NorthConnex

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Volume 3

Environmental Impact Statement - Volume 3

Appendix G - Technical working paper: Air quality

Appendix H - Technical working paper: Human health risk assessment

July 2014

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In 2012, the NSW Government received an unsolicited proposal from Transurban and the Westlink M7 Shareholders (Sponsors) to design, construct, operate, maintain and finance a tolled motorway linking the M1 Pacific Highway at Wahroonga to the Hills M2 Motorway at the Pennant Hills Road interchange at West Pennant Hills, known as NorthConnex.

Roads and Maritime Services is the Proponent for the environmental impact statement and lodgement of an application for environmental and planning approval. Roads and Maritime is working with the Sponsors on the community consultation and public exhibition of this environmental impact statement.

Appendix G

Technical working paper:
Air quality

NorthConnex

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Technical working paper: Air quality

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NorthConnex

Client: Roads and Maritime Services

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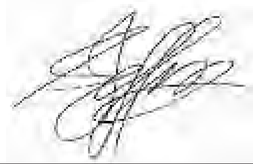
E	01-Jul-2014	Final for exhibition	Scott Jeffries Associate Director - Environment	

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Glossary

Term	Description
Airshed	Part of the atmosphere that shares a common flow of air and that is exposed to similar influences.
Ambient	Used interchangeably with 'background' in this report. Ambient/background pollutant concentrations refer to the concentrations of pollutants in the air, which are generated by all local pollutant sources, i.e. the term refers to the general pollutant loads in the air.
BOM	Bureau of Meteorology
CO	Carbon monoxide
Contemporaneous	Existing at or occurring in the same period of time. For contemporaneous pollutant assessments presented in this report (for example, for PM_{10}, $PM_{2.5}$ and NO_2, the measured ambient pollutant concentration for a particular hour (or 24 hour period) was added to the modelled pollutant contribution from the project for the same hour (or 24 hour period) at each relevant receiver location.
Cumulative assessment	The cumulative assessment was undertaken by summing the project contributions with the ambient pollutant concentrations where relevant, and comparing the predicted cumulative pollutant concentrations to the impact assessment criteria.
EPA	Environment Protection Authority
NO_2	Nitrogen dioxide
NO_X	Oxides of nitrogen, including nitric oxide (NO) and NO_2
O_3	Ozone
OEH	Office of Environment and Heritage
PAHs	Polycyclic aromatic hydrocarbons
Particulate matter	Very small solid particles or liquid droplets, which may become suspended in air.
PCU	Passenger car unit
Piston effect	The suction created behind a moving vehicle, which pulls air into and through the tunnel.
Plume	An atmospheric body in which substances (air pollutants) are present at concentrations higher than their normal ambient levels.
PM_{10}	Particulate matter with an equivalent aerodynamic diameter of 10 micrometres or less.
$PM_{2.5}$	Particulate matter with an equivalent aerodynamic diameter of 2.5 micrometres or less.
RMSE	Root mean square error
Receivers	Discrete receivers are identified by the EPA as anywhere someone works or resides or may work or reside, including residential areas, hospitals, hotels, shopping centres, play grounds, recreational centres, and the like.
TSP	Total suspended particulates; a type of particulate matter.
VOCs	Volatile organic compounds with a high vapour pressure at room temperature. Total VOCs refers to multiple VOCs considered together.
VPH	Vehicles per hour

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Executive Summary

Roads and Maritime Services is seeking approval under Part 5.1 of the *Environmental Planning and Assessment Act 1979* to construct and operate a tolled motorway linking the M1 Pacific Motorway at Wahroonga to the Hills M2 Motorway at the Pennant Hills Road interchange at West Pennant Hills in northern Sydney (the project). The project would consist of twin tunnels around nine kilometres in length, which would generally follow the alignment of the existing Pennant Hills Road. The purpose of the project is to reduce congestion on Pennant Hills Road, particularly heavy vehicle traffic. This technical working paper was prepared to assess the potential effects on air quality associated with the construction and operation of the project.

The effects of the construction works on local air quality were assessed qualitatively, through description of the proposed works, identification of the main sources of potential pollutants and development of a range of mitigation measures to reduce the pollutant emissions. The primary pollutant sources were considered to be fugitive dust and combustion emissions from plant and equipment. These emissions are manageable through standard management measures, which, if implemented, are considered to minimise and adequately mitigate any effects of the emissions on sensitive receivers.

The effects of the operation of the project were assessed quantitatively using dispersion modelling. The tunnels, if constructed, would capture emissions from vehicles passing through the tunnels (combustion emissions) and vent them to atmosphere through ventilation outlets. The ventilation system was designed such that no emissions would be vented through the portals. The dispersion of the combustion emissions released through the ventilation outlets, namely particulate matter (PM_{10} and $PM_{2.5}$), nitrogen dioxide (NO_2), carbon monoxide (CO), total volatile organic compounds (total VOCs) and polycyclic aromatic hydrocarbons (PAHs), was assessed using the CALPUFF suite of models. The tunnel ventilation systems would be operated to maximise the efficiency of the system by limiting the diameter of the emission sources depending on the number of vehicles passing through the tunnel. The emissions would vary on an hourly basis, with hourly varying flow rates and temperatures; these variations were incorporated into the dispersion modelling.

In addition to the ventilation outlet emissions, the contribution of pollutants from the surface roads to the airshed was modelled. This was undertaken using the CAL3QHCR model. Surface roads were modelled for the 'with project' (that is, with construction of the tunnels) and the 'without project' (that is, without the tunnels) scenarios.

Three principal air quality scenarios were assessed:

- Without the project (i.e. no tunnel), to enable a comparison of expected air quality changes along the surface road network with and without the project (Scenario 1).
- With the project – using predicted traffic volumes for the opening year (2019) and ten years after opening (2029) (Scenarios 2a and 2b).
- A breakdown scenario, to provide context to potential effects on air quality in the unlikely event of a breakdown in the project tunnels (the breakdown scenario).

In addition to the scenarios listed above, two design analyses were conducted to assess the predicted performance of the project's ventilation system and to assist regulatory agencies in considering air quality performance criteria that may be applied to the project. Both design analyses represented conditions unlikely to occur in practice, but were assessed to provide confidence that the project has the ability to comply with applicable air quality criteria under all conditions. The design analyses considered for the project were:

- Design analysis A – this design analysis was conducted to ensure that the project's ventilation system is adequately sized to cater for tunnels full of traffic. It assumed that during peak hours, the maximum number of vehicles that can fit into the tunnel (4,000 passenger car units per two lane main alignment tunnel adjusted for speed). This design analysis represents the physical limit of the main alignment tunnels and was based on forecast traffic volumes that are unlikely to eventuate due to a range of factors including traffic management measures, projected land use, employment, demographics and constraints on the surrounding surface road network.
- Design analysis B – this design analysis was conducted to ensure that regardless of when the peak traffic period occurs or for how long it lasts, the project's ventilation system would be able to meet applicable air quality criteria. This design analysis assumed that the project's ventilation outlets emit the maximum concentration of pollutants on a continuous basis. In reality, emissions concentrations would vary during the day depending on the number and type of vehicles using the tunnels at the time.

Meteorological input data used in the dispersion modelling included a combination of data recorded at five local monitoring stations operated by the Bureau of Meteorology (BOM) and the Office of Environment and Heritage (OEH) and prognostic data generated by the MM5 mesoscale meteorological model. Three years of meteorological data were used in the modelling, representing conditions from 2009, 2010 and 2011.

Pollutant concentrations were predicted for a total of 6,919 sensitive receiver locations. Of these, 3,332 were located along the road corridor (which were included in both the CALPUFF and CAL3QHCR models), with the remainder located around the ventilation outlets and the area surrounding the project (which were only included in the CALPUFF modelling).

Conservative background pollutant concentrations were used in the prediction of cumulative pollutant concentrations. For PM_{10}, $PM_{2.5}$ and NO_2, the ambient concentrations were determined by taking the maximum of the concentrations predicted by CAL3QHCR (with the project) and those measured by the OEH at its Lindfield and Prospect monitoring stations; this was done for each modelled receiver for each hour of each modelling year. For the modelled receivers not located along the road corridor, the maximum OEH data for each hour were adopted as ambient pollutant concentrations. For carbon monoxide, the maximum concentration recorded at the OEH monitoring station at Prospect (as carbon monoxide is not measured at Lindfield) between 2009 and 2011 was taken as the ambient concentration for all receivers. The cumulative predicted pollutant concentrations, which represented the combination of project contributions and ambient pollutant concentrations, were compared against applicable air quality assessment criteria.

For all the scenarios assessed, all predicted pollutant concentrations were well below their respective impact assessment criteria except for particulates. Exceedences of the assessment criteria were predicted to occur for PM_{10} concentrations for the 24 hour averaging period and $PM_{2.5}$ concentrations for both the 24 hour and annual averaging periods. The project's predicted contributions to the exceedences were, however, very minor, with the exceedences attributable to elevated background concentrations of these pollutants. No additional exceedences of the PM_{10} or $PM_{2.5}$ criteria were predicted to occur as a result of the project. Furthermore, analysis of the modelling results predicted that the project would reduce annual concentrations of $PM_{2.5}$ along Pennant Hills Road, and result in only slight increases in the annual $PM_{2.5}$ concentrations around the ventilation outlets, which would not be discernible from the background concentrations of this pollutant. As such, the project is expected to result in a net improvement in air quality, taking into account improvements in air quality along the Pennant Hills Road corridor balanced with very low levels of increases in $PM_{2.5}$ concentrations around the northern and southern ventilation outlets.

1.0 Introduction

Roads and Maritime Services (Roads and Maritime) is seeking approval under Part 5.1 of the *Environmental Planning and Assessment Act 1979* to construct and operate a tolled motorway linking the M1 Pacific Motorway at Wahroonga to the Hills M2 Motorway at the Pennant Hills Road interchange at Carlingford in northern Sydney (the project). An overview of the project is shown in **Figure 1**.

The project is needed to provide a safer and more efficient link between the M1 Pacific Motorway and the Hills M2 Motorway, which would better service current and future road users. The operation of the project would provide an alternative and more efficient route for travel between the M1 Pacific Motorway and the Hills M2 Motorway, improving access, connectivity and reliability of inter-regional freight across the greater Sydney area. The project would also reduce interaction between freight and other road users, thereby reducing congestion and improving safety and amenity along Pennant Hills Road.

Key features of the project would include:

- Twin motorway tunnels up to around nine kilometres in length with two lanes in each direction. The tunnels would be constructed with provision for a possible third lane in each direction if required in the future.
- A northern interchange with the M1 Pacific Motorway and Pennant Hills Road, including sections of tunnel for on-ramps and off-ramps, which would also facilitate access to and from the Pacific Highway.
- A southern interchange with the Hills M2 Motorway and Pennant Hills Road, including sections of tunnel for on-ramps and off-ramps.
- Integration works with the Hills M2 Motorway including alterations to the eastbound carriageway to accommodate traffic leaving the Hills M2 Motorway to connect to the project travelling northbound, and the provision of a new westbound lane on the Hills M2 Motorway extending through to the Windsor Road off-ramp.
- Tie-in works with the M1 Pacific Motorway extending to the north of Edgeworth David Avenue.
- A motorway operations complex located near the southern interchange on the corner of Eaton Road and Pennant Hills Road, which would include operation and maintenance facilities.
- Two tunnel support facilities, incorporating emergency smoke extraction outlet points and substations along the main alignment.
- Ancillary facilities for motorway operation, such as electronic tolling facilities, signage, ventilation systems and fire and life safety systems including emergency evacuation infrastructure.
- Modifications to service utilities and associated works at surface roads near the two interchanges and operational ancillary facilities.
- Modifications to local roads, including widening of Eaton Road near the southern interchange and repositioning of the Hewitt Avenue cul-de-sac near the northern interchange.
- Ancillary temporary construction facilities and temporary works to facilitate the construction of the project.

Construction activities would generally include:

- Enabling and temporary works, including construction power, water supply, site establishment, demolition works, property and utility adjustments and public transport modifications (if required).
- Construction of the road tunnels, interchanges, intersections and roadside infrastructure.
- Haulage of spoil generated during tunnelling and excavation activities.
- Fit-out of the road tunnels and support infrastructure, including ventilation and emergency response systems.
- Construction and fit-out of the motorway control centre.
- Realignment, modification or replacement of surface roads, bridges and / or underpasses.
- Environmental management and pollution control facilities for the project.

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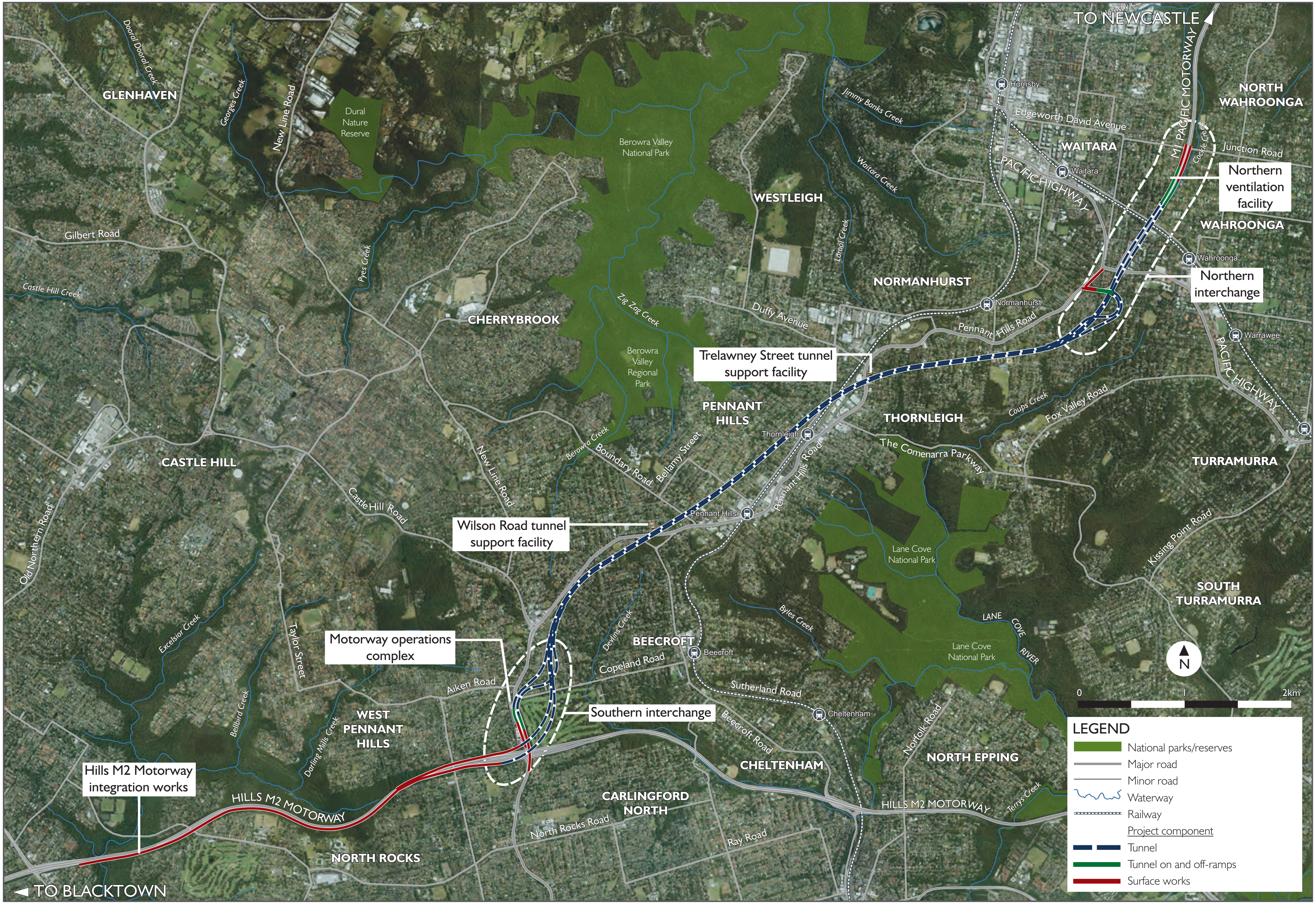

Figure 1 The project

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1.1 Project location

The project would be located within The Hills, Hornsby and Ku-ring-gai local government areas about 20 kilometres north-west of the central business district of Sydney. The regional context of the project is shown in **Figure 2**. The project would span the suburbs of Wahroonga, Normanhurst, Thornleigh, Pennant Hills, Beecroft, West Pennant Hills, Carlingford, North Rocks, Westmead and Baulkham Hills.

1.2 Scope of work

The purpose of this report is to address the Director-General's requirements (DGRs) that were issued for the project on 29 October 2013. The DGRs were re-issued with amendments on 11 April 2014.

The DGRs relevant to the air quality impact assessment state that the assessment should include but not be limited to:

> *An assessment of construction and operation activities that have the potential to impact on local and regional air quality. The assessment should provide an assessment of the risk associated with potential discharges of fugitive and point source emissions, and include:*
>
> - *details of the proposed methods to minimise adverse impacts on air quality during construction, particularly in relation to mobile plant,*
> - *air quality impact assessment and air dispersion modelling conducted in accordance with the* Approved Methods for the Modelling and Assessment of Air Pollutants in NSW *(DEC, 2005) where there is a risk of adverse air quality impacts, or where there is sufficient uncertainty as to the potential level of risk, including a particle assessment addressing* PM_{10} *and* $PM_{2.5}$ *values, consideration of impacts from dispersal of TSP, CO,* NO_2 *and other nitrogen oxides, volatile organic compounds (eg BTEX), details of the proposed mitigation measures to address air quality in tunnels and in the vicinity of portals and any mechanical ventilation systems (i.e. ventilation stacks), including details of proposed monitoring,*
> - *consideration of the requirements of* Environmental Health Risk Assessment: Guidelines for assessing human health risks from environmental hazards *(enHealth, 2012), and*
> - *take into account any applicable advice provided by the Independent Advisory Committee on Tunnel Air Quality.*

This technical report will accompany the environmental impact statement (EIS) for the project and focuses on the air quality impact assessment requirements of the DGRs. The human health risk assessment requirements are addressed in technical working paper: Human Health Risk Assessment (Environmental Risk Sciences Pty Ltd, 2014).

The specific objectives of this assessment were to:

- Gather existing information regarding regional air quality and meteorological data relevant to the study area.
- Identify the activities and associated pollutants of concern associated with the construction and operation of the project.
- Identify the relevant assessment criteria specified in *Approved Methods for the Modelling and Assessment of Air Pollutants in NSW* (DEC, 2005).
- Qualitatively assess the potential impacts associated with the construction of the project on local air quality.
- Quantitatively assess the potential impacts associated with the operation of the project, using dispersion modelling of emissions from the project ventilation systems and surface roads to determine changes in air quality at sensitive receiver locations within the study area.
- Where required, identify reasonable and feasible mitigation and management measures to minimise potential air quality impacts during the construction and operation of the project.

The NSW Government established the Advisory Committee on Tunnel Air Quality, chaired by the NSW Chief Scientist Professor Mary O'Kane, to review national and international practice and experience with motorway tunnels to safeguard the health and safety of the community and motorists. Roads and Maritime briefed the Advisory Committee on Tunnel Air Quality on the project and the air quality impact assessment approach.

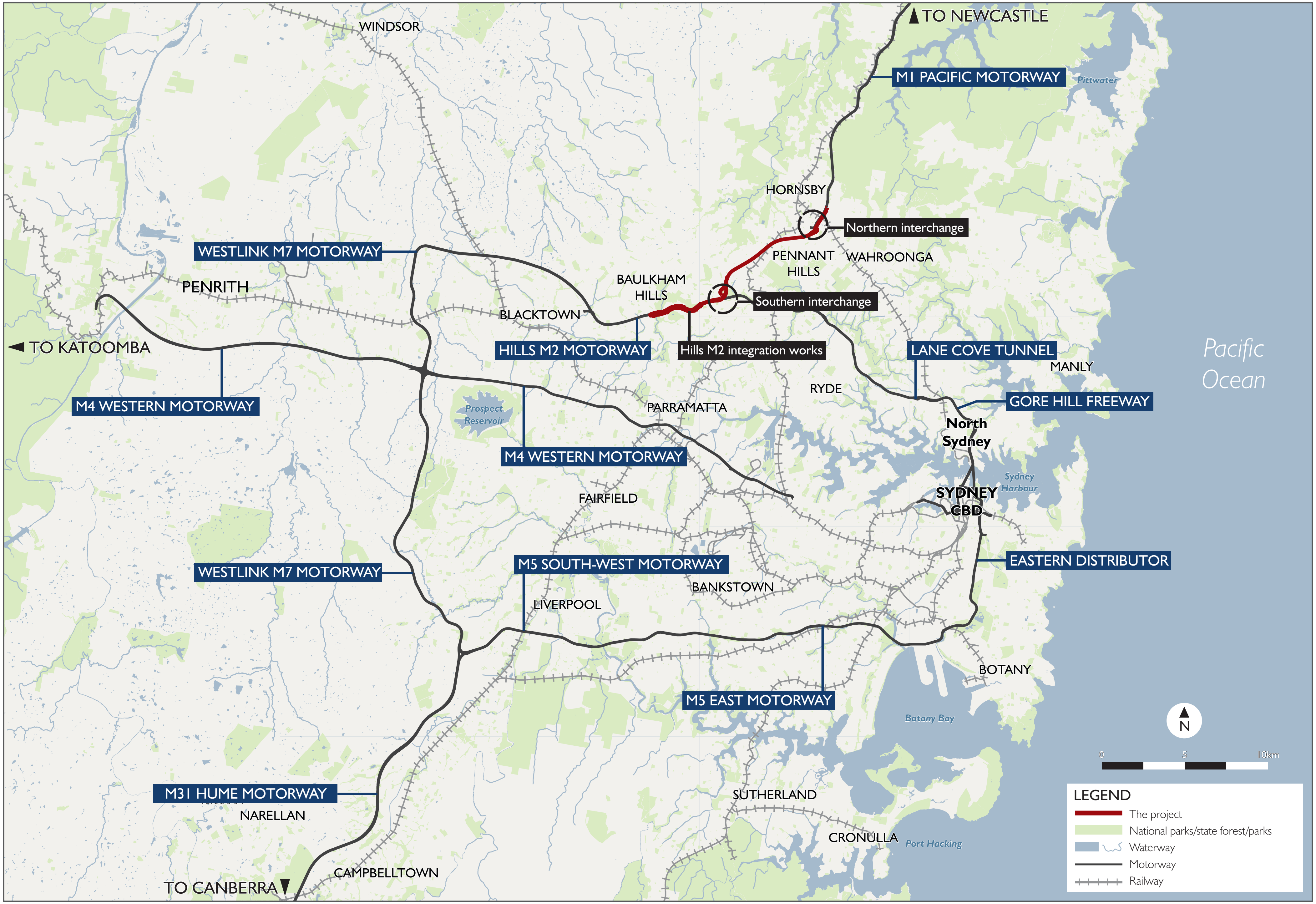

Figure 2 Regional context of the project

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1.3 Report structure

The report structure is summarised in **Table 1**.

Table 1 Report structure

Content	Reference
Introduction	**Section 1.0**
Project description	**Section 2.0**
Existing environment	**Section 3.0**
Assessment methodology	**Section 4.0**
Construction impact assessment	**Section 5.0**
Operational impact assessment	**Section 6.0**
Mitigation and management measures	**Section 7.0**
Conclusions	**Section 8.0**
References	**Section 9.0**
Construction activities	**Appendix A**
Pollutant descriptions	**Appendix B**
Ambient monitoring data review	**Appendix C**
Dispersion model details	**Appendix D**
Terrain and land use data	**Appendix E**
Meteorological data	**Appendix F**
Modelling results – Design Analysis	**Appendix G**
Emission calculations	**Appendix H**
NO_x to NO_2 conversion	**Appendix I**

1.4 The effects of vehicle emissions on air quality

Motor vehicles, which include passenger cars, light commercial vehicles (motorcycles, utilities, vans and buses / coaches) and heavy duty vehicles (HDV) (that is, trucks) typically burn fossil fuels such as petrol and diesel. The combustion of fossil fuels in the motor vehicle engines results in emissions of a number of different pollutants, which may adversely affect human health and/or the environment, namely oxides of nitrogen (NO_X), volatile organic compounds (VOCs), carbon monoxide (CO), and particulates (both PM_{10} and $PM_{2.5}$) (NPI, 2008). These pollutants are briefly described in **Appendix B**.

Emission levels are dependent on the type of fuel used and the temperature of combustion, as well as the vehicle loading. Engines are typically inefficient at low vehicle speeds; as a result, emissions of CO and VOCs from petrol engines, and CO, VOCs and particulates from diesel engines, are greatest under these conditions due to incomplete combustion. As such, the reduced congestion and higher vehicle speeds associated with the project compared with existing conditions along the Pennant Hills corridor would be expected to reduce vehicle emissions of these pollutants overall. At higher loads and speeds, the combustion process becomes more efficient, and emissions of NO_X predominate due to the oxidation of impurities in the fuel.

$PM_{2.5}$ emissions resulting from the exhaust of on-road mobile sources can be visible as white or black smoke. Diesel vehicles are known for emitting black smoke, especially when operating under high loads, while petrol vehicles that are out of repair can emit visible quantities of white smoke.

The Australian Government National Pollutant Inventory (NPI) Emission Estimation Technique Manual for Combustion Engines (2008) provides a $PM_{2.5}$ emission factor of 2.0 kg/m^3 for diesel vehicle exhaust emissions from cars. This represents approximately 95 per cent of the PM_{10} emission rate of 2.1 kg/m^3. A similar relationship is found for light, medium and heavy diesel goods vehicles, as well as buses. Petrol cars also show a similar trend, with an emission factor of 0.062 kg/m^3 for $PM_{2.5}$; this represents approximately 93 per cent of the PM_{10} factor of 0.067 kg/m^3. The emission factors are the same for E10 blends, where the trends are similar for light, medium and heavy petrol goods vehicles as for other fuelled vehicles. LPG vehicles are estimated to have negligible particulate emissions.

The NPI emission factors show that the vast majority of particulates from diesel are expected to be in the $PM_{2.5}$ size range; as such, total suspended particulates (TSP) would essentially comprise the PM_{10} and $PM_{2.5}$ fractions.

NO_X emissions from motor vehicles predominantly consist of nitrous oxide (NO) when the exhaust is emitted from the vehicle. For petrol engines, around 95 per cent of the NO_X emissions are NO (five per cent nitrogen dioxide, or NO_2), while diesel engines emit around 90 per cent NO. In the presence of ozone (O_3), which occurs naturally in the atmosphere, the NO oxidises to NO_2, which is a pollutant of interest. The rate of oxidation is dependent on many variables including temperature and humidity; in urban environments with heavy traffic, all of the available ozone can be used up, which limits the conversion of NO_X to NO_2 (Bluett et al., 2008).

VOCs are emitted both from the vehicle exhausts and from the fuel tank (breathing losses) as the fuel heats[1]. VOCs typically emitted from motor vehicles include benzene, toluene and xylenes.

1.5 Expected benefits of the project on air quality

The project is set to deliver a number of key improvements for motorists, providing time and fuel savings for freight and transport operators. Up to 5,000 trucks per day are expected to be taken off the heavily congested Pennant Hills Road, improving safety and air quality for local residents in the area. Vehicles using the project in preference to Pennant Hills Road would avoid 21 sets of traffic lights, and would have an estimated travel time of around five to six minutes. This offers travel time savings of up to 15 minutes in 2019 and up to 25 minutes in 2029 when compared to travel times for vehicles using Pennant Hills Road. In addition to the reduced transit times, the project tunnels would capture the vehicle emissions, which would then be released in a controlled manner via the ventilation facilities, which would facilitate effective pollutant dispersion.

By capturing the vehicle emissions released within the tunnels and venting them to atmosphere via the ventilation facilities, the total volume of pollutants released remains unchanged, but the pollutant dispersion would be significantly improved. Pollutants released from vehicle exhausts along surface roads normally stay close to the ground, and collect around the emission point, with dispersion dependent on passive diffusion and the movement of nearby objects. Vehicle emissions at the surface and ground level tend to disperse up to around 300 metres from the emission point. In contrast, pollutants released from the project's ventilation facilities would be released with vertical momentum, which, coupled with the height of the ventilation outlets and the positive thermal buoyancy, would result in the dispersion of pollutants at a height well above ground level. As wind speeds typically increase in speed with increasing distance above ground, this would facilitate pollutant dispersion with dilution over a greater area. So rather than the pollutants being deposited close to ground level and, subsequently, being concentrated along the surface road, the pollutants would be dispersed at a greater height and diluted much faster over a greater area, resulting in lower ground-level concentrations.

The results of dispersion modelling and pollutant monitoring studies have generally found that the air quality impacts associated with road tunnels and their outlet emissions are indistinguishable from impacts from all other surrounding sources (such as emissions from surface roads, industrial sources, domestic sources, and natural sources). In fact, an extensive literature review by the NHMRC (2008) determined that the effects of road tunnel emissions on local air quality are very small compared to the effects from other sources, particularly local surface roads, and that monitoring is often unable to distinguish road tunnel emissions from emissions from background pollutant sources. The review concluded that detectable localised health impacts would not be expected to occur as a result of emissions from road tunnels.

[1] http://www.air-quality.org.uk/08.php

As shown in **Section 6.1.6**, the project is expected to improve traffic flows along Pennant Hills Road, which was shown by the dispersion modelling to improve air quality along the road corridor. Furthermore, the controlled capture and dispersion of the emissions from the diverted traffic through well-design ventilation outlets would not simply move the pollution to another area; rather, the improved dispersion of pollutants from the ventilation facilities would be expected to result in pollutant concentrations that are indistinguishable from the background pollutant concentrations at sensitive receiver locations.

The Office of Environment and Heritage (OEH) Action for Air (DECCW, 2009) intends to improve air quality in the Greater Metropolitan Region. The document cites ozone and particles as being the biggest air quality challenges for the region, so nominates actions and objectives specifically targeted towards reducing emissions from motor vehicles. The project would assist in reducing vehicle emissions through the reduced travel times noted above, an outcome which is in keeping with the objectives of the Action for Air.

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2.0 Project description

Components of the project that are relevant to the air quality assessment are outlined in this chapter. Further details of the project are provided in Chapter 5 of the environmental impact statement.

2.1 Construction

Construction of the project would occur over a period of around four years and would include (but not be limited to) the following:

- Enabling and temporary works, including construction power, water supply, site establishment, demolition works, property and utility adjustments and public transport modifications (if required).
- Construction of the road tunnels, interchanges, intersections and roadside infrastructure.
- Haulage of spoil generated during tunnelling and excavation activities.
- Fit-out of the road tunnels and support infrastructure, including ventilation and emergency response systems.
- Construction and fit-out of the motorway control centre.
- Realignment, modification or replacement of surface roads, bridges and/or underpasses.
- Environmental management and pollution control facilities for the project.

The majority of the construction footprint would be located underground within the main tunnel alignment. Surface areas would, however, be required to support tunnelling activities, and to construct the interchanges, tunnel portals, the Hills M2 Motorway integration works and the tie-ins to the M1 Pacific Motorway. The surface construction footprint would generally align with the operational footprint, with the location of future operational ancillary facilities being used to support construction activities. Additional construction support sites around works areas and an employee parking facility would also be required.

Further details of construction works, identification of the main emission sources and mitigation measures to minimise impacts associated with the works are provided in **Appendix A**. Further detail on construction activities can be found in Chapter 5 of the environmental impact statement.

2.2 Operation

The project involves the operation of twin motorway tunnels up to around nine kilometres in length with two lanes in each direction[2]. A description of the main operational features of the project relevant to the air quality assessment is provided in the following sections.

2.2.1 Road grade and tunnel design

The main alignment tunnels would have a desired maximum grade of 3.5 per cent to cater for consistent speeds to be maintained. The absolute maximum grade of the main alignment tunnels would be four per cent. Surface road grades would be compliant with standard Austroads / Roads and Maritime design parameters.

The tunnels would be around 14 metres in width and eight metres in height. Each main alignment carriageway would consist of two lanes with a minimum posted speed limit of 80 kilometres per hour. Each lane would be 3.5 metres wide with the shoulder on the left hand side being 2.5 metres wide and the shoulder on the right hand side being one metre wide. The minimum vertical clearance of each tunnel would be 5.3 metres.

At opening of the project, each carriageway would be line marked for two lanes. If a decision is made to include a third lane in the spare physical capacity of the main alignment tunnels in the future, a separate assessment and approvals process would be pursued.

[2] Note that the project would be constructed with physical capacity to accommodate three lanes if required in the future, although approval is currently only being sought for establishment and operation of two lanes at opening of the project.

2.2.2 Ventilation system and facilities

2.2.2.1 Configuration of the ventilation system

The tunnel ventilation system would maintain appropriate air quality that is protective of the health and amenity of motorists within the tunnels during normal operation and emergency conditions.

During operation, the ventilation system would draw fresh air into the tunnels and emit air from within the tunnels via two ventilation facilities. One of the ventilation facilities would be located near the northern tunnel portal and one would be located near the southern tunnel portal. The most efficient location for ventilation outlets is close to the main alignment tunnel portals. This is because vehicles travelling through the tunnels create a piston effect, which draws air into the tunnel and pushes it forward in the direction of traffic flow. Locating the ventilation outlets near the main alignment tunnel exit portals maximises the benefit of the piston effect and minimises the need for and cost of additional energy consumption to operate tunnel jet fans and to transport the exhaust air from the tunnel to the outlet. This approach provides environmental benefits through the reduction in energy consumption and greenhouse gas emissions from the project.

The locations of ventilation outlets for the project were determined based on proximity to the main alignment tunnel exit portals, as well as consideration of other factors including land access and acquisition requirements, geology, engineering and construction constraints, potential landscape and visual impacts, and the location of other major infrastructure.

The project does not currently propose portal emissions from the main alignment tunnels. This approach may, however, be considered in the future, but would be subject to appropriate assessment and approval at the relevant time.

During emergency conditions, which are expected to occur infrequently, the ventilation system would extract smoke from the tunnel where required. The extracted smoke may be emitted from one or more of the following locations:

- Southern ventilation facility.
- Wilson Road tunnel support facility.
- Trelawney Street tunnel support facility.
- Northern ventilation facility.
- The tunnel portals.

The southern emergency smoke extraction outlet would be located on the corner of Wilson Road and Pennant Hills Road (at the Wilson Road tunnel support facility), and the northern emergency smoke extraction outlet would be located on the corner of Trelawney Street and Pennant Hills Road (at the Trelawney Street tunnel support facility). Key components of the project's ventilation system are summarised in **Table 2**.

Table 2 Key ventilation system components

Component	Description
Jet fans	- Jet fans would be mounted in pairs, with each pair separated by a distance of around 90 metres. - A total of around 65 jet fans would be installed in the northbound tunnel and ramps and around 60 jet fans in the southbound tunnel and ramps. - Jet fans would be located throughout the tunnel and would operate as required to maintain in tunnel air quality requirements.
Emergency smoke extraction outlets	- Each tunnel support facility would have a minimum exhaust capacity of around 400 cubic metres per second to generate a net flow of around five metres per second along the tunnel. - Each tunnel support facility would consist of four horizontally mounted bidirectional axial fans, each with an exhaust capacity of around 135 cubic metres per second. - Emergency smoke extraction requirements could be achieved with three fans, with the fourth fan on standby. - During low traffic conditions, the tunnel support facilities would be used to supply additional fresh air to the tunnels.
Ventilation facilities	- Two ventilation outlets would be required – one near each of the northern and southern main alignment tunnel portals. - Each ventilation outlet would have a maximum exhaust capacity of around 700 cubic metres per second. - The ventilation outlets would be serviced by five horizontally-mounted axial fans, each with an exhaust capacity of around 175 cubic metres per second. - Total ventilation requirements could be achieved with four fans, with the fifth fan on standby. During normal operation, however, all five fans would likely be operated at reduced capacity. - The southern ventilation facility would have an outlet at around 15 metres in height, and a building height of seven metres when measured from Pennant Hills Road. - The northern ventilation facility would have an outlet at around 15 metres and a building height of around seven metres when measured from the neighbouring land.

2.2.2.2 Operation of the ventilation system

The tunnel ventilation system would be operated in three principal modes:

- Normal traffic conditions.
- Low speed / congested conditions.
- Emergency conditions.

Operation of the ventilation system under each of these conditions is detailed in the following sections.

Normal traffic conditions

During normal operation, the tunnel would be longitudinally ventilated; that is, fresh air would be drawn in from the tunnel entry portals and through the tunnels by a vehicle-generated piston effect (the suction created behind a moving vehicle, which pulls air into and through the tunnel) and pushed towards the tunnel exit portals. Tunnel air, which would contain vehicle exhaust emissions, would be drawn upwards into the ventilation outlets located near the main alignment portals via ventilation fans and discharged to atmosphere.

For the tunnel off-ramps, air would be drawn back down the ramp for extraction via the ventilation facility. This would require jet fans (used to accelerate the movement of air through the tunnel) to maintain the air flow against the direction of traffic flow. A similar approach would be applied to parts of the main alignment tunnels close to the exit portals.

Air from within the tunnels, containing vehicle emissions, would be extracted from the tunnels prior to reaching the exit portals. Air would be exhausted via a ventilation take off and transferred to the ventilation facility via a vertical shaft. The air would then be discharged from the ventilation facility to the atmosphere.

Low speed traffic conditions

The piston-effect of vehicle movements would be reduced during low speed traffic conditions. As such, the tunnel jet fans would be expected to be used to assist air flow under these conditions; additional fresh air intake may also be required, which would be achieved using the reverse flow operation of the axial fans in the two emergency smoke extraction points. The operation of axial fans in the ventilation facilities would be increased to ensure that acceptable air quality is maintained in the tunnels and to achieve acceptable dispersion of tunnel air following discharge to the atmosphere.

Emergency conditions

The two emergency smoke extraction outlets would principally function to maintain air quality in the tunnels in the event of a fire incident. As a secondary feature, these facilities would also supply fresh air the tunnels during low speed traffic conditions (discussed above).

During smoke control, air would be extracted from the tunnel and transferred to the emergency smoke extraction outlet via a vertical shaft. The smoke would then be discharged from the facility to the atmosphere.

The emergency smoke extraction outlets are expected to operate infrequently for the extraction of smoke during an emergency and for a short duration while emergency services and tunnel fire and life safety systems bring the situation under control.

2.2.2.3 Electricity

The tunnel ventilation equipment would all be electrically powered, with power supplied from the grid via a project supply substation.

3.0 Existing environment

3.1 Background air quality

The most recent NSW State of the Environment Report (EPA, 2012a) states that transport emissions are the most important human-related source of air pollution in Sydney. In 2008, motor vehicles were the largest source of emissions of oxides of nitrogen (63 per cent of total emissions) and the second largest source of VOC emissions (24 per cent of total emissions) in the Sydney region.

NSW is considered to have generally good air quality in relation to international standards. Concentrations of carbon monoxide, nitrogen dioxide and volatile organic compounds are consistently lower than national standards in most areas and, according to the EPA (2012a), emissions of these pollutants in the Sydney region have decreased by 20 to 40 per cent since the early 1990s. These reductions are considered to primarily be a result of initiatives to reduce air pollution associated with industry, businesses, motor vehicles and residential premises, which were implemented since the 1980s. Concentrations of measured pollutants appeared to be stable over the past few years (EPA, 2012a).

Exceedences of PM_{10} criteria do, however, occur in Sydney, primarily as a result of bushfires and dust storms. The Air NEPM sets a national standard for PM_{10} of 50 micrograms per cubic metre ($\mu g/m^3$) as a 24 hour average, with an allowable five exceedences per year to account for potentially unavoidable and significant events such as bushfires and dust storms. As shown in **Figure 3**, the national PM_{10} standard was exceeded an average of eight times per year and a maximum of 26 times per year across all monitoring locations in the Sydney region between 1994 and 2011. Bushfires and dust storms were considered to be major contributors to the exceedences in 1994, 2001 – 03 and 2009, while hazard reduction burns and local construction activity close to individual sampling stations were considered to have caused the exceedences recorded in 2011. Most exceedences occurred in spring and summer (EPA, 2012a), which is consistent with the timing of bushfires and dust storms.

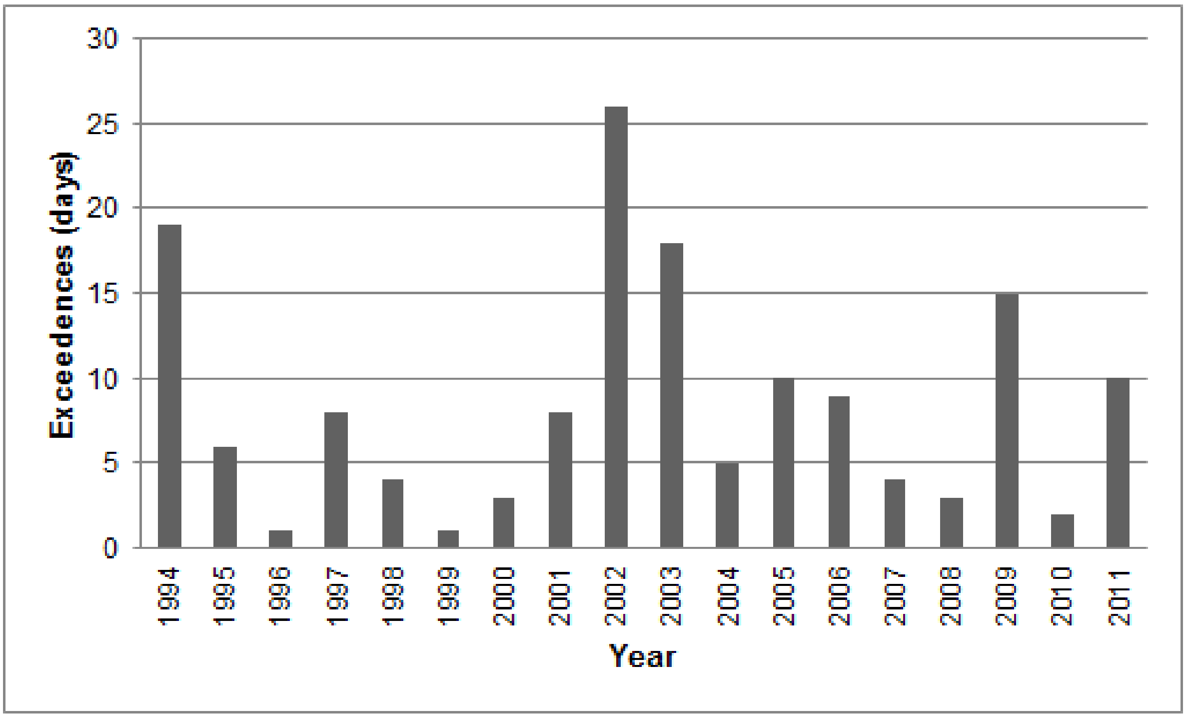

Figure 3 24 hour PM_{10} exceedences: Sydney, 1994 – 2011 (source: EPA, 2012)

The OEH measures pollutant concentrations at a number of monitoring stations located throughout Sydney. The closest stations to the project are at Lindfield (around 9.7 kilometres southeast of the southern ventilation outlet) and Prospect (around 11 kilometres southwest of the southern ventilation outlet) (refer to **Figure 4**). Relevant monitoring data recorded by these stations between 2009 and 2011 are summarised in **Table 3** to **Table 8**. The data shown represent the highest concentrations recorded at either station for the relevant pollutants and averaging periods. CO is only measured at Prospect. Exceedences of the EPA's impact assessment criteria are noted where relevant. The data were used in this assessment to represent background concentrations as described in **Section 4.2.12**.

When reviewing the data, the following points should be noted:

- Dust storms occurred on 23 September 2009 and the 26 September 2009. Measured concentrations of 24 hour PM_{10} at these times were removed, and replacement values calculated from the pre and post 24 hour values for the purpose of this assessment.
- As $PM_{2.5}$ is not measured at either Lindfield or Prospect, $PM_{2.5}$ concentrations were estimated from the PM_{10} concentrations using a PM_{10} to $PM_{2.5}$ ratio of 0.35 (average ratio for 2009 - 2011 from Sydney monitoring stations recording both pollutants)[3].
- Negative values were removed from all data sets.
- In summary, nine exceedences of the 24 hour PM_{10} criterion were noted in 2009, with no exceedences recorded in 2010 or 2011. Four exceedences of the 24 hour $PM_{2.5}$ advisory standard were estimated to have occurred in 2009. No other exceedences of particulates or other pollutants were recorded.

[3] In order to estimate $PM_{2.5}$ concentrations in the project area, the ratios of PM_{10} to $PM_{2.5}$ measured at other monitoring stations within the Sydney basin were calculated. Monitoring data from Liverpool, Chullora, Earlwood and Richmond for the period 2009 – 2011 were used. The PM_{10} to $PM_{2.5}$ ratios were calculated for each of the monitoring stations for each hour of the day. These ratios were then averaged across the monitoring stations for each hour of the day, and the maximum of those averages was adopted as the conversion ratio for the assessment, which was 0.35. This ratio was applied to the combined PM_{10} monitoring data from Lindfield/Prospect to estimate hourly $PM_{2.5}$ concentrations. Based on experience, the ratio is typically between 0.3 and 0.4, so this value was considered to be acceptable.

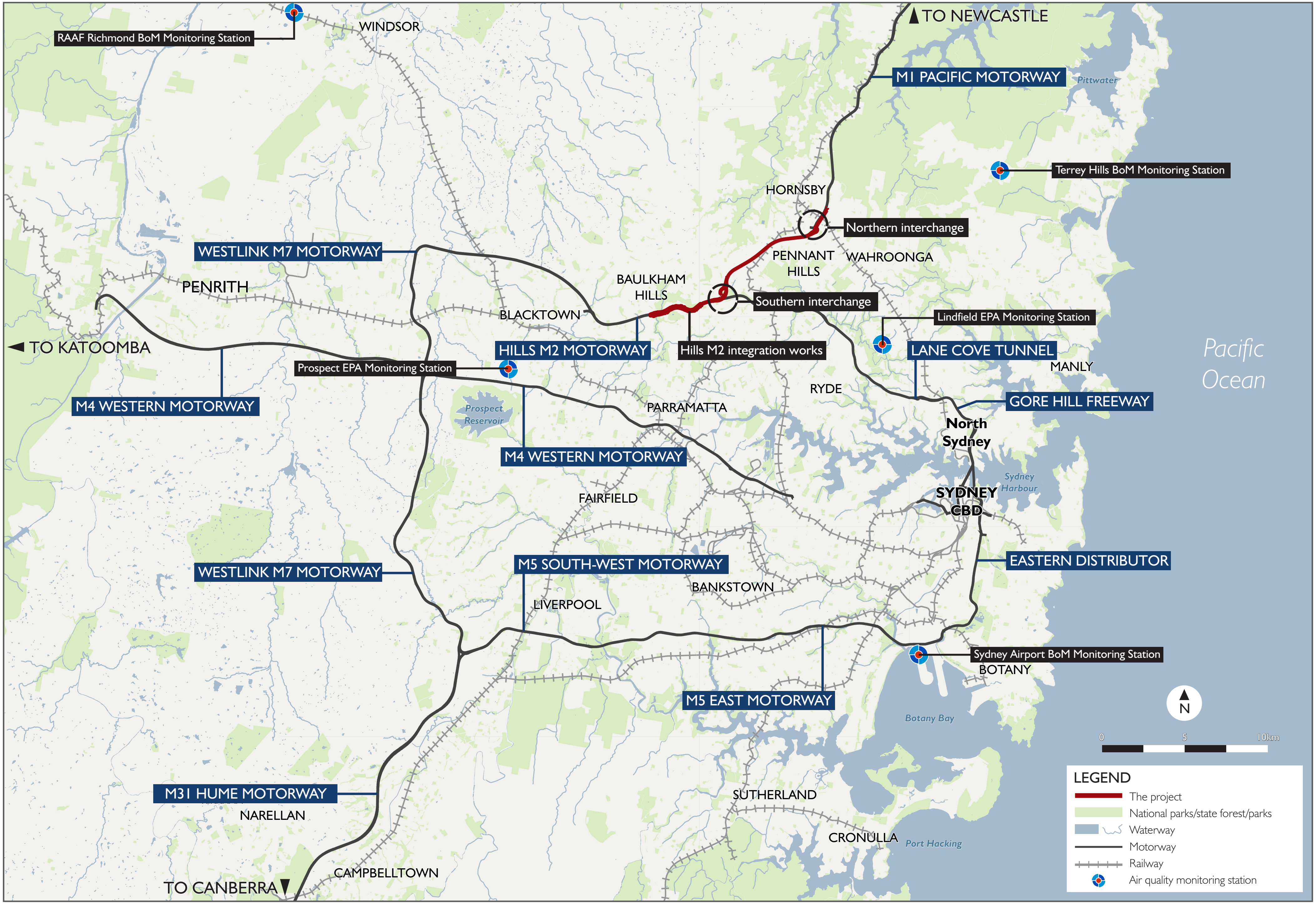

Figure 4 Regional air quality monitoring stations

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The PM_{10} data are plotted in **Chart 1** and summarised in **Table 3**. As shown, the recorded concentrations were typically well below the criterion level, although some instances of high exceedences are evident, with a maximum recorded PM_{10} concentration between 2009 and 2011 of 222 µg/m^3. Nine exceedences of the criterion were recorded in 2009.

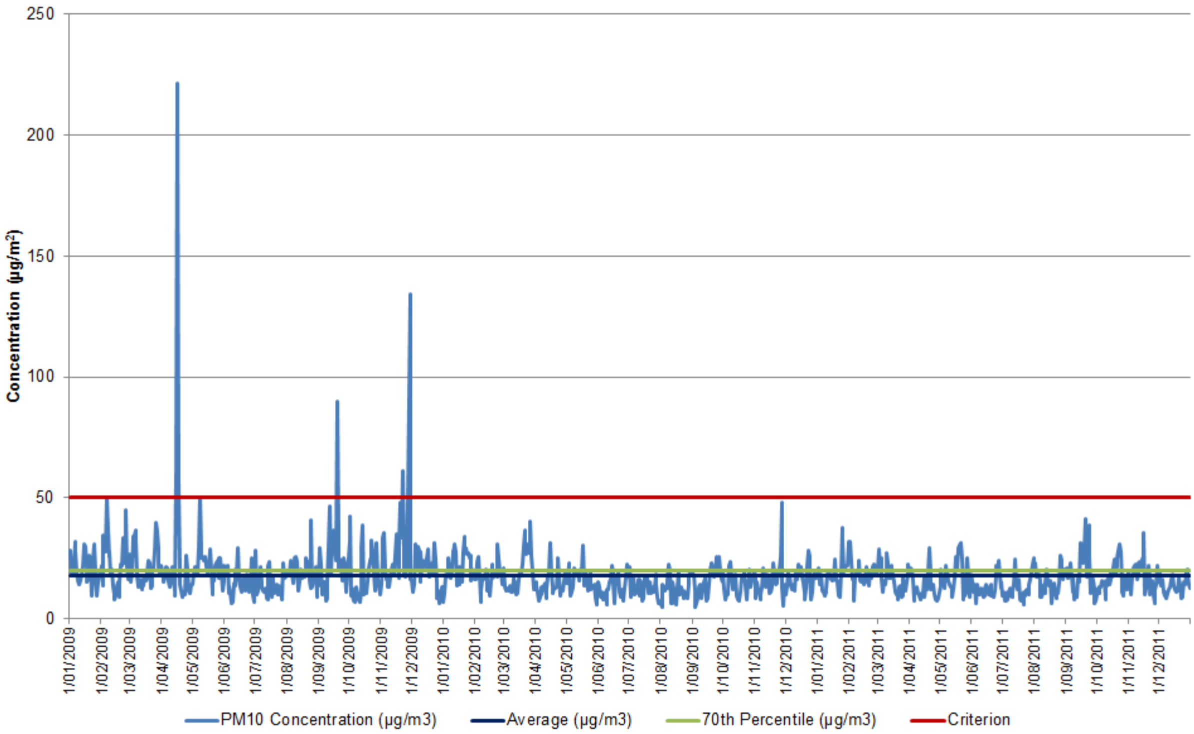

Chart 1 **Combined OEH 24 hour PM_{10} concentrations, 2009 - 2011**

Table 3 **Combined OEH monitoring data from Lindfield and Prospect – 24 hour average PM_{10} (µg/m^3) – 2009 to 2011**

Statistic	Year			
	All	2009	2010	2011
Maximum	222	222	48	42
95th percentile	31	36	27	28
Average	18	21	16	16
Number of exceedences of EPA criterion (50 µg/m^3)	9	9	0	0

The $PM_{2.5}$ data are plotted in **Chart 2** and summarised in **Table 4**. As shown, the estimated concentrations were typically well below the advisory standard level. Four exceedences of the advisory standard were, however, estimated in 2009.

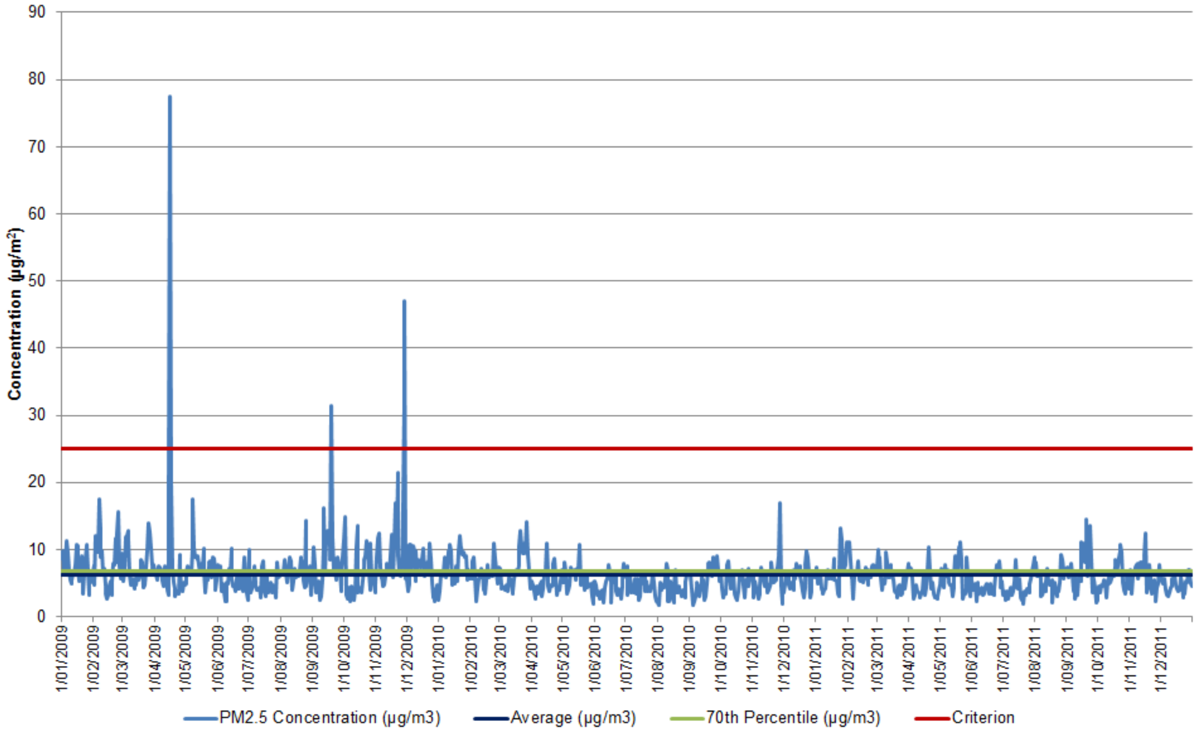

Chart 2 **Estimated OEH 24 hour $PM_{2.5}$ concentrations, 2009 - 2011**

Table 4 **Estimated concentrations from combined OEH monitoring data from Lindfield and Prospect – 24 hour average $PM_{2.5}$ ($\mu g/m^3$) – 2009 to 2011**

Statistic	Year			
	All	2009	2010	2011
Maximum	78	78	17	15
95th percentile	11	13	10	10
Average	6	7	6	6
Number of exceedences of advisory reporting standard (25 $\mu g/m^3$)	4	4	0	0

The NO_2 data are plotted in **Chart 3** and summarised in **Table 5**. As shown, the estimated concentrations were typically well below the criterion level. Ozone concentrations, which are relevant to the formation of NO_2, are summarised in **Table 6**.

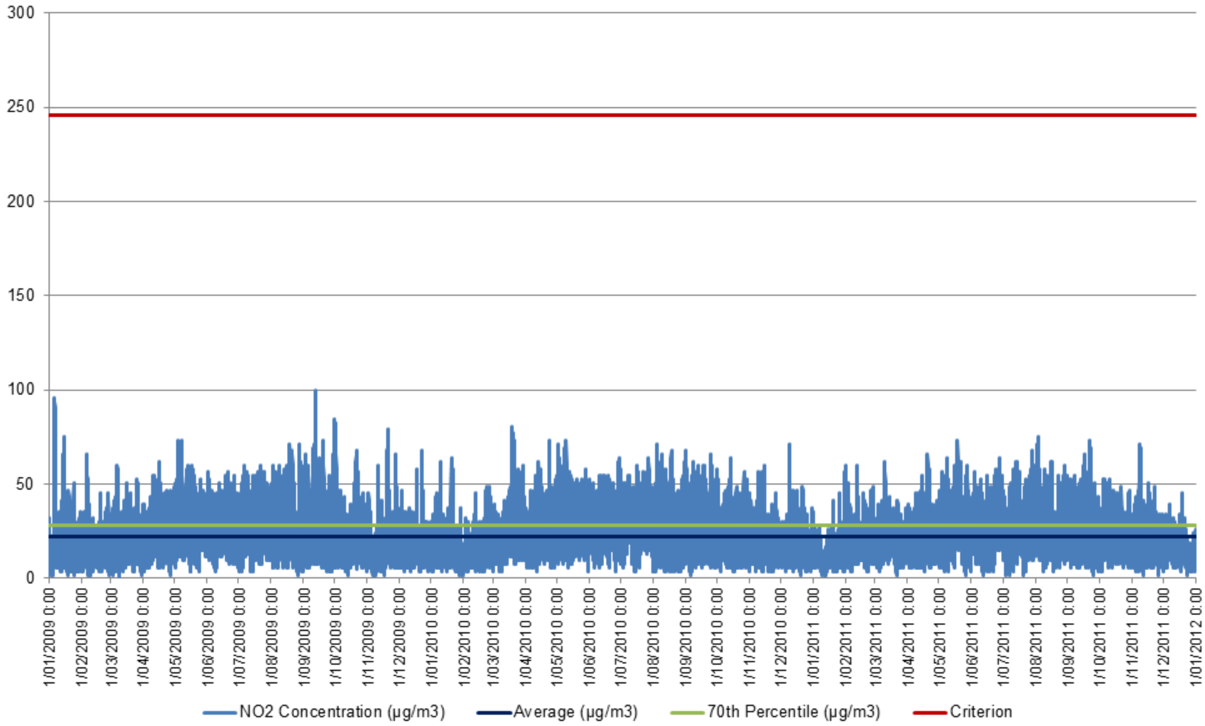

Chart 3 **Combined OEH 24 hour NO_2 concentrations, 2009 - 2011**

Table 5 **Combined OEH monitoring data from Lindfield and Prospect – one hour average NO_2 ($\mu g/m^3$) – 2009 to 2011**

Statistic	Year			
	All	2009	2010	2011
Maximum	100	100	81	75
95th percentile	47	47	49	47
Average	22	22	23	22
Number of exceedences of EPA criterion (246 $\mu g/m^3$)	0	0	0	0

Table 6 **Combined OEH monitoring data from Lindfield and Prospect – one hour average O_3 ($\mu g/m^3$) – 2009 to 2011**

Statistic	Year			
	All	2009	2010	2011
Maximum	247	218	204	247
95th percentile	76	86	76	71
Average	33	36	32	32

Carbon monoxide concentrations were very low relative to the ambient criteria for both the one hour and eight hour averaging periods, as shown in **Table 7** and **Table 8**.

Table 7 OEH monitoring data from Prospect – one hour average CO (μg/m³) – 2009 to 2011

Statistic	Year			
	All	2009	2010	2011
Maximum	3,625	3,625	3,250	2,875
95th percentile	1,000	1,125	1,000	1,000
Average	433	451	419	419

Table 8 OEH monitoring data from Prospect – eight hour average CO (μg/m³) – 2009 to 2011

Statistic	Year			
	All	2009	2010	2011
Maximum	2602	2602	1452	1337
95th percentile	791	906	748	733
Average	369	388	369	356

The OEH undertook ambient monitoring of a number of air toxics between 1996 and 2001 at 25 sites (DEC, 2004). Samples were collected for 81 pollutants, including VOCs. Of the measured pollutants, only three required further investigation to ensure they remained at acceptable levels in the future – these were benzene, 1,3-butadiene and benzo(a)pyrene. Additional testing conducted between 2008 and 2009 measured concentrations of a number of pollutants including benzene, toluene and xylenes at Turella and Rozelle. Concentrations of all measured pollutants were all well below the monitoring investigation levels. As such, concentrations of air toxics in the Sydney region are not considered to be a primary issue of concern.

3.1.1 Project monitoring

Five air quality monitoring stations were installed and commissioned along the project corridor in late 2013, hereafter referred to as the project monitoring (refer to **Figure 5** and **Table 9**). Monitoring at these stations is ongoing. The parameters monitored at each station and the data collection standards are summarised in **Table 10**.

The air quality monitoring stations were sited to serve as either a road monitoring station or an ambient monitoring station. The road stations were located along Pennant Hills Road to enable characterisation of air quality along this road. The ambient stations were used to supplement background air quality data collected at the OEH's Prospect and Lindfield regional air quality stations. The locations of the project monitoring stations were determined with consideration of a number of criteria, including distance from major roads. The locations of the monitoring stations were intended to gather background air quality information to characterise the subregional airshed and to appreciate the levels of pollutants experienced by suburban receivers. The locations of the monitoring stations were not, therefore, linked to the location of ventilation facilities or portals.

Table 9 Project monitoring network details

Site Name	Coordinates	Height above Sea (m)	Commencement Date	Station Designation
Headen Sports Park	33º43'26.6"S 151 º4'44.42"E	176	20/11/13	Ambient
James Park	33º42'2.59"S 151 º6'48.46"E	177	03/12/13	Ambient
Observatory Park	33º44'25.29"S 151 º3'49.81"E	193	05/12/13	Road
Brickpit Park	33º43'25.12"S 151 º5'23.76"E	235	13/12/13	Road
Rainbow Farm Reserve	33º45'38.83"S 151 º2'40.25"E	112	16/1/14	Ambient

Table 10 Monitoring parameters of the project monitoring stations and standards

Parameter measured	Relevant standard
NO, NO_2, NOx	AS 3580.5.1 - 1993
CO	3580.7.1-1992
Methane / non-methane / VOC	AS 3580.11.1-1993
Sulfur dioxide (SO_2)	AS 3580.1.1-2008
Ozone (O_3)	AS 3580.6.1-1990
PM_{10} (BAM 1020)	3580.9.11-2008
$PM_{2.5}$ (BAM 1020)	In-house Ecotech method
Vector wind speed (horizontal)	AS 3580.14-2011
Vector wind direction	AS 3580.14-2011
Sigma	AS 3580.14-2011
Rain	AS 3580.14-2011
Solar radiation	AS 3580.14-2011
Ambient temperature	AS 3580.14-2011
Relative humidity	AS 3580.14-2011

The data measured between December 2013 and March 2014 are summarised in **Table 11** and **Table 12**.

Table 11 Data summary: project ambient monitoring stations – December 2013 – March 2014

Pollutant	Averaging Period	Statistic	Project Ambient Monitoring Stations			Maximum
			Headen Sports Park	Rainbow Farm Reserve	James Park	
PM_{10}	24 hour	Maximum	40	22	37	40
		95th percentile	26	18	32	32
		Average	15	12	23	23
$PM_{2.5}$	24 hour	Maximum	22	8	23	23
		95th percentile	15	7	21	21
		Average	9	4	15	15
NO_2	1 hour	Maximum	59	64	59	64
		95th percentile	27	35	29	35
		Average	13	17	12	17
CO	1 hour	Maximum	100	100	91	100
		95th percentile	31	42	33	42
		Average	14	21	15	21
O_3	1 hour	Maximum	143	141	158	158
		Maximum	71	66	72	72
		Average	33	27	32	33

Table 12 Data summary: project road monitoring stations – December 2013 – March 2014

Pollutant	Averaging Period	Statistic	Project Road Monitoring Stations		Maximum
			Observatory Park	Brickpit Park	
PM_{10}	24 hour	Maximum	41	48	48
		95th percentile	35	35	35
		Average	22	21	22
$PM_{2.5}$	24 hour	Maximum	26	25	26
		95th percentile	20	17	20
		Average	11	9	11
NO_2	1 hour	Maximum	121	90	121
		95th percentile	69	42	69
		Average	32	20	32
CO	1 hour	Maximum	182	108	182
		95th percentile	88	52	88
		Average	33	25	33
O_3	1 hour	Maximum	109	148	148
		95th percentile	54	64	64
		Average	23	28	28

Further details of the background concentrations used in the assessment are provided in **Section 4.2.12**.

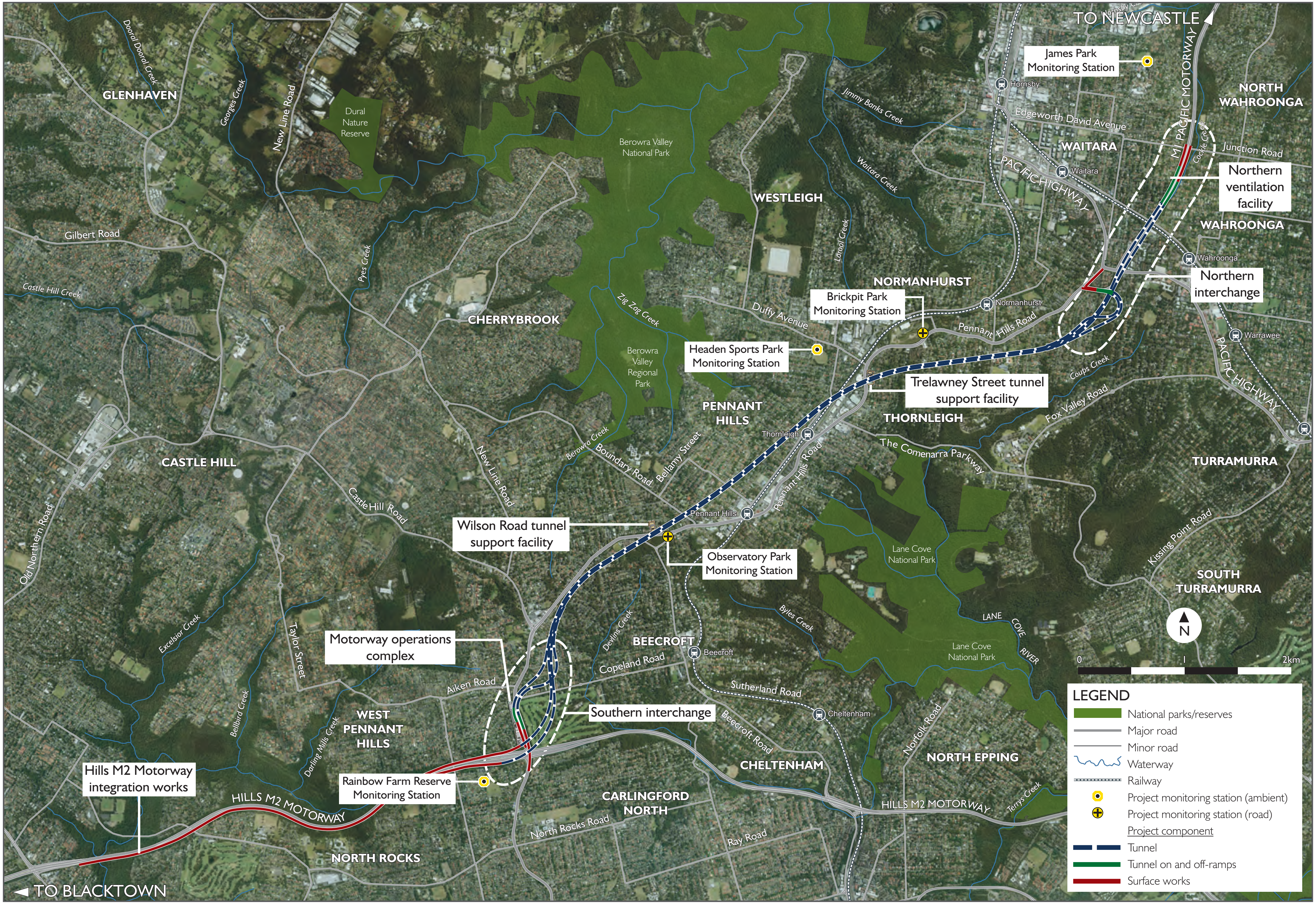

Figure 5 Local air quality monitoring stations

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3.2 Terrain and land use

The terrain along the project corridor rises from an elevation of around 144 metres (Australian Height Datum) at the southern interchange to an elevation of around 180 metres (Australian Height Datum) at the northern interchange. A number of elevated peaks occur along the project corridor, with terrain generally falling to the south-east and to the north-west away from the Pennant Hills Road ridge line.

Land use within proximity of the project primarily consists of urban areas, with pockets of open space and native vegetation. While the main alignment tunnels traverse a variety of land use zonings, surface works would only occur at a limited number of discrete locations. Operational facilities such as tunnel support facilities and ventilation outlets would be located in areas surrounded by residential dwellings, interspersed with commercial, light industrial and recreational land uses.

3.3 Receivers

Receivers are identified by the EPA as anywhere someone works or resides or may work or reside, including residential areas, hospitals, hotels, shopping centres, play grounds, recreational centres, and the like. Due to its location in a highly built-up suburban area, there are a large number of sensitive receivers in the project area. Many residences are located adjacent to the existing major road network, which would be most affected by emissions from the vehicles using those roads. Further details about the way sensitive receivers were addressed in this assessment are provided in **Section 4.2.6**.

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4.0 Assessment methodology

4.1 Construction air quality assessment

Construction emissions for large road projects are complex due to the number of construction activities, the distribution of sites across a large geographical area, and the transitory nature of many individual construction activities at particular locations. As such, the potential construction air quality impacts associated with the project were assessed qualitatively by describing the nature of proposed works, plant and equipment, potential emissions sources and levels. Proactive and reactive mitigation measures were suggested to reduce the potential for adverse effects on local air quality and sensitive receivers to occur.

4.2 Operational air quality assessment

This section outlines the approach taken to the modelling and assessment of the operational air quality implications of the project, including:

- Assessment scenarios.
- The dispersion models.
- Meteorological data.
- Terrain and land use data.
- Sensitive receivers.
- Model input parameters.
- Emissions assumptions (estimation and rates).
- Ventilation outlet parameters.
- Cumulative assessment.

4.2.1 Assessment scenarios

Following consultation with the EPA, who requested the assessment of worst-case impacts of the project, a range of operational scenarios were developed.

The three principal air quality scenarios summarised in **Table 13** were developed to assess the operational air quality impacts of the project to allow:

- Comparison of air quality with and without the project.
- Assessment of air quality at the expected opening of the project (2019), and after ten years of operation (2029), based on forecast traffic volumes for those years.
- Assessment of air quality during an infrequent event of a breakdown in one of the project's main alignment tunnels.

The function of these operational scenarios was to demonstrate the most likely performance of the project under relevant operating conditions.

The assumptions and methods used for the different scenarios are summarised in the following sections.

The emissions from the ventilation outlets would be directly proportional to the hourly traffic volumes in each tunnel. The emission rates and concentrations would both vary in accordance with these traffic volumes, as well as the ventilation outlet volumetric flow rates (fan rates). As such, all scenarios incorporated the use of hourly varying emission rates and concentrations to reflect the expected traffic volumes.

A description of emission estimation techniques applied to each scenario is provided in **Section 4.2.8**.

Table 13 Assessment scenarios – operational phase

Description	Assessment year	Model	Scenario rationale
Without project	2019	CAL3QHCR	This scenario was modelled to provide a basis for comparison with air quality predictions under scenarios that include operation of the project. This scenario is referenced as scenario 1.
	2029		
With project – expected traffic flows	2019	CALPUFF and CAL3QHCR	This scenario was modelled and assessed as representative of the likely operational performance of the project with expected traffic volumes with variable hourly emissions concentrations This scenario is referenced as 'with project – expected traffic flows 2019' (scenario 2a) and 'with project – expected traffic flows 2029' (scenario 2b).
	2029		
Breakdown scenario	N/A	N/A	This scenario was considered to provide context to potential air quality impacts in the infrequent event of a breakdown in the project tunnels.

4.2.1.1 Without project (Scenario 1)

This scenario assessed the standard 'do nothing' scenario, which predicted future pollutant concentrations from the surface roads in the event that the project is not constructed. Emissions were assessed using the CAL3QHCR model and expected future traffic volumes for the existing road network for 2019 and 2029.

The predicted pollutant concentrations for this scenario were expected to be higher than those predicted for the 'with project' scenarios for sensitive receivers located along Pennant Hills Road based on:

- Continued vehicle emissions along Pennant Hills Road at ground level in proximity to receivers along the road.
- Continued traffic growth and congestion along Pennant Hills Road in the absence of the project, leading to less efficient vehicle performance and increased emissions.

Due to size constraints in the model and the reduced zone of influence associated with road emissions compared to ventilation outlet emissions, the number of sensitive receivers assessed in this scenario (and the other scenarios involving surface road modelling) were fewer than assessed in the other scenarios. All of the sensitive receivers assessed in the CAL3QHCR model, however, were assessed in CALPUFF.

4.2.1.2 With project – expected traffic flows (Scenarios 2a and 2b)

This scenario assessed the forecast hourly traffic volumes expected to use the project at opening in 2019 (Scenario 2a) and ten years after opening in 2029 (Scenario 2b). The scenario used variable pollutant concentrations based on hourly traffic flows during a 24 hour period, which reflect increases and decreases in traffic volumes using the project over the course of a day. This scenario represents the most likely actual performance of the project in 2019 and 2029.

Pollutant emission concentrations and rates for hourly vehicle volumes were calculated using the PIARC emission factors for light and heavy vehicles (refer to PIARC, 2012 for details of the emission factors). This scenario took into account that the variations in flow rate throughout the day based on hourly traffic volumes, with the consequence that pollutant emissions concentrations would also vary as more or less fresh air is drawn into the tunnel (based on changing vehicle numbers and speed, and changing tunnel fan speeds).

Based on the design of the project, a minimum flow rate of 300 cubic metres per second of air was assumed to be vented through each ventilation outlet at any time, which would correspond with periods of the lowest traffic volumes in the project tunnels.

4.2.1.3 Breakdown scenario

This scenario was assessed semi-quantitatively by calculating worst-case pollutant concentrations during a breakdown event in the project tunnels, and comparing those concentrations to the concentrations and modelling outcomes for with project – expected traffic flows (Scenarios 2a and 2b). Breakdowns are expected to happen infrequently.

In determining a worst-case breakdown event, two potential scenarios were considered:

Breakdown scenario A

- It was assumed that one of the tunnels was completely blocked at one exit.
- Vehicles would continue to enter the tunnel for a ten minute period, after which the tunnel would be closed to inbound traffic for the direction that was affected (that is, the northbound or southbound direction).
- The number of vehicles was assumed to be 2,800 PCU, which would represent the indicative number of vehicles that could be accommodated within one tunnel when the average speed drops below 20 kilometres per hour.
- Vehicles within the tunnel would be idling continuously for 55 minutes. It was conservatively assumed that no vehicle engines would be turned off. In reality, the measures described above would prevent the tunnel from becoming full of vehicles and drivers would be directed to turn off their engines.
- The operation of the tunnel ventilation system was assumed to be the same as that occurring during peak traffic flows. The jet fans may be turned on, but the volumetric flow rate of emissions from the ventilation outlets would remain the same.

Breakdown scenario B

- The tunnel was assumed to be limited to one lane of traffic, with the assumption that the traffic was queuing from the start of the tunnel to the accident scene near the end of the tunnel. Vehicles were assumed to be moving very slowly past the accident at a low speed creating congestion in the tunnel.
- Vehicles would continue to enter the tunnel for a ten minute period, after which the tunnel would be closed to inbound traffic for the affected direction (that is, the northbound or southbound direction).
- Vehicles would travel at speeds of less than 20 kilometres per hour.
- The number of vehicles was assumed to be 2,800 PCU, which would represent the indicative number of vehicles that could be accommodated within one tunnel when the average speed drops below 20 kilometres per hour.
- The operation of the tunnel ventilation system was assumed to be the same as that occurring during peak traffic flows. The jet fans may be turned on, but the volumetric flow rate of emissions from the ventilation outlets would remain the same.

Of these two scenarios, breakdown scenario A was identified as the worst-case scenario as all vehicles entering the tunnel may be in the tunnel idling for up to one hour (assumed time to clear the accident). As vehicles would be exiting the tunnel with an ever decreasing overall emission rate, breakdown scenario B would be expected to have a lower overall emission rate compared with breakdown scenario A. On this basis, breakdown scenario A was considered the worst-case and was carried forward for more detailed assessment.

4.2.2 Design analysis

In addition to the scenarios summarised in **Table 13**, two design analyses were assessed to test the performance of the project's ventilation system and to assist regulatory agencies in considering air quality performance criteria that may be applied to the project. Both of these analyses represented conditions that are unlikely to occur in practice, but provide confidence that the project has the ability to comply with applicable air quality criteria under all conditions. The design analyses also provide a useful basis to inform further development of the project's ventilation system during detailed design. The design analyses considered for the project are detailed below. A description of emission estimation techniques applied to each scenario is provided in **Section 4.2.8**.

4.2.2.1 Design analysis A

This design analysis assessed the condition where the theoretical maximum design capacity of each main alignment tunnels, being 4,000 passenger car units (PCU) per hour, is reached during peak hours. As a constant flow of 4,000 PCU per hour would not occur for each hour of a 24 hour period, the traffic profile for 'with project –

expected traffic flows 2019 ' (scenario 2a) was scaled to create a 24 hour profile of traffic flows peaking at 4,000 PCU. That is, 'with project – expected traffic flows 2019 ' and its predicted diurnal patterns were scaled up so that the traffic volumes followed the expected diurnal (daily) pattern but the peak flow was 4,000 PCU. The design analysis was modelled for the opening year (2019) only to reflect a worst case scenario with no expected improvement in fuel standards and vehicle performance over time (such as may be expected by 2029).

Design analysis A is a theoretical worst case scenario modelled to consider what the air quality performance of the project would theoretically be in the event that the project reached 4,000 PCU during peak periods. To assess this scenario, a 24 hour profile of traffic volumes using the project was generated by scaling scenario 2a traffic volumes across the day so that the peak hour volumes reached 4,000 PCU per hour.

For the realistic scenarios, the volumes of traffic forecast to use the project in 2019 and 2029 were based on a strategic transport model, which factors in a number of external influences to forecast traffic demand, such as land use projections, population and employment forecasts and infrastructure projects either under construction or planned in the Sydney metropolitan area (refer to Chapter 5 of technical working paper: traffic and transport (AECOM, 2014). Forecast traffic volumes from the strategic model represent a realistic projection of traffic growth and demand for the project based on current knowledge of these factors, which are reflected in 'with project – expected traffic flows' scenario.

In contrast, design analysis A contemplates a substantially higher demand and usage of the project, and reflects the design capacity of the project tunnels. In order for the traffic volumes envisaged by this analysis to be reached, local and regional plans relating to land use, population and employment projects, and major transport infrastructure would have to change significantly. The probability of sufficient changes occurring to bring about the traffic volumes contemplated by design analysis A is expected to be very low.

The design analysis also does not take into account any improvements in fuel standards and vehicle performance over time beyond the year 2020. Vehicle and fuel technology is likely to change over this extended time period, with the expectation that emissions from the project and their effects on the surrounding environment would be lower than assumed for the period 2019 to 2029.

4.2.2.2 Design analysis B

Design analysis B was assessed for 2019 and 2029. The scenario was similar to Scenarios 2a and 2b, but assessed constant emission concentrations (rather than variable emission concentrations) over a 24 hour period. The design analysis is theoretical and was undertaken to assist regulatory authorities in assessing and determining potential discharge concentration limits that may be applied to the ventilation outlets through conditions of approval. Assuming that emissions concentration limits are applied to the ventilation outlets, as is common practice, the results of the design analysis will demonstrate the air quality performance of the project if it operates continuously at those emissions concentration limits. In reality, emissions concentrations would be variable (as considered in Scenarios 2a and 2b) due to changing traffic volumes and tunnel fan operation over a daily cycle.

The constant maximum pollution emissions concentrations were calculated by using the maximum hourly emission concentrations (worst case concentrations) for each pollutant for each main alignment tunnel from Scenarios 2a and 2b with the forecast hourly volumetric flow rates to back-calculate hourly emission rates. The scenarios were modelled for both 2019 (Design analysis B (2019) and 2029 (Design analysis B (2029). As the results of these scenarios are not directly applicable to the expected air quality performance of the project, they were not considered in detail in the body of this report, but included in **Appendix G** for information.

4.2.3 Dispersion models

The CALPUFF suite of models was used to model pollutant dispersion from the project ventilation outlets and to estimate the project's effects on ambient air quality. The CAL3QHCR model was used to model pollutant concentrations associated with emissions from vehicles on surface roads around the project. The outputs from CALPUFF and CAL3QHCR were combined with the adopted ambient (background) pollutant concentrations (where applicable) to provide a cumulative estimate of pollutant concentrations in the vicinity of the project during its operation.

The models are briefly described in the following sections with further details provided in **Appendix D**. The modelling was undertaken in accordance with relevant guidance documents (DEC, 2005; Barclay & Scire, 2011).

4.2.3.1 CALPUFF

The CALPUFF suite of programs, including meteorological (CALMET), dispersion (CALPUFF) and post processing modules (CALPOST), is an advanced non-steady state modelling system designed for meteorological and air quality modelling. CALPUFF is approved for use in NSW by the EPA, particularly in applications involving complex terrain, non-steady-state conditions, in areas where coastal effects may occur, and/ or when there are high frequencies of stable or calm meteorological conditions. CALPUFF was selected for use in this assessment as the topography of the area surrounding the project is complex (as shown in **Appendix E**) and is considered close enough to the coast to be potentially affected by coastal breeze circulation. The PRIME downwash algorithm was used to account for the potential effects of nearby buildings on the ventilation outlet emissions.

4.2.3.2 CAL3QHCR

The CAL3QHCR model is a specialised model for the assessment of road emissions. This model was considered to be the most appropriate choice for modelling the traffic movements on roadways external to the project tunnels for this assessment due to its ability to process hourly-varying data and large numbers of receivers. The line source model predicts pollutant concentrations of carbon monoxide, nitrogen dioxide, particulate matter, and other inert gases from idle or moving motor vehicles based on the Gaussian diffusion equation. The model was accessed through the CALRoads View user interface.

4.2.4 Meteorological data

The meteorological data used in the dispersion model are of fundamental importance, as these data drive the predictions of the transport and dispersion of the air pollutants in the atmosphere. The most critical parameters are:

- Wind direction, which determines the initial direction of transport of pollutants from their sources.
- Wind speed, which dilutes the plume in the direction of transport and determines the travel time from source to receiver.
- Atmospheric turbulence, which indicates the dispersive ability of the atmosphere.

Both measured and prognostic meteorological data were used in this assessment. Meteorological data were sourced from five local surface meteorological stations located in the Sydney basin (Lindfield, Terrey Hills, Richmond RAAF Base, Prospect and Sydney Airport), operated by the Bureau of Meteorology (BOM) and the OEH. The locations of the meteorological stations are shown in **Figure 4**. These measured data were used in conjunction with MM5 prognostic model data to simulate the complex three-dimensional meteorological patterns that exist within the modelling domain, accounting for the effects of local topography and changes in land surface characteristics.

MM5, the Fifth-Generation Penn State/NCAR Mesoscale Model (Dudhia et al., 2001) is a regional mesoscale model used for generating prognostic three-dimensional meteorological data. Gridded hourly three-dimensional MM5 data resolved at a 12 kilometre resolution were input into the CALMET model to generate the ‘initial guess’ wind field in CALMET, after which the hourly observations were included by the program to generate the final three-dimensional wind fields for use in CALPUFF.

The meteorological data used in the dispersion model are of fundamental importance, as they drive the transport and dispersion of air pollutants in the atmosphere. For dispersion modelling, regulatory air quality assessments in NSW must be conducted using at least one year of site-specific meteorological data. According to the Approved Methods (DEC, 2005), the meteorological data must be correlated against a longer-duration site-representative meteorological database of at least five years in order to be deemed acceptable. It must be clearly established that the data adequately describe the expected meteorological patterns at the site under investigation (for example, in terms of wind speed, wind direction, ambient temperature, atmospheric stability class, inversion conditions and katabatic drift).

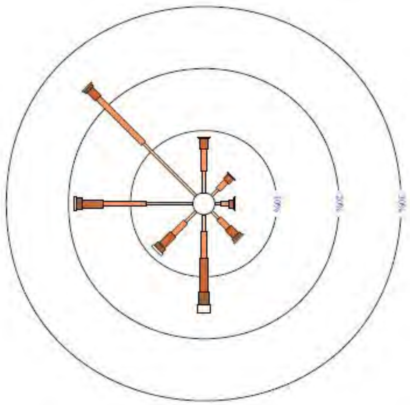
The dispersion modelling was undertaken for a three year period (January 2009 – December 2011). Further details regarding the meteorological data are provided in **Appendix F**, which also contains analyses of the meteorological data. Based on the results of the analyses, the meteorological data generated for use in the dispersion model were considered to be representative of local meteorological conditions and, therefore, suitable for use in this assessment.

In this assessment, the goal was to produce three full years of hourly weather observations containing real weather sequences, which represent the long-term climatic mean conditions for the North Sydney region. While defining the characteristics of a meteorological year which make each year ‘typical’ is difficult, properties include the following:

- The meteorological measures (temperature, wind speed, direction and RH) have frequency distributions which are similar to the long term distributions.
- The relationships among the different measurements should be similar to the relationships observed in nature.

For the purpose of analysis, the three years of data from the BOM Sydney Airport station used as inputs in the modelling, were compared to the long term (30 year) statistics from this site in order to show the suitability of these years for the modelling assessment. Sydney Airport was used in this analysis as it is one of several key surface meteorological stations used in the modelling. Wind roses are provided in **Figure 6** and **Figure 7**, and monthly summaries of temperature, relative humidity and wind speed are provided in **Table 14** and **Table 15** for 9 am and 3 pm conditions. As shown, the data used as inputs for the dispersion modelling were very similar to the long term average data at this location and were, subsequently, considered appropriate for use. The data from Sydney Airport were only one source of input data to CALMET, and the actual data used in the modelling were a combination of all the inputs. Wind roses from the CALMET output data and the wind roses from all the input meteorological stations are provided in **Appendix F**.

As well as the BOM meteorological stations (Sydney, Richmond and Terrey Hills), two NSW OEH sites were also used as inputs to the CALMET model (Lindfield and Prospect). **Table 16** shows the five-year statistics for Prospect station for each month of the year compared to the data for 2009, 2010 and 2011. As shown, the data from the years used in the modelling are very similar to the five year averages. The data used in the modelling were, therefore, considered appropriate for use.



9am Sydney Airport, BOM, Annual (1929 – 2013)

(Long term wind rose)

Legend for long term wind rose (1929 – 2013)

0 – 10 km/h 0.0 – 2.8 m/s

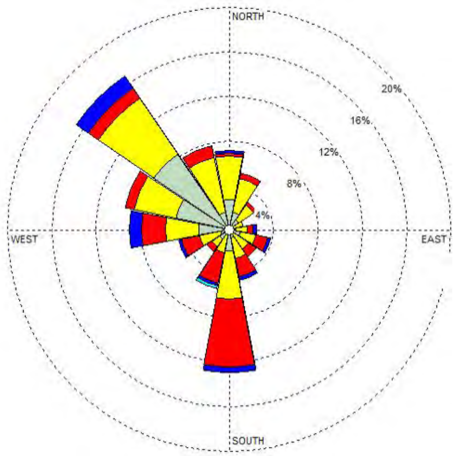
10 – 20 km/h 2.8 – 5.6 m/s

20 – 30 km/h 5.6 – 8.3 m/s

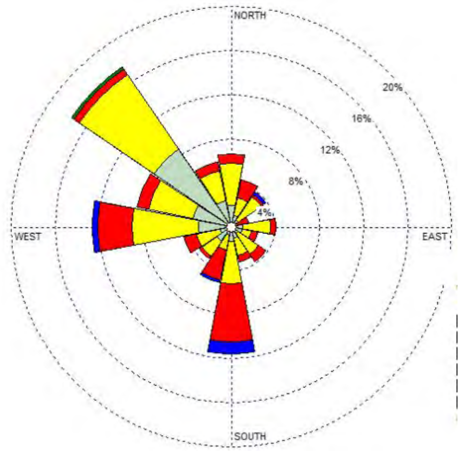
30 – 40 km/h 8.3 – 11.1 m/s

> 40 km/h > 11.1 m/s

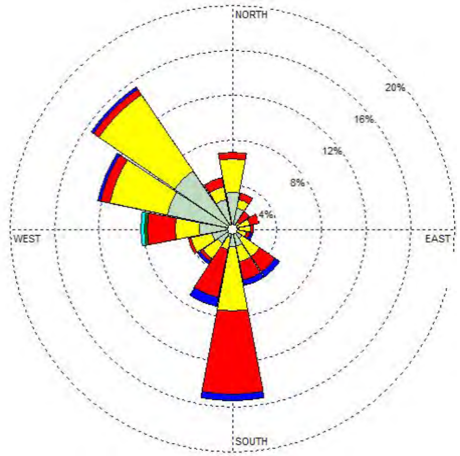
Legend for 2009, 2010, 2011



9am Sydney Airport, BOM Annual 2009



9am Sydney Airport, BOM, Annual 2010



9am Sydney Airport, BOM, Annual, 2011

Figure 6 Comparison of long term (1929 – 2013) data and data from the modelling period (2009 – 2011) from Sydney Airport - 9 am

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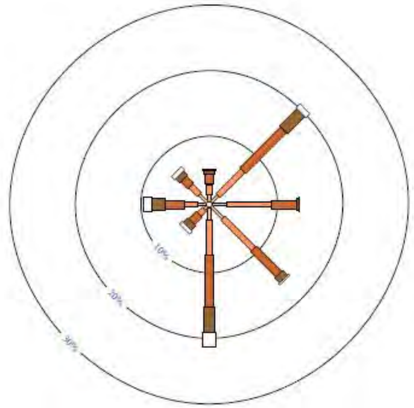


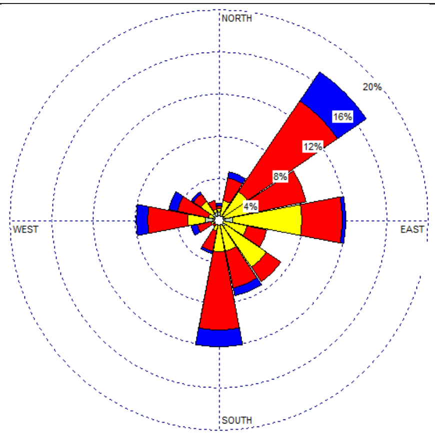
3pm Sydney Airport, BOM, Annual (1929 – 2013)

(Long term wind rose)

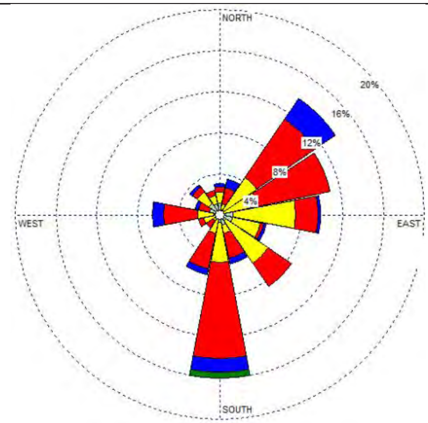
Legend for long term wind rose (1929 – 2013)

0 – 10 km/h	0.0 – 2.8 m/s
10 – 20 km/h	2.8 – 5.6 m/s
20 – 30 km/h	5.6 – 8.3 m/s
30 – 40 km/h	8.3 – 11.1 m/s
> 40 km/h	> 11.1 m/s

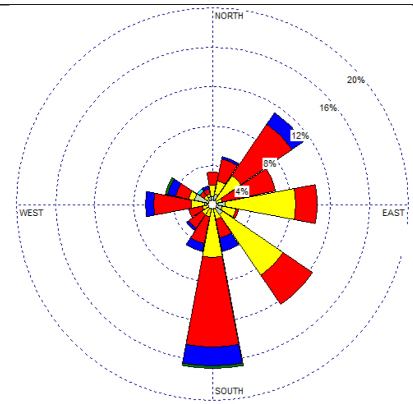
Legend for 2009, 2010, 2011



3pm Sydney Airport, BOM, Annual (2009)



3pm Sydney Airport, BOM (2010)



3pm Sydney Airport, BOM (2011)

Figure 7 Comparison of long term (1929 – 2013) data and data from the modelling period (2009 – 2011) from Sydney Airport – 3 pm

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Table 14 Comparison of 9 am long term averages (1929 – 2013) and data from the modelling period (2009, 2010 and 2011) – Sydney Airport Monitoring Station (BOM)

Data	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Temperature (^{o}C)												
30 year average	22.4	22.3	21.1	18.2	14.6	11.9	10.8	12.5	15.7	18.4	19.9	21.6
Modelling period data												
2009	24.2	23.3	22.9	19.1	16.2	13.2	12.6	14.8	18	18.2	23.2	23.2
2010	24.1	24.6	23.1	19.7	15.5	13	12.2	13.6	16.8	18.2	21.2	22.7
2011	24.8	24.8	22.8	18.3	14.3	13.4	11.9	14.2	17.1	18.4	22.1	20.1
Relative humidity (%)												
30 year average	70	73	73	71	73	74	71	65	62	61	64	66
Modelling period data												
2009	61	71	65	69	68	72	65	50	48	62	62	63
2010	67	70	65	67	70	68	72	54	58	61	67	65
2011	67	66	68	68	66	67	67	70	56	64	66	69
Wind speed (km/h)												
30 year average	4.0	3.8	3.6	3.6	3.5	3.7	3.7	4.0	4.3	4.5	4.4	4.1
Modelling period data												
2009	5.3	5.8	4.3	6.1	5.3	4.3	5.1	4.9	6	6	5.8	5.9
2010	5.6	5.9	5.4	4.6	4.8	5.6	4.7	5.6	5.2	4.8	5.9	5.8
2011	5.9	4.9	5.8	5.5	5.8	6.2	6.3	4.8	5.4	5.1	5.2	5.9
Historical data from Sydney Airport obtained from http://www.bom.gov.au/climate/averages/tables/cw_066037.shtml												

Table 15 Comparison of 3 pm long term averages (1929 – 2013) and data from the modelling period (2009, 2010 and 2011) – Sydney Airport Monitoring Station (BOM)

Data	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Temperature (^{o}C)												
30 year average	24.8	24.8	23.9	21.7	19.0	16.6	16.1	17.2	19.0	20.7	22.1	23.9
Modelling period data												
2009	26.7	24.6	24.4	21.2	19.0	17.2	17.1	20.2	21.4	20.4	25.2	24.2
2010	25.7	26.3	25.2	23.0	19.1	16.4	16.1	17.7	18.9	20.3	22.3	25.1
2011	26.9	27.2	24.1	20.6	17.9	16.5	16.5	17.9	19.6	20.6	23.6	21.7
Relative humidity (%)												
30 year average	60	63	61	59	58	57	52	49	51	54	56	58
Modelling period data												
2009	53	66	58	60	59	56	45	37	41	52	56	62
2010	61	61	58	55	60	57	62	42	53	61	64	56
2011	59	55	61	61	56	55	49	55	47	56	60	63
Wind speed (km/h)												
30 year average	6.7	6.4	5.8	5.4	4.8	4.9	5.1	5.8	6.4	6.8	7.0	7.0
Modelling period data												
2009	8.8	8.4	7.2	7.7	6.7	5.1	6.0	6.4	7.8	7.9	8.3	9.1
2010	8.6	7.4	7.5	6.0	5.9	6.1	6.0	7.0	6.8	8.1	8.0	8.1
2011	7.9	7.6	7.4	6.8	7.1	7.3	6.6	5.9	7.9	7.1	8.0	7.3
Historical data from Sydney Airport obtained from http://www.bom.gov.au/climate/averages/tables/cw_066037.shtml												

Table 16 Comparison of long term averages (2007 – 2011) and data from the modelling period (2009, 2010 and 2011) – Prospect Monitoring Station (OEH)

Data	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Temperature (^{o}C)												
5 year average	22.3	22.3	20.9	17.5	14.3	12.1	11.2	12.9	15.7	17.8	20.6	21.2
Modelling period data												
2009	23.8	22.2	21.1	17.7	14.7	12.1	11.7	14.0	16.8	17.0	22.7	22.5
2010	24.1	23.8	21.9	18.8	14.7	11.8	11.8	12.5	15.4	17.7	20.1	22.1
2011	24.2	24.5	21.5	17.3	13.5	12.2	11.3	13.6	15.9	17.5	21.4	19.0
Wind direction (degrees)												
5 year average	153	175	188	214	233	240	245	243	216	190	168	170
Modelling period data												
2009	153	177	186	214	213	248	251	245	229	190	169	161
2010	167	165	189	218	235	236	229	253	225	176	165	176
2011	143	187	198	226	236	251	254	225	210	188	168	164
Wind speed (km/h)												
5 year average	1.9	1.8	1.7	1.8	1.5	1.7	1.9	2.0	2.1	2.0	2.0	2.0
Modelling period data												
2009	1.8	1.9	1.5	1.9	1.5	1.4	1.7	1.9	2.3	2.2	2.0	2.0
2010	2.0	1.7	1.7	1.6	1.5	1.6	1.6	2.4	1.9	1.9	1.8	2.0
2011	1.8	1.9	1.7	1.8	1.8	1.9	2.0	1.5	2.1	1.6	2.0	1.7

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4.2.5 Terrain and land use data

The underlying terrain and dominant land use are important functions of plume transport modelling. Gridded terrain elevations for the modelling domain were derived from the NASA Shuttle Radar Topography Mission (SRTM). The NASA SRTM data are available as three arc-second, or around 90 metre resolution, data. Land use within the study area primarily consists of urban areas, which are interspersed with rangeland and forest land. Further details of the terrain and land use data used in the dispersion modelling are provided in **Appendix E**. Land use data within the study area were derived from the Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES) and supplied to AECOM by the OEH. The data are representative of the actual area associated with the project, are recent and of a very fine resolution to increase the accuracy of the modelling. This assessment used the S35E131.HGT, S35E150.HGT, S34E151.HGT and, S34E150.HGT files.

