacts during project construction
- The potential for ambient air quality impacts during project operation.

Recommendations for implementation of a comprehensive range of management measures to minimise and mitigate construction air quality impacts are provided.

Road traffic is a major contributor to air pollution in urban areas. Understanding the sources of road traffic pollution and dispersion pathways is crucial to its assessment, control and improvement. The methods described and applied in preparing this report are based on existing literature and best practice guidance in a number of different areas, such as road vehicle emissions and ambient air quality standards.

The operational air quality assessment for the project included:

- Understanding existing conditions, including background air quality, meteorology, land use and land form (terrain)
- Characterising changes in traffic
- Characterising road traffic emissions
- Estimating the impacts of the project on ambient air quality. This included assessing impacts at over 12,000 discrete receptor locations.

The report and assessment process was informed by existing air quality information and appropriate methods and models have been used to predict air quality outcomes from the project.

This report has been prepared to address relevant Sydney Gateway road project SEARs in accordance with requirements of the EP&A Act, and relevant MDP requirements according to the Airports Act. Requirements of relevant councils and agencies (where these refer explicitly to air quality) are also addressed. A guide to where SEARs are addressed is contained in **Table 1-1** and a guide to where MDP requirements are addressed is contained in **Table 1-2**.

Table 1-1 SEARs relevant to this assessment

Requirement of SEARs Key Issues SEARs	Section of this report where requirement is addressed
14. Air Quality	
1. The Proponent must undertake an air quality impact assessment (AQIA) for construction and operation of the proposal in accordance with the current guidelines.	The legislative and policy context of the project, including the relevant guidelines, is provided in **section 2**. A general overview of the AQIA methodology for the project is given in **section 3**. More detailed information on the assessment methods for construction and operation are presented in **sections 5** and **6** respectively. The results of the assessments are also provided in these sections, as well as in **Annexure H**.
The Proponent must ensure the AQIA also includes the following:	
(a) demonstrated ability to comply with the relevant regulatory framework, specifically the *Protection of the Environment Operations Act 1997* and the *Protection of the Environment Operations (Clean Air) Regulation 2010*;	Compliance with the regulatory framework is outlined in **section 2**.
(b) the identification of all potential sources and types of air pollution (including PM_{10}, $PM_{2.5}$, CO, NO_X, volatile organic compounds and odour sources) during construction and operation including mechanically generated, combustion and transport related emissions and potential for landfill gas generation from the former Tempe landfill;	Air quality considerations are outlined in **section 3**. Potential sources of air pollution during the construction and operation the project are identified in **sections 3.3**, **3.4.2** and **5.3**. Landfill gas generation is addressed in the landfill gas assessment report.
(c) any proposed air quality monitoring;	No air quality monitoring has been proposed for the project.
(d) a cumulative local and regional air quality impact assessment including impacts generated by the operation of nearby key infrastructure proposals* such as (but not limited to) the New M5, M4-M5 Link and Botany Rail Duplication; and	Potential cumulative air quality impacts are assessed in **sections 6** and **7.** *The New M5 is not a proposal, it is currently under construction
(e) proposed construction and operational management measures.	Measures to manage potential air quality impacts are outlined in **section 8.**

Table 1-2 MDP requirements relevant to this assessment

MDP requirement	Section where requirement is addressed
Airports Act 1996, Part 5, Division 4, Section 91(1) (Contents of major development plan)	
(1) A major development plan, or a draft of such a plan, must set out:	
(d) if a final master plan for the airport is in force—whether or not the development is consistent with the final master plan; and	**Section 5.5** (construction) and **section 6.4** (operation)
(h) the airport-lessee company's assessment of the environmental impacts that might reasonably be expected to be associated with the development; and	**Section 5.4** (construction) and **section 6.3** (operation)
(j) the airport-lessee company's plans for dealing with the environmental impacts mentioned in paragraph (h) (including plans for ameliorating or preventing environmental impacts); and	**Section 8**

1.3 The project

1.3.1 Location

The project is located about eight kilometres south of Sydney's central business district and to the north of Sydney Airport on both sides of Alexandra Canal. The northern extent of the project is located at St Peters interchange, which is currently being constructed to the north of Canal Road in St Peters. The western extent of the project is located near the entrance to Sydney Airport Terminal 1 on Airport Drive, to the north of the Giovanni Brunetti Bridge and south-west of Link Road. The eastern extent of the project is located near the intersection of Joyce Drive, Qantas Drive, O'Riordan Street and Sir Reginald Ansett Drive.

The project is located mainly on government owned land in the suburbs of Tempe, St Peters and Mascot, in the Inner West, City of Sydney and Bayside local government areas.

1.3.2 Key design features

The project provides a number of linked road connections to facilitate the movement of traffic between the Sydney motorway network, Sydney Airport Terminal 1 (Terminal 1) and Sydney Airport Terminals 2 and 3 (Terminals 2/3). The project would connect Terminal 1 and Terminals 2/3 with each other and with the Sydney motorway network. The project would also facilitate the movement of traffic towards Port Botany via General Holmes Drive. It would provide three main routes for traffic:

- Between the Sydney motorway network and Terminal 1, and towards M5 motorway and Princes Highway.
- Between the Sydney motorway network and Terminals 2/3, and towards General Holmes Drive, Port Botany and Southern Cross Drive.
- Between Terminal 1 and Terminals 2/3.

The key features of the project include:

- Road links to access between the Sydney motorway network and Sydney Airport's terminals, consisting of the following components:
    - St Peters interchange connection – a new elevated section of road extending from St Peters interchange to the Botany rail line, including an overpass over Canal Road.
    - Terminal 1 connection – a new section of road connecting Terminal 1 with the St Peters interchange connection, including a bridge over Alexandra Canal and an overpass over the Botany rail line.
    - Qantas Drive upgrade and extension – widening and upgrading Qantas Drive to connect Terminals 2/3 with the St Peters interchange connection, including a high-level bridge over Alexandra Canal.
    - Terminal links – two new sections of road connecting Terminal 1 and Terminals 2/3, including a bridge over Alexandra Canal.
    - Terminals 2/3 access – a new elevated viaduct and overpass connecting Terminals 2/3 with the upgraded Qantas Drive.
- Road links providing access to Sydney Airport land:
    - A new section of road and an overpass connecting Sydney Airport's northern lands either side of the Botany rail line (the northern lands access).
    - A new section of road, including a signalised intersection with the Terminal 1 connection and a bridge connecting Sydney Airport's existing and proposed freight facility either side of Alexandra Canal (the freight terminal access).
- An active transport link approximately 1.3 kilometres in length along the western side of Alexandra Canal to maintain connections between Sydney Airport Mascot and the Sydney central business district.
- Intersection upgrades or modifications.
- Provision of operational ancillary infrastructure including maintenance bays, new and upgraded drainage infrastructure, signage and lighting, retaining walls, noise barriers, flood mitigation basin, utility works and landscaping.

1.3.3 Construction overview

A conceptual construction methodology has been developed based on the preliminary project design to be used as a basis for the environmental assessment process. Detailed construction planning, including programming, work methodologies, staging and work sequencing would be undertaken once construction contractor(s) have been engaged.

Timing and work phases

Construction of the project would involve four main phases of work. The indicative construction activities within each phase are outlined below:

Phase	Indicative construction activities
Enabling works	• construction of the temporary active transport link, • modification of various road intersections to facilitate main construction works.
Site establishment	• installing site fencing, hoarding and signage, • establishing construction compounds, work areas and site access routes.
Main construction works	• clearing/ trimming of vegetation, • removal (or partial removal) of a number of buildings and other existing infrastructure eg concrete hardstand areas, drainage infrastructure, sheds, advertising structures, containers, etc, • roadworks, including bridge and viaduct construction and drainage works, • utility works.
Finishing works	• erecting lighting, signage and street furniture, landscaping works and site demobilisation and rehabilitation in all areas.

Specific construction issues which will require careful planning and management and close co-ordination with relevant stakeholders include:

- Works within the prescribed airspace of Sydney Airport
- Works interfacing with the Botany rail line
- Piling in the vicinity of the T8 Airport and South Line underground rail tunnels
- Works within the former Tempe landfill and Alexandra Canal which are subject to remediation orders and specific management plans
- Excavation, storage and handling of contaminated soils generally within the project site and contaminated groundwater from the Botany Sands aquifer.

Construction is planned to start in mid 2020, subject to approval of the project, and is expected to take about three and a half years to complete. Further information on construction is provided in Chapter 8 (Construction) of the EIS.

The project would include work undertaken during recommended standard hours as defined by the *Interim Construction Noise Guideline* (DECC, 2009):

- Monday to Friday: 7am to 6pm
- Saturday: 8am to 1pm
- Sundays and public holidays: no work.

It would also include work outside these hours (out-of-hours work) to minimise the potential for aviation and rail safety hazards.

Construction footprint

The land required to construct the project (the construction footprint) is shown on Figure 1-2. The construction footprint includes the land needed to construct the proposed roadways, bridges and ancillary infrastructure and land required for the proposed construction compounds. Utility works to support the project would generally occur within the construction footprint; however, some works (such as connections to existing infrastructure) may be required outside the footprint.

Compounds, access and resources

Construction would be supported by five construction compounds located to support the main construction works (shown on Figure 1-2). Construction compounds would include site offices, staff amenities, storage and laydown areas, workshops and workforce parking areas.

Materials would be transported to and from work areas via construction haul routes, which have been selected to convey vehicles directly to the nearest arterial road.

The construction workforce requirements would vary over the construction period based the activities underway and the number of active work areas. The workforce is expected to peak at about 1,000 workers for a period of about 13 months, indicatively from the fourth quarter of 2021. Either side of this peak, workforce numbers are expected to reduce to about two thirds.

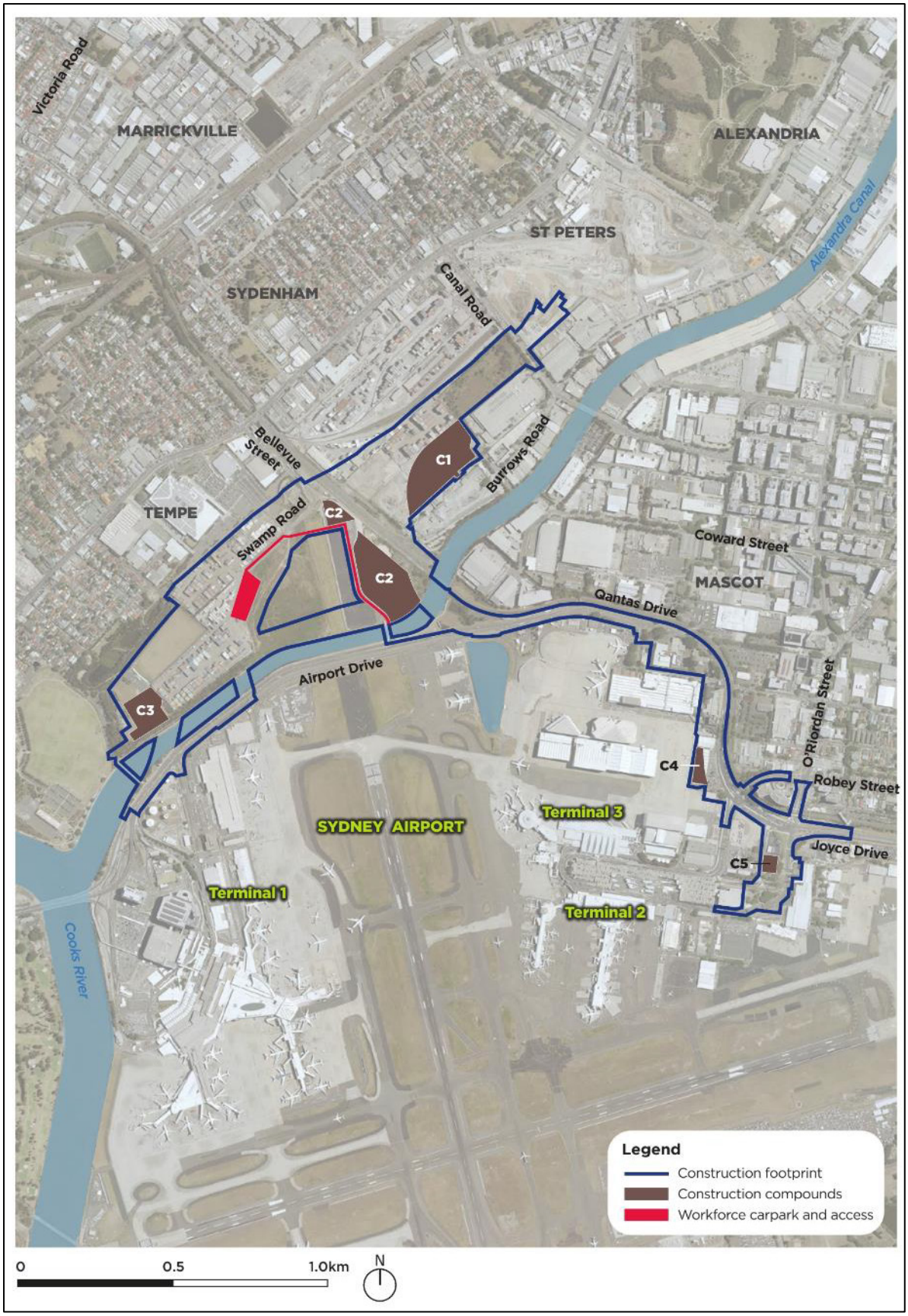


Figure 1-2 Construction footprint and facilities

1.4 Structure of this report

The structure of the report is outlined below.

- **Section 1** provides an introduction to the report
- **Section 2** summarises the legislative and policy context of the project, and covers topics such as the regulation of road vehicle emissions, fuel quality, and ambient air quality, as well as relevant Commonwealth and state legislation
- **Section 3** provides an overview of the air quality assessment methodology, outlining key documents, guidelines and policies, 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 4** 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 5** describes the assessment of the construction impacts of the project using a semi-quantitative risk-based approach
- **Section 6** describes the assessment of the operational impacts of the project. The section deals with emission modelling and dispersion modelling for ambient air quality
- **Section 7** describes the assessment of the cumulative impacts of Sydney Gateway road project, the Botany Rail Duplication, and other major road projects
- **Section 8** provides recommendations relating to air quality mitigation measures to manage any impacts of the project. This section deals with both the construction and the operation of the project
- **Section 9** summarises the assessment and presents the main conclusions
- **Section 10** provide details of documents referenced throughout the report
- **Annexures A** to **H** which address various technical aspects of the air quality assessment.

2 Legislative and policy context

2.1 Commonwealth legislation

2.1.1 Airports Act 1996 and associated regulations

The project site includes areas of Commonwealth-owned land leased by Sydney Airport Corporation (Sydney Airport). The *Airports Act 1996* (Cwlth) (the Airports Act) and associated regulations provide the assessment and approval process for development on land which is the subject of an airport lease.

Section 89 of the Airports Act specifies the types of development that constitute 'major airport development'. A major development plan (MDP) approved by the Australian Minister for Infrastructure, Transport and Regional Development is required before major airport development can be undertaken at a leased airport.

The Airports Act and regulations are the statutory controls for the ongoing regulation of development activities on Commonwealth-owned land leased from the Australian Government for the operation of Sydney Airport. Section 70 of the Airports Act requires there to be a final master plan for the airport that has been approved by the Australian Minister for Infrastructure and Transport.

Part 5 of the Airports Act also requires that each airport develop an environment strategy which is included in its master plan. Once approved, Sydney Airport and all persons who carry out activities at the airport are obliged to take all reasonable steps to ensure compliance with the environment strategy.

2.1.2 Airports (Environment Protection) Regulations 1997

The objective of the Airports (Environmental Protection) Regulations 1997 (Cwlth) is to establish a system of regulation for activities at airports that generate or have potential to generate pollution or excessive noise. The regulations impose a general duty to prevent or minimise environmental pollution, and have as one of their objectives is the promotion of improved environmental management practices at Commonwealth-leased airports.

The regulations contain detailed provisions setting out:

- Definitions, acceptable limits and objectives for air, water and soil pollution, and offensive noise
- General duties to prevent or minimise pollution, preserve significant habitat and cultural areas, and to prevent offensive noise
- Monitoring and reporting requirements for existing pollution.

Part 2 of the regulations defines pollution in relation to air (including odour), water, soil and offensive noise. Schedules 1 to 4 of the regulations provide the acceptable limits of pollutants and offensive noise, which, in conjunction with other national environment protection measures, provide the system of environmental regulation at airports.

Schedule 1 specifies the ambient air quality objectives at airports, and these are summarised in **Annexure B**. More up-to-date pollutant metrics, criteria and guidelines for assessing air quality impacts are contained in the Approved Methods for the Modelling and Assessment of Air Pollutants in NSW (NSW EPA, 2016). Where the same pollutant is noted in both sets of criteria, those in the Approved Methods are either the same or more stringent.

2.1.3 Environment Protection and Biodiversity Conservation Act 1999

The *Environment Protection and Biodiversity Conservation Act 1999* (Cwlth) (EPBC Act) is administered by the Australian Department of the Environment and Energy and provides a legal framework to protect and manage nationally important flora, fauna, ecological communities and heritage places defined as 'matters of national environmental significance'.

Under the EPBC Act, proposed actions (ie activities or projects) with the potential to significantly impact matters protected by the EPBC Act must be referred to the Australian Minister for the Environment to determine whether they are controlled actions, requiring approval from the Minister. The following matters are defined as protected matters by Part 3 of the EPBC Act:

- Matters of national environmental significance
- The environment of Commonwealth land
- The environment in general if they are being carried out by an Australian Government agency.

As part of the assessment of the draft MDP, the Department of Infrastructure, Transport, Cities and Regional Development will, on behalf of the Minister for Infrastructure, Transport and Regional Development, seek advice from the Australian Minister for Environment under section 160(1) of the EPBC Act.

Although the EPBC Act does not specify any air quality criteria that are relevant to the assessment, the EPBC Act and the EPBC significant assessment guidelines 1.2 apply to any proposed actions which may have an impact in the Commonwealth land or the environment including air quality.

2.1.4 Sydney Airport Master Plan 2039 and Environment Strategy 2019-2024

2.1.4.1 Sydney Airport Master Plan 2039

As part of the planning framework established by the Airports Act, airport operators are required to prepare a master plan for the coordinated development of their airport. Sydney Airport Master Plan 2039 (Master Plan 2039) outlines the strategic direction for Sydney Airport's operations and development over the next 20 years (SACL, 2018a). It acknowledges that the continued growth of Sydney Airport is vital to achieving local, state and national employment, tourism and development objectives. In accordance with the requirements of the Airports Act, the Master Plan 2039:

- Establishes the strategic direction for efficient and economic development at Sydney Airport over the planning period
- Provides for the development of additional uses of the Sydney Airport site
- Indicates to the public the intended uses of the Sydney Airport site
- Reduces potential conflicts between uses of the Sydney Airport site, to ensure that uses of the site are compatible with the areas surrounding the airport
- Ensures that operations at Sydney Airport are undertaken in accordance with relevant environmental legislation and standards
- Establishes a framework for assessing compliance with relevant environmental legislation and standards
- Promotes continual improvement of environmental management at Sydney Airport.

The Master Plan 2039 also notes that managing ground access in and around the airport is important, which is relevant for the Sydney Gateway road project as it expands and improves the road network in the area. The Master Plan 2039 refers to the Sydney Gateway road project and describes proposed changes in the road network that would occur as a result of the project.

2.1.4.2 Sydney Airport Environment Strategy 2019-2024

The Airports Act requires that airport operators provide an assessment of the environmental issues associated with implementing the airport master plan and the plan for dealing with those issues. This is documented in an environment strategy that forms part of the airport's master plan. The Sydney Airport Environment Strategy 2019-2024 (the Environment Strategy), which forms part of the Master Plan 2039, provides strategic direction for the environmental performance and management of Sydney Airport for the five year period between 2019 and 2024 (SACL, 2018b). The purpose of the Environment Strategy is to:

- Establish a framework for assessing compliance and ensuring that all operations at Sydney Airport are undertaken in accordance with relevant environmental legislation and standards
- Promote the continual improvement of environmental management and performance at Sydney Airport and build on the achievements and goals of previous strategies
- Realise improvements in environmental sustainability, by minimising Sydney Airport's environmental footprint and working towards a more efficient and resilient airport.

Sections of the Sydney Gateway road project that occur on the airport land would need to comply with the Environment Strategy.

2.1.4.3 Objectives and actions with respect to air quality

The Sydney Airport Master Plan 2039 and the Environmental Strategy 2019-2024 have the following key objectives for air quality:

- Minimise air emissions from ground-based airport operations and activities
- Comply with State and Commonwealth legislation and relevant standards and guidelines
- Support and encourage the progressive introduction by airlines of cleaner and more fuel efficient next generation aircraft.

To support these objectives the airport undertakes atmospheric dispersion modelling of operational activities.

The airport has implemented a number of measures to improve air quality, including fitting terminal gates with fixed electrical ground power units and introduction of electric buses. The airport actively supports the increased use of sustainable transport and active transport to minimise emissions from airport-related traffic (SACL, 2018a).

The airport is continuing to implement strategies and initiatives to improve air quality. Most of these actions relate to the introduction of cleaner and more efficient aircraft and other airside activities. Given that Sydney Gateway relates to the public road network, these measures are not directly relevant to the project. Actions of most relevance to the project include (SACL, 2018a):

- Ensuring that potential air quality impacts are assessed and managed for construction and operational phases of development proposals
- Encouraging staff and passengers travelling to and from the airport to use public transport or other sustainable modes of transport. Increased use of public transport will help reduce traffic volumes on public roads.

2.1.4.4 MDP requirements

Major developments at Sydney Airport must be compliant with the airport's Master Plan and Environment Strategy and a major development plan (MDP) must be prepared. In this respect, the Airports Act (section 91(1)(d)) identifies the specific requirements of MDPs and associated specialist reports. For this project, MDP requirements are listed in **Table 1-2**.

The MDP must consider whether the project (both construction and operation) beneficially or adversely effects the airport's current operations or future development proposals as outlined in the airport's Master Plan, or in any environmental objectives, action plans or monitoring practices.

Proposals are assessed on their performance in relation to a range of aviation, infrastructure, planning and environmental issues. Sydney Airport's development standards are identified Table E3-1 of the Master Plan 2039. This table does not refer explicitly to air quality, although in the case of 'environmentally sustainable development' (which includes air quality) it refers to the Environment Strategy.

The specific requirements of the Airports Act, and consistency of the air quality assessment with the airport's Master Plan and Environment Strategy, are considered for project construction and operation in **sections 5** and **6** respectively.

Approved Methods for priority air toxics and BTEX (benzene, toluene, ethylbenzene and xylene) compounds are given in **Annexure B**.

2.2 NSW legislation and guidelines

2.2.1 Environmental Planning and Assessment Act 1979

Parts of the project not located on Commonwealth land are declared State significant infrastructure (SSI). State significant infrastructure is regulated under the *Environmental Planning and Assessment Act 1979* (EPA Act), which requires proponents to apply to the NSW Minister of Planning for approval, supported by a detailed environmental impact statement (EIS). This report forms part of the EIS for the Sydney Gateway road project.

The NSW Department of Planning's Secretary has issued project specific environmental assessment requirements (SEARs) setting out matters to be addressed in the EIS. SEARs relevant to air quality are listed in **Table 1-1**. These SEARs refer to application of the *Protection of the Environment Operations Act 1997* and the Protection of the Environment Operations (Clean Air) Regulation 2010. The Regulation specifies discharge concentration limits, which are designed primarily for industrial activities.

The following NSW guidelines were referred to when preparing this air quality assessment:

- Approved Methods for the Modelling and Assessment of Air Pollutants in NSW (NSW EPA, 2016)
- Approved Methods for the Sampling and Analysis of Air Pollutants in NSW (DEC, 2007).

2.3 Policies and regulations for road vehicle emissions

2.3.1 Background

Road traffic is the main source of several air pollutants in Australian cities, including particulates, hydrocarbons and oxides of nitrogen. Pollutants released from motor vehicles have a variety of effects on amenity, ecosystems, heritage and health.

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' (VOCs) is also often used, particularly when there is a reference to fuel evaporation. The terms VOCs and total hydrocarbons (THC) are used interchangeably in this report. Where reference is made to a source document or model, the original term used has been retained.

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

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

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

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

- The volume, composition and operation (eg speed) of the traffic
- The road gradient
- The length of the road section.

Emitted pollutants are dispersed in the ambient air, with patterns of dispersal influenced by local topography and meteorology. Emitted pollutants may be transformed into secondary pollutants through chemical reactions that occur as they disperse. An example of this is the formation of NO_2 from NO_X emissions. The dispersion and transformation of traffic-derived pollutants is summarised in **Annexure A**.

The main direct impacts of primary traffic pollutants occur near the point of emission. Concentrations of primary pollutants decrease rapidly with increasing distance from the pollution source as a result of dispersion and dilution.

Because of the time required for the formation of secondary pollutants, their concentrations are not always highest near the emission source.

The effects of road traffic pollution on the health of a given population are influenced by the concentration to which the population is exposed, the duration of the exposure, and the susceptibility of the population to the relevant pollutants. The situation is complicated by numerous factors, such as combinations of pollutants having synergistic effects on health. More detail on health impacts is provided in "Technical Working Paper 15: Human Health".

The overall exposure of individuals to air pollutants is dependent upon the types of activity in which they are engaged, the locations of those activities, and the pollutant concentrations at those locations. In principle, an understanding of the amount of time spent in different types of environment (such as outdoors in the street, indoors at home, in transit, at the workplace, etc), and the pollutant concentrations in those environments, allows the calculation of 'integrated' personal exposure (Duan, 1982). Once the pollutant has crossed a physical boundary within the body, the concept of 'dose' is used (Ott, 1982). The dose is the mass of material absorbed or deposited in the body for an interval of time, and depends on the respiratory activity of the individuals concerned. Responses to doses (the actual health effects) can also vary from person to person, depending on physiological conditions.

The calculation of integrated exposure is often not possible because the pollutant concentrations in the different microenvironments are generally not known. The term 'average exposure' is therefore commonly used, and this is typically taken to mean the pollutant concentration over a specified period (eg annual mean) at an outdoor location which is broadly representative of where people are likely to spend time. This approach is also reflected in the regulation of ambient air quality, and has been used in this assessment.

2.3.2 National emission standards for new vehicles

Under the *Motor Vehicle Standards Act 1989* (Cwlth), new road vehicles must comply with certain safety and emissions requirements as set out in Australian Design Rules (ADRs). The specific emission limits that apply to exhaust emissions from light-duty and heavy-duty vehicles, and their timetable for adoption in the ADRs, are listed on the Australian Government website[1], and further information is provided in **Annexure B**. The evaporation of fuel from petrol vehicles constitutes a significant fraction of the total

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

on-road mobile VOC emissions in the NSW Greater Metropolitan Region (NSW EPA, 2012b). The limits for evaporative emissions in Australia are also given in **Annexure B**.

2.3.3 Checks on in-service vehicles

The *National Environment Protection (Diesel Vehicle Emissions) Measure 2001* (Cwlth) 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[2] are for modified vehicles and LPG conversions. The NSW Office of Environment and Heritage (OEH) has, in conjunction with the then NSW Roads and Traffic Authority (RTA) (Roads and Maritime), established a diesel vehicle retrofit program which involves retrofitting engines with pollution-reduction devices, primarily to reduce PM emissions. The program commenced in 2005 and, as of 2011, more than 70 vehicle fleets (covering 520 vehicles) had participated (DSEWPC, 2011). Specific measures have also been introduced to improve air quality in the M5 East tunnel, including a video camera system to identify smoky vehicles.

2.3.4 Fuel quality regulations

The *Fuel Quality Standards Act 2000* (Cwlth) 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* (Cwlth) and the *Fuel Standard (Automotive Diesel) Determination 2001* (Cwlth). These Standards prohibited the supply of leaded petrol and reduced the level of sulfur in diesel fuel. The regulation of fuel quality continued with the development of standards for LPG, biodiesel and ethanol.

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

2.4 Ambient air quality standards and criteria

Ambient air quality standards are a considered during road project design and operation. An ambient air quality standard defines a metric relating to the concentration of an air pollutant in the ambient air. Standards are usually designed to protect human health, including sensitive populations such as children, the elderly, and individuals suffering from respiratory disease, but may relate to other adverse effects such as damage to buildings and vegetation. The form of an air quality standard is typically a concentration limit for a given averaging period (eg annual mean, maximum 24-hour), 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 (ie found everywhere) and emitted in relatively large quantities, and their health effects have been studied in some detail. Air toxics are gaseous or particulate organic pollutants that are present in the air in low concentrations, but are defined on the basis that they are, for example, highly toxic, carcinogenic or highly persistent in the environment, so as to be a hazard to humans, plants or animal life.

[2] 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.

The specific pollutants and metrics that were addressed in this assessment, and the associated impact assessment criteria, are identified in **section 3.4.1**.

2.4.1 Criteria pollutants

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

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

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

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

The NEPM is a national monitoring and reporting protocol. The NEPM standards are applicable to urban background monitoring stations which are broadly representative of population exposure. The use of any NEPM air quality criteria in relation to the assessment of projects and developments is outside the scope of the NEPM itself, and is decided by the jurisdictions. The criteria for air quality assessments for projects/developments in NSW are contained in the *Approved Methods for the Modelling and Assessment of Air Pollutants in NSW* (NSW Approved Methods) (NSW EPA, 2016).

The Australian states and territories manage emissions and air quality by licensing particular types of emission sources (eg landfills, quarries, crematoria and coal mines). Each jurisdiction has legislation or guidance which includes design goals, licence conditions or other instruments for protecting local communities from ground-level impacts of pollutants in residential areas outside site boundaries. Where this is the case, the AAQ NEPM standards are often used for air quality assessments.

In NSW, the Approved Methods sets out the approaches and criteria to be used for air quality assessments for projects/developments in NSW. 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. In NSW, air quality must be assessed in relation to standards[3] and averaging periods for specific pollutants that are taken from several sources, notably the AAQ NEPM.

The metrics, criteria and goals set out for assessment of criteria pollutants in the NSW Approved Methods are provided in **Annexure B**.

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

2.4.2 Air toxics

In recognition of the potential health problems arising from the exposure to air toxics, the *National Environment Protection (Air Toxics) Measure* (Cwlth) (Air Toxics NEPM) (NEPC, 2011a) identifies 'investigation levels' for the following five priority pollutants:

- benzene
- formaldehyde
- toluene
- xylenes
- benzo(a)pyrene (B(a)P) (as a marker for polycyclic aromatic hydrocarbons (PAH)).

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, on the other hand, specify air quality impact assessment criteria and odour assessment criteria for many substances, including some air toxics. The Sydney Gateway road project SEARs 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 Sydney Airport Master Plan 2039, the Environment Strategy 2019-2039 and the Airports Environment Protection Regulation were applied.

2.5 Assessment guidelines and information used in this report

This report has been prepared in accordance with the following assessment guidelines:

- Approved Methods for the Modelling and Assessment of Air Pollutants in New South Wales (NSW EPA, 2016)
- Approved Methods for the Sampling and Analysis of Air Pollutants in NSW (DEC, 2007).

Additional references are provided in **section 10**.

3 Overview of assessment methodology

3.1 Overview

This section describes:

- Approach and methods used to assess the impacts of project construction and operation on air quality
- The pollutants and metrics and relevant criteria used in the assessment
- Specific air quality terminology
- Other projects considered as part of the cumulative impact assessment
- The accuracy and conservatism of the assessment process.

3.2 Projects assessed

This report assesses and describes air quality impacts and outcomes for:

- The Sydney Gateway road project as a whole, including:
  - The Sydney Gateway road project in isolation
  - The Sydney Gateway road project and other major road projects
- The section of the Sydney Gateway road project on Commonwealth land only, including:
  - The Sydney Gateway road project in isolation
  - The Sydney Gateway road project and other major road projects
- The cumulative impacts of both road and rail projects, including:
  - The Sydney Gateway road project and Botany Rail Duplication
  - The Sydney Gateway road project, Botany Rail Duplication and other major road projects.

The reason for this is so that sufficient targeted information is provided for efficient management of both Commonwealth and state approval processes.

3.3 Construction assessment

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

- Annoyance due to dust deposition (eg soiling of surfaces at residences) and visible dust plumes
- Elevated PM_{10} concentrations due to on-site dust-generating activities
- Increased concentrations of airborne particles 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 measureable impact on local air quality compared to local traffic, and would not need to be quantitatively assessed.

Dust emissions may occur during site preparation (eg demolition and earth moving) and during construction. Dust emissions can vary substantially from day to day depending on the level of site activity, the specific operations being undertaken, and daily wind and other weather conditions. A significant portion of the emissions results from site plant and road vehicles moving over temporary unsealed roads and open ground. If mud is tracked onto local public roads, dust levels can increase at some distance from the construction site (IAQM, 2014).

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

- The nature and duration of the activities being undertaken
- The size of the site
- The meteorological conditions (wind speed, direction and rainfall)
- The proximity of receptors to the activities
- The sensitivity of the receptors to dust
- The adequacy of the mitigation measures applied to reduce or eliminate dust.

Adverse impacts from dust emissions are more likely to occur downwind of the site and during drier periods.

It is difficult to quantify dust emissions from construction activities reliably. Due to the variability of the weather, it is impossible to predict what the weather conditions would be when specific construction activities are undertaken.

Effects of construction on airborne particle concentrations tend to be relatively short-lived. Mitigation is generally straightforward, as most of the necessary management measures used to control and reduce dust 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[4], risk-based approach was used for the Sydney Gateway road project air quality impacts assessment, and the impacts of construction were not specifically modelled. The approach followed the guidance published by the United Kingdom (UK) Institute of Air Quality Management (IAQM, 2014), which aims to identify risks and recommend appropriate mitigation measures to reduce those risks. The assessment of construction impacts using the IAQM procedure is presented in **section 7**.

3.4 Operational assessment – local air quality

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

3.4.1 Ambient air quality criteria used in the assessment

Air quality in the Sydney Gateway road project domain was assessed in relation to the most relevant pollutants and the criteria from the NSW Approved Methods. While the Approved Methods do not strictly apply to development on Commonwealth land, this has been applied for consistency and conservatism. These pollutants and criteria are summarised in **Table 3-1**. The long-term goals for $PM_{2.5}$ in the AAQ NEPM were also considered in the assessment of impacts, and these goals are shown in italics. Some further discussion is provided in **Annexure B**.

[4] 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.

Table 3-1 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.

3.4.2 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[5]:

- *Background concentration*. This is the contribution from all sources other than the modelled road traffic (major roads only). It included, for example, contributions from natural sources, industry and domestic activity, as well as minor roads. The background will also include contributions from aircraft and ground based activity at the airport. In the assessment, background concentrations were based on measurements from air quality monitoring stations at urban background locations[6]. The approaches used to determine long-term and short-term background concentrations are explained in **Annexure D**. Background concentrations were assumed to remain unchanged in future years, given that trends over the last decade have generally shown them to be quite stable (or slightly decreasing)
- *Road traffic concentration*. This is the contribution from the main surface road network and (non-project) tunnel ventilation outlets. It included 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, road traffic concentrations were estimated using a dispersion model (GRAL).

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

3.4.3 Presentation of results

The following values are presented in the report:

- The total pollutant concentration from all contributions (background, surface roads and ventilation outlets). The surface road and ventilation outlet contributions are presented as a combined 'road traffic' source
- The change in the total pollutant concentration with the project in a given year (2026 or 2036). Given the non-threshold nature[7] of some air pollutants (notably PM_{10} and $PM_{2.5}$), it was considered important to assess not only the total concentrations relative to the criteria, but also the incremental changes in concentration associated with the project.

The results are presented in the following formats:

- Charts and tables for discrete 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 6.2.2.2**
- Contour plots showing total pollutant concentrations (and changes in concentration) across the entire GRAL modelling domain. The concentrations were based on a Cartesian grid of points with an equal spacing of 10 metres in the x and y directions. This resulted in around 990,000 grid locations across the GRAL domain.

3.4.4 Model domains

Separate domains (ie modelled area in space) were required for the meteorological and dispersion modelling, and these domains are shown relative to the project in **Figure 3-1**. The GRAMM domain for the modelling of meteorology - shown by the red boundary - covered a substantial part of Sydney, extending 18 kilometres in the east–west (x) direction and 15 kilometres in the north–south (y) direction. The GRAL domain for dispersion modelling is shown by the dashed grey boundary. Every dispersion model run was undertaken for this domain, which extended 10.4 kilometres in the x direction and 9.5 kilometres in the y direction. The domain extended well beyond the project itself to allow for traffic interactions between Sydney Gateway road project and other projects (M4-M5 Link, New M5), as well as all affected 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 set-up and evaluation.

The boundaries of Commonwealth land are also shown in **Figure 3-1**.

[7] The term non-threshold relates to the fact that there is 'no safe limit' for some pollutants, notably $PM_{2.5}$.

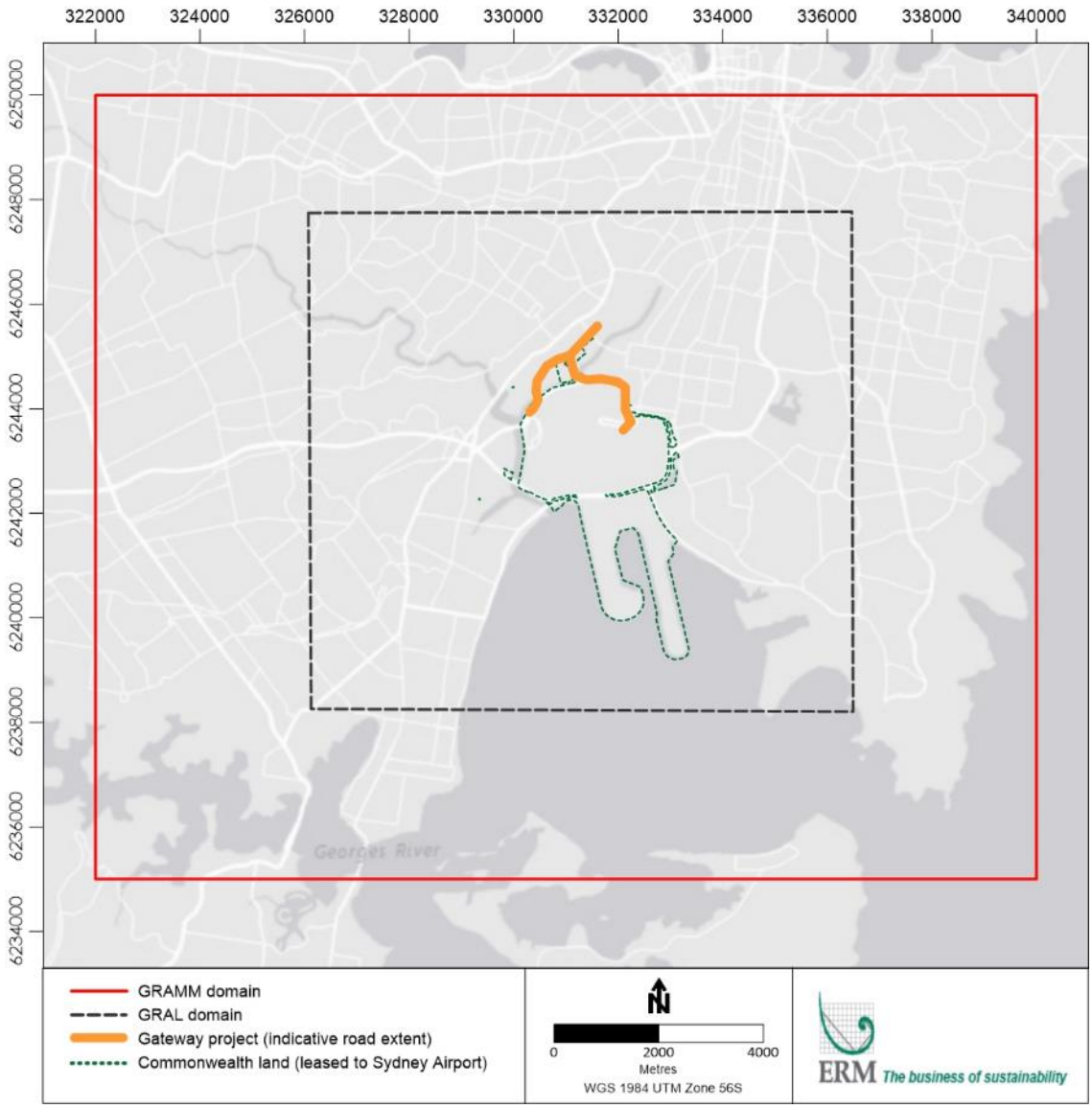


Figure 3-1 Modelling domains for GRAMM and GRAL (grid system MGA94)

3.4.5 Traffic scenarios

Air quality was modelled for seven traffic operating scenarios. These included the expected base year and six expected future traffic scenarios. These are listed in **Table 3-2**. The future years were the opening year for Sydney Gateway road project (2026) and ten years after opening (2036).

The modelled scenarios took into account:

- future changes over time in the composition and performance of the vehicle fleet
- predicted traffic volumes
- distribution of traffic on the network, and
- vehicle speed

as represented in the traffic model used for the assessment, the Strategic Motorway Project Model (SMPM).

The objective of these scenarios was to demonstrate that the expected operation of the project would result in acceptable ambient air quality, and they are the main focus of this air quality assessment. The results from modelling these scenarios were also used in the health risk assessment for the project (see **Technical Working Paper 15**).

Table 3-2 Expected traffic scenarios for the operational assessment

Scenario code	Scenario name	Scenario description	Roads/projects included					
			Existing network	Sydney Gateway road project	Other projects			
					WestConnex[a]	F6 Extension (Stage 1)	F6 Extension (full)	Western Harbour Tunnel And Beaches Link
2016-BY	2016 – Base Year [b]	This scenario represented the current road network with no new projects/upgrades, and was used to establish existing conditions. The main purpose was to enable the dispersion modelling methodology to be verified against actual air quality monitoring data [c].	✓	-	-	-	-	-
2026-WOP	2026 – Without Project	This scenario represented conditions in the opening year of the project (2026), including all stages of WestConnex (M4 East, New M5 and M4-M5 Link) but without Sydney Gateway road project. It is referred to as 'Without Project' as it assumed that some improvements would be made to the broader transport network to improve capacity and cater for traffic growth.	✓	-	✓	-	-	-
2026-WP	2026 – With Project	As 2026 Without Project, but with Sydney Gateway road project also completed.	✓	✓	✓	-	-	-
2026-WPC	2026 – Cumulative	As 2026 Without Project, but with Sydney Gateway road project and Stage 1 of the F6 Extension also completed.	✓	✓	✓	✓	-	-

Scenario code	Scenario name	Scenario description	Roads/projects included					
2036-WOP	2036 – Without Project	As 2026 Without Project, but for 10 years after project opening and without the project. This took into account changes in traffic and the emission behaviour of the fleet with time.	✓	-	✓	-	-	-
2036-WP	2036 – With Project	As 2036 Without Project, but with Sydney Gateway road project also completed.	✓	✓	✓	-	-	-
2036-WPC	2036 – Cumulative	As 2036 Without Project, but with Sydney Gateway road project, all stages of the F6 Extension, Western Harbour Tunnel, and Beaches Link also completed.	✓	✓	✓	✓	✓	✓

Notes

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

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

(c) A similar approach is used in other countries. For example, the inclusion of a base year for model evaluation is included in the Design Manual for Roads and Bridges in the UK (Highways Agency et al., 1999). The effects of the project relative to the base year are not considered, as this would confound changes in the emission performance of the fleet, and general growth in traffic, with the effects of the project itself.

3.5 Operational assessment – regional air quality

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

3.6 Operational assessment – odour

Potential for odour during the operational phase of the project was reviewed. 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 project operation.

For each of the discrete receptors, the change in the maximum 1-hour THC (potentially odorous) 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.

3.7 Treatment of uncertainty

3.7.1 Accuracy and conservatism

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

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

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

- It may unduly amplify community and stakeholder concerns about the impacts of the project
- It may lead to additional, or more stringent, conditions of approval than necessary, including the mitigation, monitoring and management of air quality
- Overstatement of vehicle contributions to local air quality may similarly lead to overstating the benefit where vehicle emissions are reduced by the project (AECOM, 2014).
- potential improvements in air quality being overestimated.

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

The operational air quality assessment for the project has been conducted, as far as possible, with the intention of providing 'accurate' or 'realistic' estimates of pollutant emissions and concentrations. The general approach has been to use inputs, models and procedures that are as accurate as possible, except where the context dictates that a degree of conservatism is sensible. An example of this is the estimation of the maximum 1-hour NO_2 concentration during a given year. Any method which provides a 'typical' or 'average' 1-hour NO_2 concentration would tend to result in an underestimate of the likely maximum concentration, and therefore a more conservative approach is required.

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

3.7.2 Key assumptions

The key assumptions underpinning the assessment of operational impacts have been summarised in **section 6.2.2.3**. 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.

4 Existing environment

4.1 Overview of section

This section describes the existing environment and conditions in the GRAMM domain (area assessed using the prognostic wind field model), and covers the following aspects:

- Terrain
- Land use
- Climate
- Meteorology
- Air pollutant emissions, with an emphasis on road traffic
- Ambient air quality (background levels including other sources such as the airport).

The meteorological inputs and background pollutant concentrations required for the operational air quality assessment are described in **section 6**.

The receptors that were included in the construction and operational assessments, including those on Commonwealth Land, are described in **section 6** and **section 7** respectively.

4.2 Terrain

Terrain data for Sydney were obtained from the Geoscience Australia Elevation Information System (ELVIS) website. 25-metre resolution terrain data were used in the GRAMM modelling and 5-metre data used in the GRAL modelling. **Figure 4-1** shows the terrain immediately surrounding the Sydney Gateway road project, based on the 5-metre resolution data. The vertical scale is exaggerated.

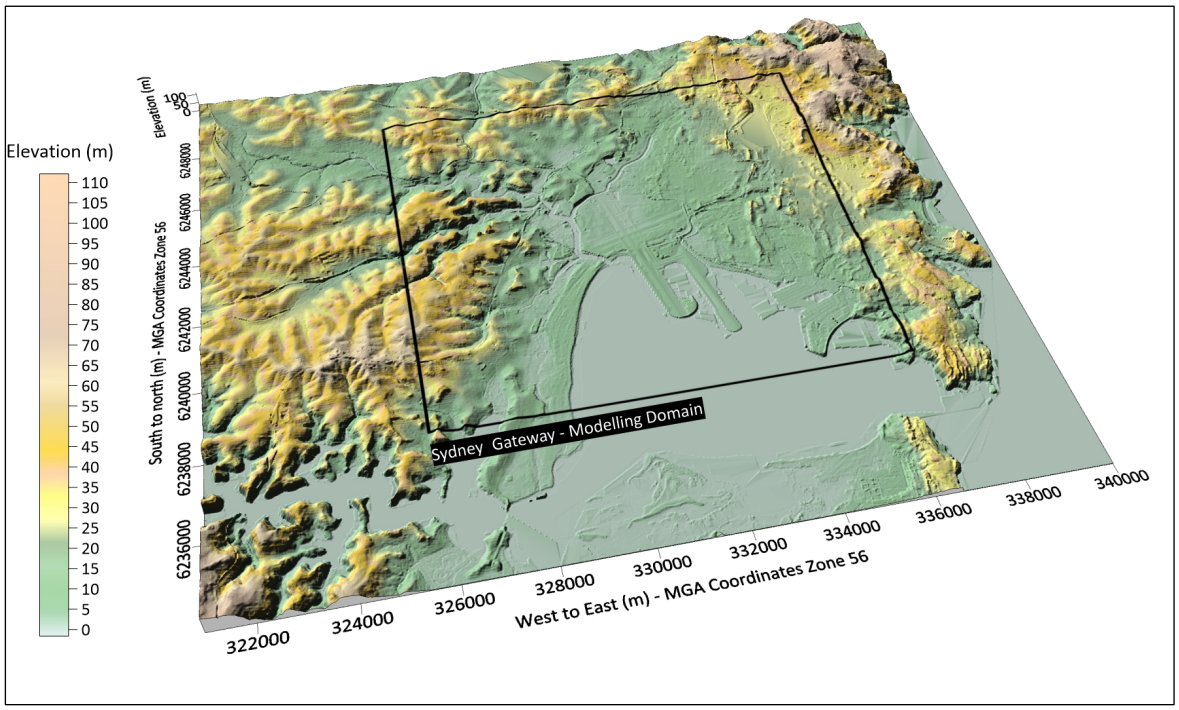


Figure 4-1 Terrain in the GRAL domain (grid system MGA94)

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

4.3 Land use

Land use within the GRAL domain consists primarily of urban areas and transport infrastructure (Sydney Airport and Port Botany), with pockets of recreational reserves and water bodies around the airport.

4.4 Climate

Table 4-1 presents the long-term average temperature and rainfall data for the Bureau of Meteorology (BoM) weather station at Sydney Airport AMO (site 066037), which is located near to the centre of the GRAL domain and is broadly representative of the area. The annual average daily maximum and minimum temperatures are 22.4°C and 13.5°C, respectively. On average, January is the hottest month with an average daily maximum temperature of 26.7°C. July is the coldest month, with an average daily minimum temperature of 7.3°C. The wettest month is June, with 124.9 millimetres falling over eight rain days. The average annual rainfall is 1,081 millimetres over an average of 96 rain days per year.

Table 4-1 Long-term average climate summary for Sydney Airport AMO

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Mean daily maximum temperature (ºC)												
26.7	26.5	25.4	23.0	20.1	17.6	17.1	18.4	20.7	22.7	24.2	25.9	22.4
Mean daily minimum temperature (ºC)												
19.0	19.1	17.6	14.3	11.0	8.7	7.3	8.2	10.5	13.3	15.5	17.6	13.5
Mean monthly rainfall (mm)												
94.5	111.5	117.0	107.8	96.1	124.9	68.9	76.0	59.8	70.6	80.6	73.6	1081.1
Mean rain days per month (number)												
8.1	8.7	9.3	8.5	8.3	8.8	6.6	6.8	6.8	7.9	8.3	7.8	95.9

Source: BoM (2019) Climate averages for Station: 066037; Commenced: 1929 – last record February 2019; Latitude: 33.99°S; Longitude: 151.17 °E

4.5 Meteorology

Meteorology is an important factor affecting the dispersion of air pollution. Six meteorological stations in the GRAMM domain were considered, and their locations are shown in **Figure 4-2**. Data relevant to the dispersion modelling such as wind speed, wind direction, temperature and cloud cover were obtained from these stations:

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

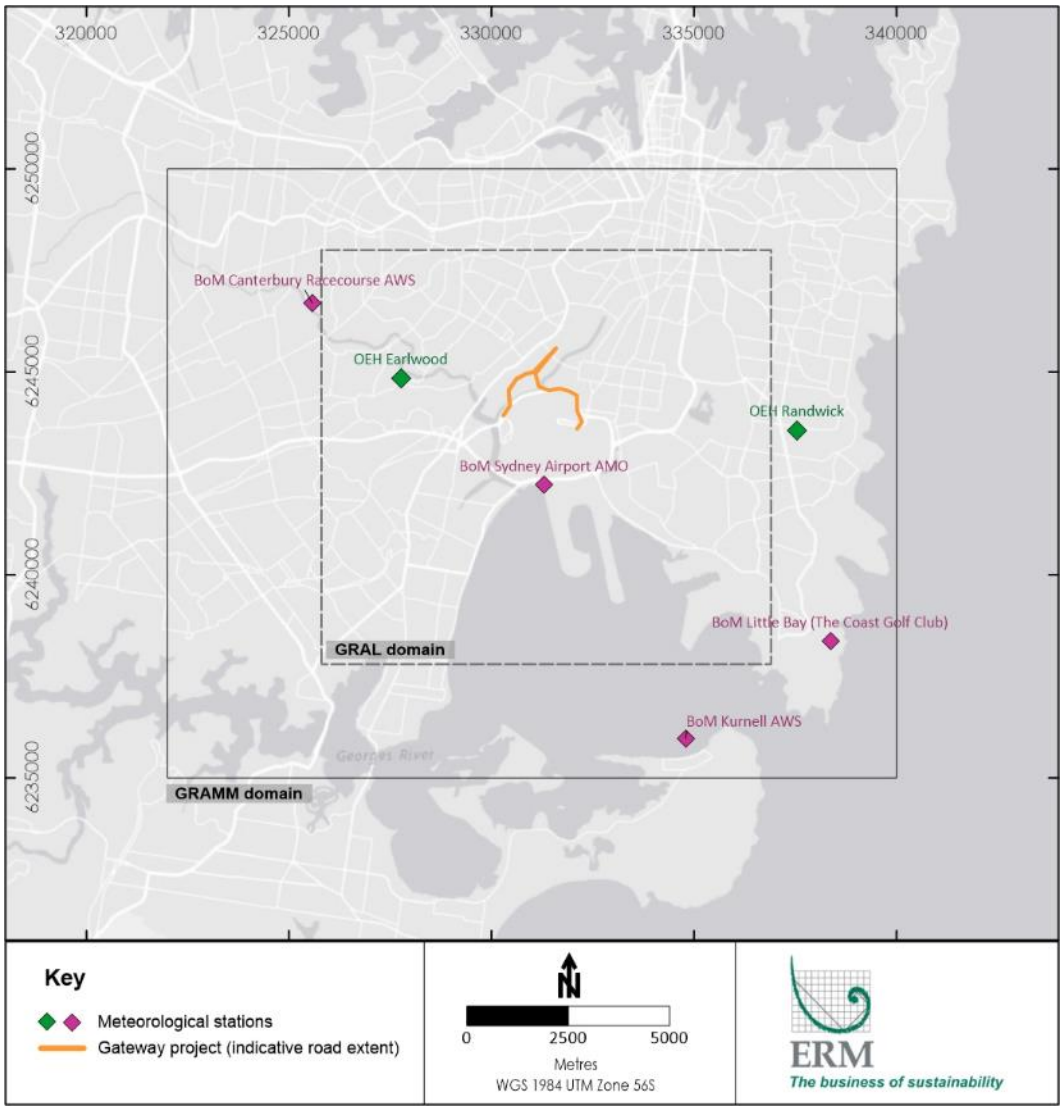


Figure 4-2 Meteorological stations in the model domains (grid system MGA94)

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

At Randwick the wind speed and wind direction patterns over the eight-year period between 2009 and 2016 were quite consistent; the annual average wind speed ranged from 1.9 metres per second to 2.6 metres per second. It is worth noting that the station was surrounded by trees until 2010 when they were removed. The annual average wind speeds between 2011 and 2016 were 2.4 to 2.6 metres per second. The annual percentage of calms (wind speeds <0.5 metres per second) ranged from 9.1 to 10.7 per cent between 2011 and 2016. **Figure 4-3** shows annual and diurnal plots of wind speed and temperature from the Randwick station for 2016. The annual plots show a typical distribution of wind speed and temperature over the course of a year. The diurnal plots also show typical patterns, with higher wind speeds and temperatures during the day and lower wind speeds and temperatures at night and in the early morning.

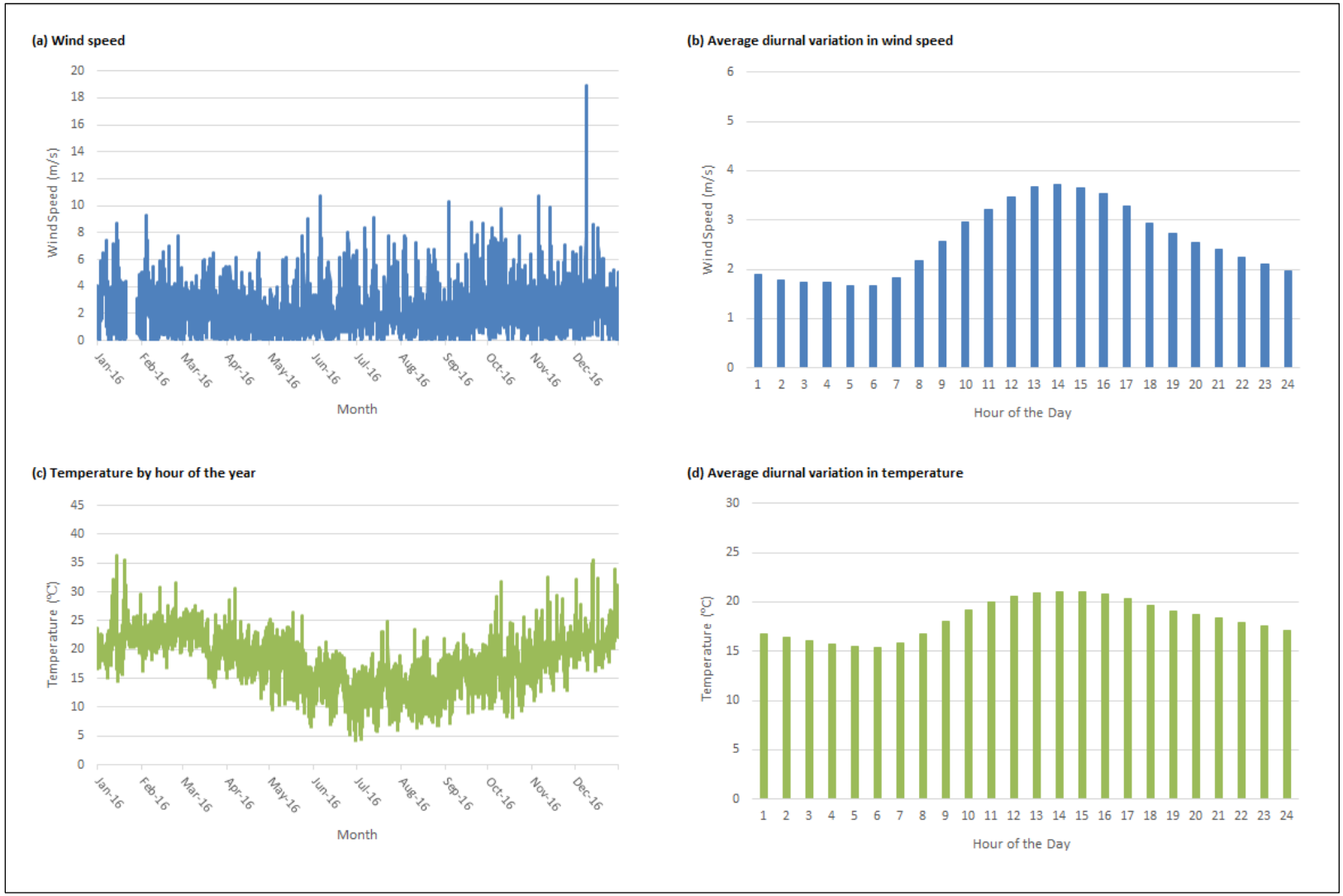


Figure 4-3 Annual and diurnal plots of wind speed and temperature for the OEH Randwick station (2016)

4.6 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). Further discussion on these trends is provided in **Annexure C**.

4.7 Ambient air quality

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

4.7.1 General characteristics of air quality in Sydney

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

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

While levels of NO_2, SO_2 and CO continue to be below national standards, levels of ozone and particles (PM_{10} and $PM_{2.5}$) still exceed the standards on occasion.

Ozone and PM levels are affected by:

- The annual variability in the weather
- Natural events such as bushfires and dust storms, as well as hazard-reduction burns. A dramatic example of this was the dust storm that swept across Eastern Australia between 22 and 24 September 2009
- The location and intensity of local emission sources, such as wood heaters, transport and industry (OEH, 2015).

In addition to the local road network, Sydney Airport is another major contributor to overall air emissions in the area. For the purposes of this assessment, the resultant concentrations from Sydney Airport are captured in the ambient air quality monitoring data described in detail in **Annexure D**.

4.7.2 Data from monitoring stations in the study area

A detailed analysis of the historical trends in Sydney's air quality (2004–2017) is provided in **Annexure D**. The analysis was based on hourly data from the following long-term monitoring stations operated by OEH and Roads and Maritime:

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

Consideration was also given to the shorter-term data from other air quality monitoring stations. The results for specific air quality metrics during the period 2004-2017 are summarised in **Table 4-2**.

Table 4-2 Air quality criteria applicable to the project assessment

Pollutant	Averaging period	Comment (for period 2004-2017)
CO	Maximum 1-hour and rolling 8-hour	All values were well below the air quality criteria of 30 mg/m^3 (1-hour) and 10 mg/m^3 (8-hour). Between 2008 and 2017 the maximum 1-hour concentrations were typically between around 1.5 and 5 mg/m^3, and the maximum 8-hour concentrations were around 2 mg/m^3. There were general downward trends in maximum concentrations, and these trends were statistically significant at most stations.
NO_2	Annual mean	Concentrations at all stations have been well below the air quality criterion of 62 µg/m^3 and have ranged between around 15 and 25 µg/m^3 (depending on the station) in recent years. Values at the OEH stations exhibited a systematic, and generally significant, downward trend overall. However, in recent years the concentrations at some stations appear to have stabilised. The long-term average NO_2 concentrations at the Roads and Maritime roadside stations (F1 and M1) were around 10 µg/m^3 higher than those at the M5 East background stations. Even so, the concentrations at the roadside stations were also well below the criterion.
	Maximum 1-hour	Although variable from year to year, maximum NO_2 concentrations have been quite stable in the longer term. The values across all stations have typically varied around 100 µg/m^3, and continue to be well below the criterion of 246 µg/m^3. The maximum 1-hour NO_2 concentrations at the two Roads and Maritime roadside stations in 2016 were 144 µg/m^3 and165 µg/m^3.
PM_{10}	Annual mean	Annual mean PM_{10} concentrations at the OEH stations showed a downward trend, and this was statistically significant at several stations. In recent years the annual mean concentration at these stations has been between 17 µg/m^3 and 20 µg/m^3. The concentrations at the Roads and Maritime background stations appear to have stabilised at around 15 µg/m^3. These values can be compared with air quality criterion of 25 µg/m^3. The measurements from the Roads and Maritime roadside sites show that the road increment for PM_{10} is small.
	Maximum 24-hour	Maximum 24-hour PM_{10} concentrations exhibited no trend with time, and there was a large amount of variation from year to year. In 2017 the concentrations at the various stations were clustered around 50-60 µg/m^3. Again, the roadside values were similar to the background values.
$PM_{2.5}$	Annual mean	$PM_{2.5}$ has been measured over several years at two OEH stations in the study area. Concentrations at Chullora and Earlwood showed a similar pattern, with a systematic reduction between 2004 and 2012 being followed by a substantial increase in 2013. The main reason for the increase was a change in the measurement method. The increases meant that background $PM_{2.5}$ concentrations in the study area between 2013 and 2017 were already very close to or above the standard in the AAQ NEPM of 8 µg/m^3, and above the long-term goal of 7 µg/m^3.
	Maximum 24-hour	There has been no systematic long-term trend in the maximum 24-hour $PM_{2.5}$ concentration. However, there has been an underlying increase in concentrations between 2014 and 2017, such that they are currently above the NSW criterion of 25 µg/m^3. In most years the maximum concentrations have been above the NEPM long-term goal of 20 µg/m^3.

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

4.8 Receptors

Predictions are made on a 10 metre by 10 metre cartesian grid across the model domain, as well as a number of discrete receptors. These individual receptors are made up of 17 community receptors and 12,145 residential, workplace and recreational (RWR) receptors. Community receptors represent particularly sensitive locations such as schools, childcare centres and hospitals, generally near significantly affected roadways. More detailed analyses were carried out for these receptors. RWR receptors refer to all discrete receptor locations included in the operational assessment and mainly cover residential and commercial uses.

The community receptors are listed in **Table 4-3** and also shown in **Figure 4-4** with the RWR receptors. These receptor codes are used throughout the assessment to refer to individual community receptors.

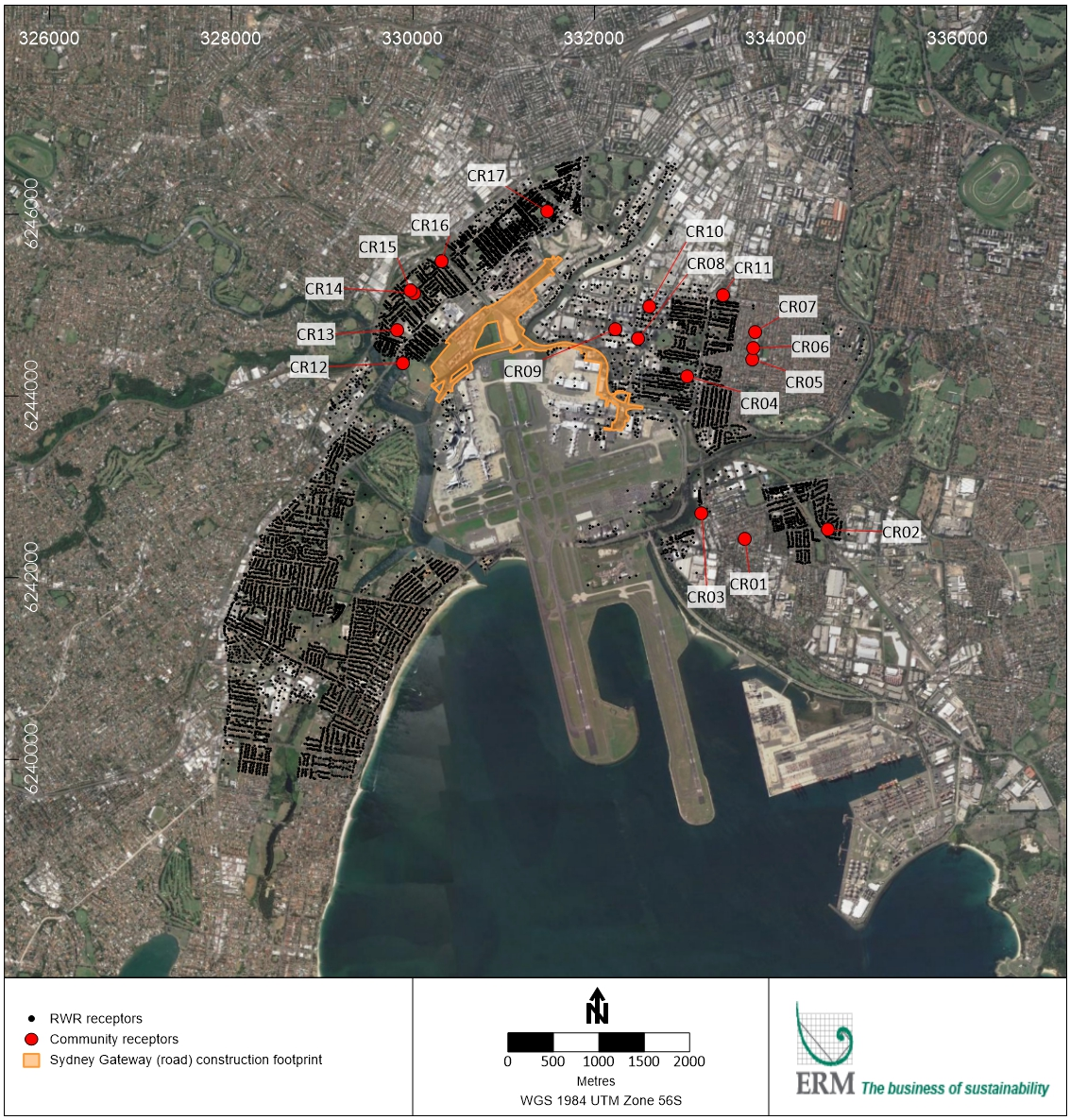


Figure 4-4 All discrete receptor locations (RWR and Community)

Table 4-3 Community receptor details

Receptor code	Receptor name	Address	Suburb	Receptor location	
				x	y
CR01	Aero Kids Early Learning Centre	211/247 Coward Street	Mascot	332232	6244737
CR02	Guardian Early Learning Centre	18 Holbeach Avenue	Tempe	329887	6244361
CR03	Gardeners Road Public School	827 Botany Road	Rosebery	333410	6245113
CR04	Botany Public School	1076 Botany Road	Botany	333180	6242707
CR05	Mascot Public School	207 King Street	Mascot	333010	6244221
CR06	Tempe High School	Unwins Bridge Road	Tempe	329973	6245160
CR07	JJ Cahill Memorial High School	Sutherland Street	Mascot	333739	6244407
CR08	St Bernard's Catholic Primary School	Ramsgate Street	Botany	333659	6242429
CR09	Active Kids Mascot	18 Church Avenue	Mascot	332601	6244985
CR10	Betty Spears Child Care Centre	1A Gannon Street	Tempe	329823	6244730
CR11	Toybox Early Learning	1-3/15 Bourke Road	Mascot	332480	6244630
CR12	Mascot Child Care Centre	53 Coward Street	Mascot	333744	6244525
CR13	St Therese Catholic Primary School	Sutherland Street	Mascot	333764	6244705
CR14	St Peters Public School	Church Street	St Peters	331484	6246029
CR15	Tillman Park Child Care Centre	81 Unwins Bridge Road	Tempe	330313	6245488
CR16	Tempe Public School	Unwins Bridge Road	St Peters	330009	6245134
CR17	Pagewood Kindergarten	1A Dudley Street	Pagewood	334569	6242527

5 Assessment of construction impacts

5.1 Summary of approach and key findings

This section deals with the potential air quality impacts of the construction phase of the project. This section:

- Identifies the construction activities and the construction footprint
- Describes the assessment procedure, which was based upon the guidance published by the UK Institute of Air Quality Management (IAQM, 2014)
- Presents results for assessment of:
  - Dust soiling impacts
  - Human health impacts
  - Ecological impacts
- Discusses the significance of the identified risks.

The assessment identified a high risk of dust soiling, human health and ecological impacts for all types of activity.

The measures recommended to minimise and manage potential air quality impacts of construction are provided in **section 8.1**.

5.2 Construction impacts of Sydney Gateway

5.2.1 Construction activities

Construction activities for the project would include:

- Enabling works
- Site establishment works
- Main construction works
- Finishing and post construction rehabilitation.

5.2.2 Construction footprint and program

The project 'construction footprint' is shown in **Figure 1-2**. This is the surface construction works area and area required for temporary construction facilities such as fencing, laydown area and offices.

The project would be constructed over a period of around five years. An indicative project program used for the purpose of completing this air quality assessment is contained in **Table 5-1**. The project is expected to be completed towards the end of 2023.

Table 5-1 Indicative construction program

Construction Activity	2020				2021				2022				2023			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Enabling works																
Site establishment																
Main construction works																
Finishing and post construction rehabilitation																

5.2.3 Assessment procedure

The IAQM procedure for assessing risk from construction dust[8] is summarised in **Figure 5-1**. If an initial screening step shows that an assessment is required, construction activities are divided into four types to reflect their different potential impacts, and the potential for dust emissions is assessed for each activity that is likely to take place. These activities are:

- **Demolition** - removal of existing structures, including when a building is removed a small part at a time
- **Earthworks** - processes of soil stripping, ground levelling, excavation and landscaping. Earthworks primarily involve excavating material, haulage, tipping and stockpiling
- **Construction** - activity for provision of new structures, modification or refurbishment of existing structures.
- **Track-out** - transport of dirt, dust or spoil on heavy-duty vehicles (HDVs) from the work sites onto the public road network, where it may be deposited and then re-suspended by other vehicles.

The assessment methodology considers three separate dust impacts:

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

The outcomes of the assessment process were used to define appropriate mitigation measures to ensure that there would be no significant adverse air quality effect.

Assessment steps for consideration of dust are summarised in **Figure 5-1**. Professional judgement was applied, and where the justification for assumptions could not be fully informed by available data, a precautionary approach was adopted.

[8] Exhaust emissions from on-site plant and site traffic would be unlikely to have a significant impact on local air quality.

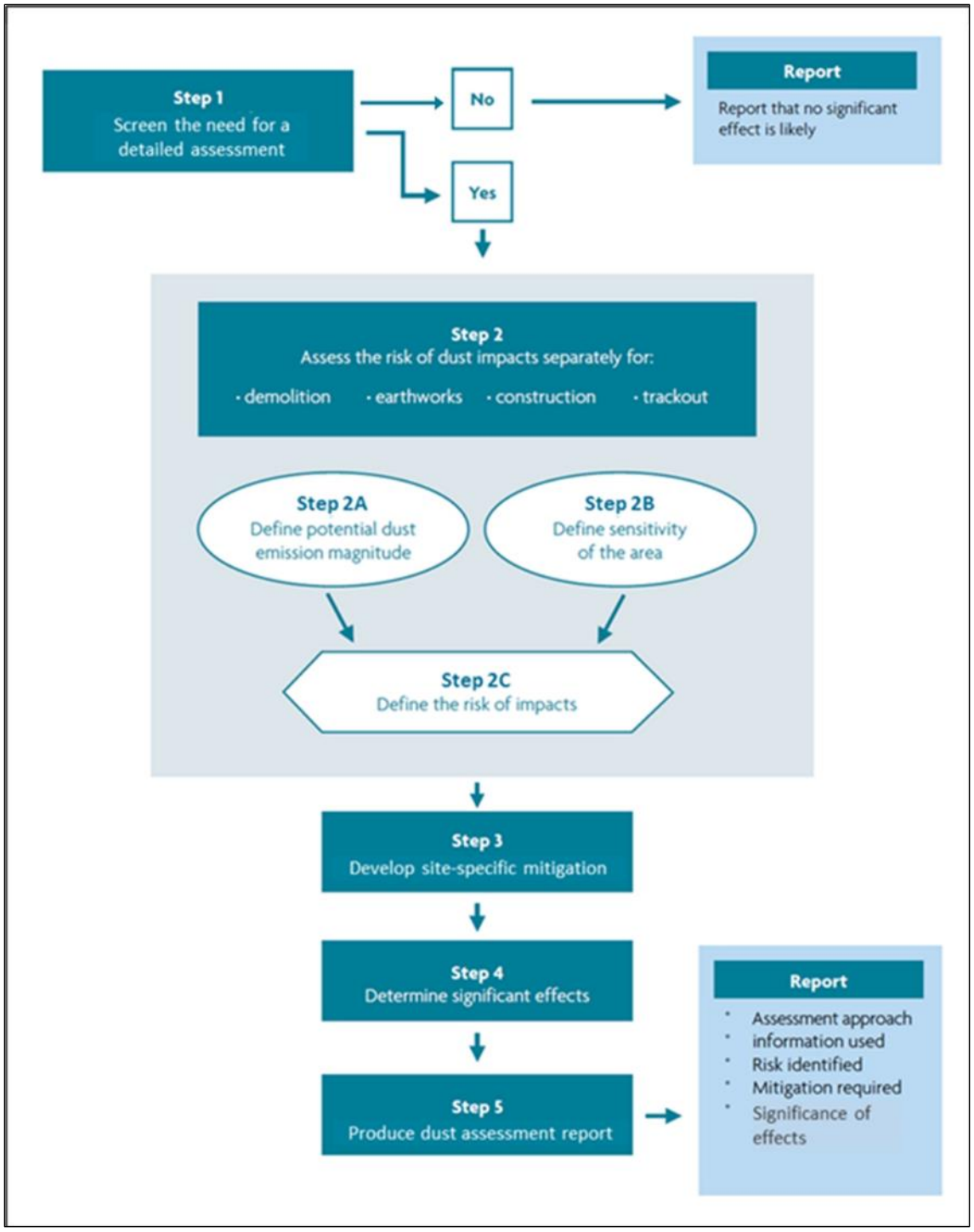


Figure 5-1 Steps in an assessment of construction dust (IAQM, 2014)

5.2.4 Step 1: Screening

A construction dust assessment is normally required where:

- There are human receptors within 350 metres of the boundary of the site and/or within 50 metres of the route(s) used by construction vehicles on the public highway, up to 500 metres from the site entrance(s)
- There are ecological receptors within 20 metres of the boundary of the site and/or within 50 metres of the route(s) used by construction vehicles on the public highway, up to 500 metres from the site entrance(s).

A 'human receptor', refers to any location where a person or property may experience the adverse effects of airborne dust or dust soiling, or exposure to PM_{10} over a time period that is relevant to air quality standards and goals. Annoyance effects would most commonly relate to dwellings, but may also refer to other premises such as buildings housing cultural heritage collections (eg museums and galleries), vehicle showrooms, food manufacturers, electronics manufacturers, amenity areas and horticultural operations (eg soft-fruit production). In relation to this assessment specifically, this also applies to receptors which may experience potential aviation hazards due to raised dust and also such receptors as flight simulation areas containing sensitive equipment.

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

Figure 5-2 shows the location of multiple off-site human receptors located within 350 metres of the boundaries of the project construction footprint. This zone also contains areas of ecological significance, including Alexandra Canal and Tempe Wetlands. It was concluded that a construction dust assessment was required. Both human receptors and areas of ecological significance are included in the assessment.

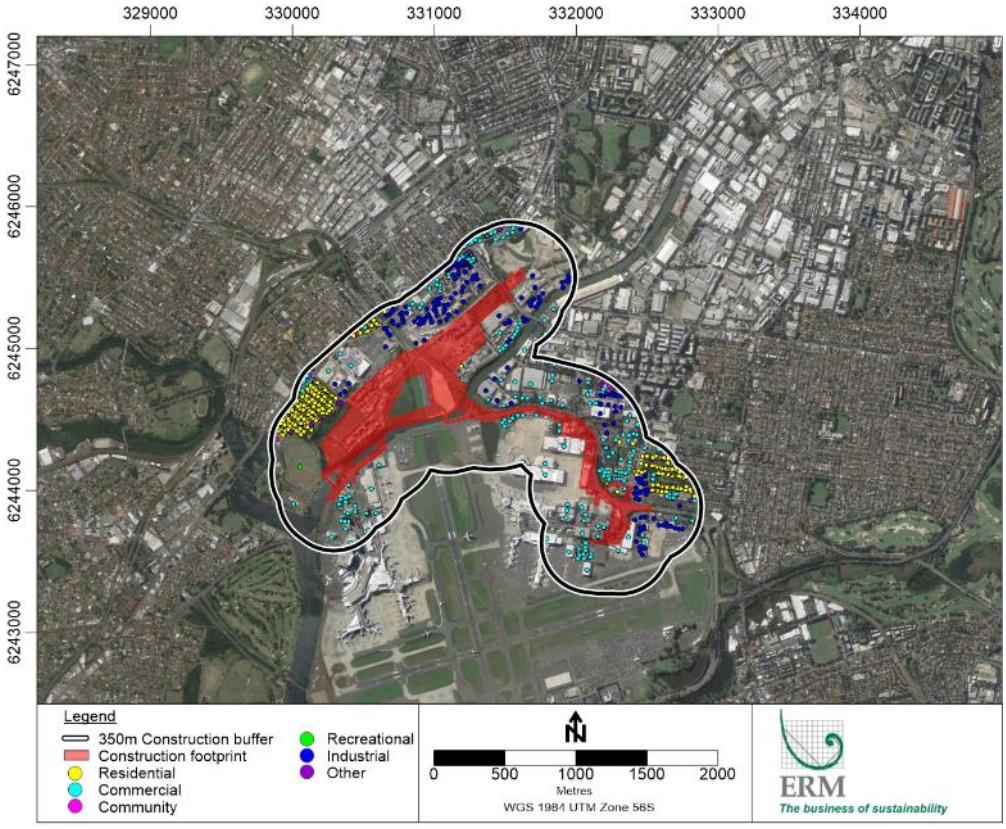


Figure 5-2 Receptors near the construction footprint of the Sydney Gateway road project

5.2.5 Step 2: Risk assessment

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

- The magnitude of potential dust emissions. This is assessed in Step 2A by considering the scale and nature of the works
- The sensitivity of the area. This includes considering proximity of sensitive receptors (ie the potential for effects). This is assessed in Step 2B.

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

5.2.5.1 Step 2A: Potential dust emissions

The IAQM criteria for assessing the potential scale of dust emissions based on the scale and nature of the works are shown in **Table 5-2**. The appropriate categories for each zone were determined based on these criteria and the types of activity proposed within the zone and are shown in **Table 5-3**. To ensure a conservative assessment it has been assumed the scale is large for all types of activity.

Table 5-2 Criteria for assessing the potential scale of emissions

Type of activity	Site category (dust emission magnitude)		
	Large	Medium	Small
Demolition	Building volume >50,000 m^3, potentially dusty construction material (eg concrete), on-site crushing and screening, demolition activities >20 m above ground level.	Building volume 20,000–50,000 m^3, potentially dusty construction material, demolition activities 10–20 m above ground level.	Building volume <20,000 m^3, construction material with low potential for dust release (eg metal cladding, timber), demolition activities <10 m above ground and during wetter months.
Earthworks	Site area >10,000 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 >100,000 tonnes.	Site area 2,500–10,000 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 20,000–100,000 tonnes.	Site area <2,500 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 <20,000 tonnes, earthworks during wetter months.
Construction	Total building volume >100,000 m^3, piling, on site concrete batching; sandblasting.	Building volume 25,000–100,000 m^3, potentially dusty construction material (eg concrete), piling, on site concrete batching.	Total building volume <25,000 m^3, construction material with low potential for dust release (eg metal cladding or timber).
Track-out	>50 HDV (>3.5 t) outward movements in any one day, potentially dusty surface material (eg high clay content), unpaved road length >100 m.	10–50 HDV (>3.5 t) outward movements in any one day, moderately dusty surface material (eg high clay content), unpaved road length 50–100 m.	<10 HDV (>3.5 t) outward movements in any one day, surface material with low potential for dust release, unpaved road length <50 m.

Table 5-3 Results of categorisation of compound for each type of activity

Type of activity	Site category (dust emission magnitude)
Demolition	Large
Earthworks	Large
Construction	Large
Track-out	Large

5.2.5.2 Step 2B: Sensitivity of area

The sensitivity of the area takes into account the specific sensitivities of local receptors, the proximity and the number of receptors, the local background PM_{10} concentration, and site-specific factors (eg presence of natural shelters). Dust soiling and health impacts are treated separately.

Sensitivity of area to dust soiling effects on people and property

The IAQM criteria for determining the sensitivity of an area to dust soiling impacts are shown in **Table 5-4**. 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 people 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. In view of the types of receptor shown in **Figure 5-2** being predominantly residences in addition to commercial areas, and in consideration of the IAQM guidance, the receptor sensitivity was assumed to be 'high'.

Table 5-4 Criteria for sensitivity of area to dust soiling impacts

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

The number of receptors in each distance band was estimated from land-use zoning of the site. The exact number of 'human receptors' is not required by the IAQM guidance. Instead, it is recommended that judgement is used to determine the approximate number of receptors within each distance band. For receptors that are not dwellings, professional judgement should be used to determine the number of human receptors. In the case of the Sydney Gateway road project the following numbers of receptors per building were assumed:

- Commercial = 5
- Community:
  - School = 500
  - Child care = 30

  - Place of worship = 20
  - Medical practice = 10
- Industrial = 10
- Recreation/park = 20
- Residential:
  - Residential = 5
  - Hotel = 200
- Other = 5.

The number of receptors for the construction activities, and the resulting outcomes, are shown in **Table 5-5**. Based on the receptor sensitivity and the number of receptors within certain distances from activities, the sensitivity to dust soiling effects for all areas and activities was determined to be 'high'.

Table 5-5 Results of sensitivity to dust soiling effects

Activity	Receptor sensitivity	Number of receptors by distance from source (m)				Sensitivity of area
		<20	20–50	50–100	100–350	
Demolition	High	105	405	555	5,860	High
Earthworks	High	105	405	555	5,860	High
Construction	High	105	405	555	5,860	High
Track-out	High	105	405	N/A	N/A	High

Sensitivity of area to human health impacts

The IAQM criteria for determining the sensitivity of an area to human health impacts caused by construction dust are shown in **Table 5-6**. Air quality monitoring data from monitoring stations in the vicinity were used to establish an annual average PM_{10} concentration of 18.5 µg/m^3 (see **Annexure D, Figure D-26)**. Based on the IAQM guidance the receptor sensitivity was assumed to be 'high'. The numbers of receptors for each activity, and the resulting outcomes, are shown in **Table 5-7**.

Table 5-6 Criteria for sensitivity of area to health impacts

Receptor sensitivity	Annual mean PM_{10} conc. ($\mu g/m^3$)[(a)]	Number of receptors	Distance from source (m)				
			<20	<50	<100	<200	<350
High	>20	>100	High	High	High	Medium	Low
		10–100	High	High	Medium	Low	Low
		1–10	High	Medium	Low	Low	Low
	17.5-20	>100	High	High	Medium	Low	Low
		10–100	High	Medium	Low	Low	Low
		1–10	High	Medium	Low	Low	Low
	15-17.5	>100	High	Medium	Low	Low	Low
		10–100	High	Medium	Low	Low	Low
		1–10	Medium	Low	Low	Low	Low
	<15	>100	Medium	Low	Low	Low	Low
		10–100	Low	Low	Low	Low	Low
		1–10	Low	Low	Low	Low	Low
Medium	-	>10	High	Medium	Low	Low	Low
		1–10	Medium	Low	Low	Low	Low
Low	-	>1	Low	Low	Low	Low	Low

(a) Scaled for Sydney, according to the ratio of NSW and UK annual mean standards (25 $\mu g/m^3$ and 40 $\mu g/m^3$ respectively).

Table 5-7 Results for sensitivity of area to health impacts

Activity	Receptor sensitivity	Annual mean PM_{10} conc. ($\mu g/m^3$)	Number of receptors by distance from source (m)					Sensitivity of area
			<20	20-50	50-100	100-200	200-350	
Demolition	High	17.5-20	105	405	555	1,965	3,985	High
Earthworks	High	17.5-20	105	405	555	1,965	3,985	High
Construction	High	17.5-20	105	405	555	1,965	3,985	High
Track-out	High	17.5-20	105	405	N/A	N/A	N/A	High

Sensitivity of area to ecological impacts

The IAQM criteria for determining the sensitivity of an area to ecological impacts of construction dust are shown in **Table 5-8**. Based on the IAQM guidance the receptor sensitivity was assumed to be 'high' for ecologically sensitive areas such as threatened flora and fauna. An area containing potential for ecological significance within 50 metres of the construction footprint is the Tempe Wetlands. Receptors within this area and within 50 metres of the construction footprint were determined to have a 'medium' sensitivity to ecological impacts as listed in **Table 5-9**.

Table 5-8 Criteria for sensitivity of area to ecological impacts

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

Table 5-9 Results of sensitivity to ecological impacts

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

5.2.5.3 Step 2C: Risk of dust impacts

The dust emission potential determined in Step 2A is combined with the sensitivity of the area determined in Step 2B to give the risk of impacts if no mitigation measures are applied. The criteria are shown in **Table 5-10**.

The final results for the Step 2C risk assessment are provided in **Table 5-11**, combining the scale of the activity and the sensitivity of the area. For all three types of dust impact (soiling, health, ecological) the risk of impacts was determined to be 'high'.

Table 5-10 Risk categories

Type of activity	Sensitivity of area (from Step 2B)	Dust emission potential (from Step 2A)		
		Large	**Medium**	**Small**
Demolition	High	High Risk	Medium Risk	Medium Risk
	Medium	High Risk	Medium Risk	Low Risk
	Low	Medium Risk	Low Risk	Negligible
Earthworks	High	High Risk	Medium Risk	Low Risk
	Medium	Medium Risk	Medium Risk	Low Risk
	Low	Low Risk	Low Risk	Negligible
Construction	High	High Risk	Medium Risk	Low Risk
	Medium	Medium Risk	Medium Risk	Low Risk
	Low	Low Risk	Low Risk	Negligible
Track-out	High	High Risk	Medium Risk	Low Risk
	Medium	Medium Risk	Low Risk	Negligible
	Low	Low Risk	Low Risk	Negligible

Table 5-11 Summary of risk assessment for construction

Activity	Step 2A: Potential for dust emissions	Step 2B: Sensitivity of area			Step 2C: Risk of dust impacts		
		Dust soiling	**Human health**	**Ecological**	**Dust soiling**	**Human health**	**Ecological**
Demolition	Large	High	High	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

5.2.6 Step 3: Mitigation

Step 3 involved determining mitigation measures for each of the four potential activities in Step 2. This was based on the risk of dust impacts identified in Step 2C. For each activity, the highest risk category was used. The suggested mitigation measures are discussed in **section 8.1**.

5.2.7 Step 4: Significance of risks

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

However, even with a rigorous dust management plan in place, it is not possible to guarantee that dust mitigation measures would be effective all the time. There is the risk that nearby residences, commercial buildings, hotel, cafés and schools in the immediate vicinity of the construction zone, will experience some occasional dust soiling impacts.

Overall construction dust is unlikely to represent a serious ongoing problem for this project on its own. Any effects would be temporary and relatively short-lived, and would generally 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 dust impacts would not normally be considered sufficient to change the conclusion that with mitigation the effects will be 'not significant'.

It is however important to note that the area near the St Peters Interchange is already undergoing significant construction works as part of the New M5 and M4-M5 Link projects and so there is likely to be an element of "construction fatigue" experienced by people who live and work in that area. Management of any mitigation activities should be extra vigilant in this area to ensure these construction works do not add significantly to that burden.

The proposed Botany Rail Duplication is adjacent to much of the southern construction area for this project. If these two projects coincide with each other, it is important to ensure the measures in the dust management plan are followed rigorously. The combined impacts of these two projects is addressed in **section 7.1.1**.

It is also noted that visibility and aviation safety is important given the proximity to Sydney Airport. With all risks identified and managed, it is not anticipated that the types of construction activities required will cause plumes of dust that would affect visibility.

5.3 Odour

Potential odour impacts due to excavation through the former Tempe Landfill, and relevant management measures, are addressed specifically in an odour assessment that is being undertaken as part of the Sydney Gateway road project.

To avoid or mitigate potential odour impacts at the site, measures may include such things as:

- Procedures for keeping areas of exposed material to a minimum while the area is uncovered
- Procedures for temporarily covering odorous material
- Modelling to understand the meteorological conditions under which odour impacts are likely to occur and to alter activities accordingly or alert local residents in advance
- Making sure the local community is aware of the potential odour issues during the site establishment period.

5.4 Construction impacts on Sydney Airport (Commonwealth) land

Figure 5-3 shows the location of sensitive receptors on Commonwealth land within 350 metres of the project footprint. These receptors are either commercial or industrial.

As observed in **section 5.2**, there is a high risk of dust impacts on nearby receptors due to the construction works associated with the project and a number of measures to reduce this risk have been identified in **section 8.1**. These mitigation measures would reduce dust on both state and Commonwealth land so that impacts are not significant.

Figure 5-3 Location of sensitive receptors on Sydney Airport (Commonwealth) land

5.5 Consistency with Sydney Airport Master Plan and Environment Strategy

Sydney Airport's Master Plan 2039 has a number of operational and environment objectives. With respect to air quality, one of the objectives is to continue to improve environmental performance at the airport in order to protect environmentally significant areas.

A key theme of the airport's Master Plan and Environment Strategy is the commitment to sustainability. All major airports have an effect on the air quality environment, due to the nature of their operations, and minimising these impacts is fundamental to operating sustainably.

The assessment of the construction impacts of the project on air quality is consistent with this objective and also the theme of sustainability, in that risks have been assessed and mitigation measures are recommended which take into account human health and amenity, and environmentally significant and sensitive areas. Any impacts would likely be temporary and short-lived.

6 Assessment of operational impacts

6.1 Summary of approach and key findings

This section sets out methods and results of the air quality assessment. Key points are:

- The assessment was undertaken using the GRAMM-GRAL model system, with traffic data taken from the Strategic Motorway Planning Model (SMPM) and emissions calculated using an emission model developed by NSW EPA. The model predictions were added to background concentrations based on data from air quality monitoring stations
- Across the whole model domain, emissions of CO from traffic increased slightly whereas emissions of all other pollutants decreased slightly
- Changes in the total emissions resulting from the project can be viewed as a proxy for its regional air quality impacts, which are likely to be negligible. The changes in emissions associated with the project in a given year would be much smaller than the underlying reductions in emissions from the traffic over time as a result of improvements in emission-control technology
- Predicted total concentrations of all criteria pollutants at receptors were usually dominated by the existing background contribution. However, for NO_2 there was also predicted to be a significant contribution from road traffic
- For several air quality metrics (notably annual mean $PM_{2.5}$, 24-hour PM_{10} and $PM_{2.5}$), exceedances of the criteria were predicted to occur both with and without the project. This was because of high 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, but not at any particularly sensitive locations and not to cause additional exceedances above criteria
- The spatial changes in air quality as a result of the project were quite complex, reflecting the complex changes in traffic on the network.

6.2 Operational impacts of Sydney Gateway

6.2.1 Emissions

6.2.1.1 Model selection

Various emission models have been developed for the road transport sector. Most models are empirical in nature, being based on data from laboratory or real-world tests. A large number of emission models have been developed for surface roads. The most appropriate emission model for surface roads was considered to be the one developed by NSW EPA for the emissions inventory covering the Greater Metropolitan Region (NSW EPA, 2012b). This selection is consistent with other recent road projects, including the F6 Extension Stage 1, M4-M5 Link, New M5 and M4 East. A description of the model, including an evaluation of its performance, is provided in **Annexure E**.

6.2.1.2 Input data

Strategic Motorway Planning Model (SMPM)

Data on traffic volume, composition and speed for surface roads in the GRAL model domain 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 Sydney Gateway. The SMPM is linked to the Strategic Travel Model, 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. SMPM version 1.0[9], which includes induced traffic demand, was used for this project.

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 includes the following time periods:

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

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

Network Description

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

The road links in the domain are shown in the figures on the following pages. Each figure shows the road links in the Without Project scenarios, as well as the additional links in the With Project and Cumulative scenarios:

- **Figure 6-1** shows the additional links in the 2026-WP and 2036-WP scenarios
- **Figure 6-2** shows the additional links in the 2026-WPC scenario
- **Figure 6-3** shows the additional links in the 2036-WPC scenario.

The road network had between 2,522 and 2,644 individual links, depending on the scenario (**Table 6-1**).

[9] Following the dispersion modelling an error was found in the traffic model. For certain links the posted speed limit of 70 km/h was incorrectly defined as 80 km/h. Reducing speed of traffic on a given road link by around 10 km/h (in this speed range) would have an effect on emissions from the traffic of no more than around ±10 per cent. Given that the predicted *change*s in concentration at receptors with the project were well within acceptable ranges (see **section 7**), the conclusions of the assessment would not be affected.

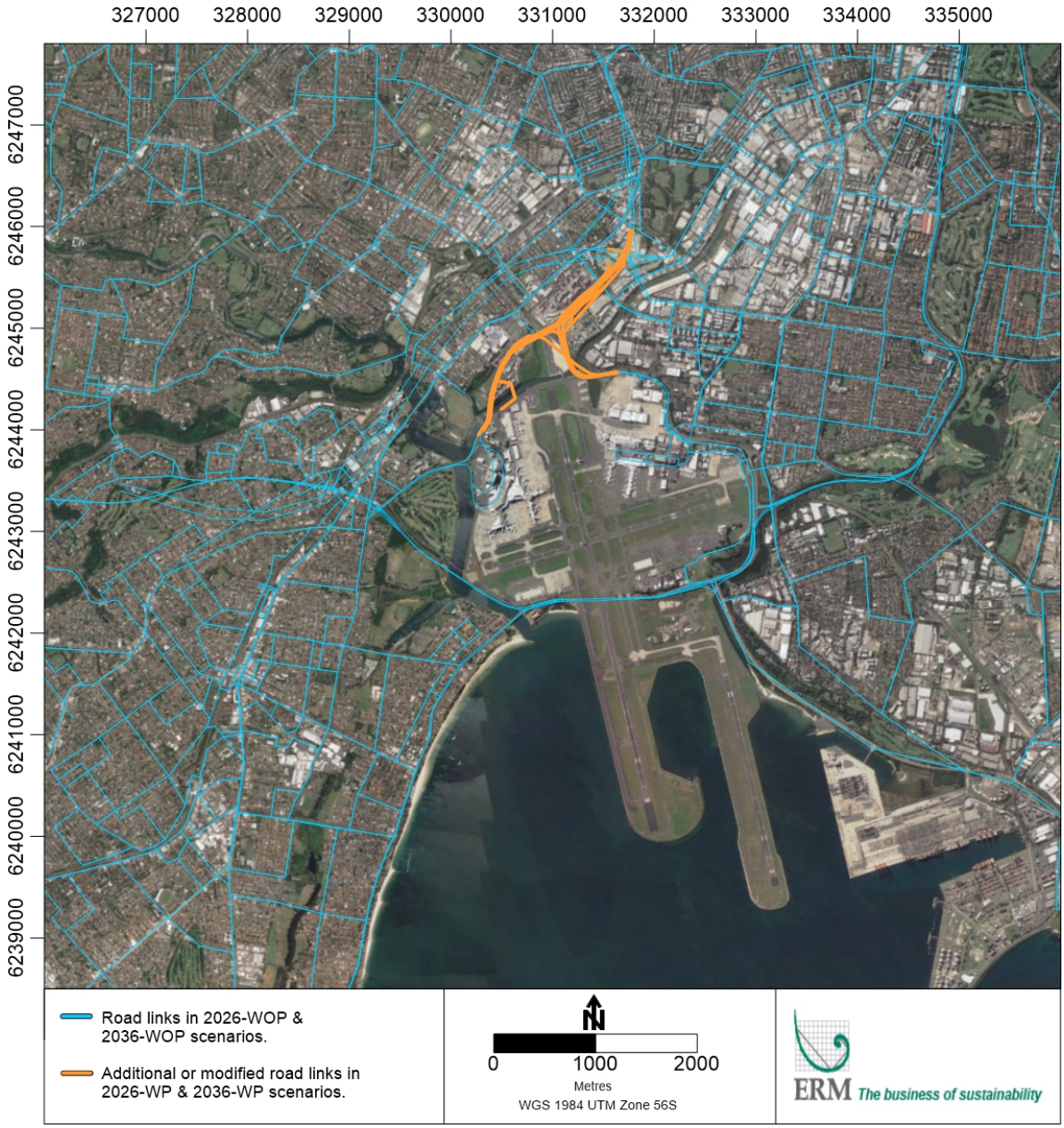


Figure 6-1 Road links in the Without Project scenarios, and additional/modified links in the 2026-WP and 2036-WP scenarios (grid system MGA94)

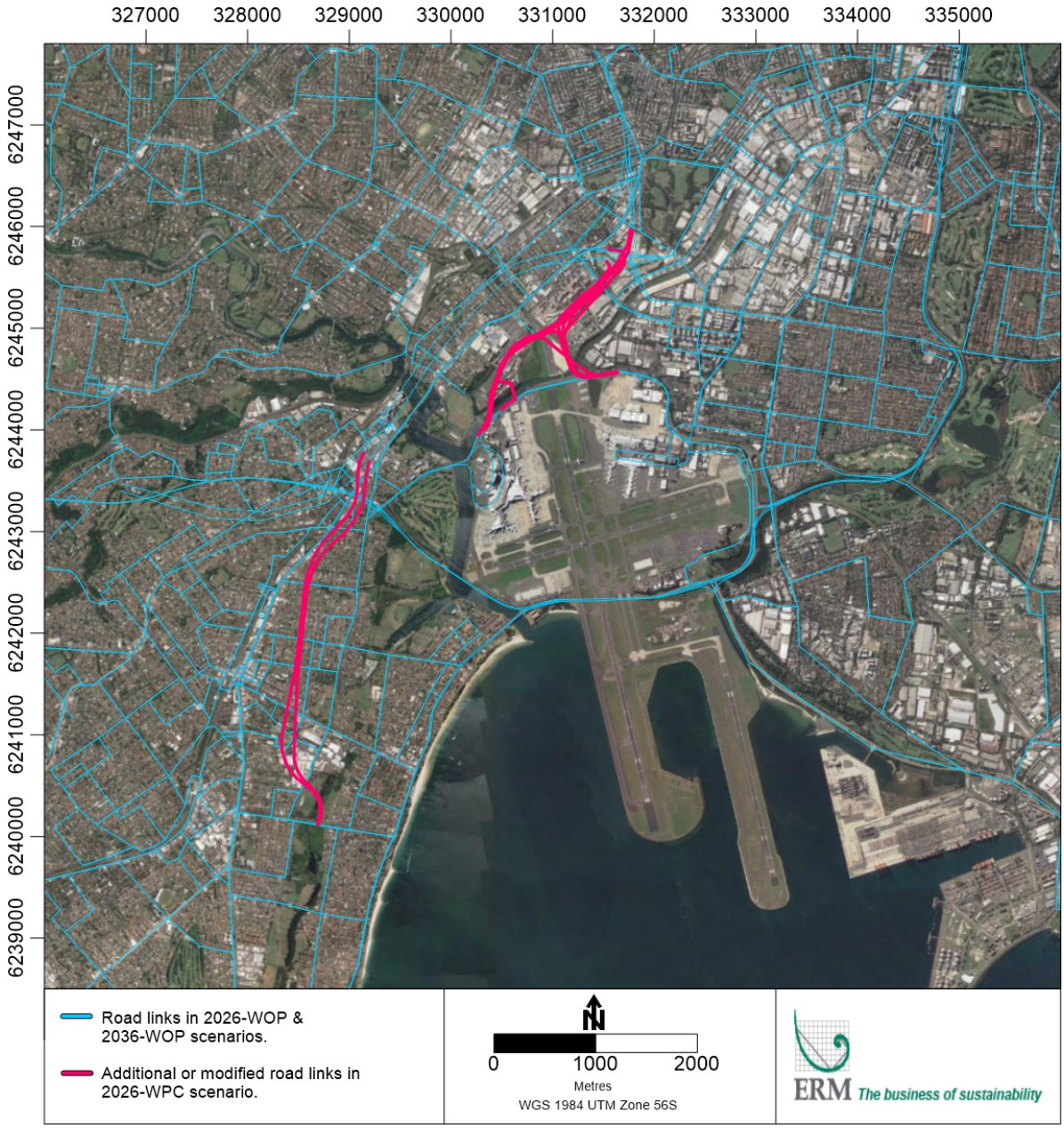


Figure 6-2 Road links in the Without Project scenarios, and additional/modified links in the 2026-WPC scenario (grid system MGA94)

Figure 6-3 Road links in the Without Project scenarios, and additional/modified links in the 2036-WPC scenario (grid system MGA94)

Table 6-1 Number of road links by scenario

Scenario code	Scenario description	Number of road links included (GRAL domain)
2016-BY	2016 – Base Year (existing conditions)	2,522
2026-WOP	2026 – Without Project (no Sydney Gateway road project)	2,570
2026-WP	2026 – With Project (with Sydney Gateway road project)	2,606
2026-WPC	2026 – With Project Cumulative (with Sydney Gateway road project and other projects)	2,618
2036-WOP	2036 – Without Project (no Sydney Gateway road project)	2,570
2036-WP	2036 – With Project (with Sydney Gateway road project)	2,606
2036-WPC	2036 – With Project Cumulative (with Sydney Gateway road project and other projects)	2,644

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 a NSW EPA road type, as shown in **Table 6-2**. 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 6-2 Assignment of SMPM road types to NSW EPA road types

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

Road width

The width of each road was not required for the emission modelling, but it was required as an input for the GRAL dispersion model to define the initial plume dispersion conditions. It was not feasible to determine the precise width of every road link in modelled road network, and therefore a twofold approach was used:

- For the roads that were considered to be the most important in terms of potential changes to 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 January 2019.

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 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 6-3**, and the typical road widths are given in **Table 6-4**. 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 Sydney Gateway road project.

Table 6-3 Assumed road width by road type – specific roads in the GRAL domain

Road	Estimated road width (m)	
	Separated links (one-way traffic)	Stacked links (two-way traffic)
Princes Highway	8.0	17.0
The Grand Parade	5.9	11.8
President Avenue	9.3	18.5
Southern Cross Drive / General Holmes Drive	9.5	19.0
Airport Drive	9.5	19.0

Table 6-4 Assumed road width by road type – typical roads in the GRAL domain

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

Road gradient

The average gradient of each road link in the 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 was then estimated based on the difference in the height of the start node and the end node and the approximate length of the link from the traffic model. The upper and lower limits of the gradient for use in the emissions model were +8 per cent and -8 per cent respectively. The real-world gradients of selection of traffic model links were also estimated using road length and height information from Google Earth, and the results were found to be in good agreement with the gradients determined from the LIDAR data.

Traffic volume, speed and mix (including fuel split)

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

The SMPM defines vehicles according to the following classes:

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

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

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

The volumes for cars, LCVs and HCVs from the strategic model were sub-divided into the nine vehicle types that are defined in the EPA model to reflect differences in emissions behaviour. These vehicle types are summarised in **Table 6-5**. The sub-division was based upon a default traffic mix for each road type in the Greater Metropolitan Region inventory, as shown in **Table 6-6**.

Table 6-5 Vehicle types in the NSW EPA emissions model

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

Notes:

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

Table 6-6 Default traffic mix by road type

Road type	Year	Proportion of traffic (%)								
		CP	CD	LCV-	LCV-	HDV-	RT	AT	BusD	MC
Residential	2016	70.4	9.7	6.3	8.9	0.0	2.8	0.8	0.6	0.5
	2026	59.2	20.0	2.4	13.1	0.0	3.2	0.9	0.6	0.5
	2036	48.0	30.7	0.7	14.9	0.0	3.5	1.0	0.6	0.5
Arterial	2016	67.5	9.3	7.2	10.1	0.0	3.8	1.2	0.5	0.5
	2026	56.8	19.2	2.7	14.7	0.0	4.2	1.3	0.5	0.5
	2036	46.0	29.4	0.8	16.8	0.0	4.6	1.4	0.5	0.5
Commercial arterial	2016	65.3	9.0	7.7	10.7	0.0	4.8	1.7	0.4	0.5
	2026	54.8	18.6	2.9	15.6	0.0	5.3	1.8	0.4	0.5
	2036	44.2	28.2	0.8	18.0	0.0	5.8	2.0	0.4	0.5
Commercial highway	2016	65.3	9.0	7.7	10.7	0.0	4.8	1.7	0.4	0.5
	2026	54.8	18.6	2.9	15.6	0.0	5.3	1.8	0.4	0.5
	2036	44.2	28.2	0.8	18.0	0.0	5.8	2.0	0.4	0.5
Highway/ freeway	2016	57.9	8.0	6.9	9.7	0.0	10.6	6.3	0.3	0.4
	2026	47.8	16.2	2.6	14.1	0.0	11.9	6.7	0.3	0.4
	2036	37.9	24.2	0.7	16.0	0.0	13.1	7.3	0.2	0.4

The default traffic mix for each road type took into account the projected fuel split (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 vehicle kilometres travelled (VKT).

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

- The proportions of LCVs in the traffic model outputs were very high compared with typical proportions on the road in relation to how such vehicles are defined in emission models. For example, it is likely that many of the vehicles defined as LCVs in the traffic model were, from an emissions perspective, cars, and some of them would have been more like rigid heavy-duty vehicles. The approach taken was therefore to combine PVs and LCVs from the traffic model, and redistribute these according to the relevant split (road type, year) between CP, CD, LVC-P and LCV-D from **Table 6-6**
- HCVs from the traffic model were redistributed according to the split for HD-P, RT and AT in **Table 6-6**
- Relatively small numbers of buses and motorcycles were added to the traffic model output, again based on the proportions in **Table 6-6**.

An example of the SMPM output for one link is shown in **Figure 6-4**, and the transformation of the data for this link into a suitable format for the NSW EPA emission model is shown in **Figure 6-5**.

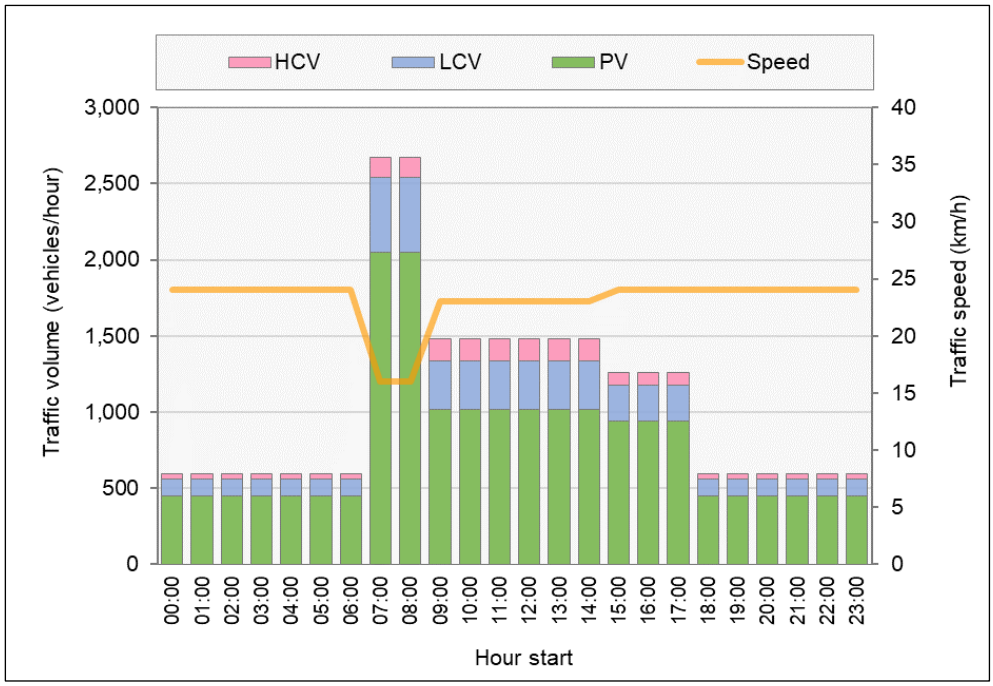


Figure 6-4 Example traffic model output (link 12239-12237, arterial road, 2026-WP scenario)

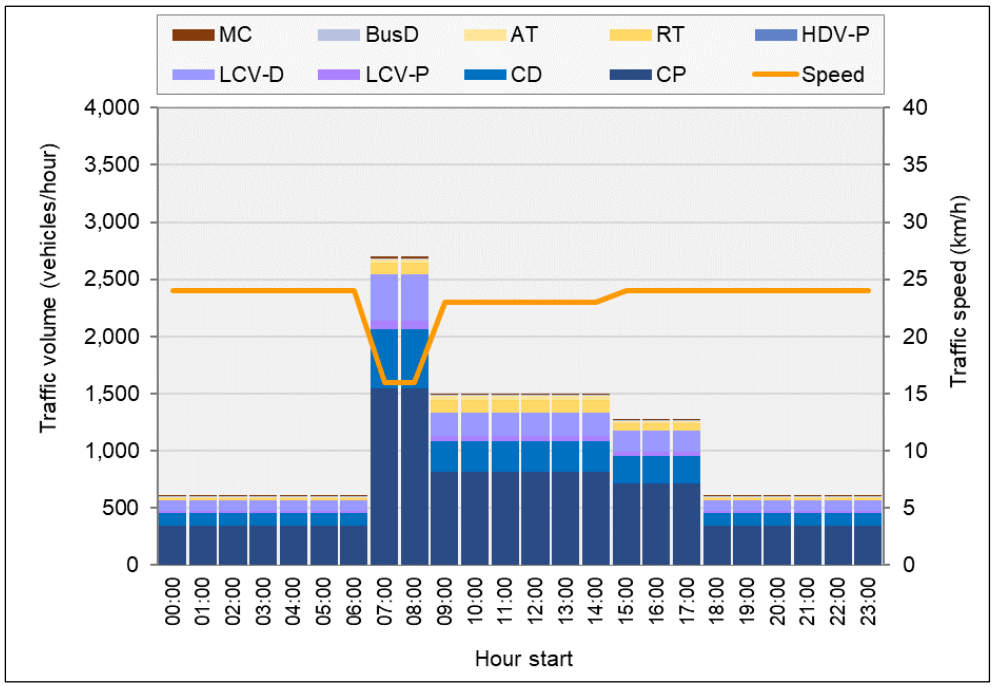


Figure 6-5 Example emission model input (link 12239-12237, arterial road, 2026-WP scenario)

6.2.1.3 Results

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

The total emissions in the GRAL domain, in tonnes per year by scenario, are presented in **Figure 6-6** and **Table 6-7**. The absolute and percentage changes in emissions between scenarios are shown in **Table 6-8** and **Table 6-9** respectively.

Comparing the With Project and Cumulative scenarios with the Without Project scenarios in 2026 and 2036, emissions of CO increased slightly whereas emissions of all other pollutants decreased slightly.

The overall changes in emissions associated with the project in a given future scenario year (2026 or 2036) would be much 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 Year and Without Project scenarios, it can be seen from **Table 6-9** that between 2016 and 2026 the total emissions of CO, NO_X and THC from the traffic on the road network are predicted to decrease by 45 per cent to 55 per cent. Between 2016 and 2036 the reductions were between 50 per cent and 65 per cent. The reductions are less between 2026 and 2036 due to the conservative assumptions made around future improvements in emissions technology. For PM_{10} and $PM_{2.5}$, the underlying reductions were smaller, at between around 10 per cent and 20 per cent. This is mainly because there is currently no anticipated regulation of non-exhaust particles, which form a substantial fraction of the total.

The changes in the total emissions resulting from the project can be viewed as a proxy for its regional air quality impacts, which on this basis are likely to be negligible. These are discussed further in **section 6.2.2.4.**

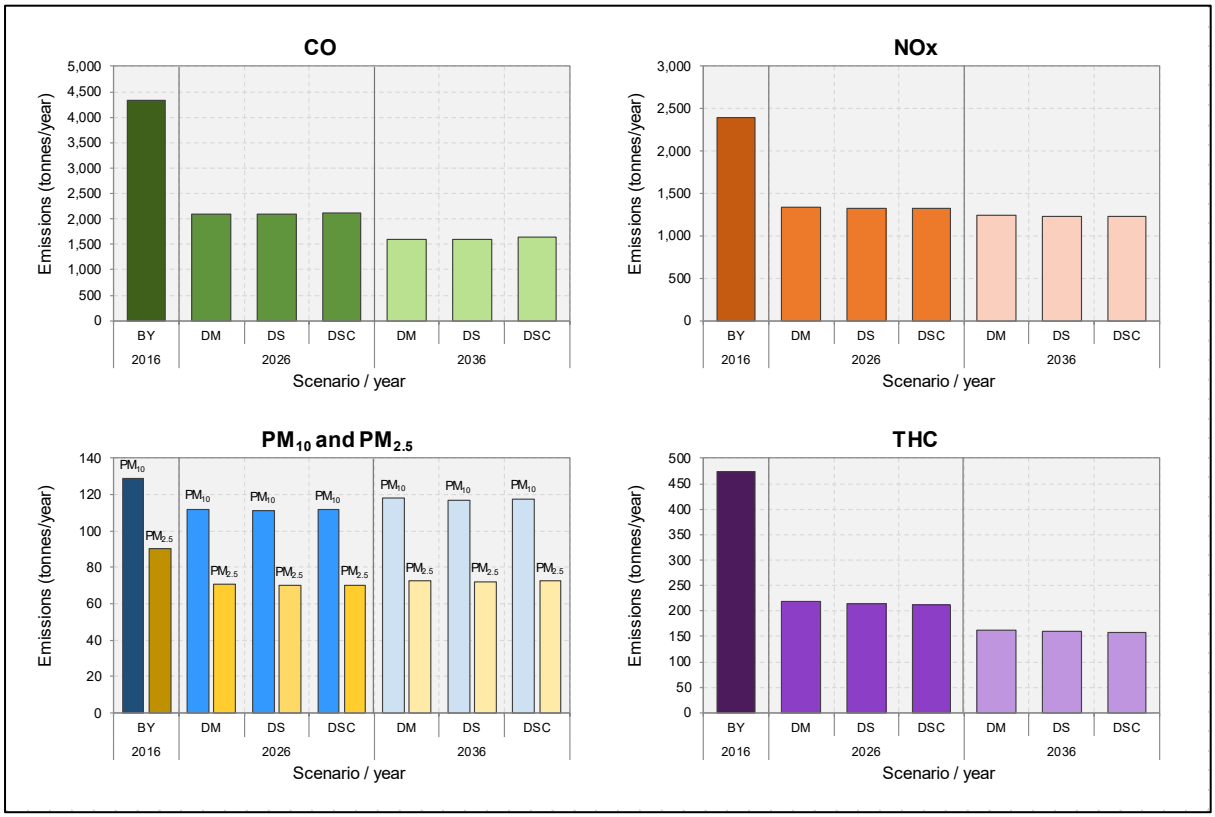


Figure 6-6 Total traffic emissions in the GRAL domain

Table 6-7 Total traffic emissions in the GRAL domain

Scenario code	Scenario description	Total daily VKT[(a)] (million vehicle-km)	Total emissions (tonnes/year)				
			CO	NO_X	PM_{10}	$PM_{2.5}$	THC
2016-BY	2016 – Base Year	6.3	4,329	2,391	129	90	474
2026-WOP	2026 – Without Project	6.8	2,086	1,338	112	71	218
2026-WP	2026 – With Project	6.9	2,093	1,320	111	70	213
2026-WPC	2026 – With Project Cumulative	7.0	2,110	1,326	112	70	213
2036-WOP	2036 – Without Project	7.3	1,596	1,245	118	72	163
2036-WP	2036 – With Project	7.5	1,607	1,227	117	72	160
2036-WPC	2036 – With Project Cumulative	7.6	1,636	1,233	118	72	158

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

Table 6-8 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)]					
2026-WOP vs 2016-BY	-2,244	-1,053	-17	-19	-256
2036-WOP vs 2016-BY	-2,734	-1,146	-11	-18	-311
Changes due to the project in a given year					
2026-WP vs 2026-WOP	+7.5	-18.2	-0.9	-0.6	-5.1
2026-WPC vs 2026-WOP	+24.5	-12.0	-0.5	-0.3	-5.6
2036-WP vs 2036-WOP	+11.7	-18.7	-0.7	-0.4	-3.0
2036-WPC vs 2036-WOP	+40.0	-12.0	-0.2	-0.1	-5.7

(a) The 2026-WOP and 2036-WOP scenarios include the M4East, New M5 and M4-M5 Link projects, the 2016-BY scenario does not.

Table 6-9 Percentage changes in total traffic emissions in the GRAL domain

Scenario comparison	Change in total emissions (%)				
	CO	NO_X	PM_{10}	$PM_{2.5}$	THC
Underlying changes in emissions with time[(a)]					
2026-WOP vs 2016-BY	-51.8%	-44.0%	-12.9%	-21.4%	-53.9%
2036-WOP vs 2016-BY	-63.1%	-47.9%	-8.4%	-19.5%	-65.6%
Changes due to the project in a given year					
2026-WP vs 2026-WOP	+0.4%	-1.4%	-0.8%	-0.8%	-2.3%
2026-WPC vs 2026-WOP	+1.2%	-0.9%	-0.4%	-0.4%	-2.6%
2036-WP vs 2036-WOP	+0.7%	-1.5%	-0.6%	-0.6%	-1.8%
2036-WPC vs 2036-WOP	+2.5%	-1.0%	-0.2%	-0.1%	-5.7%

(a) The 2026-WOP and 2036-WOP scenarios include the M4East, New M5 and M4-M5 Link projects, the 2016-BY scenario does not.

6.2.1.4 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 C**, 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 conservative assumptions in the emission model and may result in an over prediction of concentrations in the dispersion modelling.

6.2.2 Air quality

6.2.2.1 Overview

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

Details concerning model selection, performance, evaluation and set up are provided in **Annexure G**.

6.2.2.2 Results for expected traffic scenarios

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

The pollutants and metrics are treated in turn, and in each case the following have been determined for the 17 community[10] and 12,145 RWR[11] receptors:

- The total ground-level concentration for comparison against the NSW impact assessment criteria and international air quality standards
- The change in the total ground-level concentration. This was calculated as the difference in concentration between the 'With Project' and 'Without Project' scenarios
- The contributions of the background and surface road 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 $PM_{2.5}$.

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

[10] Community receptors represent particularly sensitive locations such as schools, childcare centres and hospitals, generally near significantly affected roadways. More detailed analyses were carried out for these receptors. More detail on these locations is provided in Section 4.8 and Annexure G.

[11] Residential, workplace and recreational (RWR) receptors refer to all discrete receptor locations included in the operational assessment and mainly cover residential and commercial uses. More detail on these locations is provided in Annexure G.

***NB 1**: To avoid a large amount of duplication, the main report only includes the contour plots for the 2036-WP scenario, and the corresponding Without Project scenario, 2036-WOP, where applicable. For all other scenarios, the contour plots are given in **Annexure H**.*

***NB 2:** 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

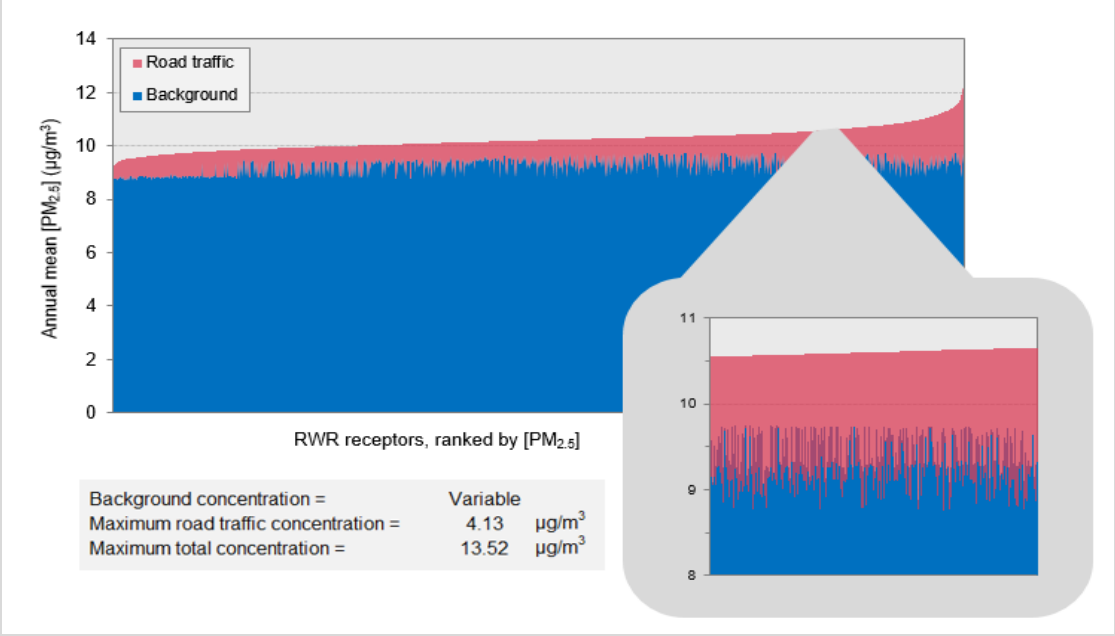
Short-term (1h and 24h) predictions for community receptors

Short-term (24h) predictions for RWR receptors

Short-term (1h) predictions for RWR receptors

Confidence in predictions

***NB 3:** The ranked RWR plots are compressed along the x-axis, as more than 12,000 receptors are included. The contributions of road traffic can be quite difficult to see on this scale. Therefore, in each plot the maximum contributions from each source, and the maximum total concentration, are also given. An example of this compression is shown in the figure below. The inset shows the results for a sub-set of 500 RWR receptors.*



Carbon monoxide (maximum 1-hour)

Results for community receptors

The maximum 1-hour CO concentrations at the 17 community receptors in the With Project scenarios (2026-WP, 2036-WP) and the Cumulative scenarios (2026-WPC and 2036-WPC) are shown in **Figure 6-7**. At all these receptor locations the CO concentration was well below the NSW impact assessment criterion of 30 mg/m^3. The concentrations were also well below the lowest international air quality standard identified in the literature (California, 22 mg/m^3).

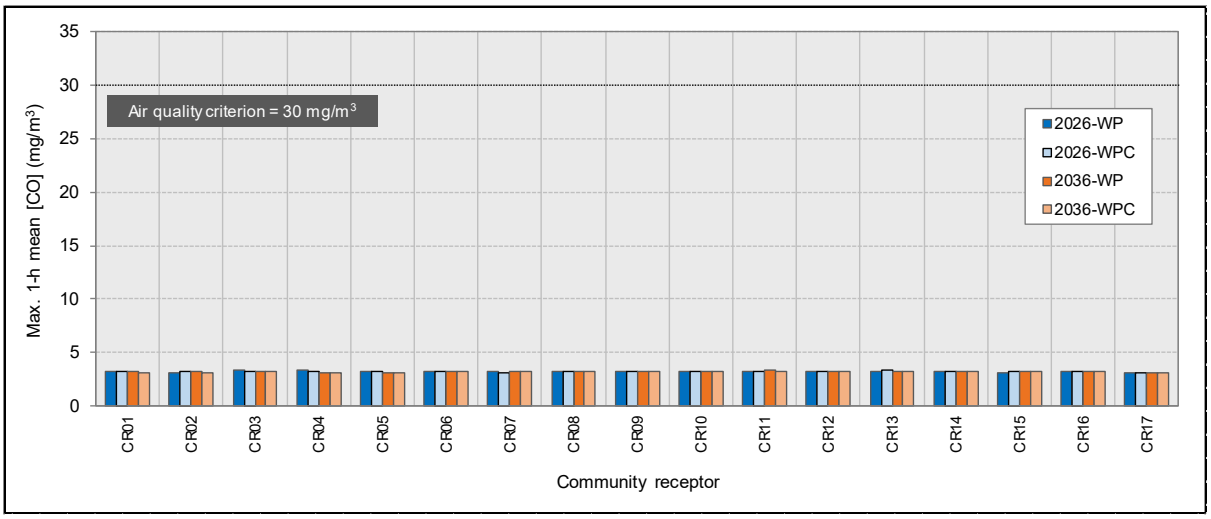


Figure 6-7 Maximum 1-hour CO concentration at community receptors (WP and WPC scenarios)

Figure 6-8 demonstrates the *changes* in the maximum 1-hour CO concentration in the With Project and Cumulative scenarios relative to the Without Project scenarios at the community receptors. There was a mixture of increases and decreases in concentration at these receptors. The largest increase at any receptor was around 0.17 mg/m^3, which equated to just 0.6 per cent of the impact assessment criterion of 30 mg/m^3.

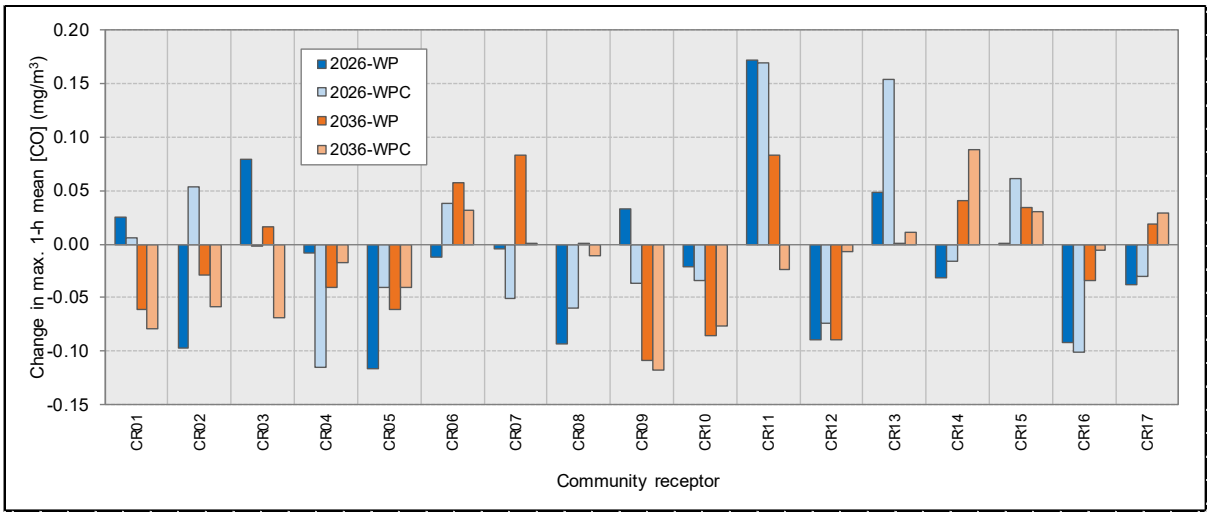


Figure 6-8 Change in maximum 1-hour CO concentration at community receptors (WP and WPC scenarios relative to Without Project scenarios)

Figure 6-9 shows the separate contributions of the background and road traffic to maximum 1-hour CO concentrations in the With-Project and Cumulative scenarios. At all 17 receptors the maximum concentration was dominated by the background. The hour of the year was the same for almost all receptors and scenarios, as it coincided with the highest background during the year. In other words, the contribution of road traffic was very low during the hour of the year when the maximum total concentration occurred. For a given receptor it is possible that larger 1-hour contributions from road traffic could have occurred during other hours of the year. However, these contributions would have been added to a lower background, and the overall total would have been lower than that given in the figure.

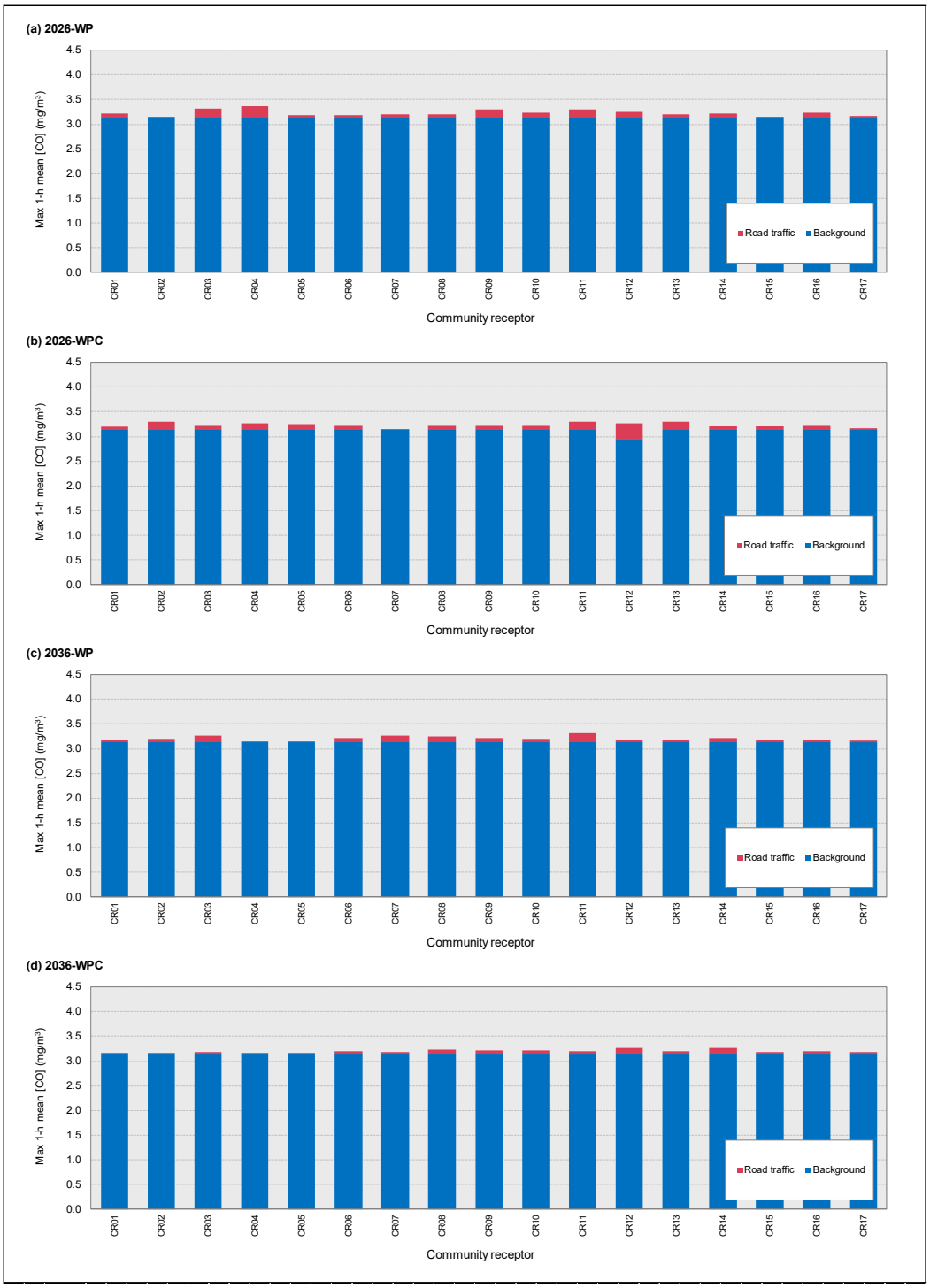


Figure 6-9 Source contributions to maximum 1-hour CO concentration at community receptors (WP and WPC scenarios)

Results for RWR receptors

The maximum 1-hour CO concentrations at the RWR receptors are shown for the with-project and cumulative scenarios in **Figure 6-10**. The values are ranked by the total CO concentration. The plots show both the assumed background concentration and the modelled roads contribution.

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 relatively high concentrations. Nevertheless, in this case, the 1-hour CO criterion for NSW was not exceeded at any of the RWR receptors in any scenario. The highest 1-hour concentration in any

with-project or cumulative scenario was predicted to be 5.6 mg/m^3. The largest contribution from road traffic at any receptor was 2.5 mg/m^3.

The changes in the maximum 1-hour CO concentration at the RWR receptors in the with-project and cumulative scenarios are shown in **Figure 6-11**. There was an increase in concentration at between 40 per cent and 51 per cent of receptors, depending on the scenario. However, even the largest increase in any scenario, which was 0.92 mg/m^3, was small compared with the criterion.

Contour plots – all sources

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

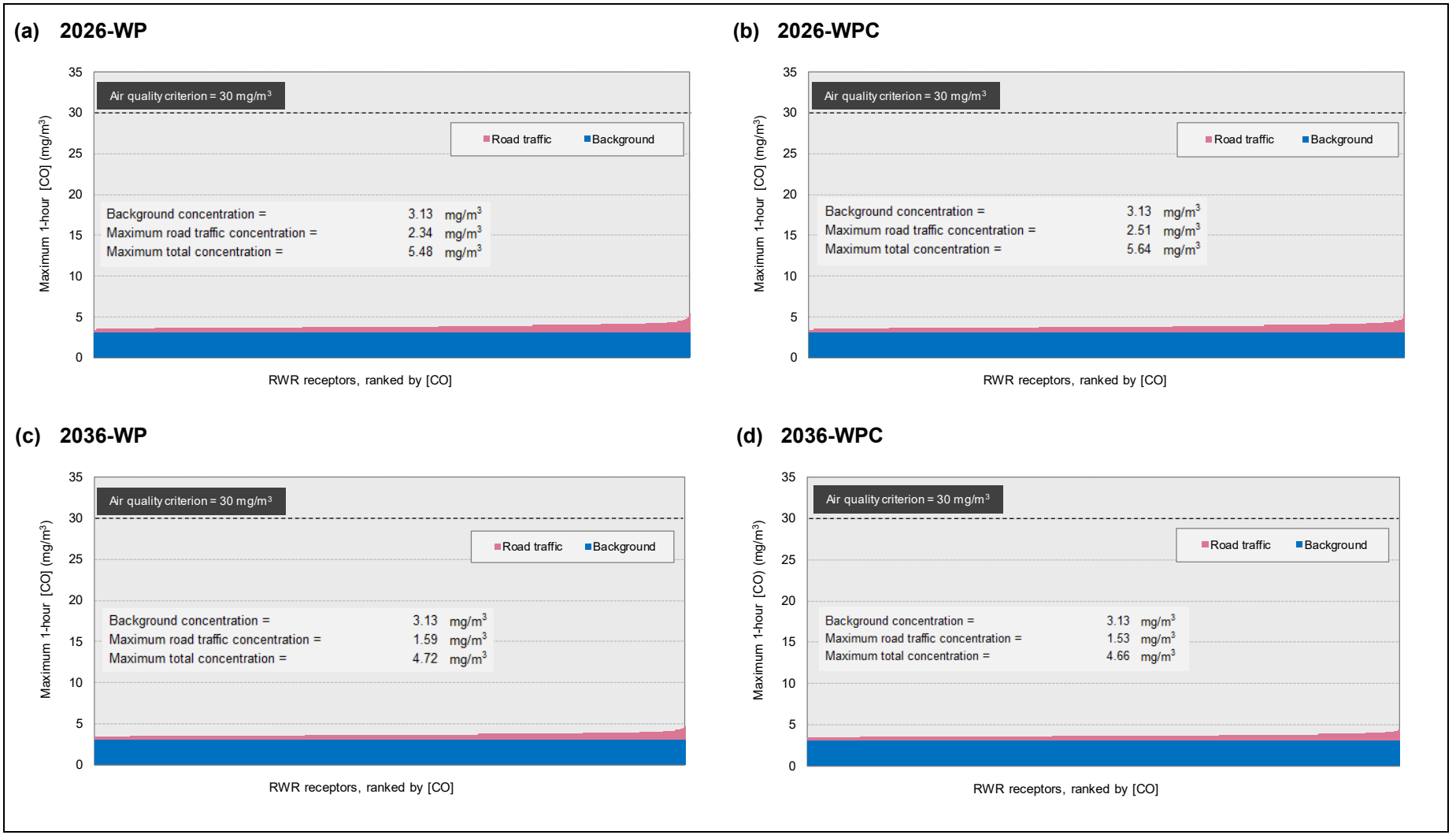


Figure 6-10 Source contributions to maximum 1-hour CO concentration at RWR receptors (with-project and cumulative scenarios)

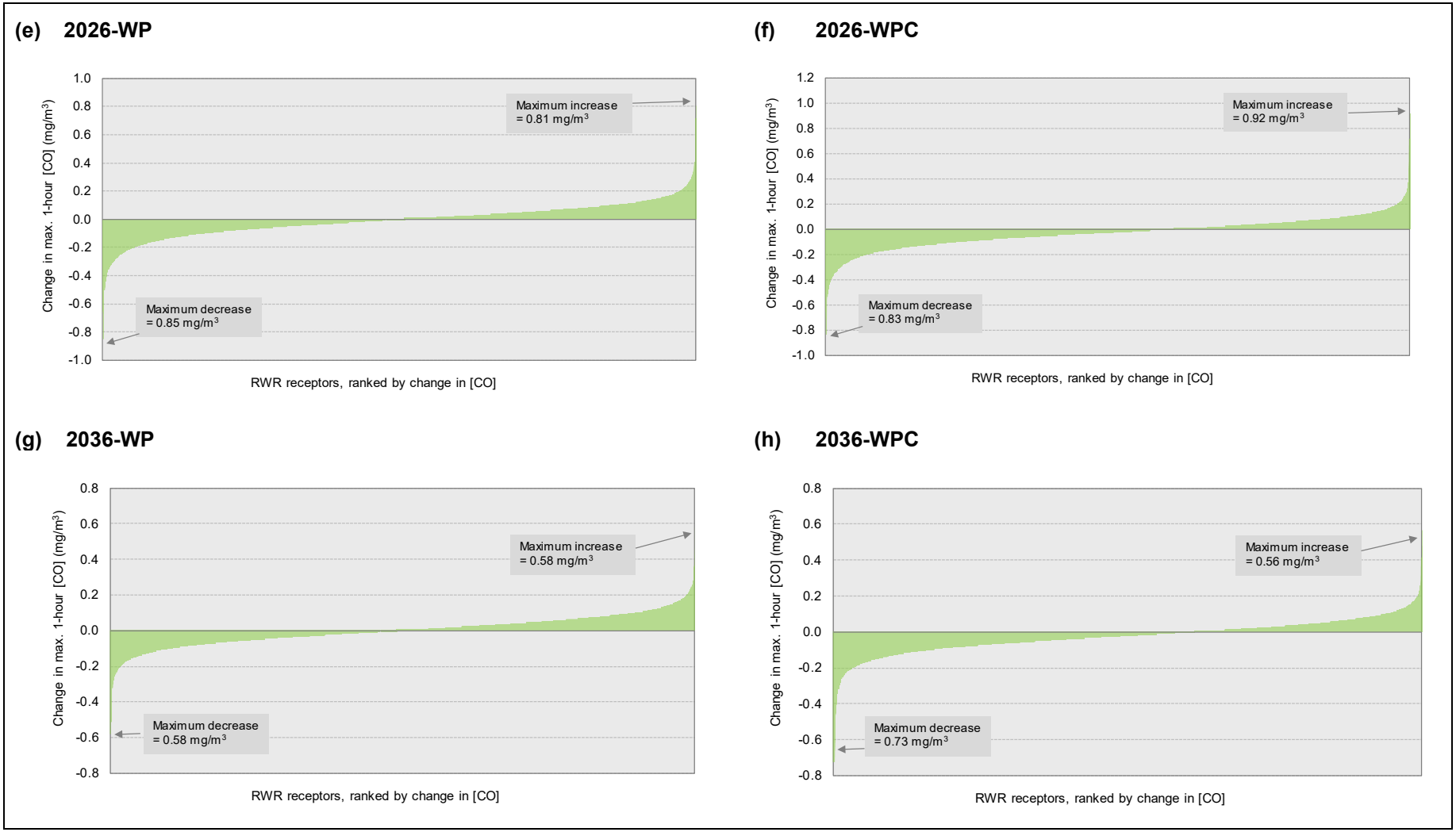


Figure 6-11 Change in maximum 1-hour CO concentration at RWR receptors (WP and WPC scenarios minus corresponding WOP scenarios)

Carbon monoxide (maximum rolling 8-hour)

Results for community receptors

Figure 6-12 shows the predicted maximum rolling 8-hour CO concentrations at the community receptors with the project and in the cumulative scenario. As with the 1-hour, at all the receptors the concentration was well below the NSW impact assessment criterion, which in this case is 10 mg/m3. No lower criteria appear to be in force internationally.

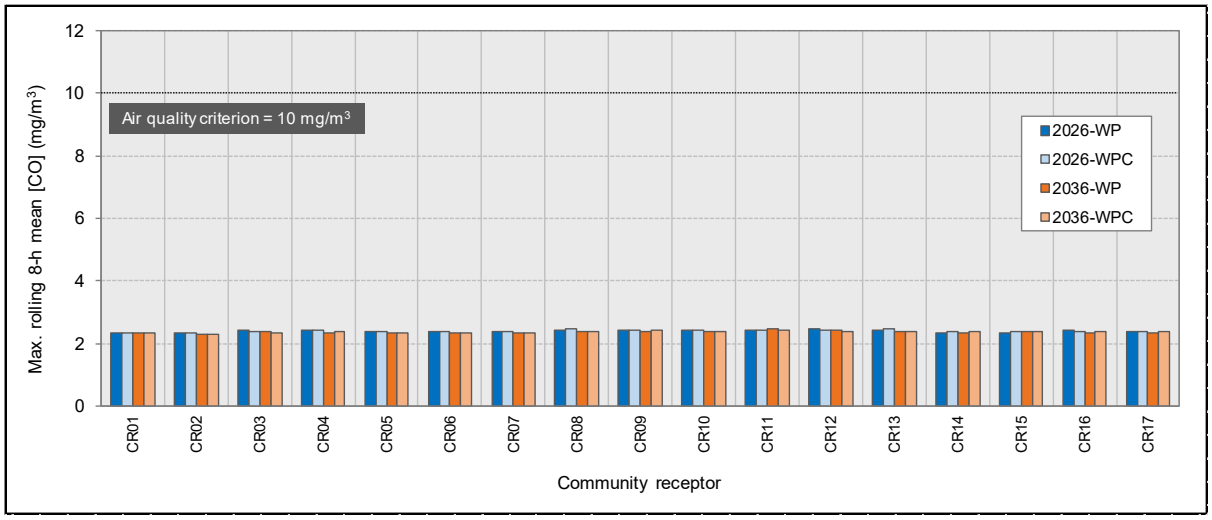


Figure 6-12 Maximum rolling 8-hour CO concentration at community receptors (WP and WPC scenarios)

It can be seen in **Figure 6-13** that the changes in the maximum rolling 8-hour CO concentration at all the community receptors were mostly less than 0.06 mg/m^3. The largest increase with the project and in the cumulative scenario was around 0.05 mg/m^3 (equating to 0.5 per cent of the criterion).

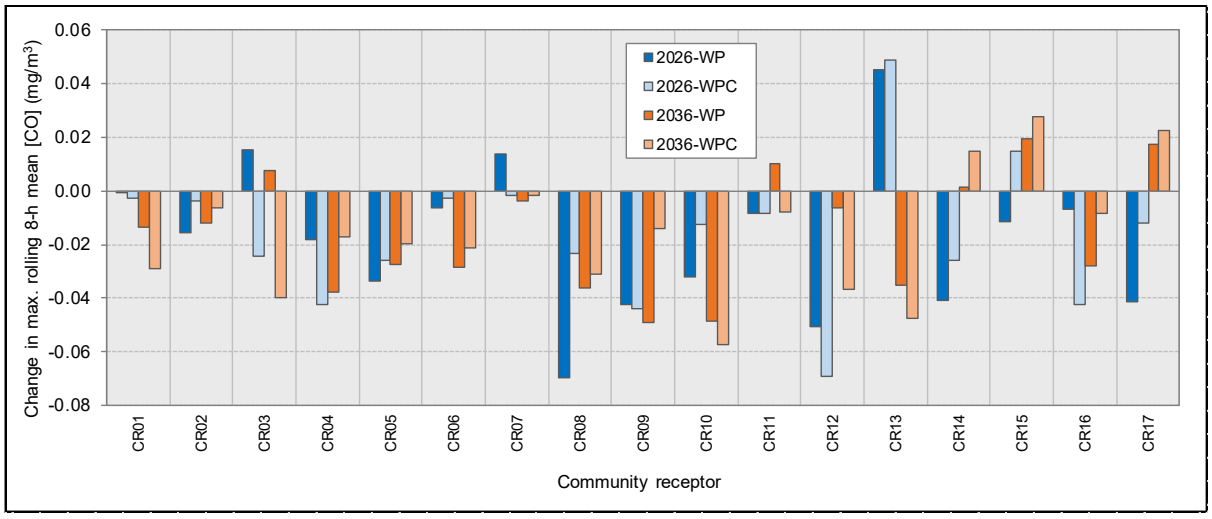


Figure 6-13 Change in maximum rolling 8-hour CO concentration at community receptors (WP and WPC scenarios minus D scenarios)

The main contributor at these receptors was the background concentration (**Figure 6-14**). The maximum road traffic contribution in any With Project or Cumulative scenario was 8 per cent.

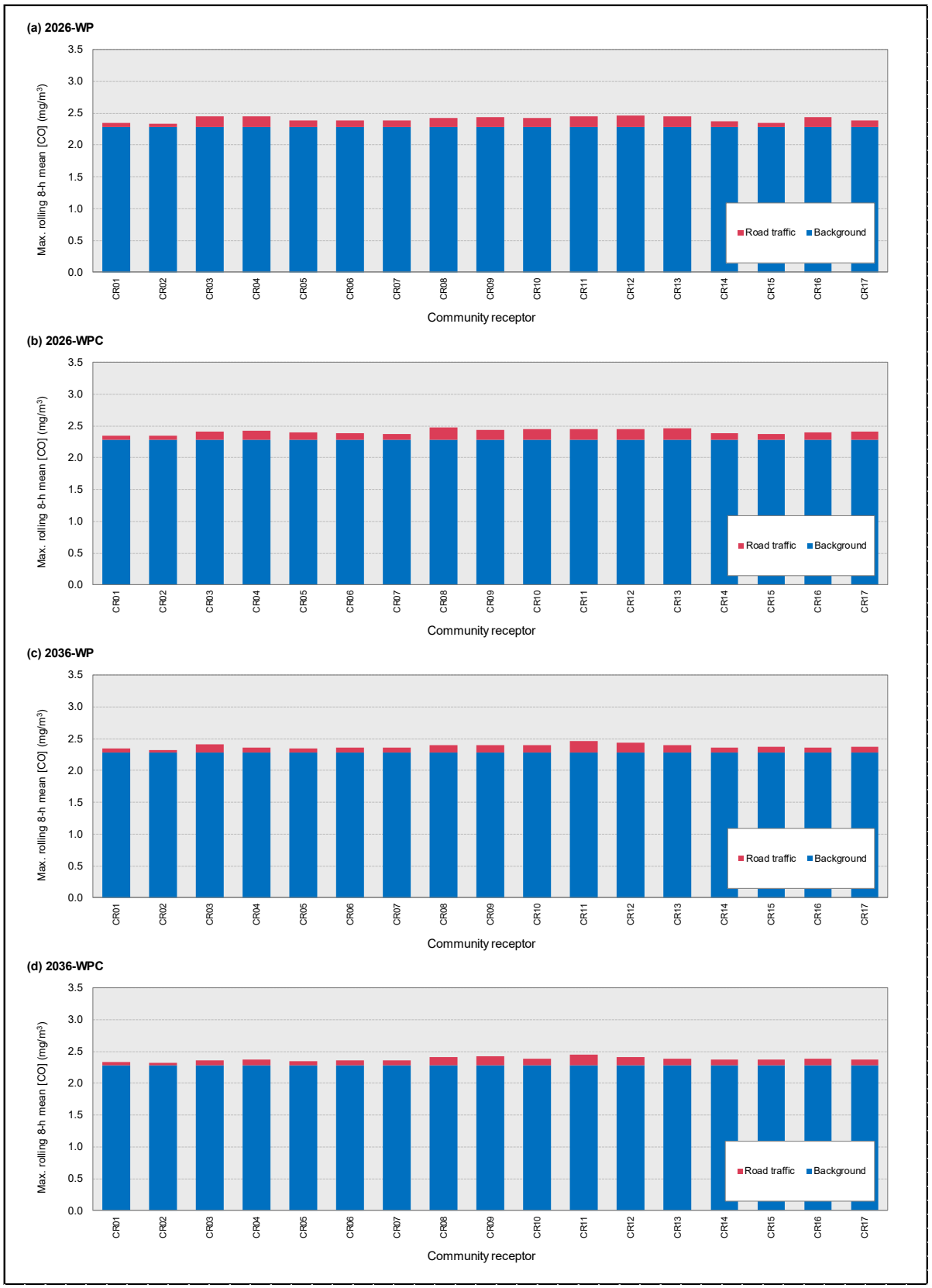


Figure 6-14 Source contributions to maximum rolling 8-hour CO at community receptors (2026-WP)

Results for RWR receptors

Rolling 8-hour CO concentrations were not extracted from GRAL for the RWR receptors. 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 6-15 shows the annual mean NO_2 concentrations for the with-project and cumulative scenarios at the community receptors. At all these locations the concentration was below 30 µg/m^3, and therefore well below the NSW impact assessment criterion of 62 µg/m^3. The concentrations at receptors were also well below the lower air quality standards that have been adopted elsewhere (eg 40 µg/m^3 in the EU).

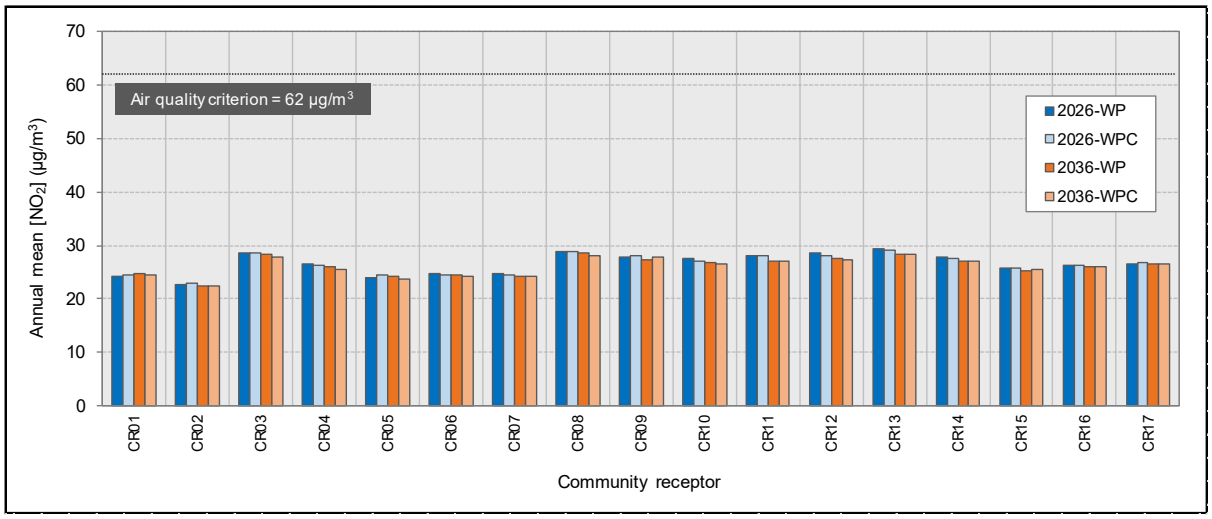


Figure 6-15 Annual mean NO_2 concentration at community receptors (WP and WPC scenarios)

Figure 6-16 shows the changes in concentration with the project. There was a small increase in the NO_2 concentration at some receptors. The largest increase with the project was around 0.5 µg/m^3 at receptor CR03 (Gardeners Road Public School, Rosebery), equating to less than one per cent of the criterion. At most receptors, there were reductions in NO_2, the largest of which – around 2.5 µg/m^3 – were predicted to occur at receptor CR08 (St Bernard's Catholic Primary School, Botany).

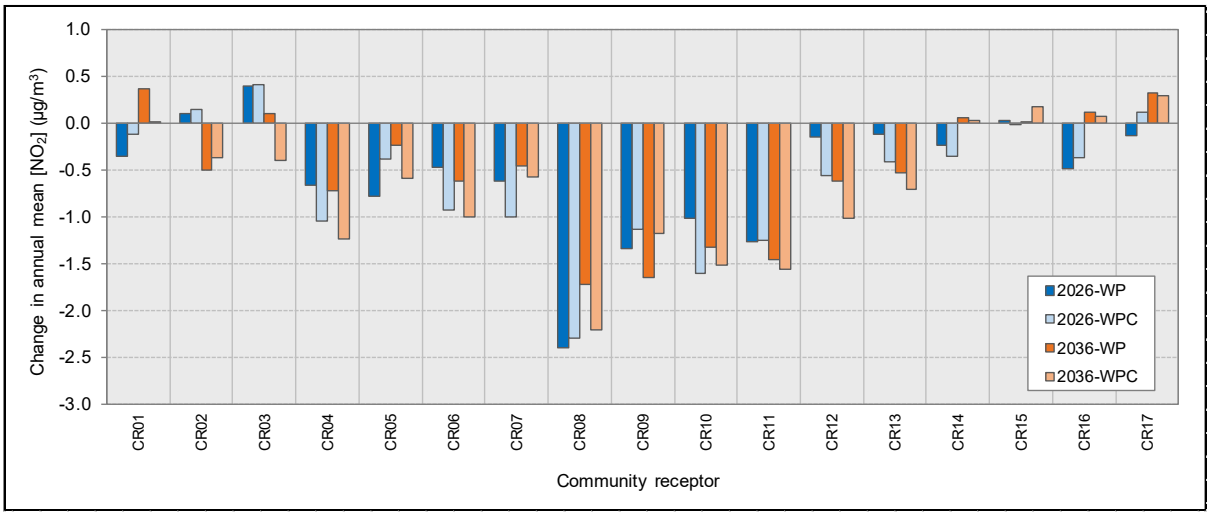


Figure 6-16 Change in annual mean NO_2 concentration at community receptors (WP and WPC scenarios minus WOP scenarios)

Figure 6-17 gives the source contributions to total annual mean NO_2 concentrations in the with-project and cumulative scenarios.

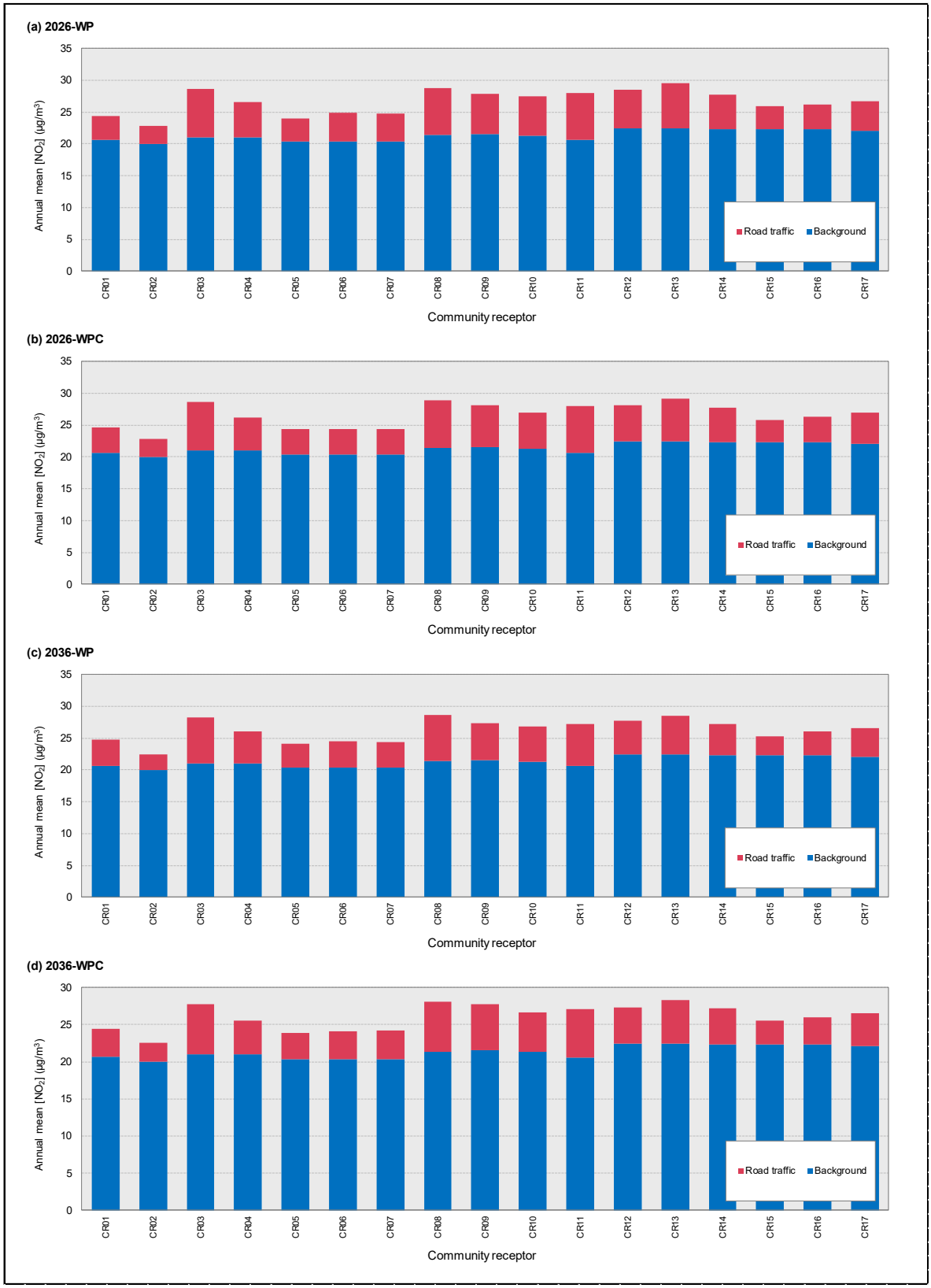


Figure 6-17 Source contributions to annual mean NO_2 concentration at community receptors (WP and WPC scenarios)

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

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

The results indicate that the background component at these receptors is likely to responsible for, on average, around 80 per cent of the predicted annual mean NO_2, with most of the remainder being due to mainly surface roads. For the with-project and cumulative scenarios, road traffic was responsible for between around 10 per cent and 30 per cent of the total, depending on the scenario and receptor.

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 6-18**. Concentrations at the majority (more than 96 per cent) of receptors were between around 20 µg/m^3 and 30 µg/m^3. The maximum contribution of road traffic in any scenario and at any receptor was 13.4 µg/m^3 (2026-WPC scenario).

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 receptors NO_2 concentrations were also below the EU limit value of 40 µg/m^3. The highest concentrations with the project and in the cumulative scenario were predicted to be around 35 µg/m^3.

The changes in the annual mean NO_2 concentration at the RWR receptors in the with-project and cumulative scenarios (minus the Without Project scenarios) are shown, ranked by the change in concentration, in **Figure 6-19**. There was predicted to be an increase in the annual mean NO_2 concentration at between 24 per cent and 43 per cent of receptors, depending on the scenario.

The largest increases in annual NO_2 were around 4 to 5 µg/m^3. However, the increase was only greater than 1 µg/m^3 for around one per cent of receptors. In other words, only a very small fraction of receptors showed a predicted increase of more than 1 µg/m^3.

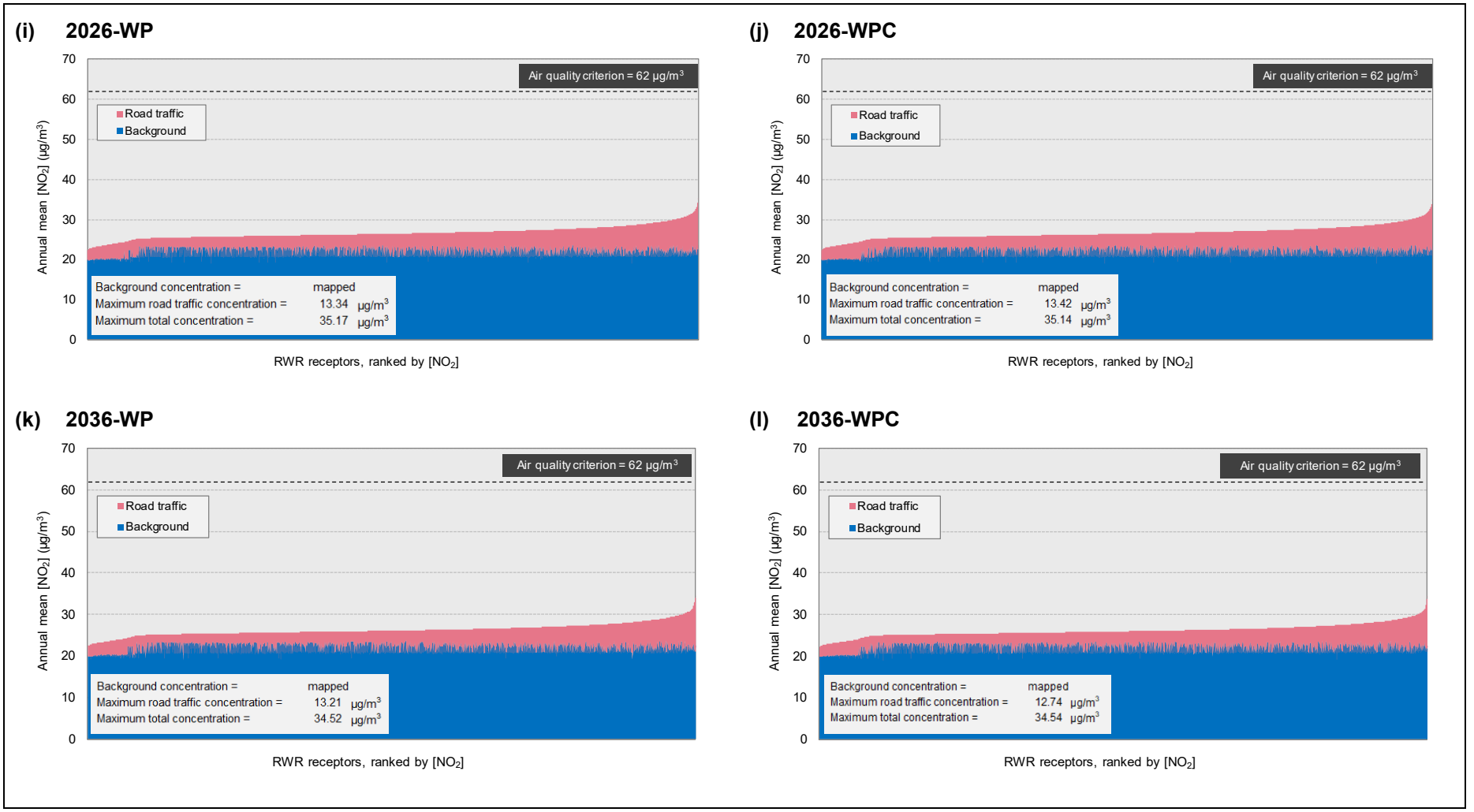


Figure 6-18 Source contributions to annual mean NO_2 concentration at RWR receptors (WP and WPC scenarios)

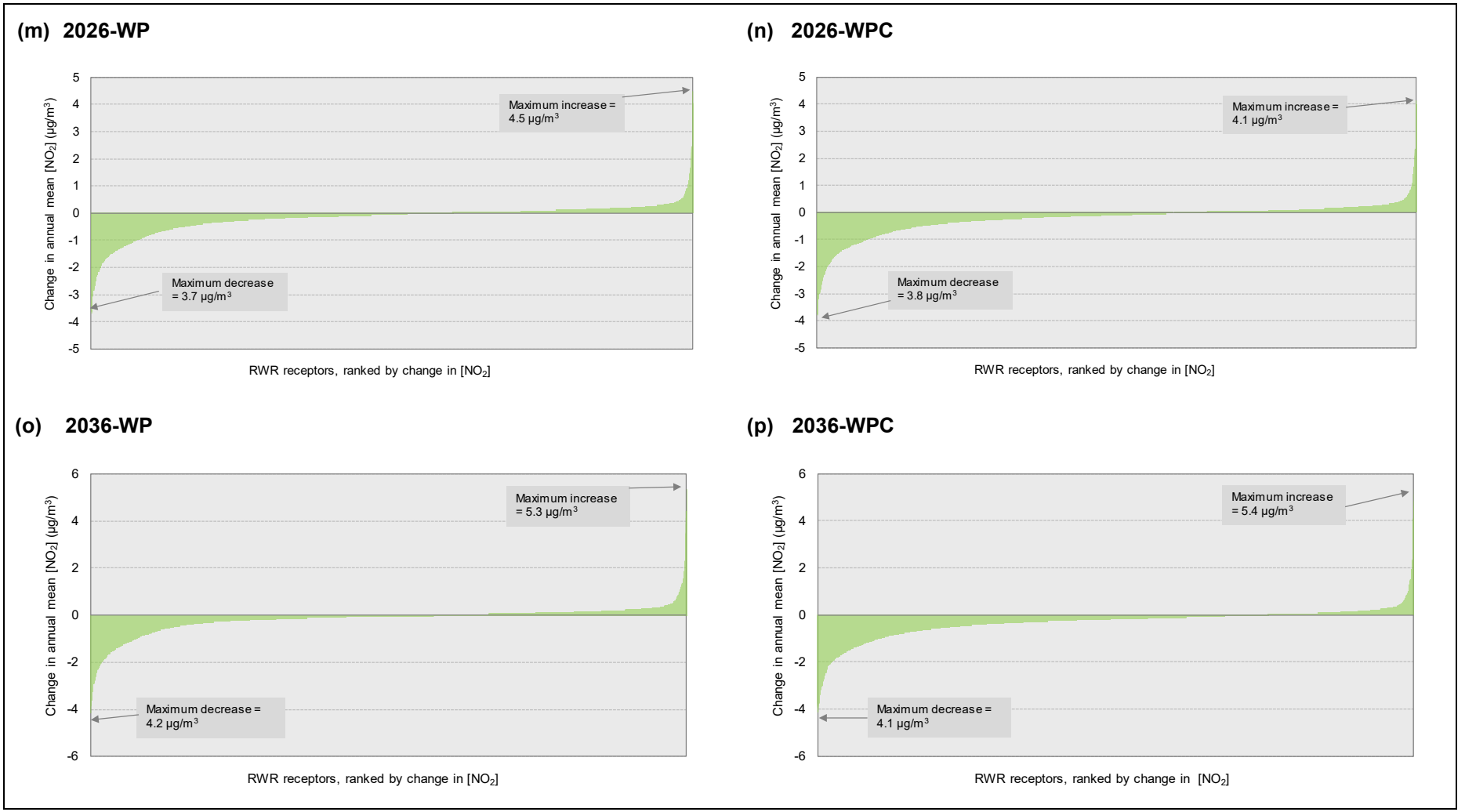


Figure 6-19 Change in annual mean NO_2 concentration at RWR receptors (WP and WPC scenarios minus corresponding WOP scenarios)

Contour plots – all sources

The contour plot of annual mean total NO_2 concentrations across the GRAL domain in the 2036-WOP scenario (ie all sources without the project) is provided in **Figure 6-20**, and an equivalent plot for the 2036-WP scenario (ie all sources with the project) is shown in **Figure 6-21**. The figures also show main surface roads, the locations of tunnel ventilation outlets, and the boundaries of Commonwealth land.

The plots are based on around 990,000 grid points, regularly spaced at ten metre intervals across the domain. Consequently, many of the points fall along the axes of roads, and are therefore not necessarily representative of population exposure.

The plots illustrate the strong links between the spatial distribution of air pollution and the traffic on the road network. The highest total concentrations are found along the most heavily trafficked roads in the GRAL domain, such as General Holmes Drive and Southern Cross Drive.

The contour plot in **Figure 6-22** shows the *changes* in annual mean NO_2 concentration in the 2036-WP scenario compared to the without project scenario. The green shading represents a decrease in concentration with the project included in the 2036-WP scenario, and the purple shading an increase in concentration. Any changes in NO_2 of less than 1 $\mu g/m^3$ are not shown.

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

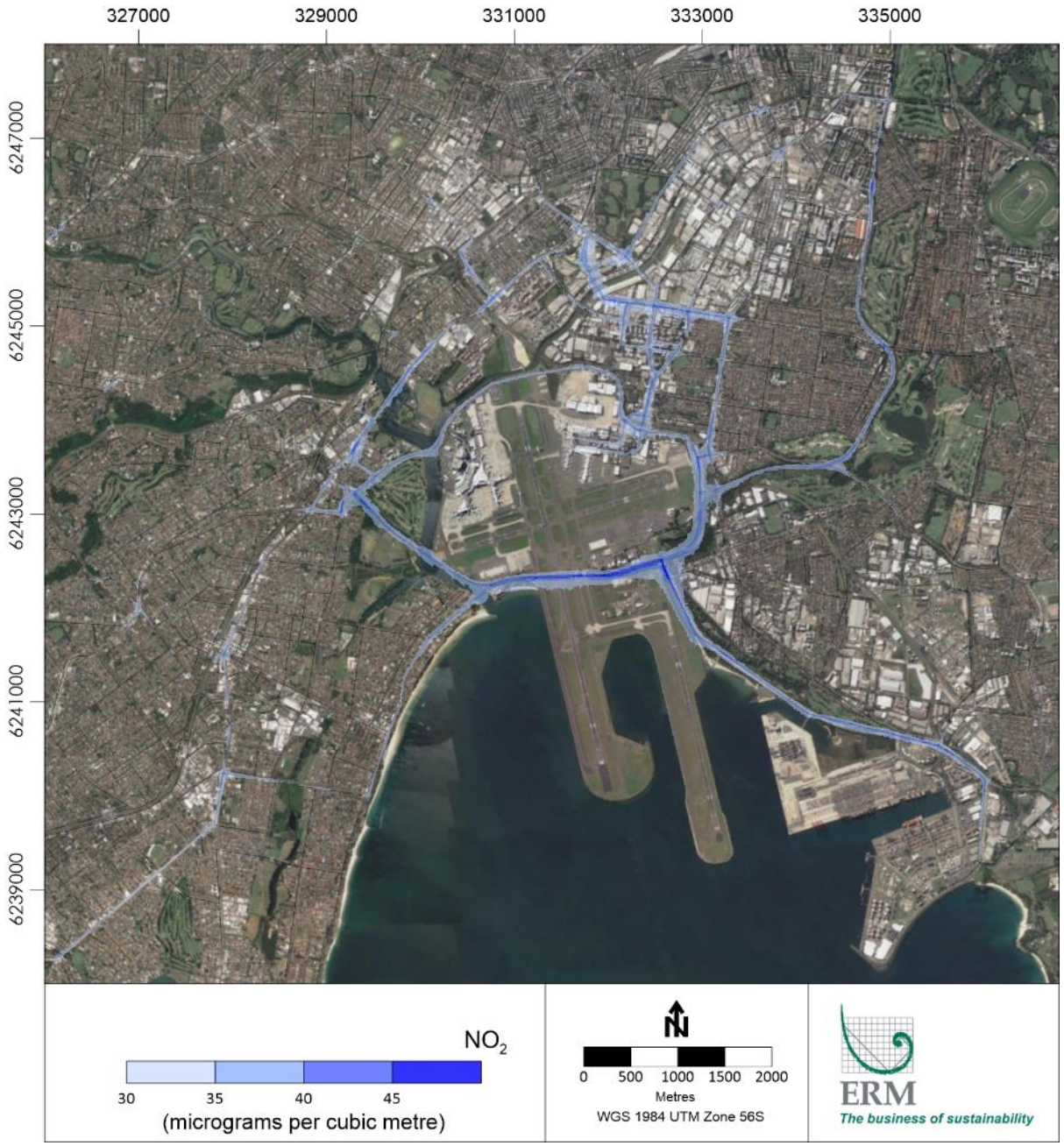


Figure 6-20 Contour plot of annual mean NO_2 concentration in the 2036 Without Project scenario (2036-WOP)

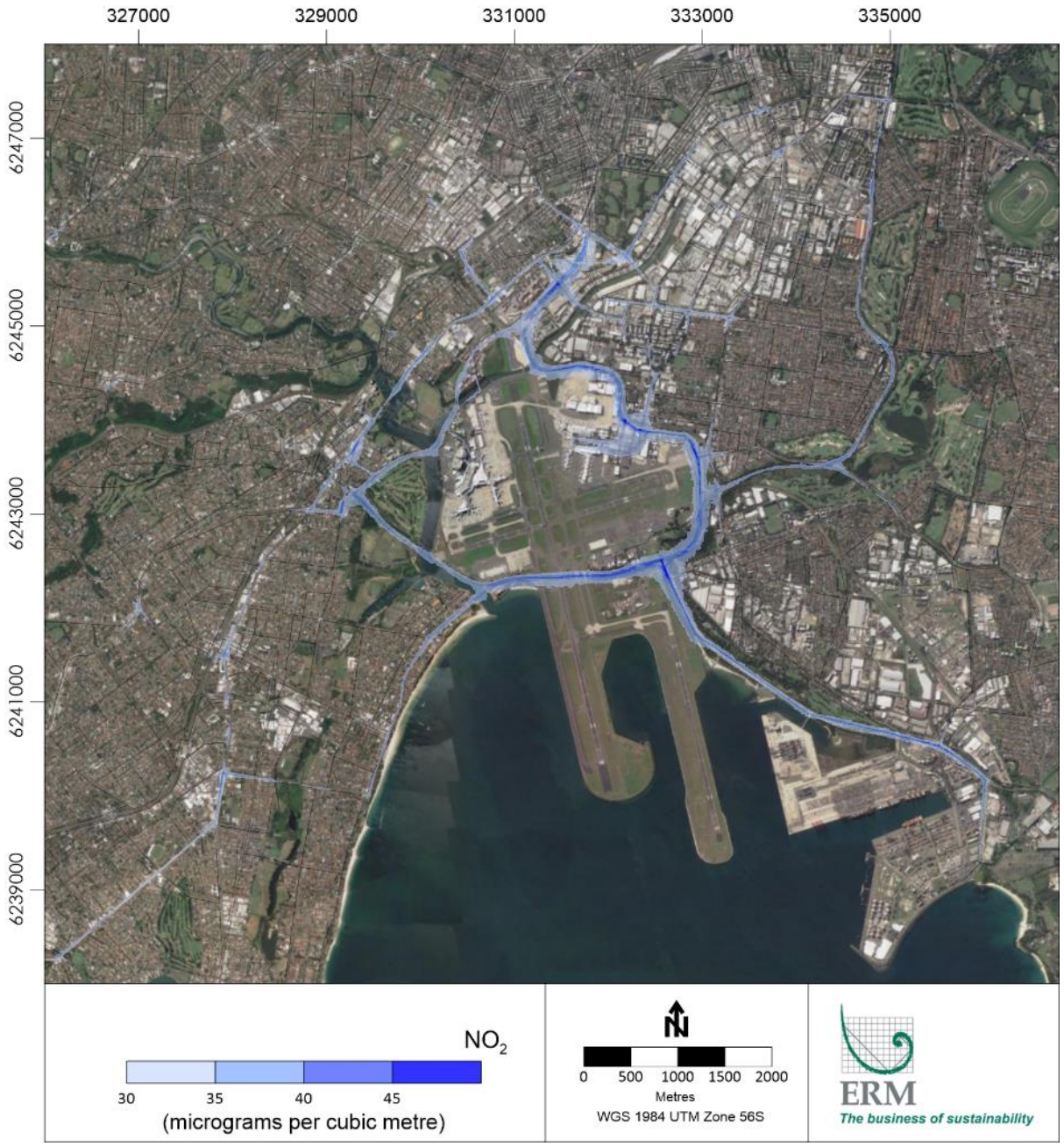


Figure 6-21 Contour plot of annual mean NO_2 concentration in the 2036 With Project scenario (2036-WP)

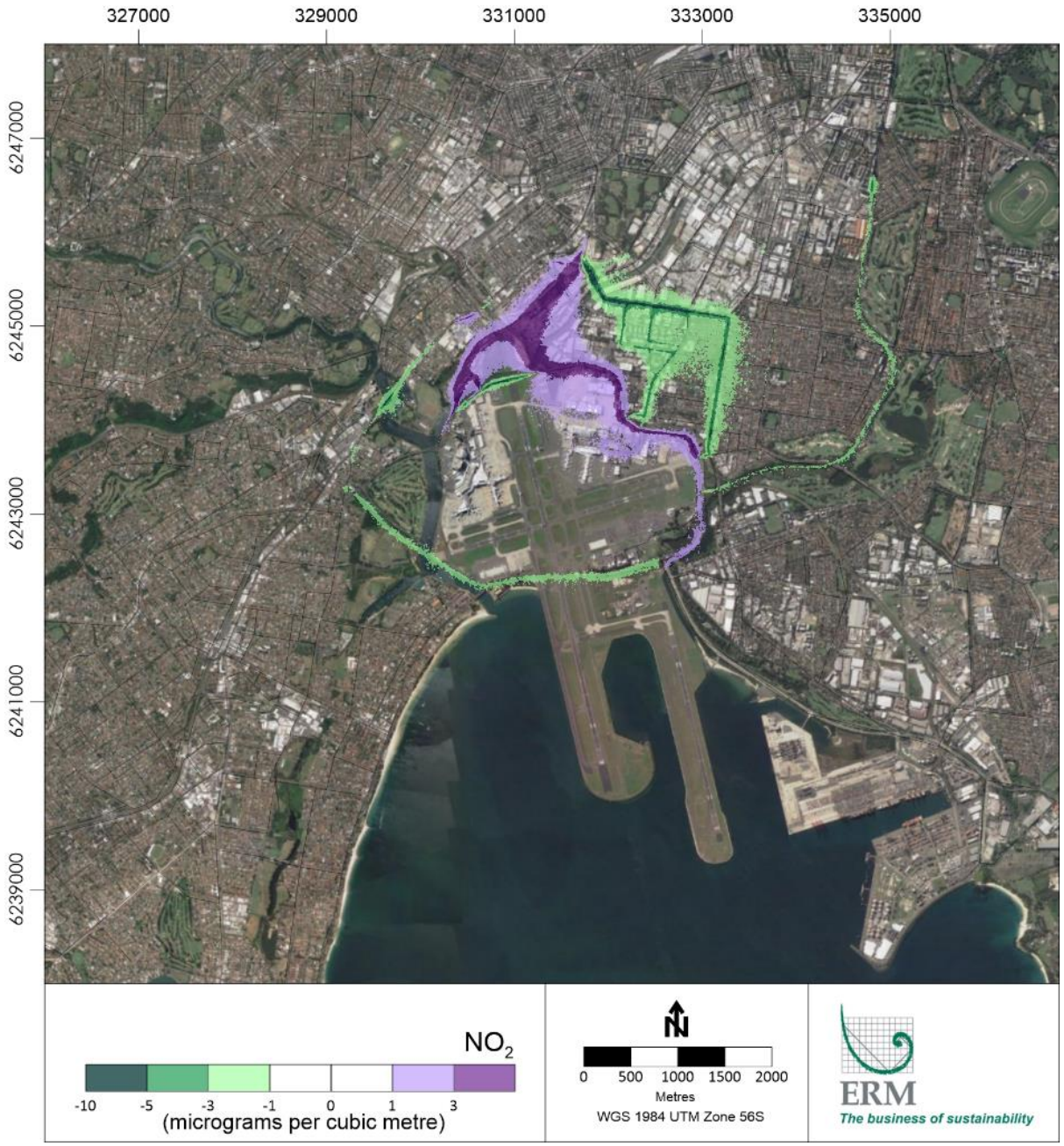


Figure 6-22 Contour plot of change in annual mean NO_2 concentration in the 2036 With Project scenario (2036-WP minus 2036-WOP)

Nitrogen dioxide (maximum 1-hour)

Results for community receptors

The maximum 1-hour NO_2 concentrations at the 17 community receptors in the with-project and cumulative scenarios are shown in **Figure 6-23**. At all receptor locations the maximum concentration was below the NSW impact assessment criterion of 246 µg/m^3.

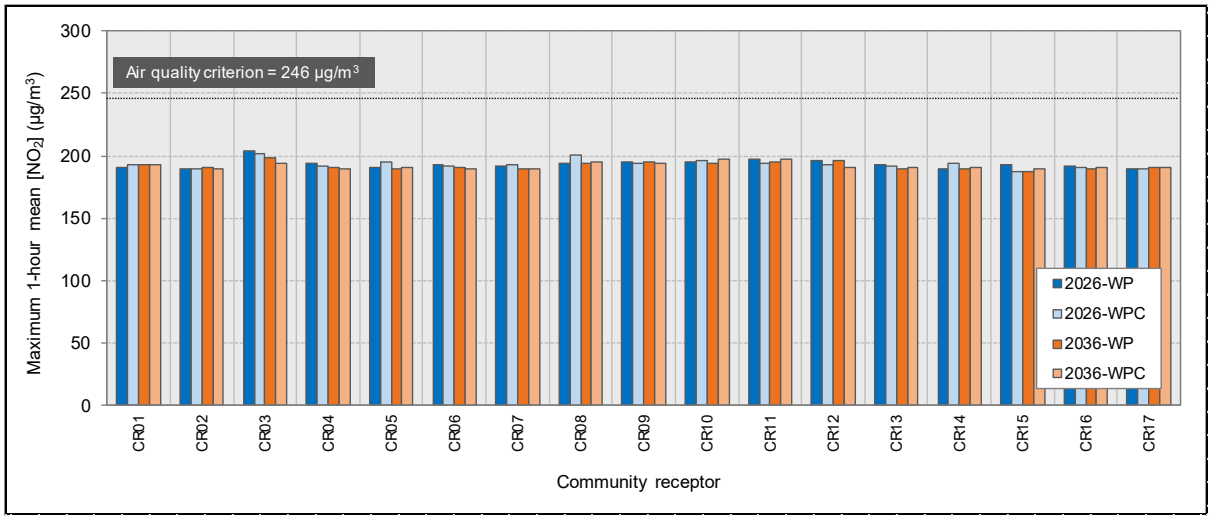


Figure 6-23 Maximum 1-hour NO_2 concentration at community receptors (with-project and cumulative scenarios)

The changes in the maximum 1-hour NO_2 concentration minus the Without Project scenarios are shown in **Figure 6-24**. Again, there was a mixture of small (relative to the NSW criterion) increases and decreases. As observed above, the increases did not result in any exceedances of the NSW criterion.

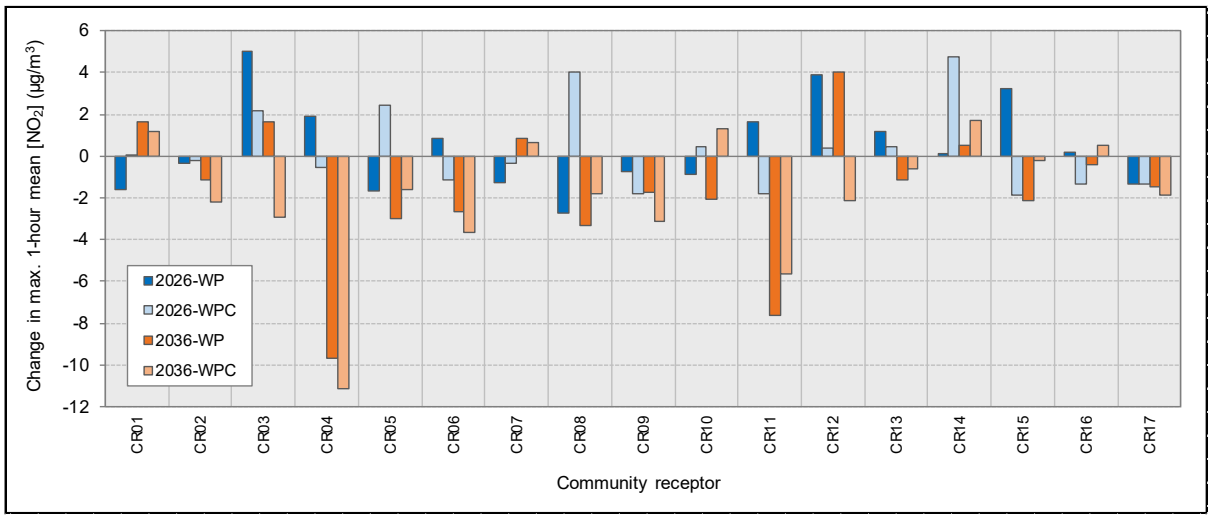


Figure 6-24 Change in maximum 1-hour NO_2 concentration at community receptors (With Project and Cumulative scenarios, minus Without Project scenarios)

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 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 6-25**. As with the annual mean, the background was the most important source, with generally a small contribution from road traffic. As with 1-hour CO concentrations, larger 1-hour NO_2 contributions from road traffic could have occurred during other hours of the year, but the total concentration would have been lower.

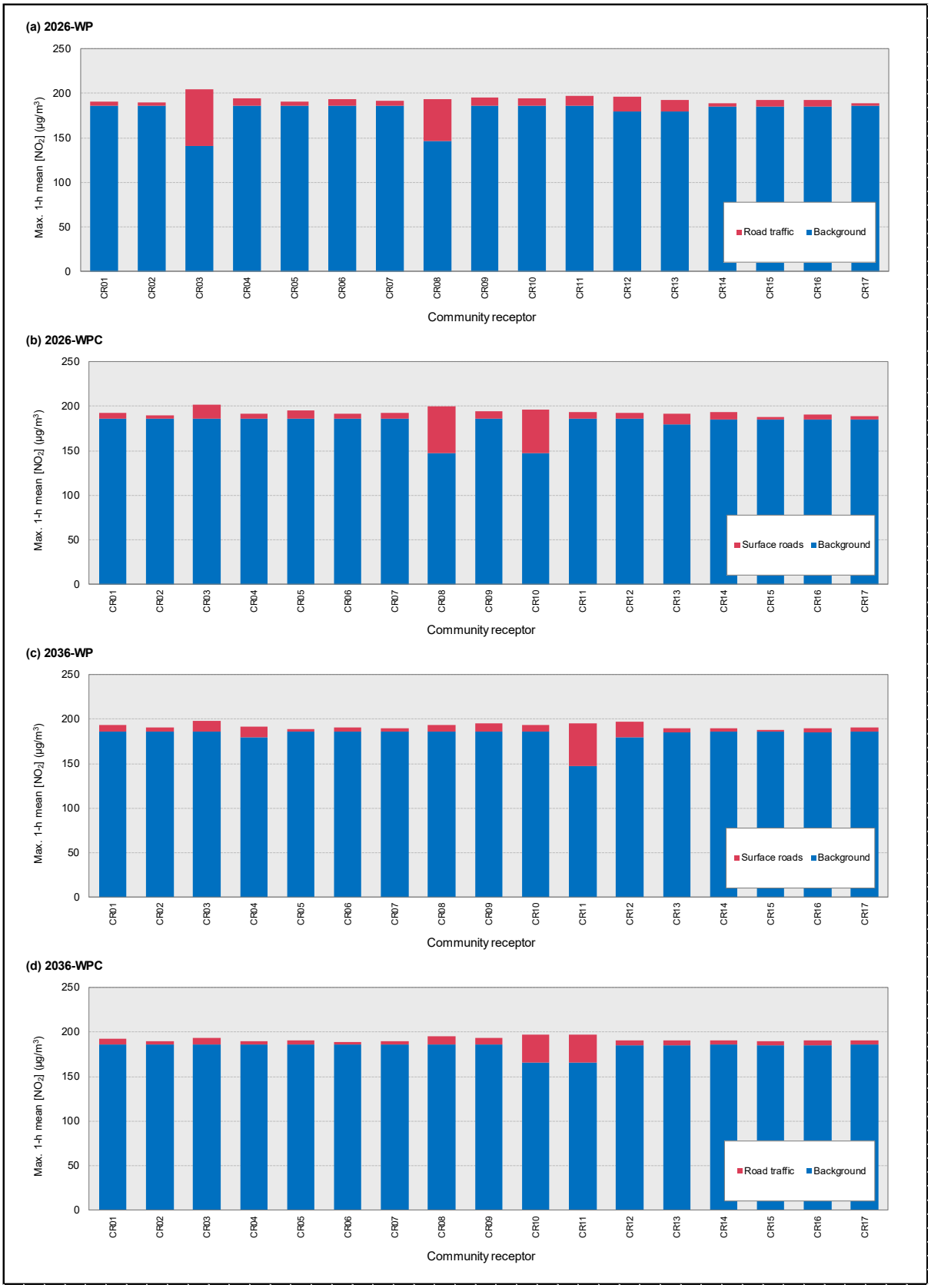


Figure 6-25 Source contributions to maximum 1-hour NO_2 concentration at community receptors (WP and WPC scenarios)

Results for RWR receptors

The maximum 1-hour 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 6-26**.

There was only one predicted location with an exceedance of the NSW 1-hour NO_2 criterion of 246 µg/m^3 in any scenario, and this was for a commercial receptor in the 2026-WPC scenario, specifically a car park within Sydney Airport.

The changes in the maximum 1-hour 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 6-27**. There was predicted to be an increase in the maximum 1-hour NO_2 concentration at between 33 per cent and 47 per cent of receptors depending on the scenario. At the majority of receptors the change was relatively small in all scenarios; for around only 5 per cent of all receptors there was an increase in concentration of more than 5 µg/m^3. The changes at a very small number of receptors were substantially larger. At the Sydney Airport receptor mentioned above, there was an increase in the maximum 1-hour NO_2 concentration of 31 µg/m^3 which resulted in an exceedance of the air quality criterion.

Contour plots – all sources

Contour plots of maximum 1-hour NO_2 concentrations in the 2036-WOP and 2036-WPC scenarios are provided in **Figure 6-28** and **Figure 6-29** 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 the 2036-WPC scenario compared to the Without Project scenario is given in **Figure 6-30**. The locations with the highest concentrations and largest changes in concentration are similar to this for annual mean NO_2.

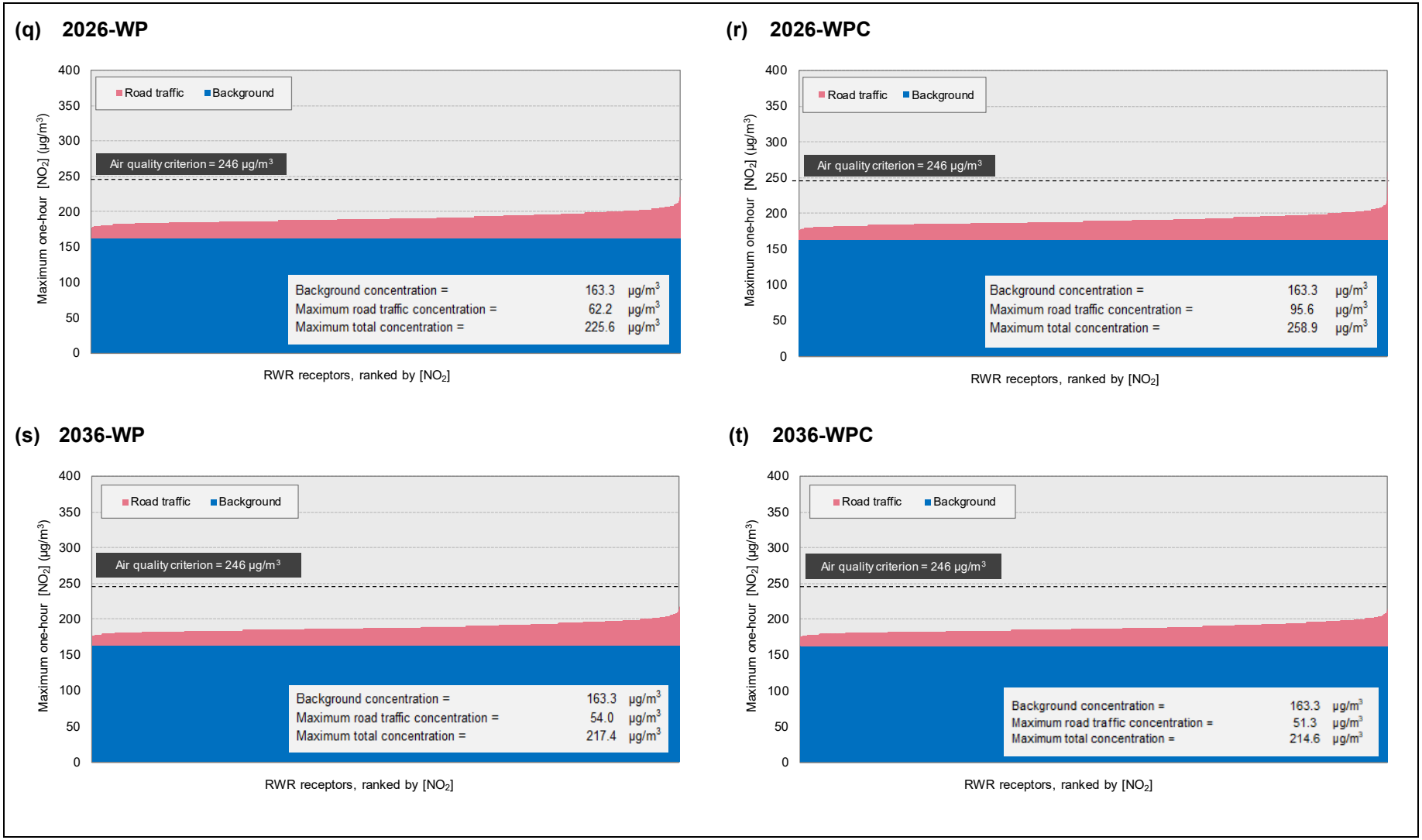


Figure 6-26 Source contributions to maximum 1-hour NO_2 concentration at RWR receptors (with-project and cumulative scenarios)

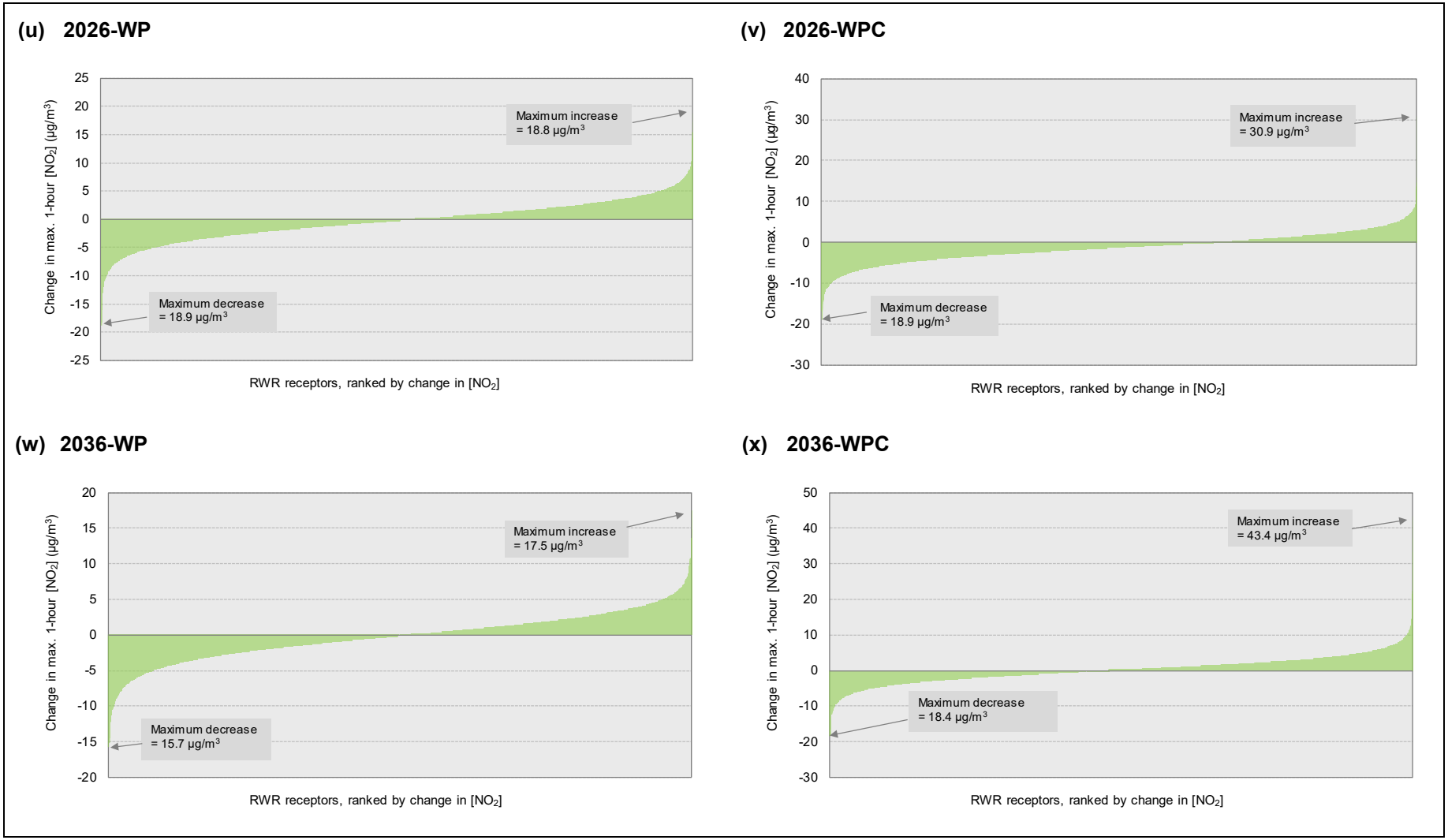


Figure 6-27 Change in maximum 1-hour NO_2 concentration at RWR receptors (with-project and cumulative scenarios, minus Without Project scenarios)

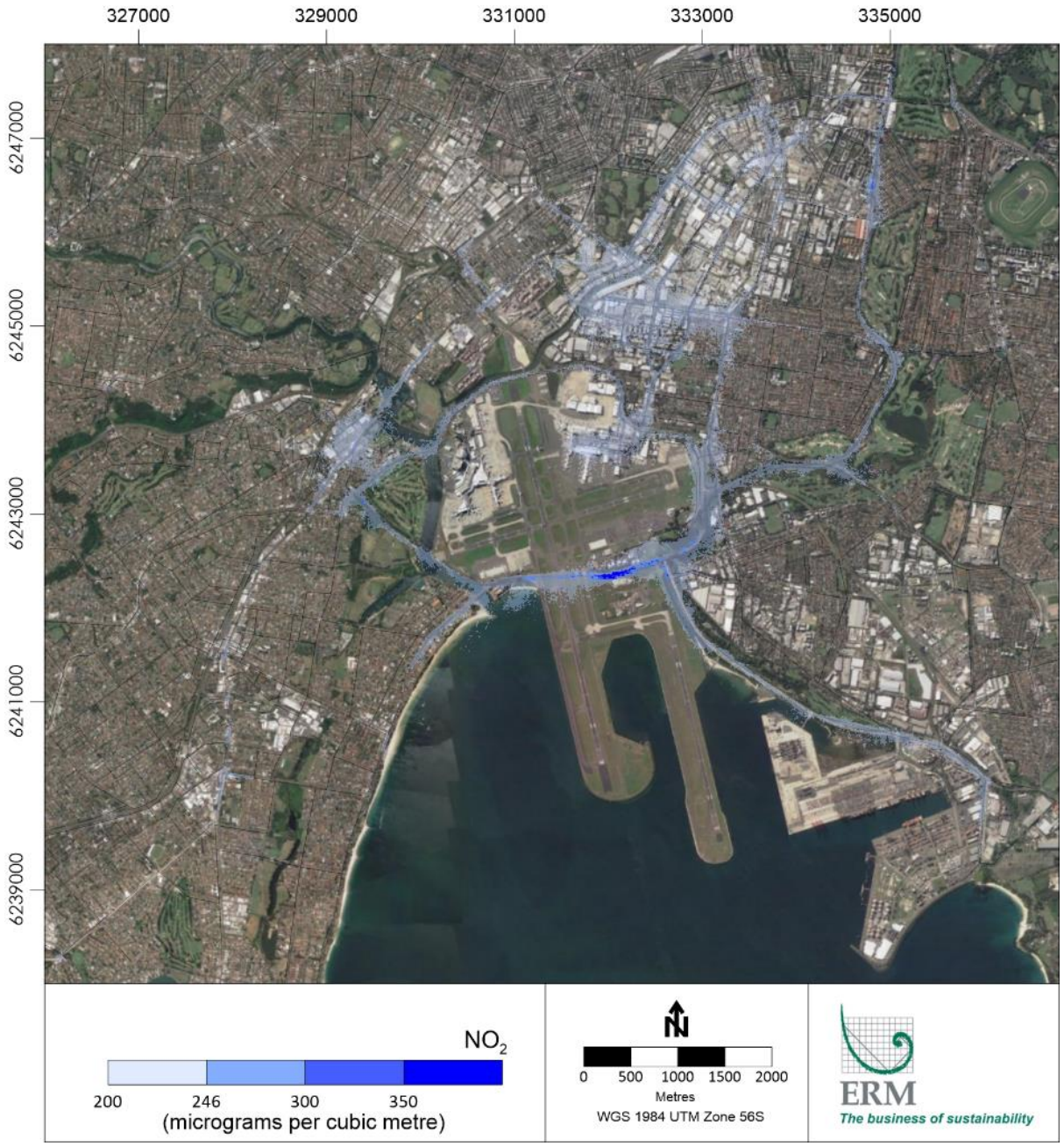


Figure 6-28 Contour plot of maximum 1-hour NO_2 concentration in the 2036 Without Project scenario (2036-WOP)

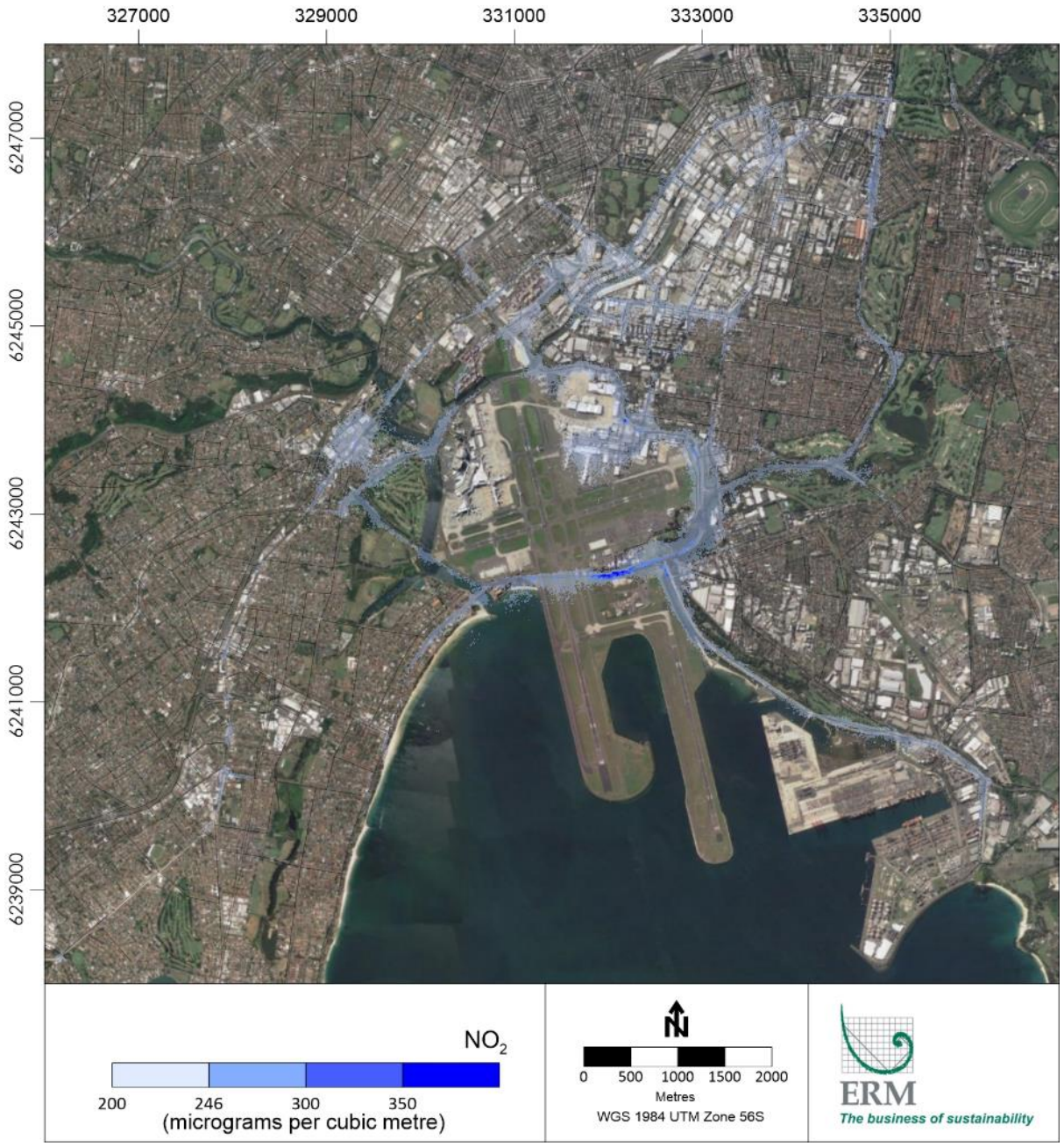


Figure 6-29 Contour plot of maximum 1-hour NO_2 concentration in the 2036 With Project scenario (2036-WP)

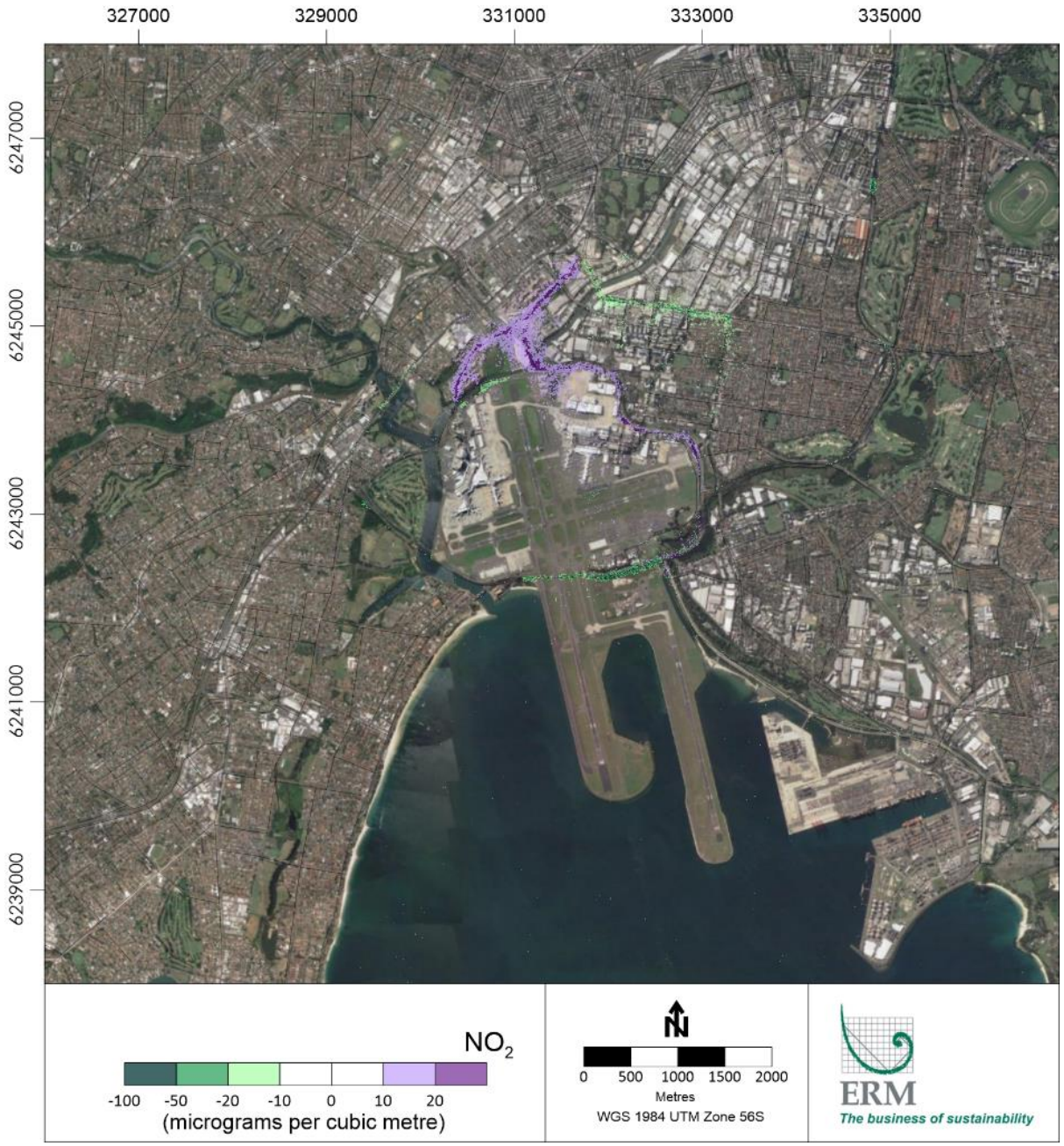


Figure 6-30 Contour plot of change in maximum 1-hour NO_2 concentration in the 2036 With Project scenario (2036-WP minus 2036-WOP)

PM_{10} (annual mean)

Results for community receptors

The annual mean PM_{10} concentrations community receptors are shown in **Figure 6-31**. These were all below the NSW impact assessment criterion of 25 µg/m^3. At most receptors the concentration was close to 20 µg/m^3, and therefore only slightly above the lowest PM_{10} standards in force in other countries (18 µg/m^3 in Scotland).

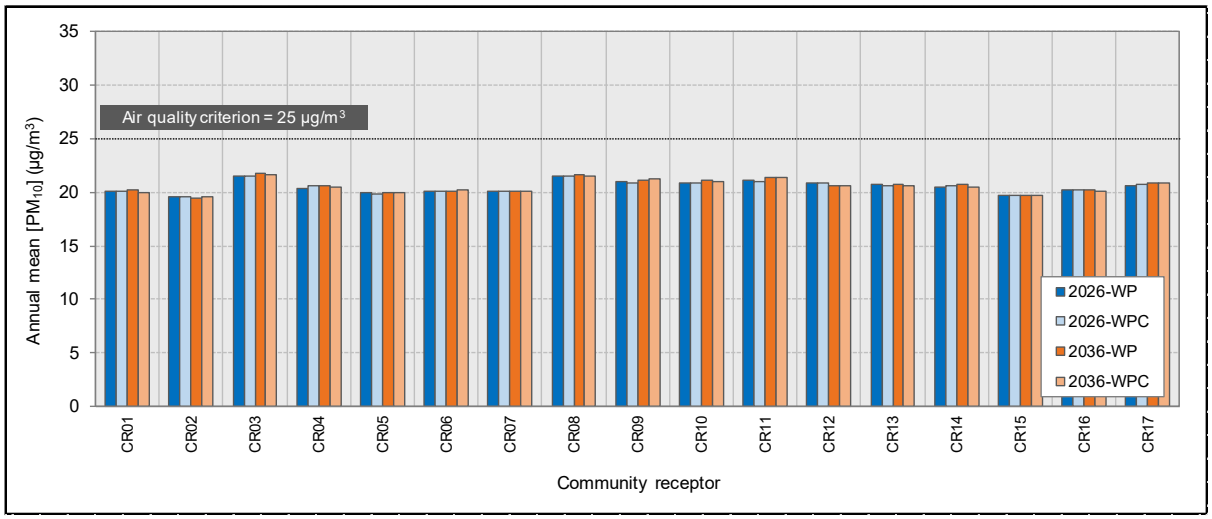


Figure 6-31 Annual mean PM_{10} concentration at community receptors (with-project and cumulative scenarios)

Figure 6-32 shows the changes in PM_{10} concentration. At most of the receptors there was a reduction in concentration in all scenarios. The largest increase in concentration was 0.13 µg/m^3 (0.5 per cent of the criterion) at receptor CR11 (Toybox Early Learning, Mascot), and the largest decrease was around 0.9 µg/m^3.

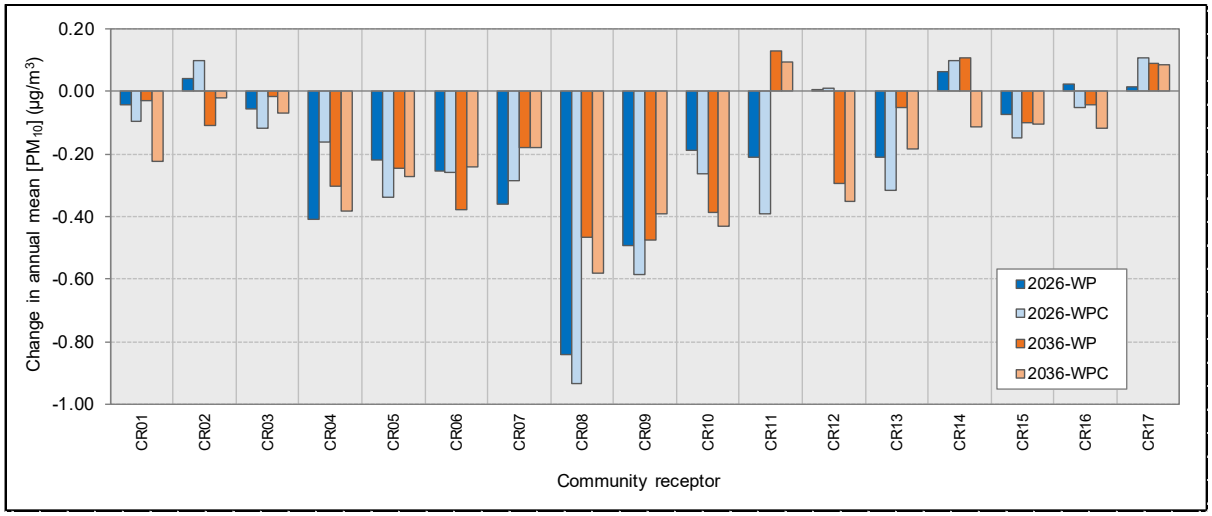


Figure 6-32 Change in annual mean PM_{10} concentration at community receptors (with-project and cumulative scenarios, minus Without Project scenarios)

Concentrations in the with-project and cumulative scenarios were again dominated by the background (**Figure 6-33**), with a relatively small contribution from road traffic (0.9-3.0 µg/m^3).

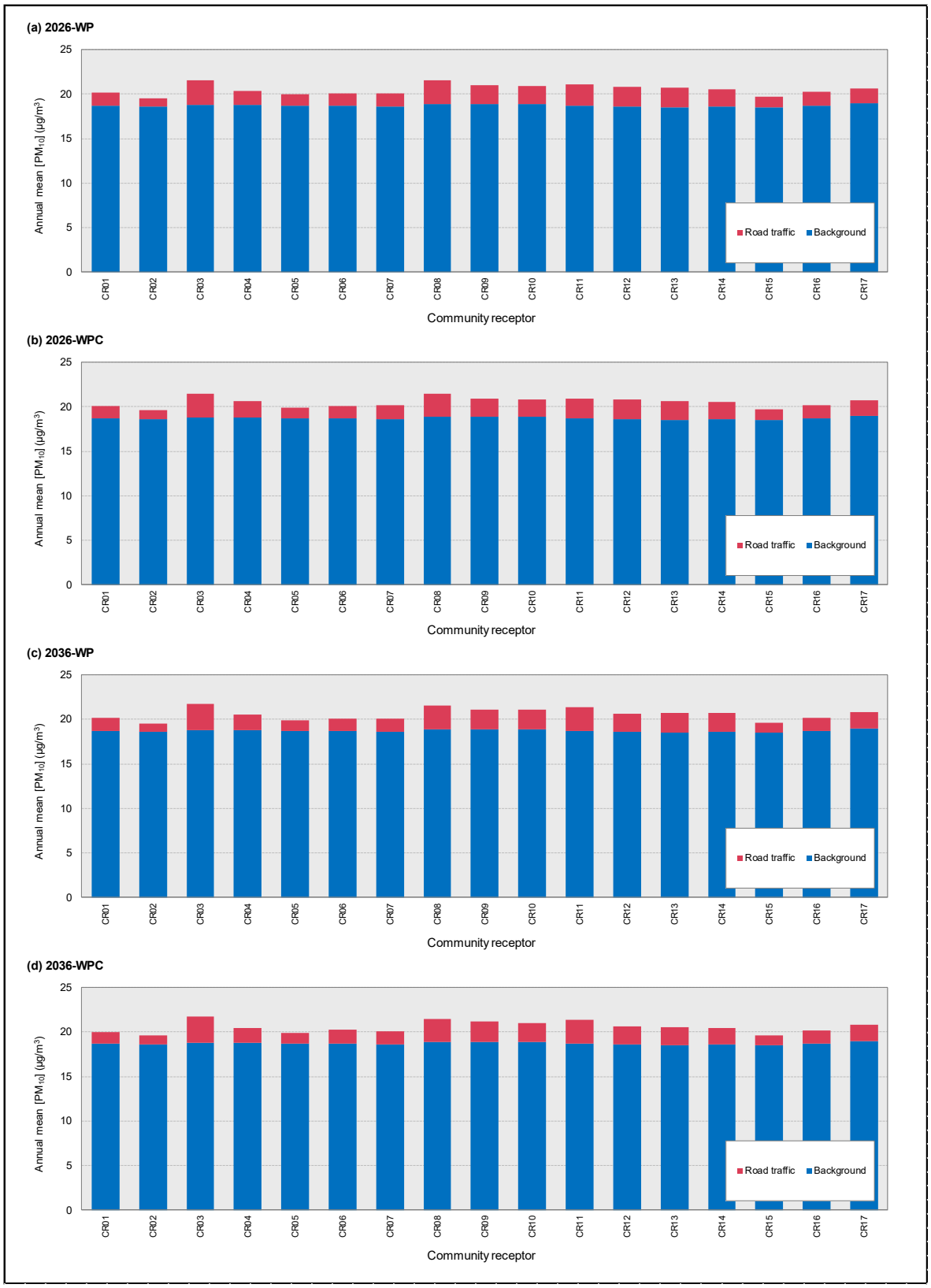


Figure 6-33 Source contributions to annual mean PM_{10} concentration at community receptors (with-project and cumulative scenarios)

Results for RWR receptors

The ranked annual mean PM_{10} concentrations at the RWR receptors in the with-project and cumulative scenarios are shown in **Figure 6-34**. The concentration at the majority (99.7 per cent) of receptors was below 23 µg/m^3, with only two receptors having a concentration just above the NSW assessment criterion of 25 µg/m^3 in any scenario. The highest predicted concentration at any receptor in a with-project or cumulative scenario was 25.7 µg/m^3. The maximum road traffic contribution in any scenario was 6.9 µg/m^3.

The changes in the annual mean PM_{10} concentration at the RWR receptors are shown, ranked by change in concentration, in **Figure 6-35**. There was an increase in concentration at 35-42 per cent of the receptors, depending on the scenario. At the majority of receptors the change was relatively small, and where there was an increase, this was greater than one per cent of the criterion at less than 1.5 per cent of receptors. The largest predicted increase in concentration at any receptor as a result of the project (including the cumulative scenarios) was 1.9 µg/m^3, and the largest increase at a residential location was 0.45 µg/m^3.

Contour plots – all sources

The contour plots for annual mean PM_{10} in the 2036-WOP and 2036-WP scenarios are given in **Figure 6-36** and **Figure 6-37**. As in the case of NO_2, elevated concentrations are evident along the major road corridors. The contour plot for the change in concentration in the cumulative scenario in (**Figure 6-38**) also shows spatial changes that are similar to those for NO_2.