The land use data used in this application are different to the default land use data used in The Air Pollution Model (TAPM) and for most CALMET model applications outside of the United States, which tend to use the USGS one kilometre land use data set. Until recently, the USGS one kilometre global land use data set was the most readily available data set for air quality applications. Limitations of this data set, however, include its age (more than 20 years old), coarse resolution (between 900 metres and 1.2 kilometres), and the fact that it is categorised according to the North American land use category system, which does not correspond to all relevant Australian land use types.

As stated above, underlying dominant land use is an important function of the plume transport. The inclusion of the Australian land use data set is, therefore, an important relevant addition to this modelling application as the data are recent, relevant and of a very fine resolution. For this project, specific surface characteristics, albedo, roughness length and leaf area index for the Sydney basin were determined from Gero and Pitman (2006) for bushland, agricultural land, dense urban, new urban and established urban areas. Bushland is described as natural vegetation (primarily around 20 metre trees with 40 per cent cover). Agricultural land incorporates all agricultural activity in western Sydney, which is mostly pasture for grazing or market gardens. Urban categories are split into dense urban (which is confined to the Sydney and Parramatta central business districts), new urban (newly established residential suburbs lacking mature trees), and established urban (residential suburbs with mature trees).

4.2.6 Discrete receivers

Due to the location of the project in a highly built-up urban area, a large number of receiver locations were generated and included in the dispersion model to generously cover the region extending around 17 x 10 kilometres from the project. For this assessment, each grid point within the modelling domain was treated as a sensitive receiver. A higher density of discrete receiver locations was entered into the dispersion model around the two ventilation outlets (grid spacing of 150 metres) and their immediate vicinity (approximately five by five kilometres around each outlet). The resolution of the receivers decreased with increased distance from the two outlet emission points (spacing of 300 metres between receivers). Additional receiver locations located along the project corridor in proximity to the portals were also included (with a spacing of 10 metres, 35 metres, 60 metres, 105 metres, 160 metres and 225 metres from the road centreline). **Figure 8** shows the receiver network used in the assessment.

A total of 6,919 discrete receiver locations were assessed, each with its own specifically computed terrain height. Of these, 3,332 were located along the project corridor.

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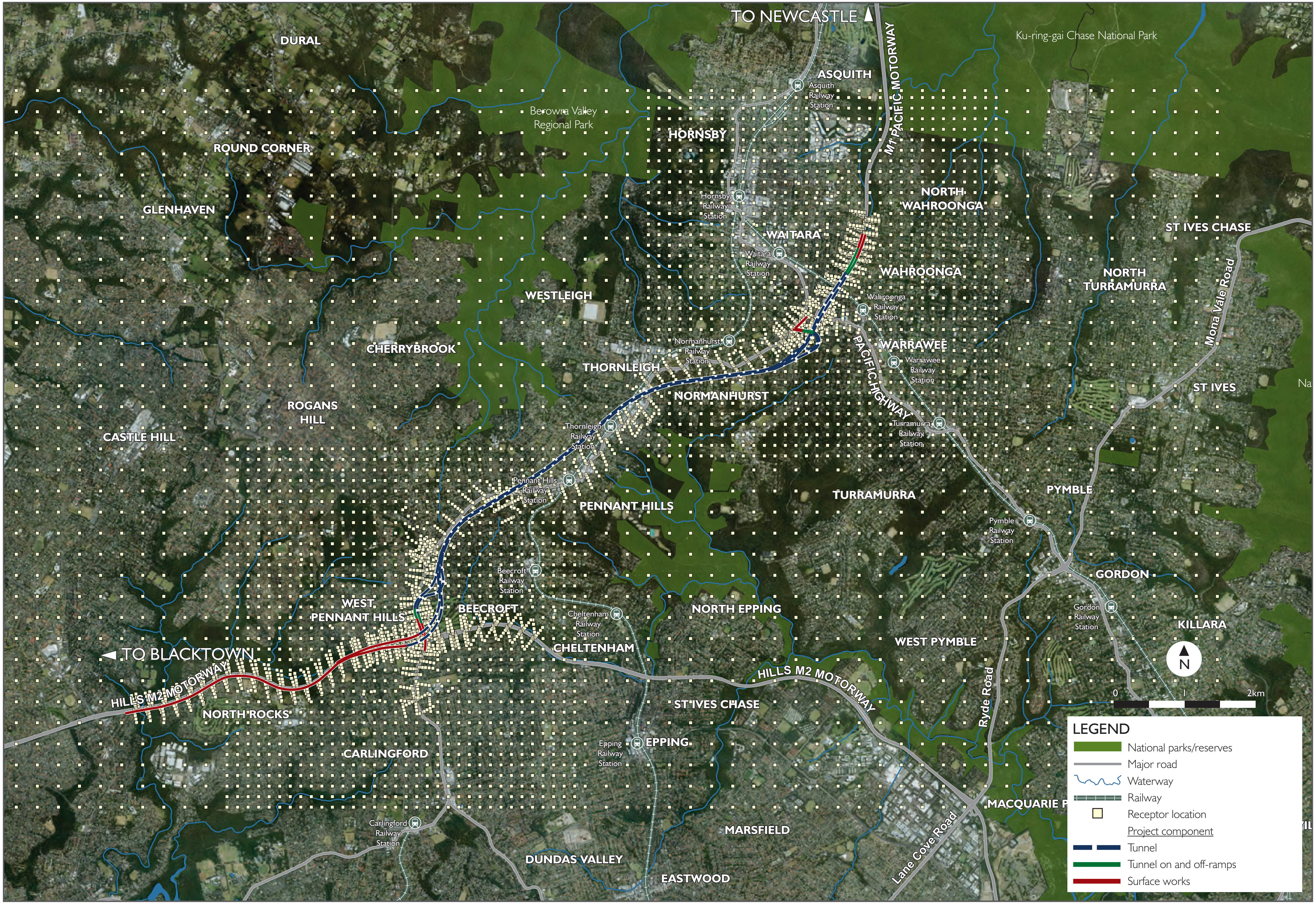

Figure 8 Receiver locations

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4.2.7 Model input parameters

A summary of the data and parameters used as input parameters for CALMET and CALPUFF is shown in **Table 17**. Detailed description and analysis of the surface meteorological station information and land use data are provided in **Appendix F** and **Appendix E** respectively.

Table 17 Summary of meteorological and CALPUFF input parameters – operational assessment

Parameter	Input
CALMET (v6.42)	
Meteorological grid domain	60 kilometres x 62.5 kilometres
Meteorological grid resolution	250 metre resolution (240 x 250 grid cells)
Reference grid coordinate of southwest corner	295.000 E, 6232.000 S
Cell face heights in vertical grid	0, 20, 40, 80, 160, 320, 700, 1300, 1700, 2300 and 3000 m
Years of analysis	2009, 2010 and 2011
Simulation length	3 years (62,280 hours/1,095 days)
Surface meteorological stations	CALMET Hybrid Mode: Run using a combination of MM5 gridded numerological data supplemented by data from five surface meteorological stations operated by BOM and OEH (described below). **Lindfield OEH Monitoring Station** *Hourly data:* Temperature, precipitation, humidity, wind speed and wind direction. *MGA Coordinates (km)*: 328.711 E, 6260.391 S **Terry Hills BOM Monitoring Station (Station No. 066059)** *Hourly data:* Temperature, precipitation, humidity, wind speed and wind direction. *MGA Coordinates (km)*: 335.509 E, 6270.714 S **Richmond RAAF BOM Monitoring Station (Station No. 067105)** *Hourly data:* Temperature, precipitation, humidity, pressure, wind speed and wind direction. *MGA Coordinates (km)*: 293.651 E, 6279.933 S **Prospect OEH Monitoring Station** *Hourly data:* Temperature, precipitation, humidity, wind speed and wind direction. *MGA Coordinates (km)*: 306.745 E, 6258.646 S **Sydney Airport BOM Monitoring Station (Station No. 066307)** *Hourly data:* Temperature, precipitation, humidity, pressure, wind speed and wind direction. *MGA Coordinates (km)*: 331.173 E, 6242.272 S
Upper air meteorological station	No upper air stations. The 3-dimensional gridded prognostic data from MM5 were used as the initial guess wind-field for CALMET.
Terrain data	Terrain elevations were extracted from the NASA Shuttle Radar Topography Mission data set (SRTM 90 metre, 3-arc sec).

Parameter	Input
MM5	
Horizontal resolution	12 kilometres; four tiles with each tile covering approximately 120 kilometres by 120 kilometres
Model Configuration	Full non-hydrostatic model Analysis nudging on outer domain One-way nesting Microphysics – Reisner2 scheme Cumulus – Kain-Fitsch scheme Moisture parameterisation – Reisner Graupel scheme Planetary boundary layer scheme – Mellor-Yamada scheme
Vertical levels	40 vertical half sigma levels, 16 vertical levels below 1000 metres; nine vertical levels above 1000 metres and below 3500 metres; 15 levels above 3500 metres
Three-dimensional variables	Wind speed; wind direction; temperature; relative humidity; pressure; mixing ratios of water vapours, cloud water, rain water, ice and snow
Two-dimensional variables	Precipitation amount, short wave and long wave solar radiation, snow cover, two metre temperature and specific humidity, 10 metre wind speed and direction
Land use data	Land use information was derived from the OEH land use data set between June 2000 and June 2007 for NSW. The data set has a resolution of 150 square metres over the modelling domain.
CALPUFF (v6.42)	
Modelling domain	Modelling domain of around 15 kilometres by 10 kilometres. *MGA SW Coordinates (km*): 315.300 E, 6260.500 S *MGA NE Coordinates (km*): 330.600 E, 6270.701 S
Modelling grid resolution	250 metre grid resolution as per the CALMET meteorological model.
Number of receivers	All grid resolutions provided above were modelled as discrete receiver locations (i.e. no gridded receivers) to account for varying grid resolution over the modelling domain. A total of 6,919 discrete receiver locations resulted from the modelling grids, including 3,332 receivers along the project corridor.
Dispersion algorithm	Turbulence-based coefficients
Hours modelled	26,280 hours (1,095 days) (8,760 hours per year)
Meteorological modelling period	1 January 2009 – 31 December 2011

4.2.8 Emissions estimation

Emission rates were based on internationally-recognised emission factors coupled with projected traffic volumes, including the proportion of heavy vehicles, and tunnel and outlet emission characteristics. Emission rates were calculated for a number of operational scenarios as described in the following sections.

4.2.8.1 Emission factors

Pollutant emissions of PM_{10}, nitrogen oxides and carbon monoxide were estimated using internationally-recognised vehicle emission factors prepared by the World Road Association (PIARC, 2012), which provide Australian-specific emissions based on fleet distribution data and emission standards relevant to Australia. The PIARC emissions dataset was used for the calculation of ventilation design parameters for the project, and is considered to be an appropriate source of emission factors for this dispersion modelling assessment[4]. It should be noted that the authors of the PIARC emission factors state that the factors were developed for the purpose of defining the minimum air flows required to achieve adequate air quality within road tunnels rather than for the purpose of developing emissions inventories, so a safety margin is added to the emission factors. This is expected to result in conservative emissions estimates when used for inventory purposes, such as this assessment.

The PIARC factors were developed to provide real world vehicle emissions, which reflect the age of the vehicle fleet and expected future emissions reductions for new vehicles. Vehicle emission factors require regular updating to reflect the changes in vehicle fleet, stricter emission laws, and advances in vehicle technology, including alternative propulsion systems (hybrid vehicles, electric cars etc.). The PIARC emission factor database was updated in 2012 to reflect existing road vehicles and was extended for vehicles following future emission standards to allow for emission projections in Australia up to the year 2020. The data on which the emission factors are based originated primarily from tests on chassis dynamometers and the application of on-board measurement devices to describe the real-world emission behaviour of on-road vehicles in road tunnels.

PIARC (2012) provides emissions data for the year 2010 for fine particulate matter (PM_{10}) (referenced as opacity), carbon monoxide and nitrogen oxides for passenger car, light duty vehicle (LDV; < 3.5 tonnes) and heavy duty vehicle (HDV; > 3.5 tonnes) classifications. Factors are provided to account for varying vehicle speeds, road gradients and fuel types. Emission factors are provided in grams per hour. PIARC (2012) also includes emission factors for non-exhaust related emissions based on brake wear and the re-suspension of particulates from road surfaces; these were incorporated into the PM_{10} emissions.

PIARC (2012) provides adjustment factors that can be used to forecast future emissions that are based on agreed assumptions on the expected continuous improvement in engine technologies, the phase-out of older, less efficient cars, and the gradual tightening of emissions legislation. The adjustment factors are provided for each year up to 2020. As this assessment considered traffic in the years 2019 and 2029, the 2020 adjustment factors were used for predicting traffic emissions in the 2029 case. This is considered to be a conservative approach due to the expected continual improvements in vehicle emissions over time and the phase out of older cars, which, subsequently, may result in an overestimation of 2029 emissions and resultant ground level pollutant concentrations.

The current Australian fleet distribution relating to the number of diesel-powered passenger vehicles and the fleet mix (proportion of LDV to HDV) data were obtained from the motor vehicle census prepared by the Australian Bureau of Statistics (ABS, 2013). Diesel-engine passenger cars were shown to make up approximately eight per cent of the current Australian fleet, and this value was used in the emission calculations. It is also noted that the infiltration of diesel-powered passenger cars into the Australian market and fleet mix since 2008 has risen by over 100 per cent. While the use of diesel-powered vehicles is likely to continue to increase in future years, no assumptions regarding future trends were made for this assessment. The current ratio of petrol to diesel vehicles was, therefore, used for both 2019 and 2029.

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[4] The recently developed database and calculation tool, COPERT Australia, was reviewed as part of the assessment process. While the software was designed specifically for road transport emission inventories across Australia, discussions with the developer determined that, due to a lack of a valid fleet mix model to allow the calculation of fleet emissions, it was not considered suitable for use in project-related road source dispersion modelling. The EPA also has vehicle emission factors, which were generated primarily for the purpose of preparing regional emissions inventories. The EPA emission factors do not account for road grade, and are only available up to the year 2008. As such, the PIARC emission factors, which were updated in 2012 and are Australian-specific, were considered to be the most appropriate emission factors for use in this assessment.

Emission factors for the other pollutants considered in the assessment, namely exhaust-related $PM_{2.5}$, total VOCs and PAHs, were not included in PIARC (2012). The emission factors published in the National Pollutant Inventory (NPI) (DEWHA, 2008) were used to estimate emissions of these pollutants. The NPI provides emission factors for a variety of different vehicle types and fuels. The ratios of PM_{10} to $PM_{2.5}$ emissions were calculated for the various vehicle types assessed. The ratios for cars and LDVs were averaged to provide an average ratio of $PM_{2.5}$ to PM_{10} for non-HDVs (0.93); this ratio was then multiplied by the PM_{10} emissions calculated using the PIARC emission factors to estimate $PM_{2.5}$ emission rates. As such, $PM_{2.5}$ emissions were calculated as 93 per cent of PM_{10} emissions for non-HDVs. A similar process was followed for HDVs, where the ratio of $PM_{2.5}$ to PM_{10} was calculated to be 0.95.

Emissions of VOCs and PAHs were similarly calculated using the carbon monoxide emission rates. The ratios of NPI emission factors for these pollutants and carbon monoxide were firstly calculated. The carbon monoxide emission rates calculated from the PIARC carbon monoxide emission factors were then multiplied by the calculated ratios to estimate emission rates of VOCs and PAHs.

Emissions from passenger cars /LDVs were calculated separately for all pollutants, and then summed with the emissions from HDVs to provide total pollutant emission rates.

Particulate emissions from vehicle exhausts primarily comprise the smaller fractions (i.e. PM_{10} and $PM_{2.5}$). As a result, PIARC and the National Pollutant Inventory do not include emission factors for total suspended particulates (TSP). For this assessment, concentrations of TSP resulting from the project were estimated from the PM_{10} modelling results.

4.2.8.2 Peer review of emission factors calculations

The emissions inventory developed for the project in 2019 and 2029 was provided to Pacific Environment Limited for peer review. This review included:

- Re-calculation of the emissions inventory using the PIARC emission factors to confirm that the PIARC calculations were appropriately used in developing the project emissions inventory.
- Calculation of the same emission inventory using the NSW Environment Protection Authority's published emission factors for the NSW vehicle fleet. This calculation was conducted to assess the conservatism of the PIARC emission factors and whether they were reasonable to use in the air quality assessment,

In-tunnel concentrations of key pollutants (CO, NO_2, PM_{10} and $PM_{2.5}$) were calculated at one kilometre lengths along the main alignment tunnels in the relevant peak hours in 2019 and 2029 for the emissions inventory assessed in this report, a PIARC-based emissions inventory calculated by Pacific Environment Limited and an EPA-based emissions inventory calculated by Pacific Environment Limited. Comparison of these calculated in-tunnel concentrations is provided below.

Verification of PIARC Calculations

The emission inventory developed and assessed as part of this air quality impact assessment was reproduced by Pacific Environment Limited with respect to the emissions calculations that derived directly and solely from PIARC emission factors (CO, NO_2 and PM_{10}). As $PM_{2.5}$ concentrations were based on additional data sources beyond PIARC (refer to **Section 4.2.8.1**), concentrations of this pollutant were not recalculated.

Table 18 shows the comparison of PIARC-based emissions concentrations calculated by AECOM (in red) and Pacific Environment Limited (in bold). The comparison shows general consistency between the two sets of calculations. Where concentrations of pollutants vary, it is a result of:

- Different assumptions around tunnel grade. The PIARC emission factors are a function of integer values for road grade (in two per cent increments). Where the tunnel grade is not an even multiple of two per cent, assumptions must be made about either rounding the grade up or down (to provide a conservative estimate) or to interpolate between grade values.
- Different assumptions about the vehicle-fuel mix, particularly the combustion of petrol or diesel in heavy and light vehicles.
- Rounding and data manipulation differences.
- Cumulative effects from addition of minor differences in calculated emissions along the length of the main alignment tunnels.

These minor differences are not considered material to the emissions inventory, as the resultant pollutant concentrations calculated by Pacific Environment Limited were very similar to those calculated by AECOM. As such, the results indicate that the PIARC emission factors were used appropriately in the calculation of the emissions inventory for the project.

Comparison with EPA Emission Factors

To test the conservatism (or otherwise) of the emissions inventory used in this assessment (based principally on PIARC emission factors as outlined in **Section 4.2.8.1**), Pacific Environment Limited prepared an alternative emissions inventory based on emission factors available from the NSW Environment Protection Authority. The NSW Environment Protection Authority emission factors are taken directly from the NSW vehicle fleet and include provision for expected improvements in fuel standards and vehicle efficiencies over time. In comparison, the PIARC emission factors provide no guidance on potential improvements in fuel standards and vehicle efficiencies after 2020. As a result, emissions inventories based on the NSW Environment Protection Authority emission factors would show improvement over time (from 2019 to 2029), whereas no similar improvement would be evident in the conservative emissions inventories used as the basis for this air quality impact assessment (which assumes no improvement in fuel standards and/ or vehicle efficiencies after 2020).

Table 19 shows the comparison of PIARC-based emissions concentrations calculated by AECOM (in red) as used in this air quality impact assessment, and equivalent emissions concentrations calculated by Pacific Environment Limited (in bold) based on NSW Environment Protection Authority emission factors. Key observations that can be made from these data are:

- The NSW Environment Protection Authority emission factors generate particulate matter concentrations that are around half of the concentrations calculated with the PIARC emissions factors in the case of PM_{10} and less than half in the case of $PM_{2.5}$. This may be a consequence of assumptions around the ratio of PM_{10} / $PM_{2.5}$ in vehicle exhaust. High concentrations of PM_{10} and $PM_{2.5}$ represent conservatism relative to emission factors available from the NSW Environment Protection Authority.
- The NSW Environment Protection Authority emission factors generate higher concentrations of carbon monoxide (about twice the concentration of the PIARC emission factors).
- The NSW Environment Protection Authority emission factors generate slightly higher concentrations of nitrogen dioxide in 2019, and slightly lower concentrations in 2029 than the PIARC emission factors. Nitrogen dioxide concentrations calculated with the two different methodologies are around the same magnitude. The minor differences in nitrogen dioxide may be a result of different assumptions around vehicle efficiency as a function of road grade,

The outcomes of the Pacific Environment Limited review support the view that the emissions inventory used in this air quality impact assessment is conservative, particularly in the case of calculated concentrations of PM_{10} and $PM_{2.5}$. The PIARC emission factors were found to predict lower carbon monoxide concentrations than the NSW Environment Protection Authority emission factors. This difference is not considered to be material to the air quality impact assessment because of the very low concentrations of this pollutant predicted by the dispersion modelling at surrounding receivers (less than one per cent of the ambient air quality criteria for carbon monoxide in all cases) (refer to **Section 6.0**).

Table 18 **Comparison of PIARC calculations (AECOM in red) and PIARC calculations (Pacific Environment in bold)**

	Pollutant concentrations (mg/m^3) (peak hour) Approximate distance along main alignment tunnels								
Pollutant	**1 km**	**2 km**	**3 km**	**4 km**	**5 km**	**6 km**	**7 km**	**8 km**	**9 km**
Southbound main alignment tunnel at 9 am (2019)									
CO	0.331 **0.317**	0.772 **0.740**	1.06 **1.03**	1.34 **1.30**	1.62 **1.56**	1.90 **1.83**	2.17 **2.10**	2.58 **2.50**	3.45 **3.36**
NO_2*	0.039 **0.040**	0.098 **0.100**	0.124 **0.126**	0.144 **0.147**	0.165 **0.169**	0.186 **0.190**	0.206 **0.211**	0.250 **0.256**	0.374 **0.382**
PM_{10}	0.039 **0.040**	0.084 **0.086**	0.122 **0.124**	0.158 **0.160**	0.193 **0.197**	0.229 **0.233**	0.265 **0.270**	0.307 **0.312**	0.377 **0.375**
Southbound main alignment tunnel at 9 am (2029)									
CO	0.411 **0.391**	0.956 **0.914**	1.32 **1.27**	1.67 **1.61**	2.01 **1.95**	2.35 **2.27**	2.70 **2.61**	3.20 **3.11**	4.29 **4.19**
NO_2*	0.043 **0.048**	0.108 **0.120**	0.136 **0.152**	0.159 **0.178**	0.182 **0.203**	0.204 **0.229**	0.277 **0.255**	0.276 **0.309**	0.411 **0.460**
PM_{10}	0.047 **0.064**	0.101 **0.136**	0.145 **0.198**	0.189 **0.258**	0.232 **0.317**	0.275 **0.377**	0.319 **0.437**	0.369 **0.504**	0.439 **0.596**
Northbound main alignment tunnel at 6 pm (2019)									
CO	0.156 **0.145**	0.911 **0.888**	1.76 **1.73**	2.62 **2.57**	3.47 **3.41**	4.32 **4.25**	5.12 **5.03**	5.59 **5.49**	6.26 **6.13**
NO_2*	0.005 **0.005**	0.110 **0.111**	0.231 **0.235**	0.352 **0.358**	0.473 **0.481**	0.594 **0.605**	0.707 **0.719**	0.771 **0.784**	0.860 **0.876**
PM_{10}	0.032 **0.032**	0.090 **0.092**	0.153 **0.156**	0.215 **0.221**	0.278 **0.285**	0.340 **0.349**	0.401 **0.412**	0.450 **0.461**	0.504 **0.518**
Northbound main alignment tunnel at 6 pm (2029)									
CO	0.195 **0.152**	1.13 **0.95**	2.19 **1.85**	3.25 **2.75**	4.31 **3.65**	5.37 **4.55**	6.35 **5.39**	6.94 **5.87**	7.76 **6.56**
NO_2*	0.005 **0.005**	0.119 **0.116**	0.250 **0.244**	0.381 **0.373**	0.512 **0.501**	0.643 **0.629**	0.765 **0.748**	0.834 **0.816**	0.932 **0.911**
PM_{10}	0.039 **0.048**	0.106 **0.126**	0.178 **0.209**	0.250 **0.292**	0.323 **0.374**	0.395 **0.457**	0.464 **0.538**	0.521 **0.605**	0.585 **0.679**

* Note: NO_2 has been assumed to be 10 per cent of total nitrogen oxides, consistent with PIARC (2012)

Table 19 Comparison of PIARC emission factors (AECOM in red) and NSW Environment Protection Authority emission factors (Pacific Environment in bold)

Pollutant	Pollutant concentrations (mg/m^3) (peak hour) — Approximate distance along main alignment tunnels								
	1 km	2 km	3 km	4 km	5 km	6 km	7 km	8 km	9 km
Southbound main alignment tunnel at 9 am (2019)									
CO	0.331 / **0.482**	0.772 / **1.042**	1.06 / **1.50**	1.34 / **1.95**	1.62 / **2.40**	1.90 / **2.85**	2.17 / **3.29**	2.58 / **4.12**	3.45 / **6.35**
NO_2^*	0.039 / **0.052**	0.098 / **0.116**	0.124 / **0.160**	0.144 / **0.202**	0.165 / **0.244**	0.186 / **0.285**	0.206 / **0.327**	0.250 / **0.386**	0.374 / **0.505**
PM_{10}	0.039 / **0.031**	0.084 / **0.064**	0.122 / **0.095**	0.158 / **0.125**	0.193 / **0.156**	0.229 / **0.187**	0.265 / **0.218**	0.307 / **0.251**	0.377 / **0.292**
$PM_{2.5}$	0.037 / **0.023**	0.080 / **0.046**	0.115 / **0.070**	0.149 / **0.094**	0.183 / **0.118**	0.217 / **0.142**	0.251 / **0.158**	0.290 / **0.182**	0.347 / **0.214**
Southbound main alignment tunnel at 9 am (2029)									
CO	0.411 / **0.569**	0.956 / **1.233**	1.32 / **1.78**	1.67 / **2.30**	2.01 / **2.83**	2.35 / **3.36**	2.70 / **3.88**	3.20 / **4.89**	4.29 / **7.64**
NO_2^*	0.043 / **0.040**	0.108 / **0.089**	0.136 / **0.123**	0.159 / **0.155**	0.182 / **0.187**	0.204 / **0.219**	0.277 / **0.251**	0.276 / **0.296**	0.411 / **0.388**
PM_{10}	0.047 / **0.032**	0.101 / **0.065**	0.145 / **0.098**	0.189 / **0.130**	0.232 / **0.162**	0.275 / **0.194**	0.319 / **0.226**	0.369 / **0.260**	0.439 / **0.297**
$PM_{2.5}$	0.046 / **0.021**	0.095 / **0.043**	0.137 / **0.064**	0.178 / **0.086**	0.219 / **0.108**	0.260 / **0.129**	0.301 / **0.147**	0.348 / **0.169**	0.414 / **0.195**
Northbound main alignment tunnel at 6 pm (2019)									
CO	0.156 / **0.378**	0.911 / **2.230**	1.76 / **4.32**	2.62 / **6.42**	3.47 / **8.51**	4.32 / **10.60**	5.12 / **12.46**	5.59 / **13.07**	6.26 / **14.37**
NO_2^*	0.005 / **0.034**	0.110 / **0.139**	0.231 / **0.256**	0.352 / **0.372**	0.473 / **0.489**	0.594 / **0.606**	0.707 / **0.715**	0.771 / **0.784**	0.860 / **0.877**
PM_{10}	0.032 / **0.032**	0.090 / **0.072**	0.153 / **0.114**	0.215 / **0.156**	0.278 / **0.198**	0.340 / **0.241**	0.401 / **0.281**	0.450 / **0.316**	0.504 / **0.355**
$PM_{2.5}$	0.030 / **0.022**	0.085 / **0.054**	0.144 / **0.087**	0.203 / **0.119**	0.263 / **0.152**	0.322 / **0.185**	0.379 / **0.217**	0.425 / **0.242**	0.477 / **0.272**
Northbound main alignment tunnel at 6 pm (2029)									
CO	0.195 / **0.374**	1.13 / **2.31**	2.19 / **4.51**	3.25 / **6.70**	4.31 / **8.89**	5.37 / **11.09**	6.35 / **13.03**	6.94 / **13.65**	7.76 / **15.00**

Pollutant	Pollutant concentrations (mg/m^3) (peak hour) – Approximate distance along main alignment tunnels: 1 km	2 km	3 km	4 km	5 km	6 km	7 km	8 km	9 km
NO_2*	0.005 **0.023**	0.119 **0.093**	0.250 **0.171**	0.381 **0.249**	0.512 **0.328**	0.643 **0.406**	0.765 **0.479**	0.834 **0.525**	0.932 **0.588**
PM_{10}	0.039 **0.029**	0.106 **0.063**	0.178 **0.097**	0.250 **0.131**	0.323 **0.166**	0.395 **0.200**	0.464 **0.234**	0.521 **0.264**	0.585 **0.297**
$PM_{2.5}$	0.037 **0.019**	0.100 **0.042**	0.169 **0.065**	0.237 **0.089**	0.305 **0.113**	0.373 **0.137**	0.439 **0.160**	0.497 **0.180**	0.553 **0.202**

* Note: NO_2 was assumed to be 10 per cent of total nitrogen oxides, consistent with PIARC (2012)

4.2.8.3 Emissions from surface roads

The forecast vehicle numbers for the surface roads potentially affected by the project were based on outputs from the strategic traffic model and traffic surveys conducted in December 2013 (refer to technical working paper: traffic and transport (AECOM, 2014). Turning movements at each of the road junctions on the network were also provided for morning and afternoon peak periods, and factors provided to allow determination of 24 hour representative traffic flows. The surface roads surrounding the project and the existing Pennant Hills Road corridor were converted to 335 road links with associated gradients, which were entered into the CAL3QHCR model. Hourly pollutant emission rates were estimated for each road link, representing combined emissions from the different vehicle types (passenger cars, light vehicles and heavy vehicles). Pollutants were modelled for both the opening year (2019) and 10 years after opening (2029) using meteorological data from 2009, 2010 and 2011 to capture the likely meteorological conditions.

CAL3QHCR does not include $PM_{2.5}$ as a modelling species. The concentrations of PM_{10} estimated by the CAL3QHCR model were multiplied by 0.95 (the maximum ratio of $PM_{2.5}$ to PM_{10} calculated for the tunnel emissions as described in **Section 4.2.7.1**) to estimate $PM_{2.5}$ pollutant concentrations at each receiver.

4.2.8.4 Emissions from the project tunnels

The number of vehicles within the northbound and southbound tunnels would vary throughout a 24-hour period and, subsequently, the level of pollutant emissions associated with vehicle movements would vary. Forecast hourly traffic data, including heavy vehicle percentages and vehicle speeds for each tunnel for the opening year of the tunnel and 10 years after opening (2019 and 2029, respectively), are shown graphically in **Figure 9** and **Figure 10**, which illustrate the forecast increase in traffic flows between 2019 and 2029 assessment years for the northbound and southbound tunnels.

For 2019, the predicted percentage of heavy vehicles varied hourly, and ranged from 28.0 per cent to 28.5 percent for the northbound tunnel and from 27.8 per cent to 28.6 per cent in the southbound tunnel.

For 2029, the percentage of heavy vehicles ranged from 24.5 per cent to 25.0 per cent in the northbound tunnel and from 24.5 per cent to 25.2 per cent in the southbound tunnel over the course of a 24 hour period.

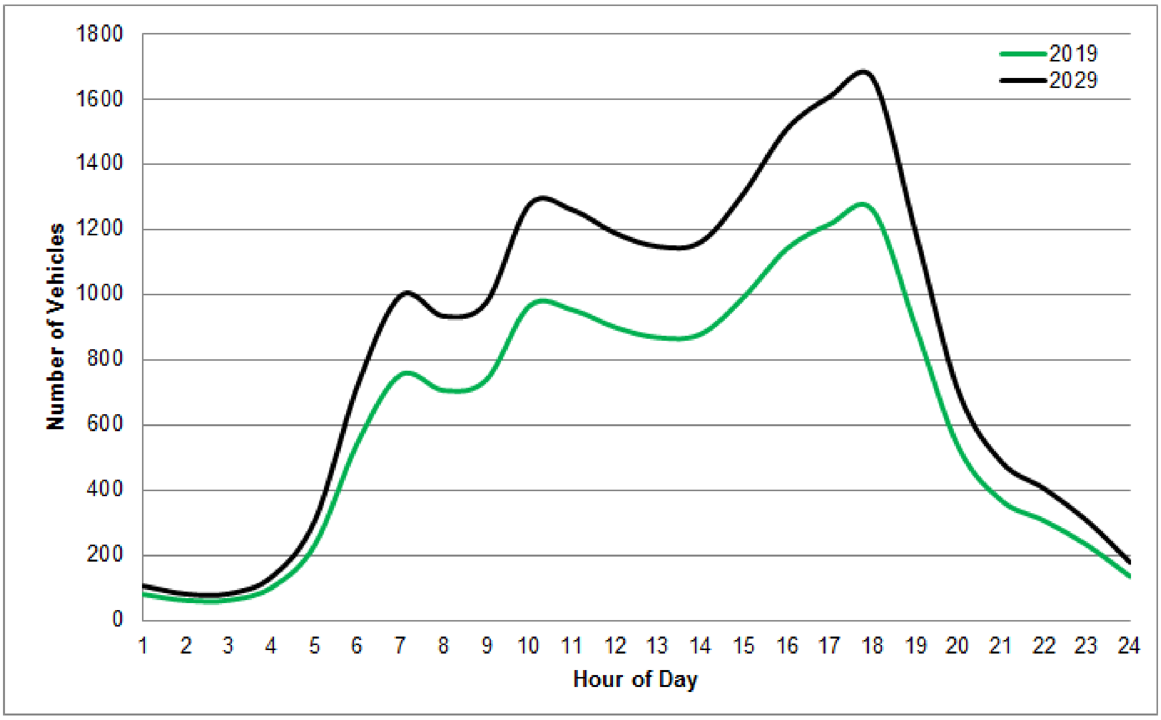

Figure 9 Predicted tunnel traffic flows – northbound

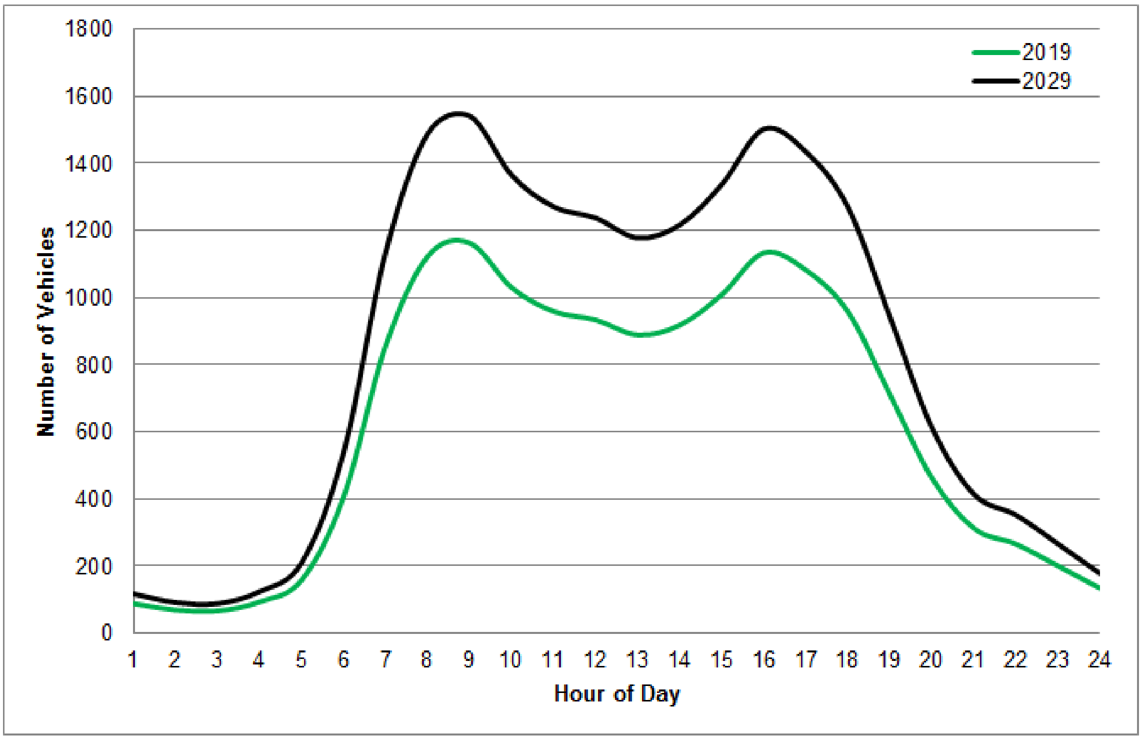

Figure 10 Predicted tunnel traffic flows – southbound

The gradient of roads is an important factor in estimating vehicle emissions due to the differing vehicle engine-loads required at both positive and negative grades. Vehicle emissions resulting from positive gradients (inclines) outweigh emissions for the same magnitude negative gradients (declines). The gradients of each road and tunnel link within the project were used in the emission calculations (refer to **Table 20**).

Table 20 Mainline chainages and gradients

Northbound Tunnel				Southbound Tunnel			
Chainage (metres) - Start	Chainage (metres) - End	Length (metres)	Grade (%)	Chainage (metres) - Start	Chainage (metres) - End	Length (metres)	Grade %
1002	1230	229	- 4	9944	9576	368	- 4
1230	2142	911	- 4	9576	8464	1111	0
2142	7847	5705	2	8464	7820	645	0
7847	8466	619	0	7820	2202	5618	- 2
8466	9777	1311	0	2202	1148	1054	+ 2
9777	10027	250	4	1148	688	460	+ 4

The vehicle densities in the project tunnels were calculated using the forecast hourly vehicle and speed data. These densities were used to estimate total hourly emissions from the ventilation outlets servicing each tunnel. The gradients were accounted for through the PIARC emissions data, with data for the most representative grades extracted from PIARC for both assessment years. The calculated hourly tunnel outlet emissions data used in the assessment are detailed in **Appendix H**.

Predicted vehicle emissions from the tunnels are greater in 2029 (10 years following opening) than in the opening year, 2019. This is due to the fact that the 2029 emissions were based on emission factors for 2020 as outlined in **Section 6.2.1**. Fleet emissions are, however, expected to continue to decrease beyond 2029 (EPA, 2012b). When coupled with the predicted increase in vehicle numbers between 2019 and 2029, the emission factors used in this assessment are conservative.

4.2.9 Emission rates

Hourly emission rates used in the CALPUFF dispersion modelling of the project for the different assessment scenarios are detailed in **Appendix H**. Emission rates are provided in grams per second (g/s).

4.2.10 Ventilation outlet parameters

4.2.10.1 Temperature

The temperature of outlet emissions is an important factor in determining the ultimate dispersion of pollutants. Emissions with higher temperatures have higher buoyancy, which generally means that the pollution plume is carried higher before dispersion begins, resulting in improved dispersion.

The temperature of outlet emissions would be affected by the number of vehicles moving through the tunnels, as some of the heat from the vehicle exhaust emissions would be carried through to the ventilation outlets. In order to estimate the likely temperature of the ventilation outlet emissions from the project, outlet temperature data measured at the Lane Cove tunnel were analysed. As the Lane Cove Tunnel is located in a different area of Sydney in relation to the project, the actual temperatures measured at this facility were not considered appropriate for use. Instead, the differences between the outlet emission temperatures and the ambient temperatures were determined for every hour of the meteorological modelling period (2009 – 2011). The average temperature variations for each hour of each season were then calculated (for example, the average variation between ambient and outlet emission temperatures at 1 am between December 1 and February 28 for each year was calculated, then 2 am, 3 am , 4 am and so on for each hour of the day and for each season). The hourly seasonal average temperature differences were then applied to the temperature data predicted for the project's ambient environment to calculate the estimated temperatures of emissions from the ventilation outlets.

4.2.10.2 Ventilation outlet diameter and volumetric flow rate

The project would be serviced by ventilation systems, the operating parameters of which would vary depending on traffic flows. As such, the volume of air to be extracted from the tunnels would vary each hour and, therefore, the number of fans and the output of the fans would vary on an hourly basis, resulting in hourly-varying outlet emission velocities and flow rates. In order to accommodate this variation, the ventilation outlets would be partitioned so that portions of the ventilation outlets can be closed off when traffic flows are low in order to maintain good plume dispersion. This would result in time-varying ventilation outlet diameters. The CALPUFF model does not provide the functionality to enter time-varying outlet diameters. In order to accurately model the outlet emissions, each ventilation outlet was, therefore, modelled as three separate concentric outlets to allow for the operation of the different segments to be incorporated into the model.

The ventilation areas and settings the systems were designed for were provided by Roads and Maritime; details are provided in **Table 21**.

Table 21 Ventilation outlet parameters

Ventilation outlet airflow (m^3/s)	VSO running level	Ventilation outlet partition 1 status (29 m^2)	Ventilation outlet partition 2 status (17 m^2)	Ventilation outlet velocity (m/s)
700	6	Open	Open	15.2
620	5	Open	Open	13.5
540	4	Open	Closed	18.6
460	3	Open	Closed	15.9
380	2	Open	Closed	13.1
300	1	Closed	Open	17.6

4.2.11 Assessment of pollutants

For most of the assessed pollutants, the models' output data were in a form that could be directly used for the assessment. For NO_2 and VOCs, additional analysis of the model outputs was required. For PM_{10}, $PM_{2.5}$, NO_2 and CO, consideration of existing pollutant concentrations in the ambient air required consideration. Further information is provided in the following sections.

4.2.11.1 Conversion of NO_X to NO_2

Nitrogen oxides are produced in most combustion processes and are formed during the oxidation of nitrogen in fuel and nitrogen in the air. During high-temperature processes, a variety of oxides are formed including nitric oxide (NO) and nitrogen dioxide (NO_2). NO will generally comprise 95 per cent of the volume of NO_X at the point of emission. The remaining NO_X will consist of NO_2. The conversion of NO to NO_2 requires ozone to be present in the air, as ozone is the catalyst for the conversion. Ultimately, however, all NO emitted into the atmosphere is oxidised to NO_2 and then further to other higher oxides of nitrogen.

The USEPA's Ozone Limiting Method (OLM) was used to predict ground-level concentrations of NO_2. The OLM is based on the assumption that approximately 10 per cent of the initial NO_X emissions are emitted as NO_2. If the ozone (O_3) concentration is greater than 90 per cent of the predicted NO_X concentrations, all the NO_X is assumed to be converted to NO_2, otherwise NO_2 concentrations are predicted using the equation:

$$NO_2 = 46/48 \times O_3 + 0.1 \times NO_X$$

This method assumes instant conversion of NO to NO_2 in the plume, which overestimates concentrations close to the source since conversion usually occurs over periods of hours. This method is described in detail in DEC (2005). Background ozone data from the Lindfield monitoring station (refer to **Section 5.1**) were used to convert the modelled NO_2 concentrations in accordance with the EPA-approved OLM (Method 2, Level 2 Assessment; DEC, 2005).

The OLM is a conservative approach. Common situations where 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 and night conditions when both NO_2 and O_3 are removed by reaction with vegetation and other surfaces (NIWAR, 2004). Further information is provided in **Appendix I**.

4.2.11.2 VOCs and toxic pollutants

The total VOC concentrations were speciated using the profile (i.e. the types of pollutants) provided in OEH (2012) and the mass fraction for the project fleet determined by the Health Risk Assessment (refer to technical working paper: human health risk assessment). These data are summarised in **Table 22**.

The VOCs considered for the vehicle emissions were benzene, toluene, xylenes, 1,3-butadiene, acetaldehyde and formaldehyde. For passenger cars, sixty per cent[5] of fuel used was assumed to be E10. This percentage represents the target for petrol sold in New South Wales under the *Biofuels Act 2007*. For the purpose of this speciation, the composition of VOCs in vehicle emissions was assumed to remain the same over time.

The mass fraction percentages reported in **Table 22** were multiplied by the 99.9th percentile total VOC concentrations predicted by the dispersion modelling to estimate the concentrations of the individual VOC species at sensitive receiver locations around the project.

Table 22 VOC speciation profile for vehicle emissions

VOC	Mass Fraction (% VOC)					Mass fraction for vehicle fleet in project (% VOC)	
	Passenger cars		Light vehicles		Heavy vehicles	2019	2029
	No ethanol	E10	Petrol	Diesel*	Diesel		
1,3-butadiene	1.27	1.2	1.27	0.4	0.4	0.91	1.0
acetaldehyde	0.46	1.3	0.46	3.81	3.81	2.1	1.6
benzene	4.96	4.54	4.96	1.07	1.07	3.3	3.8
formaldehyde	1.46	1.82	1.46	9.86	9.86	4.9	3.9
xylenes	7.6	7.22	7.6	0.38	0.38	4.6	5.5
toluene	9.18	8.79	9.18	0.47	0.47	5.6	6.7

VOC speciation from OEH (2012)
* speciation for diesel emissions also adopted for diesel passenger cars

4.2.12 Cumulative assessment

The assessment investigated pollutant concentrations associated with emissions from the tunnel ventilation outlets (via CALPUFF). For the PM_{10}, $PM_{2.5}$, NO_2 and CO, the predicted concentrations were added to the relevant ambient (background) pollutant concentrations to estimate cumulative pollutant concentrations, which were compared to the relevant assessment criteria. As outlined in **Section 3.1.1**, the ambient concentrations of PM_{10}, $PM_{2.5}$ and NO_2, were determined by taking the maximum of the concentrations predicted by CAL3QHCR

[5] The value of 60 % of ethanol in total fuel volume sales was adopted as the target for petrol sold in NSW as outlined in the Biofuels Act 2007.

(for the do something case) and those measured by the OEH at its Lindfield and Prospect monitoring stations. This was done for each modelled receiver along the road corridor for each hour of each modelling year.

For the modelled receivers not located along the road corridor, the maximum OEH data for each hour were adopted as ambient pollutant concentrations. Ambient concentrations of these pollutants were added contemporaneously – that is, the ambient pollutant concentrations for each hour of the modelling period were added to the modelling predictions from the same hour at each receiver location.

For CO, the maximum measured concentrations recorded at the OEH station at Lindfield. The cumulative predicted pollutant concentrations, which represented the combination of project contributions and ambient pollutant concentrations, were compared against applicable air quality assessment criteria. This approach was expected to lead to higher concentrations of pollutants predicted along the road corridor, which would be expected due to the proximity of receivers to vehicle emission points.

For PAHs and VOCs, cumulative assessment using background data is not required by the EPA (DEC, 2005). Furthermore, background data are not available to conduct a cumulative assessment of these pollutants.

4.2.12.1 Background pollutant concentrations

Statistical comparisons of the project monitoring data collected between December 2013 and March 2014 with the OEH monitoring data were undertaken to determine the best data to use in the assessment to represent background air quality (refer to **Appendix C**). While the project data were not collected at the same time as the OEH data, the data sets were matched to the same relative dates (that is, project monitoring data recorded on 1 January 2014 were matched to OEH data recorded on January 1 in 2009, 2010 and 2011). As the ambient pollutant concentrations used in contemporaneous cumulative assessments (such as this assessment for PM_{10}, $PM_{2.5}$ and NO_2) must match the modelling dates (which were 2009 to 2011), this was considered the most appropriate way to compare the project monitoring data to the OEH data. The ambient project monitoring PM_{10} data were typically less than the PM_{10} concentrations measured by the OEH, while the NO_2 concentrations were slightly higher. As such, the OEH data are not expected to underestimate actual ambient pollutant concentrations in the study area. The pollutant concentrations predicted by the CAL3QHCR model were generally higher than the ambient concentrations recorded by the OEH. This was expected, as concentrations of combustion emissions along major roadways are typically higher than the concentrations occurring at locations away from major roadways, such as the OEH Lindfield and Prospect monitoring stations, as the receivers are located closer to the emission sources, and, subsequently, the pollutants have not dispersed to the same extent by the time they reach receivers.

A comparison of the project monitoring data and the pollutant concentrations predicted by the road modelling (using CAL3QHCR as described in **Section 4.2.3.1**) in this assessment was also undertaken. The concentrations of both PM_{10} and NO_2 measured at the project road monitoring stations were typically well below the pollutant concentrations predicted by the road modelling.

PM_{10} and NO_X

The ambient pollutant data for PM_{10} and NO_X were calculated in one of two ways relating to the type of sensitive receiver assessed. Five monitoring stations were commissioned for the project to measure site-specific concentrations of PM_{10} and NO_X. At the time of preparation of this assessment, data recorded between December 2013 and March 2014 were available. Two of the stations were located along Pennant Hills Road, and represented road emissions. The other three monitoring stations were sited to represent local ambient pollutant concentrations.

Background pollutant concentrations along the surface roads are expected to primarily comprise vehicle emissions – this was confirmed through comparison of the road modelling results and the results of monitoring data from stations located adjacent to the Pennant Hills Road. For the purpose of this comparison, the 2019 modelling results for the without project scenario (Scenario 1) were used to represent expected current traffic emissions in the absence of a modelled 2013 / 2014 scenario. While the emission rates for vehicles in 2019 are expected to be lower than current emission levels measured at the two road monitoring stations due to expected future improvements in vehicle emissions, the expected increased traffic volumes are likely to result in similar pollutant loads at roadside receiver locations. As such, the 2019 data are considered to be essentially representative of current pollutant loads.

A review of the data is provided in **Appendix C** and summarised below. Two receivers from the modelling were selected for the comparison. These receivers were selected as they are located as close to the project road monitoring stations as possible and at a similar distance from the road as the road monitoring stations. The concentrations of PM_{10} and NO_2 predicted by the CAL3QHCR modelling for the two receivers were compared to the road monitoring data for each hour of the monitoring period. The comparison showed that the pollutant concentrations recorded by the road monitoring stations were typically lower than the concentrations predicted by the modelling. This suggests that the pollutant concentrations predicted by the CAL3QHCR model represent concentrations higher than those that are expected to be experienced at those locations from all pollutant sources. This led to the conclusion that the modelling data would be conservative. As such, the CAL3QHCR modelling predictions were adopted as conservative background concentrations for the receivers located along the main roadways.

The measured pollutant concentrations (PM_{10} and NO_2) at the project ambient monitoring stations were compared to the relevant periods within the monitoring data obtained from the Lindfield and Prospect monitoring stations operated by the OEH. For the purpose of the comparison, the maximum pollutant concentrations from Lindfield and Prospect recorded between December and March in each meteorological year included in the modelling (2009, 2010 and 2011) were identified and compared to the maximum data recorded by the project ambient monitoring stations. The comparison indicated that the pollutant concentrations measured at Lindfield/Prospect were typically higher than those recorded at the project ambient monitoring stations. As such, the maximum data recorded for each hour of the modelling period at Lindfield and Prospect were considered to represent conservative background pollutant concentrations. The maxima of the OEH monitoring data and the CAL3QHCR predictions (with project, to represent more likely concentrations) at each receiver location assessed were adopted as hourly background pollutant concentrations.

$PM_{2.5}$

$PM_{2.5}$ concentrations are not measured at Lindfield or Prospect. In order to estimate $PM_{2.5}$ concentrations in the project area, the ratios of PM_{10} to $PM_{2.5}$ measured at other monitoring stations within the Sydney basin were calculated. Monitoring data from Liverpool, Chullora, Earlwood and Richmond recorded between 2009 and 2011 were used. The PM_{10} to $PM_{2.5}$ ratios were calculated for each of the monitoring stations for each hour of the day. These ratios were then averaged across the monitoring stations for each hour of the day, and the maximum of the hourly averages was adopted as the conversion ratio for the assessment, which was 0.35. This ratio was applied to the combined PM_{10} monitoring data from Lindfield/Prospect to estimate hourly $PM_{2.5}$ concentrations. That is, the maximum hourly concentrations of PM_{10} recorded at either Lindfield or Prospect were multiplied by 0.35 to provide an estimate of the $PM_{2.5}$ concentrations for those hours. The maximum of the calculated data and the CAL3QHCR predictions were used to represent background $PM_{2.5}$ concentrations at receivers.

CO

The predicted concentrations of CO from Scenario 1 were compared to the measured CO concentrations at Prospect as shown in **Table 23** (note that CO is not measured at Lindfield). As the maximum measured concentrations of CO at Prospect are substantially higher than the predicted concentrations from the road modelling, the maximum measured concentrations at Prospect were adopted for use as background CO concentrations for the purpose of this assessment (that is, 3,335 $\mu g/m^3$ for 1 hour CO and 2,601 $\mu g/m^3$ for 8 hour CO).

Table 23 Maximum carbon monoxide concentrations – CAL3QHCR predictions compared to Prospect monitoring data ($\mu g/m^3$)

Source	Averaging period	Year		
		2009	2010	2011
Road modelling – without project 2019	1 hour	583	575	574
	8 hours	401	406	399
Road modelling – without project 2029	1 hour	647	640	642
	8 hours	459	462	457
Prospect monitoring station	1 hour	3,335	2,990	2,645
	8 hours	2,601	1,993	1,969

Summary

Based on the results of the comparison, a conservative approach was adopted for background pollutant concentrations used in this assessment. For PM_{10}, $PM_{2.5}$ and NO_2, the ambient concentrations were determined by taking the maximum of the concentrations predicted by CAL3QHCR and those measured by the OEH at its Lindfield and Prospect monitoring stations. This was done for each receiver for each hour of each modelling year. The cumulative predicted pollutant concentrations, which represented the combination of project contributions and ambient pollutant concentrations, were compared against applicable air quality assessment criteria.

4.2.13 Contemporaneous assessment methodology

A contemporaneous assessment of PM_{10}, $PM_{2.5}$ and NO_2 was conducted in accordance with the EPA Approved Methods (DEC 2005). A contemporaneous assessment involves adding the pollutant concentrations predicted by the dispersion modelling to the background pollutant concentrations relating to the same time period; that is, the predicted pollutant concentration for 9 am on January 1, 2009 would be added to the background pollutant concentration recorded/ calculated for 9 am on January 1, 2009. This pairs the project emissions to background pollutant concentrations occurring at the same point in time. Assessing the total predicted ground level concentrations using a contemporaneous approach provides a more realistic estimation of the likely total pollutant concentrations at any point in time, and also can be used to provide an indication of the extent of any exceedences of the impact assessment criteria.

The contemporaneous assessment methodology was applied to particulate concentrations as exceedences of the EPA's criteria for PM_{10} and $PM_{2.5}$ were recorded in the background pollutant data. NO_2 was also assessed contemporaneously, as the EPA's basic level conversion of NO_X to NO_2 (Level 1, Method 2 - maximum predicted NO_2 concentration with maximum NO_2 background not paired in time per DEC, 2005) resulted in predicted exceedences, which were not considered realistic given the background ambient monitoring data. An example of a contemporaneous assessment is provided below as an indication of how the assessment works.

Table 24 presents two main areas of information as follows:

- Columns 2 - 4 present the results ranked by cumulative concentration and the project contribution and background concentration associated with those cumulative concentrations. For all the $PM_{2.5}$ data for this particular scenario, the top five cumulative concentrations show that there are predicted cumulative exceedences of the advisory standard for one day out of the three years modelled. On the day where the exceedence occurred, the exceedence can be seen to be primarily the result of the background concentration.
- Columns 5 - 7 present results ranked by project contribution and the cumulative and background concentrations corresponding to those predicted project contributions. For all of the $PM_{2.5}$ data for this particular scenario, the top five project contribution concentrations show that the predicted contribution from the project is very low, and that the cumulative concentrations are low and well below the advisory standard when the project contribution is at a maximum.

Table 24 Example contemporaneous assessment table

Rank	Maximum cumulative concentrations (μg/m^3)			Maximum project contributions (μg/m^3)		
	Cumulative concentration	Project contribution	Background contribution	Project contribution	Cumulative concentration	Background contribution
	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7
1	77.9	0.3	77.6	1.6	2.5	0.9
2	47.3	0.4	46.9	1.5	2.2	0.7
3	32.6	0.5	32.1	1.3	2.1	0.8
4	31.9	0.5	31.4	1.3	2.3	1
5	21.7	0.3	21.4	1.2	1.7	0.5

4.2.13.1 Pennant Hills Road analysis

To evaluate the overall effect of the project on local air quality, the predicted difference in concentrations of annual average $PM_{2.5}$ (the primary pollutant of interest from a health perspective) with and without the project was calculated. This analysis was undertaken in the following manner:

- Step 1: The differences between the predicted pollutant concentrations from the modelling of the roadways with and without the project were calculated for each receiver location for 2019 traffic volumes.
- Step 2: The predicted contributions to $PM_{2.5}$ concentrations resulting from emissions from the northern and southern ventilation facilities were then added to the difference values calculated in Step 1 for each sensitive receiver location.

The results of this analysis are presented in **Section 6.2**

4.2.14 Limitations

The atmosphere is a complex, physical system, and the movement of air in a given location is dependent on a number of different 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. The model equations necessarily involve some level of simplification of these very complex processes based on our understanding of the processes involved and their interactions, available input data, and processing time and data storage limitations.

These simplifications come at the expense of accuracy, which 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 wind speeds less than 1 m/s) or for low-level, non-buoyant sources, is problematic for most dispersion models. To accommodate these known deficiencies, the model outputs tend to provide conservative estimates of pollutant concentrations at particular locations.

While the models contain a large number of variables that can be modified to increase the accuracy of the predictions under any given circumstances, the constraints of model use in a commercial setting, as well as the lack of data against which to compare the results in most instances, typically precludes extensive testing of the effects of modification of these variables. With this in mind, model developers typically specify a range of default values for model variables, which are applicable under most modelling circumstances. These default values are recommended for use unless there is sufficient evidence to support their modification.

As a result, the results of dispersion modelling provide an indication of the likely level of pollutants within the modelling domain. 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 where the maximum concentrations may occur, their outputs should not be considered to be representative of exact pollutant concentrations at any given location or point in time. As stated above, however, the model predictions are typically conservative, and tend to over predict maximum pollutant concentrations at receiver locations.

This assessment was undertaken with the data available at the time of the assessment. Should changes to the project be made, further assessment may be required to determine if the findings of this assessment are still applicable.

4.3 Impact assessment criteria

4.3.1 NSW assessment criteria

In addition to specifying the statutory methods that are to be used to model and assess emissions of air pollutants from sources in NSW, the *Approved Methods for the Modelling and Assessment of Air Pollutants* (DEC, 2005) provides assessment criteria against which the emissions from a site or activity are to be assessed. These criteria are intended to minimise the adverse effects of airborne pollutants on receivers and are summarised in **Table 25**.

There are currently no formally adopted criteria for the assessment and regulation of $PM_{2.5}$ in NSW. For the purpose of this assessment, the advisory reporting standards and goals for airsheds were adopted from the *National Environment Protection Measure for Ambient Air Quality* (Air NEPM) (NEPC, 2003). It should be noted that these standards are not criteria for specific facility emissions, but were nonetheless applied in a similar manner as other air quality criteria for this assessment for consistency and completeness. The advisory reporting standards for $PM_{2.5}$ are summarised in Table **26**.

The assessment criteria for PM_{10}, NO_2 and CO) apply to the maximum predicted total pollutant concentrations (that is, the 100th percentile, or maximum, incremental contribution from the site or activity added to the background pollutant concentration). The 100th percentile was also assessed for $PM_{2.5}$ in this assessment. The assessment criteria for the other pollutants assessed (benzene,1,3-butadiene, formaldehyde, toluene, xylenes and acetaldehyde) apply to the 99.9th percentile incremental concentrations (that is, concentrations from the assessed sources alone) from the activity for a refined dispersion modelling assessment, such as the current study.

Table 25 NSW air quality criteria adopted by the EPA

Pollutant	Averaging Period	Percentile	Criteria ($\mu g/m^3$)	Source
PM_{10}	24 hour	100	50	DEC (2005)
	Annual	100	30	DEC (2005)
Total suspended particulates (TSP)	Annual	100	90	DEC (2005)
Nitrogen dioxide (NO_2)	1 hour	100	246	DEC (2005)
	Annual	100	62	DEC (2005)
Carbon monoxide (CO)	15 minutes	100	100,000	DEC (2005)
	1 hour	100	30,000	DEC (2005)
	8 hours	100	10,000	DEC (2005)
Benzene (VOC)	1 hour	99.9*	29	DEC (2005)
Toluene (VOC)	1 hour	99.9*	360	DEC (2005)
Xylenes (VOC)	1 hour	99.9*	190	DEC (2005)
1,3-butadiene	1 hour	99.9*	40	DEC (2005)
acetaldehyde	1 hour	99.9*	42	DEC (2005)
formaldehyde	1 hour	99.9*	20	DEC (2005)
PAHs (as benzo(a)pyrene)	1 hour	99.9*	0.4	DEC (2005)

* The 99.9th percentile concentrations are used for Level 2 assessments, which are those conducted using at least one year of site-specific meteorological data. These concentrations are appropriate for this assessment, which used three years of site-specific meteorological data.

Table 26 **Advisory reporting standards for $PM_{2.5}$ in the Air NEPM**

Pollutant	Averaging Period	Percentile	Criteria (μg/m³)	Source
$PM_{2.5}$	24 hour	100	25	NEPM (2003)
	Annual	100	8	NEPM (2003)

4.3.2 Comparison of guidelines / assessment criteria

Table 27 shows the assessment criteria applied to the project for PM_{10}, $PM_{2.5}$ and NO_2 and comparable criteria from the US EPA and the World Health Organisation (WHO). The following points should be noted:

- The NSW criterion for 24 hour PM_{10} is the same as the WHO guideline and is a third of the US EPA standard.
- The US EPA does not have a standard for annual PM_{10}; the NSW EPA criterion for this averaging period is higher than the WHO guideline of 20 μg/m³.
- For $PM_{2.5}$, the advisory reporting standards in the Air NEPM adopted for this assessment are lower than both the US and WHO criteria for the 24 hour and annual averages.
- For NO_2, the NSW one hour criterion is slightly higher than that of both the US EPA and the WHO, while the annual average criterion is lower than the US EPA standard but higher than the WHO guideline.

In summary, the NSW criteria are similar to those specified by the US EPA and the WHO.

Table 27 **Comparison of criteria for PM_{10}, $PM_{2.5}$ and NO_2**

		Guidelines/ assessment criteria (μg/m³)		
Pollutant	**Averaging Period**	**NSW EPA/NEPM**	**US EPA NAAQS**	**WHO Guideline**
PM_{10}	24 hour average	50	150	50
	Annual average	30	-	20
$PM_{2.5}$	24 hour average	25	35	25
	Annual average	8	15	10
NO_2	1 hour average	246	189 (100 ppb)	200
	Annual average	62	100 (53 ppb)	40

5.0 Construction impact assessment

5.1.1 Surface works

There are a number of receivers located in the vicinity of the project construction sites, which have the potential to be affected by dust emissions from above-ground works. The construction works associated with earth moving, excavation and demolition activities would be the key source of emissions to the local airshed, and would include:

- Worksite establishment activities such as vegetation clearing and earthworks.
- Demolition of buildings, structures and road pavement.
- General earthworks.
- Exposure of surfaces, which may be susceptible to wind erosion.
- Handling and stockpiling of spoil material.
- Vehicle movements on unsealed roads, resulting in wheel generated dust.
- Materials storage and handling.

Activities that move or manipulate dusty material can be a source of particulate emissions. The NPI manual for fugitive emissions (NPI, 2012b) indicates that emission factors developed for mining are applicable to other types of activities involving earth moving, excavation and demolition works.

Katestone (2011) prepared a best practice guide for the management of mining emissions, which was based on the results of environmental audits conducted for coal mines within the Greater Metropolitan Region. The different mining activities were ranked according to their emission levels of Total Suspended Particulates (TSP), PM_{10} and $PM_{2.5}$. The highest levels of particulates were determined to be generated from vehicle movements on unpaved roads and wind erosion of material stockpiles, which are similar to the types of construction activities associated with the project. As such, these activities would be expected to be the primary potential emission sources for the proposed construction works.

The most effective mitigation strategy for wheel-generated dust is the sealing of roads, followed by watering at a rate of greater than two litres per square metre per hour. For wind erosion of stockpiles, total enclosure is considered to reduce 99 per cent of potential emissions. For this project, the majority of haul truck travel would be undertaken on sealed roads, and the stockpiles of material excavated from the tunnels would be stored within acoustic sheds in the majority of cases. These actions would substantially mitigate the potential for dust emissions associated with the construction works.

Diesel and petroleum-powered plant and equipment can generate substantial emissions of oxides of nitrogen and lesser amounts of carbon monoxide, particulates and VOCs. Light and heavy vehicles are also a source of these emissions. Electrically-powered plant and equipment do not generate combustion emissions. Road headers used in this project would be driven by mains power supply and would not, therefore, contribute to exhaust emissions.

All plant and equipment used during construction would comply with the emissions concentration limits outlined in the *Protection of the Environment Operations (Clean Air) Regulation 2010*. As such, vehicular and plant emissions arising from the civil construction works are unlikely to have a substantial effect on surrounding air quality. Emissions can be minimised through switching engines off when not in use, maintaining vehicles in accordance with manufacturers' specifications, using fuel efficient vehicles and limiting the number of trips.

Emissions generated by underground works include vehicle and potential blasting emissions. An air filtration system would be provided to filter particulate matter from underground works. As the underground emissions would be controlled, surface works are considered to be the most important source of emissions associated with the construction works.

Table 28 provides a summary of potential types of construction emissions associated with the various construction areas for the project.

Table 28 Construction emission sources associated with the project

Emissions source	Surface construction locations													
	Windsor Road compound (C1)	Darling Mills Creek compound (C2)	Barclay Road compound (C3)	Yale Close compound (C4)	Southern interchange compound (C5)	Wilson Road compound (C6)	Trelawney Street compound (C7)	Pioneer Avenue compound (C8)	Northern interchange compound (C9)	Bareena Avenue compound (C10)	Junction Road compound (C11)	Interchange construction	M1 Pacific Motorway tie-in	Hills M2 Motorway integration
Site preparation (vegetation clearance and earthworks)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Earthworks		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Material haulage	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Exposed surfaces (wind erosion)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Exhaust (plant and equipment)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Construction ventilation					✓	✓	✓		✓					
Demolition					✓	✓	✓	✓		✓		✓	✓	✓
Spoil handling and stockpiling	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			
Tunnel spoil handling and stockpiling					✓	✓	✓		✓					
Vehicle movements (unsealed roads / wheel-generated dust)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

The potential for dust to be emitted from above-ground construction works would be managed through standard mitigation measures identified in **Section 7.1**, such as water spraying of unsealed areas, wetting down of dust-generating activities and progressive stabilisation works.

5.1.2 Tunnelling

The underground tunnels would be ventilated during construction in order to provide a safe working environment for the construction workforce. Tunnel ventilation would be provided at the four tunnel support sites, which are:

- The southern interchange compound (C5).
- The Wilson Road compound (C6).
- The Trelawney Street compound (C7).
- The northern interchange compound (C9).

This ventilation equipment would have dust extraction and filtration systems installed to minimise dust emissions. Additionally, as the road headers would require water for dust suppression while cutting rock, dust generation from tunnelling activities is expected to be minimal.

The primary pollutants emitted from the detonation of explosives used for blasting (if it is required) are carbon monoxide, hydrogen sulfide, sulfur dioxide, oxides of nitrogen and ammonia (NPI, 2012a). In addition to the emissions associated with the fuel detonation, particulates are also emitted.

As blasting would be undertaken underground on an intermittent basis, the pollution emissions associated with these activities would be expected to be of short duration. Particulates generated by underground blasting would be captured by the air filtration system. As blasting works would only be carried out underground, the potential for dust emissions from this activity to affect receivers is considered to be negligible.

5.1.3 Water treatment

Water treatment plants would be located at the southern interchange compound (C5), Wilson Street compound (C6), Trelawney Street compound (C7) and the northern interchange compound (C9) to treat groundwater extracted from the underground workings. Emissions to air associated with water treatment depend on the nature of the contamination of the wastewater being treated and the treatment process. Primary air emissions associated with water treatment may include odorous compounds, such as ammonia and VOCs, which are associated with aeration (primary treatment), aerobic digestion, anaerobic digestion and sedimentation (NPI, 2011).

The nature of any odours would depend on the degree and type of any contamination present in the groundwater. A management plan would be developed to address any odours should contamination be encountered and if odours arise. The plan would include identification of odours, identification of the extent to which the odours are detectable, and, if necessary, mitigation measures to reduce any odours affecting receivers if they arise. Such mitigation measures could include modifications to the operating process, or the installation of carbon filters to capture odorous compounds before they are emitted. The water treatment plants would be located as far from receivers as can be reasonably and feasibly achieved.

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6.0 Operational impact assessment

As discussed in **Section 4.2**, dispersion modelling was used to predict resultant pollutant concentrations from the ventilation outlets (using CALPUFF) and from vehicles using the surface road network in proximity to the project portals at the southern and northern interchanges (using CAL3QHCR). The predicted emission concentrations from each model at each receiver location (where relevant) were combined to provide a total project contribution for each pollutant for each assessment scenario.

For PM_{10}, $PM_{2.5}$, NO_2 and CO, the predicted concentrations were added to the relevant ambient (background) pollutant concentrations to estimate cumulative pollutant concentrations, which were compared to the relevant assessment criteria. For PM_{10}, $PM_{2.5}$ and NO_2, the ambient pollutant concentrations were added contemporaneously – that is, the measured ambient pollutant concentrations were added to the associated model predictions for each receiver for that same time period. The maximum of the CAL3QHCR predictions and the OEH monitoring data at each receiver location were used to represent ambient pollutant concentrations.

6.1 Summary of results

This section of the report presents the results for:

- With project – expected traffic flows 2019 (scenario 2a) and 2029 (scenario 2b).
- The comparison of air quality with and without the project.
- The breakdown scenario.

Results for the design analysis assessments are presented in **Appendix G**.

6.1.1 With project – ventilation facilities – expected traffic flows

A summary of the dispersion modelling results for expected operation of the project in 2019 and 2029 (scenarios 2a/ 2b) for each ventilation outlet is presented in **Table 29** to. Predicted exceedences of the applicable air quality criteria are shown in bold text. Contour plots of project contributions were prepared for the pollutants with predicted cumulative concentrations closest to the relevant impact assessment criteria (i.e. PM_{10}, $PM_{2.5}$ and NO_2). **Figure 11** to **Figure 34** show contour plots for the maximum predicted project contributions of PM_{10}, $PM_{2.5}$ and NO_2 for the relevant averaging periods. It should be noted that plots of cumulative concentrations are not provided.

In the following tables, the 'project contribution' reflects the pollutant concentrations at receiver locations attributable to emissions from the ventilation outlets. The background data presented represent the maximum background pollutant concentrations from the road modelling or the background concentrations measured at Lindfield/Prospect for the associated time period. The values for PM_{10}, $PM_{2.5}$, NO_2 and CO in the following tables represent the peak predicted concentrations from the project alone or the peak cumulative concentration (where relevant) across the modelling domain. The NO_2 results represent the conversion of the model NO_X predictions to NO_2 using the OLM as described in **Section 4.2.11.1**. Results are presented in terms of maximum concentrations relative to each of the ventilation outlets; the maximum concentrations anywhere in the modelling domain equal the maximum of the northern and southern ventilation data.

The results in **Table 29** to show that applicable air quality criteria are comfortably met, with the exception of cumulative PM_{10} and $PM_{2.5}$ concentrations over a 24-hour averaging period. In the case of these two pollutants, however, the following should be noted:

- For 24 hour PM_{10}, the contribution from the project is predicted to be very minor, with a maximum of 2.1 $\mu g/m^3$ attributable to the ventilation outlet emissions (2029). This contribution represents 4.2 per cent of the applicable impact assessment criterion of 50 $\mu g/m^3$ (refer to **Table 29**).
- For 24 hour $PM_{2.5,}$ the maximum contribution from the project was predicted to be 2.0 $\mu g/m^3$ (2029), which is eight per cent of the Air NEPM advisory reporting standard of 25 $\mu g/m^3$ (refer to **Table 30**).

Because background concentrations for PM_{10} (24-hour average) are already elevated across the Sydney airshed, the predicted 24-hour average PM_{10} concentrations for the project were subjected to a contemporaneous analysis, which considered the actual modelled contribution of the project for a particular period with the actual background concentration for that same period rather than combining the maxima in both cases. This approach allows a more refined assessment of air quality impacts, taking into account the likelihood of maximum project contributions and maximum background concentrations occurring at the same time. Contemporaneous analyses were also conducted for $PM_{2.5}$, given that this pollutant is key to the air quality performance of the project (refer to **Section 6.1.2** and **Section 6.1.3**).

The predicted concentrations of NO_2, CO and PAHs were well below the relevant impact assessment criteria. As such, no further analysis of these pollutants was undertaken.

The total VOC concentrations were speciated based on data published by the NSW Office of Environment and Heritage (2012), and are discussed further in **Section 6.1.5**.

As stated previously, the particulate emissions from vehicles primarily comprise the smaller fractions, such as PM_{10} and $PM_{2.5}$. As such, the estimated TSP emissions from vehicles essentially equate to PM_{10} emissions. The EPA has an annual criterion for TSP of 90 $\mu g/m^3$. The maximum annual average PM_{10} concentrations predicted by the modelling are well below this criterion. As a consequence, no adverse impacts from TSP are expected to result from the project.

Table 29 Predicted maximum PM_{10} pollutant concentrations – 'with project – expected traffic flows' ($\mu g/m^3$)

Averaging period	Source	Predicted maximum PM_{10} concentrations ($\mu g/m^3$) With project – expected traffic flows 2019 (Scenario 2a)		With project – expected traffic flows 2029 (Scenario 2b)		Impact assessment criteria ($\mu g/m^3$)
		Northern ventilation outlet	Southern ventilation outlet	Northern ventilation outlet	Southern ventilation outlet	
24 hours	Peak project contribution	1.0	1.4	1.4	2.1	-
	Peak cumulative concentration (project plus background)	Refer to **Table 34**				50
	Project contribution (% of criteria)	2.0 %	2.8 %	2.8 %	4.2 %	-
Annual average	Peak project contribution	0.09	0.11	0.11	0.13	-
	Peak cumulative concentration (project plus background)	21.27	21.31	21.29	21.35	30
	Project contribution (% of criteria)	0.3 %	0.4 %	0.4 %	0.4 %	-

Table 30 Predicted maximum $PM_{2.5}$ pollutant concentrations – 'with project – expected traffic flows' (μg/m³)

Averaging period	Source	Predicted maximum $PM_{2.5}$ concentrations (μg/m³) With project – expected traffic flows 2019 (Scenario 2a)		With project – expected traffic flows 2029 (Scenario 2b)		Advisory reporting standards (μg/m³)
		Northern ventilation outlet	Southern ventilation outlet	Northern ventilation outlet	Southern ventilation outlet	
24 hours	Peak project contribution	0.9	1.3	1.3	2.0	-
	Peak cumulative concentration (project plus background)	Refer to **Table 35**				25
	Project contribution (% of criteria)	3.6 %	5.2 %	5.2 %	8.0 %	-
Annual average	Peak project contribution	0.08	0.11	0.10	0.13	-
	Peak cumulative concentration (project plus background)	**8.70**	**10.28**	**8.71**	**10.29**	8
	Project contribution (% of criteria)	1.0 %	1.4 %	1.3 %	1.6 %	-
Exceedences denoted in **bold type**						

Table 31 Predicted maximum NO_2 pollutant concentrations – 'with project – expected traffic flows' (μg/m³)

Averaging period	Source	Predicted maximum NO_2 concentrations (μg/m³) With project – expected traffic flows 2019 (Scenario 2a)		With project – expected traffic flows 2029 (Scenario 2b)		Impact assessment criteria (μg/m³)
		Northern ventilation outlet	Southern ventilation outlet	Northern ventilation outlet	Southern ventilation outlet	
1 hour	Peak project contribution	68.9	61.8	74.6	65.0	-
	Peak cumulative concentration (project plus background)	150.8	165.1	159.3	166.7	246
	Project contribution (% of criteria)	28 %	25 %	30 %	26 %	-
Annual average	Peak project contribution	1.4	1.2	1.7	1.4	-
	Peak cumulative concentration (project plus background)	38.7	42.4	39.9	42.8	62
	Project contribution (% of criteria)	2 %	2 %	3 %	2 %	-

Table 32 Predicted maximum CO pollutant concentrations – 'with project – expected traffic flows' (μg/m^3)

Averaging period	Source	Predicted maximum CO concentrations (μg/m^3) – With project – expected traffic flows 2019 (Scenario 2a)		With project – expected traffic flows 2029 (Scenario 2b)		Impact assessment criteria (μg/m^3)
		Northern ventilation outlet	Southern ventilation outlet	Northern ventilation outlet	Southern ventilation outlet	
1 hour	Peak project contribution	86.6	70.1	107.4	90.3	-
	Peak cumulative concentration (project plus background)	3,712	3,695	3,732	3,715	30,000
	Project contribution (% of criteria)	0.29 %	0.23 %	0.36 %	0.30 %	-
8 hour	Peak project contribution	32.4	33.1	54.2	57.9	-
	Peak cumulative concentration (project plus background)	2,634	2,635	2,656	2,660	10,000
	Project contribution (% of criteria)	0.32 %	0.33 %	0.54 %	0.58 %	-

Table 33 Predicted 99.9th percentile total VOC and PAH pollutant concentrations – 'with project – expected traffic flows' (μg/m^3)

Pollutant	Source	Predicted 99.9th percentile concentrations (μg/m^3) (one hour) – With project – expected traffic flows 2019 (Scenario 2a)		With project – expected traffic flows 2029 (Scenario 2b)		Impact assessment criteria (μg/m^3)
		Northern ventilation outlet	Southern ventilation outlet	Northern ventilation outlet	Southern ventilation outlet	
Total VOCs	Peak project contribution	4.07	3.72	5.38	5.36	29*
	Project contribution (% of criteria)	14 %	13 %	19 %	18 %	-
PAHs	Peak project contribution	0.00074	0.00068	0.00089	0.00092	0.4**
	Project contribution (% of criteria)	0.19 %	0.17 %	0.22 %	0.23 %	-

* as benzo(a)pyrene
** as benzene

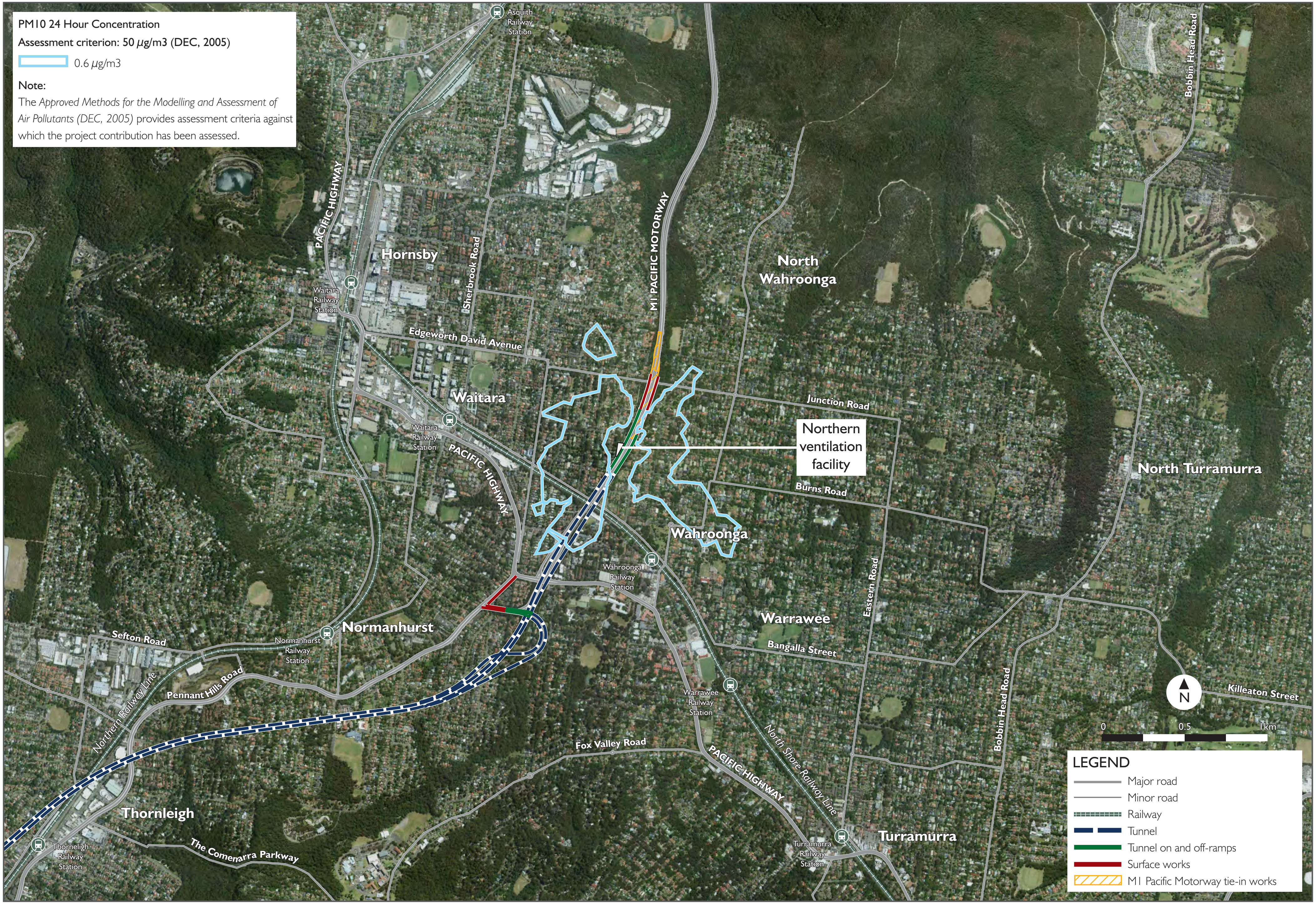

Figure 11 Maximum predicted 24 hour PM10 concentrations (ug/m3) - northern ventilation outlet - project only contribution - expected traffic flows, 2019 (Scenario 2a)

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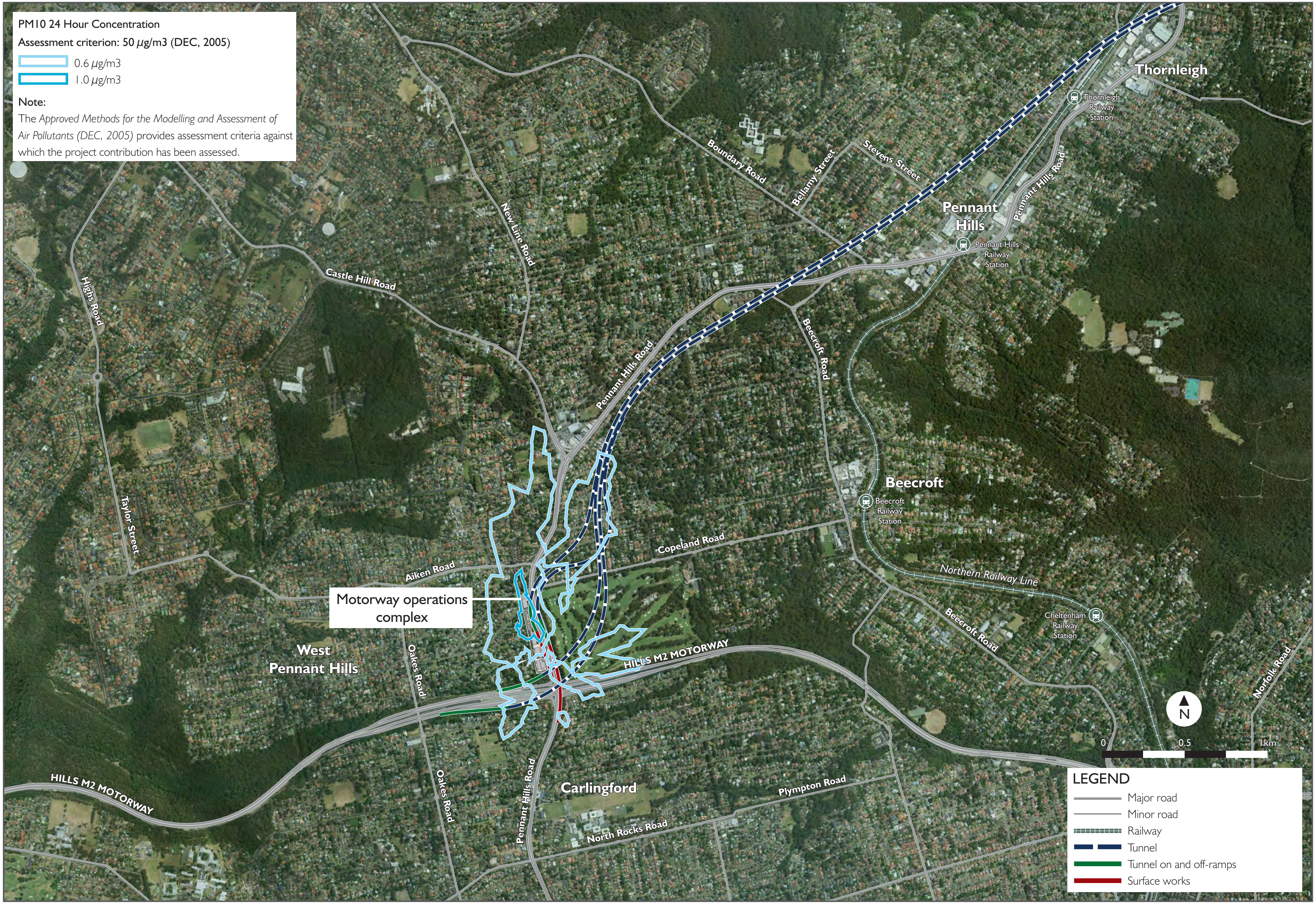

Figure 12 Maximum predicted 24 hour PM10 concentrations (ug/m3) - southern ventilation outlet - project only contribution - expected traffic flows, 2019 (scenario 2a)

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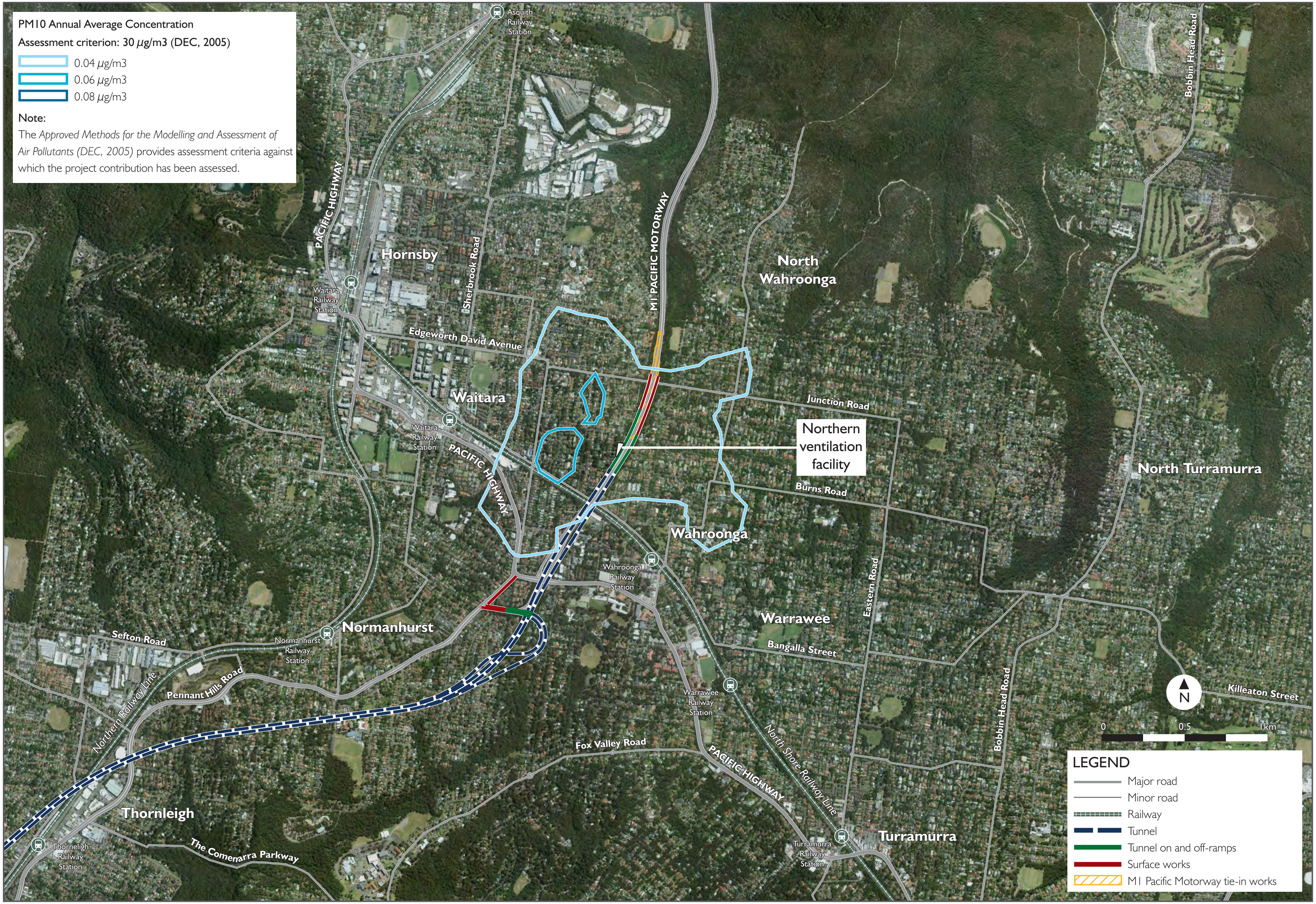

Figure 13 Maximum predicted annual average PM10 concentrations (ug/m3) - northern ventilation outlet - project only contribution - expected traffic flows, 2019 (scenario 2a)

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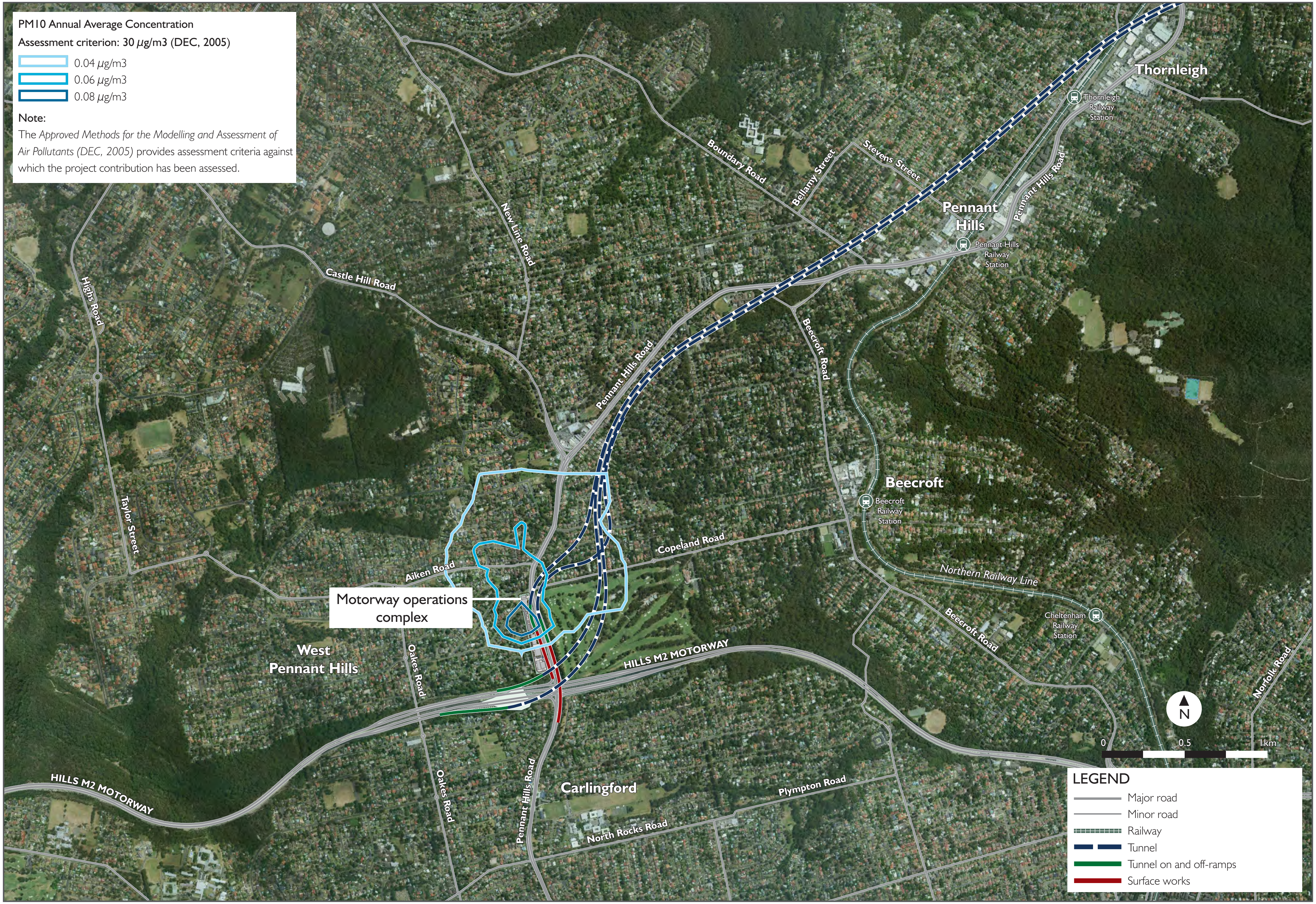

Figure 14 Maximum predicted annual average PM10 concentrations (ug/m3) - southern ventilation outlet - project only contribution - expected traffic flows, 2019 (scenario 2a)