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

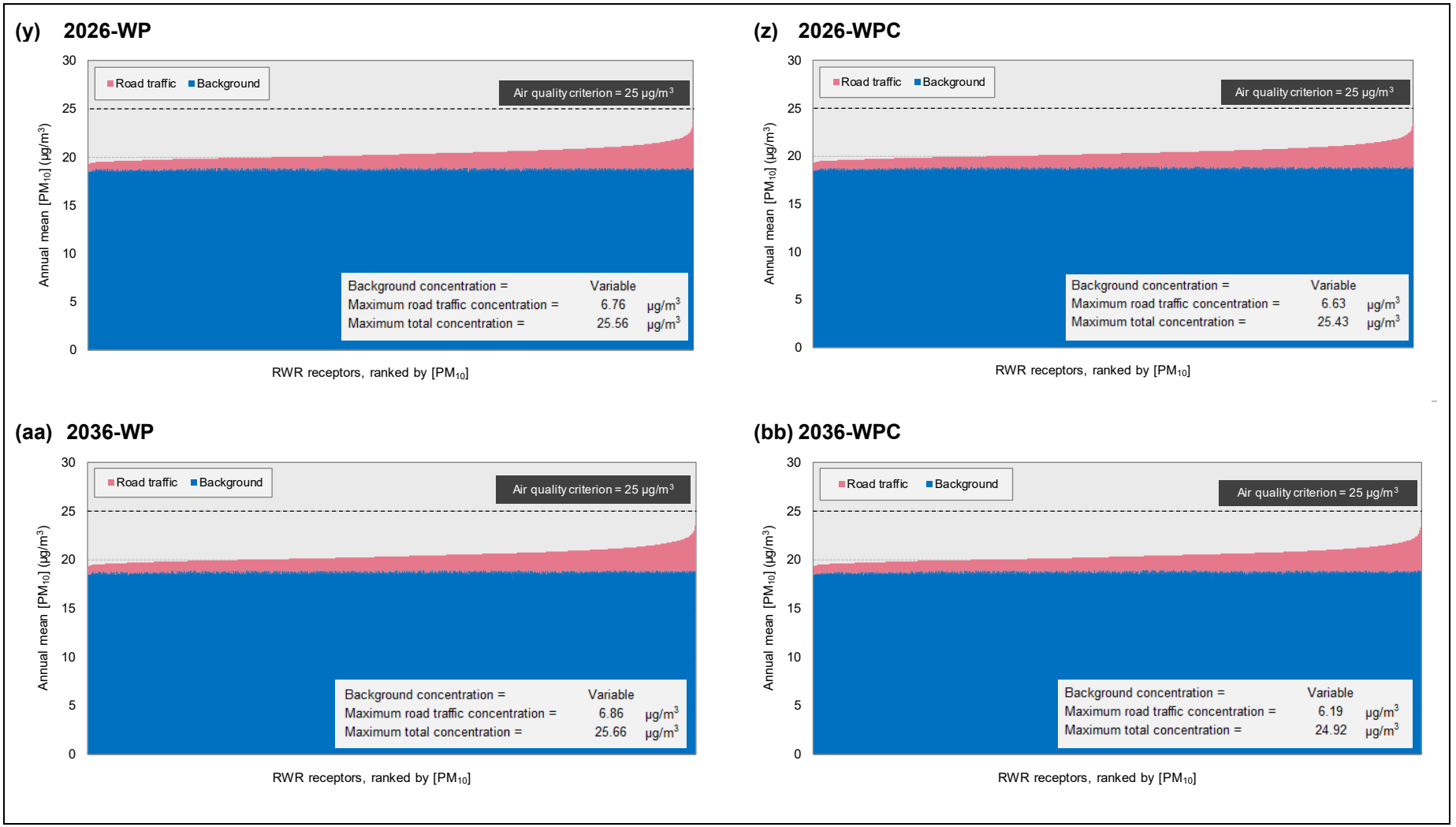


Figure 6-34 Source contributions to annual mean PM_{10} concentration at RWR receptors (with-project and cumulative scenarios)

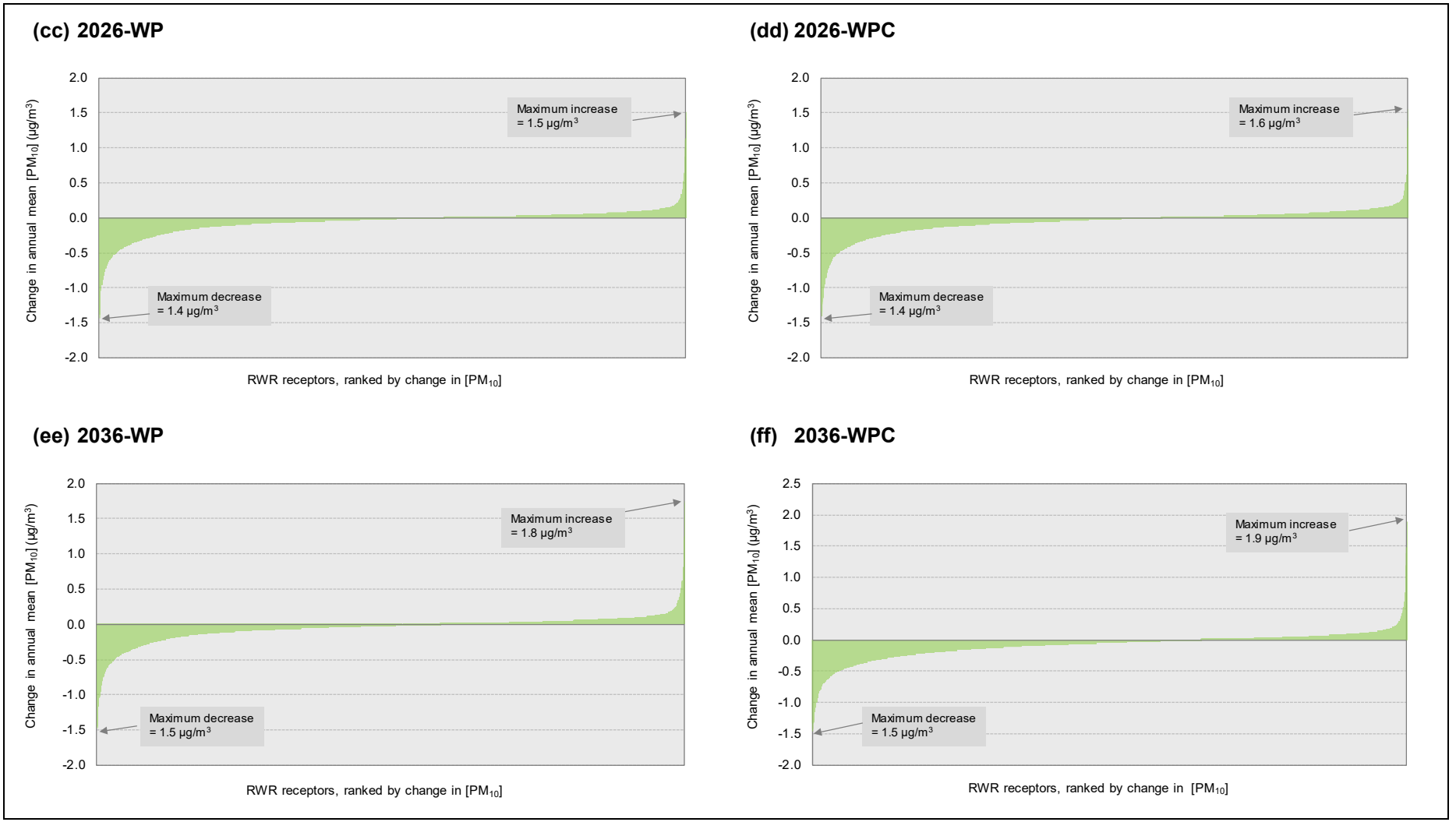


Figure 6-35 Changes in annual mean PM_{10} concentration at RWR receptors (with-project and cumulative scenarios, minus Without Project scenarios)

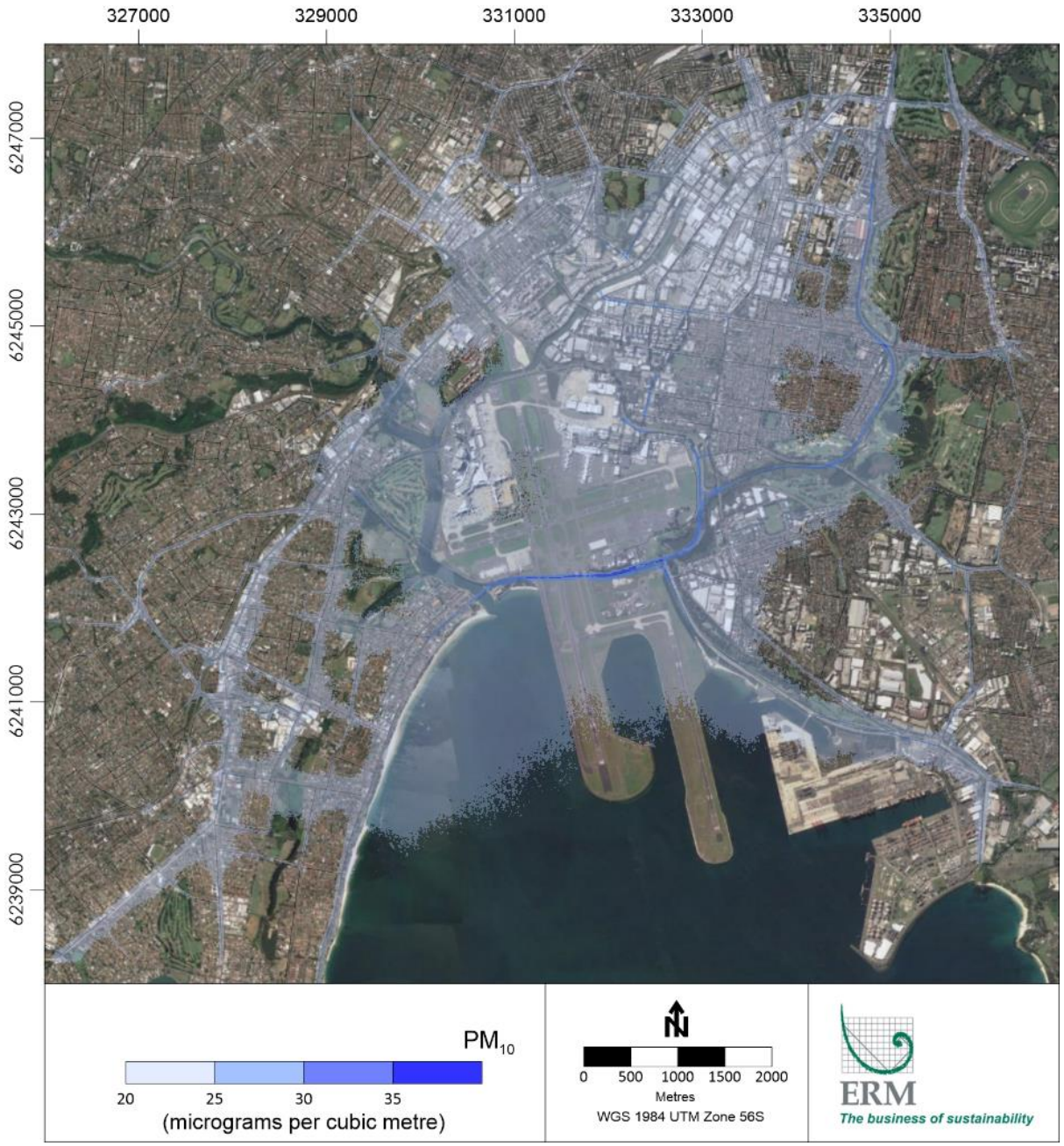


Figure 6-36 Contour plot of annual mean PM_{10} concentration in the 2036 Without Project scenario (2036-WOP)

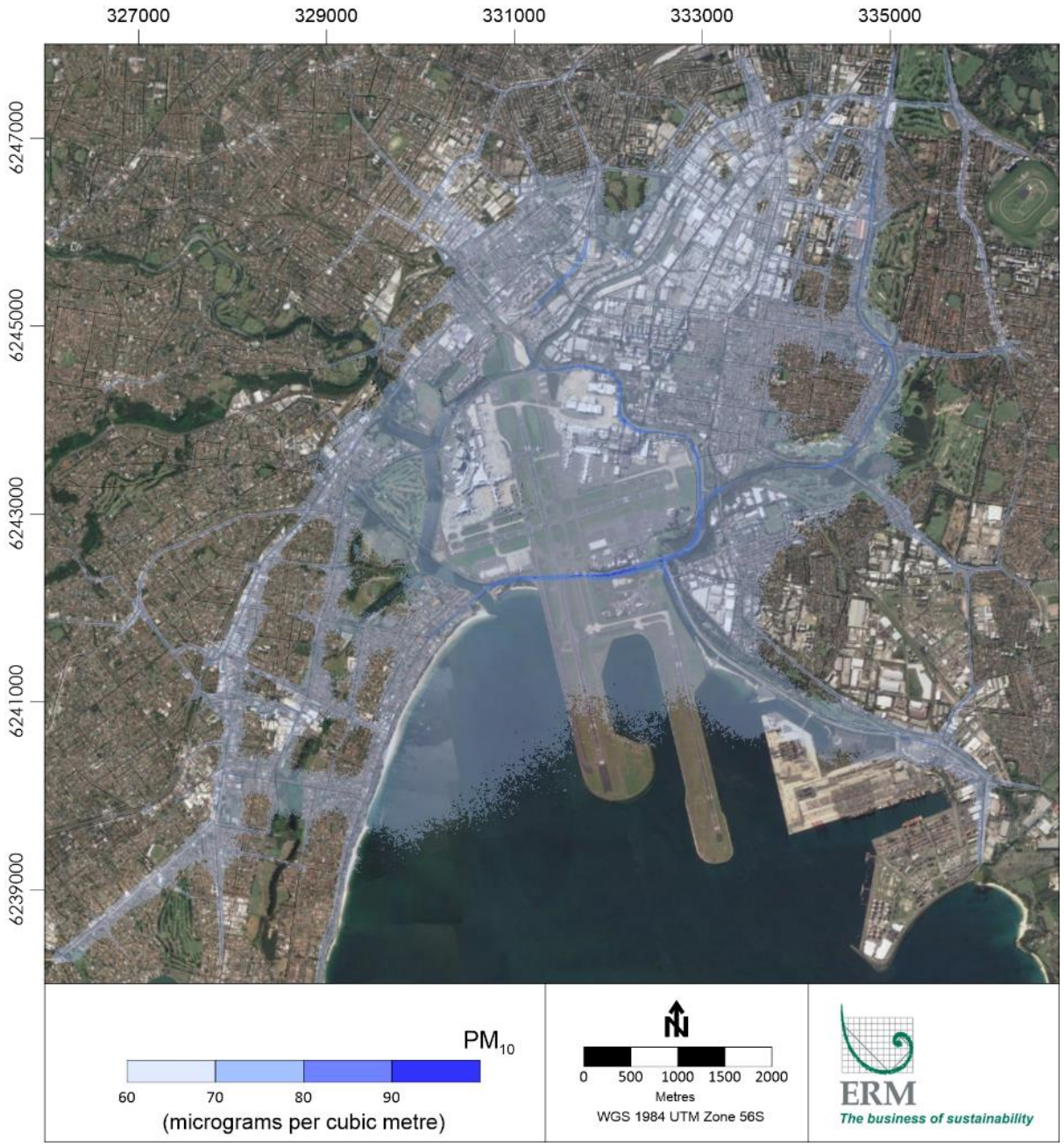


Figure 6-37 Contour plot of annual mean PM_{10} concentration in the 2036 With Project scenario (2036-WP)

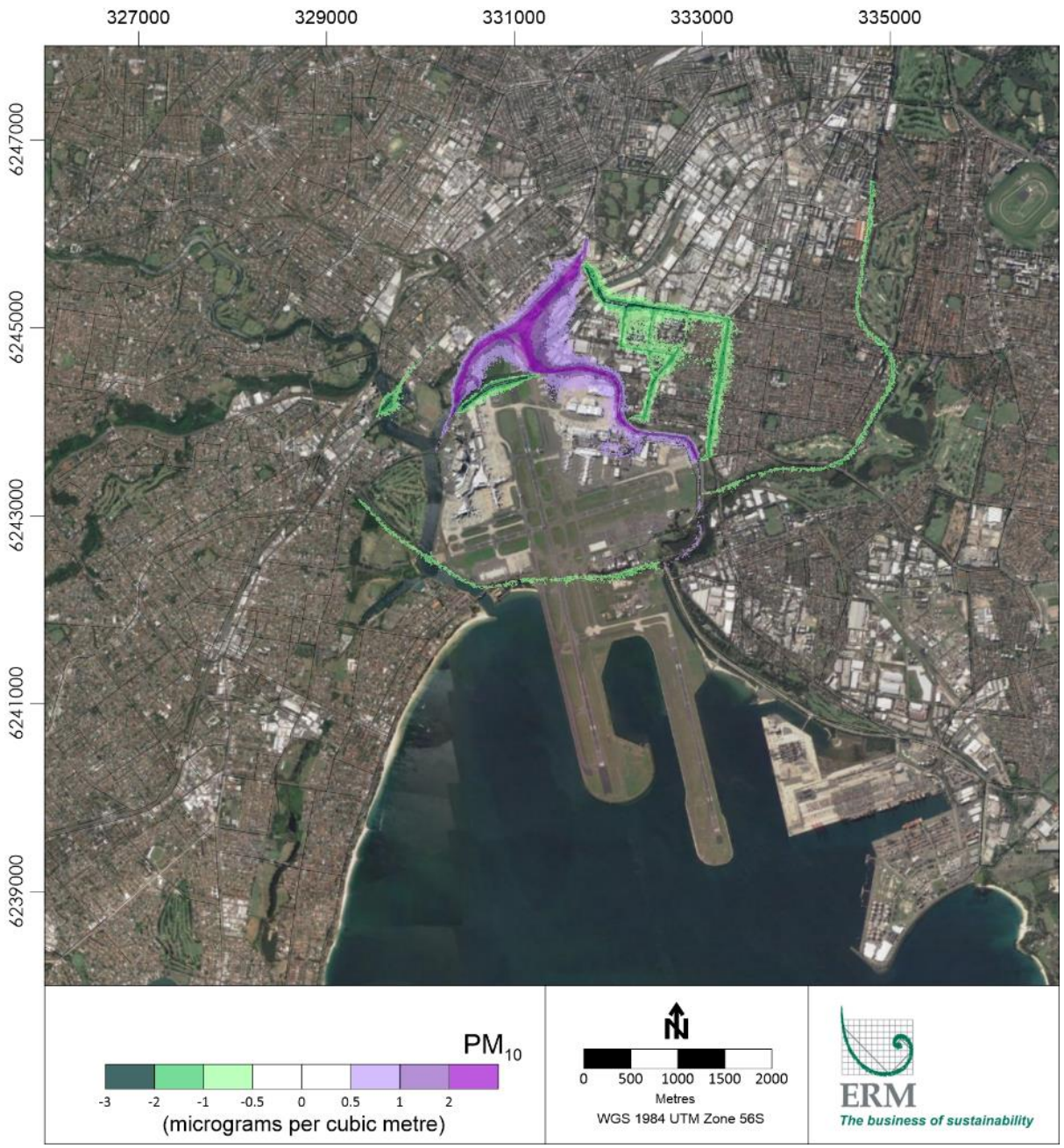


Figure 6-38 Contour plot of change in annual mean PM_{10} concentration in the 2036 With Project scenario (2036-WP minus 2036-WOP)

PM_{10} (maximum 24-hour)

Results for community receptors

Figure 6-39 presents the maximum 24-hour PM_{10} concentrations at the community receptors. At all locations, and in all scenarios, the concentration was above the NSW impact assessment criterion of 50 µg/m^3, which is also the most stringent standard in force internationally. This is because the maximum concentration in the synthetic background profile (described in **Annexure D**) was already above the criterion.

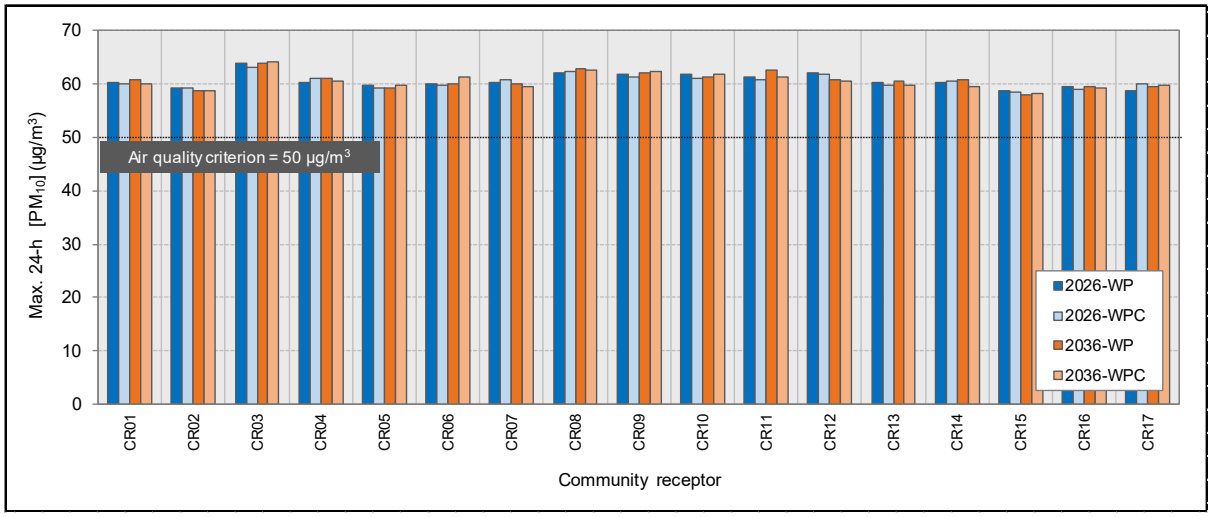


Figure 6-39 Maximum 24-hour PM_{10} concentration at community receptors (with-project and cumulative scenarios)

Figure 6-40 shows the changes in concentration in the With Project scenarios minus the Without Project scenarios for the community receptors. At most receptors there was a decrease in concentration with the project. The largest increase was 1.3 µg/m^3 at receptor CR11 (Toybox Early Learning, Mascot) in the 2036-WP scenario.

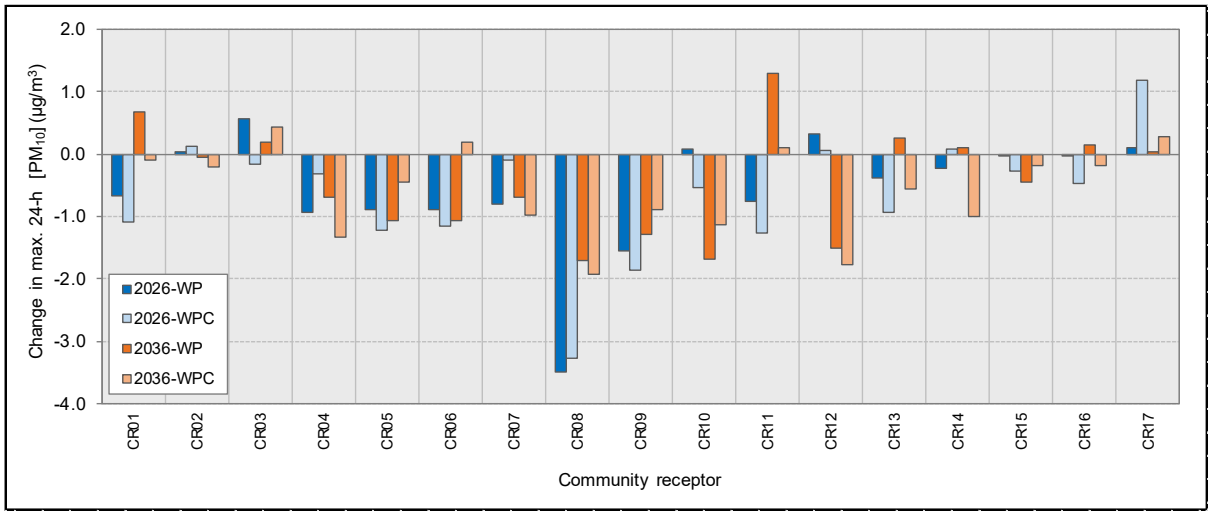


Figure 6-40 Change in maximum 24-hour PM_{10} concentration at community receptors (with-project and cumulative scenarios, minus Without Project scenarios)

Figure 6-41 demonstrates that the road traffic contribution to the maximum 24-hour PM_{10} concentration at community receptors was between around 1.5 and 8 µg/m^3. At all community receptors the maximum total 24-hour concentration occurred on one day of the year, and coincided with the highest 24-hour background concentration in the synthetic PM_{10} profile (56.4 µg/m^3). This calculation of the synthetic background is described in detail in **Annexure D**.

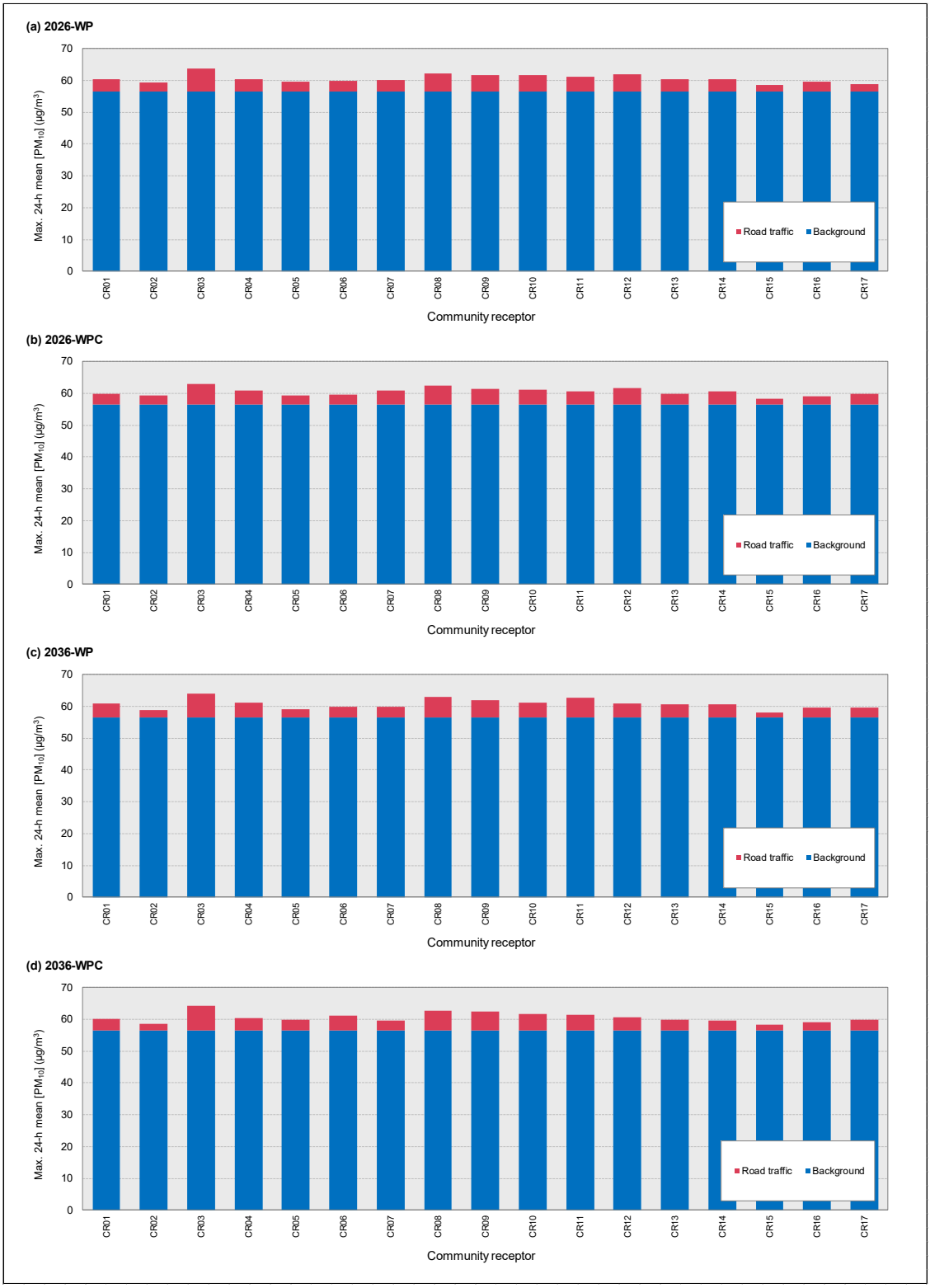


Figure 6-41 Source contributions to maximum 24-hour PM_{10} concentration at community receptors (with-project and cumulative scenarios)

Results for RWR receptors

The ranked maximum 24-hour PM_{10} concentrations at the RWR receptors are shown in **Figure 6-42**. The results for the RWR receptors were highly dependent on the assumption for the background concentration. Because this was assumed to be the maximum concentration in the synthetic background profile (ie 56.4 µg/m^3), the total concentration in the with-project and cumulative scenarios was above the NSW impact assessment criterion of 50 µg/m^3 at all receptors. The maximum contribution of road traffic at any receptor in a with-project or cumulative scenario was 18.4 µg/m^3.

The changes in the maximum 24-hour PM_{10} concentration with the project and in the cumulative scenarios are ranked, by change in concentration, in **Figure 6-43**. There was an increase in concentration at between 33 and 46 per cent of the receptors, depending on the scenario. Where there was an increase, this was greater than one per cent of the criterion at 7-10 per cent of all receptors depending on the scenario. The largest predicted increase in concentration at any receptor as a result of the project (including the cumulative scenarios) was 5.9 µg/m^3, and the largest increase at a residential location was 3.3 µg/m^3.

Contour plots – all sources

The contour plots for maximum 24-hour average PM_{10} in the 2036-WOP and 2036-WP scenarios are given in **Figure 6-44** and **Figure 6-45**. The spatial changes in maximum 24-hour PM_{10} are shown in **Figure 6-46**.

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

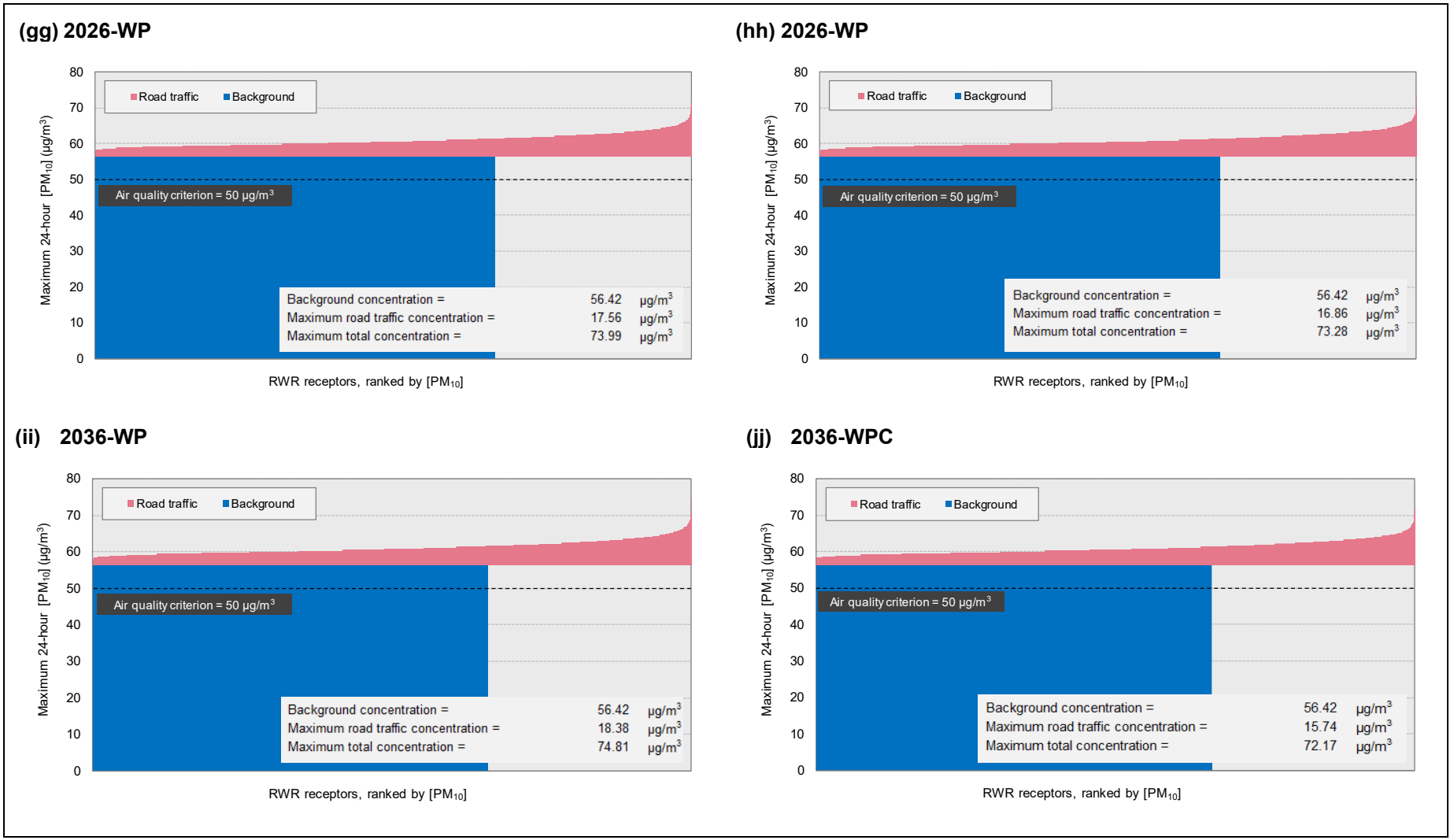


Figure 6-42 Source contributions to maximum 24-hour PM_{10} concentration at RWR receptors (with-project and cumulative scenarios)

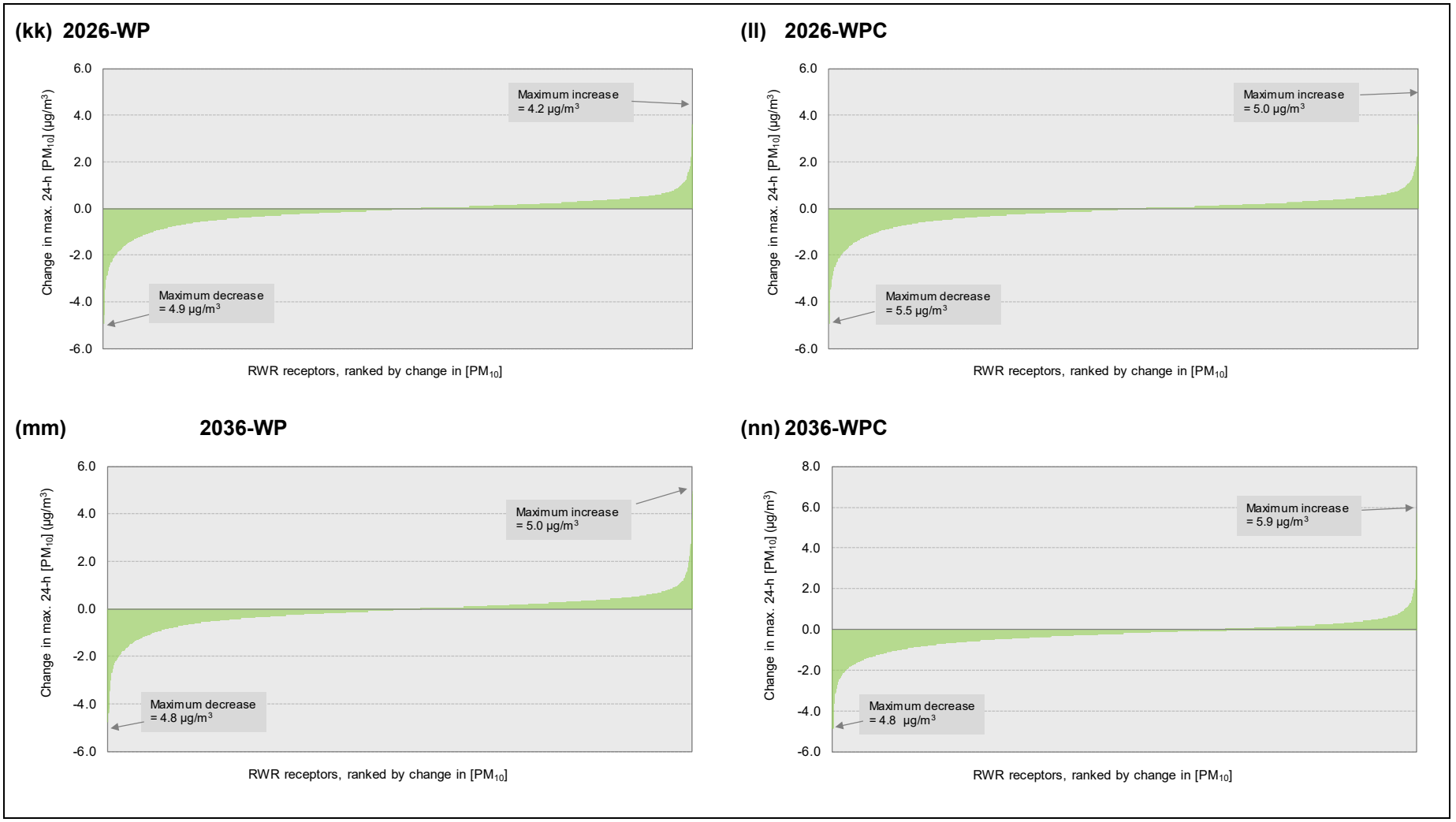


Figure 6-43 Change in maximum 24-hour PM_{10} concentration at RWR receptors (with-project and cumulative scenarios, minus Without Project scenarios)

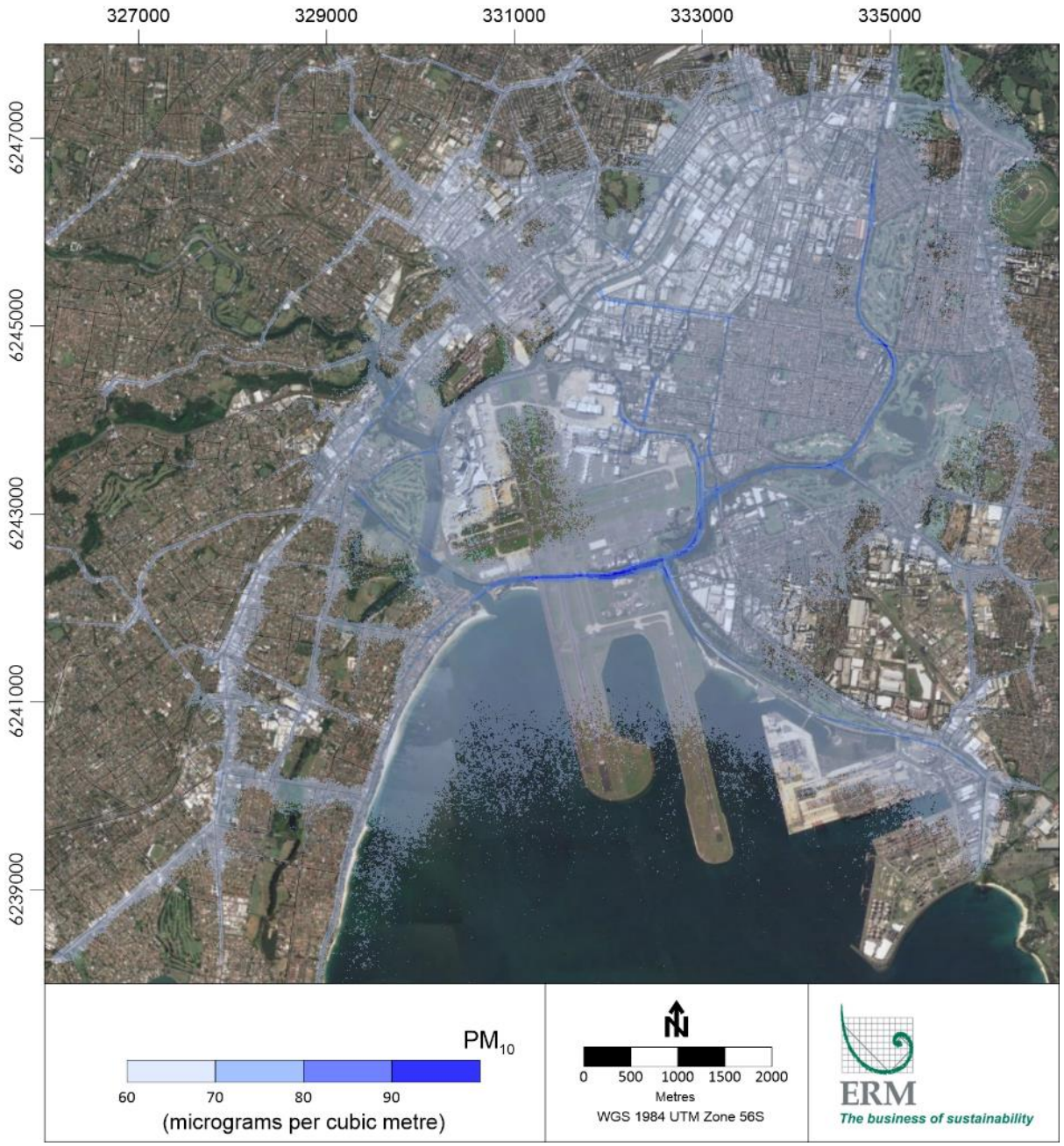


Figure 6-44 Contour plot of maximum 24-hour average PM_{10} concentration in the 2036 Without Project scenario (2036-WOP)

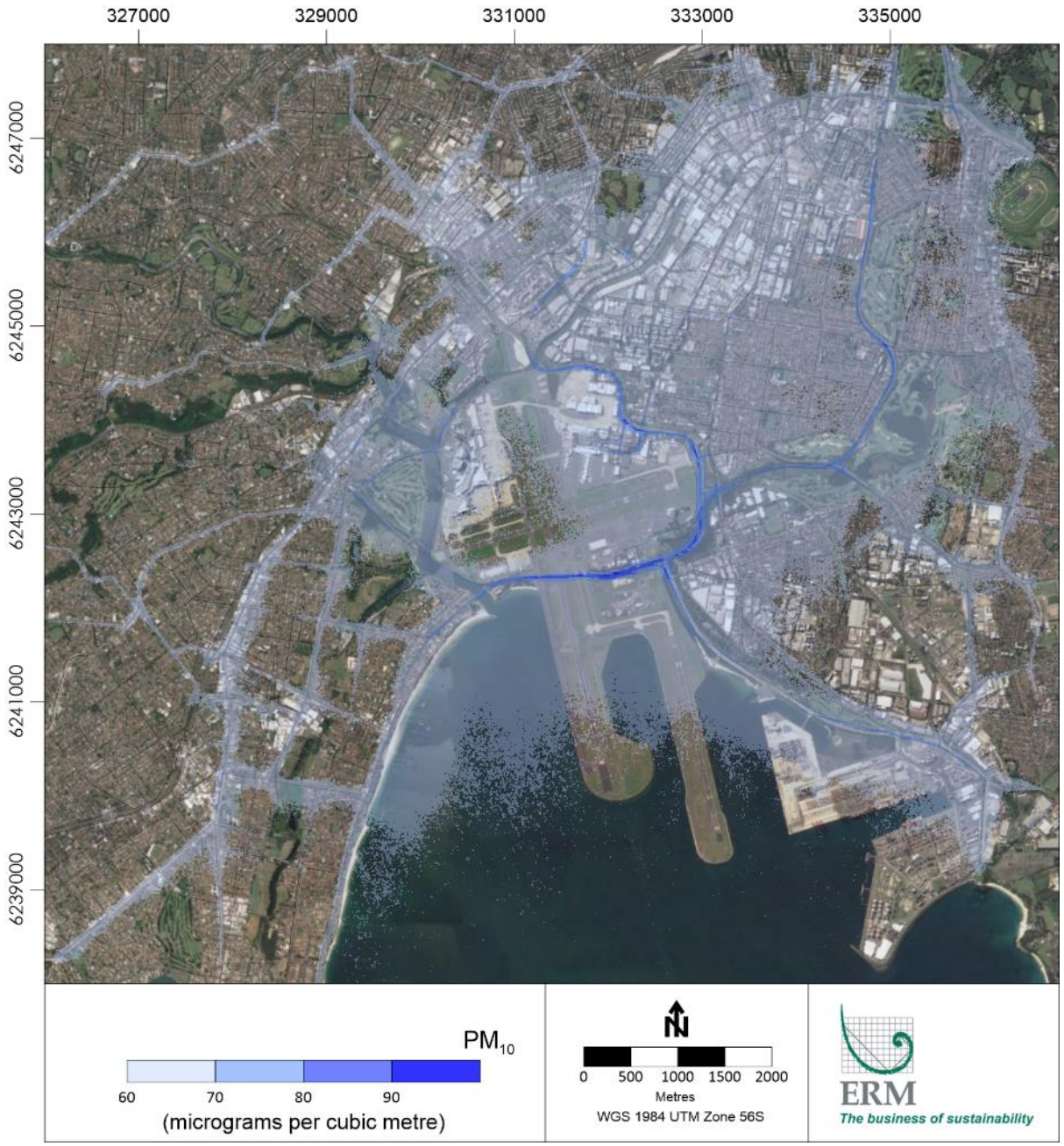


Figure 6-45 Contour plot of maximum 24-hour average PM_{10} concentration in the 2036 With Project scenario (2036-WP)

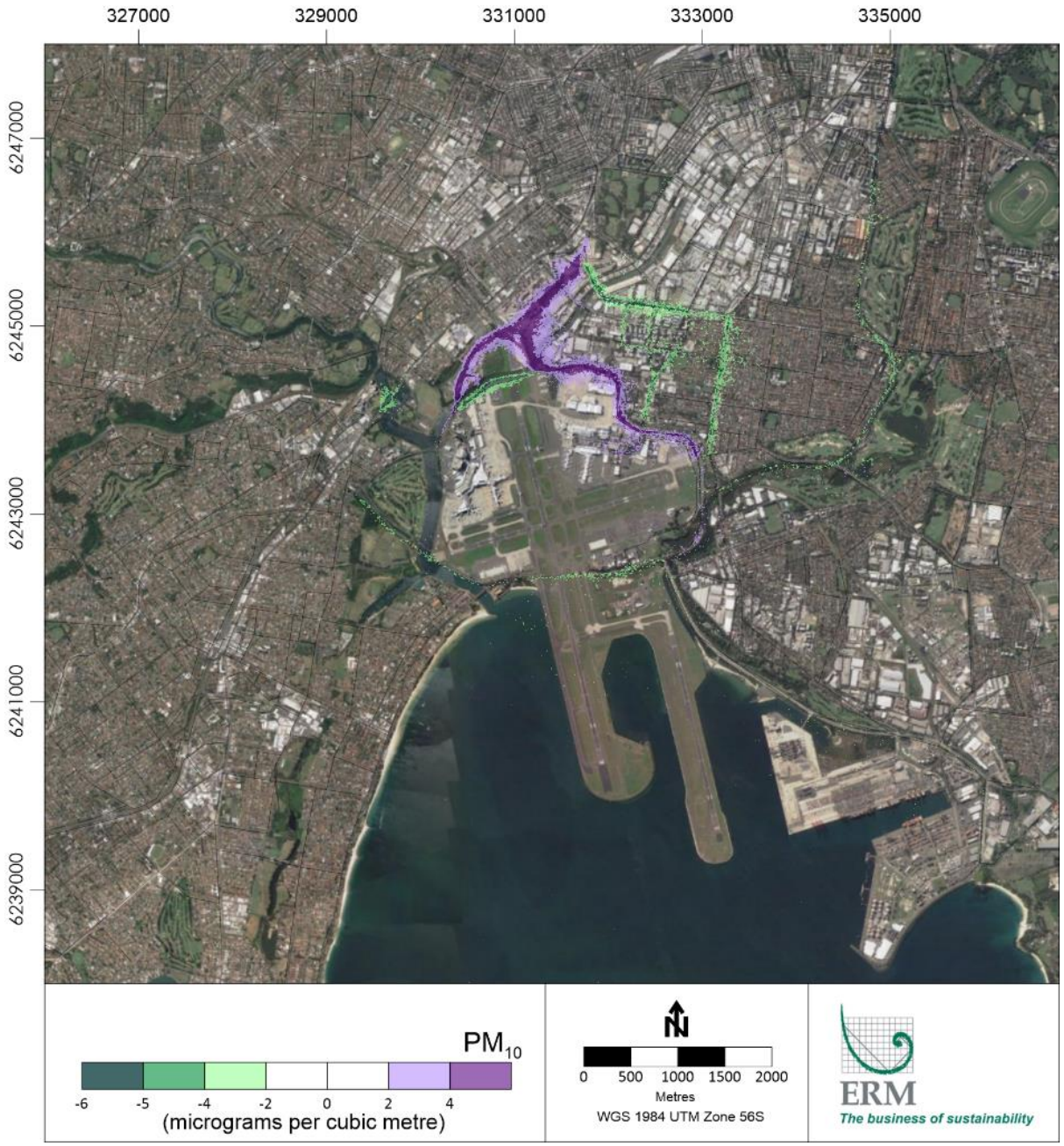


Figure 6-46 Contour plot of change in maximum 24-hour PM_{10} concentration in the 2036 With Project scenario (2036-WP minus 2036-WOP)

$PM_{2.5}$ (annual mean)

Results for community receptors

Figure 6-47 presents the annual mean $PM_{2.5}$ concentrations at the community receptors. The results are based on a mapped background concentration with values at these locations of between 8.8 and 9.5 µg/m^3, and therefore the figure shows exceedances of the NSW criterion of 8 µg/m^3 at all receptors. Clearly, there would also be exceedances of the AAQ NEPM long-term target of 7 µg/m^3. Internationally, there are no standards lower than 8 µg/m^3 for annual mean $PM_{2.5}$. The next lowest is 12 µg/m^3 (California, Scotland).

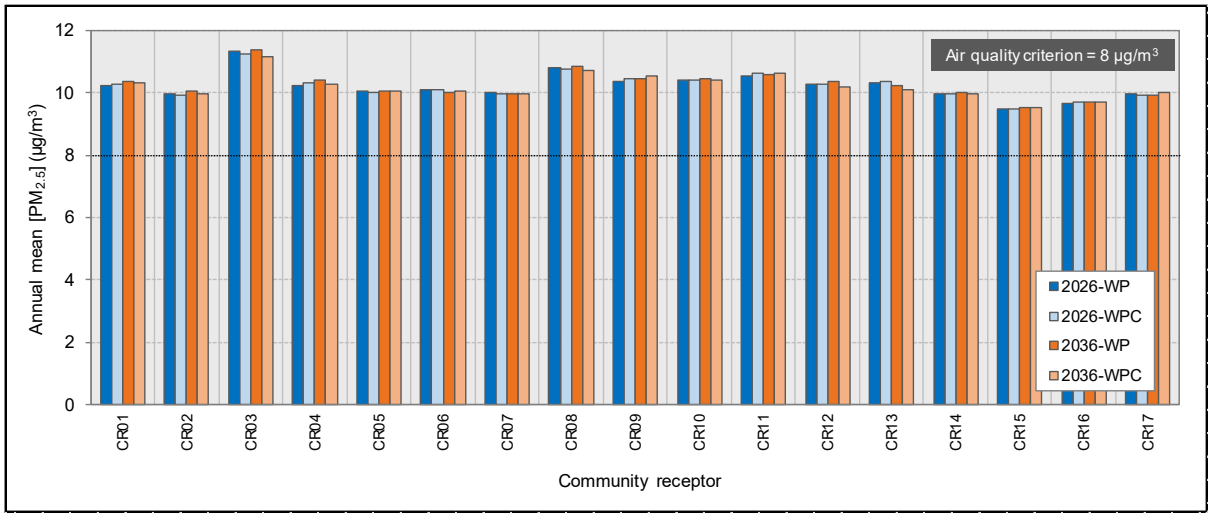


Figure 6-47 Annual mean $PM_{2.5}$ concentration at community receptors (with-project and cumulative scenarios)

Figure 6-48 presents the changes in annual mean $PM_{2.5}$ at the community receptors. Any increases in concentration at these locations were less than 0.2 µg/m^3; the largest increase (0.17 µg/m^3 at receptor CR03 in the 2026-WP scenario) equated to two per cent of the air quality criterion of 8 µg/m^3.

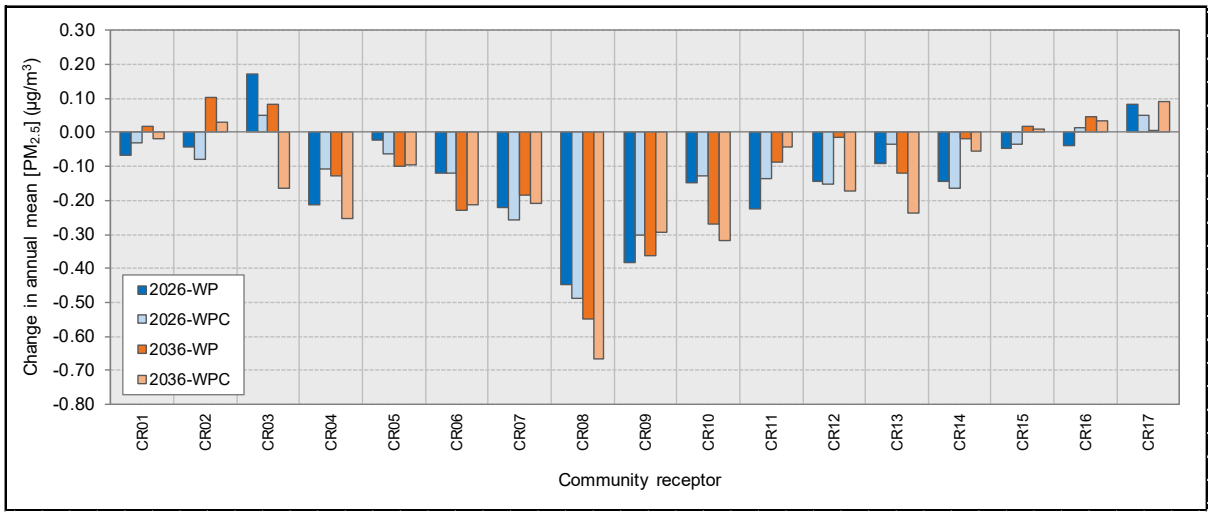


Figure 6-48 Change in annual mean $PM_{2.5}$ concentration at community receptors (with-project and cumulative scenarios, minus Without Project scenarios)

Figure 6-49 shows that total concentrations were again dominated by the background contribution. The road traffic contribution was between 0.5 µg/m^3 and 2.2 µg/m^3, depending on the receptor and scenario.

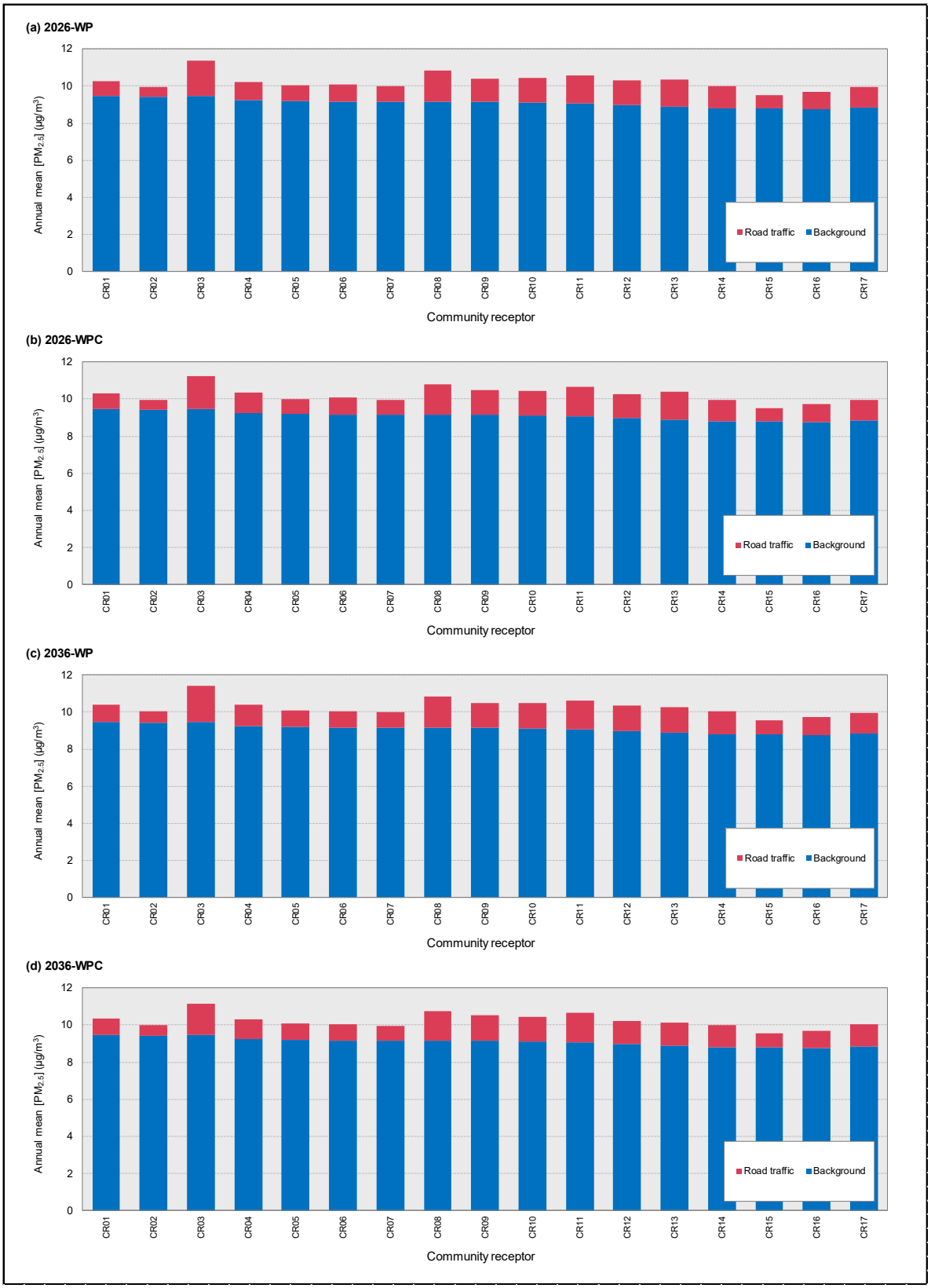


Figure 6-49 Source contributions to annual mean $PM_{2.5}$ concentration at community receptors (WP and WPC)

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 6-50**, including the contributions from road traffic and the background. As the background concentration was already above the NSW criterion of 8 µg/m^3, the total concentration at all receptors was also above this value. The highest concentration at any receptor was 13.6 µg/m^3 but, as with other pollutants and metrics, the highest values were only predicted for a very small proportion of receptors. The largest road traffic contribution at any receptor was 4.2 µg/m^3.

The change in the annual mean $PM_{2.5}$ concentration at the RWR receptors in the with-project and cumulative scenarios are ranked in **Figure 6-51**. There was an increase in concentration at between 37 per cent and 44 per cent of the receptors, depending on the scenario. Where there was an increase, this was greater than 0.1 µg/m^3 at around 2 to 4 per cent of receptors.

The largest predicted increase in concentration at any receptor as a result of the project (including the cumulative scenarios) was 1.3 µg/m^3, and the largest increase at a residential location was 0.27 µg/m^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. This was calculated to be 1.8 µg/m^3 and methodology is described in **Annexure B**. For the Sydney Gateway road project, the acceptable value of $\Delta PM_{2.5}$ was determined to be 1.8 µg/m^3. Clearly no receptors had a predicted increase 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 6-52** (2036-WOP) and **Figure 6-53** (2036-WP). The contour plot for the associated change in concentration in this scenario is shown in **Figure 6-54**.

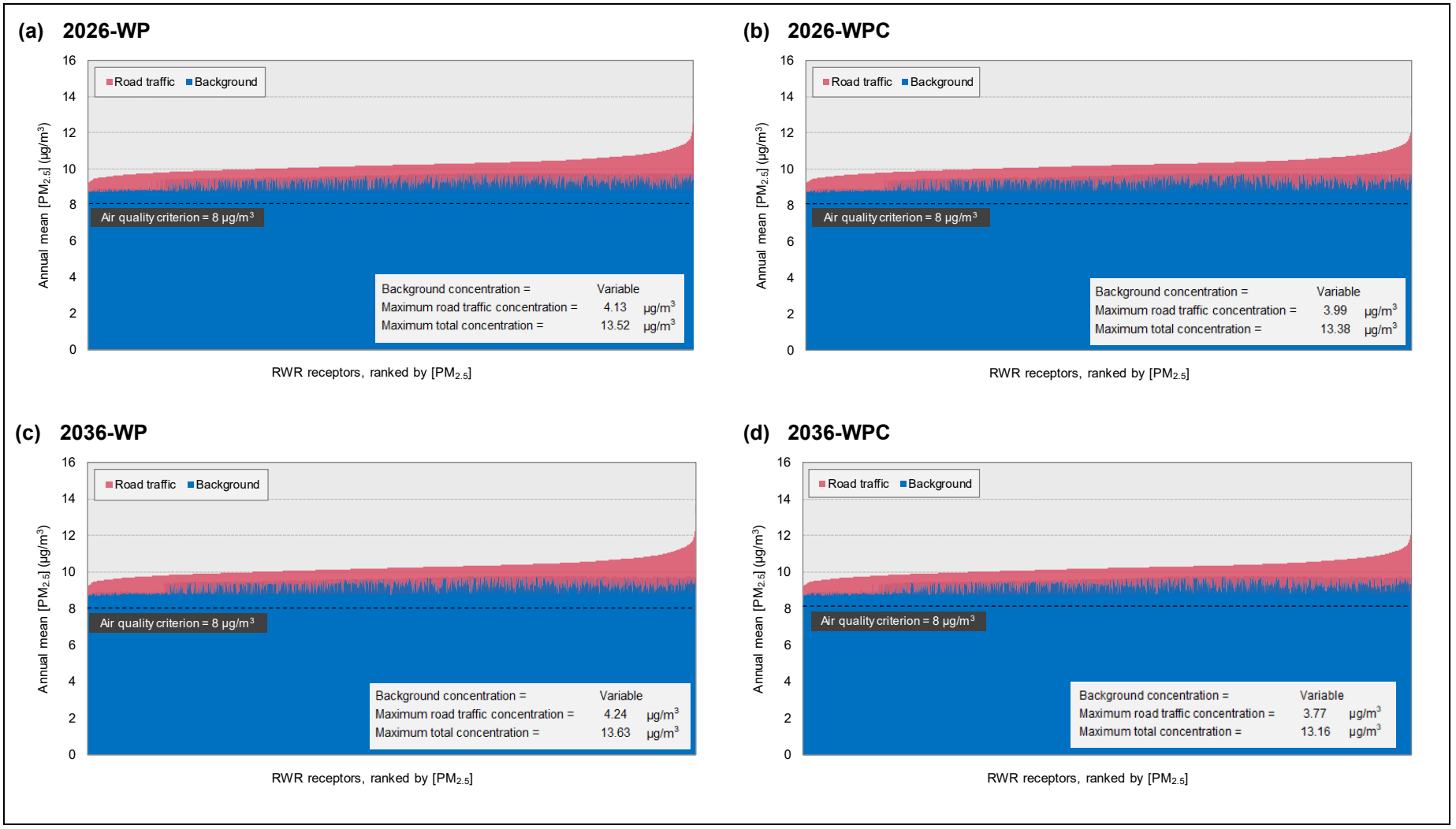


Figure 6-50 Source contributions to annual mean $PM_{2.5}$ concentration at RWR receptors (with-project and cumulative scenarios)

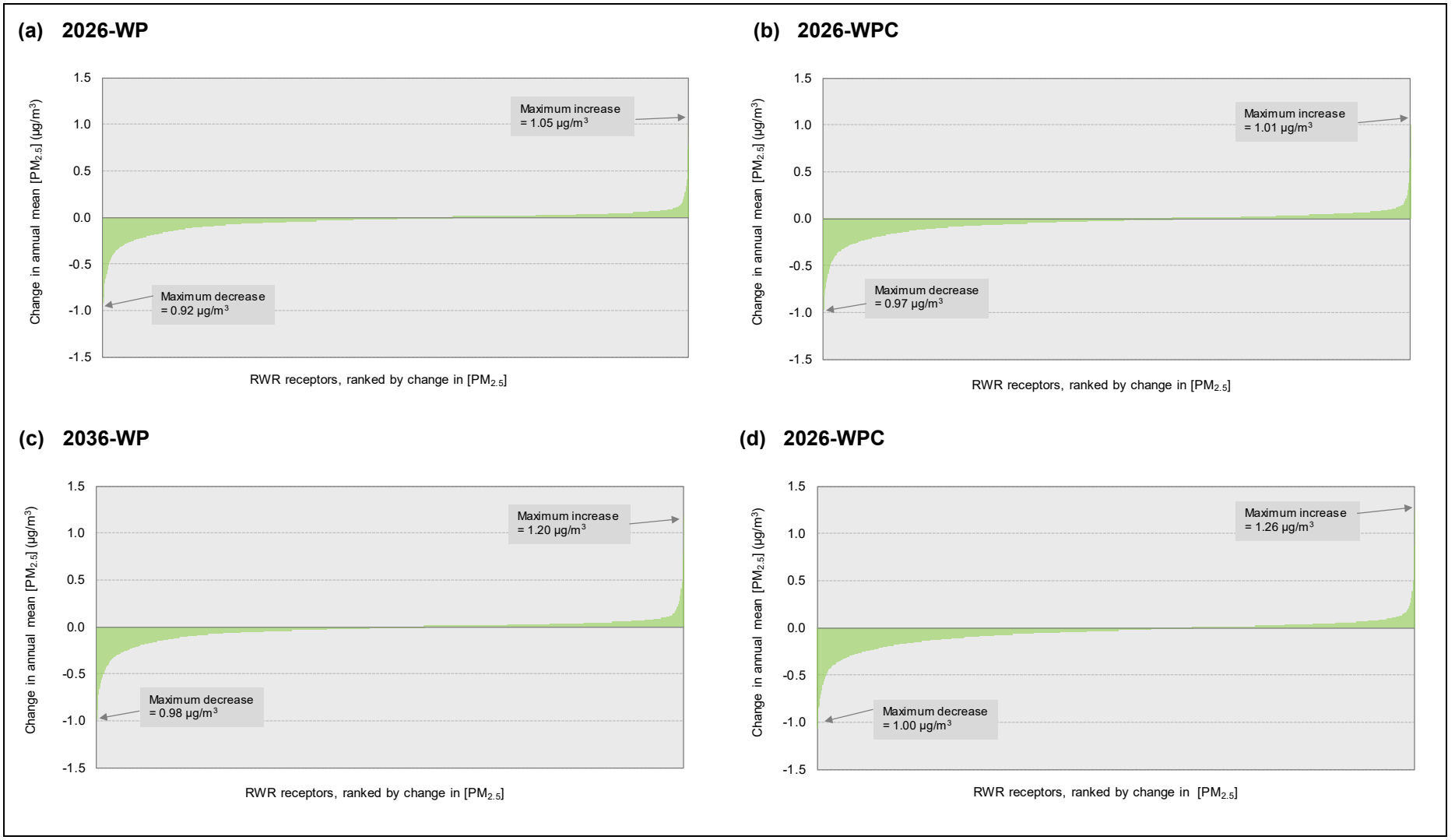


Figure 6-51 Change in annual mean $PM_{2.5}$ concentration at RWR receptors (with-project and cumulative scenarios, minus Without Project scenarios)

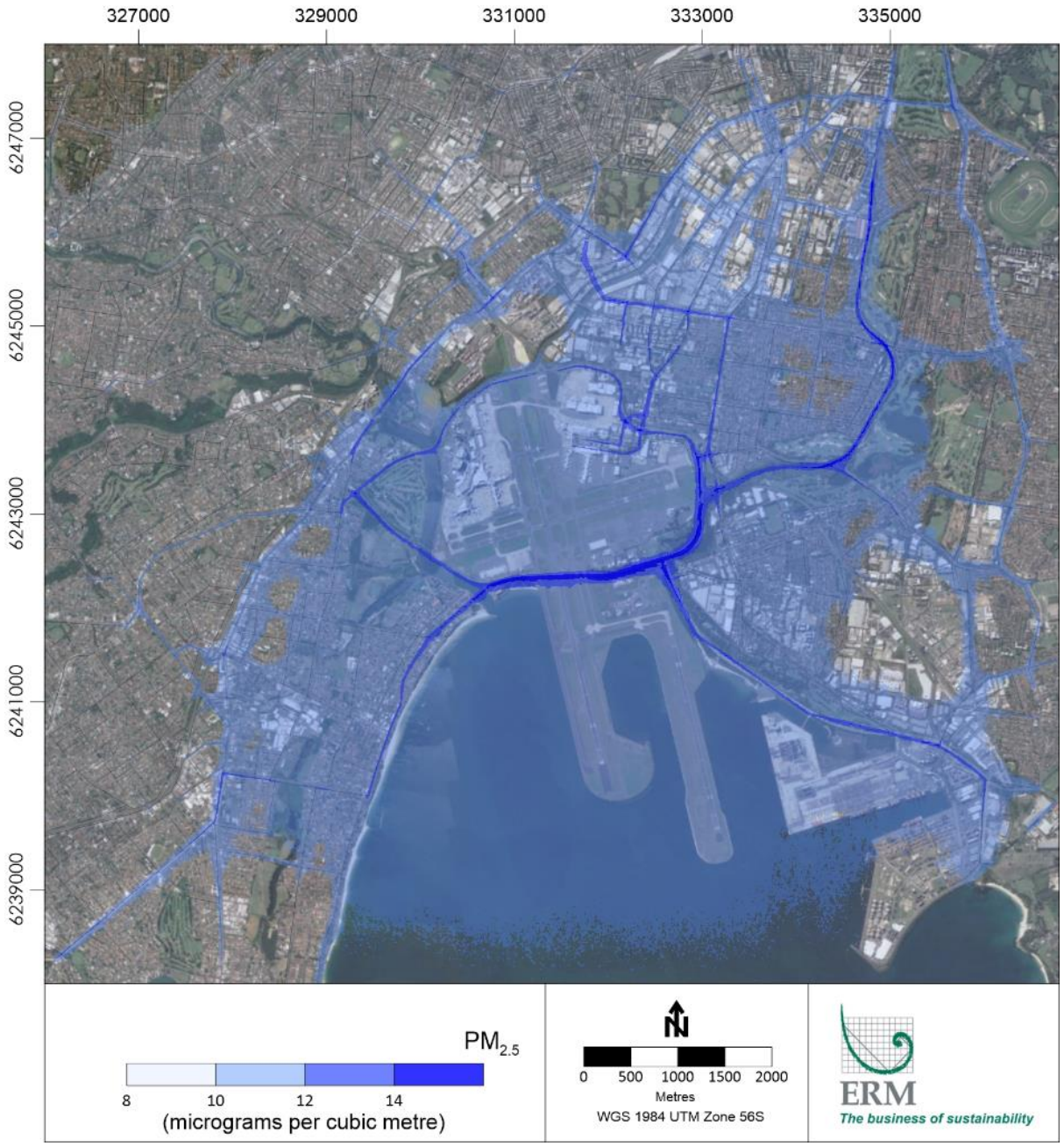


Figure 6-52 Contour plot of annual mean $PM_{2.5}$ concentration in the 2036 Without Project scenario (2036-WOP)

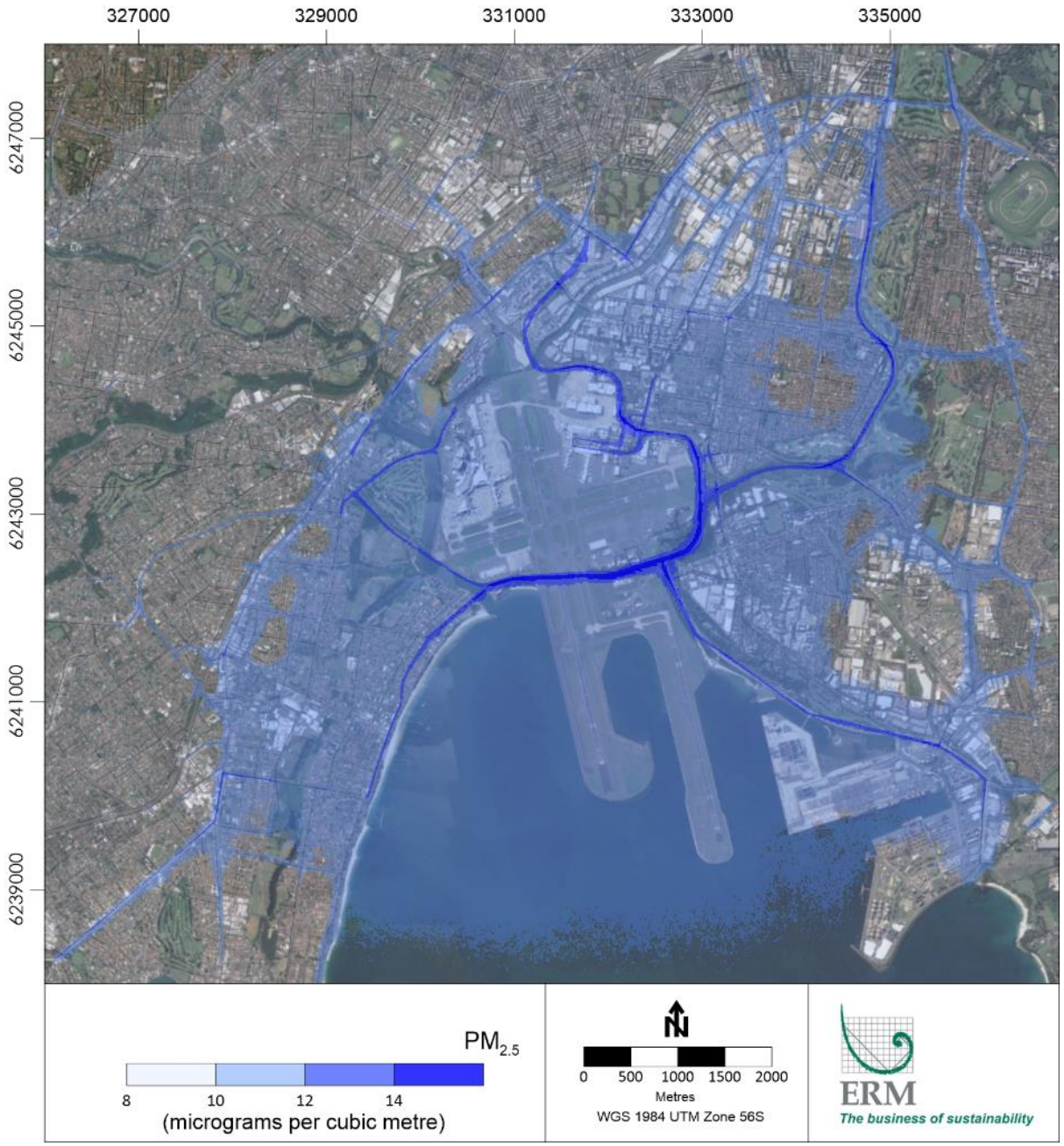


Figure 6-53 Contour plot of annual mean $PM_{2.5}$ concentration in the 2036 With Project scenario (2036-WP)

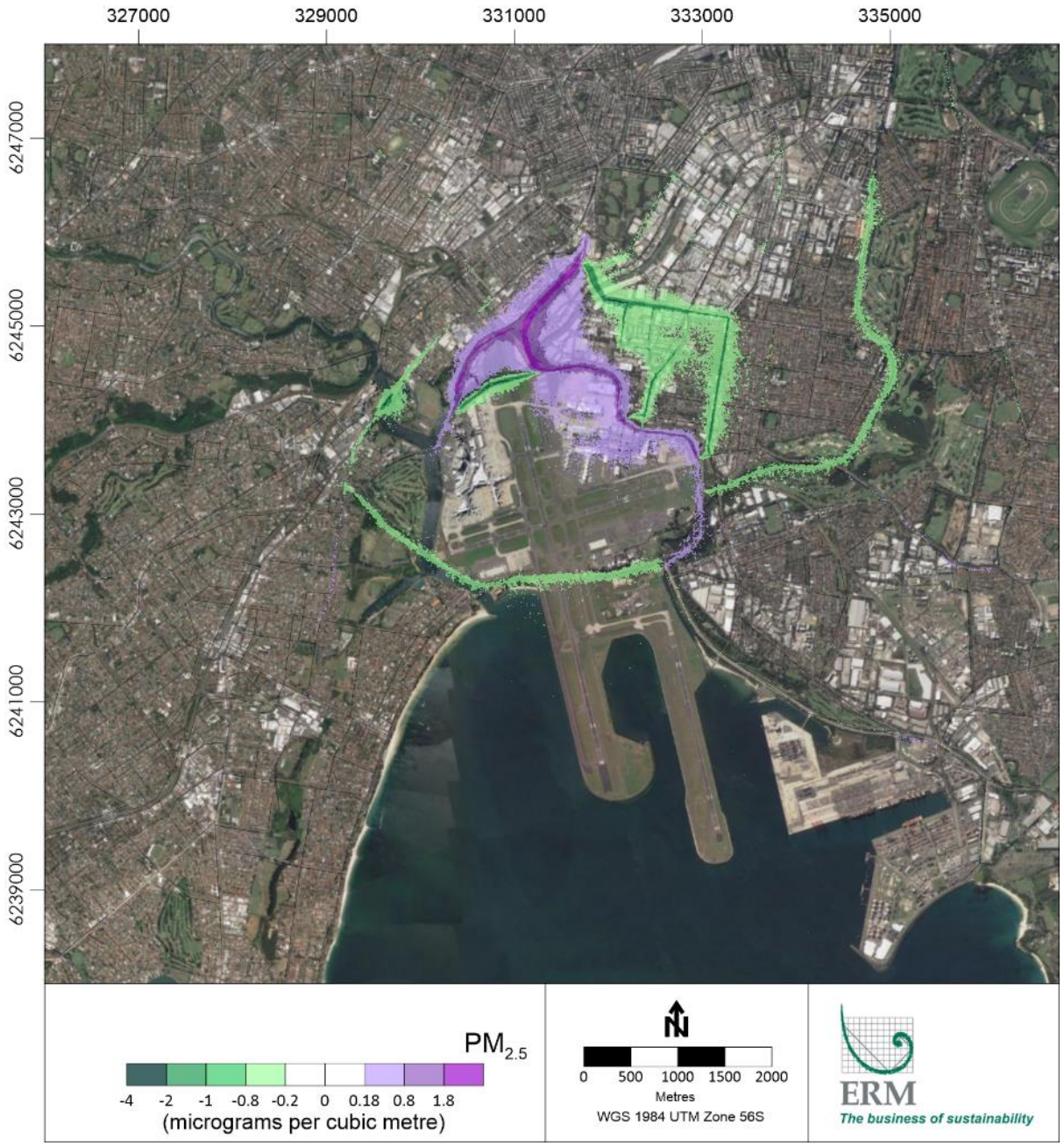


Figure 6-54 Contour plot of change in annual mean $PM_{2.5}$ concentration in the 2036 With Project scenario (2036-WP minus 2036-WOP)

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

Results for community receptors

The maximum 24-hour $PM_{2.5}$ concentrations at the community receptors with the project and in the cumulative scenarios are presented in **Figure 6-55**. At all receptors the maximum concentration was well above the NSW impact assessment criterion of 25 µg/m^3. Internationally, there are no standards lower than 25 µg/m^3 for 24-hour $PM_{2.5}$. However, the AAQ NEPM includes a long-term goal of 20 µg/m^3, and the results suggest that this would be difficult to achieve in the study area at present.

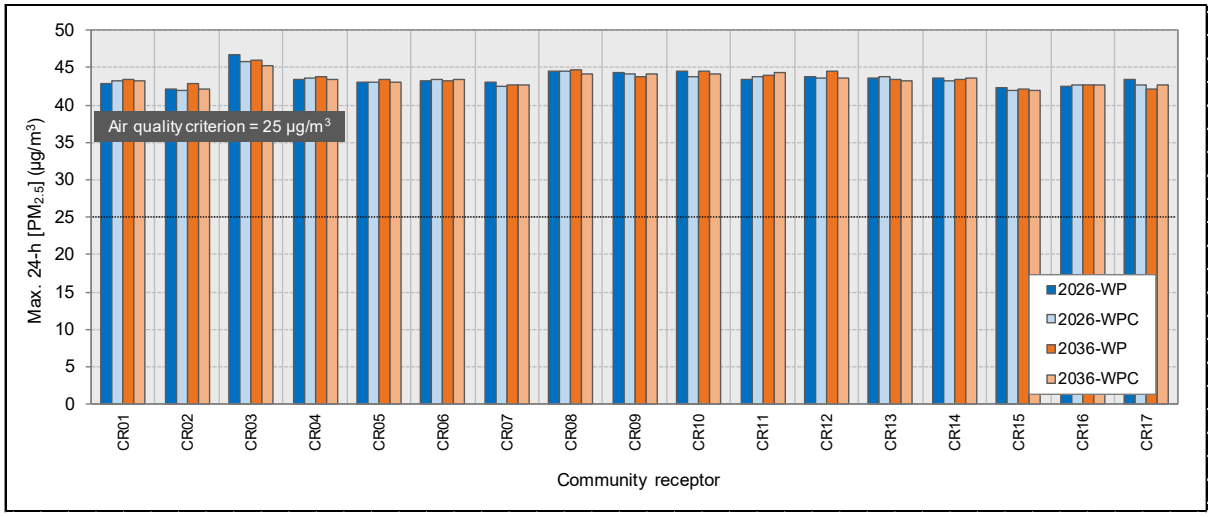


Figure 6-55 Maximum 24-hour $PM_{2.5}$ concentration at community receptors (with-project and cumulative scenarios)

Figure 6-56 presents the changes in maximum 24-hour $PM_{2.5}$ with the project and in the cumulative scenarios at the community receptors. Any increases in concentration were less than 1.5 µg/m^3. The largest increase (1.4 µg/m^3 at receptor CR03 (Botany Public School) in the 2026-WP scenario) equated to 6 per cent of the air quality criterion.

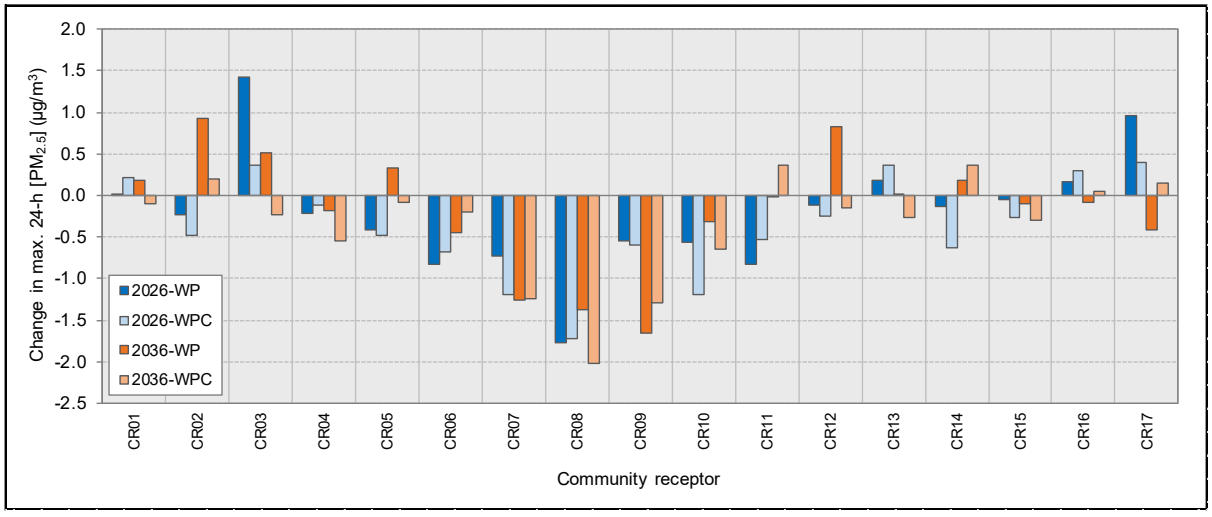


Figure 6-56 Change in maximum 24-hour $PM_{2.5}$ concentration at community receptors (with-project and cumulative scenarios, minus Without Project scenarios)

The road contributions to the maximum 24-hour $PM_{2.5}$ concentration at the community receptors were relatively small, as shown in **Figure 6-57**. The road traffic contribution was between 1.0 µg/m^3 and 5.9 µg/m^3.

At all community receptors, the maximum total 24-hour concentration occurred on the same date, and coincided with the highest 24-hour background concentrations in the synthetic $PM_{2.5}$ profile (40.8 µg/m^3).

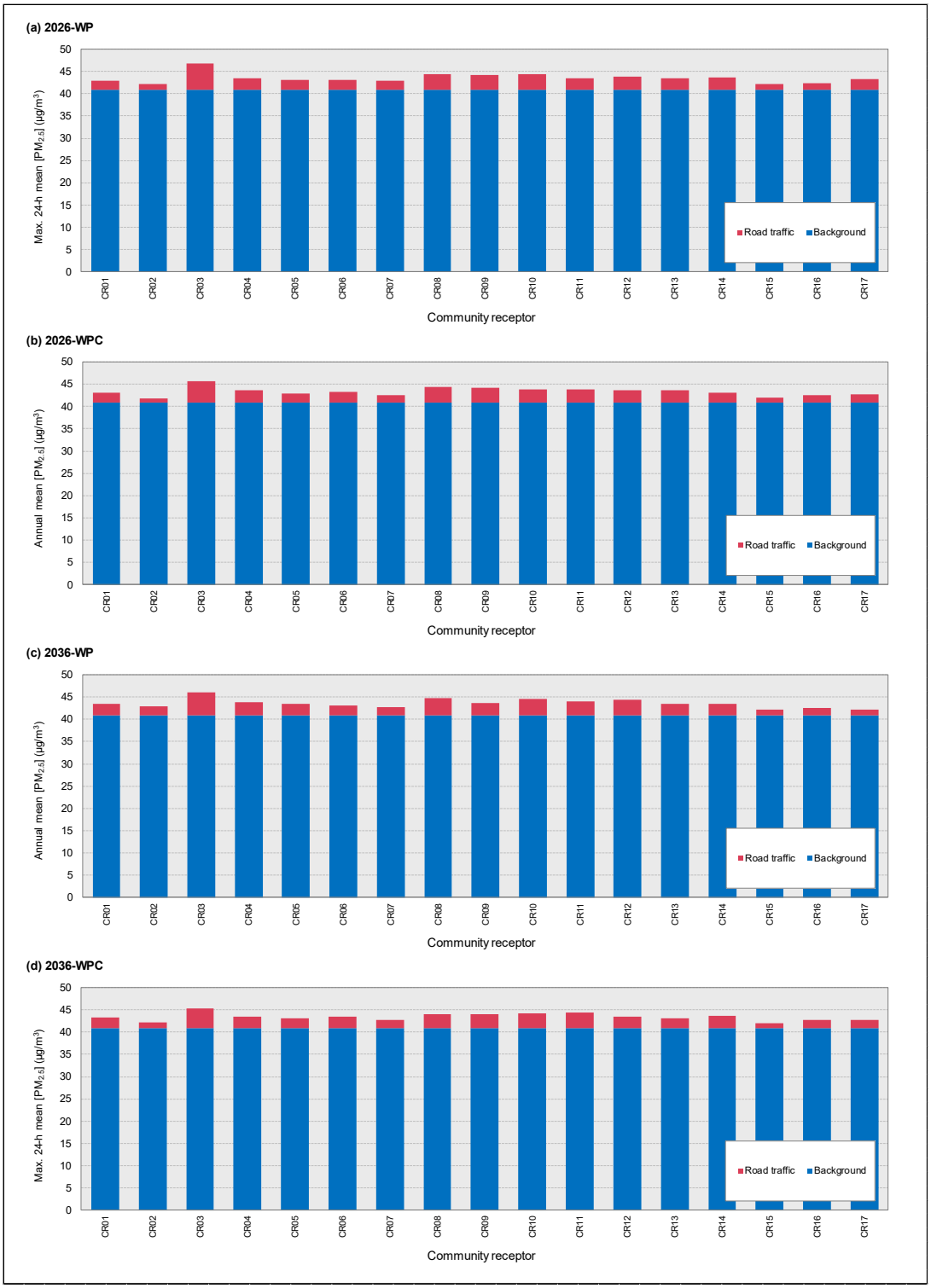


Figure 6-57 Source contributions to maximum 24-hour $PM_{2.5}$ concentration at community receptors (WP and WPC scenarios)

Results for RWR receptors

The ranked maximum 24-hour $PM_{2.5}$ concentrations at the RWR receptors in the with-project and cumulative scenarios are shown in **Figure 6-58**. The maximum contribution of road traffic at any receptor and in any scenario was 11.1 µg/m^3. Given the high background concentration (40.9 µg/m^3), the total concentration at all receptors and in all scenarios was well above the NSW impact assessment criterion of 25 µg/m^3. It is therefore not possible to comment on the effects of the project on exceedances of the criterion.

The changes in the maximum 24-hour $PM_{2.5}$ concentration at the RWR receptors in the with-project and cumulative scenarios are ranked in **Figure 6-59**. There was an increase in concentration at between 33 per cent and 47 per cent of the receptors, depending on the scenario. For most of the receptors the change in concentration was small; where there was an increase in concentration, this was greater than 0.5 µg/m^3 at only around 2 to 4 per cent of receptors.

The largest predicted increase in concentration at any receptor as a result of the project (including the cumulative scenarios) was 3.8 µg/m^3, and the largest increase at a residential location was 2.0 µg/m^3.

Contour plots – all sources

The contour plots for maximum 24-hour $PM_{2.5}$ in the 2036-WOP and 2036-WP scenarios are given in **Figure 6-60** and **Figure 6-61** respectively. The changes with the project and in the cumulative scenarios are shown in **Figure 6-62**.

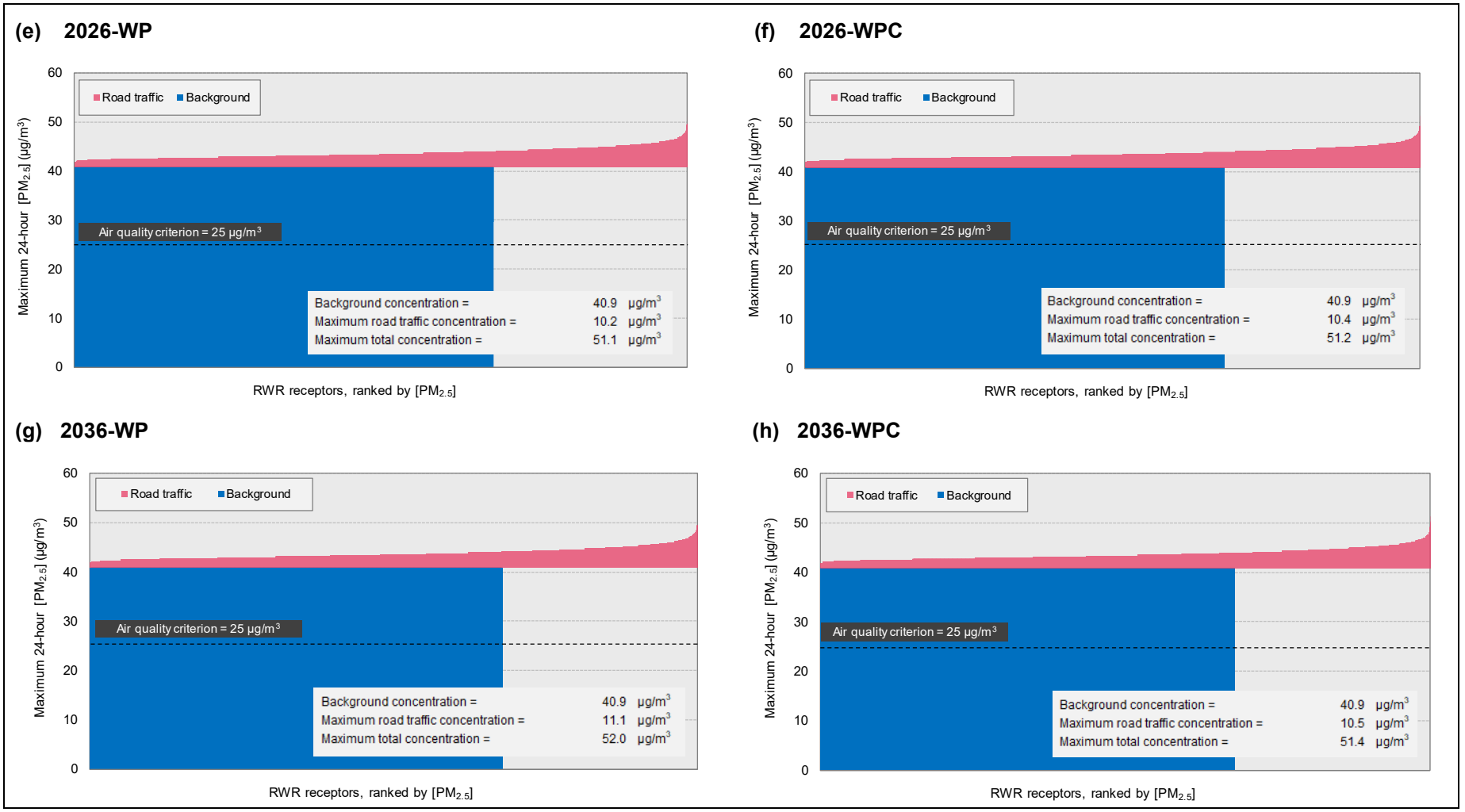


Figure 6-58 Source contributions to maximum 24-hour $PM_{2.5}$ concentration at RWR receptors (with-project and cumulative scenarios)

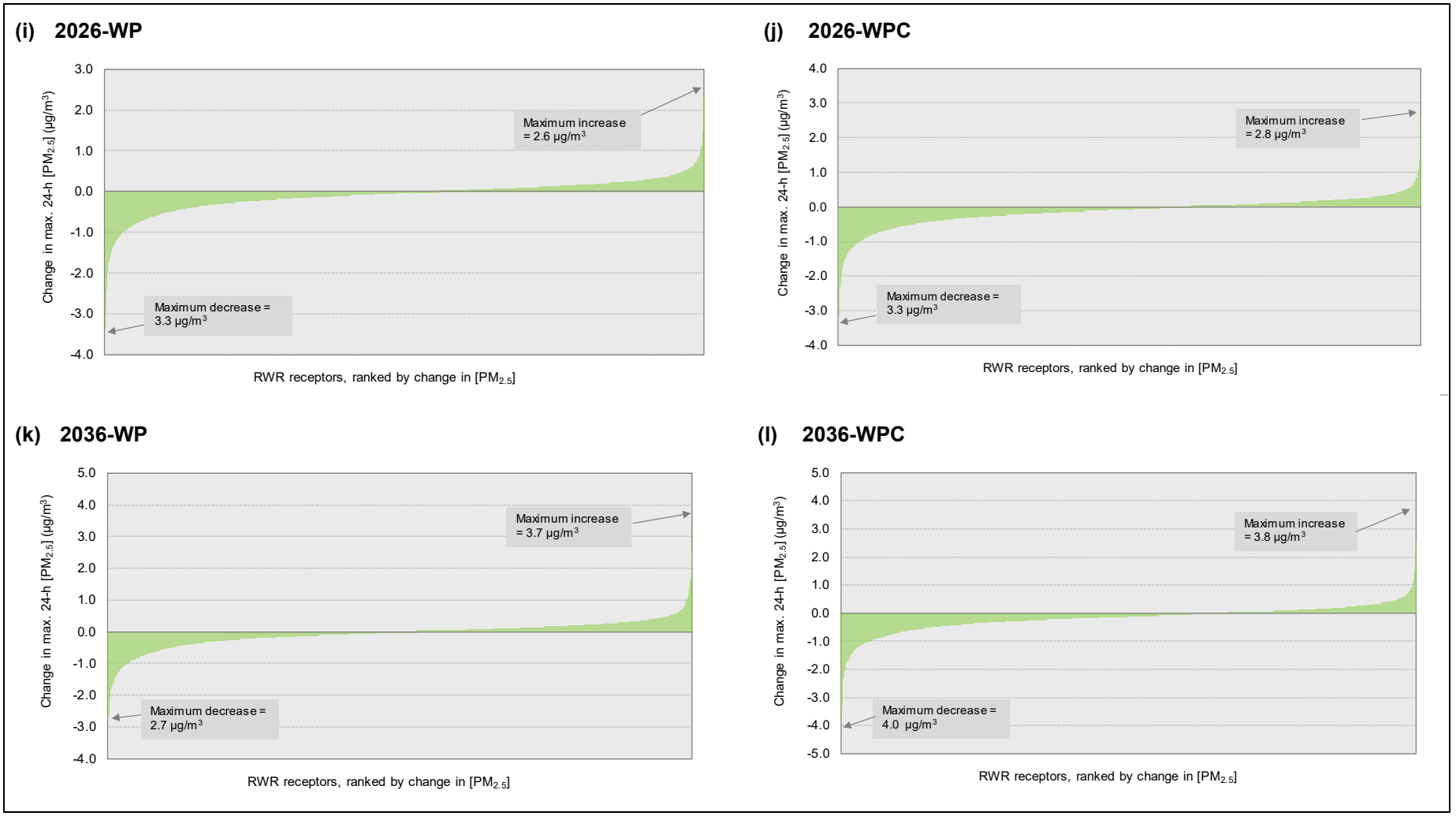


Figure 6-59 Change in maximum 24-hour $PM_{2.5}$ concentration at RWR receptors (with-project and cumulative scenarios, minus Without Project scenarios)

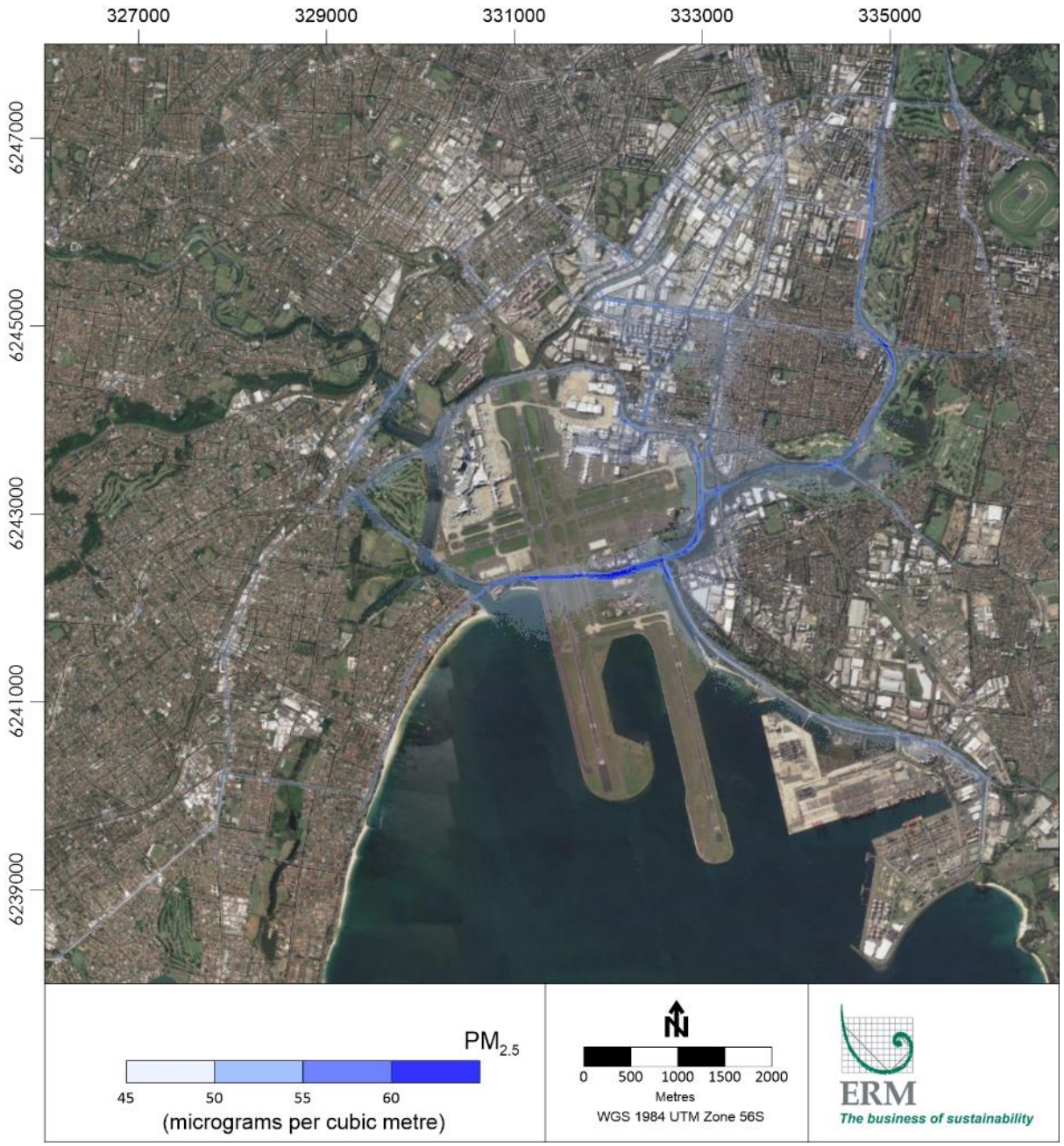


Figure 6-60 Contour plot of maximum 24-hour average $PM_{2.5}$ concentration in the 2036 Without Project scenario (2036-WOP)

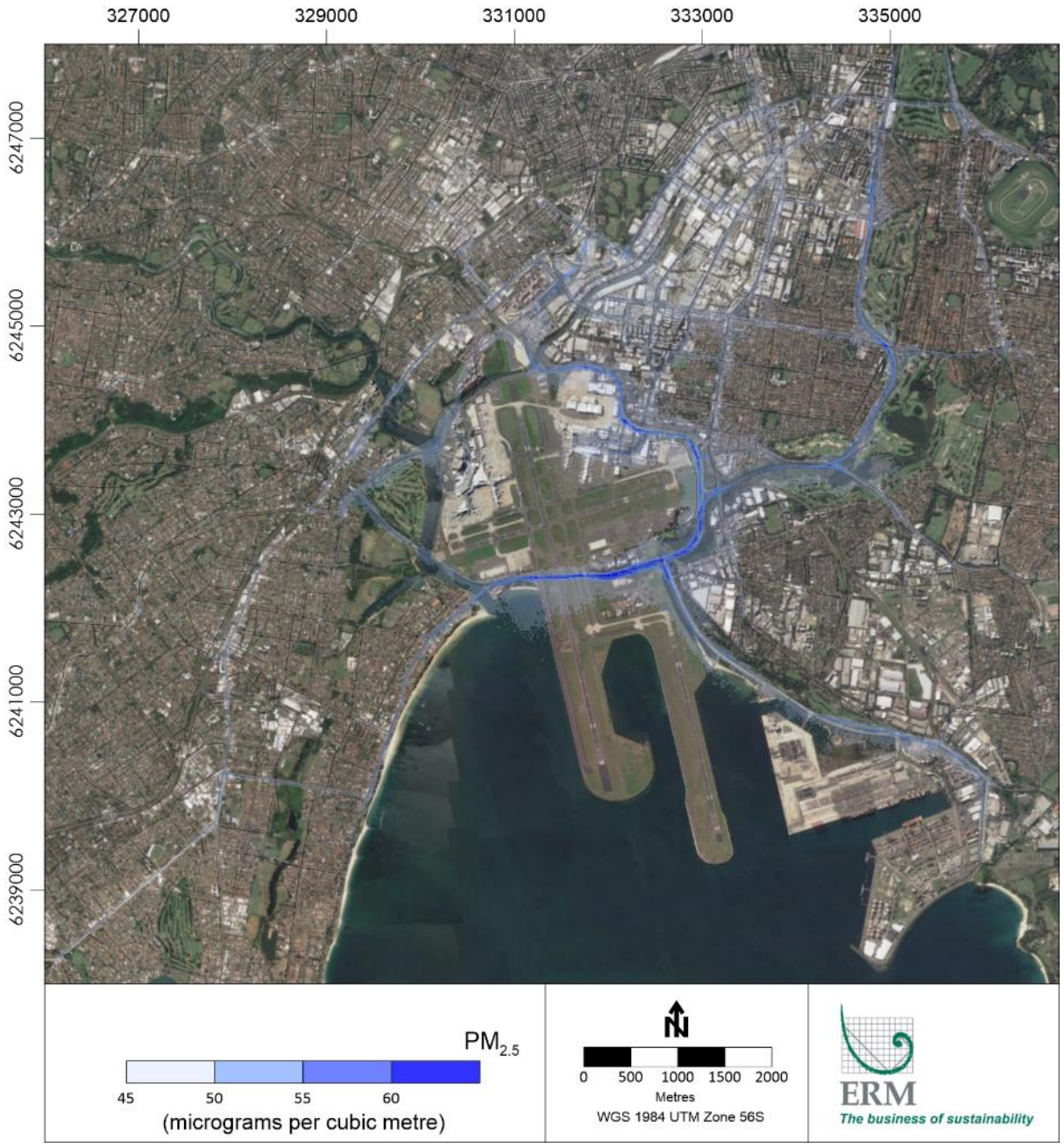


Figure 6-61 Contour plot of maximum 24-hour average $PM_{2.5}$ concentration in the 2036 With Project scenario (2036-WP)

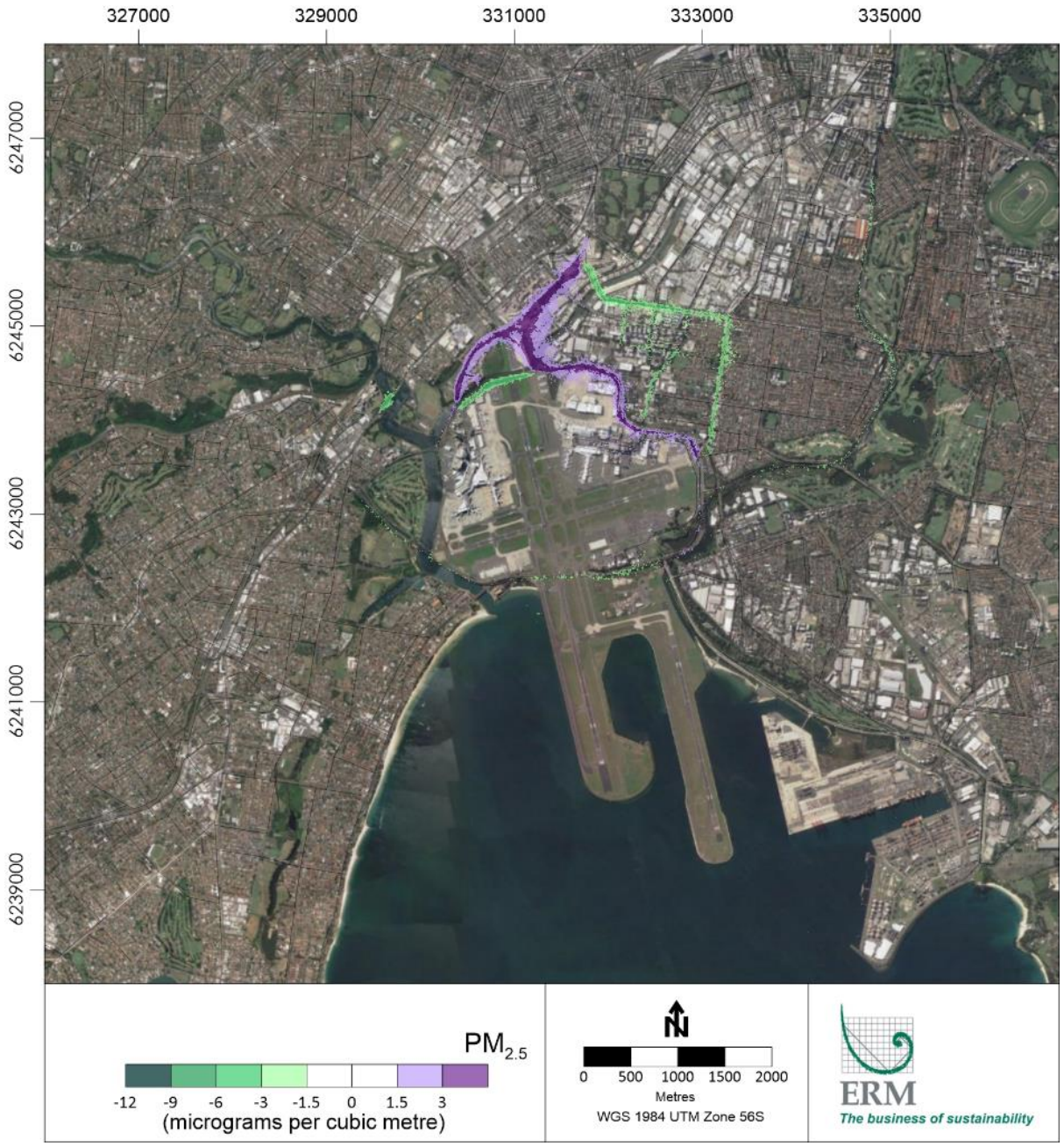


Figure 6-62 Contour plot of change in maximum 24-hour $PM_{2.5}$ concentration in the 2036 With Project scenario (2036-WP minus 2036-WOP)

Air toxics

Five air toxics (benzene, PAHs (as B(a)P), 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 predicted maximum 1-hour benzene, B(a)P, formaldehyde, 1,3-butadiene and ethylbenzene concentration are presented in **Figure 6-63**, **Figure 6-64**, **Figure 6-65**, **Figure 6-66** and **Figure 6-67** respectively. All predicted levels are well below their relative maximum 1 hour criterion.

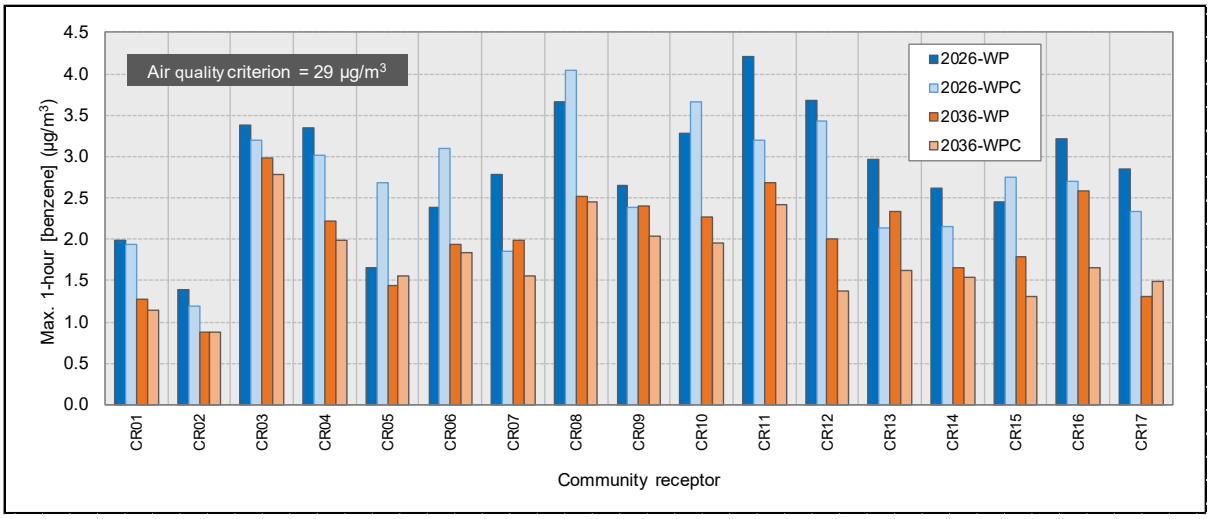


Figure 6-63 Maximum 1-hour benzene concentration at community receptors (criterion 29 µg/m³)

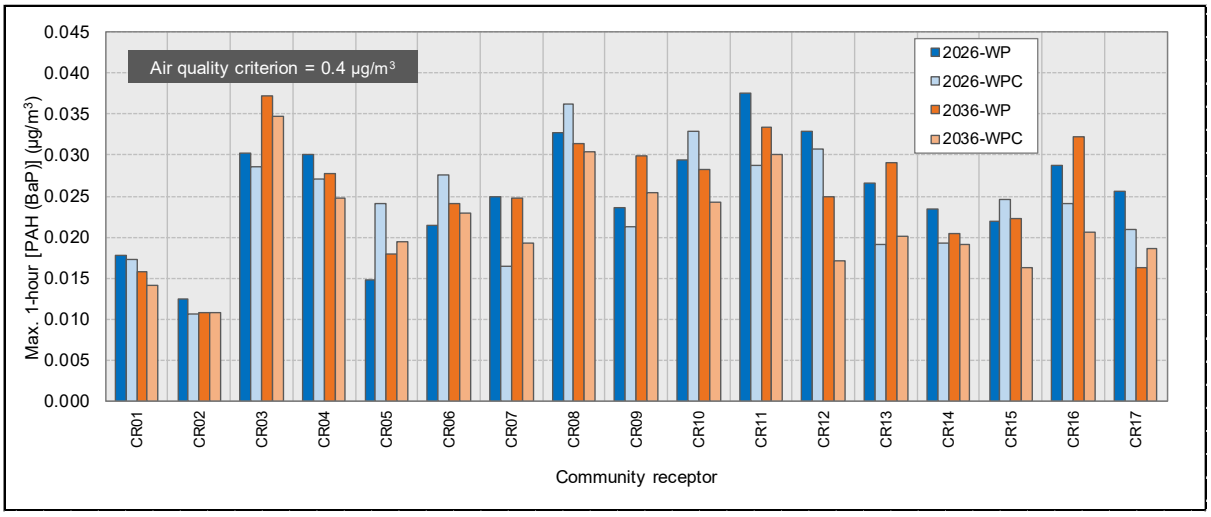


Figure 6-64 Maximum 1-hour B(a)P concentration at community receptors (criterion 0.4 µg/m³)

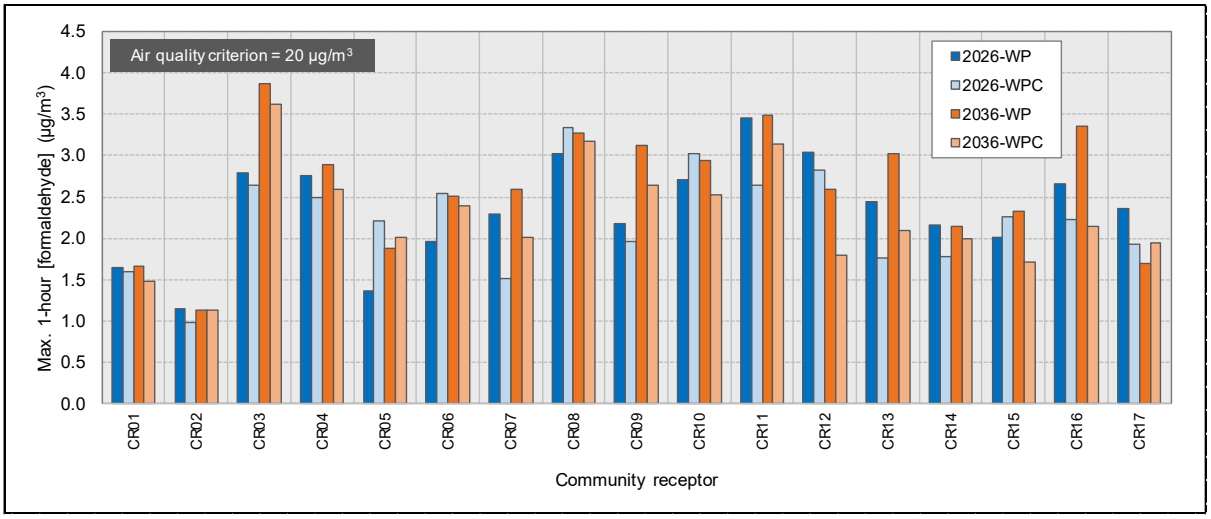


Figure 6-65 Maximum 1-hour formaldehyde concentration at community receptors (criterion 20 µg/m³)

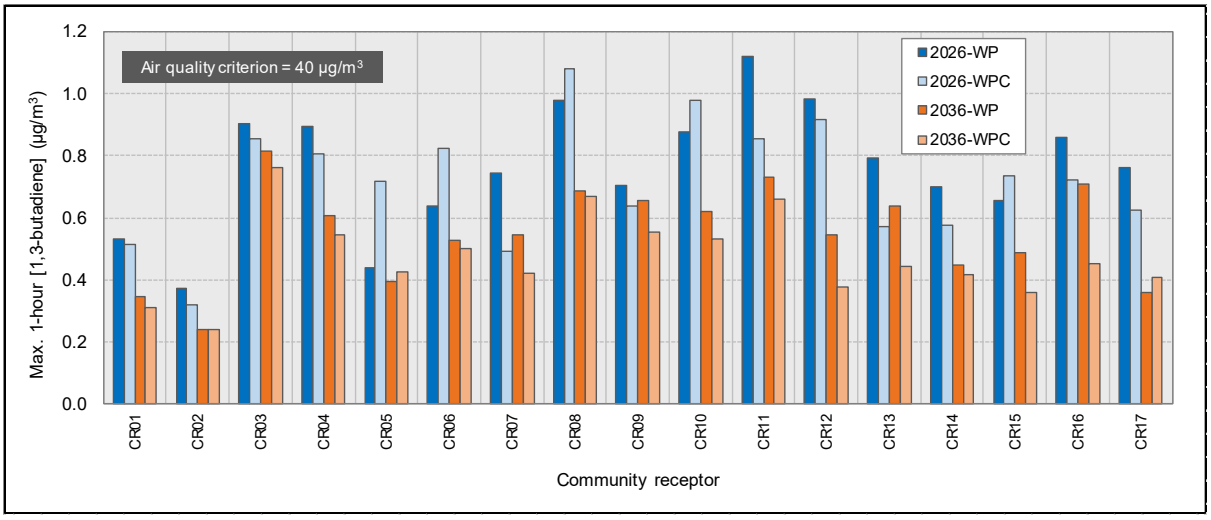


Figure 6-66 Maximum 1-hour 1,3 butadiene concentration at community receptors (criterion 40 µg/m³)

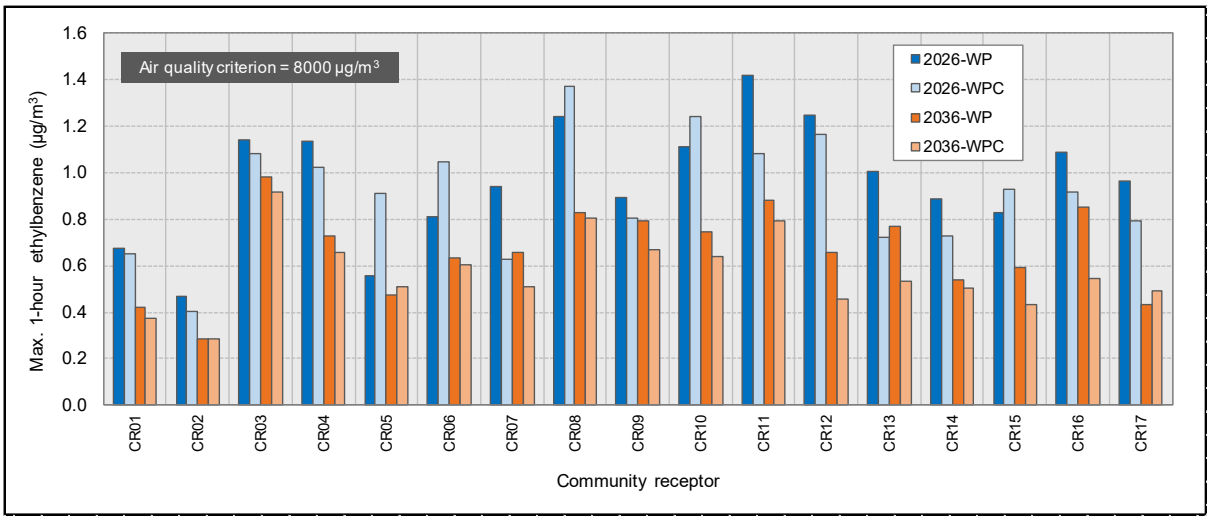


Figure 6-67 Maximum 1-hour ethylbenzene concentration at community receptors (criterion 8000 µg/m³)

The changes in the maximum 1-hour benzene concentration at the community receptors as a result of the project are shown in **Figure 6-68**. It can be seen from the figure that all changes where predicted to be extremely minor. The changes in the maximum 1-hour B(a)P, formaldehyde, 1,3-butadiene and ethylbenzene concentration are presented in **Figure 6-69**, **Figure 6-70**, **Figure 6-71** and **Figure 6-72** respectively. The largest increases for the community receptors were also representative of the largest increases for the RWR receptors.

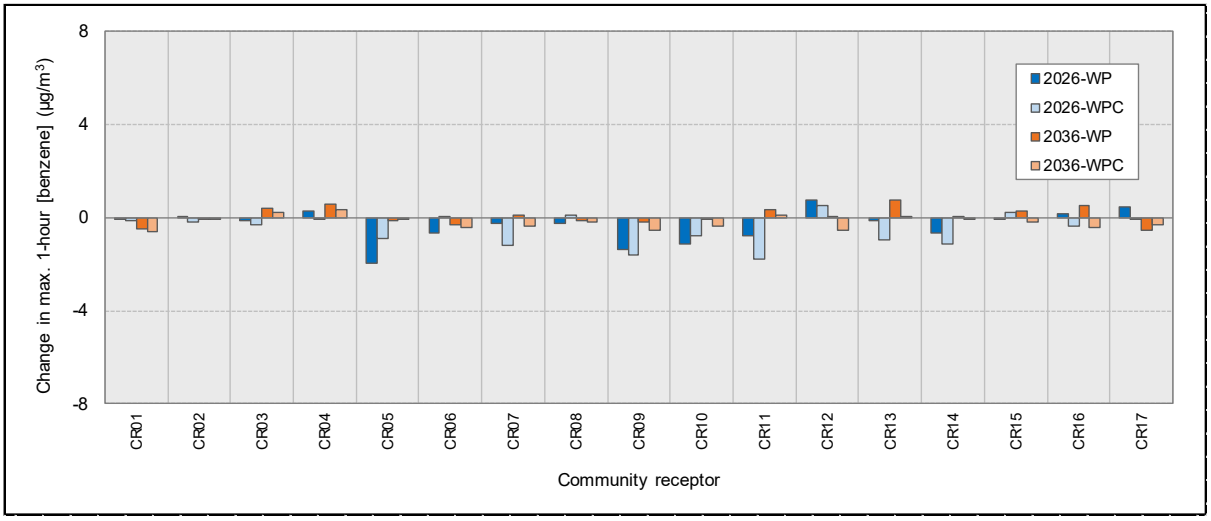


Figure 6-68 Change in maximum 1-hour benzene concentration at community receptors (WP and WPC scenarios)

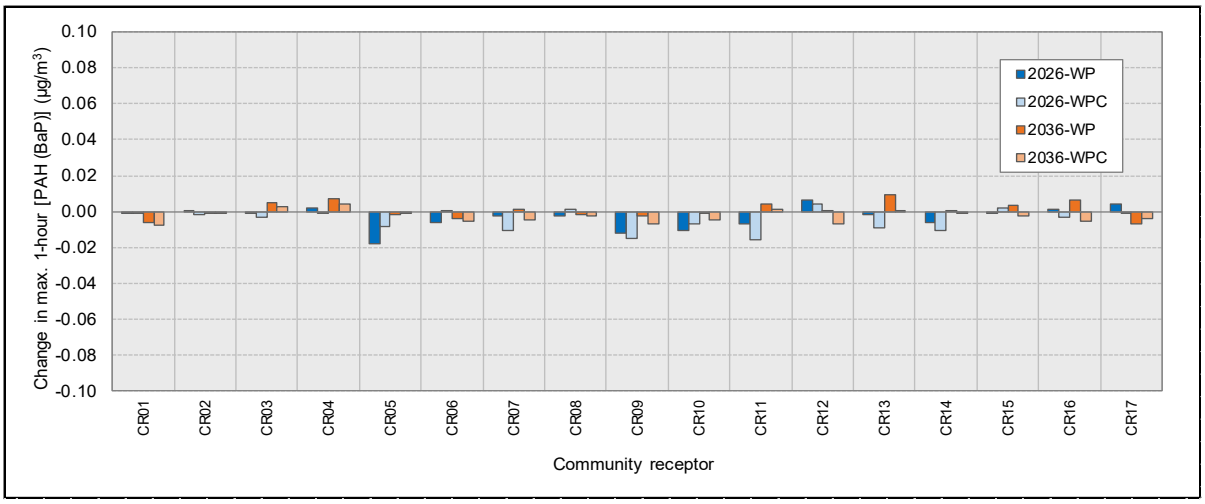


Figure 6-69 Change in maximum 1-hour B(a)P concentration at community receptors (WP and WPC scenarios)

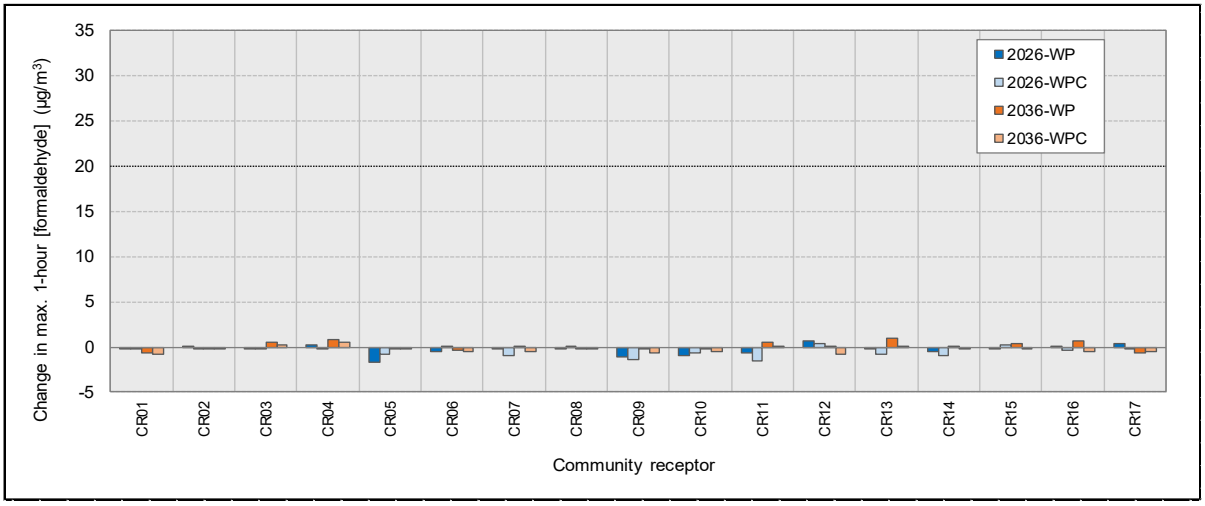


Figure 6-70 Change in maximum 1-hour formaldehyde concentration at community receptors (WP and WPC scenarios)

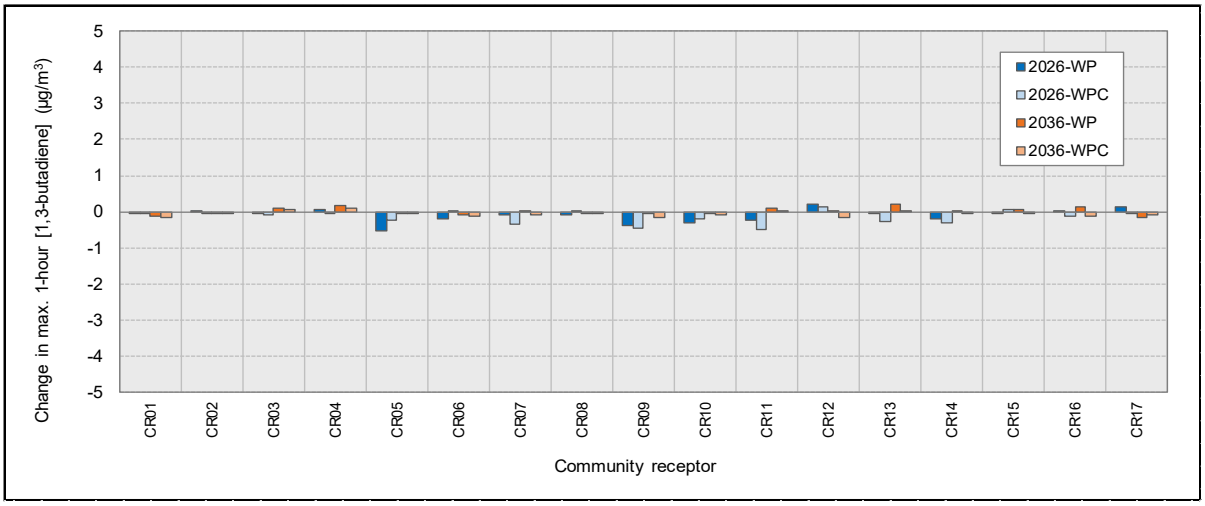


Figure 6-71 Change in maximum 1-hour 1,3-butadiene concentration at community receptors (WP and WPC scenarios)

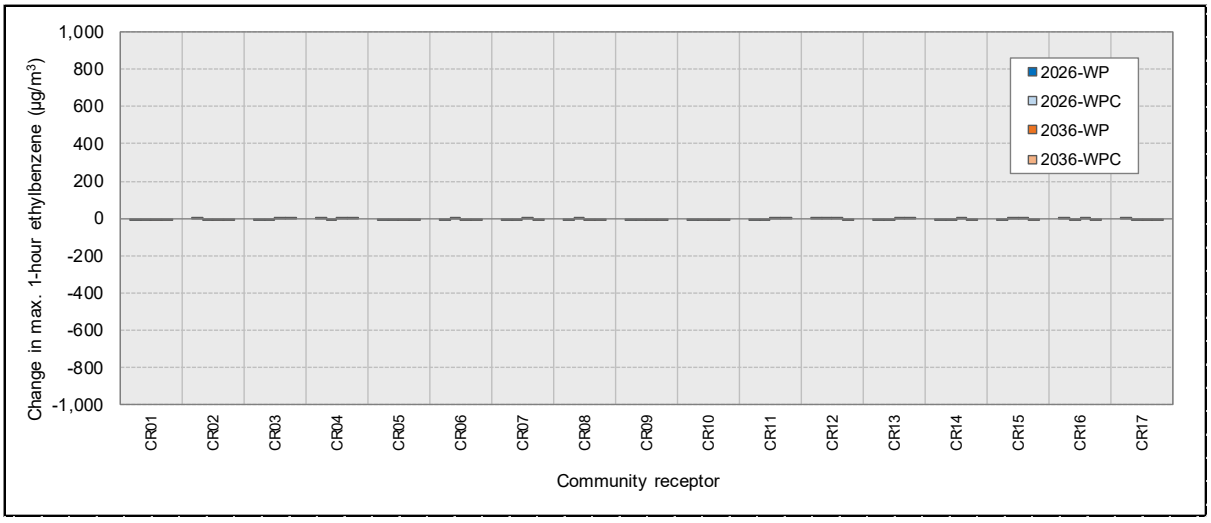


Figure 6-72 Change in maximum 1-hour ethylbenzene concentration at community receptors (WP and WPC scenarios)

Spatial redistribution of air quality impacts

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

The spatial changes in concentration broadly reflected the effects of the project on traffic in SMPM, also taking into account factors such as road gradient and meteorology. **Table 6-10** summarises the average weekday two-way traffic on some affected roads in all scenarios, and **Table 6-11** gives the changes between scenarios.

Unsurprisingly, there were predicted to be marked increases in concentration on the new roads associated with the Sydney Gateway road project (With Project scenarios): the Terminal 1 connection, the St Peters interchange connection, and the Qantas Drive upgrade and extension. For example, in the case of the Qantas Drive upgrade and extension, the new road was forecast to have a weekday traffic volume of around 75,000-80,000 vehicles per day. There were also increases in concentration along Qantas Drive itself, Joyce Drive, General Holmes Drive, and Airport Drive near Terminal 1.

With the Sydney Gateway road project (With Project scenarios) project there were noticeable decreases in $PM_{2.5}$ concentration along several roads, including the M5 East, Southern Cross Drive, Botany Road and Canal Road. **Table 6-11** shows that there were reductions in traffic of between 8 per cent and 28 per cent on these roads.

For the cumulative scenarios (2026-WPC and 2036-WPC) there were some additional changes associated with the introduction of the F6 Extension project rather than the Sydney Gateway road project, including further reductions in concentration along Southern Cross Drive and the M5 East, a reduction in concentrations along The Grand Parade, and an increase in concentration along President Avenue.

Table 6-10 Average weekday two-way traffic volume on selected roads

Road	Average weekday two-way traffic volume by scenario (vehicles per day)					
	2026-WOP	2026-WP	2026-WPC	2036-WOP	2036-WP	2036-WPC
Increases in traffic						
Terminal 1 connection	N/A	34,577	30,018	N/A	34,912	34,680
St Peters interchange connection	N/A	84,771	79,234	N/A	87,832	90,060
Qantas Drive upgrade and extension	N/A	74,102	73,940	N/A	78,636	82,147
Joyce Drive	57,518	62,915	58,640	49,298	65,423	77,268
General Holmes Drive	150,037	146,074	137,953	160,805	155,329	140,364
Decreases in traffic						
M5 East	48,403	44,659	46,387	53,330	47,787	47,009
Southern Cross Drive	134,050	120,852	118,571	136,987	124,232	111,684
Botany Road	36,608	26,257	23,790	36,292	26,825	23,173
Canal Road	27,725	30,494	30,368	30,179	32,910	32,508

Table 6-11 Changes in average weekday two-way traffic volume on selected roads

Road	Change in average weekday two-way traffic volume by scenario (vehicles per day / %)							
	2026-WP minus 2026-WOP		2026-WPC minus 2026-WOP		2036-WP minus 2036-WOP		2036-WPC minus 2036-WOP	
Increases in traffic								
Terminal 1 connection	34,577	N/A	30,018	N/A	34,912	N/A	34,680	N/A
St Peters interchange	84,771	N/A	79,234	N/A	87,832	N/A	90,060	N/A
Qantas Drive upgrade and	74,102	N/A	73,940	N/A	78,636	N/A	82,147	N/A
Joyce Drive	5,397	9	1,122	2	16,125	33	27,970	57
General Holmes Drive	-3,963	-3	-	-8	-5,476	-3	-20,441	-13
Decreases in traffic								
M5 East	-3,744	-8	-2,016	-4	-5,543	-10	-6,321	-12
Southern Cross Drive	-	-10	-	-12	-	-9	-25,303	-18
Botany Road	-	-28	-	-35	-9,467	-26	-13,119	-36
Canal Road	2,769	10	2,643	10	2,731	9	2,329	8

6.2.2.3 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 **Table 6-12**. 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 6-12 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 air quality monitoring stations in the study area.	The monitoring sites were considered to reflect background air quality in the study area accurately.
		Pollutant concentrations at background monitoring stations in 2016 were assumed to be representative of background concentrations in 2026 and 2036.	The implications of this cannot be quantified. It could be argued that concentrations in the future would decrease as emission controls improve (across all sectors of activity). However, any improvements could also be offset by increases in population and activity.
		It was assumed that there would be no contribution from the road network to the concentrations at the background monitoring sites. The GRAL model actually gave non-zero (but generally small) values at the locations of the background monitoring sites.	Total predicted concentrations (GRAL + background) would generally be overestimated across the GRAL domain. The maximum annual mean GRAL-only predictions at background sites were: - CO 0.04 mg/m^3 - NO_X 16.3 µg/m^3 - PM_{10} 0.9 µg/m^3. This added an element of conservatism to the total concentration predictions.
1.2	Community receptors *CO, maximum rolling 8-hour*	Hourly monitoring data from several 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 in 2016 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, maximum 1-hour*	Hourly monitoring data several 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 in 2016 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}, maximum 24-hour*	24-hour monitoring data from several 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 $PM_{2.5}$ concentrations in 2016 were mapped across the GRAL domain.	The measurement of $PM_{2.5}$ is rather uncertain, and therefore it cannot be stated with confidence that this approach is either accurate or conservative.
1.8	Community receptors *$PM_{2.5}$, maximum 24-hour*	24-hour monitoring data from several 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 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. For 1-hour NO_X, the 99th percentile value was used.	This approach would tend to be conservative for the great majority of receptors.
2	Traffic forecasts		
2.1	General	Traffic volume, composition and speed on each road link was taken from SMPM.	The accurate characterisation of traffic activity (such as number of vehicles, trip distances and modes of operation) and the fleet composition is vital to the estimation of emissions. Although models and emission factors are continually improving, activity data remains one of the main sources of uncertainty in the calculation of emissions. 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.

Topic and sub-topic		Method and assumptions	Implications for conservatism
2.2	Traffic volumes at weekends	The traffic data for a typical weekday were applied to every day of the year in the dispersion model.	This assumption 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, but the analysis presented in **Annexure C** indicates that for the conditions in the Lane Cove Tunnel (LCT) the NSW EPA emission factors overestimate real-world emissions (see below).
3.2	CO emission factors	NSW EPA model.	LCT analysis indicated an overestimation of real-world emissions in 2013 by a factor of 2.0 to 2.8.
3.3	NO_X emission factors	NSW EPA model.	LCT analysis indicated an overestimation of real-world emissions in 2013 by a factor of 2.2 to 3.3.
3.4	PM_{10} emission factors	NSW EPA model, includes both exhaust and non-exhaust sources.	LCT analysis indicated an overestimation of real-world emissions in 2013 by a factor of 1.8 to 3.2.
3.5	$PM_{2.5}$ emission factors	NSW EPA model, includes both exhaust and non-exhaust sources.	LCT analysis indicated an overestimation of real-world emissions in 2013 by a factor of 1.7 to 2.9.
3.6	THC emission factors	NSW EPA model. Exhaust emissions only (no evaporation).	Not included in LCT analysis so unable to comment on the implications for conservatism
4	Dispersion modelling (general)		
4.1	Terrain	Terrain data were obtained from the Geoscience Australia Elevation Information System (ELVIS). A 25-metre resolution was used in the GRAMM modelling, and a 5-metre resolution was used in the GRAL modelling.	The terrain data were assumed to reflect the study area accurately. In addition, the terrain within the GRAL domain was relatively flat, and should have had little influence on overall model accuracy.

Topic and sub-topic		Method and assumptions	Implications for conservatism
4.2	Meteorology	The measurements from the OEH Randwick and Earlwood stations in 2016 were chosen as the reference meteorological data for modelling, with varying influence. OEH Randwick was considered the most representative of the GRAL domain and specifically the project corridor.	The stations were considered to be representative of the meteorology in the GRAL domain.
6	Post-processing (NO_2) – community receptors		
6.1	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.
6.2	NO_X-to-NO_2 conversion, maximum 1-hour	A 'detailed' contemporaneous approach was used. This involved the use of a conservative upper bound empirical function which gave the maximum likely 1-hour NO_2 concentration for a given 1-hour 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 NO_2 concentrations conservatively. The dispersion modelling evaluation showed, however, that this method was less conservative than, for example, the ozone limiting method.
7	Post-processing (NO_2) – RWR receptors		
7.1	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.
7.2	NO_X-to-NO_2 conversion, maximum 1-hour	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 NO_X value predicted by GRAL was added to the 99th percentile NO_X value for the background in the synthetic profile for 2016. 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 that for community receptors, and the same comments apply.

6.2.2.4 Regional air quality

The changes in the total emissions resulting from the project were given in **Table 6-8** and **Table 6-9**. 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:

- Total NO_X emissions on the assessed road network in a given year decreased by between around 12 and 19 tonnes per year. These decreases equated to a very small proportion (less than 0.05 per cent) of anthropogenic NO_X emissions in the Sydney airshed in 2016 (around 53,700 tonnes)
- The change in NO_X due to the project in a given year was much smaller than the projected underlying reduction in emissions between 2016 and 2036 (around 1,150 tonnes per year).

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

The first step in the procedure involved the classification of the region within which the project is to be located as either an ozone 'attainment' or 'non-attainment' area, based on measurements from OEH monitoring stations over the past five years and criteria specified in the procedure. Following this approach, the project was identified as being in an ozone non-attainment area, although there are few long-term monitoring sites in the study area. The second step involved the evaluation of the change in emissions due to the project against thresholds for NO_X and VOCs. For both attainment and non-attainment areas the procedure gives an emission threshold for NO_X and VOCs (separately) of 90 tonnes/year for new sources, above which a detailed modelling assessment for ozone may be required.

The results in **Table 6-8** show that all scenarios were associated with a reduction in both NO_X and THC. This means that the project should result in a small reduction in ozone concentrations. Overall, it is concluded that the regional impacts of the project would be negligible, and undetectable in ambient air quality measurements at background locations.

6.2.2.5 Odour (vehicles)

For each of the RWR receptors, the change in the maximum one hour THC concentration as a result of the project was calculated. The largest change in the maximum 1-hour THC concentration across all receptors was then determined, and this was converted into an equivalent change for three of the odorous pollutants identified in the Approved Methods (toluene, xylenes, and acetaldehyde). These pollutants were taken to be representative of other odorous pollutants from motor vehicles. The changes in the levels of three odorous pollutants as a result of the project, and the corresponding odour assessment criteria from the Approved Methods, are given in **Table 6-13**. It can be seen that the change in the maximum 1-hour concentration of each pollutant was an order of magnitude below the corresponding odour assessment criterion in the Approved Methods.

Table 6-13 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 Without Project scenario (µg/m^3)	Largest increase in maximum 1-hour concentration		
		Toluene (µg/m^3)	Xylenes (µg/m^3)	Acetaldehyde (µg/m^3)
2026-WP	56.1	4.1	3.4	0.9
2026-WPC	50.5	3.7	3.0	0.8
2036-WP	39.1	2.4	1.9	0.8
2036-WPC	35.5	2.1	1.8	0.7
Odour criterion (µg/m^3)		360	190	42

6.3 Operational impacts on Commonwealth land

Operational air quality impacts on Commonwealth land were determined using the same approach as that applied to the Sydney Gateway road project as a whole. The main distinction was that the assessment was restricted to the Commonwealth land boundaries and the receptors within those boundaries.

The 162 RWR receptors that were located on Commonwealth land are shown in **Figure 6-73**, and the numbers of RWR receptors are listed by category in **Table 6-14**. None of the RWR receptors represented particularly sensitive locations from an air quality perspective. None of the community receptors were located on Commonwealth land.

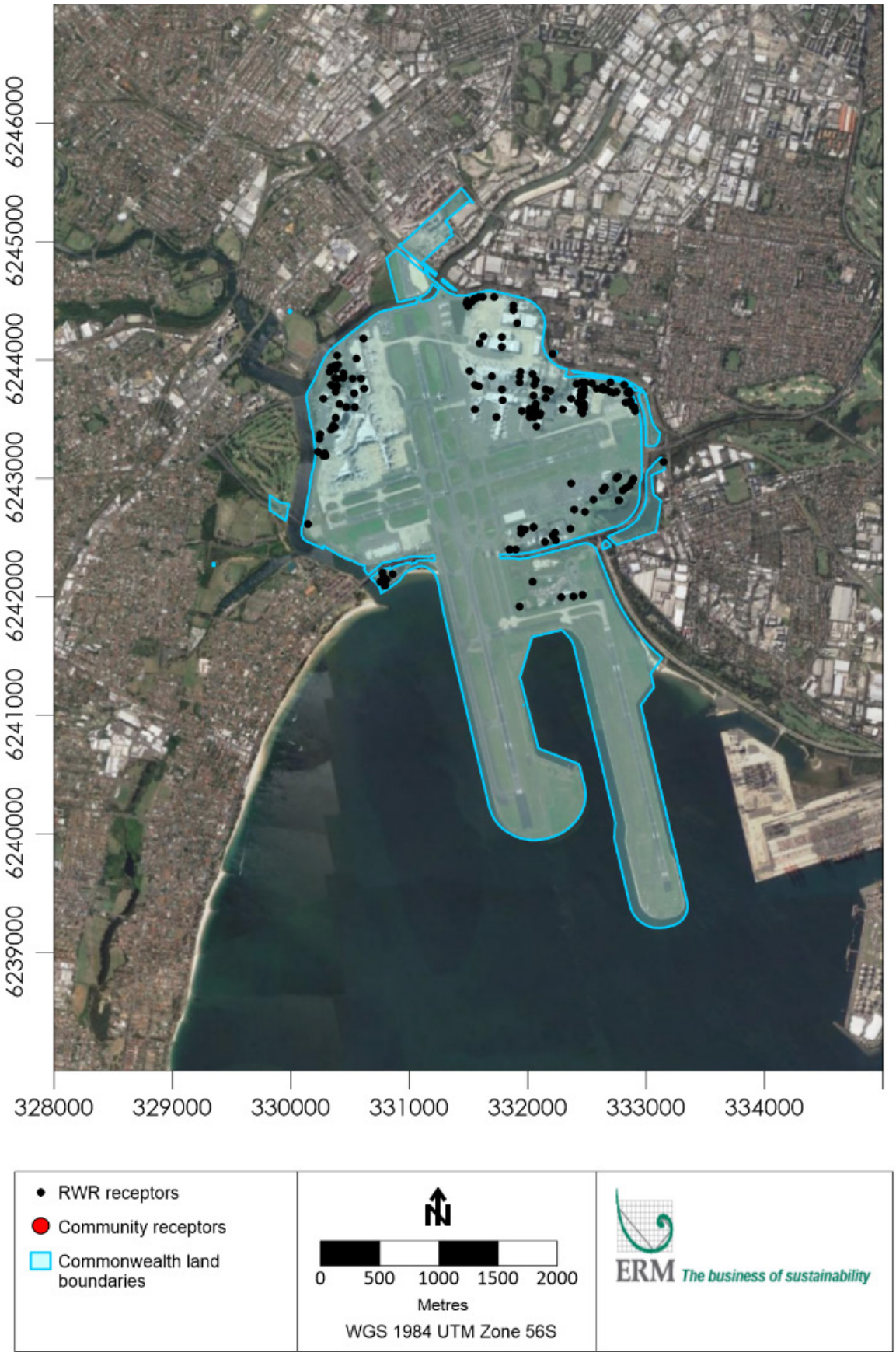


Figure 6-73 RWR receptors within Commonwealth land boundaries

Table 6-14 Summary of RWR receptor types within Commonwealth land boundaries

Receptor type	Number	% of total
Commercial	82	50.6%
Industrial	67	41.4%
Park / sport / recreation	1	0.6%
Other	12	7.4%
Total	**162**	**100.0%**

The maximum concentrations across the 162 RWR receptors are summarised in **Table 6-15**. These can be compared to the NSW Approved Methods for conservatism. The results show exceedances of the $PM_{2.5}$ criteria, both 24-hour annual average, and the 24-hour average PM_{10} criterion. In all these cases, the exceedances are caused by elevated background levels, while the project contribution is relatively small. As in the assessment for the whole domain, for each pollutant and metric there were increases in concentration at some receptors and decreases at others. The largest increases in concentration are given in **Table 6-16**. Unsurprisingly, given the proximity of the project to the Commonwealth land, these changes were amongst the largest determined for the whole domain. Nevertheless, the increases were within acceptable ranges, most notably, no receptors had a predicted increase in $PM_{2.5}$ above the acceptable value of 1.8 $\mu g/m^3$ (as discussed in **Annexure B**).

Table 6-15 Maximum concentrations for RWR receptors within Commonwealth land boundaries

Pollutant	Concentration metric	Concentration by scenario					
		2026-WOP	2026-WP	2026-WPC	2036-WOP	2036-WP	2036-WPC
CO	Max. 1-hour (mg/m^3)	5.3	5.3	5.6	4.5	4.5	4.7
	Max. rolling 8-hour (mg/m^3)	3.7	3.7	3.9	3.1	3.1	3.2
NO_2	Max. 1-hour ($\mu g/m^3$)	232.7	225.6	258.9	214.2	215.8	214.6
	Annual mean ($\mu g/m^3$)	33.5	33.7	33.7	33.2	34.5	34.5
$PM_{2.5}$	Max. 24-h mean ($\mu g/m^3$)	49.2	49.7	49.0	50.6	50.3	50.7
	Annual mean ($\mu g/m^3$)	12.6	12.5	12.4	12.8	12.6	12.4
PM_{10}	Max. 24-h mean ($\mu g/m^3$)	70.1	70.6	70.0	71.3	70.8	71.3
	Annual mean ($\mu g/m^3$)	23.8	23.8	23.5	24.2	24.0	24.1
Benzene	Max. 1-hour ($\mu g/m^3$)[(a)]	7.8	8.6	8.0	4.3	4.4	4.3
Benzo(a)pyrene	Max. 1-hour ($\mu g/m^3$)[(a)]	0.07	0.08	0.07	0.05	0.05	0.05
Formaldehyde	Max. 1-hour ($\mu g/m^3$)[(a)]	6.5	7.1	6.6	5.6	5.7	5.6
1,3-butadiene	Max. 1-hour ($\mu g/m^3$)[(a)]	2.1	2.3	2.1	1.2	1.2	1.2
Ethylbenzene	Max. 1-hour ($\mu g/m^3$)[(a)]	2.7	2.9	2.7	1.4	1.4	1.4
(a) Excluding background							

Table 6-16 Largest increases in concentration for RWR receptors within Commonwealth land boundaries

Pollutant	Concentration metric	Increase in concentration by scenario			
		2026-WP	2026-WPC	2036-WP	2036-WPC
CO	Max. 1-hour (mg/m^3)	0.8	0.9	0.6	0.6
	Max. rolling 8-hour (mg/m^3)	0.6	0.6	0.4	0.2
NO_2	Max. 1-hour (µg/m^3)	15.5	30.9	17.5	18.7
	Annual mean (µg/m^3)	4.5	4.1	5.3	5.3
$PM_{2.5}$	Max. 24-h mean (µg/m^3)	2.3	2.8	3.7	3.8
	Annual mean (µg/m^3)	0.9	0.9	1.2	1.3
PM_{10}	Max. 24-h mean (µg/m^3)	4.2	5.0	5.0	5.8
	Annual mean (µg/m^3)	1.4	1.4	1.7	1.9
Benzene	Max. 1-hour (µg/m^3)	1.6	2.0	1.0	1.3
Benzo(a)pyrene	Max. 1-hour (µg/m^3)	0.014	0.018	0.013	0.017
Formaldehyde	Max. 1-hour (µg/m^3)	1.3	1.7	1.3	1.7
1,3-butadiene	Max. 1-hour (µg/m^3)	0.4	0.5	0.3	0.04
Ethylbenzene	Max. 1-hour (µg/m^3)	0.5	0.7	0.3	0.4

Figure 6-74 to **Figure 6-77** show the contour plots for the changes in annual mean and maximum 24-hour $PM_{2.5}$ in the 2036-WP and 2036-WPC scenarios. Each plot focuses on the area within the Commonwealth land boundaries. The most marked changes in $PM_{2.5}$ were the increases at the north of the airport, around Terminal 2/3 and to the west of Terminal 1, as well as the reductions in $PM_{2.5}$ near the existing Airport Drive to the north of Terminal 1.

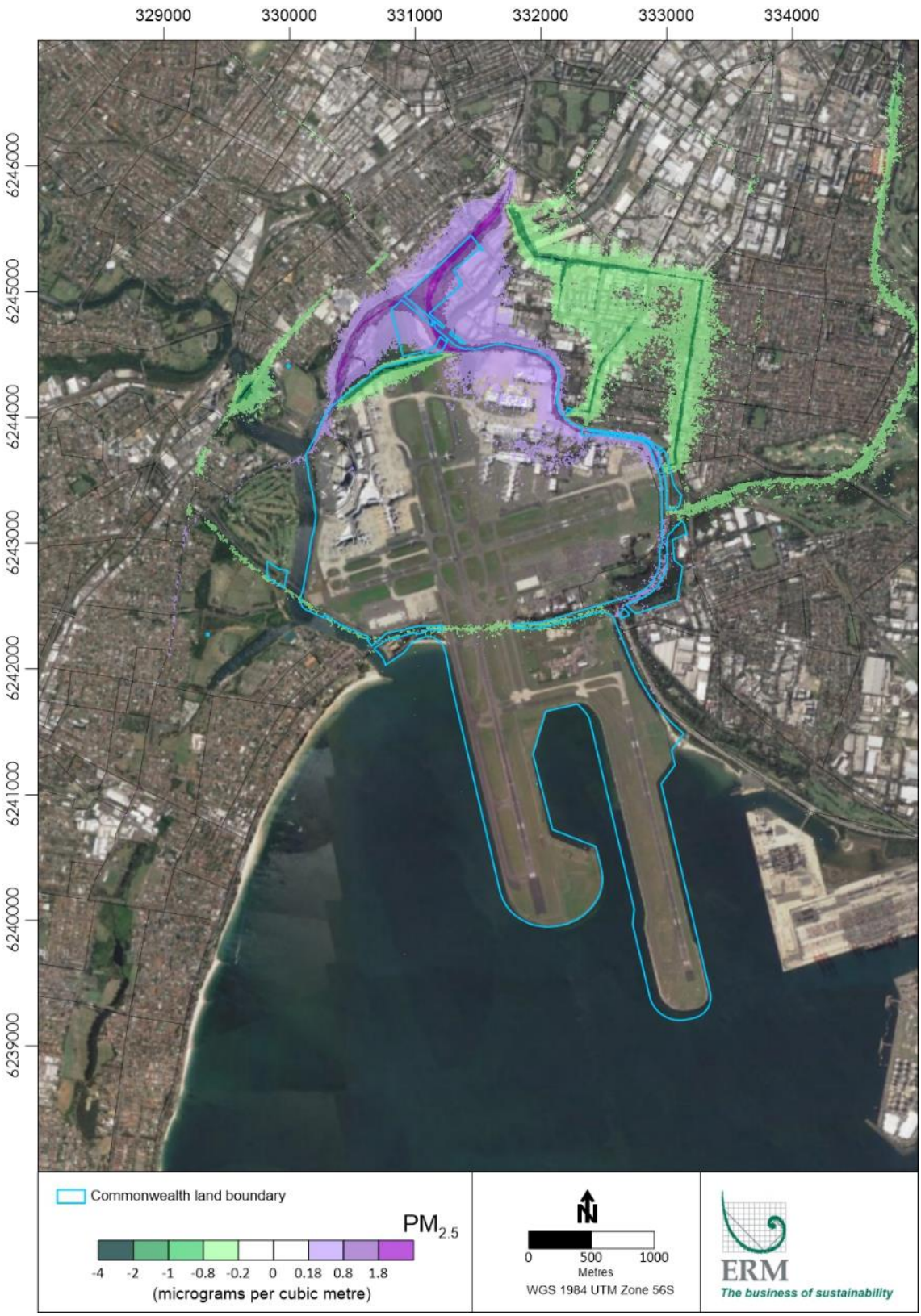


Figure 6-74 Contour plot of change in annual mean $PM_{2.5}$ concentration in the 2036 With Project scenario (2036-WP minus 2036-WOP), including Commonwealth land

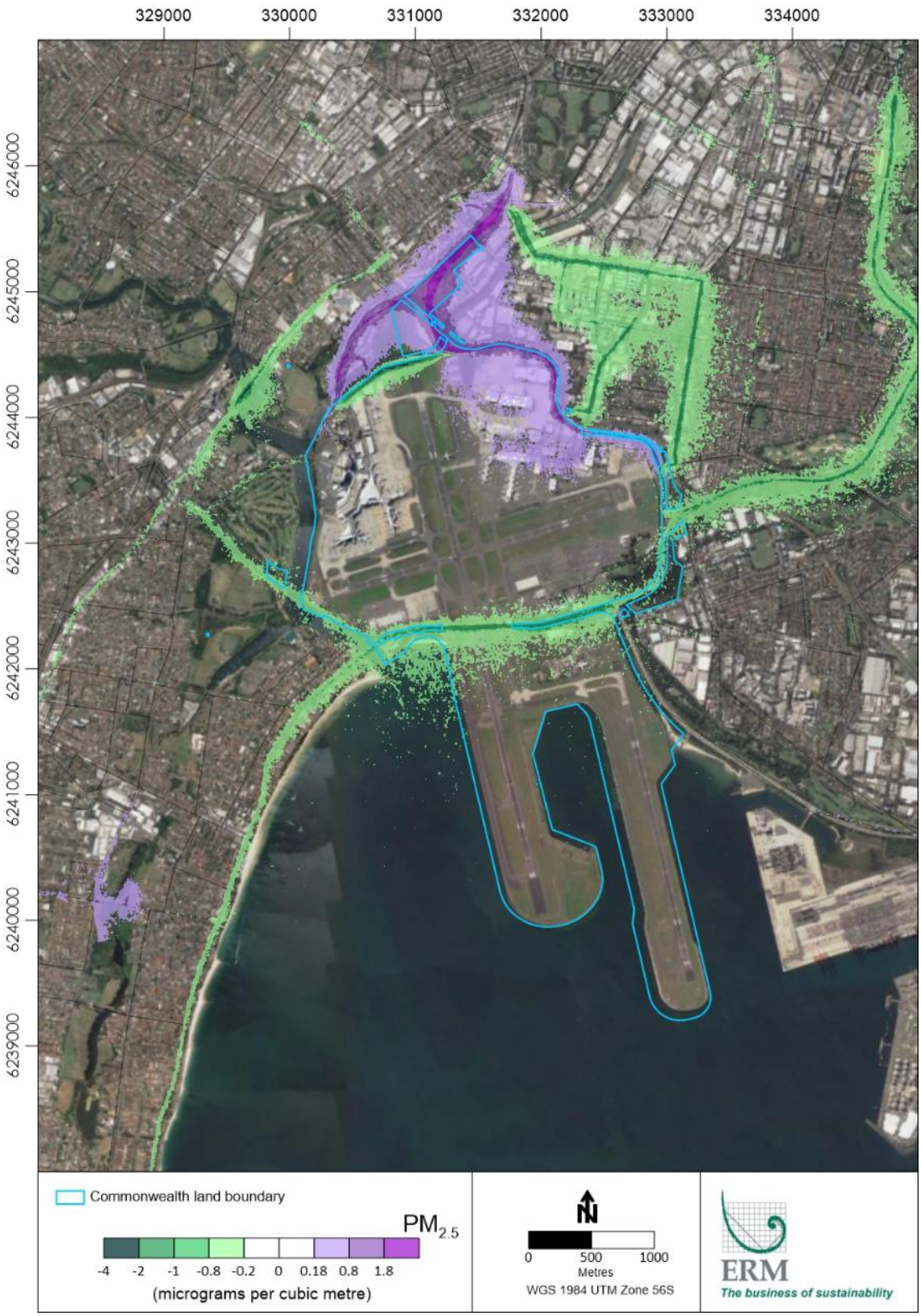


Figure 6-75 Contour plot of change in annual mean $PM_{2.5}$ concentration in the 2036 Cumulative scenario (2036-WPC minus 2036-WOP), including Commonwealth land

Figure 6-76 Contour plot of change in maximum 24-hour $PM_{2.5}$ concentration in the 2036 With Project scenario (2036-WP minus 2036-WOP), including Commonwealth land.

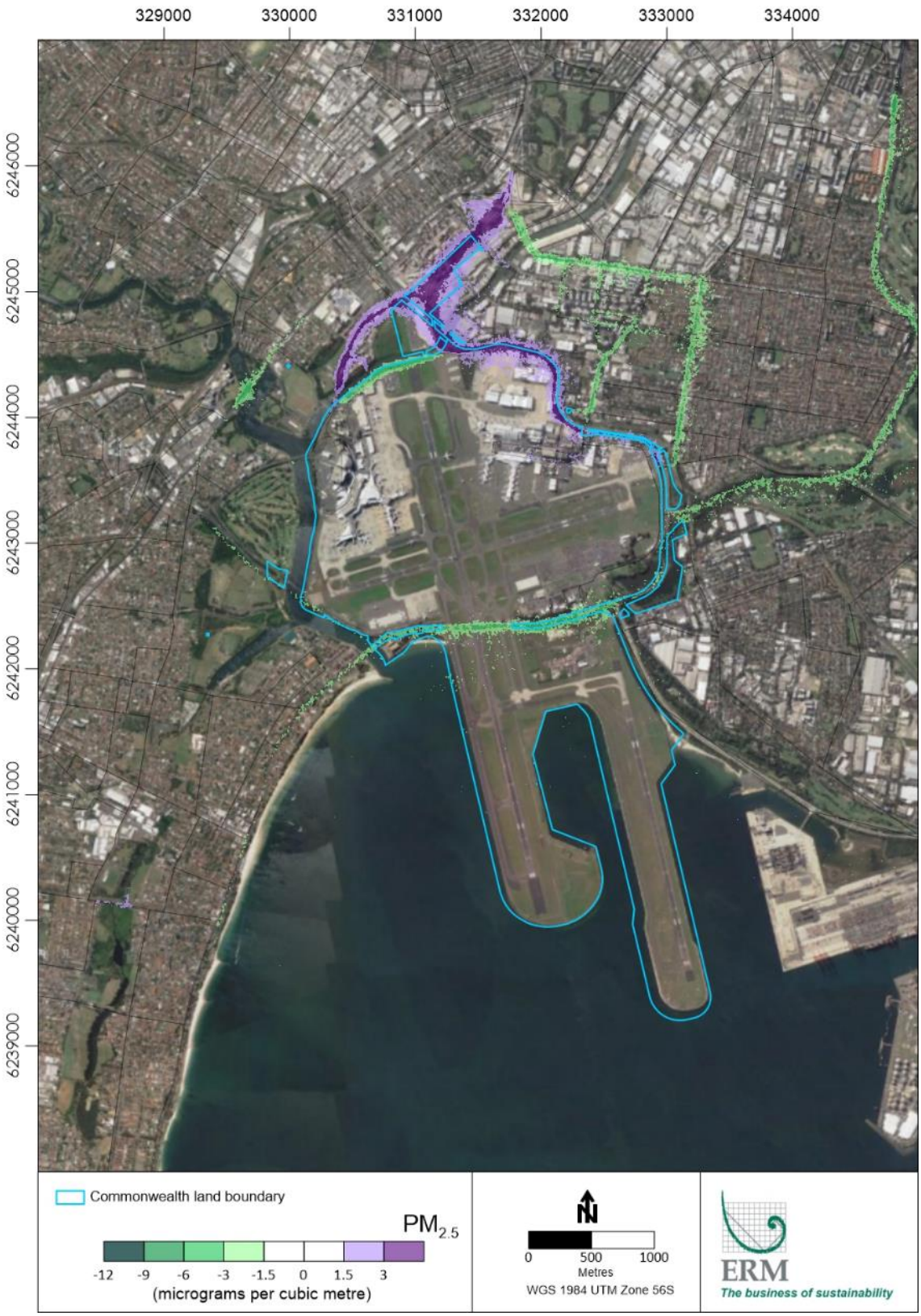


Figure 6-77 Contour plot of change in maximum 24-hour $PM_{2.5}$ concentration in the 2036 Cumulative scenario (2036-WPC minus 2036-WOP), including Commonwealth land

6.4 Consistency with Sydney Airport Master Plan and Environment Strategy

With respect to air quality, the objectives of Sydney Airport's Master Plan 2039 and Environmental Strategy 2019-2024 were noted in **section 2.1.4.3**. The objectives that are of relevance here are:

- Minimise air emissions from ground-based airport operations and activities
- Comply with State and Commonwealth legislation and relevant standards and guidelines.

The Sydney Gateway road project would be associated with predicted increases in the concentrations of air pollutants in at least some areas of the airport. However, the same could be said for any individual action which leads to a growth in activity at the airport. With respect to the Sydney Gateway road project, any increases in concentration are likely to be lower in magnitude than those associated with the longer-term reductions in emissions between 2016 and 2036 (see, for example, **Table 6-9**).

As shown in **Table 6-15**, there are some exceedances of the short term PM_{10} and $PM_{2.5}$ criteria on Commonwealth land, resulting from the conservative background values used which are above the criteria. Similarly, while the project contributions to the annual mean $PM_{2.5}$ concentrations are low (**Table 6-16**), background value is above the criterion. The largest contributor to background levels at these receptors is likely to be the airport itself with emissions from aircraft and ground support vehicles.

7 Cumulative impacts with Botany Rail Duplication

7.1 Botany Rail Duplication and Sydney Gateway road project

7.1.1 Construction impacts

The risks of air quality (dust) impacts construction of the Sydney Gateway road project were addressed in **section 5**. The construction footprint including the Botany Rail Duplication, is shown in **Figure 7-1**. The outcomes of the cumulative risk assessment are shown in **Table 7-1**.

The assessment indicated that without mitigation, nearby receptors were at a high risk of experiencing dust impacts due to construction activities, including near the rail duplication areas. If the potential risks for the Sydney Gateway road project (**section 8**) are adequately managed, then the potential risk of cumulative impacts associated with the project and the Botany Rail Duplication would be reduced.

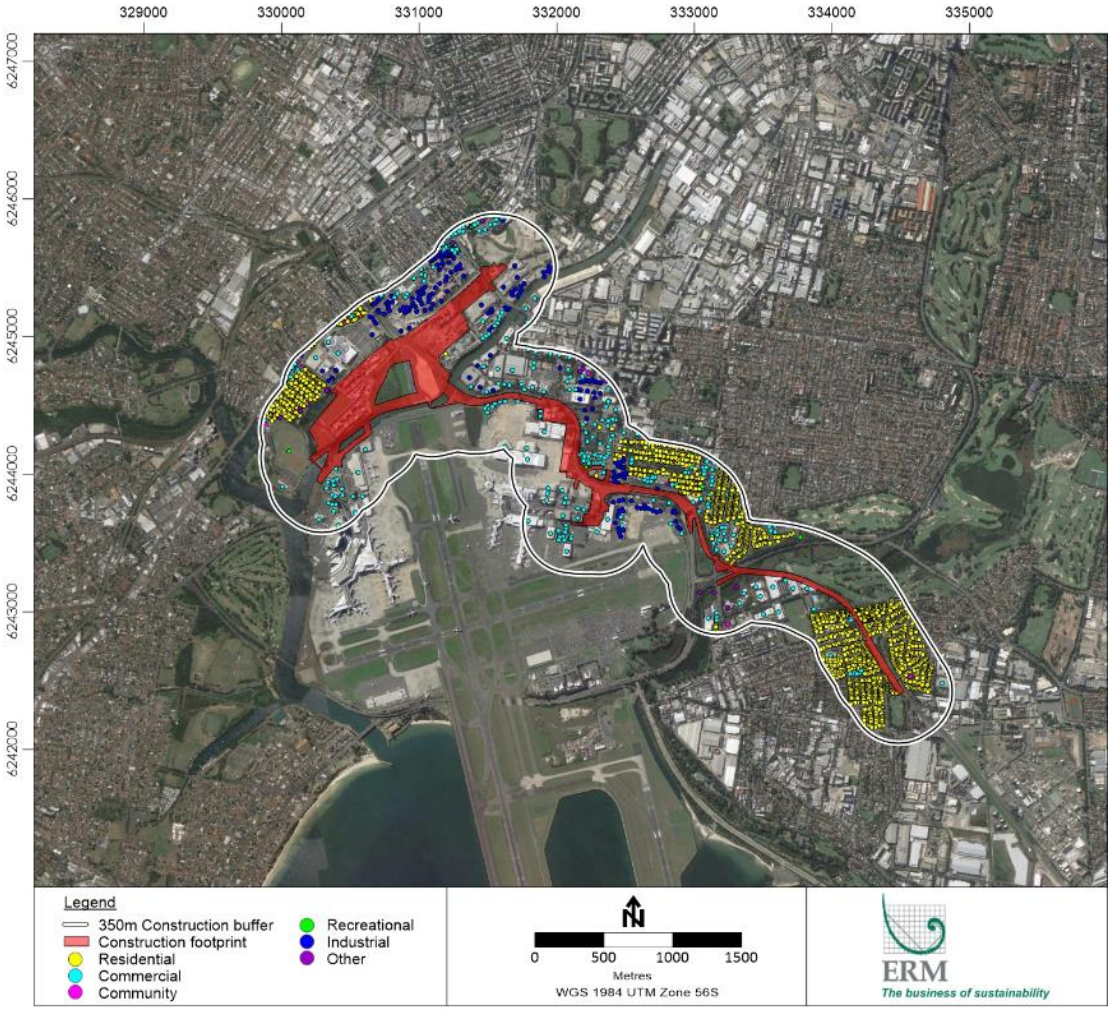


Figure 7-1 Receptors near the construction footprint of the combined Sydney Gateway road project and Botany Rail Duplication projects

Table 7-1 Summary of cumulative risk assessment for construction

Activity	Step 2A: Potential for dust emissions	Step 2B: Sensitivity of area			Step 2C: Risk of dust impacts		
		Dust soiling	Human health	Ecological	Dust soiling	Human health	Ecological
Demolition	Large	High	High	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

7.1.2 Operational impacts

The SMPM does not account for any changes in freight traffic that may be associated with the Botany Rail Duplication (BRD). However, it is unlikely that these changes would have a measurable impact on cumulative concentrations. Any contribution from the rail line itself is likely to be minor in relation to contributions from the road network and background concentrations.

The predominant pollutant of concern from the rail component will be $PM_{2.5}$ from the diesel locomotive engines. When considering total concentrations of $PM_{2.5}$ it is necessary to consider the existing background levels due to sources other than the project. **Figure 6-50** and **Figure 6-58** show the relative contributions from both background and surface road traffic for annual average and maximum 24-hour average concentrations, respectively. It is clear from both that the most significant contributor is the existing background, with a relatively minor contribution from the surface roads. It is therefore noted that any additional $PM_{2.5}$ from the diesel locomotives will only result in minor increases to an already minor contributor to total $PM_{2.5}$ concentrations. It is unlikely that these increases would be measurable.

In addition, given that the BRD may provide an opportunity for a number of heavy freight vehicles to be removed from the surface roads, and given that the main pollutant of concern from these vehicles is also $PM_{2.5}$, there is potential for the surface road contribution to actually decrease. Again, this is unlikely to be measurable.

7.2 Botany Rail Duplication and other major developments

7.2.1 Construction impacts

There are other significant infrastructure projects in the area also under construction, such as the St Peters Interchange and various proposed works at Sydney Airport. As noted previously, there is likely to be an element of “construction fatigue” experienced by people who live and work in the area. In light of this, it is important that the management of any mitigation measures should ensure these construction works to add significantly to that burden. If the recommended measures are implemented this would reduce this risk considerably.

7.2.2 Operational impacts

Future developments in the area such as the F6 Extension, the New M5 and the M4-M5 Link have been included in this assessment, as detailed in **section 6.2.2.2**.

There are also two other major existing developments in the area, namely Sydney Airport and Port Botany. These have been taken into account as part of the background monitoring in terms of the contribution they make to the existing airshed as a whole (**section 4.7**).

8 Management of impacts

8.1 Management of construction dust

This section of the report describes recommended mitigation measures for minimisation, control and mitigation of construction dust.

Step 3 of the construction assessment involved determining mitigation measures for each of the four potential activities in Step 2, as described in **section 5.2**. This was based on the level of risk of dust impacts identified in the assessment. For each activity, the highest risk category was used and the results are shown in **Table 8-1**, and are all highly recommended and routinely employed as 'good practice' on construction sites.

A Construction Environmental Management Plan would be prepared to cover all construction phases and activities needed to build the project. This Plan would include details of site-specific measures to be applied to reduce and mitigate air quality impacts.

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[12]. Detailed guidance is also available from the UK (GLA, 2006) and the United States (Countess Environmental, 2006). The recommended measures outlined below are consistent with these guidelines.

Table 8-1 Recommended mitigation measures

	Mitigation measure
1	Demolition activities would be planned and carried out to minimise the potential for dust generation.
2	Adequate dust suppression would be applied during all demolition works where required.
3	All potentially hazardous material would be identified and removed from each building in an appropriate manner prior to demolition.
4	Areas of soil exposed during construction would be minimised at all times to reduce the potential for dust generation.
5	Exposed soils would be temporarily stabilised during weather conditions conducive to dust generation and prior to extended periods of inactivity to prevent dust generation.
6	Stockpiles of loose materials would be adequately stabilised or protected to minimise dust emissions.
7	Fine materials (such as bulk cement and other fine powder) would be delivered, stored and handled to minimise dust.
8	Site access points and adjacent areas would be monitored for deposited loose materials that could result in dust emissions. The deposits would be removed and surface cleaned as required.
9	During establishment of project compounds, controls such as wheel washing systems and rumble grids would be installed at site exits to prevent deposition of loose material on sealed surfaces outside project sites to reduce potential dust generation.

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

	Mitigation measure
10	Dust and air quality complaints would be recorded, cause(s) identified, appropriate measures to reduce emissions taken in a timely manner, and the measures taken would be recorded.
11	Regular site inspections would be carried out to ensure that implemented air quality management measures are effective. The site inspection, and issues arising, would be recorded. Management measures would be adjusted or additional management measures implemented as required to address any identified issues.
12	Construction activities with the potential to generate visible dust would be modified or ceased during unfavourable weather conditions to reduce the potential for dust generation.
13	Measures to reduce potential dust generation, such as the use of water carts, sprinklers, dust screens and surface treatments, would be implemented within project sites as required for each specific site.
14	Unsealed access roads within project sites would be maintained and managed to reduce dust generation.
15	Where reasonable and feasible, appropriate control methods would be implemented to minimise dust emissions from the project site.
16	All construction vehicles and plant would be inspected regularly and maintained to ensure that they comply with relevant emission standards.
17	Engine idling would be minimised when plant are stationary, and plant would be switched off when not in use to reduce emissions.
18	The use of mains electricity would be favoured over diesel or petrol-powered generators where practicable to reduce site emissions.
19	Suitable dust suppression and/or collection techniques would be used during cutting, grinding, sawing and any other activities likely to generate dust in close proximity to sensitive receivers.
20	The potential for dust generation would be considered during the handling of loose materials. Equipment would be selected and handling protocols developed to minimise the potential for dust generation.
21	All vehicles loads would be covered to prevent escape of loose materials during transport.

8.2 Mitigation of operational impacts

Modelling outcomes indicate that localised increases in pollutant concentrations from the Sydney Gateway road project are likely to be smaller than the longer-term reductions in vehicle emissions with time (eg between 2016 and 2036; see, for example, **Table 6-9**). In other words, even though there will be increases in traffic volumes, better emissions technology means that the impacts will not increase accordingly. Moreover, the predicted changes in concentration are likely to be undetectable in ambient air quality measurements at most locations.

The Sydney Gateway road project has been designed, as far as practicable, to optimise the throughput and operation of vehicles on the local road network. This includes, for example, the optimisation of signalised intersections, the minimisation of road gradients, and the application of appropriate speed limits. Such measures will generally tend to reduce fuel consumption and reduce emissions on a per vehicle basis.

Emissions from road vehicles are primarily addressed through national legislation (ie Australian Design Rules) and state programs that focus on, for example, inspection and maintenance. The broader reduction of emissions from the vehicle fleet is beyond what could reasonably be expected of any given infrastructure project.

8.3 Consistency with Sydney Airport Master Plan and Environment Strategy

Sydney Airport's Master Plan and Environment Strategy define the plans and actions for reducing or preventing the operational air quality impacts of developments associated with the Airport. One action is to ensure that potential air quality impacts are managed for the construction and operational phases of development proposals. Sydney Gateway road project is one such project and this assessment report is one aspect of meeting that commitment.

8.3.1 Construction impacts

The management of the construction impacts of the Sydney Gateway road project on air quality is consistent with the objectives of the Sydney Airport Master Plan and Environment Strategy in so far as the recommended mitigation measures aim to minimise the risk of dust impacts on humans and environmentally sensitive areas. With appropriate dust management and controls there should not be any adverse impacts at Sydney Airport.

8.3.2 Operational impacts

As noted in **section 6.2**, most of operational actions in the Sydney Airport Master Plan and Environment Strategy relate to the introduction of cleaner and more efficient aircraft, as well as other airside activities that may improve air quality. Providing more efficient transport and direct access to and from the airport as a result of the Sydney Gateway road project will contribute to the aims of the Master Plan.

9 Conclusions

This report presents a technical assessment of the construction and operational activities for the Sydney Gateway road project that have the potential to affect ambient air quality. The main conclusions are summarised below.

9.1 Construction impacts

In the absence of specific direction for road and tunnel projects in NSW, the potential dust 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, and has been used in all major Sydney road projects in recent years.

This risk based methodology was used to assess the risks of dust emissions for four types of construction activity:

- demolition
- earthworks
- construction
- track-out.

The assessment methodology considered three separate dust impacts:

- annoyance due to dust soiling
- the risk of health effects due to an increase in exposure to PM_{10}
- harm to ecological receptors.

For annoyance and health risk, dust impact the sensitivity of the assessment zone and all relevant activities was determined to be 'high', and the risk of impacts was also determined to be 'high'.

Consequently, a wide range of management measures are recommended to minimise dust and mitigate effects of construction works on local air quality at the nearest receptors. The recommended measures are routinely employed as 'good practice' on construction sites in NSW and should not be difficult to implement.

With the application of the recommended management measures, risk of dust would not be completely eliminated, but it should be substantially minimised and well managed. Outcomes that the community, neighbours and sensitive environments would experience will be short term.

There is the potential for odour impacts due to excavation through the former Tempe Landfill and further details of the modelling and assessment are provided in the combined EIS/preliminary draft MDP. A list of measures have also been suggested in the report to manage potential odour impacts.

9.2 Operational impacts

The following conclusions have been drawn from the operational air quality assessment:

- The predicted total concentrations of all criteria pollutants at receptors were usually dominated by the existing background contribution
- For NO_2 there was predicted to be a substantial contribution from the modelled road traffic but levels remain well below air quality criteria
- For several air quality metrics (notably annual mean and 24-hour $PM_{2.5}$ and PM_{10}), exceedances of the criteria were predicted to occur both with and without the project. This was because of high background concentrations in the model domain. In other words, the background levels already exceed the relevant criteria without the project

- 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 and these were near new sections of road due to the project
- The modelled spatial changes in air quality as a result of the project are quite complex, reflecting the complex changes in traffic on the network. Key outcomes are predicted to include:
  - Marked increases in pollutant concentrations on the new roads associated with Sydney Gateway (Terminal 1 connection, the St Peters interchange connection, and the Qantas Drive upgrade and extension)
  - Increases in pollutant concentrations on several existing roads (Qantas Drive, Joyce Drive, General Holmes Drive, and Airport Drive near Terminal 1) due to increased traffic
  - Decreases in pollutant concentrations along several existing roads (M5 East, Southern Cross Drive, Botany Road, and Canal Road) due to reductions in traffic of between 8 per cent and 28 per cent on these roads
  - For the cumulative scenarios (2026-WPC and 2036-WPC) there were some additional air quality changes associated with the future introduction of the proposed F6 Extension project, including further reductions in concentration along Southern Cross Drive and the M5 East, a reduction in concentrations along The Grand Parade, and an increase in concentration along President Avenue
- For selected odorous pollutants the changes in the maximum 1-hour concentrations were very small and likely to be undiscernible by the community.

9.2.1 Pollutant-specific summary

9.2.1.1 Carbon monoxide (maximum 1-hour)

- 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 40 per cent and 51 per cent of RWR receptors, although even the largest increases were small compared with the criterion.

9.2.1.2 Carbon monoxide (maximum rolling 8-hour)

- As with the maximum 1-hour CO concentration, at all receptors the predicted concentration was well below the NSW impact assessment criterion, which in this case is 10 µg/m^3. No lower criteria appear to be in force internationally.

9.2.1.3 Nitrogen dioxide (annual mean)

- At all receptors, the NO_2 concentration was well below the NSW impact assessment criterion of 62 µg/m^3. At all receptors the NO_2 concentration was also below the EU limit value of 40 µg/m^3. Concentrations at the vast majority (more than 96 per cent) of receptors were between around 20 µg/m^3 and 30 µg/m^3.
- The maximum contribution of road traffic in any scenario and at any receptor was 13.4 µg/m^3.
- There was predicted to be an increase in the annual mean NO_2 concentration at between 24 per cent and 43 per cent of receptors, depending on the scenario. Whilst the largest increases in annual NO_2 were around 4-5 µg/m^3, the increase was greater than 1 µg/m^3 for no more than around one per cent of receptors.

9.2.1.4 Nitrogen dioxide (maximum 1-hour)

- There was only one receptor (out of 12,145) with an exceedance of the NSW 1-hour NO_2 criterion of 246 µg/m^3 in any scenario, and this was not a sensitive location (a car park within Sydney Airport).
- There was predicted to be an increase in the maximum 1-hour NO_2 concentration at between 33 per cent and 47 per cent of receptors depending on the scenario. At the majority of receptors the change was relatively small in all scenarios; for around only 3 to 5 per cent of all receptors there was an increase in concentration of more than 5 µg/m^3. At the Sydney Airport receptor mentioned above, there was an increase in the maximum 1-hour NO_2 concentration of 31 µg/m^3 which resulted in an exceedance of the air quality criterion.

9.2.1.5 PM_{10} (annual mean)

- The concentration at the vast majority of receptors was below 23 µg/m^3, with only two receptors having a concentration just above the NSW assessment criterion of 25 µg/m^3 in any scenario.
- The maximum road traffic contribution in any scenario was 6.9 µg/m^3.
- There was an increase in concentration at 35 to 42 per cent of the receptors, depending on the scenario. At the majority of receptors the change was relatively small, and where there was an increase, this was greater than one per cent of the criterion at less than 1.5 per cent of receptors. The largest predicted increase in concentration at any receptor as a result of the project (including the cumulative scenarios) was 1.9 µg/m^3, and the largest increase at a residential location was 0.45 µg/m^3.

9.2.1.6 PM_{10} (maximum 24-hour)

- The results for maximum 24-hour PM_{10} were highly dependent on the assumption for the background concentration. Because this was quite high (56.4 µg/m^3), the total concentration was above the NSW impact assessment criterion of 50 µg/m^3 at all receptors.
- There was an increase in concentration at between 33 per cent and 46 per cent of receptors, depending on the scenario. Where there was an increase, this was greater than one per cent of the criterion at 7 to 10 per cent of receptors, depending on the scenario.

9.2.1.7 $PM_{2.5}$ (annual mean)

- The predictions for annual mean $PM_{2.5}$ were highly dependent on the assumptions on background values, based on a mapped background which already exceeded the NSW criterion of 8 µg/m^3 at all receptors (see Figure D-27 **Annexure D**). Clearly, there would also be exceedances of the AAQ NEPM long-term target of 7 µg/m^3. Internationally, there are no standards lower than 8 µg/m^3 for annual mean $PM_{2.5}$.
- The highest predicted concentration at any receptor was 13.6 µg/m^3, and the road traffic contribution was 4.2 µg/m^3.
- There was an increase in concentration at between 37 per cent and 44 per cent of receptors, depending on the scenario. Where there was an increase, this was greater than 0.1 µg/m^3 at around 2 to 4 per cent of receptors. The largest predicted increase in concentration at any receptor as a result of the project (including the cumulative scenarios) was 1.3 µg/m^3, and the largest increase at a residential location was 0.27 µg/m^3.
- No RWR receptor had a value for an increase in annual mean $PM_{2.5}$ that was above the acceptable threshold of 1.8 µg/m^3.

9.2.1.8 $PM_{2.5}$ (maximum 24-hour)

- Given the high background concentration for 24-hour $PM_{2.5}$ (40.9 µg/m^3) in all scenarios the total concentration at all receptors was above the NSW impact assessment criterion of 25 µg/m^3.

- The largest predicted increase in concentration at any receptor as a result of the project in any scenario was 3.8 µg/m^3. For most of the receptors the change in concentration was small; where there was an increase in concentration, this was greater than 0.5 µg/m^3 at only 2 to 4 per cent of receptors.

9.2.1.9 Air toxics

- Five air toxics (benzene, PAHs (as B(a)P), 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 very low and likely to be undetectable in the ambient environment. For each compound, where there was an increase in the concentration, this was well below the NSW impact assessment criterion.

9.3 Impacts on Commonwealth land

9.3.1 Construction impacts

There was determined to be a high risk of dust impacts for nearby receptors on Commonwealth land, due to construction works associated with the project, without dust abatement measures in place. A number of management measures to reduce this risk have been identified and would also apply to Commonwealth land to reduce risk at those locations too.

9.3.2 Operational impacts

A total of 162 RWR receptors were located on Commonwealth land. None of the receptors represented particularly sensitive locations from an air quality perspective. As in the assessment for the whole domain, for each pollutant and metric there were increases in concentration at some receptors and decreases at others, depending on their proximity to new sections of road and changes in the traffic network. As most of the main network changes occur near Commonwealth land, it is not surprising that the increases there were amongst the largest determined for the whole domain. Nevertheless, the increases were within acceptable ranges. The most marked changes in concentration were the increases at the north of the airport, around Terminal 2/3 and to the west of Terminal 1, as well as the reductions near the existing Airport Drive to the north of Terminal 1.

9.4 Consistency with Sydney Airport Master Plan 2039 and Environment Strategy 2019-2024

9.4.1 Construction impacts

A key theme of the Sydney Airport Master Plan and Environment Strategy is commitment to sustainability. All major airports have an unavoidable effect on the air quality environment, and minimising these impacts is fundamental to operating sustainably. The assessment of the construction impacts of Sydney Gateway road project on air quality is consistent with this objective. In particular, air quality risks have been assessed and mitigation measures recommended which take into account both human health and amenity, as well as environmentally significant and sensitive areas.

9.4.2 Operational impacts

Modelling indicates the Sydney Gateway road project would result in predicted increases in the concentrations of air pollutants in at least some areas of the airport. However, any increases in concentrations are likely to be smaller than future predicted emissions reductions between 2016 and 2036 due to advances in vehicle emissions technology.

10 References

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Annexure A- Pollutant formation, dispersion and transformation

A.1 Overview

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

A.2 Formation of primary pollutants

A.2.1 Combustion

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

A.2.1.1 Carbon monoxide

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

A.2.1.2 Hydrocarbons

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

A.2.1.3 Oxides of nitrogen

At the high temperatures and pressures in the combustion chamber some of the nitrogen in the air is oxidised, forming mainly nitric oxide (NO) with some nitrogen dioxide (NO_2). NO and NO2 are collectively termed 'oxides of nitrogen' (NO_X). NO formation is also enhanced by oxygen-rich fuelling conditions. NO_2 is predominantly a secondary pollutant, being produced by the oxidation of NO in atmospheric photochemical reactions (see Section A.3.3.1). Any NO_2 that is emitted directly from vehicles is referred to as 'primary NO_2'.

NO_X emissions from petrol vehicles have also decreased as a consequence of TWCs. However, analyses in Europe have shown that, despite the considerable reductions in vehicle emissions that are calculated in inventories, NO_2 concentrations at many roadside monitoring sites are not decreasing to the same extent. This is also reflected in the ambient NO_X and NO_2 data for Sydney (see Annexure D). Further analyses in Europe have indicated that a significant proportion of ambient NO_2 is emitted directly from vehicle exhaust (Carslaw and Beevers, 2004; Carslaw, 2005; Hueglin *et al*., 2006; Grice *et al*., 2009). Two contributing factors have been cited. Firstly, the market share of diesel vehicles increased. Diesel vehicles emit more NO_x than petrol vehicles, and with a larger proportion of NO_2 in NO_x (termed *f*-NO_2). Secondly, the average value of *f*-NO_2 in diesel exhaust increased. This was linked to the growth in the use of specific after-treatment technologies which involved *in situ* generation of NO_2, such as catalytically regenerative particle filters (Carslaw, 2005).

[1] A TWC results in the simultaneous conversion of CO to CO_2, HC to water, and NO_X to nitrogen.

Historically a fairly low value for *f*-NO_2 (5-10 per cent) has been used in air quality assessments in NSW. Work by Pacific Environment (2015) suggested that there has been a gradual increase in fleet-average *f*-NO_2 from less than 10 per cent before 2008 to around 15 per cent in 2014. The main reason for the increase in *f*-NO_2 is the increased market penetration of diesel cars into the Sydney vehicle fleet.

A.2.1.4 Particulate matter

Incomplete combustion also results in the production of particulate matter (PM). Diesel vehicles represent the main (exhaust) source of PM from road transport, although studies indicate that petrol vehicles with direct fuel injection also contribute (PIARC, 2012). Exhaust particles cover a range of sizes, and the shape of the size distribution depends on whether the PM metric is number or mass. In terms of number, most particles are smaller than 0.1 µm, whereas most of the mass is attributable to particles smaller than 1 µm. The usual means of complying with the stringent PM mass emission limits for modern diesel vehicles is through the use of a diesel particulate filter which physically captures particles in the exhaust stream.

A.2.2 Evaporation

Volatile organic compounds (VOCs) are emitted from the fuel systems of petrol vehicles as a result of evaporation. The compounds which are emitted are mainly light hydrocarbons (C_4-C_6) (CONCAWE, 1987). Evaporative emissions from diesel-fuelled vehicles are due to the low volatility of diesel fuel. There are several different mechanisms of evaporation. 'Diurnal losses' result from the thermal expansion and emission of vapour, mainly in the fuel tank, in response to changes in ambient temperature during the day. 'Hot-soak losses' occur when a warm engine is turned off and heat is dissipated into the fuel system. Whilst a vehicle is being driven the engine provides a continuous input of heat into the fuel system, resulting in 'running losses'. Evaporative emissions are dependent upon four major factors: the vehicle design, the ambient temperature, the volatility of the petrol and the driving conditions. Emissions are decreasing as a result of new cars being equipped with sealed fuel injection systems and activated carbon canisters in fuel tank vents.

A.2.3 Abrasion and resuspension

As well as being present in vehicle exhaust, PM is generated by various abrasion processes including tyre wear and brake wear. Tyre wear is a complex process. The amount, size, and chemical composition of the emitted PM is influenced by various factors including tyre characteristics, the type of road surface, vehicle characteristics and vehicle operation. Tyres contain a vast array of organic compounds and several important inorganic constituents. Although some research has been carried out to characterise wear particles, the understanding remains incomplete (Thorpe and Harrison, 2008). Brake wear particles are composed of metals (iron, copper, lead, etc), organic material, and silicon compounds which are used as binders in brake pads, but again composition varies greatly (Thorpe and Harrison, 2008). Test track and wind tunnel measurements have revealed that typically 50 per cent of the brake wear debris escapes the vehicle and enters the atmosphere, although the actual proportion depends on the severity of the braking and the design of the vehicle (Sanders *et al*., 2003). It appears that most airborne brake wear particles are quite coarse, although a substantial proportion has a diameter of less than 2.5 µm (Garg *et al*., 2000; Abu-Allaban *et al*., 2003; Iijimia *et al*., 2007).

Another process – the resuspension of material previously deposited on the road surface – occurs as a result of tyre shear, vehicle-generated turbulence, and the action of the wind. Large contributions of resuspension have been observed in some US and European studies (notably in Scandinavia), although the conditions in these studies (eg responses to climate such as the use of studded tyres and grit on roads in winter) are not necessarily representative of those in Sydney.

A.2.4 Construction dust and odour

Dust emissions occur as a result of construction activities, and these can lead to elevated PM_{10} concentrations and nuisance. A potential source of PM (both airborne and on the road surface), especially during the project construction phase, is fugitive dust from uncovered loads. However, the *Protection of the Environment Operations (Waste) Regulation 2014* requires waste transported by a vehicle to be covered during its transportation. Exhaust emissions from diesel-powered construction equipment can also be substantial.

Where construction activities involve, for example, the excavation of waste and its subsequent exposure to the atmosphere, this is likely to result in odour emissions which also need to be managed.

Construction-related air quality issues need to be considered and managed on a site-by-site basis.

A.3 Pollutant dispersion and transformation

A.3.1 Spatial distribution of pollution in an urban area

Once pollutants have been released into the atmosphere they are subject to various physical dispersion and chemical transformation processes (see Section A.3.3). When combined with the complex mixture of sources in urban areas, these processes result in a very uneven spatial distribution of pollution.

Figure A-1 shows a simplified representation of pollutant concentrations in and around an urban area with a high density of population and activity in the centre and a lower density in the surrounding districts. Regional background pollution originates from a range of sources, extends over a wide area, and is relatively constant outside the urban area. Within the urban area there is an additional 'urban background' component which is influenced by area-wide emission sources such as domestic and commercial heating, as well as transport and industry. Alongside heavily-trafficked roads there is likely to be a significant local contribution to the concentration. This local traffic contribution is more pronounced for some pollutants (notably NO_X) than others (such as PM).

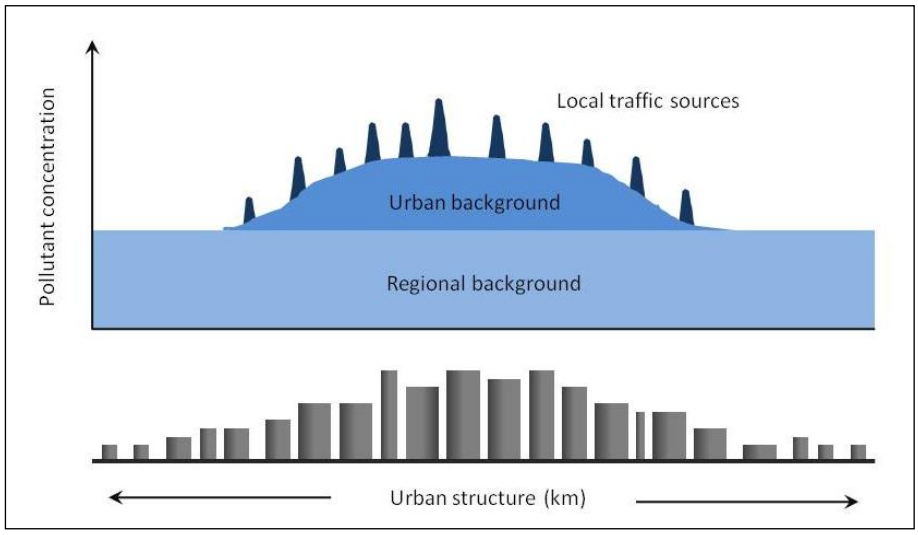

Figure A-1 Simplified representation of urban structure and pollution levels (adapted from Keuken *et al*., 2005)

The general dispersion and transformation of pollutants is influenced to a large extent by the local meteorology. For example, the temperature inversions and low wind speeds associated with stable, high-pressure systems can restrict dispersion and lead to high concentrations. High temperatures in summer promote the formation of ozone and other photochemical pollutants, and extreme weather events are often associated with peak levels of pollution.

The topography of the land in an area plays an important role in the dispersion of air pollutants. It steers winds, generates turbulence and large scale eddies, and generates drainage flows at night and upslope flows during the day. The frequency and severity of pollution events in Sydney are strongly influenced by the regional terrain and the presence of the sea, both of which affect the circulation of air (DSEWPC, 2011). Local dispersion is also influenced by the smaller-scale topography and by obstacles such as buildings. In the vicinity of roads, vehicle-induced turbulence needs to be considered; the turbulence caused by the moving vehicles is likely to be more significant than that caused by buildings.

A.3.2 Concentration gradients near roads

Traffic pollutants undergo rapid changes in the near-road environment, and concentration gradients in the vicinity of roads have been examined in various studies. Some examples of the results for different

pollutants and periods of the day are shown in Figure A-2. The Figure is based on the findings of Gordon *et al.* (2012), who used a mobile laboratory to measure the concentration gradients of ultrafine particles (UFP), black carbon (BC), CO_2, NO, and NO_2 at varying distances from a major highway in Toronto, Canada.

For primary pollutants such as NO and BC, concentrations decay exponentially with increasing distance from the road. Reviews have shown that these typically decrease to background levels between around 100 and 500 metres from roads (e.g. Karner *et al*., 2010; Zhou and Levy, 2007).

Many primary pollutants react together, and with pollutants from other sources, to form secondary pollutants (a substantial proportion of NO_2 is secondary). For these the situation is more complex; because of the time required for their formation, the concentrations of secondary pollutants are not always highest near the emission source.

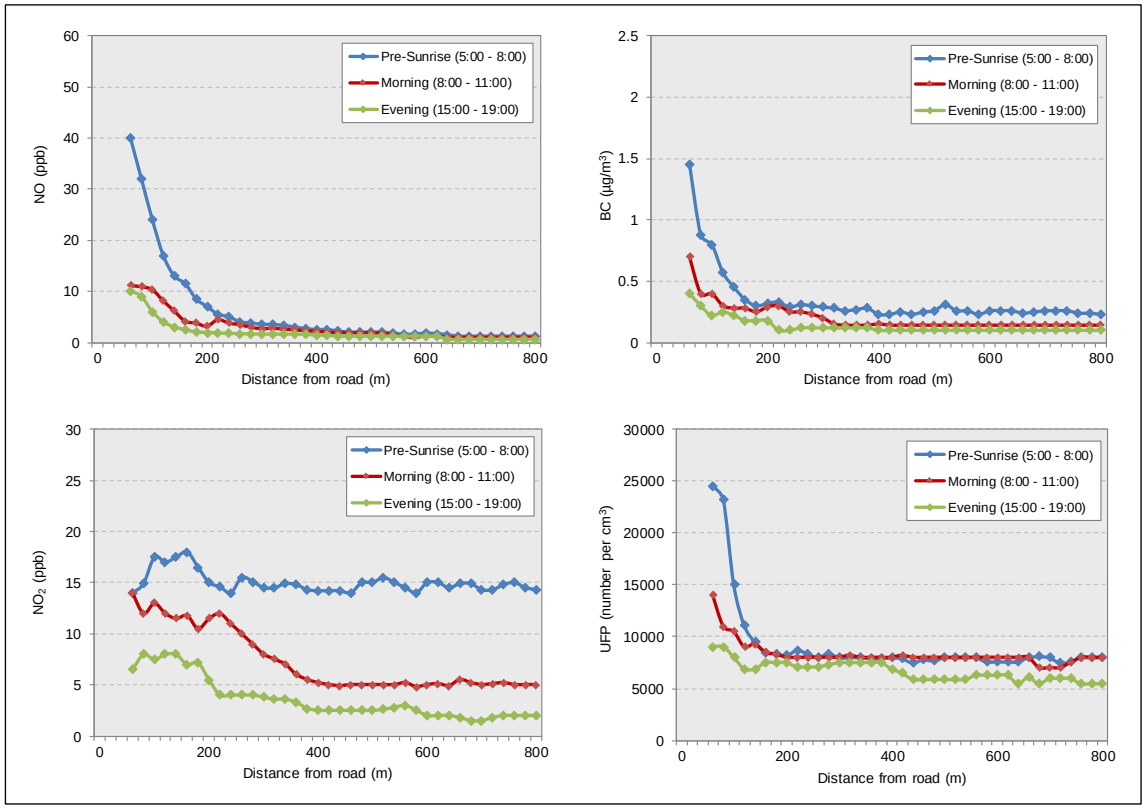

Figure A-2 **Median concentrations of pollutants in the vicinity of a major highway (adapted from Gordon et al., 2012)**

A.3.3 Pollutant transformation

A.3.3.1 Nitrogen dioxide

Some of the most important reactions for near-road air quality are those that lead to the formation and destruction of NO_2. Under the majority of atmospheric conditions, the main mechanism for NO_2 formation in the atmosphere is through rapid reaction of NO with ozone (O_3):

Equation A1

$$\mathbf{NO + O_3 \rightarrow NO_2 + O_2}$$

When this is the only important reaction (e.g. at night-time), NO is transformed into NO_2 until either all the NO has been converted to NO_2 or all the ozone has been used up. At polluted locations comparatively close to sources of NO_x (such as roads) NO is in large excess and it is the availability of O_3 which limits the quantity of NO_2 that can be produced by this reaction. The timescale for consumption of O_3 depends on the concentration of NO. Under normal ambient daytime conditions the reverse

process also occurs – the destruction of NO_2 by photolysis to form NO and ozone, as shown in Equation A2 and Equation A3:

Equation A2

NO_2 + sunlight → NO + O

Equation A3

O + O_2 (+M) → O_3 (+M)

where **M** is a third body, most commonly nitrogen.

Dilution processes decrease the NO_2 concentration with distance from the road, whereas chemical reactions tend to favour NO_2 production. As a result, the decay rate of NO_2 is lower than that of NO in near-road environments (see Figure A-2). The NO_2/NO_X ratio typically increases with increasing distance from the roadway until it reaches the background level.

A.3.3.2 Particulate matter

The fate of emitted particles in the atmosphere depends upon their size. The smallest particles, with a diameter of less than 50 nm, have a short lifetime since they are readily transformed into larger particles and deposit efficiently onto surfaces. Particles with a diameter of between 0.1 μm and 1 μm have a long atmospheric lifetime (typically weeks). For coarser particles, larger than 1 μm, gravitational settling velocities become appreciable and therefore atmospheric lifetimes are again short.

A substantial fraction of the fine PM mass, especially at background locations, is secondary in nature. Secondary particles are formed by atmospheric reactions involving both inorganic and organic gaseous precursors. Inorganic secondary aerosol is composed mainly of ammonium sulfate ($(NH_4)_2SO_4$) and ammonium nitrate (NH_4NO_3). These compounds originate from the conversion of sulfur oxides (SO_X) and nitrogen oxides (NO_X) in the atmosphere to sulfuric and nitric acids, which are then neutralised by atmospheric ammonium (NH_4^+). The precursor to atmospheric ammonium is ammonia (NH_3). SO_X and NO_X typically arise from combustion sources. NH_3 emissions are dominated by agricultural sources, such as the decomposition of urea and uric acid in livestock waste (AQEG, 2005). Secondary organic aerosol is linked to the formation and transformation of low-volatility organic compounds in the atmosphere through a complex series of reactions (Kroll and Seinfeld, 2008), and a great deal of uncertainty exists around the process of formation (USEPA, 2009). The formation of secondary particles happens slowly. The slowness of the processes – and the fact that the resulting particles are small and therefore have a relatively long atmospheric lifetime – means that secondary particles are usually observed many kilometres downwind of the source of the precursors.

Particles are removed from the atmosphere by both dry deposition and wet deposition processes. Dry deposition is caused by gravitational sedimentation, interception/impaction, diffusion or turbulence, although other processes can occur. In wet deposition, atmospheric water (raindrops, snow, etc) scavenges airborne particles, with subsequent deposition on the earth's surface.

Annexure B - Review of legislation and criteria relating to emissions and air quality

B.1 Overview

This Annexure provides supplementary information, including an international context, on key legislative instruments and guidelines of relevance to the project.

B.2 National emission standards for new vehicles

B.2.1 Exhaust emissions

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

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

  The light-duty vehicle legislation also distinguishes between petrol and diesel vehicles.
- Heavy-duty vehicles (HDVs) with a gross vehicle mass of more than 3,500 kilograms.

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

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

Australia is currently implementing the Euro 5[3] emission standards for new light-duty vehicle models (cars and light commercial vehicles). New vehicle models have been required to comply with these standards since November 2013. The introduction in Australia of Euro 6 emissions standards is currently on hold and is being reviewed by the Ministerial Forum on Vehicle Emissions. With full implementation of Euro 6, the World Harmonized Light-duty Vehicle Test Cycle (WLTC) will replace the current test cycle (Mock et al., 2014).

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

[2] United Nations Economic Commission for Europe.

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

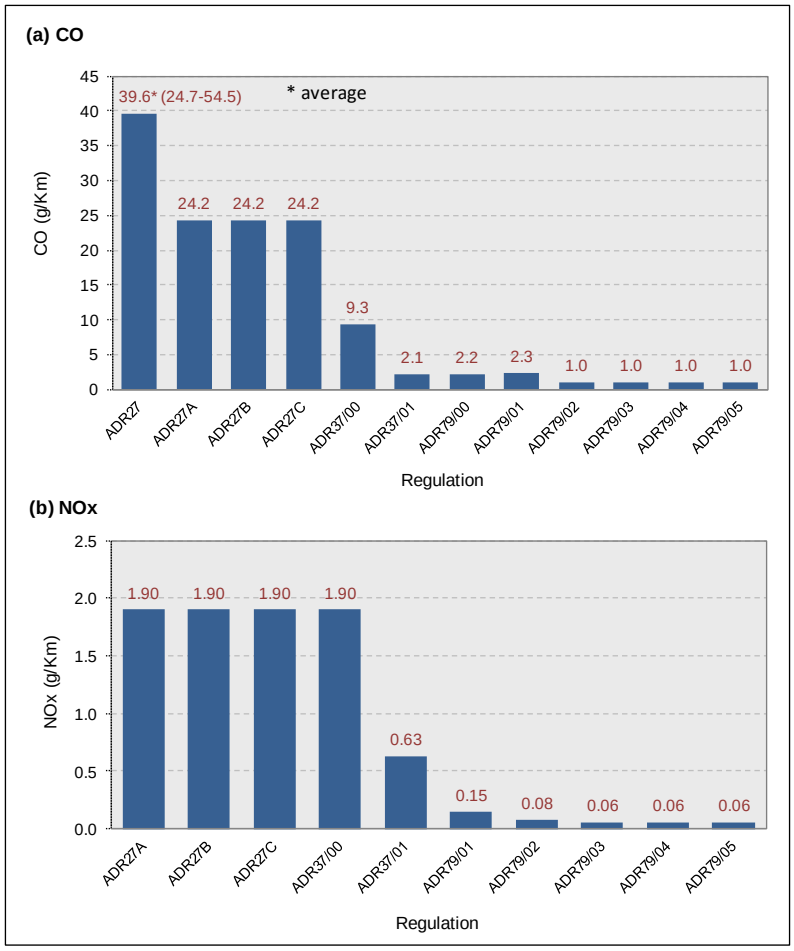

Figure B-1 Exhaust emission limits for CO and NO_X applicable to new petrol cars in Australia

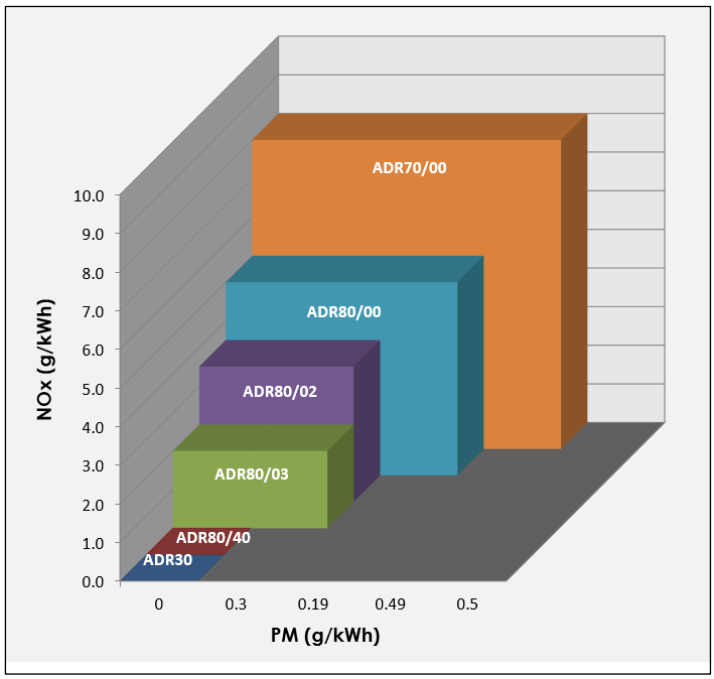

Figure B-2 Exhaust emission limits for NO_X and PM applicable to heavy-duty vehicles in Australia

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

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

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

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

B.2.2 Evaporative emissions

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

B.3 Ambient air quality standards and goals

B.3.1 Criteria pollutants

The metrics, criteria and goals set out for criteria pollutants in the NSW Approved Methods are listed in Table B-1. The pollutants shaded in grey were not included in the Sydney Gateway assessment.

For the criteria pollutants included in the assessment, the impact assessment criteria in the NSW Approved Methods and the National Environment Protection (Ambient Air Quality) Measure (AAQ NEPM) from February 2016 are compared with the WHO guidelines and the standards in other countries/organisations in Table B-2. For CO the NSW standards are numerically lower than, or equivalent to, those in most other countries and organisations. The NSW standards for NO_2 are higher than in the other countries and organisations except for the United States. In the case of PM_{10}, the NSW standard for the 24-hour mean is lower than, or equivalent to, the standards in force elsewhere, whereas the annual mean standard is in the middle of the range of values for other locations. The $PM_{2.5}$ standards are lower than, or equivalent to, those used elsewhere.

Such comparisons do not necessarily mean that the Australian standards are more or less stringent than those elsewhere. For example, to a large degree the lower standards in Australia for PM are made possible by relatively low natural background concentrations and the absence of significant anthropogenic transboundary pollution (which is a major issue in Europe, for example). Moreover there are differences in implementation. For example, there is no legal requirement for compliance with the standards and goals in Australia, whereas there is in some other countries and regions.

Schedule 1 of the *Airports (Environmental Protection) Regulations 1997* also defines ambient air quality objectives at airports, and these are included in Table B-1 where relevant (as '*[AEPR, 1997]*'). Where

the metrics are comparable, the values in the Regulations are effectively the same as those in the Approved Methods or are less stringent.

Table B-1 Impact assessment criteria for 'criteria pollutants' in NSW Approved Methods (NSW EPA, 2016)

Pollutant or metric	Criterion		Calculation	Source
	Concentration	Averaging period		
Carbon monoxide (CO)	87 ppm or 100 mg/m^3	15 minutes		WHO (2000)
	25 ppm or 30 mg/m^3	1 hour	One hour clock mean	WHO (2000)
	9 ppm or 10 mg/m^3	8 hours	Rolling mean of 1-hour clock means	NEPC (1998) *[AEPR, 1997]*
Nitrogen dioxide (NO_2)	120 ppb or 246 μg/m^3	1 hour	One hour clock mean	NEPC (1998)
	320 μg/m^3	1 hour	One hour clock mean	*[AEPR, 1997]*
	30 ppb or 62 μg/m^3	1 year	Calendar year mean	NEPC (1998)
Particulate matter <10 μm (PM_{10})	50 μg/m^3	24 hours	Calendar day mean	NEPC (2016)
	25 μg/m^3	1 year	Calendar year mean	NEPC (2016)
Particulate matter <2.5 μm ($PM_{2.5}$)	25 μg/m^3	24 hours	Calendar day mean	NEPC (2016)
	8 μg/m^3	1 year	Calendar year mean	NEPC (2016)
Sulfur dioxide (SO_2)	250 ppb or 712 μg/m^3	10 minutes		NHMRC (1996) *[AEPR, 1997]*
	200 ppb or 570 μg/m^3	1 hour	One hour clock mean	NEPC (1998) *[AEPR, 1997]*
	80 ppb or 228 μg/m^3	1 day	Calendar day mean	NEPC (1998)
	20 ppb or 60 μg/m^3	1 year	Calendar year mean	NEPC (1998) *[AEPR, 1997]*
Sulfates	15 μg/m^3	1 year	Calendar year mean	*[AEPR, 1997]*
Lead (Pb)	0.5 μg/m^3	1 year	Calendar year mean	NEPC (1998)
	1.5 ppm	3 months		*[AEPR, 1997]*
Total suspended particulate matter (TSP)	90 μg/m^3	1 year	Calendar year mean	NHMRC (1996) *[AEPR, 1997]*
Photochemical oxidants (as ozone (O_3))	100 ppb or 214 μg/m^3	1 hour	One hour clock mean	NEPC (1998) *[AEPR, 1997]* (b)
	80 ppb or 171 μg/m^3	4 hours	Rolling mean of 1-hour clock means	NEPC (1998) *[AEPR, 1997]* (c)
Hydrogen fluoride (HF)(a)	0.50/0.25 μg/m^3	90 days		ANZECC (1990)
	0.84/0.40 μg/m^3	30 days		ANZECC (1990)
	1.70/0.40 μg/m^3	7 days		ANZECC (1990)
	2.90/1.50 μg/m^3	24 hours		ANZECC (1990)

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

(b) Given as 210 μg/m^3 in the *Airports (Environment Protection) Regulations 1997*.

(c) Given as 170 μg/m^3 in the *Airports (Environment Protection) Regulations 1997*.

Table B-2 Comparison of international health-related ambient air quality standards and criteria[a]

Country/Region/ Organisation	CO			NO_2			PM_{10}		$PM_{2.5}$	
	15 min. (mg/m^3)	1 hour (mg/m^3)	8 hours (mg/m^3)	1 hour ($\mu g/m^3$)	1 day ($\mu g/m^3$)	1 year ($\mu g/m^3$)	24-hours ($\mu g/m^3$)	1 year ($\mu g/m^3$)	24-hours ($\mu g/m^3$)	1 year ($\mu g/m^3$)
NSW Approved Methods	**100(0)**	**30(0)**	**10(0)**	**246(0)**	**-**	**62**	**50(0)**	**25**	**25(0)**	**8**
AAQ NEPM	**-**	**-**	**10(1)[b]**	**246(1)[b]**	**-**	**62**	**50(0)**	**25**	**25(0)/20(0)[c]**	**8/7[c]**
WHO	100(0)	30(0)	10(0)	200	-	40	50[d]	20	25[d]	10
Canada	-	-	-	-	-	-	120[e,f]	-[e]	28/27[g]	10/8.8[g]
European Union	-	-	10(0)	200(18)	-	40	50(35)	40	-	25[h]
Japan	-	-	22(0)	-	75-115	-	-	-	-	-
New Zealand	-	-	10(1)	200(9)	-	-	50(1)	-	-	-
UK	-	-	10(0)[i]	200(18)	-	40	50(35)	40	-	25
UK (Scotland)	-	-	10(0)[j]	200(18)	-	40	50(7)	18	-	12
United States (USEPA)	-	39(1)	10(1)	190[k]	-	100	150(1)	-	35[l,m]	12[l]
United States (California)	-	22(0)	10(0)	344(0)	-	57	50	20	-	12

(a) Numbers in brackets shows allowed exceedances per year for short-term standards. Non-health standards (eg for vegetation) have been excluded.
(b) One day per year.
(c) Goal by 2025.
(d) Stated as 99th percentile.
(e) Although there is no national standard, some provinces have standards.
(f) As a goal.
(g) By 2015/2020.
(h) The 25 $\mu g/m^3$ value is initially a target, but became a limit in 2015. There is also an indicative 'Stage 2' limit of 20 $\mu g/m^3$ for 2020.
(i) Maximum daily running 8-hour mean.
(j) Running 8-hour mean.
(k) 98th percentile, averaged over 3 years.
(l) Averaged over three years.
(m) Stated as 98th percentile.

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

For criteria pollutants the following steps must be applied:

- The predicted concentrations should be compared with the standards for the nearest existing or likely future 'off-site' sensitive receptor. In this assessment, this concept has been extended to include all potentially affected receptor locations outside the construction footprint
- The incremental impact (predicted impacts due to the pollutant source alone) for each pollutant must be reported in units and averaging periods that are consistent with the air quality criteria
- Background concentrations must be included using the procedures specified in section 5 of the NSW Approved Methods

- The total impact (incremental impact plus background) must be reported as the 100th percentile in concentration units that are consistent with the criteria, and compared with the relevant criteria.

For air toxics, the steps mostly correspond to those above, with some slight differences. For example, the criteria for individual pollutants must be applied 'at and beyond the boundary of the facility', and incremental impacts must be reported for an averaging period of one hour and as the 100th percentile of model predictions for screening assessments or the 99.9th percentile of model predictions for more detailed assessments.

However, any assessment against these goals would not have been very meaningful because the measured background concentrations of $PM_{2.5}$ were already above the goals. This is also one reason why the change in the annual mean $PM_{2.5}$ concentration was also considered.

The human health risk assessment (**Technical Working Paper 15** of the EIS) has adopted a risk level in excess of 10^{-4} (one chance in 10,000) as a point where risk is considered to be unacceptable. Although the health assessment considers a comprehensive range of health endpoints, the key metric that emerged during the assessment of the NorthConnex and WestConnex projects was the increase of risk in all-cause mortality for ages 30 and over. An increase in risk of all-cause mortality is related directly to the change in the annual mean $PM_{2.5}$ concentration ($\Delta PM_{2.5}$) (Pacific Environment, 2015b; Pacific Environment, 2015c). A risk of one in 10,000 equates to a value for $\Delta PM_{2.5}$ that varies depending on the baseline mortality, and is calculated as follows:

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

Where, for the project study area:

R = additional risk

β = slope coefficient for the % 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) (976.6 per 100,000 for mortality all causes ≥ 30 years) (Golder Associates, 2013)

This equation can be rewritten as:

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

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

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

Pollutants and metrics excluded from the assessment

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

- Sulfur dioxide (SO_2). SO_2 is emitted from road vehicles, and results from the oxidation of the sulfur present in fuels during combustion. However, SO_2 emissions are directly proportional to the sulfur content of the fuel, and emissions have decreased considerably as a result of controls on fuel quality. For example, in 1999 the average sulfur content of diesel was 1,300 ppm. In December 2002, a new standard was introduced, reducing the maximum sulfur content of diesel to 500 ppm. Currently, the sulfur level in premium

unleaded petrol is 50 ppm, and in diesel it is 10 ppm[4]. The emissions of SO_2 from road vehicles are therefore now very low, and SO_2 is no longer a major concern in terms of transport-related air quality

- Lead (Pb). In cities, motor vehicles operating on leaded petrol used to be the main source of lead in the atmosphere. However, as a result of the introduction of unleaded petrol in 1985, the progressive reduction of the lead content of leaded petrol, and reductions in emissions of lead from industry, there has been a significant fall in annual average concentrations of lead in ambient air throughout NSW (often to below the minimum detection limit) (DECCW, 2010). Since 2002 the lead content of petrol has been limited to 0.005 grams per litre. As a result, lead is no longer considered to be an air quality and health concern away from specific industrial activities (such as smelting)
- Total suspended particulate (TSP). TSP is rather an old metric that is no longer the focus of health studies. For example, the USEPA replaced its TSP standard with a PM_{10} standard in 1987. For exhaust emissions from road transport, it can be assumed that TSP is equivalent to PM_{10} (and also $PM_{2.5}$). Although it is possible that a fraction of non-exhaust particles is greater than 10 µm in diameter, this is not well quantified
- Ozone (O_3). Because of its secondary and regional nature, ozone cannot practicably be considered in a local air quality assessment. Emissions of ozone precursors (NO_X and VOCs) are distributed unevenly in urban areas, and concentrations vary during the day. Complicating this further are the temporal and spatial variations in meteorological processes. Ozone formation is non-linear, so reducing or increasing NO_X or VOC emissions does not necessarily result in an equivalent decrease or increase in the ozone concentration. This non-linearity makes it difficult to develop management scenarios for ozone control (DECCW, 2010). Ozone was, however, considered in the regional air quality assessment (refer to **section** Error! Reference source not found.)
- Hydrogen fluoride (HF). The standards for HF relate to sensitive vegetation rather than human health, and HF is not a pollutant that is relevant to road vehicle operation.

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

It is also worth noting that in recent years a considerable amount of attention has focussed on 'ultrafine' particles (UFPs). These are particles with a diameter of less than 0.1 µm. Although there is some evidence particles in this size range are associated with adverse health effects, it is not currently practical to incorporate them into an environmental impact assessment. There are several reasons for this, including:

- The rapid transformation of such particles in the atmosphere
- The need to treat UFPs in terms of number rather than mass
- The lack of robust emission factors
- The lack of robust concentration-response functions
- The lack of ambient background measurements
- The absence of air quality standards.

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

> 'The richest set of studies provides quantitative information for $PM_{2.5}$. For ultrafine particle numbers, no general risk functions have been published yet, and there are far

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

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 $PM_{2.5}$.

B.3.2 Air toxics

The investigation levels in the Air Toxics NEPM are summarised in Table B-3. These are not compliance standards but are for use in assessing the significance of the monitored levels of air toxics with respect to protection of human health. They have therefore not been considered further in the assessment.

The NSW Approved Methods, on the other hand, specify air quality impact assessment criteria and odour assessment criteria for many substances, including air toxics, and these are too numerous to reproduce here. The SEARs for the project require an evaluation of BTEX compounds: benzene, toluene, ethylbenzene, and xylenes. The impact assessment criteria in the NSW Approved Methods for priority air toxics and BTEX compounds are given in Table B-4. The criteria for some other specific compounds which are typically assessed for road traffic are also included.

Table B-3 Investigation levels for air toxics

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

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

Table B-4 Impact assessment criteria for air toxics

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

(a) Odour criterion

Annexure C- Description and evaluation of NSW EPA emission model

C.1 Overview

A spatial emissions inventory was developed for the traffic on the surface road network in the GRAL domain, including any new roads associated with the project. Emissions were calculated on a link-by-link basis using a model[1] developed by NSW EPA (2012b). A description of the NSW EPA model, and an evaluation of its performance, is provided in the following sections.

C.2 NSW EPA model

C.2.1 Hot running exhaust emissions

The NSW EPA method for calculating hot running exhaust emissions involves the use of matrices of 'base composite' emission factors for:

- Six pollutants (CO, NO_X, NO_2, PM_{10}, $PM_{2.5}$, THC)[2].
- The following vehicle types:
    - Light-duty vehicles (LDVs), which include:
        - Petrol passenger vehicles
        - Diesel passenger vehicles
        - Petrol light-duty commercial vehicles (LCVs) (≤3,500 kg)
        - Diesel light-duty commercial vehicles (≤3,500 kg)
    - Heavy-duty vehicles (HDVs), which include:
        - Petrol heavy-duty commercial vehicles (>3,500 kg)
        - Diesel heavy good vehicles (HGVs), which include:
            - Rigid trucks (3,500-25,000 kg)
            - Articulated trucks (>25,000 kg)
        - Diesel heavy public transport buses
    - Motorcycles

  The composite emission factor for each vehicle type took into account vehicle-kilometres travelled (VKT) by age, and the emission factors for specific emission standards.
- Five road types (residential, arterial, commercial arterial, commercial highway, highway/ freeway), to allow for differences in traffic composition and driving patterns.
- Nine model years (2003, 2008, 2011, 2016, 2021, 2026, 2031, 2036 and 2041). The year defines the composition of the fleet for each type of vehicle, allowing for technological changes. The base year for the inventory was 2008, and the data for years after 2008 were projections.

The road types used in the emission inventory for the NSW Greater Metropolitan Region (GMR) were mapped to Roads and Maritime functional classes by NSW EPA (Table C-1). Further information on the mapping of these categories is provided in the inventory report (NSW EPA, 2012b).

[1] The model used for this assessment was a simplified version of the full inventory model that was developed by NSW EPA for use in the Roads and Maritime air quality screening model TRAQ.

[2] It is assumed that $PM_{2.5}$ is equivalent to PM_{10}, which is appropriate for exhaust emissions. The NO_2 emission factors were not used in the assessment.

Each base composite emission factor was defined for a VKT-weighted average speed (the base speed) associated with the corresponding road type. Dimensionless correction factors – in the form of 6th-order polynomial functions – were then applied to the base emission factors to take into account the actual speed on a road. According to NSW EPA, the speed correction factors are valid up to 110 kilometres per hour for light-duty vehicles, and up to 100 kilometres per hour for heavy-duty vehicles.

Emission factors have also been provided by NSW EPA for heavy-duty vehicles with and without the implementation of the Euro VI regulation. Given the uncertainty in the implementation of Euro VI in Australia, the (higher) 'without Euro VI' emission factors were used in the assessment.

Table C-1 Road types used in the NSW EPA emissions inventory model

NSW GMR inventory road type	Roads and Maritime functional class	Definition/description
Local/residential	Local road	Secondary road with prime purpose of access to property. Low congestion and low level of heavy vehicles. Generally one lane each way, undivided with speed limit up to 50 km/h. Regular intersections, mostly unsignalised, and low intersection delays.
Arterial	Sub-arterial and arterial	Connection from local roads to arterials. May provide support role to arterial roads for movement of traffic during peak periods. Distribute traffic within residential, commercial and industrial areas. Speed limit 50-70 km/h, 1-2 lanes. Regular intersections, mostly uncontrolled. Lower intersection delays than residential roads, but significant congestion impact at high volume:capacity ratio (V/C).
Commercial arterial	Arterial	Major road for purpose of regional and inter-regional traffic movement. Provides connection between motorways and sub-arterials/collectors. May be subject to high congestion in peak periods. Speed limit 60-80 km/h, typically dual carriageway. Regular intersections, many signalised, characterised by stop-start flow, moderate to high intersection delays and queuing with higher V/C.
Commercial highway	Arterial	Major road for purpose of regional and inter-regional traffic movement. Provides connection between motorways and sub-arterials/collectors. May be subject to moderate congestion in peak periods. Speed limit 70-90 km/h, predominantly dual carriageway. Fewer intersections than commercial arterial, with smoother flow but subject to some congestion at high V/C.
Highway/freeway	Motorway	High volume road with primary purpose of inter-regional traffic movement with strict access control (ie no direct property access). Speed limit 80-110 km/h, predominantly 2+ lanes and divided carriageway. Relatively free-flowing when not congested, slowing with congestion approaching V/C limit but minimal stopping.

The emission factor for a given traffic speed was calculated as follows:

Equation C1

$$\mathbf{EF_{HotSpd}} = \mathbf{EF_{HotBasSpd}} \times \frac{\mathbf{SCF_{Spd}}}{\mathbf{SCF_{BasSpd}}}$$

Where:

EF_{HotSpd} is the composite emission factor (in g/km) for the defined speed

$EF_{HotBasSpd}$ is the composite emission factor (in g/km) for the base speed

SCF_{Spd} is the speed-correction factor for the defined speed

SCF_{BasSpd} is the speed-correction factor for the base speed

Each speed-correction factor is a 6th order polynomial: $\mathbf{SCF = aV^6 + bV^5 + \ldots + fV + g}$, where **a** to **g** are constants and **V** is the speed in kilometres per hour.

Some examples of the resulting emission factors are shown in the Figures below. Figure C-1 shows how NO_X emissions (mass per vehicle-km) from petrol cars vary as a function of average speed[3] on different road types. The Figures show that some types of road, notably arterial roads, are associated with higher emissions for a given average speed than others. Figure C-2 shows how emissions (again, per vehicle-km) of different pollutants from petrol cars will decrease in the future as emission-control technology improves. PM emissions from petrol vehicles are projected to be dominated by non-exhaust particles. Because these are unregulated the reduction in emissions in the future will be lower than for the other pollutants.