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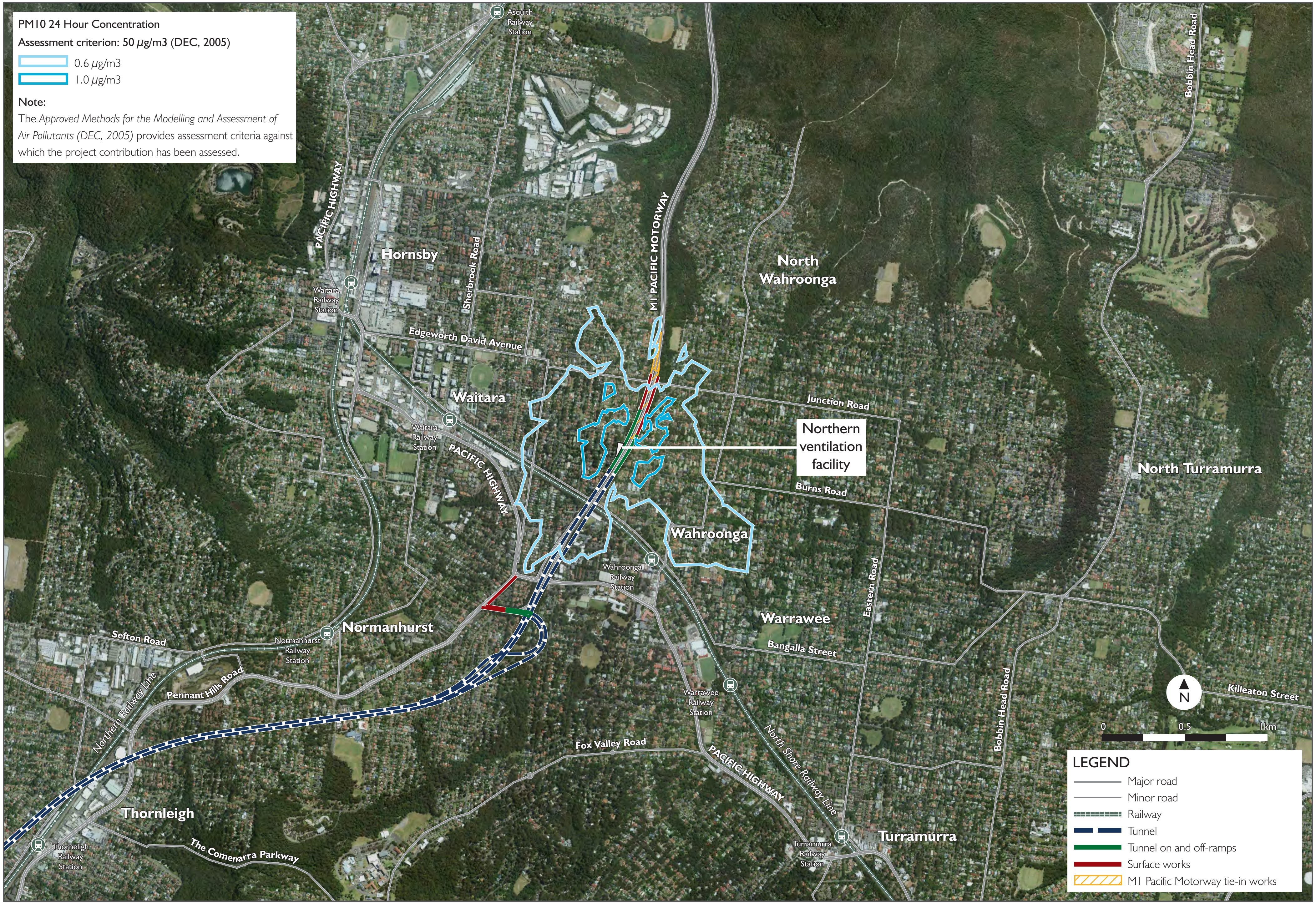

Figure 15 Maximum predicted 24 hour PM10 concentrations (ug/m3) - northern ventilation outlet - project only contribution - expected traffic flows, 2029 (scenario 2b)

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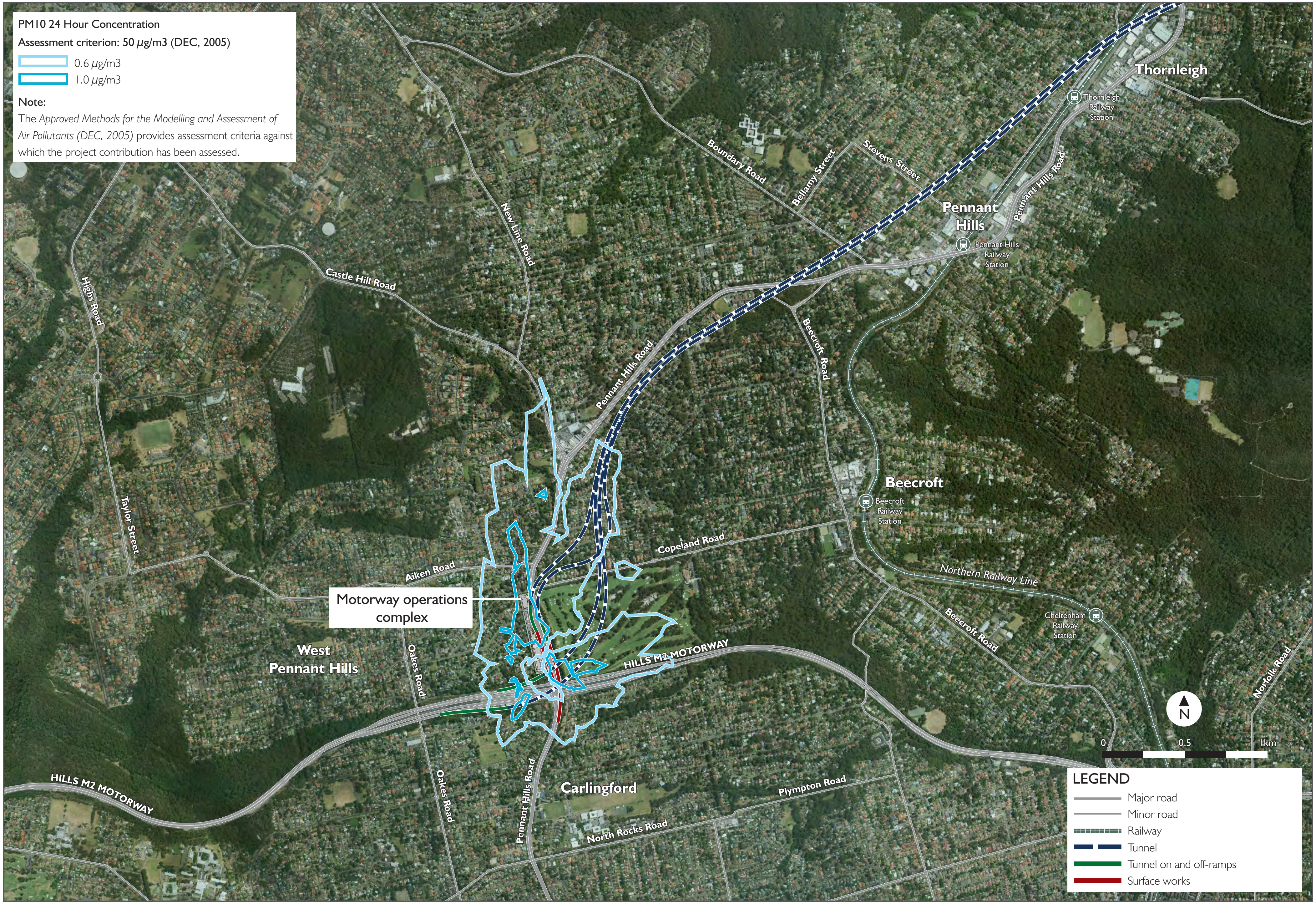

Figure 16 Maximum predicted 24 hour PM10 concentrations (ug/m3) - southern ventilation outlet - project only contribution - expected traffic flows, 2029 (scenario 2b)

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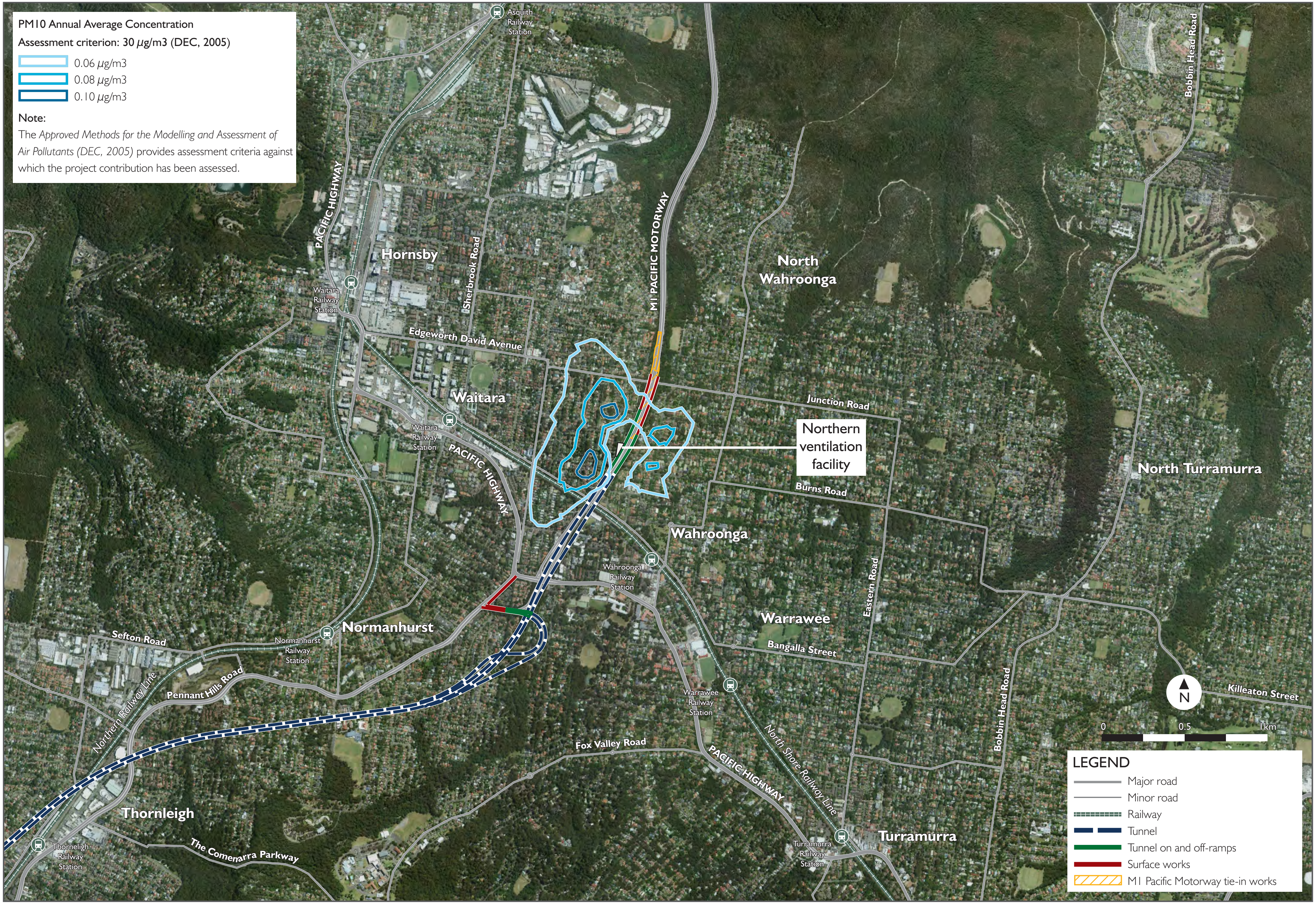

Figure 17 Maximum predicted annual average PM10 concentrations (ug/m3) - northern ventilation outlet - project only contribution - expected traffic flows, 2029 (scenario 2b)

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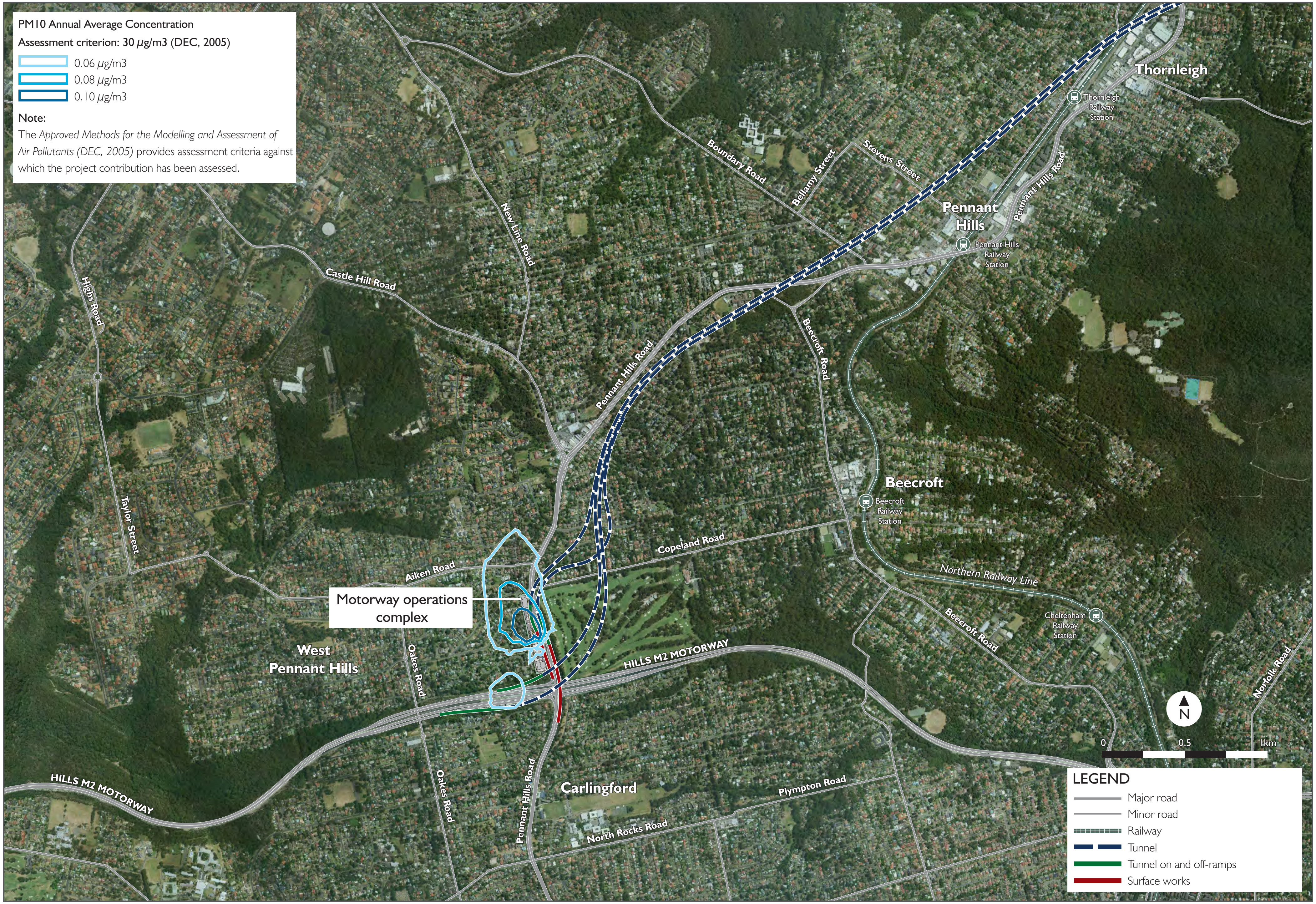

Figure 18 Maximum predicted annual average PM10 concentrations (ug/m3) - southern ventilation outlet - project only contribution - expected traffic flows, 2029 (scenario 2b)

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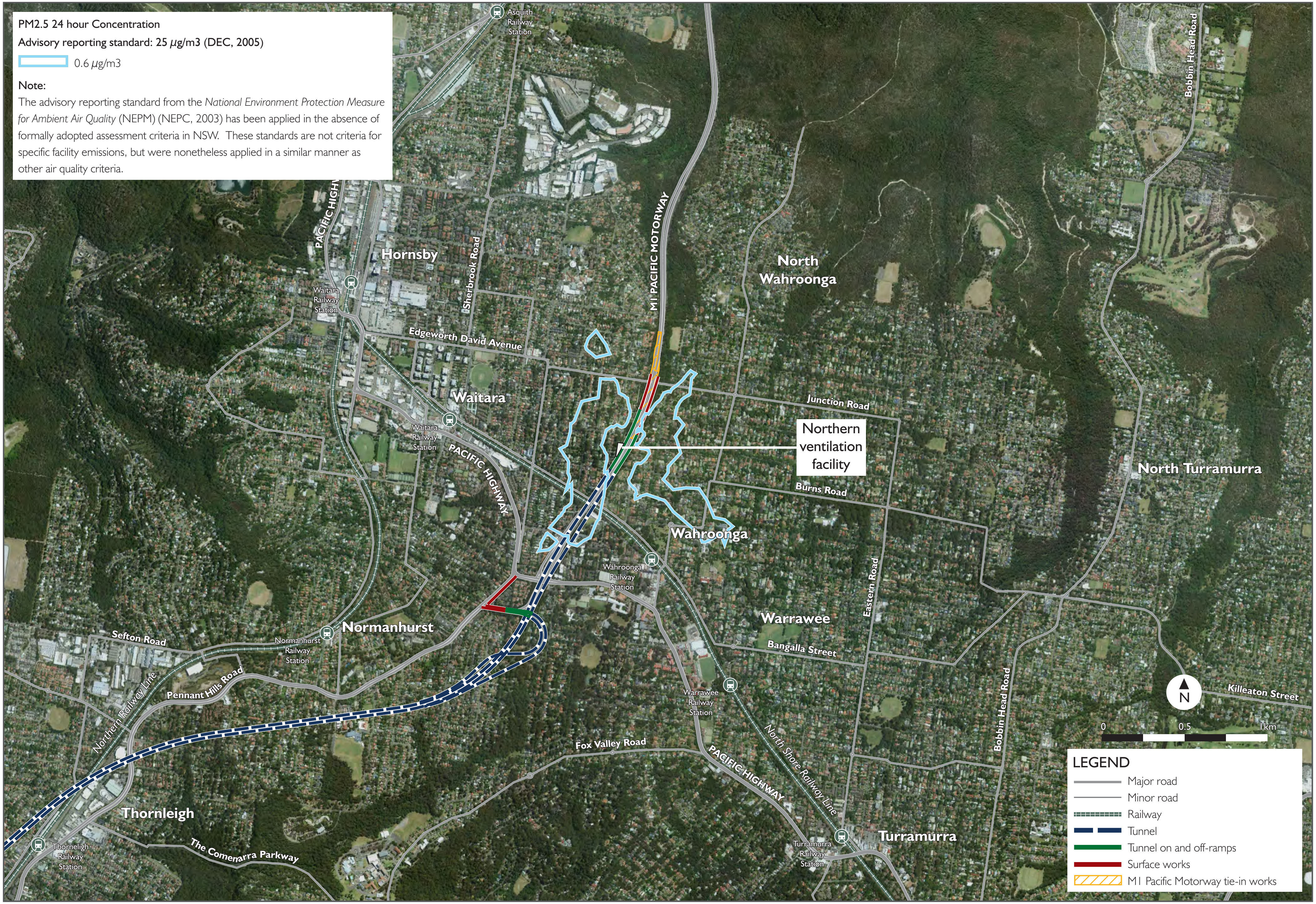

Figure 19 Maximum predicted 24 hour PM2.5 concentrations (ug/m3) - northern ventilation outlet - project only contribution - expected traffic flows, 2019 (scenario 2a)

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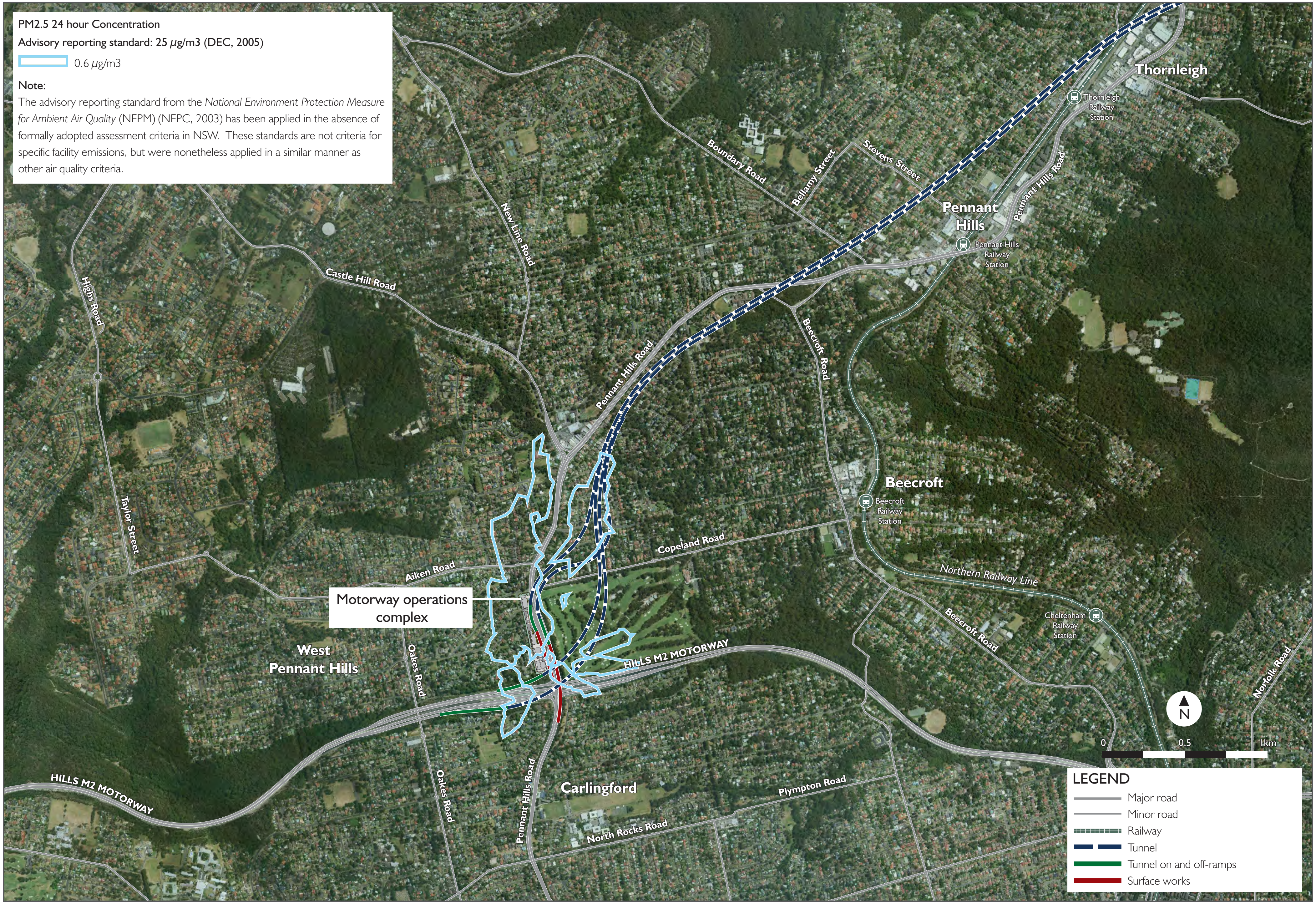

Figure 20 Maximum predicted 24 hour PM2.5 concentrations (ug/m3) - southern ventilation outlet - project only contribution - expected traffic flows, 2019 (scenario 2a)

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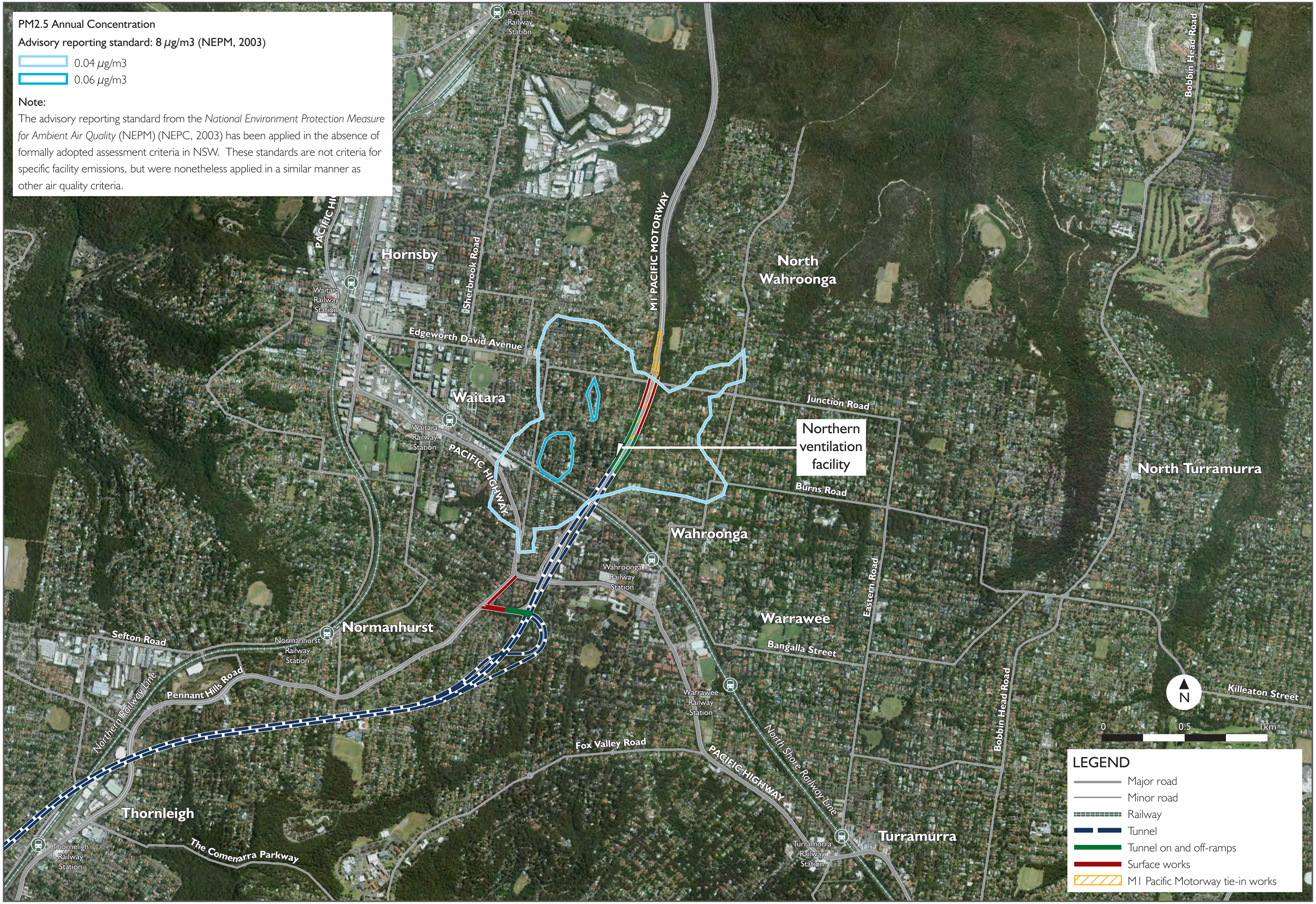

Figure 21 Maximum predicted annual average PM2.5 concentrations (ug/m3) - northern ventilation outlet - project only contribution - expected traffic flows, 2019 (scenario 2a)

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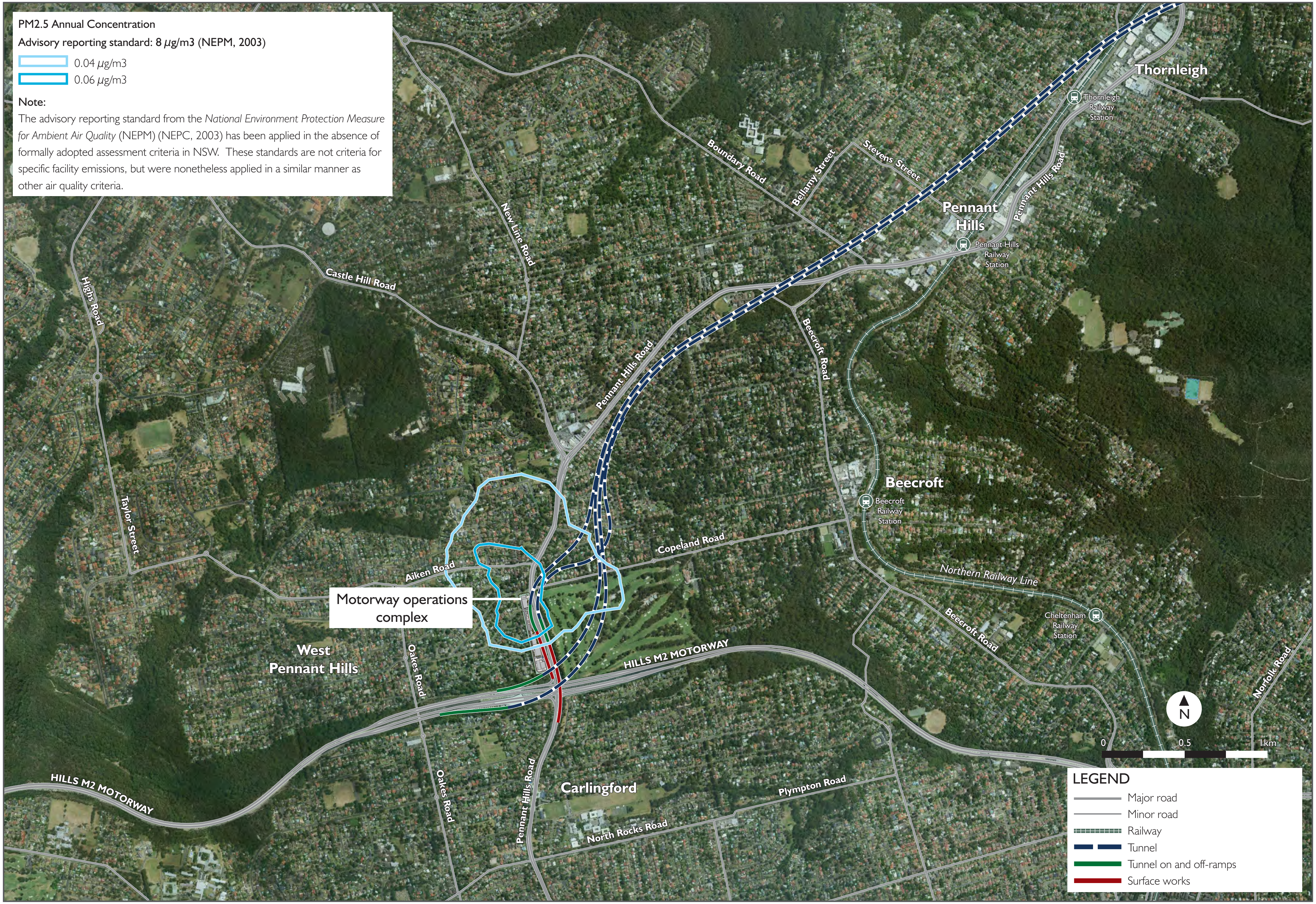

Figure 22 Maximum predicted annual average PM2.5 concentrations (ug/m3) - southern ventilation outlet - project only contribution - expected traffic flows, 2019 (scenario 2a)

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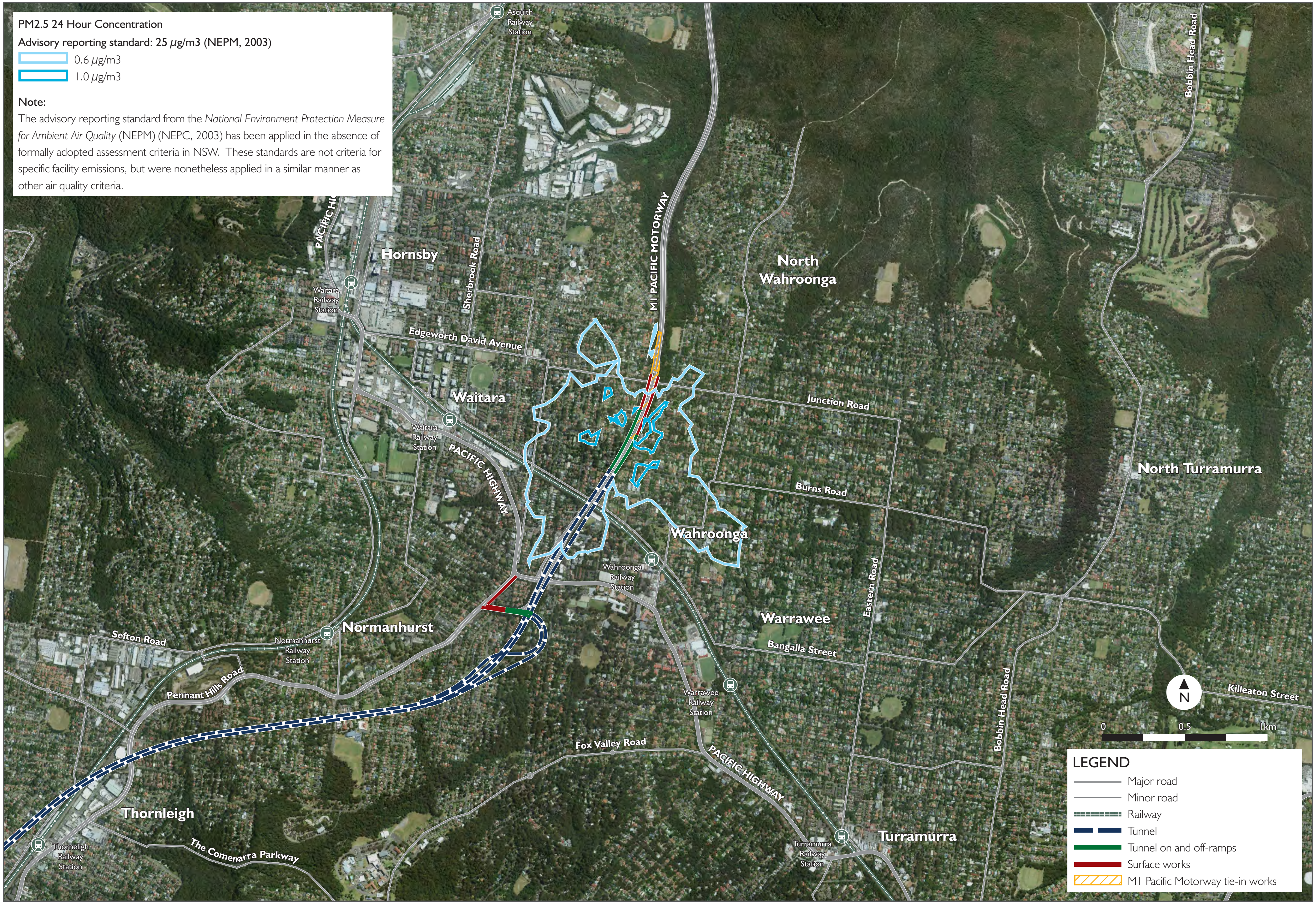

Figure 23 Maximum predicted 24 hour PM2.5 concentrations (ug/m3) - northern ventilation outlet - project only contribution - expected traffic flows, 2029 (scenario 2b)

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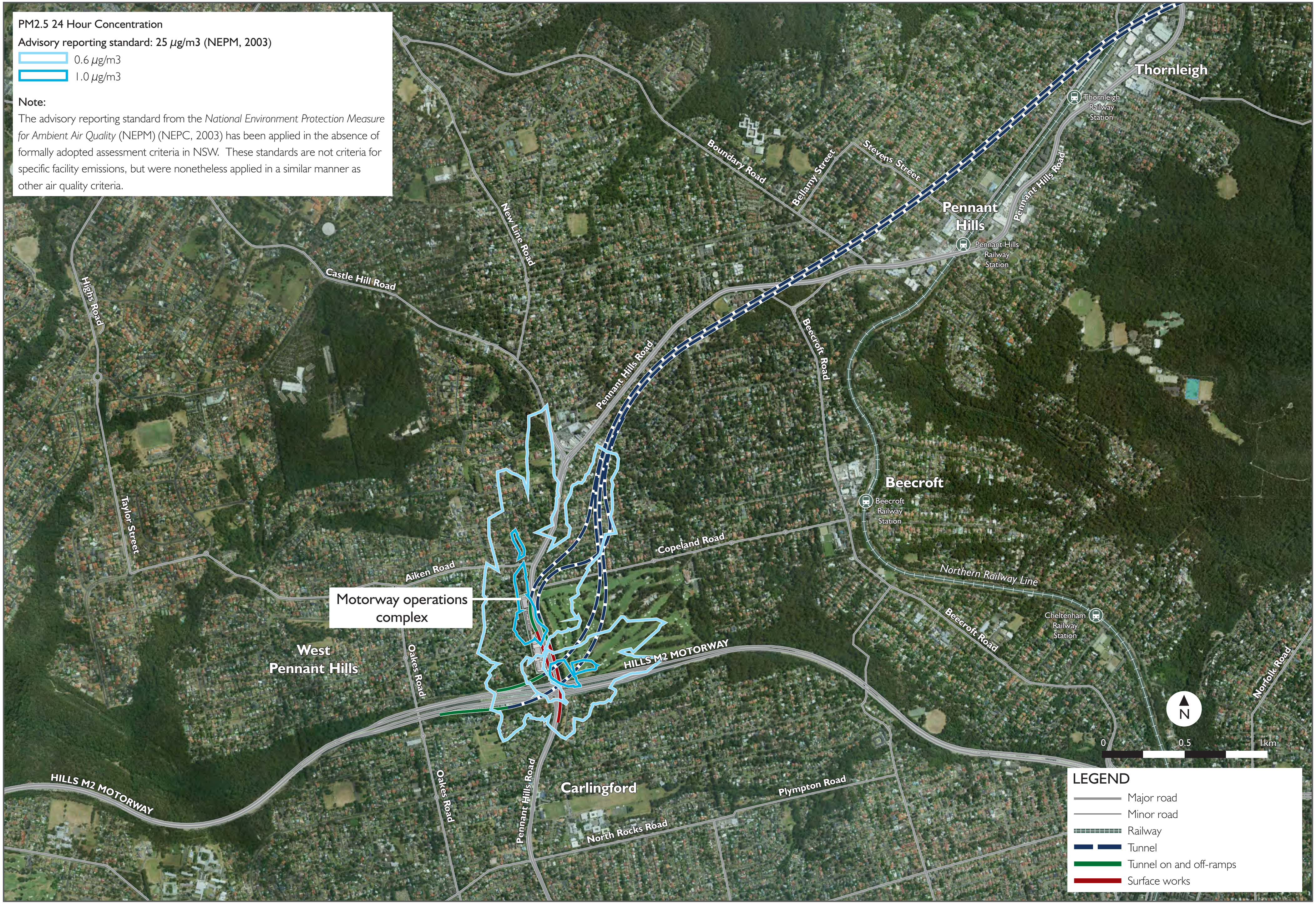

Figure 24 Maximum predicted 24 hour PM2.5 concentrations (ug/m3) - southern ventilation outlet - project only contribution - expected traffic flows, 2029 (scenario 2b)

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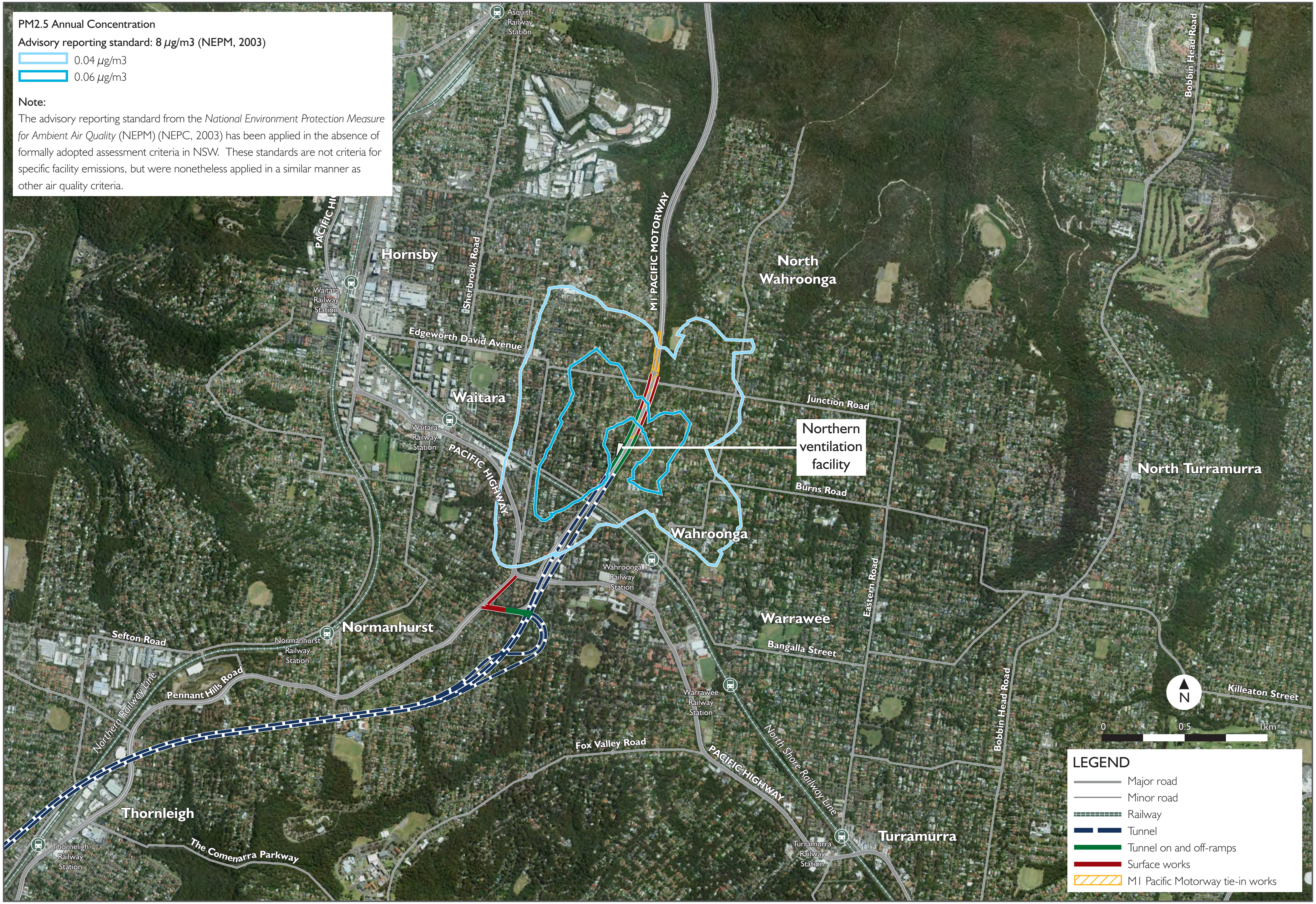

Figure 25 Maximum predicted annual average PM2.5 concentrations (ug/m3) - northern ventilation outlet - project only contribution - expected traffic flows, 2029 (scenario 2b)

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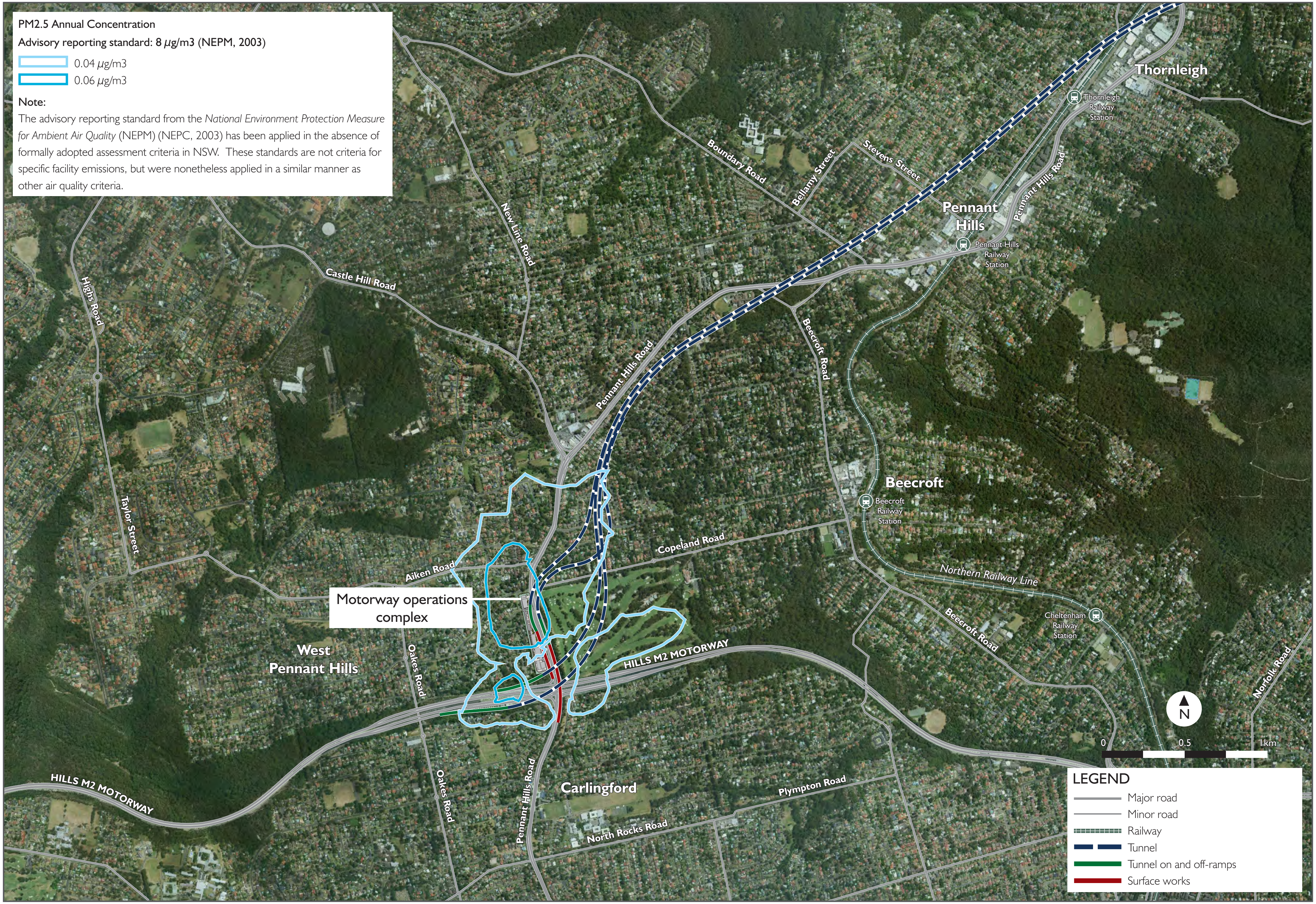

Figure 26 Maximum predicted annual average PM2.5 concentrations (ug/m3) - southern ventilation outlet - project only contribution - expected traffic flows, 2029 (scenario 2b)

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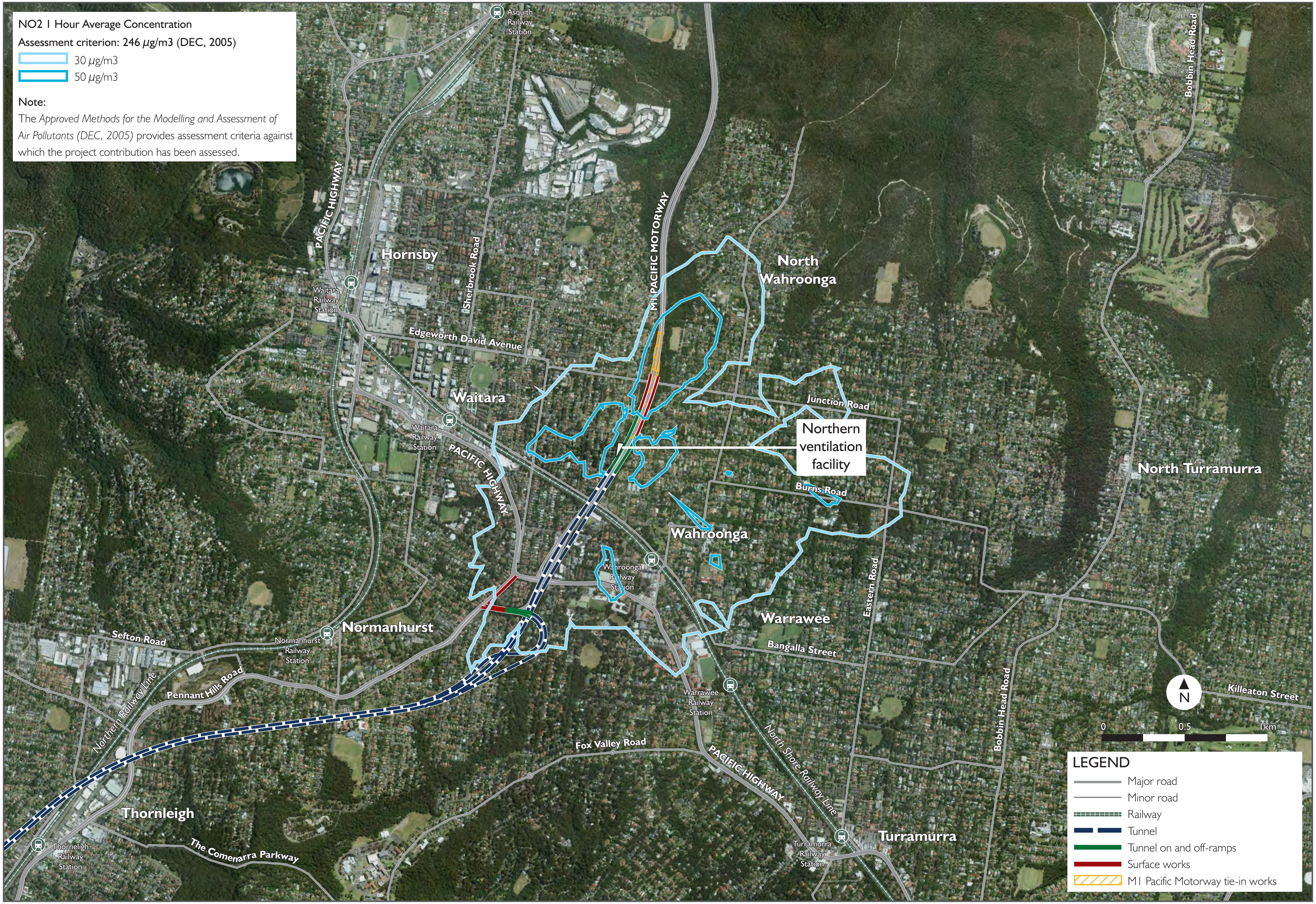

Figure 27 Maximum predicted 1 hour NO2 concentrations (ug/m3) - northern ventilation outlet - project only contribution - expected traffic flows, 2019 (scenario 2a)

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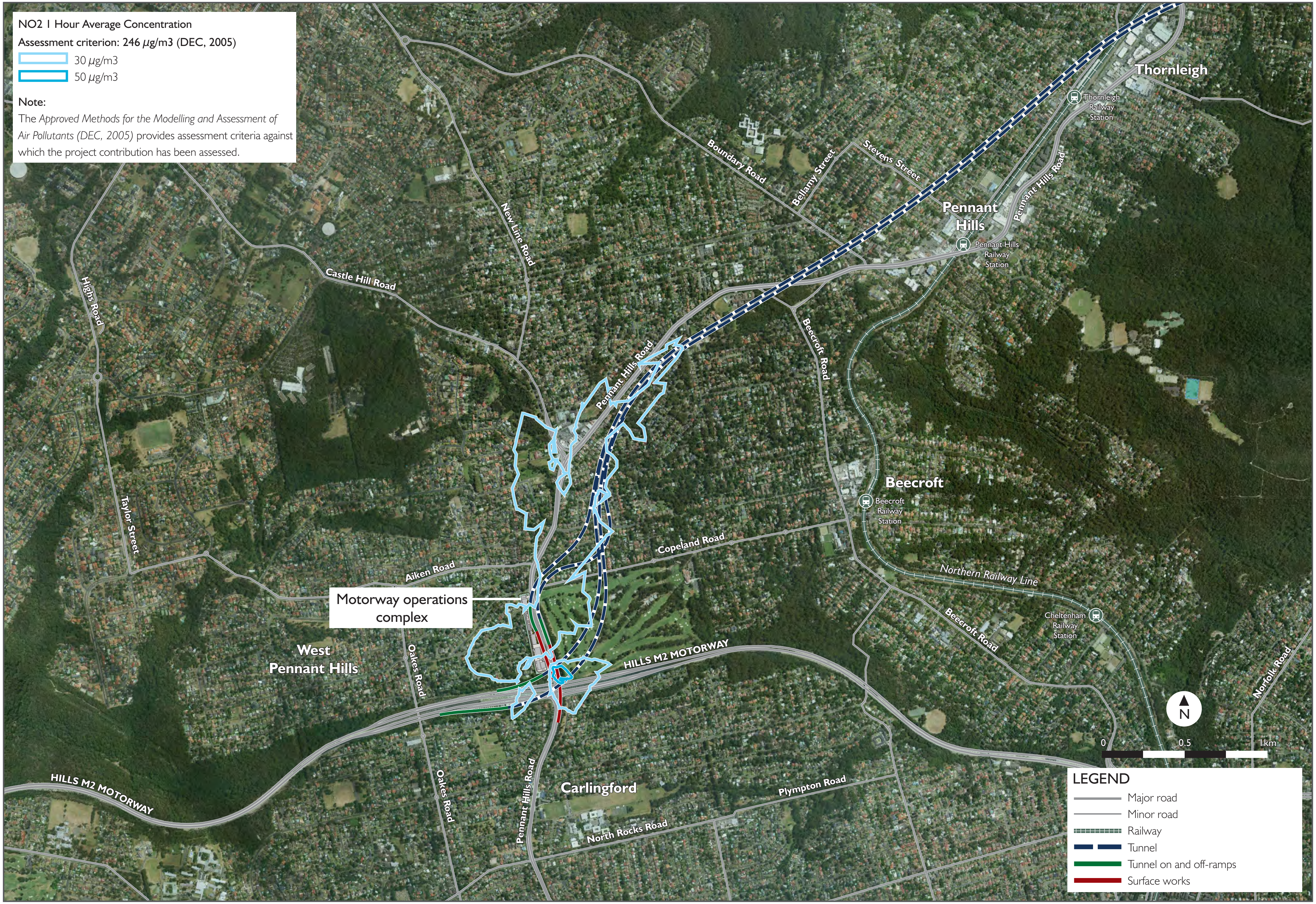

Figure 28 Maximum predicted 1 hour NO2 concentrations (ug/m3) - southern ventilation outlet - project only contribution - expected traffic flows, 2019 (scenario 2a)

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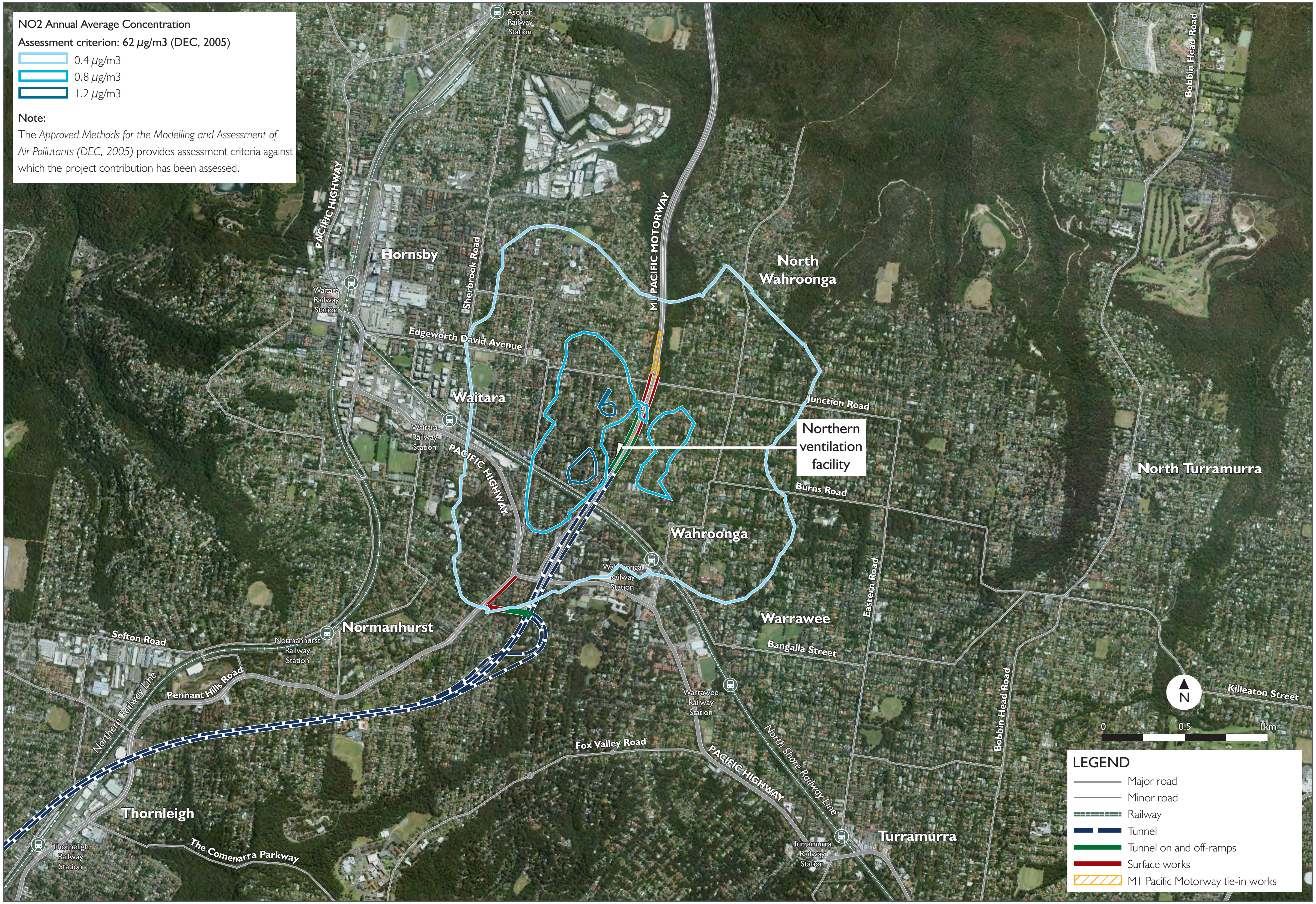

Figure 29 Maximum predicted annual average NO2 concentrations (ug/m3) - northern ventilation outlet - project only contribution - expected traffic flows, 2019 (scenario 2a)

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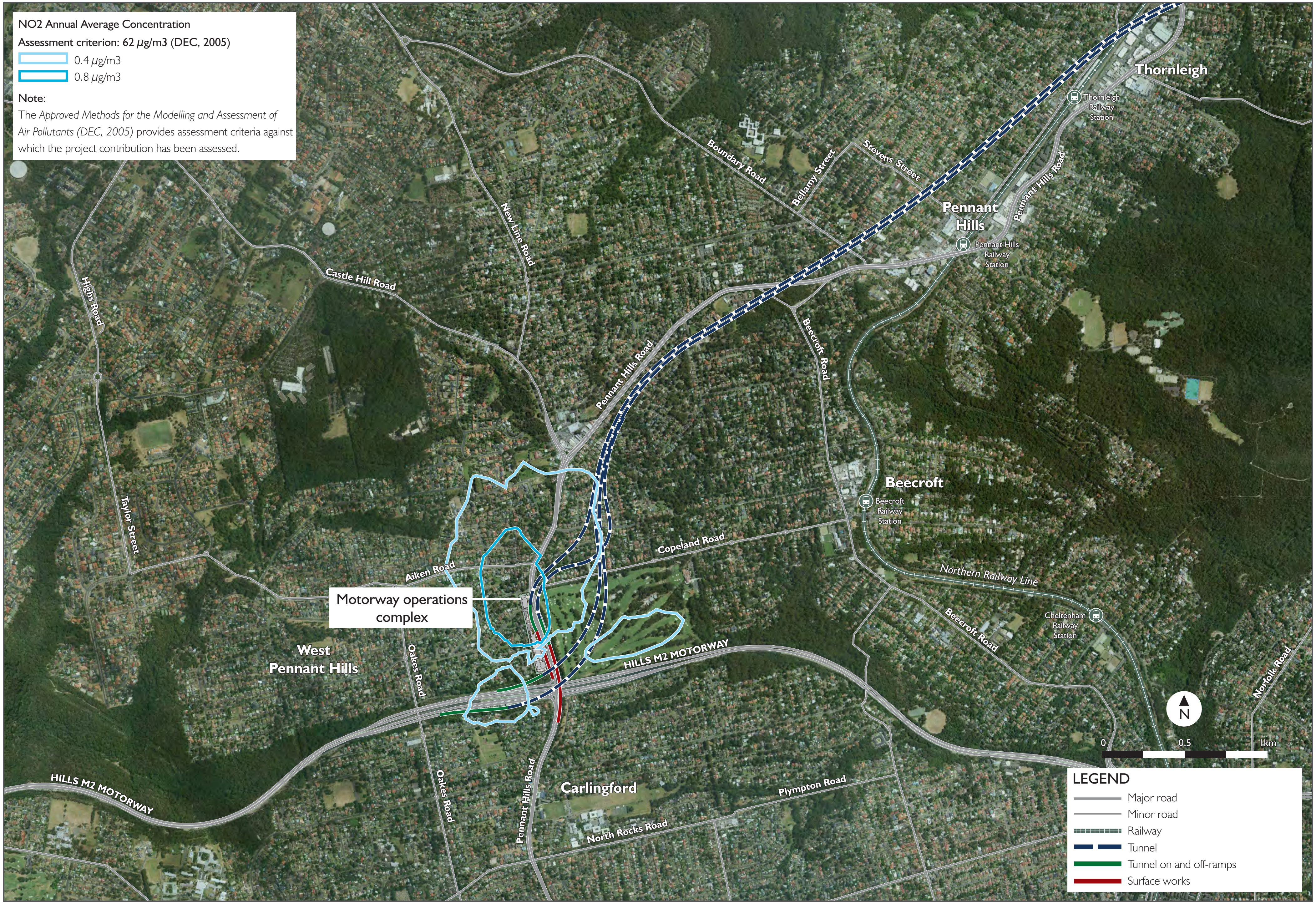

Figure 30 Maximum predicted annual average NO2 concentrations (ug/m3) - southern ventilation outlet - project only contribution - expected traffic flows, 2019 (scenario 2a)

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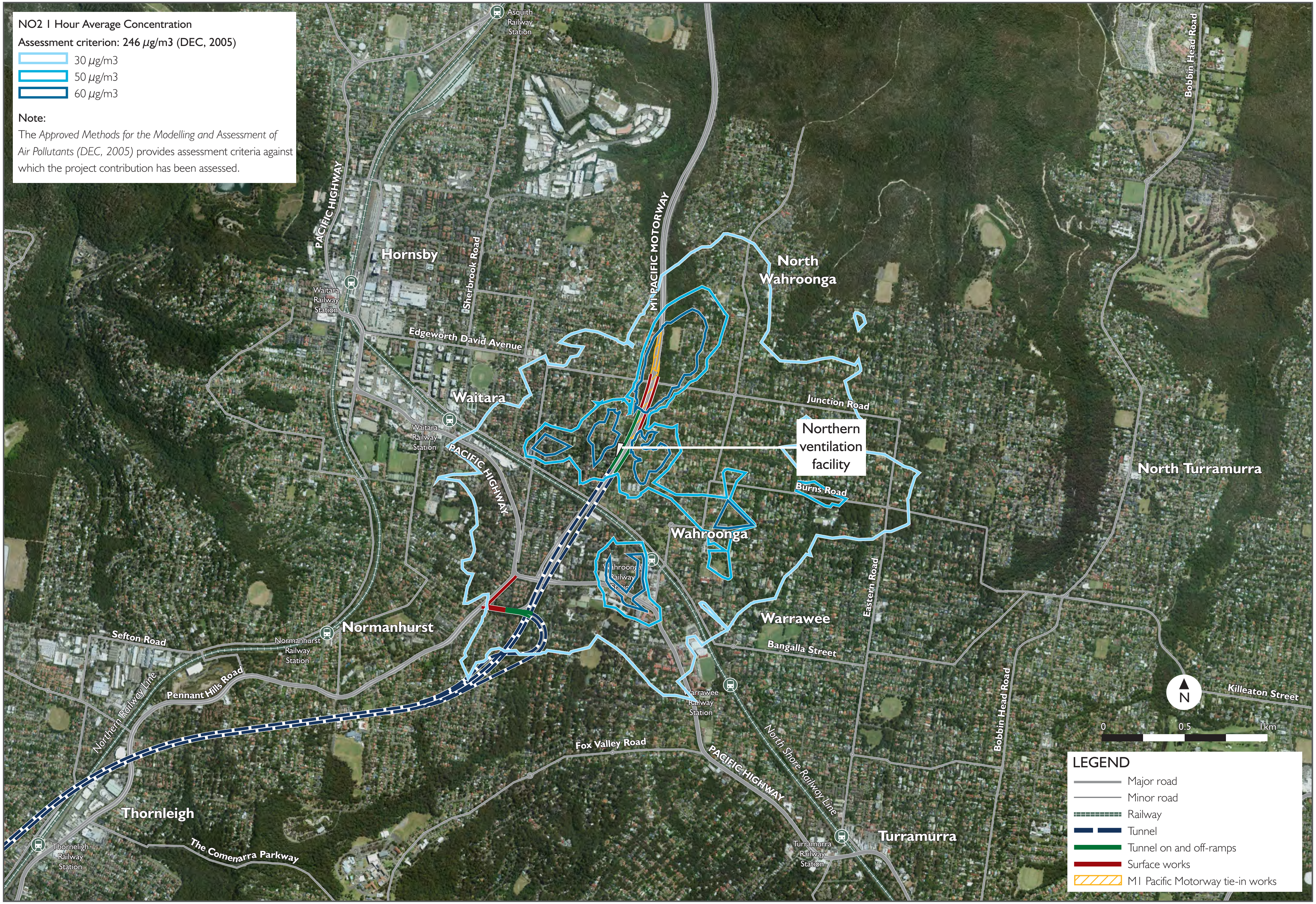

Figure 31 Maximum predicted 1 hour NO2 concentrations (ug/m3) - northern ventilation outlet - project only contribution - expected traffic flows, 2029 (scenario 2b)

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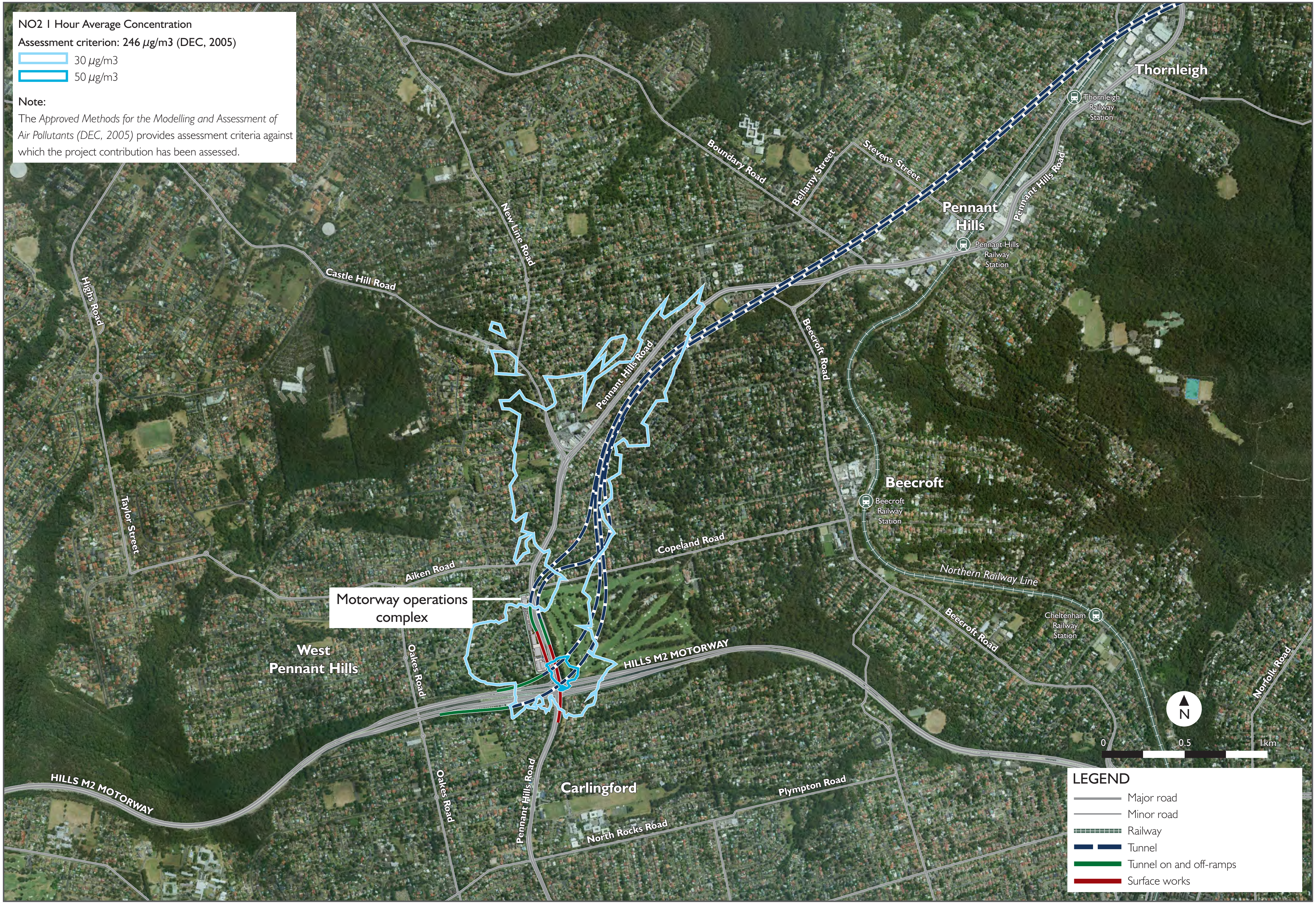

Figure 32 Maximum predicted 1 hour NO2 concentrations (ug/m3) - southern ventilation outlet - project only contribution - expected traffic flows, 2029 (scenario 2b)

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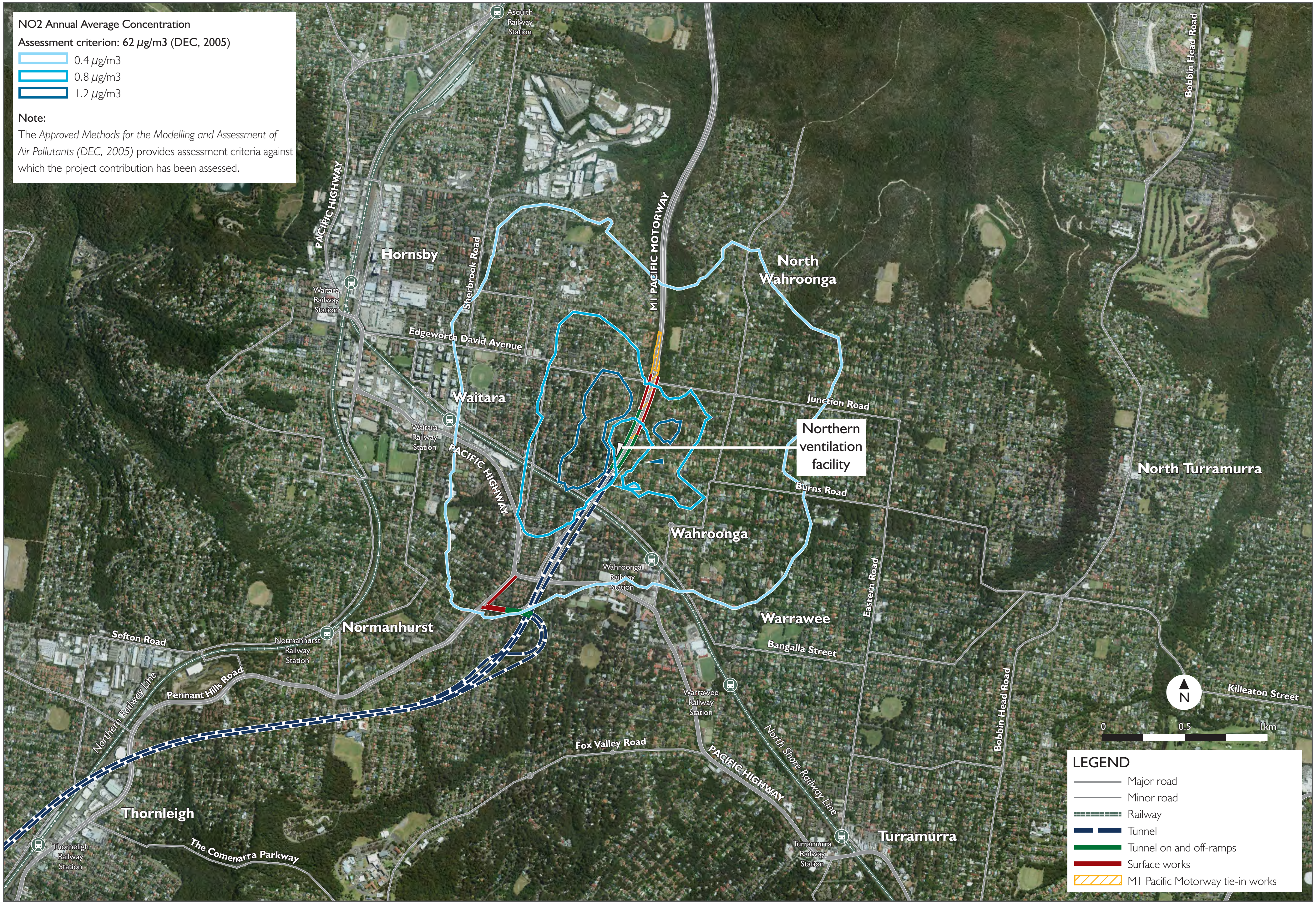

Figure 33 Maximum predicted annual average NO2 concentrations (ug/m3) - northern ventilation outlet - project only contribution - expected traffic flows, 2029 (scenario 2b)

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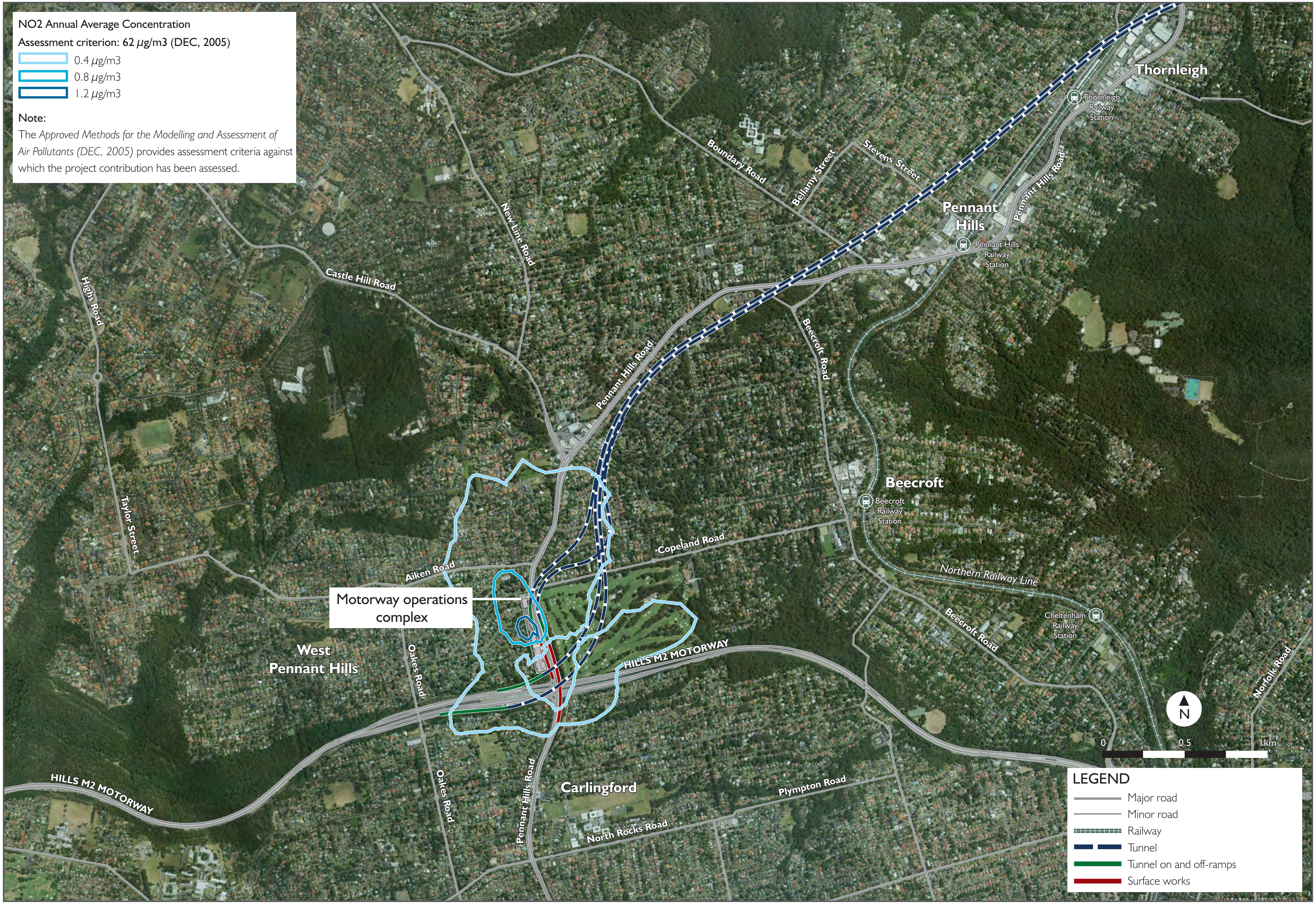

Figure 34 Maximum predicted annual average NO2 concentrations (ug/m3) - southern ventilation outlet - project only contribution - expected traffic flows, 2029 (scenario 2b)

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6.1.2 Cumulative assessment – With project – expected traffic flows – PM_{10} 24-hour average

Chart 4 and **Chart 5** show the project contributions and associated background concentrations for the modelling period for the ‘with project – expected traffic flows’ scenario for 2019 for the northern and southern ventilation outlets respectively, while **Chart 6** and **Chart 7** show the same data for 2029. The charts show the project contribution and the associated background concentration for each day of the modelling period for the receivers with the highest predicted project contributions (one receiver per chart). It should be noted that the maximum background concentrations are beyond the scale of the charts, and that the scales of the vertical axes were restricted so that the small project contributions could be seen. Even so, the project contributions are still barely visible, as the maximum project contributions were orders of magnitude lower than the background concentrations.

Table 34 provides further details of the contemporaneous assessment of the predicted 24 hour average PM_{10} concentrations, specifically:

- The top ten predicted cumulative concentrations (the project with background) for ‘with project – expected traffic flows’ in 2019 and 2029 (referred to as the maximum cumulative concentrations).
- The top ten predicted concentrations from each ventilation outlet for ‘with project – expected traffic flows’ in 2019 and 2029, and the cumulative concentration that would result (referred to as the maximum project concentrations).

As discussed in **Section 3.1**, nine exceedences of the PM_{10} 24 hour average criterion are present in the background OEH air quality data for 2009. These exceedences are likely to have resulted from bushfires or unusual short term natural events. These elevated concentrations are not considered representative of the area, with the average PM_{10} concentrations well below the relevant criteria.

The results of the contemporaneous analysis show:

- The maximum predicted contribution from the project would be 2.1 $\mu g/m^3$ (‘with project – expected traffic flows’ in 2029), which is substantially less than the applicable impact assessment criterion of 50 $\mu g/m^3$.
- The highest cumulative concentrations (background plus the project) occur at times where the maximum predicted project contributions for the assessed scenarios are all low (less than or equal to 0.3 $\mu g/m^3$) and well below the applicable impact assessment criterion of 50 $\mu g/m^3$.

This demonstrates that the predicted exceedences of the PM_{10} criterion would result from elevated background concentrations and would, therefore, be associated with other sources in the airshed. Furthermore, the cumulative assessment demonstrated that the project is not predicted to result in any additional exceedences of the 24 hour criterion (there were nine exceedences in the background data, and nine exceedences predicted by the dispersion modelling). As such, the project is predicted to have very little effect on local PM_{10} concentrations. The data were also ranked according to background concentrations; these are provided in **Appendix H**.

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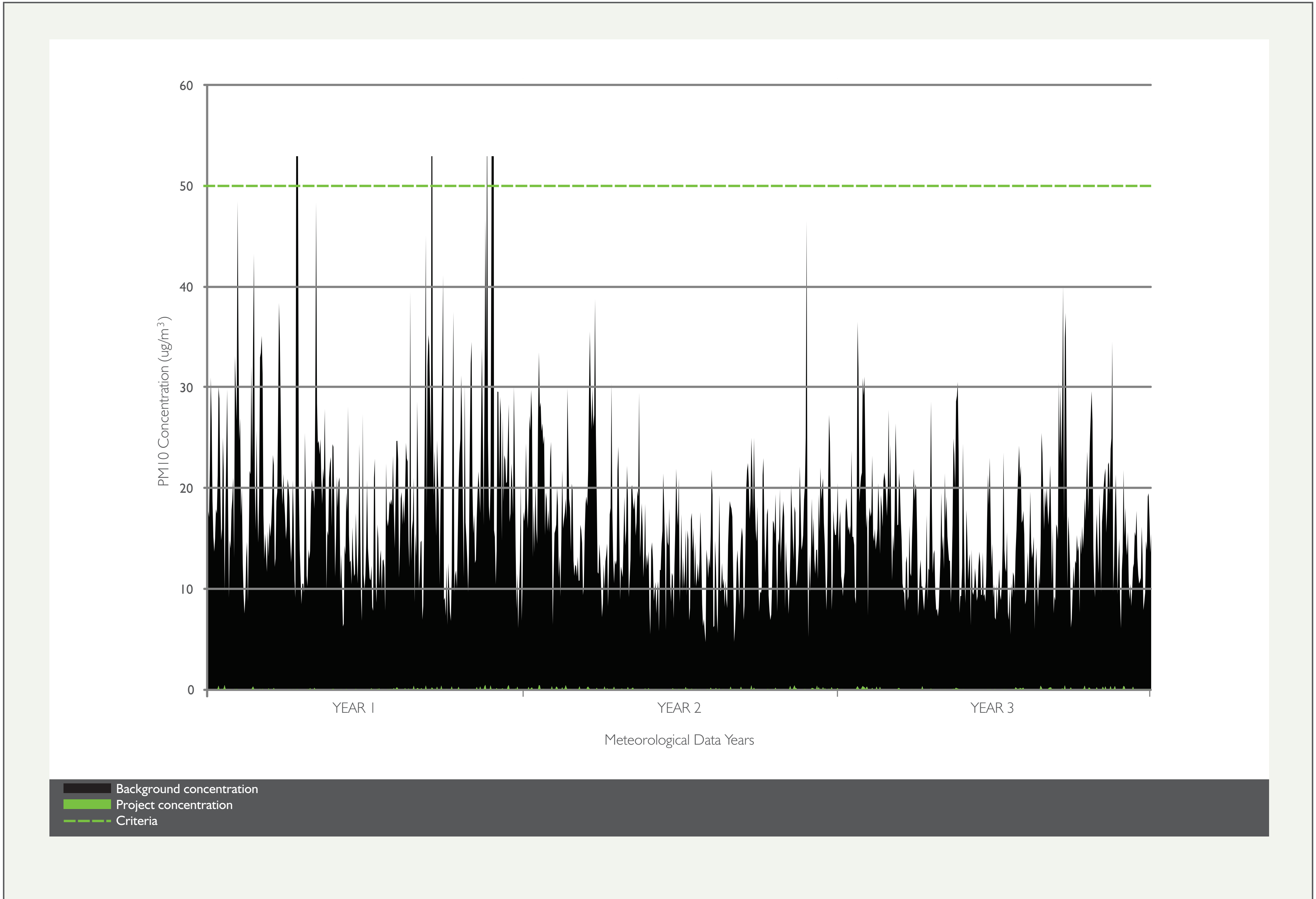

Chart 4 Predicted maximum cumulative PM10 concentrations (ug/m3) – 24 hour averaging period – 'with project – expected traffic flows' in 2019 – northern ventilation outlet

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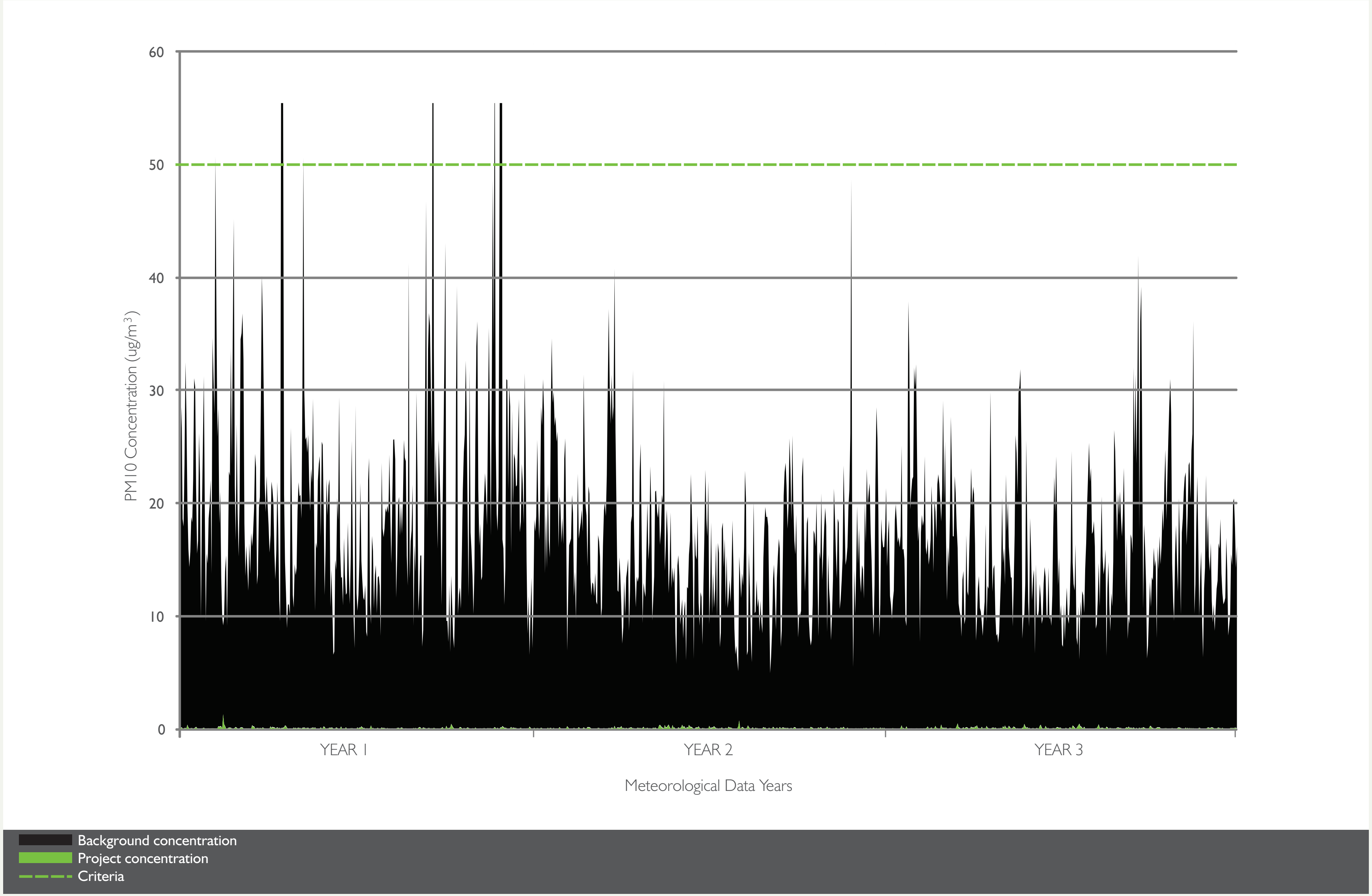

Chart 5 Predicted maximum cumulative PM10 concentrations (ug/m3) – 24 hour averaging period – 'with project – expected traffic flows' in 2019 – southern ventilation outlet

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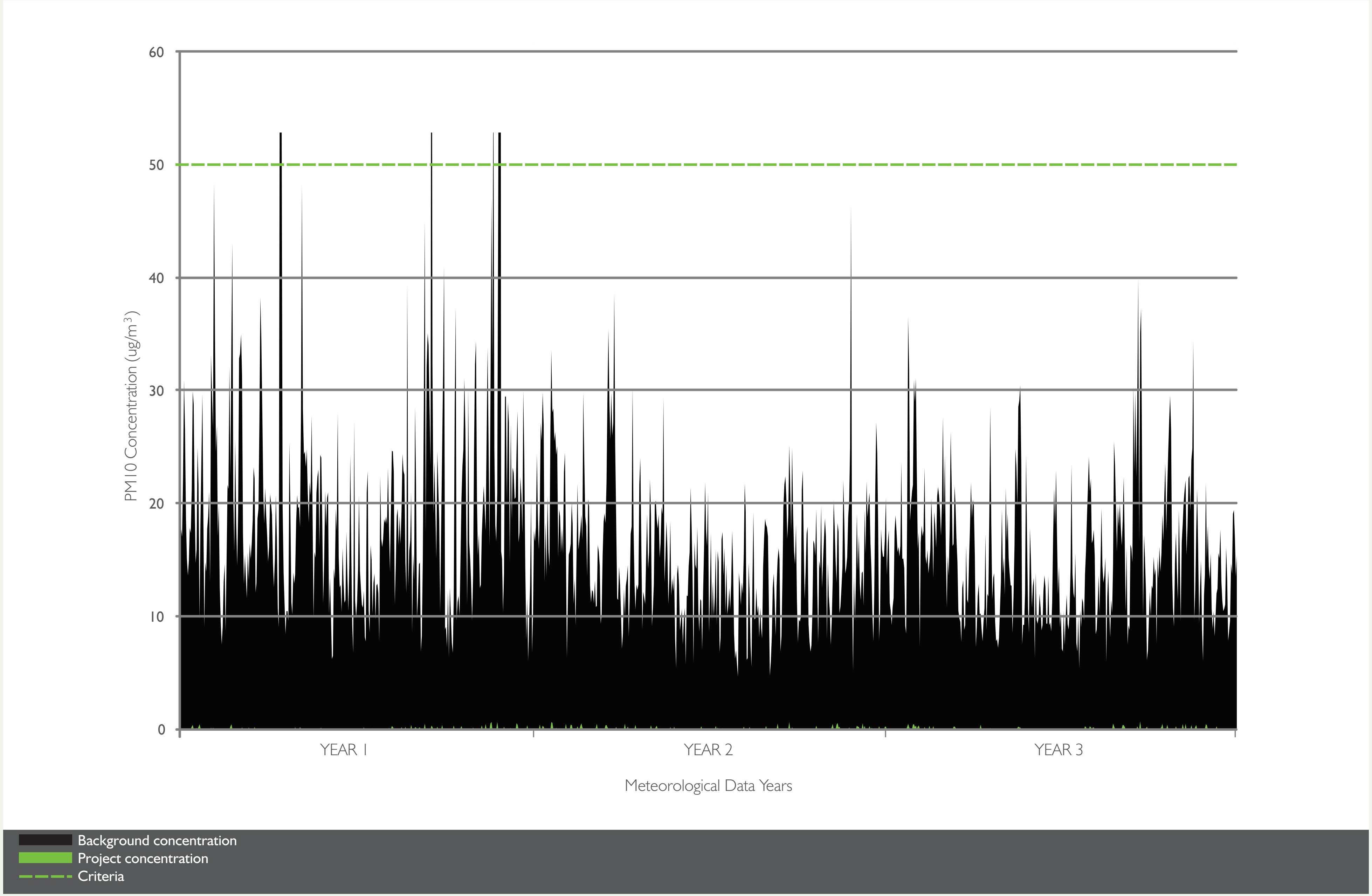

Chart 6 Predicted maximum cumulative PM10 concentrations (ug/m3) – 24 hour averaging period – 'with project – expected traffic flows' in 2029 – northern ventilation outlet

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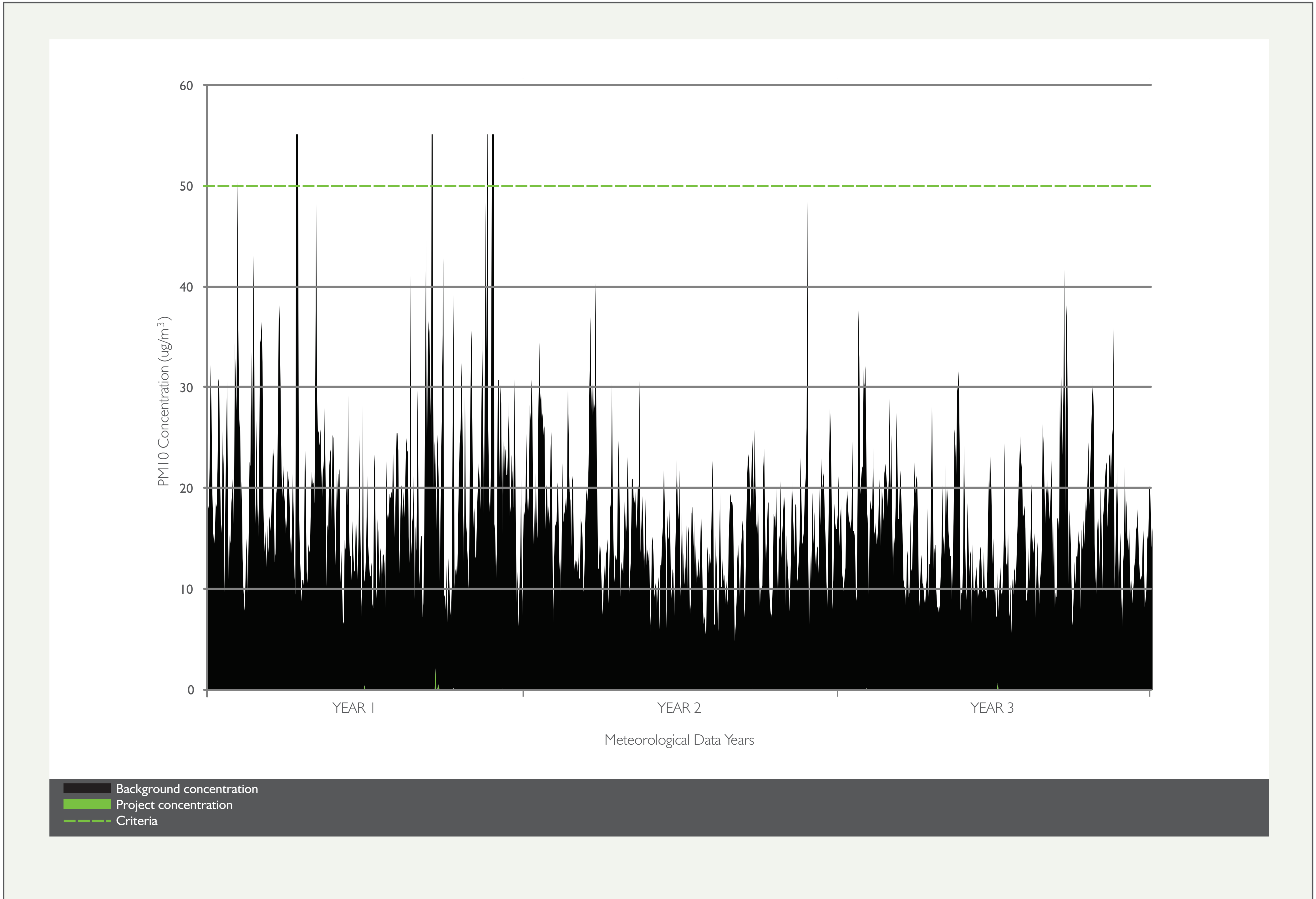

Chart 7 Predicted maximum cumulative PM10 concentrations (ug/m3) – 24 hour averaging period – 'with project – expected traffic flows' in 2029 – southern ventilation outlet

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Table 34 Predicted maximum cumulative PM_{10} concentrations ($\mu g/m^3$) – 24 hour averaging period – 'with project – expected traffic flows' in 2019 and 2029

Scenario	Outlet	Rank	Maximum cumulative concentration ($\mu g/m^3$)			Maximum project contribution ($\mu g/m^3$)		
			Cumulative concentration	Project contribution	Background contribution	Project contribution	Background contribution	Cumulative concentration
With project – expected traffic flows 2019 (Scenario 2a)	Northern ventilation outlet	1	221.8	0.2	221.6	1.0	11.1	12.1
		2	134.3	0.2	134.1	0.9	9.4	10.3
		3	92.0	0.3	91.7	0.9	11.9	12.8
		4	90.1	0.3	89.8	0.9	14.4	15.3
		5	61.3	0.2	61.1	0.9	20.2	21.1
		6	60.4	0.0	60.4	0.9	8.1	9.0
		7	56.3	0.3	56.0	0.9	19.6	20.4
		8	50.4	0.2	50.2	0.9	9.0	9.9
		9	50.2	0.0	50.2	0.9	21.0	21.9
		10	48.9	0.4	48.5	0.9	18.5	19.4
	Southern ventilation outlet	1	221.8	0.2	221.6	1.4	11.1	12.5
		2	134.4	0.3	134.1	1.3	17.8	19.1
		3	92.2	0.5	91.7	1.2	7.8	9.0
		4	90.0	0.3	89.8	1.2	15.0	16.2
		5	61.5	0.4	61.1	1.2	17.5	18.6
		6	60.4	0.3	60.1	1.1	8.9	10.0
		7	56.4	0.4	56.0	1.1	20.2	21.3
		8	50.7	0.5	50.2	1.1	13.3	14.4
		9	50.3	0.2	50.1	1.1	17.1	18.2
		10	49.0	0.5	48.5	1.0	19.8	20.9

Scenario	Outlet	Rank	Maximum cumulative concentration (μg/m³)			Maximum project contribution (μg/m³)		
			Cumulative concentration	Project contribution	Background contribution	Project contribution	Background contribution	Cumulative concentration
With project – expected traffic flows 2029 (Scenario 2b)	North ventilation outlet	1	221.8	0.2	221.6	1.4	20.2	21.5
		2	134.4	0.2	134.1	1.2	9.4	10.6
		3	92.1	0.4	91.7	1.2	11.6	12.8
		4	90.1	0.3	89.8	1.2	11.1	12.3
		5	61.3	0.2	61.1	1.2	18.5	19.7
		6	60.5	0.0	60.5	1.2	15.2	16.4
		7	56.3	0.3	56.0	1.2	21.0	22.2
		8	50.4	0.2	50.2	1.2	14.3	15.5
		9	50.3	0.2	50.1	1.2	19.2	20.3
		10	49.0	0.5	48.5	1.2	8.1	9.3
	South ventilation outlet	1	221.8	0.3	221.6	2.1	20.2	22.3
		2	134.5	0.3	134.1	1.8	7.8	9.6
		3	92.3	0.7	91.7	1.7	22.3	24.0
		4	90.1	0.4	89.8	1.6	11.1	12.7
		5	61.5	0.4	61.1	1.5	17.5	19.0
		6	60.5	0.4	60.1	1.5	10.2	11.8
		7	56.5	0.5	56.0	1.4	17.8	19.2
		8	50.9	0.7	50.2	1.3	15.0	16.4
		9	50.4	0.3	50.1	1.3	21.0	22.3
		10	49.1	0.6	48.5	1.3	18.3	19.6

6.1.3 Cumulative assessment – With project – expected traffic flows – $PM_{2.5}$ 24-hour average –

Chart 8 and **Chart 9** show the project contributions and associated background concentrations for the modelling period for the 'with project – expected traffic flows' scenario for 2019 for the northern and southern ventilation outlets respectively. The 2029 data are shown in **Chart 10** and **Chart 11** respectively. The charts again show the project contribution and the associated background concentration for each day of the modelling period for the receivers with the highest predicted project contributions (one receiver per chart). The vertical axes were again restricted to enable the project contributions to be seen. As was evident for PM_{10}, the project contributions of $PM_{2.5}$ were orders of magnitude lower than the background concentrations, and are barely visible compared to the background concentrations.

Table 35 presents further details of the contemporaneous assessment of the predicted 24 hour average $PM_{2.5}$ concentrations, specifically:

- The top five predicted cumulative concentrations (the project with background) for 'with project – expected traffic flows' in 2019 and 2029 (the maximum cumulative concentrations).
- The top five predicted concentrations from each ventilation outlet for 'with project – expected traffic flows' in 2019 and 2029, and the cumulative concentration that would result (the maximum project concentrations).

There were four exceedences of the $PM_{2.5}$ 24 hour average advisory reporting standard in 2009 in the background $PM_{2.5}$ concentrations (which were derived from the PM_{10} data). As with PM_{10}, these exceedences are likely to have been caused by infrequent, unusual events such as bushfires.

The results of the contemporaneous analysis show:

- The maximum predicted contributions from the project would be 2.0 $\mu g/m^3$ for 'with project – expected traffic flows' in 2019 and 2029, which is substantially lower than the $PM_{2.5}$ 24 hour average advisory reporting standard of 25 $\mu g/m^3$.
- The highest cumulative concentrations (background plus the project) were predicted to occur at times where the maximum predicted project contributions for the assessed scenarios are all low (below 0.8 $\mu g/m^3$) and well below the advisory reporting standard of 25 $\mu g/m^3$.

This demonstrates that the predicted exceedences of the $PM_{2.5}$ 24 hour average advisory reporting standard would result from elevated background concentrations and would be associated with other sources in the airshed. Furthermore, the project would not result in any additional exceedences of the 24 hour advisory reporting standard (there were four exceedences of the criterion in the background data, and four predicted to occur by the dispersion modelling). The project is, therefore, predicted to have very little effect on local $PM_{2.5}$ concentrations.

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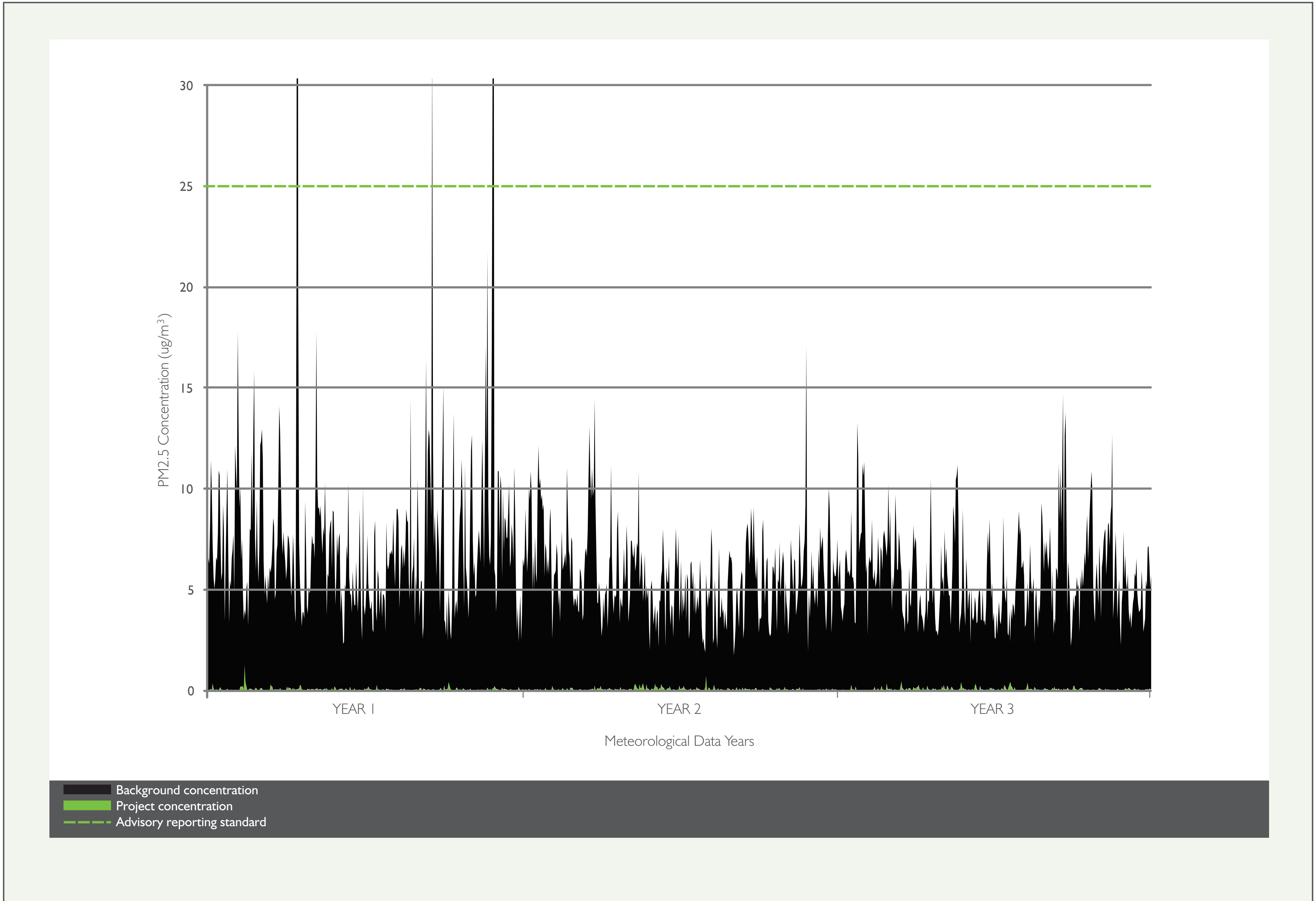

Chart 8 Predicted maximum cumulative PM2.5 concentrations (ug/m3) – 24 hour averaging period – 'with project – expected traffic flows' in 2019 – northern ventilation outlet

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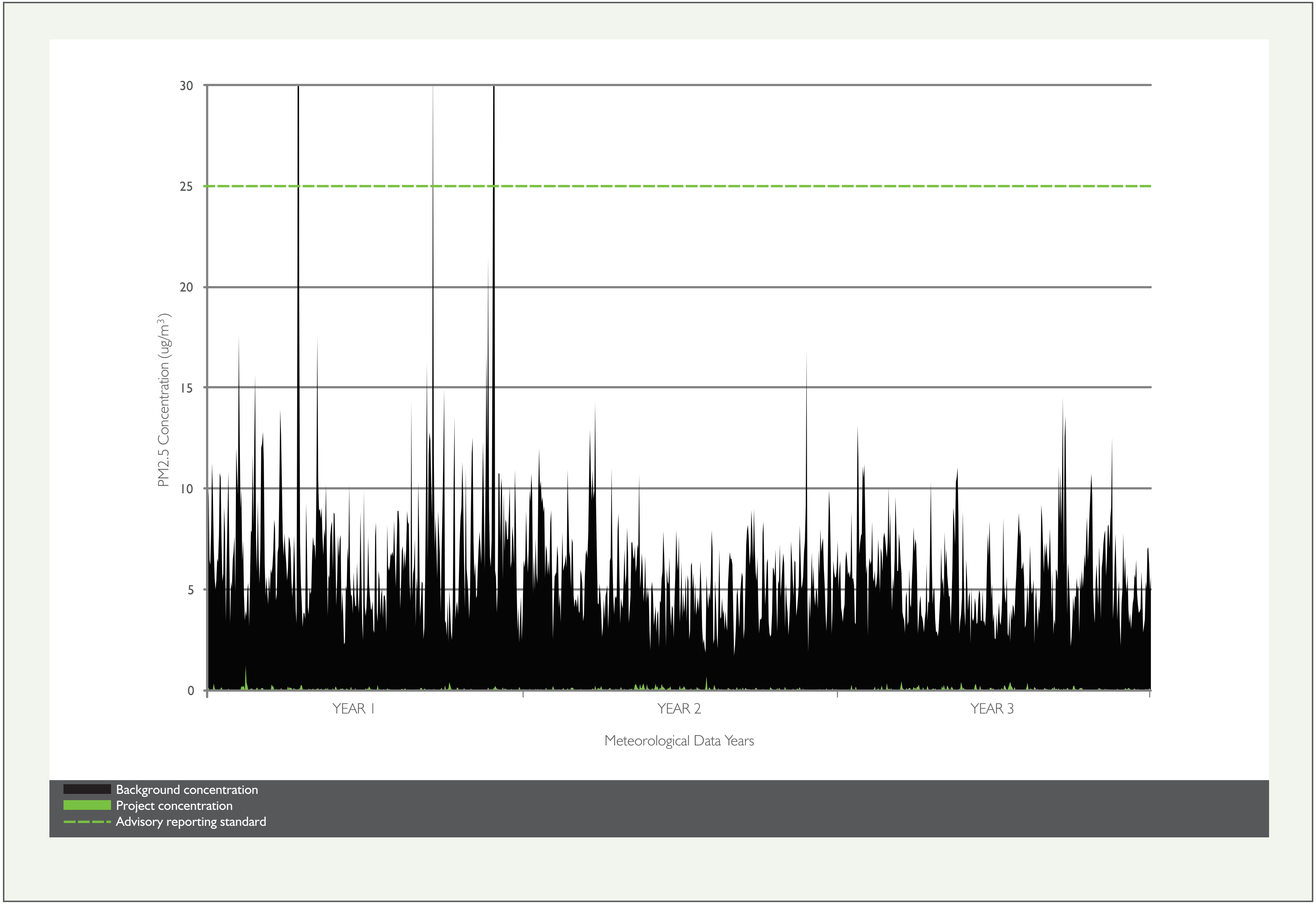

Chart 9 Predicted maximum cumulative PM2.5 concentrations (ug/m3) – 24 hour averaging period – 'with project – expected traffic flows' in 2019 – southern ventilation outlet

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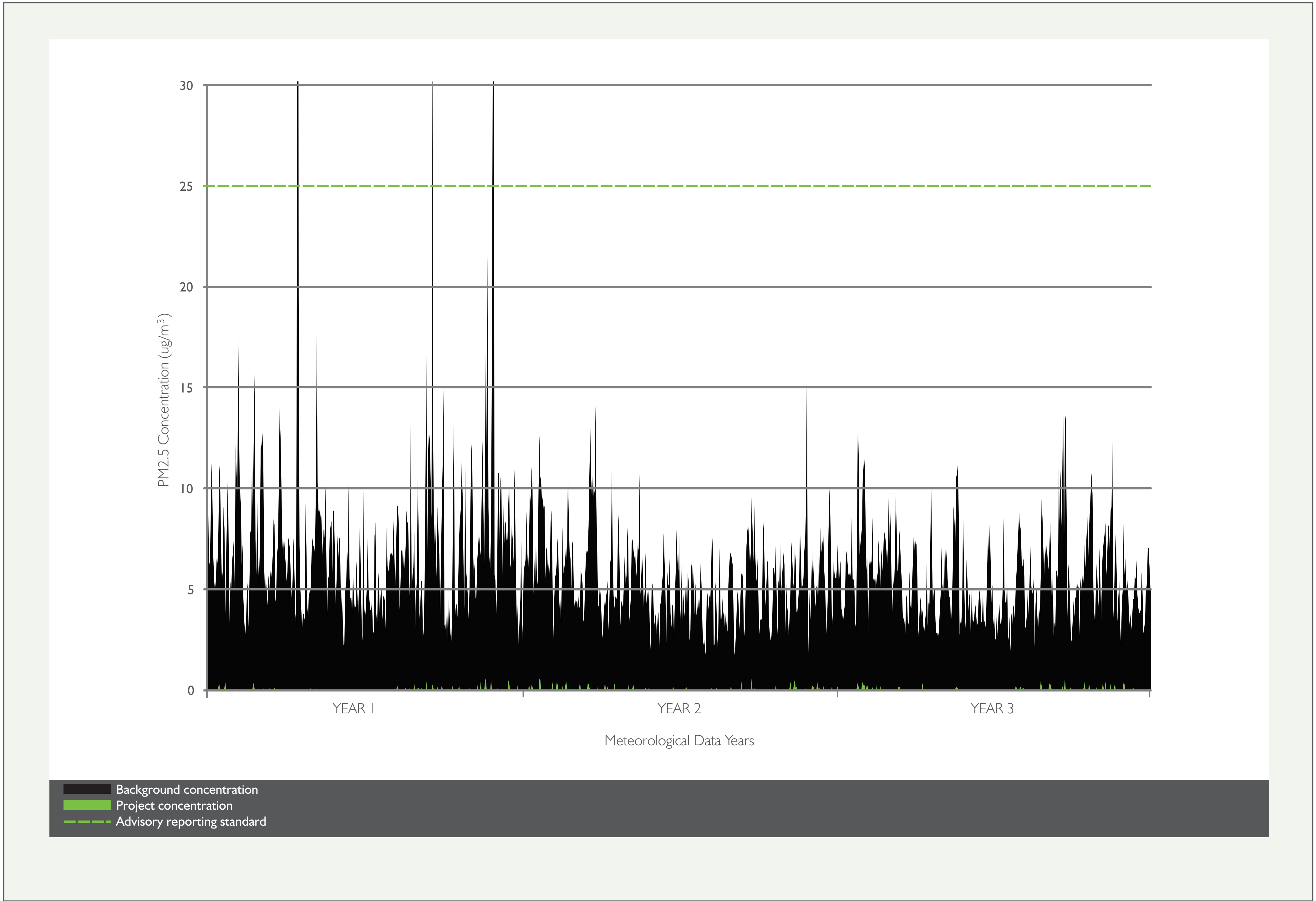

Chart 10 Predicted maximum cumulative PM2.5 concentrations (ug/m3) – 24 hour averaging period – 'with project – expected traffic flows' in 2029 – northern ventilation outlet

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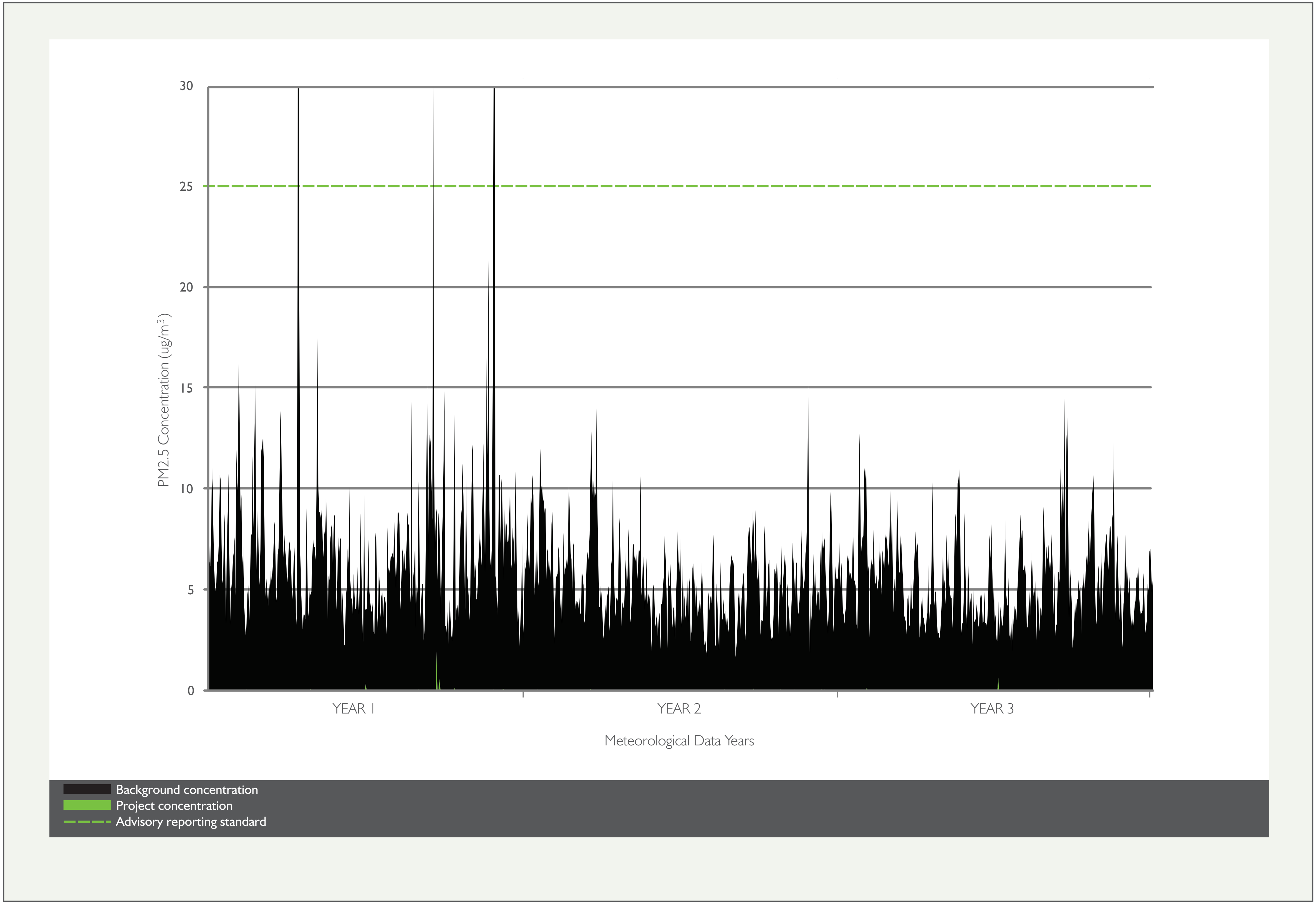

Chart 11 Predicted maximum cumulative PM2.5 concentrations (ug/m3) – 24 hour averaging period – 'with project – expected traffic flows' in 2029 – southern ventilation outlet

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Table 35 Predicted maximum cumulative $PM_{2.5}$ concentrations (μg/m³) – 24 hour averaging period – 'with project – expected traffic flows' (Scenario 2)

Scenario	Outlet	Rank	Maximum cumulative concentrations (μg/m³)			Maximum project contributions (μg/m³)		
			Background concentration	Project contribution	Cumulative concentration	Project contribution	Background concentration	Cumulative concentration
With project – expected traffic flows 2019 (Scenario 2a)	Northern ventilation outlet	1	77.6	0.2	77.8	1.0	11.1	12.1
		2	46.9	0.3	47.3	0.9	9.4	10.3
		3	32.1	0.6	32.6	0.9	11.9	12.8
		4	31.4	0.4	31.8	0.9	14.4	15.3
		5	21.4	0.2	21.6	0.9	20.2	21.1
	Southern ventilation outlet	1	77.6	0.2	77.8	1.4	11.1	12.5
		2	47.0	0.2	47.2	1.3	17.8	19.1
		3	32.1	0.5	32.5	1.2	7.8	9.0
		4	31.4	0.2	31.7	1.2	15.0	16.2
		5	21.4	0.3	21.7	1.2	17.5	18.6
With project – expected traffic flows 2029 (Scenario 2b)	Northern ventilation outlet	1	77.6	0.2	77.8	1.3	7.1	8.4
		2	47.0	0.4	47.4	1.2	3.3	4.5
		3	32.1	0.8	32.9	1.1	4.1	5.2
		4	31.4	0.5	31.9	1.1	6.5	7.6
		5	21.4	0.3	21.7	1.1	5.3	6.4
	Southern ventilation outlet	1	77.6	0.2	77.8	2.0	7.1	9.1
		2	47.0	0.3	47.2	1.7	5.7	7.4
		3	32.1	0.6	32.7	1.6	7.8	9.4
		4	31.4	0.3	31.8	1.5	3.9	5.4
		5	21.4	0.4	21.8	1.4	6.1	7.6

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6.1.4 Nitrogen dioxide

The predicted cumulative concentrations of 1 hour NO_2 were all well below the impact assessment criterion. For example, the maximum project contribution for the 'with project – expected operation, 2019' scenario was predicted to be 68.9 $\mu g/m^3$, which is around 28 per cent of the criterion level. **Chart 8** shows the predicted NO_2 contributions for the receiver with the maximum predicted contributions over the course of the modelling period for this scenario, which are ranked in order of size. As shown, the project contributions are at a negligible level for around 70 per cent of the modelling period. The NO_2 contributions associated with the other assessed scenarios followed the same trend. This demonstrates that predicted project contributions of NO_2 are expected to be minimal for most of the time.

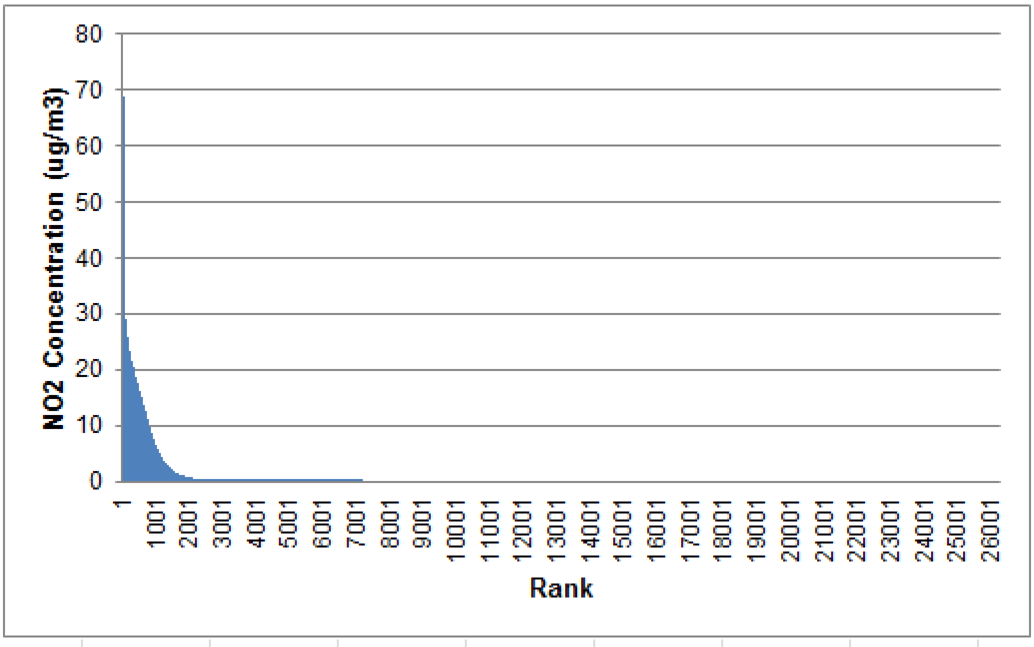

Chart 8 **Ranked NO_2 concentrations at the receiver with the maximum predicted project contribution, 'with project – expected operation, 2019**

6.1.5 VOCs

The total VOC concentrations from **Table 22** were speciated using the profile provided in OEH (2012) and the mass fraction for the project fleet determined by the health risk assessment for the project (refer to technical working paper: human health risk assessment). As shown in **Table 36**, the predicted concentrations of individual VOC species were all orders of magnitude below the applicable impact assessment criteria for the individual compounds.

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Table 36 Predicted concentration of speciated VOCs (µg/m³) (project contribution) – 'with project – expected traffic flows' in 2019 and 2029

Pollutant	Averaging Period	Predicted concentrations of speciated VOCs (µg/m³)				Impact assessment criteria (µg/m³)
		With project – expected traffic flows 2019 (Scenario 2a)		With project – expected traffic flows 2029 (Scenario 2b)		
		Northern ventilation outlet	Southern ventilation outlet	Northern ventilation outlet	Southern ventilation outlet	
Total VOCs	1 hour 99.9%	4.1	3.7	5.4	5.4	-
1,3-butadiene	1 hour 99.9%	0.04	0.03	0.05	0.05	40
Acetaldehyde	1 hour 99.9%	0.09	0.08	0.09	0.09	42
Benzene	1 hour 99.9%	0.13	0.12	0.20	0.20	29
Formaldehyde	1 hour 99.9%	0.20	0.18	0.21	0.21	20
Xylenes	1 hour 99.9%	0.19	0.17	0.30	0.29	190
Toluene	1 hour 99.9%	0.23	0.21	0.36	0.36	360

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6.1.6 Without project – Pennant Hills Road

The ‘without project’ scenario (Scenario 1) assessed the expected future pollutant concentrations along the main surface roads considered in the assessment in the absence of the project. These results were compared to the surface road modelling results for the ‘with project – expected traffic flows’ (Scenario 2a and 2b) along the road corridor, and are presented in **Table 37**.

It should be noted that the road emissions do not form part of the predicted emissions from the project; rather, they essentially reflect background pollutant concentrations. The results do, however, demonstrate that the project would result in lower levels of PM_{10}, VOCs and PAHs in the short term, while levels of CO are not expected to change substantially, and are expected to remain orders of magnitude lower than the applicable impact assessment criteria.

Table 37 Comparison of without and with project along the road corridor

Pollutant	Averaging period	Condition	Maximum predicted concentrations (µg/m³) 2019	2029	Criteria (µg/m³)
PM_{10}	24 hour	Without project (Scenario 1)	27.1	32.8	50
		With project (Scenario 2a / 2b)	19.8	20.4	
	Annual	Without project (Scenario 1)	13.3	16.1	30
		With project (Scenario 2a / 2b)	10.6	10.8	
$PM_{2.5}$	24 hour	Without project (Scenario 1)	25.7	31.2	25*
		With project (Scenario 2a / 2b)	18.8	19.4	
	Annual	Without project (Scenario 1)	12.6	15.3	8*
		With project (Scenario 2a / 2b)	10.1	10.2	
NO_2	1 hour	Without project (Scenario 1)	183	207	246
		With project (Scenario 2a / 2b)	165	167	
	Annual	Without project (Scenario 1)	45	49	62
		With project (Scenario 2a / 2b)	39	44	
CO	1 hour	Without project (Scenario 1)	583	647	30,000
		With project (Scenario 2a / 2b)	575	643	
	8 hour	Without project (Scenario 1)	406	462	10,000
		With project (Scenario 2a / 2b)	414	459	
Total VOCs	1 hour	Without project (Scenario 1)	44.4	49.3	-
		With project (Scenario 2a / 2b)	42.0	45.9	
PAHs	1 hour	Without project (Scenario 1)	0.026	0.007	0.4
		With project (Scenario 2a / 2b)	0.005	0.005	

* Advisory reporting standards

6.1.7 Project air quality benefits (combined effects)

Vehicles using the project in preference to Pennant Hills Road would avoid 21 sets of traffic lights, and would have an estimated travel time of around five to six minutes. This would offer significant travel time savings over the alternative of using Pennant Hills Road or if the project was not constructed (refer to technical working paper: traffic and transport (AECOM, 2014)). In addition to the reduced travel times, the project tunnels would capture vehicle emissions, which would then be released in a controlled and efficient manner via the tunnel ventilation outlets, facilitating effective pollutant dispersion.

The results of dispersion modelling and pollutant monitoring studies of existing road tunnels generally show that the pollutant concentrations associated with outlet emissions are indistinguishable from pollutant concentrations from all other surrounding sources (such as emissions from surface roads, industrial sources, domestic sources, and natural sources). An extensive literature review by the National Health and Medical Research Council (2008) determined that the effects of road tunnel emissions on local air quality are very small compared to the effects from other sources, particularly local surface roads, and that monitoring is often unable to distinguish emissions from road tunnels from background pollutant sources.

The project is expected to improve traffic flows along Pennant Hills Road, which would be expected to improve air quality along that road corridor. Further, the capture and dispersion of emissions from the diverted traffic through ventilation outlets would improve the dispersion of pollutants.

In order to evaluate the total effect of the project on local air quality, the incremental increases from the ventilation stations and the relative decreases in pollutant concentration along the road corridor were combined, using the predicted concentrations for $PM_{2.5}$ (annual average and 24 hour average).

Figure 35 to **Figure 38** show the relative change in $PM_{2.5}$ concentrations along the Pennant Hills Road corridor as a percentage of the 8 $\mu g/m^3$ (annual average) and 25 $\mu g/m^3$ (24-hour average) advisory reporting standards, respectively, for the 'with project – expected traffic volumes' for 2019 and 2029. The contour labels represent the change in concentration as a percentage of the advisory reporting standard. Due to the scale of the figures, it is only possible to clearly shown changes up to ten per cent.

The assessment found that:

- In the case of both 24-hour average and annual average $PM_{2.5}$ concentrations, the project's ventilation outlets would effectively disperse emissions to very low levels in the surrounding environment. The peak $PM_{2.5}$ contributions from the project would be around five to 10 per cent (24-hour average) and one to five per cent (annual average) of the advisory reporting standards for $PM_{2.5}$. Both of these percentages are well within the normal variability in background $PM_{2.5}$ concentrations measured at existing regional monitoring stations managed by the Office of Environment and Heritage, and as recorded at monitoring stations established along the Pennant Hills Road corridor for the project.
- Substantial reductions in annual average $PM_{2.5}$ concentrations are expected along the Pennant Hills Road corridor (refer to **Figure 35** and **Figure 37**). These improvements in air quality are expected to peak at up to 40 percent of the 8 $\mu g/m^3$ (annual average) advisory reporting standard for $PM_{2.5}$ within the Pennant Hills road reserve. Receivers along the road corridor are predicted to benefit from improvements in $PM_{2.5}$ concentrations (annual average) of between around around five to 35 per cent as a result of the project.
- Substantial reductions in 24-hour average $PM_{2.5}$ concentrations are expected along the Pennant Hills Road corridor (refer to **Figure 36** and **Figure 38**). These improvements in air quality are expected to peak at up to 25 percent of the 25 $\mu g/m^3$ (24-hour average) advisory reporting standard for $PM_{2.5}$ within the Pennant Hills road reserve. Receivers along the road corridor are expected to benefit from improvements in $PM_{2.5}$ concentrations (24 hour average average) of between five to 35 per cent as a result of the project.
- The project is expected to result in a net improvement in air quality, taking into account the predicted substantial improvements in air quality along the Pennant Hills Road corridor balanced with less extensive, very low increases in $PM_{2.5}$ concentrations around the northern and southern ventilation outlets.

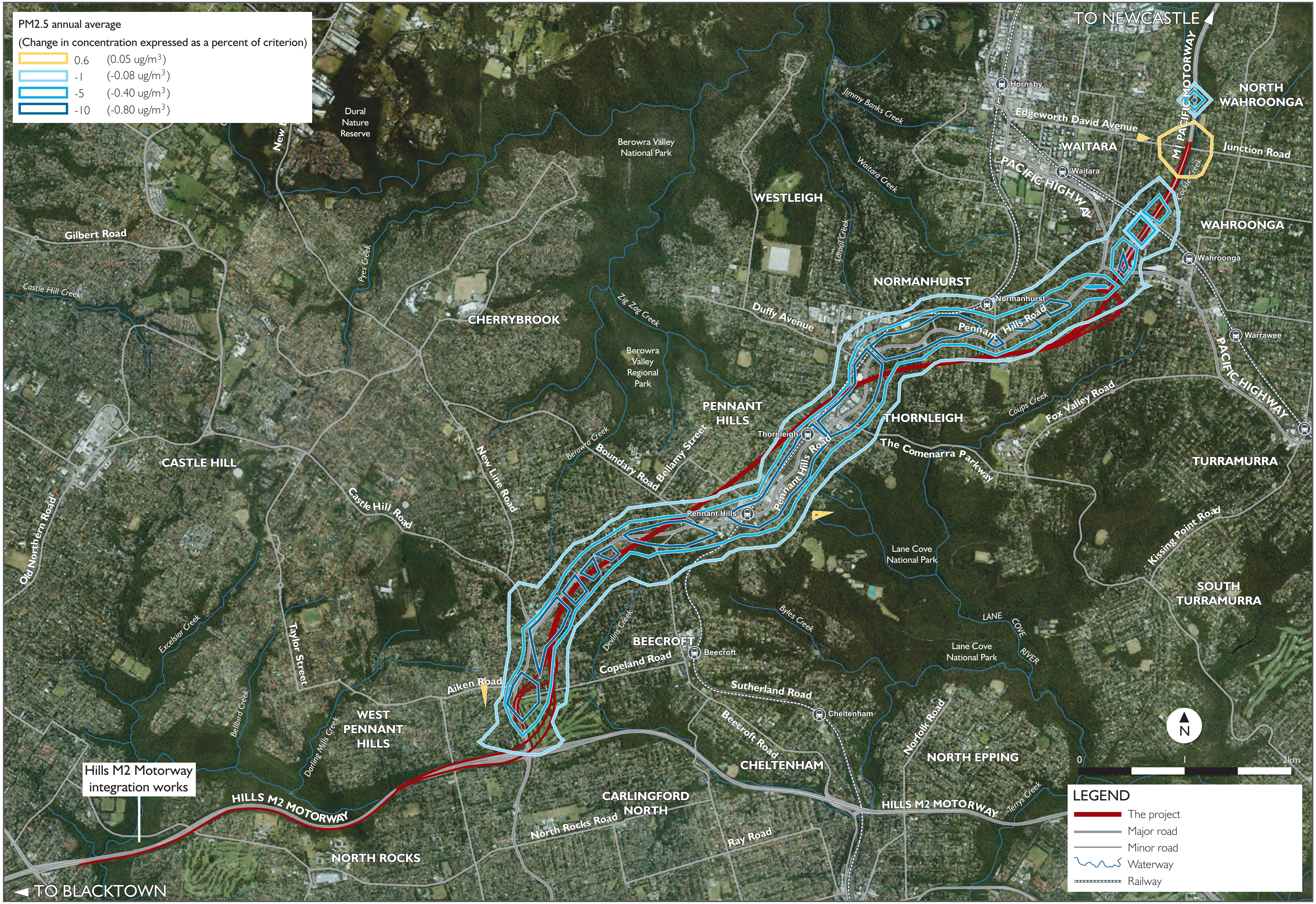

Figure 35 Relative change in annual average PM2.5 due to project (with project - expected traffic flows (2019)

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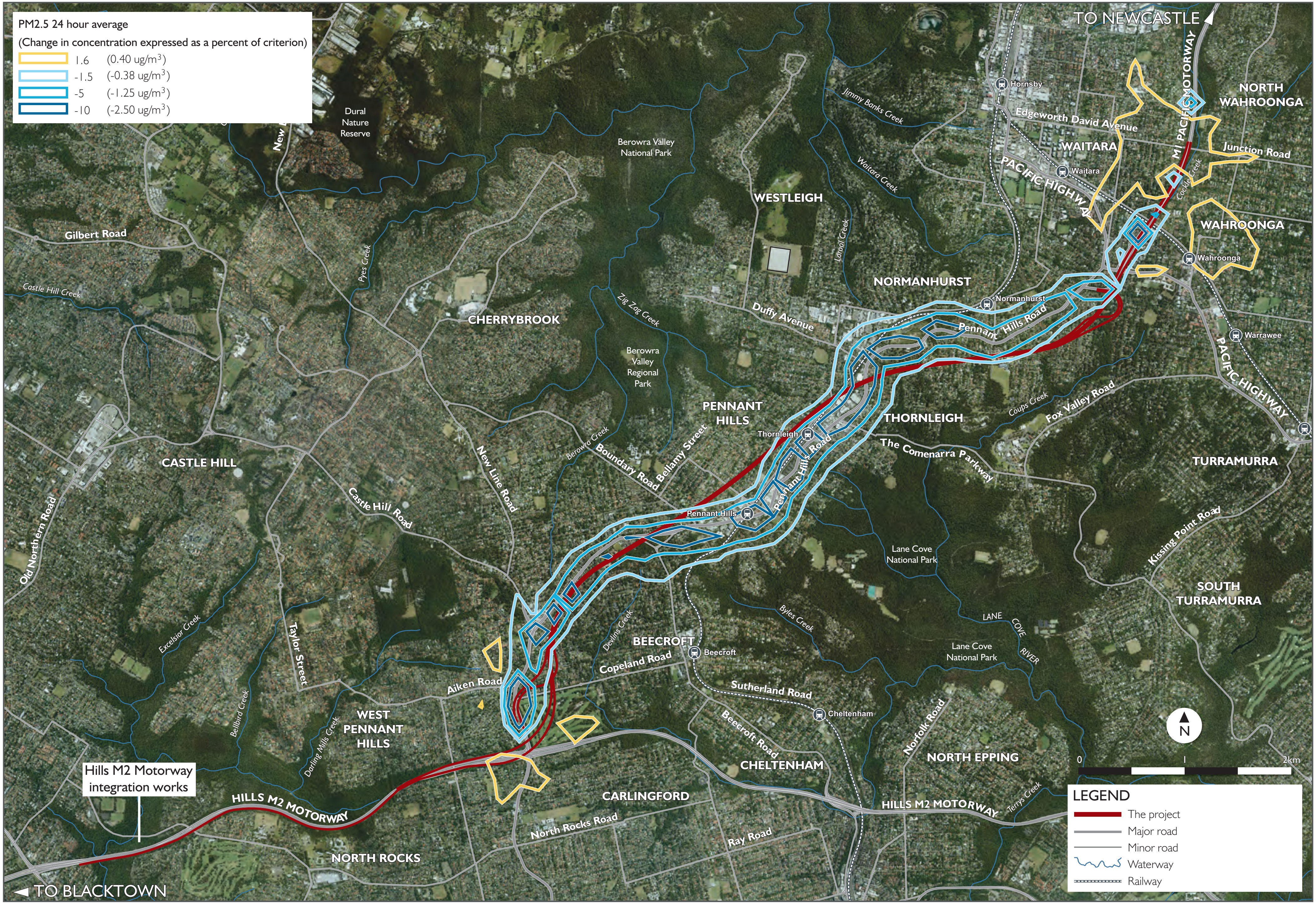

Figure 36 Relative change in 24 hour average PM2.5 due to project (with project - expected traffic flows (2019)

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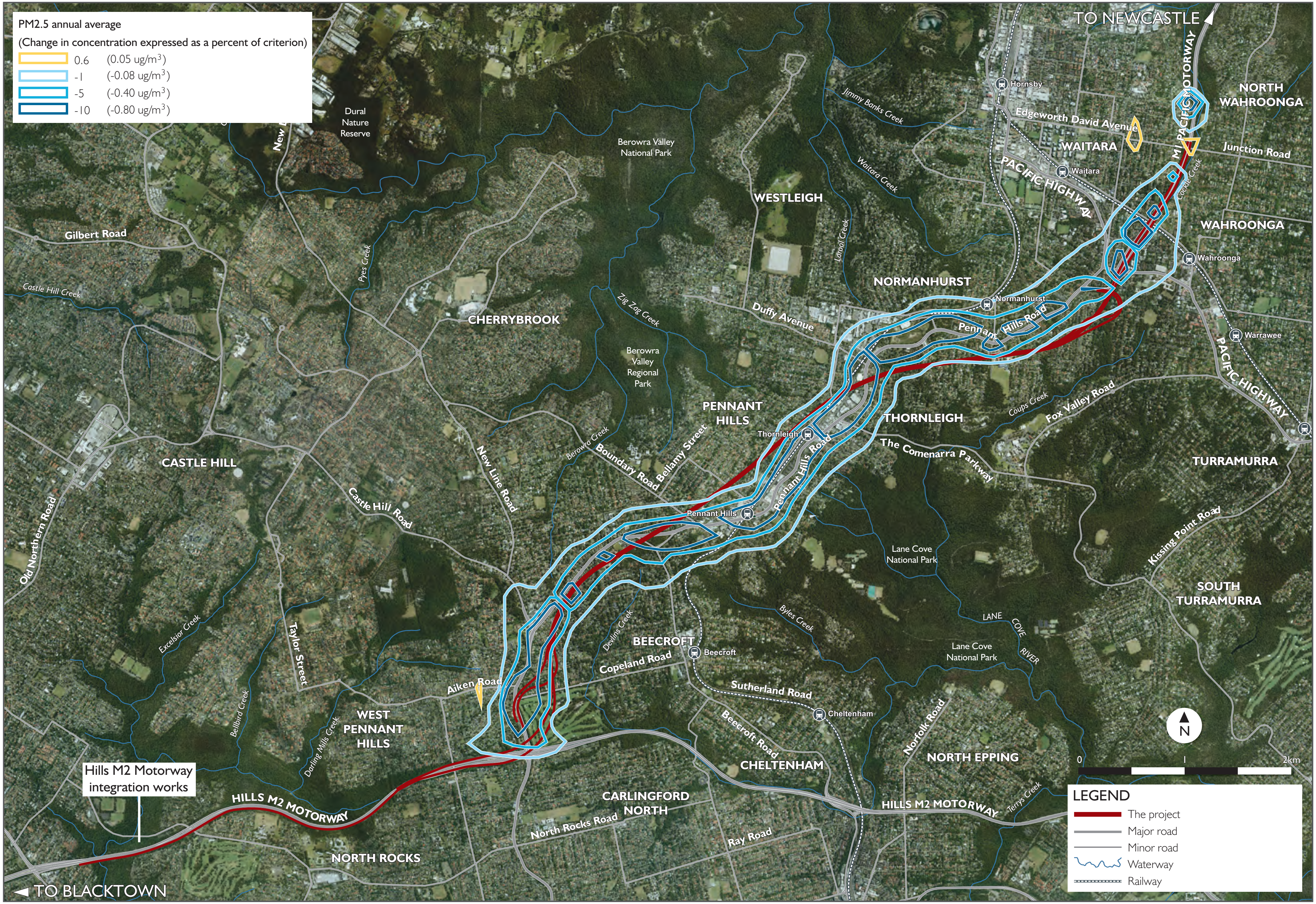

Figure 37 Relative change in annual average PM2.5 due to project (with project - expected traffic flows (2029)

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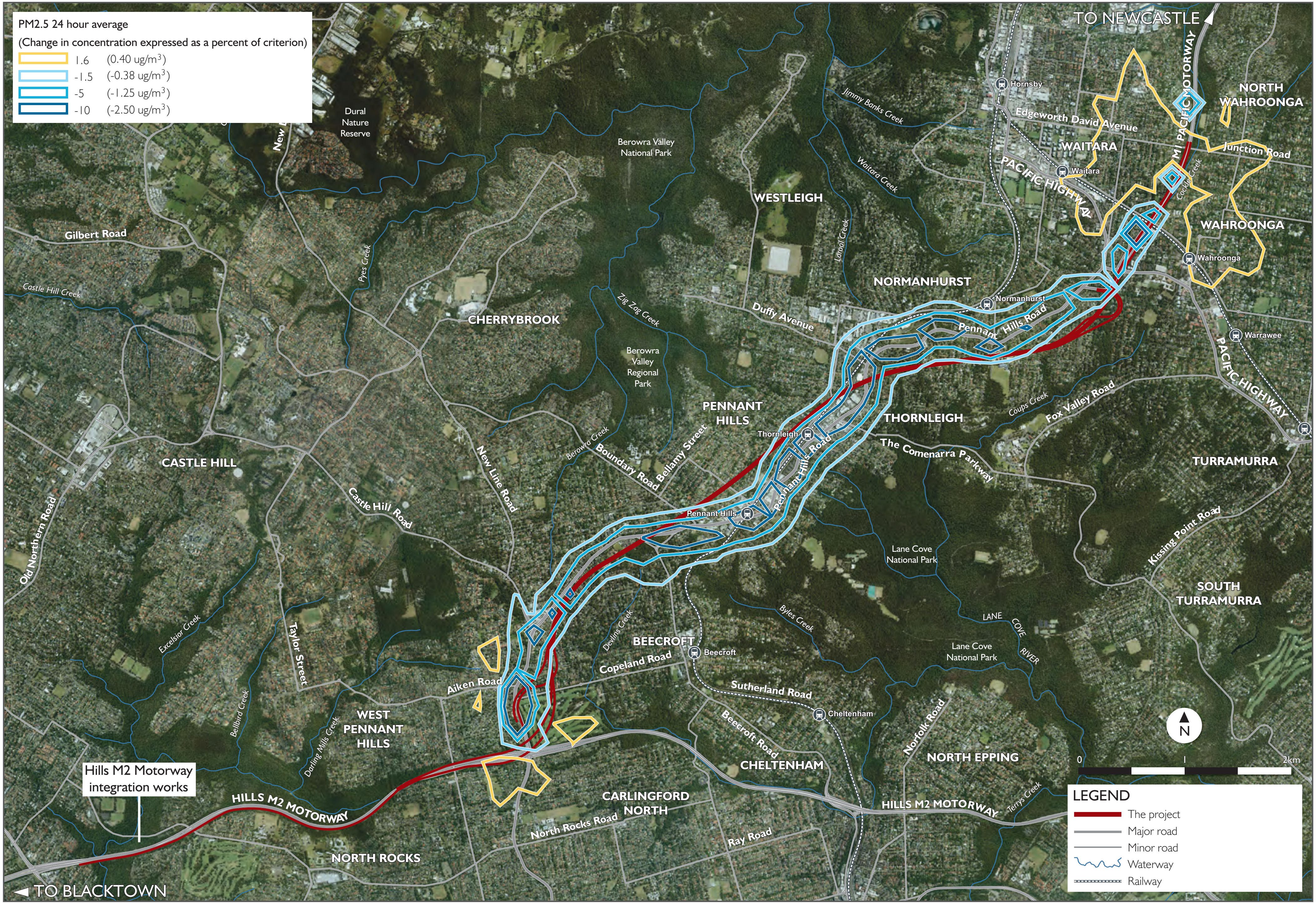

Figure 38 Relative change in 24 hour average PM2.5 due to project (with project - expected traffic flows (2029)

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6.1.8 Design analysis A

For design analysis A, which assessed the maximum design capacity of the main alignment tunnels during peak hours, the results of the dispersion modelling predicted that:

- The peak incremental contribution of PM_{10} (24-hour average) from the project would be 3.1 µg/m^3, which is around six per cent of the 50 µg/m^3 assessment criterion.
- The peak incremental contribution of PM_{10} (annual average) from the project would be 0.26 µg/m^3, which is less than one per cent of the 30 µg/m^3 assessment criterion.
- The peak incremental contribution of $PM_{2.5}$ (24-hour average) from the project would be 3.0 µg/m^3, which is around 12 per cent of the 25 µg/m^3 advisory reporting standard.
- The peak incremental contribution of $PM_{2.5}$ (annual average) from the project would be 0.25 µg/m^3, which is around three per cent of the 8 µg/m^3 advisory reporting standard.
- The peak incremental contribution of NO_2 (24-hour average) from the project would be 114.8 µg/m^3, which is around 47 per cent of the 246 µg/m^3 assessment criterion.
- The peak incremental contribution of NO_2 (annual average) from the project would be 2.5 µg/m^3, which is around four per cent of the 62 µg/m^3 assessment criterion.

The predicted concentrations of $PM_{2.5}$, which is considered to be the primary pollutant of interest for this project, for design analysis A are shown in **Table 38** and **Table 39**. Results of the modelling of other pollutants for this scenario are provided in **Appendix G**. In all cases, the contributions from the project to the surrounding airshed were predicted to be well below applicable air quality assessment criteria.

Table 38 Predicted concentrations of $PM_{2.5}$ – Design analysis A (µg/m^3)

Source	Averaging period	Predicted maximum concentrations (µg/m^3) (Design Analysis A)		Impact assessment criteria (µg/m^3)
		Northern ventilation outlet	Southern ventilation outlet	
Peak project contribution	24 hour maximum	2.2	3.1	-
	Annual average	0.2	0.3	-
Peak cumulative concentration (project plus background)	24 hour maximum	Refer to **Table 33**		25
	Annual average	**8.73**	**10.30**	8
Project contribution (% of criteria)	24 hour maximum	8.4 %	12.0 %	-
	Annual average	2.0 %	3.1 %	-
Exceedences denoted in **bold type**.				

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Table 39 Predicted maximum cumulative $PM_{2.5}$ concentrations (µg/m3) – 24 hour averaging period – Design analysis A

Outlet	Rank	Maximum cumulative concentration (µg/m³)			Maximum project contribution (µg/m³)		
		Background concentration	Project contribution	Cumulative concentration	Project contribution	Background concentration	Cumulative concentration
Northern ventilation outlet	1	77.6	0.4	77.9	2.1	7.1	9.2
	2	47.0	0.7	47.7	1.8	2.8	4.7
	3	32.1	1.2	33.2	1.8	6.8	8.6
	4	31.4	0.6	32.1	1.8	3.9	5.6
	5	21.0	0.9	22.0	1.7	6.7	8.5
Southern ventilation outlet	1	77.6	0.4	78.0	3.0	3.9	6.9
	2	47.0	0.5	47.5	2.8	6.2	9.1
	3	32.1	1.1	33.2	2.7	5.4	8.1
	4	31.4	0.6	32.0	2.7	5.3	7.9
	5	21.4	0.8	22.1	2.6	7.8	10.4

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6.1.9 Breakdown scenario

A semi-quantitative assessment was undertaken to consider a breakdown scenario and the potential emissions associated with such an event. The estimated vehicle emissions within the tunnel were calculated under each scenario for comparison with the results from 'with project – expected traffic flows 2029' scenario (scenario 2b).

The project was designed and would be managed to minimise the potential for prolonged congestion within the tunnels, and specifically includes the following features:

- A tunnel height of 5.3 metres, which is greater than other Sydney tunnels. This would reduce the likelihood of incidents involving over-height vehicles.
- An over-height detection system, which would comprise of an electronic over-height prior to the tunnel portals, vehicle presence detectors, and warning signs with lanterns, which would light up upon detection of an over-height vehicle.
- Provision of two vehicle cross passages, which would allow emergency response vehicles to bypass a congested tunnel.
- Wide shoulders to accommodate breakdowns and provide access by recovery and emergency vehicles.
- Ability for the in-take of air from tunnel support facilities along the alignment to bring in additional fresh air, if required.
- Tunnel barrier gates to prevent access in the event of a tunnel closure.
- CCTV and audible systems to detect and manage incidents.
- Monitoring of vehicle speeds and traffic management infrastructure to reduce or prevent vehicle access to the tunnels if congestion is experienced.

In the event of an incident, approaching traffic would be prevented from entering both the incident main alignment tunnel and the non-incident main alignment tunnel. Traffic flow and speeds would also be monitored, so that in the event that traffic flow starts to fall below 40 kilometres per hour, traffic closure responses would be in place before traffic speeds fall below 20 kilometres per hour.

The assumptions made in the assessment of the breakdown scenario are summarised below:

- The tunnel is completely blocked at one exit.
- The number of vehicles was assumed to be 2,800 PCU, which would represent the indicative number of vehicles that could be accommodated within one tunnel when the average speed drops below 20 kilometres.
- Vehicles would continue to enter the tunnel for a ten minute period, after which the tunnel would be closed to inbound traffic for the affected direction (that is, the northbound or southbound direction), which would prevent more vehicles from entering the tunnel.
- Vehicles within the tunnel would be idling continuously for 55 minutes. It was conservatively assumed that no vehicles would turn off their engines. In reality, the measures described above would prevent the tunnel from becoming full of vehicles, and drivers would be directed to turn off their engines.
- The operation of the ventilation system was assumed to be the same as that occurring during peak traffic flows. The jet fans may be turned on, but the volumetric flow rate of emissions from the tunnel ventilation outlets would remain the same.

Emissions calculations

Vehicle emissions were calculated using country specific factors prepared by the World Road Association (PIARC, 2012), based largely on European vehicle standards, incorporating pre-Euro engine classifications through to new Euro-6 classifications, together with the penetration of hybrid fuel and electric vehicles. These factors are the same as those used in the main modelling assessment.

In order to calculate the predicted emissions from the breakdown scenario, the following parameters and assumptions detailed in **Table 40** were used.

Table 40 Breakdown scenario assumptions

Parameter	Value
Maximum proposed tunnel length	9,000 metres
Maximum traffic flow	1,828 vehicles per hour (2,800 PCU)
Maximum traffic in tunnel during breakdown period (55 minutes)	511 vehicles

Results

Vehicle emissions within the tunnel were calculated based on the worst case breakdown scenario outlined above for the primary vehicle exhaust pollutants of concern (CO, NO_x and PM_{10}). The estimated emissions are detailed in **Table 41**. For comparative purposes, the estimated emissions for the 'with project – expected traffic flows' (northern ventilation outlet in 2029) are also presented (as the highest expected mass emission rates of the scenarios considered in this assessment). The numbers in parentheses represent the breakdown scenario emission rates expressed as a percentage of the 'with project – expected traffic flows' scenario (northern ventilation outlet in 2029).

Table 41 Predicted tunnel emissions under breakdown scenario (grams per second)

Scenario	Emission rates (grams per second)		
	CO	NOx	PM_{10}
Breakdown scenario	3.6 (74 per cent)	4.0 (69 per cent)	0.3 (74 per cent)
With project – forecast traffic flows (northern ventilation outlet, 2029)	4.84	5.81	0.36
N.B. The numbers in parentheses represent the emission rates expressed as a percentage of the calculated worst case emission rates for Scenario 2			

When compared to the 'with project – expected traffic flows' scenario (northern ventilation outlet, 2029), the results in **Table 41** show that, during a breakdown scenario, emissions of carbon monoxide, oxides of nitrogen and PM_{10} are all expected to be lower. Given the similarities between both scenarios, the modelling results for 'with project – expected traffic flows' scenario were considered applicable for the breakdown scenario. The predicted pollutant concentrations of the 'with project – expected traffic flows' scenario were shown to comply with applicable air quality criteria (refer to Error! Reference source not found.). Because the mass emission rates for the breakdown scenario are comparable to, but no greater than, the 'with project – forecast traffic flows' scenario, and the breakdown scenario would occur over a relatively short period, it is expected that the breakdown scenario would also comply with applicable air quality criteria.

6.1.10 Water treatment plant

An operational water treatment plant would be established at the motorway operations complex to treat groundwater inflow into the tunnels. Emissions to air associated with water treatment depend on the nature of the contamination of the water being treated and the treatment process. Primary air emissions associated with water treatment are odorous compounds, such as ammonia and volatile organic compounds, which are associated with aeration (primary treatment), aerobic digestion, sludge thickening, anaerobic digestion and sludge drying (NPI, 2011).

The nature of any odours would depend on the degree and type of any contamination present in the water. A management plan would be developed to address any odours should contamination be encountered and if odours arise. The plan would include identification of odours, identification of the extent to which the odours are detectable, and, if necessary, mitigation measures to reduce any odours affecting receivers. Such mitigation measures could include modifications to the operating process, or the installation of carbon filters to capture odorous compounds before they are emitted.

7.0 Mitigation and management measures

7.1 Construction mitigation and management measures

Construction emissions can generally be well managed through best practice management and mitigation strategies. A hierarchy of emission control is recommended as best practice, where prevention of emissions is the primary goal of management actions, followed by suppression and containment.

The management and mitigation measures described in the following table would be included in the Construction Environmental Management Plan(s) and associated sub plans for the project. As shown, the primary dust generating activities associated with the tunnel excavations (stockpiling and materials handling) would be undertaken within enclosures to minimise dust emissions.

Table 42 Proposed construction air quality management and mitigation measures

Proposed management and mitigation measures
General
Site inductions and ongoing toolbox talks would be provided to make construction workers aware of sound air quality control practices and responsibilities.
Construction activities would be modified, reduced or controlled during high or unfavourable wind conditions if they may potentially increase off-site dust emissions.
Control measures would be implemented to control dust emissions, which could include water carts, sprinklers, sprays and dust screens. The frequency of use would be modified to accommodate prevailing conditions.
Air filtration systems would be installed to filter particulate matter generated by underground works.
Management measures would be developed and implemented though the air quality environmental management plan to mitigate any odour emissions from the groundwater treatment plants or stockpiles, should they arise.
Disturbed areas would be stabilised as soon as practicable to prevent or minimise windblown dust.
Cutting of materials such as concrete slabs or bricks would be undertaken in a manner that minimises the generation of dust where possible, such as wetting of the cutting face.
Controls, such as rumble grids or wheel wash facilities, would be implemented to minimise the tracking of dirt onto public roads.
Hardstand areas and surrounding public roads would be cleaned, as required.
Speed limits would be posted and observed by all construction vehicles on the construction site.
All loaded haulage trucks would be covered at all times on public roads and on site where there is a risk of release of dust or other materials.
Haul trucks and plant equipment would be switched off when not in operation for periods of greater than 15 minutes.
Construction plant, vehicles and machinery would be maintained in good working order and in accordance with manufacturers' specifications.
Monitoring
A formal dust observation program would be implemented during construction, involving daily reviews of weather forecasts, observations of meteorological conditions and on site dust generation. This would inform mitigation measures or alterations to construction activities to be implemented during unfavourable weather conditions (such as dry weather and strong winds).

7.2 Operational mitigation and management measures

The project includes a well-designed ventilation system, including ventilation outlets for the effective and efficient dispersion of emissions. The modelling and assessment presented in this report demonstrated the high efficiency of the ventilation system, which would achieve contributions to ambient air quality that are well below applicable air quality criteria, even under worst case operational and meteorological conditions.

Further opportunities to improve the performance of the project's ventilation system would be taken into account where reasonable and feasible during the detailed design of the project. This may include further modelling and analysis to confirm that the detailed design of the project would achieve air quality outcomes equivalent to or better than those predicted in this report.

During operation of the project, monitoring of key pollutants would be undertaken at the project's ventilation outlets and in the surrounding environment to confirm that the operation of the project is consistent with this assessment and within acceptable air quality limits. In the event that elevated concentrations of pollutants are detected, further consideration would be given to the application of additional reasonable and feasible mitigation measures.

An operational air quality management plan would also be developed to manage air quality within the project tunnels. This would include strategies for management of ventilation during emergencies.

7.3 Discussion of filtration

Air pollution control technology has been used in a limited number of tunnels in a few countries including Norway, Austria, Germany and Japan, as well as in the M5 East Motorway tunnel trial in Sydney. This technology includes the use of electrostatic precipitators to remove particles and catalytic and biological processes and adsorption technologies to remove nitrogen oxides.

Evidence to date suggests that the effectiveness of such measures is questionable when applied to road tunnels. These technologies are pollutant specific, only address local and not regional transport related air pollution, generate chemical waste and have significant capital and operational costs (NZ Transport Agency, 2013). The French government undertook an international assessment of the air in road tunnels (CETU, 2010), and concluded that filtration systems are:

> *'bulky and less cost-effective than conventional ventilation systems, both in terms of investment and operation. Generally-speaking, these systems are also energy-intensive given the surplus ventilation requirements.'*

There are a large number of factors influencing the decision as to whether a tunnel ventilation outlet should be fitted with mitigation equipment. The relevant factors, which were identified in a previous assessment of the M5 East road tunnel ventilation facility (AMOG, 2012), are:

- Whether unfiltered tunnel exhaust emissions are expected to adversely affect local air quality.
- Whether there are consistently high background pollutant concentrations in the local area, which would result in an increased risk of tunnel emissions affecting the surrounding environment.
- Whether the proposed mitigation equipment is effective.
- Whether the costs involved with the installation and operation of the mitigation equipment are justified given the factors outlined above.
- Whether there are other sources of pollution in the region that would result in a larger relative drop in emissions for a smaller cost.

This consideration of the costs and benefits of filtration was based on analysis of a filtration system similar to that trialled on the M5 East Motorway. That filtration system consisted of a combined electrostatic precipitator and activated carbon filtration device.

7.3.1 Predicted air quality

The emissions from the project were examined as part of this air quality impact assessment. The assessment found that the expected pollutant concentrations resulting from the project are low, with the expected incremental increases of PM_{10} and $PM_{2.5}$ being negligible at surrounding receivers. A small number of elevated pollutant concentrations were predicted for the worst case dispersion conditions over the three years of meteorology considered. For PM_{10} and $PM_{2.5}$, the maximum short term incremental increases (24 hour maximum concentrations) are expected to represent less than eight per cent of the applicable criteria, and less than two per cent of the existing background pollutant concentrations for the annual time period.

NO_2 emissions for the ventilation outlets are expected to be higher than the particulate emissions in terms of relative percentage of the criteria or background. Under normal operational conditions, the 1 hour NO_2 concentrations are expected to represent less than 30 per cent of the criterion under worst case dispersion conditions and less than three per cent of the criterion over a full year of emissions.

Concentrations of other pollutants, such as CO, VOCs and PAHs, are predicted to fall well below their respective criteria, and are not expected to be able to be discernable from existing concentrations.

Based on the findings of this assessment, the low levels of predicted pollutant concentrations do not indicate that further mitigation would be required for the operation of the tunnel. The predicted pollutant concentrations represent careful design of the ventilation system and ventilation outlets to achieve optimum exhaust velocities while minimising the potential for wake-effects on the plume when emitting from the ventilation outlet.

7.3.2 Background air quality

In cases where consistently high background pollutant concentrations are present, small incremental contributions from a project may result in additional exceedences of the EPA's impact assessment criteria. Additional exceedences are generally interpreted as equating to a greater potential for adverse impacts to occur. Such circumstances could support the need for additional mitigation, such as filtration.

Analysis of the background pollutant concentrations recorded at the OEH stations at Lindfield and Prospect and the project monitoring data do not suggest that this is the case. On an individual pollutant perspective the following was shown:

- PM_{10} and $PM_{2.5}$ concentrations from Lindfield and Prospect were found to exceed the ambient criteria nine and four times respectively in 2009, with no exceedences noted in 2010 and 2011. This excluded the 2009 dust storm data as it is an extreme event. The exceedences noted in 2009 were likely to be due to bushfires or unusual short term natural events, and are not considered to be representative of typical pollutant concentrations in the area as the average PM_{10} and $PM_{2.5}$ concentrations were well below the relevant criteria for all three years assessed.
- Monitoring data along the Pennant Hills Road corridor followed a similar trend to the Lindfield and Prospect data, with no exceedences recorded for PM_{10} or $PM_{2.5}$ and the average concentrations falling well below the long term criteria.
- Monitoring stations at Lindfield, Prospect and the project monitoring stations along the Pennant Hills Road corridor all recorded NO_2 values well below the 1 hour ambient criterion of 246 $\mu g/m^3$.
- The Prospect monitoring station and the monitoring stations along the Pennant Hills Road corridor recorded CO values well below the 1 hour ambient criterion of 30,000 $\mu g/m^3$. Peak CO concentrations of 2,602 $\mu g/m^3$ were recorded by the Pennant Hills Road monitoring stations compared to peak values of 3,625 $\mu g/m^3$ recorded at the OEH Prospect monitoring station.

Based on the data analysed for the region in which the ventilation outlets would be located, there is no compelling evidence indicating that the airshed is 'full' and in need of further project mitigation in the form of filtration to be fitted.

7.3.3 Mitigation equipment effectiveness

A study of the M5 East Tunnel filtration trial was undertaken by AMOG Pty Ltd in February 2012. The study found the following:

- Based on the results of three methods to establish the effectiveness of the system in reducing NO_2 emissions:
  - The DeNOx filter removed 55 per cent of the NO_2 from the air being treated. This was a much lower reduction efficiency than expected.
  - The NO_2 within the gas stream being treated was converted to NO and released into the environment. No NO_2 was retained within the filter medium.
  - The $DeNO_X$ filter only processed 14 per cent of the air in the westbound tunnel and, as such, would not have had a large effect on NO_2 levels in the overall tunnel. The authors found that "*Using activated carbon to reduce NO_2 in a tunnel will only slightly reduce total NO_X emissions from the stack*" (AMOG, 2012).
- The capture of particulates was evaluated through the analysis of the performance of the Electrostatic Precipitator (ESP) unit installed in the filtration building. The analysis found:
  - The ESP filter was found to remove approximately 65 per cent of the particulate matter from the tunnel air being treated. This was a much lower reduction efficiency than expected (80 per cent targeted).
  - Investigations into the cause of the lower reduction efficiency found that the ESP was not operating within its operating limits, and that modifications, such as expanding the collector plates or decreasing the air flow rate over the plates, may increase the effectiveness of the system.
- The authors concluded that mitigation equipment was operated for longer periods of time than is typical in other road tunnels and that it did not operate efficiently. The authors recommended that the system should cease operation in its current form and that alternative methods be sought for filtration.

Based on the investigation into the mitigation equipment effectiveness, it was concluded that the equipment is not an effective means by which pollution can be removed from a ventilation outlet. On this basis, given the factors above, the installation of this mitigation equipment is not recommended.

7.3.4 Cost of mitigation

The cost of the mitigation equipment (including retrofitting the equipment) was analysed as part of the AMOG study outlined above (AMOG, 2012). Cost estimates were based around the relative cost for the equipment to remove pollutants; that is, cost per tonne of pollution removed. The various capital and operating costs were calculated for the equipment and contrasted against industry standards for pollution capture. The costs were as follows:

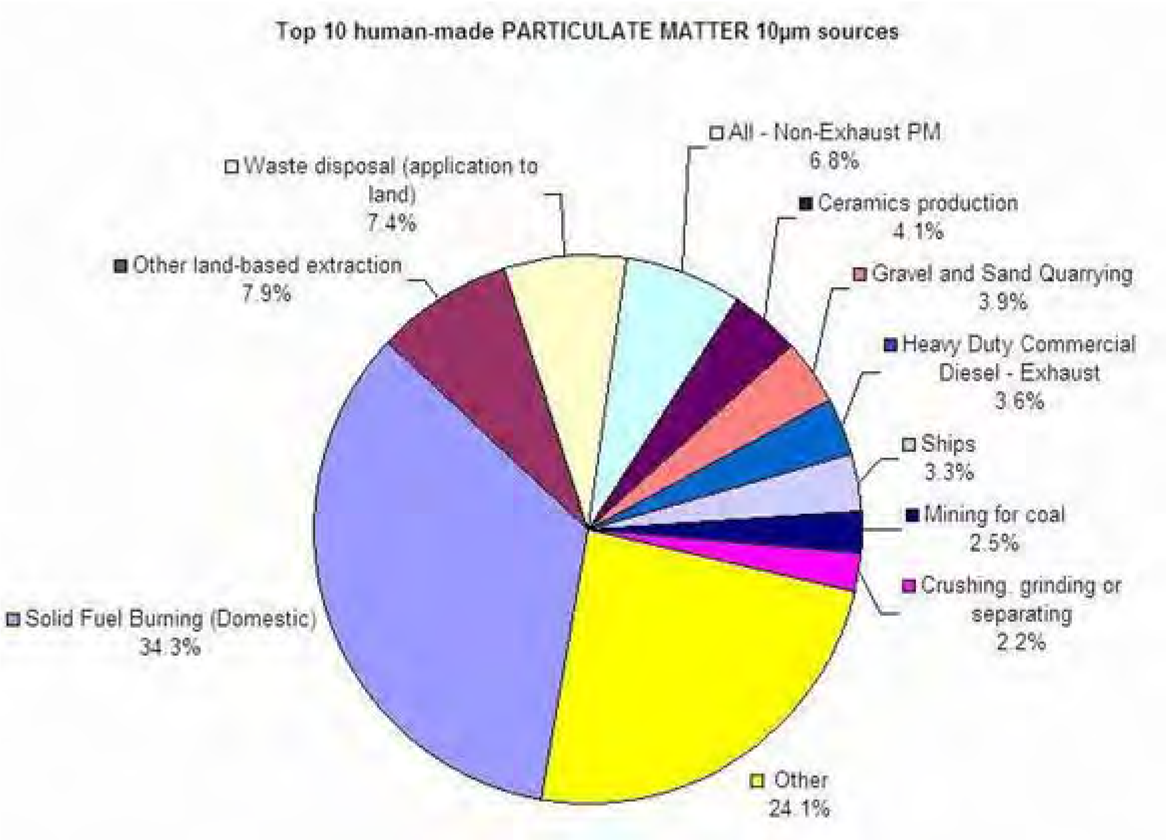
- Cost of NO_2 removal was calculated at:
  - $4,014,000 per tonne if civil construction and machinery costs were amortised over 20 years and operating costs included.
  - $874,000 per tonne if operating costs only were included (civil construction and machinery costs excluded).
- Cost of particulate matter removal was calculated at:
  - $17,393,000 per tonne if civil construction and machinery costs were amortised over 20 years and operating costs included.
  - $3,787,000 per tonne if operating costs only were included (civil construction and machinery costs excluded).

In comparison, the cost of removing particulate pollution using vehicle particulate filters ranges from $150,000 per tonne to $300,000 per tonne. The costs above suggest a high cost for a poorly operating mitigation solution.

7.3.5 Other sources of pollution in the area

In addition to the analysis focusing on the ability of the mitigation equipment to reduce the levels of pollution being emitted into the environment, it is worth considering whether there are other local sources of pollution that could be mitigated to achieve the same, or better, improvements in air quality for the same or lower costs as filtering the project emissions.

According to the NSW EPA Air Emissions inventory (EPA, 2008), the largest source of PM_{10} pollution in the Greater Metropolitan Region of NSW is domestic solid fuel burning (34.3 per cent of overall PM_{10} emissions). As shown in the following graphic, heavy duty commercial vehicles (which are the major source of particulates emissions for the project) are a relatively minor contributor of particulates to the airshed, with their emissions estimated to represent only 3.6 per cent to particulate emissions in NSW.



Based on these broad data, programs targeting the reduction of emissions from areas such as solid fuel burning would have a far greater effect on reducing the State's PM_{10} emissions than installing mitigation equipment on a source which is contributing only minor levels of pollution to the environment.

In 2010, the then Department of Environment, Climate Change and Water engaged Sinclair Knight Merz (SKM, 2010) to undertake a study to identify and analyse a range of emissions abatement initiatives. In the Sydney region, 12 emissions reduction measures were identified, with associated costs ranging from $1,000 to $274,000 per tonne of PM_{10} removed. The cost of removing PM_{10} using particle filters was $151,000 per tonne. In contrast, two emissions reduction programs (the SmartWay program and shifting transport mode the cycling) were found to have a negative cost; that is, a cost benefit.

Roads and Maritime compared the M5 East Tunnel filtrations system against other pollution mitigation measures in terms of both costs and abatement of $PM_{2.5}$ emissions based on the findings of SKM (2010), who analysed the various costs and effectiveness of various air emission reduction actions, and AMOG (2012), who estimated the costs and effectiveness of the M5 East filtration system. As shown in **Table 43**, the costs of tunnel filtration were well above the costs of mitigating emissions from sources such as wood heaters, off-road vehicles, diesel locomotives and vehicle emission standards. Furthermore, the tunnel filtration removed only a fraction of $PM_{2.5}$ compared to the other measures.

In 2013, the EPA commissioned PAEHolmes to develop a valuation methodology to account for the health impacts associated with changes in particulate matter emissions (PAEHolmes, 2013). This study estimated the health benefit of removing one tonne of $PM_{2.5}$ in Sydney to be $280,000.

Nearly all of the particles removed in the M5 East Motorway trial consisted of $PM_{2.5}$. Based on the above valuation, the M5 East Motorway filtration trial had operational costs of more than ten times the estimated health benefit. All of the measures considered by the SKM (2010) study cost less than one tenth the cost of the M5 East Motorway filtration trial and would remove substantially more particulate matter, delivering a much greater health benefit than tunnel filtration. This is consistent with the conclusions of the National Medical and Health Research Council, which determined that the most effective method to manage air quality in and around tunnels is through vehicle fleet emission reductions (NHMRC, 2008).

Table 43 Comparison of particulate matter reduction measures

Reduction measures	Cost of reduction per tonne	Annual tonnes reduced
SmartWay program[1]	-$54,266,000	5
Two per cent transport mode shift to cycling	-$16,146,000	7
National emissions standards for wood heaters (1 g/kg)	$1,000	1,701
National emissions standards for wood heaters (3 g/kg)	$1,000	45
Emission limits for industry	$5,000	359
Tier 4 emissions standards for off-road vehicles and equipment	$12,000	31
Wood heaters – reduce moisture content of firewood	$20,000	93
Small engines (2 stroke to 4 stroke) recreational boating and lawn mowers	$39,000	261
Truck and bus diesel retrofit	$151,000	1
Diesel locomotive replacement (USEPA Tier 0 to Tier 2)	$156,000	53
Diesel locomotive replacement (USEPA Tier 0 to Tier 2) plus Tier 2 locomotives with selective catalytic reduction)	$191,000	72
Euro 5/6 emission standards for new passenger vehicles	$209,000	131
Recommission and electrify Enfield to Port Botany freight line	$244,000	3
Port Botany shore-side power	$274,000	11
M5 East Motorway tunnel filtration (operating costs only)	$3,800,000	0.2
M5 East Motorway tunnel filtration (total cost)	$17,400,000	0.2
Note: 1 USEPA's SmartWay Transport Partnership is a market-driven partnership aimed at helping businesses move goods in the cleanest most efficient way possible		

As a comparison, Roads and Maritime and the NSW EPA instigated a smoky vehicle strategy on the M5 East Motorway in 2006. This strategy involves the use of smoke detectors, video and still cameras to detect smoky vehicles. Fines and suspensions are issued to encourage vehicles to be repaired or removed from the road network. This strategy has proved to be effective in resulting in improvements to air quality within the M5 East Motorway tunnels, and, therefore, improvements in the quality of air is exhausted from the M5 East Motorway tunnels to the environment.

One measure of in-tunnel air quality is visibility, which is measured as an extinction coefficient. Visibility can be used as a measure of in-tunnel particulate matter using a conversion factor from the PIARC (2012). The PIARC definitions of extinction coefficients (visibility) are as follows:

- 0.003 m^{-1} means a clear air tunnel (visibility of several hundred metres).
- 0.007 m^{-1} approximates a haziness of in-tunnel air.
- 0.009 m^{-1} approximates a foggy atmosphere.
- 0.012 m^{-1} is the threshold value that should not be exceeded during operation and which results in a very uncomfortable in-tunnel atmosphere. At this level, however, visibility is normally sufficient to stop safely at an obstacle.

In 2004, prior to the implementation of the strategy, the extinction coefficient within the M5 East Motorway tunnels exceeded 0.004 m^{-1} in the most months. Contemporary data (from April 2013 to April 2014) show that the M5 East Motorway now operates with an extinction coefficient of less than 0.003 m^{-1} (that is, a clear air tunnel) for the majority of the time. The NorthConnex project would include smoky vehicle regulatory measures similar to those used for the M5 East Motorway. Further details on the improvement in air quality in the M5 East Motorway tunnels since the implementation of the smoky vehicle strategy and the NorthConnex strategy in relation to smoky vehicles are provided in **Section 7.3.4** of the EIS.

7.3.6 Summary

The pollutant concentrations predicted by the dispersion modelling do not indicate that tunnel filtration is warranted or that it would provide any benefit to the surrounding community. The ventilation outlets were designed to ensure little, if any, increase in exposure to vehicle emissions at receiver locations. Even if filtration was 100 per cent effective, if would be expected to deliver negligible benefits to the environment in terms of air quality. Greater improvements in air quality could be achieved through investment in programs targeting other emission sources that contribute higher levels of pollution to the surrounding environment.

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8.0 Conclusion

Roads and Maritime Services is seeking approval to construct and operate a tolled motorway linking the M1 Pacific Motorway at Wahroonga to the Hills M2 Motorway at the Pennant Hills Road interchange at Carlingford. The project would include twin tunnels approximately nine kilometres in length, which would generally follow the alignment of the existing Pennant Hills Road. The purpose of the project is to reduce congestion on Pennant Hills Road, particularly heavy vehicle traffic. This technical working paper assessed the potential effects on air quality associated with the construction and operation of the project.

The qualitative assessment of the effects of the construction works on local air quality determined that standard management measures would be sufficient to mitigate the effects of these works on local air quality and receivers.

A quantitative assessment of the operational stage of the project was undertaken using the CALPUFF suite of models, and was coupled with estimations of emissions along the surface roads from the CAL3QHCR model. The results of the dispersion modelling determined that concentrations of nitrogen dioxide, carbon monoxide, volatile organic compounds and PAHs would all be well below the applicable impact assessment criteria. While exceedences of the criteria for PM_{10} and $PM_{2.5}$ were predicted to occur, these were attributable to elevated background concentrations of these pollutants, with the project contributing only minor levels of particulates to the airshed. The estimated annual TSP concentrations, using the annual PM_{10} concentrations as a surrogate, were also determined to be well below the assessment criteria. As such, the project is considered unlikely to adversely affect local or regional air quality.

An assessment of changes to the air quality environment was also undertaken along the project corridor, which took into account the changes in traffic flows along Pennant Hills Road as a result of the project, and the improved dispersion of emissions from diverted traffic through ventilation outlets. This found that:

- In the case of both 24-hour average and annual average $PM_{2.5}$ concentrations, the project's ventilation outlets would effectively disperse emissions to very low levels in the surrounding environment. The peak contributions from the project would be around five to 10 per cent (24-hour average) and one to five per cent (annual average) of the advisory reporting standards for $PM_{2.5}$. Both of these percentages are well within the normal variability in background $PM_{2.5}$ concentrations.
- Substantial reductions in 24-hour average and annual average $PM_{2.5}$ concentrations were predicted to occur along the Pennant Hills Road corridor as a result of the project. Receivers along the road corridor were predicted to benefit from improvements in $PM_{2.5}$ concentrations (24-hour average) of around five to 20 per cent in as a result of the project. For annual average $PM_{2.5}$ concentrations, receivers along the road corridor are expected to benefit from improvements in $PM_{2.5}$ concentrations (annual average) of around five to 35 per cent in as a result of the project.

As such, the project is expected to result in a net improvement in air quality, taking into account substantial improvements in air quality along the Pennant Hills Road corridor balanced with less extensive, very low levels of increases in $PM_{2.5}$ concentrations around the northern and southern ventilation outlets.

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Appendix A

Construction activities

Appendix A Construction activities

Construction works would include the excavation of the road tunnels and access tunnels, road widening works, demolition works, road and bridge construction, material storage and handling and wastewater treatment (groundwater). Around 2.6 million cubic metres of surplus spoil would be generated from the project, primarily from the tunnel excavations. Most of this material would be uncontaminated crushed sandstone and shale material classified as virgin excavated natural material (VENM), which can be reused or disposed of at disposal sites. Some materials excavated from construction sites may be contaminated; such contamination would be identified through soil sampling, and contaminated material would be disposed of at a licensed waste facility.

Construction emissions for large road projects are difficult to quantify due to the number of construction sites, the distribution of sites across a large geographical area, and the transitory nature of many individual construction activities at particular locations. Construction emissions can generally be well managed through best practice management and mitigation strategies. As such, the excavation and construction works were assessed qualitatively by describing the nature of the proposed work, the proposed plant and equipment, the potential emission sources and their potential emission levels. Proactive and reactive mitigation measures were then identified to reduce the likelihood of the works adversely affecting local air quality and receivers.

A description of the works is provided below.

High level construction activities associated with potential emissions to air

Component	Typical activities
Hills M2 Motorway integration works	- Establishment of work areas. - Earthworks associated the formation of the finished design levels for the additional lane, cuttings and embankments. - Bridge construction works, including piling. - General civil works. - Spoil handling and management, estimated at around 39,800m^3 of spoil. - Paving. - Exhaust emissions from the operation of construction vehicles and plant. - Surface site rehabilitation and restoration.
Windsor Road compound (C1), Darling Mills Creek compound (C2), Barclay Road compound (C3) and Yale Close compound (C4)	- Establishment of work sites. - Exhaust emissions from the operation of construction vehicles and plant. - Surface site rehabilitation and restoration.
Southern interchange and southern interchange compound (C5)	- Establishment of work areas, including vegetation removal and building demolition. - Earthworks associated with the formation of finished design levels, cuttings, cut-and-cover sections (including tunnel structures), and the excavation of decline ramps, main alignment tunnels, and shafts. - General civil works, including retaining walls. - Removal, storage and transport of around 613,900m^3 of spoil from construction activities. - Paving. - Exhaust emissions from the operation of construction vehicles and plant. - Construction of permanent operational ancillary facilities. - Surface site rehabilitation and restoration.

Component	Typical activities
Wilson Road compound (C6)	- Establishment of work site, including building demolition and vegetation clearance. - Earthworks associated with the formation of the finished design levels for the site and the excavation of the decline to the main alignment tunnels. - Removal, storage and transport of around 441,950m^3 of spoil from tunnelling activities. - Exhaust emissions from the operation of construction vehicles and plant. - Decommissioning and removal of construction-related buildings and plant. - Construction of permanent operational ancillary facilities. - Surface site rehabilitation and restoration.
Trelawney Street compound (C7)	- Establishment of work site, including building demolition and vegetation clearance. - Earthworks associated with the formation of the finished design levels for the site and the excavation of the decline to the main alignment tunnels. - Removal, storage and transport of around 492,200m^3 of spoil from tunnelling activities. - Exhaust emissions from the operation of construction vehicles and plant. - Decommissioning and removal of construction-related buildings and plant. - Construction of permanent operational ancillary facilities. - Surface site rehabilitation and restoration.
Pioneer Avenue compound (C8)	- Establishment of work site, including building demolition. - Construction of temporary structures, and paving for car parking areas. - Decommissioning and removal of construction-related buildings. - Surface site rehabilitation and restoration. - Exhaust emissions from the vehicles.
Northern interchange, the northern interchange compound (C9), Bareena Avenue compound (C10) and Junction Road compound (C11).	- Establishment of work areas, including vegetation removal and building demolition. - Earthworks associated with the formation of the finished design levels for the interchange, cuttings, cut-and-cover sections (including tunnel structures), and the excavation of on-ramps and off-ramps, shafts and the main alignment tunnels, - Removal, storage and transport of around 1,024,350m^3 of spoil from construction activities from the northern interchange compound. - General civil works. - Paving. - Exhaust emissions from the operation of construction vehicles and plant. - Decommissioning and removal of construction-related buildings and plant. - Construction of permanent operational ancillary facilities at the Bareena Avenue compound. - Surface site rehabilitation and restoration.

Tunnel excavation

The project would involve the excavation of two tunnels around nine kilometres in length for the main alignment and additional tunnels for on and off-ramps at both the northern and southern interchanges. Tunnel depth along the corridor would vary depending on geological constraints, with a maximum depth of around 90 metres below ground level, with shallower sections approaching the northern and southern portals. The tunnels would be around 14 metres in width.

It is anticipated that tunnel excavation would be undertaken using a number of road headers and surface miners, supported from multiple sites. A road header is an excavation machine consisting of a boom-mounted rotating cutter head mounted on bulldozer-style tracks, a loader device usually on a conveyor, and a crawler travelling track to move the machine forward into the rock face. A surface miner is a mechanically driven excavation machine capable of cutting, crushing and loading in one continuous process.

The mainline tunnels would be constructed using a heading and bench excavation method. The top heading would be excavated by a road header and the bench would be excavated by a surface miner operating behind the main face excavation. Localised blasting works may be carried out underground depending of the geological conditions encountered. Following tunnel excavation, ground support would be installed by way of tunnel lining.

Each of the tunnelling sites would require support services for the tunnelling activity including power supply, ventilation, water supply, construction water treatment plants, workforce facilities and spoil handling and removal.

In addition to the main alignment and on and off-ramp tunnels, pedestrian cross passages would be excavated between the main alignment tunnels at 120 metre intervals and vehicle cross passages would be excavated around the Wilson Road and Trelawney Street sites. These cross passages would be excavated using small road headers, excavators with rock hammer, drilling and blasting.

Construction program

Construction of the project is planned to begin in early 2015, with completion of construction in the fourth quarter of 2018. The total period of construction works is expected to be around four years. The indicative construction program is shown below.

Indicative construction program

Construction activity	Indicative construction timeframe 2014				2015				2016				2017				2018				2019			
Site establishment					■	■	■	■	■	■														
Shaft excavations							■	■	■	■	■	■	■	■	■									
Tunnelling							■	■	■	■	■	■	■	■	■	■	■							
Tunnel lining											■	■	■	■	■	■	■	■						
Concrete pavement													■	■	■	■	■	■	■					
Tunnel mechanical and electrical fit-out												■	■	■	■	■	■	■	■	■	■			
Southern portal					■	■	■																	
Hills M2 Motorway integration works								■	■	■	■	■	■	■	■									
Northern portal								■	■	■	■	■	■	■	■	■	■	■	■					
M1 Pacific Motorway tie-in works								■	■	■	■	■	■	■	■	■	■	■	■	■				
Wilson Road tunnel support facility													■	■	■	■	■	■	■	■	■			
Trelawney Street tunnel support facility													■	■	■	■	■	■	■	■	■			
Southern ventilation facility												■	■	■	■	■	■	■	■	■				
Northern ventilation facility														■	■	■	■	■	■	■	■			
Motorway control centre												■	■	■	■	■	■	■						
Commissioning																					■	■	■	

Plant and equipment

Plant and equipment expected to be used during the construction the project include standard construction equipment, such as gantry cranes, fans, excavators, compressors, loaders, road sweepers, water carts, pumps, excavators, concrete agitators and dump trucks. The following table provides a list of plant and equipment likely to be used during construction of the project.

Indicative construction plant and equipment

Plant / equipment	Hills M2 Motorway integration	Southern interchange compound (C5)	Wilson Road compound (C6)	Trelawney Street compound (C7)	Northern interchange compound (C9)	Bareena Avenue compound (C10)
Surface						
100 tonne / 10 tonne gantry crane			✓	✓	✓	
160 kilowatt fan		✓(4)	✓(4)	✓(4)	✓(4)	
20 tonne excavator		✓	✓	✓		✓
24 tonne excavator		✓(2)	✓	✓	✓	
30 tonne excavator	✓(6)	✓	✓	✓		✓
Backhoe	✓(6)	✓	✓	✓		
Bobcat		✓	✓	✓		
80 tonne piling rig	✓(3)	✓	✓	✓		✓
Dozer	✓(6)					✓
Dump truck						✓(4)
25 tonne mobile crane		✓	✓	✓		✓
50 tonne mobile crane	✓(6)	✓	✓	✓		✓
100 tonne mobile crane		✓	✓	✓		✓
Hiab truck		✓	✓	✓		✓
10 tonne smooth drum vibrating roller	✓(6)	✓	✓	✓		✓
Compactor						✓
Grader	✓(6)					
Concrete saw / cutter	✓(4)					
Rock saw	✓(4)					
Hydraulic hammer / rock breaker	✓(6)					
Jackhammer	✓(6)					
Rock crusher	✓(6)					
Asphalt laying machine	✓(2)					
Truck	✓(10)					
Line marking machine	✓(2)					
Paving machine	✓(2)					
30 tonne gantry crane			✓	✓	✓	
60 kilowatt fan		✓				
Air compressor		✓(2)	✓(2)	✓(2)	✓(2)	
Bucket loader		✓(2)	✓	✓	✓	✓
100 tonne crawler crane		✓(2)	✓	✓	✓	
Grout plant / paddle mixer		✓(2)	✓	✓	✓	
Jumbo drill (shaft)		✓(2)	✓	✓	✓	
Road sweeper truck		✓	✓	✓	✓	✓
Skid steer loader		✓	✓	✓	✓	✓

Submersible pump		✓(8)	✓(6)	✓(6)	✓(6)	✓
Sump pump		✓(3)	✓(2)	✓(2)	✓(2)	✓(3)
Water cart	✓(2)	✓	✓	✓	✓	✓
Water treatment plant		✓	✓	✓	✓	
100 kilovolt ampere generator	✓(4)	✓	✓	✓		✓
Underground						
12 tonne mini excavator with hammer		✓	✓	✓	✓	
24 tonne excavator		✓	✓	✓	✓	
24 tonne excavator with diamond cutting tool		✓(2)	✓	✓	✓	
Booster pumps		✓	✓	✓	✓	
Bucket loader		✓(3)	✓(3)	✓(3)	✓(3)	
Colloidal grout mixer		✓	✓	✓	✓	
Concrete agitator		✓(4)	✓(4)	✓(4)	✓(4)	
Deduster (dry type) and fan		✓(4)	✓(5)	✓(5)	✓(5)	
25 tonne articulated dump truck		✓(7)	✓(6)	✓(6)	✓(6)	
Gate end box		✓(4)	✓(4)	✓(4)	✓(4)	
200 kilowatt roadheader (for cross passages)			✓	✓	✓	
300 kilowatt roadheader		✓(4)	✓(4)	✓(4)	✓(4)	
Rockbolting rig		✓(3)	✓(3)	✓(3)	✓(3)	
Shotcrete robot		✓(3)	✓(3)	✓(3)	✓(3)	
Skid steer loader			✓	✓	✓	
Water cart					✓	

Spoil and waste disposal

Based on the current project design, the project would generate around 2.6 million cubic metres of spoil. The spoil generated by the road headers would predominantly be transported to the extraction shaft sites via trucks within the tunnels. Where the excavation occurs close to the extraction points, the material would be transferred directly from the road headers. Smaller quantities of excavated spoil would remain in the tunnels.

The majority of stockpiling of spoil would occur within acoustic (noise-reducing) sheds. Front end loaders or excavators would be used to load the stockpiled materials onto haulage trucks (truck and dog trucks with around 30 tonne capacity) for transport off site. The stockpile would be approximately 2,400 cubic metres in size, representing between one and two days' excavation volumes.

Other waste streams which would be generated during construction of the project include:

- Demolition waste from existing structures and properties.
- Contaminated soil, which may be encountered during construction.
- General construction waste such as concrete, steel and timber formwork off-cuts.
- Vegetation waste from clearing.
- Plant and vehicle maintenance waste such as oils and lubricants.
- General office waste such as paper, cardboard, plastics and food waste.
- Sewage waste.

Spoil generation and disposal would occur throughout the majority of the four year construction period. A number of potential sites were identified for the disposal of spoil generated by the project. The final disposal location(s) would be determined during detailed design.

Construction vehicles

Construction vehicles required for the works are summarised in the following table. The numbers provided represent those required for the excavation phase, as they represent the highest vehicle numbers of all the working phases (vehicle numbers associated with the fit out phases are expected to be substantially lower than the excavation phase vehicle numbers).

Construction vehicle numbers

Site	Daily heavy vehicles*	Daily light vehicles*
Windsor Road compound (C1)	20	85
Darling Mills compound (C2)	50	20
Barclay Road compound (C3)	50	52
Yale Close compound (C4)	50	20
Southern interchange	740	165
Wilson Road compound	600	100
Trelawney Street compound	570	100
Pioneer Avenue compound	12	650
Northern interchange	720	100
Bareena Avenue compound	20	25
Junction Road compound	1	100

Emission sources

The proposed construction works may generate air pollutant emissions through earthworks; material stockpiling, handling and transport; demolition works; combustion emissions from plant and equipment; and wind erosion of exposed areas. Particulate emissions generated by underground works, including vehicle and blasting emissions, would be captured and filtered to an acceptable standard before being emitted through the ventilation systems. As the underground emissions would be controlled, surface works are considered to be the most important source of emissions associated with the construction works.

Equipment associated with excavating, handling or moving material -- such as road headers, excavators, jack hammers and piling rigs -- generate particulate emissions. Particulates are also emitted from exposed, unvegetated areas and uncovered stockpiles through wind erosion. Diesel and petroleum-powered plant and equipment are sources of pollutants such as particulates (PM_{10} and $PM_{2.5}$), nitrogen dioxide, carbon dioxide and VOCs through their exhaust (combustion) emissions. Electrically-powered plant and equipment do not generate combustion emissions.

The most substantial particulate emissions potentially generated by the construction works are those associated by surface earthworks, material stockpiles, wind erosion and wheel-generated dust from vehicles on unsealed roads. Off-road plant and equipment can generate substantial emissions of oxides of nitrogen and lesser amounts of carbon monoxide, particulates and VOCs. Passenger vehicles are also a source of these emissions. All emissions are expected to be confined to the local area surrounding the emission points, with no lasting effects on local air quality.

Motor vehicles and plant

The main sources of emissions from heavy vehicles, mobile excavation machinery and stationary combustion plants would be related to diesel combustion. Construction plant would generally be diesel-powered and would emit gaseous and particulate matter into the air. Road headers would be driven by mains power supply and would therefore not contribute the exhaust emissions.

Most of the emissions generated by combustion engines are emitted from the exhaust (NPI, 2008). Emissions from combustion engines are affected by the engine power, fuel consumption and distance travelled or operating hours.

The NPI (2008) provides emission factors for road transport vehicles (that is, cars, light and heavy goods vehicles and buses used on either sealed roads or on well-formed unsealed roads) and industrial (off-road) vehicles, such as heavy earth moving and construction equipment and a range of miscellaneous vehicles such as forklifts. According to these factors, diesel light goods vehicles emit the greatest amount of PM_{10} of all road vehicles on a volume-of-fuel-used basis; buses emit the greatest level of NO_X; petrol LGVs emit the greatest level of total

VOCs; and petrol cars have the highest emissions of benzene and 1,3-butadiene. Within each vehicle category, emissions of PM_{10} and $PM_{2.5}$ are very similar.

Wheeled tractors powered by diesel emit the highest level of particulates per kilowatt hour; forklifts have the highest emissions of carbon monoxide and VOCs; and diesel rollers have the highest emissions of oxides of nitrogen.