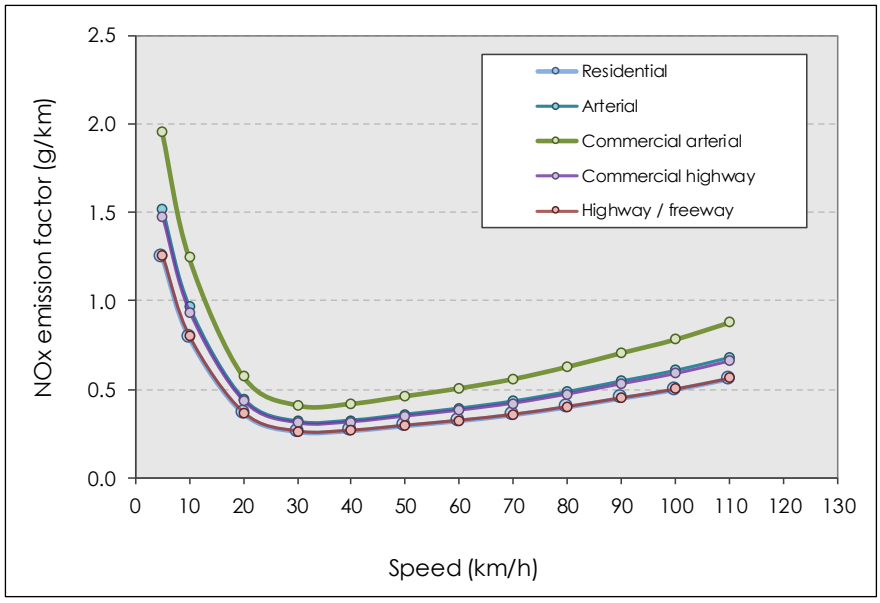

Figure C-1 NO_X emission factors for petrol cars in 2014

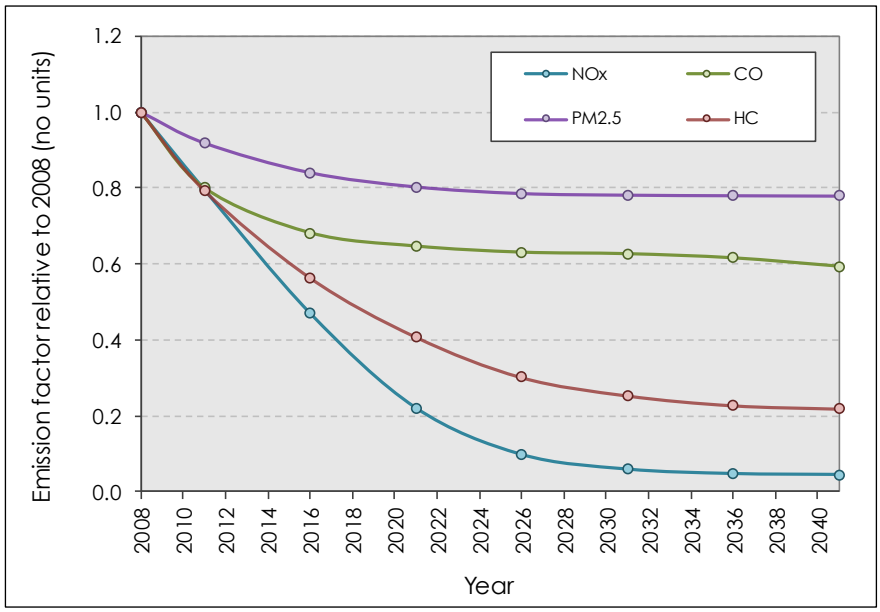

Figure C-2 Emission factors for petrol cars at 80 kilometres per hour, normalised to 2008

[3] 'Average speed' should not be confused with 'constant speed'. The former is calculated for a driving cycle which includes periods of acceleration, deceleration, cruise, and idle, as encountered in real-world traffic.

C.2.2 Gradient factors

NSW EPA has not developed any factors to allow for the effects of road gradient on hot running emissions. For this assessment, gradient factors were determined using the emission rates in PIARC (2012)[4]. For each gradient and speed, the gradient correction factor was determined by dividing the corresponding PIARC emission rate by the emission rate for zero gradient.

The gradient correction is introduced as follows:

Equation C2

$$\mathbf{EF_{HotGradCor} = EF_{HotSpd} \times G}$$

Where:

$EF_{HotGradCor}$ is the composite emission factor (in g/km), corrected for road gradient

G is the road gradient correction factor. Different values of **G** are used for each pollutant, vehicle type and speed.

No gradient corrections were applied to THC (any vehicles) or to PM emissions from petrol vehicles.

C.2.3 Cold-start emissions

The method for calculating cold-start emissions involved the application of adjustments to the base hot emission factors to represent the extra emissions which occur during 'cold running'. The adjustments took into account the distance driven from the start of a trip, the parking duration and the ambient temperature. Cold-start emissions were only calculated for light-duty vehicles, and no cold-start adjustment was made for PM. The amount of 'cold running' was dependent on the road type, and no cold running was assumed for highways.

Cold-start emissions were therefore calculated as follows:

Equation C3

$$\mathbf{EF_{Cold} = EF_{HotBasSpd} \times (CS-1)}$$

Where:

EF_{Cold} is the cold-start emission factor (in g/km)

CS is a cold start adjustment factor (>1). Different values of **CS** are used for each pollutant, vehicle type, road type and year.

C.2.4 Non-exhaust PM emissions

The method for non-exhaust PM_{10} and $PM_{2.5}$ emissions was taken from the EMEP/EEA Air Pollutant Emission Inventory Guidebook (EEA, 2016), and included tyre wear, brake wear and road surface wear. Emission factors (in g/km) were provided for each vehicle type, road type and year. Information was required for parameters such as vehicle load and number of axles, and the assumptions used for vehicles in the NSW GMR are described in NSW EPA (2012b).

C.2.5 Evaporative emissions

Evaporative emissions of VOCs were not included in the version of the NSW EPA model described here, although they were included in the more detailed full inventory model. The calculation of evaporative emissions is relatively complex, as it requires an understanding of temperature profiles, fuel vapour pressure, fuel composition, and operational patterns. Moreover, it is difficult to allocate

[4] PIARC has subsequently updated its guidance (PIARC, 2019). However, the changes in the PIARC gradient scaling factors in the 2019 version of the guidance are relatively small overall compared with the inherent overestimation of the emission model.

evaporative emissions to traffic activity on specific road links, as running losses are only one component (for example, evaporative emissions also occur when vehicles are stationary). For these reasons evaporative emissions were excluded from the assessment. Ambient concentrations of VOCs are also very low, and the inclusion of evaporative emissions would be unlikely to result in adverse impacts on air quality.

C.3 Fleet data

In order to combine the emission factors in the models with traffic data, information was also required on the following:

- The fuel split (petrol/diesel) for cars. This was assumed to be the same for all road types.
- The fuel split (petrol/diesel) for LCVs. This was also assumed to be the same for all road types.
- The sub-division of HDVs into rigid HGVs, articulated HGVs and buses. This was dependent on road type. For example, the proportion of HGVs on major roads is typically higher than that on minor roads.

The fuel splits were originally provided by NSW EPA for the road types included in the emission model. More recently, Roads and Maritime has provided a revised fleet model to support the calculation of in-tunnel emissions (O'Kelly, 2016). The fuel splits for cars and LCVs from the Roads and Maritime work were used by Pacific Environment to update the fleet data provided by NSW EPA.

The Roads and Maritime fleet model did not differentiate between different types of road. For the sub-division of HDVs the default traffic mix information provided by NSW EPA was therefore used.

C.4 Model validation

C.4.1 Overall model performance

The accuracy of the NSW EPA model[5] in representing vehicle emissions (CO, NO_X, NO_2, PM_{10} and $PM_{2.5}$) was investigated using measurements from the ventilation outlets of the Lane Cove Tunnel during October and November 2013, as described in Pacific Environment (2014). The ventilation conditions in the tunnel result in all vehicle emissions being released from the ventilation outlets. No pollution is released from the tunnel portals. This makes it possible to compare the predicted mass emission rate (in g/h) for the traffic in each direction of the tunnel with the observed emission rate in the corresponding ventilation outlet.

The predicted and observed total (ie for all traffic) emission rates in the Lane Cove Tunnel were compared using a linear regression approach. The regression plots are shown in Figure C-3. Separate results are shown for each pollutant and each direction in the tunnel; the eastbound tunnel is predominantly uphill, and the westbound tunnel is predominantly downhill. In each graph the dashed red line represents a 1:1 ratio between the predicted and observed emission rates, and the solid lines show the linear regression fits to the data, forced through the origin[6]. The average quotients of the predicted and observed values are given in Table C-2.

[5] It should be noted that this work excluded the changes to the fuel splits for cars and LCVs following the Roads and Maritime fleet model revision in 2016. It was also based on gradient scaling factors in the emission model that were taken from PIARC (2012). As noted earlier, the changes in the PIARC gradient scaling factors in the 2019 version of the guidance are relatively small overall compared with the inherent overestimation of the emission model.

[6] As the outlet emission rates were adjusted for the background contribution, and there were no other in-tunnel emission sources, it was considered acceptable to run the regression model with the constant constrained to zero.

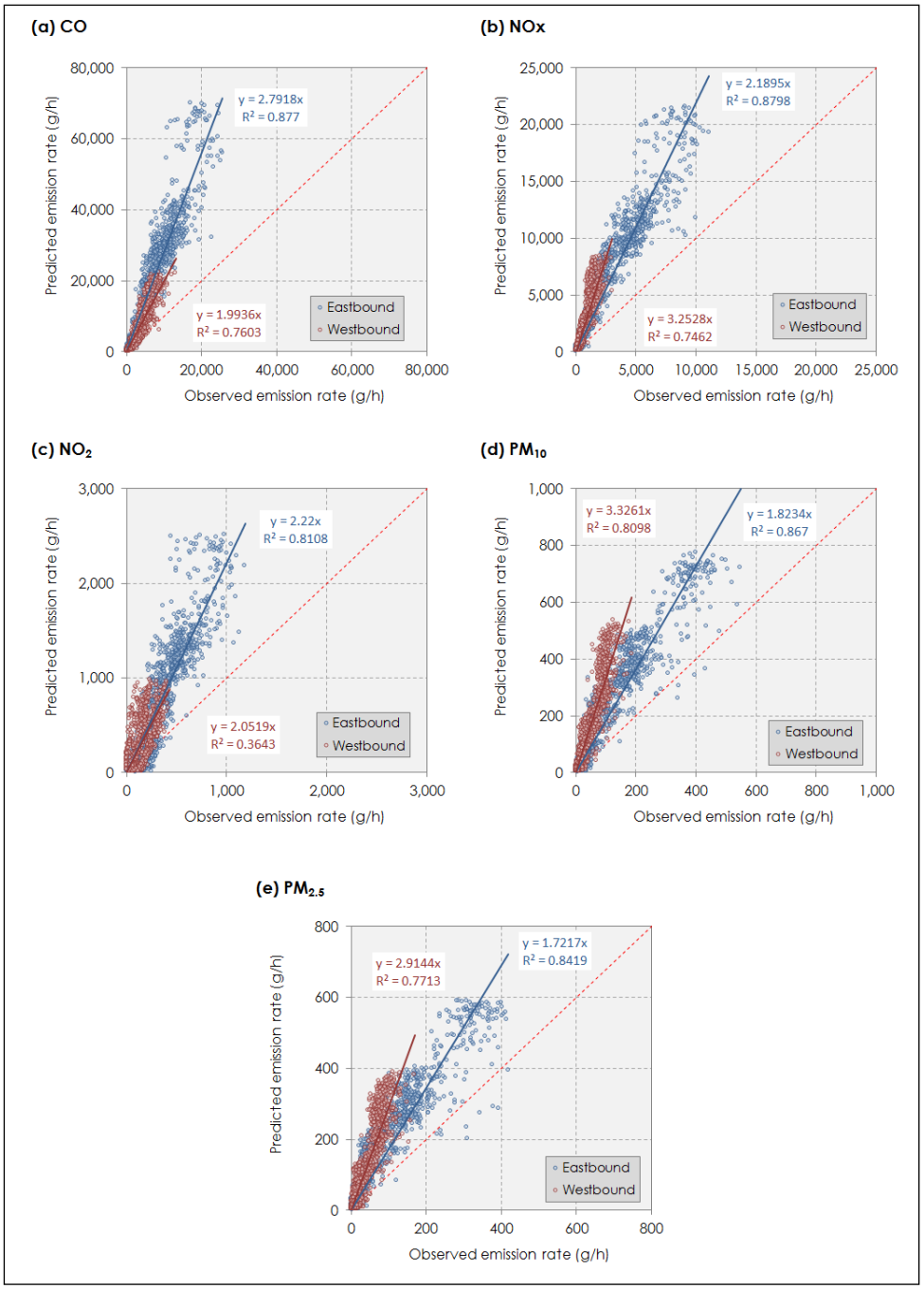

Figure C-3 Predicted vs observed emission rates – NSW EPA model

Table C-2 Summary of predicted vs observed emission rates – NSW EPA model

Model	Predicted emission rate / observed emission rate				
	CO	NO_x	NO_2	PM_{10}	$PM_{2.5}$
Eastbound					
NSW EPA	2.79	2.19	2.22	1.82	1.72
Westbound					
NSW EPA	1.99	3.25	2.06	3.32	2.91

Some general patterns were apparent in the results:

- 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 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 the age of the vehicle fleet in the tunnel.

  However, the differences between the predicted and observed emission rates are influenced not only by errors in the emission factors in the model, but also errors in the assumptions concerning the fleet composition and age distribution.

- 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. The strong correlations were due in large part to the narrow range of operational conditions (ie traffic composition, speed) in the Lane Cove Tunnel. In fact, the modelled emission rates were more or less directly proportional to the traffic volume.
- Different regression slopes were obtained for the eastbound and westbound directions. The eastbound tunnel has a net uphill gradient which would increase engine load and emissions, whereas in the downhill westbound tunnel engines would tend to be under lower load, with some newer vehicles with electronic fuel injection possibly having very low fuelling on downgrades. Such effects may not be adequately reflected in the gradient adjustment approach in the model.
- In the westbound tunnel the NO_2 data had more scatter than the NO_X data, and a low correlation coefficient was obtained. This is in part due to the relatively low emissions in the westbound tunnel and is possibly also a consequence of the measurement technique (chemiluminescence), which does not generally respond well to NO_2 concentrations which fluctuate rapidly on short timescales. The NO_X measurements are less affected by this problem, and ought to be more reliable.

C.4.2 Emission factors by vehicle type

A multiple linear regression (MLR) approach was used to determine mean emission factors (in g/km) for LDVs and HDVs based on the adjusted outlet emission rates (CO, NO_X, PM_{10} and $PM_{2.5}$). A similar MLR method has been used in various studies to derive emission factors (eg Imhof et al., 2005; Colberg et al., 2005).

The overall mean observed and predicted emission factors for LDVs, HDVs and all traffic (weighted for traffic volume) are shown in Table C-3, and the predicted/observed ratios are given in Table C-4.

It has already been observed that the NSW EPA model overestimated emissions in the Lane Cove Tunnel. It was noted in Pacific Environment (2014) that this is due in large part to the use of conservative gradient scaling factors. These additional results show that:

- For LDVs the predicted emissions were higher than the observed emissions in both the eastbound and westbound tunnels.
- For HDVs, emissions of CO, NO_X, PM_{10} and $PM_{2.5}$ in the eastbound 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.

Table C-3 Emission factors by vehicle type and direction

Direction	Pollutant	LDV (g/vehicle.km)		HDV (g/vehicle.km)		All traffic (g/vehicle.km)[a]	
		Observed	NSW EPA	Observed	NSW EPA	Observed	NSW EPA
Eastbound	CO	1.47	4.61	3.66	1.09	1.62	4.48
	NO_X	0.29	1.18	8.42	6.93	0.61	1.39
	NO_2	0.06	0.14	0.37	0.85	0.08	0.16
	PM_{10}	0.01	0.04	0.36	0.31	0.03	0.05
	$PM_{2.5}$	0.01	0.03	0.32	0.27	0.02	0.04
Westbound	CO	0.72[b]	1.53	-[c]	0.48	0.78	1.49
	NO_X	0.13	0.51	1.07	2.78	0.18	0.60
	NO_2	0.03	0.06	0.03	0.34	0.03	0.07
	PM_{10}	0.01	0.03	0.08	0.21	0.01	0.04
	$PM_{2.5}$	0.01	0.02	0.07	0.17	0.01	0.03

(a) Weighted for traffic volume.
(b) Based on regression for LDV only (see point (c) below).
(c) Multiple regression analysis did not result in a valid emission rate.

Table C-4 Predicted/observed emission factors by vehicle type and direction

Direction	Pollutant	LDV (predicted/observed)	HDV (predicted/observed)	All traffic (predicted/observed)[a]
Eastbound	CO	3.1	0.3	2.8
	NO_X	4.0	0.8	2.3
	NO_2	2.4	2.3	2.1
	PM_{10}	3.0	0.9	1.9
	$PM_{2.5}$	3.2	0.8	1.9
Westbound	CO	N/A	N/A	1.9
	NO_X	3.8	2.6	3.2
	NO_2	2.2	11.6	2.2
	PM_{10}	3.9	2.7	3.3
	$PM_{2.5}$	3.3	2.6	2.9

(a) Weighted for traffic volume.

C.5 Further general discussion on vehicle emission trends

The most detailed and comprehensive source of information on current and future emissions in the Sydney area is the emissions inventory[7] that is compiled periodically by NSW EPA. The base year of the latest published inventory is 2008 (NSW EPA, 2012a), and projections are available for 2011, 2016, 2021, 2026, 2031 and 2036. The importance of road transport as a source of pollution in Sydney can be illustrated by reference to sectoral emissions. The data for anthropogenic and biogenic emissions in Sydney, as well as a detailed breakdown of emissions from road transport, were extracted from the inventory by NSW EPA[8] and are presented here. Emissions were considered for the most recent historical year (2016) and for the future years.

Figure C-4 shows that road transport was the second largest sectoral contributor to emissions of CO (34 per cent) and the largest contributor to NO_X (47 per cent) in Sydney during 2016. It was also responsible for a significant proportion of emissions of VOCs (13 per cent), PM_{10} (9 per cent) and $PM_{2.5}$ (10 per cent). The main contributors to VOCs were domestic-commercial activity and biogenic sources. The most important sources of PM_{10} and $PM_{2.5}$ emissions were the domestic-commercial sector and industry. The contribution to PM from the domestic sector in Sydney was due largely to wood burning for heating in winter. Emissions from natural sources, such as bushfires, dust storms and marine aerosol, will have contributed significantly to ambient PM concentrations. Road transport contributed only two per cent of total SO_2 emissions in Sydney, reflecting the desulfurisation of road transport fuels in recent years. SO_2 emissions in Sydney were dominated by the off-road mobile sector and industry.

The projections of sectoral emissions in **Figure C-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 C-6**. Petrol passenger vehicles (mainly cars) accounted for a large proportion of the vehicle kilometres travelled (VKT) in Sydney[9]. Exhaust emissions from these vehicles were responsible for 65 per cent of CO from road transport in Sydney in 2016, 37 per cent of NOx, and 71 per cent of SO_2. They were a minor source of PM_{10} (3 per cent) and $PM_{2.5}$ (4 per cent). Non-exhaust processes were the largest source of road transport PM_{10} (71 per cent) and $PM_{2.5}$ (57 per cent). This is a larger proportion than in, say, most European countries, as there are relatively few diesel cars in Australia. It is also a cause for concern, as there are currently no controls for non-exhaust particles (and no legislation), and emissions would increase in line with projected traffic growth. Heavy-duty diesel vehicles are disproportionate contributors to NOx and PM emissions due to their inherent combustion characteristics, high operating mass (and hence high fuel usage) and level of emission control technology (NSW EPA, 2012b). Evaporation is the main source of VOCs.

The projections of road transport emissions are broken down by process and vehicle group in **Figure C-7**. There are projected to be substantial reductions in emissions of CO, VOCs, and NO_X between 2011 and 2036. There would be smaller changes in emissions of PM_{10} and $PM_{2.5}$ on account of the growing contribution of non-exhaust particles. SO_2 emissions are proportional to fuel sulfur content, and this is assumed to remain constant in the inventory. The inventory also provides emissions of specific organic compounds, based on speciation profiles of petrol and diesel fuels.

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

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

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

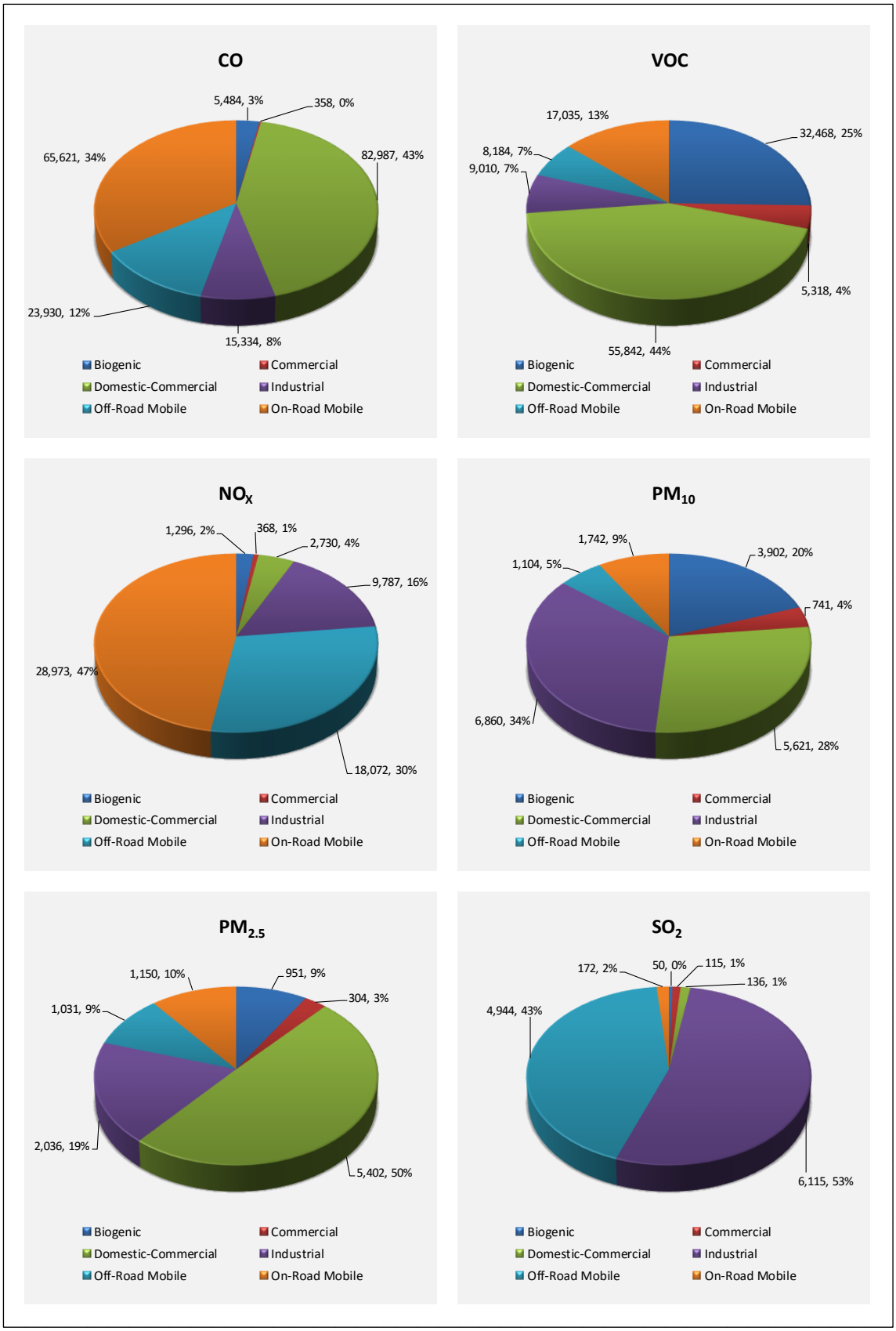

Figure C-4 Sectoral emissions in Sydney, 2016 (tonnes per year and percentage of total)

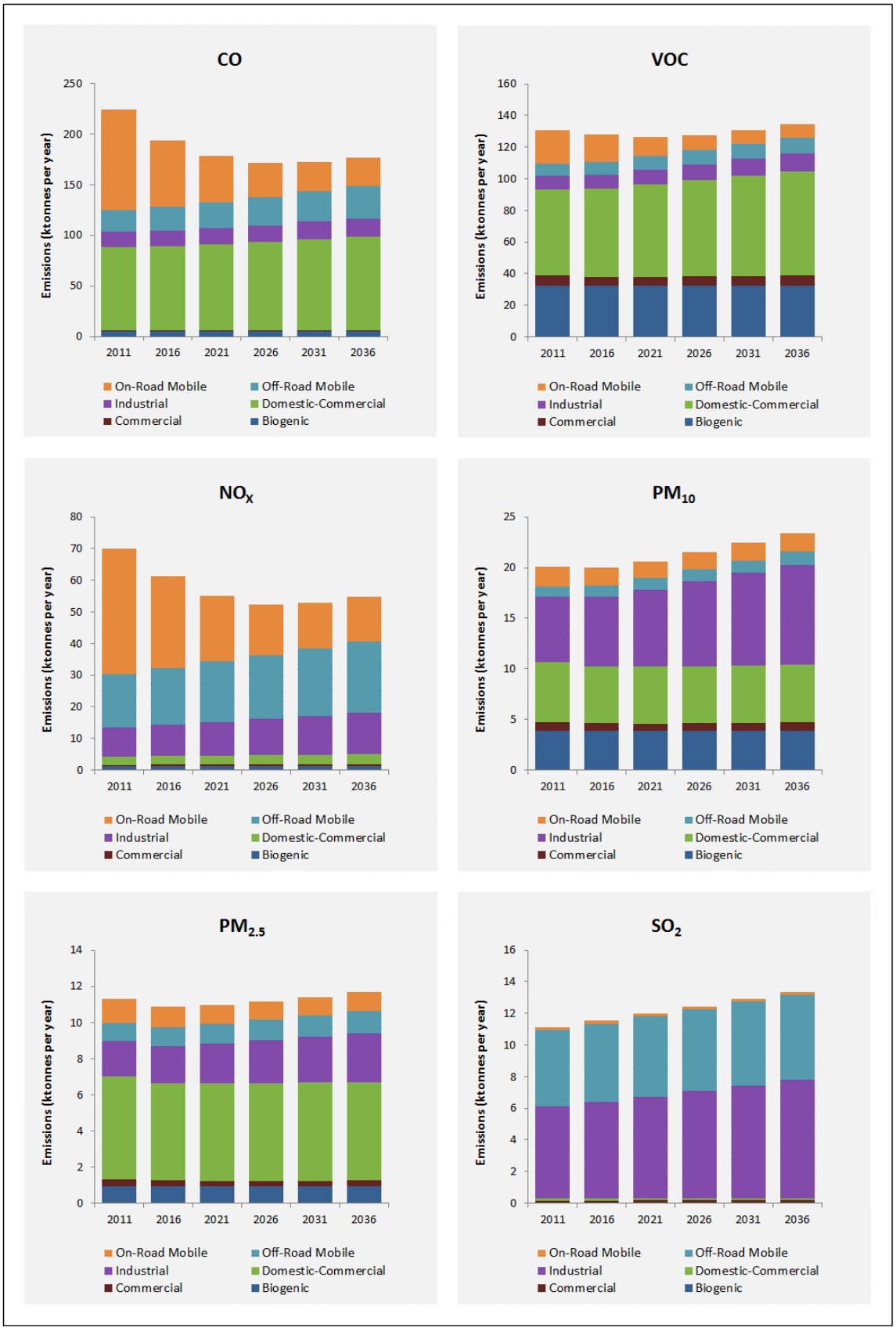

Figure C-5 Projections of sectoral emissions – Sydney, 2011-2036

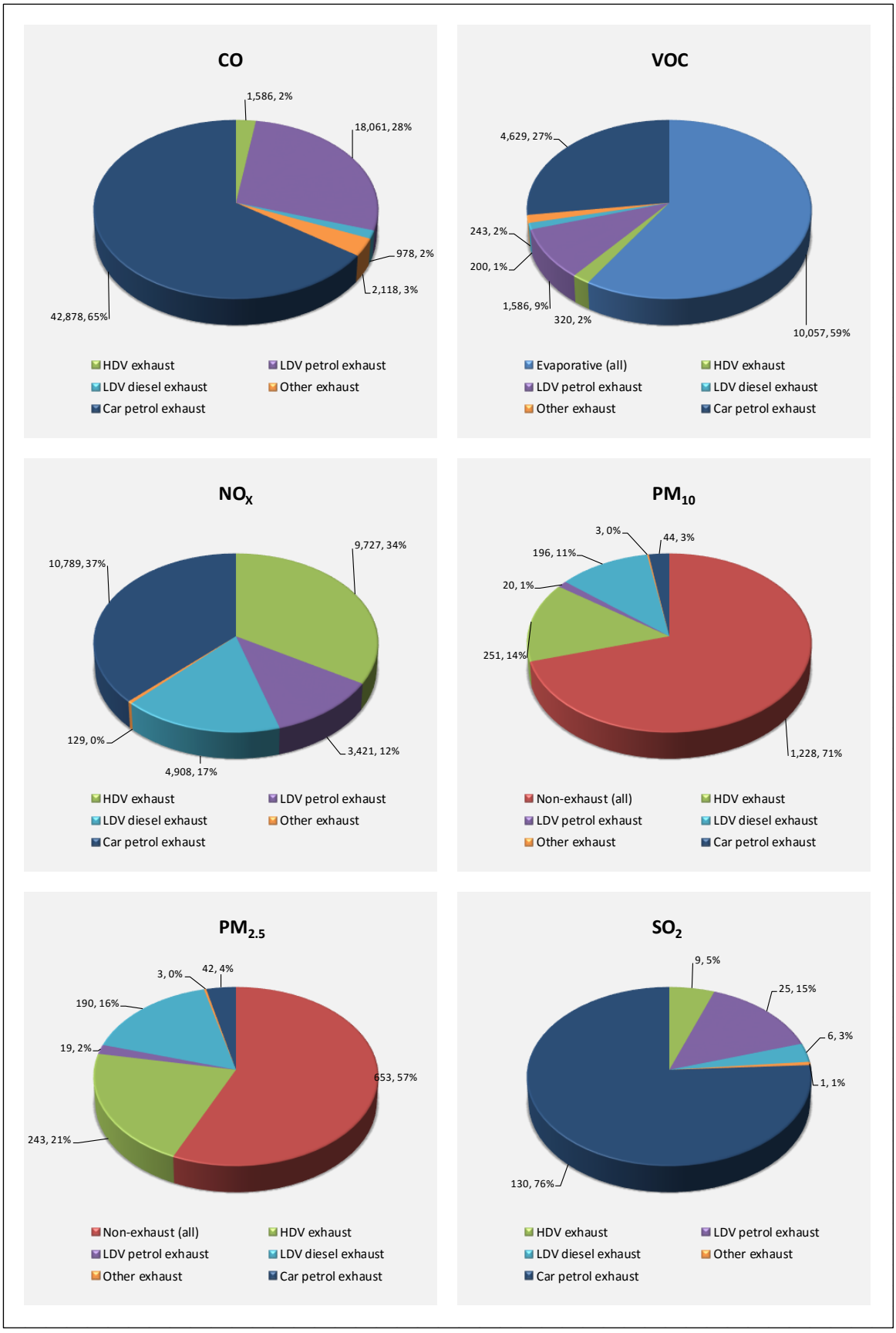

Figure C-6 Breakdown of road transport emissions – Sydney, 2016 (tonnes per year and percentage of total)

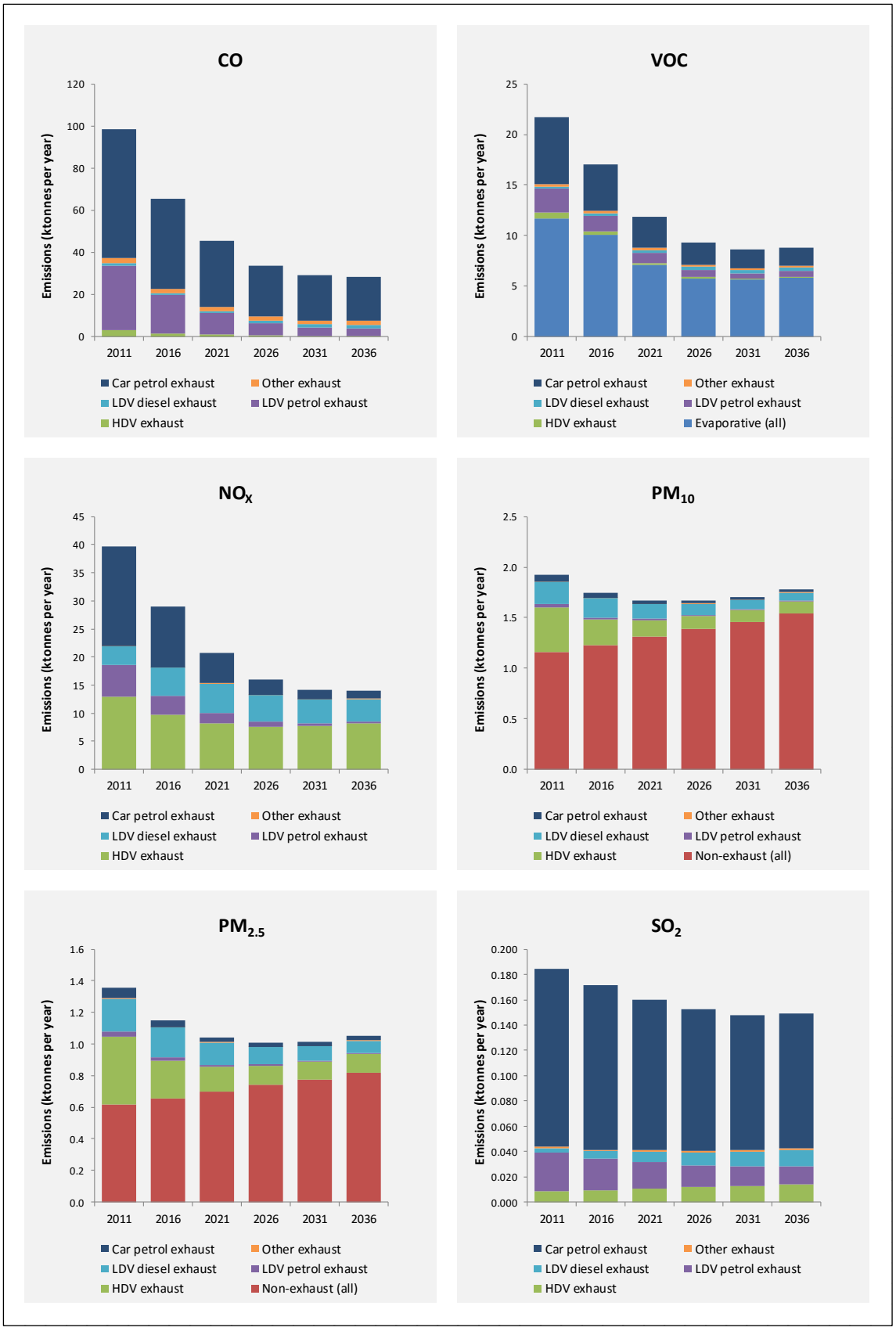

Figure C-7 Projections of road transport emissions – Sydney, 2011-2036

Annexure D- Existing air quality and background concentrations

D.1 Introduction and objectives

This Annexure provides the results of an analysis of the air quality monitoring data from multiple monitoring stations in and around the GRAL domain for Sydney Gateway.

The data were used for the following purposes:

(A) To define long-term trends and patterns in air quality in Sydney.

(B) To define background concentrations[1] in the 2016 base year[2]. Only monitoring stations with data for 2016 were used to derive background concentrations.

(C) To develop an empirical method for converting maximum 1-hour CO to maximum 8-hour CO.

(D) To develop an empirical method for converting modelled NO_X to NO_2.

(E) To evaluate dispersion model performance. This involved a comparison of model predictions with roadside measurements for the 2016 base year.

This Annexure focusses on items (A), (B) and (C). Items (D) and (E) are presented in Annexures E and G, respectively. However, all the stations used in the analysis are identified here.

D.2 Monitoring stations

The siting and classification of air quality monitoring stations is governed by the requirements of *Australian Standard AS/NZS 3580.1.1:2007 - Methods for sampling and analysis of ambient air - Guide to siting air monitoring equipment*. The Standard classifies monitoring stations as follows:

- Peak stations. These are located where the highest concentrations and exposures are expected to occur (such as near busy roads or industrial sources).
- Neighbourhood stations. These are located in areas which have broadly uniform land use and activity (e.g. residential areas or commercial zones).
- Background stations. These stations are located in urban or rural areas to provide information on air quality away from specific sources of pollution such as major roads or industry.

The Standard also recognises that, in practice, a given station may serve more than one function. Considerations when siting a monitoring station include the possibility of restricted air flow caused by buildings, trees, walls, etc, and chemical interference due to, for example, local emissions.

Air pollutants and meteorological parameters – such as temperature, wind speed and wind direction – are usually measured automatically and continuously, and such monitoring is conducted at several locations across Sydney for various purposes. The main monitoring stations used in the air quality assessment are listed in Table D-1 (background stations) and Table D-2 (roadside stations). The application of the data from each station in the air quality assessment is identified. All the main monitoring stations were within around 15 kilometres of the centre of the GRAL domain, as shown in Figure D-1 (background stations) and Figure D-2 (roadside stations).

[1] When predicting the impact of any new or modified source of air pollution, it is necessary to take into account the ways in which the emissions from the source will interact with existing ('background') pollutant levels.

[2] Although air quality monitoring data were available for 2017, the base year was taken to be 2016. The use of 2016 was consistent with the assessment for the F6 Extension Stage 1 project, which had a similar domain. The meteorological data for the main site (Randwick) were more complete in 2016 (98%) than in 2017 (86%), more monitoring stations could be included in the background maps for 2016 than 2017, and a more data from near-road sites were available for model evaluation.

Table D-1 Air quality monitoring stations – background

Organisation	Project	Station name	Location	Station type	Easting	Northing	Period covered in analysis	Application				
								Air quality trends	Background concentrations (mapped annual)	Background concentrations (synthetic hourly profile)	NO_X to NO_2 conversion[(a)]	CO 1h to 8h conversion[(a)]
OEH	N/A	Chullora	Southern Sydney TAFE - Worth St	Urban background	319315	6248145	Jan 2004 to Dec 2017	✓	✓	-	✓	✓
		Earlwood	Beaman Park	Urban background	327663	6245576	Jan 2004 to Dec 2017	✓	✓	✓	✓	-
		Randwick	Randwick Barracks	Urban background	337588	6244021	Jan 2004 to Dec 2017	✓	✓	-	✓	-
		Rozelle	Rozelle Hospital	Urban background	330169	6251372	Jan 2004 to Dec 2017	✓	✓	-	✓	✓
RMS	M5 East Tunnel	M5E: CBMS	Gipps Street, Bardwell Valley	Urban background	327713	6243517	Jan 2008 to Dec 2017	✓	-	-	✓	✓
		M5E: T1	Thompson Street, Turrella	Urban background	328820	6244172	Jan 2008 to Dec 2017	✓	-	-	✓	✓
		M5E: U1	Jackson Place, Earlwood	Urban background	328277	6244422	Jan 2008 to Dec 2017	✓	-	-	✓	✓
		M5E: X1	Wavell Parade, Earlwood	Urban background	327923	6244507	Jan 2008 to Dec 2017	✓	-	-	✓	✓
RMS	F6 Extension	F6:01	Kings Road, Rockdale	Urban background	328954	6240641	Dec 2017 to Jun 2018	-	-	-	✓	-
SMC	WestConnex M4 East	M4E:05	St Lukes Park, Concord	Urban background	325187	6251158	Nov 2014 to Sep 2017	-	✓	-	✓	✓
	WestConnex New M5	New M5:01	St Peters Public School, Church St	Urban Background	331330	6246007	Aug 2015 to Dec 2017	-	✓	✓	✓	✓
		New M5:04	Bestic St, Rockdale	Urban Background	329175	6241749	Jul 2015 to Sep 2016	-	✓[(b)]	✓	✓	-
		New M5:06	Beverly Hills Park, Beverly Hills	Urban Background	323296	6242297	Jul 2015 to Sep 2016	-	✓[(b)]	-	✓	-

(a) Data from the OEH stations at Lindfield, Liverpool and Prospect, as well as from other road projects, were also used for this purpose.
(b) Adjusted to give annual mean for 2016.

Table D-2 Air quality monitoring stations – roadside

Organisation	Project	Station name	Location	Station type	Easting	Northing	Period covered in analysis	Application			
								Air quality trends	NO_X to NO_2 conversion	CO 1h to 8h conversion	Model performance
RMS	M5 East Tunnel	M5E: F1	Flat Rock Rd, Kingsgrove (M5 East)	Peak (roadside)	325204	6243339	Jan 2008 to Dec 2017	✓	✓	✓	-
		M5E: M1	M5 East tunnel portal	Peak (roadside)	329258	6243283	Jan 2008 to Dec 2017	✓	✓	✓	✓
RMS	F6 Extension	F6:01	Kings Road, Rockdale	Urban background	330321	6241909	Dec 2017 to Jun 2018	-	✓	-	-
SMC	WestConnex M4 East	M4E:01	Wattle Street, Haberfield	Peak (roadside)	327563	6250234	Aug 2014 to Mar 2016	-	✓	✓	-
		M4E:02	Edward Street, Concord	Peak (near-road)	323764	6251146	Sep 2014 to Mar 2016	-	✓	✓	-
		M4E:03	Bill Boyce Reserve, Homebush	Peak (near-road)	322467	6251602	Sep 2014 to Mar 2016	-	✓	✓	-
		M4E:04	Concord Oval, Concord	Peak (roadside)	325030	6250752	Nov 2014 to Sep 2017	-	✓	✓	-
	WestConnex New M5	New M5:02	Princes Highway, St Peters	Peak (roadside)	331661	6246053	Jul 2015 to Apr 2016	-	✓	-	✓[(a)]
		New M5:03	West Botany St, Arncliffe	Peak (roadside)	329182	6243268	Aug 2015 to Jun 2016	-	✓	-	✓[(a)]
		New M5:07	Canal Rd, St Peters	Peak (road/industrial)	331520	6245420	Jul 2015 to Apr 2016	-	✓	-	✓[(a)]
	WestConnex M4-M5 Link	M4-M5:01	City West Link, Rozelle	Peak (roadside)	331142	6250768	Apr 2016 to Dec 2016	-	✓	-	-
		M4-M5:02	Ramsay Street, Haberfield	Peak (roadside)	327363	6250306	Apr 2016 to Dec 2016	-	✓	-	-

(a) Only partial data for 2016 were available for model evaluation.

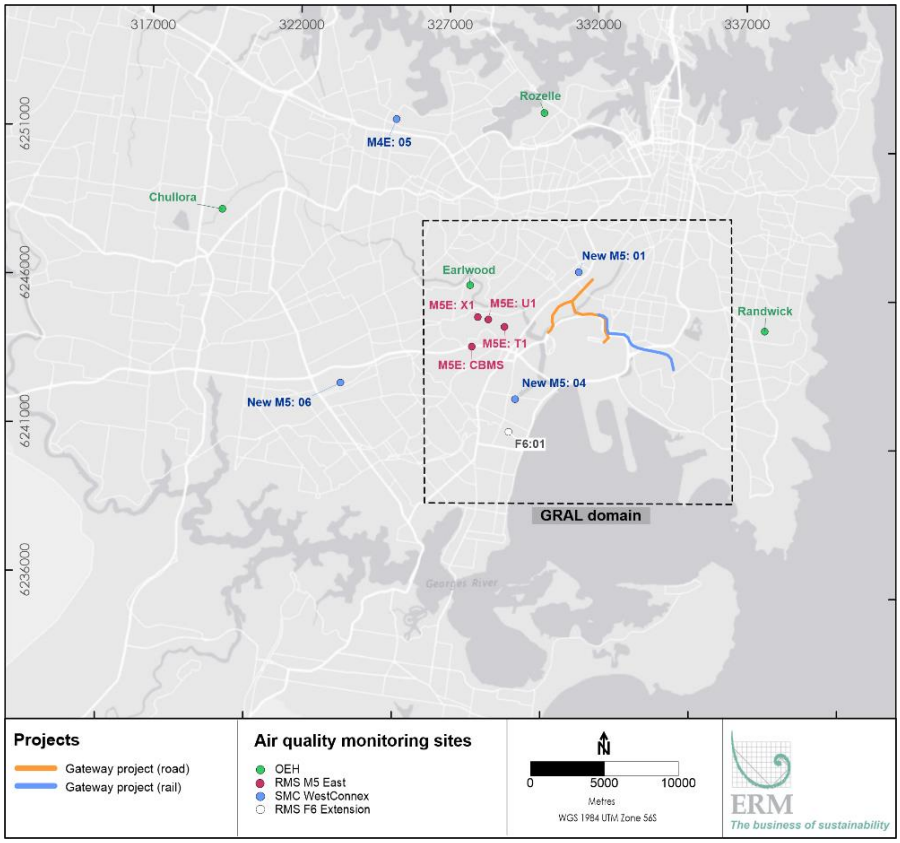

Figure D-1 Locations of background air quality monitoring stations

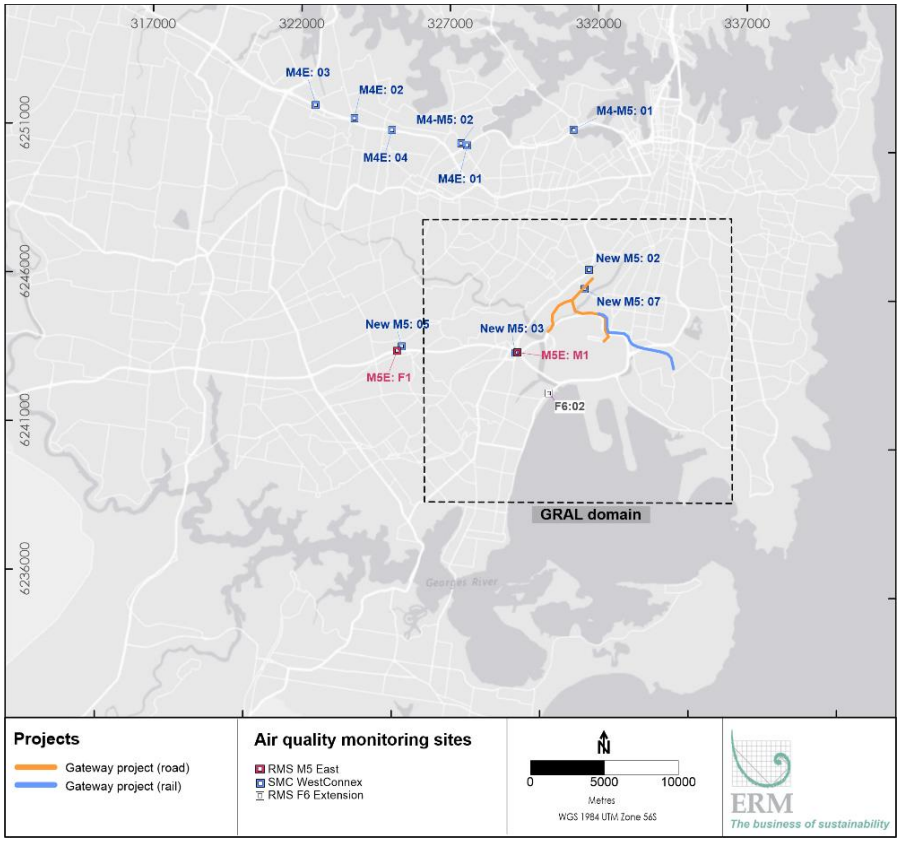

Figure D-2 Locations of roadside air quality monitoring stations

Long-term trends in air quality were evaluated using data from stations operated by NSW Office of Environment and Heritage (OEH) and Roads and Maritime. Until relatively recently, most of the monitoring in Sydney has focussed on background locations in urban agglomerations but away from specific sources such as major roads. The monitoring stations operated by OEH are located in such environments, and these have provided a vital record of regional air quality over the years. The only OEH station in the GRAL domain was at Earlwood. Roads and Maritime has established several long-term monitoring stations near the M5 East Tunnel ventilation outlet to track operational compliance with air quality standards. Four of the M5 East stations (CBMS, T1, U1, X1) are in the vicinity of the M5 East ventilation outlet. Stations U1 and X1 are located on a ridge to the north of the outlet, in the region of the predicted maximum impact. However, the impacts of the outlet at the monitoring stations are very small in practice, and these can effectively be considered as urban background stations. Two M5 East stations (F1 and M1) are much closer to busy roads near the M5 East tunnel portals.

For some aspects of the assessment, such as the conversion of NO_X to NO_2, shorter time series data from other air quality monitoring stations were also used. These included the stations established for the NorthConnex, Western Harbour Tunnel, Beaches Link and F6 Extension projects. Some of these stations were located outside the areas shown in Figure D-1 and Figure D-2.

No project-specific monitoring was undertaken for Sydney Gateway.

D.3 Measured parameters and methods

The parameters measured at each station are given in Table D-3. Ozone and $PM_{2.5}$ were not measured at the Roads and Maritime M5 East stations. Although not shown in Table D-3, hydrocarbons[3] were measured continuously at the SMC and Roads and Maritime F6 stations. Hydrocarbons were not measured routinely at the OEH and Roads and Maritime M5 East stations.

Table D-3 Parameters by monitoring station

Monitoring station		Pollutants					Meteorological parameters			
		CO	NO, NO_2, NO_X	O_3	PM_{10}[(a)]	$PM_{2.5}$[(a)]	WS, WD[(b)]	Temp.	Humidity	Solar radiation
OEH	Chullora	✓	✓	✓	✓†	✓§	✓	✓	✓	✓
	Earlwood	-	✓	✓	✓†	✓§	✓	✓	✓	-
	Randwick	-	✓	✓	✓†	-	✓	✓	✓	-
	Rozelle	✓	✓	✓	✓†	✓‡	✓	✓	✓	✓
RMS	M5E: CBMS	✓	✓	-	✓†	-	✓	✓	✓	✓
	M5E: T1	✓	✓	-	✓†	-	✓	✓	✓	✓
	M5E: U1	✓	✓	-	✓†	-	✓	✓	✓	✓
	M5E: X1	✓	✓	-	✓†	-	✓	✓	✓	✓
	M5E: F1	✓	✓	-	✓†	-	✓	✓	✓	✓
	M5E: M1	✓	✓	-	✓†	-	✓	✓	✓	✓
	F6:01	✓	✓	✓	✓‡	✓‡	✓	✓	✓	✓
	F6:02	✓	✓	✓	✓‡	✓‡	✓	✓	✓	✓
SMC	M4E:01	✓	✓	✓	✓‡	✓‡	✓	✓	✓	✓
	M4E:02	✓	✓	✓	✓‡	✓‡	✓	✓	✓	✓
	M4E:03	✓	✓	✓	✓‡	✓‡	✓	✓	✓	✓
	M4E:04	✓	✓	✓	✓‡	✓‡	✓	✓	✓	✓
	M4E:05	✓	✓	✓	✓‡	✓‡	✓	✓	✓	✓
	New M5:01	✓	✓	✓	✓‡	✓‡	✓	✓	✓	✓
	New M5:02	✓	✓	✓	✓‡	✓‡	✓	✓	✓	✓
	New M5:03	✓	✓	✓	✓‡	✓‡	✓	✓	✓	✓
	New M5:04	✓	✓	✓	✓‡	✓‡	✓	✓	✓	✓
	New M5:05	✓	✓	✓	✓‡	✓‡	✓	✓	✓	✓
	New M5:06	✓	✓	✓	✓‡	✓‡	✓	✓	✓	✓
	New M5:07	✓	✓	✓	✓‡	✓‡	✓	✓	✓	✓

(a) † TEOM; ‡ BAM; § TEOM/BAM depending on year
(b) WS = wind speed; WD = wind direction

[3] Total hydrocarbons, methane, and non-methane hydrocarbons.

The pollutant measurements at each station were conducted in accordance with the relevant Australian Standards[4]. The methods used were, in general terms:

- CO - gas filter correlation infrared (GFC-IR)
- $NO/NO_2/NO_X$ - chemiluminescence detection (CLD)
- O_3 - non-dispersive ultra-violet (NDUV) spectroscopy
- $PM_{10}/PM_{2.5}$ - tapered-element oscillating microbalance (TEOM) and/or beta-attenuation monitor (BAM)

In the case of $PM_{2.5}$, it is well documented that the measurements are sensitive to the technique used. The data used in this analysis were collected using different instruments, and this clearly introduces some uncertainty in the results. For example, TEOMs were used at the Roads and Maritime M5 East stations, whereas BAMs were used at the WestConnex, WHTBL and F6 Extension stations. For the measurement of $PM_{2.5}$ at the OEH stations, TEOMs were used until early 2012. A combination of TEOMs and BAMs were used during 2012, when a decision was made to replace the continuous TEOM $PM_{2.5}$ monitors with the USEPA equivalent-method BAM. However, for traceability, in this assessment all data were used as received.

D.4 Data processing and analysis

The monitoring data were used in the form provided. However, for gases, any volumetric concentrations (eg ppm or ppb) were converted to mass units (eg mg/m^3 or $\mu g/m^3$). For consistency, an ambient pressure of 1 atmosphere and a temperature of 0°C were assumed throughout for the conversions. In the NSW Approved Methods, for some pollutants a conversion temperature of 25°C is used, which gives slightly lower mass concentrations. The use of 0°C is therefore slightly conservative.

Importantly, for PM_{10} and $PM_{2.5}$ the data on days with bush fires and/or dust storms were not removed. Although the inclusion of the high concentrations that occurred on some of these days could have obscured any underlying trends, the inclusion of all data is consistent with the National Environment Protection (Ambient Air Quality) Measure (AAQ NEPM), which is cited in the Approved Methods.

All measurements were initially analysed using an averaging period of one hour. The data were then further averaged, where appropriate, according to the time periods for the criteria in the NSW Approved Methods. Values were only deemed to be valid where the data capture rate was greater than 75 per cent[5] in any given period.

D.5 Long-term trends at background stations

In this part of the analysis the long-term trends in air pollution at background monitoring stations in Sydney were investigated. Only the OEH and Roads and Maritime monitoring stations with a multi-year record were considered (i.e. Chullora, Earlwood, Randwick, Rozelle, CBMS, T1, U1 and X1).

The trend analysis was based mainly on measurements conducted during the 14-year period between 1 January 2004 and 31 December 2017, the principal aims being (i) to understand the temporal and spatial patterns in the data and (ii) to establish background pollutant concentrations for use in the assessment (2016 base year).

This approach was in accordance with the NSW Approved Methods, which states:

> ”Including background concentrations in the assessment enables the total impact of the proposal to be assessed. The background concentrations of air pollutants are ideally obtained from ambient monitoring data collected at the proposed station. As this is

[4] Full details of the methods and procedures used at the SMC monitoring stations are presented in monthly monitoring reports for the M4 East network, and these are available on request from SMC.

[5] Clause 18 (5) of the AAQ NEPM specifies that the annual report for a pollutant must include the percentage of data available in the reporting period. An average concentration can be valid only if it is based on at least 75 per cent of the expected samples in the averaging period. The 75 per cent data availability criterion is specified as an absolute minimum requirement for data completeness (PRC, 2001).

extremely rare, data is typically obtained from a monitoring station as close as possible to the proposed location where the sources of air pollution resemble the existing sources at the proposal station." (NSW EPA, 2016)

Trends were determined for the following pollutants and metrics, as these are especially relevant to road transport:

- CO - maximum 1-hour mean
- CO - maximum rolling 8-hour mean
- NO_X - annual mean
- NO_X - maximum 1-hour mean
- PM_{10} - annual mean
- PM_{10} - maximum 24-hour mean
- $PM_{2.5}$ - annual mean
- $PM_{2.5}$ - maximum 24-hour mean

The Mann–Kendall nonparametric test was used to determine the statistical significance of trends at the 90 per cent confidence level.

Trends in NO_2 and O_3 were also investigated, as these were required for the testing of different NO_X-to-NO_2 conversion methods (see Annexure E).

For air toxics the NSW Approved Methods do not require the consideration of background concentrations. However, some data have been presented to demonstrate that prevailing concentrations in Sydney are very low.

D.5.1 Carbon monoxide

D.5.1.1 Maximum 1-hour mean concentration

The trends in the maximum 1-hour mean CO concentration by year are shown in Figure D-3 and Table D-4. All maximum values were well below the air quality criterion of 30 mg/m^3. Between 2008 and 2017 concentrations have typically been between around 2 and 5 mg/m^3 at all stations.

The patterns at all background stations were broadly similar, with a general downward trend. The Mann-Kendall test showed that there was a significant downward trend in annual mean CO concentration at all but one of the stations.

The long-term (2008-2017) concentrations at the background stations were between 1.5 and 4.8 mg/m^3. During the same period, the mean CO concentrations at the Roads and Maritime roadside stations F1 and M1 (2.2 and 5.8 mg/m^3 respectively) were only slightly elevated above the background.

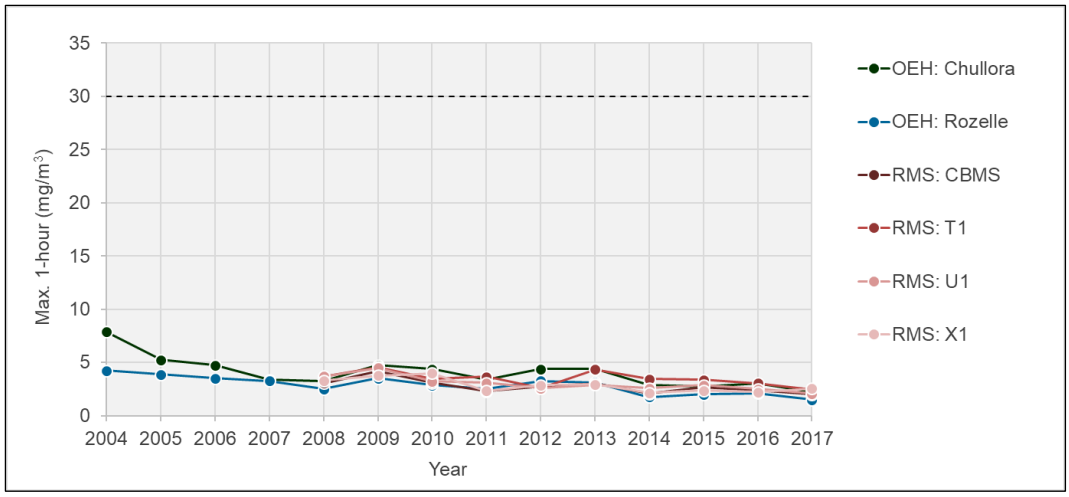

Figure D-3 **Trend in maximum 1-hour mean CO concentration (2004-2017)**

Table D-4 **Maximum 1-hour mean CO at OEH and Roads and Maritime background stations (2008-2017)**

Year	Concentration (mg/m^3)[a]							
	OEH Chullora	OEH Earlwood	OEH Randwick	OEH Rozelle	RMS CBMS	RMS T1	RMS U1	RMS X1
2008	3.25	-	-	2.50	3.03	3.66	3.69	3.30
2009	4.75	-	-	3.50	4.18	4.55	4.47	3.77
2010	4.37	-	-	2.87	3.10	3.43	3.24	3.98
2011	3.37	-	-	2.50	2.29	3.65	3.09	2.33
2012	4.37	-	-	3.25	2.73	2.57	2.58	2.87
2013	4.37	-	-	3.12	3.00	4.36	2.89	2.95
2014	2.87	-	-	1.75	2.06	3.45	2.56	2.15
2015	2.75	-	-	2.00	2.68	3.37	2.88	2.34
2016	3.00	-	-	2.12	2.36	3.06	2.52	2.22
2017	2.25	-	-	1.50	-	-	-	-
Mean (2008-17)	**3.54**	-	-	**2.51**	**2.74**	**3.45**	**3.00**	**2.84**
Significance[b]	▼	-	-	▼	▼	◄►	▼	▼

(a) Only years with >75 per cent complete data shown

(b) ▼ = significantly decreasing, ▲ = significantly increasing, ◄► = stable/no trend (based on 2004-2017)

D.5.1.2 Maximum rolling 8-hour mean concentration

The trends in the maximum rolling 8-hour mean CO concentration by year are shown in Figure D-4 and Table D-5. All maximum values were well below the air quality criterion of 10 mg/m^3; the long-term averages were between around 1.8 and 2.3 mg/m^3. For comparison, the long-term mean values at the Roads and Maritime roadside stations (F1 and M1) were 3.1 and 2.2 mg/m^3 respectively. The patterns at all background stations were broadly similar; there was a general downward trend that was statistically significant at all but one of the stations. The between-station variation was small compared with the criterion.

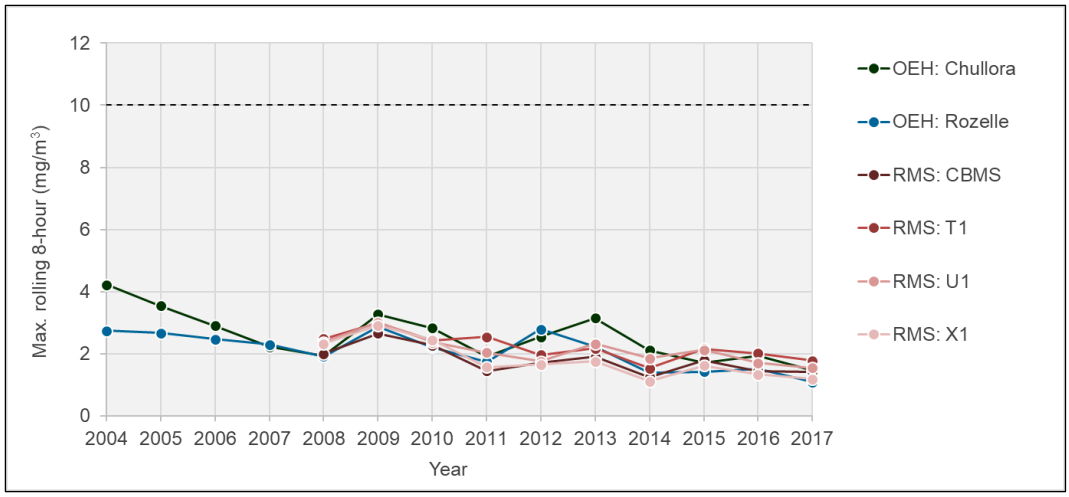

Figure D-4 **Trend in maximum rolling 8-hour mean CO concentration (2004-2017)**

Table D-5 **Maximum rolling 8-hour mean CO at OEH and Roads and Maritime background stations (2008-2017)**

Year	Concentration (mg/m^3)[a]							
	OEH Chullora	OEH Earlwood	OEH Randwick	OEH Rozelle	RMS CBMS	RMS T1	RMS U1	RMS X1
2008	1.93	-	-	1.91	2.08	2.60	2.46	2.38
2009	3.27	-	-	2.87	2.84	3.10	3.14	3.01
2010	2.82	-	-	2.21	2.33	2.51	2.50	2.51
2011	1.89	-	-	1.73	1.51	2.67	2.23	1.66
2012	2.53	-	-	2.79	1.81	2.02	1.83	1.68
2013	3.14	-	-	2.23	1.97	2.27	2.43	1.82
2014	2.11	-	-	1.37	1.31	1.61	1.84	1.13
2015	1.70	-	-	1.41	1.91	2.27	2.22	1.69
2016	1.93	-	-	1.50	1.52	2.13	1.79	1.38
2017	1.45	-	-	-	-	-	-	-
Mean (2008-17)	**2.28**	-	-	**1.91**	**1.78**	**2.20**	**2.10**	**1.79**
Significance[b]	▼	-	-	▼	◄►	▼	▼	▼

(a) Only years with >75 per cent complete data shown

(b) ▼ = significantly decreasing, ▲ = significantly increasing, ◄► = stable/no trend (based on 2004-2017)

D.5.1.3 Exceedances of air quality criteria

Between 2004 and 2016 there were no exceedances of the rolling 8-hour mean criterion for CO of 10 mg/m^3, or the 1-hour criterion of 30 mg/m^3, at any of the background or roadside stations.

D.5.2 Nitrogen oxides

D.5.2.1 Annual mean concentration

The annual mean NO_X concentrations at the monitoring stations between 2002 and 2017 are shown in Figure D-5**,** and the corresponding statistics for 2008 to 2017 are provided in Table D-6. There are no air quality criteria for NO_X in NSW, but it is important to understand NO_X in order to characterise NO_2 (see Annexure E).

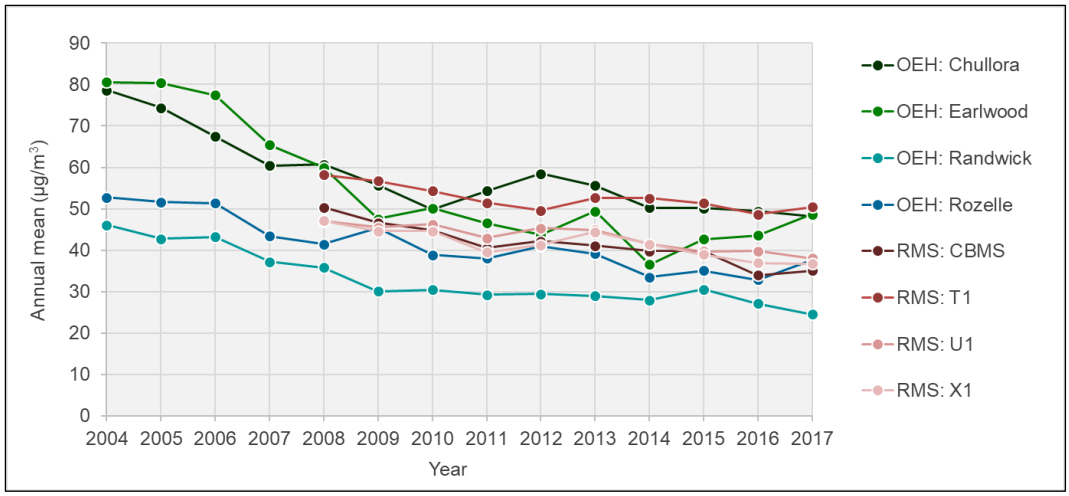

Figure D-5 **Trend in annual mean NO_X concentration (2004-2017)**

Table D-6 **Annual mean NO_X concentration at OEH and Roads and Maritime background stations (2008-2017)**

Year	Concentration (µg/m³)[a]							
	OEH Chullora	OEH Earlwood	OEH Randwick	OEH Rozelle	RMS CBMS	RMS T1	RMS U1	RMS X1
2008	60.7	60.0	35.8	41.5	50.3	58.2	47.0	47.1
2009	55.7	47.5	30.1	45.4	46.7	56.7	45.5	44.6
2010	49.7	50.2	30.4	38.9	44.8	54.3	46.2	44.6
2011	54.3	46.5	29.2	38.0	40.5	51.5	42.9	39.4
2012	58.5	43.8	29.4	40.9	42.2	49.6	45.3	41.3
2013	55.6	49.4	28.9	39.1	41.0	52.7	44.8	44.4
2014	50.2	36.5	27.9	33.5	39.8	52.5	41.4	41.4
2015	50.1	42.6	30.6	35.1	39.9	51.3	39.7	38.9
2016	49.4	43.6	27.1	32.8	33.9	48.6	39.8	36.9
2017	48.2	48.7	24.5	37.6	35.0	50.4	38.0	36.7
Mean (2008-17)	**53.2**	**46.9**	**29.4**	**38.3**	**41.4**	**52.6**	**43.1**	**41.5**
Significance[b]	▼	▼	▼	▼	▼	▼	▼	▼

(a) Only years with >75 per cent complete data shown

(b) ▼ = significantly decreasing, ▲ = significantly increasing, ◄► = stable/no trend (based on 2004-2017)

The T1 station had a systematically higher NO_X concentration than the other Roads and Maritime stations, which all had very similar concentrations. Given that all the Roads and Maritime stations are relatively close together, the measurements at the T1 station could have been influenced by a local source. The station is alongside Thompson Street, but the traffic volume is likely to be very low. However, concentrations may have been affected by truck movements at a factory (manufacture of crop protection products) across the road.

There has been a general tendency for annual mean NO_X concentrations to decrease. At the OEH stations concentrations decreased by between 10 per cent and 32 per cent between 2008 and 2017. The Mann-Kendall test showed that the downward trend in concentrations was statistically significant at all stations. There is, however, a suggestion of a levelling-off of concentrations, and in certain cases an increase in concentration, at some stations in recent years.

There was a noticeable spatial variation in the annual mean NO_X concentration. For example, at the OEH Chullora and Earlwood stations the long-term mean concentration during this period was around 50 µg/m^3, compared with around 40 µg/m^3 at Rozelle and around 30 µg/m^3 at Randwick. The long-term concentration at the Roads and Maritime T1 station was around 53 µg/m^3, with concentrations at the CBMS, U1 and X1 stations being slightly lower (around 42-43 µg/m^3).

Although not shown, the long-term mean (2008-2017) NO_X concentrations at the Roads and Maritime roadside stations (F1 and M1) were substantially higher than those at the background stations, and very similar at 102 and 100 µg/m^3 respectively. The road increment – the average roadside concentration minus the average background concentration – remained relatively stable, at around 50-60 µg/m^3, between 2008 and 2017 (there was a slight downward trend overall). This illustrates the ongoing contribution of NO_X emissions from road transport.

D.5.2.2 Maximum 1-hour mean concentration

The long-term trends in the maximum 1-hour mean NO_X concentration are shown in Figure D-6 and Table D-7. Again, there are no air quality criteria for NO_X, and these data are largely of interest in relation to the 1-hour criterion for NO_2. As with the annual mean concentration, there has been a general downward trend in peak concentrations, with some levelling-off in recent years.

For comparison, the maximum 1-hour mean NO_X concentrations at the Roads and Maritime roadside stations (F1 and M1) in 2017 were 1056 and 755 µg/m^3 respectively. These values are similar to or higher than the upper end of the range of values for the background stations.

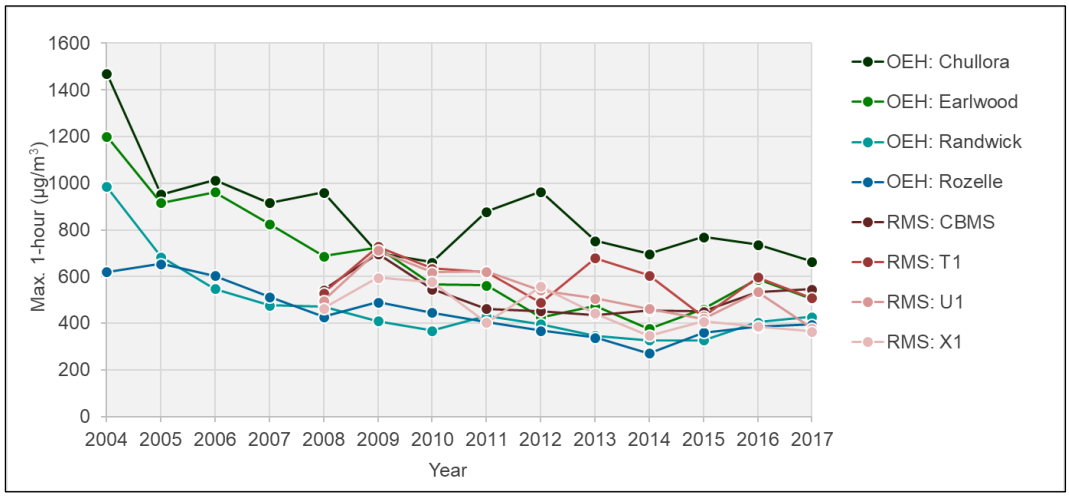

Figure D-6 Trend in maximum 1-hour mean NO_X concentration (2004-2017)

Table D-7 Maximum 1-hour NO_X concentration at OEH and Roads and Maritime background stations (2008-2017)

Year	Concentration (µg/m^3)[a]							
	OEH Chullora	OEH Earlwood	OEH Randwick	OEH Rozelle	RMS CBMS	RMS T1	RMS U1	RMS X1
2008	960.5	687.5	472.0	426.9	542.2	529.6	496.4	463.0
2009	699.9	724.5	408.4	490.5	696.5	728.9	712.1	595.0
2010	660.9	566.5	367.4	445.4	546.0	634.2	617.6	576.8
2011	878.4	562.3	431.0	404.3	461.1	619.8	621.2	402.5
2012	964.6	424.8	396.1	367.4	451.3	488.1	541.0	557.0
2013	753.2	474.1	346.8	338.6	435.6	679.4	505.9	442.4
2014	697.8	375.6	326.3	270.9	454.9	605.4	461.6	346.4
2015	769.6	459.7	326.3	359.2	449.6	429.4	419.0	407.5
2016	736.8	589.0	404.3	383.8	533.4	596.7	533.8	386.4
2017	665.0	504.9	426.9	394.1	545.3	507.8	377.8	365.2
Mean (2008-17)	**665.0**	**536.9**	**390.6**	**388.1**	**511.6**	**581.9**	**528.6**	**454.2**
Significance[b]	▼	▼	▼	▼	◄►	▼	▼	▼

(a) Only years with >75 per cent complete data shown

(b) ▼ = significantly decreasing, ▲ = significantly increasing, ◄► = stable/no trend (based on 2004-2017)

D.5.3 Nitrogen dioxide

D.5.3.1 Annual mean concentration

The long-term trends in annual mean NO_2 concentrations are shown in Figure D-7, and the corresponding statistics are provided in Table D-8. The concentrations at all stations were well below the NSW air quality assessment criterion of 62 µg/m^3. In recent years concentrations have ranged between around 15 and 25 µg/m^3, depending on the station.

The NO_2 concentrations at the OEH stations exhibited a systematic downward trend, with a reduction of between around 3 per cent and 23 per cent between 2008 and 2017, depending on the station. The trend was statistically significant at most of the OEH and Roads and Maritime stations. However, in recent years the concentration at some stations appears to have stabilised.

As with NO_X, there was some spatial variation in NO_2 concentrations, but the pattern across the monitoring stations was not quite the same. Nevertheless, concentrations were again generally highest at the Chullora station and lowest at Randwick.

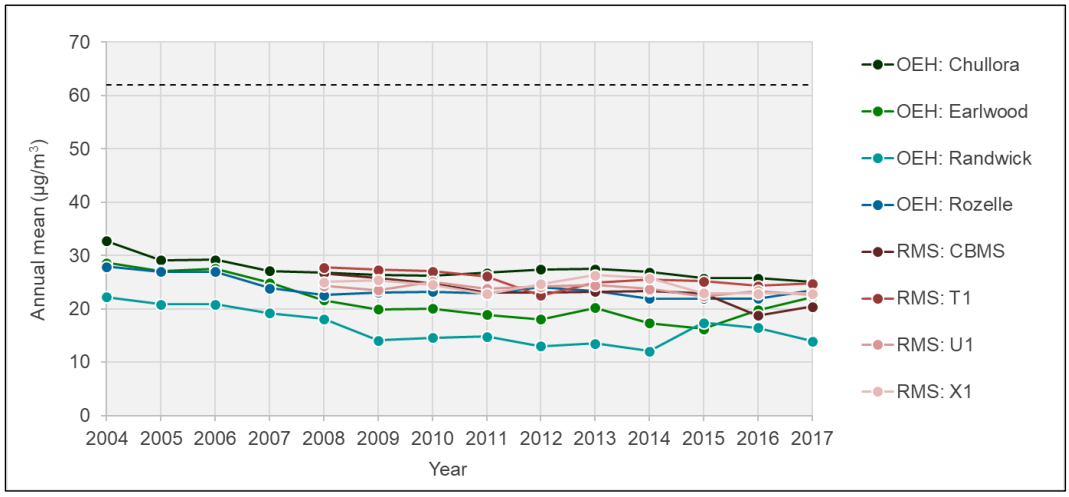

Figure D-7 Trend in annual mean NO_2 concentration (2004-2017)

Table D-8 Annual mean NO_2 concentration at OEH and Roads and Maritime background stations (2008-2017)

Year	Concentration (µg/m^3)[(a)]							
	OEH Chullora	OEH Earlwood	OEH Randwick	OEH Rozelle	RMS CBMS	RMS T1	RMS U1	RMS X1
2008	26.7	21.7	18.1	22.6	26.7	27.7	24.3	25.0
2009	26.3	19.9	14.1	23.1	25.7	27.4	23.5	25.4
2010	26.2	20.1	14.6	23.2	24.8	27.1	25.1	24.5
2011	26.8	18.9	14.8	22.9	23.1	26.1	23.8	22.8
2012	27.4	18.1	13.0	24.0	23.1	22.5	24.2	24.7
2013	27.5	20.2	13.5	23.4	23.2	25.0	24.5	26.3
2014	26.9	17.3	12.1	21.9	23.4	25.5	23.7	25.7
2015	25.8	16.2	17.4	21.9	22.9	25.1	22.4	23.0
2016	25.8	19.8	16.4	21.9	18.7	24.3	23.3	22.8
2017	25.0	22.2	13.9	23.5	20.4	24.7	22.6	22.9
Mean (2008-17)	**26.4**	**19.4**	**13.9**	**22.8**	**24.1**	**25.6**	**23.9**	**24.5**
Significance[(b)]	▼	▼	▼	▼	▼	▼	▼	◄►

(a) Only years with >75 per cent complete data shown.
(b) ▼ = significantly decreasing, ▲ = significantly increasing, ◄► = stable/no trend (based on 2004-2017)

The long-term (2008-2016) average NO_2 concentrations at the Roads and Maritime roadside stations (F1 and M1) were 34 and 37 µg/m^3 respectively, and therefore around 10 µg/m^3 higher than those at the Roads and Maritime background stations. Even so, the NO_2 concentrations at roadside were also well below the NSW assessment criterion.

D.5.3.2 Maximum 1-hour mean concentration

The trends in the maximum 1-hour mean NO_2 concentration by year are given in Figure D-8 and Table D-9. The within-station variation for this metric was similar to the between-site variation, but when viewed overall the values have been quite stable with time (broadly varying around 100 µg/m^3), and are all below the NSW air quality assessment criterion of 246 µg/m^3. Peak concentrations at most sites were relatively high in 2017. The maximum 1-hour mean NO_2 concentrations at the Roads and Maritime roadside stations (F1 and M1) in 2016 were 144 µg/m^3 and 165 µg/m^3 respectively.

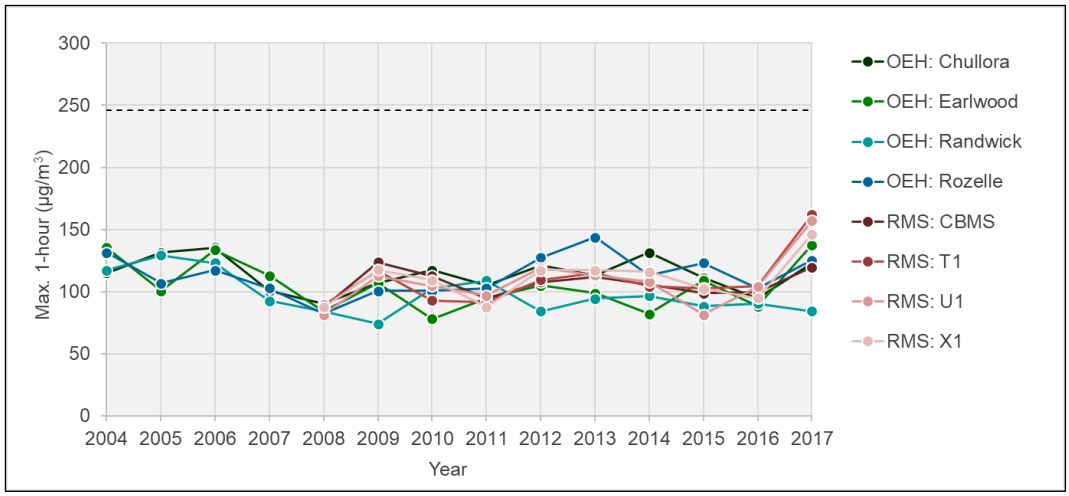

Figure D-8 Trend in maximum 1-hour mean NO_2 concentration (2004-2017)

Table D-9 Maximum 1-hour NO_2 concentration at OEH and Roads and Maritime background stations (2008-2017)

Year	Concentration (µg/m^3)[a]							
	OEH Chullora	OEH Earlwood	OEH Randwick	OEH Rozelle	RMS CBMS	RMS T1	RMS U1	RMS X1
2008	90.3	84.1	84.1	82.1	87.3	89.1	81.5	87.3
2009	106.7	106.7	73.9	100.6	123.6	116.6	112.6	117.4
2010	117.0	78.0	102.6	100.6	112.5	92.8	104.4	109.2
2011	104.7	94.4	108.8	102.6	94.7	91.4	96.7	87.5
2012	121.1	104.7	84.1	127.2	107.7	109.5	119.0	117.1
2013	112.9	98.5	94.4	143.7	111.8	114.9	113.1	117.1
2014	131.4	82.1	96.5	112.9	105.3	104.1	107.8	115.9
2015	110.8	108.8	88.3	123.1	98.6	102.7	81.5	102.2
2016	94.4	88.3	90.3	102.6	99.4	104.4	103.7	94.7
2017	123.1	137.5	84.1	125.2	119.6	161.8	157.0	146.2
Mean (2008-17)	**111.2**	**98.3**	**90.7**	**112.1**	**106.0**	**108.7**	**107.7**	**109.4**
Significance[b]	◄►	◄►	▼	◄►	◄►	◄►	◄►	◄►

(a) Only years with >75 per cent complete data shown

(b) ▼ = significantly decreasing, ▲ = significantly increasing, ◄► = stable/no trend (based on 2004-2017)

D.5.3.3 Exceedances of air quality criteria

There were no exceedances of the annual mean criterion for NO_2 of 62 µg/m^3 (Table D-8). In fact, annual mean concentrations were well below the criterion at all stations and in all years. There were also no exceedances of the 1-hour mean criterion for NO_2 (246 µg/m^3).

D.5.4 Ozone

D.5.4.1 Annual mean concentration

Annual mean ozone concentrations at the OEH stations - presented in Figure D-9 and Table D-10 - were relatively stable between 2004 and 2016, being typically around 30-35 µg/m^3. The main exception was the Randwick station, where the typical annual mean concentration was substantially higher, at closer to 40-45 µg/m^3. This is likely to be due to the coastal nature of Randwick, with easterly winds having low concentrations of ozone-scavenging species, notably NO_X (see Figure D-5).

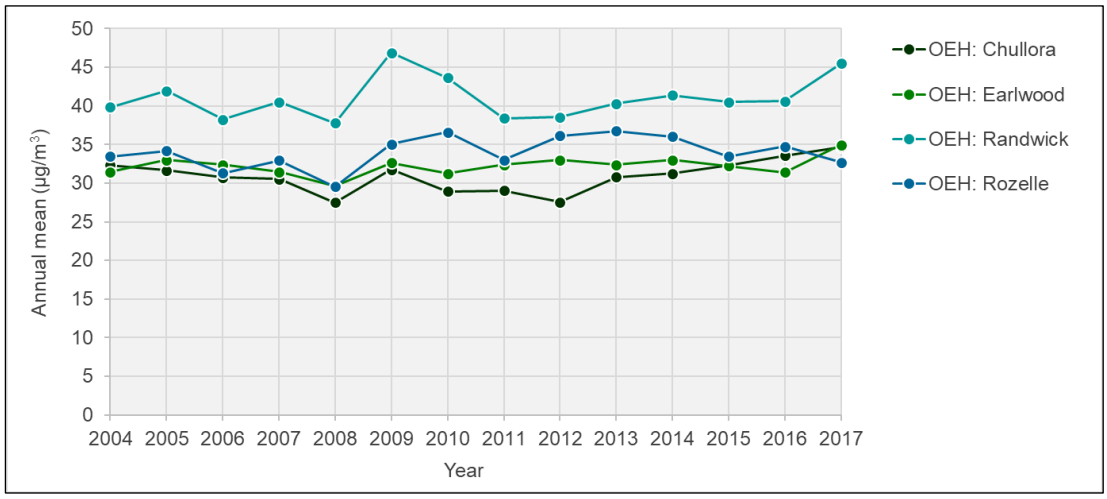

Figure D-9 Trend in annual mean O_3 concentration (2004-2017)

Table D-10 Annual mean O_3 concentration at OEH background stations (2008-2017)

Year	Concentration (µg/m^3) [(a)]			
	Chullora	Earlwood	Randwick	Rozelle
2008	27.5	29.7	37.8	29.6
2009	31.8	32.7	46.9	35.1
2010	28.9	31.3	43.6	36.6
2011	29.0	32.4	38.4	33.0
2012	27.5	33.0	38.6	36.1
2013	30.8	32.4	40.3	36.8
2014	31.3	33.0	41.4	36.0
2015	32.3	32.2	40.5	33.5
2016	33.6	31.4	40.6	34.7
2017	34.7	34.9	45.5	32.7
Mean (2008-17)	**30.7**	**32.3**	**41.4**	**34.4**
Significance[(b)]	◄►	◄►	◄►	◄►

(a) Only years with >75 per cent complete data shown

(b) ▼ = significantly decreasing, ▲ = significantly increasing, ◄► = stable/no trend (based on 2004-2017)

D.5.4.2 Exceedances of air quality criteria

Table D-11 and Table D-12 show that there were exceedances of the rolling 4-hour mean and 1-hour mean standards for ozone at the OEH monitoring stations, with an increase in frequency in 2017.

Table D-11 Exceedances of rolling 4-hour mean O_3 standard (2008-2017)

Year	Number of exceedances of rolling 4-hour standard per year (171 µg/m^3)			
	Chullora	Earlwood	Randwick	Rozelle
2008	0	0	0	0
2009	6	7	0	0
2010	0	0	0	0
2011	4	3	0	0
2012	0	0	0	0
2013	3	3	0	0
2014	0	0	0	0
2015	0	1	2	0
2016	0	2	3	0
2017	11	14	13	5

Table D-12 Exceedances of 1-hour O_3 standard (2008-2017)

Year	Number of exceedances of 1-hour standard per year (214 µg/m^3)			
	Chullora	Earlwood	Randwick	Rozelle
2008	0	0	0	0
2009	3	3	0	0
2010	0	0	0	0
2011	1	0	0	0
2012	0	0	0	0
2013	1	1	0	0
2014	0	0	0	0
2015	0	0	1	0
2016	0	0	0	0
2017	5	2	4	3

D.5.5 PM_{10}

D.5.5.1 Annual mean concentration

Annual mean PM_{10} concentrations at the OEH and Roads and Maritime stations are given in Figure D-10 and Table D-13. The large peak in the data was a consequence of the major dust storm in Sydney in September 2009. Concentrations at the OEH stations showed a net decrease between 2008 and 2016, by up to 19 per cent in the case of the Earlwood station. Some stations had a statistically significant downward trend in concentration.

In recent years the annual mean PM_{10} concentration at the OEH stations has been between around 17 µg/m^3 and 20 µg/m^3. The concentration at the Roads and Maritime stations appears to have stabilised at around 15 µg/m^3, although the CBMS station had a concentration closer to 19 µg/m^3 in 2017. These values can be compared with the air quality criterion of 25 µg/m^3 in the NSW Approved Methods. The annual mean PM_{10} concentrations at the Roads and Maritime roadside stations (F1 and M1) in 2017 were 17.1 µg/m^3 and 16.4 µg/m^3 respectively. In other words, the road increment for PM_{10} is small.

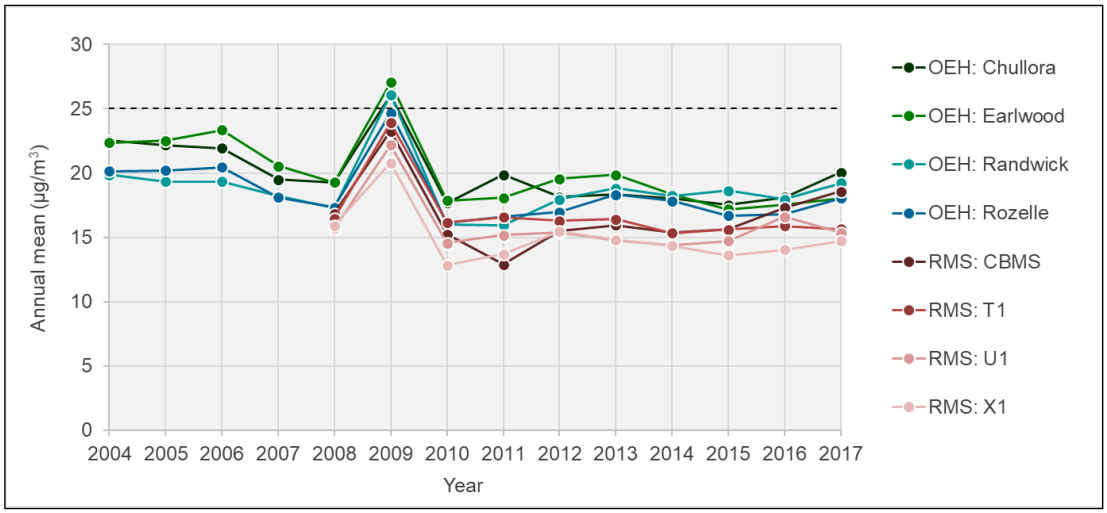

Figure D-10 Trend in annual mean PM_{10} concentration (2004-2017)

Table D-13 Annual mean PM_{10} concentration at OEH and Roads and Maritime background stations (2008-2017)

Year	Concentration (µg/m³)[(a)]							
	OEH Chullora	OEH Earlwood	OEH Randwick	OEH Rozelle	RMS CBMS	RMS T1	RMS U1	RMS X1
2008	19.3	19.3	17.3	17.3	16.8	16.5	15.7	15.9
2009	26.0	27.1	26.1	24.7	23.3	23.9	22.2	20.8
2010	17.7	17.9	16.0	16.1	15.2	16.2	14.6	12.8
2011	19.9	18.1	15.9	16.6	12.9	16.6	15.2	13.7
2012	18.1	19.6	18.0	17.0	15.5	16.3	15.3	15.4
2013	18.3	19.9	18.8	18.3	15.9	16.4	14.8	14.8
2014	18.1	18.3	18.2	17.8	15.4	15.3	14.4	14.4
2015	17.5	17.2	18.6	16.7	15.6	15.6	14.7	13.6
2016	18.1	17.5	17.9	16.8	17.3	15.9	16.6	14.0
2017	20.0	18.0	19.2	18.0	18.6	15.6	15.4	14.7
Mean (2008-17)	**19.3**	**19.3**	**18.6**	**17.9**	**16.7**	**16.8**	**15.9**	**15.0**
Significance[(b)]	▼	▼	◄►	▼	◄►	▼	◄►	◄►

(a) Only years with >75 per cent complete data shown

(b) ▼ = significantly decreasing, ▲ = significantly increasing, ◄► = stable/no trend (based on 2004-2017)

D.5.5.2 Maximum 24-hour mean concentration

The maximum 24-hour mean PM_{10} concentrations for the background stations are shown in Figure D-11. Again, there was a very large peak in the data associated with the 2009 dust storm, and this masked any underlying trend. However, when the 2009 measurements were removed (Figure D-12), the data exhibited no underlying trend overall (see also the significance of trends in Table D-14), and there was a large variation from year-to-year at most stations. In 2017 the concentrations at the various background stations were clustered around 50-60 µg/m³. The maximum 24-hour PM_{10} concentrations at the Roads and Maritime roadside stations (F1 and M1) in 2017 were 62 µg/m³ and 57 µg/m³ respectively. Again, the roadside values were similar to the background values.

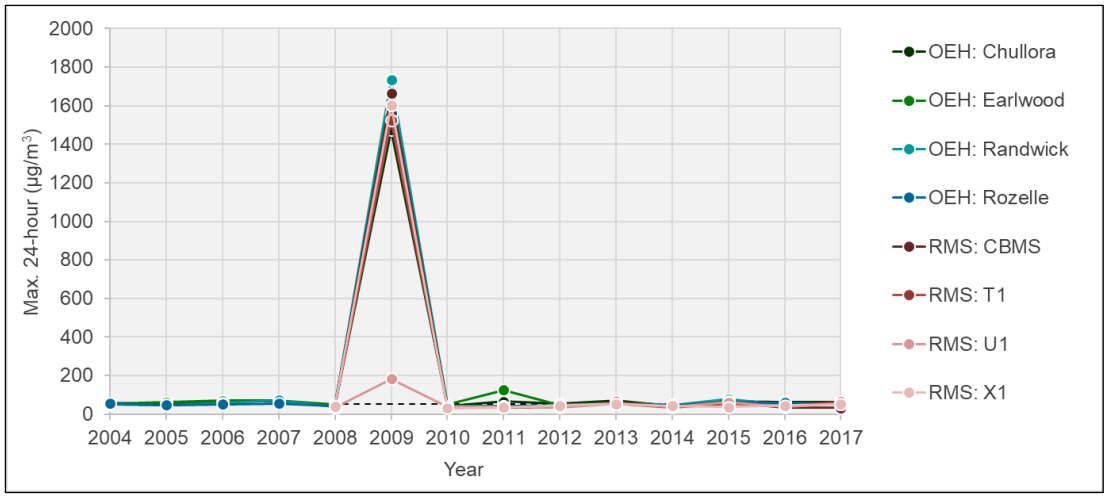

Figure D-11 **Trend in maximum 24-hour mean PM_{10} concentration (2004-2017)**

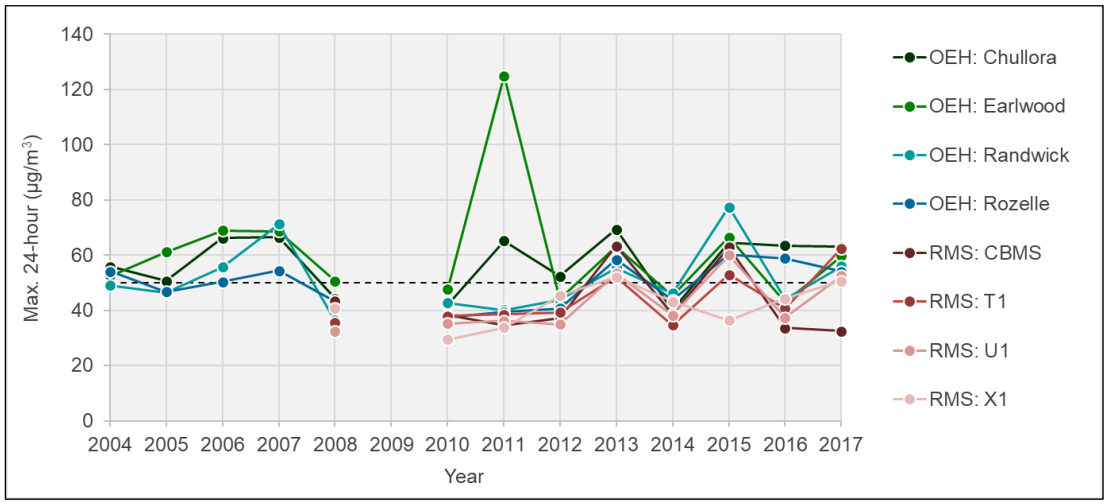

Figure D-12 **Trend in maximum 24-hour mean PM_{10} concentration (2004-2017, excluding 2009)**

Table D-14 **Maximum 24-hour PM_{10} concentration at OEH and Roads and Maritime background stations (2008-2017)**

Year	Concentration (µg/m³)[a]							
	OEH Chullora	OEH Earlwood	OEH Randwick	OEH Rozelle	RMS CBMS	RMS T1	RMS U1	RMS X1
2008	44.3	50.6	36.3	43.1	43.3	35.5	32.4	40.7
2009	1474.7	1653.7	1735.6	1562.8	1663.3	1526.3	181.8	1604.3
2010	42.1	47.8	42.7	37.6	38.2	37.9	35.3	29.5
2011	65.2	124.9	40.1	39.4	34.7	38.5	36.3	33.7
2012	52.4	44.2	43.7	40.7	37.3	39.3	34.9	45.3
2013	69.4	63.1	55.4	58.5	63.3	52.3	53.4	52.1
2014	40.0	45.2	46.1	43.8	38.7	34.7	38.2	43.2
2015	64.6	66.5	77.4	60.3	62.9	52.9	59.9	36.3
2016	63.5	42.9	44.1	58.8	33.6	40.7	37.3	44.2
2017	63.0	59.8	56.0	54.1	32.5	62.5	52.5	50.6
Mean (2008-17)	**197.9**	**219.9**	**217.7**	**199.9**	**204.8**	**192.1**	**56.2**	**198.0**
Mean (2008-17, excl. 2009)	***56.1***	***60.5***	***49.1***	***48.5***	***42.7***	***43.8***	***42.2***	***41.8***
Significance[b]	◄►	◄►	◄►	◄►	▼	◄►	◄►	◄►

(a) Only years with >75 per cent complete data shown

(b) ▼ = significantly decreasing, ▲ = significantly increasing, ◄► = stable/no trend (based on 2004-2017)

D.5.5.3 Exceedances of air quality criteria

There were no exceedances of the annual mean criterion for PM_{10} in the NSW Approved Methods of 25 µg/m^3, except during 2009 because of the major dust storm. Table D-15 shows that there were multiple exceedances of the 24-hour criterion of 50 µg/m^3, most notably in 2009.

Table D-15 Exceedances of 24-hour PM_{10} standard (2008-2017)

Year	Number of exceedances of 24-hour criterion per year (50 µg/m^3)			
	Chullora	Earlwood	Randwick	Rozelle
2008	0	1	0	0
2009	8	8	8	7
2010	0	0	0	0
2011	7	2	0	0
2012	1	0	0	0
2013	4	5	3	3
2014	0	0	0	0
2015	1	1	1	1
2016	1	0	0	1
2017	4	1	1	1

D.5.6 $PM_{2.5}$

D.5.6.1 Annual mean concentration

An extensive time series of $PM_{2.5}$ measurements was only available for the OEH Chullora and Earlwood stations (Figure D-13, Table D-16). The peak in 2009 was less pronounced for $PM_{2.5}$ than for PM_{10}, indicating the that dust storm particles were mainly in the coarse fraction.

Concentrations at the two stations had a broadly similar pattern, with a reduction between 2004 and 2012 followed by a substantial increase in 2013 and then (broadly) stabilisation. It is important to recognise that during 2012 OEH made a decision to replace its continuous TEOM $PM_{2.5}$ monitors with USEPA-equivalent BAMs. This is the main reason for the increase in the measured concentrations. It is well documented that there are considerable uncertainties in the measurement of $PM_{2.5}$, and the results are instrument-specific (e.g. AQEG, 2012). The increases meant that background $PM_{2.5}$ concentrations at the three stations between 2013 and 2017 were very close to, or above, the NSW criterion of 8 µg/m^3, as well as being above the AAQ NEPM long-term goal of 7 µg/m^3. In 2017 the concentrations at Chullora and Earlwood diverged, but the reason for this is unclear.

A shorter time series of $PM_{2.5}$ (2015-2017) was also available for Rozelle. The concentrations at Rozelle were noticeably lower, at around 7 µg/m^3.

Overall, the data indicated that there was likely to be little spatial variation in $PM_{2.5}$ concentrations across the GRAL domain.

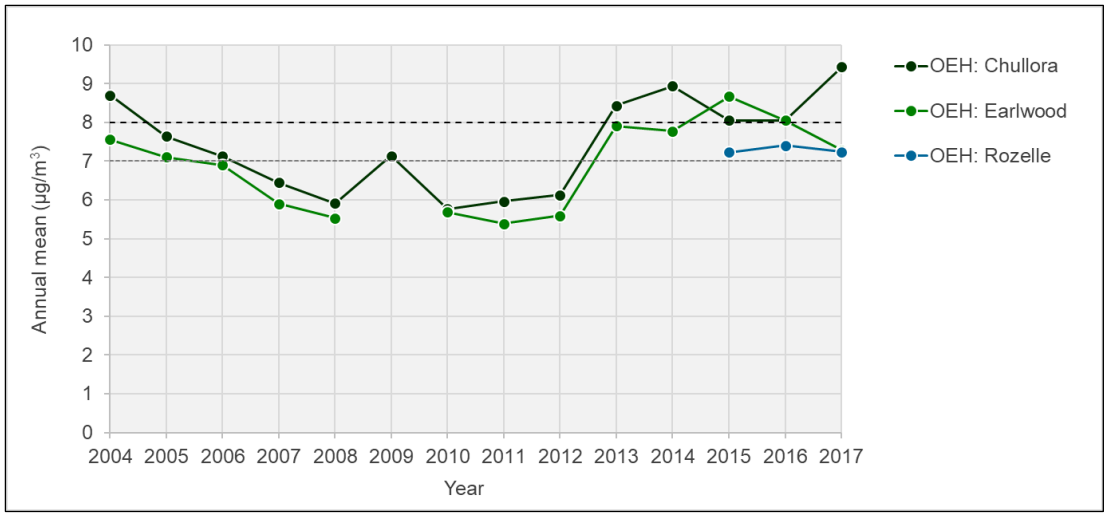

Figure D-13 Long-term trends in annual mean $PM_{2.5}$ concentration (2004-2017)

Table D-16 Annual mean $PM_{2.5}$ concentration at OEH background stations (2008-2017)

Year	Concentration (µg/m³) [a]			
	Chullora	Earlwood	Randwick	Rozelle
2008	5.9	5.5	-	-
2009	7.1	-	-	-
2010	5.8	5.7	-	-
2011	6.0	5.4	-	-
2012	6.1	5.6	-	-
2013	8.4	7.9	-	-
2014	8.9	7.8	-	-
2015	8.1	8.7	-	7.2
2016	8.1	8.1	-	7.4
2017	9.4	7.3	-	7.2
Mean (2008-17)	**7.4**	**6.9**	**-**	**-**
Significance[b]	◄►	◄►	-	-

(a) Only years with >75 per cent complete data shown

(b) ▼ = significantly decreasing, ▲ = significantly increasing, ◄► = stable/no trend (based on 2004-2017)

D.5.6.2 Maximum 24-hour mean concentration

The maximum 24-hour mean $PM_{2.5}$ concentrations at the long-term $PM_{2.5}$ monitoring stations are shown in Figure D-14. Again, there was a pronounced peak due to the 2009 dust storm, and Figure D-15 shows the data with the 2009 measurements removed. This shows that there has been an underlying increase in maximum 24-hour concentrations between 2014 and 2017, such that they are currently above the NSW criterion of 25 µg/m³. In most years the maximum concentrations have been above the NEPM long-term goal of 20 µg/m³.

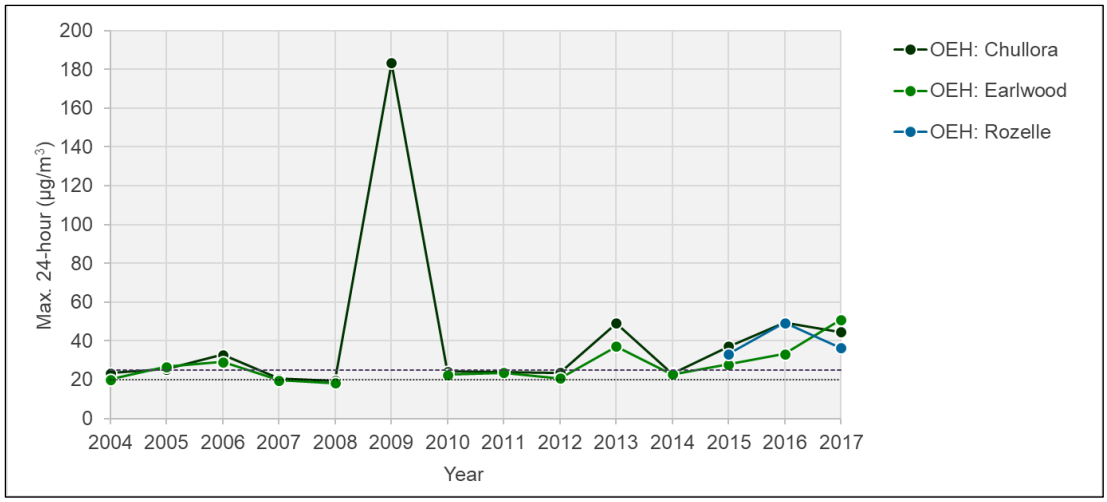

Figure D-14 Trend in maximum 24-hour mean $PM_{2.5}$ concentration (2004-2017)

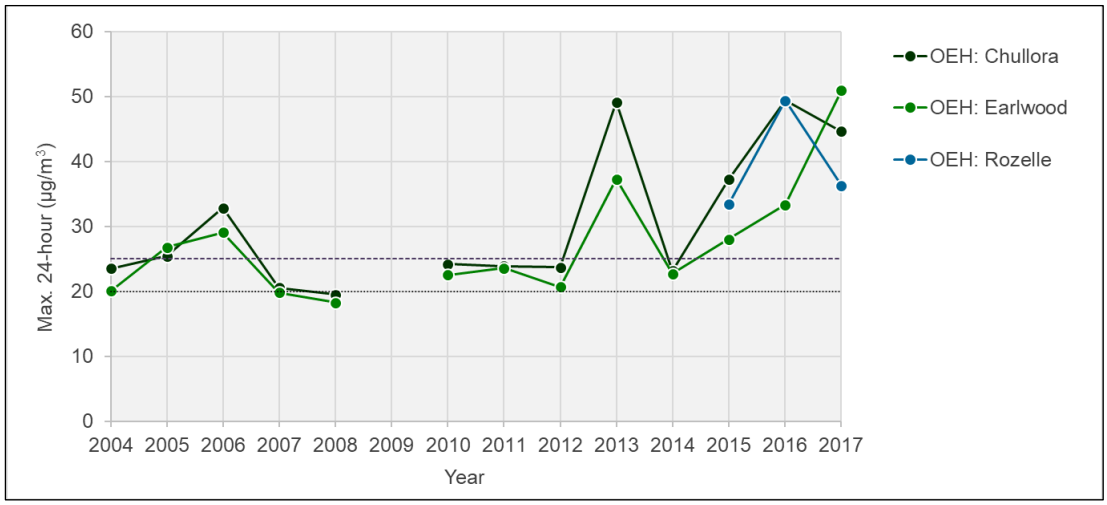

Figure D-15 Trend in maximum 24-hour mean $PM_{2.5}$ concentration (2004-2017, excluding 2009)

Table D-17 Maximum 24-hour $PM_{2.5}$ concentration at OEH background stations (2008-2017)

Year	Concentration (µg/m^3) [a]			
	Chullora	Earlwood	Randwick	Rozelle
2008	19.5	18.3	-	-
2009	183.2	-	-	-
2010	24.2	22.5	-	-
2011	23.9	23.6	-	-
2012	23.7	20.7	-	-
2013	49.1	37.3	-	-
2014	23.1	22.7	-	-
2015	37.2	28.0	-	33.4
2016	49.4	33.3	-	49.4
2017	44.6	50.9	-	36.3
Mean (2008-17)	**47.8**	**28.6**	-	-
Mean (2008-17, excl. 2009)	***32.7***	***28.6***	-	-
Significance[b]	◄► [c]	▲	-	-

(a) Only years with >75 per cent complete data shown

(b) ▼ = significantly decreasing, ▲ = significantly increasing, ◄► = stable/no trend (based on 2004-2017)

(c) Increasing trend with the 2009 data removed.

D.5.6.3 Exceedances of air quality criteria

As noted earlier, there have been some exceedances of the NSW criterion for annual mean $PM_{2.5}$ of 8 µg/m^3, and these also seem likely to occur in the future given the recent trend in concentrations.

Table D-18 summarises the exceedances of the NSW criterion for 24-hour mean $PM_{2.5}$ of 25 µg/m^3, as well as the long-term NEPM goal of 20 µg/m^3.

Table D-18 Exceedances of 24-hour $PM_{2.5}$ criterion (2008-2017)

Year	Number of exceedances of 24-hour criterion per year (25 µg/m^3) (exceedances of the NEPM goal of 20 µg/m^3 are given in brackets)						
	Chullora	Earlwood	Lindfield	Liverpool	Prospect	Randwick	Rozelle
2008	0 (0)	0 (0)	-	1 (1)	-	-	-
2009	3 (3)	-	-	3 (6)	-	-	-
2010	0 (3)	0 (1)	-	0 (2)	-	-	-
2011	0 (1)	0 (2)	-	2 (4)	-	-	-
2012	0 (2)	0 (1)	-	0 (4)	-	-	-
2013	3 (6)	4 (8)	-	2 (12)	-	-	-
2014	0 (3)	0 (1)	-	0 (5)	-	-	-
2015	1 (1)	2 (8)	-	2 (8)	1 (6)	-	1 (1)
2016	5 (7)	5 (8)	-	4 (9)	5 (10)	-	5 (8)
2017	8 (18)	2 (4)	-	3 (10)	3 (8)	-	2 (3)

D.5.7 Air toxics

Fewer data were available to characterise the concentrations of air toxics in Sydney. The main sources of data used in the assessment were the following:

- An Ambient Air Quality Research Project that was conducted between 1996 and 2001 (NSW EPA, 2002). The project investigated concentrations of 81 air toxics, including dioxins, VOCs, PAHs and heavy metals. More than 1,400 samples were collected at 25 sites. Three air toxics – benzene, 1,3-butadiene and benzo(α)pyrene – were identified as requiring ongoing assessment to ensure they remain at acceptable levels in the future.
- An additional round of data collection between October 2008 and October 2009. The five NEPM air toxics and additional VOCs were monitored at two sites in Sydney:
    - Turrella: formaldehyde, acetaldehyde, 19 PAHs including benzo(a)pyrene, and 41 VOCs including benzene, toluene and xylenes.
    - Rozelle: formaldehyde, acetaldehyde, 41 VOCs including benzene, toluene and xylenes.

  This study collected 24-hour concentrations of formaldehyde, acetaldehyde, and 34 organic compounds every sixth day, and 19 PAHs at one location on the same days. Sixty-one samples were collected at each location during the sampling period.
- Measurements conducted to support the WestConnex M4 East, New M5 and M4-M5 Link projects: benzene, toluene, ethylbenzene and xylenes.

The findings of the first two studies were summarised by DECCW (2010), and some results for selected pollutants are given in Table D-19. In the 1996-2001 monitoring campaign the concentrations of most compounds were very low. Some 23 compounds were not, or rarely, detected. Annual average concentrations of benzene were below the Air Toxics NEPM investigation level (0.003 ppm or 3 ppb) at all sites. The maximum annual concentrations of toluene and xylenes were less than 5 per cent of the investigation levels, and maximum 24-hour concentrations were less than 2 per cent and 4 per cent of

the investigation levels respectively. The 2008-09 monitoring campaign also found low concentrations of all compounds, with many observations below detection limits. Concentrations of the five pollutants in the Air Toxics NEPM were low compared to the respective investigation levels.

The concentrations of the pollutants in Table D-19 generally halved between the two campaigns. Improved engine technology and a greater proportion of the vehicle fleet being fitted with catalysts reduced emissions from road vehicles. Benzene concentrations showed a larger decrease as a result of a reduction in the maximum allowed benzene concentration in automotive fuels (DECCW, 2010).

Table D-19 Average concentrations of selected organic pollutants

Pollutant	Concentration (ppb)				
	1996-2001			2008-2009	
	Sydney CBD	Rozelle	St Marys	Turrella	Rozelle
Benzene	2.3	1.1	0.4	0.4	0.3
Toluene	4.2	2.2	0.8	1.8	0.9
Xylene (m + p)	2.2	1.0	0.4	0.7	0.5
Xylene (o)	0.8	0.4	0.1	0.3	0.2
1,3-butadiene	0.4	0.2	0.1	<0.1	<0.1

Source: (DECCW, 2010)

In the 2008-2009 campaign the highest benzo(a)pyrene concentration was 0.4 ng/m^3, and the average for the year was 0.12 ng/m^3. Concentrations of formaldehyde were low: the highest concentration was only 11 per cent of the investigation level (DECCW, 2010).