All plant and equipment used during construction would comply with the emissions concentration limits outlined in the *Protection of the Environment Operations (Clean Air) Regulation 2010*. As such, vehicular and plant emissions arising from the civil construction works are not likely to have a substantial effect on the surrounding air quality.

Emissions are minimised through switching engines off when not in use, maintaining vehicles in accordance with manufacturers' specifications, using fuel efficient vehicles and limiting the number of trips.

Earth moving, excavation and demolition

The operations commonly found in earth moving, excavation and demolition activities include:

- Worksite establishment activities such as vegetation clearing and earthworks.
- Demolition of buildings, structures and road pavement.
- General earthworks.
- Exposure of surfaces, which may be susceptible to wind erosion.
- Handling and stockpiling of spoil material.
- Vehicle movements on unsealed roads, resulting in wheel generated dust.
- Drilling and blasting.
- Tunnelling activities and tunnel ventilation during construction.
- Materials storage and handling.

Any operations that move or manipulate dusty material can be a source of particulate emissions. The NPI manual for fugitive emissions (NPI, 2012b) indicates that emission factors developed for mining are applicable to earth moving, excavation and demolition works associated with demolition and debris removal, site preparatory works and general material handling activities.

Katestone (2011) prepared a best practice guide for the management of mining emissions, which was based on the results of environmental audits conducted for coal mines within the Greater Metropolitan Region. The different mining activities were ranked according to their emission levels of TSP, PM_{10} and $PM_{2.5}$. The highest levels of particulates were generated from vehicle movements on unpaved roads and wind erosion of material stockpiles; these activities are similar to those associated with the proposed excavation works. As such, these activities would be expected to be primary potential emission sources for the proposed construction works.

The NPI specifies control efficiencies for various management and mitigation measures. As shown in the following table, the most effective mitigation strategy for wheel-generated dust is the sealing of roads, followed by watering at a rate of greater than two litres per square metre per hour. For wind erosion of stockpiles, total enclosure is considered to reduce 99 per cent of emissions. For this project, the majority of haul truck travel would be undertaken on sealed roads, and the stockpiles of material excavated from the tunnels would be stored within acoustic sheds in the majority of case. These actions would substantially mitigate emissions associated with the construction works.

Estimated control factors for various mining operations (NPI, 2012c)

Operation / Activity	Control method and emission reduction
Scrapers on topsoil	50 % control when soil is naturally or artificially moist
Dozers	No control
Drilling	99 % for fabric filters 70 % for water sprays
Blasting coal or overburden	No control
Loading trucks	No control
Hauling	50 % for level 1 watering (2 litres/m^2/h) 75 % for level 2 watering (> 2 litres/m^2/h) 100 % for sealed or salt-encrusted roads
Unloading trucks	70 % for water sprays
Loading stockpiles	50 % for water sprays 25 % for variable height stacker 75 % for telescopic chute with water sprays 99 % for total enclosure
Unloading from stockpiles	50 % for water sprays (unless underground recovery, where no controls are needed)
Wind erosion from stockpiles	50 % for water sprays 30 % for wind breaks 99 % for total enclosure 30 % for primary earthworks (reshaping/profiling, drainage structures installed) 30 % for rock armour and/or topsoil applied
Miscellaneous transfer and conveying	90 % control allowed for water sprays with chemicals 70 % for enclosure 99 % for enclosure and use of fabric filters
Wind erosion	30 % for primary rehabilitation 40 % for vegetation established but not demonstrated to be self-sustaining. Weed control and grazing control. 60 % for secondary rehabilitation 90 % for revegetation 100 % for fully rehabilitated (release) vegetation

It should be noted that the effects of control measures are multiplicative, so the implementation of a number of control measures increases the overall emission reductions.

There are a number of receivers located in the vicinity of the construction sites, which have the potential to be affected by dust emissions from above-ground works. The potential for dust emissions from above-ground construction works would be managed through standard mitigation measures identified in **Section 5.2**, such as water spraying of unsealed areas, wetting down of dust activities and progressive stabilisation works.

The underground tunnels would be required to be ventilated during construction in order to provide a safe working environment for the construction workforce. Tunnel ventilation would be provided at the four tunnel support sites, which are:

- The southern interchange compound (C5).
- The Wilson Road compound (C6).
- The Trelawney Street compound (C7).
- The northern interchange compound (C9).

This ventilation equipment would have dust extraction and filtration systems installed to minimise dust emissions. Additionally, as the road headers would require water for dust suppression while cutting rock, dust generation from tunnelling activities is expected to be minimal.

The primary pollutants emitted from the detonation of explosives used for blasting are carbon monoxide, hydrogen sulfide, sulfur dioxide, oxides of nitrogen and ammonia (NPI, 2012a). In addition to the emissions associated with the fuel detonation, particulates are also emitted.

As blasting would be undertaken on an intermittent basis and underground, the pollution emissions associated with these activities would be expected to be of short duration. Underground particulate blasting emissions would be captured by the tunnel filtration systems. As blasting works would only be carried out underground, the potential for dust impacts from this activity is negligible.

Water treatment

Water treatment plants are proposed for the southern interchange, Wilson Street compound, Trelawney Street compound and the northern interchange to treat groundwater extracted from the workings. Emissions to air associated with water treatment depend on the nature of the contamination of the water being treated and the treatment process. Primary air emissions associated with water treatment are odorous compounds, such as ammonia and VOCs, which are associated with aeration (primary treatment), aerobic digestion, sludge thickening, anaerobic digestion and sludge drying (NPI, 2011).

The nature of any odours would depend on the degree and type of any contamination present in the groundwater. As this is not currently known, a reactive management plan should be developed to address any odours if they arise. The plan should include identification of odours, identification of the extent to which the odours are detectable, and, if necessary, mitigation measures to reduce any odours affecting receivers if they arise. Such mitigation measures could include modifications to the operating process, or the installation of carbon filters to capture odorous compounds before they are emitted. The water treatment plants should be located as far from receivers as can feasibly be achieved.

Appendix B

Pollutant descriptions

Appendix B Pollutant descriptions

Particulate matter – PM_{10}, $PM_{2.5}$ and TSP

Airborne particles are commonly differentiated according to size based on their equivalent aerodynamic diameter. Particles with a diameter of less than or equal to 50 micrometres (μm) are collectively referred to as total suspended particulates (TSP). TSP primarily cause aesthetic impacts associated with coarse particles settling on surfaces, which also causes soiling and discolouration. These large particles can, however, cause some irritation of mucosal membranes; they pose a greater risk to health when ingested if they are contaminated. Particles with diameters less than or equal to 10 μm (known as PM_{10}) are primarily created through crushing and grinding of rocks and soil, and typically comprise soot, dirt, mould and pollen. These particles tend to remain suspended in the air for longer periods than larger particles (minutes or hours), and can penetrate into human lungs. Fine particulates (those with diameters less than or equal to 2.5 μm, known as $PM_{2.5}$) are typically generated from vehicle exhaust, bushfires and some industrial activities, and can remain suspended in the air for days or weeks. As these fine particulates can travel further into human lungs than the larger particulates and are often made up of heavy metals and carcinogens, fine particulates are considered to pose a greater risk to health.

Exposure to particulate matter has been linked to a variety of adverse health effects, such as respiratory problems (for example coughing, aggravated asthma, chronic bronchitis), lung damage and non-fatal heart attacks. Furthermore, if the particles contain toxic materials (such as lead, cadmium, zinc) or live organisms (such as bacteria or fungi), toxic effects or infection can occur from inhalation of the dust.

Particulate Matter – PM_1

There are a large number of studies establishing links between concentration of ambient aerosols level of air pollution and adverse health and environmental effects. While PM_{10} and $PM_{2.5}$ measures provide very important steps toward air quality assessment, it is also apparent that more accurate descriptors of the actual atmosphere are still needed. There is a growing consensus that PM_1 would be a more suitable size than $PM_{2.5}$ to assess health impacts; there is, however, a limited amount of data for the sub-micrometre ambient particle fraction available. Very little data currently exist relating to ambient PM_1 concentrations, and existing PM_1 data sets are restricted to measurements of limited time periods from field campaigns, and little information exists regarding the chemical compositions of these particles.

Small particles around 1 μm in size are affected by relative humidity, wind speed and traffic. Knowledge regarding this fraction of particulate matter includes the following points:

- Particles in 1 μm range are equally spread throughout air layer, and evenly spread regionally, meaning that fine particles in this size range are transported globally.
- Increasing humidity causes these particles to grow in size to the $PM_{2.5}$ due to hygroscopic growth; similarly, evaporation can cause particles to reduce in size again.
- As wind speed increases, dispersion of PM_1 is increased.
- As traffic increases, fine particles increase.

A study conducted in Austria (Gomiscek et al., 2004) determined that PM_1 counted for about 50 – 60 percent and $PM_{2.5}$ accounted for about 70 percent of all PM_{10}.

As no monitoring of PM_1 is currently conducted in Sydney, and no criteria for this fraction exist, PM_1 was not modelled in this assessment.

Carbon monoxide

Carbon monoxide (CO) is a colourless, odourless gas produced by the incomplete combustion of fuels containing carbon (for example, oil, gas, coal and wood). CO is absorbed through the lungs, where it reacts to reduce the blood's oxygen-carrying capacity. In urban areas, motor vehicles account for up to 90 per cent of all CO emissions.

Nitrogen dioxide

Nitrogen dioxide (NO_2) is a brownish gas with a pungent odour. It exists in the atmosphere in equilibrium with nitric oxide. The mixture of these two gases is commonly referred to as oxides of nitrogen (NO_x). As NO_x is a product of combustion processes, motor vehicles and industrial combustion processes are the major sources of ambient NO_x in urban areas. NO_2 can cause damage to the human respiratory tract, increasing a person's susceptibility to respiratory infections and asthma. NO_2 can also cause damage to plants, especially in the presence of other pollutants such as ozone and sulfur dioxide. NO_x are primary ingredients in the reactions that lead to photochemical smog formation.

Volatile organic compounds

Organic compounds with a vapour pressure at 20 °C exceeding 0.13 kPa are referred to as volatile organic compounds (VOCs). VOCs were implicated as a major precursor in the production of photochemical smog, which causes atmospheric haze, eye irritation and respiratory problems. VOCs are emitted from vehicle exhausts.

Three primary VOCs (benzene, toluene and xylenes) are components of petroleum and diesel fuel and are typically the focus for assessments of engine combustion emissions.

Benzene

Benzene is an airborne substance that is a precursor to photochemical smog. Benzene exposure commonly occurs through inhalation of air containing the substance. It can also enter the body through the skin, although it is poorly absorbed this way. Low levels of benzene exposure result from car exhaust.

Benzene is considered to be a toxic health hazard and a carcinogen. It has high acute toxic effects on aquatic life and long-term effects on marine life and agricultural crops. Human exposure to very high levels for even brief periods of time can potentially result in death, while lower level exposure can cause skin and eye irritation, drowsiness, dizziness, headaches and vomiting, damage to the immune system, leukaemia and birth defects.

Toluene

Toluene (methylbenzene) is a highly volatile chemical that quickly evaporates to a gas if released as a liquid. Due to relatively fast degradation, toluene emissions are usually confined to the local area in which it is emitted. Human exposure typically occurs through breathing contaminated air, but toluene can also be ingested or absorbed through the skin (in liquid form). Toluene usually leaves the body within twelve hours.

Short-term exposure to high levels of toluene can cause dizziness, sleepiness, unconsciousness and sometimes death. Long-term exposure can cause kidney damage and permanent brain damage that can lead to speech, vision and hearing problems, as well as loss of muscle and memory functions. The substance can cause membrane damage in plant leaves, and is moderately toxic to aquatic life with long-term exposure.

Xylenes

Xylenes are flammable liquids that are moderately soluble in water. They are quickly degraded by sunlight when released to air, and rapidly evaporate when released to soil or water. They are used as solvents and in petrol and chemical manufacturing.

Xylenes can enter the body through inhalation or skin absorption (liquid form), and can cause irritation of the eyes and nose, stomach problems, memory and concentration problems, nausea and dizziness. High-level exposure can cause death. The substances have high acute and chronic toxicity to aquatic life and can adversely affect crops.

Polycyclic Aromatic Hydrocarbons (PAHs)

PAHs are a group of over 100 chemicals, which are formed through the incomplete combustion of organic materials, such as petrol. Exposure to these chemicals can cause a range of adverse reactions, including irritation of the eyes, nose and throat and skin. Exposure to very high levels can result in symptoms such as headaches, nausea, damage to the liver and kidneys, and damage to red blood cells. A number of PAHs were declared to be probably or possibly carcinogenic to humans by the IARC.

PAHs can attach to dust particles and be transported through the air. The compounds break down over days or weeks through chemical reactions in the atmosphere.

PAHs are moderately or highly acutely toxic to birds and aquatic organisms and moderately/highly chronic toxicity to aquatic life. Some can cause damage and death to crops. PAHs can bioaccumulate, and are moderately persistent in the environment.

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Appendix C

Ambient monitoring data review

Appendix C Ambient monitoring data review

Five air quality monitoring stations were commissioned within the study area to determine local pollution concentrations; the three ambient monitoring stations to represent general ambient air quality in the study area, and the two road monitoring stations to represent ambient air quality along Pennant Hills Road. At the time of the preparation of this report, data had been collected for a four month period (December 2013 to March 2014).

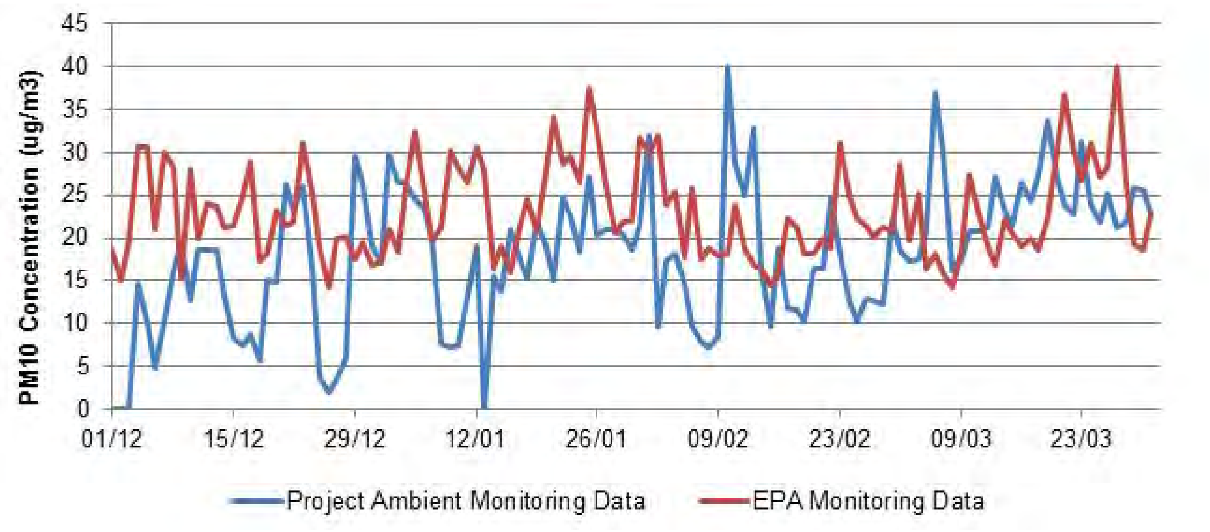
The dispersion modelling was undertaken for years 2009, 2010 and 2011, incorporating meteorological data measured by the OEH. As the data from the project monitoring stations did not cover the modelling period, they could not be used as ambient pollutant concentrations for the contemporaneous assessment of PM_{10} and NO_2. The data were, however, compared to OEH monitoring data to determine whether the OEH data adequately reflected local pollutant concentrations, or whether adjustment of the OEH data was required.

The two OEH monitoring stations located closest to the study area are at Prospect and Lindfield. Ambient pollutant data from these monitoring stations for the modelling period (2009 – 2011) were obtained. The data collected in December – March for each of the modelling years were compared to the project monitoring data from the ambient air quality monitoring stations. The maximum hourly concentrations of PM_{10} and NO_2 from either OEH station for the comparison period (December – March) were compared to the data recorded by the project ambient air quality monitoring stations. Statistical analyses of the hourly PM_{10} and NO_2 data were undertaken to identify whether the data sets are statistically different.

The results of a two sample t-test for PM_{10} are presented in the following table and figure. The t-test determined that the OEH and project ambient air quality monitoring stations are significantly different as the absolute value of the t statistic was greater than the critical t values. The pollutant concentrations recorded by the OEH are higher than the project monitoring data for the majority of the time as shown in the following chart. The conclusion was made, therefore, that the OEH data were satisfactory for use as conservative PM_{10} background concentrations in the assessment without any adjustment of the data.

Two-sample t-test assuming unequal variances – project ambient air quality monitoring stations vs OEH monitoring – PM_{10}

Parameter	Variable 1 (project community monitoring)	Variable 2 (OEH monitoring)
Mean	18.0	23.0
Variance	66.4	30.5
Observations	121.0	121.0
Hypothesised mean difference	0.0	
df	211.0	
t stat	-5.6	
P(T<=t) one-tail	0.0	
t Critical one-tail	1.7	
P(T<=t) two-tail	0.0	
t critical two-tail	2.0	

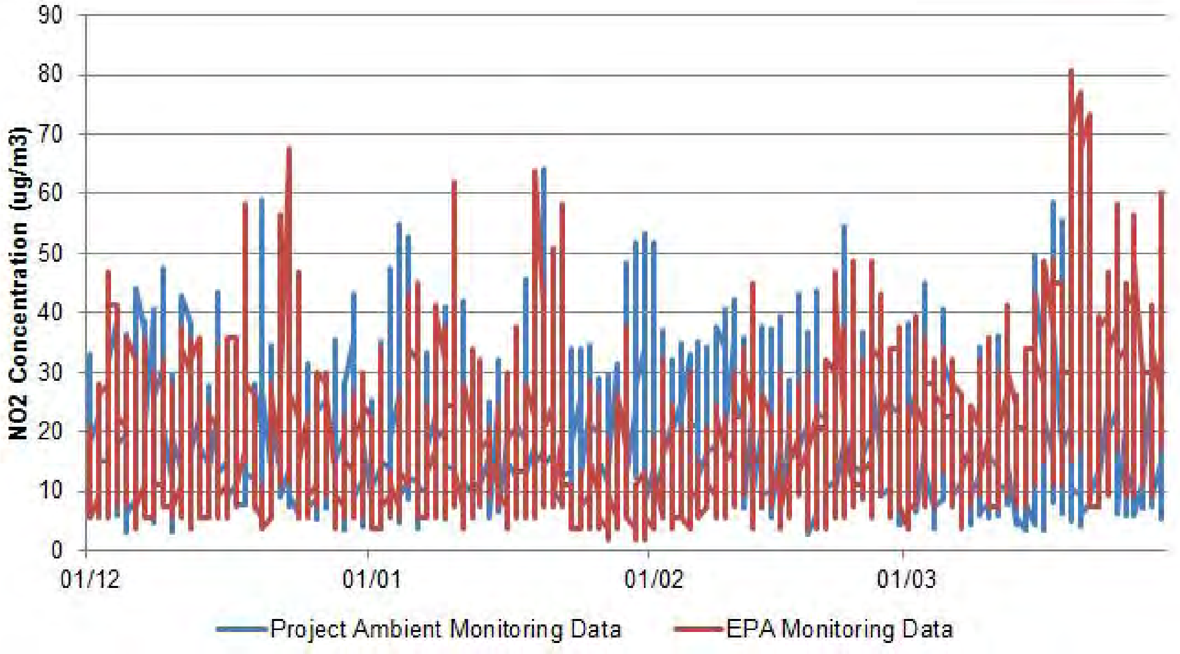


Comparison of project ambient air quality station data and OEH monitoring data – PM_{10}

The results of a two sample t-test for NO_2 are presented in the following table and chart. As the t statistic was greater than the critical t values, the data sets are statistically different. While the project monitoring data had marginally higher pollutant concentrations than the OEH monitoring for the majority of the time as shown in the following figure, the average percentage difference between the two data sets was only 0.7 per cent. As such, the OEH data were considered satisfactory for use as background pollutant concentrations in the assessment without any adjustment of the data.

Two-sample t-test assuming unequal variances – project ambient air quality monitoring stations vs OEH monitoring – NO_2

Parameter	Variable 1 (project community monitoring)	Variable 2 (OEH monitoring)
Mean	19.1	17.1
Variance	86.3	125.7
Observations	2598.0	2598.0
Hypothesised mean difference	0.0	
df	5021.0	
t stat	7.3	
P(T<=t) one-tail	0.0	
t critical one-tail	1.6	
P(T<=t) two-tail	0.0	
t critical two-tail	2.0	



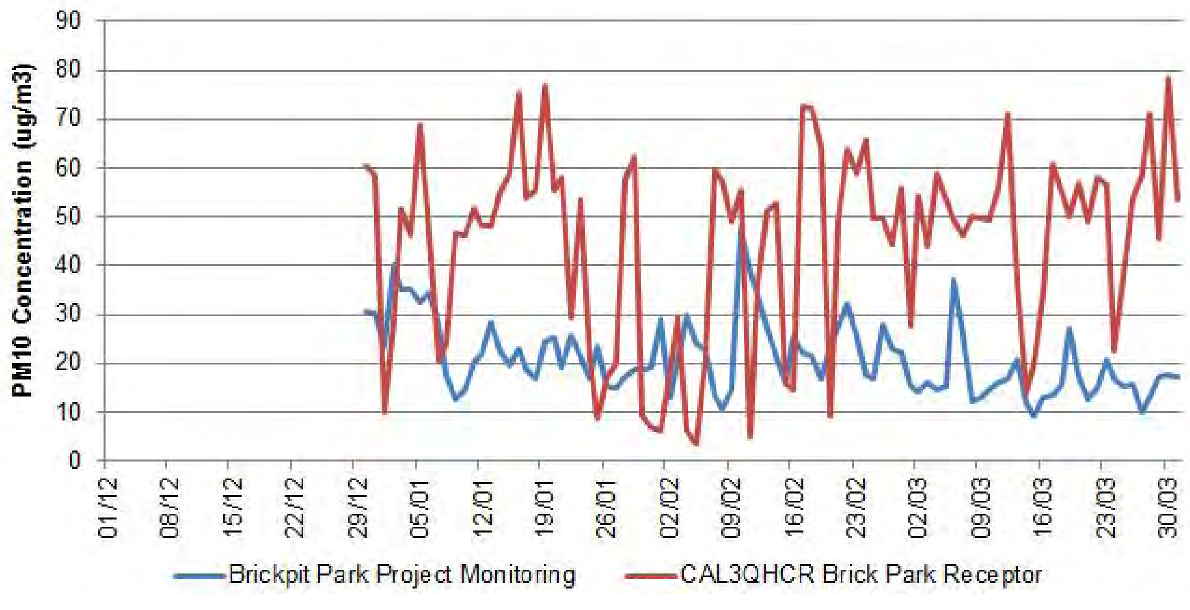
Comparison of Project ambient air quality station data and OEH monitoring data – NO_2

Similar to the assessment described above, an analysis was undertaken of the predicted surface road modelling (CAL3QHCR) concentrations to determine whether they adequately represent background pollutant concentrations for the receivers in proximity to the major arterial roads (Pennant Hills Road, M1 Pacific Motorway, Hills M2 Motorway) (road receivers) considered in the assessment. Receivers representing the locations of the two road monitoring stations were identified; the surface road modelling predictions for 2019 without the project, for these receivers were compared to the monitoring data. The 2019 data were chosen as they are the closest modelled year to the present, when monitoring data were collected (current traffic volumes were not assessed in this report). The results of the t-tests are provided for two PM_{10} and NO_2 data sets to represent the two project road monitoring stations (Brickpit Park and Observatory Park).

The results of the two sample t-test for PM_{10} are presented in the following table and chart for the PM_{10} Brickpit Park Road monitoring station and the CAL3QHCR Brickpit Park receiver. As the t statistic was greater than the critical t values, the data sets are statistically different. The road modelling data are greater than the project monitoring for the majority of the time as shown in the following figure. The road modelling data were, therefore, considered satisfactory for use as the PM_{10} background for the road receivers in the assessment without any adjustment of the data.

Two-sample t-test assuming unequal variances – Brickpit Park project road monitoring station vs CAL3QHCR Brickpit Park receiver – PM_{10}

Parameter	Variable 1 (Brickpit Park project road monitoring station)	Variable 2 (CAL3QHCR Brickpit Park receiver)
Mean	21.1	44.4
Variance	57.3	378.0
Observations	92.0	92.0
Hypothesised mean difference	0.0	
df	118.0	
t Stat	-10.7	
P(T<=t) one-tail	0.0	
t Critical one-tail	1.7	
P(T<=t) two-tail	0.0	
t critical two-tail	2.0	

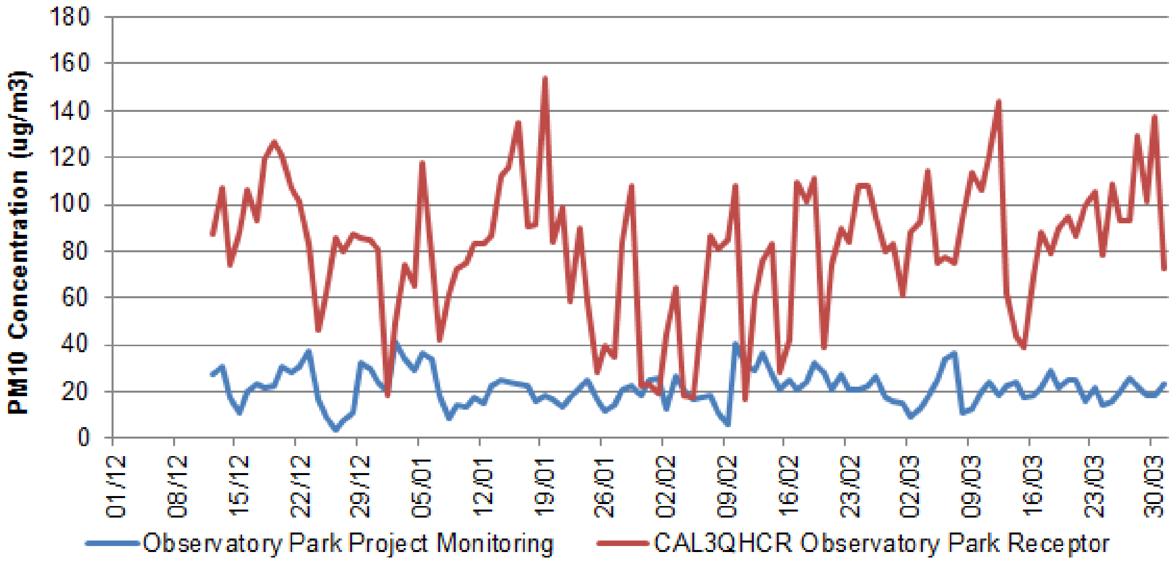


Comparison of Brickpit Park project road monitoring station data and CAL3QHCR predictions – PM_{10}

The results of the two sample t-test for the PM_{10} Observatory Park project road monitoring station and the CAL3QHCR Observatory Park road receiver are presented in the following table and chart. As the t statistic is greater than the critical t values, the data sets are statistically different. The road modelling data are greater than the project monitoring for the majority of the time as shown in the following figure. The predicted pollutant concentrations from the road modelling were, therefore, considered appropriate for use as conservative PM_{10} background concentrations for the road receivers in the assessment without any adjustment of the data.

Two-sample t-test assuming unequal variances – Observatory Park Road project road monitoring station vs CAL3QHCR Observatory Park receiver –PM_{10}

Parameter	Variable 1 (Observatory Park project road monitoring station)	Variable 2 (CAL3QHCR Observatory Park receiver)
Mean	21.6	81.4
Variance	56.3	874.0
Observations	110.0	110.0
Hypothesised mean difference	0.0	
df	123.0	
t Stat	-20.6	
P(T<=t) one-tail	0.0	
t critical one-tail	1.7	
P(T<=t) two-tail	0.0	
t critical two-tail	2.0	

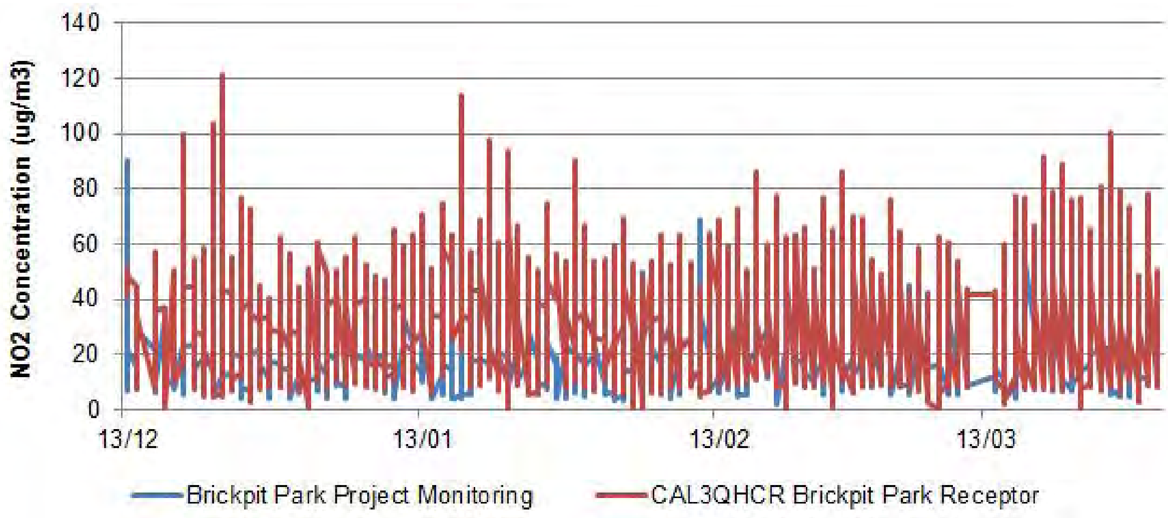


Comparison of Observatory Park project road monitoring station data and CAL3QHCR predictions – PM_{10}

The results of a two sample t-test for the Brickpit Park road monitoring station and the CAL3QHCR Brick Park road receiver are presented in the following table and chart. The results of the t-test show that the two data sets are statistically different. The road modelling predictions are greater than the project monitoring for the majority of the time as shown in the following figure. The road modelling predictions were, therefore, considered satisfactory for use as the NO_2 background concentrations for the road receivers in the assessment without any adjustment of the data.

Two-sample t-test assuming unequal variances – Brickpit Park Road project road monitoring station vs CAL3QHCR Brickpit Park receiver –NO_2

Parameter	Variable 1 (Brickpit Park project road monitoring)	Variable 2 (CAL3QHCR Brickpit Park receiver)
Mean	19.6	36.7
Variance	135.3	323.0
Observations	2263.0	2263.0
Hypothesised mean difference	0.0	
df	3874.0	
t stat	-38.2	
P(T<=t) one-tail	0.0	
t critical one-tail	1.6	
P(T<=t) two-tail	0.0	
t critical two-tail	2.0	

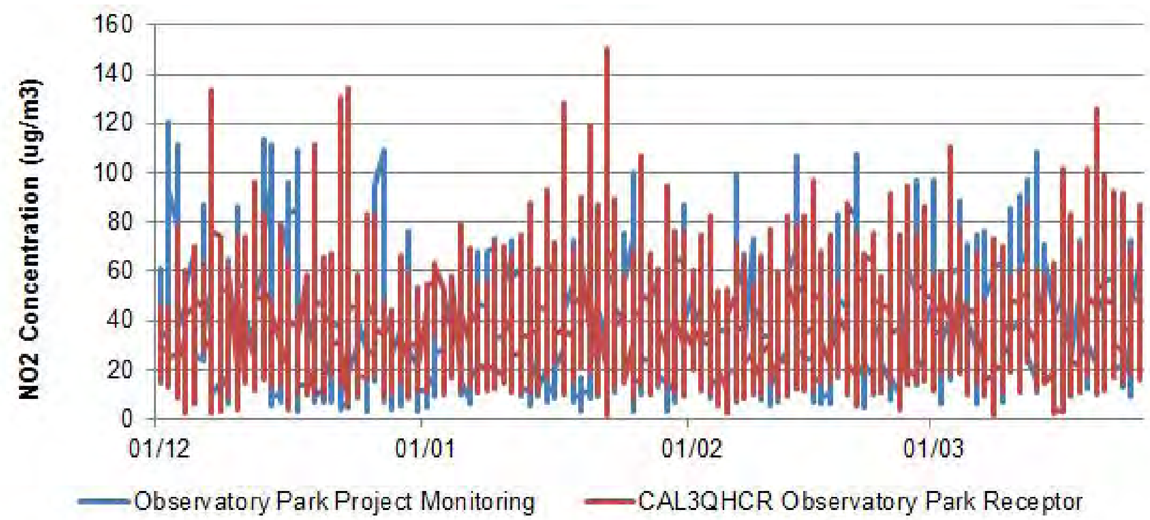


Comparison of Brickpit Park project road monitoring station data and CAL3QHCR predictions – NO_2

The results of the two sample t-test for the NO_2 Observatory Park Road project road monitoring station and the CAL3QHCR Observatory Park road receiver are presented in the following table and chart for NO_2. The results of the t-test showed that the two data sets are statistically different. The road modelling predictions are greater than the project monitoring data for the majority of the time as shown in the following figure. The road modelling predictions were, therefore, considered satisfactory for use as the NO_2 background concentrations for the road receivers in the assessment without any adjustment of the data.

Two-sample t-test assuming unequal variances – Observatory Park project road monitoring station vs CAL3QHCR Observatory Park receiver –NO_2

Parameter	Variable 1 (Observatory Park project road monitoring station)	Variable 2 (CAL3QHCR Observatory Park receiver)
Mean	31.6	42.9
Variance	387.5	398.6
Observations	2629.0	2629.0
Hypothesised mean difference	0.0	
df	5255.0	
t Stat	-20.8	
P(T<=t) one-tail	0.0	
t Critical one-tail	1.6	
P(T<=t) two-tail	0.0	
t Critical two-tail	2.0	



Comparison of Observatory Park project road monitoring station data and CAL3QHCR predictions – NO_2

Appendix D

Dispersion model details

Appendix D Dispersion model details

Dispersion modelling uses mathematical equations to characterise atmospheric processes, which disperse a pollutant emitted by a source. Based on emissions and meteorological inputs, dispersion models can be used to predict concentrations at selected downwind receiver locations. Air quality models are used to determine compliance with air quality standards. Two well-known and internationally used US EPA guideline models were used in this assessment - CALPUFF and CAL3QHCR. Details of both these models can be found on the US EPA SCRAM (Support Centre for Regulatory Atmospheric Modelling) Bulletin board. The models are addressed in Appendix A of the US EPA's Guideline on Air Quality Models (also published as Appendix W.pdf) of 40 CFR Part 51.

Dispersion models

Two dispersion models are recommended for regulatory assessments in Australia and New Zealand, which are CALPUFF and AERMOD. AERMOD has recently replaced AUSPLUME as the guideline model for all near-field, steady state modelling applications in Victoria. CALPUFF is recommended for use for all modelling applications where the steady state assumption does not apply; this includes complex terrain and coastal environments. A major difference between AERMOD and CALPUFF is in the models' treatment of meteorology. AERMOD is a 2-dimensional model where the effects of one single surface station and one single upper air station are assumed to be spatially uniform across the entire modelling region in its meteorological processor. In contrast, CALMET (CALPUFF's meteorological module) is a 3-dimensional model and is able to use the output of numerical prognostic meteorological models as well as multiple observation sites to assist in the development of three-dimensional wind fields.

Overview of the CALPUFF suite of models

The CALPUFF modelling system provides a non-steady state modelling approach, which evaluates the effects of spatial changes in the meteorological and surface characteristics. It offers the ability to treat stagnation, multiple-hour pollutant build-up, recirculation and causality effects, which are beyond the capabilities of steady-state models. The CALPUFF modelling system was adopted by the U.S. EPA as a guideline model for long range transport applications and, on a case-by-case basis, for near-field applications involving complex flows (Federal Register, April 15, 2003, pp 18,440-18,482). CALPUFF is also recommended by both the Federal Land Managers Air Quality Workgroup (FLAG, 2000, 2008) and the Interagency Workgroup on Air Quality Modelling (IWAQM, 1998). It was adopted for world-wide use by the United Nations International Atomic Energy Agency (IAEA). CALPUFF is widely used in many countries (over 100 countries) throughout the world, and has been incorporated as a regulatory model in several countries.

The CALPUFF modelling system includes three main components - CALMET, CALPUFF and CALPOST - and a large set of pre-processing programs designed to interface the model to standard, routinely-available meteorological and geophysical datasets. In simple terms, CALMET is a meteorological model, which develops hourly wind and temperature fields on a three-dimensional gridded modelling domain. CALPUFF is a transport and dispersion model, which advects 'puffs' of material emitted from modelled source, simulating dispersion and transformation processes along the way. In doing so, it uses the fields generated by CALMET. The primary output files from CALPUFF contain either hourly concentrations or hourly deposition fluxes evaluated at selected receiver locations. CALPOST is used to process these files, producing summaries of the results of the simulation.

CALMET overview

CALMET is a diagnostic meteorological model, which produces three-dimensional wind fields based on parameterised treatments of terrain effects such as slope flows and terrain blocking effects. Meteorological observations are used to determine the wind field in areas of the domain within which the observations are representative. Fine scale terrain effects are determined by the diagnostic wind module in CALMET.

The CALMET meteorological model consists of a diagnostic wind field module and micrometeorological modules for overwater and overland boundary layers (Scire et al., 2000a). When using large domains, the user has the option to adjust input winds to a Lambert Conformal Projection coordinate system to account for the Earth's curvature. The diagnostic wind field module uses a two-step approach to the computation of the wind fields (Douglas and Kessler, 1988). In the first step, an initial-guess wind field is adjusted for kinematic effects of terrain, slope flows, and terrain blocking effects to produce a Step 1 wind field. The second step consists of an objective analysis procedure to introduce observational data into the Step 1 wind field in order to produce a final wind field. An option is provided to allow gridded prognostic wind fields to be used by CALMET, which may better represent regional flows and certain aspects of sea breeze circulations and slope/valley circulations. The prognostic data (as a 3D.DAT file) can be introduced into CALMET in three different ways;

- As a replacement for the initial guess wind field.
- As a replacement for the Step 1 field.
- As observations in the objective analysis procedure.

The techniques used in the CALMET model are briefly described below.

Step 1 wind field

Kinematic effects on terrain: CALMET uses the approach of Liu and Yocke (1980) to evaluate kinematic terrain effects. The domain-scale winds are used to compute a terrain-forced vertical velocity, subject to an exponential stability-dependent decay function. The kinematic effects of terrain on the horizontal wind components are evaluated by applying a divergence-minimisation scheme to the initial guess wind field. The divergence minimisation scheme is applied iteratively until the three dimensional divergence is less than a threshold value.

Slope flows. Slope flows are computed based on the shooting flow parameterisation of Mahrt (1982). Shooting flows are buoyancy-driven flows, balanced by advection of weaker momentum, surface drag and entrainment at the top of the slope flow layer. The slope flow is parameterised in terms of the terrain slope, distance to the crest and local sensible heat flux. The thickness of the slope flow layer varies with the elevation drop from the crest.

Blocking effects. The thermodynamic blocking effects of terrain on the wind flow are parameterised in terms of the local Froude number (Allwine and Whiteman 1985). If the Froude number at a particular grid point is less than a critical value and the wind has an uphill component, the wind direction is adjusted to be tangential to the terrain.

Step 2 wind field

The wind field resulting from the adjustments of the initial guess wind described above is the Step 1 wind field. The second step of the procedure involves the introduction of observational data into the Step 1 wind field through an objective analysis procedure. An inverse-distance squared interpolation scheme is used, which weighs observational data heavily in the vicinity of the observational station, while the Step 1 wind field dominates the interpolated wind field in regions with no observational data. The resulting wind field is subject to smoothing, an optional adjustment of vertical velocities based on the O'Brien (1970) method, and divergence minimisation to produce final Step 2 wind fields.

Overview of CALPUFF

CALPUFF is a non-steady-state puff dispersion model. It accounts for spatial changes in the meteorological fields, variability in surface conditions such as (elevation, surface roughness, vegetation type, etc.), chemical transformation, wet removal due to rain and snow, dry deposition and terrain influences on plume interaction with the surface. CALPUFF can simulate the effects of time- and space-varying meteorological conditions on pollutant transport, transformation and removal. CALPUFF contains algorithms for near-source effects, such as building downwash, transitional plume rise, partial plume penetration, sub-grid scale terrain interactions, as well as longer range effects, such as pollutant removal (wet scavenging and dry deposition), chemical transformation, vertical wind shear, overwater transport and coastal interaction effects. It can accommodate arbitrarily-varying point source and gridded area source emissions. The major features of CALPUFF model are detailed below (after Scire et al., 2002).

Major features of the CALPUFF model

- Source types:
  - Point sources (constant or variable emissions).
  - Line sources (constant or variable emissions).
  - Area sources (constant or variable emissions).
  - Volume sources (constant or variable emissions).
- Non-steady-state emissions and meteorological conditions:
  - Gridded 3D fields of meteorological variables.

  - Spatially variable 3D fields of mixing height, friction velocity, convective velocity scale, Monin-Obukhov length, precipitation rate.
  - Vertically and horizontally-varying turbulence and dispersion rates.
  - Time-dependent source and emissions data.
- Efficient sampling functions:
  - Integrated puff formulation.
  - Elongated puff (slug) formulation.
- Dispersion coefficient options:
  - Direct measures of sigma v and sigma w.
  - Estimated values of sigma v and sigma w based on similarity theory.
  - PG dispersion coefficients (rural areas).
  - McElroy Pooler dispersion coefficients (urban areas).
  - CTDM dispersion coefficients (neutral/stable).
- Vertical wind shear :
  - Puff Splitting.
  - Differential advection and dispersion.
- Plume Rise:
  - Partial penetration.
  - Buoyant and momentum rise.
  - Stack tip downwash effects.
  - Vertical wind shear.
  - Building downwash effects.
- Building downwash:
  - Huber-Snyder method.
  - PRIME downwash.
  - Schulman Scire method.
- Dry deposition:
  - Gases and particulate matter.
  - Three options:
    - Full treatment of space and time variations of deposition with a resistance model.
    - User-specified diurnal cycles for each pollutant.
    - No dry deposition.
- Overwater and coastal interaction effects:
  - Overwater boundary layer parameters.
  - Abrupt change in meteorological conditions, plume dispersion at coastal boundary.
  - Plume fumigation.
  - Option to introduce sub grid scale TIBLs into coastal grid cells.
- Chemical transformation options:
  - Pseudo-first-order chemical mechanism for SO2, SO4, NOx HNO3 and NO3 (MESOPUFF II method).

- User specified diurnal cycles of transformation rates.
- No chemical conversion.
- Wet Removal.
- Scavenging coefficient approach.
- Removal rate a function of precipitation intensity and precipitation type.

Overview of CAL3QHCR

CAL3QHCR is a CALINE3-based model with queuing and hot spot calculations and with a traffic model to calculate delays and queues that occur at signalised intersections. The CALINE3 model on which it is based is a steady-state Gaussian dispersion model designed to determine air pollution concentrations at receiver locations downwind of highways located in relatively uncomplicated terrain.

The CAL3QHC model can predict carbon monoxide and other inert pollutant concentrations from motor vehicles at roadway intersections. The model includes the CALINE-3 line source dispersion model and a traffic algorithm for estimating vehicular queue lengths at signalised intersections. CALINE-3 was designed to predict air pollutant concentrations near highways and arterial streets due to emissions from motor vehicles operating under free flow conditions. CALINE-3, however, does not permit the direct estimation of the contribution of emissions from idling vehicles. CAL3QHC was developed to enhance CALINE-3 by incorporating methods for estimating queue lengths and the contributions of emissions from idling vehicles. The model permits the estimation of total air pollution concentrations from both moving and idling vehicles. CAL3QHC requires details on roadway geometries, receiver locations, meteorological conditions and vehicular emission rates. In addition, the model requires other parameters such as signal timing data and information describing the configuration of the intersection being modelled.

The CAL3QHCR model is an enhanced version of CAL3QHC, which can process up to a year of hourly meteorological data. Vehicular emissions, traffic volume, and signalisation data can be specified for each hour of a week. Furthermore, the latest version also accommodates up to 5,000 receivers and 5,000 sources (previously 60 receivers and 120 sources). In order to accommodate the large number of receivers associated with this assessment, the CAL3QHCR model was considered to be the most appropriate choice for modelling the traffic movements on roadways external to the tunnels. The line source model predicts pollutant concentrations based on the Gaussian diffusion equation. CAL3QHCR was used to predict concentrations of carbon monoxide, nitrogen dioxide and particulate matter (PM) in this assessment.

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Appendix E

Terrain and land use data

Appendix E Terrain and land use data

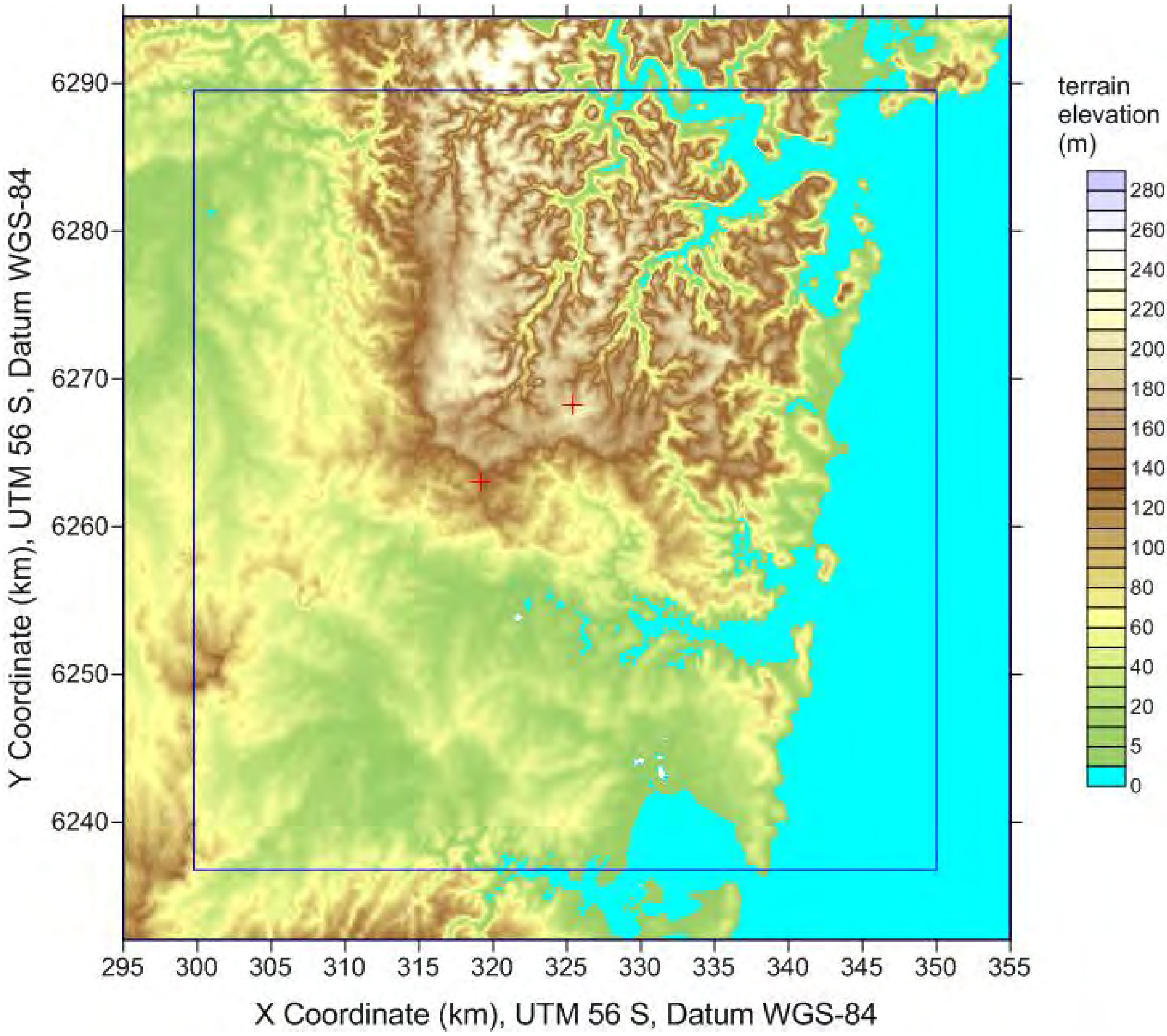
Gridded terrain elevations for the modelling domain were derived from the Shuttle Radar Topography Mission (SRTM) 3 arc-second or around 90 metre resolution data. The SRTM data represent a near-global digital elevation model (DEM) of the earth generated using radar interferometry. Data are provided in files covering one degree by one degree blocks of latitude and longitude. All elevations are in metres referenced to the WGS84/EGM96 geoid. SRTM terrain data were extracted from four files S34E150.HGT, S34E151.HGT, S35E150.HGT and S35E151.HGT which are available for download from the USGS website

Land use data within the study area were derived from the Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES) and supplied to AECOM by the Department of Environment and Heritage.

This data set was compiled using the nationally agreed land use mapping principles and procedures of the Australian Land Use and Management (ALUM) Classification version 7. The land use dataset was collected as part of State and Territory mapping programs and the Australian Collaborative Land Use and Management Program (ACLUMP). The data over the country vary according to year (1997 to 2009) and scale (1:25,0000 to 1:250,000). The land use database was recently updated in November 2012 and includes a combined 50 metre raster for Australia including new data for Tasmania, Victoria, parts of southwest Western Australia and parts of Queensland. While there are no new data for New South Wales, edge-matching errors were corrected.

All contributing polygon datasets were re-gridded and mosaicked to minimise sampling errors. NODATA voids were filled with Australian Bureau of Statistics meshblocks land use attributes with modifications based on 1:250,000 scale topographic data for built up areas published by Geoscience Australia in 2006, land tenure data compiled by the Bureau of Rural Sciences (BRS) in 2007 and native and plantation forest data compiled by BRS in 2007. The following figure shows the land use data over the model domain at 250 m grid resolution.

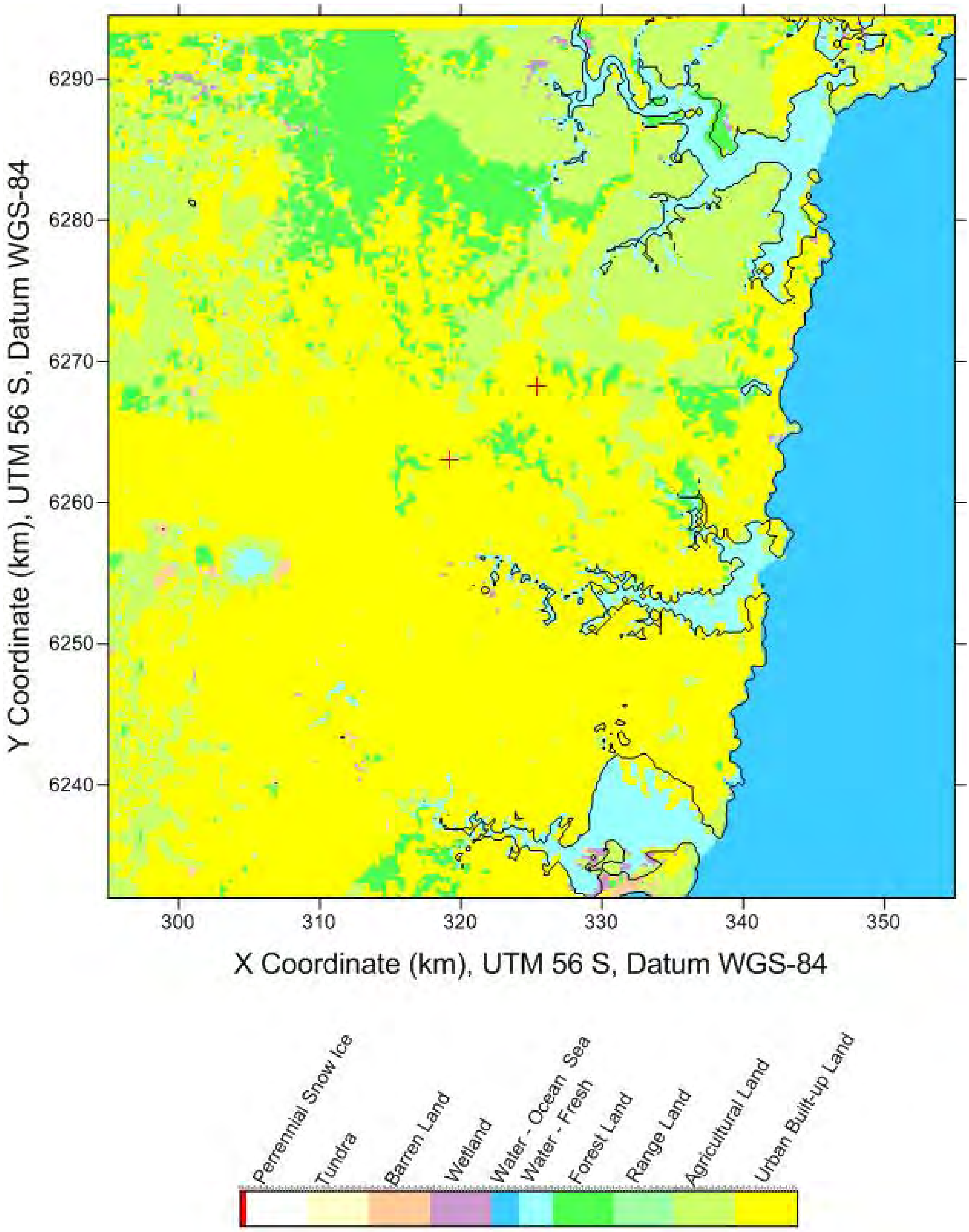
Land use within the study area primarily consists of urban areas with occasional rangeland and forest land areas as shown in the following figure.



Terrain elevations over the modelling domain

Terrain elevations were determined from 90 metre SRTM data. Red cross hairs mark the ventilation outlet locations at the southern and northern ends of the tunnels according to the design scenarios. The blue rectangle delineates the computational model domain, which is a subset of the meteorological model domain.

The land use data used in this application is different to the default land use data used in TAPM and for most CALMET model applications outside the United States, which is the USGS one kilometre land use data. Until recently, the USGS one kilometre global land use data set was the most readily available data set for air quality applications. Limitations of these data set, however, include its age (more than 20 years old), coarse resolution (between 900 metres and 1.2 kilometres), and the fact that it is categorised according to the North American land use category system, which does not correspond to all relevant Australian land use types. For air quality modelling purposes where a grid system is used, such as CALMET and TAPM, the underlying dominant land use is an important function of plume transport. The inclusion of the Australian land use data set is, therefore, an important relevant addition to this modelling application as the data are recent, relevant and of a very fine resolution. In this application, specific surface characteristics, albedo, roughness length and leaf area index for the Sydney basin were determined from Gero and Pitman (2006) for bushland, agricultural land, dense urban, new urban and established urban areas. Bushland is described as natural vegetation (primarily around 20 metre trees with 40 per cent cover). Agricultural land incorporates all agricultural activity in western Sydney, which is mostly pasture for grazing or market gardens. Urban categories are split into dense urban (which is confined to the city core and Parramatta CBD), new urban (newly established residential suburbs lacking mature trees), and established urban (residential suburbs with mature trees).



Dominant land use within the study area

The one metre terrain elevation contour is shown. Red cross hair symbols mark the locations of the ventilation outlets at the southern and northern ends of the tunnels. The dominant land use categories are urban areas – mostly established residential areas - and the agricultural land is mostly market gardens and pasture. Specific surface characteristics for Sydney region were derived from Gero and Pitman (2006).

Appendix F

Meteorological data

Appendix F Meteorological data

Representativeness of years

Representative is defined as the extent to which a set of measurements taken at the collection site spatially and temporally reflects the actual conditions at the application site. The collected meteorological data should closely mimic the conditions affecting the transport and dispersion of pollutants in the area of interest as determined by the locations of the source/receivers being modelled. Representativeness of meteorological data depends on the following factors:

- Character and complexity of the terrain in the source surroundings and between the source and the meteorological monitoring or observing site
- Proximity of the meteorological monitoring site to the source;
- Instrumentation and exposure of the meteorological monitoring site; and
- Quality, completeness, and period of record of the meteorological data.

The spatial representativeness of the data can be adversely affected by large distances between the source and receivers of interest and the complex topographic characteristics of the area. Temporal representativeness is a function of the year-to-year variations in the weather conditions.

In this study, meteorological input data were taken from the BOM and OEH. The data are of good quality and although none of the monitoring stations are expressly close to the source, their combined contributions of variables paired in space and time meant that the full spatial and temporal variability of the flow was captured across the modelling domain. All data sets for all three years had less than 10 per cent missing data, i.e., more than 90 per cent capture. When one station is missing data for a particular hour, the model will use the meteorological conditions from the next nearest station for that hour.

Period of record

Studies have demonstrated that variability of model estimates due to the meteorological data input was adequately reduced if a five year period of meteorological input was used. Based on these findings, the US EPA stated that a minimum of five years of meteorological data must be modelled. Consecutive years from the most recent, readily available five year period are preferred. If the data are recorded on site, however, then at least one year or more years of data are deemed as sufficient. This criterion was developed on the use of ISC and AERMOD, which are steady state Gaussian plume models that require only one surface station as meteorological input.

In Australia, DEC (2005) specifies that at least one year of site specific meteorological data must be used (Level 2 assessment). These data must be 90 per cent complete, that is with no more than 876 hours missing per year. If site-specific meteorological data are not available, at least one year of site-representative meteorological data must be used. These data should be either collected at a meteorological monitoring station or generated from a prognostic model such as TAPM, and the data must be correlated against a longer-duration site-representative meteorological database of at least five consecutive years. It must be established that the data adequately describe the expected meteorological patterns at the site under investigation.

For this assessment, modelling was conducted using three years of meteorological data to ensure the meteorological conditions assessed were representative of local conditions. A brief summary of each of the years with respect to climatic history is provided below.

Brief climate summary of 2009

The year 2009 was the warmest year on record for the state of NSW. It had the warmest year on record for average minimum temperatures and fourth warmest year for average maximum temperatures. The year 2009 was the ninth consecutive year with below average rainfall and the thirteenth consecutive year with above average min and max temperatures.

The annual average rainfall in NSW for 2009 was 484.0 millimetres. This is below the average of 559 millimetres. Inland areas and the southern half of the NSW coast recorded below average rainfall. In contrast, the Mid North Coast recorded well above average falls for the year, with Coffs Harbour in particular flooding five times.

The generally warm conditions were exacerbated by three extreme heat events in 2009; a heatwave at the end of January/early February in southwest NSW, extreme heat during August in northern NSW and an exceptional heatwave - both in strength and duration - in November across all of NSW. These extremely warm conditions also contributed to the recording of the warmest winter and warmest spring on record for NSW.

NSW experienced two large and extensive dust storms. The most extreme storm occurred on 23 September 2009, and resulted in reduced visibility at many locations. On the morning of the 23 September 2009, visibility in Sydney was reduced to 400 metres over much of the city. A thick layer of red dust coated all exposed surfaces with many flights delayed or cancelled at Sydney Airport. The dust originated from South Australia and western NSW, and affected areas as far north as Cairns. A few days later, strong winds on 25 September 2009 again caused elevated dust levels, reducing visibility to 800 metres at 3 pm at Broken Hill, with the dust extending to Sydney by the morning of 26 September 2009. More dust storms of lesser extent occurred in October 2009.

Brief climate summary of 2010

The year 2010 was the wettest year on record for NSW and the ninth consecutive year with above average minimum temperatures. A total of 803.14 millimetres of rainfall was recorded in NSW during 2010, which was well above the average of 559.0 millimetres, and made 2010 the third wettest year on record. This is the highest rainfall recorded in the state in over fifty years, following the very strong La Niña events in 1956 (829.52 millimetres) and 1950 (908.45 millimetres), and slightly higher than the rainfall recorded during strong La Niña events in the 1970s. In addition, 2010 was the wettest year on record for the Murray-Darling Basin with a total rainfall of 794.27 millimetres, which was slightly higher than the previous record set in the La Niña of 1956 (786.53 millimetres).

The wet conditions were the result of a very strong La Niña event in the Pacific Ocean combined with combination with a negative Indian Ocean Dipole event, both of which bring increased rainfall to Australia. In particular, Spring 2010 was the wettest on record for both NSW and Australia, with above average rainfall for six consecutive months (July – December) in addition to high rainfall in February and March as the 2009 El Niño event broke down.

NSW had close to average temperatures during 2010, with mean temperatures only 0.06 °C above the 1961-1990 average. This was significantly cooler than 2009, which was the warmest year on record in NSW, and was the coolest year since 1996. In general, years of high rainfall (and most La Niña years) have lower daytime maximum temperatures. The cooler temperatures in 2010 were primarily due to La Niña. This year was, however, significantly warmer than the previous strong La Niña years in 1974 and 1956, which had mean temperatures 0.51 °C and 1.17 °C below average respectively. This demonstrates the fact that although individual years may show variability, the underlying warming trend has not stopped, with global average temperatures in 2010 likely to be among the three hottest years on record (http://www.wmo.int/pages/mediacentre/press_releases/pr_904_en.html).

The eastern seaboard of NSW continued to have above average temperatures during 2010, with Sydney Observatory Hill recording mean maximum temperatures of 22.6 °C, 0.9 °C above average.

Brief climate summary of 2011

The year 2011 was warm and wet as La Niña ended and another cycle began. La Niña brought the fourth wettest two-year period on record for NSW, close to average maximum and minimum temperatures, and the fifteenth consecutive warm year for NSW.

A total of 660.9 millimetres of rain was recorded in 2011, which was above the historical average of 552.8 millimetres and the 12th wettest year on record. The year was substantially drier than 2010 (815.1 millimetres), but otherwise the wettest year since 1988, when 689.4 millimetres fell. The high rainfall during 2011 was associated with the lingering impacts of the strong 2010 La Niña event, in addition to a weak La Niña, which developed towards the end of the year.

The average maximum temperature in NSW was 0.3 °C above average during 2011, which made it warmer than 2010 but otherwise the coolest year since 2000. Temperatures were generally within 1 °C of average across the state, despite the increased rainfall during the year, with coolest conditions recorded along the coast. Temperatures were particularly cool as the 2010 La Niña broke down during autumn, which was the 10th coolest on record and the coolest since 1995, while temperatures were well above average between July and September under drier conditions as well as a weak positive Indian Ocean Dipole event.

Very cold conditions returned during December, which was the fourth coolest on record for NSW, as well as the third coldest for maximum temperatures, which were 2.5 °C below average. This was associated with cloudy conditions, cool southerly winds, and a lack of hot days. The average temperature in December was 28.1 °C, almost 1 °C lower than recorded in November. November was recorded as being warmer than December on only three previous occasions, most recently in 2009 when November was 5 °C above average. Interestingly, in NSW, five days during November had temperatures above 40 °C compared to just two days in December.

An average minimum temperature of 11.0 °C was recorded in NSW during 2011, which was 0.3 °C above the historical average. Temperatures were warm during the first part of the year, particularly along the coast, with well above average temperatures in January and February. This included a record five consecutive nights above 24 °C in Sydney between the second and sixth of February. Nights were also very warm during August, while November was the sixth warmest on record for minimum temperatures. In comparison, nights were cold during the middle of 2011, including the fourth coldest May on record for NSW, while December was 0.9 °C below average.

The statewide average temperature in NSW was consequently 0.3 °C above average at 17.6 °C, making 2011 the fifteenth consecutive warm year for NSW.

Meteorological evaluation

Rigorous tests exist to evaluate the performance of prognostic meteorological performance. The aim of any evaluation exercise is to determine whether and to what extent confidence may be placed in the prognostic meteorological data that are used as inputs to emission and dispersion models.

The two specific objectives of meteorological evaluation are to:

- Determine if the prognostic meteorological data represent a reasonable approximation of the actual meteorology that occurred during the modelling period; and
- Identify and quantify the existing biases and errors in the prognostic meteorological predictions in order to allow for a downstream assessment of how the air quality modelling results are affected by issues associated with the meteorological data.

Statistical evaluation

Several statistical measures are typically calculated as part of a meteorological model evaluation. These measures are calculated for wind speed, wind direction, temperature, and humidity at the surface. Examples of the suite of statistical performance measures that are routinely used include scalar and vector mean wind speeds, standard deviations in measured and observed winds, root mean square errors (RMSE) (total plus systematic and unsystematic components), two model skill measures, the Index of Agreement (IOA), and the mean and standard deviations in modelled and observed wind speeds.

The statistical measures considered in this study are described below. The statistics used to evaluate meteorological model performance are all given in absolute terms; that is, wind speed error is given in metres per second rather than percentage error.

Mean (average) value: eg mean observation and mean prediction

Bias error (B): calculated as the mean difference in prediction-observation pairings with valid data within a given analysis region and for a given time period (hourly or daily) as described by the following equation:

$$B = \frac{1}{IJ}\sum_{j=1}^{J}\left|\sum_{i=1}^{I}\left(P_j^i - O_j^i\right)\right.$$

Gross error (E): or absolute error. Calculated as the mean *absolute* difference in prediction-observation pairings with valid data within a given analysis region and for a given time period (hourly or daily) as described by the following equation.

$$E = \frac{1}{IJ}\sum_{j=1}^{J}\sum_{i=1}^{I}\left|P_j^i - O_j^i\right|$$

Root mean square error (RMSE): calculated as the square root of the mean squared difference in prediction-observation pairings with valid data within a given analysis region and for a given time period (hourly or daily) as described by the following equation:

$$RMSE = \left[\frac{1}{IJ}\sum_{j=1}^{J}\sum_{i=1}^{I}\left(P_j^i - O_j^i\right)^2\right]^{1/2}$$

The RMSE, as with the gross error, is a good overall measure of model performance. Since large errors are weighted heavily due to squaring, however, large errors in a small sub region may produce a large RMSE even though the errors may be small and quite acceptable elsewhere.

Systematic root mean square error (RMSEs): calculated as the square root of the mean squared difference in *regressed* prediction-observation pairings within a given analysis region and for a given time period (hourly or daily) as described by the following equation:

$$RMSE_S = \left[\frac{1}{IJ}\sum_{j=1}^{J}\sum_{i=1}^{I}\left(\hat{P}_j^i - O_j^i\right)^2\right]^{1/2}$$

where the regressed prediction is estimated for each observation from the least square fit described above. The RMSEs estimates the model's linear (or systematic) error; as such, the better the regression between predictions and observations, the smaller the systematic error.

Unsystematic root mean square error (RMSEu): calculated as the square root of the mean squared difference in prediction-regressed prediction pairings within a given analysis region and for a given time period (hourly or daily) as described by the following equation:

$$RMSE_U = \left[\frac{1}{IJ}\sum_{j=1}^{J}\sum_{i=1}^{I}\left(P_j^i - \hat{P}_j^i\right)^2\right]^{1/2}$$

The unsystematic difference is a measure of how much of the discrepancy between estimates and observations is due to random processes or influences outside the legitimate range of the model. A "good" model will provide low values of the RMSE, explaining most of the variation in the observations. The systematic error should approach zero and the unsystematic error should approach RMSE since:

$$\mathrm{RMSE}^2 = \mathrm{RMSE_S}^2 + \mathrm{RMSE_U}^2$$

It is important that RMSE, RMSES, and RMSEU are all analysed. For example, if only RMSE is estimated (and it appears acceptable) it could consist largely of the systematic component. This error might be removed through improvements in the model inputs or use of more appropriate options, thereby reducing the error transferred to the dispersion model. On the other hand, if the RMSE consists largely of the unsystematic component, this indicates that further error reduction may require model refinement (new algorithms, higher resolution grids, etc.), or that the phenomena to be replicated cannot be fully addressed by the model. It also provides error bars that may be used with the inputs in subsequent sensitivity analyses. Generally a good/reasonable performance will provide low values of RMSE, explaining most of the variation in the observations. The RMSEs should approach zero and the unsystematic error RMSEu should approach RMSSE since $RMSE^2 = (RMSES)^2 + (RMSEU)^2$

Index of agreement (IOA): calculated following the approach of Willmont (1981). This metric condenses all the differences between model estimates and observations within a given analysis region and for a given time period (hourly and daily) into one statistical quantity. It is the ratio of the total RMSE to the sum of two differences – between each prediction and the observed mean, and each observation and the observed mean as described by the following equation:

$$IOA = 1 - \left[\frac{IJ \cdot RMSE^2}{\sum_{j=1}^{J}\sum_{i=1}^{I}\left|P_j^i - M_o\right| + \left|O_j^i - M_o\right|} \right]$$

Viewed from another perspective, the index of agreement is a measure of the match between the departure of each prediction from the observed mean and the departure of each observation from the observed mean. Thus, the correspondence between predicted and observed values across the domain at a given time may be quantified in a single metric and displayed as a time series. The index of agreement has a theoretical range of 0 to 1, the latter score suggesting perfect agreement.

Benchmarks

The model evaluation results were compared against the following benchmarks, developed by Emory et al. (2001) and Tesche et al. (2001b).

Benchmarks for MM5 modelling evaluation

Statistical Method	Wind Speed	Wind Direction	Temperature	Humidity
IOA	≥ 0.6	-	≥ 0.8	≥ 0.6
RMSE	≤ 2 m/s	-		
Mean Bias	± ≤ 0.5 m/s	≤ 10^0	≤ ± 0.5 K	< ± 1 g/kg
Gross Error	-	≤ 30^0	≤ 2 K	≤ 2 g/kg

It must be noted that simply meeting the performance goals cannot be considered an adequate demonstration of the model, and that performance can only be gauged from the results of many different analyses and tests.

Statistical evaluation of MM5 data vs observations for 2009, 2010 and 2011

All years analysed met the IOA benchmark for wind speed. The IOA developed by Willmott (1981) is a standardised measure of the degree of model prediction error and varies between 0 and 1, where 1 indicates perfect agreement. The IOA is often thought as the best indicator of overall model performance. The 12 km MM5 data showed a positive wind speed bias for all years. This is not unexpected for MM5 model data. The strongest wind bias was observed for 2011.

For wind direction, all the years met the benchmark requirements for the Bias statistic. The models were slightly higher than the benchmark statistics for the Gross Error indicating some randomness to the MM5 data that is not in the observation data. Both temperature and humidity met all the benchmark criteria for all three years.

Neither the wind speed and direction statistics are unexpected due to the 12 kilometre data used in the model.

Statistical evaluation between MM5 and 5 observation stations for 2009, 2010 and 2011 for wind speed, direction, temperature and specific humidity.

Wind Speed (m/s)

Years Modelled	IOA	BIAS	RMSE	RMSES/RMSE	Gross Error
Mean					
2009	0.64	0.80	2.27	0.83	1.86
2010	0.62	0.98	2.33	0.85	1.94
2011	0.62	1.05	2.28	0.85	1.90
Fraction meeting benchmark					
2009	0.65	0.30	0.33		
2010	0.56	0.25	0.30		
2011	0.62	0.17	0.33		
Total no. days	365	365	365	365	365

Wind Direction (deg)

Years Modelled	BIAS	Gross Error
Mean		
2009	-4.86	51.51
2010	-6.87	48.16
2011	-7.02	53.61
Fraction meeting benchmark		
2009	0.31	0.20
2010	0.34	0.24
2011	0.26	0.13
Total no. days	365	365

Temperature (K)

Years Modelled	IOA	BIAS	Gross Error	RMSE	RMSES/RMSE
Mean					
2009	0.81	-0.50	2.09	2.53	0.73
2010	0.82	-0.36	1.94	2.36	0.70
2011	0.79	-0.29	2.00	2.43	0.71
Fraction meeting benchmark					
2009	0.65	0.25	0.62		
2010	0.64	0.30	0.64		
2011	0.59	0.31	0.60		
Total no. days	365	365	365	365	365

Specific humidity (g/kg)					
Years Modelled	**IOA**	**BIAS**	**Gross Error**	**RMSE**	**RMSES/RMSE**
Mean					
2009	0.48	0.210	1.29	1.53	0.81
2010	0.49	-0.02	1.26	1.49	0.80
2011	0.47	0.22	1.35	1.60	0.83
Fraction meeting benchmark					
2009	0.27	0.65	0.87		
2010	0.28	0.66	0.88		
2011	0.24	0.59	0.83		
Total no. days	365	365	365	365	365

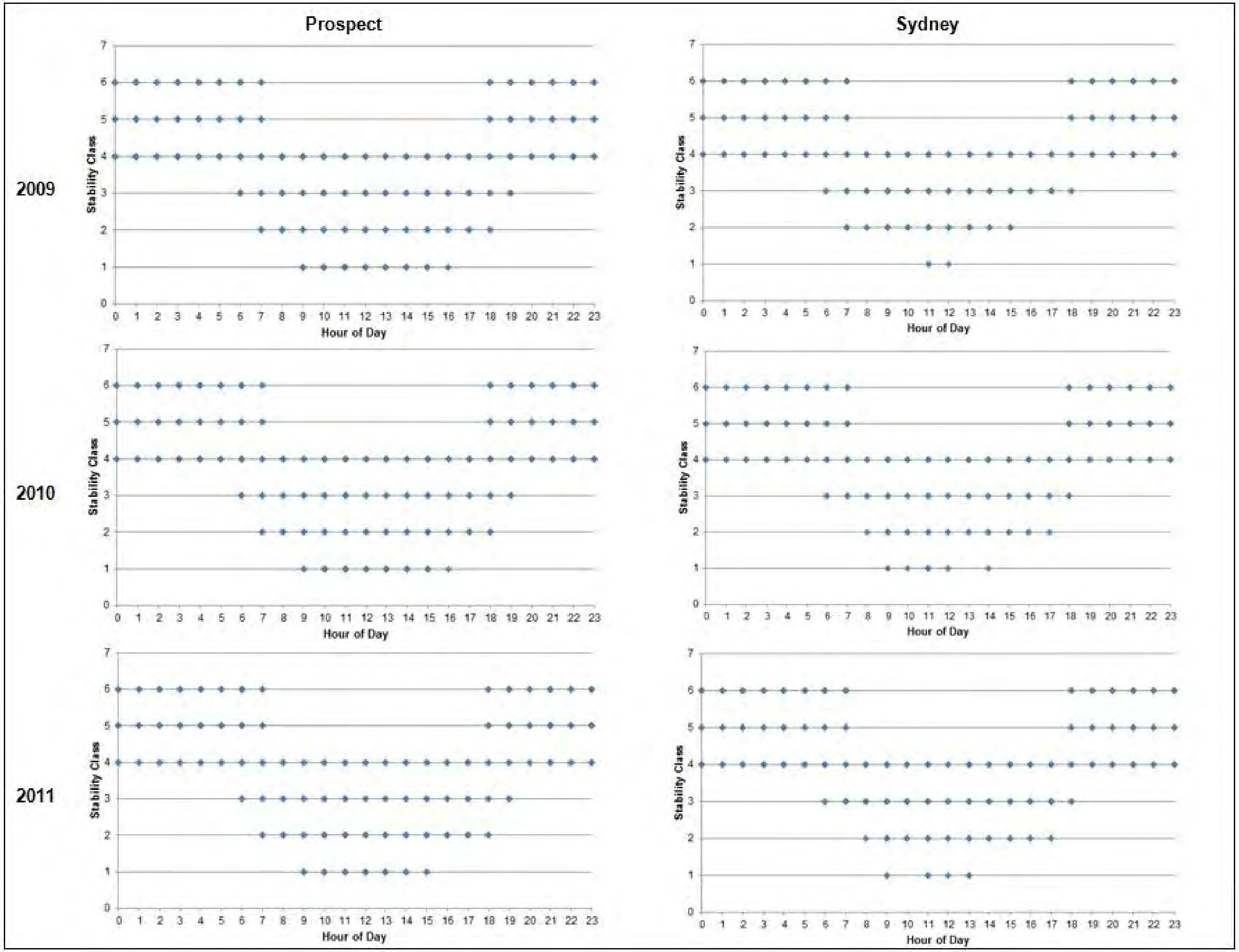
Stability class

Stability is a measure of the convective properties of a parcel of air. Stable conditions occur when convective processes are low, while unstable conditions are associated with stronger convective processes, which are associated with potentially rapid changes in temperature. Stable atmospheres occur when a parcel of air is cooler than the surrounding environment, so the parcel of air (and any pollution within it) sinks. Conversely, unstable atmospheres occur when a parcel of air is warmer than the surrounding environment, making the parcel of air buoyant and, subsequently, leading to the parcel of air rising.

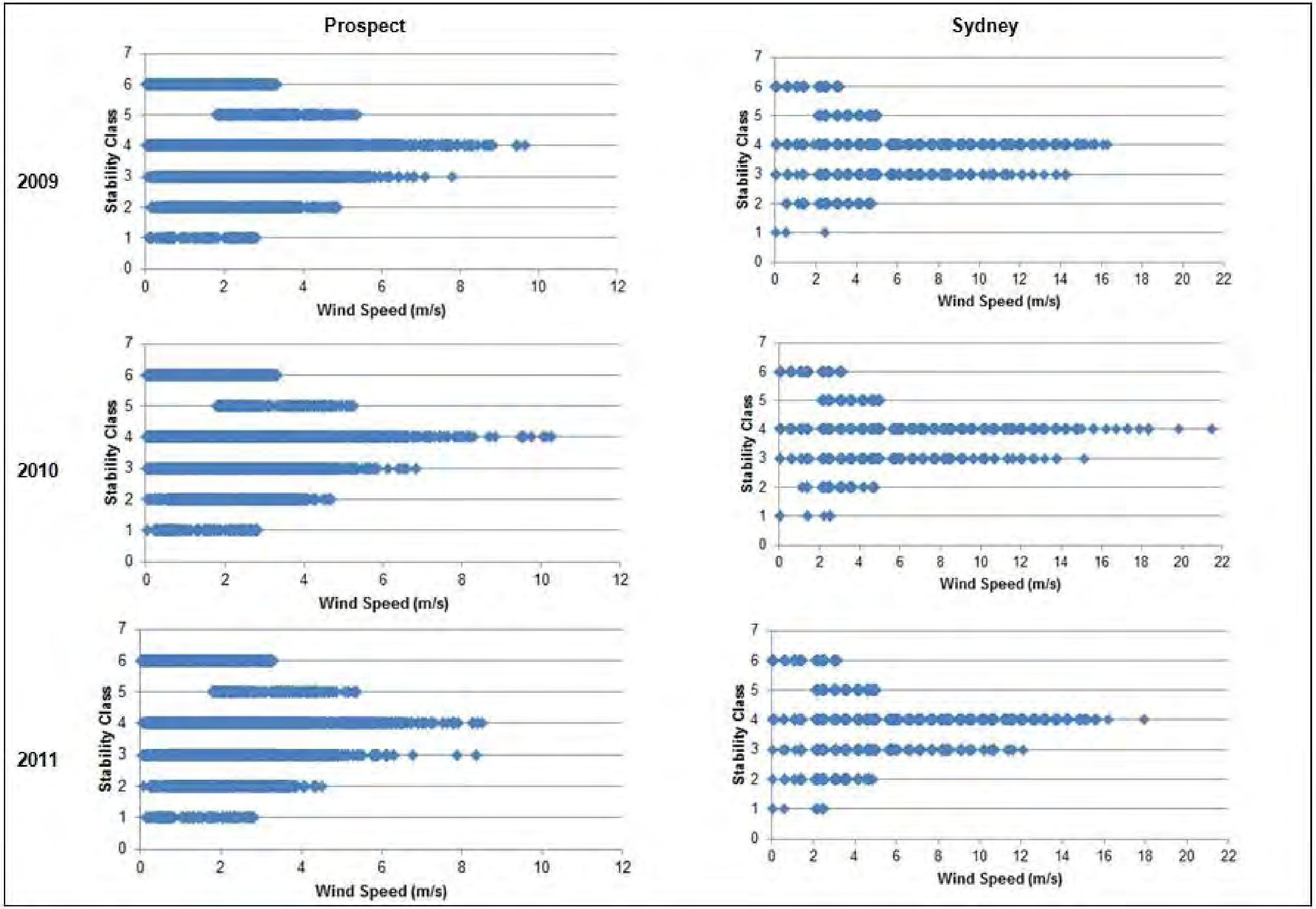
Stability class data extracted from the CALMET files at locations representing the Prospect and Sydney Airport monitoring stations were analysed. The following charts indicate stability classes designated as 1 to 6, which correspond to the Pasquill-Gifford A – F stability class designations (1 corresponds to A class and 6 corresponds to F class). Classes A, B and C (or 1, 2 and 3) represent unstable conditions, with class A representing very unstable conditions and C representing slightly unstable conditions. Class D (4) stability corresponds to neutral conditions, which are typical during overcast days and nights. Classes E and F (5 and 6) correspond to slightly stable and stable conditions respectively, which occur at night.

The stability class data were charted for time of day as shown in the first of the following charts. As expected, the stability classes indicate stable conditions during the night hours and neutral and unstable conditions during the day.

The stability classes were then plotted by wind speed as shown in the second of the following charts. The plots show the typical patterns of wind speed by stability class as expected. The wind speeds logged at Sydney were higher than those recorded at Prospect, but both sites displayed the same pattern, where, as expected, the highest wind speeds were associated with neutral conditions.



Stability classes by hour of day – Prospect and Sydney, 2009 – 2011

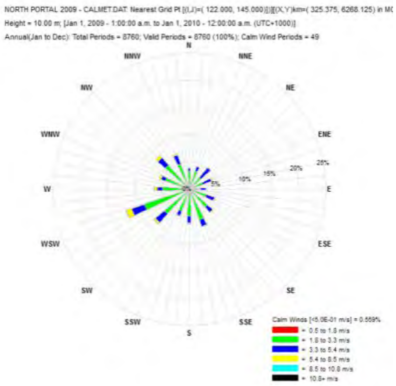


Stability classes by wind speeds – Prospect and Sydney, 2009 - 2011

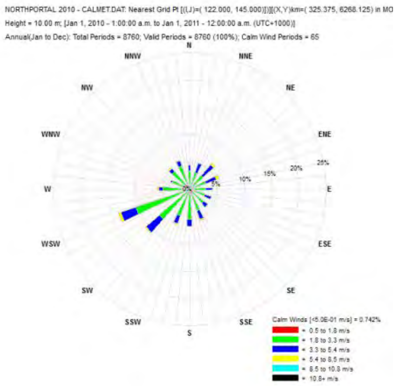
Wind roses

Wind roses extracted from CALMET for the northern and southern ventilation outlet locations are provided below, and are followed by wind roses for each of the BOM and OEH site used in the modelling for each of the three years. For evaluation purposes, the roses for each station are shown side by side for each of the three years. Year by year intercomparison in this way provided a simple method to evaluate the suitableness of each year analysed. The wind roses are split by season and by time of day into morning (7 am – 11 am), afternoon (12 pm – 6 pm), evening, (7 pm – 12 am) and night (1 am – 6 am). Wind direction is taken as the direction of the wind bar toward the centre of the rose.