The results clearly showed levels of air toxics were below the monitoring investigation levels, and well below levels observed in overseas cities. There were no occasions on which any of the air toxics monitored exceeded the monitoring investigation levels at any location. The results for benzo(a)pyrene, with levels of approximately 65 per cent of the NEPM monitoring investigation level, were the most significant (NEPC, 2011b).

To support the air quality assessments for the M4 East, New M5 and M4-M5 Link projects, concentrations of BTEX compounds (benzene, toluene, ethylbenzene and xylenes) were measured at each of the project-specific air quality monitoring stations (five stations for the M4 East, seven stations for the New M5, and three stations for the M4-M5 Link) (Oswald, 2015a, 2015b; Phillips, 2017). The sites included background and roadside locations. Samples of air were obtained and analysed for BTEX compounds during four rounds of sampling between September and October of 2015 for the M4 East and New M5, and between January and February of 2017 for the M4-M5 Link. The results are summarised in Table D-20. In many cases the concentration for a given compound was lower than the corresponding limit of reporting (LOR)[6]. The results were therefore similar to those from the earlier studies, and confirmed that the concentrations of air toxics in Sydney remain very low.

[6] The LOR represents the lowest concentration at which a compound can be detected in the samples during laboratory analysis.

Table D-20 Results of BTEX sampling for the M4 East, New M5 and M4-M5 Link projects

Compound(s)	Range of concentrations measured		
	M4 East sites (5)	New M5 sites (7)	M4-M5 Link sites (3)
Benzene	All measurements <1.6 µg/m^3 [(a)] (<0.5 ppb)	All measurements <1.6 µg/m^3 [(a)] (<0.5 ppb)	All measurements <1.6 µg/m^3 [(a)] (<0.5 ppb)
Toluene	<1.9 µg/m^3 [(a)] to 6.8 µg/m^3 (<0.5 to 1.7 ppb)	<1.9 µg/m^3 [(a)] to 6.8 µg/m^3 (<0.5 to 1.7 ppb)	<1.9 µg/m^3 [(a)] to 5.3 µg/m^3 (<0.5 to 1.4 ppb)
Ethylbenzene	All measurements <2.2 µg/m^3 [(a)] (<0.5 ppb)	All measurements <2.2 µg/m^3 [(a)] (<0.5 ppb)	All measurements <2.2 µg/m^3 [(a)] (<0.5 ppb)
Total xylenes[(b)]	All measurements <6.6 µg/m^3 [(a)] (<1.4 ppb)	All measurements <6.6 µg/m^3 [(a)] (<1.4 ppb)	All measurements <6.6 µg/m^3 [(a)] (<1.4 ppb)

(a) Limit of reporting
(b) Sum of meta-, para- and ortho- isomers

D.6 Assumed background concentrations

D.6.1 Overview

Defining background levels of air pollutants, and the interactions between emissions from the project sources and the existing mix of pollutants, can be challenging, especially in a large urban area such as Sydney where there is a complex mix of sources. For example, pollutant concentrations can fluctuate a great deal on short time scales, and substantial concentration gradients can occur in the vicinity of sources such as busy roads. Meteorological conditions and local topography are also very important; cold nights and clear skies can create temperature inversions which trap air pollution near ground level, and local topography can increase the frequency and strength of these inversions. In the case of particulate matter, dust storms, natural bush fires and planned burning activities are often associated with the highest concentrations (SEC, 2011).

The data from the background air quality monitoring stations described in this Annexure were used to define appropriate background concentrations of pollutants for the project assessment. The modelled concentrations from the road network were then added to the background concentrations. This is appropriate because the background stations are located well away from busy roads. One potential shortcoming of this approach is that Sydney Gateway is located close to Sydney Airport, and the contribution of the airport to background levels (as defined in the assessment) would tend to increase with proximity to the airport. The explicit incorporation of an airport contribution to local air pollution was beyond the scope of the project. However, the emphasis in the assessment was on the change in contribution associated with the project, which would have been largely unaffected by any airport contribution. Moreover, several aspects of conservatism were built into the assessment.

Various approaches can be used to define long-term (annual mean) and short-term (eg 1-hour, 24-hour) background concentrations. The selection of a suitable method is strongly dependent on the quantity and quality of available data, and this varies from project to project.

Firstly, it is important that that the same year is used for background air quality data and the meteorological data used in the dispersion modelling, given the influence of the latter on the former. The year selected for the meteorological data was 2016. This was also the base year for the assessment, which permitted model evaluation for this year. Becasue there was a general downward trend, or stabilisation, in pollutant concentrations between 2004 and 2017 (see section D.5), the concentrations in 2016 were considered to be appropriate for use in the assessment. On balance, it was considered that the concentrations in 2016 would represent typical (but probably slightly conservative) background concentrations in the future. It is worth noting that for some stations and metrics there was an increase in concentration between 2016 and 2017. This may be an anomoly, or it may be a sign of a new trend.

The approaches for establishing background concentrations in the Sydney Gateway assessment, and for combining these with model predictions, were similar to those developed to support the EISs for the WestConnex M4 East, New M5 and M4-M5 Link projects (Pacific Environment, 2015b; Pacific

Environment, 2015c; Pacific Environment, 2017a). Three types of background concentration data were required:

- For community receptors, time series of background concentrations for the whole of 2016, and using time intervals that corresponded to the air quality criteria (eg 1-hour average, 24-hour average). These profiles were used in the 'contemporaneous' assessment for each receptor.
- For 'residential, workplace and recreational (RWR) receptors, single annual mean background concentrations.
- For RWR receptors, single short-term background concentrations.

The general approaches used, and the results for the various pollutants and metrics, are described in sections D6.2, D6.3 and D6.4. The various approaches are summarised in section D6.5, and some limitations are discussed in section D6.5.

D.6.2 Synthetic background profiles for community receptors (contemporaneous assessment)

D.6.2.1 General approach

A contemporaneous approach was used for community receptors. This was broadly consistent with the 'Level 2' method described in the NSW Approved methods. The approach requires that existing background concentrations of a pollutant in the vicinity of a proposal should be included in the assessment as follows (NSW EPA, 2016):

- At least one year of continuous ambient pollutant measurements should be obtained for a suitable background station. The background data should be contemporaneous with the meteorological data used in the dispersion modelling.
- At each receptor, each individual dispersion model prediction is added to the corresponding measured background concentration (eg the first hourly average dispersion model prediction is added to the first hourly average background concentration) to obtain total hourly predictions.
- At each receptor, the maximum concentration for the relevant averaging period is determined.

The unstated assumption is that one of the paired project-background concentration combinations will result in a realistic estimate of the maximum concentration that could be expected.

For Sydney Gateway this approach was applied to 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). NO_X (1-hour mean) was used in place of NO_2 for the reasons given in Annexure E.

For 1-hour NO_X, 24-hour PM_{10} and 24-hour $PM_{2.5}$, the three stations inside the GRAL domain were used to construct synthetic background profiles (OEH Earlwood, SMC NewM5:01, SMC NewM5:04). As CO was not measured at Earlwood, the data from the two SMC stations were used for this pollutant.

It was assumed that the three stations would represent the range of short-term concentrations in the GRAL domain. Gap-filling techniques were used to ensure that a complete time series of concentrations was available. The approach for each pollutant is described in the relevant section below. To maintain a margin of safety, in each synthetic profile the concentration for a given time step (eg 1 hour or 24 hours) was taken as the maximum of the values from all the relevant stations.

D.6.2.2 Carbon monoxide: 1-hour mean

Figure D-16 shows examples of 1-hour mean CO concentration profiles at the two SMC stations in the GRAL domain during June of 2016. Peak concentrations generally occurred simultaneously at the different stations, indicating a regional background influence. This synthetic background profile for 2016, which was constructed using the data from these stations, is shown in Figure D-17.

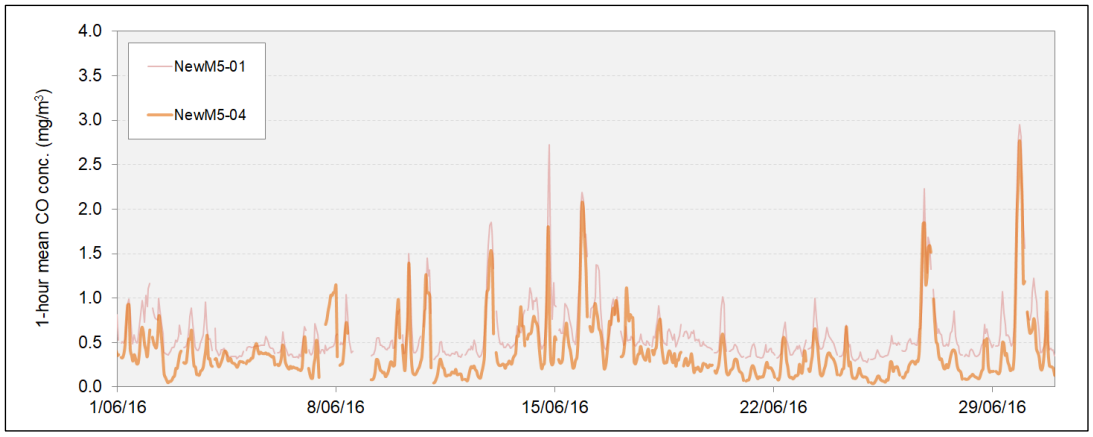

Figure D-16 1-hour mean CO concentration at SMC stations (example for June 2016)

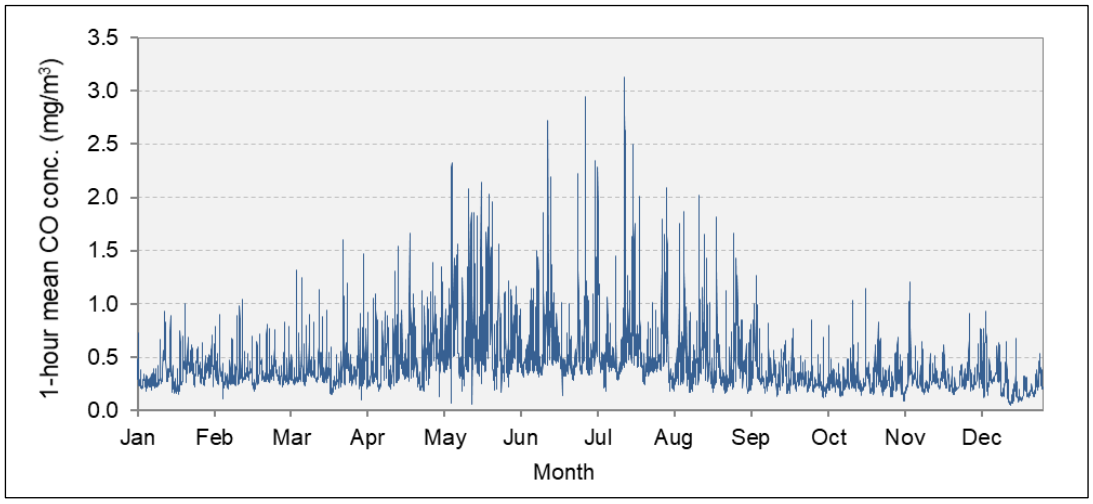

Figure D-17 Synthetic background concentration profile for 1-hour mean CO in 2016

D.6.2.3 Carbon monoxide: rolling 8-hour mean

The synthetic profile for the rolling 8-hour mean CO concentration was constructed using the data from the two stations identified in Figure D-16. This profile is shown in Figure D-18.

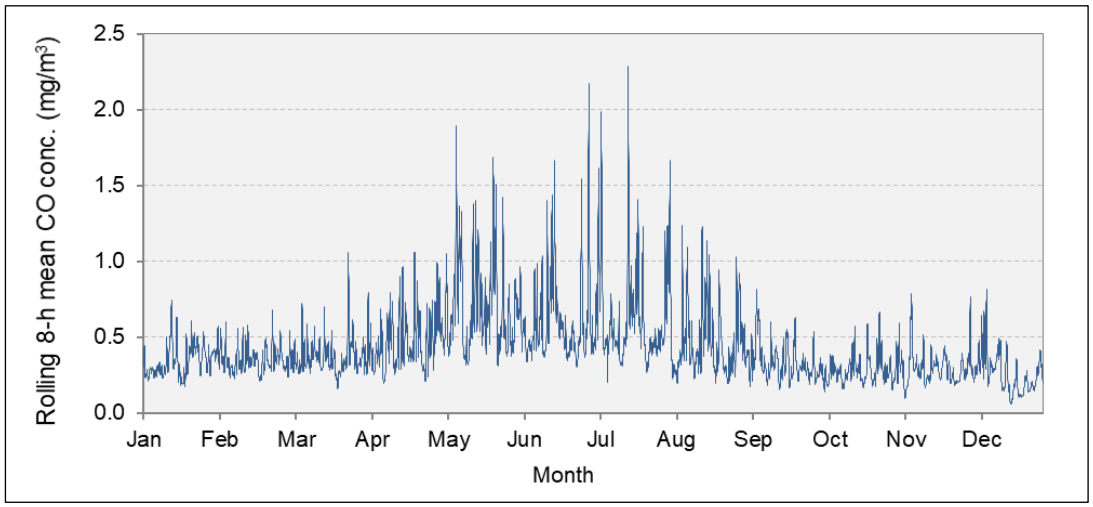

Figure D-18 Synthetic background concentration profile for rolling 8-hour mean CO in 2016

D.6.2.4 NO_X: 1-hour mean

Figure D-19 shows examples (for June 2016) of 1-hour NO_X concentration profiles at the three background stations inside the GRAL domain. As with CO, peak concentrations regularly occurred simultaneously at the different stations, indicating a regional influence. The synthetic profile is shown in Figure D-20.

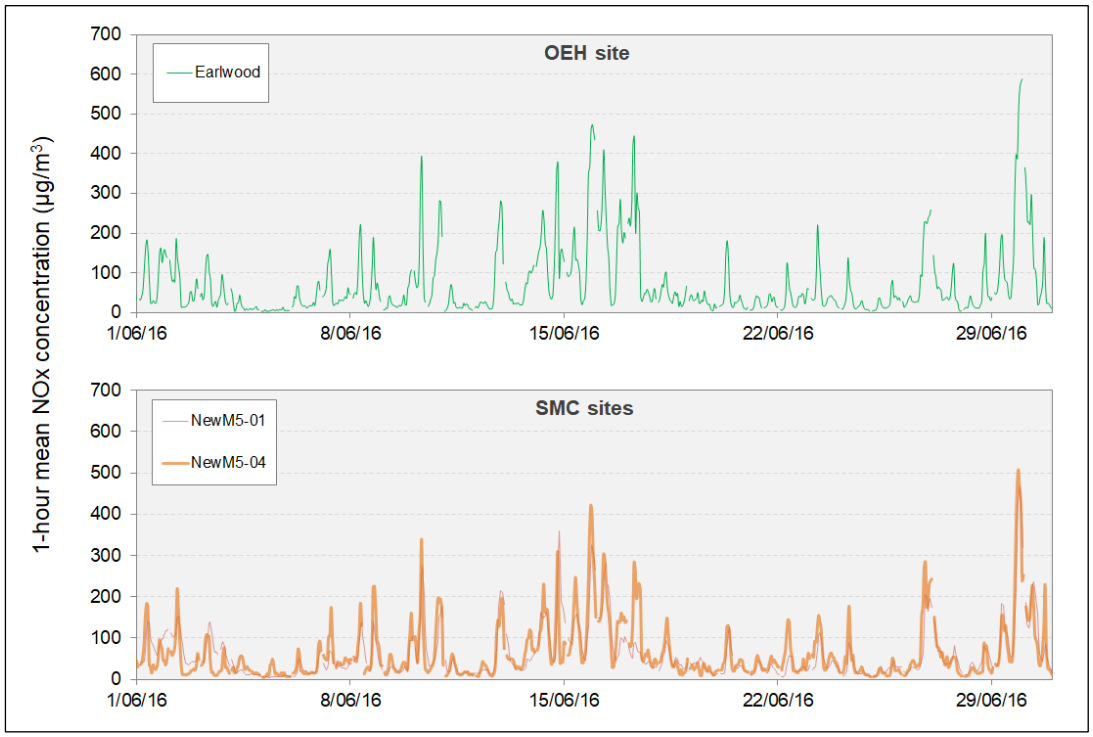

Figure D-19 1-hour mean NO_X concentration at OEH and SMC stations (example for June 2016)

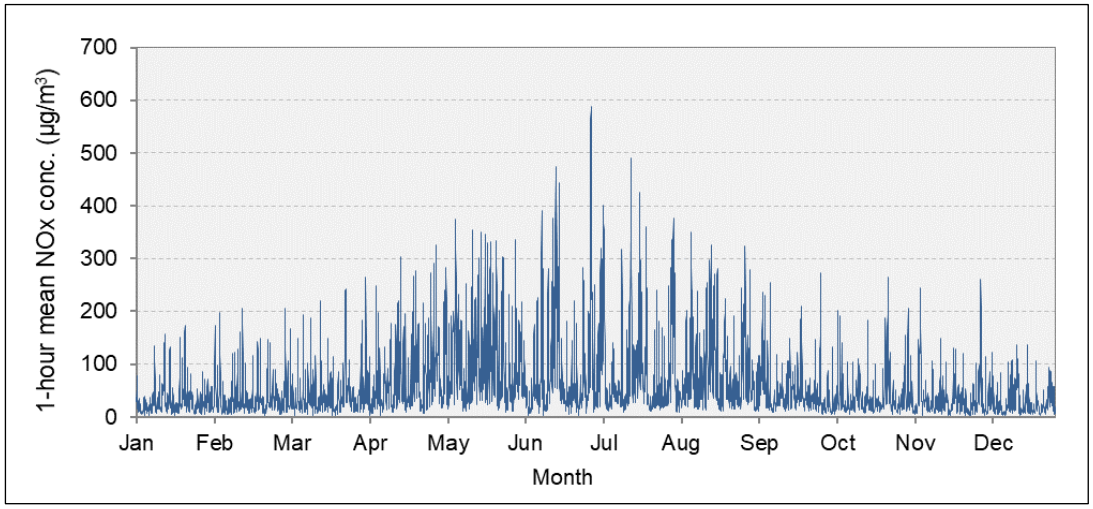

Figure D-20 Synthetic background concentration profile for 1-hour mean NO_X in 2016

D.6.2.5 PM_{10}: 24-hour mean

Figure D-21 shows the concentration profiles for 24-hour mean PM_{10} in 2016 at the three stations inside the GRAL domain. As before, the strong similarities between the peaks and troughs in the profiles at the three stations show that the stations are characterising the same (ie regional) patterns in PM_{10}. The

synthetic background concentration profile for 24-hour PM_{10} is shown in Figure D-22. There were two exceedances of the criterion of 50 µg/m^3.

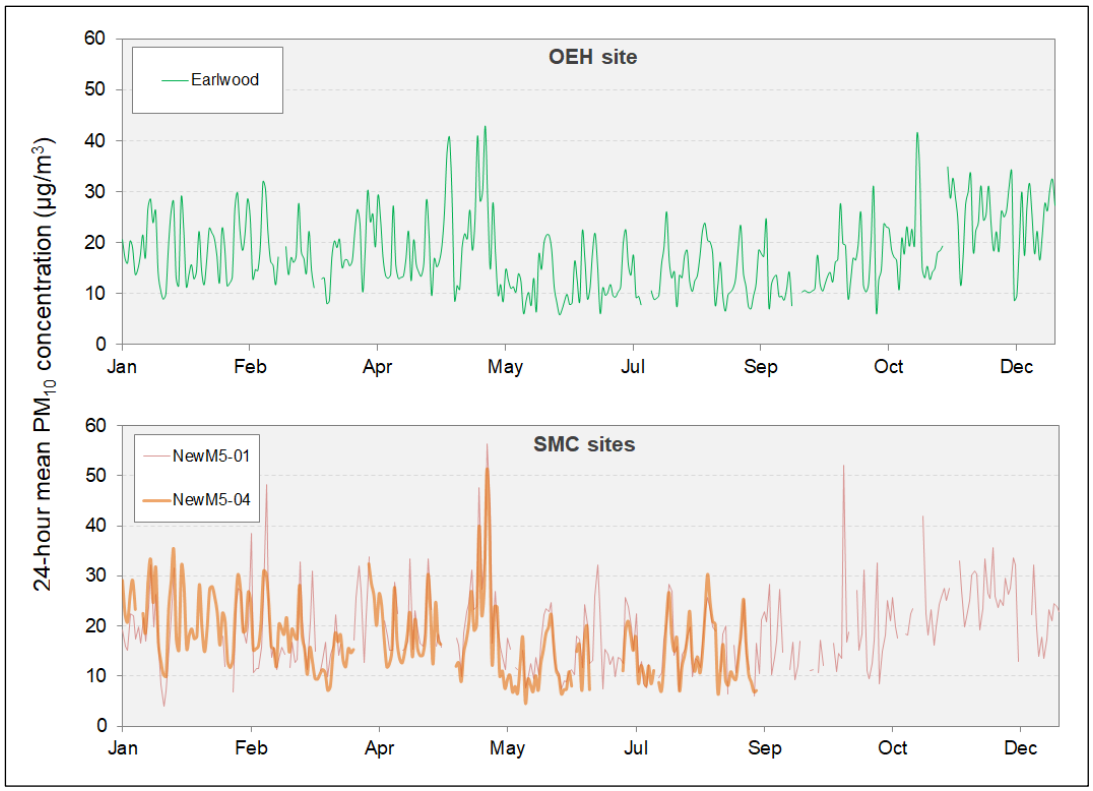

Figure D-21 24-hour mean PM_{10} concentration at OEH and SMC stations in 2016

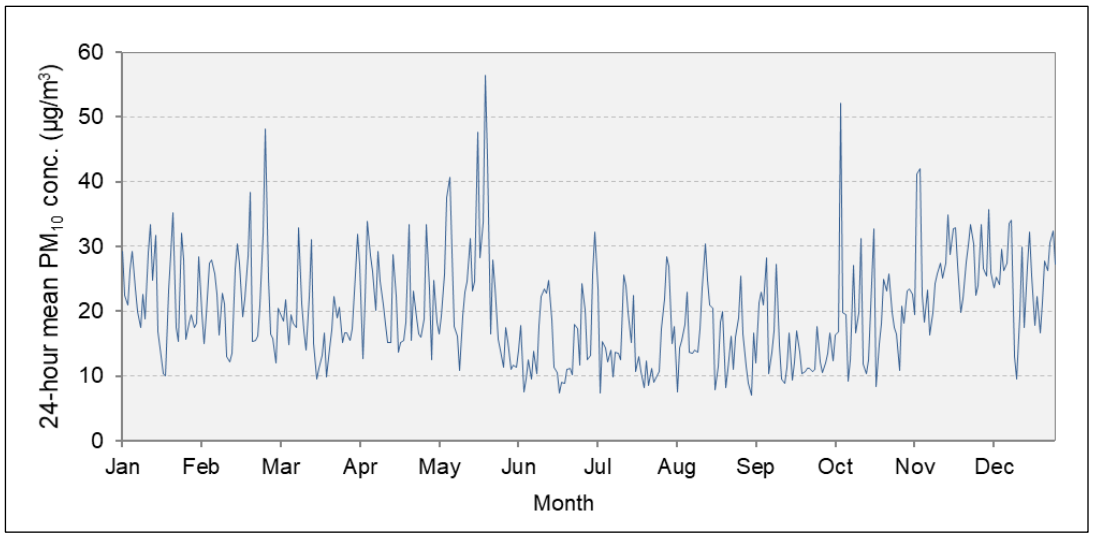

Figure D-22 Synthetic background concentration profiles for 24-hour mean PM_{10} in 2016

D.6.2.6 $PM_{2.5}$: 24-hour mean

The concentrations from the these stations are shown in Figure D-23, and the synthetic profile is given in Figure D-24. There were six exceedances of the criterion of 25 µg/m^3.

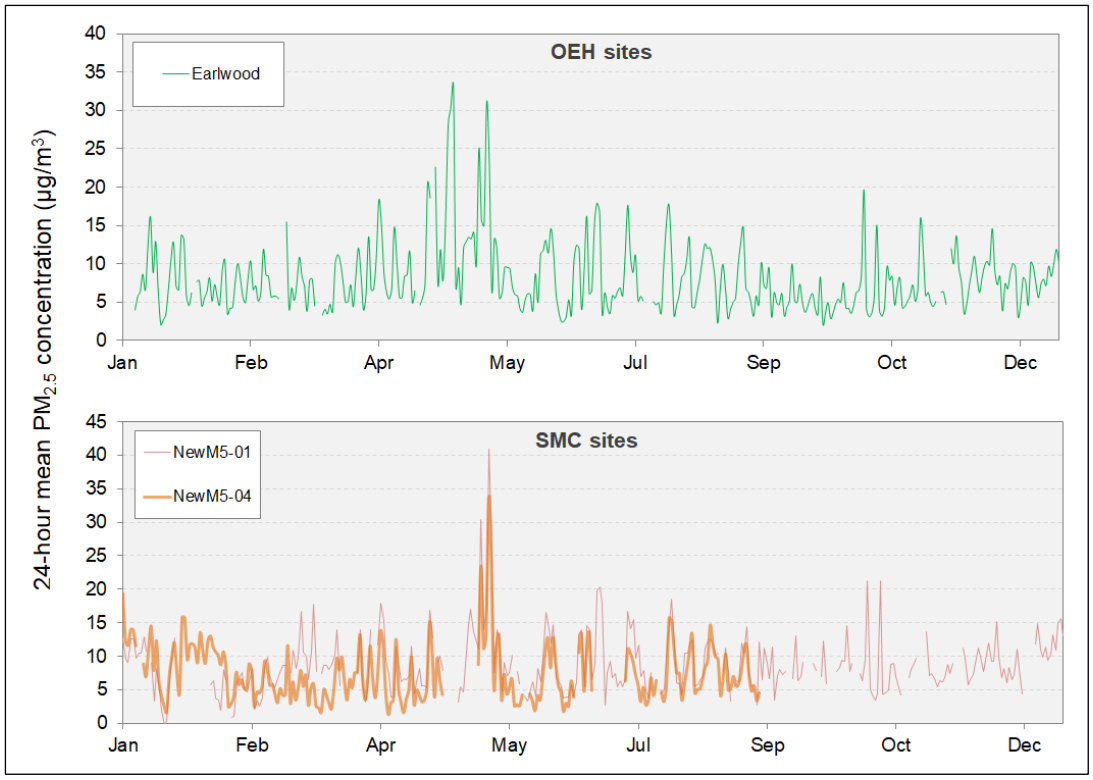

Figure D-23 24-hour mean $PM_{2.5}$ concentration at OEH and SMC stations in 2016

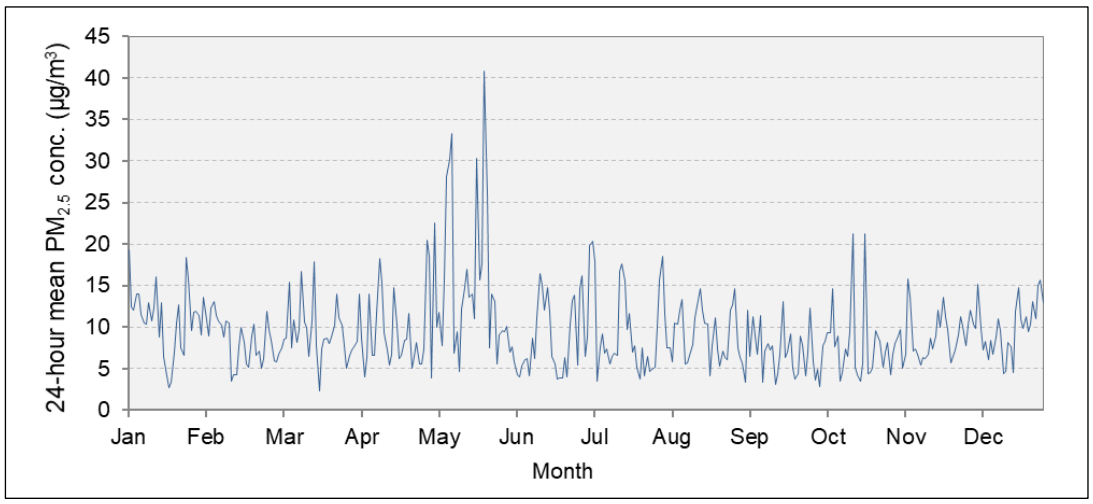

Figure D-24 Synthetic background concentration profile for 24-hour mean $PM_{2.5}$ in 2016

D.6.3 Annual mean background concentrations at RWR receptors

In the case of annual mean concentrations it is relatively straightforward to define background values. For smaller projects it has often been sufficient to use a single background value, and to assume that this is representative of the whole study area. However, for a project such as F6 Extension, 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.

The background maps were created in the Golden Software Surfer package using a geostatistical Kriging method, whereby gridded values are interpolated based on the statistical relationship of the surrounding measured values. Clearly, the absence of monitoring data for much of the GRAL domain meant that there was some uncertainity in the extrapolation. For the creation of the background maps the data from all background stations in Sydney with relevant measurements were used.

To determine background pollutant concentrations for any discrete receptor location within the GRAL domain, the 'grid residual' function in Surfer was used. This function calculates the difference between the grid value and a specified data value at any x-y location. By setting the data value for a given x-y point to zero, it can be used to return the estimated concentration for the point. Although this approach did not allow for localised influences on background concentrations, it was considered to be better than the alternatives (eg using a single annual mean value for the whole domain).

D.6.3.1 NO_X: annual mean

It was noted in the trend analysis that there was a spatial variation in NO_X concentrations. To allow for this spatial variation, the data from the OEH and SMC background monitoring stations were used to determine a background map for annual mean NO_X across Sydney in 2016, as shown in Figure D-25. The GRAL domain is also identified in the Figure. The Roads and Maritime M5 East stations were not used in the development of these maps as they resulted in a localised and adjacent areas of relatively low and high concentration. It was therefore assumed that these stations were spatially unrepresentative of the general pattern if NO_X concentrations across the domain.

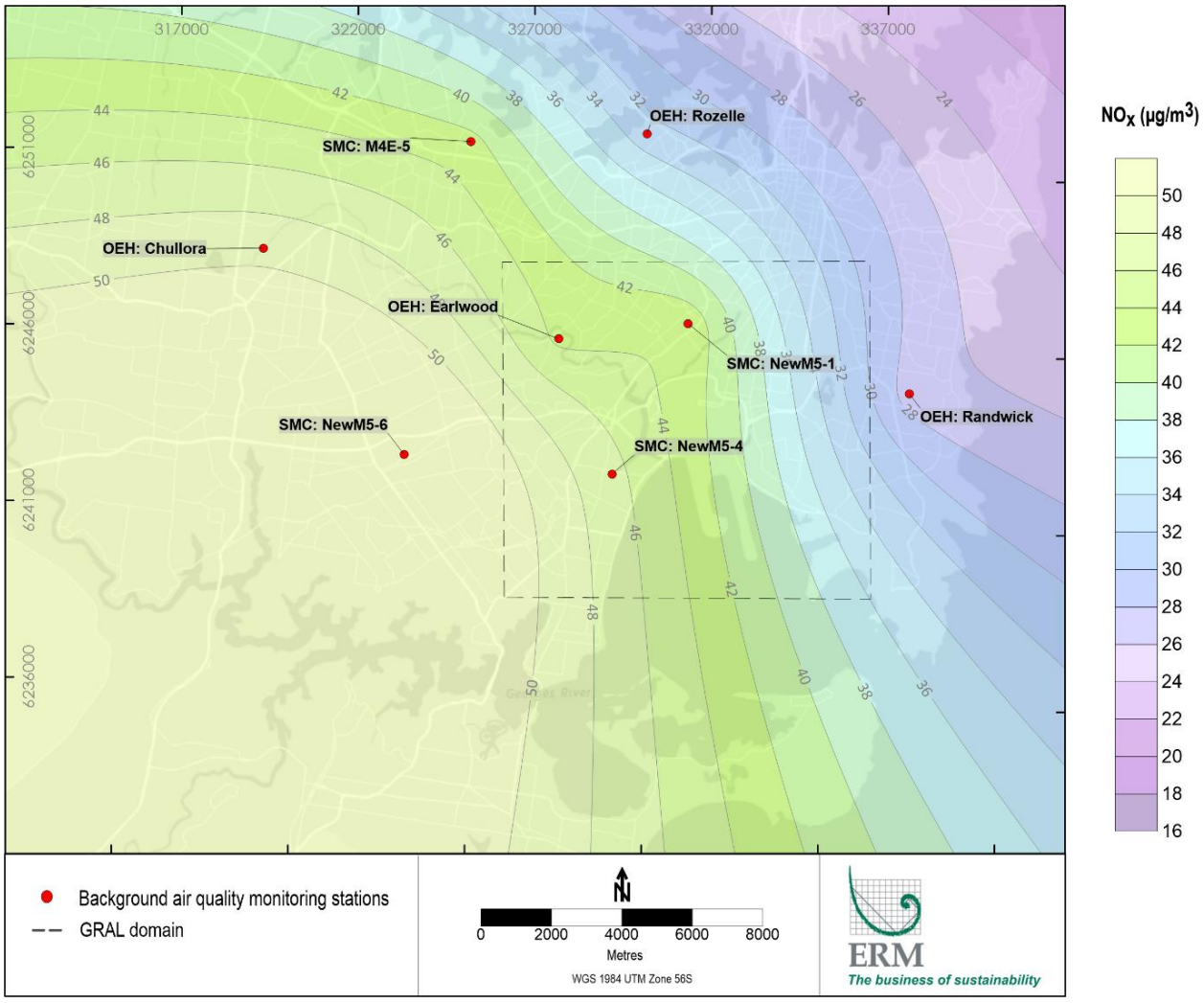

Figure D-25 Background map for annual mean NO_X concentration across Sydney in 2016

The Figure shows that there was a decreasing NO_X concentration gradient across Sydney, from the south-west to the north-east. This was also the case for the GRAL domain, with concentrations decreasing from around 50 µg/m^3 in the south-west to around 30 µg/m^3 in the north-east.

D.6.3.2 PM_{10}: annual mean

The background map for annual mean PM_{10} in Sydney in 2016 is shown in Figure D-26. Compared with NO_X, the concentration gradient for PM_{10} across the GRAL domain was quite small ranging from around 17 µg/m^3 in the north-west to around 19 µg/m^3 in the south.

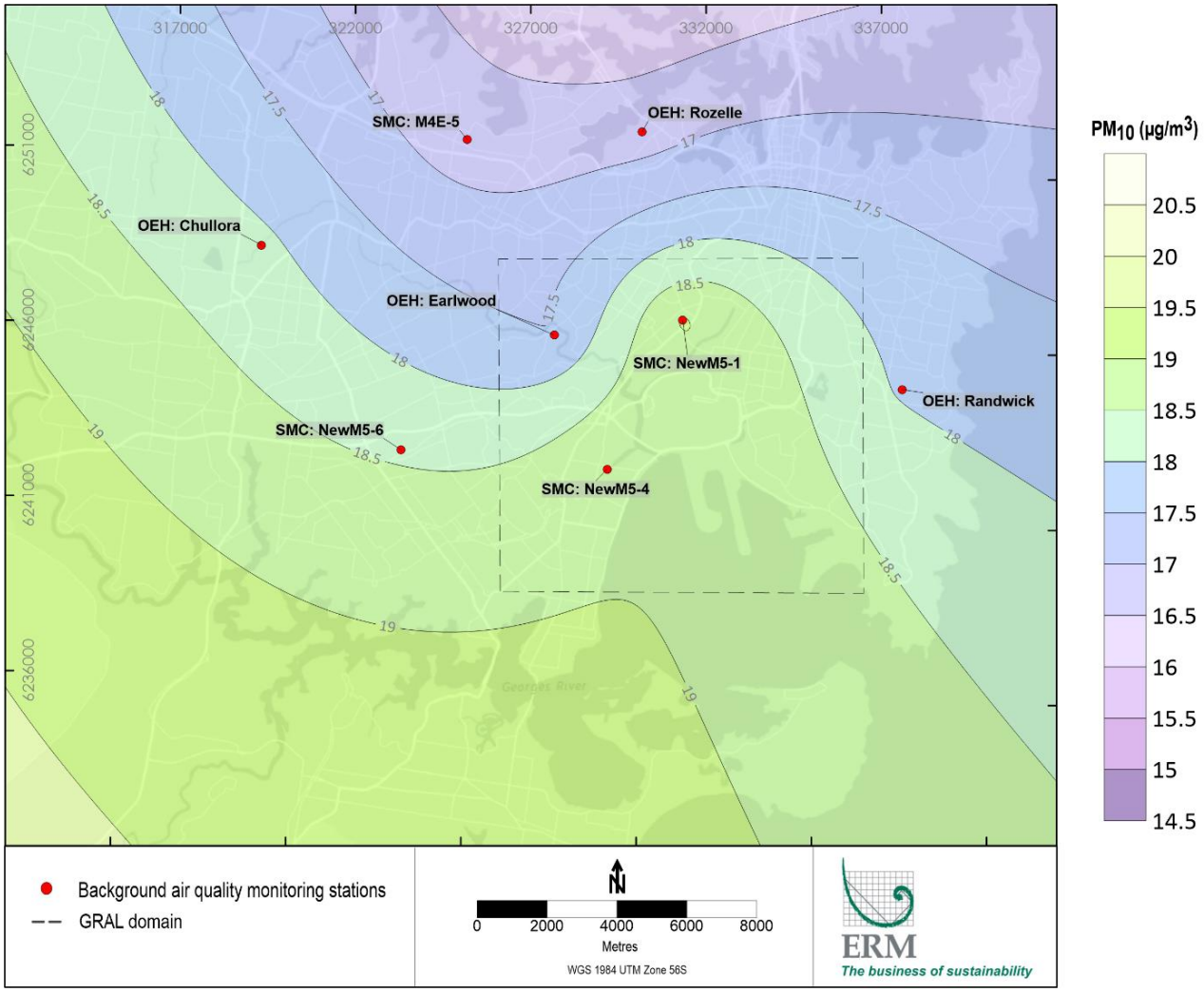

Figure D-26 Background map for annual mean PM_{10} concentration across Sydney in 2016

D.6.3.3 $PM_{2.5}$: annual mean

The background map for annual mean $PM_{2.5}$ in Sydney in 2016 is shown in Figure D-27. The concentration range across the GRAL domain was small, varying from around 7.6 µg/m^3 in the north-west to around 9.6 µg/m^3 in the south.

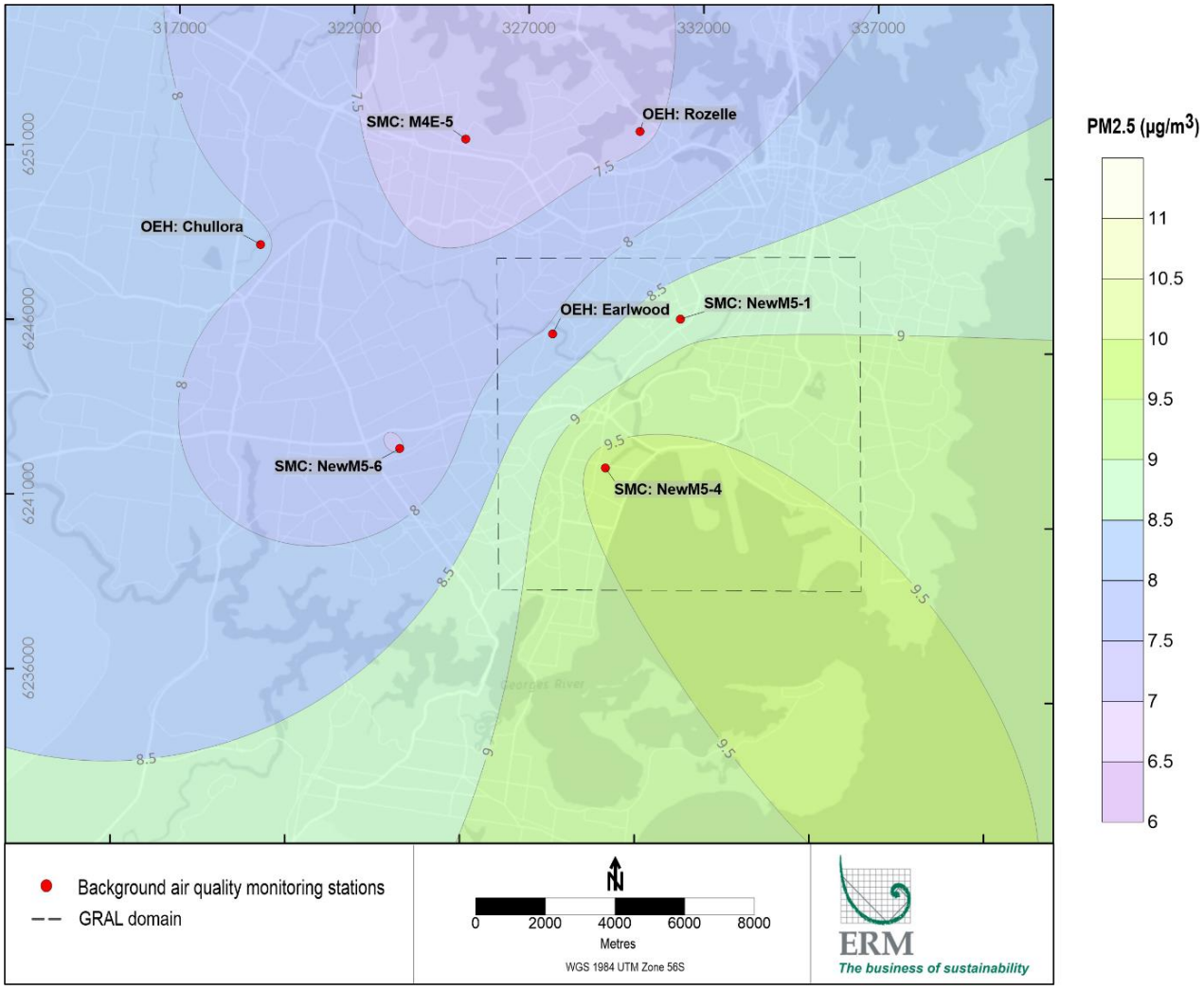

Figure D-27 Background map for annual mean $PM_{2.5}$ concentration across Sydney in 2016

D.6.4 Background concentrations for short-term metrics at RWR receptors

The background concentrations for short-term metrics at all RWR receptors were taken to be single values with no spatial variation. It should be noted that the approaches described below for RWR receptors were also applied to the development of the contour plots for the corresponding pollutant metrics.

D.6.4.1 CO

For RWR receptors the maximum 1-hour CO concentration from GRAL was added to the maximum 1-hour background concentration from the synthetic profile (3.13 mg/m^3). The result from this calculation was also used to derive the maximum rolling 8-hour CO concentration using a relationship based on the data from the air quality monitoring stations in Sydney between 2004 and 2016 (Figure D-28). This relationship is expressed in Equation D1.

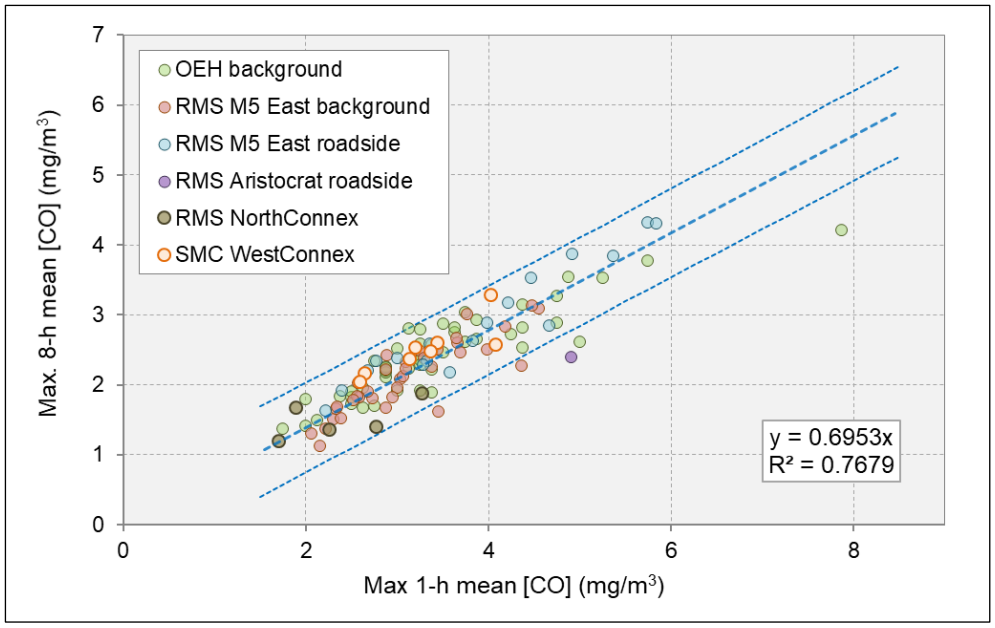

Figure D-28 **Relationship between maximum rolling 8-hour mean CO and maximum 1-hour mean CO (dotted blue lines show 95 per cent prediction intervals)**

Equation D1

$$[CO]_{8h,max} = 0.6953 \times [CO]_{1h,max}$$

Where:

$[CO]_{8h,max}$ = maximum rolling 8-hour CO concentration (including background) (mg/m^3)

$[CO]_{1h,max}$ = maximum 1-hour CO concentration (including background) (mg/m^3)

D.6.4.2 NO_X, PM_{10} and $PM_{2.5}$

For NO_X the maximum 1-hour concentration from GRAL was added to the 99th percentile 1-hour concentration from the synthetic background profile (305.6 µg/m^3), and the resulting total was converted to NO_2 using the empirical approach described in Annexure E. For PM_{10} and $PM_{2.5}$ the maximum 24-hour concentration from GRAL was added to the maximum 24-hour concentration from the synthetic background profile (56.4 µg/m^3 for PM_{10} and 40.9 µg/m^3 for $PM_{2.5}$).

These background values were selected based on a comparison between the statistical and contemporaneous approaches at the community receptors, as shown in Figure D-29 to Figure D-32. The use of a 99th percentile background concentration for NO_X, and a maximum background concentration for PM_{10} and $PM_{2.5}$ across the domain gave total concentrations that we similar to those obtained with contemporaneous approach.

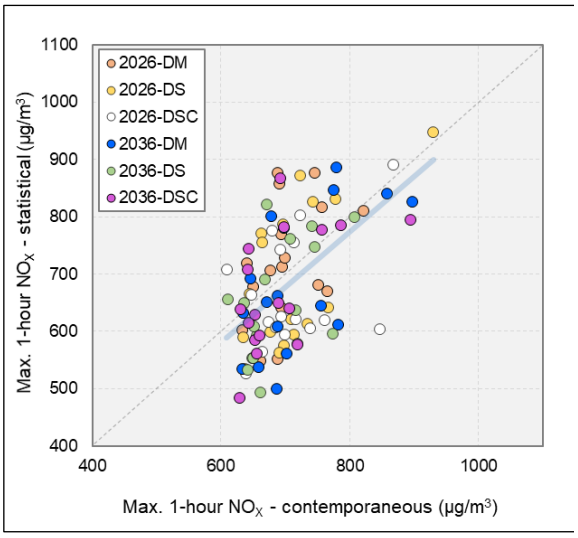

Figure D-29 Comparison between statistical and contemporaneous approaches for calculating maximum 1-hour NO_X at community receptors (99th percentile background NO_X)

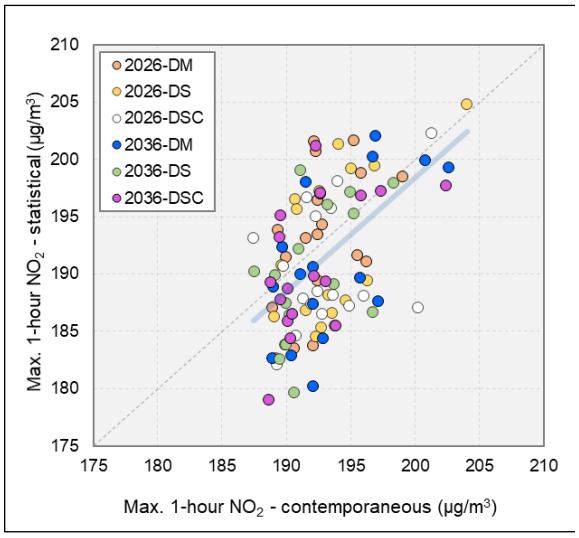

Figure D-30 Comparison between statistical and contemporaneous approaches for calculating maximum 1-hour NO_2 at community receptors (99th percentile background NO_X)

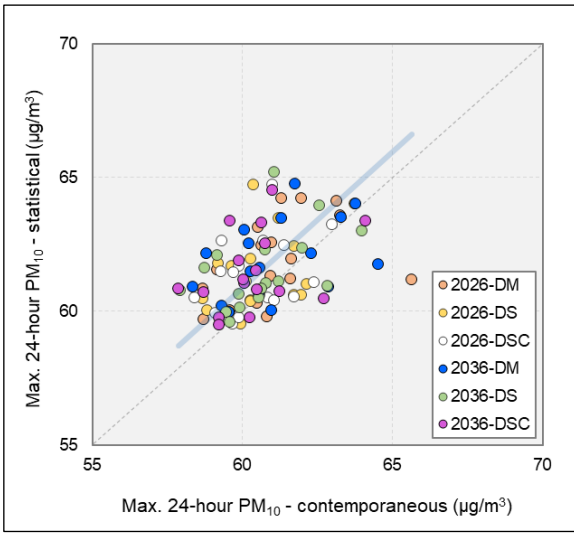

Figure D-31 Comparison between statistical and contemporaneous approaches for calculating maximum 24-hour PM_{10} at community receptors (maximum background PM_{10})

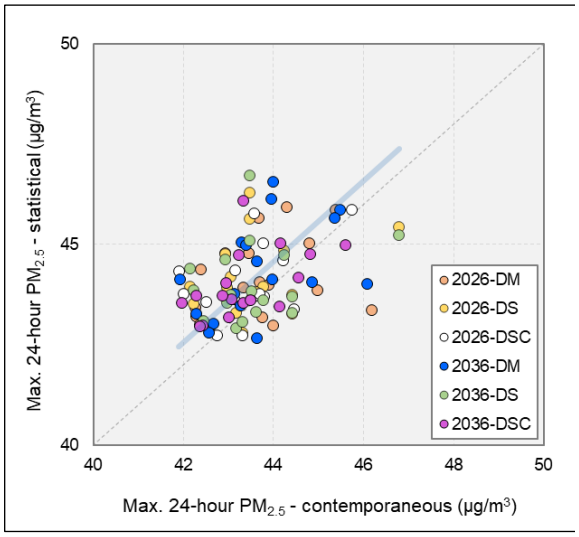

Figure D-32 Comparison between statistical and contemporaneous approaches for calculating maximum 24-hour $PM_{2.5}$ at community receptors (maximum background $PM_{2.5}$)

D.6.5 Summary of background concentration approaches

The approaches used to characterise background concentrations for community and RWR receptors, and some basic statistics, are provided in Table D-21.

Table D-21 Characteristics of assumed background concentrations (year = 2016)

Pollutant/ metric	Averaging period	Form	Units	Statistical descriptors		
				Mean	Max.	99th percentile
Community receptors – contemporaneous assessment						
CO	1-hour	Synthetic profile	mg/m^3	0.43	3.13	1.61
	8 hour (rolling)	Synthetic profile	mg/m^3	0.43	2.29	1.36
NO_X	Annual, 1-hour	Synthetic profile	$\mu g/m^3$	56.2	589.0	305.6
PM_{10}	Annual, 24-hour	Synthetic profile	$\mu g/m^3$	20.1	56.4	45.0
$PM_{2.5}$	Annual, 24-hour	Synthetic profile	$\mu g/m^3$	9.5	40.9	28.9
RWR receptors – statistical assessment						
CO	1-hour	Maximum	mg/m^3	-	3.13	-
	8 hour (rolling)	Not applicable (see Equation D1)				
NO_X	Annual	Map	$\mu g/m^3$	Spatially varying	-	-
	1-hour	Maximum	$\mu g/m^3$	-	-	305.6
PM_{10}	Annual	Map	$\mu g/m^3$	Spatially varying	-	-
	24-hour	Maximum	$\mu g/m^3$	-	56.4	-
$PM_{2.5}$	Annual	Map	$\mu g/m^3$	Spatially varying	-	-
	24-hour	Maximum	$\mu g/m^3$	-	40.9	-

D.7 Limitations

It is important to understand the limitations of the various approaches for combining model predictions with background concentrations, and the inherent uncertainty in the overall results. For annual mean concentrations the approaches used were considered to be robust, taking into account the spatial variation in the background concentration with reasonable accuracy. However, for short-term metrics there is always more uncertainty in both the model predictions and the background. Measured short-term concentration peaks vary considerably in terms of the magnitude, time of occurrence and location. It is well know that models do not accurately predict peak concentrations in both time and space. It is also very difficult to define both the spatial and temporal variation in short-term background concentrations in great detail, especially where the monitoring data are not very extensive. The uncertainty in the prediction of short-term concentrations relates to both the contemporaneous and statistical approaches used in this assessment, as noted below.

The contemporaneous approach gives a reasonably good representation of the temporal variation in model predictions and background concentrations. As the temporal variation in concentrations is generally more pronounced than the spatial variation, it is usually considered to be more important to focus on this aspect. The main shortcoming of the contemporaneous approach is that a single background profile is applied across a wide geographic area, whereas peak concentrations vary spatially. It is likely that that the synthetic profile would underestimate peak concentrations at some locations, and would overestimate concentrations at other locations, although given the conservative nature of the synthetic profile the latter would be more likely to occur.

For RWR receptors a single (maximum) value was used for short-term background concentrations. However, such an approach can be very conservative, and can result in unrealistically high cumulative concentrations; it is very unlikely that the maximum background value will coincide in space and time with the maximum predicted value at all locations, or even at a single location.

Annexure E - NO_X-to-NO_2 conversion

E.1 Overview

Some atmospheric pollutants have slow chemical reaction rates, and for air quality modelling on an urban scale they can essentially be treated as inert (Denby, 2011). This is not the case for NO_2 since it is rapidly formed through the atmospheric reaction of NO with O_3, and is destroyed by sunlight during the day (see Annexure A). This is one reason why air pollution models are generally configured to predict NO_X concentrations, with the spread of NO_X being simulated as though it were a non-reactive gas (NZMfE, 2008). However, as air quality criteria address NO_2 rather than NO_X it is necessary to estimate NO_2 concentrations from the modelled NO_X concentrations. Many different approaches to this conversion have been developed over the years, and this Annexure describes some of these. The approach used for the Sydney Gateway assessment is also detailed.

The estimation of NO_2 concentrations near roads is not straightforward. It requires an understanding of NO_2 formation and destruction, and here there are a number of challenges. These include:

- How to account for the amount of primary NO_2 emitted in vehicle exhaust. This is dependent on the composition of the traffic, and is changing as the vehicle fleet evolves.
- How to account for the amount of conversion of NO to NO_2 in the atmosphere following release from the source, as this is dependent on the local atmospheric conditions, including the amount of ozone available.
- How to determine cumulative NO_2 concentrations, or in other words how to combine the road traffic contribution and the background (non-road) contribution.
- How to provide a realistic estimate of the change (whether this be an increment or decrement) in the NO_2 concentration that results from a road project.

The challenges are also greater for the 1-hour air quality criterion than for the annual mean criterion. For example, the maximum predicted NO_X concentration will not occur during the same hour of the year at all locations in the model domain.

In order to ensure that an appropriate and pragmatic method was selected for the Sydney Gateway assessment, a review of the literature and data was undertaken. This Annexure presents the findings of the review and contains the following:

- A brief summary of the available guidance relating to the estimation of NO_2 concentrations.
- A review of the methods that are commonly used for estimating NO_2 concentrations. These either involve the use of empirical data or the modelling of atmospheric chemistry. In practice empirical approaches tend to be applied, as local knowledge on the inputs required for modelling chemistry is often incomplete.
- An analysis of the NO_X and NO_2 data from ambient air quality monitoring stations in Sydney, including the monitoring stations that were established specifically for the Sydney Gateway project. This analysis was used to estimate NO_X-to-NO_2 conversion methods for the specific purpose of the Sydney Gateway assessment, and more widely for complex road projects in Sydney.

E.2 Guidance on NO_2 estimation

E.2.1 New South Wales

Guidance on the conversion of NO_X to NO_2 is provided in the NSW Approved Methods (NSW EPA, 2016). Three methods are described, from Method 1, the most simple, to Method 3, the most complex.

E.2.2 North America

The USEPA's Guideline on Air Quality Models (GAQM) provides recommendations on the use of air quality models to determine compliance with National Ambient Air Quality Standards (NAAQS) (USEPA, 2011). In this case, three 'Tiers' of assessment are provided, with Tier 1 being the simplest

and Tier 3 the most complex. Additional guidance on the assessment of 1-hour NO_2 concentrations has recently been provided in the following:

- Applicability of Appendix W Modeling Guidance for the 1-hour NO_2 National Ambient Air Quality Standard, June 28, 2010[1].
- Additional Clarification Regarding Application of Appendix W Modeling Guidance for the 1-hour NO_2 National Ambient Air Quality Standard, March 1, 2011[2].

Other recent guidelines from North America include:

- Modeling Compliance of the Federal 1-Hour NO_2 NAAQS (CAPCOA, 2011).
- Air Quality Model Guideline (Alberta Government, 2013).
- Guidelines for Air Quality Dispersion Modelling in British Columbia (BCMoE, 2008).

E.2.3 New Zealand

The following documents provide guidance on the estimation of NO_2 for air quality assessments in New Zealand:

- Good Practice Guide for Atmospheric Dispersion Modelling (NZMfE, 2004).
- Good Practice Guide for Assessing Discharges to Air from Industry (NZMfE, 2008), which updates the 2004 document.

E.2.4 United Kingdom

Guidance documents from the UK include:

- Review of background air-quality data and methods to combine these with process contributions (Environment Agency, 2006).
- Review of methods for NO to NO_2 conversion in plumes at short ranges (Environment Agency, 2007). This report focusses on the regulation of large industrial point sources.
- Local Air Quality Management Technical Guidance LAQM.TG(16) (Defra, 2016). This document is designed to support UK local authorities in carrying out their duties with respect to air quality management. A number of tools have been developed to support the guidance, including background maps of air pollutants, with year adjustment factors and a calculator that can be used to derive NO_2 from NO_X which is predicted when modelling emissions from roads.

E.3 Estimation methods

E.3.1 General approaches

In some assessments the road traffic and background concentrations to NO_2 at any given receptor have simply been added together to give the cumulative concentration, ie:

Equation E1

$$[NO_2]_{total} = [NO_2]_{road} + [NO_2]_{background}$$

Where:

$[NO_2]_{total}$ is the total estimated NO_2 concentration at the receptor

$[NO_2]_{road}$ is the modelled NO_2 concentration at the receptor due to a road (or roads) in the modelling domain

[1] http://www.epa.gov/scram001/guidance/clarification/ClarificationMemo_AppendixW_Hourly-NO2-NAAQS_FINAL_06-28-2010.pdf
[2] http://www.epa.gov/region7/air/nsr/nsrmemos/appwno2_2.pdf

$[NO_2]_{background}$ is the existing background NO_2 concentration at the receptor due to emissions from all sources other than roads

As the background is often assumed to be fixed, in this formulation the NO_2 increment or decrement associated with a project is simply the change in the value of $[NO_2]_{road}$ for model runs with and without the project. This has to be determined in some way from the road NO_X increment. However, there is a flaw in this approach. Although the road and background contributions to NO_X are additive, this is not the case for NO_2. The potential for oxidising NO to NO_2 is dependent on the amount of ozone that is available, which in turn is dependent on the NO concentration. The higher the existing background NO concentration, the less ozone that is available and the smaller the possibility of oxidising the NO from road vehicles to NO_2.

For any given model prediction/scenario it is therefore more appropriate to determine the total NO_2 concentration from the total NO_X concentration. This can be expressed as follows:

Equation E2

$$[NO_X]_{total} = [NO_X]_{road} + [NO_X]_{background}$$

Equation E3

$$[NO_2]_{total} = f([NO_X]_{total})$$

Where $f([NO_X]_{total})$ is the method used to convert total NO_X to total NO_2.

The NO_2 increment or decrement associated with the project is then calculated as follows:

Equation E4

$$[NO_2]_{project} = [NO_2]_{total\ (with\ project)} - [NO_2]_{total\ (without\ project)}$$

E.3.2 Specific methods

Several methods are available for characterising the transformation of NO to NO_2. These include:

- Total conversion method:
    - Assuming that all NO_X from the emission source being modelled is present as NO_2 (ie there is always total conversion of NO to NO_2. This is 'Method 1' in the NSW Approved Methods and the USEPA's 'Tier 1' approach).
- NO_2/NO_X ratio methods, including:
    - Assuming a constant NO_2/NO_X ratio. This is the USEPA's 'Tier 2' approach, which is referred to as the 'ambient ratio method' (ARM).
    - Assuming a variable NO_2/NO_X ratio to all for influences such as the season and distance from source.

  NO_X to NO_2 conversion methods that use ambient ratios are usually based on empirical data. Empirical relationships fall within the 'Method 3' in the NSW Approved Methods.
- Reactant-limited methods, whereby the instantaneous conversion of NO is constrained only by the amount of oxidant(s) available. Such methods include:
    - The 'ozone limiting method (OLM)', in which NO to NO_2 conversion is limited by the amount of ozone available (known as 'ozone titration'). This is 'Method 2' in the NSW Approved Methods, and is a USEPA Tier 3 approach.
    - The plume volume molar ratio method (PVMRM), which is also based on ozone titration. This is a USEPA 'Tier 3' approach. It is not mentioned in the NSW Approved Methods.

- Reactive plume methods. These use complex or simplified atmospheric photochemical reaction schemes which derive NO_2 concentrations from first principles. Such approaches have been incorporated into some of the latest generation of air pollution models.

The different methods presented in the literature are summarised in the following Sections.

E.3.3 Total conversion of NO to NO_2

E.3.3.1 Description

The most basic – and most conservative – method for estimating the NO_2 concentration at a receptor is based on the assumption that all emitted NO is oxidised to NO_2, or in other words all modelled NO_X from roads is present as NO_2:

Equation E5

$$[NO_2]_{road} = [NO_X]_{road}$$

Equation E6

$$[NO_2]_{total} = [NO_2]_{road} + [NO_2]_{background}$$

This approach is often used as a screening step; if compliance with air quality standards is obtained using this approach, then it can be assumed that there will be negligible risk of exceedances in reality and more detailed calculations for NO_2 are not required. If, on the other hand, the estimated NO_2 concentrations are close to or higher than the air quality standards then more detailed, less conservative methods should subsequently be applied.

E.3.3.2 Application in NSW Approved Methods

For annual mean concentrations the modelled NO_x concentration is converted to NO_2 (assuming 100 per cent conversion of NO), and the result is then simply added to the background NO_2 concentration.

For 1-hour means, the cumulative concentration can be determined in one of two ways:

- Level 1 (maximum): The maximum modelled 1-hour mean NO_2 concentration is added to the maximum background 1-hour mean NO_2 concentration.
- Level 2 (contemporaneous): Using contemporaneous assessment of model predictions and ambient concentrations. The cumulative NO_2 concentration is determined by adding the modelled 1-hour mean NO_2 concentration with the contemporaneous background 1-hour mean NO_2 concentration.

E.3.3.3 Limitations and performance

This method represents a worst case situation. It does not allow for the availability of ozone or NO_2 destruction through photolysis, and will overestimate NO_2 concentrations. The overestimation will be largest at high NO_X concentrations where NO_2 formation is ozone-limited. This is explored further in Section G5. The total conversion method is therefore of limited use where an accurate estimate of NO_2 is required.

E.3.4 NO_2/NO_X ratio methods

E.3.4.1 Description

Constant ratio

In the USEPA's ARM, the predicted NO_X concentration for a receptor is multiplied by an empirically derived NO_2/NO_X ratio to determine the NO_2 concentration at the receptor. The NO_2/NO_X ratio is based upon average NO_2 and NO_X concentrations in ambient air at a representative site. For example, in the USEPA 'Tier 2' approach the modelled annual mean NO_X concentrations is multiplied by a default NO_2/NO_X ratio of 0.75. For 1-hour concentrations a NO_2/NO_X ratio of 0.80 is used.

Variable ratio

ARM2

A new empirical method, known as ARM2, has recently been developed by the American Petroleum Institute in response to the frequent observation that hourly NO_2 concentrations estimated using the existing USEPA three-tier approach are much higher than observed concentrations. ARM2 is based on an empirical fit to the 98th percentiles of the binned 1-hour NO_2/NO_X and NO_X values collected from different monitoring stations between 2001 and 2010 (RTP, 2013; Podrez, 2015). The USEPA has approved the use of ARM2 for regulatory 1-hour NO_2 assessments under certain circumstances.

Janssen method

The NSW Approved Methods refer to the approach of Janssen et al. (1988). This involves the use of an empirical equation for estimating the oxidation rate of NO in power plant plumes. The equation is dependent on distance downwind from the source, and has the following form:

Equation E7

$$[NO_2]/[NO_X] = A (1 - \exp(-\alpha x))$$

Where:

x = the distance from the source

A and **α** are classified according to the O_3 concentration, wind speed and season; Janssen et al. (1988) provide values for **A** and **α**.

Given that this method requires the distance from the source to be quantified, the method is not suitable for complex road networks.

Defra method

An empirical approach to calculating NO_2 from NO_X concentrations at roadside sites was developed by Defra in the UK in 2002, and has most recently been updated in 2017. The approach takes account of the difference between fresh emissions of NO_x, the background NO_X, the concentration of O_3, and the different proportions of primary NO_2 emissions in different years. The approach has been incorporated into a spreadsheet which is available from the Defra web site[3].

E.3.4.2 Limitations and performance

The ARM2 method has some advantages over other USEPA Tier 3 methods. For example, it does not require ambient ozone data. The performance of the ARM2 method is comparable to that of the OLM and the PVMRM. However, all three methods over-predict NO_2/NO_X ratios (RTP, 2013).

According to NZMfE (2004) the Janssen approach is based upon the rate of diffusion of O_3 into the emission plume rather than the rates of reaction. It is therefore probably only applicable to the particular power station studied, and is of questionable application to other sources. Although the Approved Methods describe the application of the Janssen method to determine annual mean and 1-hour mean concentrations, its lack of applicability to road networks means that it has not been explored in detail in this Annexure. There is little information on how the NO_2/NO_X ratio changes with distance from the road; monitoring data are usually only available for roadside and/or background locations.

Given that it has been developed to represent vehicle fleets and near-road atmospheres in the UK, it is unlikely that the Defra calculator is suitable for use in Sydney, although this ought to be investigated further. However, this was beyond the scope of the Sydney Gateway assessment.

[3] https://laqm.defra.gov.uk/review-and-assessment/tools/background-maps.html#NOxNO2calc

E.3.5 Reactant-limited methods

E.3.5.1 Description

Ozone limiting method

The USEPA's ozone limiting method (OLM) is one of several reactant-limited approaches. It uses a simple approach to the reaction chemistry of NO and O_3 in order to estimate NO_2 concentrations. It is assumed that all the available O_3 in the atmosphere will react with the NO from the source until either all the O_3 is consumed or all the NO is used up (Cole and Summerhays, 1979; Tikvart, 1996). A slightly different approach to the OLM has been developed for use in New Zealand (NZMfE, 2008).

Plume volume molar ratio method

The plume volume molar ratio method (PVMRM) extends the basic chemistry of the OLM. The PVMRM determines the conversion rate for NO_x to NO_2 based on a calculation of the number of NO_x moles emitted into the plume, and the number of O_3 moles contained within the volume of the plume between the source and receptor. The ratio between the two molar quantities is multiplied by the NO_X concentration to calculate the NO_2 concentration.

Both the OLM and PVMRM require two key model inputs, namely the NO_2/NO_X emission ratio at the source and background ozone concentrations.

E.3.5.2 Implementation in NSW Approved Methods

The USEPA version of the OLM is represented by the equation (NSW EPA, 2016):

Equation E8

$$[NO_2]_{total} = \{0.1 \times [NO_X]_{road}\} + MIN\ \{(0.9) \times [NO_X]_{road}\ or\ (46/48) \times [O_3]_{background}\} + [NO_2]_{background}$$

Where:

$[NO_2]_{total}$	=	predicted concentration of NO_2 in µg/m^3
$[NO_X]_{road}$	=	dispersion model prediction of NO_X from roads in µg/m^3
MIN	=	minimum of the two quantities within the braces
$[O_3]_{background}$	=	background ambient O_3 concentration in µg/m^3
(46/48)	=	molecular weight of NO_2 divided by the molecular weight of O_3 in µg/m^3
$[NO_2]_{background}$	=	background ambient NO_2 concentration in µg/m^3

The method involves an initial comparison of the estimated maximum NO_X concentration and the ambient O_3 concentration to determine the limiting factor to NO_2 formation:

- If the O_3 concentration is greater than the maximum NO_X concentration, then total NO_X to NO_2 conversion is assumed.
- If the maximum NO_X concentration is greater than the ozone concentration, the formation of NO_2 is limited by the ambient ozone concentration.

The OLM – in the above form – is based on the assumption that 10 per cent of the initial NO_X emissions are NO_2. The emitted NO reacts with ambient ozone to form additional NO_2. If the ozone concentration is greater than 90 per cent of the predicted NO_X concentration, all the NO_X is assumed to be converted to NO_2. Otherwise, NO_2 concentrations are calculated on the assumption of total conversion of the ozone. The predicted NO_2 concentration is then added to the background NO_2 concentration.

The following approaches are presented in the Approved methods for the 'maximum' and 'contemporaneous' calculations:

- Level 1 (maximum): The maximum 1-hour and annual average background concentrations of NO_2 and O_3 ($[NO_2]_{background}$, $[O_3]_{background}$) are used in Equation E8.

- Level 2 (contemporaneous): Continuous 1-hour average background concentrations of NO_2 and O_3 are obtained for the same period as the dispersion modelling predictions (usually one year). The value of $[NO_2]_{total}$ is then calculated for every hour of the dispersion model simulation by substituting the hourly values of $[NO_X]_{road}$, $[NO_2]_{background}$ and $[O_3]_{background}$ into Equation E8.

As before, the Level 1 approach is used as a screening step. The OLM is usually applied using the Level 2 approach, and this has the advantage of yielding various statistics for NO_2, including:

- The annual mean concentration (based on the 1-hour predictions for a year).
- The maximum concentration.
- Percentile concentration values.
- The frequency with which the 1-hour NO_2 criterion is exceeded.

In the NSW EPA's submission to the EIS for the NorthConnex project in Sydney, it is stated that that an average value for the NO_2/NO_X ratio of 16 per cent would be more appropriate than 10 per cent. The OLM equation should therefore be adjusted as follows (AECOM, 2014):

Equation E9

$$[NO_2]_{total} = \{0.16 \times [NO_X]_{road}\} + MIN\ \{(0.84) \times [NO_X]_{road}\ or\ (46/48) \times [O_3]_{background}\} + [NO_2]_{background}$$

The effect of the adjustment is to increase the amount of NO_2 emitted directly, potentially increasing the NO_2 concentrations that are predicted under low ambient O_3 concentrations.

E.3.5.3 Limitations and performance

Several limitations of the OLM have been noted in the literature. For example:

- The approach is known to be conservative. As noted by NZMfE (2004):
    - The method assumes that the atmospheric conversion of NO to NO_2 occurs instantaneously. In reality, the reaction requires time. This assumption therefore leads to an overestimate of NO_2 concentrations close to the source.
    - The method assumes that all ozone is available to the emission source being evaluated. The OLM will be too conservative when, for example, a new source is to be located in close proximity to existing sources. The new source will be competing with the existing sources for the available ozone, and the rate of conversion of NO to NO_2 will not be as great as if the new source is in an isolated location.
    - Ozone is assumed to be uniformly and continuously mixed across the cross section of the plume. The OLM does not account for the molar ratio of NO to ozone in the plume (reactions occur in proportion to the moles of each gas rather than in proportion to the concentrations assumed by the OLM), nor does it account for the gradual entrainment and mixing of ambient ozone in the plume.
    - Situations in which the OLM has been demonstrated to substantially overestimate NO_2 concentrations include during daylight hours when the photochemical equilibrium reverses the oxidation of NO by O_3, and during stable, night-time conditions when both NO_2 and O_3 are removed by reaction with vegetation and other surfaces.
- The OLM model requires a record of 1-hour average background concentrations over a year. Apart from the expense of obtaining such information at a single location, there are significant problems in locating the monitoring site relative to existing emission sources and a proposed new emission source because of the perceived difficulty of accounting for scavenging of O_3 by NO (NZMfE, 2004).
- The USEPA states that the OLM should only be used on a 'plume-by-plume' basis. This is a severe limitation in relation to road projects.

Some of these limitations also apply to the PVMRM. Because of the different methods used, there are cases where PVMRM will perform better than OLM, and vice versa. The PVMRM better simulates the NO to NO_2 conversion chemistry during plume expansion, and works well for isolated elevated point

sources. However, OLM may be the better choice for low-level releases and area sources. For low-level releases the modelled plume may extend below ground level, but the PVMRM will still use the full volume of the plume to estimate the NO_X-to-NO_2 conversion. This may again lead to overly conservative NO_2 concentrations.

E.3.6 Reactive plume models

Various photochemical reaction schemes are applied in regional-scale and urban-scale air pollution models. One of the most commonly used is the Generic Reaction Scheme (Azzi et al., 1992). More detailed photochemical models and schemes have been developed in recent years, including the 'EMEP MSC-W chemical transport model' (Simpson et al., 2003), the 'Carbon Bond-IV mechanism' (Gery et al., 1989), and the 'CB05 photochemical mechanism' (Yarwood et al., 2005).

However, the use of such models is uncommon for regulatory local air quality assessments. A major drawback of these methods is that the near-source chemical reactions may not be well described. Many of the atmospheric chemistry schemes developed for regional and global models include reactions on timescales that are much longer than the residence times of pollutants in urban areas, and as such introduce an additional complexity and computational time that is unnecessary (Denby, 2011). As noted by the Environment Agency (2007) in the UK, care is required to select a chemical mechanism, and advanced photochemical modelling requires a comprehensive set of emissions data for a wide range of compounds (notably hydrocarbons), as well as the appropriate meteorological data. These are major constraints for any regulatory work.

E.4 Development of empirical conversion methods for Sydney

E.4.1 Overview

Various guidance documents recommend the use of local monitoring data, where available, to estimate NO_2 from modelled NO_X. Functions have been fitted to NO_X and NO_2 monitoring data for many years, notably in the form of the 'Derwent-Middleton' equation (Derwent and Middleton, 1996), and this continues to be the case (eg Podrez, 2015).

Both NO_X and NO_2 have been measured for several years at a range of stations across Sydney, as described in Annexure D. A substantial amount of data from these stations was used to develop empirical NO_X-to-NO_2 conversion functions for the WestConnex M4 East and New M5 projects (Pacific Environment, 2015b; Pacific Environment, 2015c), with separate approaches for annual mean and 1-hour mean NO_2. These functions were also used for the Sydney Gateway assessment, although the supporting data were updated. One reason for the analysis was to quantify and address the conservatism in some of the other methods in use, whereby exceedances of NO_2 air quality standards can be predicted for a given NO_X concentration, even where the monitoring data show that this situation is extremely uncommon for real-world receptor locations. The methods for the WestConnex projects will also be applicable to other complex road projects in the airshed.

The methods that were developed are described below.

E.4.2 Methods used in the project assessment

E.4.2.1 Annual mean concentrations

Figure E-1 shows the relationship between the annual mean concentrations of NO_X and NO_2 at the monitoring stations in Sydney across all years. As the values shown are measurements, they equate to $\mathbf{[NO_X]_{total}}$ and $\mathbf{[NO_2]_{total}}$. In the low-NO_X range of the graph there is an excess of ozone and therefore NO_2 formation is limited by the availability of NO. In the high-NO_X range there is an excess of NO, and therefore NO_2 formation is limited by the availability of ozone. The Figure also shows that there is not a large amount of scatter in the data, and for this reason a central-estimate approach was considered to be appropriate.

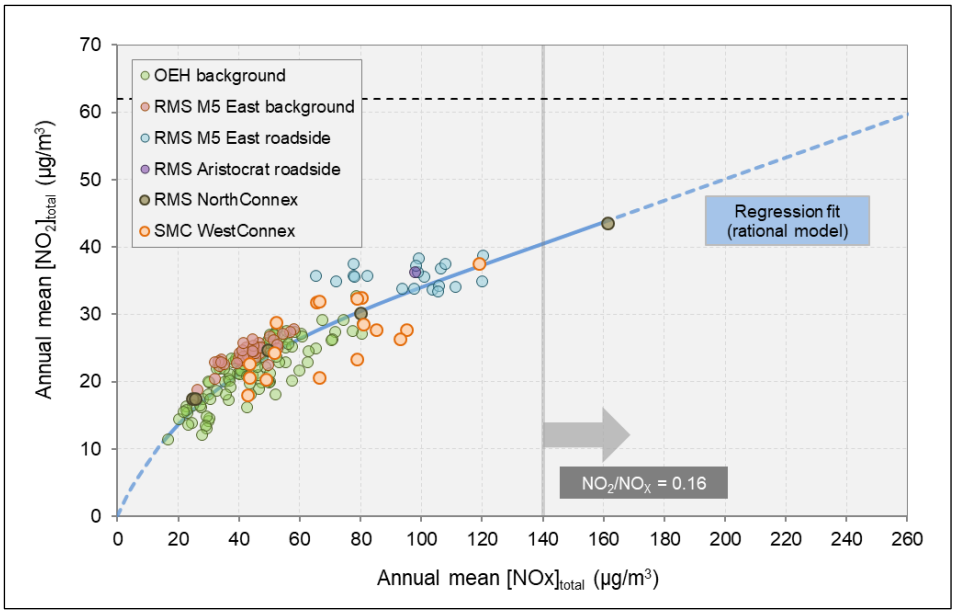

Figure E-1 Annual mean NO_X and NO_2 concentrations at monitoring stations in Sydney

The solid blue in Figure E-1 represents a regression model fit to the data (ie the central-estimate situation) which will give the most likely NO_2 concentration for a given NO_X concentration. The function giving the best fit – the rational model – was selected from a large number of alternatives using curve-fitting software. This function, which was used in the Sydney Gateway assessment, is described by the following equations:

For $\mathbf{[NO_X]_{total}}$ values less than or equal to 140 µg/m^3:

Equation E10

$$\mathbf{[NO_2]_{total}} = \frac{\mathbf{a + b[NOx]_{total}}}{\mathbf{1 + c[NOx]_{total} + d([NOx]_{total})^2}}$$

Where:

a = -7.6313 x 10^{-4}

b = 9.9470 x 10^{-1}

c = 2.3750 x 10^{-2}

d = -4.5287 x 10^{-5}

For $\mathbf{[NO_X]_{total}}$ greater than 140 µg/m^3 it has been assumed that the available ozone has been consumed and so NO_2 is linearly proportional to NO_X with a NO_2/NO_X ratio of 0.16, representing the current f-NO_2 value for vehicle exhaust quoted by NSW EPA in its response to the EIS for the NorthConnex project (AECOM, 2014):

Equation E11

$$\mathbf{[NO_2]_{total} = 40.513 + (0.16 \times ([NO_X]_{total} - 140))}$$

The work presented in Pacific Environment (2015a) suggests that an annual average value for f-NO_2 of 0.16 is an overestimate for the 2016 vehicle fleet, but is likely to be more representative for future years.

The dashed blue line represents the extrapolation of the function to values below and above the range of measurements. Given the absence of high annual mean NO_X concentrations, the extrapolation to concentrations above the measurement range is rather uncertain, but on the basis of the primary NO_2 assumption it is likely to be rather conservative.

Given that the total NO_X concentration was used to determine the total NO_2 concentration, in order to determine the change in NO_2 associated with the project the background NO_2 concentration was subtracted. That is:

Equation E13

$$[NO_2]_{project} = [NO_2]_{total} - [NO_2]_{background}$$

Where both $[NO_2]_{total}$ and $[NO_2]_{background}$ were determined using Equations G10 and G11.

For a given project contribution to NO_X at a receptor, the higher the background NO_X the lower the project NO_2 increment will tend to be, as less ozone will generally be available for converting the NO from the project to NO_2.

The use of the function could theoretically lead to exceedances of the annual mean criterion for NO_2 in NSW of 62 µg/m^3. However, a very high annual mean NO_X concentration - more than 260 µg/m^3 - would be required. This is much higher than the measurements in Sydney have yielded to date.

E.4.2.2 One-hour mean concentrations

For the maximum 1-hour mean NO_2 concentrations the situation was more complicated. One-hour mean NO_X and NO_2 concentrations are much more variable than annual mean concentrations. Patterns in the hourly data can be most easily visualised by plotting the 1-hour mean NO_2/NO_X ratio against the 1-hour mean NO_X concentration. The data from all Sydney monitoring stations between 2004 and 2017 – a total of more than 1.3 million data points – are shown in Figure E-2. Around 20 per cent of the data points were for roadside monitoring stations. Although the range and variability of the data varied by station type, the general patterns in the data were quite consistent. It was therefore considered appropriate to combine the individual datasets.

It is clear that for low NO_x concentrations there is a wide range of possible NO_2/NO_x ratios, whereas for higher NO_X concentrations the range is much more constrained. A distinct outer envelope (equating to a conservative assumption regarding conversion) could be fitted to the data which included all (or very nearly all) the measurement points, and this envelope has a strong inverse relationship with the NO_X concentration. In the envelope the NO_2/NO_X ratio is highest (1.0) at low NO_X concentrations, representing complete, or near-complete, conversion of NO to NO_2. At the high end of the NO_X concentration range the ratio is much lower and levels out at a value of around 0.1. The highest NO_X concentrations occur mostly during the winter months when temperature inversions prevent the effective dispersion of pollution.

The derivation of a conversion method from these data for the Sydney Gateway assessment was adapted from that recommended by BCMoE (2008)[4]. This method involved the following steps:

- The range of NO_X concentrations for which the NO_2/NO_X ratio is equal to 1.0 is estimated.
- The NO_X concentration for which NO_2/NO_X is equal to 0.1 is estimated.
- An exponential equation of the following form is fitted to the upper envelope of the scatter:

  $$NO_2/NO_X = a \times [NOx]^b$$

  where **a** and **b** are selected through an iterative process to produce a curve that fits the upper bound of the envelope of the scatter.

  The equation is defined so that the NO_2/ NO_x ratio never exceeds unity or falls below 0.1.

- The equation is checked to ensure that NO_2 does not decrease with an increase in NO_X.

[4] BCMoE (2008) recommends that the ozone limiting method should only be applied if adequate monitoring data are not available to establish representative NO/NO_2 ratios.

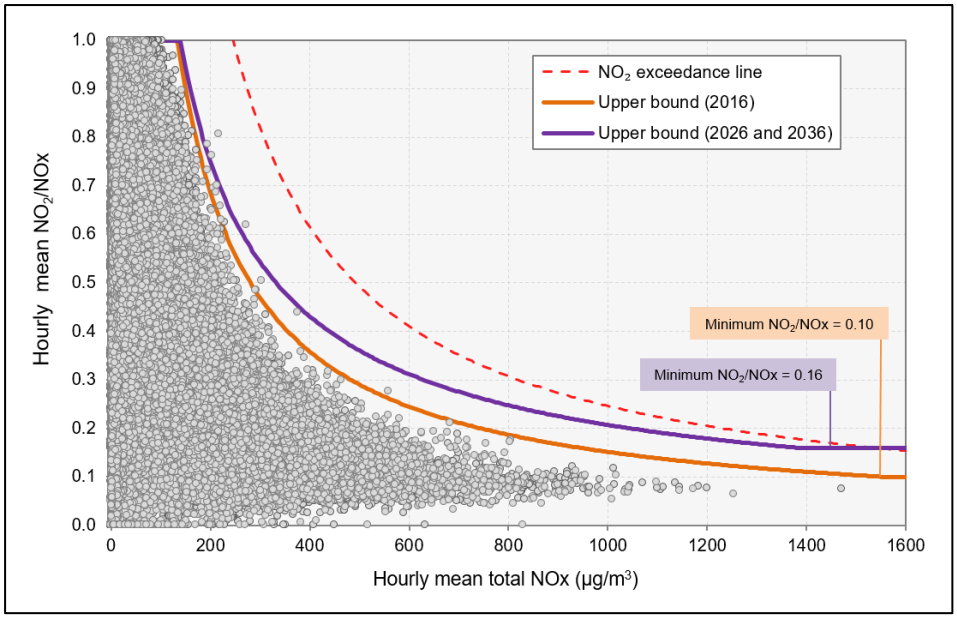

Figure E-2 **Hourly mean NO_2/NO_X ratio vs NO_X for monitoring stations at various locations in Sydney**

The solid orange line in Figure E-2 represents the outer envelope of all data points, and approximates to a conservative upper bound estimate for 2016, or in other words the maximum NO_2/NO_X ratio for a given NO_X concentration in 2016. This is described by the following equations:

For $\mathbf{[NO_X]_{total}}$ values less than or equal to 130 µg/m^3:

Equation E14

$$\frac{\mathbf{[NO_2]_{total}}}{\mathbf{[NOx]_{total}}} = \mathbf{1.0}$$

For $\mathbf{[NO_X]_{total}}$ values greater than 130 µg/m^3 and less than or equal to 1,555 µg/m^3:

Equation E15

$$\frac{\mathbf{[NO_2]_{total}}}{\mathbf{[NOx]_{total}}} = \mathbf{a} \times \mathbf{[NOx]_{total}}^{\mathbf{b}}$$

where:

a = 100
b = -0.94

For $[NO_X]_{total}$ values greater than 1,555 µg/m^3 a cut-off for the NO_2/NO_X ratio of 0.10 has been assumed. That is:

Equation E16

$$\frac{\mathbf{[NO_2]_{total}}}{\mathbf{[NOx]_{total}}} = \mathbf{0.1}$$

The dashed red line in Figure E-2 shows the NO_2/NO_X ratio that would be required for an exceedance of the NO_2 criterion of 246 µg/m^3 at each NO_X concentration. It is clear from Figure E-2 that an exceedance of the 1-hour criterion for NO_2 cannot be predicted using the upper bound curve for 2016 across a wide range of NO_X concentrations.

For future years it is possible that the upper bound estimate for 2016 will not be appropriate, given that primary NO_2 emissions could increase. An exploratory analysis by Pacific Environment (2015a) indicated that, on average for highway traffic in Sydney, *f*-NO_2 could increase to 0.16 by around 2030 Although the increase in *f*-NO_2 would be combined with lower overall NO_X emissions, it could be expected that for high ambient NO_X concentrations the ambient NO_2/NO_X ratio could exceed 0.1. Here, it has therefore been assumed that a minimum value for the NO_2/NO_X ratio of 0.16 would be appropriate for the 2026 and 2036 scenarios, and a corresponding (conservative) upper bound function is shown as a purple line in Figure E-2.

This function, which is essentially arbitrary, is described by the following equations:

For $\mathbf{[NO_X]_{total}}$ values less than or equal to 140 µg/m^3, Equation E14 applies.

For $\mathbf{[NO_X]_{total}}$ values greater than 140 µg/m^3 and less than or equal to 1,375 µg/m^3, Equation 15 applies with the following coefficients:

a = 52

b = -0.80

For $\mathbf{[NO_X]_{total}}$ values greater than 1,375 µg/m^3 a cut-off for the NO_2/NO_X ratio of 0.16 has been assumed. That is:

Equation E17

$$\frac{[\mathbf{NO_2}]_{\mathbf{total}}}{[\mathbf{NO_x}]_{\mathbf{total}}} = \mathbf{0.16}$$

Even this assumption would only result in an exceedance of the NO_2 criterion at very high NO_X concentrations (above around 1,500 µg/m^3). If a more conservative estimate for the minimum ambient NO_2/NO_X ratio of 0.20 were to be assumed, the total NO_X concentration required for NO_2 exceedance in Figure E-2 would be around 1,200 µg/m^3.

Given that the background NO_X concentrations developed for the Sydney Gateway assessment were also slightly conservative (see Annexure D), it is likely that there will be a conservative overall estimate of NO_2 using this approach.

E.4.2.3 Limitations and performance

The general limitations of empirical methods for NO_X-to-NO_2 conversion include the following:

- They do not make any allowance for future changes, such as a potential increase in primary NO_2 emissions or changes in ozone concentrations. Here, this has been addressed as in part through the use of a more conservative function for converting NO_X to NO_2 than the ambient measurements in Sydney to date would suggest.
- They do not differentiate between receptor locations at different distances from emission sources.
- They are only useful for the general locations where they were developed. The methods will not provide the correct dynamic response to changes in emissions, boundary conditions or meteorology unless these influences are implicitly included in their formulation (Denby, 2011).

However, despite, or as a result of, their empirical nature such models can give satisfactory results, especially for annual mean concentrations as there is a clear dependence of NO_2 on NO_X concentrations (Denby, 2011).

E.5 Comparison of methods

As part of the analysis for the M4 East project the functions for calculating NO_2 from NO_X based on the monitoring data from Sydney (up to and including 2016) were compared with some alternative

approaches (Pacific Environment, 2015b). The results of these comparisons for both annual mean and 1-hour mean NO_2 concentration are given below.

E.5.1 Annual mean NO_2 concentrations

The following methods for calculating annual mean NO_2 concentrations were compared:

- The central-estimate approach based on the Sydney monitoring data (see Section G.4.2.1).
- The complete conversion method (see Section G.3.3).
- The USEPA constant ambient ratio method (ARM), with a NO_2/NO_X ratio of 0.75 (see Section G.3.4.1).
- The ozone limiting method (OLM), with an *f*-NO_2 value of 0.16 (see Section G.3.5.1).

In order to compare the different methods for annual mean NO_2 it was necessary to assume background concentrations of NO_X, NO_2 and, in the case of the OLM, O_3. The synthetic profiles for the M4 East modelling domain (and associated annual mean concentrations) described in Pacific Environment (2015b) were used for this purpose.

In the case of the OLM, the conversion method was applied to the contemporaneous hourly background data and project increment data for one year. An example dataset from another road project was used to provide the NO_X project increments. This project had an hourly time series for more than 500 receptor points. However, many of the receptors had similar concentrations and therefore a much smaller sample was extracted. The sample included a wide range of NO_X concentrations. The results of the comparison are shown in Figure E-3.

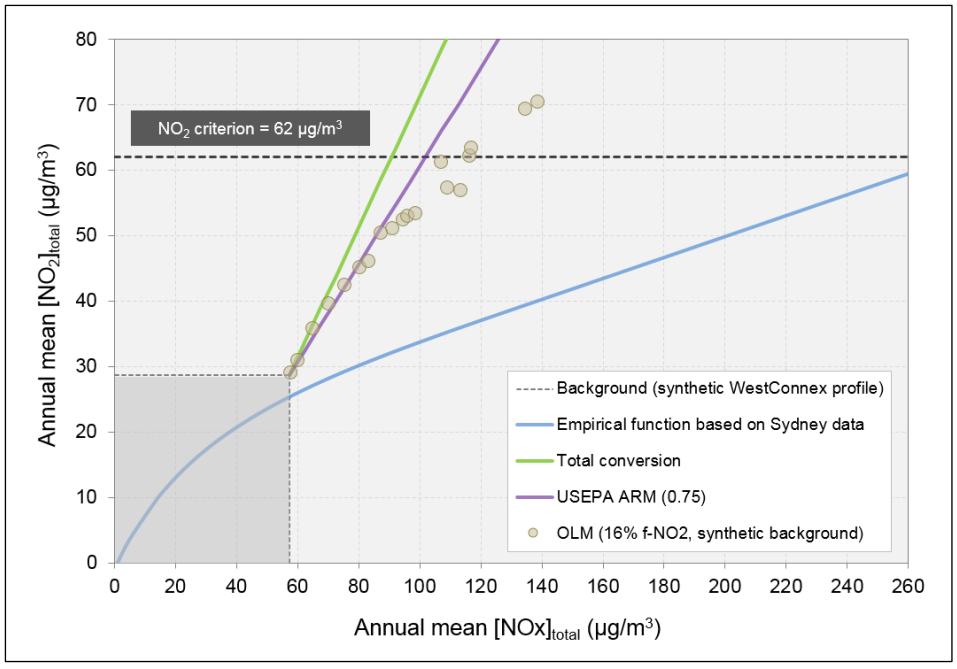

Figure E-3 Comparison of methods for calculating annual mean NO_2 concentration

The total conversion method gave the highest NO_2 concentrations, and for the conditions defined here it resulted in an exceedance of the NO_2 criterion of 62 µg/m^3 when the total NO_X concentration was around 90 µg/m^3. The ARM and the OLM gave quite similar results, and also resulted in exceedances of the NO_2 criterion when the total NO_X concentration was around 100-120 µg/m^3. All three of these methods gave much higher NO_2 concentrations than the envelope and regression functions based on the Sydney monitoring data.

It is also worth repeating that work in the United States has shown that the performance of the ARM2, PVMRM, and OLM methods is very similar (RTP, 2013).

Although the concentrations in the synthetic background profiles were quite conservative, the results show that that the annual mean NO_2 concentrations predicted using the total conversion, ARM and OLM methods are unrealistically high, and would tend to result in an improbable number of exceedance of the NO_2 criterion. These methods were therefore considered to be unsuitable for the Sydney Gateway assessment.

E.5.2 One-hour mean NO_2 concentrations

In the case of 1-hour mean NO_2 concentrations, only the OLM was compared with the empirical method. Again, the synthetic background profiles for the M4 East modelling domain were used, and an *f*-NO_2 value of 0.16 was assumed.

For the road contribution to NO_X, the same example dataset as that mentioned above for annual mean concentrations was used. The hourly results for ten receptors from the dataset, with representative NO_X concentrations across the range, are shown in Figure E-4. It can be seen that the OLM predicted NO_2/NO_X ratios for many 1-hour periods that were higher than those predicted by the conservative upper bound function. The OLM gave a small number of exceedances of the NO_2 criterion of 246 µg/m^3. This work shows that the OLM will yield overly conservative maximum NO_2 concentrations for road projects in Sydney.

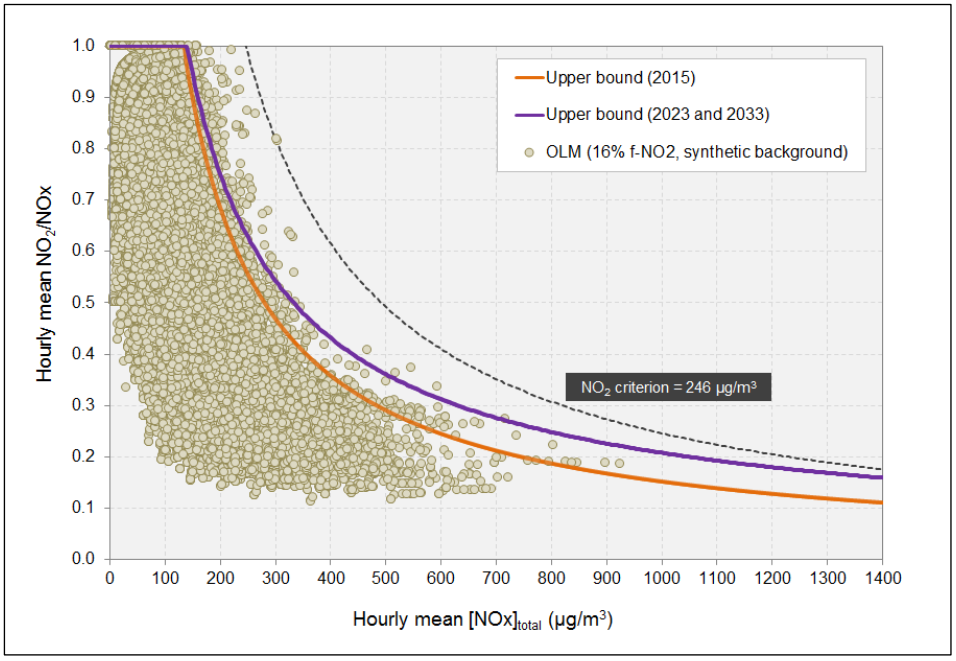

Figure E-4 Comparison of OLM and empirical methods for calculating 1-hour mean NO_2 concentration

Annexure F - Analysis of meteorological data and GRAMM evaluation

F.1 Introduction

The Sydney Gateway GRAMM domain covered an area with diverse land use types, including a mixture of ocean coast, harbour and near-coastal inland locations which would have different local meteorological characteristics.

Whilst meteorology may not always be the main driver of predicted concentrations near to roads, where the peak impacts could be expected to occur, it was nevertheless important to characterise the meteorology as accurately as possible within the GRAL domain.

F.2 Monitoring stations and summary statistics

There were few meteorological stations within the GRAL domain. The only stations located within the domain were OEH Rozelle, BoM Fort Denison and BoM Wedding Cake West. However, when setting up GRAMM it is possible to include meteorological stations outside of the GRAL domain but within the GRAMM domain. For this reason, a number of other meteorological stations have been considered as a part of the wider analysis of meteorological data. These stations were a mixture of OEH, BoM and SMC and Roads and Maritime owned stations. These are listed below.

- OEH meteorological stations:
  - Earlwood
  - Randwick
- BoM meteorological stations:
  - Canterbury Racecourse Automatic Weather Station (AWS) (Station No. 066194)
  - Kurnell AWS (Station No. 066043)
  - Little Bay (The Coast Golf Club) (Station No. 066051)
  - Sydney Airport AMO (Station No. 066037)
- SMC and Roads and Maritime meteorological stations:
  - SMC NewM5:01
  - SMC NewM5:04
  - SMC NewM5:06
  - Roads and Maritime T1
  - Roads and Maritime X1
  - Roads and Maritime CBMS

Some of the stations listed in the previous section were not carried through for further consideration in the GRAMM modelling given their distance from the project, data availability and siting issues. For example, all SMC and Roads and Maritime sites were excluded as some are located at roadside and they also had limited data availability to inform a long-term site representativeness analysis. The data from these sites may be useful, however, to provide an idea of the general wind patterns in the area and have been discussed in this context in subsequent sections.

Table F-1 provides a summary of the annual data recovery, average wind speed and percentage of calms (wind speeds < 0.5 m/s) for six of the remaining OEH and BoM meteorological stations to be considered for further analysis. The parameters that were obtained were wind speed, wind direction, temperature and cloud cover for the years 2009 to 2017 inclusive.

The table shows a generally high percentage of data recovery at each station. The NSW Approved Methods require a meteorological dataset for modelling to be at least 90 per cent complete to be deemed acceptable for a Level 2 (detailed) impact assessment.

There was a high level of year-on-year consistency in the annual average wind speed and annual percentage of calms at each meteorological station. The wind speeds at the BoM Kurnell, BoM Little Bay (The Coast Golf Club) and BoM Sydney Airport stations were relatively high, with annual averages of 4.2 m/s to 5.9 m/s. This is not unusual given the exposed nature of these stations and their proximity to large coastal waterbodies (Sydney Harbour and Botany Bay). Wind speeds at Earlwood were the lowest, with annual averages between 1.3 m/s and 1.6 m/s.

There was also a fairly good year-on-year consistency in the annual percentage of calms at each station, although the values at the OEH Earlwood station showed an increasing trend between 2009 and 2017. There were few calm conditions at Sydney Airport.

Table F-1 Summary of meteorological data

Site and parameter	2009	2010	2011	2012	2013	2014	2015	2016	2017
OEH Earlwood									
Data recovery (%)	100	100	97	100	99	100	100	99	100
Average wind speed (m/s)	1.6	1.6	1.4	1.4	1.4	1.3	1.3	1.3	1.3
Annual calms (%)	18.1	16.8	17.5	22.0	23.1	22.0	23.6	24.6	20.4
OEH Randwick									
Data recovery (%)	99	98	98	99	99	97	96	98	86
Average wind speed (m/s)	2.2	1.9	2.4	2.6	2.6	2.6	2.6	2.6	2.7
Annual calms (%)	11.5	14.5	10.7	9.3	10.5	9.4	9.1	9.6	7.2
BoM Canterbury Racecourse AWS									
Data recovery (%)	61	88	91	89	89	90	90	89	89
Average wind speed (m/s)	3.3	3.2	3.3	3.3	3.3	3.3	3.2	3.3	3.4
Annual calms (%)	9.4	8.4	8.0	8.7	8.8	8.6	9.1	9.0	8.0
BoM Kurnell (AWS)									
Data recovery (%)	100	69	100	100	100	99	100	100	99
Average wind speed (m/s)	5.6	5.9	5.9	5.8	5.8	5.7	5.6	5.7	5.8
Annual calms (%)	1.7	0.5	0.4	0.5	0.6	0.4	0.6	0.6	0.8
BoM Little Bay (The Coast Golf Club)									
Data recovery (%)	99	99	99	100	98	100	99	99	97
Average wind speed (m/s)	5.1	4.9	5.4	4.6	4.5	4.4	4.4	4.2	4.4
Annual calms (%)	0.6	2.8	1.1	0.9	1.2	1.2	1.2	1.0	1.1
BoM Sydney Airport AMO									
Data recovery (%)	67	66	100	100	100	100	100	100	100
Average wind speed (m/s)	5.7	5.7	5.7	5.6	5.7	5.5	5.5	5.5	5.7
Annual calms (%)	0.3	0.2	0.2	0.3	0.1	0.1	0.2	0.1	0.2

F.3 Selection of reference station and year for modelling

The measurements from the OEH Randwick and OEH Earlwood stations in 2016 were chosen as the reference meteorological data for modelling across the GRAMM domain. The reasons for the selection of these stations and the year are given below.

The meteorological stations located within the GRAMM domain are owned and operated by various organisations, and each organisation uses different instrumentation. Notably, the OEH stations use a

sonic anemometer and the BoM stations use a cup and vane system. It is important to understand that these differences in instrumentation are likely to contribute to the variability in the measurements (eg BoM wind speeds may be higher on average due to a higher stall speed using the cup and vane instrumentation compared with an OEH sonic anemometer).

It is also known that several of the sites in the GRAMM domain are affected by siting effects/issues that are likely to result in localised meteorological effects which mean that the measurements may not be representative of the GRAL domain. BoM stations such as Kurnell and Little Bay will be less affected by obstacles such as trees, but are located close to large water bodies or at elevated locations, and have particularly high wind speeds. The use of these data in GRAMM would obviously have an effect on the resultant wind fields in the GRAL domain, as the area has both inland and coastal characteristics.

The above issues also need to be considered with the GRAMM modelling process in mind. GRAMM, unlike other common meteorological models (CALMET etc), uses a different process to develop meteorological wind fields for use in GRAL. The common and recommended GRAMM process was implemented for the Sydney Gateway GRAMM modelling. In short, this includes an initial GRAMM run using a synthetic meteorological file (with a range of meteorological conditions). The resultant GRAMM wind fields will then be matched to selected meteorological station data using the GRAMM 'Match-to-Observations' (MtO) function. Whilst a 'radius of influence' cannot be set for different stations, weighting factors for wind speed and direction can be defined by the user to gain the 'best fit' of data across the domain. This means that all meteorological data included in the matching process will affect the wind fields across the entire GRAMM domain, and to a greater or lesser degree depending on the weighting factors. The weighting factors are based on user judgment, taking into account, for example, the representativeness of the data for the study area. The final wind fields for GRAL will then be a 'compromise' of the meteorological data used in the MtO process. It is then important to select the most appropriate stations to represent the domain, along with appropriate weighting factors.

For the reasons stated above, a basic multi-criteria analysis has been used to select the most appropriate meteorological stations for the Sydney Gateway GRAMM modelling.

The selection of a meteorological year is linked to the selection of the ambient air quality monitoring (background) year, as the two years need to be the same in any assessment. In both cases the selected year should also be taken as the base year for the assessment. One of the main purposes of including a base year is to enable the dispersion modelling methodology to be verified against real-world air pollution monitoring data.

The base year for the Sydney Gateway air quality assessment was taken to be 2016. The main reasons for this can be summarised as follows:

- The use of 2016 provided the most roadside air quality monitoring data for dispersion model evaluation.
- The air quality monitoring data for 2016 were representative of the longer-term trends.
- The long-term wind speed and direction analysis for the selected meteorological stations showed consistency across the monitored years.

Although meteorological data were available for 2017, the base year was taken to be 2016. The use of 2017 was consistent with the assessment for the F6 Extension Stage 1 project, which had a similar domain. The meteorological data for the main site (Randwick) were also more complete in 2016 (98 per cent) than in 2017 (86 per cent).

F.3.1 Station selection

F.3.1.1 Analysis of average wind speeds

To provide an overview of all the available meteorological data in the Sydney Gateway GRAMM domain for 2016, Figure F-1 shows a contour plot of annual average wind speeds based on all of the meteorological stations within the study area. It is important to keep in mind that the plot shows annual average wind speeds from each site interpolated over the GRAMM domain area. Therefore, areas with few or no measurements will be influenced by the closest meteorological station(s). As noted in the previous section, many of these stations (mostly the SMC and RMS stations) have not been considered

for the GRAMM modelling. Basic wind speed data has been shown here however to provide some context of the overall patterns in the area.

Figure F-1 shows that BoM Sydney Airport, Little Bay, and Kurnell drive the higher average wind speeds in the south-eastern part of the GRAMM domain, which is unsurprising given their proximity to the coast and (in the case of Sydney Airport) local activities. The first third of the domain (from west to east) shows average wind speeds of around 2 m/s to 3.5 m/s, with the project corridor falling mostly. Figure F-1 shows the monthly average wind speeds in 2016 for the stations presented in Figure F-1. Again, it shows that a large number of stations within the GRAMM domain have average wind speeds between 2 and 3.5 m/s.

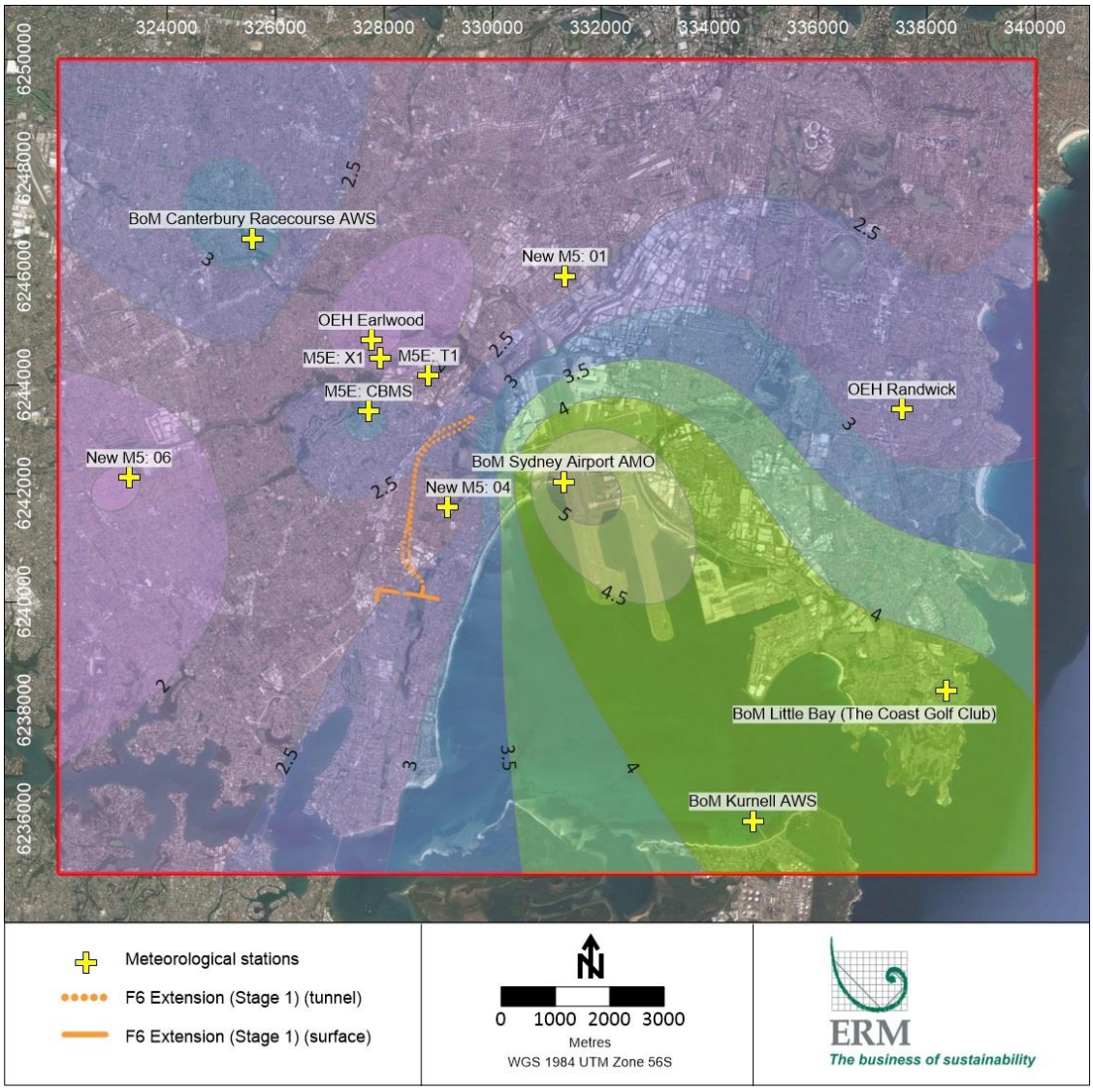

Figure F-1 Contour plot of average wind speed in the GRAMM domain in 2016

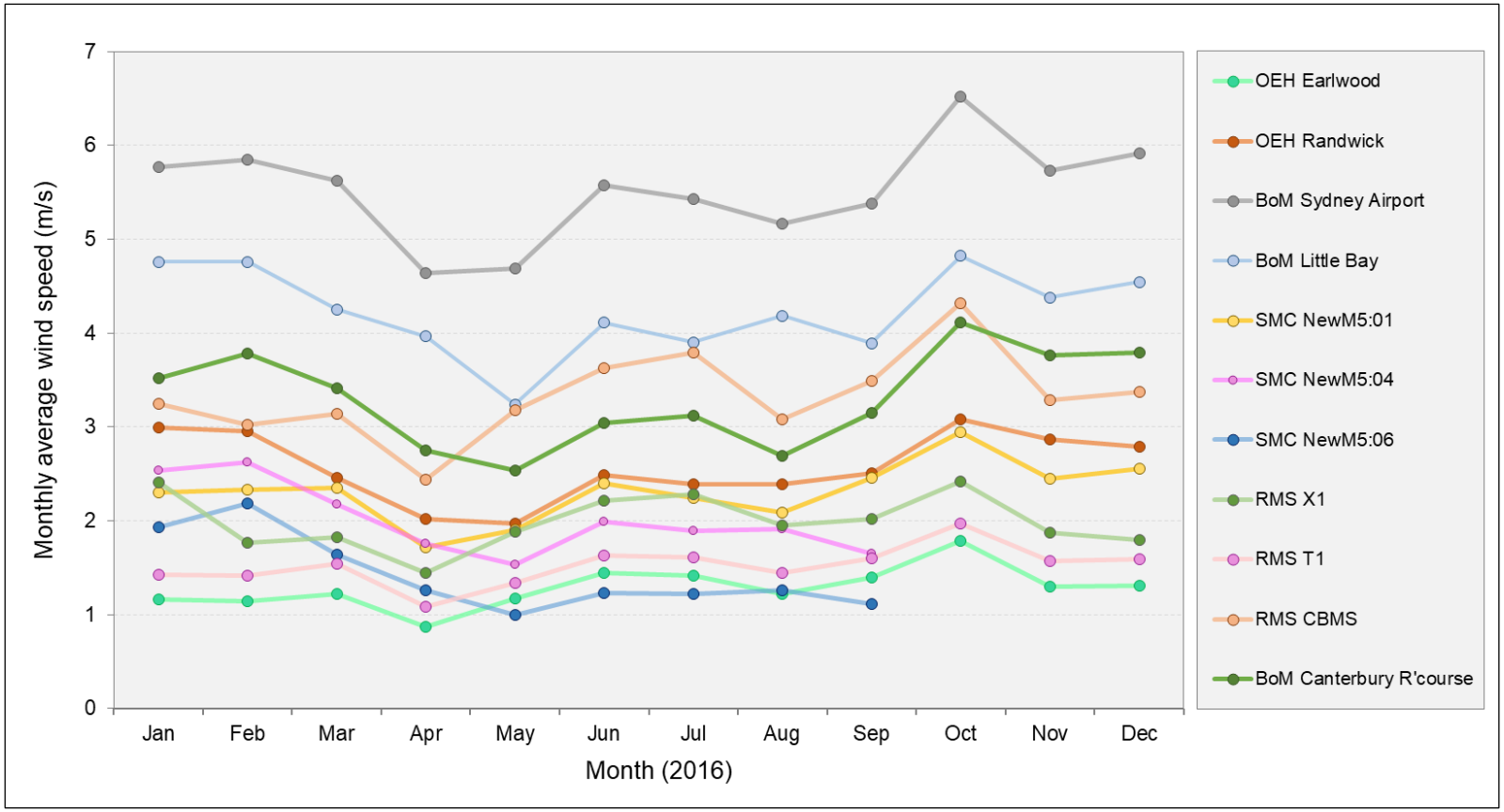

Figure F-2 Monthly average wind speed in 2016

F.3.1.2 Analysis of wind directions

Annual and seasonal wind roses for 2016 were created for the six meteorological stations presented in Table F-1. The wind roses are shown in Figures F-3 to F-5.

The wind patterns across all of the stations in 2016 are quite varied and the reasons will include those mentioned previously (different instrumentation, siting issues etc.). Stations OEH Earlwood and OEH Randwick showed most similar patterns to each other with dominant wind directions from the west, west-north-west and north-eastern directions. With the exception of Sydney Airport, these stations are also closest to the project.

Previous years of data have also been analysed as wind roses for all meteorological stations. These data have not been included here for practicality purposes but are discussed in subsequent sections for the meteorological stations selected for the GRAMM modelling.

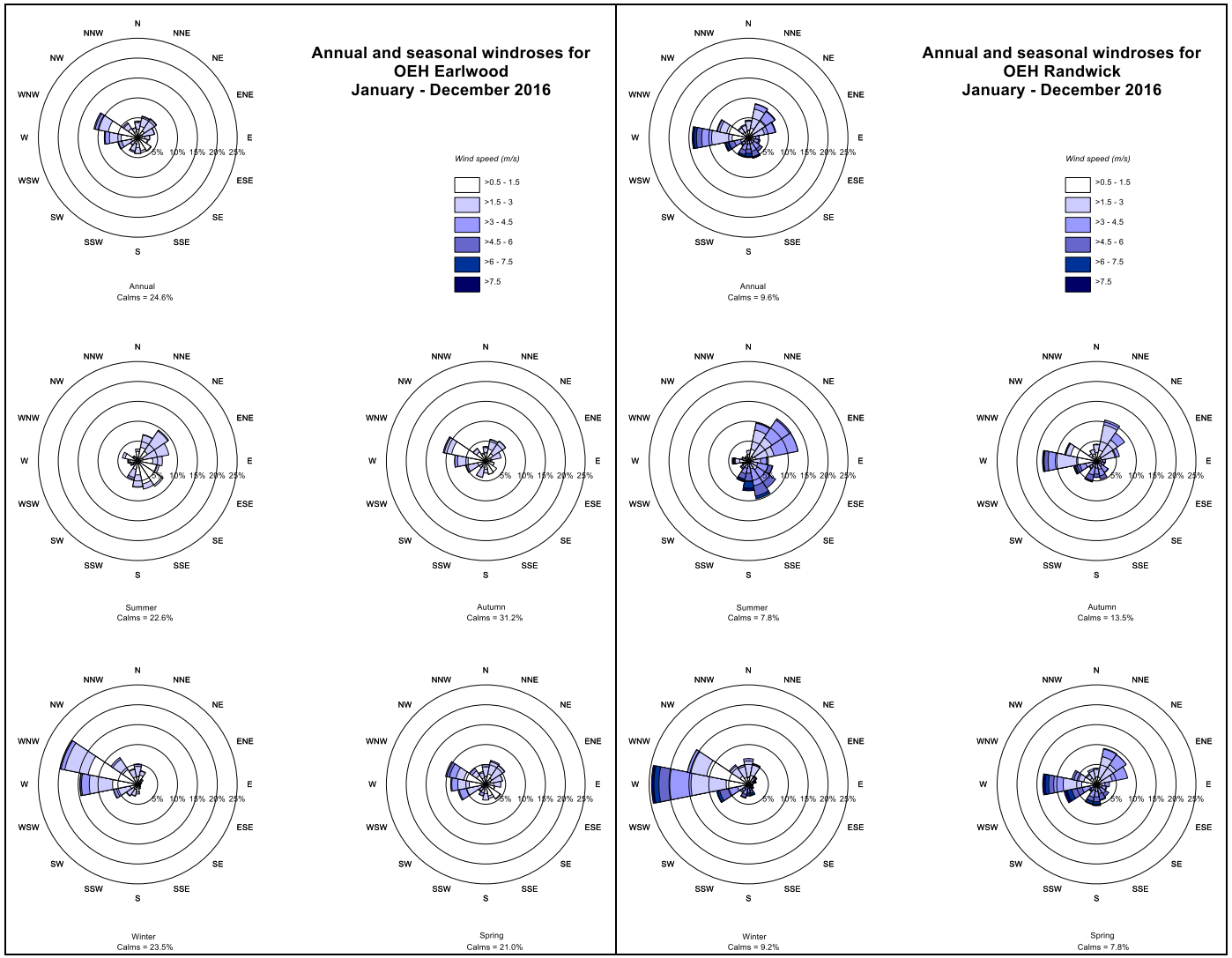

Figure F-3 Annual and seasonal wind roses for OEH meteorological stations Earlwood and Randwick (2016)

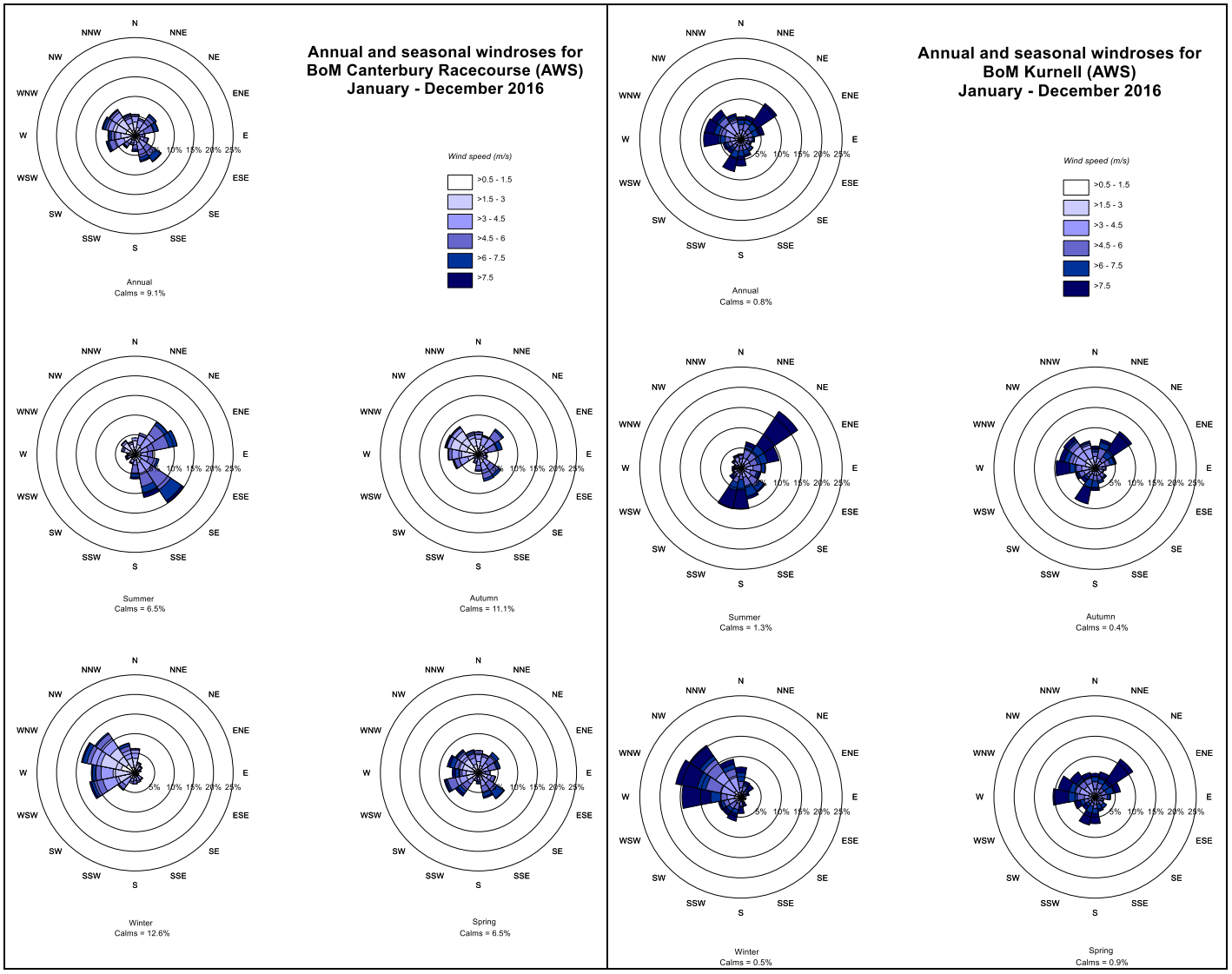

Figure F-4 Annual and seasonal wind roses for BoM stations Canterbury Racecourse (AWS) and Kurnell AWS (2016)

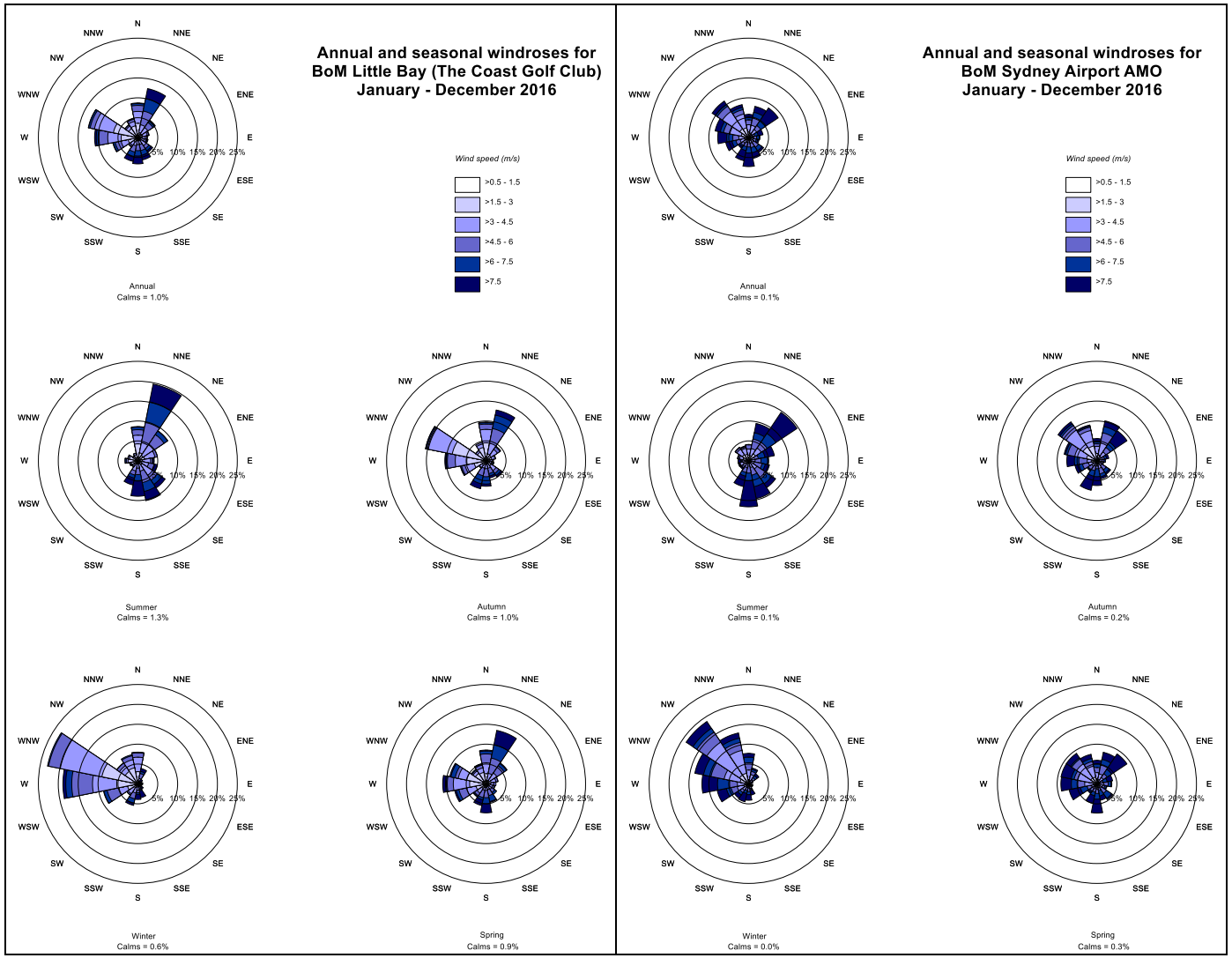

Figure F-5 Annual and seasonal wind roses for BoM meteorological stations Little Bay (The Coast Golf Club) and Sydney Airport AMO (2016)

F.3.1.3 Determination of meteorological stations for GRAMM modelling

Based on the consideration of station siting, wind speed and wind direction analysis, stations were included/excluded from additional consideration in the GRAMM modelling for the reasons provided in Table F-2 below.

Table F-2 Consideration of meteorological stations for use in GRAMM modelling

Station	Further consideration for use in modelling
OEH Earlwood	Considered in GRAMM modelling given its location within the GRAL domain. Long-term wind speed analysis shows that wind speeds are low and annual calms are high. This may be in part due to some siting issues (proximity to trees). However, wind patterns are consistent year-on-year and general wind directions are consistent when compared to other stations in the area. Due to the reasons stated above, Earlwood was included in the GRAMM modelling but with lower weighting factors.
OEH Randwick	Considered in GRAMM modelling given its proximity to the GRAL domain and its location inland but also slightly coastal. Average wind speeds at this site appear to be representative of general project corridor (2.5 to 3 m/s). This station is located outside of the GRAL domain but appears to be well sited and wind speeds/directions are consistent throughout the past years. Higher weightings will therefore be applied in the modelling for this station.
BoM Canterbury Racecourse	Excluded from further consideration given its distance from the GRAL domain and the dominant wind direction patterns observed which differ from the dominant patterns observed at sites closer to the GRAL domain.
BoM Sydney Airport	Excluded from further consideration given the nature of the very localised land use (higher wind speeds driven by airport activities and location in exposed ocean). Inclusion of these data may result in an overestimate of higher wind speeds as modelled by GRAMM and which could ultimately lead to an underestimate of higher GRAL concentrations.
BoM Little Bay	
BoM Kurnell	
SMC NewM5:01	Excluded from further consideration given distance from the GRAL domain, roadside location of some sites, and (for the SMC stations) lack of historical data to provide a long-term representativeness analysis to show that 2016 is an appropriate year.
SMC NewM5:04	
SMC NewM5:06	
RMS X1	
RMS T1	
RMS CBMS	

The above assessment has therefore resulted in the following stations being selected for the GRAMM modelling:

- OEH Earlwood
- OEH Randwick

Table F-3 presents the weighting factors applied in the GRAMM MtO modelling for the two stations selected. These factors were based on the analysis provided above.

Table F-3 Weighting factors applied to meteorological stations in GRAMM modelling

Station	Overall MtO weighting factor	Directional MtO weighting factor
OEH Randwick	1	1
OEH Earlwood	0.2	0.5

F.4 Meteorological model evaluation

F.4.1 GRAL optimisation study

Pacific Environment (2017b) examined the performance of the GRAMM-GRAL system in an urban area of Sydney. The main objectives of the study were to assess the performance of GRAMM (version: July 2016) and GRAL (version: August 2016) against meteorological measurements and air quality measurements respectively. GRAMM and GRAL were also compared against other models that are commonly used in Australia: CALMET version 6.334 for meteorology, and CAL3QHCR version 2.0 for dispersion. The study provided recommendations regarding the configuration and application of GRAMM and GRAL to the assessment urban road networks/projects in Australia.

The recommendations on GRAMM modelling from that project have been considered in the GRAMM set up for the Western Harbour Tunnel project. The main outcome was the use of the Match to Observations (MtO) function, with recommendations regarding testing and input data. These recommendations have been adopted in the GRAMM modelling for this project, and are detailed below

F.4.2 Wind speed

Table F-4 provides, for 2016, a comparison between the predicted and measured annual average wind speed, standard deviation of wind speed, and percentage of calms at OEH Earlwood and OEH Randwick. To enable a direct comparison, the table contains statistics that cover only the time periods for which valid data were available at all monitoring stations. The results show that there was a good agreement between the predicted and observed meteorology at the OEH Randwick site, but a lesser agreement at OEH Earlwood. This is unsurpising given the weighting factors applied at this station.

The MtO function applies a 'comprimise' across the model domain using the meteorological data included in the matching process. This explains why the agreement of observations and predictions at OEH Randwick, albiet very strong, is not exact.

Table F-4 Summary statistics – observed and predicted (2016)

Site	Observed			Predicted		
	Annual average wind speed (m/s)	Standard deviation wind speed (m/s)	% calms	Annual average wind speed (m/s)	Standard deviation wind speed (m/s)	% calms
OEH Earlwood	1.3	1.0	25.5	2.1	1.5	10.2
OEH Randwick	2.6	1.7	9.6	2.3	1.6	12.7

Time series, regression and percentile plots of wind speed in 2016 for OEH Randwick and OEH Earlwood are shown in Figure F-6.

The results of the regression analysis (predicted wind speed versus observed wind speed) are summarised below. For the correlation coefficient (r), and the associated coefficient of determination (R^2), the strength of any relationship was described according to the scheme by Evans (1996) (for R^2: 0.00-0.04 = "very weak", 0.04-0.16 = "weak", 0.16-0.36 = "moderate", 0.36-0.64 = "strong", 0.64-1.00 = "very strong").

- OEH Randwick $R^2 = 0.87$
- OEH Earlwood $R^2 = 0.43$

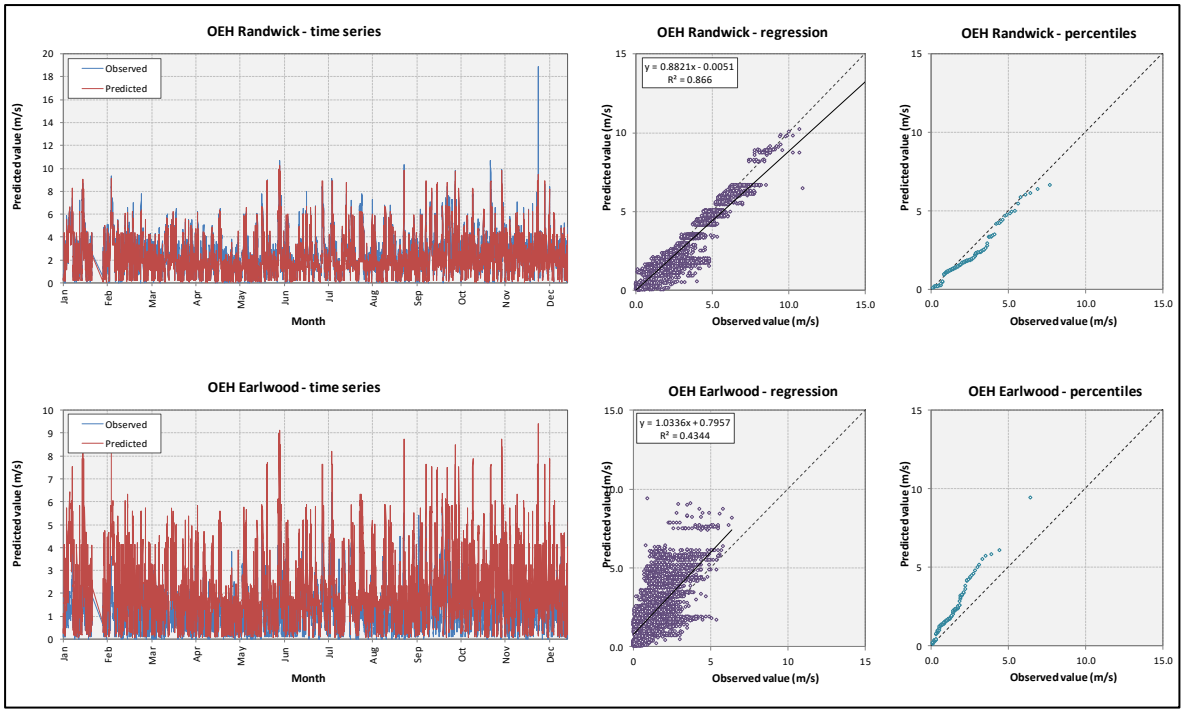

Figure F-6 **GRAMM predicted and observed hourly average wind speed (time series, regression and percentile plots) (2016)**

The analysis showed a very good agreement between the predicted and observed wind speeds at the OEH Randwick station, which was the site with the highest weightings applied in the MtO function (1 for overall weighting and 1 for wind direction weighting). It is therefore unsurprising that there is a very strong agreement between the observed and predicted wind speeds at the OEH Randwick site.

There was a strong agreement at OEH Earlwood site although the performance was not as strong as at OEH Randwick. This reflects the lower weighting applied compared to at Randwick.

The percentile plots shown in Figure F-6 demonstrates a slight under-prediction of mid-rangewind speeds at OEH Randwick but OEH an overall very strong agreement of the wind speed range at this site. There is an over prediction at Earlwood at the lower wind speeds.

Whilst meteorological conditions are an important aspect of any dispersion modelling excercise, it may not always be the most important aspect in determining predicted concentrations in near-source environments such as this. Annexure G of the report provides an evaluation of the GRAL predictions through comparison with measured data. The analysis showed a reasonably good agreement between the pattterns in the predictions and measurements. Although GRAMM may not be predicting meteorology accurately at all locations across the domain, the GRAL model (for which GRAMM is an input), is predicting results at an appropriate level at locations across the study area (see Annexure G).

Summaries of the average temporal patterns in wind speed at OEH Randwick and OEH Earlwood are provided in Figure F-7 and Figure F-8. These plots reflect the discussions provided above and show:

- A very strong agreement between the observed and predicted average wind speeds at OEH Randwick. There is a tendency for GRAMM to underestimate the higher wind speeds during the middle of the day, but this will add a level of conservatism to the modelling. Times of peak traffic volumes when wind speeds are often lower, show better agreement.

- GRAMM has over-predicted average wind speeds at OEH Rozelle which again is a reflection of the weighting factors applied. Typical diurnal and monthly average wind speeds patterns have been picked up by the model.

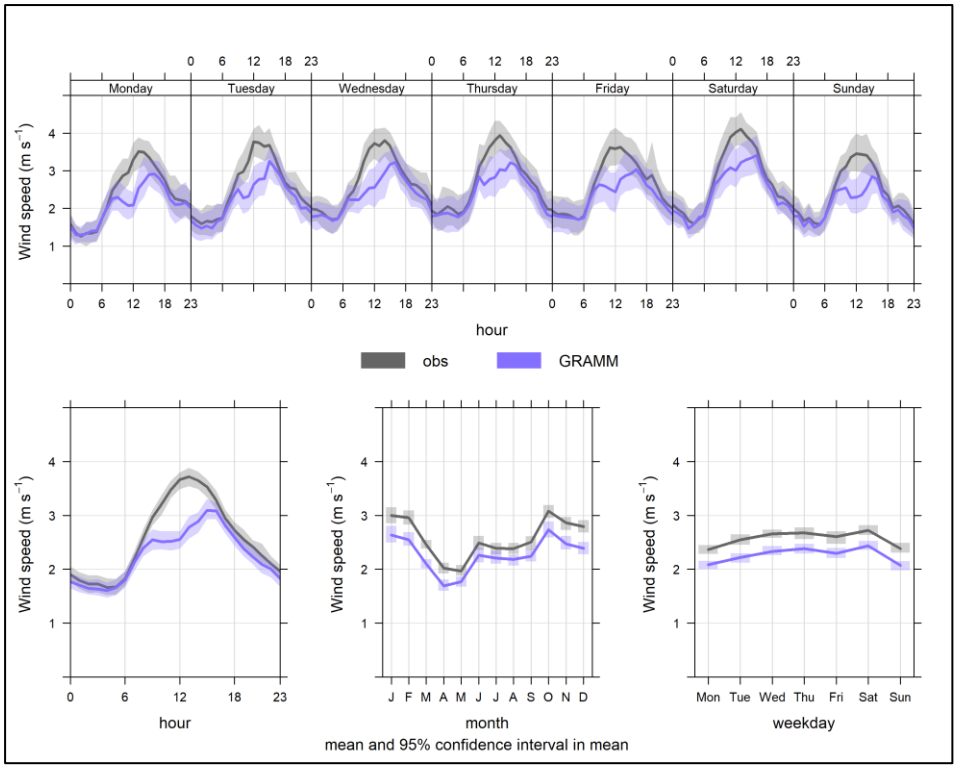

Figure F-7 **Openair 'timeVariation' plot of observed vs predicted wind speeds at OEH Randwick (2016)**

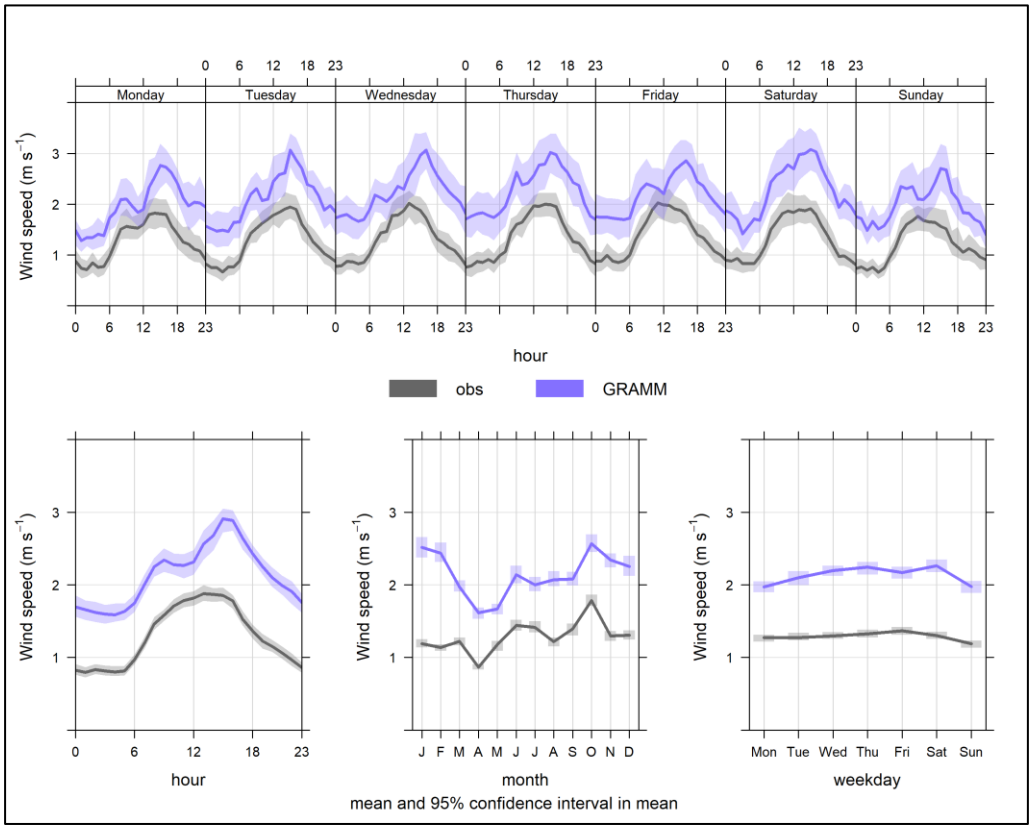

Figure F-8 **Openair 'timeVariation' plot of observed vs predicted wind speeds at OEH Earlwood (2016)**

F.4.3 Wind direction

Annual and seasonal wind roses for the measured and predicted winds in 2016 for OEH Randwick and OEH Earlwood are provided in Figure F-9 and Figure F-10.

The measured and predicted winds for the two sites reflect the discussion above regarding the weighting factors used in the MtO process. There is a good agreement of the prominent wind directions at OEH Randwick between the observed and predicted results.

There is a fair level of agreement between the observed and predicted dominant winds at the OEH Earlwood site with prominent winds from the western and north-eastern directions reflected in both cases.

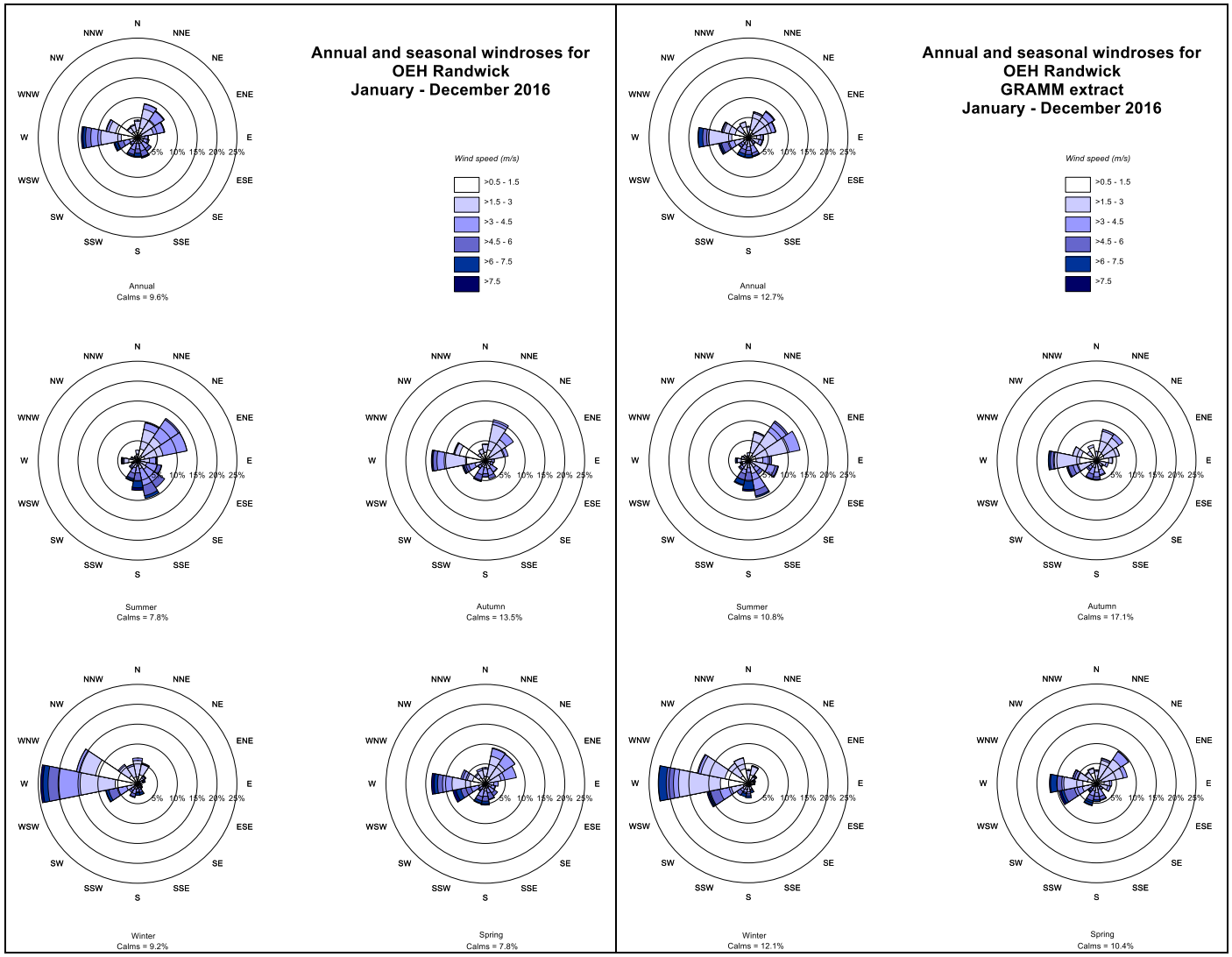

Figure F-9 Annual and seasonal wind roses for observed and predicted winds at OEH Randwick (2016)

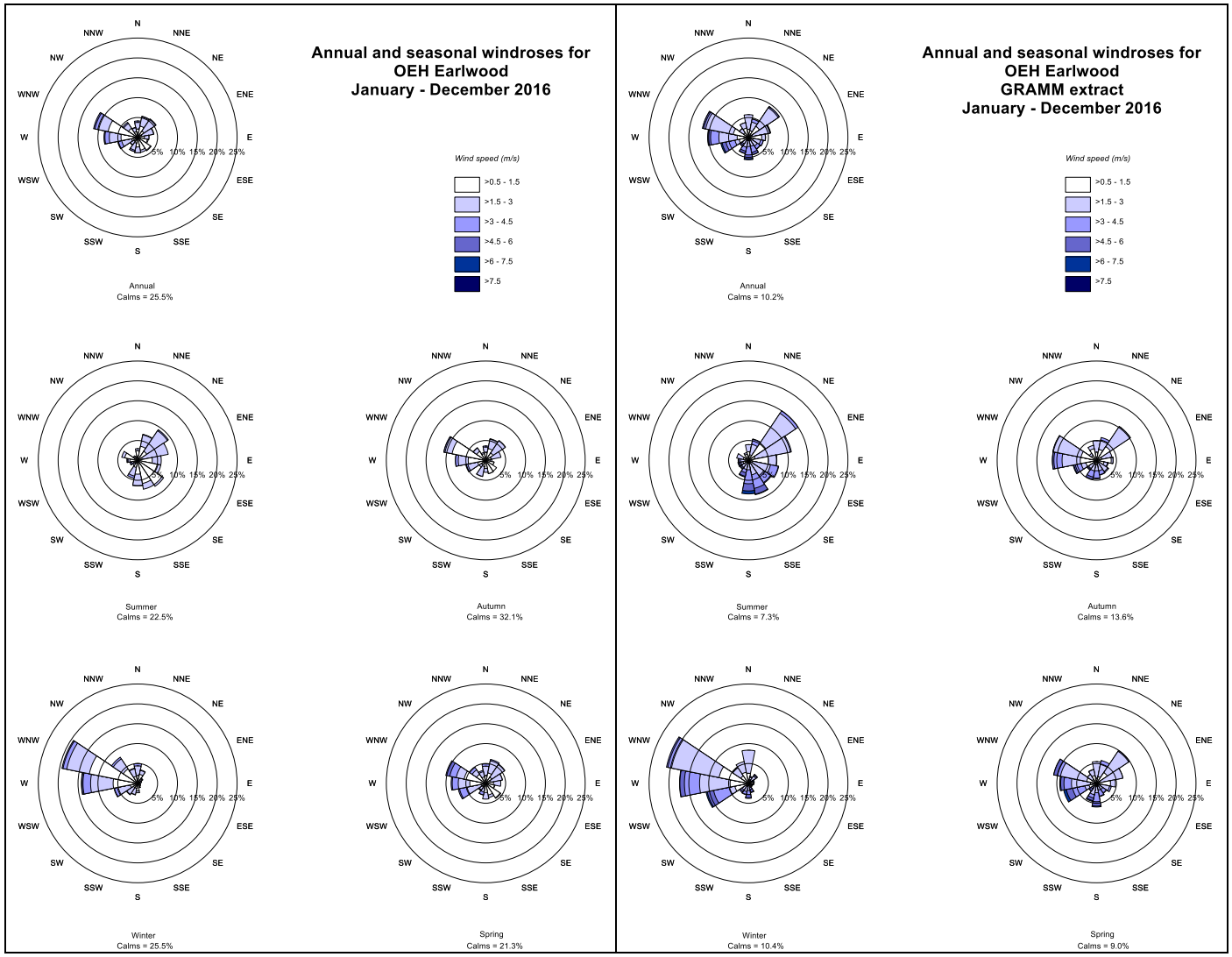

Figure F-10 Annual and seasonal wind roses for observed and predicted winds at OEH Earlwood (2016)

Annexure G - Dispersion model configuration and evaluation

G.1 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 (although the latter feature was not used).

G.2 Model overview

The model system consists of two main modules: a prognostic wind field model (Graz Mesoscale Model – GRAMM) and a dispersion model (GRAL itself). An overview of the GRAMM/GRAL modelling system is presented in Error! Reference source not found.. 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 8,760 hours of the year. Other general parameters required by the program include the surface roughness length, dispersion time, and the number of traced particles (influences the statistical accuracy of results).

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.

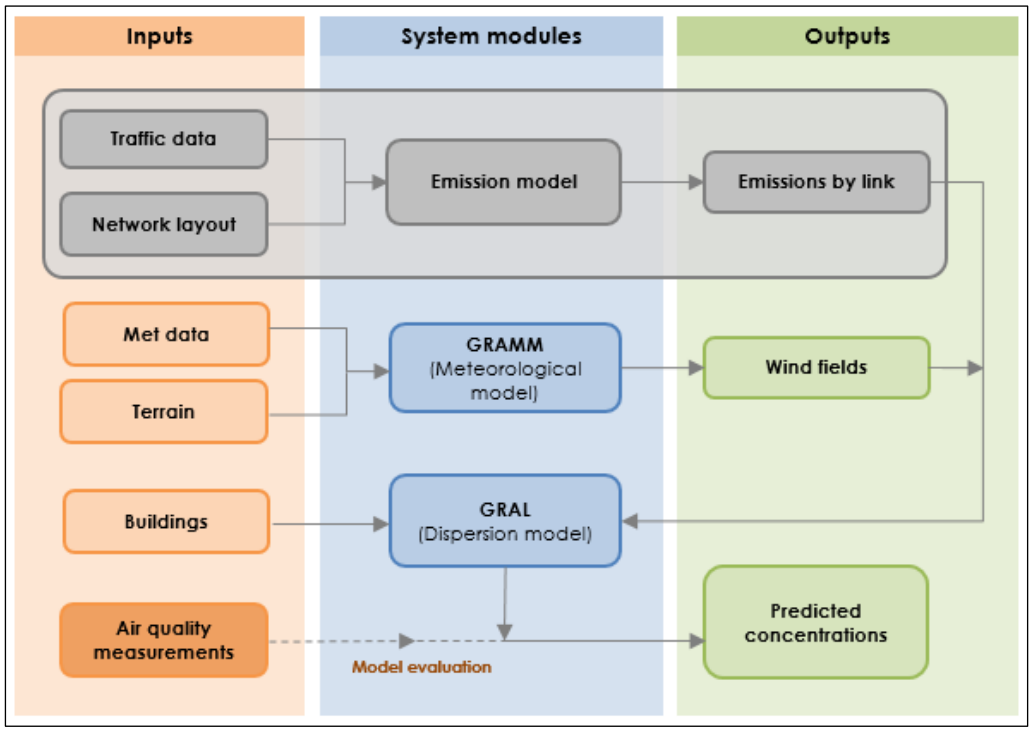

Figure G-1 Overview of the GRAMM/GRAL modelling system

G.3 Model performance

The GRAMM/GRAL system has been validated in numerous studies, as documented by Öttl (2018). 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 conditions, etc).

The performance of GRAMM-GRAL is discussed further in **section G.10**.

G.4 GRAMM configuration

GRAMM domain and set-up

The GRAMM domain was defined so that it covered the Sydney Gateway project with a sufficient buffer zone to minimise boundary effects in GRAL. The domain was 18 kilometres along the east-west axis and 15 kilometres along the north-south axis. **Table G-1** presents the meteorological and topographical parameters that were selected in GRAMM.

Table G-1 GRAMM set-up parameters

Parameter	Input/value
Meteorology	
Meteorological input data method	Match-to-Observations (MtO)

Meteorological stations used in MtO	OEH Randwick OEH Earlwood
Weighting factors applied to meteorological data	Randwick: Weighting factor = 1, directional weighting factor = 1 Earlwood: Weighting factor = 0.2, directional weighting factor = 0.5
Period of meteorology	1 January 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 = 6250000, S = 6235000, E = 322000, W = 340000
Horizontal grid resolution (m)[(a)]	200
Vertical thickness of the first layer (m)[(b)]	10
Number of vertical layers	15
Vertical stretching factor[(c)]	1.4
Relative top level height (m)[(d)]	3,874
Maximum time step (s)[(e)]	10
Modelling time (s)	3,600
Relaxation velocity[(f)]	0.1
Relaxation scalars[(f)]	0.1

Notes:

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

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

(c) Defines how quickly cell heights increase with height above ground. For example, a factor of 1.1 means a cell is 10 per cent higher than the one below it.

(d) Defined as the relative height from the lowest level in the domain.

(e) Defines the amount of time taken to ensure that calculations are done efficiently but stably.

(f) These are chosen to ensure the numerical stability of GRAMM simulations.

Terrain

Terrain data were processed within the GEOM (Geographical/Geometrical grid processor) component of GRAMM. The terrain data for the GRAMM domain were obtained from the Geoscience Australia Elevation Information System (ELVIS) website, and converted into a text file for use in GRAMM. The terrain data used in GRAMM had a resolution of 25 metres. 5 metre terrain data from the same source were used to run GRAL. The terrain in the area is predominantly flat, but increases in elevation to the north of the Airport area towards Alexandria and to the west towards Kingsgrove. The terrain along the project corridor varies from an elevation of around 2 metres Australian Height Datum (AHD) at the southern end at President Avenue to an elevation of around 10 metres at St Peters, at the northern end. To the east of the project and the south of the Airport is Botany Bay which covers a large portion of the southern area of the GRAL domain.

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

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

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

Figure G-2 provides an example of a wind field situation across the GRAMM domain. In total, 720 different wind fields were produced to represent the different conditions in each hour of the meteorological file. The wind fields are based upon the GRAMM wind speeds and wind directions using the input data from the OEH Randwick and Earlwood sites. In this particular example, winds are from a northeast direction, with higher wind speeds over elevated terrain to the northeast. The terrain of the study area was not especially complex (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.

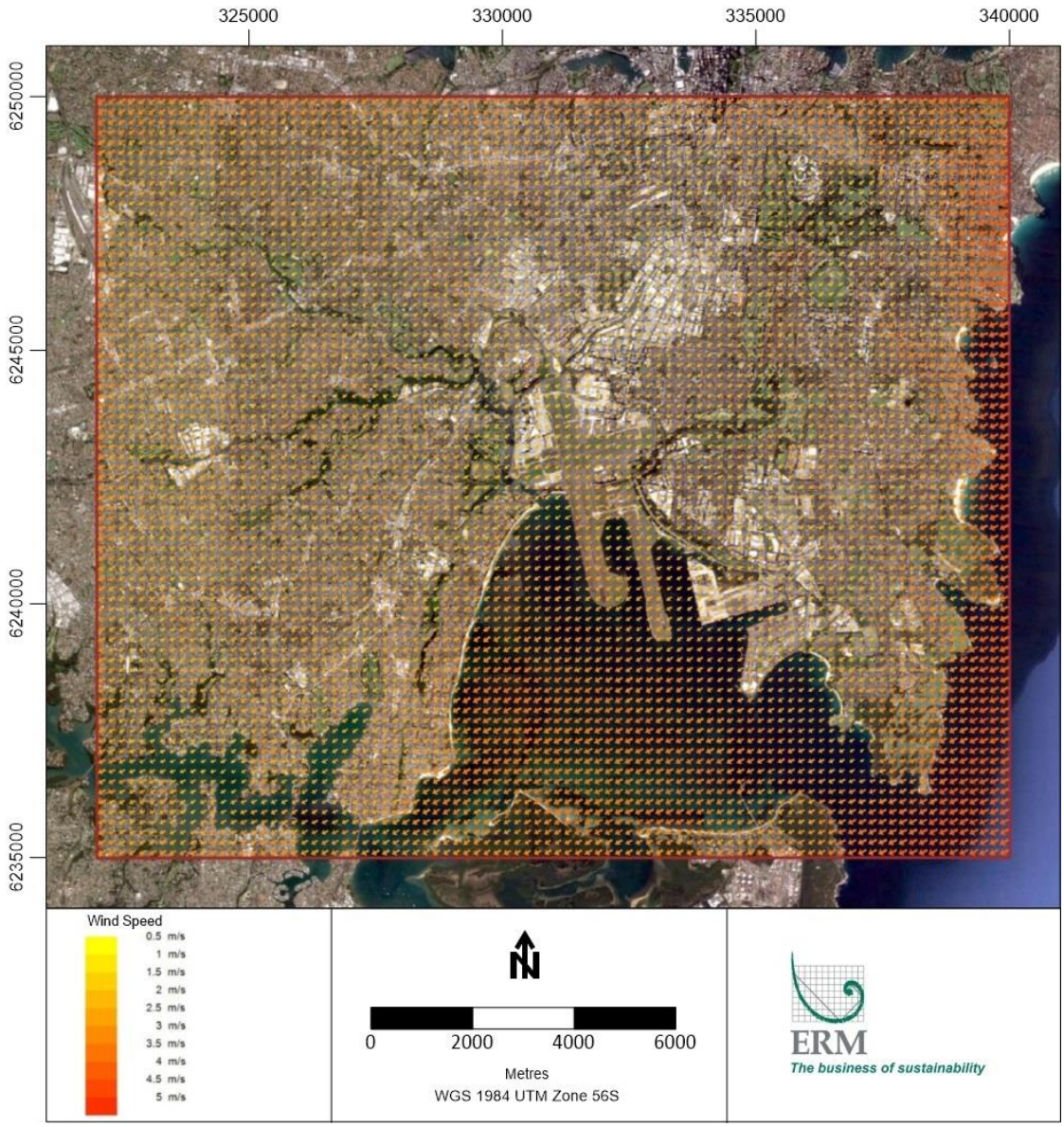

Figure G-2 Example of a wind field across the GRAMM domain (grid system MGA94)

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

Where MtO is used for multiple reference stations the result will be a compromise. The match is optimised across all stations, and therefore the overall model performance should improve. However, for any given station the predictions may or may not improve, particularly where the meteorological data across multiple stations in a domain are dissimilar. One way of accounting for this is through the use of

the weighting factors. The MtO function allows the user to apply an overall weighting factor and a specific wind direction factor. The following weighting factors were applied for this study:

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

G.5 Evaluation of meteorological model

Wind speed and wind direction values were extracted for each of the meteorological stations 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**.

G.6 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

Table G-2 presents the main parameters selected in GRAL for the model runs.

GRAL was configured to provide predictions for a Cartesian grid of points with an equal spacing of 11 kilometres in the x direction and 10 kilometres in the y direction. For the GRAL domain, the total number of points in the grid was around 990,000. Typically, GRAMM simulations are performed with a coarse resolution relative to that of the GRAL resolution (in this case a GRAMM resolution of 200 metres compared with the GRAL resolution of 10 metres) to capture meteorological conditions over a larger study area. For the project, the terrain was resolved even further by selecting the original terrain file (with a much higher resolution of 30 metres) to be included in the GRAL model.

Table G-2 GRAL configuration

Parameter	Value(s)
General	
Domain in UTM	N = 6248000, S = 6237800, E = 336900, W = 325800
Dispersion time (s)	3600
Number of particles per second[a]	400 for roads and outlets
Surface roughness[b]	0.5
Latitude (°)[c]	-33
Buildings	None
Concentration grid	
Vertical thickness of concentration layers (m)	1
Horizontal grid resolution (m)	10
Number of horizontal slices	1
Height above ground level (m)[d]	3 (effectively ground level)

(a) Defines the total number of particles released in each dispersion situation.
(b) Defines the roughness length in the whole model domain. The roughness length alters the shape of the velocity profile near the surface.
(c) Average latitude of the model domain.

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

Representation of buildings

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

Contour plots

The Air Quality Assessment Report presents contour plots showing concentrations, and changes in concentration, across the entire GRAL domain. The concentrations were based on the Cartesian grid described above.

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 represented particularly sensitive locations such as schools, child care centres and hospitals along the broad project alignment, and generally near significantly affected roadways. For these receptors a detailed approach was used to calculate the total concentration of each pollutant. This involved the combination of the contemporaneous road/outlet time series of concentrations from GRAL and the background time series of concentrations, stated as mean values for each hour of the year in each case. In total, 17 community receptors were included in the assessment
- 'Residential, workplace and recreational (RWR) receptors'. These were all discrete receptor locations along the project alignment and other affected roads, and mainly covered residential and commercial uses. For these receptors, a simpler[1] statistical approach was used to combine a concentration statistic for the modelled roads and outlets (eg maximum 24-hour PM_{10}) with an appropriate background statistic. In total, 12,145 RWR receptors were included in the assessment (these included the 17 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 at the location. The RWR receptors do not identify the number of residential (or other) properties or occupants at the location; the residential land use at an RWR receptor location may range from a single-storey dwelling to a multi-storey, multi-dwelling building. The RWR receptors are therefore not designed for the assessment of changes in total population exposure. The human health risk assessment (**Technical Working Paper 15** of the EIS) combines the air quality information with the highest resolution population data from the Australian Bureau of Statistics to calculate key health indicators that reflect varying population density across the study area.

The main reason for the distinction between the receptor types was to permit a more detailed analysis of short-term metrics (community receptors) whilst retaining a good level of spatial coverage (RWR

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

receptors). The number of community receptors that could be included in the assessment was dictated by the limit on the number of time series for individual receptors that could practically 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 G-3 shows the locations of the various discrete receptors in the full domain. The details of the community receptors are given in **Table G-3**, and the numbers of RWR receptors are listed by category in **Table G-4**. 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 footprints for the Sydney Gateway, M4-M5 Link and F6 Extension Stage 1 project were excluded. These project construction footprints are shown in **Figure G-3**.

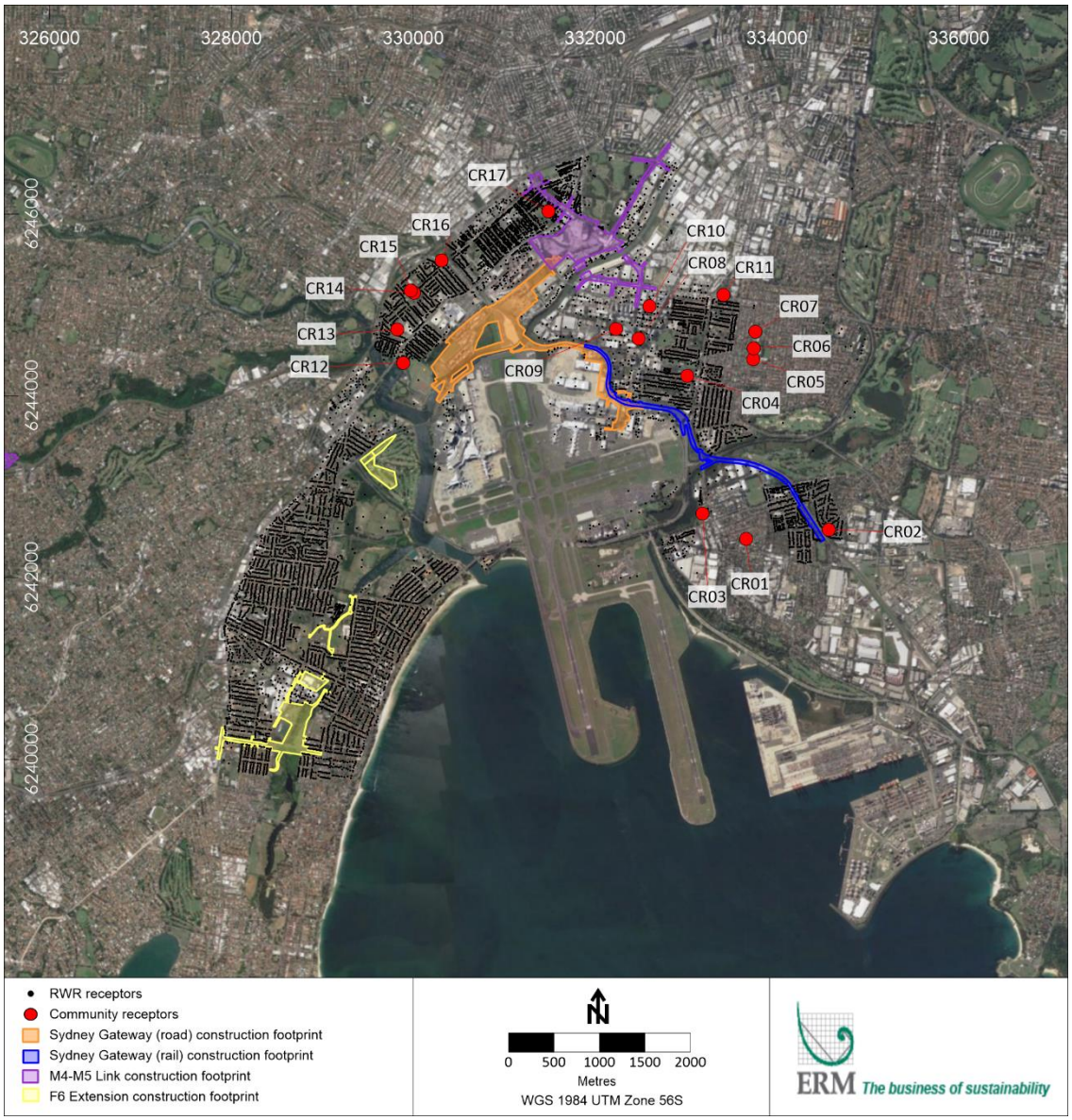

Figure G-3 Modelled discrete receptor locations and construction footprints

Table G-3 Full list of community receptors (grid system MGA94)

Receptor code	Receptor name	Address	Suburb	Receptor location	
				x	y
CR01	Aero Kids Early Learning Centre	211/247 Coward Street	Mascot	332232	6244737
CR02	Guardian Early Learning Centre	18 Holbeach Avenue	Tempe	329887	6244361
CR03	Gardeners Road Public School	827 Botany Road	Rosebery	333410	6245113
CR04	Botany Public School	1076 Botany Road	Botany	333180	6242707
CR05	Mascot Public School	207 King Street	Mascot	333010	6244221
CR06	Tempe High School	Unwins Bridge Road	Tempe	329973	6245160
CR07	JJ Cahill Memorial High School	Sutherland Street	Mascot	333739	6244407
CR08	St Bernard's Catholic Primary School	Ramsgate Street	Botany	333659	6242429
CR09	Active Kids Mascot	18 Church Avenue	Mascot	332601	6244985
CR10	Betty Spears Child Care Centre	1A Gannon Street	Tempe	329823	6244730
CR11	Toybox Early Learning	1-3/15 Bourke Road	Mascot	332480	6244630
CR12	Mascot Child Care Centre	53 Coward Street	Mascot	333744	6244525
CR13	St Theres Catholic Primary School	Sutherland Street	Mascot	333764	6244705
CR14	St Peters Public School	Church Street	St Peters	331484	6246029
CR15	Tillman Park Child Care Centre	81 Unwins Bridge Road	Tempe	330313	6245488
CR16	Tempe Public School	Unwins Bridge Road	St Peters	330009	6245134
CR17	Pagewood Kindergarten	1A Dudley Street	Pagewood	334569	6242527

Table G-4 Summary of RWR receptor types

Receptor type	Number	% of total
Aged care	1	0.01%
Child care / pre-school	20	0.16%
Commercial	1,163	9.58%
Community facility	38	0.31%
Further education	2	0.02%
Hotel	8	0.07%
Industrial	724	5.96%
Medical practice	19	0.16%
Mixed use	50	0.41%
Other	124	1.02%
Park / sport / recreation	102	0.84%
Place of worship	18	0.15%
Residential	9,853	81.13%
School	23	0.19%
Total	**12,145**	**100.00%**[(a)]

Notes:

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

Mesh Block centroids

The human health risk assessment (**Technical Working Paper 15** of the EIS) includes a population exposure assessment based on annual mean $PM_{2.5}$. A population-weighted average $PM_{2.5}$ concentration has been calculated on the basis of the smallest statistical division provided by the Australian Bureau of Statistics, termed 'Mesh Blocks'. These are small blocks that cover an area of around 30 urban residences.

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

Tunnel ventilation facilities and outlets

As with emissions, the dispersion-related parameters for tunnel ventilation outlets - including locations, dimensions, exit velocities and temperatures – were taken directly from the air quality study for the F6 Extension Stage 1 project (NSW Roads and Maritime Services, 2018).

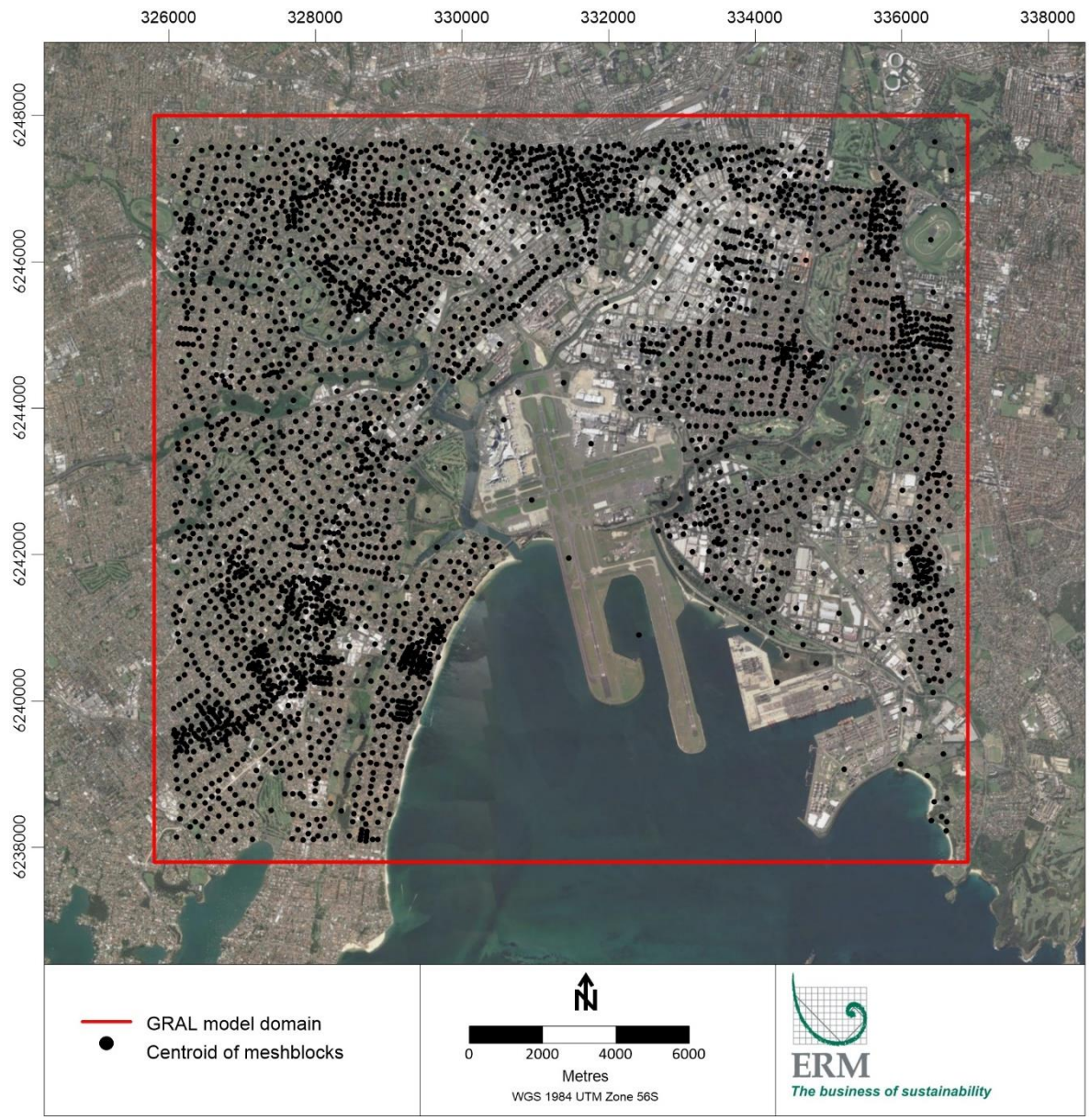

Figure G-4 Mesh Block centroids in the GRAL domain

G.7 Calculation of total concentrations

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

For these pollutants the total concentrations were required for comparison with the applicable air quality criteria. This required a variety of different methods because of the range of metrics in the criteria, as well as the nature of the information that could be extracted from GRAL for the two types of receptor. For the 17 community receptors a contemporaneous method[2] was used to incorporate background concentrations, but this was not possible for the large number of RWR receptors included in the assessment, and therefore simpler approaches were required for these.

[2] 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.

The derivation of background concentrations is explained in **Annexure D**. The approaches used for determining the total concentration of each pollutant for the community and RWR receptors are summarised in **Table G-5**.

Table G-5 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 hour (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 99th percentile 1-hour background NO_X from synthetic profile, then converted to maximum 1-hour NO_2
	1 year	GRAL NO_X added to mapped background NO_X, then converted to NO_2	GRAL NO_X added to mapped background NO_X, then converted to NO_2
PM_{10}	24 hour	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 hour	24-hour GRAL $PM_{2.5}$ added to contemporaneous 24-hour background $PM_{2.5}$	Maximum 24-hour GRAL $PM_{2.5}$ added to maximum 24-hour background $PM_{2.5}$ from synthetic profile
	1 year	GRAL $PM_{2.5}$ added to mapped background $PM_{2.5}$	GRAL $PM_{2.5}$ added to mapped background $PM_{2.5}$

Air toxics

For both the community and RWR receptors, the THC concentrations from GRAL were converted to concentrations for specific air toxics using vehicle exhaust emission speciation profiles. The speciation profiles for the compounds of interest are given in **Table G-6**. NSW EPA provides profiles for petrol light-duty vehicles (cars and LCVs) running on petrol with no ethanol (E0) and petrol with 10 per cent ethanol (E10), as well as diesel vehicles (the profiles are the same for light-duty and heavy-duty diesel vehicles).

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 G-6** were weighted according to THC emissions from the different vehicle categories. In practice, THC emissions for each vehicle type vary according to the year, the road type (fleet mix) and the traffic speed. Given the uncertainties associated with the speciation profiles, for this assessment a single combination of road type and speed was used to represent a 'central estimate' of THC emissions (commercial highway road type, with a speed of 50 kilometres per hour), although emissions for three years were estimated (2016, 2026 and 2036). The weighted profiles are given in **Table G-7**.

Table G-6 THC speciation profiles by fuel type (NSW EPA, 2012b; Environment Australia, 2003)

Pollutant/metric	% of THC (where THC=VOC)			
	Petrol light duty		Diesel light duty	Diesel heavy duty
	Petrol (E0)	Petrol (E10)		
Benzene	4.95	4.54	1.07	1.07
PAHs (as b(a)p) [(a)]	0.03	0.03	0.08	0.08
Formaldehyde	1.46	1.82	9.85	9.85
1,3-butadiene	1.27	1.20	0.40	0.40
Ethylbenzene	1.65	1.63	0.18	0.18

Notes:

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

(b) Based on a combination of PAH fraction of THC from NSW EPA (2012b) and the b(a)p fraction of PAH of 4.6 per cent from Environment Australia (2003).

Table G-7 Weighted THC speciation profiles for 2016, 2026 and 2036

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

Where a refined dispersion modelling technique has been used (as in this case), the criteria in the Approved Methods for individual air toxics relate to incremental impacts (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 Approved Methods.

G.8 Evaluation of dispersion model

The evaluation of the GRAMM-GRAL system performance is described in **sections G.9** and **G.10**. This includes a summary of the GRAL optimisation study (Pacific Environment, 2017b) and a project-specific evaluation. For Sydney Gateway the model evaluation was based on the monitoring data and model predictions for the 2016 base year. In total, 13 stations were located inside the GRAL domain. Of these, seven had data for all months of 2016 and four had partial data. The 11 stations with data for 2016 were therefore the only ones used in the evaluation.

GRAL was configured to predict hourly concentrations of NO_X, CO and PM_{10} at the 11 stations. For PM_{10}, daily average concentrations were also calculated. The GRAL predictions were combined with an average synthetic background profile which was less conservative than the profile used in the assessment (see **sections G.9** and **G.10**). The emphasis was on NO_X as the road traffic increment for CO and PM tends to be small relative to the background. NO_2 was excluded for the model evaluation

in order to focus on the performance of GRAMM-GRAL rather than any assumptions concerning NO_X-to-NO_2 conversion.

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

The results can be summarised as follows:

- At the background stations average NO_X concentrations were overestimated by around 10-30 µg/m^3, or 20-60 per cent. The 98th percentile and maximum concentrations were overestimated by up to around 35 per cent and 60 per cent respectively.
- At the near-road stations the mean NO_X concentration was overestimated by up to 140 per cent. The 98th percentile and maximum NO_X concentrations were also mostly overestimated.
- The temporal assessment of NO_X at four near-road stations revealed the following:
    - The average diurnal pattern was reasonably well reproduced at one station (Canal Road). At the other three stations there were some pronounced differences between the predictions and the observations. For example, there was a marked overestimation of NO_X concentrations at these stations during the night-time period. The inter-peak concentrations were reasonably well reproduced, although there was still a marked overestimation at the Princes Highway and West Botany Street stations.
    - The seasonal pattern in NO_X was well reproduced, although there was a consistent overestimation of the monthly average concentration at three of the four stations (again, the pattern at the Canal Road station matched closely to the observations).
    - At some stations the overestimation was larger at the weekend than on weekdays. This is likely to be due in large part to the assumption of weekday traffic volumes on every day of the year in the modelling.

Overall, the results supported the application of GRAL in the assessment, suggesting that the estimated concentrations ought to be conservative for most of the modelling domain, introducing a clear margin of safety into the assessment.

G.9 GRAL optimisation study

Pacific Environment (2017b) examined the performance of the GRAMM-GRAL system in an urban area of Sydney. GRAMM (version: July 2016) and GRAL (version: August 2016) were assessed against meteorological measurements and air quality measurements respectively. GRAMM and GRAL were also compared against other models that are commonly used in Australia: CALMET version 6.334 for meteorology, and CAL3QHCR version 2.0 for dispersion. The study provided recommendations regarding the configuration and application of GRAMM and GRAL to the assessment urban road networks in Australia. The emphasis was on NO_X, as the road traffic increment for CO and PM_{10} tends to be small relative to the background.

The study showed that the combination of GRAMM and GRAL is capable of giving good average predictions which reflect the spatial distribution of concentrations near roads with reasonable accuracy. The model chain gives results that are at least as good as those produced by other models that are currently in use in Australia. For example, Figure G-1 compares the performance of GRAL and CAL3QHCR with respect to the prediction of two-week average NO_X concentrations at the passive sampling locations. The slight overestimation of GRAM is desirable in an air quality assessment context. As with all air pollution models, the prediction of short-term (1-hour) concentrations remains a challenge. This is not surprising given the complexity of the processes involved.

Another challenge for the study was the treatment of short-term average NO_2 concentrations. This was because of the need to simulate several complex processes, including adequate representation of background concentrations, quantification of primary NO_2 (which is especially uncertain), and the short-term chemical formation of NO_2 through its reaction with ozone. The latter point was particularly important for this study; the time scales for atmospheric mixing and chemical reactions are very similar, which makes this task difficult.

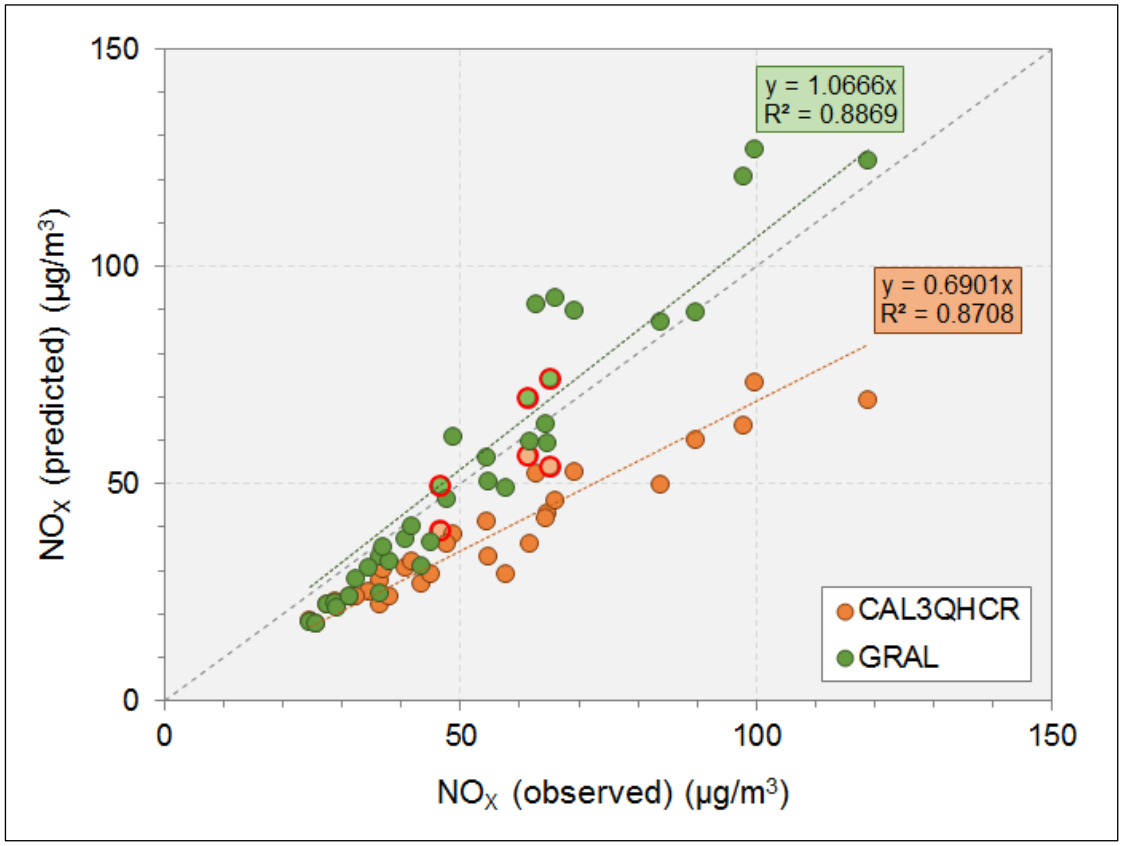

Figure G-5 **Model evaluation at passive sampling locations (red circles show Concord Oval) (Pacific Environment, 2017b)**

G.10 Project-specific GRAL evaluation

G.10.1 Approach

A simpler model evaluation was conducted for Sydney Gateway, based on the monitoring data and model predictions for monitoring stations in the GRAL domain and with data for the 2016 base year. The characteristics of the background and near-road monitoring stations inside the GRAL domain are summarised in Table G-8, and for those located near roads the approximate two-way traffic volumes are also given. In total, 11 stations were located inside the GRAL domain and had data for 2016. Of these, seven (highlighted in blue) had data for all months of 2016 and four (highlighted in green) had partial data.

Table G-8 Characteristics of monitoring stations in the GRAL domain

Station code	Organisation (project)	Station name	Location	Station type	Nearest busy road(s) (road stations only)			Monitoring data for 2016
					Road(s)	Distance to kerb (m)	Traffic vol. (approx. vpd)	
M01	OEH (-)	Earlwood[(a)]	Beaman Park	Background	-	-	-	Jan-Dec
M02	RMS (M5 East tunnel)	M5E:CBMS	Gipps Street, Bardwell Valley	Background	-	-	-	Jan-Dec
M03		M5E:T1	Thompson Street, Turrella	Background	-	-	-	Jan-Dec
M04		M5E:U1	Jackson Place, Undercliffe	Background	-	-	-	Jan-Dec
M05		M5E:X1	Wavell Parade, Earlwood	Background	-	-	-	Jan-Dec
M06		M5E:M1	M5 East tunnel off-ramp	Peak (near-road)	Off-ramp, M5 East tunnel	~8	~20,000	Jan-Dec
M07	SMC (New M5 Motorway)	New M5:01	St Peters Public School, Church St, St Peters	Background	-	-	-	Jan-Dec
M08		New M5:02	Princes Highway, St Peters	Peak (near-road)	Princes Highway Campbell Street	~5 ~20	~35,000 ~5,000	Jan-Apr
M09		New M5:03	West Botany Street, Arncliffe	Peak (near-road)	West Botany Street On-ramp, M5 East tunnel	~11 ~35	~32,000 ~30,000	Jan-Jun
M10		New M5:04	Bestic Street, Rockdale	Background	-	-	-	Jan-Sep
M11		New M5:07	Canal Road, St Peters	Peak (near-road)	Canal Road	~5	~45,000	Jan-Apr

(a) CO was not measured at this station.

GRAL was configured to predict hourly concentrations of NO_X, CO and PM_{10} at the 11 stations. For PM_{10}, daily average concentrations were also calculated. NO_2 was excluded for the model evaluation in order to focus on the performance of GRAMM-GRAL rather than any assumptions concerning NO_X-to-NO_2 conversion.

The contemporaneous method was used to add the background contribution to the predicted concentrations. However, rather than the conservative 'maximum' synthetic background profiles that were used in the air quality assessment, more representative 'average' synthetic profile were used for the model evaluation. The average synthetic background profiles were constructed in a similar way to the maximum synthetic background profiles, but to enable a more direct comparison with the monitoring data, they were calculated using an average value for each hour of the year across several monitoring stations rather than the maximum value used in the assessment. Three evaluation statistics were then determined for each dataset: mean, 99th percentile and maximum.

In the following sections, the results of the evaluation are presented by pollutant.

G.10.2 Results for NOx

Figure G-6 and Figure G-7 show examples of the modelled 1-hour mean NO_X concentrations for a background station (New M5:01, St Peters Public School) and a near-road station (M5E:M1, M5 East tunnel off-ramp), along with the measured NO_X concentrations at these stations. The modelled concentration includes both the background contribution and the GRAL prediction. At the near-road station there was a larger modelled contribution from GRAL.

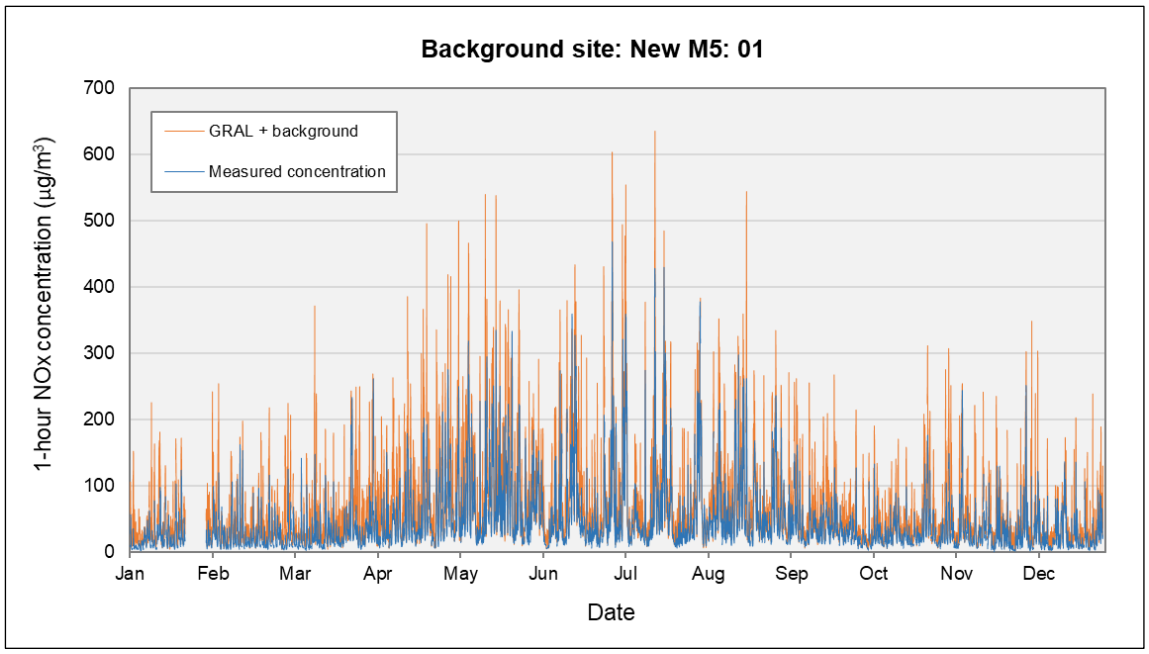

Figure G-6 **Measured 1-hour mean NO_X concentrations and GRAL predictions (including background) for the New M5:01 (St Peters Public School) background monitoring station**

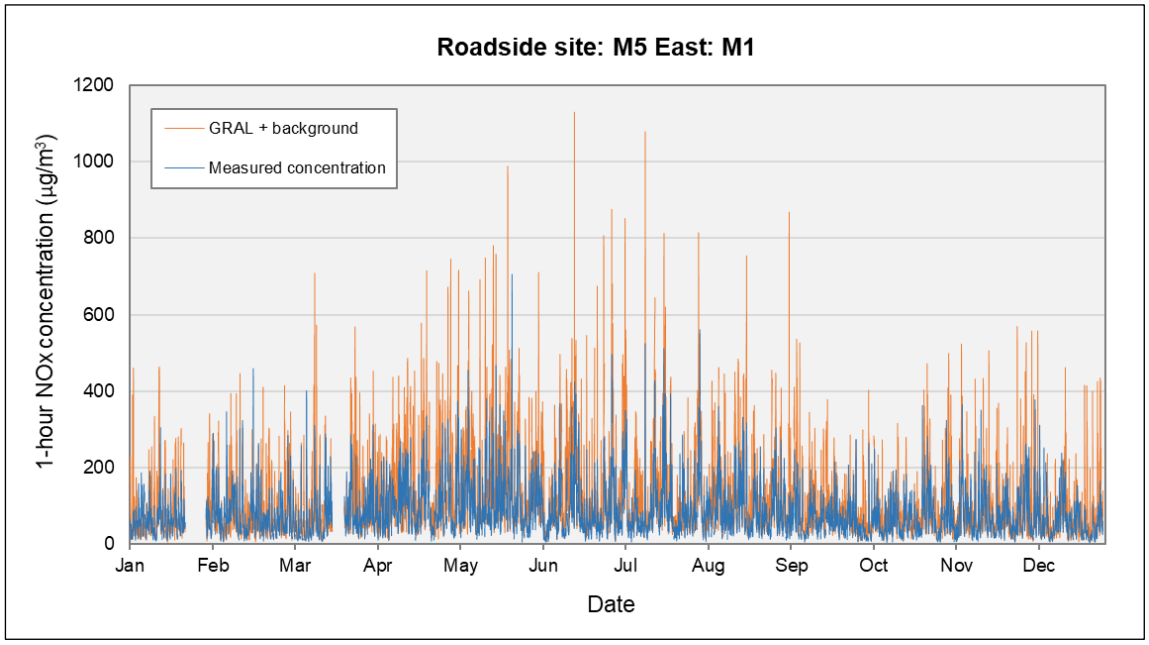

Figure G-7 **Measured 1-hour mean NO_X concentrations and GRAL predictions (including background) for the M5E: M1 (M5 East tunnel off-ramp) monitoring station**

In Figure G-8 the measured and predicted NO_X concentrations are compared for each of the monitoring stations. Again, the stations with full monitoring data for 2016 are shown in blue, whereas the stations with partial data are shown in green.

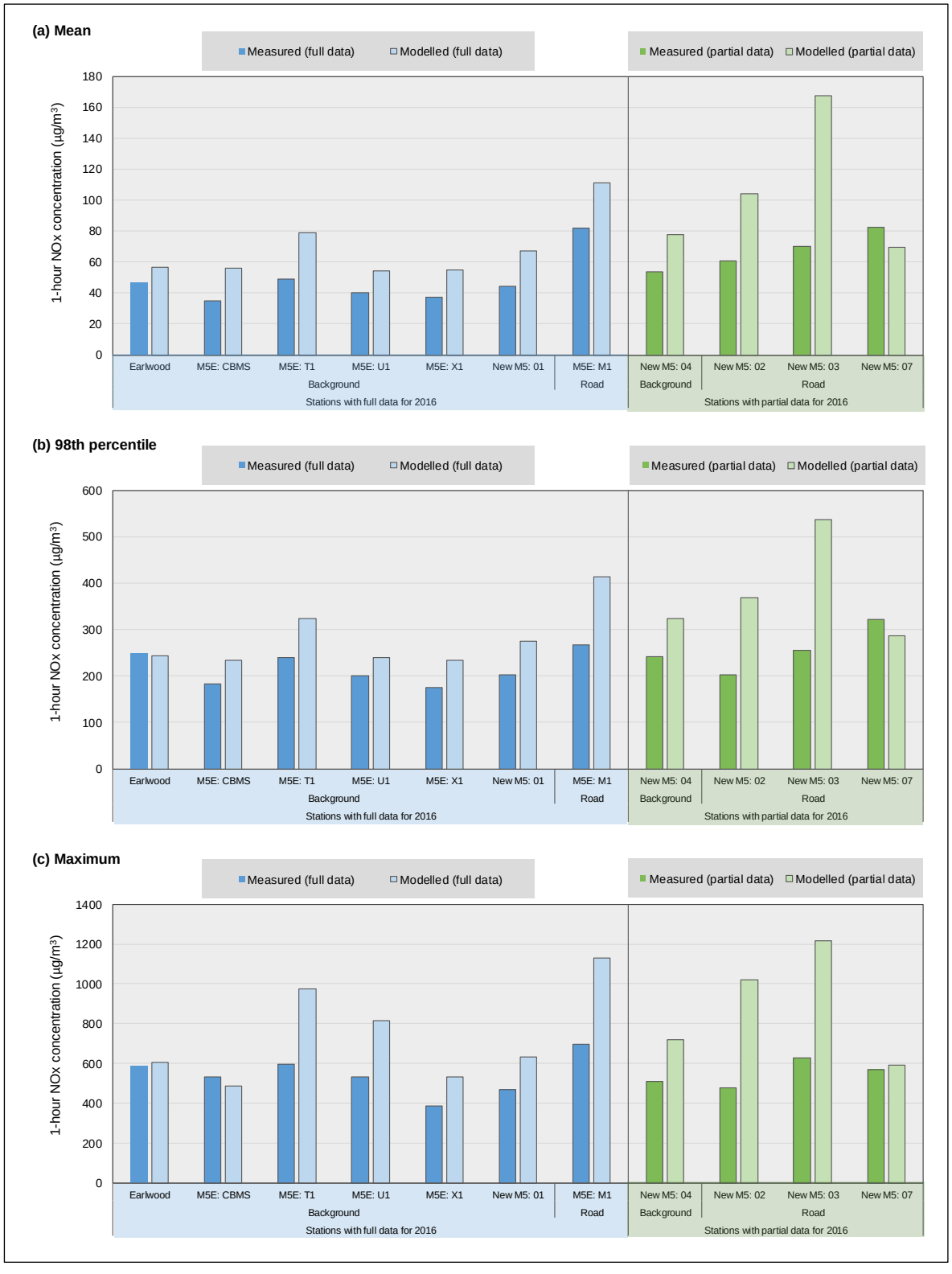

Figure G-8 Comparison between measured and predicted total NO_X concentrations

At the **background** stations average NO_X concentrations were overestimated, as would be expected. For the purpose of the air quality assessment it was assumed that the measured background stations were not influenced by road transport sources, and therefore in principle the concentrations predicted by GRAL at these stations should have been zero. In practice, dispersion models will often give non-zero values at background stations, and this was also the case here. This overestimation of mean NO_X at the background stations was around 10-30 µg/m^3, or 20-60 per cent. The 98th percentile concentrations were overestimated by up to around 35 per cent, and the maximum concentrations by up to around 60 per cent.

At the **near-road** stations the mean NO_X concentration was overestimated by up to 140 per cent. The 98th percentile and maximum NO_X concentrations were also mostly overestimated. It is worth noting that, for some of the near-road stations included in the assessment, the measured NO_X increment above the background was not very pronounced. At the near-road stations the background contributed 30-50 per cent of the total NO_X concentration.

The inference from these results is that NO_X concentrations across the domain were probably overestimated.

Because there is generally a stronger road traffic signal for NO_X than for other criteria pollutants, the model performance at the four near-road stations was also examined in more detail using the '*timeVariation*' function in the Openair software (Carslaw, 2018). Figure G-9 to Figure G-12 show the results from the *timeVariation* function for the predicted ('GRAL') and monitored ('MON') hourly NO_X concentrations at the four near-road stations included in the evaluation.

The variation of a pollutant by time of day and day of week can reveal useful information concerning the likely sources. For example, road vehicle emissions tend to follow regular patterns both on a daily and weekly basis. The *timeVariation* function produces four plots: day of the week variation, mean hour of day variation, a combined hour of day – day of week plot, and a monthly plot. Also shown on the plots is the 95 per cent confidence interval in the mean. For model evaluation it is important to consider the difference between observations and modelled values over these different time scales (Carslaw, 2018).

The plots show the following:

- The average diurnal pattern was reasonably well reproduced at the Canal Road station. At the other three stations there were some pronounced differences between the predictions and the observations. For example, there was a marked overestimation of NO_X concentrations at these stations during the night-time period. The inter-peak concentrations were reasonably well reproduced, although there was still a marked overestimation at the Princes Highway and West Botany Street stations.
- The seasonal pattern in NO_X was well reproduced, although there was a consistent overestimation of the monthly average concentration at three of the four stations (again, the pattern at the Canal Road station matched closely to the observations).
- At some stations the overestimation was larger at the weekend than on weekdays. This is likely to be due in large part to the assumption of weekday traffic volumes on every day of the year in the modelling.

Overall, the results for NO_X confirm that the estimated total annual mean and short-term NO_X concentrations ought to be quite conservative for most of the modelling domain and time periods. The selected approaches should introduce a clear margin of safety into the Sydney Gateway assessment.

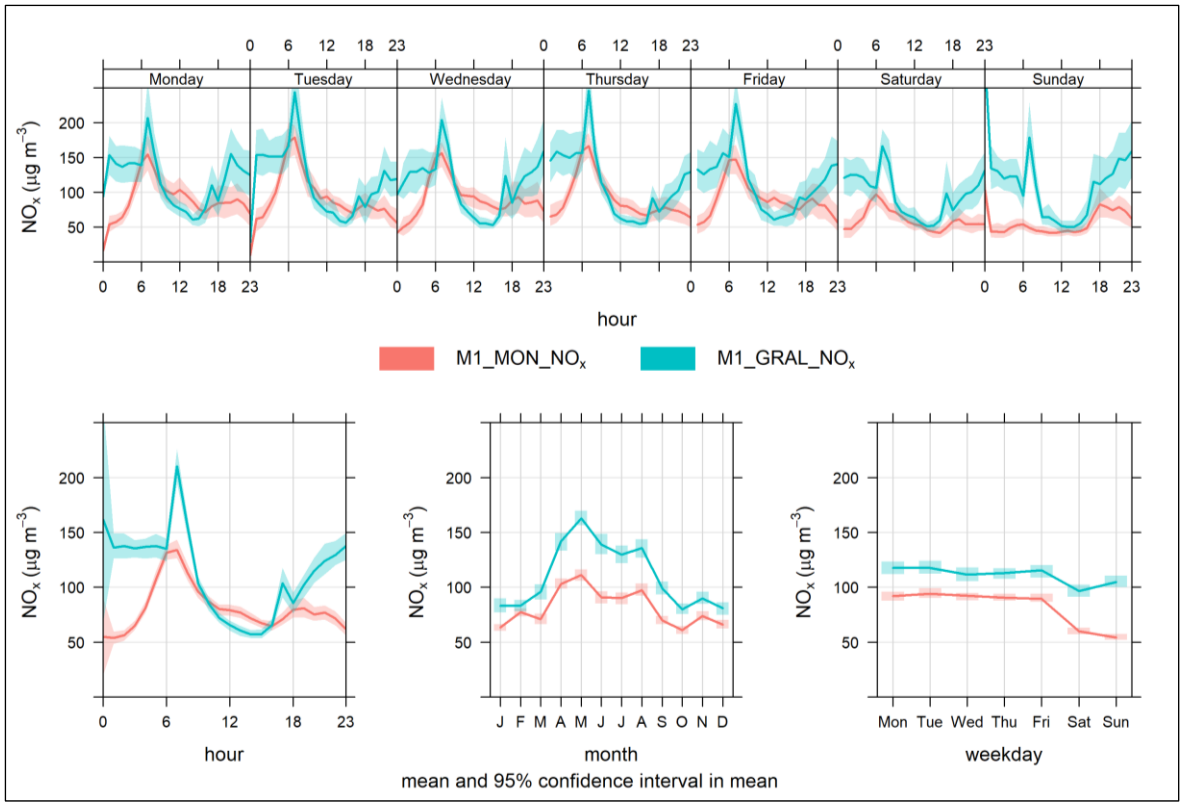

Figure G-9 **Time variation of measured and predicted total NO_X concentrations at the M5E:M1 (M5 East tunnel off-ramp) near-road monitoring station**

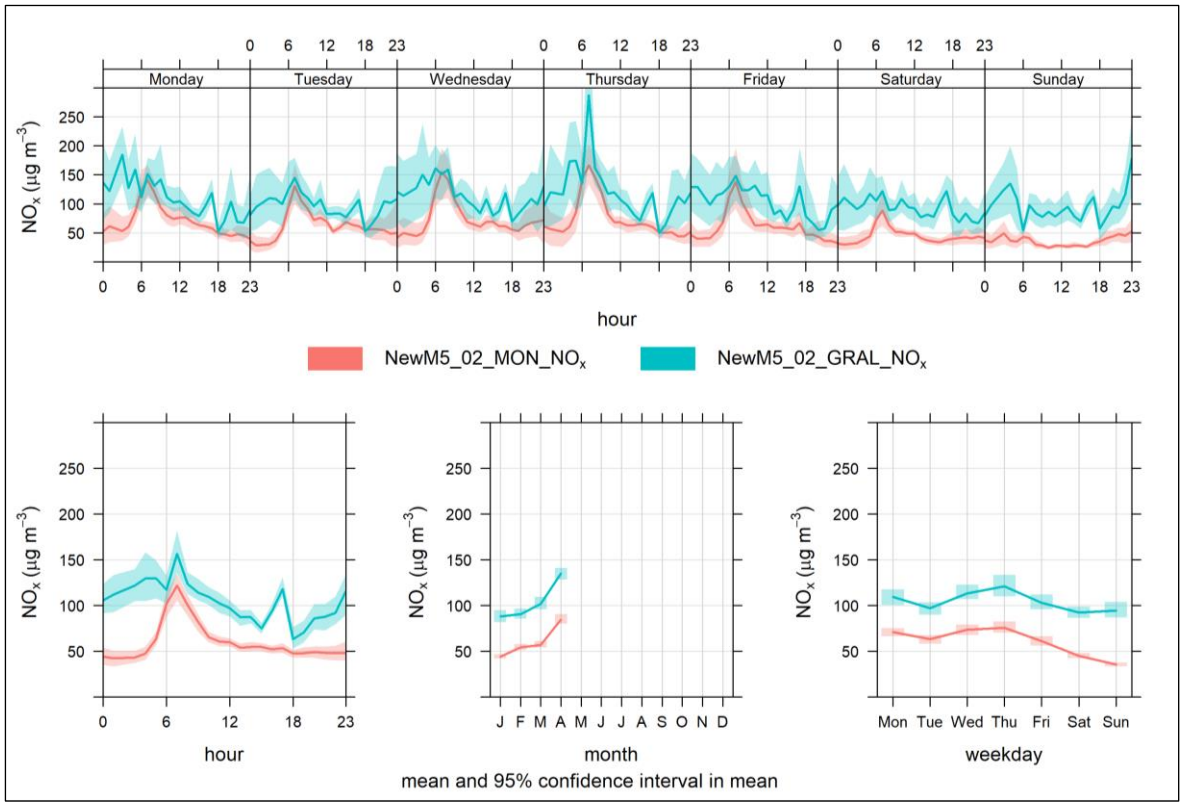

Figure G-10 **Time variation of measured and predicted total NO_X concentrations at the New M5:02 (Princes Highway) near-road monitoring station**

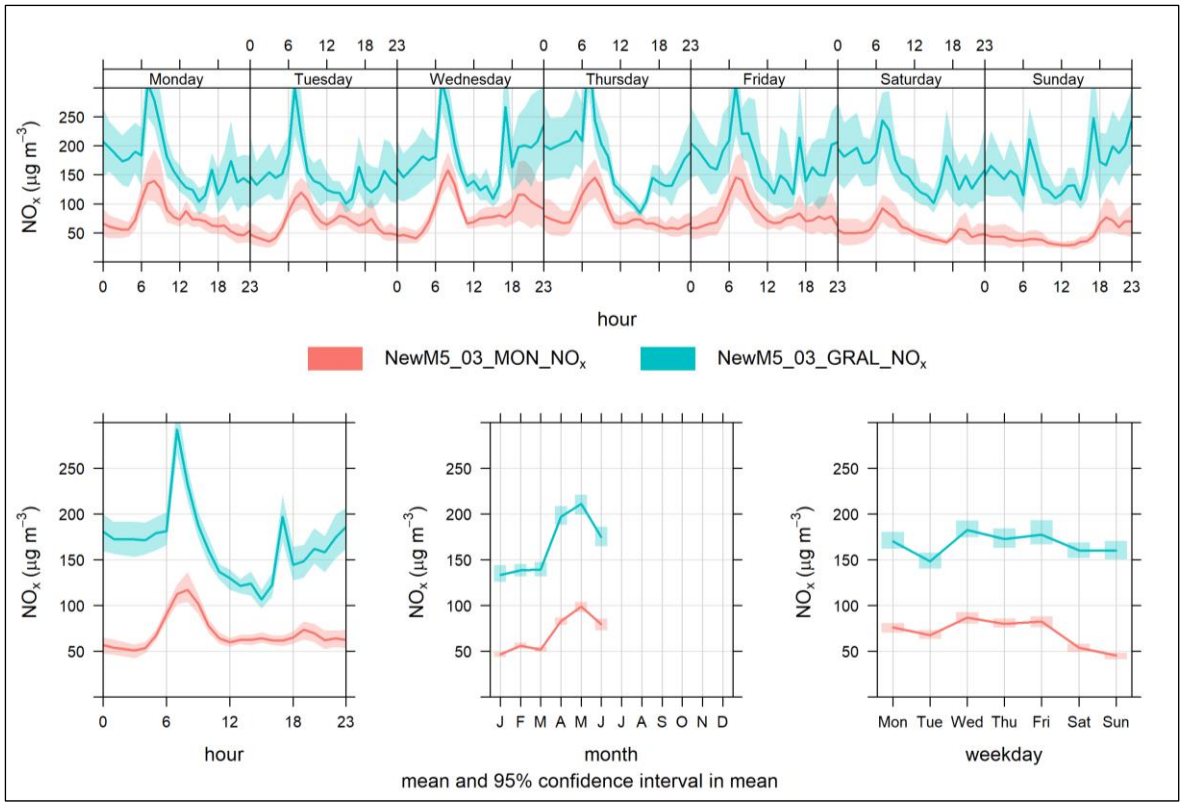

Figure G-11 **Time variation of measured and predicted total NO_X concentrations at the New M5:03 (West Botany Street) near-road monitoring station**

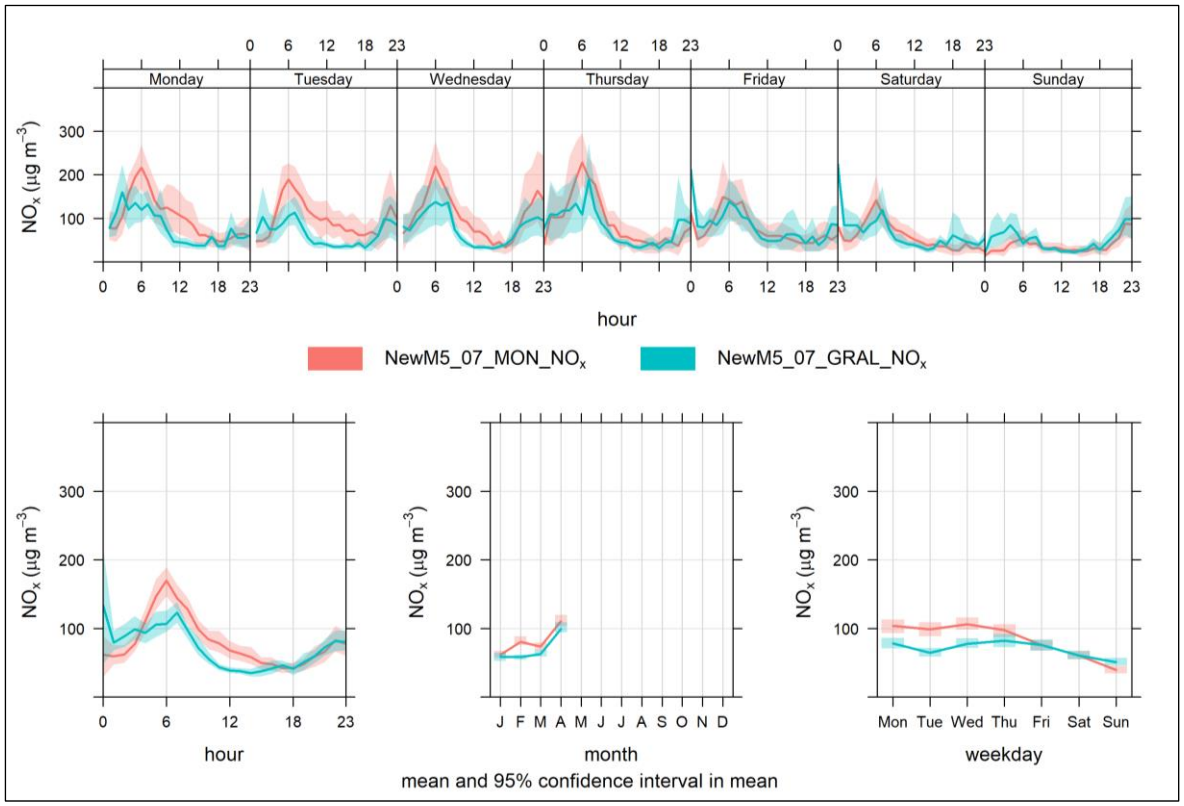

Figure G-12 **Time variation of measured and predicted total NO_X concentrations at the New M5:07 (Canal Road) near-road monitoring station**

G.10.3 Results for CO

Figure G-13 and Figure G-14 show examples of the 1-hour mean CO concentrations predicted by GRAL for the background and near-road stations. The GRAL predictions include the background contribution. The GRAL concentration was, however, generally much lower than the measured background. The concentration profiles at the background and near-road stations were quite similar, indicating a small road traffic influence on CO.

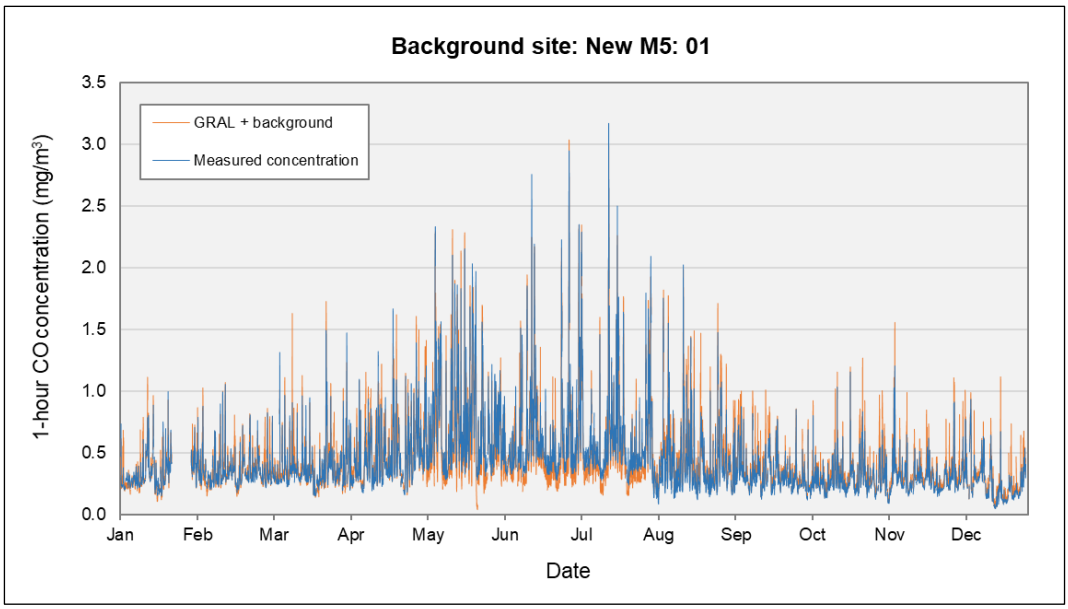

Figure G-13 **Measured 1-hour mean CO concentrations and GRAL predictions (including background) for the New M5:01 (St Peters Public School) background monitoring station**

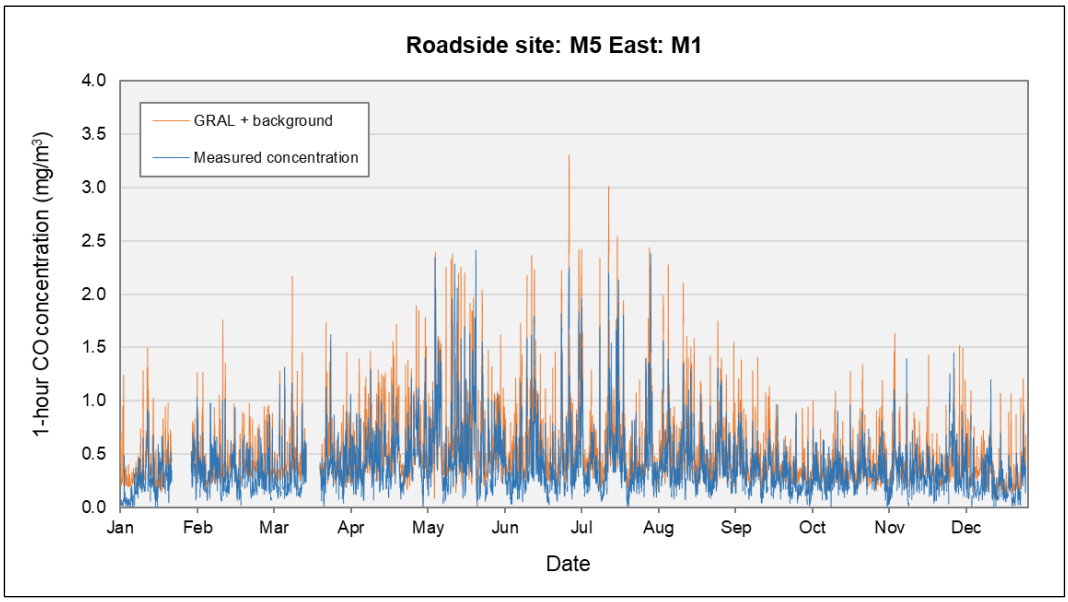

Figure G-14 **Measured 1-hour mean CO concentrations and GRAL predictions (including background) for the M5E:M1 (M5 East tunnel off-ramp) monitoring station**

The statistics for the measured and predicted total CO concentrations are compared in Figure G-15. The predictions generally showed a good agreement with the measurements. Mean CO concentrations were usually overestimated, and typically by 35-55 per cent. This is not surprising given the strong influence of the background. At the near-road stations the background contributed 70-85 per cent of the mean total CO concentration.

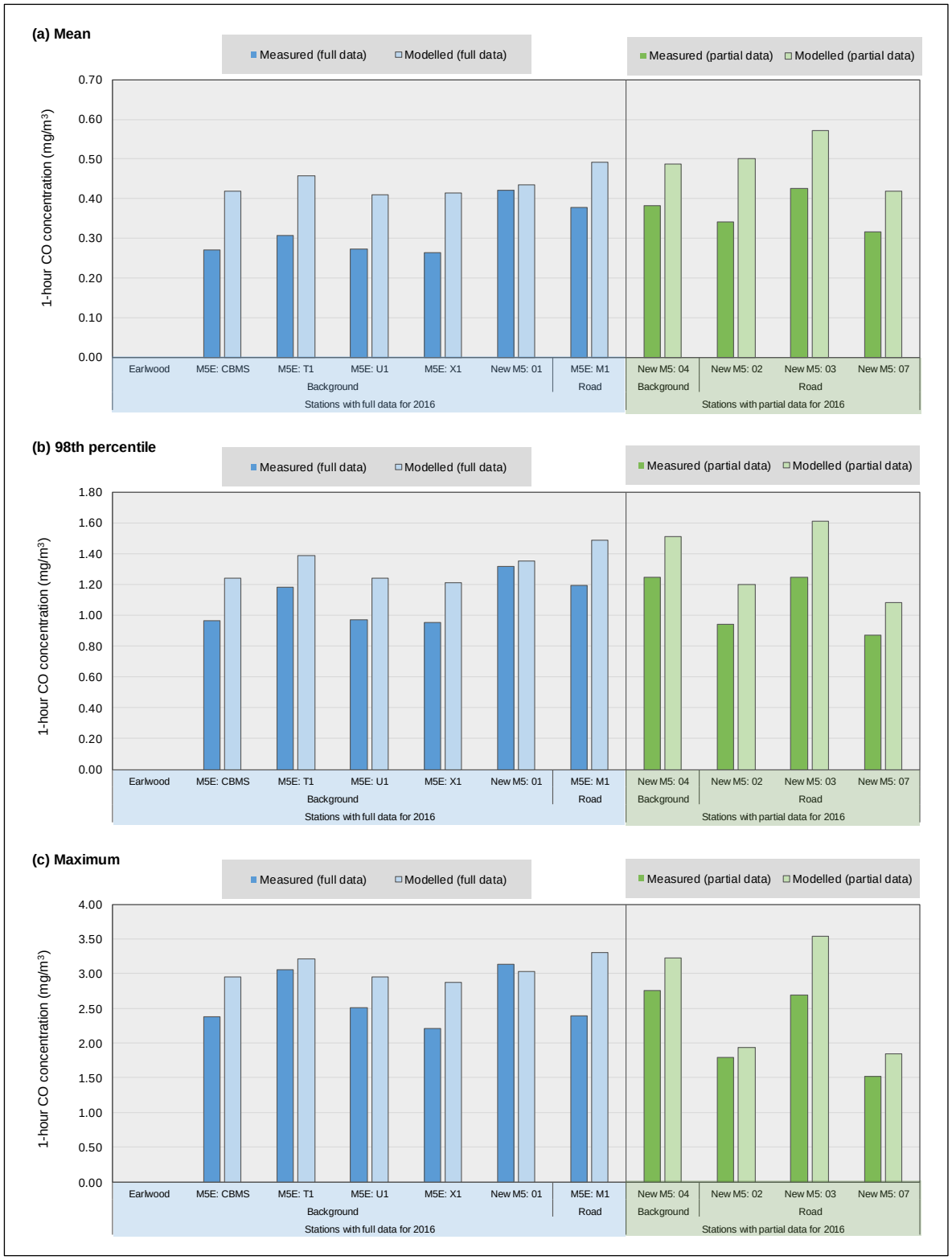

Figure G-15 Comparison between measured and predicted total CO concentrations

G.10.4 Results for PM_{10}

Figure G-16 compares the measured 24-hour mean PM_{10} concentrations with those predicted by GRAL for the background station, and Figure G-17 shows the results for the near-road station. Unsurprisingly, given the large background contribution, there was a good agreement between the model predictions and the measurements.

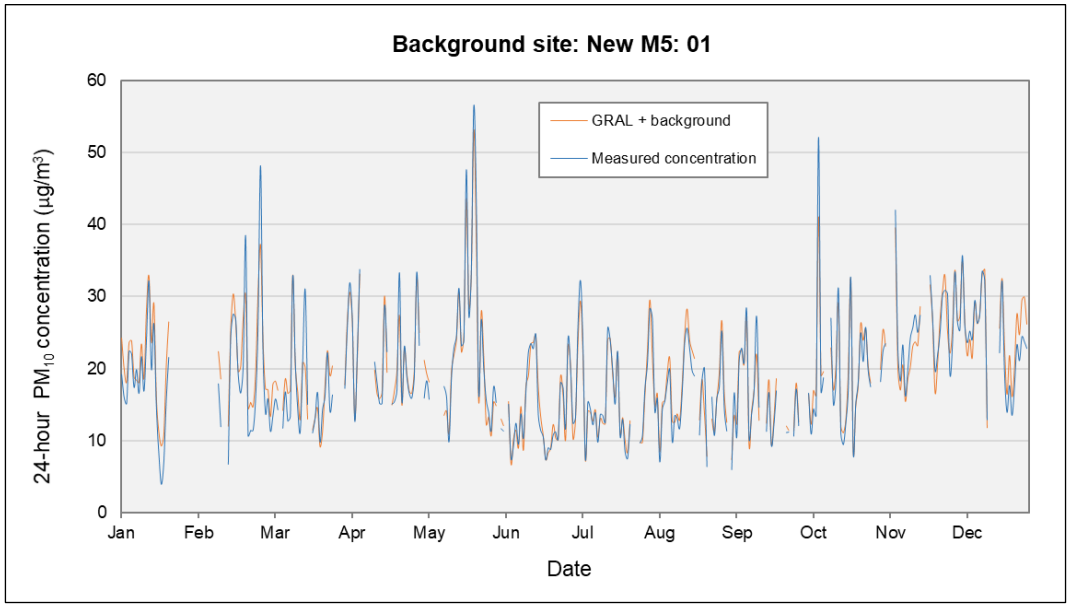

Figure G-16 **Measured 24-hour mean PM_{10} concentrations and GRAL predictions (including background) for the New M5:01 (St Peters Public School) background monitoring station**

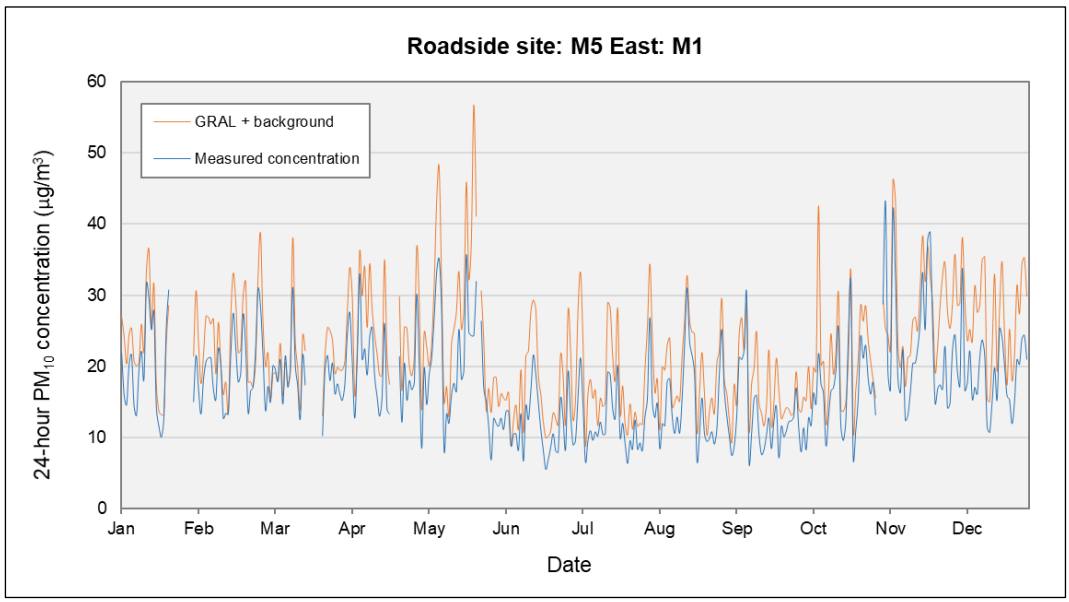

Figure G-17 **Measured 24-hour mean PM_{10} concentrations and GRAL predictions (including background) for the M5E:M1 (M5 East tunnel off-ramp) monitoring station**

The summary plots and statistics for the PM_{10} comparisons are provided in Figure G-18. As with NO_X, calculations based on the contemporaneous background approaches are also included for comparison with the mapped background approach. There was a large background contribution (between 80 and 90 per cent) at all near-road stations.