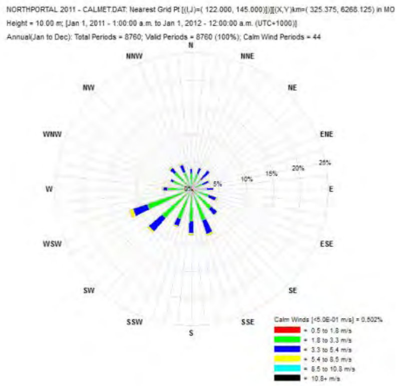
Annual, seasonal and diurnal wind roses for northern ventilation outlet for 2009, 2010, 2011 (CALMET-generated data)



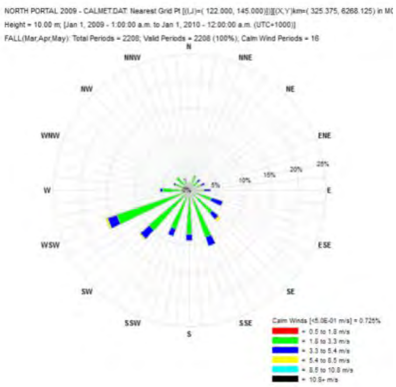
Annual – 2009, northern ventilation outlet



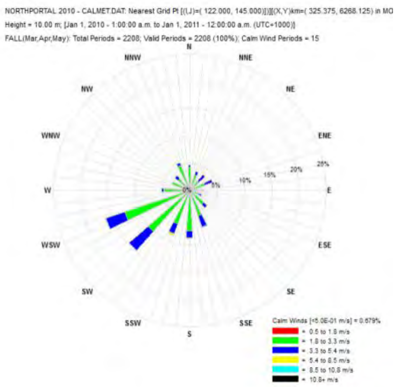
Annual – 2010, northern ventilation outlet



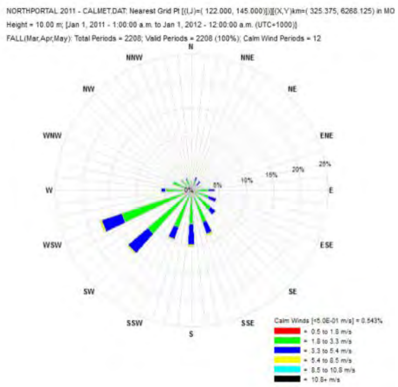
Annual – 2011, northern ventilation outlet



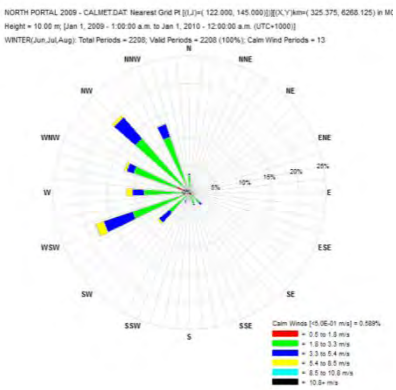
Autumn – March, April, May 2009, northern ventilation outlet



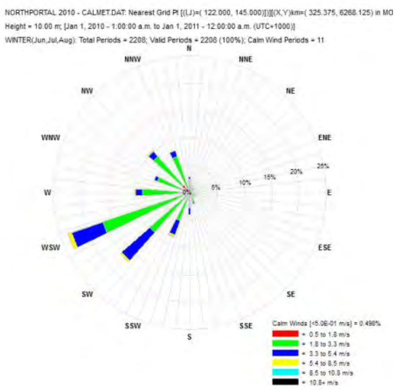
Autumn – March, April, May 2010, northern ventilation outlet



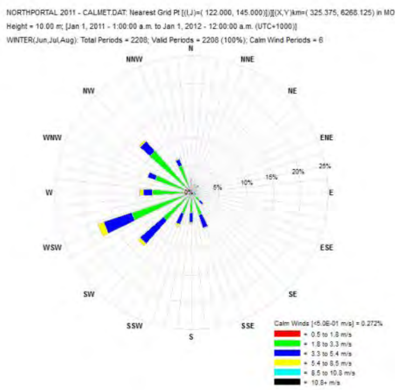
Autumn – March, April, May 2011, northern ventilation outlet



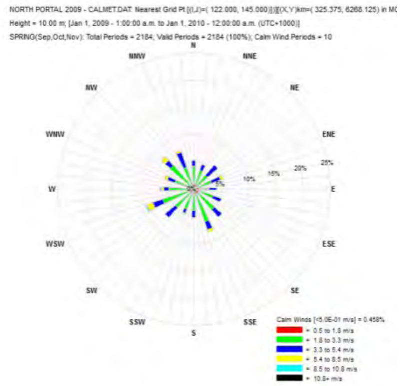
Winter – June, July, August 2009, northern ventilation outlet



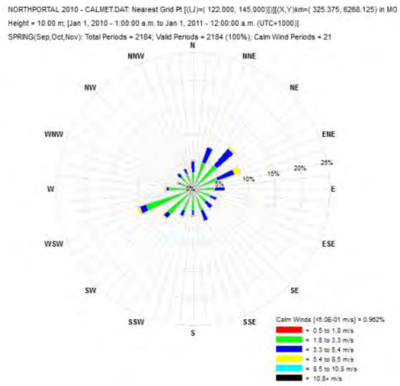
Winter – June, July, August 2010, northern ventilation outlet



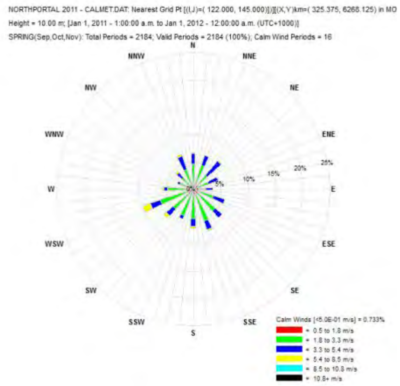
Winter – June, July, August 2011, northern ventilation outlet



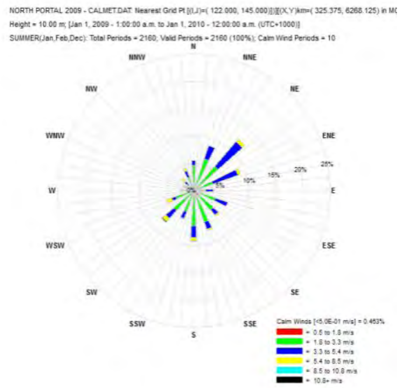
Spring –Sep, Oct, Nov, 2009, northern ventilation outlet



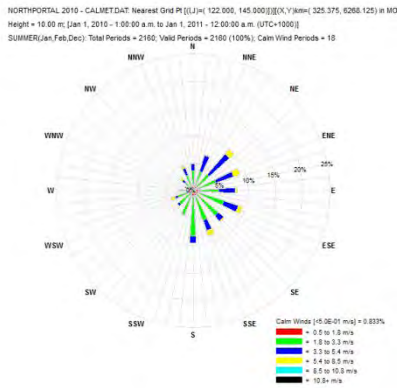
Spring –Sep, Oct, Nov, 2010, northern ventilation outlet



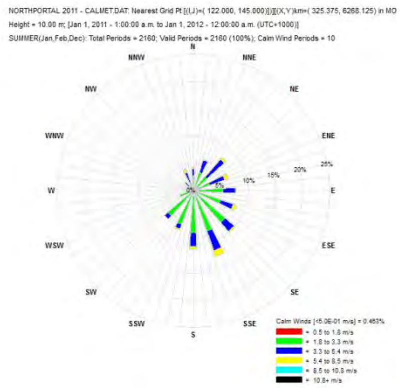
Spring –Sep, Oct, Nov, 2011, northern ventilation outlet



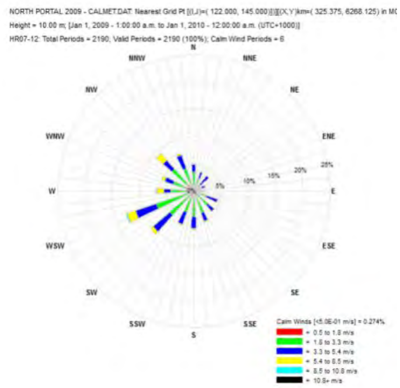
Summer –Dec, Jan, Feb, 2009, northern ventilation outlet



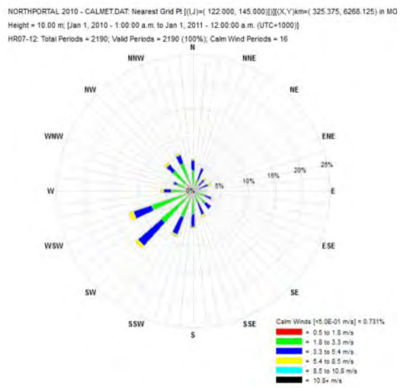
Summer –Dec, Jan, Feb, 2010, northern ventilation outlet



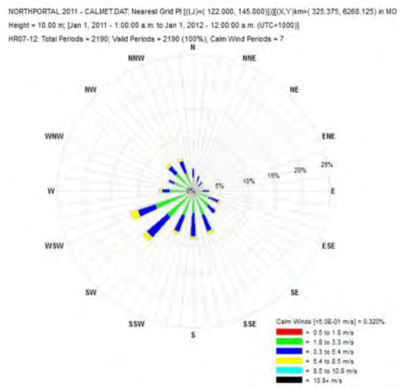
Summer –Dec, Jan, Feb, 2011, northern ventilation outlet



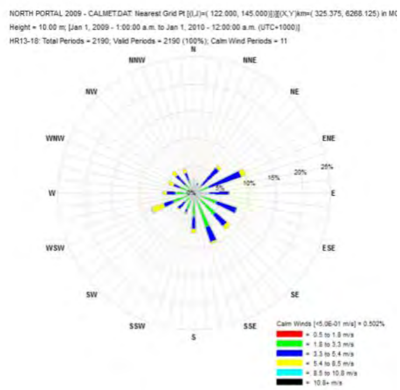
Morning (7am – 11am), 2009 northern ventilation outlet

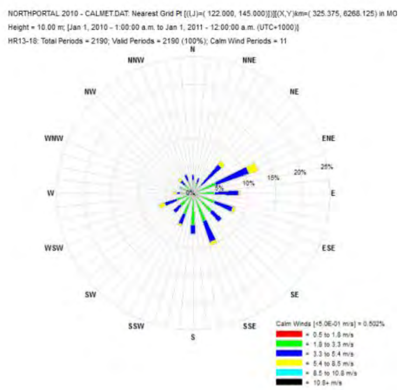


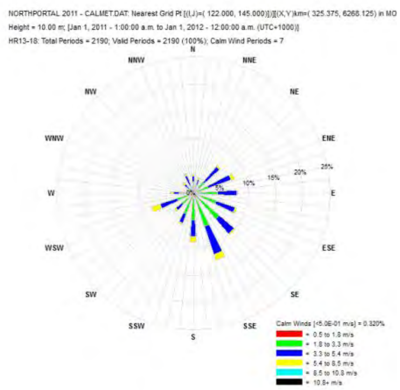
Morning (7am – 11am), 2010 northern ventilation outlet



Morning (7am – 11am), 2011, northern ventilation outlet



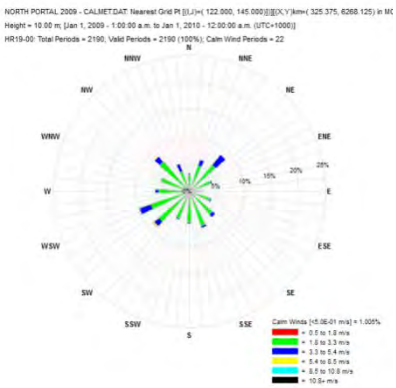


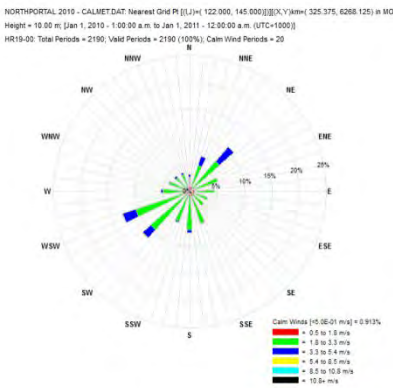


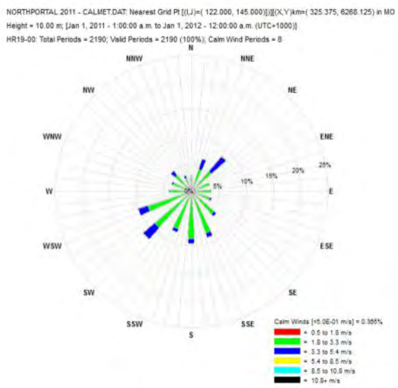
Afternoon (12pm – 6pm), northern ventilation outlet, 2009

Afternoon (12pm – 6pm), northern ventilation outlet, 2010

Afternoon (12pm – 6pm), northern ventilation outlet, 2011



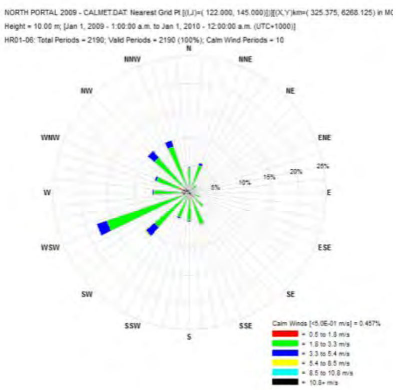


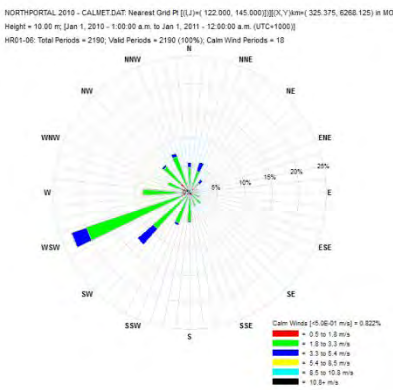


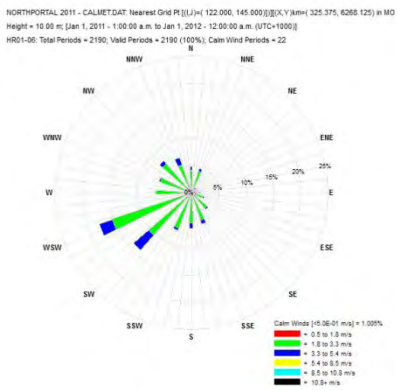
Evening (7pm – 12am), northern ventilation outlet, 2009

Evening (7pm – 12am), northern ventilation outlet, 2010

Evening (7pm – 12am), northern ventilation outlet t, 2011





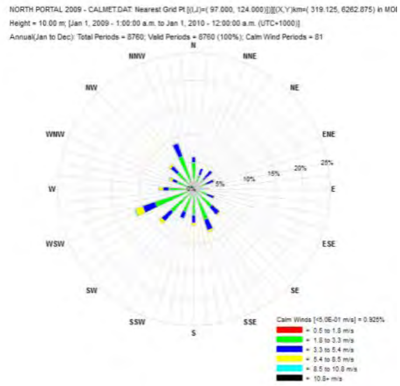


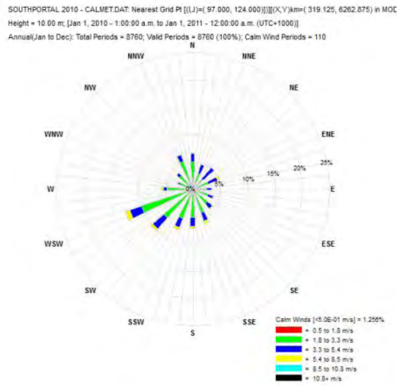
Night (1am – 6am), northern ventilation outlet, 2009

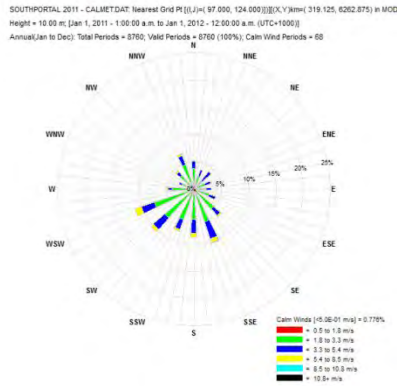
Night (1am – 6am), northern ventilation outlet, 2010

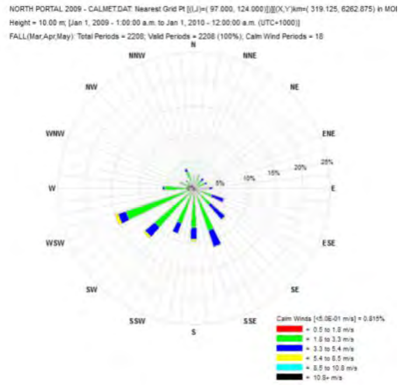
Night (1am – 6am), northern ventilation outlet, 2011

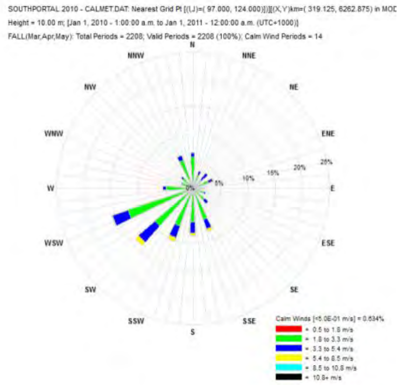
Annual, seasonal and diurnal wind roses for southern ventilation outlet for 2009, 2010, 2011 (CALMET-generated data)

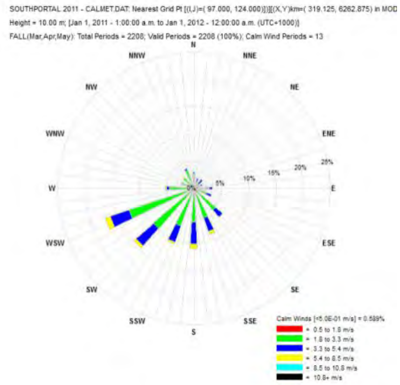

Annual – southern ventilation outlet, 2009

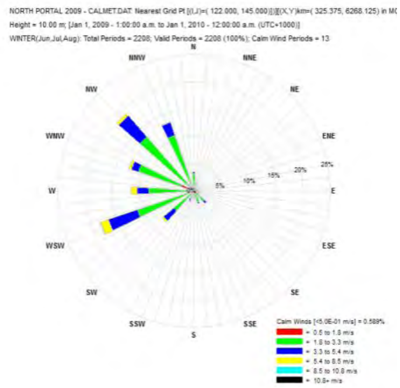

Annual – southern ventilation outlet, 2010

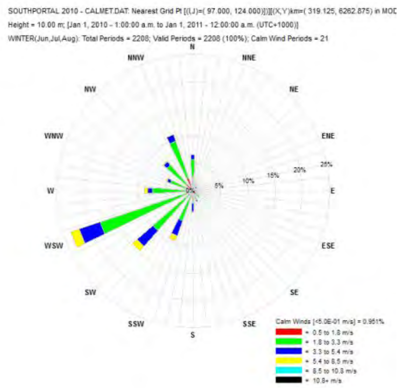

Annual –southern ventilation outlet, 2011

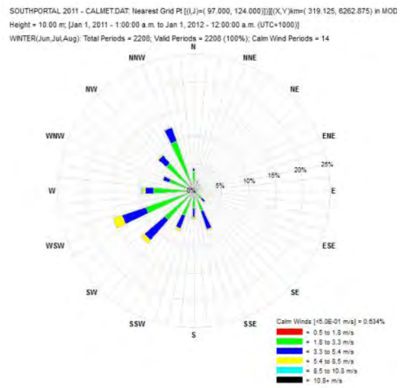

Autumn –southern ventilation outlet, 2009

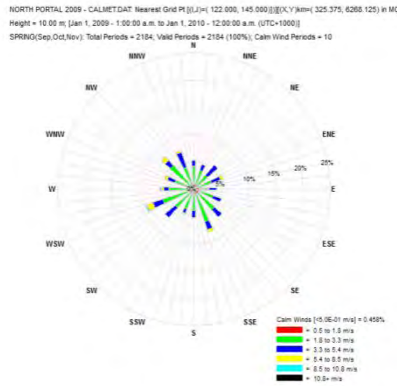

Autumn –southern ventilation outlet, 2010


Autumn –southern ventilation outlet, 2011

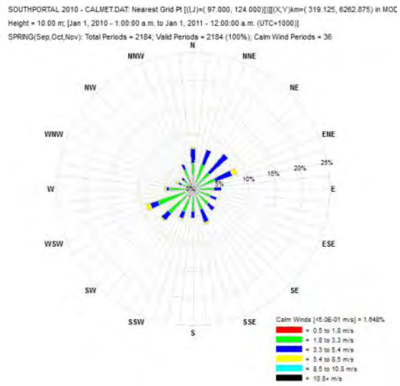

Winter –southern ventilation outlet, 2009


Winter – southern ventilation outlet, 2010

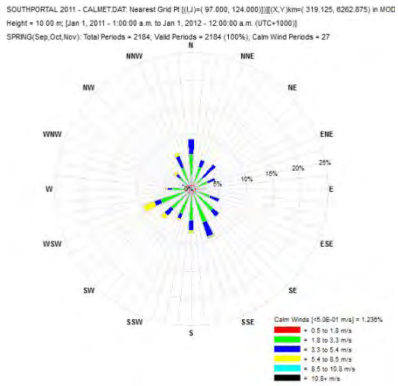

Winter – southern ventilation outlet, 2011



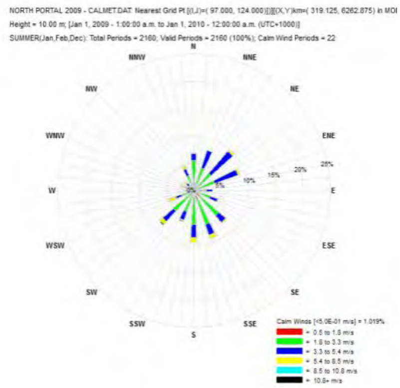
Spring – southern ventilation outlet, 2009



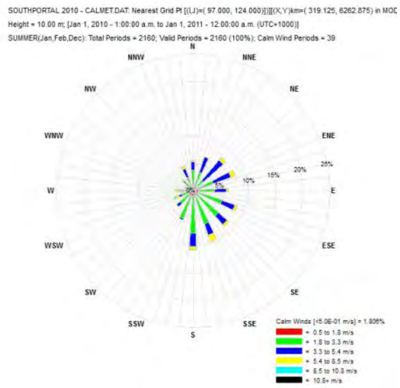
Spring – southern ventilation outlet, 2010



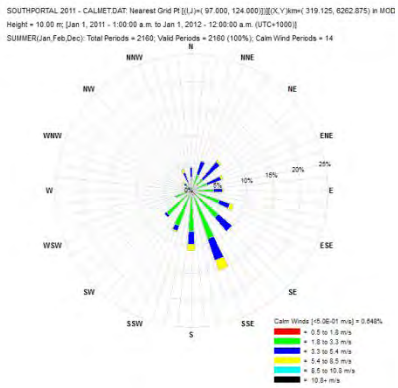
Spring – southern ventilation outlet, 2011



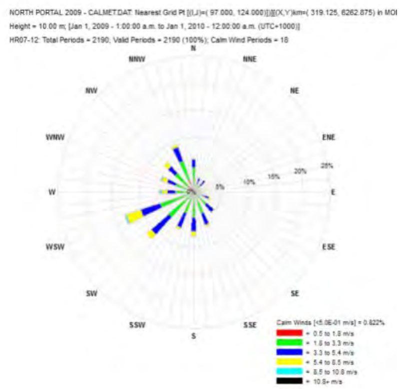
Summer –southern ventilation outlet, 2009



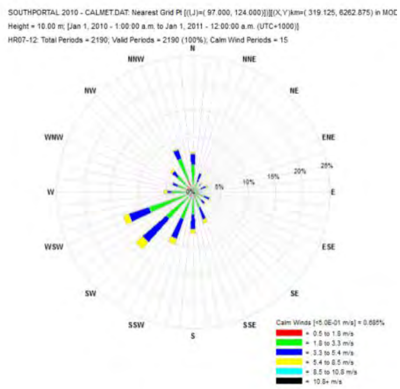
Summer – southern ventilation outlet, 2010



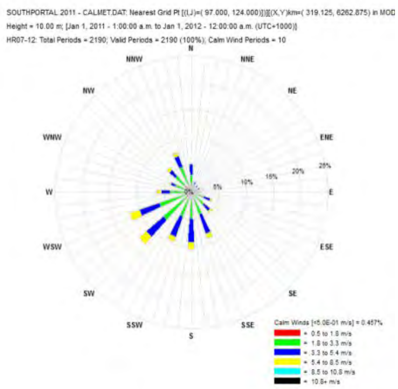
Summer –southern ventilation outlet, 2011



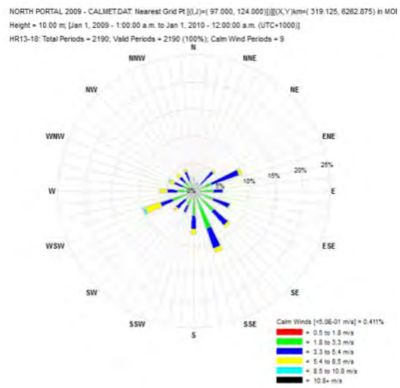
Morning (7am – 12pm) – southern ventilation outlet, 2009

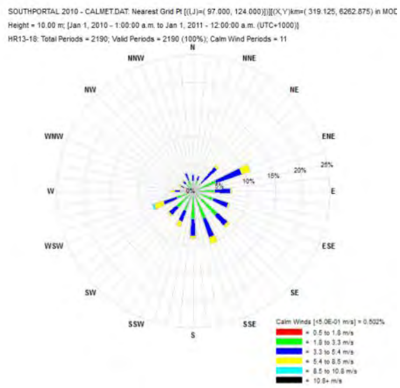


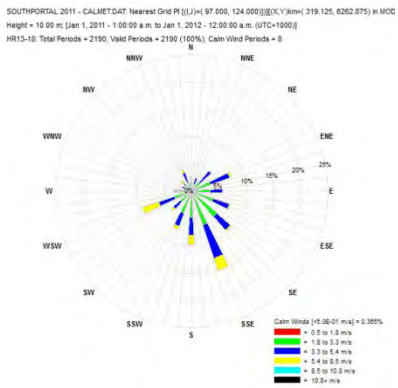
Morning (7am – 12pm) – southern ventilation outlet, 2010



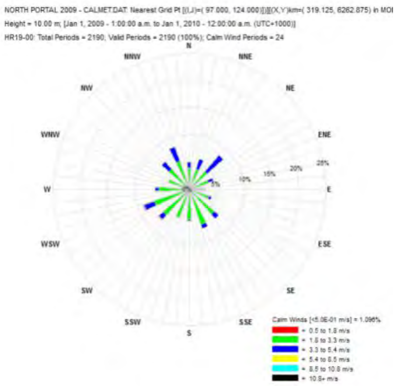
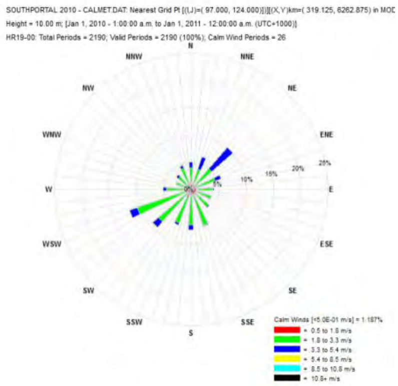
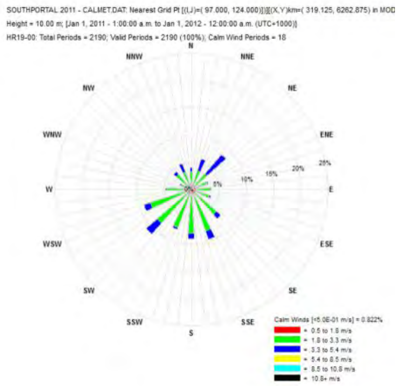
Morning (7am – 12pm) – southern ventilation outlet, 2011



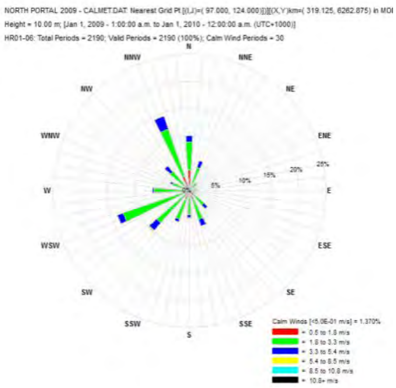
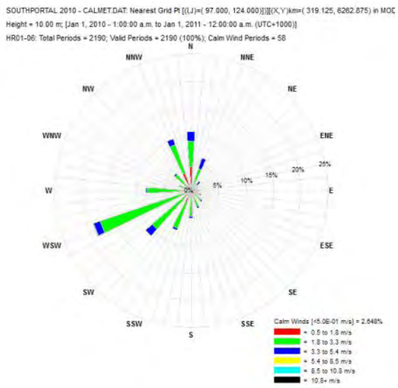
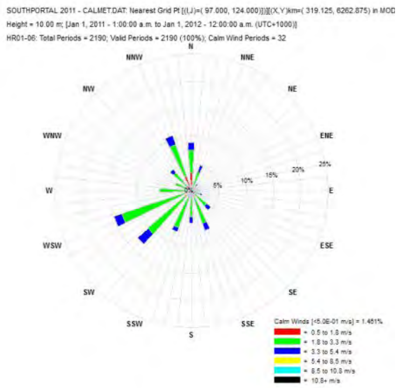




Afternoon (1pm – 6pm – southern ventilation outlet, 2009	Afternoon (1pm – 6pm) – southern ventilation outlet, 2010	Afternoon (1pm – 6pm) – southern ventilation outlet, 2011

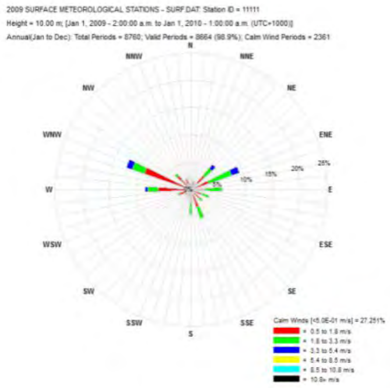




Evening (7pm – 12am) – southern ventilation outlet, 2009	Evening (7pm – 12am) – southern ventilation outlet, 2010	Evening (7pm – 12am) – southern ventilation outlet, 2011

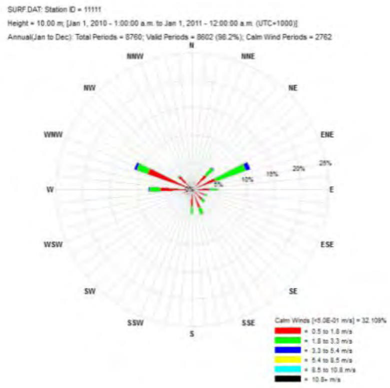




Night (1am – 6am) – southern ventilation outlet, 2009	Night (1am – 6am) – southern ventilation outlet, 2010	Night (1am – 6am) – southern ventilation outlet, 2011

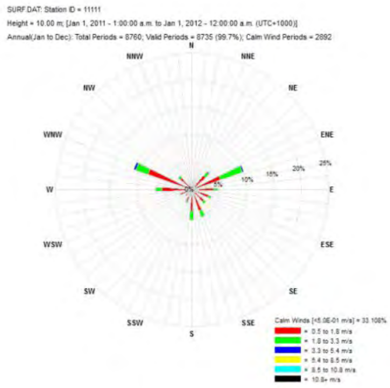
Annual, seasonal and diurnal wind roses for Lindfield Meteorological Station for 2009, 2010, 2011 (Measured data)



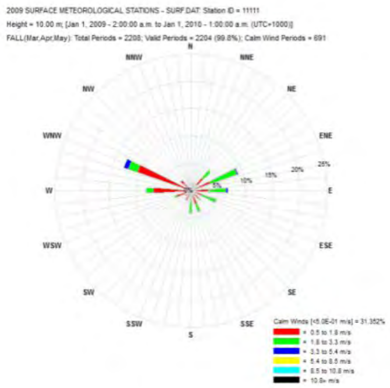
Annual – 2009, Lindfield



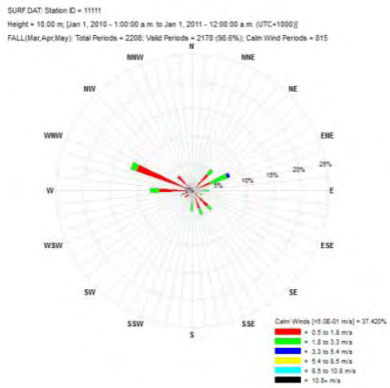
Annual – 2010, Lindfield



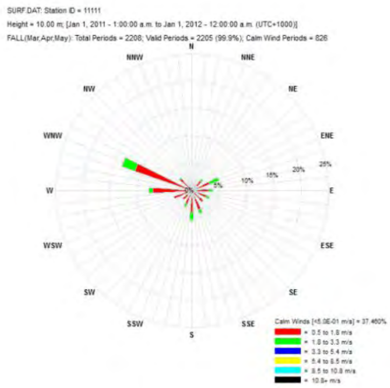
Annual – 2011, Lindfield



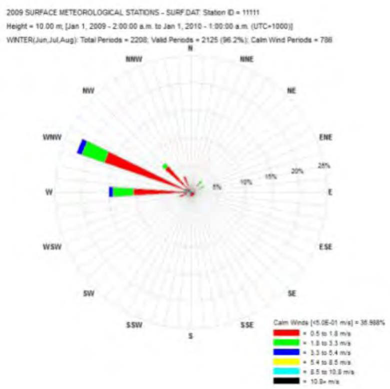
Autumn – March, April, May 2009, Lindfield



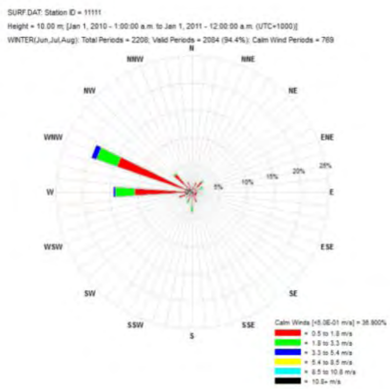
Autumn – March, April, May 2010, Lindfield



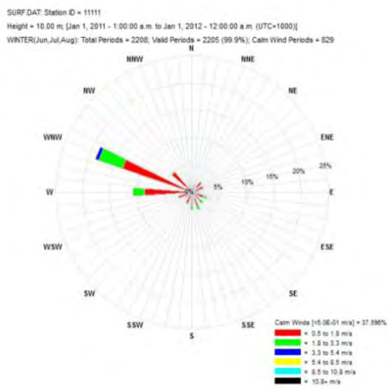
Autumn – March, April, May 2011, Lindfield



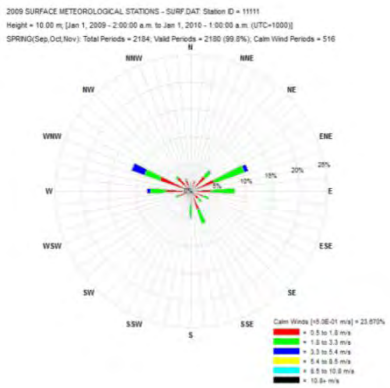
Winter – June, July, August 2009, Lindfield

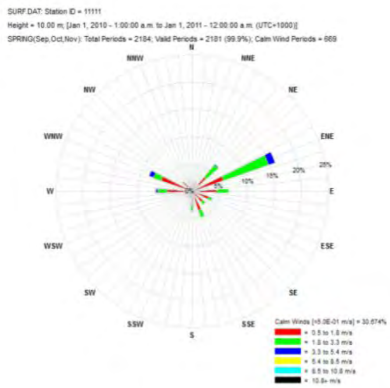


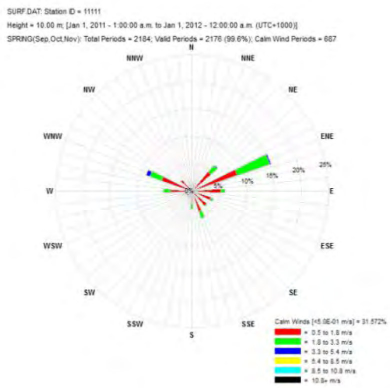
Winter – June, July, August 2010, Lindfield



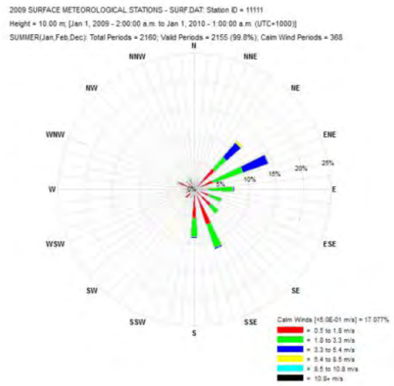
Winter – June, July, August 2011, Lindfield



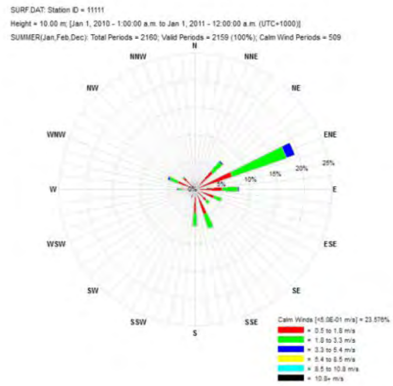




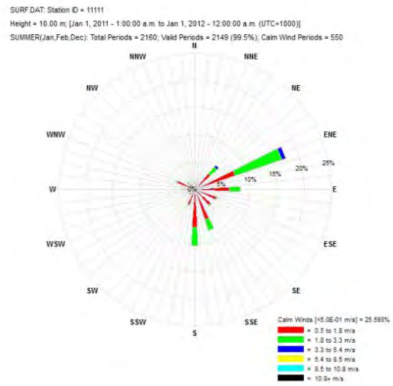
Spring –September, October, November, 2009



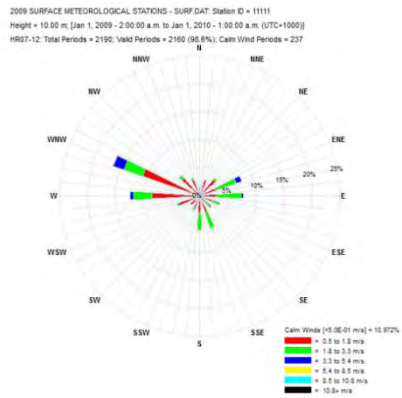
Spring –September, October, November, 2010



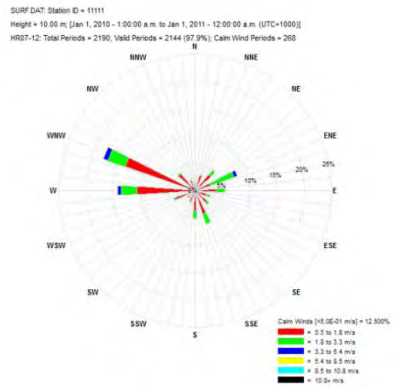
Spring –September, October, November, 2011



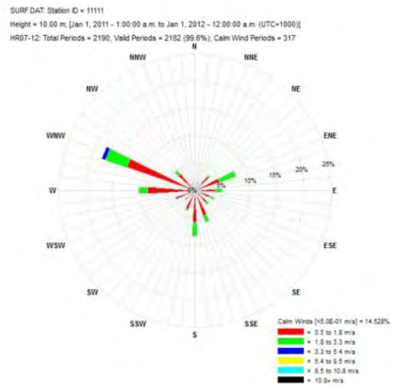
Summer –December, January, February, 2009, Lindfield



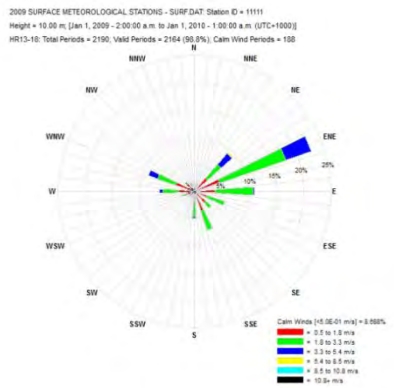
Summer –December, January, February, 2010, Lindfield



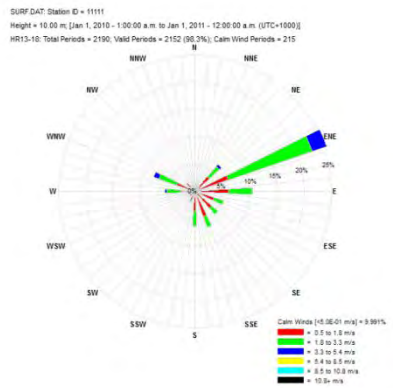
Summer –December, January, February, 2011, Lindfield



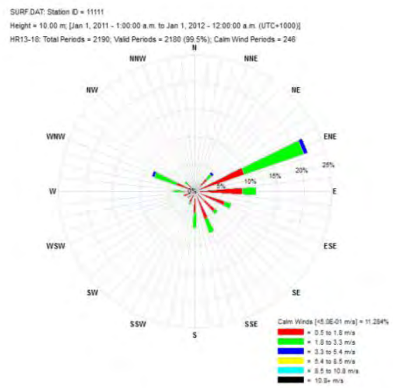
Morning (7am – 12pm), Lindfield, 2009



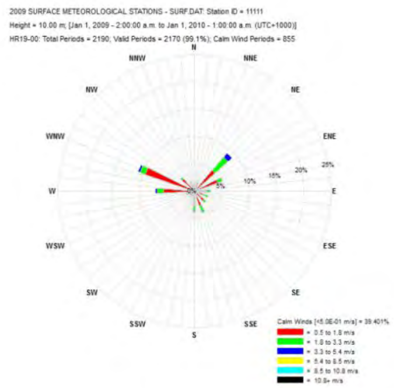
Morning (7am – 12pm), Lindfield, 2010



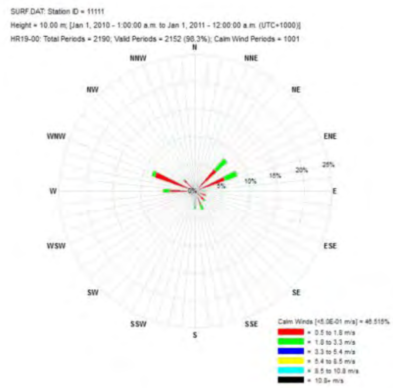
Morning (7am – 12pm), Lindfield, 2011



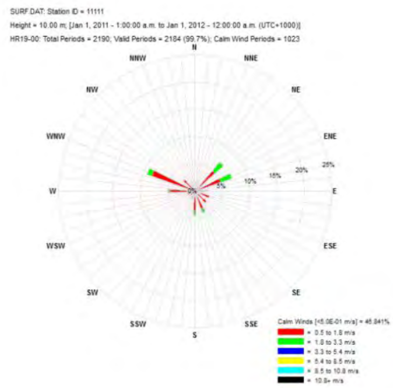
Afternoon (1pm – 6pm), Lindfield, 2009



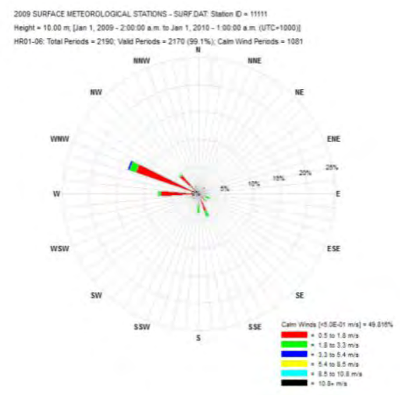
Afternoon (1pm – 6pm), Lindfield, 2010

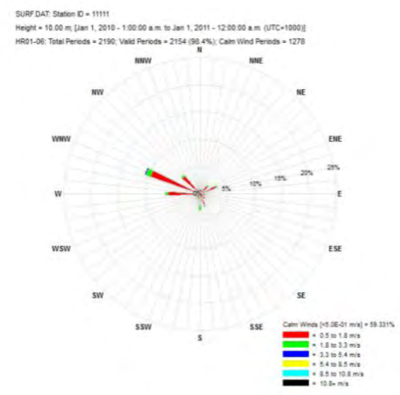


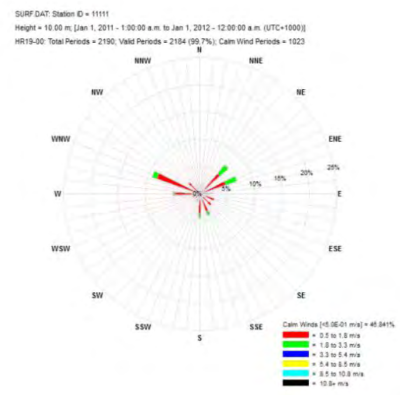
Afternoon (1pm – 6pm), Lindfield, 2011



Evening (7pm – 12am), Lindfield, 2009 | Evening (7pm – 12am), Lindfield, 2010 | Evening (7pm – 12am), Lindfield, 2011

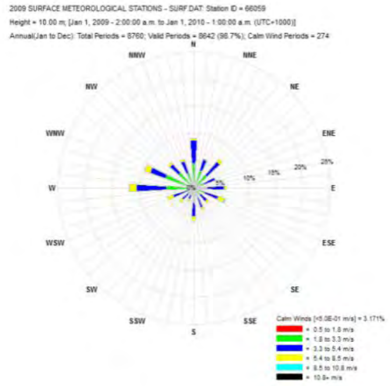




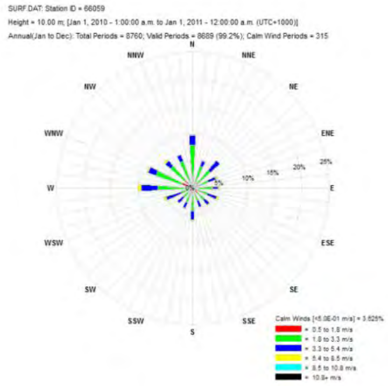


Night (1am – 6am), Lindfield, 2009 | Night (1am – 6am), Lindfield, 2010 | Night (1am – 6am), Lindfield, 2011

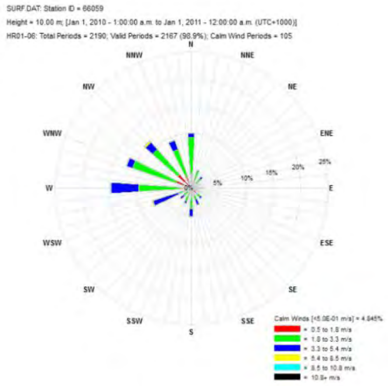
Annual, seasonal and diurnal wind roses for Terrey Hills Meteorological Station for 2009, 2010, 2011 (Measured data)



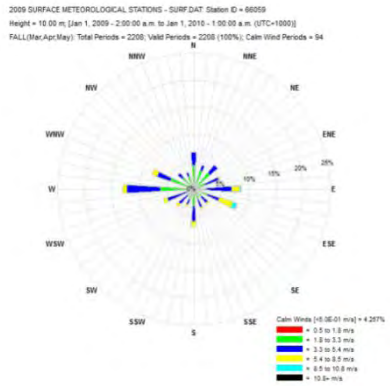
Annual – Terrey Hills (66059), 2009



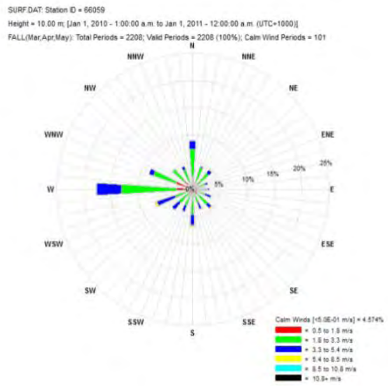
Annual – Terrey Hills (66059), 2010



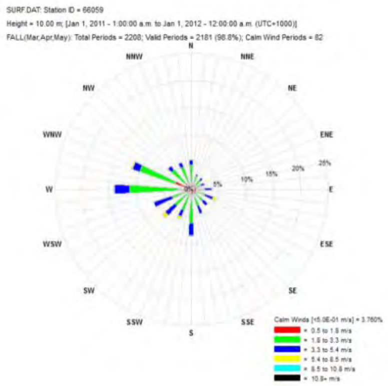
Annual –Terrey Hills (66059), 2011



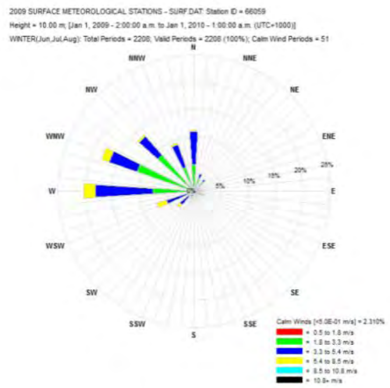
Autumn –Terrey Hills (66059), 2009



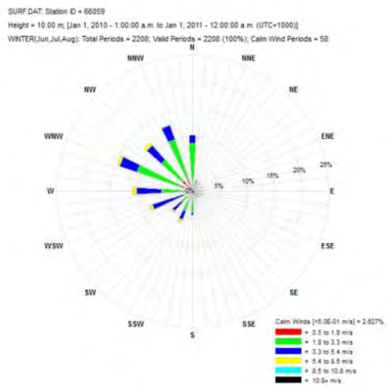
Autumn –Terrey Hills (66059), 2010



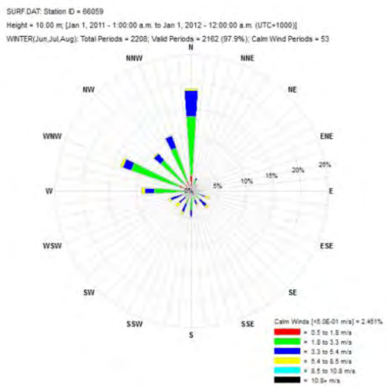
Autumn –Terrey Hills (66059), 2011



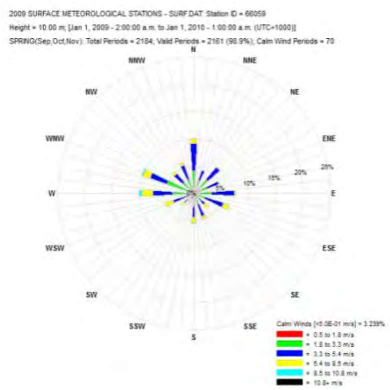
Winter –Terrey Hills (66059), 2009



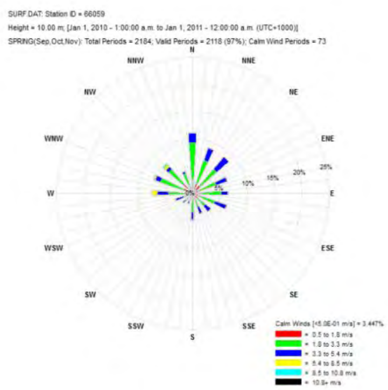
Winter – Terrey Hills (66059), 2010



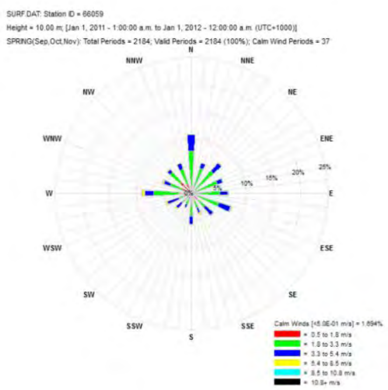
Winter – Terrey Hills (66059), 2011



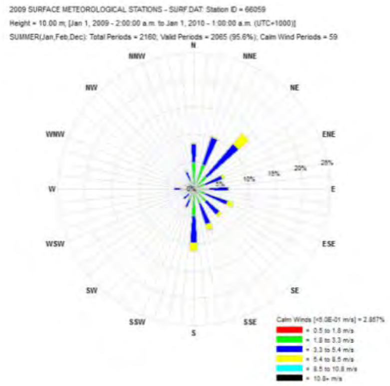
Spring – Terrey Hills (66059), 2009



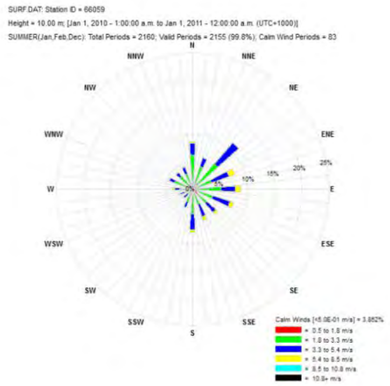
Spring – Terrey Hills (66059), 2010



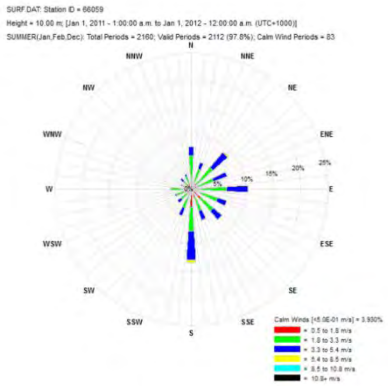
Spring – Terrey Hills (66059), 2011



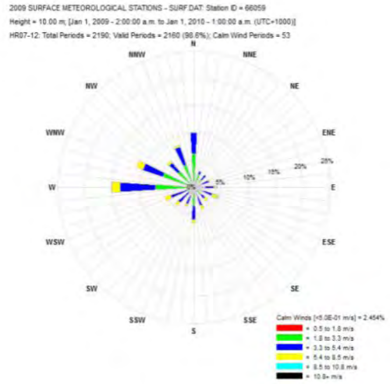
Summer –Terrey Hills (66059), 2009



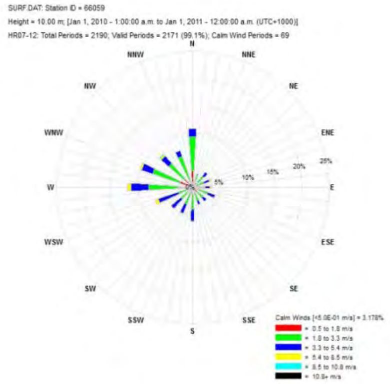
Summer – Terrey Hills (66059), 2010



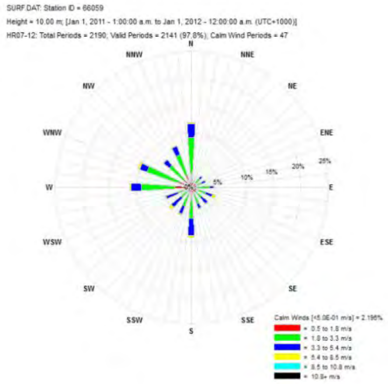
Summer –Terrey Hills (66059), 2011



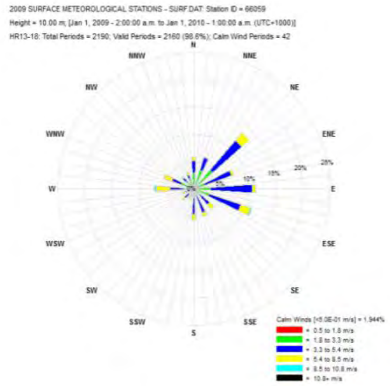
Morning (7am – 12pm) – Terrey Hills, 2009



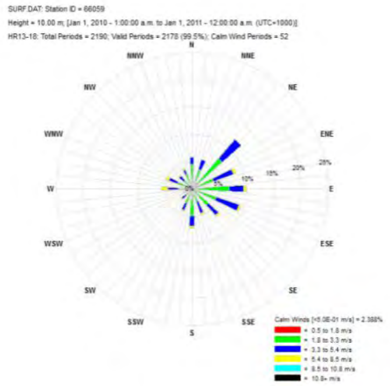
Morning (7am – 12pm) – Terrey Hills, 2010



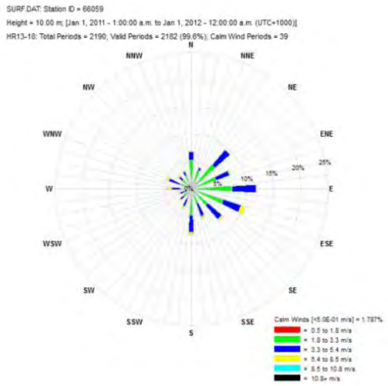
Morning (7am – 12pm) – Terrey Hills, 2011



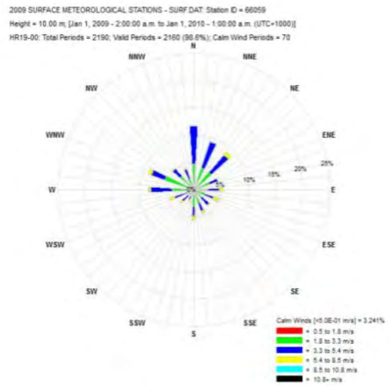
Afternoon (1pm – 6pm) – Terrey Hills, 2009



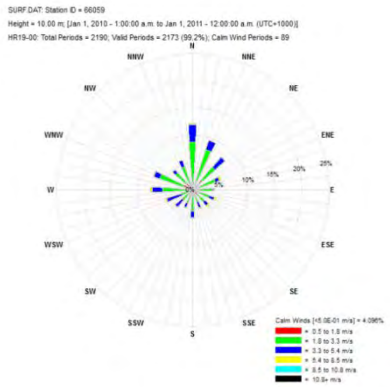
Afternoon (1pm – 6pm) – Terrey Hills, 2010



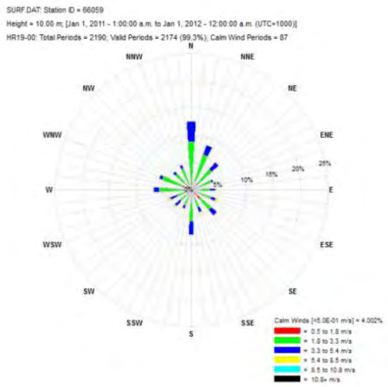
Afternoon (1pm – 6pm) – Terrey Hills, 2011



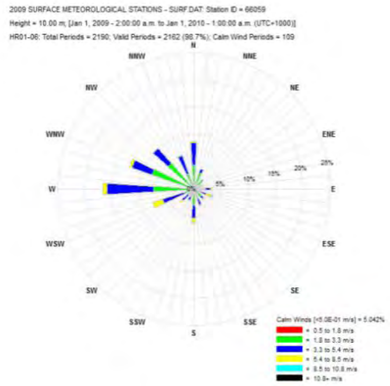
Evening (7pm – 12am) – Terrey Hills, 2009



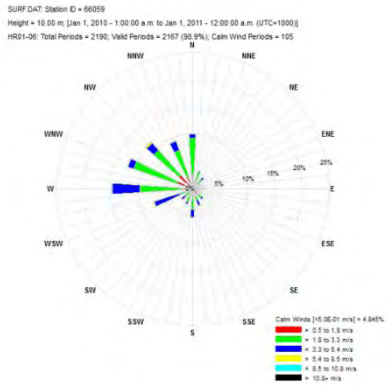
Evening (7pm – 12am) – Terrey Hills, 2010



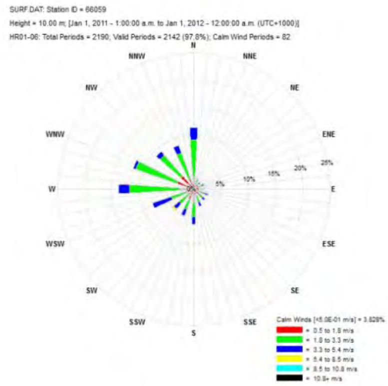
Evening (7pm – 12am) – Terrey Hills, 2011



Night (1am – 6am) – Terrey Hills, 2009

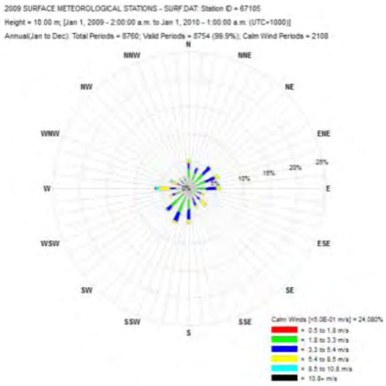


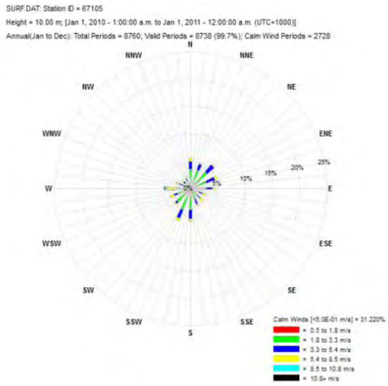
Night (1am – 6am) – Terrey Hills, 2010

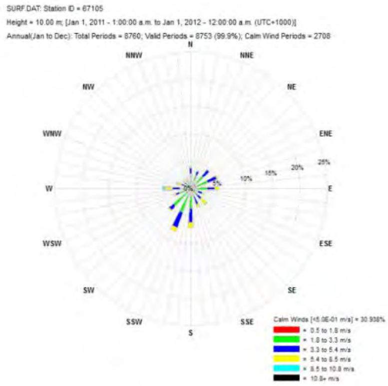


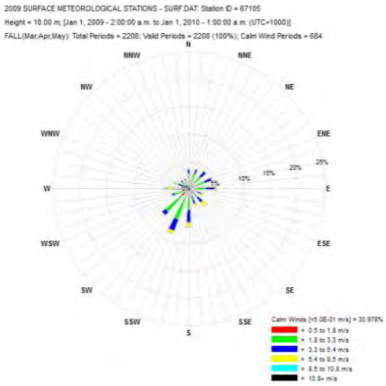
Night (1am – 6am) – Terrey Hills, 2011

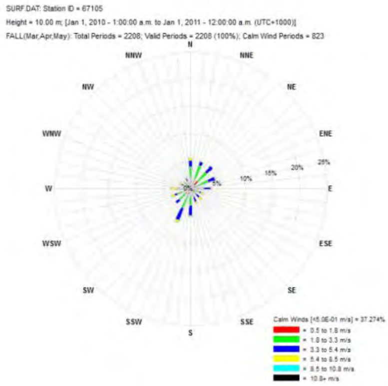
Annual, seasonal and diurnal wind roses for Richmond Meteorological Station for 2009, 2010, 2011 (Measured data)

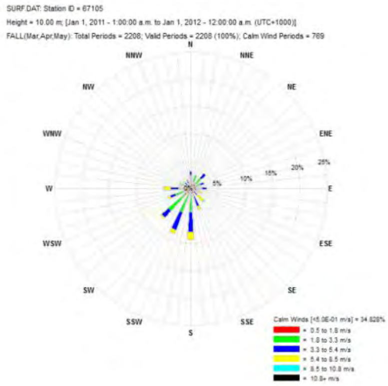

Annual – Richmond RAAF, 2009

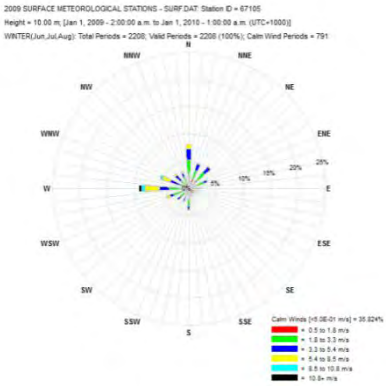

Annual – Richmond RAAF, 2010

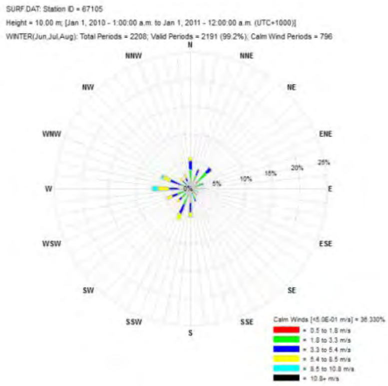

Annual – Richmond RAAF, 2011

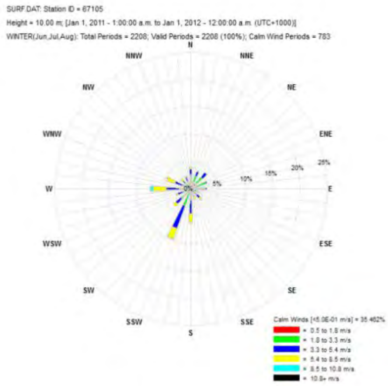

Autumn –Richmond RAAF, 2009

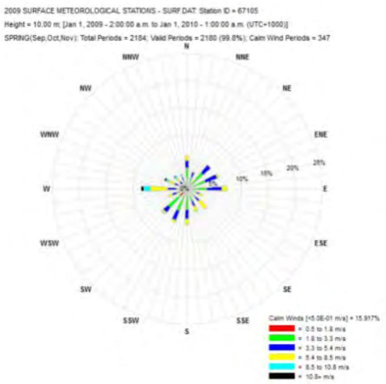

Autumn –Richmond RAAF, 2010

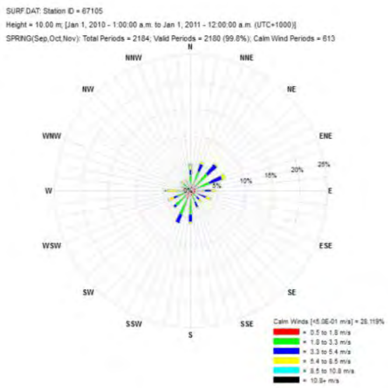

Autumn –Richmond RAAF, 2011

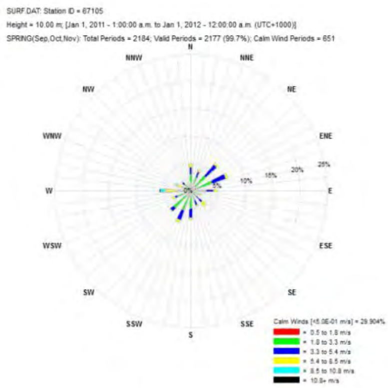

Winter – Richmond RAAF, 2009

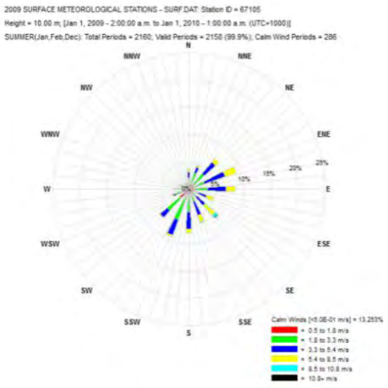

Winter – Richmond RAAF, 2010


Winter – Richmond RAAF, 2011

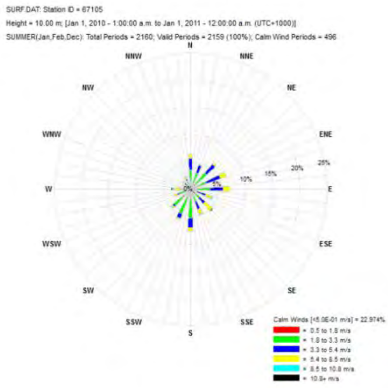

Spring – Richmond RAAF, 2009


Spring – Richmond RAAF, 2010

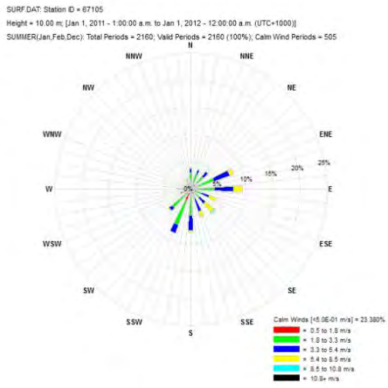

Spring – Richmond RAAF, 2011



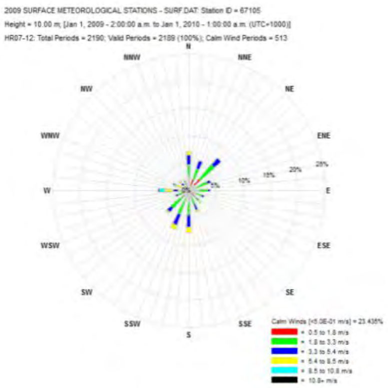
Summer –Richmond RAAF, 2009



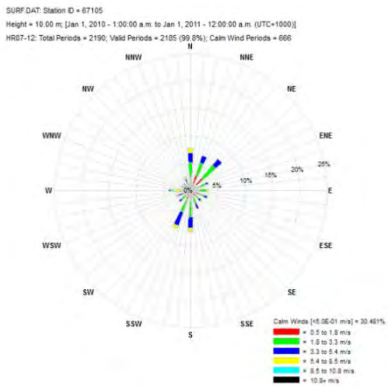
Summer –Richmond RAAF, 2010



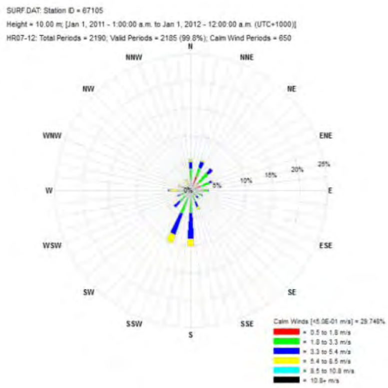
Summer –Richmond RAAF, 2011



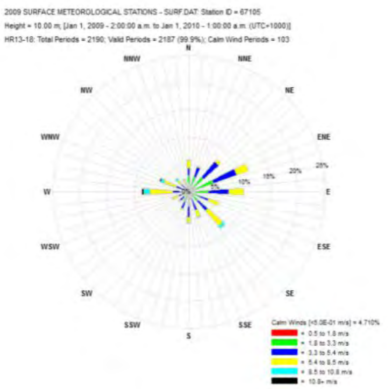
Morning (7am – 12pm) – Richmond, 2009



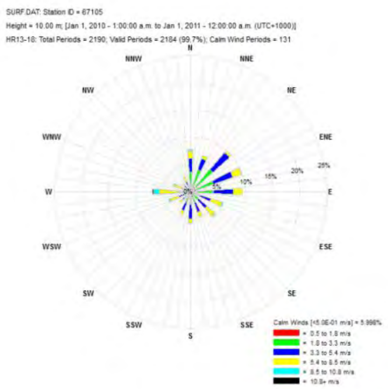
Morning (7am – 12pm) – Richmond, 2010



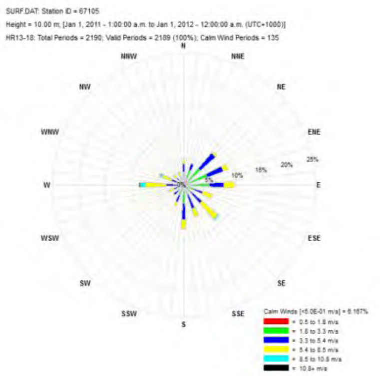
Morning (7am – 12pm) – Richmond, 2011



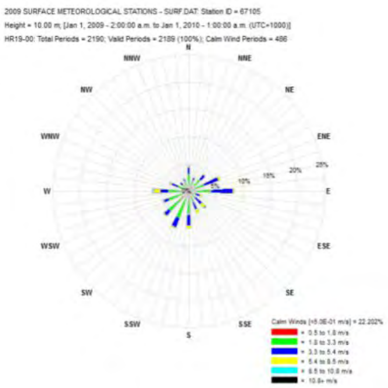
Afternoon (1pm – 6pm) – Richmond, 2009

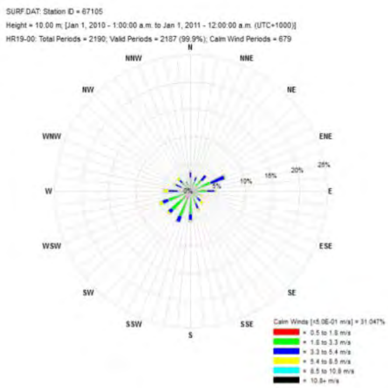


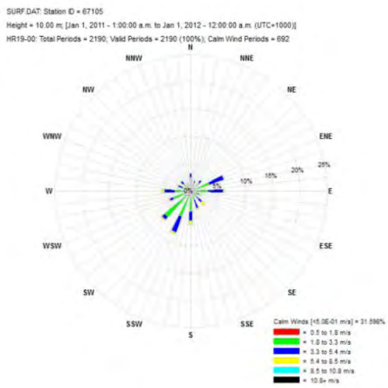
Afternoon (1pm – 6pm) – Richmond, 2010



Afternoon (1pm – 6pm) – Richmond, 2011







Evening (7pm – 12am) – Richmond, 2009

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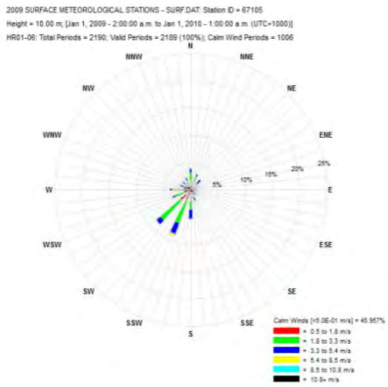
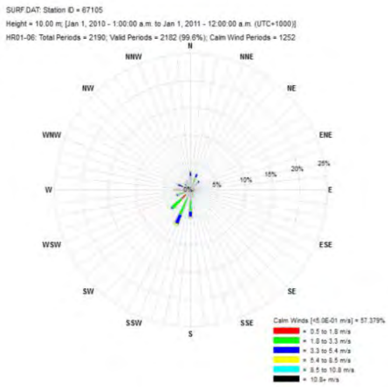
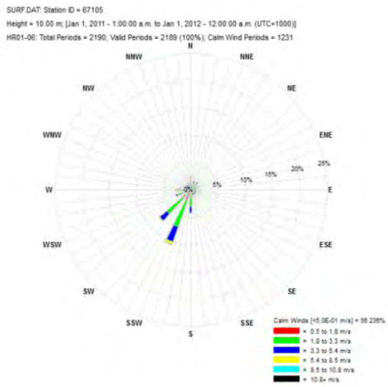


Night (1am – 6am) – Richmond, 2009

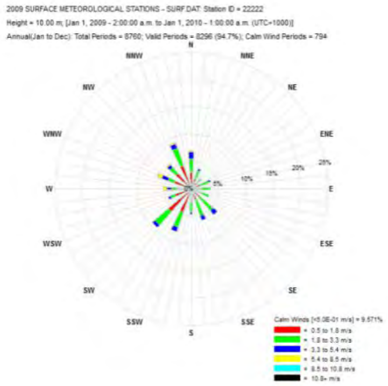


Night (1am – 6am) – Richmond, 2010

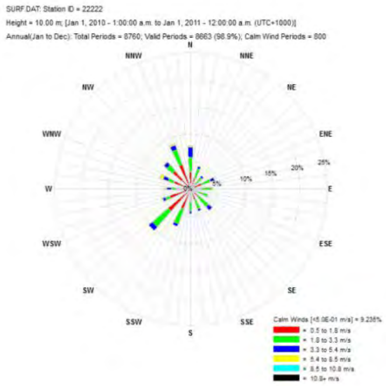


Night (1am – 6am) – Richmond, 2011

Annual, seasonal and diurnal wind roses for Richmond Meteorological Station for 2009, 2010, 2011 (Measured data)



Annual – Prospect , 2009



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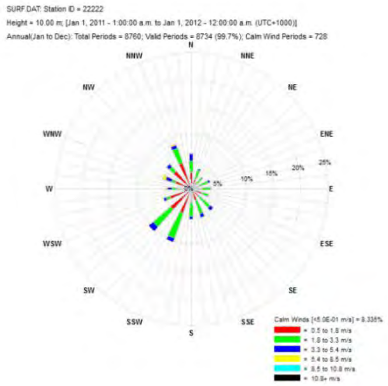

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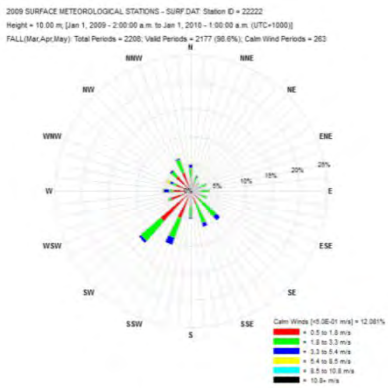

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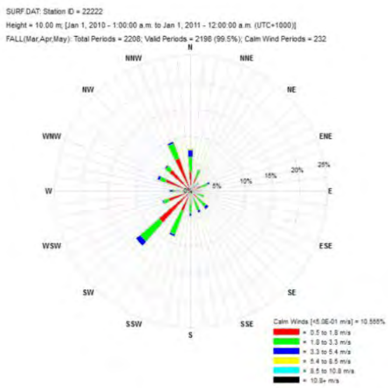

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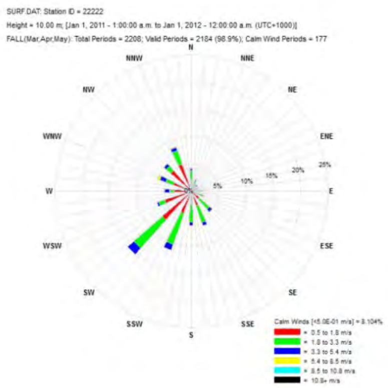

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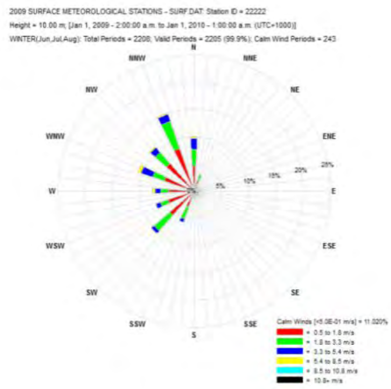
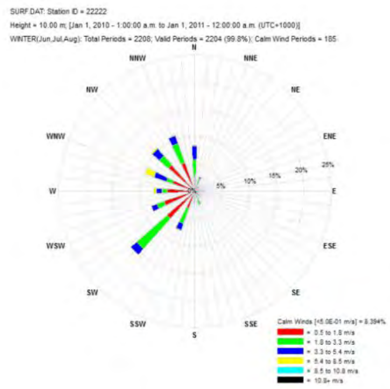
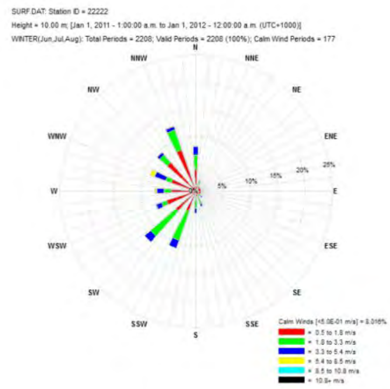


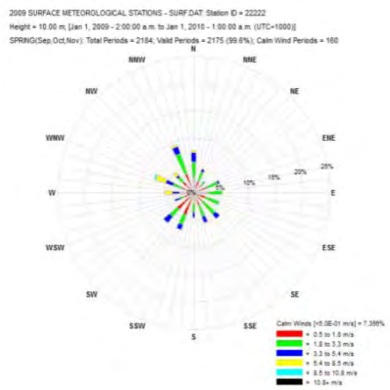
Winter – Prospect , 2009



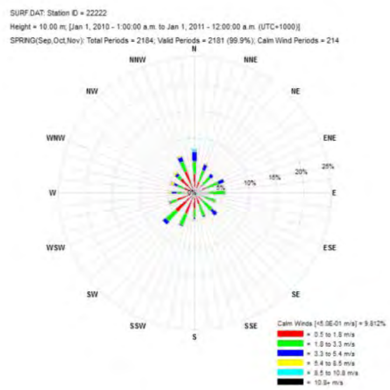
Winter – Prospect , 2010



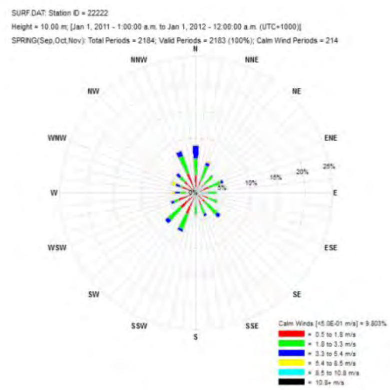
Winter – Prospect , 2011



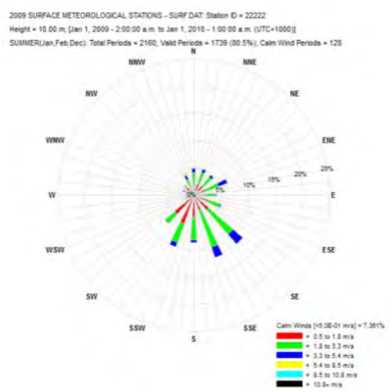
Spring – Prospect , 2009



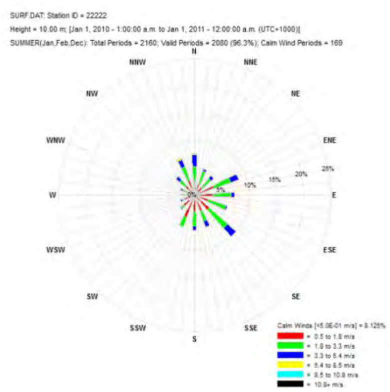
Spring – Prospect , 2010



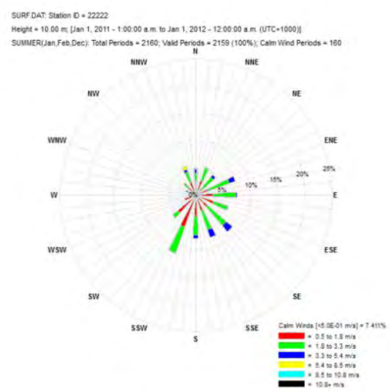
Spring – Prospect , 2011



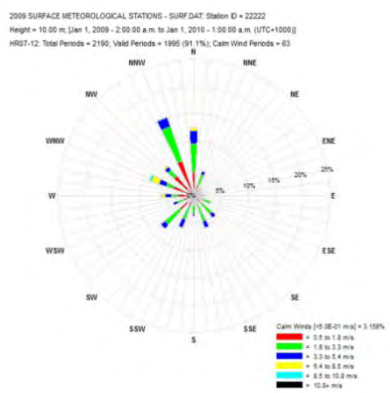
Summer –Prospect , 2009



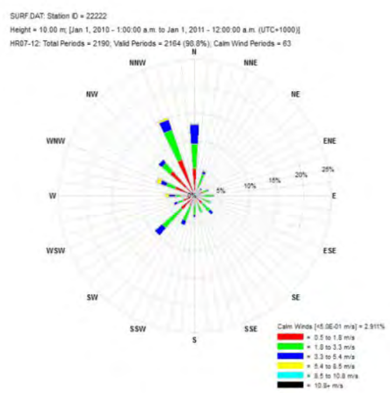
Summer –Prospect , 2010



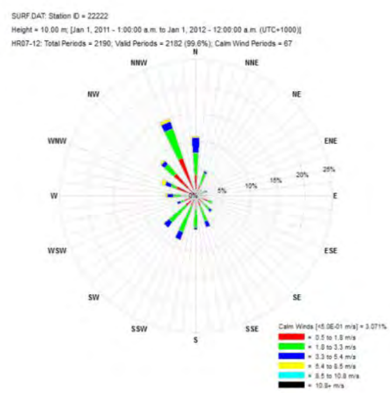
Summer –Prospect , 2011



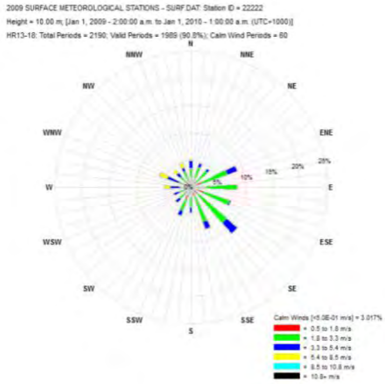
Morning (7am – 12pm) – Prospect, 2009



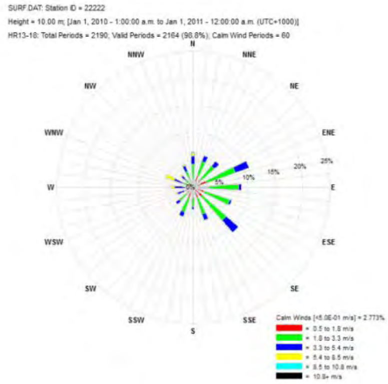
Morning (7am – 12pm) – Prospect, 2010



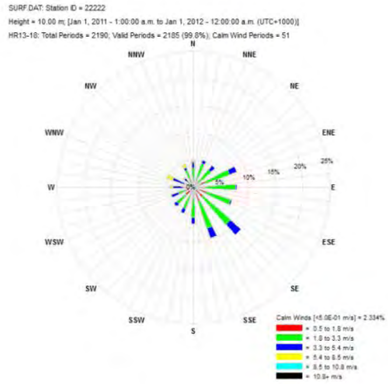
Morning (7am – 12pm) – Prospect, 2011



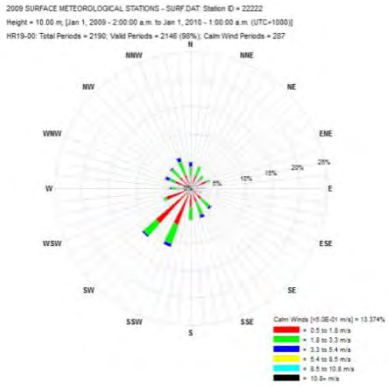
Afternoon (1pm – 6pm) – Prospect, 2009



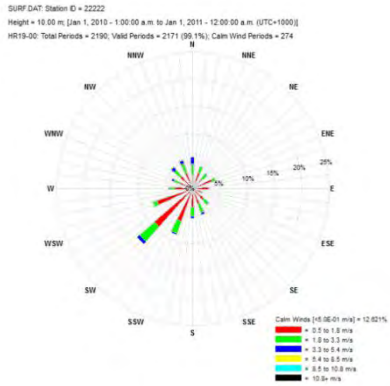
Afternoon (1pm – 6pm) – Prospect, 2010



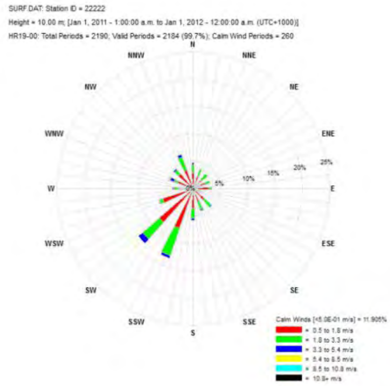
Afternoon (1pm – 6pm) – Prospect, 2011



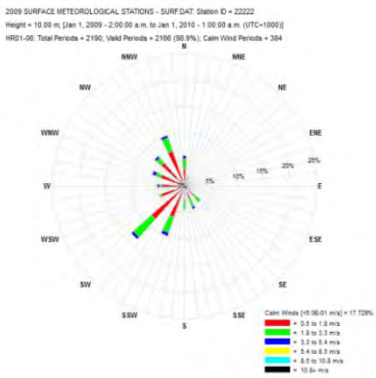
Evening (7pm – 12am) – Prospect, 2009



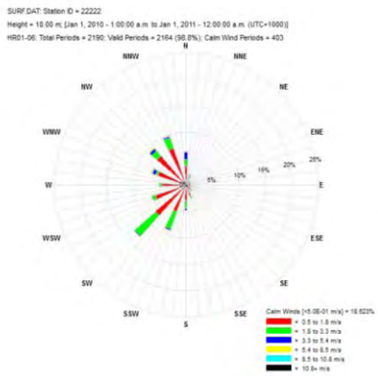
Evening (7pm – 12am) – Prospect, 2010



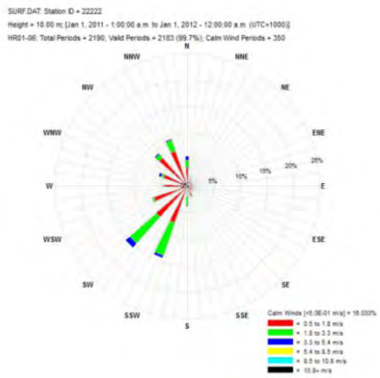
Evening (7pm – 12am) – Prospect, 2011



Night (1am – 6am) – Prospect, 2009

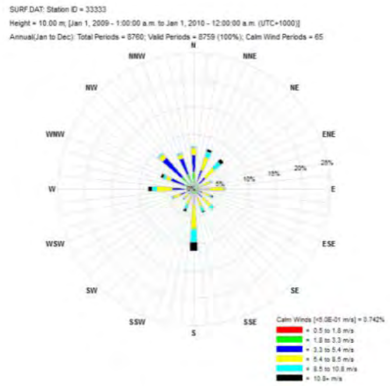


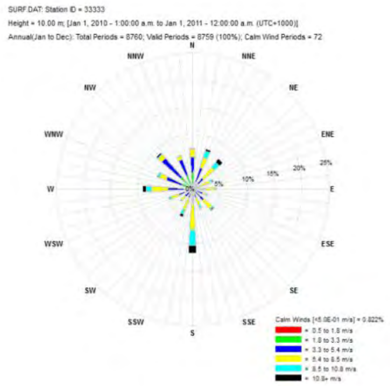
Night (1am – 6am) – Prospect, 2010

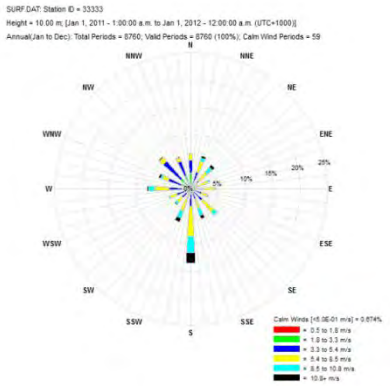


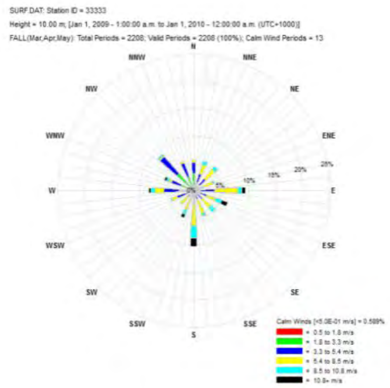
Night (1am – 6am) – Prospect, 2011

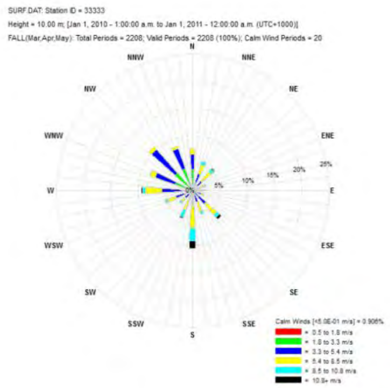
Annual, seasonal and diurnal wind roses for Sydney Airport Meteorological Station for 2009, 2010, 2011 (Measured data)

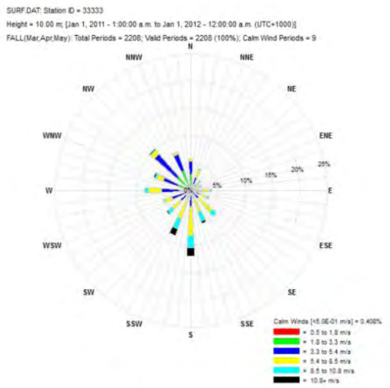

Annual – Sydney , 2009


Annual – Sydney , 2010


Annual – Sydney , 2011


Autumn –Sydney , 2009


Autumn –Sydney , 2010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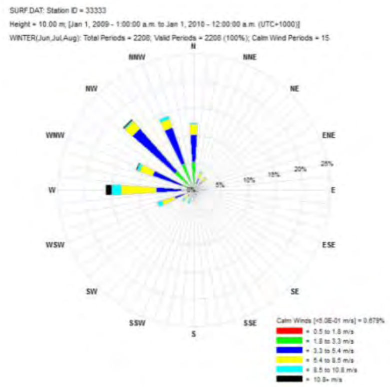
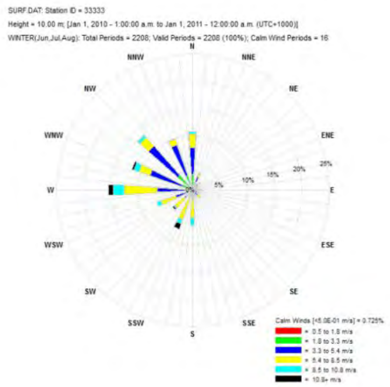
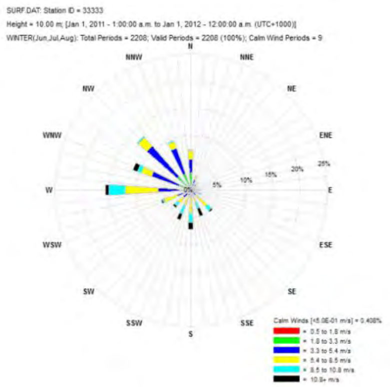
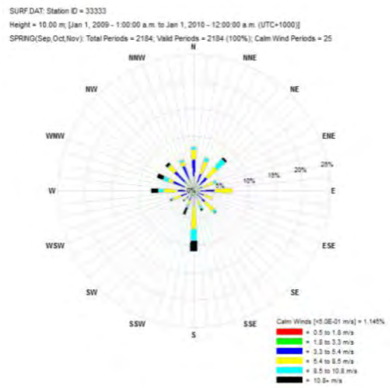
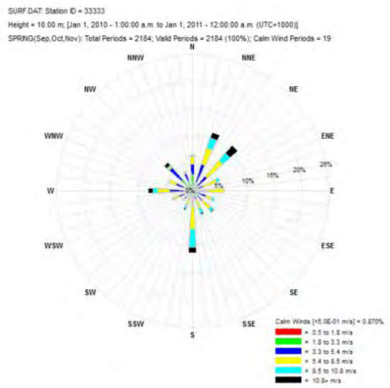
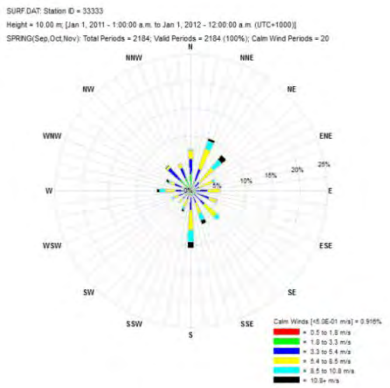

Winter – Sydney , 2009

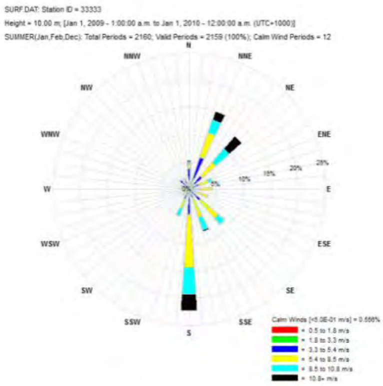

Winter – Sydney , 2010


Winter – Sydney , 2011

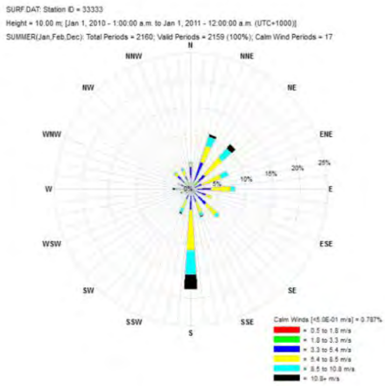

Spring – Sydney , 2009


Spring – Sydney , 2010

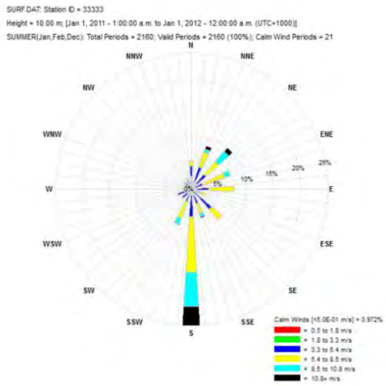

Spring – Sydney , 2011



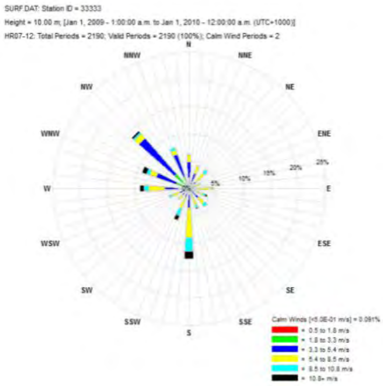
Summer –Sydney , 2009



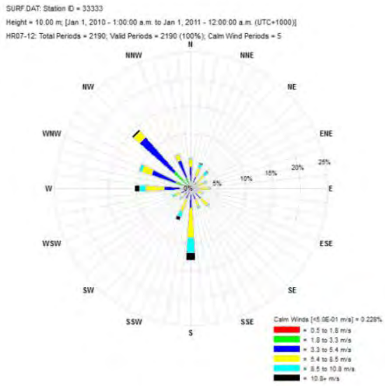
Summer –Sydney , 2010



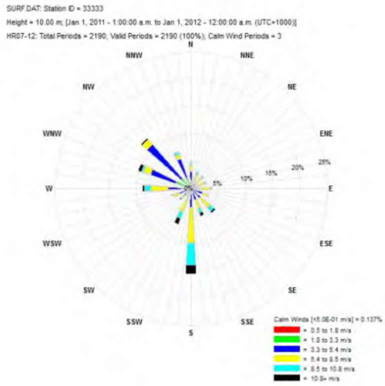
Summer –Sydney , 2011



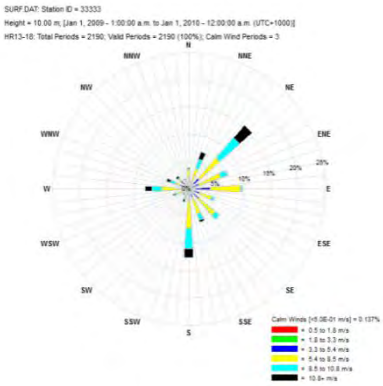
Morning (7am – 12pm) – Sydney, 2009



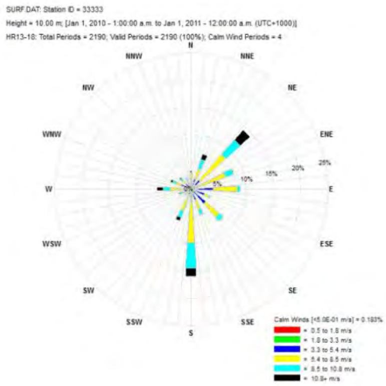
Morning (7am – 12pm) – Sydney, 2010



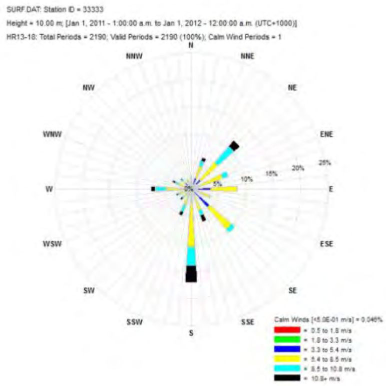
Morning (7am – 12pm) – Sydney, 2011



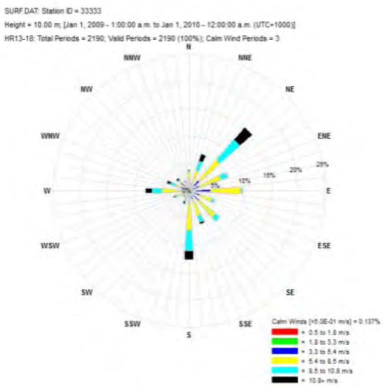
Afternoon (1pm – 6pm) – Sydney, 2009



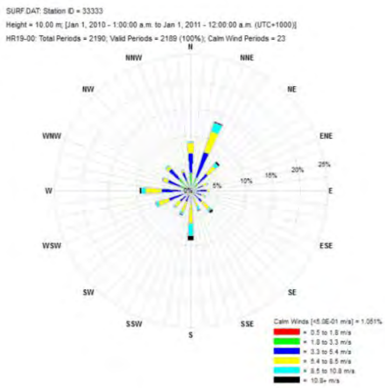
Afternoon (1pm – 6pm) – Sydney, 2010



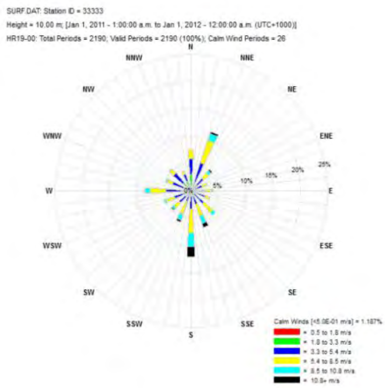
Afternoon (1pm – 6pm) – Sydney, 2011



Evening (7pm – 12am) – Sydney, 2009



Evening (7pm – 12am) – Sydney, 2010



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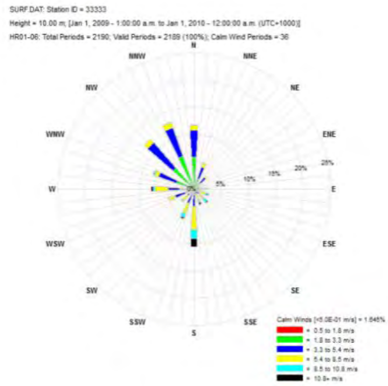
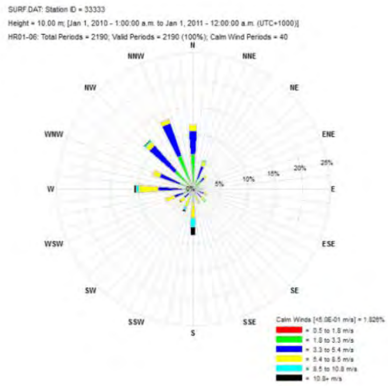
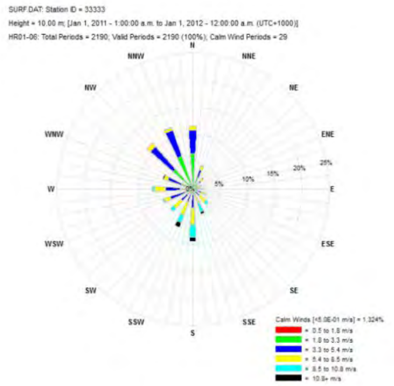


Night (1am – 6am) – Sydney, 2009



Night (1am – 6am) – Sydney, 2010



Night (1am – 6am) – Sydney, 2011

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Appendix G

Additional modelling results

Appendix G Additional modelling results

Design Analysis A

A summary of the dispersion modelling results under the theoretical maximum peak hour capacity of the project (design analysis A) for each ventilation outlet are presented in **Table G1**. Where applicable air quality criteria are predicted to be exceeded, these values are shown in bold. The 'project contribution' reflects the pollutant concentrations at receiver locations attributable to emissions from the ventilation outlets. The background data presented represent either the predicted road modelling concentrations (for road receivers) or the maximum background concentrations measured at Lindfield/Prospect for the associated time period (for receivers away from roads).

The values for PM_{10}, $PM_{2.5}$, NO_2 and CO represent the peak predicted concentrations from the project alone or the peak cumulative concentration (where relevant) across the modelling domain. The NO_2 results represent the conversion of the model NO_X predictions to NO_2 using the OLM as described in **Section 4.2.11.1**. **Figures G1** to **G12** show contour plots for the maximum predicted project contributions of PM_{10}, $PM_{2.5}$ and NO_2 for the relevant averaging periods. It should be noted that plots of cumulative concentrations are not provided.

As shown, the applicable air quality criteria are comfortably met, with the exception of cumulative 24 hour PM_{10} and $PM_{2.5}$ concentrations and annual $PM_{2.5}$. In the case of these pollutants, however, the following should be noted:

- For 24 hour PM_{10}, the contribution from the project is predicted to be very minor, with a maximum of 3.1 $\mu g/m^3$ attributable to the ventilation outlet emissions. This contribution represents six per cent of the applicable impact assessment criterion of 50 $\mu g/m^3$.
- For 24 hour $PM_{2.5,}$ the maximum contribution from the project was predicted to be 3.0 $\mu g/m^3$, which is 12 per cent of the advisory reporting standard of 25 $\mu g/m^3$.
- For annual $PM_{2.5,}$ the maximum contribution from the project was predicted to be 0.25 $\mu g/m^3$, which is three per cent of the advisory reporting standard of 8 $\mu g/m^3$.

The top ten concentrations ranked by cumulative concentration, project contribution and background concentration for PM_{10} and $PM_{2.5}$ are shown in **Tables G2** – **Table G5**. These results demonstrate that predicted exceedences of applicable assessment criteria for PM_{10} and $PM_{2.5}$ are the result of background air quality rather than contributions from the project.

The total VOC concentrations were speciated based on data published by the OEH (2012). Results are shown in **Table G6**. The predicted concentrations of individual VOC species were all well below the impact assessment criteria.

Predicted concentrations of CO and PAHs were well below the relevant impact assessment criteria. As such, no further analysis of these pollutants was undertaken.

As stated previously, the particulate emissions from vehicles primarily comprise the smaller fractions, such as PM_{10} and $PM_{2.5}$. As such, the estimated Total Suspended Particulates (TSP) emissions from vehicles essentially equate to PM_{10} emissions. The EPA has an annual criterion for TSP of 90 $\mu g/m^3$. The maximum annual average PM_{10} concentrations predicted by the modelling are well below this criterion. As a consequence, no adverse impacts from TSP are expected to result from the project.