In general, the results suggest that the use of GRAL and the background mapping approach should give good (and slightly conservative) estimates of PM_{10} concentrations.

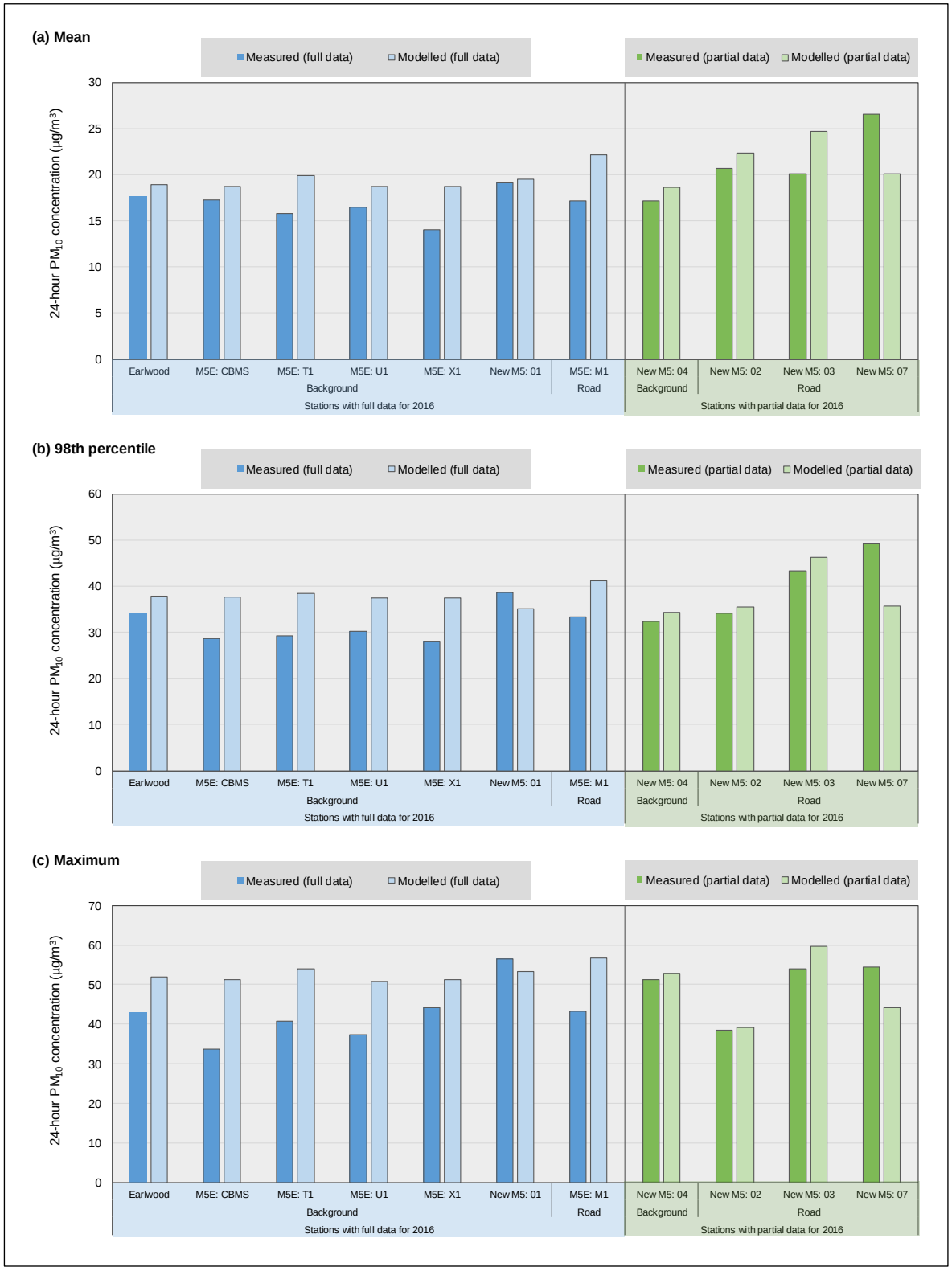

Figure G-18 Comparison between measured and predicted total PM_{10} concentrations

Annexure H - Dispersion modelling results - all sources

This Annexure provides all results of the dispersion modelling for the **expected traffic** scenarios. The following notes apply:

- Data are not presented for the 2016-BY scenario, as this scenario was designed primarily for model evaluation.
- For community receptors the Figures presented in the main body of the report have not been duplicated. The results for these receptors have been tabulated. The largest value for a given parameter is highlighted in bold.
- For short-term air quality criteria, such as the maximum 1-hour NO_2 concentrations, the contour plots should be viewed as indicative. This is a consequence of the difficulties associated with the prediction of short-term concentrations.

H.1 Carbon monoxide (maximum 1-hour)

Table H-1 Maximum 1-hour CO concentration at community receptors

Receptor	Maximum 1-hour CO concentration (mg/m³)							Change relative to Do Minimum (mg/m³)				Change relative to Do Minimum (%)			
	2016-BY	2026-DM	2026-WP	2026-WPC	2036-DM	2036-WP	2036-WPC	2026-WP	2026-WPC	2036-WP	2036-WPC	2026-WP	2026-WPC	2036-WP	2036-WPC
CR01	-	3.19	3.21	3.19	3.25	3.19	3.17	0.02	0.01	-0.06	-0.08	0.8%	0.2%	-1.9%	-2.4%
CR02	-	3.25	3.15	3.30	3.22	3.19	3.16	-0.10	0.05	-0.03	-0.06	-3.0%	1.6%	-0.9%	-1.8%
CR03	-	3.23	3.31	3.23	3.25	3.26	3.18	0.08	0.00	0.02	-0.07	2.5%	0.0%	0.5%	-2.1%
CR04	-	**3.37**	**3.37**	3.26	3.19	3.15	3.17	-0.01	-0.12	-0.04	-0.02	-0.2%	-3.4%	-1.3%	-0.6%
CR05	-	3.29	3.18	3.25	3.21	3.15	3.17	-0.12	-0.04	-0.06	-0.04	-3.5%	-1.2%	-1.9%	-1.3%
CR06	-	3.20	3.19	3.24	3.17	3.22	3.20	-0.01	0.04	0.06	0.03	-0.4%	1.2%	1.8%	1.0%
CR07	-	3.21	3.20	3.16	3.18	3.27	3.18	0.00	-0.05	**0.08**	0.00	-0.1%	-1.6%	**2.6%**	0.0%
CR08	-	3.29	3.20	3.23	3.25	3.25	3.24	-0.09	-0.06	0.00	-0.01	-2.8%	-1.8%	0.0%	-0.3%
CR09	-	3.27	3.30	3.23	**3.33**	3.22	3.21	0.03	-0.04	-0.11	-0.12	1.0%	-1.1%	-3.2%	-3.5%
CR10	-	3.26	3.24	3.23	3.29	3.20	3.21	-0.02	-0.03	-0.09	-0.08	-0.6%	-1.0%	-2.6%	-2.3%
CR11	-	3.13	3.30	3.30	3.23	**3.31**	3.21	**0.17**	**0.17**	0.08	-0.02	**5.5%**	**5.4%**	2.6%	-0.7%
CR12	-	3.34	3.25	3.26	3.26	3.18	**3.26**	-0.09	-0.07	-0.09	-0.01	-2.7%	-2.2%	-2.7%	-0.2%
CR13	-	3.15	3.20	**3.30**	3.19	3.19	3.20	0.05	0.15	0.00	0.01	1.5%	4.9%	0.0%	0.3%
CR14	-	3.24	3.21	3.22	3.18	3.22	3.26	-0.03	-0.02	0.04	**0.09**	-1.0%	-0.5%	1.3%	**2.8%**
CR15	-	3.15	3.15	3.21	3.15	3.19	3.18	0.00	0.06	0.03	0.03	0.0%	1.9%	1.1%	1.0%
CR16	-	3.33	3.24	3.23	3.21	3.18	3.21	-0.09	-0.10	-0.03	-0.01	-2.8%	-3.0%	-1.1%	-0.2%
CR17	-	3.20	3.16	3.17	3.15	3.16	3.18	-0.04	-0.03	0.02	0.03	-1.2%	-0.9%	0.6%	0.9%

Table H-2 Maximum 1-hour CO concentration at RWR receptors, ranked by concentration

Rank	Ranking by concentration (mg/m^3)						
	2016-BY	2026-DM	2026-WP	2026-WPC	2036-DM	2036-WP	2036-WPC
1	-	5.3	5.5	5.6	4.7	4.7	4.7
2	-	5.2	5.3	5.4	4.6	4.7	4.5
3	-	5.1	5.3	5.4	4.6	4.6	4.5
4	-	5.1	5.2	5.2	4.6	4.6	4.5
5	-	5.1	5.2	5.1	4.6	4.6	4.4
6	-	5.0	5.1	5.1	4.6	4.6	4.4
7	-	5.0	5.1	5.0	4.6	4.6	4.4
8	-	5.0	5.1	5.0	4.6	4.6	4.4
9	-	5.0	5.0	5.0	4.5	4.6	4.4
10	-	5.0	5.0	5.0	4.5	4.6	4.4

Table H-3 Maximum 1-hour CO concentration at RWR receptors, ranked by increase and by decrease in concentration

Rank	Ranking by increase in concentration relative to Do Minimum (mg/m^3)				Ranking by decrease in concentration relative to Do Minimum (mg/m^3)			
	2026-WP	2026-WPC	2036-WP	2036-WPC	2026-WP	2026-WPC	2036-WP	2036-WPC
1	0.8	0.9	0.6	0.6	-0.9	-0.8	-0.6	-0.7
2	0.7	0.7	0.5	0.5	-0.7	-0.8	-0.5	-0.7
3	0.7	0.7	0.4	0.5	-0.7	-0.7	-0.5	-0.7
4	0.6	0.6	0.4	0.4	-0.7	-0.7	-0.4	-0.7
5	0.6	0.5	0.4	0.4	-0.6	-0.7	-0.4	-0.7
6	0.5	0.5	0.4	0.4	-0.6	-0.6	-0.4	-0.6
7	0.5	0.5	0.4	0.4	-0.6	-0.6	-0.4	-0.6
8	0.5	0.5	0.4	0.4	-0.6	-0.6	-0.4	-0.6
9	0.5	0.5	0.4	0.4	-0.5	-0.6	-0.4	-0.6
10	0.5	0.5	0.4	0.4	-0.5	-0.5	-0.4	-0.6

Table H-4 Maximum 1-hour CO concentration at RWR receptors, ranked by percentage increase and by decrease in concentration

Rank	Ranking by % increase in concentration relative to Do Minimum				Ranking by % decrease in concentration relative to Do Minimum			
	2026-WP	2026-WPC	2036-WP	2036-WPC	2026-WP	2026-WPC	2036-WP	2036-WPC
1	21.8%	19.5%	15.6%	16.1%	-16.9%	-17.7%	-13.1%	-16.3%
2	17.6%	19.0%	12.2%	12.8%	-14.1%	-16.6%	-11.9%	-16.2%
3	15.8%	18.1%	12.2%	12.1%	-14.0%	-15.2%	-11.8%	-15.2%
4	15.4%	15.9%	11.7%	11.9%	-13.8%	-15.0%	-10.1%	-15.1%
5	15.0%	14.6%	10.6%	11.7%	-13.8%	-14.0%	-9.8%	-14.9%
6	14.9%	14.0%	10.2%	11.4%	-13.0%	-13.8%	-9.6%	-14.6%
7	14.3%	12.7%	10.1%	11.2%	-12.1%	-12.6%	-9.3%	-13.9%
8	14.1%	12.3%	9.9%	10.5%	-12.0%	-12.6%	-9.2%	-13.9%
9	13.0%	12.2%	9.6%	10.1%	-11.9%	-12.2%	-9.1%	-13.8%
10	13.0%	12.0%	9.5%	10.0%	-11.8%	-12.1%	-8.8%	-13.6%

H.2 Carbon monoxide (maximum rolling 8-hour)

Table H-5 Maximum rolling 8-hour CO concentration at community receptors

Receptor	Maximum rolling 8-hour CO concentration (mg/m^3)							Change relative to Do Minimum (mg/m^3)				Change relative to Do Minimum (%)			
	2016-BY	2026-DM	2026-WP	2026-WPC	2036-DM	2036-WP	2036-WPC	2026-WP	2026-WPC	2036-WP	2036-WPC	2026-WP	2026-WPC	2036-WP	2036-WPC
CR01	-	2.35	2.35	2.35	2.36	2.35	2.33	0.00	0.00	-0.01	-0.03	0.0%	-0.1%	-0.6%	-1.2%
CR02	-	2.35	2.34	2.35	2.33	2.32	2.32	-0.02	0.00	-0.01	-0.01	-0.7%	-0.2%	-0.5%	-0.3%
CR03	-	2.43	2.45	2.41	2.40	2.41	2.36	0.02	-0.02	0.01	-0.04	0.6%	-1.0%	0.3%	-1.7%
CR04	-	2.47	2.45	2.43	2.39	2.35	2.37	-0.02	-0.04	-0.04	-0.02	-0.7%	-1.7%	-1.6%	-0.7%
CR05	-	2.42	2.38	2.39	2.37	2.34	2.35	-0.03	-0.03	-0.03	-0.02	-1.4%	-1.1%	-1.2%	-0.8%
CR06	-	2.39	2.39	2.39	2.38	2.36	2.36	-0.01	0.00	-0.03	-0.02	-0.3%	-0.1%	-1.2%	-0.9%
CR07	-	2.37	2.38	2.37	2.36	2.36	2.36	0.01	0.00	0.00	0.00	0.6%	-0.1%	-0.2%	-0.1%
CR08	-	2.50	2.43	**2.48**	2.44	2.40	2.41	-0.07	-0.02	-0.04	-0.03	-2.8%	-0.9%	-1.5%	-1.3%
CR09	-	2.48	2.44	2.44	2.44	2.39	2.43	-0.04	-0.04	-0.05	-0.01	-1.7%	-1.8%	-2.0%	-0.6%
CR10	-	2.46	2.43	2.45	2.45	2.40	2.39	-0.03	-0.01	-0.05	-0.06	-1.3%	-0.5%	-2.0%	-2.3%
CR11	-	2.46	2.46	2.46	**2.45**	**2.46**	**2.44**	-0.01	-0.01	0.01	-0.01	-0.3%	-0.3%	0.4%	-0.3%
CR12	-	**2.51**	**2.46**	2.44	2.44	2.44	2.41	-0.05	-0.07	-0.01	-0.04	-2.0%	-2.7%	-0.3%	-1.5%
CR13	-	2.41	2.45	2.46	2.43	2.40	2.39	**0.05**	**0.05**	-0.04	-0.05	**1.9%**	**2.0%**	-1.4%	-2.0%
CR14	-	2.41	2.37	2.38	2.36	2.36	2.38	-0.04	-0.03	0.00	0.02	-1.7%	-1.1%	0.1%	0.6%
CR15	-	2.36	2.35	2.38	2.35	2.37	2.38	-0.01	0.01	**0.02**	**0.03**	-0.5%	0.6%	**0.8%**	**1.2%**
CR16	-	2.44	2.43	2.40	2.39	2.36	2.38	-0.01	-0.04	-0.03	-0.01	-0.3%	-1.7%	-1.2%	-0.3%
CR17	-	2.42	2.38	2.41	2.35	2.37	2.37	-0.04	-0.01	0.02	0.02	-1.7%	-0.5%	0.7%	1.0%

Table H-6 Maximum rolling 8-hour CO concentration at RWR receptors, ranked by concentration

Rank	Ranking by concentration (mg/m^3)						
	2016-BY	2026-DM	2026-WP	2026-WPC	2036-DM	2036-WP	2036-WPC
1	-	3.7	3.8	3.9	3.3	3.3	3.2
2	-	3.6	3.7	3.8	3.2	3.2	3.1
3	-	3.5	3.7	3.8	3.2	3.2	3.1
4	-	3.5	3.6	3.6	3.2	3.2	3.1
5	-	3.5	3.6	3.6	3.2	3.2	3.1
6	-	3.5	3.5	3.6	3.2	3.2	3.1
7	-	3.5	3.5	3.5	3.2	3.2	3.1
8	-	3.5	3.5	3.5	3.2	3.2	3.1
9	-	3.5	3.5	3.5	3.2	3.2	3.1
10	-	3.5	3.5	3.5	3.2	3.2	3.0

Table H-7 Maximum rolling 8-hour CO concentration at RWR receptors, ranked by increase and by decrease in concentration

Rank	Ranking by increase in concentration relative to Do Minimum (mg/m^3)				Ranking by decrease in concentration relative to Do Minimum (mg/m^3)			
	2026-WP	2026-WPC	2036-WP	2036-WPC	2026-WP	2026-WPC	2036-WP	2036-WPC
1	0.6	0.6	0.4	0.4	-0.6	-0.6	-0.4	-0.5
2	0.5	0.5	0.3	0.3	-0.5	-0.6	-0.4	-0.5
3	0.5	0.5	0.3	0.3	-0.5	-0.5	-0.4	-0.5
4	0.4	0.4	0.3	0.3	-0.5	-0.5	-0.3	-0.5
5	0.4	0.4	0.3	0.3	-0.4	-0.5	-0.3	-0.5
6	0.4	0.4	0.3	0.3	-0.4	-0.4	-0.3	-0.4
7	0.4	0.4	0.3	0.3	-0.4	-0.4	-0.3	-0.4
8	0.4	0.3	0.2	0.3	-0.4	-0.4	-0.3	-0.4
9	0.4	0.3	0.2	0.3	-0.4	-0.4	-0.3	-0.4
10	0.4	0.3	0.2	0.3	-0.4	-0.4	-0.3	-0.4

Table H-8 Maximum rolling 8-hour CO concentration at RWR receptors, ranked by percentage increase and by decrease in concentration

Rank	Ranking by % increase in concentration relative to Do Minimum				Ranking by % decrease in concentration relative to Do Minimum			
	2026-WP	2026-WPC	2036-WP	2036-WPC	2026-WP	2026-WPC	2036-WP	2036-WPC
1	21.8%	19.5%	15.6%	16.1%	-16.9%	-17.7%	-13.1%	-16.3%
2	17.6%	19.0%	12.2%	12.8%	-14.1%	-16.6%	-11.9%	-16.2%
3	15.8%	18.1%	12.2%	12.1%	-14.0%	-15.2%	-11.8%	-15.2%
4	15.4%	15.9%	11.7%	11.9%	-13.8%	-15.0%	-10.1%	-15.1%
5	15.0%	14.6%	10.6%	11.7%	-13.8%	-14.0%	-9.8%	-14.9%
6	14.9%	14.0%	10.2%	11.4%	-13.0%	-13.8%	-9.6%	-14.6%
7	14.3%	12.7%	10.1%	11.2%	-12.1%	-12.6%	-9.3%	-13.9%
8	14.1%	12.3%	9.9%	10.5%	-12.0%	-12.6%	-9.2%	-13.9%
9	13.0%	12.2%	9.6%	10.1%	-11.9%	-12.2%	-9.1%	-13.8%
10	13.0%	12.0%	9.5%	10.0%	-11.8%	-12.1%	-8.8%	-13.6%

H.3 Nitrogen dioxide (annual mean)

Table H-9 Annual mean NO_2 concentration at community receptors

Receptor	Annual mean NO_2 concentration (µg/m^3)							Change relative to Do Minimum (µg/m^3)				Change relative to Do Minimum (%)			
	2016-BY	2026-DM	2026-WP	2026-WPC	2036-DM	2036-WP	2036-WPC	2026-WP	2026-WPC	2036-WP	2036-WPC	2026-WP	2026-WPC	2036-WP	2036-WPC
CR01	-	24.7	24.3	24.6	24.4	24.8	24.4	-0.35	-0.12	0.37	0.02	-1.4%	-0.5%	1.5%	0.1%
CR02	-	22.7	22.8	22.8	22.9	22.4	22.5	0.10	0.15	-0.49	-0.37	0.4%	0.7%	-2.1%	-1.6%
CR03	-	28.2	28.6	28.6	28.2	28.3	27.8	**0.41**	**0.41**	0.11	-0.40	**1.4%**	**1.4%**	0.4%	-1.4%
CR04	-	27.2	26.6	26.2	26.8	26.0	25.5	-0.65	-1.04	-0.72	-1.23	-2.4%	-3.8%	-2.7%	-4.6%
CR05	-	24.8	24.0	24.4	24.4	24.2	23.8	-0.78	-0.38	-0.23	-0.59	-3.2%	-1.5%	-1.0%	-2.4%
CR06	-	25.3	24.8	24.4	25.1	24.5	24.1	-0.46	-0.93	-0.62	-0.99	-1.8%	-3.7%	-2.5%	-4.0%
CR07	-	25.4	24.8	24.4	24.8	24.3	24.2	-0.61	-1.00	-0.45	-0.56	-2.4%	-3.9%	-1.8%	-2.3%
CR08	-	**31.1**	28.7	28.8	**30.3**	**28.6**	28.1	-2.39	-2.30	-1.71	-2.21	-7.7%	-7.4%	-5.7%	-7.3%
CR09	-	29.2	27.9	28.1	28.9	27.3	27.8	-1.33	-1.13	-1.64	-1.18	-4.6%	-3.9%	-5.7%	-4.1%
CR10	-	28.5	27.5	26.9	28.1	26.8	26.6	-1.01	-1.60	-1.33	-1.51	-3.5%	-5.6%	-4.7%	-5.4%
CR11	-	29.3	28.0	28.0	28.6	27.2	27.1	-1.26	-1.25	-1.45	-1.56	-4.3%	-4.3%	-5.1%	-5.4%
CR12	-	28.7	28.5	28.1	28.3	27.7	27.3	-0.14	-0.55	-0.62	-1.01	-0.5%	-1.9%	-2.2%	-3.6%
CR13	-	29.6	**29.5**	**29.2**	29.0	28.5	**28.3**	-0.12	-0.41	-0.53	-0.70	-0.4%	-1.4%	-1.8%	-2.4%
CR14	-	28.0	27.8	27.7	27.1	27.2	27.2	-0.24	-0.35	0.06	0.04	-0.9%	-1.2%	0.2%	0.1%
CR15	-	25.8	25.9	25.8	25.3	25.3	25.5	0.03	-0.01	0.02	0.17	0.1%	0.0%	0.1%	0.7%
CR16	-	26.7	26.2	26.3	25.9	26.0	26.0	-0.48	-0.37	0.12	0.07	-1.8%	-1.4%	0.5%	0.3%
CR17	-	26.8	26.6	26.9	26.3	26.6	26.6	-0.14	0.12	**0.33**	**0.30**	-0.5%	0.5%	**1.2%**	**1.1%**

Table H-10 Annual mean NO_2 concentration at RWR receptors, ranked by concentration

Rank	Ranking by concentration (µg/m^3)						
	2016-BY	2026-DM	2026-WP	2026-WPC	2036-DM	2036-WP	2036-WPC
1	-	36.4	35.2	35.1	35.1	34.5	34.5
2	-	36.2	35.0	34.6	34.9	34.3	33.9
3	-	36.2	34.9	34.6	34.7	34.2	33.9
4	-	36.2	34.9	34.4	34.7	34.0	33.8
5	-	35.9	34.8	34.4	34.7	34.0	33.7
6	-	35.9	34.7	34.4	34.5	34.0	33.7
7	-	35.8	34.5	34.3	34.4	33.9	33.5
8	-	35.7	34.4	34.3	34.3	33.9	33.5
9	-	35.7	34.4	34.3	34.3	33.8	33.1
10	-	35.5	34.4	34.1	34.3	33.7	33.1

Table H-11 Annual mean NO_2 concentration at RWR receptors, ranked by increase and by decrease in concentration

Rank	Ranking by increase in concentration relative to Do Minimum (µg/m^3)				Ranking by decrease in concentration relative to Do Minimum (µg/m^3)			
	2026-WP	2026-WPC	2036-WP	2036-WPC	2026-WP	2026-WPC	2036-WP	2036-WPC
1	4.5	4.1	5.3	5.3	-3.7	-3.8	-4.2	-4.1
2	4.1	4.0	5.3	5.1	-3.6	-3.8	-3.9	-4.1
3	4.0	4.0	4.9	4.9	-3.5	-3.7	-3.8	-4.0
4	3.6	4.0	4.7	4.8	-3.5	-3.6	-3.8	-3.9
5	3.5	3.7	4.4	4.6	-3.5	-3.6	-3.8	-3.9
6	3.2	3.2	4.4	4.1	-3.4	-3.5	-3.7	-3.8
7	3.1	3.0	4.1	4.1	-3.4	-3.5	-3.7	-3.8
8	3.0	2.8	3.9	3.9	-3.4	-3.5	-3.6	-3.8
9	3.0	2.8	3.5	3.8	-3.4	-3.4	-3.6	-3.8
10	2.7	2.6	3.5	3.5	-3.4	-3.4	-3.6	-3.7

Table H-12 Annual mean NO_2 concentration at RWR receptors, ranked by percentage increase and by decrease in concentration

Rank	Ranking by % increase in concentration relative to Do Minimum				Ranking by % decrease in concentration relative to Do Minimum			
	2026-WP	2026-WPC	2036-WP	2036-WPC	2026-WP	2026-WPC	2036-WP	2036-WPC
1	15.6%	15.4%	20.8%	20.3%	-11.3%	-11.7%	-12.7%	-13.1%
2	15.5%	13.9%	18.3%	18.3%	-11.0%	-11.7%	-12.3%	-13.1%
3	14.2%	13.8%	16.7%	16.8%	-11.0%	-11.0%	-12.1%	-12.7%
4	12.2%	13.7%	16.2%	16.7%	-10.8%	-10.8%	-12.0%	-12.6%
5	12.0%	13.2%	15.5%	15.9%	-10.8%	-10.8%	-11.7%	-12.4%
6	11.1%	11.1%	15.3%	14.5%	-10.8%	-10.8%	-11.6%	-12.3%
7	10.8%	10.8%	14.4%	14.3%	-10.5%	-10.8%	-11.5%	-12.1%
8	10.6%	10.7%	14.0%	14.1%	-10.4%	-10.7%	-11.3%	-11.9%
9	10.5%	9.9%	12.5%	13.6%	-10.1%	-10.7%	-11.3%	-11.9%
10	10.3%	9.9%	12.4%	12.2%	-10.1%	-10.6%	-11.2%	-11.8%

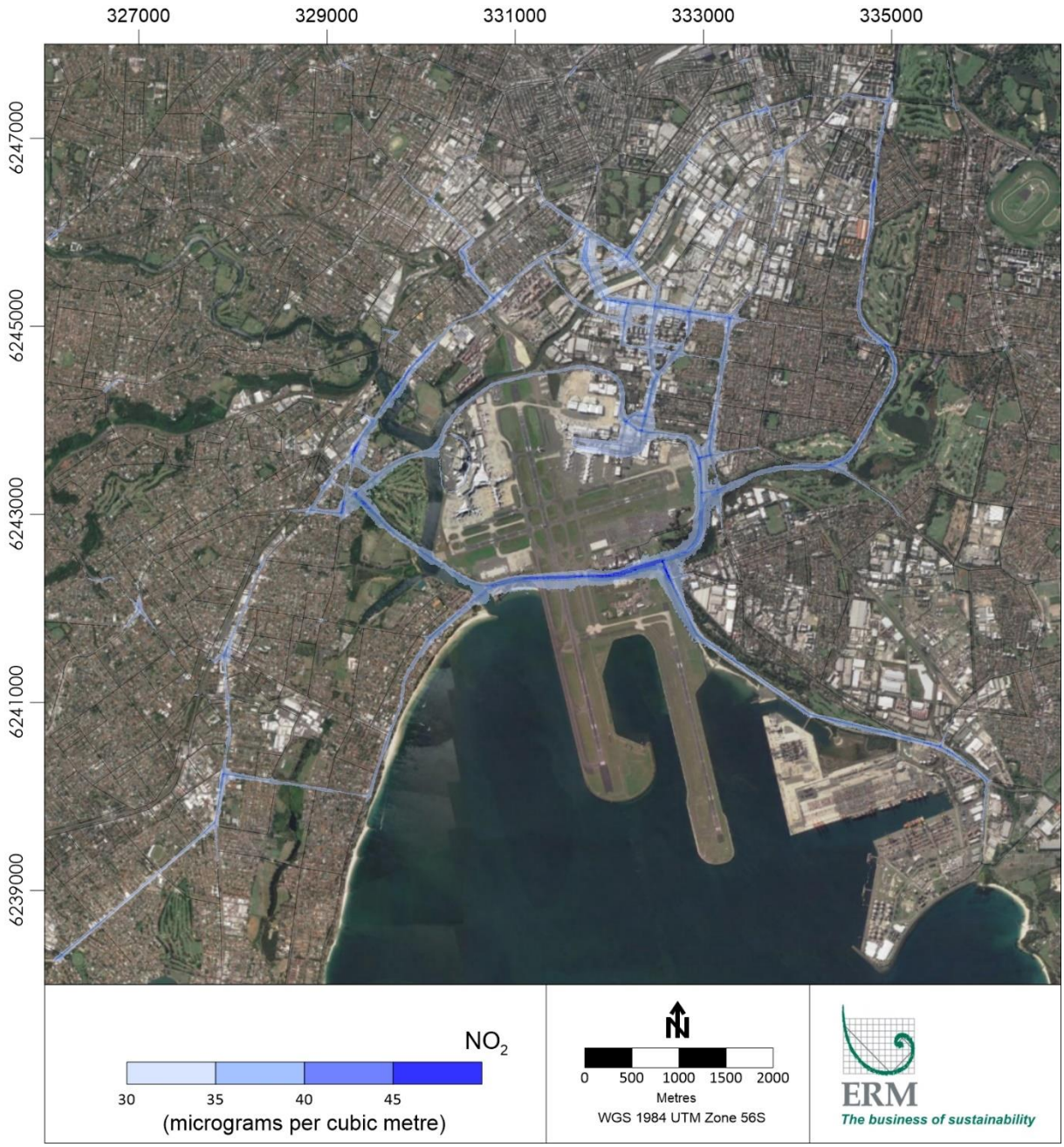

Figure H-1 **Contour plot of annual mean NO_2 concentration in the 2026 Do Minimum scenario (all sources, 2026-DM)**

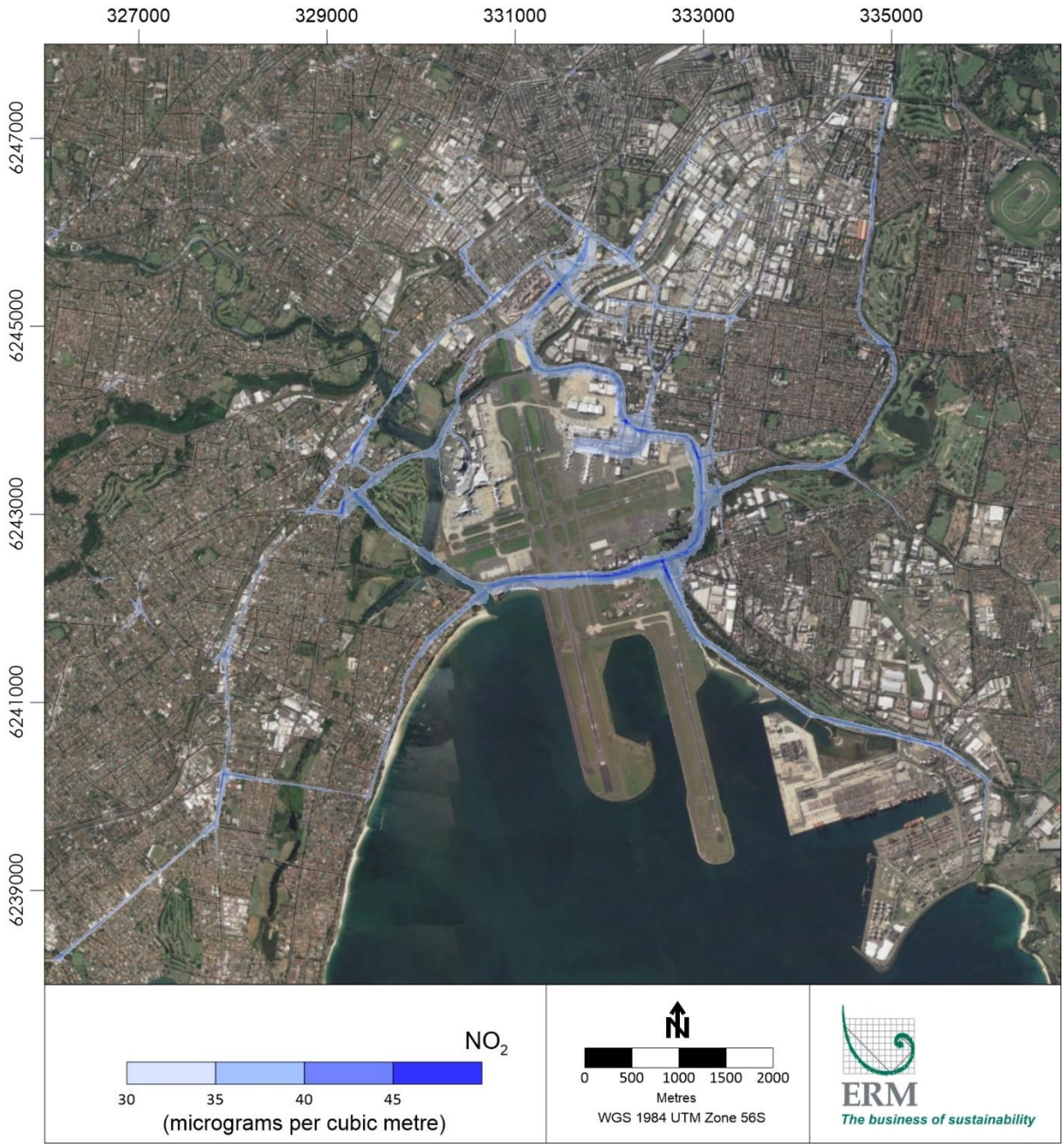

Figure H-2 **Contour plot of annual mean NO_2 concentration in the 2026 Do Something scenario (all sources, 2026-WP)**

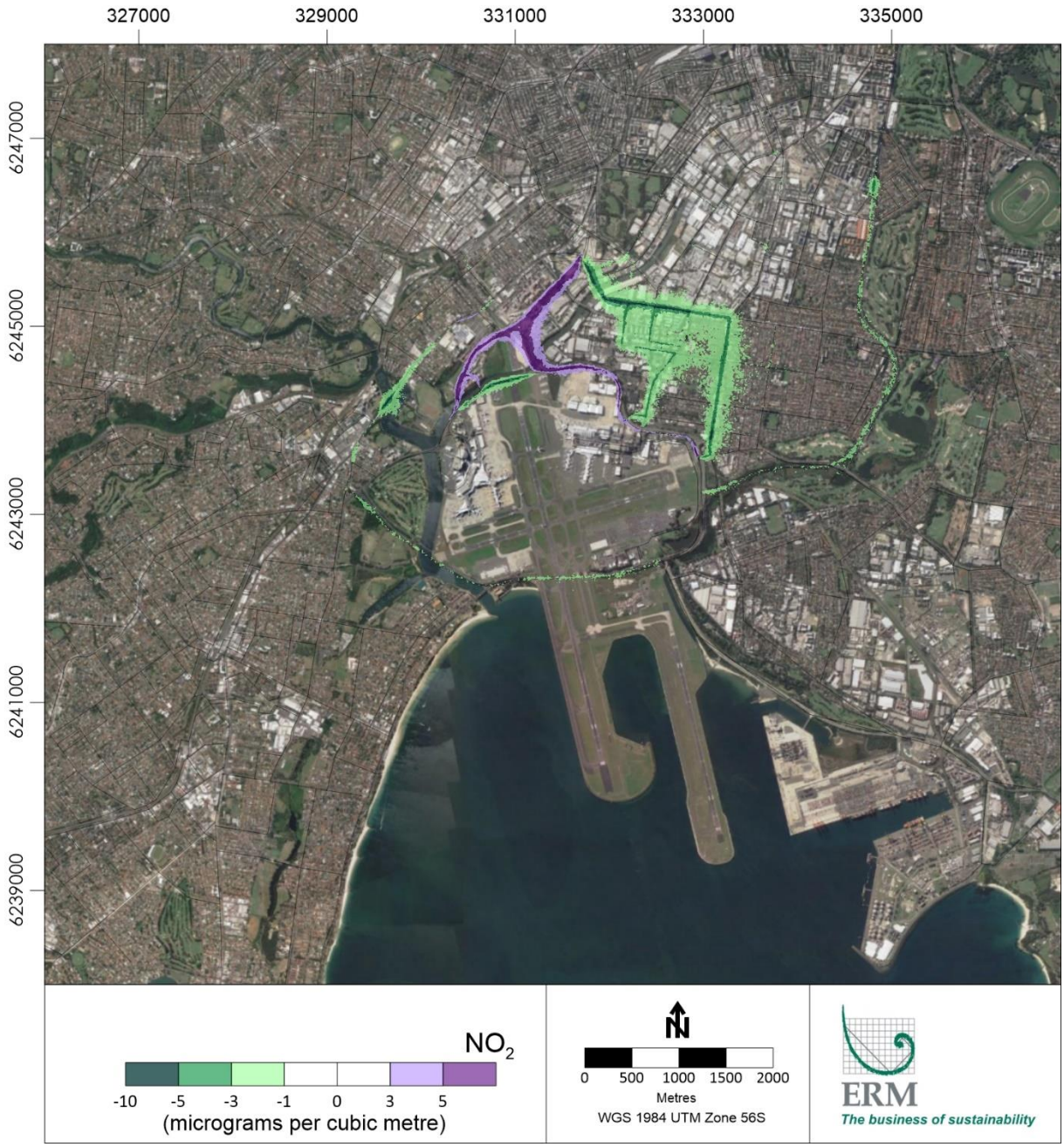

Figure H-3 **Contour plot of change in annual mean NO_2 concentration in the 2026 Do something scenario (all sources, 2026-WP minus 2026-DM)**

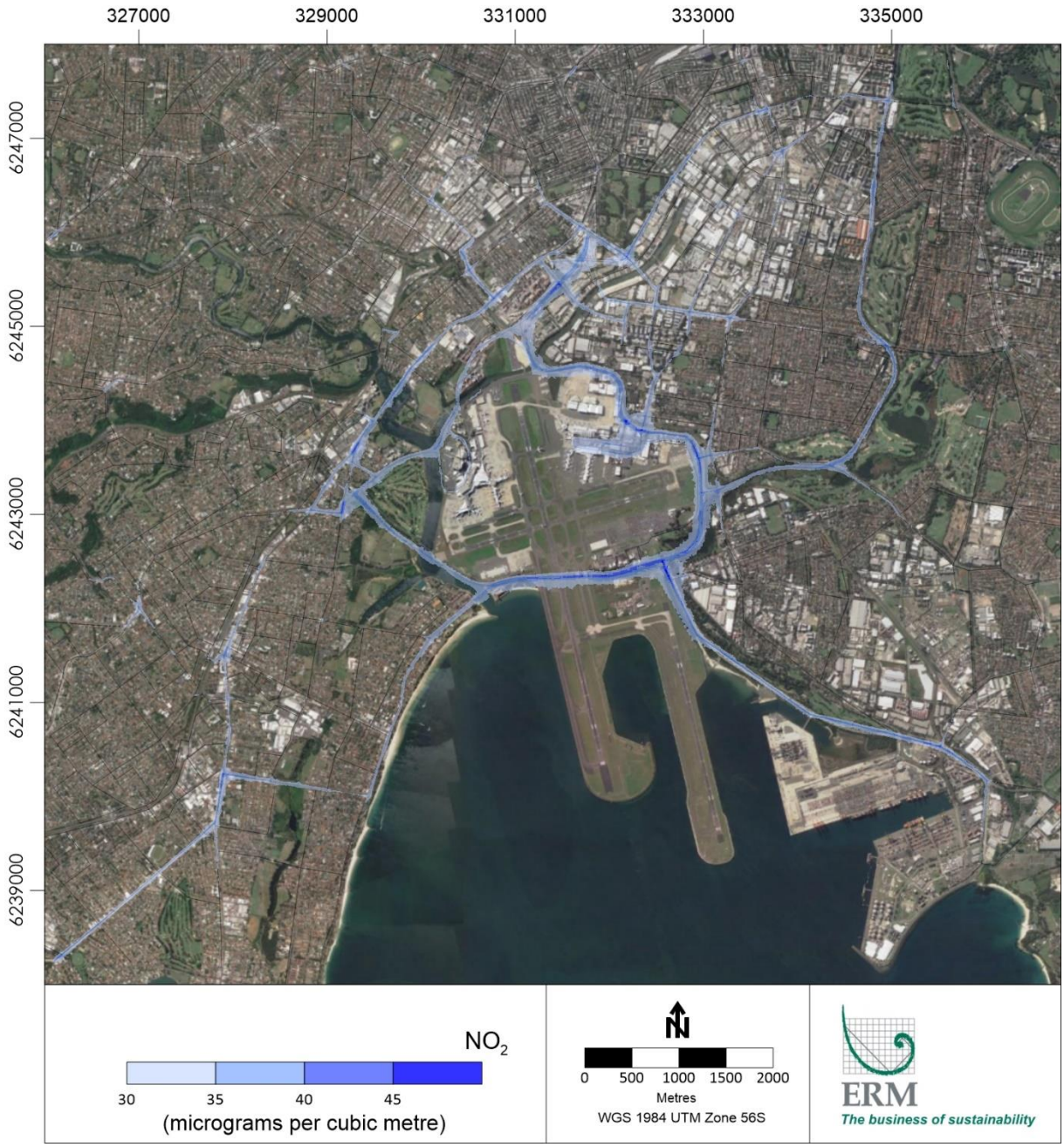

Figure H-4 **Contour plot of annual mean NO_2 concentration in the 2026 cumulative scenario (all sources, 2026-WPC)**

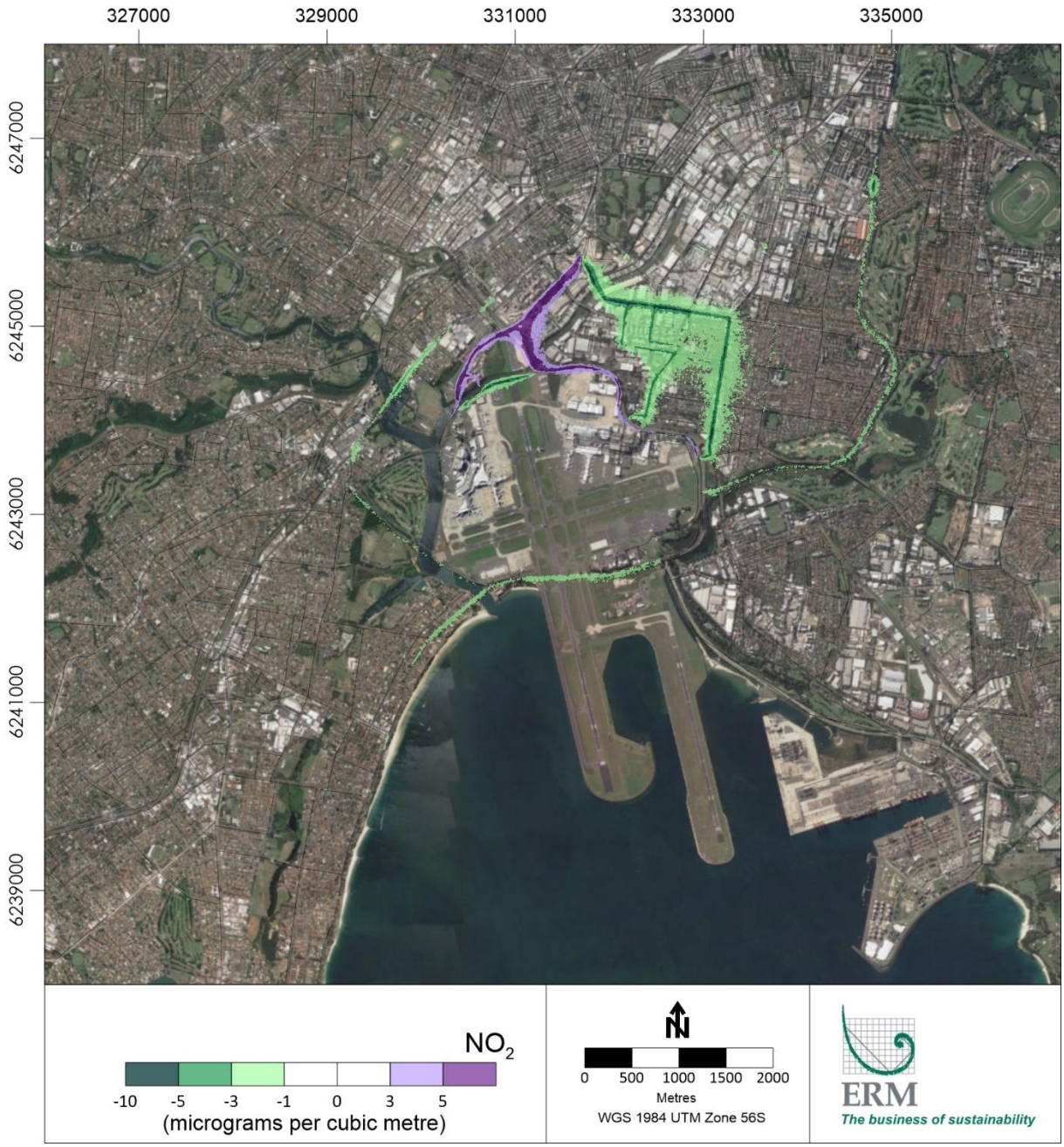

Figure H-5 **Contour plot of change in annual mean NO_2 concentration in the 2026 cumulative scenario (all sources, 2026-WPC minus 2026-DM)**

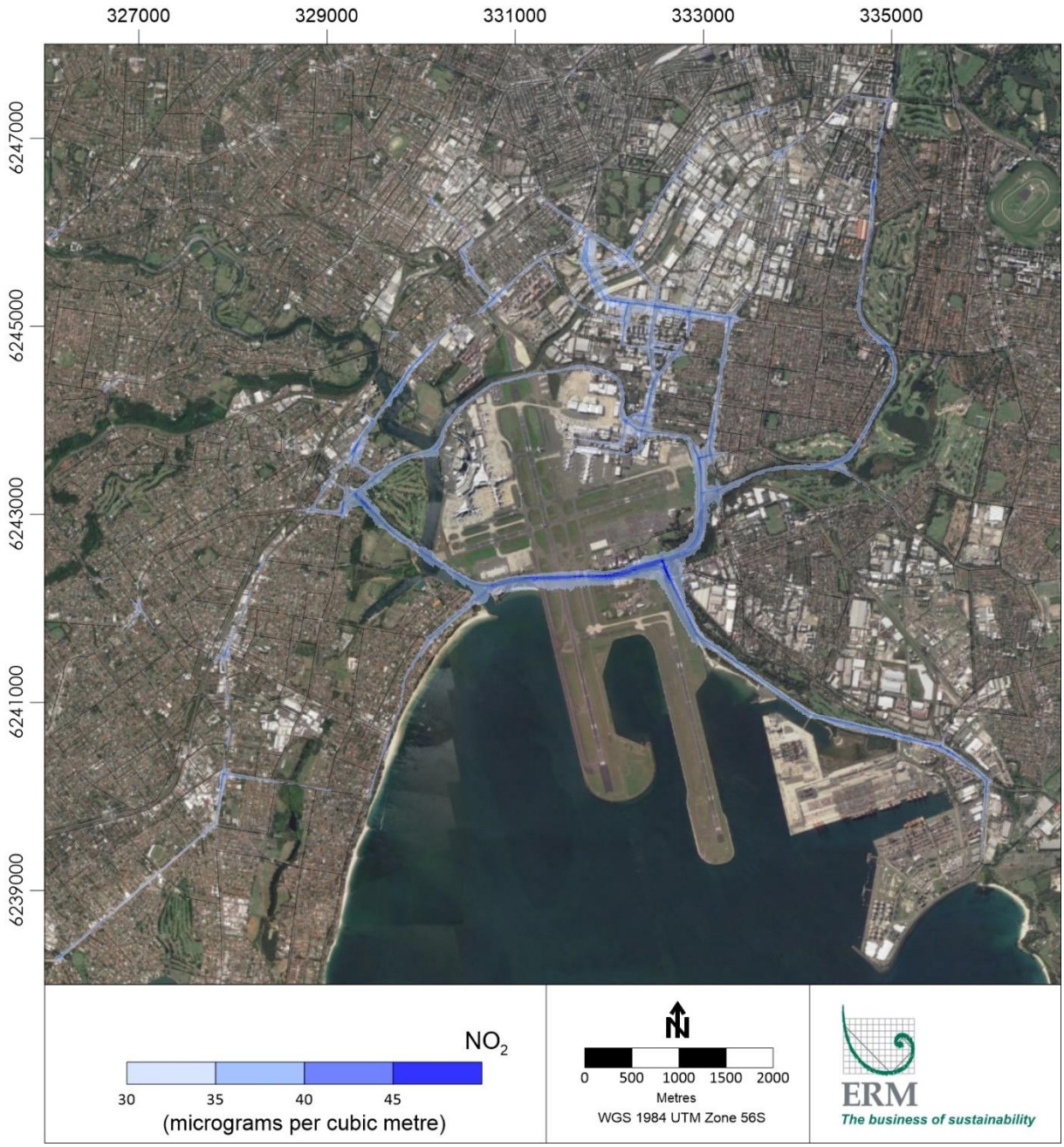

Figure H-6 **Contour plot of annual mean NO_2 concentration in the 2036 Do Minimum scenario (all sources, 2036-DM)**

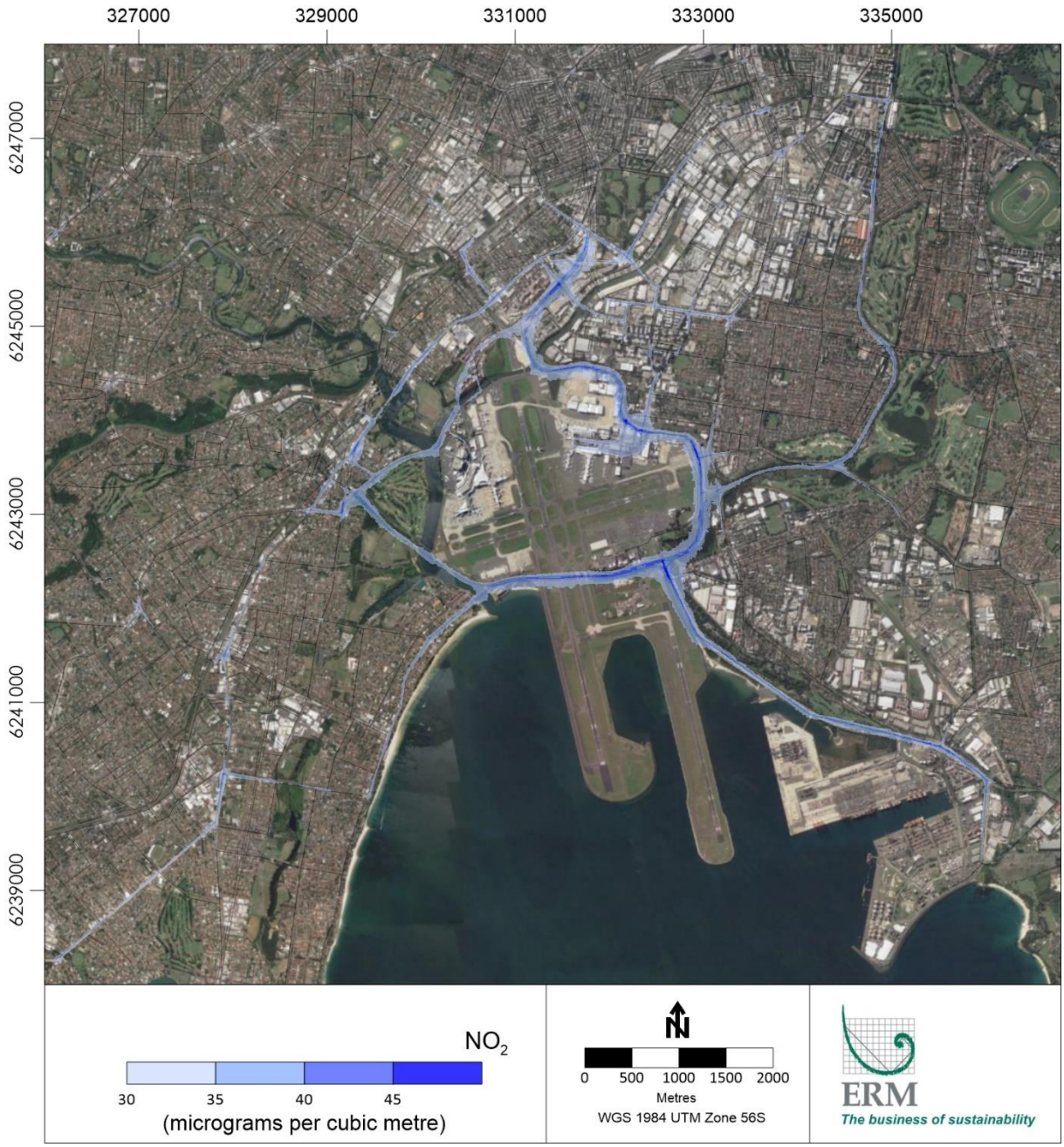

Figure H-7 **Contour plot of annual mean NO_2 concentration in the 2036 Do Something scenario (all sources, 2036-WP))**

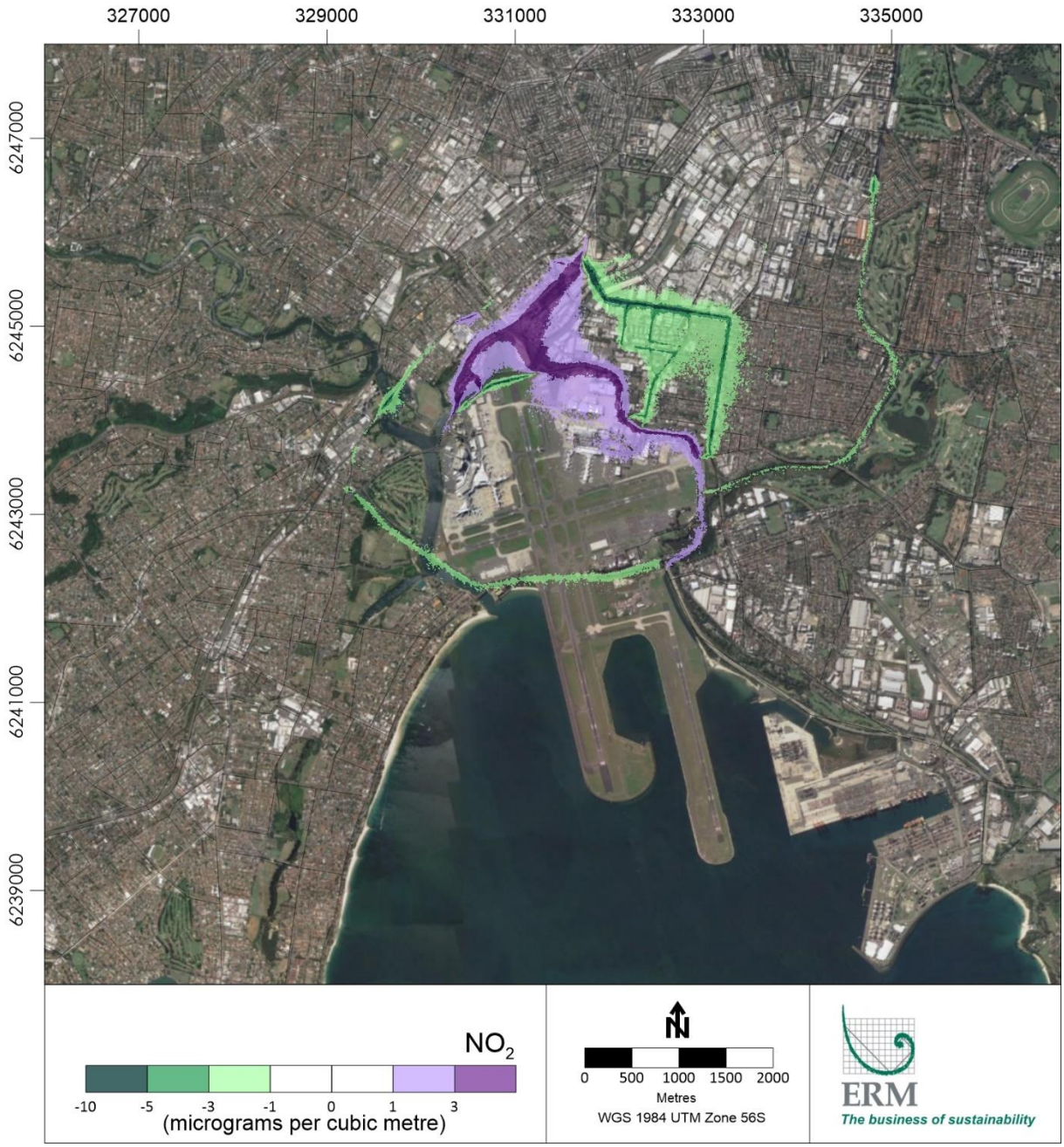

Figure H-8 **Contour plot of change in annual mean NO_2 concentration in the 2036 Do Something scenario (all sources, 2036-WP minus 2036-DM)**

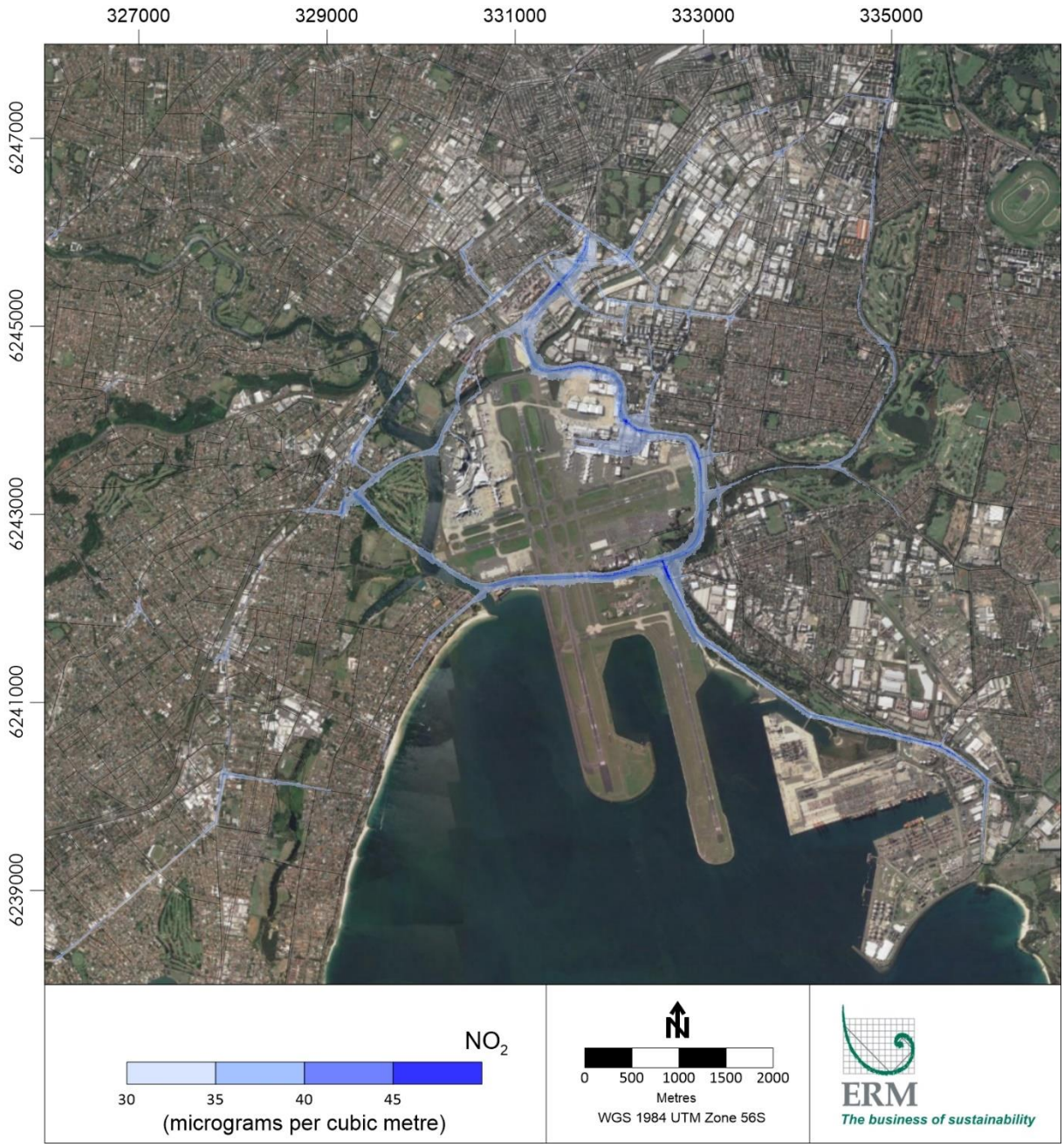

Figure H-9 **Contour plot of annual mean NO_2 concentration in the 2036 cumulative scenario (all sources, 2036-WPC)**

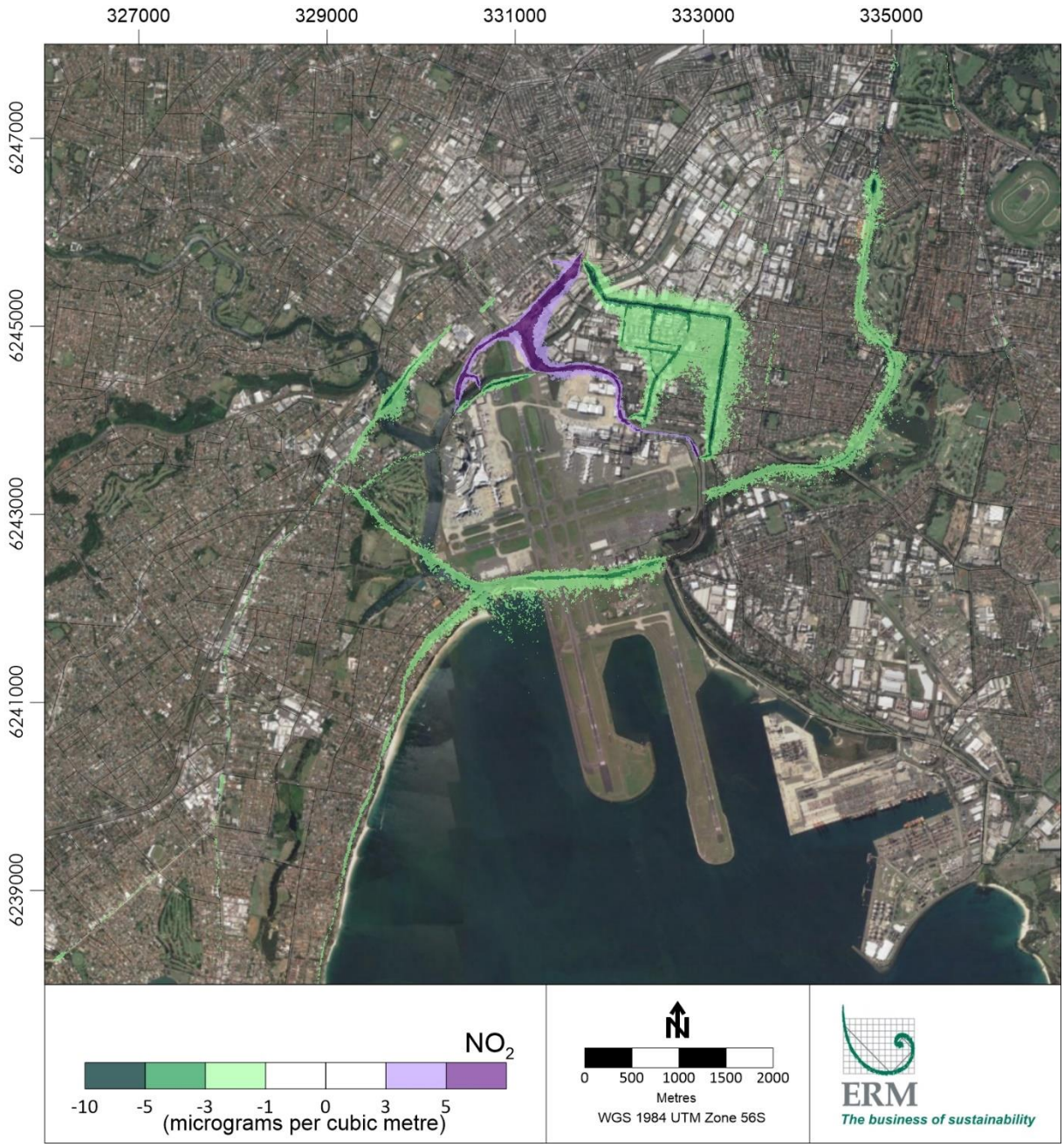

Figure H-10 **Contour plot of change in annual mean NO_2 concentration in the 2036 cumulative scenario (all sources, 2036-WPC minus 2036-DM)**

H.4 Nitrogen dioxide (maximum 1-hour)

Table H-13 Maximum 1-hour NO_2 concentration at community receptors

Receptor	Maximum 1-hour NO_2 concentration (µg/m³)							Change relative to Do Minimum (µg/m³)				Change relative to Do Minimum (%)			
	2016-BY	2026-DM	2026-WP	2026-WPC	2036-DM	2036-WP	2036-WPC	2026-WP	2026-WPC	2036-WP	2036-WPC	2026-WP	2026-WPC	2036-WP	2036-WPC
CR01	-	192.3	190.6	192.3	191.5	193.2	192.7	-1.61	0.06	1.66	1.20	-0.8%	0.0%	0.9%	0.6%
CR02	-	189.9	189.6	189.8	192.1	191.0	189.9	-0.35	-0.18	-1.11	-2.20	-0.2%	-0.1%	-0.6%	-1.1%
CR03	-	**199.1**	**204.0**	**201.2**	196.7	**198.3**	193.8	**4.98**	2.19	1.63	-2.95	**2.5%**	1.1%	0.8%	-1.5%
CR04	-	192.1	194.0	191.6	200.8	191.1	189.7	1.88	-0.52	-9.66	-11.12	1.0%	-0.3%	-4.8%	-5.5%
CR05	-	192.4	190.8	194.9	192.1	189.1	190.5	-1.68	2.41	-2.98	-1.60	-0.9%	1.3%	-1.6%	-0.8%
CR06	-	192.4	193.3	191.3	192.9	190.2	189.2	0.84	-1.14	-2.66	-3.67	0.4%	-0.6%	-1.4%	-1.9%
CR07	-	192.8	191.5	192.4	189.0	189.9	189.7	-1.26	-0.34	0.87	0.65	-0.7%	-0.2%	0.5%	0.3%
CR08	-	196.2	193.5	200.2	197.1	193.8	195.3	-2.73	3.99	-3.34	-1.83	-1.4%	2.0%	-1.7%	-0.9%
CR09	-	195.8	195.0	194.0	197.0	195.2	193.9	-0.71	-1.77	-1.71	-3.10	-0.4%	-0.9%	-0.9%	-1.6%
CR10	-	195.5	194.6	196.0	195.7	193.7	**197.1**	-0.90	0.46	-2.08	1.32	-0.5%	0.2%	-1.1%	0.7%
CR11	-	195.2	196.9	193.5	**202.6**	195.0	196.9	1.65	-1.77	-7.62	-5.63	0.8%	-0.9%	-3.8%	-2.8%
CR12	-	192.4	196.3	192.8	192.7	196.7	190.5	3.90	0.36	**4.03**	-2.15	2.0%	0.2%	**2.1%**	-1.1%
CR13	-	191.5	192.7	191.9	191.1	190.0	190.5	1.19	0.45	-1.13	-0.64	0.6%	0.2%	-0.6%	-0.3%
CR14	-	188.9	189.0	193.6	188.9	189.4	190.6	0.14	**4.72**	0.53	**1.71**	0.1%	**2.5%**	0.3%	**0.9%**
CR15	-	189.3	192.6	187.4	189.7	187.5	189.5	3.22	-1.90	-2.14	-0.18	1.7%	-1.0%	-1.1%	-0.1%
CR16	-	192.1	192.3	190.7	190.4	190.0	190.9	0.20	-1.36	-0.44	0.51	0.1%	-0.7%	-0.2%	0.3%
CR17	-	190.6	189.2	189.2	192.0	190.6	190.2	-1.35	-1.34	-1.46	-1.84	-0.7%	-0.7%	-0.8%	-1.0%

Table H-14 Maximum 1-hour NO_2 concentration at RWR receptors, ranked by concentration

Rank	Ranking by concentration (µg/m^3)						
	2016-BY	2026-DM	2026-WP	2026-WPC	2036-DM	2036-WP	2036-WPC
1	-	232.7	225.6	258.9	220.5	217.4	214.6
2	-	228.1	223.8	237.2	219.8	215.8	213.7
3	-	224.9	220.4	226.7	219.7	214.9	213.1
4	-	222.5	220.4	220.6	219.1	214.0	212.7
5	-	220.5	220.1	219.4	218.1	213.8	212.0
6	-	220.1	219.2	218.3	217.8	213.3	211.0
7	-	220.1	218.9	216.9	217.6	212.9	211.0
8	-	220.1	218.7	216.9	217.1	212.6	211.0
9	-	220.0	217.9	216.9	216.9	212.1	210.8
10	-	218.9	217.7	216.7	216.3	212.0	210.7

Table H-15 Maximum 1-hour NO_2 concentration at RWR receptors, ranked by increase and by decrease in concentration

Rank	Ranking by increase in concentration relative to Do Minimum (µg/m^3)				Ranking by decrease in concentration relative to Do Minimum (µg/m^3)			
	2026-WP	2026-WPC	2036-WP	2036-WPC	2026-WP	2026-WPC	2036-WP	2036-WPC
1	18.8	30.9	17.5	18.7	-18.9	-18.9	-15.7	-17.5
2	17.2	15.7	14.8	15.2	-18.3	-17.0	-15.2	-17.4
3	15.5	14.7	14.3	14.5	-16.0	-16.8	-15.1	-17.3
4	14.4	14.6	14.3	14.0	-15.3	-16.7	-14.5	-16.5
5	14.0	13.8	14.2	13.9	-15.1	-16.5	-14.4	-15.9
6	13.7	13.5	13.7	13.5	-15.0	-16.4	-14.4	-15.3
7	12.7	12.9	13.6	13.3	-14.7	-16.2	-14.1	-15.1
8	12.2	12.7	13.6	13.3	-14.6	-16.0	-14.0	-14.7
9	12.1	11.5	13.3	13.1	-14.3	-15.3	-13.8	-14.4
10	12.0	11.3	13.0	13.0	-13.8	-15.2	-13.7	-14.4

Table H-16 Maximum 1-hour NO_2 concentration at RWR receptors, ranked by percentage increase and by decrease in concentration

Rank	Ranking by % increase in concentration relative to Do Minimum				Ranking by % decrease in concentration relative to Do Minimum			
	2026-WP	2026-WPC	2036-WP	2036-WPC	2026-WP	2026-WPC	2036-WP	2036-WPC
1	9.8%	13.5%	9.0%	10.0%	-8.6%	-9.1%	-7.5%	-8.2%
2	8.9%	8.1%	8.0%	7.8%	-7.8%	-8.2%	-7.2%	-8.0%
3	8.1%	7.3%	7.6%	7.8%	-7.6%	-8.0%	-7.2%	-7.9%
4	7.4%	7.2%	7.5%	7.2%	-7.2%	-7.8%	-7.1%	-7.8%
5	7.2%	6.8%	7.3%	7.2%	-7.2%	-7.7%	-7.1%	-7.4%
6	7.0%	6.7%	7.3%	7.0%	-7.0%	-7.5%	-6.9%	-7.3%
7	6.8%	6.7%	7.1%	6.9%	-6.9%	-7.4%	-6.8%	-7.2%
8	6.7%	6.6%	7.1%	6.8%	-6.9%	-7.3%	-6.6%	-7.0%
9	6.6%	6.0%	7.0%	6.8%	-6.9%	-7.3%	-6.6%	-6.9%
10	6.4%	5.9%	7.0%	6.7%	-6.8%	-7.3%	-6.4%	-6.8%

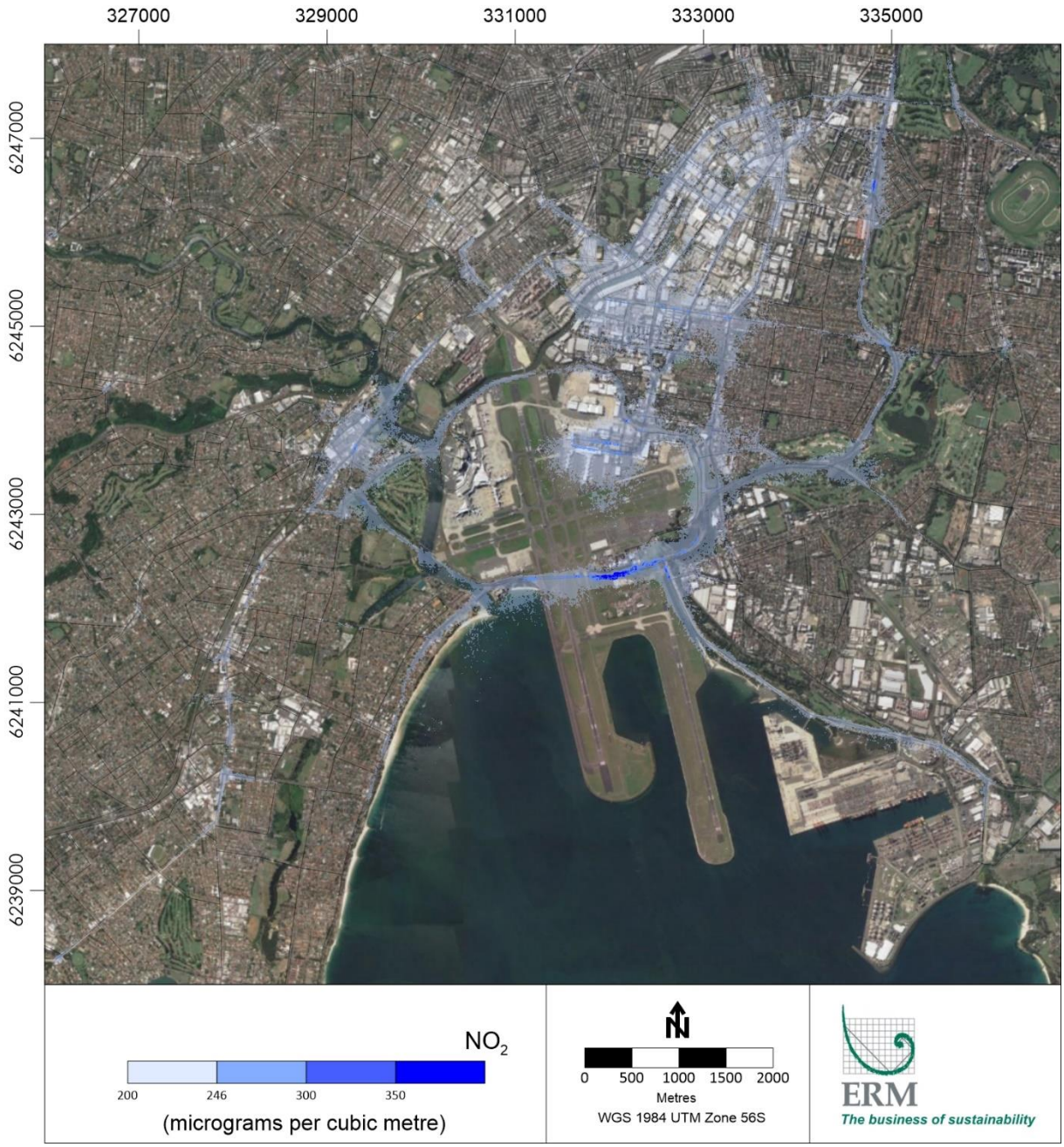

Figure H-11 Contour plot of maximum 1-hour NO_2 concentration in the 2026 Do Minimum scenario (all sources, 2026-DM)

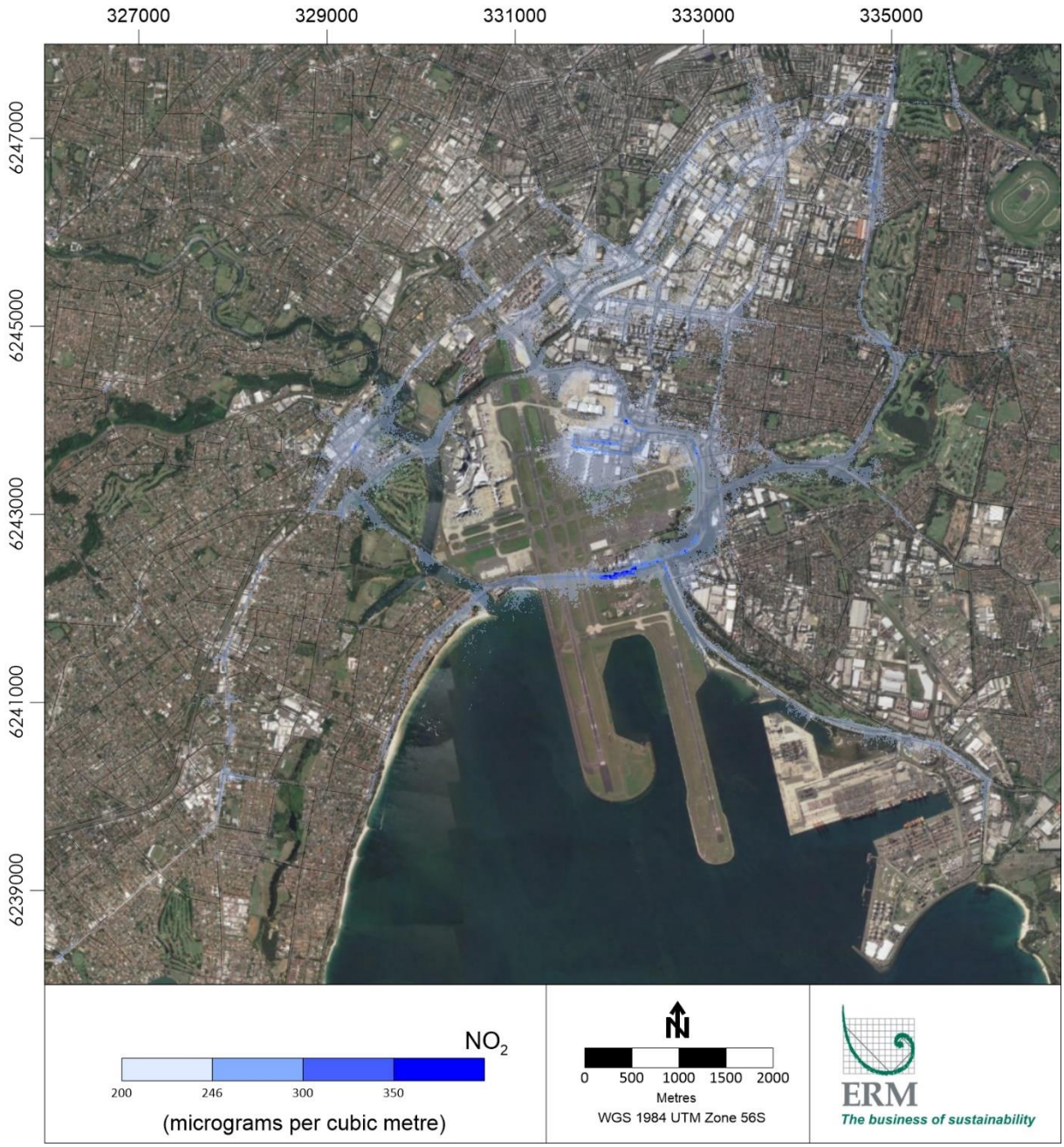

Figure H-12 Contour plot of maximum 1-hour NO_2 concentration in the 2026 Do Something scenario (all sources, 2026-WP)

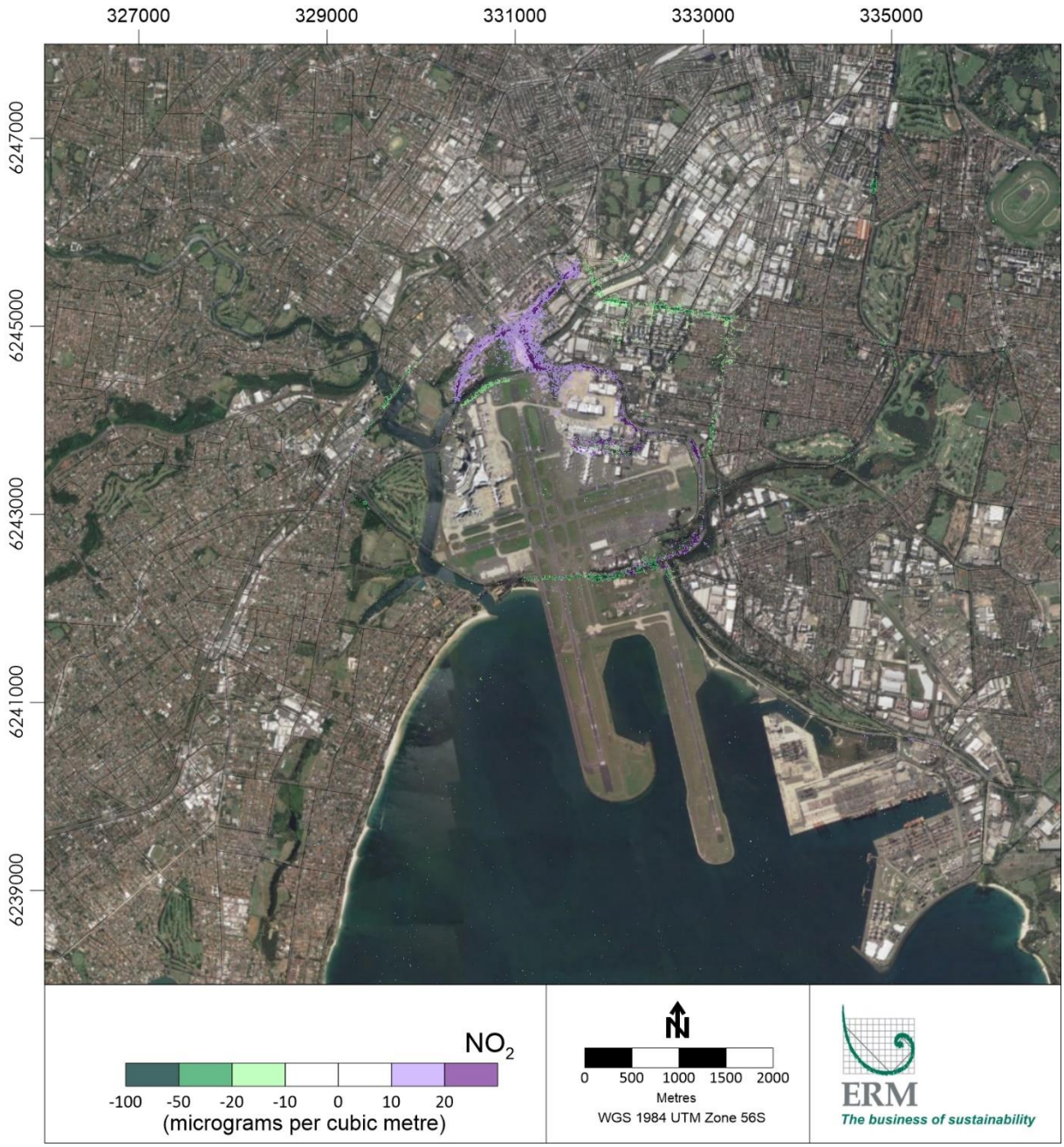

Figure H-13 Contour plot of change in maximum 1-hour NO_2 concentration in the 2026 Do Something scenario (all sources, 2026-WP minus 2026-DM)

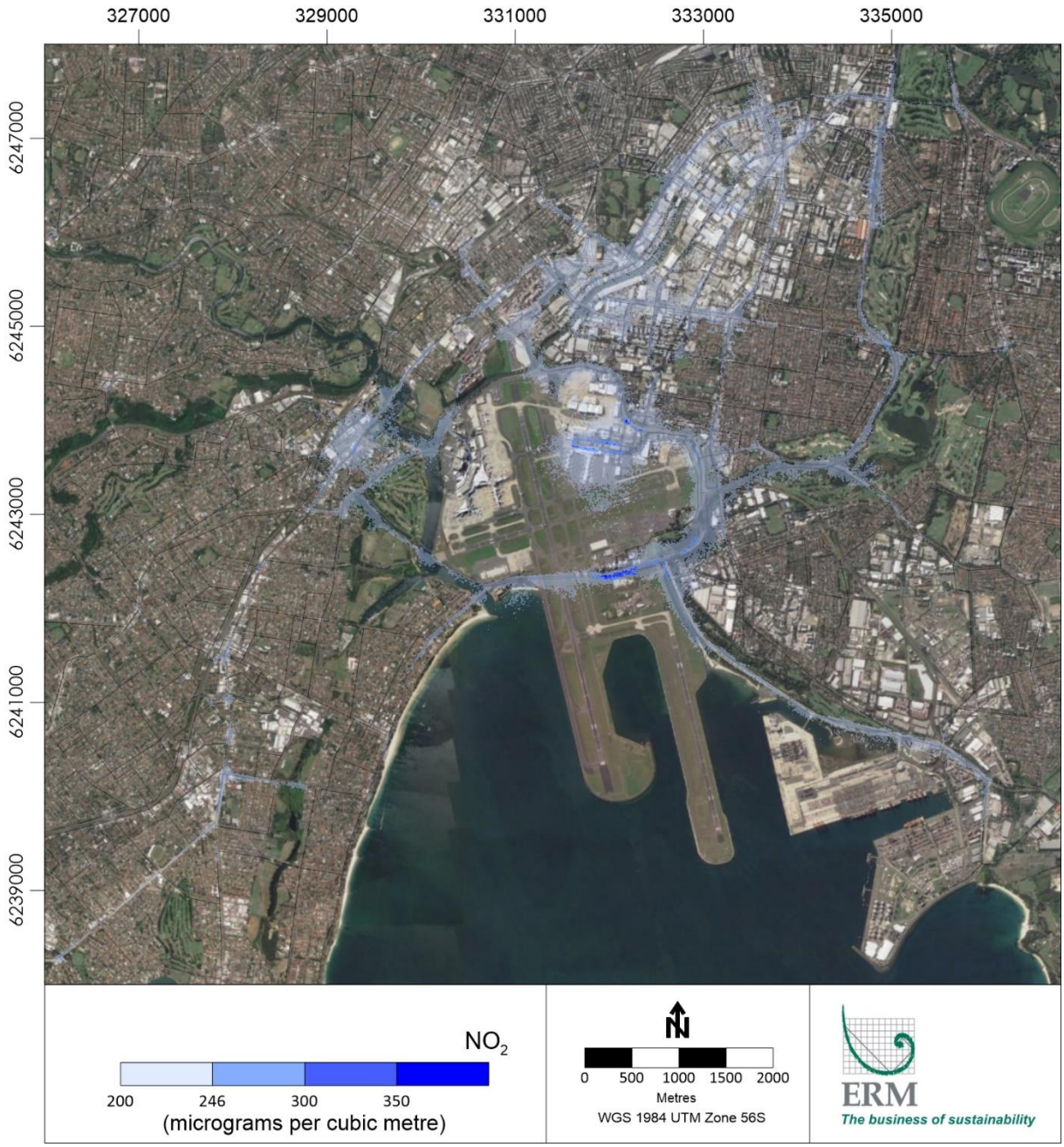

Figure H-14 **Contour plot of maximum 1-hour NO_2 concentration in the 2026 cumulative scenario (all sources, 2026-WPC)**

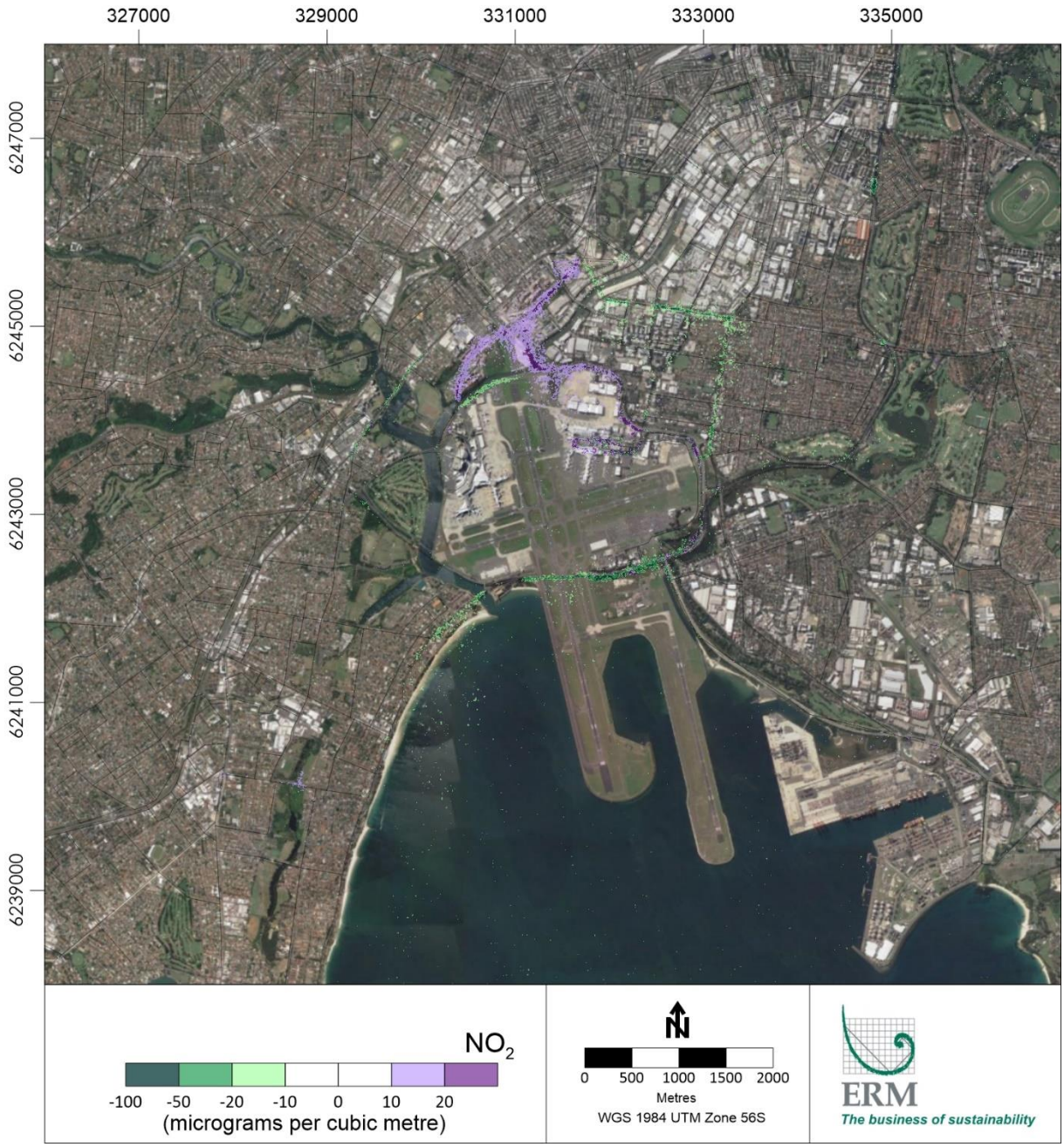

Figure H-15 Contour plot of change in maximum 1-hour NO_2 concentration in the 2026 cumulative scenario (all sources, 2026-WPC minus 2026-DM)

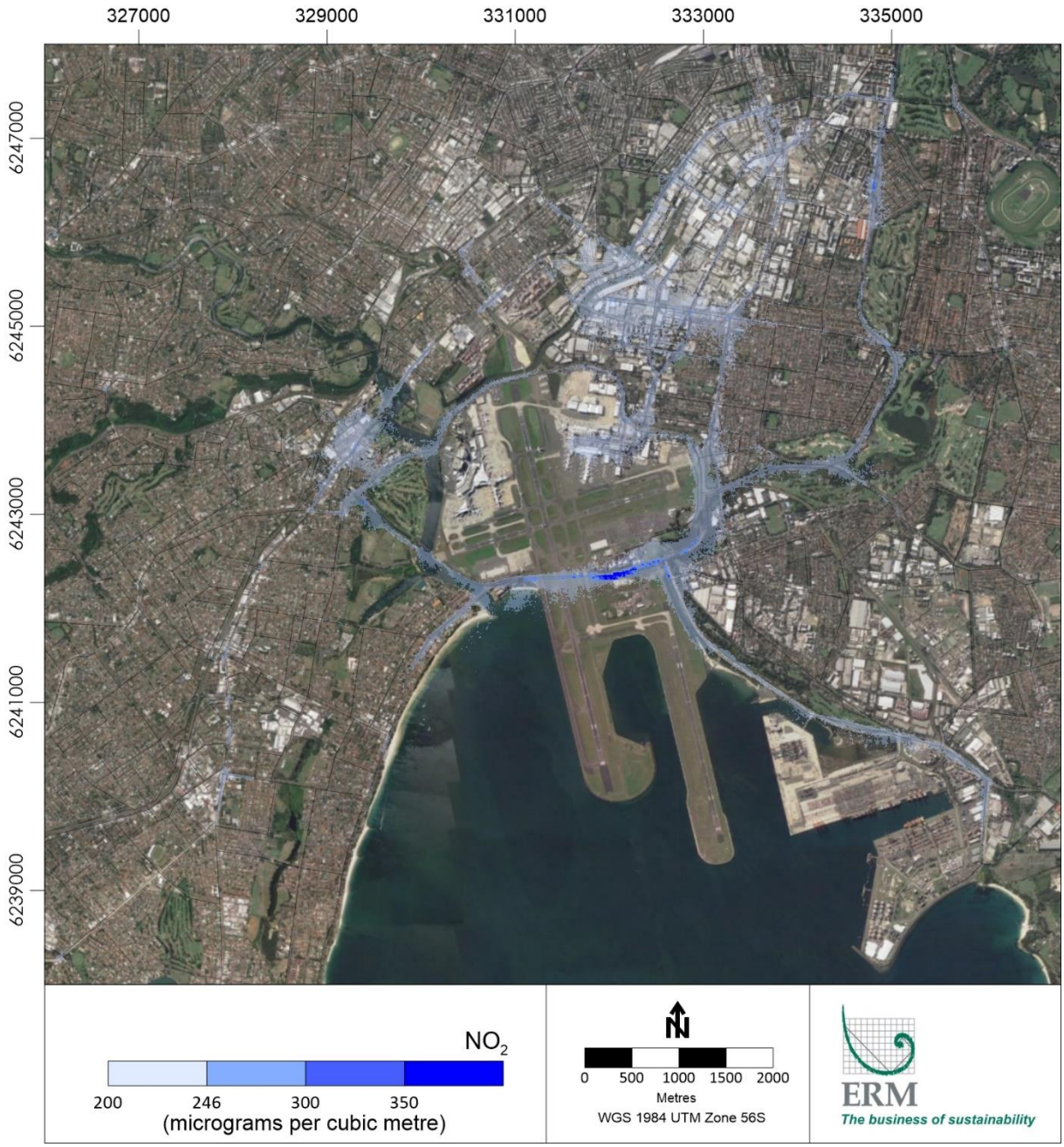

Figure H-16 Contour plot of maximum 1-hour NO_2 concentration in the 2036 Do Minimum scenario (all sources, 2036-DM)

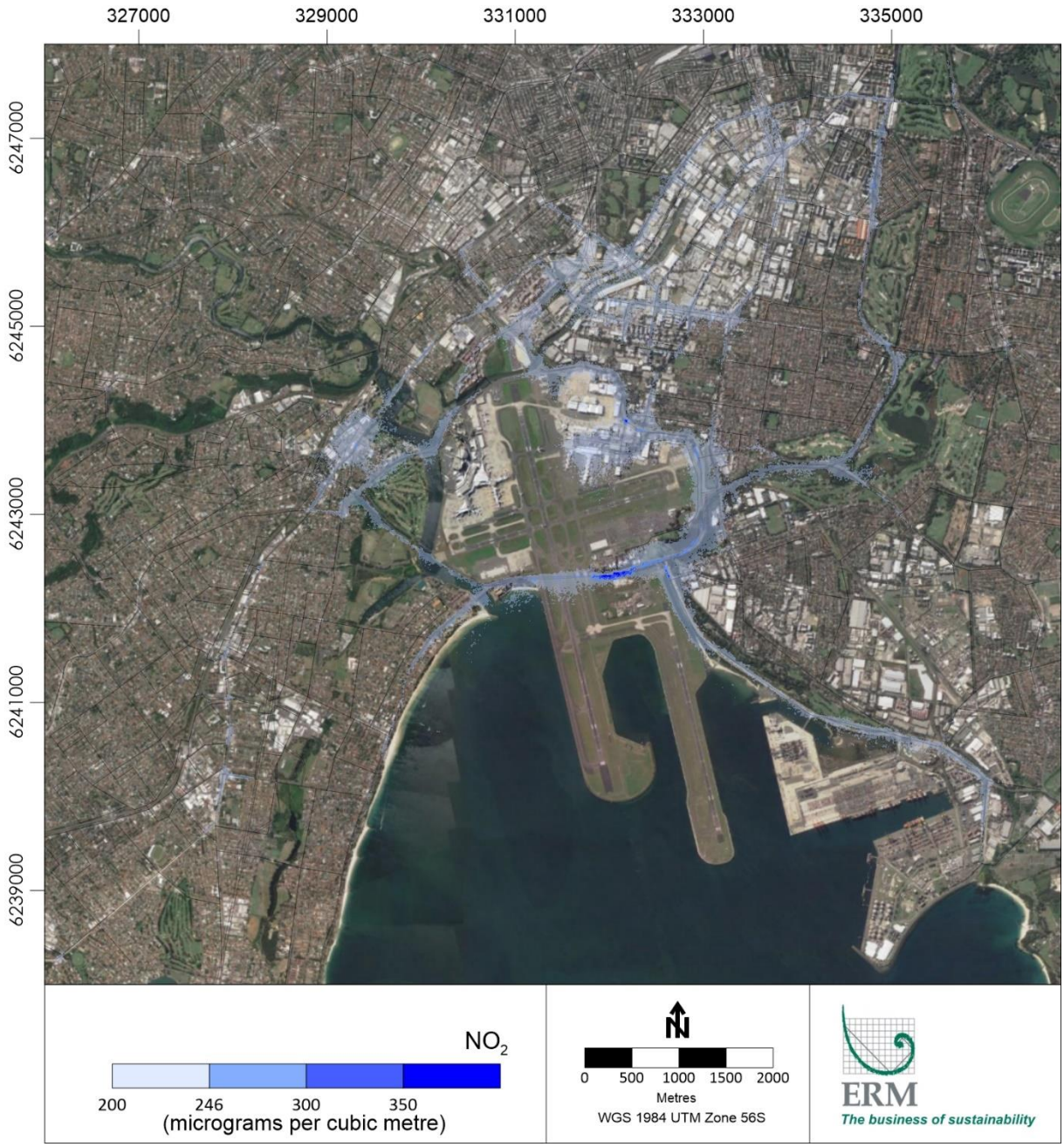

Figure H-17 Contour plot of maximum 1-hour NO_2 concentration in the 2036 Do Something scenario (all sources, 2036-WP)

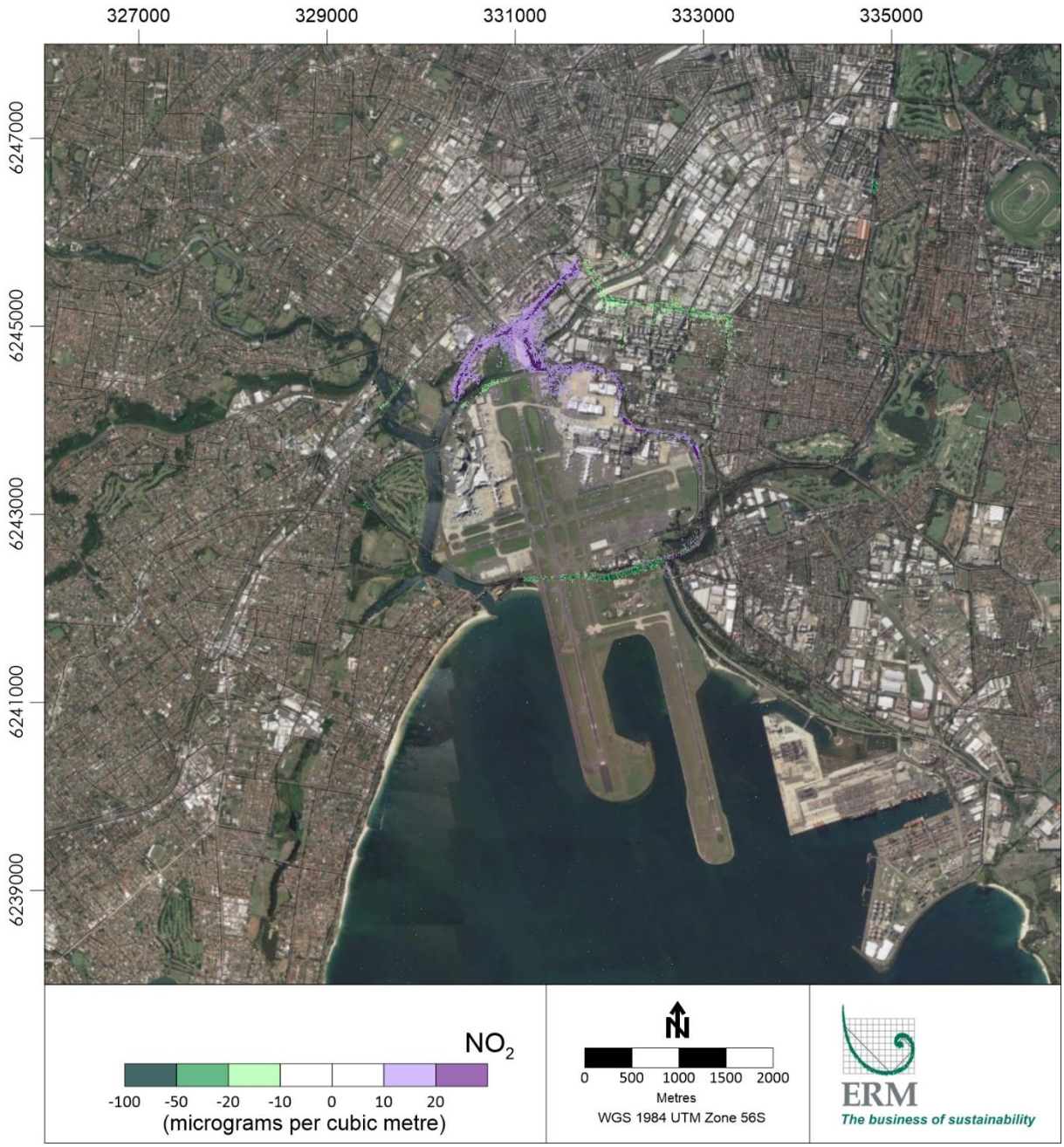

Figure H-18 Contour plot of change in maximum 1-hour NO_2 concentration in the 2036 Do Something scenario (all sources, 2036-WP minus 2036-DM)

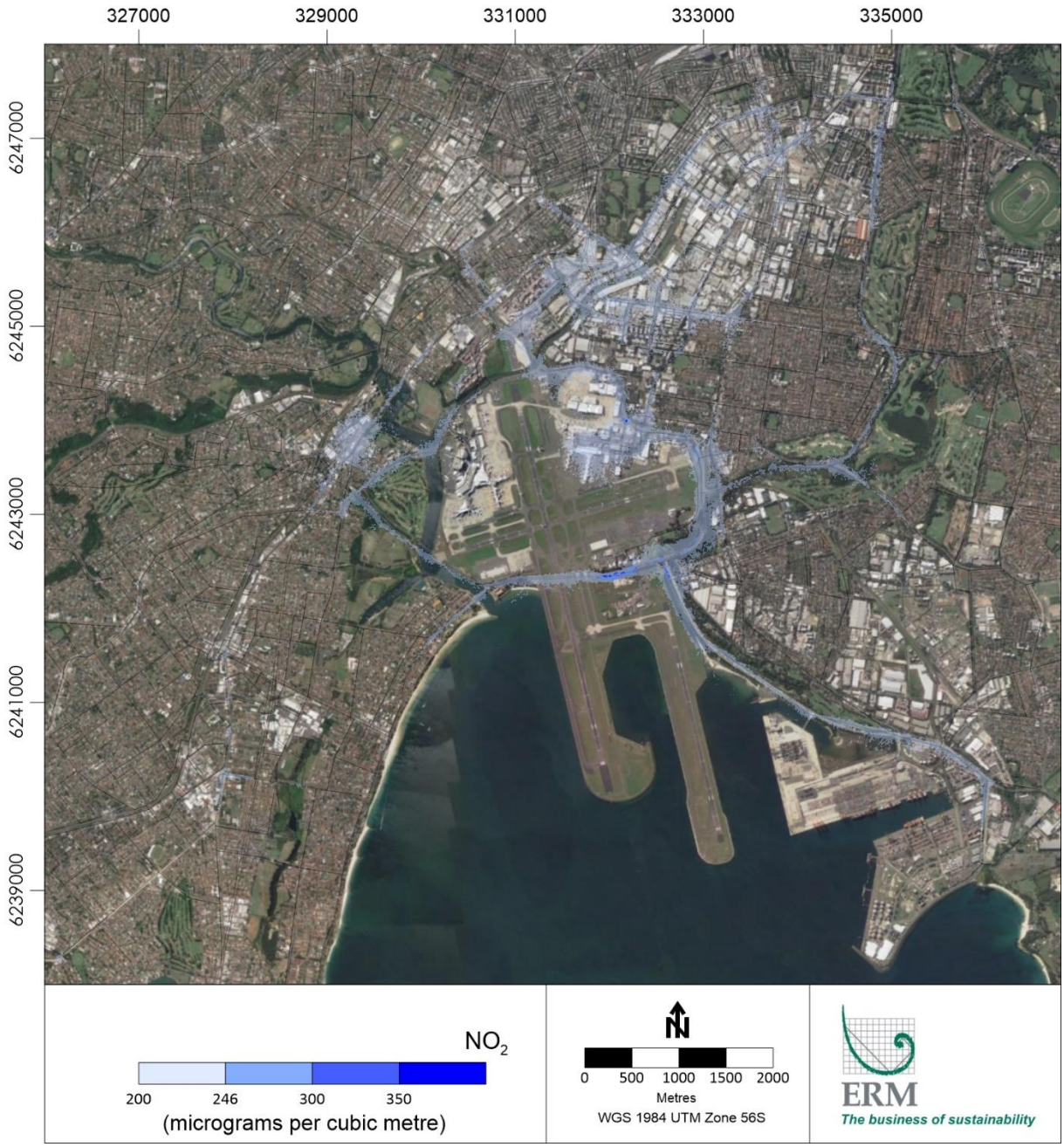

Figure H-19 Contour plot of maximum 1-hour NO_2 concentration in the 2036 cumulative scenario (all sources, 2036-WPC)

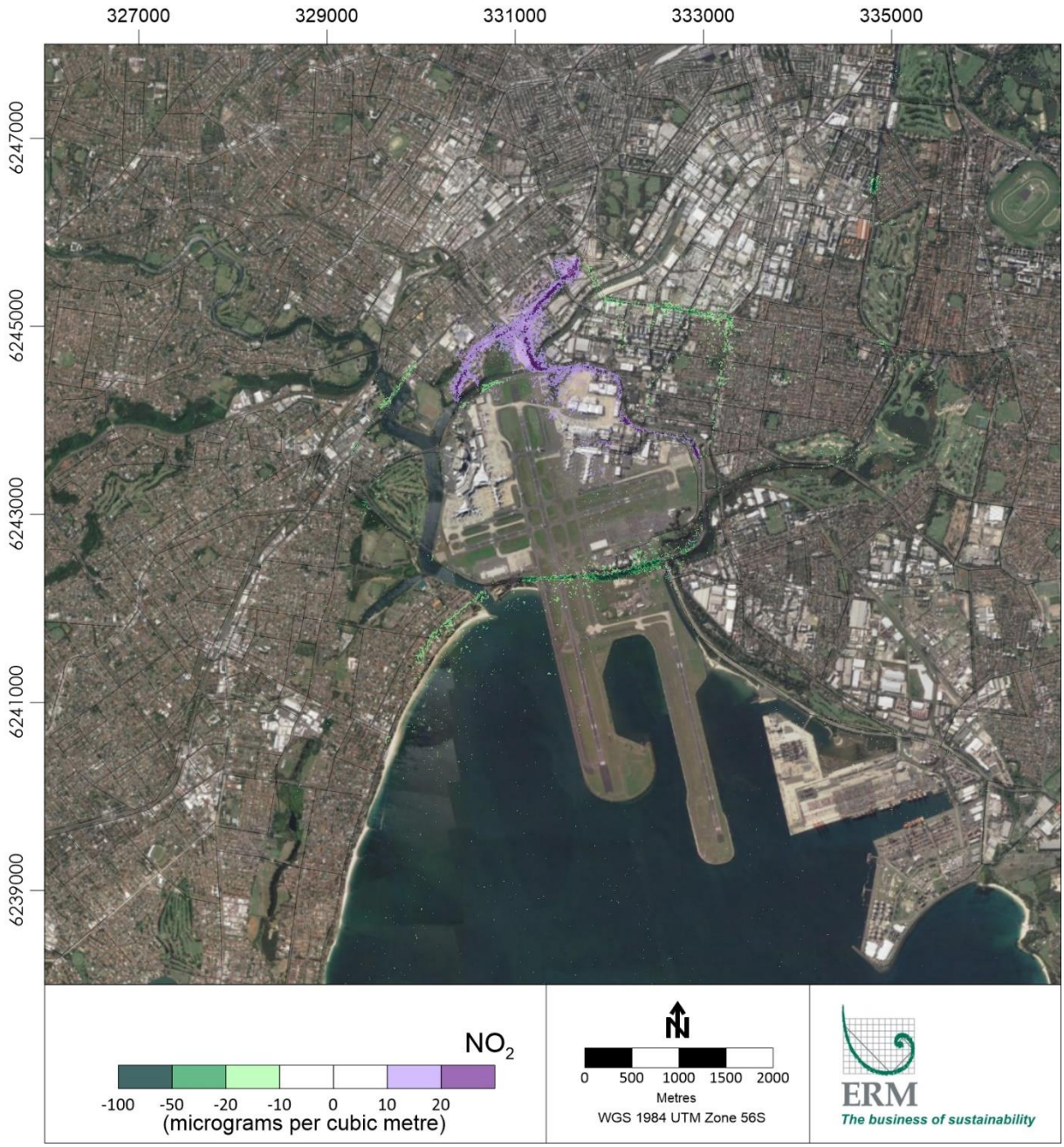

Figure H-20 Contour plot of change in maximum 1-hour NO_2 concentration in the 2036 cumulative scenario (all sources, 2036-WPC minus 2036-DM)

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