Table G1 Predicted Pollutant Concentrations – Design Analysis A (μg/m^3)

Pollutant	Source	Averaging period	Predicted maximum concentrations (μg/m^3)		Impact assessment criteria (μg/m^3)
			Northern ventilation outlet	Southern ventilation outlet	
PM_{10}	Peak project contribution	24 hour maximum	2.2	3.1	-
		Annual average	0.2	0.3	-
	Peak cumulative concentration (project plus background)	24 hour maximum	**Cumulative concentrations shown in Table G2**		50
		Annual average	21.3	21.4	30
	Project contribution (% of criteria)	24 hour maximum	4 %	6 %	-
		Annual average	0.6 %	0.9 %	-
$PM_{2.5}$	Peak project contribution	24 hour maximum	2.1	3.0	-
		Annual average	0.16	0.25	-
	Peak cumulative concentration (project plus background)	24 hour maximum	**Cumulative concentrations shown in Table G3**		25
		Annual average	8.7	10.3	8
	Project contribution (% of criteria)	24 hour maximum	8 %	12 %	-
		Annual average	2 %	3 %	-
NO_2	Peak project contribution	1 hour maximum	114.8	98.2	-
		Annual average	2.5	2.4	-
	Peak cumulative concentration (project plus background)	1 hour maximum	182	167	246
		Annual average	39	43	62
	Project contribution (% of criteria)	1 hour maximum	47 %	40 %	-
		Annual average	4 %	4 %	-

Pollutant	Source	Averaging period	Predicted maximum concentrations (μg/m^3)		Impact assessment criteria (μg/m^3)
			Northern ventilation outlet	Southern ventilation outlet	
CO	Peak project contribution	1 hour maximum	179	167	-
		8 hour maximum	80	82	-
	Peak cumulative concentration (project plus background)	1 hour maximum	3,804	3,792	30,000
		8 hour maximum	2,682	2,684	10,000
	Project contribution (% of criteria)	1 hour maximum	0.6 %	0.6%	-
		8 hour maximum	0.8 %	0.8 %	-
Total VOC	Peak project contribution	1 hour 99.9%	7.4	9.0	29*
	Project contribution (% of criteria)	1 hour 99.9%	26 %	31 %	-
PAH	Peak project contribution	1 hour 99.9%	0.0015	0.0018	0.4
	Project contribution (% of criteria)	1 hour 99.9%	0.4 %	0.4 %	-

* as benzo(a)pyrene
** as benzene

Table G2 Predicted maximum PM_{10} concentrations (μg/m³) sorted by cumulative concentrations and project contributions – 24 hour averaging period3

Outlet	Rank	Maximum cumulative concentration (μg/m³)			Maximum project contribution (μg/m³)		
		Cumulative concentration	Project contribution	Background contribution	Project contribution	Background contribution	Cumulative concentration
Northern ventilation outlet	1	222.0	0.4	221.6	2.2	20.2	22.4
	2	134.9	0.8	134.1	1.9	8.1	10.1
	3	92.9	1.2	91.7	1.9	19.6	21.4
	4	90.5	0.7	89.8	1.9	11.1	13.0
	5	61.6	1.5	60.1	1.8	19.2	21.0
	6	61.1	1.0	60.1	1.8	9.4	11.3
	7	56.6	0.6	56.0	1.8	18.5	20.3
	8	51.5	1.3	50.2	1.8	21.0	22.8
	9	50.6	0.5	50.1	1.8	11.9	13.7
	10	49.9	1.4	48.5	1.8	9.0	10.8
Southern ventilation outlet	1	222.1	0.5	221.6	3.1	11.1	14.2
	2	134.7	0.6	134.1	3.0	17.8	20.8
	3	92.8	1.1	91.7	2.9	7.8	10.7
	4	90.4	0.6	89.8	2.8	15.0	17.9
	5	61.9	0.8	61.1	2.8	22.3	25.0
	6	60.8	0.7	60.1	2.7	19.5	22.2
	7	56.9	0.9	56.0	2.6	8.9	11.5
	8	51.4	1.2	50.2	2.6	20.2	22.7
	9	50.6	0.5	50.1	2.5	13.3	15.8
	10	49.6	1.1	48.5	2.5	17.1	19.6

Table G3 Predicted maximum PM_{10} concentrations (μg/m³) sorted by background – 24 hour averaging period –Design Analysis A

Rank	Maximum concentrations sorted by background (μg/m³)					
	Northern ventilation outlet			Southern ventilation outlet		
	Background	Project	Cumulative	Background	Project	Cumulative
1	221.6	0.4	222.0	221.6	0.5	222.1
2	134.1	0.8	134.9	134.1	0.6	134.7
3	91.7	1.2	92.9	91.7	1.1	92.8
4	89.8	0.7	90.5	89.8	0.6	90.4
5	60.1	1.5	61.6	61.1	0.8	61.9
6	60.1	1.0	61.1	60.1	0.7	60.8
7	56.0	0.6	56.6	56.0	0.9	56.9
8	50.2	1.3	51.5	50.2	1.2	51.4
9	50.1	0.5	50.6	50.1	0.5	50.6
10	48.5	1.4	49.9	48.5	1.1	49.6

Table G4 Predicted maximum $PM_{2.5}$ concentrations (μg/m³) sorted by cumulative concentrations and project contributions – 24 hour averaging period –Design analysis A

Outlet	Rank	Maximum cumulative concentration (μg/m³)			Maximum project contribution (μg/m³)		
		Cumulative concentration	Project contribution	Background contribution	Project contribution	Background contribution	Cumulative concentration
Northern ventilation outlet	1	77.9	0.4	77.6	2.1	7.1	9.2
	2	47.7	0.7	47.0	1.8	2.8	4.7
	3	33.2	1.2	32.1	1.8	6.8	8.6
	4	32.1	0.6	31.4	1.8	3.9	5.6
	5	22.0	0.9	21.0	1.7	6.7	8.5
	6	21.9	0.5	21.4	1.7	3.3	5.0
	7	20.2	0.6	19.6	1.7	6.5	8.2
	8	18.8	1.3	17.6	1.7	7.4	9.1
	9	18.3	1.3	17.0	1.7	4.2	5.9
	10	18.1	1.2	16.9	1.7	3.2	4.9
Southern ventilation outlet	1	78.0	0.4	77.6	3.0	3.9	6.9
	2	47.5	0.5	47.0	2.8	6.2	9.1
	3	33.2	1.1	32.1	2.7	5.4	8.1
	4	32.0	0.6	31.4	2.7	5.3	7.9
	5	22.1	0.8	21.4	2.6	7.8	10.4
	6	21.7	0.6	21.0	2.6	6.8	9.4
	7	20.4	0.8	19.6	2.5	3.1	5.6
	8	18.7	1.1	17.6	2.4	7.1	9.5
	9	18.2	0.0	18.2	2.4	4.6	7.1
	10	18.1	1.2	16.9	2.4	6.0	8.4

Table G5 Predicted maximum cumulative $PM_{2.5}$ concentrations ($\mu g/m^3$) sorted by background– 24 hour averaging period – Design analysis A

Rank	Design Analysis A					
	Northern ventilation outlet			Southern ventilation outlet		
	Background	Project	Cumulative	Background	Project	Cumulative
1	77.6	0.4	77.9	77.6	0.4	78.0
2	47.0	0.5	47.7	47.0	0.5	47.5
3	32.1	1.1	33.2	32.1	1.1	33.2
4	31.4	0.6	32.1	31.4	0.6	32.0
5	21.4	0.8	21.9	21.4	0.8	22.1
6	21.0	0.6	22.0	21.0	0.6	21.7
7	19.6	0.8	20.2	19.6	0.8	20.4
8	18.2	0.0	18.8	18.2	0.0	18.2
9	18.0	0.0	18.0	18.0	0.0	18.0
10	17.9	0.0	18.3	17.9	0.0	17.9

Table G6 Predicted concentrations of speciated VOCs (μg/m^3) (project contribution) – Design Analysis A

Pollutant	Averaging Period	Predicted concentrations of speciated VOCs (μg/m^3)		Impact assessment criteria (μg/m^3)
		Northern ventilation outlet	Southern ventilation outlet	
Total VOCs	1 hour 99.9 %	7.4	9.0	-
1,3-butadiene	1 hour 99.9 %	0.07	0.08	40
Acetaldehyde	1 hour 99.9 %	0.16	0.19	42
Benzene	1 hour 99.9 %	0.24	0.30	29
Formaldehyde	1 hour 99.9 %	0.36	0.44	20
Xylenes	1 hour 99.9 %	0.34	0.41	190
Toluene	1 hour 99.9 %	0.41	0.50	360

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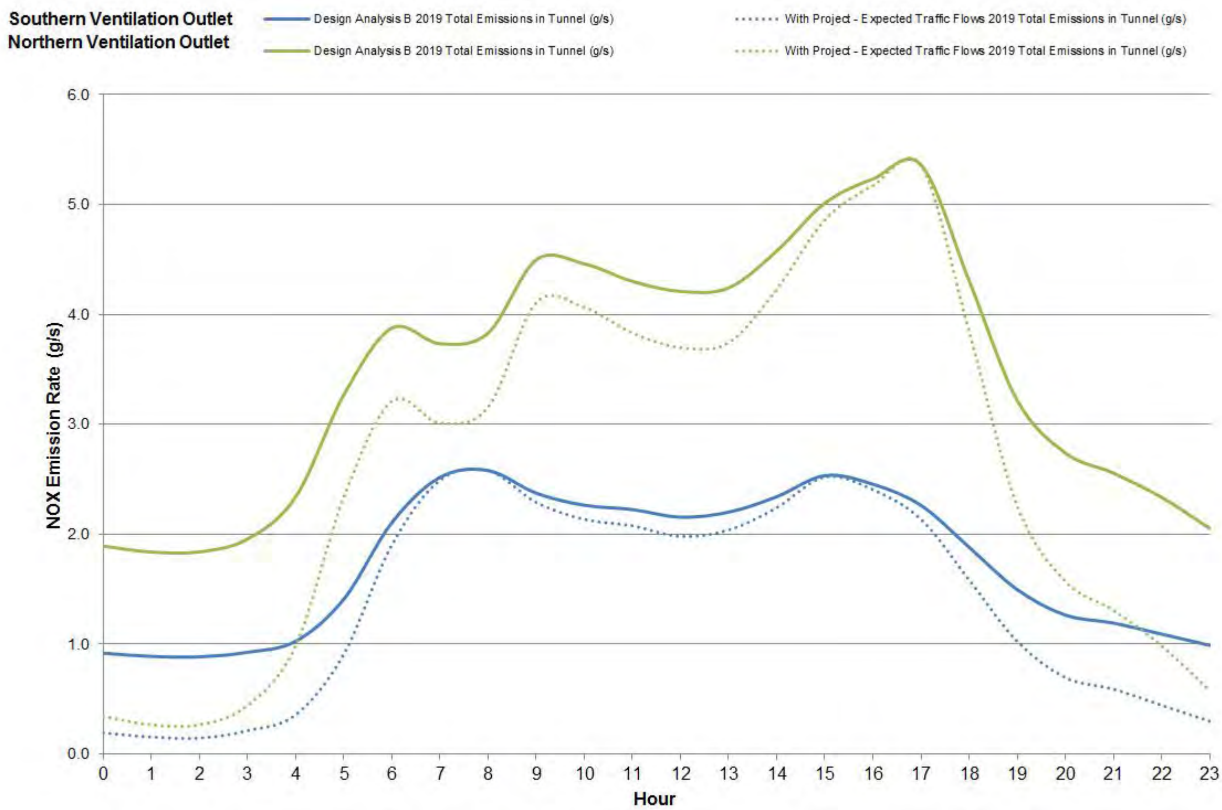
Design Analysis B

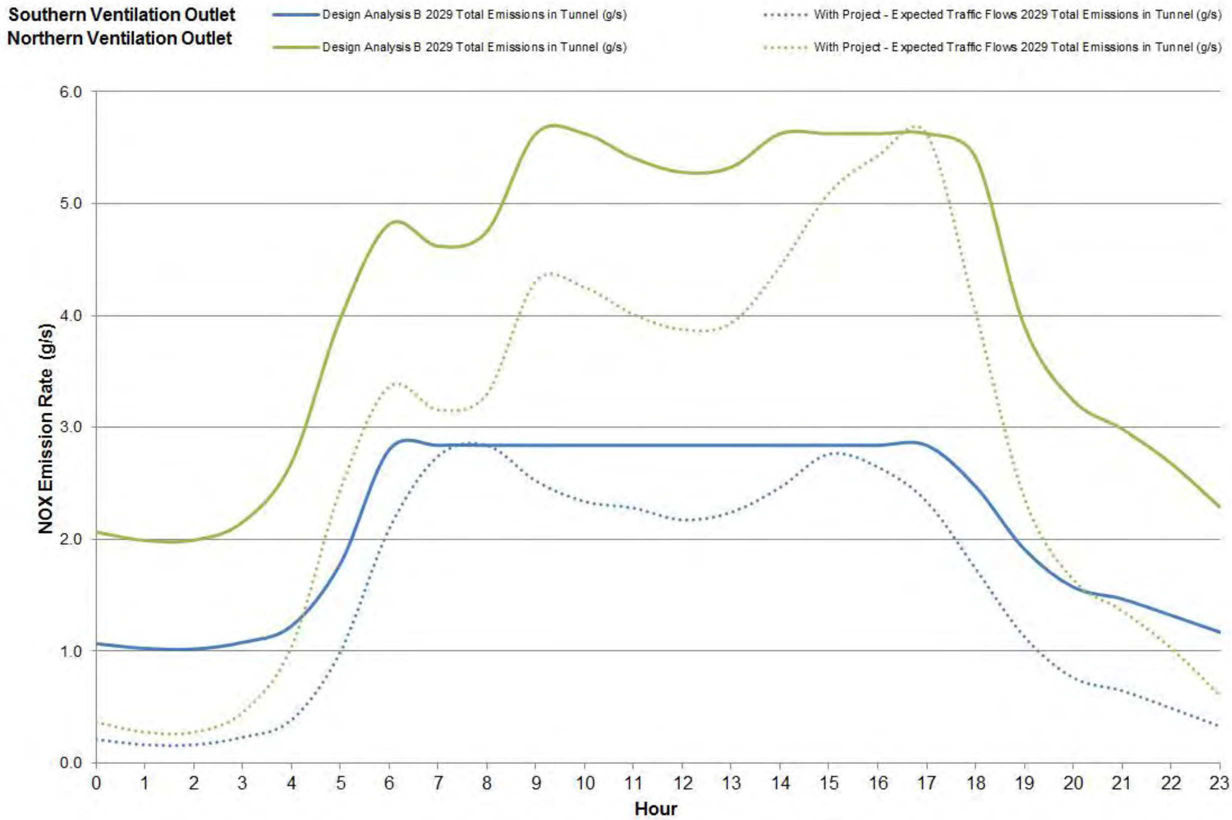
The purpose of design analysis B was to inform regulatory agencies of maximum emission concentrations from the project, which could then be used to develop licensing conditions for the project if it is approved. The Design analysis B emissions were based on those calculated for 'with project – expected traffic flows; (scenario 2a / 2b). The maximum concentrations calculated for each tunnel in 2019 and 2029 were used to develop the emission profiles for design analysis B (2019) and design analysis B (2029) respectively. For design analysis B, the maximum emission concentrations from the 'with project – expected traffic flows' 2019 and 2029 scenarios were assumed to be constant throughout each hour of the day. Those maximum emission concentrations were used to back-calculate emission rates using hourly varying volumetric flow rates, which were interpolated between the maximum and minimum flow rates from 'with project – expected traffic flows, 2019' (scenario 2a) based on predicted traffic flows.

The differences between the emission rates for the 'with project – expected traffic flows' and design analysis B are illustrated graphically in the following two figures. The solid lines show the indicative profile of the design analysis B emissions, while the dotted lines reflect the emissions calculated for 'with project – expected traffic flows'. As shown, the maxima between the two scenarios are consistent, while the other emissions vary hourly. The maximum emissions remain the same but, in effect, the other hourly emissions are shifted upwards, with the greatest differences apparent in the hours of low traffic flows. The ceiling and floor effects in the design analysis B emissions, illustrated by the shifted minima in both figures and the slight plateaus in the second figure, are a result of the application of the maximum and minimum flow rates.

The results of the dispersion modelling for design analysis B, which represented maximum / 99.9th percentile pollutant concentrations at receivers, are shown in the following table. The results represent project contributions. As expected, the predicted concentrations from design analysis B are higher than those predicted for 'with project – expected traffic flows'. The differences are, however, relatively minor.



Comparison of 'with project – expected traffic flows' and design analysis B emission profiles (2019 traffic data)



Comparison of 'with project – expected traffic flows' and design analysis B emission profiles (2029 traffic data)

Comparison of modelling results – of 'with project – expected traffic flows' and design analysis B

Pollutant	Averaging period	Predicted concentrations (μg/m³): With project – expected traffic flows, 2019 variable emission (Scenario 2a)		With project – expected traffic flows, 2019 constant emission (Design Analysis B)		With project – expected traffic flows, 2029 variable emission (Scenario 2a)		With project – expected traffic flows, 2029 constant emission (Design Analysis B)		Applicable air quality criteria (μg/m³)
		North	South	North	South	North	South	North	South	
PM_{10}	24 hour maximum	1.0	1.4	1.6	3.1	1.4	2.1	2.2	4.2	50
	Annual average	0.09	0.11	0.1	0.1	0.11	0.13	0.2	0.2	30
$PM_{2.5}$	24 hour maximum	0.9	1.3	1.5	2.9	1.3	2.0	2.1	3.9	25
	Annual average	0.08	0.11	0.10	0.13	0.10	0.13	0.10	0.18	8
NO_2	1 hour maximum	68.9	61.8	85.2	64.9	74.6	65	96.4	65.6	246
	Annual average	1.4	1.2	1.7	1.4	1.7	1.4	2.1	1.9	62
CO	1 hour maximum	86.6	70.1	128.5	143.4	107.4	90.3	159.5	178.8	30,000
	8 hour maximum	32.4	33.1	44.5	77.6	54.2	57.9	72.6	108.4	10,000
Total VOCs	1 hour 99.9%	4.0	3.7	4.5	3.9	5.38	5.36	7.07	6.92	29
PAH	1 hour 99.9%	0.00074	0.00068	0.0008	0.0007	0.00089	0.00092	0.0012	0.0012	0.4

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Appendix H

Emission calculations

Appendix H Emission calculations

This appendix provides an outline of the methodology and data sources used to calculate the emissions inventory used in this air quality impact assessment. An example calculation based on carbon monoxide is provided at the end of the appendix to demonstrate how the emissions inventory was determined.

Operational traffic data emissions

Internationally-recognised vehicle emission factors prepared by the World Road Association (PIARC, 2012) were used for the assessment. These factors are based largely on European vehicle standards, incorporating pre-Euro engine classifications through to new Euro-6 classifications, together with the penetration of hybrid fuel and electric vehicles. The document, however, includes country-specific emissions based on respective fleet compositions for a number of other locations including Australia, which is a contributing member to the World Road Association.

The PIARC emissions dataset was developed and intended for *"ventilation design purposes and differs from emissions data used for environmental assessments, as a safety margin is added to take a certain proportion of high emitting vehicles into account."* (PIARC, 2012, p.7). As the PIARC emissions data were used for the calculation of all road links in the study (i.e. the tunnel emissions and surface road emissions), the use of these emission factors was considered to be an appropriate, if conservative, approach, particularly in the absence of more applicable emission factors[6].

PIARC (2012) provides emissions data for the year 2010 for fine particulate matter (PM_{10}) (with opacity a proxy for PM_{10}), carbon monoxide and oxides of nitrogen for passenger car, light duty vehicle (LDV; < 3.5 tonnes) and heavy duty vehicle (HDV; > 3.5 tonnes) classifications. The effects of varying vehicle speeds (0 - 130 km/h) and road gradients (-6 per cent to 6 per cent) on engine load and resultant emissions are also taken into account within the emissions data. Non-exhaust related particulate emissions ($PM_{2.5}$), based on brake wear and the re-suspension of particulates from road surfaces, are also provided.

Adjustment factors provided within PIARC (2012) were used to forecast emissions for the proposed opening year of 2019 and the design year of 2029. These adjustment factors are based upon agreed assumptions on the expected continuous improvement in engine technologies, the phase-out of older, less efficient cars, and the gradual tightening of emissions legislation expected to occur between 2010 and 2020. No adjustment forecasts are provided past the year 2020; the 2020 emission data were, therefore, used to represent 2029 emissions in this assessment. This is considered to be a conservative approach due to the expected continual improvements in vehicle emissions over time and the phase out of older cars, which, subsequently, may result in an overestimation of 2029 emissions and resultant ground level pollutant concentrations.

The current Australian fleet distribution relating to the number of diesel-powered passenger vehicles and the fleet mix (proportion of LDV to HDV) data were obtained from the motor vehicle census prepared by the Australian Bureau of Statistics (ABS, 2013). Diesel-engine passenger cars were shown to make up approximately eight per cent of the current Australian fleet; this value was used in the emission calculations. The infiltration of diesel-powered passenger cars into the Australian market and fleet mix since 2008 has risen by over 100 per cent. While the use of diesel-powered vehicles is likely to continue to increase in future years, no reliable data was available regarding future trends and as such the assumption relating to eight percent of the vehicle fleet being diesel was made for this assessment. The current known petrol to diesel ratio (ABS, 2013) was, therefore, used for both 2019 and 2029.

Additional relevant road vehicle emissions not contained within PIARC (2012) (that is, exhaust-related $PM_{2.5}$, total volatile organic compounds (VOCs) and total polycyclic aromatic hydrocarbons (PAHs)) were sourced from the National Pollutant Inventory (DEWHA, 2008). Total suspended particulates were not included in the modelling as explicit emissions factors were not available from NPI or PIARC.

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[6] The recently developed database and calculation tool, COPERT Australia, was reviewed as part of the assessment process. While the software was designed specifically for road transport emission inventories across Australia, discussions with the developer determined that, due to a lack of a valid fleet mix model to allow the calculation of fleet emissions, it was not considered suitable for use in project-related road source dispersion modelling.

Surface roads emissions

Forecast vehicle numbers for the surface roads potentially affected by the project were provided based on the strategic traffic model and traffic survey counts at key locations, undertaken as part of the project (refer to technical working paper: traffic and transport (AECOM, 2014)). These data consisted of the number of passenger cars, LDVs and HDVs. Turning movements at each of the road junctions on the network were also provided for the morning and afternoon peak periods, which were then factored by AECOM transport consultants to calculate 24 hour Annual Average Weekday Traffic (AAWT) flows for use in the air quality assessment.

The use of 24 hour AAWT data was considered to be a conservative approach in the assessment, rather than the use of 24 hour Annual Average Daily Traffic (AADT), as AAWT data only take into account the weekday traffic volumes, which are typically busier than weekend traffic volumes.

Surface roads traffic emissions

The CALRoads modelling package (version 6.2.0), using the CAL3QHCR line source dispersion model, was used for the prediction of pollutant concentrations from road vehicles. The model requires roads to be split into a series of ‘links’, which represent sections where traffic conditions are reasonably homogenous in regard to vehicle flow, vehicle fleet mix, average speed and road gradient.

A network of spatially correct road ‘links’ were, therefore, entered into the model, for the roads within the assessment study area considered to be affected by the project. This was based on the existing road layout and design proposals, for both with and without the project in place.

Speed limits and congestion advice on the road network were provided by AECOM transport consultants. Vehicle speeds at junctions were adjusted based on professional judgement. Between 300 – 400 road ‘links’ were entered into the model for each scenario to comprehensively represent the variable sections of road across the network in terms of vehicle emissions.

All roads modelled within the surface network were taken as being at 0 per cent grade (that is, flat), with the exception of the M1 Pacific Motorway and Hills M2 Motorway exit and entry ramps and the project portal entry and exit ramps.

Predicted emissions for the surface roads were calculated using the methodology (for the pollutants of concern) discussed in **Section 5** and entered into the model as grams per vehicle-mile, as required for the dispersion model.

Tunnel outlet ventilation emissions

Total traffic data emissions

<u>Traffic data counts</u>

Tunnel traffic data for ‘with project – expected traffic flows, 2019’ (Scenario 2a) and ‘with project – expected traffic flows, 2029’ (Scenario 2b) were obtained from strategic transport model.

For design analysis A, both northbound and southbound traffic, hourly traffic data were scaled from the 2019 hourly traffic data profiles using :

Equation 1

$$VPH_h^{Max} = VPH_h^{2019} \times \frac{4000}{VPH_{Max}^{2019}}$$

where:

VPH_h^{Max} = Maximum vehicles per hour for a given hour

VPH_h^{2019} = Vehicles per hour for 2019 for a given hour

VPH_{Max}^{2019} = Vehicles per hour for 2019 during peak hour

In-tunnel traffic vehicle emissions

As stated previously, the proposed project consists of two two-lane tunnels – one to carry southbound vehicles, and one to carry northbound vehicles. The number of vehicles within the proposed tunnels would vary throughout a 24-hour period and, subsequently, the level of pollutant emissions associated with vehicle movements would vary. Forecast hourly mainline vehicle numbers, heavy vehicle percentages and vehicle speeds for each tunnel were provided to AECOM for the opening year of the tunnel and 10 years after opening (2019 and 2029, respectively) for both southbound and northbound tunnels.

Predicted pollutant emissions from vehicles within the tunnel were calculated based on the methodology outlined in Section A1, taking into account the number of vehicles each hour, the speed and the fleet composition. The vertical design alignment of the tunnel was also taken into account, and each tunnel was split into a series of homogenous sections to calculate the differing emissions resulting from gradient changes along the lengths of the tunnels. Gradient data for the emission calculations were obtained from the design documents.

The assessment was conducted assuming zero emissions from the tunnel portals; that is, all vehicle emissions were assumed to be force vented via the tunnel ventilation outlets at the end of each tunnel. As such, the total tunnel emissions were calculated based on the sum of each section’s emissions, factoring in the length of each section, the time taken for vehicles in the tunnel to pass through each section, the density of vehicles in the tunnel and the respective gradients. Hourly emission rates in grams per second were generated for the identified pollutants of concern for each individual tunnel for the expected traffic flows in the assessment years 2019 and 2029. The calculated emission rates used in the modelling assessment for the two tunnels are detailed at the end of this section.

Volumetric flow rates

Hourly volumetric flow rates (VFRs) were provided by for all scenarios modelled in this assessment. Volumetric flow rates were initially calculated for each hourly predicted traffic flow rates. This volumetric flow rate was then assigned to one of the “VSO Running Levels”, which defined the conditions under which the ventilation stations will be operated. The running level above the predicted volumetric flow rate was adopted for each hour. Rates were based on a minimum VFR of 300 Nm^3/s and a maximum design capacity of 700 Nm^3/s (four fans operating at a maximum capacity of 175 Nm^3/s each). Settings provided to AECOM are shown in the following table.

Variable flow rates and velocities

Ventilation outlet airflow (m^3/s)	VSO running level	Ventilation outlet partition 1 status ($29\ m^2$)	Ventilation outlet partition 2 status ($17\ m^2$)	Ventilation outlet velocity (m/s)
700	6	Open	Open	15.2
620	5	Open	Open	13.5
540	4	Open	Closed	18.6
460	3	Open	Closed	15.9
380	2	Open	Closed	13.1
300	1	Closed	Open	17.6

Hourly variable outlet velocity and temperature

In order to estimate the likely temperature of the ventilation outlet emissions from the project, outlet temperature data measured at the Lane Cove tunnel were analysed. As the Lane Cove Tunnel is located in a different area of Sydney in relation to the project, the actual temperatures measured at this facility were not considered appropriate for use. Instead, the differences between the outlet emission temperatures and the ambient temperatures were determined for every hour of the meteorological modelling period (2009 – 2011). The average temperature variations for each hour of each season were then calculated (for example, the average variation between ambient and outlet emission temperatures at 1 am between December 1 and February 28 for each year was calculated, then 2 am, 3 am , 4 am and so on for each hour of the day and for each season). The hourly seasonal average temperature differences were then applied to the temperature data predicted for the project's ambient environment to calculate the estimated temperatures of emissions from the ventilation outlets.

The project would be serviced by ventilation systems, the operating parameters of which would vary depending on traffic flows. As such, the volume of air to be extracted from the tunnels would vary each hour and, therefore, the number of fans and the output of the fans would vary on an hourly basis, resulting in hourly-varying outlet emission velocities and flow rates. In order to accommodate this variation, the ventilation outlets would be partitioned so that portions of the ventilation outlets can be closed off when traffic flows are low in order to maintain good plume dispersion. This would result in time-varying ventilation outlet diameters. The CALPUFF model does not provide the functionality to enter time-varying outlet diameters. In order to accurately model the outlet emissions, each ventilation outlet was, therefore, modelled as three separate concentric outlets to allow for the operation of the different segments to be incorporated into the model.

The ventilation areas and settings the systems were designed for were provided by Roads and Maritime. Details are provided below.

Maximum outlet concentrations

Outlet concentrations

In-tunnel traffic vehicle emissions calculated using the methodology described above and the hourly-varying VFR profiles for each outlet were used to calculate the hourly-varying pollutant emission concentrations using .

Equation 2

$$C_h^s = {E_{h_i}^s}/{VFR_h^s}$$

where:

C_h^s	=	*Outlet concentration for a given scenario (s) at a given hour (h) in (g/Nm^3)*
$E_{h_i}^s$	=	*Emission rate for pollutant 'i' for a given scenario (s) at a given hour (h) in (g/s)*
VFR_h^s	=	*Volumetric flow rate for scenario being examined for a given hour (Nm^3/s)*

Worst case emission concentrations

The diurnal outlet concentration profile was examined to determine the maximum outlet concentration for 'with project – expected traffic flows' for 2019 and 2029 (scenarios 2a and 2b). This value was used to identify the likely worst case scenario and provide guidance to the EPA for determining the conditions of consent for the project. The maximum outlet concentration was then used to calculate the worst case emission concentrations for the project by applying the maximum outlet concentration to the VFR profiles as calculated using the equations above.

Emission rates calculated using the maximum outlet concentrations and the calculated volumetric flow rates were then incorporated into the model to predict ground level concentrations using .

Equation 3

$$ME^s_{h_i} = C^s_{Max} \times VFR^s_h$$

Where:

C^s_{Max}	=	Maximum outlet concentration for a given scenario (s) in (g/Nm^3)
$ME^s_{h_i}$	=	Emission rate for pollutant 'i' for a given scenario (s) at a given hour (h) in (g/s) using the maximum outlet concentration.
VFR^s_h	=	Volumetric flow rate for scenario being examined for a given hour (Nm^3/s)

Summary of ventilation outlet input parameters

The following tables provide a description of the assumptions made for the north and south outlet input parameters respectively including reference sources.

Northern ventilation outlet input parameters

Parameter	Value	Reference	Comments and assumptions
Outlet location	325,359 m E, 6,268,211 m S (MGA 56)	F3M2-5000-DR-UD-547	Estimated from plan.
Outlet height	15 metres	F3M2-5000-DR-UD-550	Outlet 15 metres above adjacent land taken from plan.
Outlet diameter	Hourly variable	F3M2-440-DR-US-0106	Based on maximum outlet opening area of 46 m^2.
Outlet temperature	Hourly variable	CALMET.DAT files	Hourly temperature data assumed to be equal to ambient temperature with a correction. Temperature data were extracted from CALMET outputs at 325,060 m E, 6,267,858 m S (MGA 56). Ventilation outlet temperature differentials were added to outlet parameters to better replicate the expected hotter air leaving the ventilation outlets than the ambient air conditions.
Outlet velocity	Hourly variable	Not applicable	Hourly velocity was calculated based on the hourly volumetric flow rates corrected for the expected ventilation outlet temperatures.
Building wakes[1]	Variable	F3M2-5000-DR-UD-547 F3M2-5000-DR-UD-550 F3M2-5000-DR-UD-555 F3M2-5000-DR-UD-556	Building dimensions from the sub-station, northern ventilation station (VS07) and deluge tanks were estimated from plans and input into the BPIP to estimate building wake effects on the northern outlet

[1] Note that building heights were modified to a maximum of 7 metres above surrounding land height for the modelling. This is different to the information provided in the engineering drawing and was adopted after consultation with Transurban.

Southern ventilation outlet input parameters

Parameter	Value	Reference	Comments and assumptions
Outlet location	319,233 m E, 6,262,984 m S (MGA 56)	F3M2-5000-DR-UD-0516	Estimated from plan.
Outlet height	15 m	F3M2-5000-DR-SK-UD-0525	Outlet 15 metres above adjacent land taken from plan
Outlet diameter	7.90 m	F3M2-440-DR-US-0100.	Based on outlet opening area of 46 m^2.
Outlet temperature	Hourly variable	CALMET.DAT Files	Hourly temperature data assumed to be equal to ambient temperature with a correction. Temperature data were extracted from CALMET output at 319.244 m E, 6,262,993 m S (MGA 56). Ventilation outlet temperature differentials were added to outlet parameters to better replicate the expected hotter air leaving the ventilation outlets than the ambient air conditions.
Outlet velocity	Hourly variable	Not applicable	Hourly velocities were calculated based on the hourly volumetric flow rates.
Building wakes[1]	Variable	F3M2-5000-DR-UD-0516 F3M2-5000-DR-SK-UD-0510 F3M2-5000-DR-SK-UD-0508 F3M2-5000-DR-UD-DU-0513 F3M2-5000-DR-SK-UD-0525	Building dimensions from the southern ventilation station (VS01), water tank, covered service yard, workshop and Motorway Control Centre (MCC) were estimated from plans and input into the BPIP to estimate building wake effects on the southern outlet. Building parameters used to calculate building wakes are presented in the following table.
[1] Note that building heights were modified to a maximum of 7metres above surrounding land height for the modelling. This is different to the information provided in the engineering drawing and was adopted after consultation with Transurban.			

Building parameters used to calculate building wakes are presented in the following table.

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Building parameters used to calculate building wakes

ID	Description	Tier	Tier height (metres)	Diameter (metres)	Coordinates (MGA 56)							
					X1	Y1	X2	Y2	X3	Y3	X4	Y4
1	Deluge Tank 1	1	6.0	12	325,339	6,268,237						
2	Deluge Tank 2	1	6.0	12	325,356	6,268,235						
3	Northern ventilation facility	1	7.0		325,352	6,268,217	325,369	6,268,208	325,345	6,268,163	325,328	6,268,172
		2	15.0		325,355	6,268,215	325,353	6,268,210	325,362	6,268,206	325,364	6,268,211
4	North substation	1	4.5		325,328	6,268,168	325,311	6,268,135	325,318	6,268,131	325,336	6,268,164
5	Southern ventilation facility	1	6.0		319,206	6,263,028	319,196	6,263,026	319,198	6,263,016	319,208	6,263,018
		2	6.0		319,201	6,263,016	319,205	6,262,992	319,213	6,262,994	319,208	6,263,018
		3	6.0		319,213	6,262,994	319,202	6,262,992	319,205	6,262,981	319,215	6,262,983
		4	13.2		319,244	6,263,041	319,205	6,263,034	319,216	6,262,978	319,255	6,262,985
		5	18.0		319,227	6,262,985	319,238	6,262,988	319,240	6,262,981	319,228	6,262,979
		6	20.4		319,232	6,262,980	319,232	6,262,979	319,239	6,262,981	319,239	6,262,981
6	Covered service yard	1	8.7		319,192	6,263,095	319,200	6,263,055	319,225	6,263,060	319,217	6,263,100
7	Workshop	1	8.4		319,183	6,263,187	319,172	6,263,185	319,185	6,263,115	319,196	6,263,117
		2	8.4		319,205	6,263,118	319,194	6,263,175	319,185	6,263,174	319,196	6,263,117
8	Motorway control centre	1	11.5		319,127	6,263,370	319,139	6,263,306	319,169	6,263,312	319,156	6,263,376
9	Water tank	1	7.6	9	319,230	6,263,045	319,230	6,263,045	319,230	6,263,045	319,230	6,263,045

Emission rates

‘With project – expected traffic flows’

Tunnel outlet emission rates (g/s) – ‘With project – expected traffic flows, 2019’ (Scenario 2a)

Northbound							Southbound						
Hour	Calculated total emissions in tunnel (g/s)						Hour	Calculated total emissions in tunnel (g/s)					
	CO	NOx	PM_{10}	$PM_{2.5}$	TVOCs	PAHs		CO	NOx	PM_{10}	$PM_{2.5}$	TVOCs	PAHs
1	0.248	0.344	0.044	0.042	0.025	0.000005	1	0.177	0.194	0.030	0.028	0.0176	0.000003
2	0.190	0.266	0.034	0.032	0.019	0.000004	2	0.139	0.153	0.024	0.022	0.0138	0.000003
3	0.193	0.266	0.034	0.032	0.019	0.000004	3	0.134	0.146	0.022	0.021	0.0133	0.000002
4	0.316	0.438	0.056	0.053	0.031	0.000006	4	0.187	0.210	0.032	0.031	0.0187	0.000003
5	0.720	0.988	0.126	0.120	0.071	0.000013	5	0.317	0.355	0.055	0.052	0.0318	0.000006
6	1.696	2.336	0.299	0.284	0.168	0.000031	6	0.813	0.904	0.139	0.132	0.0812	0.000015
7	2.336	3.214	0.411	0.390	0.232	0.000042	7	1.717	1.905	0.293	0.278	0.1714	0.000032
8	2.187	3.010	0.385	0.366	0.217	0.000040	8	2.252	2.494	0.384	0.365	0.2247	0.000042
9	2.289	3.151	0.403	0.383	0.227	0.000041	9	2.331	2.583	0.397	0.378	0.2327	0.000043
10	2.991	4.108	0.525	0.499	0.296	0.000054	10	2.064	2.292	0.353	0.335	0.2061	0.000038
11	2.952	4.061	0.519	0.493	0.293	0.000053	11	1.922	2.131	0.328	0.311	0.1918	0.000036
12	2.785	3.826	0.489	0.465	0.276	0.000050	12	1.872	2.074	0.319	0.303	0.1868	0.000035
13	2.688	3.700	0.473	0.449	0.267	0.000049	13	1.781	1.977	0.304	0.289	0.1779	0.000033
14	2.722	3.747	0.479	0.455	0.270	0.000049	14	1.840	2.042	0.314	0.298	0.1837	0.000034
15	3.074	4.233	0.541	0.514	0.305	0.000056	15	2.022	2.244	0.345	0.328	0.2019	0.000037
16	3.534	4.860	0.621	0.590	0.350	0.000064	16	2.272	2.518	0.387	0.368	0.2268	0.000042
17	3.766	5.175	0.661	0.628	0.373	0.000068	17	2.170	2.405	0.370	0.352	0.2166	0.000040
18	3.899	5.362	0.685	0.651	0.387	0.000071	18	1.920	2.131	0.328	0.311	0.1917	0.000036

Northbound							Southbound						
Hour	Calculated total emissions in tunnel (g/s)						Hour	Calculated total emissions in tunnel (g/s)					
	CO	NOx	PM_{10}	$PM_{2.5}$	TVOCs	PAHs		CO	NOx	PM_{10}	$PM_{2.5}$	TVOCs	PAHs
19	2.790	3.841	0.491	0.466	0.277	0.000051	19	1.426	1.582	0.243	0.231	0.1423	0.000026
20	1.644	2.258	0.289	0.274	0.163	0.000030	20	0.926	1.025	0.158	0.150	0.0924	0.000017
21	1.141	1.568	0.200	0.190	0.113	0.000021	21	0.626	0.694	0.107	0.101	0.0625	0.000012
22	0.947	1.302	0.166	0.158	0.094	0.000017	22	0.533	0.589	0.091	0.086	0.0531	0.000010
23	0.715	0.987	0.126	0.120	0.071	0.000013	23	0.403	0.444	0.068	0.065	0.0401	0.000007
24	0.417	0.579	0.074	0.070	0.042	0.000008	24	0.269	0.299	0.046	0.044	0.0268	0.000005

Tunnel outlet emission rates (g/s) – 'With project – expected traffic flows, 2029' (Scenario 2b)

Northbound							Southbound						
Hour	Calculated total emissions in tunnel (g/s)						Hour	Calculated total emissions in tunnel (g/s)					
	CO	NOx	PM_{10}	$PM_{2.5}$	TVOCs	PAHs		CO	NOx	PM_{10}	$PM_{2.5}$	TVOCs	PAHs
1	0.307	0.373	0.047	0.044	0.029	0.000005	1	0.220	0.213	0.032	0.030	0.021	0.000004
2	0.236	0.288	0.036	0.034	0.023	0.000004	2	0.172	0.169	0.025	0.024	0.017	0.000003
3	0.240	0.288	0.036	0.034	0.023	0.000004	3	0.166	0.160	0.024	0.023	0.016	0.000003
4	0.392	0.475	0.059	0.056	0.037	0.000006	4	0.233	0.230	0.035	0.033	0.022	0.000004
5	0.894	1.070	0.134	0.127	0.085	0.000014	5	0.394	0.389	0.059	0.056	0.038	0.000006
6	2.105	2.529	0.316	0.301	0.201	0.000033	6	1.010	0.993	0.149	0.142	0.097	0.000016
7	2.898	3.480	0.435	0.413	0.276	0.000046	7	2.133	2.092	0.314	0.299	0.205	0.000035
8	2.714	3.259	0.408	0.387	0.259	0.000043	8	2.797	2.740	0.412	0.391	0.269	0.000046
9	2.840	3.411	0.427	0.405	0.271	0.000045	9	2.896	2.837	0.426	0.405	0.278	0.000047
10	3.712	4.448	0.556	0.528	0.353	0.000059	10	2.564	2.517	0.378	0.359	0.246	0.000042
11	3.663	4.396	0.550	0.522	0.349	0.000058	11	2.388	2.341	0.352	0.334	0.229	0.000039

Northbound							Southbound						
Hour	Calculated total emissions in tunnel (g/s)						Hour	Calculated total emissions in tunnel (g/s)					
	CO	NOx	PM_{10}	$PM_{2.5}$	TVOCs	PAHs		CO	NOx	PM_{10}	$PM_{2.5}$	TVOCs	PAHs
12	3.456	4.143	0.518	0.492	0.329	0.000055	12	2.325	2.279	0.342	0.325	0.223	0.000038
13	3.335	4.006	0.501	0.476	0.318	0.000053	13	2.213	2.172	0.326	0.310	0.213	0.000036
14	3.377	4.056	0.507	0.482	0.322	0.000053	14	2.286	2.243	0.337	0.320	0.220	0.000037
15	3.815	4.582	0.573	0.545	0.363	0.000060	15	2.512	2.464	0.370	0.352	0.241	0.000041
16	4.385	5.262	0.658	0.625	0.418	0.000069	16	2.823	2.766	0.416	0.395	0.271	0.000046
17	4.673	5.603	0.701	0.666	0.445	0.000074	17	2.696	2.642	0.397	0.377	0.259	0.000044
18	4.838	5.805	0.726	0.690	0.461	0.000076	18	2.385	2.340	0.352	0.334	0.229	0.000039
19	3.462	4.158	0.520	0.494	0.330	0.000055	19	1.771	1.737	0.261	0.248	0.170	0.000029
20	2.040	2.445	0.306	0.290	0.194	0.000032	20	1.151	1.126	0.169	0.161	0.111	0.000019
21	1.415	1.698	0.212	0.202	0.135	0.000022	21	0.778	0.762	0.115	0.109	0.075	0.000013
22	1.176	1.409	0.176	0.167	0.112	0.000019	22	0.662	0.647	0.097	0.092	0.064	0.000011
23	0.887	1.069	0.134	0.127	0.085	0.000014	23	0.500	0.488	0.073	0.070	0.048	0.000008
24	0.518	0.627	0.078	0.075	0.049	0.000008	24	0.334	0.328	0.049	0.047	0.032	0.000005

Design Analysis A

Emission rates (g/s) from scaled vehicle numbers (Design analysis A) (2019)

Northbound							Southbound						
Hour	Calculated total emissions in tunnel (g/s)						Hour	Calculated total emissions in tunnel (g/s)					
	CO	NOx	PM_{10}	$PM_{2.5}$	TVOCs	PAHs		CO	NOx	PM_{10}	$PM_{2.5}$	TVOCs	PAHs
1	0.51	0.71	0.04	0.0394	0.0511	0.000009	1	0.397	0.435	0.040	0.0382	0.039	0.000007
2	0.39	0.55	0.03	0.0304	0.0393	0.000007	2	0.311	0.344	0.032	0.0301	0.031	0.000006
3	0.40	0.55	0.03	0.0305	0.0397	0.000007	3	0.300	0.327	0.030	0.0287	0.030	0.000005
4	0.65	0.91	0.05	0.0501	0.0650	0.000012	4	0.420	0.470	0.043	0.0410	0.042	0.000008
5	1.49	2.05	0.12	0.1133	0.1479	0.000027	5	0.711	0.795	0.073	0.0694	0.071	0.000013
6	3.51	4.84	0.28	0.2676	0.3486	0.000064	6	1.824	2.026	0.187	0.1771	0.182	0.000034
7	4.84	6.66	0.39	0.3683	0.4799	0.000088	7	3.850	4.270	0.395	0.3734	0.384	0.000071
8	4.53	6.24	0.36	0.3449	0.4494	0.000082	8	5.348	5.828	0.544	0.5146	0.551	0.000109
9	4.74	6.53	0.38	0.3611	0.4703	0.000086	9	5.538	6.036	0.564	0.5329	0.571	0.000113
10	6.20	8.51	0.50	0.4710	0.6142	0.000112	10	4.903	5.355	0.500	0.4725	0.506	0.000100
11	6.12	8.41	0.49	0.4654	0.6064	0.000111	11	4.309	4.777	0.442	0.4178	0.430	0.000080
12	5.77	7.93	0.46	0.4386	0.5719	0.000104	12	4.196	4.650	0.430	0.4068	0.419	0.000078
13	5.57	7.67	0.45	0.4240	0.5523	0.000101	13	3.993	4.432	0.410	0.3876	0.399	0.000074
14	5.64	7.76	0.45	0.4293	0.5593	0.000102	14	4.126	4.577	0.424	0.4003	0.412	0.000076
15	6.37	8.77	0.51	0.4850	0.6317	0.000115	15	4.804	5.242	0.489	0.4627	0.495	0.000098
16	6.63	9.88	0.60	0.5713	0.6940	0.000142	16	5.398	5.884	0.550	0.5195	0.556	0.000110
17	7.06	10.52	0.64	0.6084	0.7393	0.000151	17	5.154	5.620	0.525	0.4962	0.531	0.000105
18	7.31	10.90	0.67	0.6303	0.7657	0.000157	18	4.305	4.776	0.442	0.4177	0.430	0.000080
19	5.78	7.96	0.47	0.4401	0.5733	0.000105	19	3.196	3.546	0.328	0.3101	0.319	0.000059

Northbound							Southbound						
Hour	Calculated total emissions in tunnel (g/s)						Hour	Calculated total emissions in tunnel (g/s)					
	CO	NOx	PM_{10}	$PM_{2.5}$	TVOCs	PAHs		CO	NOx	PM_{10}	$PM_{2.5}$	TVOCs	PAHs
20	3.41	4.68	0.27	0.2589	0.3376	0.000062	20	2.077	2.299	0.213	0.2011	0.207	0.000038
21	2.36	3.25	0.19	0.1797	0.2343	0.000043	21	1.404	1.556	0.144	0.1361	0.140	0.000026
22	1.96	2.70	0.16	0.1492	0.1946	0.000036	22	1.194	1.321	0.122	0.1156	0.119	0.000022
23	1.48	2.05	0.12	0.1130	0.1471	0.000027	23	0.902	0.996	0.092	0.0872	0.090	0.000017
24	0.86	1.20	0.07	0.0663	0.0860	0.000016	24	0.603	0.669	0.062	0.0585	0.060	0.000011

Design analysis B – expected traffic flows with maximum emission concentrations

Tunnel outlet emission rates (g/s) – Design analysis B (2019)

Northbound							Southbound						
Hour	Calculated total emissions in tunnel (g/s)						Hour	Calculated total emissions in tunnel (g/s)					
	CO	NOx	PM_{10}	$PM_{2.5}$	TVOCs	TPAHs		CO	NOx	PM_{10}	$PM_{2.5}$	TVOCs	TPAHs
1	1.89	2.59	0.15	0.14	0.187	0.000034	1	1.13	1.25	0.12	0.1093	0.113	0.000021
2	1.89	2.59	0.15	0.14	0.187	0.000034	2	1.13	1.25	0.12	0.1093	0.113	0.000021
3	1.89	2.59	0.15	0.14	0.187	0.000034	3	1.13	1.25	0.12	0.1093	0.113	0.000021
4	1.89	2.59	0.15	0.14	0.187	0.000034	4	1.13	1.25	0.12	0.1093	0.113	0.000021
5	2.39	3.29	0.19	0.18	0.237	0.000043	5	1.43	1.58	0.15	0.1385	0.143	0.000026
6	2.89	3.98	0.23	0.22	0.287	0.000052	6	1.73	1.92	0.18	0.1677	0.173	0.000032
7	3.40	4.67	0.27	0.26	0.337	0.000061	7	2.03	2.25	0.21	0.1968	0.203	0.000038
8	3.40	4.67	0.27	0.26	0.337	0.000061	8	2.33	2.58	0.24	0.2260	0.233	0.000043
9	3.40	4.67	0.27	0.26	0.337	0.000061	9	2.33	2.58	0.24	0.2260	0.233	0.000043
10	3.40	4.67	0.27	0.26	0.337	0.000061	10	2.33	2.58	0.24	0.2260	0.233	0.000043
11	3.40	4.67	0.27	0.26	0.337	0.000061	11	2.03	2.25	0.21	0.1968	0.203	0.000038
12	3.40	4.67	0.27	0.26	0.337	0.000061	12	2.03	2.25	0.21	0.1968	0.203	0.000038
13	3.40	4.67	0.27	0.26	0.337	0.000061	13	2.03	2.25	0.21	0.1968	0.203	0.000038
14	3.40	4.67	0.27	0.26	0.337	0.000061	14	2.03	2.25	0.21	0.1968	0.203	0.000038
15	3.40	4.67	0.27	0.26	0.337	0.000061	15	2.33	2.58	0.24	0.2260	0.233	0.000043
16	3.90	5.36	0.31	0.30	0.387	0.000071	16	2.33	2.58	0.24	0.2260	0.233	0.000043
17	3.90	5.36	0.31	0.30	0.387	0.000071	17	2.33	2.58	0.24	0.2260	0.233	0.000043
18	3.90	5.36	0.31	0.30	0.387	0.000071	18	2.03	2.25	0.21	0.1968	0.203	0.000038
19	3.40	4.67	0.27	0.26	0.337	0.000061	19	2.03	2.25	0.21	0.1968	0.203	0.000038

Northbound							Southbound						
Hour	Calculated total emissions in tunnel (g/s)						Hour	Calculated total emissions in tunnel (g/s)					
	CO	NOx	PM_{10}	$PM_{2.5}$	TVOCs	TPAHs		CO	NOx	PM_{10}	$PM_{2.5}$	TVOCs	TPAHs
20	2.89	3.98	0.23	0.22	0.287	0.000052	20	1.73	1.92	0.18	0.1677	0.173	0.000032
21	2.89	3.98	0.23	0.22	0.287	0.000052	21	1.73	1.92	0.18	0.1677	0.173	0.000032
22	2.39	3.29	0.19	0.18	0.237	0.000043	22	1.43	1.58	0.15	0.1385	0.143	0.000026
23	2.39	3.29	0.19	0.18	0.237	0.000043	23	1.43	1.58	0.15	0.1385	0.143	0.000026
24	2.39	3.29	0.19	0.18	0.237	0.000043	24	1.43	1.58	0.15	0.1385	0.143	0.000026

Tunnel outlet emission rates – Design analysis B (2029)

Northbound							Southbound						
Hour	Calculated total emissions in tunnel (g/s)						Hour	Calculated total emissions in tunnel (g/s)					
	CO	NOx	PM_{10}	$PM_{2.5}$	TVOCs	TPAHs		CO	NOx	PM_{10}	$PM_{2.5}$	TVOCs	TPAHs
1	2.34	2.81	0.18	0.17	0.223	0.000037	1	1.40	1.37	0.14	0.13	0.135	0.000023
2	2.34	2.81	0.18	0.17	0.223	0.000037	2	1.40	1.37	0.14	0.13	0.135	0.000023
3	2.34	2.81	0.18	0.17	0.223	0.000037	3	1.40	1.37	0.14	0.13	0.135	0.000023
4	2.97	3.56	0.22	0.21	0.282	0.000047	4	1.40	1.37	0.14	0.13	0.135	0.000023
5	2.97	3.56	0.22	0.21	0.282	0.000047	5	1.78	1.74	0.17	0.16	0.170	0.000029
6	4.21	5.06	0.32	0.30	0.401	0.000067	6	2.15	2.11	0.21	0.20	0.206	0.000035
7	4.21	5.06	0.32	0.30	0.401	0.000067	7	2.90	2.84	0.29	0.27	0.278	0.000047
8	4.21	5.06	0.32	0.30	0.401	0.000067	8	2.90	2.84	0.29	0.27	0.278	0.000047
9	4.21	5.06	0.32	0.30	0.401	0.000067	9	2.90	2.84	0.29	0.27	0.278	0.000047
10	4.84	5.81	0.36	0.34	0.461	0.000076	10	2.90	2.84	0.29	0.27	0.278	0.000047
11	4.84	5.81	0.36	0.34	0.461	0.000076	11	2.90	2.84	0.29	0.27	0.278	0.000047
12	4.84	5.81	0.36	0.34	0.461	0.000076	12	2.90	2.84	0.29	0.27	0.278	0.000047
13	4.84	5.81	0.36	0.34	0.461	0.000076	13	2.90	2.84	0.29	0.27	0.278	0.000047
14	4.84	5.81	0.36	0.34	0.461	0.000076	14	2.90	2.84	0.29	0.27	0.278	0.000047
15	4.84	5.81	0.36	0.34	0.461	0.000076	15	2.90	2.84	0.29	0.27	0.278	0.000047
16	4.84	5.81	0.36	0.34	0.461	0.000076	16	2.90	2.84	0.29	0.27	0.278	0.000047
17	4.84	5.81	0.36	0.34	0.461	0.000076	17	2.90	2.84	0.29	0.27	0.278	0.000047
18	4.84	5.81	0.36	0.34	0.461	0.000076	18	2.90	2.84	0.29	0.27	0.278	0.000047
19	4.84	5.81	0.36	0.34	0.461	0.000076	19	2.52	2.47	0.25	0.23	0.242	0.000041
20	4.21	5.06	0.32	0.30	0.401	0.000067	20	2.15	2.11	0.21	0.20	0.206	0.000035

Northbound							Southbound						
Hour	Calculated total emissions in tunnel (g/s)						Hour	Calculated total emissions in tunnel (g/s)					
	CO	NOx	PM_{10}	$PM_{2.5}$	TVOCs	TPAHs		CO	NOx	PM_{10}	$PM_{2.5}$	TVOCs	TPAHs
21	3.59	4.31	0.27	0.26	0.342	0.000057	21	2.15	2.11	0.21	0.20	0.206	0.000035
22	3.59	4.31	0.27	0.26	0.342	0.000057	22	2.15	2.11	0.21	0.20	0.206	0.000035
23	2.97	3.56	0.22	0.21	0.282	0.000047	23	1.78	1.74	0.17	0.16	0.170	0.000029
24	2.97	3.56	0.22	0.21	0.282	0.000047	24	1.78	1.74	0.17	0.16	0.170	0.000029

Example calculation – carbon monoxide

The emissions data for the project were compiled based on the expected diurnal traffic volumes, vehicle fleet mix, fleet emissions profile (based on year of emission) and tunnel characteristics (length, grade capacity etc.).

An example of an emissions calculation (using carbon monoxide) is provided below to explain how the emissions were calculated and to define the sources of the data.

The emission factors used in this assessment were sourced from PIARC (2012), which provides different emission factors for different vehicle speeds and road gradients (slopes). The PIARC (2012) emissions data for carbon monoxide for passenger cars, light diesel vehicles and heavy vehicles are shown in the following tables.

Base emission factors for carbon monoxide – Passenger cars (gasoline) (Table 29 of PIARC, 2012)

Passenger car – gasoline CO (g/h) 2010							
	Gradient %						
v (km/h)	-6	-4	-2	0	2	4	6
0	38.9	38.9	38.9	38.9	38.9	38.9	38.9
10	45.3	48.5	52.4	56.3	61.9	68.1	80.3
20	51.6	58.2	66	73.7	84.8	97.3	121.7
30	51.7	61.4	73.4	88.3	106.1	126.2	166.7
40	51.4	64.4	81.8	106.1	136.1	177.3	227.3
50	50.3	66.1	88.9	120.8	164.6	228	307
60	48.8	66.5	93.9	132.8	191.4	274.1	408.6
70	47.4	66.1	96.9	145.2	221.8	326.7	532.1
80	46.7	65.9	99.7	161	262.8	408.1	677.6
90	47.5	67.4	105	181.6	318.4	543.9	849
100	50.1	72.2	115.9	207.5	396	753.9	1049.5
110	54.7	81.5	135.2	240	501.1	1040	1307
120	60.7	96.1	163.8	284.7	643.9	1302.3	1679.9
130	67.1	115.6	199.3	356.2	843.7	1589.2	2163.5

Base emission factors for carbon monoxide – Passenger cars (diesel) (Table 31 of PIARC, 2012)

Passenger car – Diesel CO (g/h) 2010							
	Gradient %						
v (km/h)	-6	-4	-2	0	2	4	6
0	3.3	3.3	3.3	3.3	3.3	3.3	3.3
10	9.6	9.6	9.6	10.3	10.9	11.4	12.9
20	9.6	9.6	9.8	11	11.9	11.2	12.9
30	9.6	9.6	10.1	11.6	11.2	13.3	12.9
40	9.6	9.6	10.1	12	12.4	13.3	9.8
50	9.6	9.6	10	11.5	13.7	10.8	8.1
60	9.6	9.6	10.2	11.2	13.2	8.8	7.5
70	9.6	9.6	10.7	12.4	10.7	7.3	8.5
80	9.6	9.6	11.4	12.2	8.8	7.9	9.5
90	9.6	9.6	11.5	12.3	7.4	8.8	10.5
100	9.6	9.6	11.5	9.8	7.8	9.8	11.6
110	9.6	9.6	11.7	7.9	8.8	10.9	12.8
120	9.6	10.5	11.7	7.6	9.9	12.1	14.1
130	9.6	11	11	10	11.1	13.3	15.4

Base emission factors for carbon monoxide – Light delivery vehicles (diesel/gasoline) (Table 37 of PIARC, 2012)

Light delivery vehicles (diesel/gasoline) – CO (g/h) 2010							
	Gradient %						
v (km/h)	-6	-4	-2	0	2	4	6
0	10.7	10.7	10.7	10.7	10.7	10.7	10.7
10	34.8	34.8	35.8	73.8	100.3	124.5	126
20	34.8	34.8	53.3	108.4	96.9	53.9	63.1
30	34.8	34.8	70.6	116	51.1	78.4	145.2
40	34.8	34.8	85.9	72.8	66.2	148.6	274.5
50	34.8	34.8	92.5	54.8	105.8	239	439.6
60	34.8	34.8	115	56.5	179.4	393.2	616.9
70	34.8	34.8	120	102.9	299.8	567.8	831.4
80	34.8	34.8	130	181.4	474.8	758.9	1089.6
90	34.8	76.8	140	304.8	637.6	988.4	1393.1
100	34.8	105.1	153.4	498.6	858.7	1286.6	1775.3
110	34.8	119.9	300.8	698.6	1138	1651.9	2233.2
120	58.1	128.3	520.5	957.2	1485.2	2094.2	2394
130	86.3	293.6	755.5	1284.5	1910.5	2194.8	2592

Base emission factors for carbon monoxide – Heavy delivery vehicles (diesel) (Table 41 of PIARC, 2012)

Heavy delivery vehicles (diesel) – CO (g/h) 2010							
	Gradient %						
v (km/h)	-6	-4	-2	0	2	4	6
0	38.6	38.6	38.6	38.6	38.6	38.6	38.6
10	30.4	35	52.3	63.6	69.5	75.2	81.7
20	21.9	31.4	55	67.6	76	90.2	105.1
30	20	32.3	60.2	71.6	85.8	109.7	131.2
40	18.2	29.6	62.1	75.4	97.9	129.4	156.3
50	18.2	27.2	60.6	78.3	112.3	147.8	183.9
60	18.2	23.5	56.2	82.1	127	167.4	212.1
70	18.2	19.4	51.6	88.3	140.5	188.6	242.1
80	18.2	20.3	56.9	98.9	156.3	212.2	274.5
90	18.2	22.3	62.7	113.3	173.1	236	306.8
100	18.2	26.5	71.8	129.5	190.1	260	339
110	18.2	30.3	80.6	143.5	206.2	283.7	371
120	18.5	44.4	91.5	154	222.5	307.1	402.7
130	21.1	50.9	105.3	163.3	238.5	330.4	434.8

As noted in the above tables, these data are for 2010 vehicle emissions. To account for changes in emission profiles with time, PIARC (2012) provide future years influencing factors to allow for scaling of the emissions. The following table outlines the PIARC (2012) influencing factors for future years.

Influencing factor for years different to 2010 (base year) (Table 34 of PIARC, 2012)

Influencing factor	CO	
Passenger Cars	**Gasoline**	**Diesel**
2010	*1*	*1*
2011	0.92	0.93
2012	0.84	0.87
2013	0.75	0.80
2014	0.67	0.74
2015	*0.59*	*0.67*
2016	0.56	0.62
2017	0.52	0.57
2018	0.49	0.53
2019	*0.45*	*0.48*
2020	*0.42*	*0.43*
2025/2030	*n/a*	*n/a*
Factors between 2010 and 2015 and factors between 2015 and 2020 were linearly interpolated from the charts provided in PIARC (2012).		

Given that the PIARC tables do not extend beyond 2020, the influencing factor for 2029 was assumed to be the same as 2020. This is a conservative assumption, as emission standards are expected to continue to drive emissions lower between 2020 and 2029. For this example calculation, however, the 2019 influencing factors were used.

The resultant emissions following the application of the 2019 influencing factors are shown in the following tables for passenger cars, light diesel vehicles and heavy vehicles.

Adjusted factors for carbon monoxide – Passenger cars (gasoline)

Passenger car – gasoline CO (g/h) 2019							
	Gradient %						
v (km/h)	-6	-4	-2	0	2	4	6
0	17.7	17.7	17.7	17.7	17.7	17.7	17.7
10	20.6	22.0	23.8	25.6	28.1	30.9	36.5
20	23.4	26.4	30.0	33.5	38.5	44.2	55.3
30	23.5	27.9	33.3	40.1	48.2	57.3	75.7
40	23.3	29.2	37.1	48.2	61.8	80.5	103.2
50	22.8	30.0	40.4	54.8	74.7	103.5	139.4
60	22.2	30.2	42.6	60.3	86.9	124.4	185.5
70	21.5	30.0	44.0	65.9	100.7	148.3	241.6
80	21.2	29.9	45.3	73.1	119.3	185.3	307.6
90	21.6	30.6	47.7	82.4	144.6	246.9	385.4
100	22.7	32.8	52.6	94.2	179.8	342.3	476.5
110	24.8	37.0	61.4	109.0	227.5	472.2	593.4
120	27.6	43.6	74.4	129.3	292.3	591.2	762.7
130	30.5	52.5	90.5	161.7	383.0	721.5	982.2

Adjusted factors for carbon monoxide – Passenger cars (diesel)

Passenger car – Diesel CO (g/h) 2019							
	Gradient %						
v (km/h)	-6	-4	-2	0	2	4	6
0	1.58	1.58	1.58	1.58	1.58	1.58	1.58
10	4.59	4.59	4.59	4.92	5.21	5.45	6.17
20	4.59	4.59	4.68	5.26	5.69	5.35	6.17
30	4.59	4.59	4.83	5.54	5.35	6.36	6.17
40	4.59	4.59	4.83	5.74	5.93	6.36	4.68
50	4.59	4.59	4.78	5.50	6.55	5.16	3.87
60	4.59	4.59	4.88	5.35	6.31	4.21	3.59
70	4.59	4.59	5.11	5.93	5.11	3.49	4.06
80	4.59	4.59	5.45	5.83	4.21	3.78	4.54
90	4.59	4.59	5.50	5.88	3.54	4.21	5.02
100	4.59	4.59	5.50	4.68	3.73	4.68	5.54
110	4.59	4.59	5.59	3.78	4.21	5.21	6.12
120	4.59	5.02	5.59	3.63	4.73	5.78	6.74
130	4.59	5.26	5.26	4.78	5.31	6.36	7.36

Adjusted factors for carbon monoxide – Light delivery vehicles (diesel/gasoline)

Light delivery vehicles (diesel/gasoline) – CO (g/h) 2019							
	Gradient %						
v (km/h)	-6	-4	-2	0	2	4	6
0	5.8	5.8	5.8	5.8	5.8	5.8	5.8
10	19.0	19.0	19.5	40.3	54.8	68.0	68.8
20	19.0	19.0	29.1	59.2	52.9	29.4	34.5
30	19.0	19.0	38.5	63.3	27.9	42.8	79.3
40	19.0	19.0	46.9	39.7	36.1	81.1	149.9
50	19.0	19.0	50.5	29.9	57.8	130.5	240.0
60	19.0	19.0	62.8	30.8	98.0	214.7	336.8
70	19.0	19.0	65.5	56.2	163.7	310.0	453.9
80	19.0	19.0	71.0	99.0	259.2	414.4	594.9
90	19.0	41.9	76.4	166.4	348.1	539.7	760.6
100	19.0	57.4	83.8	272.2	468.9	702.5	969.3
110	19.0	65.5	164.2	381.4	621.3	901.9	1219.3
120	31.7	70.1	284.2	522.6	810.9	1143.4	1307.1
130	47.1	160.3	412.5	701.3	1043.1	1198.4	1415.2

Adjusted factors for carbon monoxide – Heavy delivery vehicles (diesel)

Heavy delivery vehicles (diesel) – CO (g/h) 2019							
	Gradient %						
v (km/h)	-6	-4	-2	0	2	4	6
0	21.08	21.08	21.08	21.08	21.08	21.08	21.08
10	16.60	19.11	28.56	34.73	37.95	41.06	44.61
20	11.96	17.14	30.03	36.91	41.50	49.25	57.38
30	10.92	17.64	32.87	39.09	46.85	59.90	71.64
40	9.94	16.16	33.91	41.17	53.45	70.65	85.34
50	9.94	14.85	33.09	42.75	61.32	80.70	100.41
60	9.94	12.83	30.69	44.83	69.34	91.40	115.81
70	9.94	10.59	28.17	48.21	76.71	102.98	132.19
80	9.94	11.08	31.07	54.00	85.34	115.86	149.88
90	9.94	12.18	34.23	61.86	94.51	128.86	167.51
100	9.94	14.47	39.20	70.71	103.79	141.96	185.09
110	9.94	16.54	44.01	78.35	112.59	154.90	202.57
120	10.10	24.24	49.96	84.08	121.49	167.68	219.87
130	11.52	27.79	57.49	89.16	130.22	180.40	237.40

The numbers provided in the tables above were used with the ratio of petrol to diesel vehicles (eight per cent diesel vehicles and 92 per cent petrol vehicles) and the proportion of light duty vehicles to passenger vehicles (16 per cent light duty vehicles to 84 per cent passenger vehicles) to calculate a fleet-weighted emission factor table for passenger and light duty vehicles. The final emission factors were calculated as shown in the following tables.

Final base factors for carbon monoxide – Passenger cars and delivery vehicles (diesel/gasoline)

CO (g/h) 2019							
	Gradient %						
v (km/h)	-6	-4	-2	0	2	4	6
0	14.6	14.6	14.6	14.6	14.6	14.6	14.6
10	19.3	20.4	21.8	26.6	31.0	35.4	39.8
20	21.4	23.8	28.2	35.9	38.7	39.2	48.6
30	21.5	24.9	32.3	41.7	42.0	51.5	71.7
40	21.4	25.9	36.6	44.0	53.9	75.7	104.4
50	21.0	26.5	39.7	47.5	67.4	101.5	147.1
60	20.5	26.6	43.5	51.8	83.4	131.5	198.6
70	20.0	26.5	45.0	60.3	104.8	165.6	261.1
80	19.7	26.4	46.9	73.0	134.9	211.3	335.2
90	20.0	30.8	49.7	91.3	169.0	279.4	422.5
100	20.9	35.0	54.7	117.8	216.1	379.7	527.0
110	22.5	39.6	74.7	147.2	278.0	512.5	658.3
120	26.7	45.5	104.6	186.1	359.3	644.1	803.0
130	31.5	67.2	138.2	240.8	467.5	753.3	989.6

The following parameters were then assumed for illustrative purposes:

- Project (tunnel) link distance of 0.367 kilometres.
- Tunnel link gradient of -4.
- Two traffic lanes.
- Traffic flow of 100 vehicles per hour.
- A constant vehicle speed of 80 kilometres per hour for the link.
- Heavy vehicle percentage of 28 per cent.

Using the assumed parameters above and the calculated emission factors, the vehicle carbon monoxide emissions were then calculated to be:

- PC and LDV combined EF of 26.4 grams per hour = 0.0073 (grams per second per vehicle (g/s/vehicle)).
- HDV combined EF of 11.08 grams per hour = 0.0031 g/s/vehicle.

For a heavy vehicle fleet fraction of 28 per cent, the final combined vehicle emission factor was calculated to be 0.0062 g/s/vehicle.

In order to calculate a final mass emission rate from that section of the tunnel, the number of vehicles per second in the road tunnel was first calculated as follows::

$$Vehicles\ in\ tunnel\ section = \frac{VPH}{3600} \times \ [(\text{Time to travel 1km}) \text{ x } (\text{Length of Tunnel Section})]$$

For the assumed data, the vehicles in tunnel section = 100/3600 x [(45 x 0.367) = 0.46 vehicles per second per section.

Using the calculated final combined vehicle emission factor of 0.0062 g/s/vehicle, the final mass emission rate for carbon monoxide for this section of the tunnel was calculated to be 0.0028 g/s.

Mass emission rates were calculated for each hour of day for each tunnel link for carbon monoxide, PM_{10} and nitrogen dioxide in a similar manner to that outlined above. The sum of all of the individual pollutant link data was assumed to be the mass emission rate emitted from the tunnel ventilation outlet.

Emission factors for the other pollutants considered in the assessment, namely $PM_{2.5}$, total VOCs and PAHs, were not included in PIARC (2012). The emission factors published in the National Pollutant Inventory (NPI) (DEWHA, 2008) were used to estimate emissions of these pollutants. The NPI provides emission factors for a variety of different vehicle types and fuels. The ratios of PM_{10} to $PM_{2.5}$ emissions were calculated for the various vehicle types assessed. The ratios for cars and LDVs were averaged to provide an average ratio of $PM_{2.5}$ to PM_{10} for non-HDVs (0.93); this ratio was then multiplied by the PM_{10} emissions calculated using the PIARC emission factors to estimate $PM_{2.5}$ emission rates. As such, $PM_{2.5}$ emissions were calculated as 93 per cent of PM_{10} emissions for non-HDVs. A similar process was followed for HDVs, where the ratio of $PM_{2.5}$ to PM_{10} was calculated to be 0.95.

Emissions of VOCs and PAHs were similarly calculated using the carbon monoxide emission rates. The ratios of NPI emission factors for these pollutants and carbon monoxide were firstly calculated. The carbon monoxide emission rates calculated from the PIARC carbon monoxide emission factors were then multiplied by the calculated ratios to estimate emission rates of VOCs and PAHs.

Appendix I

NO_x to NO_2 conversion

Appendix I NO$_x$ to NO$_2$ conversion

One of the challenges of modelling NOx emissions is determining the amount of NO_2 at a receiver, due to uncertainties in the conversion rates. Early studies (Hegg et al., 1977) showed that the rate of oxidation is controlled by the rate of plume mixing rather than by gas reaction kinetics. Ozone is usually the chemical that is responsible for most of the oxidation, but other reactive atmospheric gases can also oxidise NO.

Several methods were proposed for evaluating the amount of NO_2 that is formed from NO. These include:

1) Total conversion;
2) The Ambient Ratio Method (ARM) (0.75 is the US default value) when no measured nearby NOx/NO_2 ratios are available;
3) Ozone Limiting Method (OLM);
4) Jansenn's equations (which assume approximately 10 per cent of all NOx is NO_2) – used in Australia and New Zealand; and
5) Plume Volume Molar Ratio method.

All of these methods are referenced in the Federal Guideline on Air Quality Models (GAQM) and DEC (2005).

NO$_x$ to NO$_2$ conversion in NSW

In NSW, the oxidation of NO to NO_2 is assessed by three methods (Method 1, the most simple, to Method 3, the most complex). Method 1, which assumes 100 per cent conversion of NO to NO2, can be used in one of two ways. A Level 1 assessment uses maximum predicted NO_X concentrations (assuming NOx = NO_2) and maximum ambient NO_2 concentrations to determine a cumulative NO_2 concentration. If the facility fails to meet the NO_2 impact assessment criteria, a Level 2 assessment is conducted, which again assumes 100 per cent conversion but with contemporaneous assessment of model predictions and ambient concentrations.

Method 2 is the OLM, where NO to NO_2 conversion is limited by the amount of ozone available. The OLM uses a simple approach to the reaction chemistry; it assumes that O_3 and NO react to form NO_2 in proportion to their ground level concentrations. That is, for each hour,

- if $O_3 < NO_{plume}$,
  - $NO_{2\ plume} = NO_{2\ initial} + O_3$, and if
- $O_3 \geq NO_{plume}$, $NO_{2\ plume} = NO_{x\ plume}$

Method 3 uses an empirical relationship to convert NO to NO_2 based on the equation developed by Janssen et al. (1988). The conversion is based on the distance of the receiver downwind from the source, and can be used with various levels of refinement (i.e. using maxima or contemporaneous data).

NO$_x$ to NO$_2$ assessment in the United States

In the United States, the first level recommended technique in the Guideline on Air Quality Models (GAQM) is to assume the total conversion of NO to NO_2. This is the same first tier level as DEC (2005). It is a conservative, first-level technique, which may lead to unnecessary control in areas where the predicted impacts are close to ambient air quality criteria.

The Ambient Ratio Method (ARM) is the second-level technique recommended in the GAQM. The ARM is defined as the ratio of the average NO_2 and NOx ambient concentrations measured at a representative site. It uses local monitoring or a default 75 per cent ratio to find the ambient equilibrium NO_2/NOx ratio (annual average). Theoretically, equilibrium occurs when the rate of NO_2 formation equals the rate of dissociation of NO_2 by sunlight. Chu and Meyer (1991), who developed this technique, recommended that this monitoring be performed far away so that true equilibrium would occur. Unfortunately, ambient monitoring is usually insufficient for determining this ratio because ambient concentrations are frequently below the minimum monitoring threshold for NOx (20 ppb). Further, if the monitoring is performed too close to an existing source, the ARM's assumption of equilibrium is violated and the monitoring results are not applicable to receivers further downwind.

The third-level tier is the OLM (stated above) and a Plume Volume Molar Ratio method (PVMRM). The PVMRM method better simulates the NO to NO_2 conversion chemistry during plume expansion and is particularly well suited for the receivers located close to sources where maximum modelled NO concentrations are usually predicted. The PVMRM method follows the chemistry of the main forward reaction of NO with O_3 as it occurs during expansion of a plume segment travelling downwind:

$NO + O_3 \rightarrow NO_2 + O_2$

This is accomplished by computing the number of moles of NOx and O_3 that are contained within a plume segment as it reaches a receiver. Although the PVMRM follows the same chemical reactions as those used in the OLM, it uses both plume size and O_3 concentration to derive the amount of O_3 available for the reaction. NOx moles are determined by emission rate and travel time through the plume segment. The number of O_3 moles is determined by the size of the plume segment and the measured background O_3 concentration. This plume segment always contains the same amount of primary NOx emissions as it travels downwind. The amount of O_3 available for reaction, however, increases as the plume segment enlarges downwind. The last approach, which is not yet included in any US Guideline criteria, is based on an empirical approach of some 3,000 co-located NOx and NO_2 monitors in Europe. The approach uses a scaled approach to NOx bins of concentration levels. This method was developed by the Atmospheric Studies Group and is included in the US EPA guideline model CALPOST. It has been used on a case-by-case basis when all other methods fail.

Concerns with and likely conservatism of the OLM

The OLM employed by the EPA (DEC, 2005) was taken from the US EPA OLM, originally developed by Cole and Summerhays (1979) and Tikvart (1996). The method assumes that all the available ozone in the atmosphere will react with NO in the plume until either all the O_3 or all the NO is used up. The approach is known to be conservative. Some of the reasons for its lack of robustness and conservatism are listed below:

- The OLM approach assumes that the atmospheric reaction is instant, whereas in reality the reaction takes place over a number of hours.
- The actual reactions of NO to NO_2 occur in proportion to the moles of each reactant rather than in proportion to the concentration assumed by the OLM. At constant volume, 1 ppm of a gas is proportional to 1 mole of a gas. This assumption is not valid in the open atmosphere, as there is virtually unlimited amount of O_3 available for reaction. As plumes expand downwind, more O_3 is available for reaction, and even lower concentrations of O_3 can react with NO in the plume.
- The OLM is further complicated as some of the NOx is already converted to NO_2 upstream in the plume before it reaches the receiver.
- Studies have shown that the NOx emission rates are extremely important with respect to the rate of conversion to NO_2. The size of the plume is not affected by the NOx emission rate, which means that there is the same amount of O_3 available for chemical conversion regardless of the NOx emission rate. Larger NOx emission rates lead to lower predicted ratios of NO_2/NOx. Maximum impacts that occur at receivers located further away have high predicted NO_2/NOx ratios. Further emissions emitted into stable (narrow) plumes will have less conversion to NO_2 compared to those emissions emitted into less stable (wider) plumes. The OLM does not take the NOx emission rate or plume size into consideration.
- The OLM can only be used on one plume at a time. The US EPA states that the OLM should be used with a ‘plume-by-plume’ approach. This is a big limitation to a facility with lots of different plumes. The OLM will therefore be very conservative for close in NO_2 impacts for large multi plume sources. The OLM may not be conservative for single plumes downwind, where low concentrations of O_3 can still react with the plume.

The OLM is expected to be conservative during daylight hours when the photochemical equilibrium reverses the oxidation of NO by O_3. It is also expected to be conservative during stable and night conditions when both NO_2 and O_3 are removed by reaction with vegetation and other surfaces.

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Appendix H

Technical working paper:
Human health risk assessment

NorthConnex

Building for the future

Australian Government

NSW NOW The new state of business

transurban

Technical working paper: Human Health Risk Assessment

Prepared for: Roads and Maritime Services

Document History and Status

Report Reference	ARM/14/M1M2R001
Revision	E - Final
Date	30 June 2014
Previous Revisions	A – Internal Draft issued on 9 May 2014 B – Draft issued for adequacy review on 13 May 2014 C,D – Drafts issued for internal review on 10 and 25 June 2014

Limitations

Environmental Risk Sciences has prepared this technical working paper for the use of Roads and Maritime Services in accordance with the usual care and thoroughness of the consulting profession. It is based on generally accepted practices and standards at the time it was prepared. No other warranty, expressed or implied, is made as to the professional advice included in this technical working paper.

It is prepared in accordance with the scope of work and for the purpose outlined in the Section 1 of this technical working paper.

The methodology adopted and sources of information used are outlined in this technical working paper. Environmental Risk Sciences has made no independent verification of this information beyond the agreed scope of works and assumes no responsibility for any inaccuracies or omissions. No indications were found that information contained in the reports for use in this assessment was false.

This report was prepared from January to June 2014 and is based on the information provided and reviewed at that time. Environmental Risk Sciences disclaims responsibility for any changes that may have occurred after this time.

This report should be read in full. No responsibility is accepted for use of any part of this technical working paper in any other context or for any other purpose or by third parties. This technical working paper does not purport to give legal advice. Legal advice can only be given by qualified legal practitioners.

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Appendices

Glossary of Terms

Acute exposure	Contact with a substance that occurs once or for only a short time (up to 14 days).
absorption	The process of taking in. For a person or an animal, absorption is the process of a substance getting into the body through the eyes, skin, stomach, intestines, or lungs.
Adverse health effect	A change in body function or cell structure that might lead to disease or health problems.
ANZECC	Australia and New Zealand Environment and Conservation Council
AQIA	Technical Working Paper: Air Quality (AECOM, 2014) for the NorthConnex project.
Background level	An average or expected amount of a substance or material in a specific environment, or typical amounts of substances that occur naturally in an environment.
Biodegradation	Decomposition or breakdown of a substance through the action of micro-organisms (such as bacteria or fungi) or other natural physical processes (such as sunlight).
Body burden	The total amount of a substance in the body. Some substances build up in the body because they are stored in fat or bone or because they leave the body very slowly.
BTX	Benzene, toluene and total xylenes
Carcinogen	A substance that causes cancer.
Chronic exposure	Contact with a substance that occurs over a long time (more than 1 year) [compare with acute exposure and intermediate duration exposure].
COPD	Chronic Obstructive Pulmonary Disease
DECCW	Department of Environment, Climate Change and Water
Detection limit	The lowest concentration of a chemical that can reliably be distinguished from a zero concentration.
DGRs	Director General Requirements
Dose	The amount of a substance to which a person is exposed over some time period. Dose is a measurement of exposure. Dose is often expressed as milligram (amount) per kilogram (a measure of body weight) per day (a measure of time) when people eat or drink contaminated water, food, or soil. In general, the greater the dose, the greater the likelihood of an effect. An "exposure dose" is how much of a substance is encountered in the environment. An "absorbed dose" is the amount of a substance that actually got into the body through the eyes, skin, stomach, intestines, or lungs.
EC	European Commission
EP&A Act	Environmental Planning and Assessment Act 1979
EPA	Environment Protection Authority
Exposure	Contact with a substance by swallowing, breathing, or touching the skin or eyes. Exposure may be short-term [acute exposure], of intermediate duration, or long-term [chronic exposure].
Exposure assessment	The process of finding out how people come into contact with a hazardous substance, how often and for how long they are in contact with the substance, and how much of the substance they are in contact with.

Exposure pathway	The route a substance takes from its source (where it began) to its end point (where it ends), and how people can come into contact with (or get exposed) to it. An exposure pathway has five parts: a source of contamination (such as chemical leakage into the subsurface); an environmental media and transport mechanism (such as movement through groundwater); a point of exposure (such as a private well); a route of exposure (eating, drinking, breathing, or touching), and a receiver population (people potentially or actually exposed). When all five parts are present, the exposure pathway is termed a completed exposure pathway.
Guideline value	Guideline value is a concentration in soil, sediment, water, biota or air (established by relevant regulatory authorities such as the NSW Department of Environment and Conservation (DEC) or institutions such as the National Health and Medical Research Council (NHMRC), Australia and New Zealand Environment and Conservation Council (ANZECC) and World Health Organisation (WHO)), that is used to identify conditions below which no adverse effects, nuisance or indirect health effects are expected. The derivation of a guideline value utilises relevant studies on animals or humans and relevant factors to account for inter- and intra-species variations and uncertainty factors. Separate guidelines may be identified for protection of human health and the environment. Dependent on the source, guidelines will have different names, such as investigation level, trigger value, ambient guideline etc.
HIA	Health Impact Assessment
HHRA	Human Health Risk Assessment
Inhalation	The act of breathing. A hazardous substance can enter the body this way [see route of exposure].
Intermediate exposure Duration	Contact with a substance that occurs for more than 14 days and less than a year [compare with acute exposure and chronic exposure].
LGA	Local Government Area
LOAEL	Lowest-observed-adverse-effect-level - The lowest tested dose of a substance that has been reported to cause harmful (adverse) health effects in people or animals.
LOR	Limit of Reporting
Metabolism	The conversion or breakdown of a substance from one form to another by a living organism.
NEPC	National Environment Protection Council
NEPM	National Environment Protection Measure
NHMRC	National Health and Medical Research Council
NOAEL	No-observed-adverse-effect-level - The highest tested dose of a substance that has been reported to have no harmful (adverse) health effects on people or animals.
NSW	New South Wales
OEH	Office of Environment and Heritage
OEHHA	Office of Environmental Health Hazard Assessment, California Environment Protection Agency (Cal EPA)
PAH	Polycyclic aromatic hydrocarbon
PM	Particulate matter
$PM_{2.5}$	Particulate matter of aerodynamic diameter 2.5 µm and less
PM_{10}	Particulate matter of aerodynamic diameter 10 µm and less
Point of exposure	The place where someone can come into contact with a substance present in the environment [see exposure pathway].
Population	A group or number of people living within a specified area or sharing similar characteristics (such as occupation or age).

Receiver population	People who could come into contact with hazardous substances [see exposure pathway].
Risk	The probability that something will cause injury or harm.
Route of exposure	The way people come into contact with a hazardous substance. Three routes of exposure are breathing [inhalation], eating or drinking [ingestion], or contact with the skin [dermal contact]
Toxicity	The degree of danger posed by a substance to human, animal or plant life.
Toxicity data	Characterisation or quantitative value estimated (by recognised authorities) for each individual chemical for relevant exposure pathway (inhalation, oral or dermal), with special emphasis on dose-response characteristics. The data are based on based on available toxicity studies relevant to humans and/or animals and relevant safety factors.
Toxicological profile	An assessment that examines, summarizes, and interprets information about a hazardous substance to determine harmful levels of exposure and associated health effects. A toxicological profile also identifies significant gaps in knowledge on the substance and describes areas where further research is needed.
Toxicology	The study of the harmful effects of substances on humans or animals.
TSP	Total suspended particulate
Uncertainty factor	Mathematical adjustments for reasons of safety when knowledge is incomplete. For example, factors used in the calculation of doses that are not harmful (adverse) to people. These factors are applied to the lowest-observed-adverse-effect-level (LOAEL) or the no-observed-adverse-effect-level (NOAEL) to derive a minimal risk level (MRL). Uncertainty factors are used to account for variations in people's sensitivity, for differences between animals and humans, and for differences between a LOAEL and a NOAEL. Scientists use uncertainty factors when they have some, but not all, the information from animal or human studies to decide whether an exposure will cause harm to people [also sometimes called a safety factor].
USEPA	United States Environmental Protection Agency
VOC	Volatile Organic Compound
WHO	World Health Organisation

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Executive Summary

Roads and Maritime Services is seeking approval under Part 5.1 of the *Environmental Planning and Assessment Act 1979* to construct and operate a tolled motorway linking the M1 Pacific Motorway at Wahroonga to the Hills M2 Motorway at the Pennant Hills Road interchange at Carlingford in northern Sydney (the project), which would consist of twin tunnels approximately nine kilometres in length that would generally follow the alignment of the existing Pennant Hills Road. The purpose of the project is to reduce congestion on Pennant Hills Road, particularly for heavy vehicle traffic. This technical working paper was prepared to assess potential risks to human health associated with key aspects of the project, namely local air quality impacts, noise and vibration.

A human health risk assessment is a way of deciding now, what the consequences (to health) of some future action (such as this project) may be. We try to learn from previous experience about impacts from road tunnels and their potential effects on people who live or work around them. We then use this information to predict the impacts of the project on community health.

In this case the technical working paper includes a detailed review of what impacts to air quality, noise and vibration may occur, who may be exposed to these impacts and whether there is potential for these impacts to result in adverse health effects within the local community. It is conducted in accordance with national guidance available from enHealth (enHealth 2001, 2012a) and it has involved the following:

- review of predicted impacts to air quality, noise and vibration during construction and operation of the project. In some cases the issues identified (such as those during construction) are short-term and can be mitigated/managed through the implementation of specific management measures. For other impacts (such as those from operations) the impacts may occur over a longer period of time and require a more detailed assessment of how these impacts affect health;
- identification and characterisation of the community (including the presence of sensitive receivers such as childcare centres, aged care centres, schools and hospitals) who may be affected by these impacts;
- assessment of air quality impacts on health including:
    - review of the key pollutants (associated with vehicle emissions) to air that are predicted from the operation of the project;
    - identify guidelines that are based on protection of the health of all members of the population for exposure to these pollutants all day, every day;
    - compare the predicted impacts with the health based guidelines;
    - for particulate matter, the guidelines available do not adequately address all the potential health effects that may occur and hence a more detailed assessment has been undertaken;
    - a more detailed assessment of exposure to particulate matter has utilised robust (published) associations between exposure to increased concentrations of particulates (as $PM_{2.5}$ or PM_{10}) and specific health effects (or health endpoints). The assessment conducted has evaluated the impact of the project on these health endpoints within the local community;
    - The potential for adverse health impacts in the community has been assessed on the basis of a range of considerations (including the size of the population exposed, calculated annual risk from exposure and the increase in the number of cases [for a

specific health endpoint] that may occur in the community as a result of exposure and benefits of the project)

- assessment of noise and vibration impacts on health including:
  - review of the impacts that are predicted from the operation of the project;
  - identify guidelines that are based on the protection of the health and wellbeing (including sleep disturbance) during all phases of the project (construction and operations);
  - compare the predicted impacts with the health based guidelines. Where the health based guidelines cannot be met, consideration of the implementation of mitigation/management measures and whether these can be effectively implemented to ensure the identified impacts meet the health based guidelines.

Based on the assessment undertaken and presented in this technical working paper the following has been concluded:

- In relation to impacts to air quality, potential health impacts have been evaluated using appropriate health based guidelines (that are protective of public health), or, in the case of exposure to $PM_{2.5}$ and PM_{10}, a detailed assessment of the impact of the emissions on key community health indicators. All predicted concentrations of carbon monoxide, nitrogen dioxide, key individual volatile organic compounds and polycyclic aromatic hydrocarbons are below health based guidelines. For the assessment of potential impacts of $PM_{2.5}$ and PM_{10} from the operation of the tunnel, potential health impacts are low and essentially negligible in proximity to the ventilation outlets. Overall, taking a significant number of vehicles, in particular trucks off the existing road corridor along Pennant Hills Road, and managing emissions via the tunnel ventilation system, would lead to a net benefit to health within the community.
- In relation to noise and vibration, potential impacts during construction and operation have been considered. During construction potential impacts from noise and vibration on the local community can be managed and/or mitigated through the implementation of a range of measures. For construction noise and vibration, these management and mitigation measures (including the requirement for noise monitoring) are to be outlined in detail within the Construction Noise and Vibration Management Plan.
- During operation of the project a number of individual homes located adjacent to the northern interchange as well as the southern interchange and the Hills M2 Motorway integration works have been identified where noise impacts are in excess of the health based guidelines.. The recommended mitigation measures would ensure that the levels of road traffic noise experienced by residents would be reduced as low as feasible and reasonable. The requirements and the form of operational noise mitigation will be confirmed when assessed against the detailed road and tunnel designs. This would include consideration of the feasibility of noise barriers given potential engineering constraints, and the outcomes of consultation with the affected community.

Section 1. Introduction

1.1 Project overview

Roads and Maritime Services (Roads and Maritime) is seeking approval under Part 5.1 of the *Environmental Planning and Assessment Act 1979* (EP&A Act) for the construction and operation of a multi-lane tolled motorway linking the M1 Pacific Motorway at Wahroonga to the Hills M2 Motorway at the Pennant Hills Road interchange at West Pennant Hills in northern Sydney (the project) (refer to **Figure 1-1**).

Key features of the project would include:

- Twin motorway tunnels up to around nine kilometres in length with two lanes in each direction. The tunnels would be constructed with provision for a possible third lane in each direction if required in the future.
- A northern interchange with the M1 Pacific Motorway and Pennant Hills Road, including sections of tunnel for on-ramps and off-ramps, which also facilitate access to and from the Pacific Highway.
- A southern interchange with the Hills M2 Motorway and Pennant Hills Road, including sections of tunnel for on-ramps and off-ramps.
- Integration works with the Hills M2 Motorway including alterations to the eastbound carriageway to accommodate traffic leaving the Hills M2 Motorway to connect to the project travelling northbound, and the provision of a new westbound lane on the Hills M2 Motorway extending through to the Windsor Road off-ramp.
- Tie-in works with the M1 Pacific Motorway extending to the north of Edgeworth David Avenue.
- A motorway operations complex located near the southern interchange on the corner of Eaton Road and Pennant Hills Road that includes operation and maintenance facilities.
- Two tunnel support facilities, which incorporates emergency smoke extraction outlet points and substations along the main alignment.
- Ancillary facilities for motorway operation, such as electronic tolling facilities, signage, ventilation systems and fire and life safety systems including emergency evacuation infrastructure.
- Modifications to service utilities and associated works at surface roads near the two interchanges and operational ancillary facilities.
- Modifications to local roads, including widening of Eaton Road near the southern interchange and repositioning of the Hewitt Avenue cul-de-sac near the northern interchange.
- Ancillary temporary construction facilities and temporary works to facilitate the construction of the project.

Subject to the project obtaining planning approval, construction of the project is anticipated to commence in early 2015 and is expected to take around four years to complete.

1.2 Project location

The project would be located within The Hills, Hornsby and Ku-ring-gai local government areas about 20 kilometres north-west of the central business district of Sydney. The regional context of the project is shown in **Figure 1-2**.

1.3 Purpose of this report

The Director-General's environmental assessment requirements (DGRs) for the project were issued on 29 October 2013 and re-issued with amendments on 11 April 2014. The DGRs have informed the preparation of the environmental impact statement for the project.

The DGRs require an assessment of potential impacts on air quality during construction and operation of the project, and to include a human health risk assessment (HHRA). Specifically, the DGR states that the assessment should include but not be limited to:

> *An assessment of construction and operation activities that have the potential to impact on local and regional air quality. The assessment should provide an assessment of the risk associated with potential discharges of fugitive and point source emissions, and include:.....*
>
> *consideration of the requirements of Environmental Health Risk Assessment: Guidelines for assessing human health risks from environmental hazards (enHealth, 2012),.....*

This technical working paper presents a Human Health Risk Assessment (HHRA) associated with key aspects of the project, namely local air quality impacts, noise and vibration (as proposed in the design as outlined in **Section 2**).

Other aspects of the DGR relating to air quality have been addressed in technical working paper: air quality (AECOM, 2014).

In providing input into the DGRs, the Ministry of Health (NSW Health) had provided a letter to the then Department of Planning and Infrastructure, dated 4 October 2013, outlining a range of aspects to be considered in the HHRA, including an assessment of:

- Impacts to air during construction and operation (impacts to the surrounding community and in-tunnel exposures);
- Impacts associated with noise and vibration during construction and operation.

These matters have also been considered within this technical working paper.

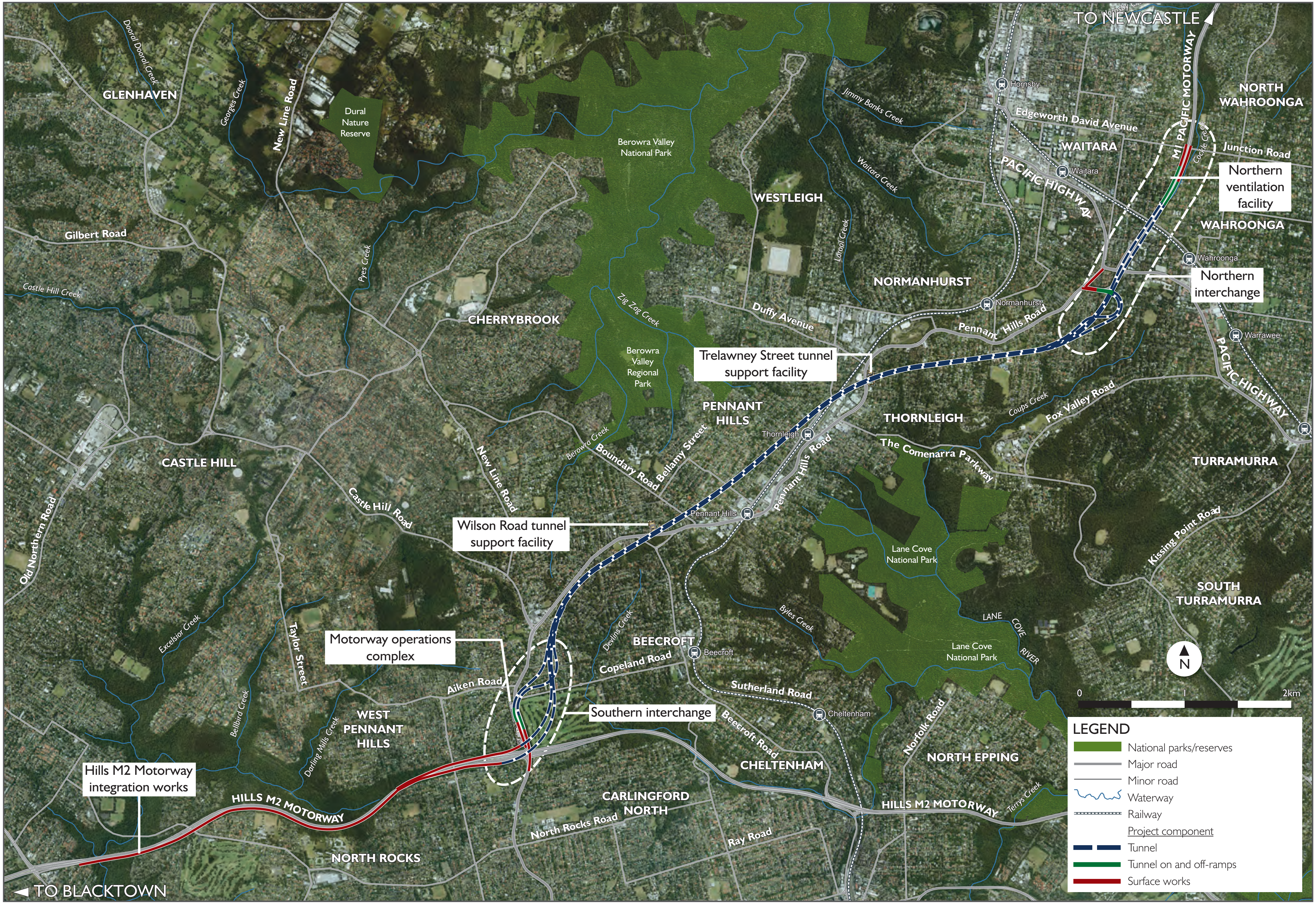

Figure 1-1 The project

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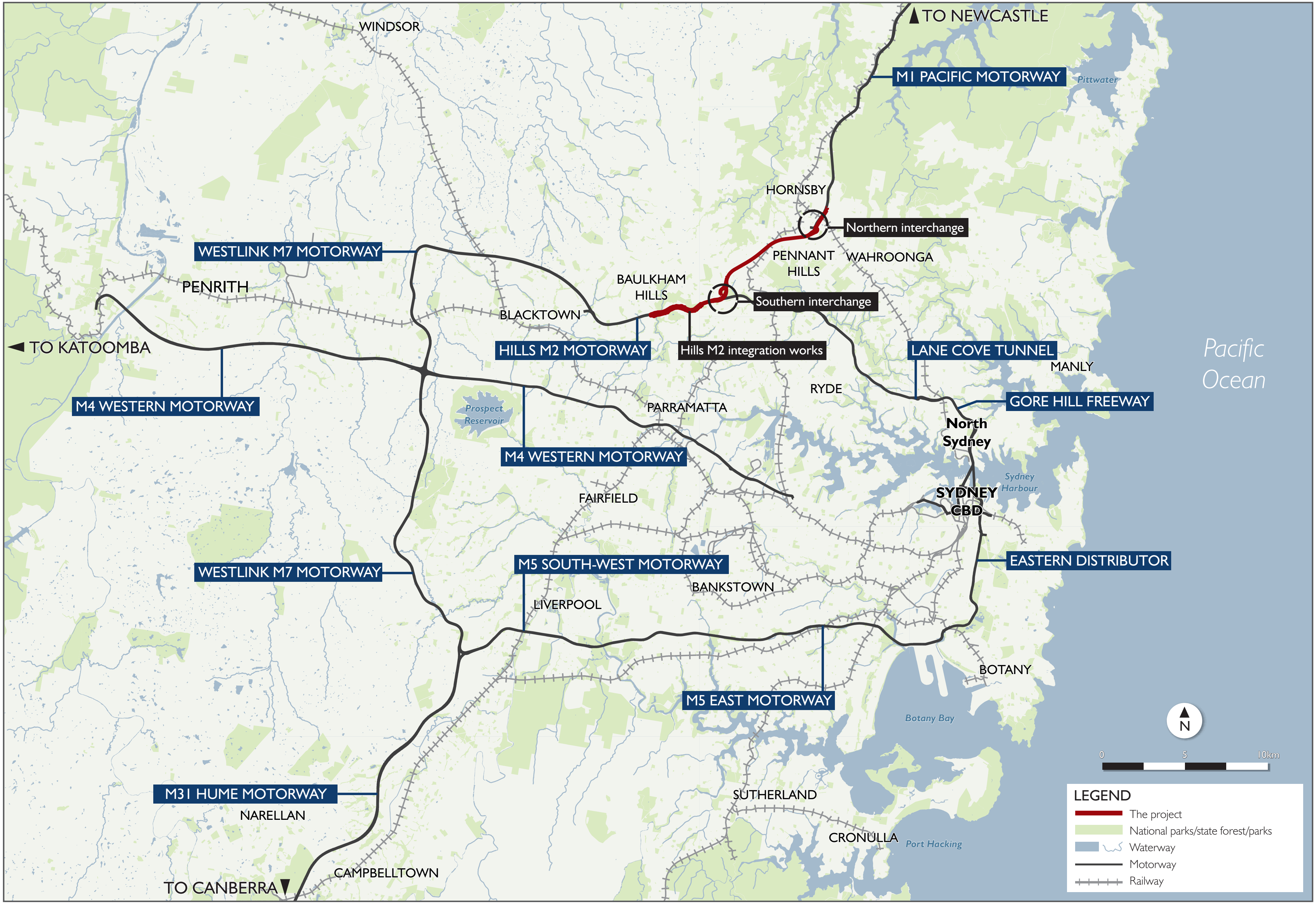

Figure 1-2 Regional context of the project

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1.4 Objectives

The overall objective of the HHRA presented in this technical working paper is to assess health risks associated with the following:

- Emissions to air and exposures in the local community (principally dust) during construction works (construction of the tunnel, interchanges, intersections and roadside infrastructure).
- Emissions to air (associated with vehicle emissions) and exposures of the local community to emissions from the ventilation facilities during the operation of the competed tunnels.
- Exposures that may occur in the tunnel (by users of the tunnel) during operation (normal operations and during breakdown situations).
- Noise and vibration, primarily during construction works.

The assessment presented has considered both short-term/acute and long-term/chronic risks to surrounding communities, based on outcomes presented in the technical working papers that have been completed as part of the environmental impact statement for air quality, noise and vibration.

1.5 Approach to Human Health Risk Assessment

1.5.1 What is a risk assessment?

Risk

Risk assessment is used extensively in Australia and overseas to assist in decision making on the acceptability of the risks associated with the presence of contaminants in the environment and evaluation of projects with potential risks to the public. Risk is commonly defined as the chance of injury, damage, or loss. Therefore, to put oneself or the environment "at risk" means to participate, either voluntarily or involuntarily, in an activity or activities that could lead to injury, damage, or loss.

Voluntary risks are those associated with activities that we decide to undertake such as driving a vehicle, riding a motorcycle and smoking cigarettes.

Involuntary risks are those associated with activities that may happen to us without our prior consent or forewarning. Acts of nature such as being struck by lightning, fires, floods, tornados, etc, and exposures to environmental contaminants are examples of involuntary risks.

Defining risk

Risks to the public and the environment are determined by direct observation or by applying mathematical models and a series of assumptions to infer risk. No matter how risks are defined or quantified, they are usually expressed as a probability of adverse effects associated with a particular activity. Risk is typically expressed as a likelihood of occurrence and/or consequence (such as negligible, low or significant) or quantified as a fraction of, or relative to, an acceptable risk number.

Risks from a range of facilities (eg industrial or infrastructure) are usually assessed through qualitative and/or quantitative risk assessment techniques. In general, risk assessments seek to identify all relevant hazards; assess or quantify their likelihood of occurrence and the consequences associated with these events occurring; and provision of an estimate of the risk levels for people who could be exposed, including those beyond the perimeter boundary of a facility.

1.5.2 Overall approach

The methodology adopted for the conduct of the HHRA is in accordance with national and international guidance that is endorsed/accepted by Australian health and environmental authorities, and includes:

- EnHealth Environmental Health Risk Assessment: Guidelines for Assessing Human Health Risks from Environmental Hazards: 2012 (enHealth 2012a);
- EnHealth Health Impact Assessment Guidelines: September 2001 (enHealth 2001);
- EnHealth Exposure Factors Guide, EnHealth Council, 2012 (enHealth 2012b);
- National Environment Protection Council (NEPC) Schedule B(8) Guideline on Community Consultation and Risk Communication, National Environment Protection (Assessment of Site Contamination) Measure, 1999 (NEPC 1999 amended 2013);
- NEPC National Environmental Protection (Air Toxics) Measure, Impact Statement for the National Environment Protection (Air Toxics) Measure, 2003 (NEPC 2003); and
- United States Environment Protection Agency (USEPA) Risk Assessment Guidance for Superfund, Volume I: Human Health Evaluation Manual (Part F, Supplemental Guidance for Inhalation Risk Assessment), EPA-540-R-070-002, January 2009 (USEPA 2009a).

More specifically in relation to the assessment of health impacts associated with exposure to particulates, guidelines available from the NEPC ((Burgers & Walsh 2002; NEPC 1998, 2002, 2003, 2009, 2010), World Health Organisation (Ostro 2004; WHO 2003, 2006b; 2006a, {Ostro, 2004 #861; 2013b) and the USEPA (USEPA 2005, 2009b) have been used as required.

The methodology used for the conduct of the HHRA presented in this reported has been presented to and discussed with NSW Health prior to the completion of this assessment.

In following this guidance, the following tasks have been completed and are presented in this technical working paper.

Data evaluation and issue identification

This task involves a review of all available information that relates to the proposed design and outcomes from relevant specialist studies undertaken in relation to air quality, noise and vibration. Specifically the assessment has considered existing conditions (in relation to air quality and noise) and estimation of short-term (acute) and long-term (chronic) impacts during construction and operation of the project.

This aspect of the assessment also considers the available guidelines for air quality and noise, whether these guidelines are based on the protection of community health, and if a more detailed evaluation of specific impacts is required. The HHRA has considered a more detailed evaluation of exposures to particulate emissions within the surrounding community from the operation of the tunnel.

Exposure assessment

This involves the identification of populations located in the vicinity of the project who may be exposed to impacts from the project, in particular, the populations in areas adjacent to the southern and northern interchanges. The existing air and noise environments as well as the health of the existing population has been considered in relation to the key health endpoints, relevant to the assessment of exposures to particulate matter, that require further detailed consideration in this assessment. The assessment of potential particulate matter exposure has considered both short-term (acute) and chronic inhalation exposures relevant to the project.

Toxicity assessment

The objective of the toxicity assessment is to identify the adverse health effects and quantitative toxicity values or exposure-response relationships that are associated with the key pollutants that have been identified and evaluated as part of this assessment. This has been applied to the assessment of exposures to particulate matter where the following has been undertaken:

1. Identify the adverse health effects associated with exposure to particulate matter. Based on the available information, the most robust health end-points (effects or outcomes) for the assessment of inhalation exposure to particulate matter (assessed over different size fractions) have been identified. The most robust health end-points are where a relationship has been established between exposure to particulate matter and a specific health end-point (effect/outcome).

2. Identify the most relevant and robust exposure-response relationship for the quantitative assessment of exposure to particulate matter. The exposure-response relationships are derived from published peer reviewed sources and relate to the identified health end-points (effects/outcomes).

The health-endpoints and associated exposure-response relationships adopted for the assessment of particulate matter, particularly derived from combustion sources (such as petrol and diesel vehicles) have been agreed with NSW Health prior to the completion of this assessment.

For other air pollutants national guidelines based on the protection of health have been adopted.

Risk characterisation

Risks have been characterised using quantitative and qualitative assessment methods. The quantitative assessment of potential exposure to particulate emissions from the project combined with information on exposure (ie what additional concentrations of particulate matter would be present in the community as a result of the project) and the exposure-response relationships relevant for the health-endpoints (effect) has been used. This enables an assessment of an increased annual risk and an increased incidence of the effect occurring within the population of concern.

In some cases a qualitative assessment has been undertaken. A qualitative assessment does not specifically require the quantification of risk or exposure. Rather the assessment provides a relative or comparative evaluation of whether the exposure or impact considered is unacceptable in the local population.

The assessment presented has also considered the level of uncertainty associated with all aspects of the technical studies relied on for the conduct of the HHRA and within the HHRA. The final determination of risks to human health will be based on the quantification of risks as well as consideration of these uncertainties.

The overall approach is outlined in **Figure 1-3**.

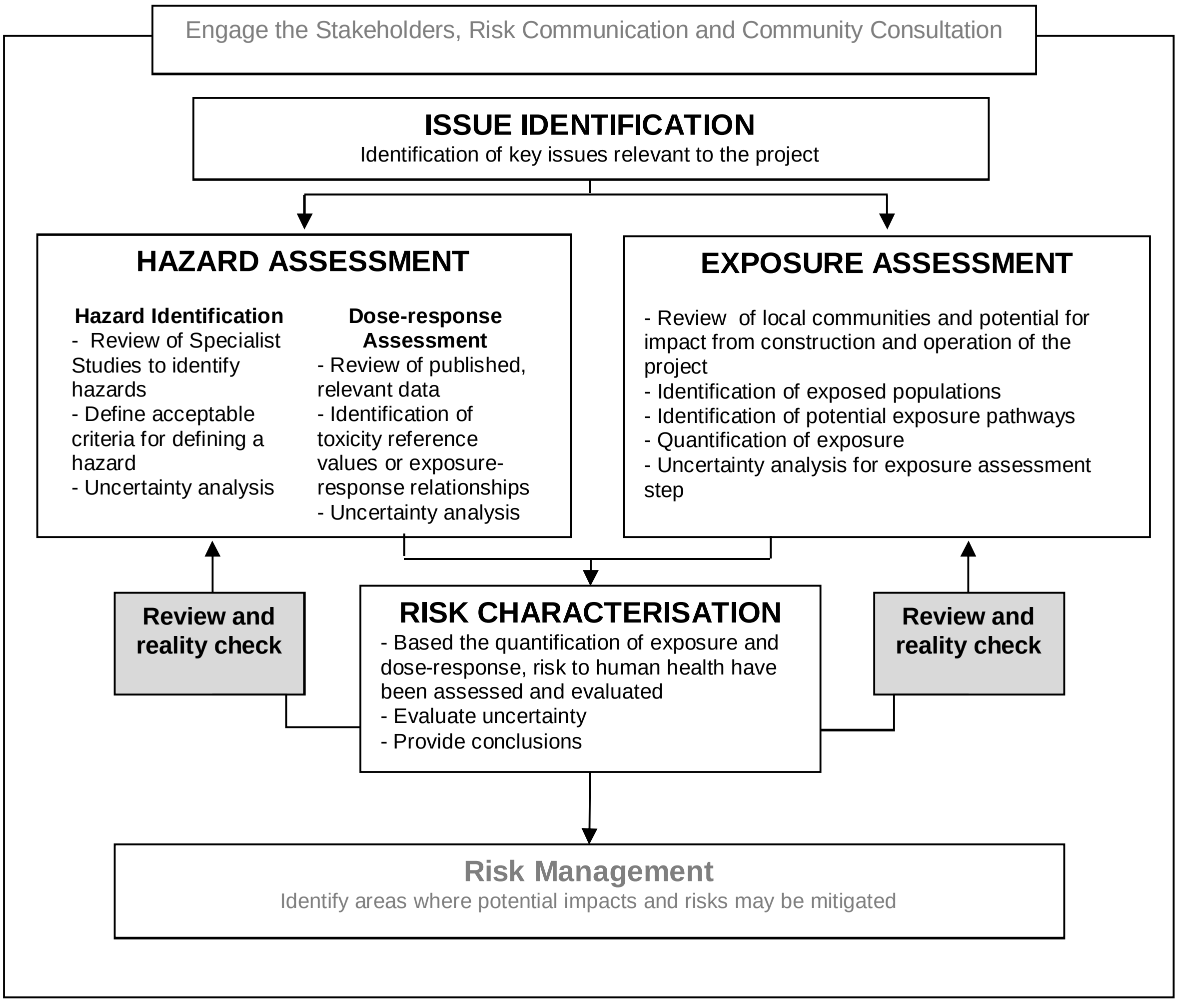

Figure 1-3 Overall human health risk assessment approach (modified from enHealth, 2012)

1.5.3 Features of the risk assessment

The HHRA has been carried out in accordance with international best practice and general principles and methodology accepted in Australia by groups such as NHMRC, NEPC and enHealth. There are certain features of risk assessment methodology that are fundamental to the assessment of the outputs and to drawing conclusions on the significance of the results. These are summarised below:

- A risk assessment is a tool (that is systematic) that addresses potential exposure pathways based on an understanding of the nature and extent of the impact assessed and the uses of the local area by the general public. The risk assessment is based on an estimation of maximum, or worst-case, ground level concentrations modelled in the local community and hence is expected to overestimate the actual risks.
- Conclusions can only be drawn with respect to emissions to air derived from the project as outlined in this technical working paper.
- Available statistics in relation to the existing health status of the existing community are presented in the technical working paper; however the HHRA does not provide an evaluation of the overall health status of the community or any individuals. Rather, it is a logical process of calculating and comparing potential exposure concentrations (acute and chronic) in surrounding areas (associated with the project) with regulatory and published acceptable air concentrations that any person may be exposed to over a lifetime without unacceptable risk to their health. It can also involve calculating an incremental impact that can be evaluated in terms of an acceptable level of risk.
- The risk assessment reflects the current state of knowledge regarding the potential health effects of chemicals identified and evaluated in this assessment. This knowledge base may change as more insight into biological processes is gained, further studies are undertaken and more detailed and critical review of information is conducted.

This assessment does not address all the health impacts, both positive and negative, associated with the project. Rather the assessment presented in this technical working paper has focused on key impacts (negative impacts) to air quality and noise/vibration identified by NSW Health as requiring detailed consideration within the environmental impact statement. It is noted that the project is set to deliver a number of key improvements and these are further outlined in Chapter 11 of the environmental impact statement.

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Section 2. Project design

2.1 General

This section presents an overview of the project design being considered in this technical working paper. The details presented provide a summary of key aspects of the project that are discussed in detail within Chapter 5 of the environmental impact statement.

Key features of the project would include:

- Twin motorway tunnels up to around nine kilometres in length with two lanes in each direction. The tunnels would be constructed with provision for a possible third lane in each direction if required in the future.
- A northern interchange with the M1 Pacific Motorway and Pennant Hills Road, including sections of tunnel for on-ramps and off-ramps, which also facilitate access to and from the Pacific Highway.
- A southern interchange with the Hills M2 Motorway and Pennant Hills Road, including sections of tunnel for on-ramps and off-ramps.
- Integration works with the Hills M2 Motorway including alterations to the eastbound carriageway to accommodate traffic leaving the Hills M2 Motorway to connect to the project travelling northbound, and the provision of a new westbound lane on the Hills M2 Motorway extending through to the Windsor Road off-ramp.
- Tie-in works with the M1 Pacific Motorway extending to the north of Edgeworth David Avenue.
- A motorway operations complex located near the southern interchange on the corner of Eaton Road and Pennant Hills Road that includes operation and maintenance facilities.
- Two tunnel support facilities, which incorporates emergency smoke extraction outlet points and substations along the main alignment.
- Ancillary facilities for motorway operation, such as electronic tolling facilities, signage, ventilation systems and fire and life safety systems including emergency evacuation infrastructure.
- Modifications to service utilities and associated works at surface roads near the two interchanges and operational ancillary facilities.
- Modifications to local roads, including widening of Eaton Road near the southern interchange and repositioning of the Hewitt Avenue cul-de-sac near the northern interchange.
- Ancillary temporary construction facilities and temporary works to facilitate the construction of the project.

Construction activities would generally include:

- Enabling and temporary works, including construction power, water supply, site establishment, demolition works, property and utility adjustments and public transport modifications (if required).
- Construction of the road tunnels, interchanges, intersections and roadside infrastructure.
- Haulage of spoil generated during tunnelling and excavation activities.
- Fit-out of the road tunnels and support infrastructure, including ventilation and emergency response systems.
- Construction and fit-out of the motorway control centre and ancillary operations buildings.
- Realignment, modification or replacement of surface roads, bridges and/or underpasses.
- Environmental management and pollution control facilities for the project.

2.2 Interchanges

2.2.1 Southern interchange

The southern interchange would be located near the existing intersection of the Hills M2 Motorway and Pennant Hills Road at Carlingford (refer to **Figure 2-1**). The interchange would provide connections to and from the project with the Hills M2 Motorway and Pennant Hills Road.

To enable these new connections, surface road works along Pennant Hills Road immediately north of the Hills M2 Motorway would be required. Works along the Hills M2 Motorway for connection to the project tunnel portals would also be required.

Portals to the northbound on-ramp and southbound off-ramp along Pennant Hills Road would be located south of Eaton Road. The main alignment tunnel portals would emerge adjacent to the shoulders of the Hills M2 Motorway to the west of Pennant Hills Road providing an uninterrupted connection between the Hills M2 Motorway.

2.2.2 Northern interchange

The northern interchange would be located near the intersection of the M1 Pacific Motorway and Pennant Hills Road at Wahroonga (refer to **Figure 2-2**). The northern interchange would connect the project with the M1 Pacific Motorway and Pennant Hills Road to enable traffic to travel north, south or east. In addition to this, the northern interchange would provide connections for traffic on or from Pennant Hills Road and the Pacific Highway to continue travelling via these existing roads.

Portals to the southbound on-ramp and northbound off-ramp for Pennant Hills Road would be located to the east of Pennant Hills Road within the median of the Pennant Hills Road / M1 Pacific Motorway connector. This would require a widened section of road between these portals and Pennant Hills Road. This design approach has been adopted to minimise the need for permanent alterations to existing roadways and traffic arrangements.

The portals of the main alignment tunnels would emerge in the shoulders of the M1 Pacific Motorway to the north of Alexandria Parade in the vicinity of Bareena Avenue, Wahroonga.

Figure 2-1 Southern interchange operational layout

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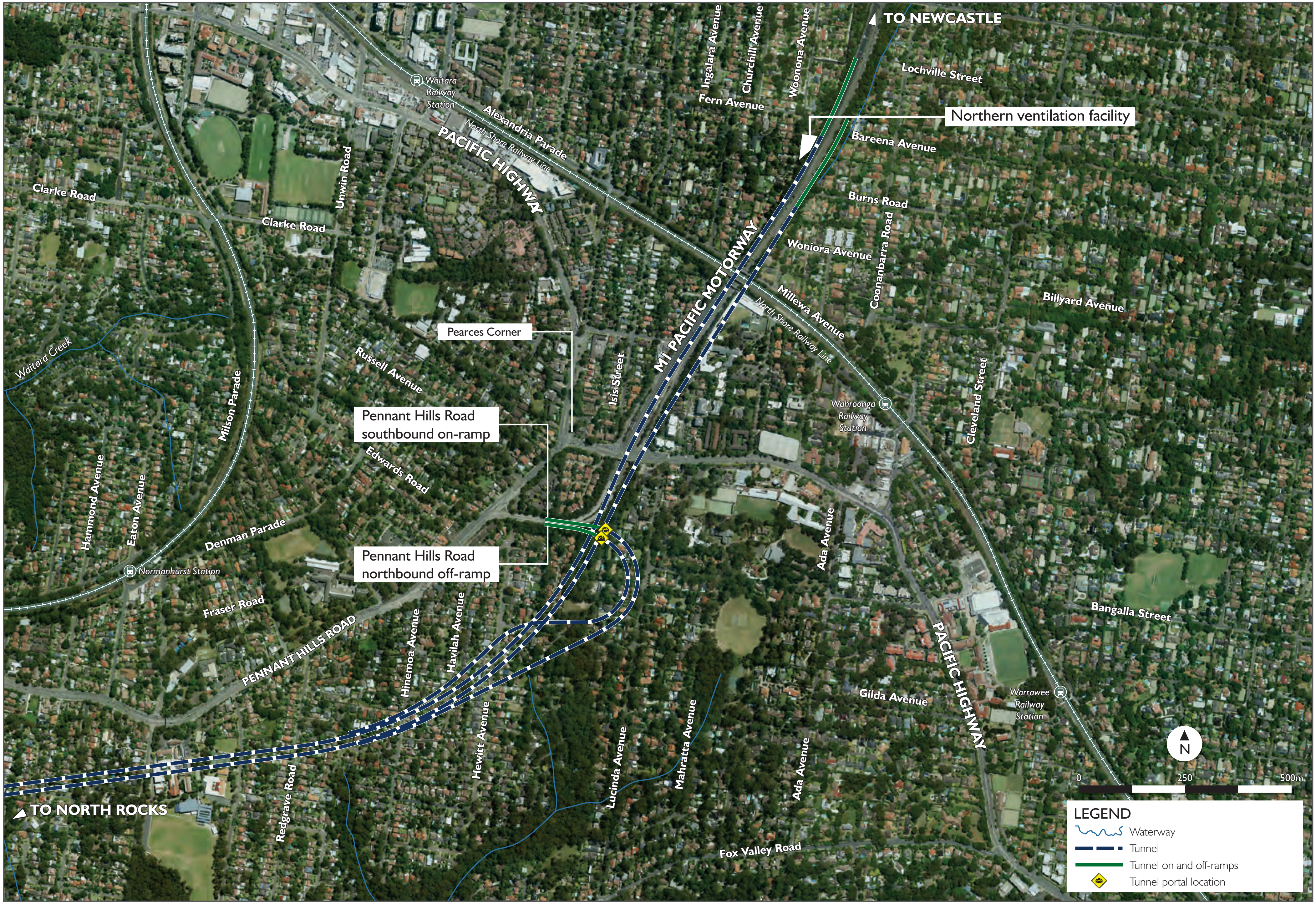

Figure 2-2 Northern interchange operational layout

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2.3 Ventilation system

Tunnel ventilation is proposed to be undertaken through the use of the following:

- During normal operation fresh air is drawn into the portals via a vehicle generated piston effect (ie the suction created behind a moving vehicle pulls air into and through the tunnel). Air in the tunnels would be pushed towards the main tunnel exit portals. Near the main tunnel exit portals air would be drawn upwards into the ventilation facilities and vented to atmosphere via the discharge points.
- Jet fans, mounted in pairs within the northbound and southbound tunnels, separated by a minimum of 90 metres. Jet fans would be located throughout the tunnel and would operate as required to maintain in tunnel air quality requirements.
- Ventilation facilities near the northern and southern main alignment portals (refer to **Figure 2-3**. Near the main tunnel exit portals air from the tunnel would be drawn into the ventilation facility where it would be discharged via a 15 metres high discharge point (when measured from adjoining land). Jet fans are used to draw air back in to the ventilation facility from the on and off-ramps.
- The ventilation system has been designed so there are no portal emissions (ie emissions from the tunnel exit portals directly to surrounding air). All air within the tunnel would be extracted from the tunnel and discharged to the atmosphere via the ventilation facilities.
- Two emergency smoke extraction facilities would be located on the corner of Wilson Road and Pennant Hills Road (southern) and on the corner of Trelawney Street and Pennant Hills Road (northern), refer to **Figure 2-3**. These facilities would be designed to extract smoke in the event of an emergency fire incident with a capacity of around 400 m^3/s. During low speed traffic conditions the emergency smoke extraction facilities could be used to provide additional fresh air into the tunnels.
- During low-speed traffic conditions there is the potential for additional fresh air to be supplied to the main tunnels via the reverse flow operation of the fans in the two tunnel support facilities.

The project has been designed so that all air from the project tunnels can be discharged via the two tunnel ventilation facilities.

The project does not currently propose portal emissions from the main alignment tunnels, however this approach may be considered in future and would be subject to appropriate assessment and approval. This would include a human health risk assessment.

2.4 Construction works

The majority of the construction footprint is located underground within the main alignment tunnels, however surface areas would be required to support tunnelling activities, and to construct the interchanges, tunnel portals, the Hills M2 Motorway integration, the M1 Pacific Motorway tie-in, the motorway operations complex, northern and southern ventilation buildings, tunnel support facilities and ancillary operations buildings and facilities. The surface construction footprint is presented in **Figure 2-4**.

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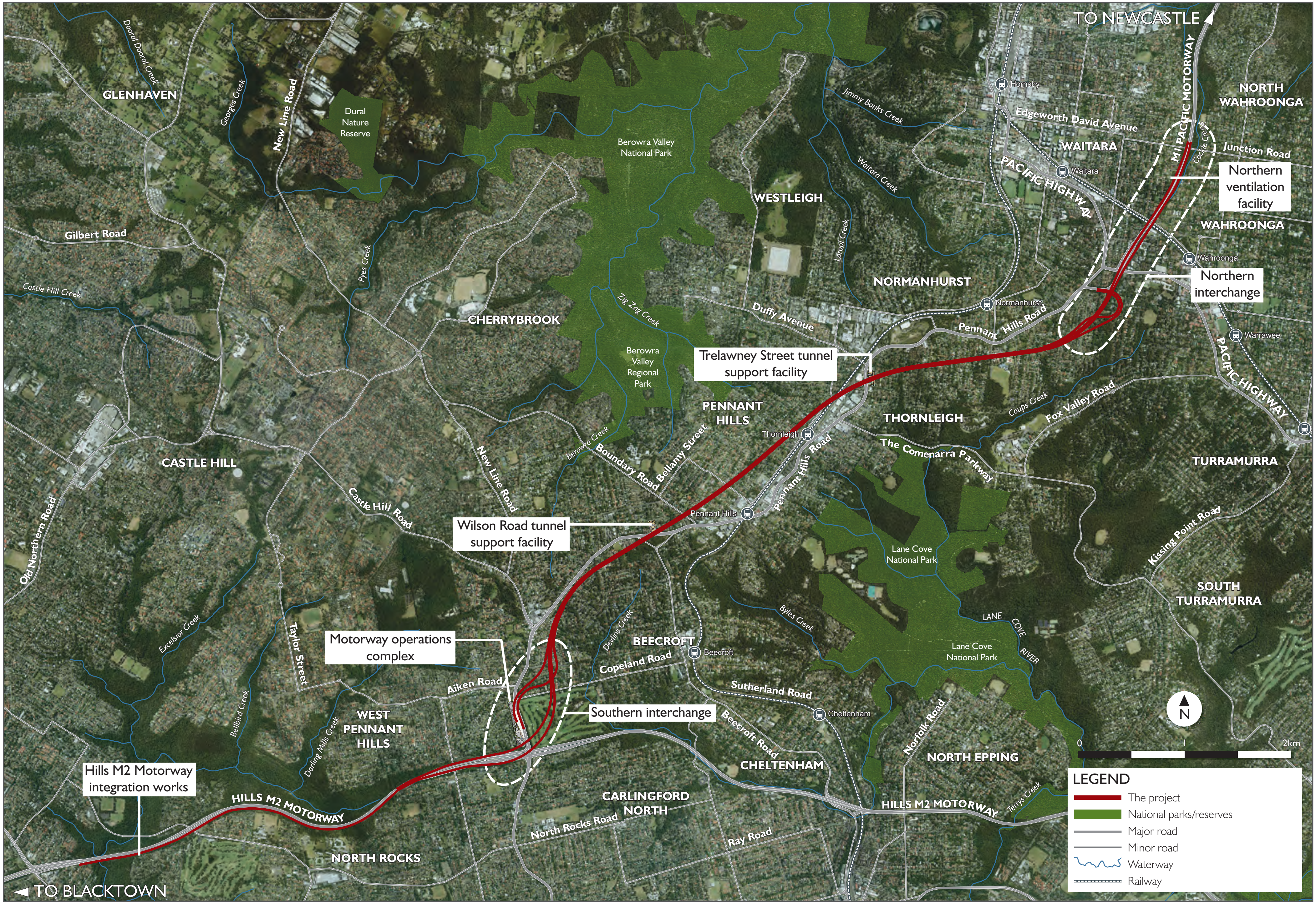

Figure 2-3 Ventilation and emergency smoke extraction facilities

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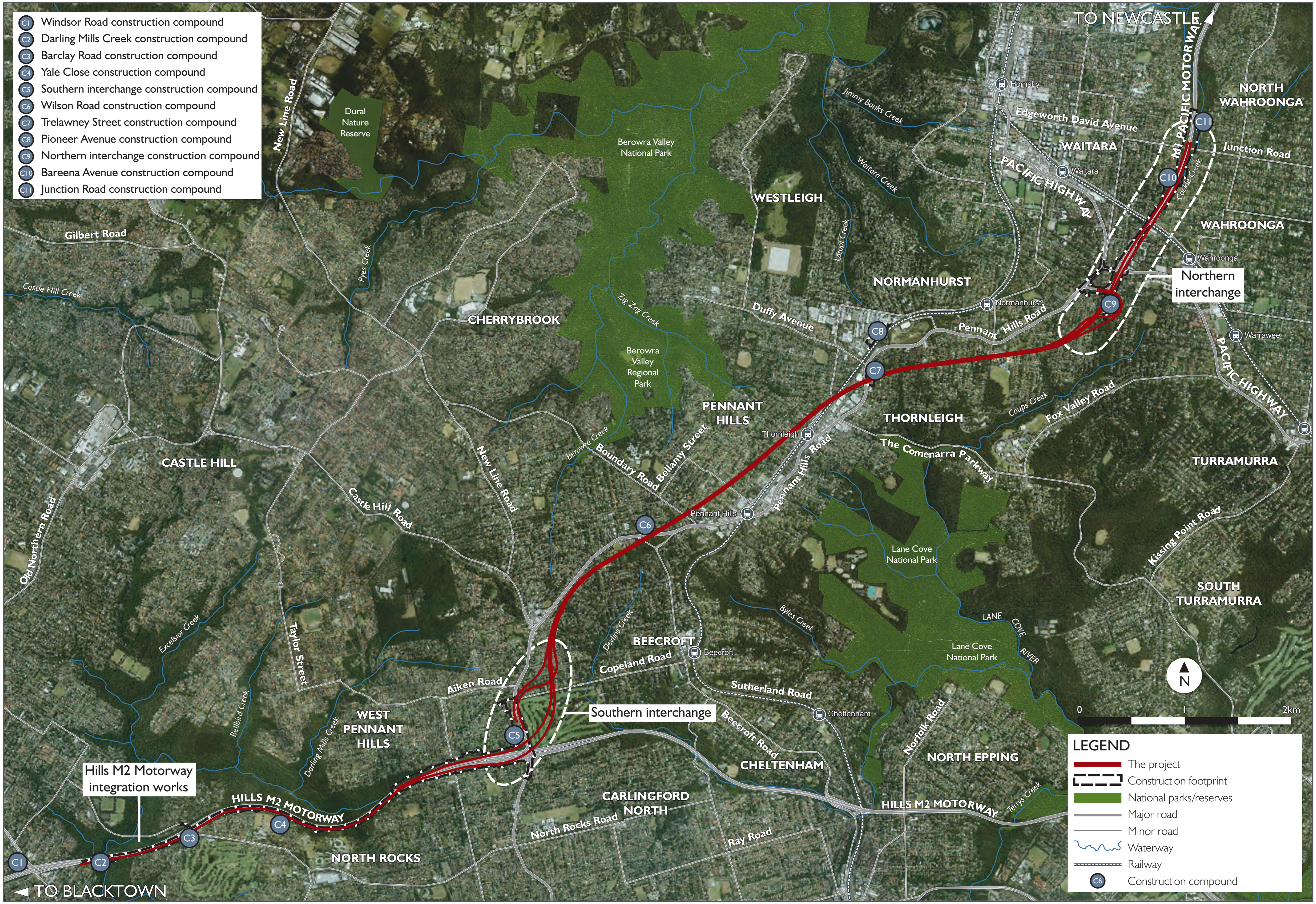

Figure 2-4 Overview of construction footprint and ancillary facilities

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2.5 Benefits of the project

The project is set to deliver a number of key improvements that are outlined in Chapter 11 of the environmental impact statement. In summary the benefits of the project include:

- Providing the missing link in Sydney's motorway network and the National Land Transport Network between the Hills M2 Motorway and the M1 Pacific Motorway.
- Future travel time savings of up to 40 minutes compared to without the project.
- Bypassing of 21 sets of traffic lights.
- Improving the efficiencies of intrastate and interstate freight movements through travel time saving and reduced operating costs.
- Improving safety of motorists, cyclists and pedestrians on Pennant Hills Road through the reduction in heavy vehicles.
- Improving local amenity and connectivity for people living, working and traveling along Pennant Hills Road.
- Providing opportunities for future public transport improvements and the reinvigoration of the Pennant Hills Road corridor.

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Section 3. Community profile

3.1 General

This section provides an overview of the community potentially impacted by the project. The key focus of the assessment presented is the local community, however some aspects of the assessment require consideration of statistics that are derived from larger populations, such as those within the Northern Area Health District and the greater Sydney Area. Hence, where relevant, information related to both the local community and other areas within Sydney (and NSW) have been presented.

3.2 Surrounding area and population

The main alignment tunnel covers a distance of around nine kilometres from Carlingford in the south to Wahroonga in the north. The population considered in this assessment includes those who live along Pennant Hills Road (where a reduction in road use and vehicle emissions is expected as part of this project) as well as within the vicinity of the southern and northern interchanges (ie where the tunnel interfaces with the surface road network).

Southern interchange

The southern interchange and ventilation facility is located near the current intersection between Pennant Hills Road and the M2 Hills Motorway. This is located in West Pennant Hills. The suburbs (or partial suburbs) surrounding the southern interchange include:

- West Pennant Hills.
- Carlingford.
- Beecroft/Cheltenham.
- North Rocks.
- Epping.

These suburbs surrounding the interchange are predominantly low to medium/high density residential areas with some retail/commercial areas. There are a number of day care centres and schools located in the suburbs surrounding the interchange.

Northern interchange

The northern interchange is located near the current intersection of Pennant Hills Road and the M1 Pacific Highway. This is located in the central western portion of Wahroonga. The ventilation facility is located on the western side of the M1 Pacific Motorway near Woonona Avenue in Wahroonga. The suburbs (or parts of these suburbs) surrounding the northern interchange include:

- Wahroonga.
- North Wahroonga.
- Waitara.
- Hornsby.
- Normanhurst.

Pennant Hills Road Alignment (parts of these suburbs):

- Wahroonga.
- Normanhurst.
- Thornleigh.
- Pennant Hills.
- West Pennant Hills
- Beecroft.

The suburbs located adjacent to Pennant Hills Road and surrounding the southern and northern interchanges are predominantly low to medium/high density residential areas with some retail/commercial areas. There are a number of day care centres, schools, aged care and hospitals located in these suburbs.

Sensitive receivers

The assessment of potential impacts on the surrounding community, particularly in relation to air quality, has considered the location where maximum impacts from the project may occur. In addition, impacts in the wider community have also been considered. Within the wider community, a number of additional locations, referred to as sensitive receivers, have been identified in the suburbs surrounding the southern and northern interchanges and evaluated. Sensitive receivers are locations in the local community where more sensitive members of the population, such as infants and young children, the elderly or those with existing health conditions or illnesses, may spend a significant period of time. These locations comprise hospitals, child care facilities, schools and aged care homes/facilities.

The location of sensitive receivers within one to two kilometres of the southern and northern interchanges are shown on **Figure 3-1** and **Figure 3-2**, and listed in **Table 3-1** and **Table 3-2**. The receivers presented in **Tables 3-1 and 3-2** are not an exhaustive list and some receivers have been grouped together (where they are located close to each other).

Table 3-1 Location of sensitive receivers surrounding the southern interchange

No.	Sensitive receivers	Address
Child Care		
51	Bird House Early Learning Centre	4/6 Leigh Place West Pennant Hills
52	Shine Preschool	54 Dryden Ave Carlingford
53	Thinking Hats Early Learning Centre and Twinklestar Childcare	3 and 3A Welham St Beecroft
54	Beecroft Long Day & Early Learning Centre	23A Wongala Crescent, Beecroft
Aged Care		
55	Twilight Aged Care: Jamieson House	8 York St Beecroft
56	Southern Cross Nordby Village	15 Hill Road West Pennant Hills
57	Beecroft Nursing Home	134 Beecroft Rd, Beecroft
Schools		
58	Murray Farm Public School	Tracey Ave Carlingford
59	Beecroft Primary School	90-98 Beecroft Rd Beecroft
60	North Rocks Public School	359 North Rocks Rd North Rocks
61	St Gerards Primary School	543 North Rocks Rd Carlingford
62	Roselea Primary School	549 North Rocks Rd Carlingford
63	Carlingford High School	North Rocks Rd Carlingford
64	Colin Place Out of School Care	2 Colin Place Carlingford
65	Muirfield High School	9-13 Barclay Road, North Rocks
66	West Pennant Hills Public School	Church Street, West Pennant Hills
67	Arden Anglican School	50 Oxford Street Epping
Other		
68	Pennant Hills Golf Course	Burns Rd Beecroft/Carlingford
69	West Pennant Hills Community Church	41-43 Eaton Rd West Pennant Hills
70	Roselea Community Centre	647-671 Pennant Hills Rd Carlingford

Table 3-2 Location of sensitive receivers surrounding the northern interchange

No.	Sensitive receivers	Address
Child Care		
1	KU Wahroonga	23 Millewa Lane Wahroonga
2	Next Generation Child Care	30 Myra St Wahroonga
3	Bumble Bees Early Learning Centre	76 King Road Hornsby
4	Balamara Preschool	79 Edgeworth David Ave Waitara
5	Peter Rabbit Community Preschool	St Pauls Church Hall, Pearces Corner Wahroonga
6	Centacare Broken Bay Waitara Children's Services Long Daycare (Waitara Family Centre)	29 Yardley Ave Waitara
7	Wahroonga Long Day Care	37 Hewitt Ave Wahroonga
8	Normanhurst Child Care Centre	66 Denman Pde Normanhurst
9	Pymble Turramurra Kindergarten	21 Handley Ave, Turramurra
10	Wahroonga Beehive Pre-School	168 Eastern Rd, Wahroonga
11	Kids Academy Hornsby	36-38 Northcote Rd, Hornsby
12	Twinkle Tots Cottage	18 Wentworth Ave, Waitara
13	Explore & Develop Waitara Little Learning School Hornsby Bright Horizons Early Learning Centre	41 Balmoral Street, Hornsby 90 Balmoral Street, Hornsby 94 Balmoral Street, Hornsby
14	Little Learning School Wahroonga	89 Burdett Street, Wahroonga
Aged Care		
15	The Woniora Aged Care	9 Woniora Ave Wahroonga
16	Tallwoods Corner	1 Myra St Wahroonga
17	The Grange	2 McAuley Place Waitara
18	B'nai B'rith Retirement Village	3-9 Jubilee St Wahroonga
19	Bowden Brae Retirement Village	40-50 Pennant Hills Rd, Normanhurst
20	Greenwood Aged Care	9-17 Hinemoa Ave, Normanhurst
21	Wahroonga Nursing Home	31 Pacific Hwy, Wahroonga

No.	Sensitive receivers	Address
22	Netherby Aged Care Belvedere Aged Care Wahroonga Waldorf Apartments	17-19 Pacific Hwy, Wahroonga 9 Pacific Hwy, Hornsby 1 Woolcott Ave, Wahroonga
25	Thomas & Rosetta Aged Care Facility Redleaf Serviced Apartments/Aged Care	1634 Pacific Hwy, Wahroonga 1630 Pacific Hwy, Wahroonga
26	UPA of NSW Ltd (United Prodestant Association, aged care facility)	1614 Pacific Hwy, Wahroonga
Schools		
28	Waitara Public School	68 Edgeworth David Ave Wahroonga
29	Wahroonga Preparatory School	61 Coonanbarra Rd Wahroonga
30	Wahroonga Public School	71 Burns Road, Wahroonga
31	Hornsby Girls High School	Edgeworth David Ave Hornsby
32	Normanhurst Boys High School	Pennant Hills Rd Normanhurst
33	Normanhurst Public School	2/14 Normanhurst Rd Normanhurst
34	Abbotsleigh	1666 Pacific Highway Wahroonga
35	Abbotsleigh Junior School and Early Learning Centre	22 Woonona Ave Wahroonga
36	Knox Grammar	7 Woodville Ave Wahroonga
37	Knox Preparatory School	1-13 Billyard Ave, Wahroonga
38	Our Lady of the Rosary Primary School	23 Yardley Ave Waitara
39	St Lucys School	21 Cleveland Street Wahroonga
40	Prouille Catholic College	Cleveland Street, Wahroonga
41	Prouille Catholic Primary School	5 Water Street Wahroonga
42	St Leos	Woolcott Ave Wahroonga
43	Barker College	Pacific Highway, Hornsby
44	Warrawee Public School	1486 Pacific Hwy Warrawee
45	St Edmund's School for Blind and Visually Impaired	60 Burns Road, Wahroonga
46	Hornsby South Public School Clarke Road School	57-63 Clarke Road, Hornsby Clarke Road and Neutral Rd, Hornsby
48	Retaval School	100 Fox Valley Rd, Wahroonga
Other		
49	Hornsby Hospital (and childcare centre)	Palmerston Rd Hornsby
50	Neringah Hospital (hope Healthcare)	4 Neringah Ave Wahroonga

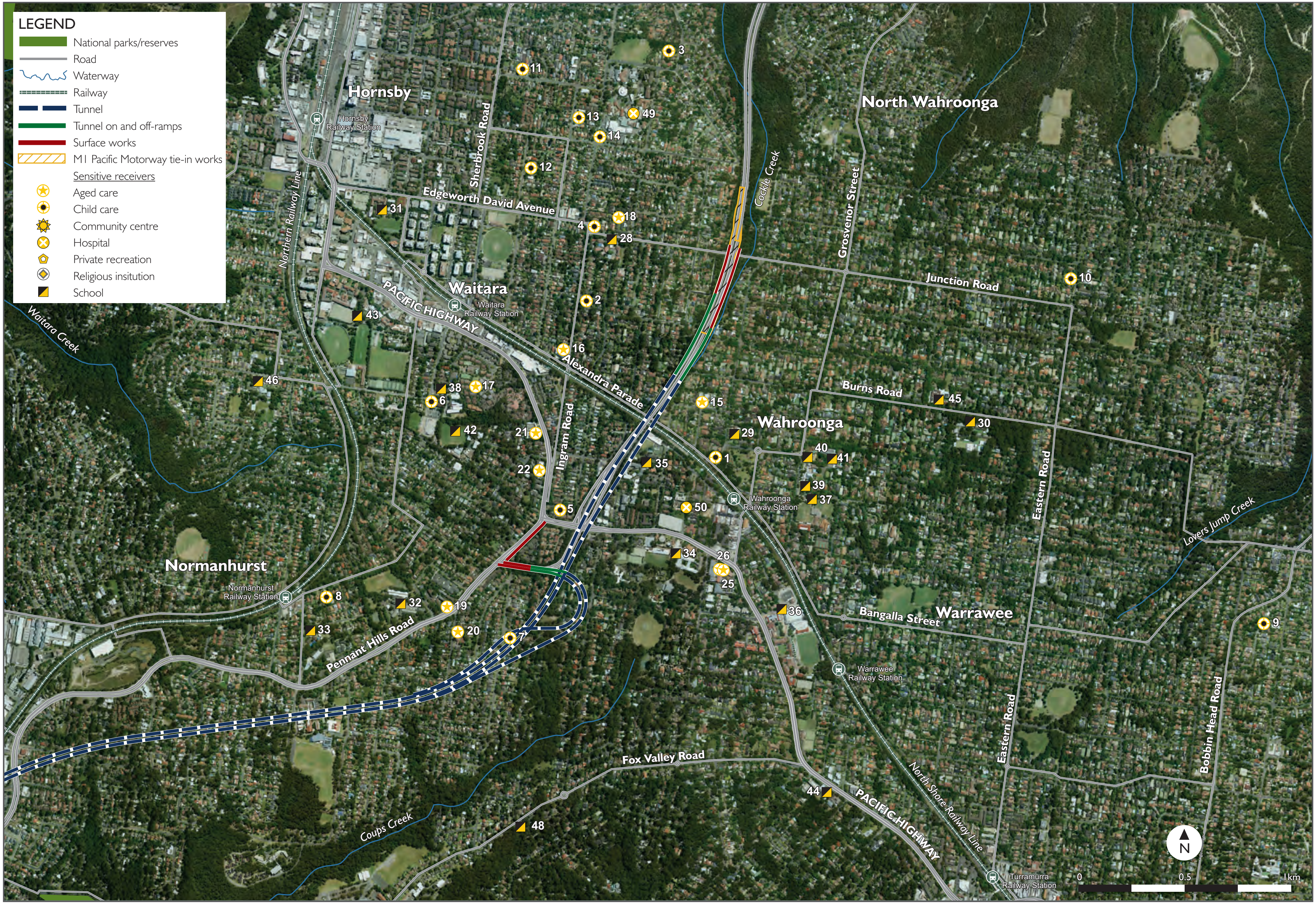

Figure 3-1 Location of sensitive receivers - northern interchange

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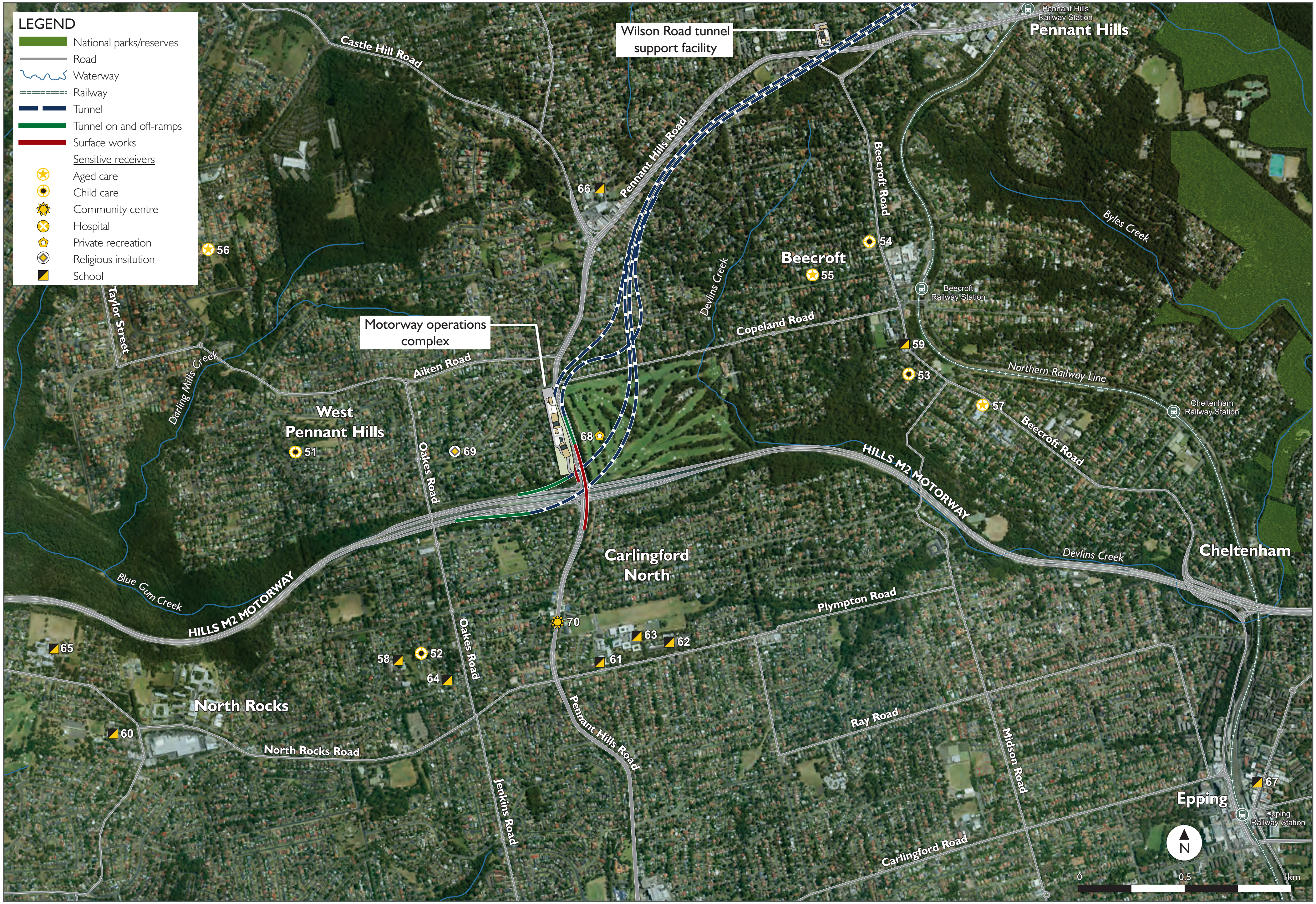

Figure 3-2 Location of sensitive receivers - southern interchange

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3.3 Population profile

The population within the areas surrounding the southern and northern interchanges comprise residents and workers as well as those attending schools, day-care and recreational areas within the surrounding suburbs. The composition of the populations located within one to two kilometres km of the northern and southern interchanges is expected to be generally consistent with population statistics for the larger individual suburbs. Population statistics for the suburbs (based on state suburb areas) surrounding the northern and southern interchanges are available from the Australian Bureau of Statistics for the census year 2011 and are summarised in **Figure 3-3** and the following graph. For the purpose of comparison the population statistics presented also include the statistics for the larger statistical areas of Hornsby South (which includes most of the suburbs of interest for this project), greater Sydney and the rest of the NSW (excluding greater Sydney).

Table 3-3 presents a summary of a selected range of demographic measures relevant to the population of interest with comparison to statistical local area of Hornsby South, greater Sydney and the rest of the NSW (excluding greater Sydney).

Table 3-3 Summary of population statistics

Location	Total Population		% Population by Key Age Groups				
	Male	Female	0-4	5-19	20-64	65+	30+
Southern interchange							
Carlingford	10594	10976	5.2	20	58.6	16.1	63
West Pennant Hills	7813	8154	5.1	21.3	61.2	12.4	61
Beecroft	4186	4650	4.7	21.8	54.9	18.5	63
North Rocks	3761	3864	6.5	19.9	57.4	16.2	64
Epping	9883	10344	4.8	18.9	63	13.3	60
Northern interchange							
Wahroonga	8001	8725	5.6	23	53.7	17.7	62
North Wahroonga	949	937	4.8	22.3	56.6	16.3	63
Warrawee	1440	1472	4.6	23.7	58.1	13.6	58
Waitara	2584	2786	7.8	14.3	62.9	14.9	64
Hornsby	9694	10169	7.2	15.7	65.5	11.6	62
Normanhurst	2410	2746	6.6	22.9	52	18.5	61
Additional Suburbs Along Pennant Hills Road							
Thornleigh	3976	4139	7.7	20.6	58.2	13.6	70
Pennant Hills	3443	3588	5.8	20	58.6	15.6	74
Larger Statistical Areas							
Hornsby South (Statistical Area)	43701	46404	6.2	19.4	59.6	14.7	62
Greater Sydney	2162221	2229453	6.8	18.7	61.7	12.9	60
Rest of NSW (excluding greater Sydney)	1239007	1273942	6.3	19.7	55.9	18	63

Ref: Australian Bureau of Statistics, Census Data 2011

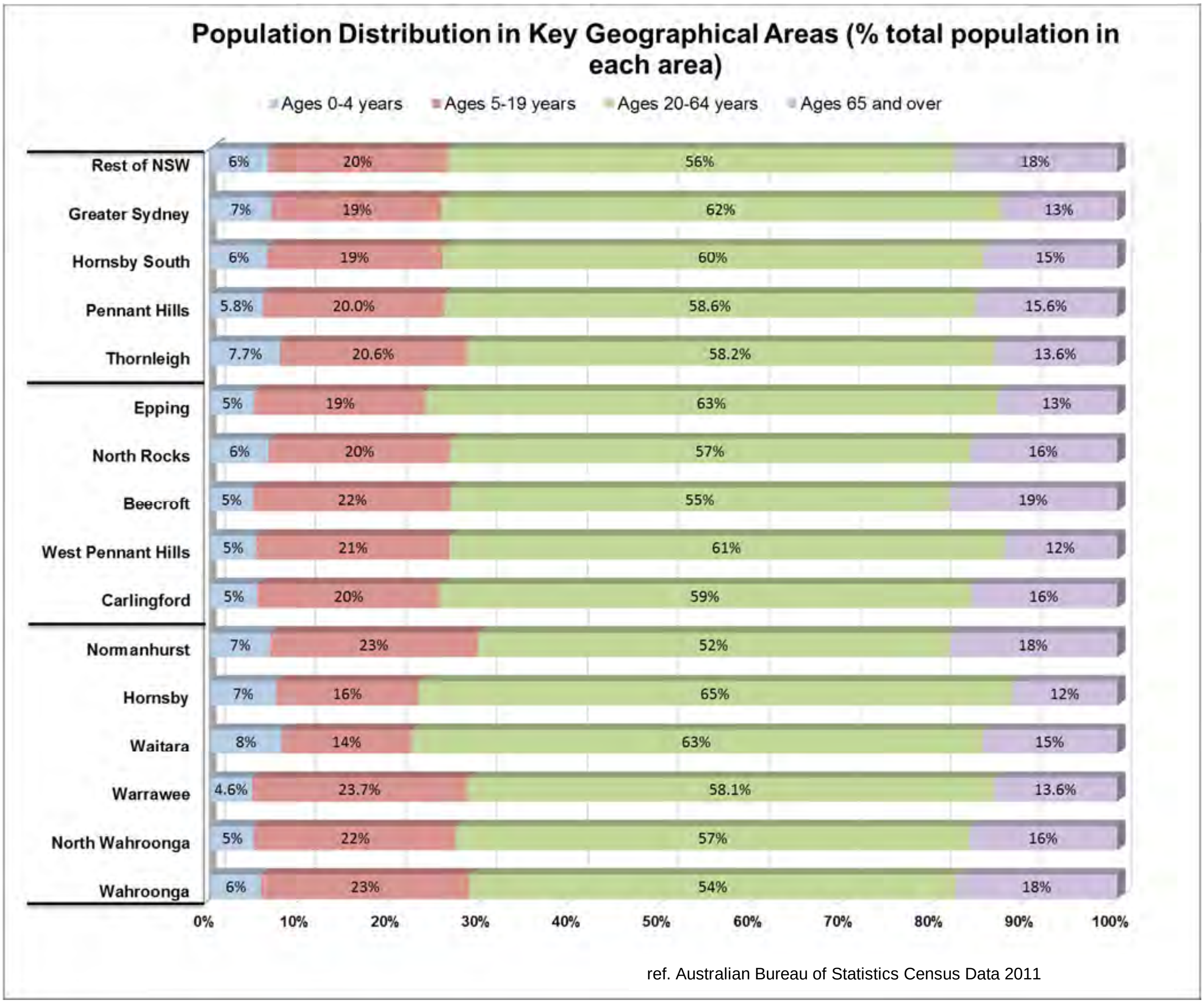

Figure 3-3 Population distribution

Based on this general population data, the suburbs surrounding the southern interchange are generally similar to Greater Sydney with the exception of Beecroft where there is a higher percentage of people aged 65 years and older. The suburbs surrounding the northern interchange are a little more variable with the suburbs of Wahroonga, North Wahroonga, Warrawee and Normanhurst indicating a slightly higher proportion of people aged 5-19 years and 65 years and older (with a corresponding lower proportion of people aged 20-64 years), and the suburbs of Waitara and Hornsby indicating a lower proportion of people aged 5-19 years when compared with the larger area of Greater Sydney. Hornsby South includes most of the suburbs of interest in this project and shows a relatively similar population distribution to that of Greater Sydney.

The suburbs of interest in the project are located in three different local government areas – Hornsby Shire Council, Hills Shire Council and Ku-ring-gai Council.

The estimated population growth for these areas are:

- 37 per cent in the Hills Shire local government area from 2014-2031[1]
- 9 per cent in Hornsby Shire local government area from 2011-2031[2]
- 12 per cent in Ku-ring-gai Shire local government area from 2011-2031[2]

Table 3-4 Selected demographics of population of interest

Location	Median age	Median household income ($/week)	Median mortgage repayment ($/month)	Median rent ($/week)	Average household size	Unemployment rate (%)
Southern Interchange						
Carlingford	40	1572	2200	410	2.9	5.5
West Pennant Hills	41	2449	2600	480	3.1	4.3
Beecroft	43	2523	2650	500	3.0	4.1
North Rocks	40	1891	2500	450	3.0	4.0
Epping	38	1683	2286	420	2.8	6.1
Northern Interchange						
Wahroonga	41	2381	3000	501	2.9	4.2
North Wahroonga	42	2519	3360	673	3.1	4.2
Warrawee	40	2658	3200	530	3.0	5.6
Waitara	34	1413	2167	420	2.3	7.7
Hornsby	35	1436	2167	380	2.5	5.7
Normanhurst	40	1775	2531	334	2.8	5.2
Additional Suburbs Along Pennant Hills Road						
Thornleigh	38	1964	2600	395	2.9	5.6
Pennant Hills	40	1842	2400	400	2.8	5.6
Larger Statistical Areas						
Hornsby South (Statistical Area)	38	1730	2383	400	2.8	5.2
Greater Sydney	36	1447	2167	351	2.7	5.7
Rest of NSW (excluding greater Sydney)	41	961	1560	220	2.4	6.1

Ref: Australian Bureau of Statistics, Census Data 2011

The social demographics of an area have some influence on the health of the existing population. As shown in **Table 3-4**, the population located in the vicinity of the northern and southern interchanges, and along Pennant Hills Road, generally has lower unemployment (with the exception of Waitara and Epping) with a higher income and also higher mortgage repayments and rental costs compared with Greater Sydney and the rest of NSW.

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[1] http://forecast.id.com.au/the-hills/home

[2] http://www.nsforum.org.au/files/HACC-Misc/HACC-Planning-Framework/Northern%20Sydney%20Planning%20Framework%202008%20S3.pdf

3.4 Existing health of population

3.4.1 General

The assessment presented in this report has focused on key pollutants that are associated with construction and combustion sources (from vehicles), including particulate matter (namely $PM_{2.5}$ and PM_{10}). For these pollutants there are a large number of sources in the project area including other combustion sources (other than from the project), other local construction/earthworks and personal exposures (such as smoking) and risk taking behaviours that have the potential to affect the health of any population.

When considering the health of a local community there are a large number of factors to consider. The health of the community is influenced by a complex range of interacting factors including age, socio-economic status, social capital, behaviours, beliefs and lifestyle, life experiences, country of origin, genetic predisposition and access to health and social care. Hence, while it is possible to review existing health statistics for the local areas surrounding the project, and compare them to the greater Sydney area and NSW, it is not possible or appropriate to be able to identify a causal source, particularly individual or localised sources.

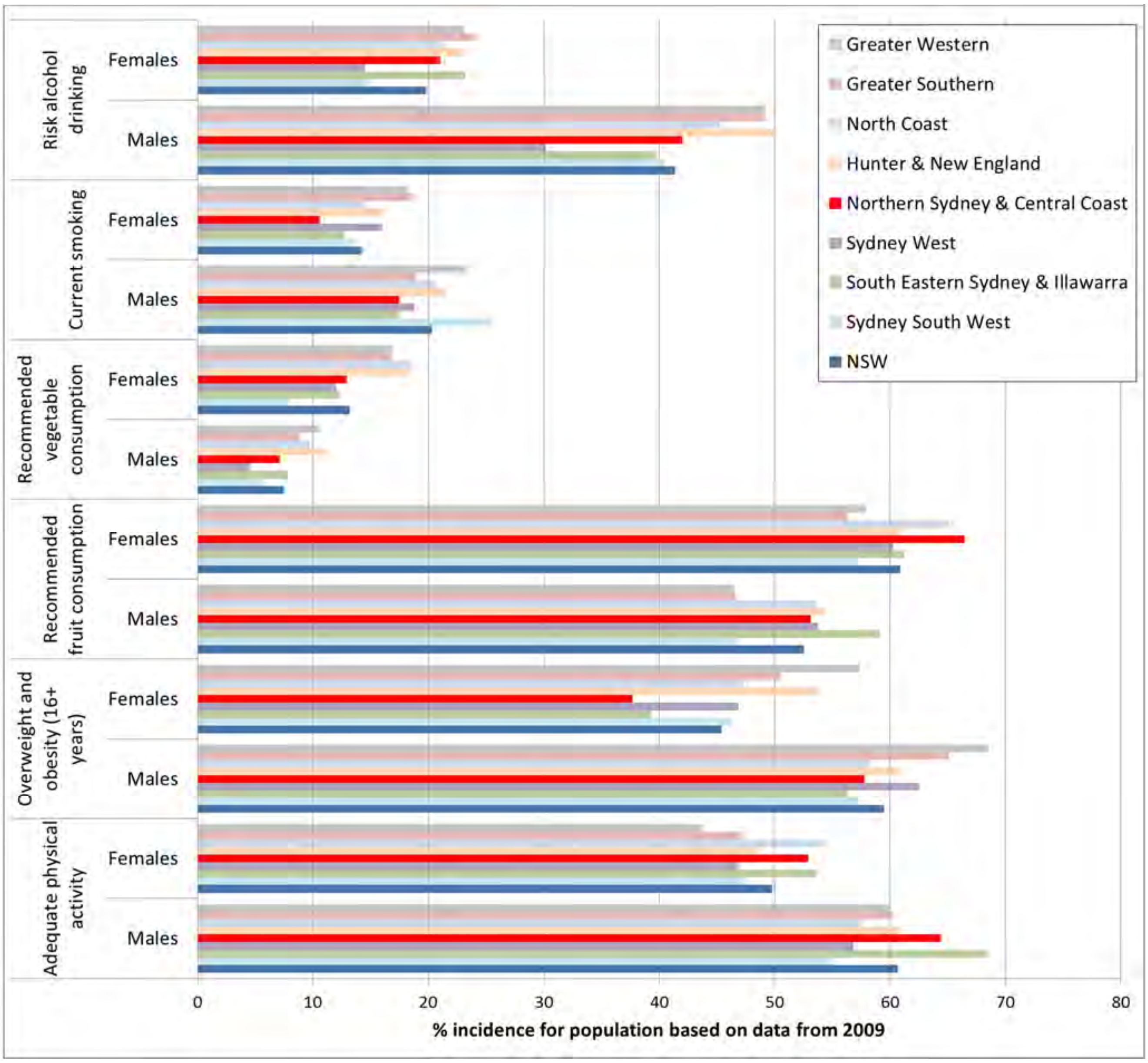
Most of the health indicators presented in this report are not available for each of the smaller suburbs/statistical areas surrounding the site, as outlined in **Section 3.1** to **Section 3.3**. Health indicators are only available from a mix of larger areas (that incorporate the study area) - the Northern Sydney Area Health Service and/or the combined area of Northern Sydney and the Central Coast. There are few health statistics that are reported for the smaller local government areas relevant to this project. The health statistics for these larger areas (and in some cases data for the Greater Sydney area) are assumed to be representative of the smaller population located in the vicinity of the northern and southern interchanges given the similarity of the demographics of these populations to Greater Sydney.

3.4.2 Health-related behaviours

Information in relation to health-related behaviours (that are linked to poorer health status and chronic disease including cardiovascular and respiratory diseases, cancer, and other conditions that account for much of the burden of morbidity and mortality in later life) are available for large health population areas in Sydney and NSW. This includes risky alcohol drinking, smoking, consumption of fruit and vegetables, overweight and obesity and adequate physical activity. The study population is grouped in the larger population area of Northern Sydney and Central Coast. The incidence of these health-related behaviours in this area, compared with other health areas in NSW, and the state of NSW (based on data from 2009) is illustrated in Figure 3-4.

Review of this data generally indicates the population in the Northern Sydney and Central Coast area:

- Have similar rates of risky alcohol drinking, recommended consumption of vegetables and overweight and obesity compared with NSW.
- Have higher rates of recommended consumption of fruit and adequate physical activity compared with NSW.



Note: these health-related behaviours include those where the behaviour/factor may adversely affect health (e.g. alcohol drinking, smoking, being overweight and obesity) and others where the behaviour/factor may positively affect (enhance) health (e.g. adequate fruit and vegetable consumption and adequate physical activity)

Figure 3-4 Summary of incidence of health-related behaviours 2009 (source: NSW Health, 2010)

3.4.3 Health indicators

Figure 3-5 and **Figure 3-6** present a comparison of the rates of the key mortality indicators (all causes, potentially avoidable, cardiovascular disease, lung cancer and chronic obstructive pulmonary disease (COPD in the elderly 65+ years)) and hospitalisations (diabetes, cardiovascular disease, asthma (5-34 years) and COPD (65+ years)) reported in the larger Northern Sydney and Central Coast Area Health Service, with comparison to other NSW area health services (in urban and regional areas) as well as NSW as a whole.

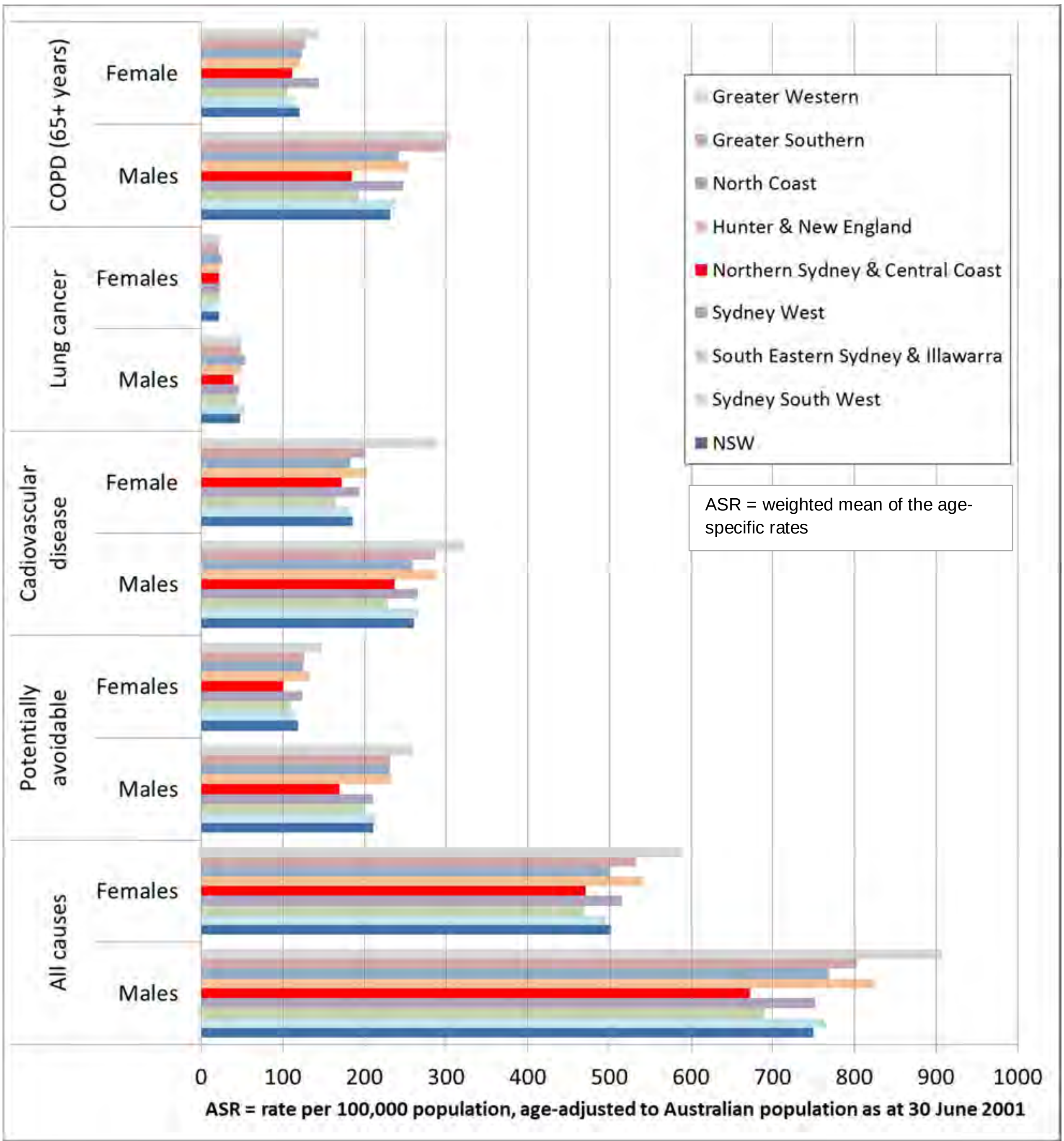


Figure 3-5 Summary of mortality data 2003 – 2007 (source: NSW Health, 2010)

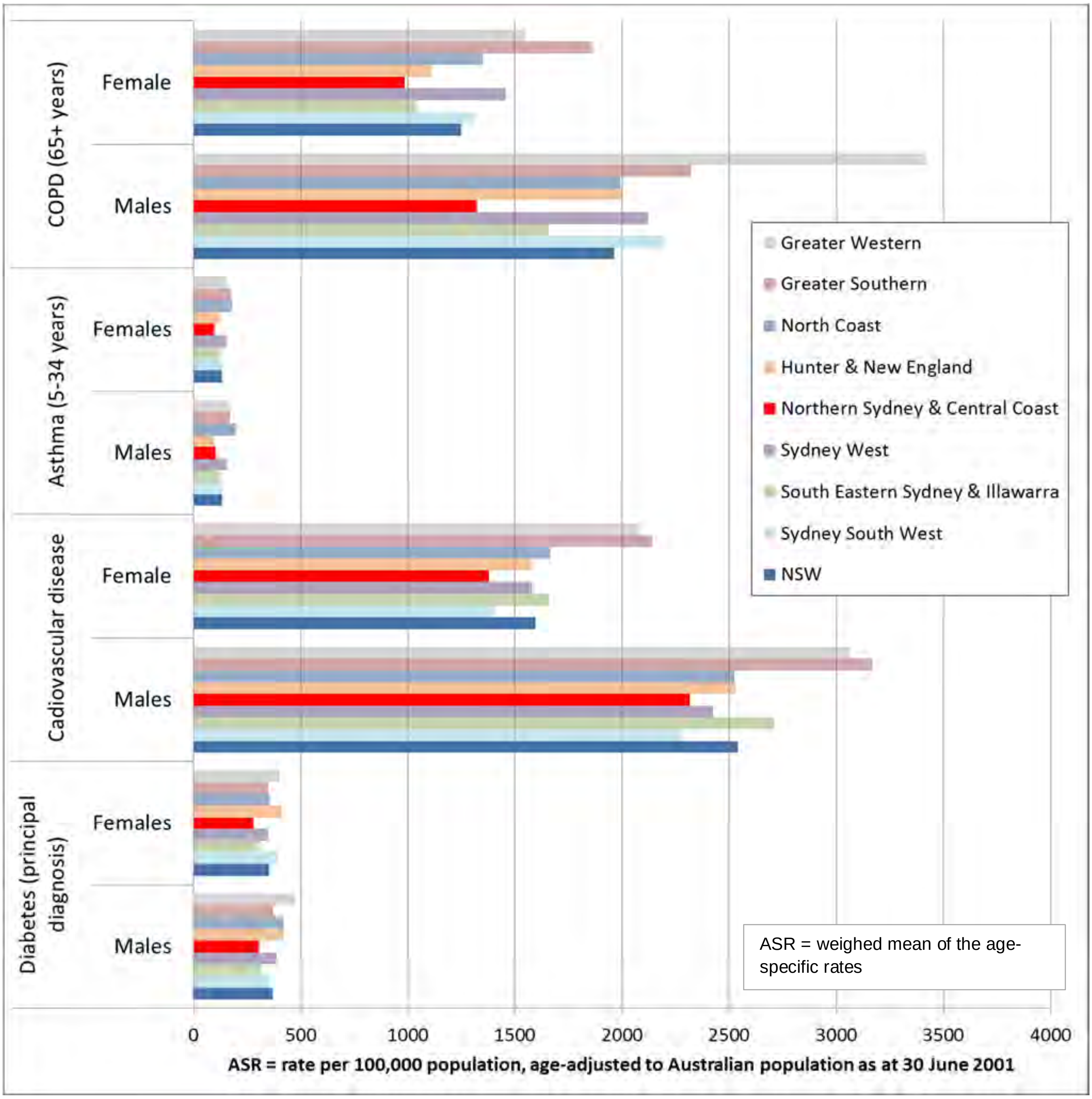


Figure 3-6 Summary of hospitalisation data 2008 – 2009 (source: NSW Health 2010)

In relation to some more specific health indicators **Table 3-5** presents the available data for the slightly smaller population areas defined under the Northern Sydney Area Health and for the Hornsby, Ku-ring-gai and the Hills local government areas (or GP health areas). These have been compared with available data for Sydney and NSW. The health indicators include those that are specifically relevant to the quantification of exposure to particulate matter presented in **Section 5.**

Table 3-5 Summary of key health indicators

Health Indicator	Data available for Population (rate per 100,000 population)					
	Hornsby Shire	Ku-ring-gai Shire	The Hills Shire	Northern Sydney Area Health	Greater Sydney	NSW
Mortality						
All causes – all ages*	--	--	--	496.6[1]	586.9[1]	670#[2]
All causes ≥30 years*	--	--	--	--	--	1087#[2]
Cardiopulmonary ≥30 years*	--	--	--	--	--	490#[2]
Cardiovascular – all ages*	--	--	--	--	--	164#[2]
Respiratory – all ages*	--	--	--	--	--	57#[2]
Hospital admissions						
Coronary heart disease	539.5[3]	462.7[3]	597.5[3]	442.3[4]	391.6[4]	608.7[4]
COPD >65 years	647.9[3]	558.1[3]	735.6[3]	745.2[4]	1194.2[4]	1470.4[4]
Cardiovascular disease						
All ages	--	--	--	1642.3[5]	1582.6[5]	1949.9[5]
>65 years*	--	--	--			23352#[3]
Respiratory Disease						
All ages	--	--	--	1520.1[5]	1530.3[5]	1770.2[5]
>65 years*	--	--	--	--	--	8807#[3]
Asthma						
Asthma hospitalisations (ages 5-34 years)	--	--	--	85.7[4]	105.1[4]	133.6[4]
Current asthma for ages 16 and over	--	--	--	12.1%[4]	7.8%[4]	11.3%[4]

* Health indicators directly relevant to the characterisation of potential impacts associated with exposure to particulate matter as presented in **Section 5**

Data provided by NSW Health (upon written request) for the purpose of this assessment.

All other data has been obtained from Health Statistics New South Wales

1 - Data from 2006-2007

2 – Data for 2005-2007

3 - Data for 2009-2011

4 – Data for 2010-2011

5 – Data for 2011-2012

-- No data available

In relation to asthma, the **Figure 3-7** shows the general indicators reported for the larger population area of Northern Sydney and Central Coast compared with the data available for NSW (also refer to **Appendix A** for comparison with other area health services).

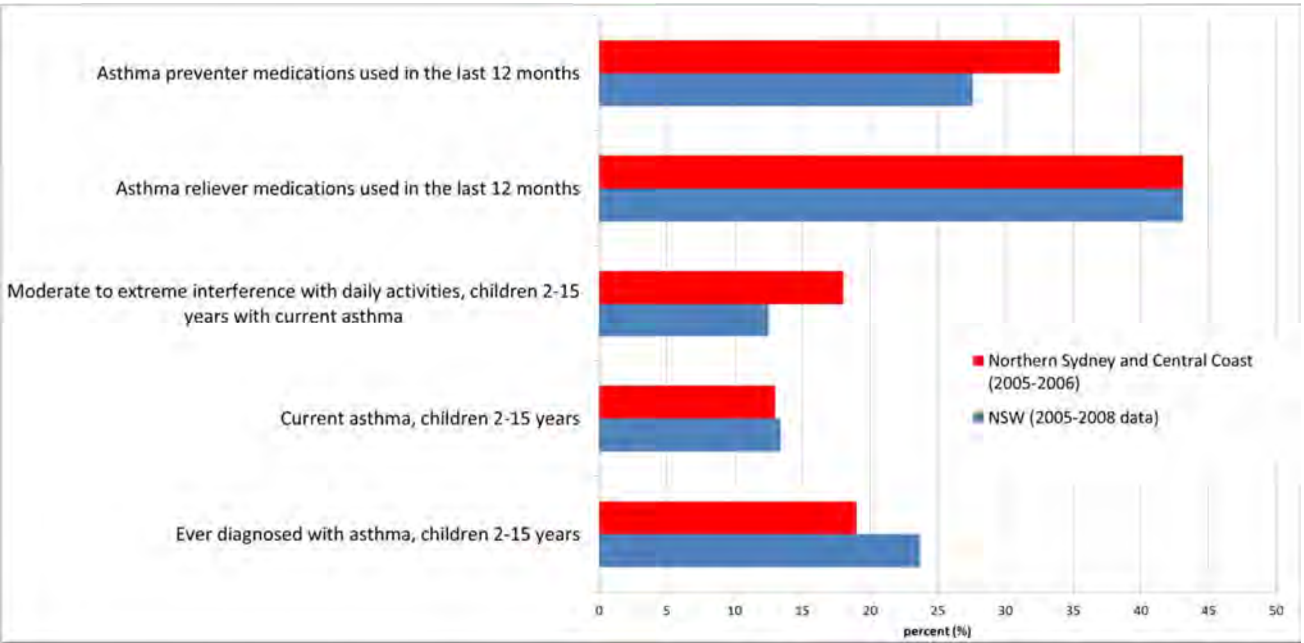


Figure 3-7 Summary of asthma prevalence and management (NSW and Northern Sydney/Central Coast)

Review of the available data generally indicates that for the population in the Northern Sydney area (including the Northern Sydney and Central Coast combined areas where relevant) the health statistics (including mortality rates and hospitalisation rates for most of these categories) are generally lower than compared with a number of other health areas and the whole of NSW.

For the assessment of potential health impacts from the project, where specific health statistics for the smaller population adjacent to the southern and northern interchanges is not available (and not reliable due to the small size of the population), adopting health statistics from the whole of NSW is considered to provide a representative, if not cautious (ie over estimating existing health issues), summary of the existing health of the population of interest.

Uncertainties

There are limitations in the use of this data for the quantification of impact and risk. This data is derived from statistics recorded by hospitals and doctors, reported by postcode of residence, and are dependent on the correct categorisation of health problems upon presentation at the hospital. There may be some individuals who may not seek medical assistance particularly with less serious conditions and hence there is expected to be some level of under-reporting of effects commonly considered in relation to morbidity. Quantitatively, the baseline data considered in this assessment is only a general indicator (not a precise measure) of the incidence of these health endpoints.

3.5 Existing environment

3.5.1 Existing air quality

The existing air quality in the study area is described in the technical working paper: air quality (AQIA) (AECOM, 2014). This technical working paper has used background air quality data collected by the Office of Environment and Heritage at Lindfield and Prospect, which are the closest stations to the project area. The Lindfield monitoring station is around 9.7 kilometres southeast of the southern ventilation outlet and the Prospect monitoring station is around 11 kilometres southwest of the southern ventilation outlet).

Air quality in the greater Sydney area is most significantly affected by bushfires (including hazard reduction burns) and dust storms with transport-related emissions identified as the largest source of human-related pollution. In general, NSW is considered to have good air quality in relation to international standards. Review of $PM_{2.5}$ and PM_{10} in many countries by the WHO[3] identified that concentrations reported in Australia low (amongst the lowest of all countries evaluated) compared with international levels.

Exceedances of the NEPC guidelines and advisory goals for particulate matter (PM) do occur in Sydney (as presented in the AQIA), primarily due to occasional bushfires, dust storms and hazard reduction burns rather than more every day conditions.

In relation to $PM_{2.5}$, review of the sources (emissions) that contribute to the measured $PM_{2.5}$ reported in the Sydney area by the NSW EPA (based on emissions inventory data – for the year 2008, published 2012[4]), as illustrated in **Figure 3-8**, indicates that the most significant sources are household activities (including residential wood heaters – with peak emissions in the winter months from wood-smoke). Emissions from road transport in the Sydney area contribute a consistent amount to the total $PM_{2.5}$ emissions (as would be expected as use of vehicles in Sydney is relatively constant throughout the year). As a percentage of the total emissions, road transport comprises a greater proportion of the total $PM_{2.5}$ emissions in summer compared with winter (where other sources are more dominant).

In relation to the project, five air quality monitoring stations where commissioned in locations along project corridor to supplement data collected by the Office of Environment and Heritage. This data has been collected since late 2013 and has been considered in the AQIA.

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[3] WHO, Ambient (outdoors) air pollution in cities database 2014, available from http://www.who.int/phe/health_topics/outdoorair/databases/cities/en/

[4] http://www.epa.nsw.gov.au/woodsmoke/index.htm

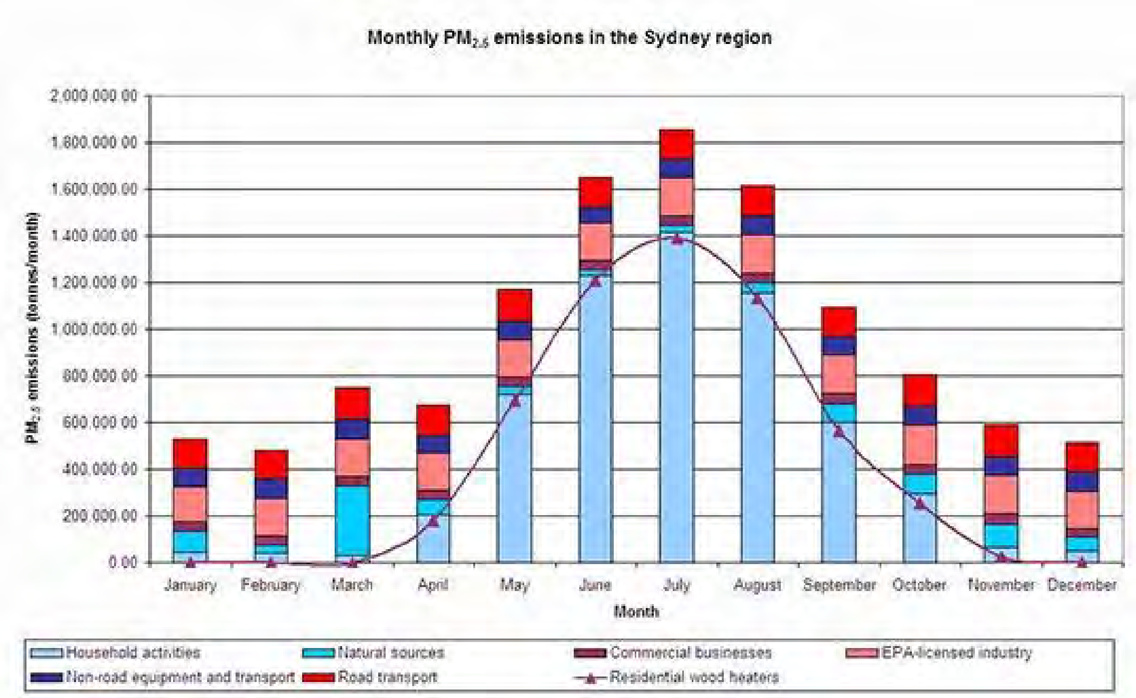

Figure 3-8 $PM_{2.5}$ emissions in Sydney – variability and contributions on monthly basis (2008, source: NSW EPA)

3.5.2 Existing noise environment

The existing noise environment in the study area (particularly adjacent to the Hills M2 Motorway east from Windsor Road, near the southern interchange, Pennant Hills Road, the northern interchange and the M1 Pacific Motorway) is described in the Noise and Vibration Technical Paper (AECOM 2014).

Existing noise in the study area is dominated by road traffic noise, primarily from the M1 Pacific Motorway, Pacific Highway, Pennant Hills Road and the Hills M2 Motorway. Noise in the study area is highly dependent on proximity to the existing roads.

Background noise monitoring (along with traffic counts) has been undertaken at 23 locations throughout the study area to determine the existing background noise levels. The background noise data is used to define appropriate construction noise management limits consistent with the NSW EPA Interim Construction Noise Guideline, and criteria to assess operational road noise or 'fixed' ancillary facilities such as the ventilation facilities (consistent with the NSW EPA Industrial Noise Policy). Background noise monitoring was also used in the assessment of operational traffic noise.

Background noise levels for the 23 locations in the study area were as follows:

- Day (7am to 6pm): rating background levels ranged from 41 to 59 dB(A) as $LA_{90,15}$
- Evening (6pm to 10pm): rating background levels range from 42 to 54 dB(A) as $LA_{90,15}$
- Night (10pm to 7am): rating background levels ranged from 30 to 45 dB(A) as $LA_{90,15}$

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Section 4. Review of air impacts

4.1 Air impact assessment

4.1.1 Summary

Emissions to air associated with the project have been evaluated in detail within the technical working paper: air quality (AECOM 2014) (AQIA). The AQIA has considered emissions to air that may occur during construction activities as well as during the operation of the project.

In relation to construction, emissions to air have been considered from the following sources:

- Construction traffic, plant and equipment where emissions to air are primarily derived from diesel powered vehicles and equipment, however some emissions are derived from motor vehicles.
- Bulk earthworks (underground vented at the surface via a tunnel ventilation system and aboveground) where emissions to air are associated with dust.

Impacts associated with the construction activities were evaluated in the AQIA along with a range of best practice mitigation measures. With the implementation of mitigation measures, the effects of the proposed works on local air quality and receivers are expected to be minimal and of short duration. Hence the focus of the more detailed (quantitative) evaluation of impacts to air quality has focused on the operation of the tunnel ventilation system.

Operational emissions have been estimated from petrol and diesel powered vehicles using the tunnel (in both directions) which are vented to atmosphere via the southern and northern interchange ventilation facilities, and increases in traffic volumes on approaches to the tunnel.

Emissions to air from the operation of the tunnel have been assessed using CALPUFF and CAL3QHCR models, meteorological data collected by the Office of Environment and Heritage (over 2009, 2010 and 2011) and terrain information relevant for the area. The modelling has considered impacts to sensitive receivers located close to the southern and northern interchanges extending (at increasingly reduced density of coverage as distance to the interchanges increase) around 20 kilometres in all directions. In addition a number of sensitive receivers have been included in the modelling for the purposes of this assessment as outlined in **Section 3.2**.

Emission factors for the pollutants of interest from the vehicles proposed to be using the tunnel have been obtained from published sources that include Australian-specific emissions based on the relevant vehicle fleet composition. These factors were used to estimate emissions in the years up to 2020 (taking into account improvements in vehicle emissions over time). The emission factors estimated in 2029 were conservatively assumed to be the same as those determined for 2020 (ie no further improvements in emissions technology assumed).

Vehicle emissions within the tunnel are discharged to air via the ventilation facilities located at the southern and northern interchanges. Specific details of the ventilations facilities (height and diameter, exit velocity and temperature) are presented in the AQIA. These emissions have been used to model air quality using the CALPUFF air dispersion model. In addition, emissions to air that occur on the road network proximal to the main tunnel portals (ie on the approaches) have been modelled using the CAL3QHCR dispersion model. Predicted impacts from both these models have been summed to obtain the combined impact from the project for the scenarios evaluated. This approach is appropriate for the estimation of impacts associated with the project.

The AQIA has evaluated the key pollutants that are relevant to emissions to air during the operation of the project, which include:

- Particulate matter (PM) including size fractions PM_{10} and $PM_{2.5}$ which are of importance for the assessment of potential health impacts from combustion sources.
- Oxides of nitrogen (in particular NO_2).
- Carbon monoxide (CO).
- Volatile organic compounds (VOCs) as total VOCs.
- Polycyclic aromatic hydrocarbons (PAHs, as total PAHs) which are particularly associated with diesel emissions.

Background levels of key pollutants (particulate matter, carbon monoxide and nitrogen dioxide) levels have been determined from available data on existing air quality from monitoring stations located in Lindfield and Prospect. The background air quality data is relevant for the assessment of cumulative impacts from the project.

Predicted impacts at all gridded and sensitive receiver locations and the maximum predicted concentration, for the scenarios considered, have been provided for consideration in this assessment. The impacts have been presented as incremental impacts (ie the project only) and cumulative impacts (ie the project plus background air quality).

4.1.2 Assessment scenarios

The assessment of emissions to air from the project has been undertaken within the AQIA for a number of scenarios, as outlined below:

Without project (scenario 1)

- This scenario assessed the standard ‘do nothing’ scenario, which predicted future pollutant concentrations from the surface roads in the event that the project is not constructed, with impacts compared with those predicted with the tunnel operating. Emissions were assessed using the CAL3QHCR model and expected future traffic volumes for the existing road network for 2019 and 2029.
- The outcome of the assessment of this scenario presented within the AQIA identified that predicted roadside concentrations of particulate matter would go down (by between five per cent and 35 per cent) along the existing road corridor of Pennant Hills Road and near the southern interchange. Roadside concentrations of particulate matter near the northern interchange are more variable (due to existing low levels of particulate matter at some locations) with some concentrations predicted to be lower with the tunnel (44 per cent lower) and others slightly higher (14 per cent).
- Overall air quality along the road corridor considered was improved with the construction and operation of the tunnel.

- The assessment presented in this technical working paper has not specifically considered this scenario further in relation to health impacts. However the calculations undertaken for scenario 1 have been utilised in an assessment of the project as a whole (impacts form the ventilation stacks as well as decreases in impacts along the existing road corridor of Pennant Hills Road) as presented in **Section 5.3.6**.

With Project – Expected traffic volumes – 2019 (scenario 2a) and 2029 (scenario 2b):

- This scenario assessed the forecast hourly traffic volumes with variable emission concentrations based on hourly traffic flows, and volumetric flow rates scaled by the predicted traffic volumes. This was done for 2019 (scenario 2a, the proposed year of opening) and 2029 (scenario 2b, design year).
- This scenario is representative of likely traffic flows (and variability including peak hour traffic flows) and hence is considered to be representative of more likely emissions and potential exposures that may occur during normal/expected operations.
- These scenarios have been further evaluated in this technical working paper.

With project – Theoretical maximum peak hour capacity (design analysis A)

- This design analysis has been conducted to ensure that the project's ventilation system is adequately sized to cater for tunnel full of traffic. It assumes that during peak hours, the maximum number of vehicles that can fit into the tunnel (4,000 passenger car units per two lane main alignment tunnel adjusted for speed). This design analysis represents the physical limit of the main alignment tunnels and is based on forecast traffic volumes that are unlikely to eventuate due to a range of factors including traffic management measures, projected land use, employment, demographics and constraints on the surrounding surface road network.

  As this design analysis is not likely to occur (particularly as modelled in 2019) the impacts predicted for this scenario, and the potential for exposure, are considered to be unlikely. The impacts predicted have only been considered (and presented in **Appendix E**) as an indication of worst-case conditions.

With project – Forecast traffic volumes with maximum hourly emissions – 2019/2029 (design analysis B):

- This design analysis has been conducted to ensure that regardless of when the peak traffic period occurs or for how it lasts, the project's ventilation system would be able to meet applicable air quality criteria. This design analysis assumes that the project's ventilation outlets emit the maximum concentration of pollutants based on peak forecast traffic flows on a continuous basis. In reality, emissions concentrations would vary during the day depending on the number and type of vehicles using the tunnels at the time.

  The design analysis is not representative of emissions that may occur during normal or peak traffic flow conditions and is therefore not relevant for the further assessment of exposure and health impacts in the local community.

Breakdown traffic flow:

- Expected vehicle emissions in the tunnel during a credible worst-case breakdown situation were used to calculate the associated pollutant concentrations. This scenario has been addressed on a qualitative basis within the AQIA, where the following has been concluded:
    - Emission rates of carbon monoxide, oxides of nitrogen and particulates during a breakdown are generally lower than the 'with project – expected traffic flows (northern ventilation outlet) in 2029 (which was presented as the highest expected mass emission rates of the scenarios considered in the AQIA) (scenario 2b).
    - Because the mass emission rates for the breakdown scenario are comparable to, but no greater than, the 'with project – forecast traffic flows' scenario, and the breakdown scenario would occur over a relatively short period, it is expected that the breakdown scenario would also comply with applicable air quality criteria it is expected that the breakdown scenario would also comply with applicable air quality criteria

  On the basis of the above, no separate assessment of the breakdown scenario is presented in this report.

This technical working paper has focused on air quality impacts predicted during scenarios 2a (2019) and 2b (2029). Calculations relevant to design analysis A is presented in **Appendix E**.

The following sections provide an initial, or screening level review of the predicted impacts associated with these scenarios. This screening level assessment has focused on the maximum predicted impacts (incremental and cumulative as relevant) from the project to determine if a more detailed review of health impacts would be required.

Impacts in all other areas (including the sensitive receivers) are lower than these maximum predicted impacts/concentrations. Further assessment of the sensitive receivers has been undertaken in the detailed review of exposures to particulate matter emissions presented in **Section 5**.

4.1.3 Vehicle emissions

Petrol and diesel vehicles emit a range of air pollutants that are known to be associated with adverse health impacts. Common air pollutants emitted from these vehicles include:

- Petrol vehicles: nitrogen oxides, in particular nitrogen dioxide, carbon monoxide, fine particulates and volatile organic compounds. The key volatile organic compounds of concern from motor vehicle emissions include benzene, toluene and xylenes (BTX) which have been associated with a range of health effects that range from headaches to eye irritation and cancer (depending on the compound).
- Diesel vehicles: nitrogen oxides, in particular nitrogen dioxide, carbon monoxide, fine particulates, volatile organic compounds (in particular BTX and 1,3-butadiene) and aldehydes (formaldehyde and acetaldehyde); and polycyclic aromatic hydrocarbons (EA 2003). Polycyclic aromatic hydrocarbons are another group of compounds where the toxicity will vary depending on the presence of individual polycyclic aromatic hydrocarbons.

The assessment of emissions from vehicles requires consideration of key urban air pollutants (nitrogen oxides, carbon monoxide), the individual compounds likely to be present in the more general measures of volatile organic compounds (which include BTX, 1,3-butadiene and the aldehydes) and polycyclic aromatic hydrocarbons, and particulates. These are further discussed in the following sections.

4.2 Review of key air pollutants

4.2.1 Oxides of nitrogen

Nitrogen oxides (NOx) refer to a collection of highly reactive gases containing nitrogen and oxygen, most of which are colourless and odourless. Nitrogen oxide gases form when fuel is burnt. Motor vehicles, along with industrial, commercial and residential combustion sources, are primary producers of nitrogen oxides.

In Sydney, the OEH (2012) estimated that on-road vehicles account for about 62 per cent of emissions of nitrogen oxides, industrial facilities account for 12 per cent, other mobile sources account for about 22 per cent with the remainder from domestic/commercial sources.

In terms of health effects, nitrogen dioxide is the only oxide of nitrogen of concern (WHO 2000a). Nitrogen dioxide is a colourless and tasteless gas with a sharp odour. Nitrogen dioxide can cause inflammation of the respiratory system and increase susceptibility to respiratory infection. Exposure to elevated levels of nitrogen dioxide has also been associated with increased mortality, particularly related to respiratory disease, and with increased hospital admissions for asthma and heart disease patients (Morgan et al. 1998). Asthmatics, the elderly and people with existing cardiovascular and respiratory disease are particularly susceptible to the effects of nitrogen dioxide (NEPC, 2010). The health effects associated with exposure to nitrogen dioxide depend on the duration or exposure as well as the concentration; hence guidelines have been developed in Australia (and internationally) that reflect both acute and chronic exposures.

Guidelines are available from the NSW EPA and NEPC (NEPC 2003) that are based on protection from adverse health effects following short-term (acute) and longer-term (chronic) exposure. Review of these guidelines by NEPC (2010) identified additional supporting studies for the evaluation of potential adverse health effects and indicated that these should be considered in the current review of the National Ambient Air Quality NEPM (no interim or finalisation date available). The air guidelines currently available from NEPC are consistent with health based guidelines currently available from the WHO (2005) and the USEPA (2010[5], specifically listed to be protective of exposures to sensitive populations including asthmatics, children and the elderly). On this basis the current NEPC guidelines are considered appropriate for the assessment of potential health impacts associated with the project.

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[5] Most recent review of the Primary National Ambient Air Quality Standards for Nitrogen Dioxide published by the USEPA in the Federal Register Volume 75, No. 26, 2010, available from: http://www.gpo.gov/fdsys/pkg/FR-2010-02-09/html/2010-1990.htm

Assessment of acute exposures:

The NEPC ambient air quality guideline for the assessment of acute (short-term) exposures to nitrogen dioxide relates to the maximum predicted total (cumulative) 1-hour average concentration in air. The guideline of 246 µg/m³ (or 120 ppbv) is based on a lowest observed adverse effect level (LOAEL) of 409 to 613 µg/m³ derived from statistical reviews of epidemiological data suggesting an increased incidence of lower respiratory tract symptoms in children and aggravation of asthma. An uncertainty factor of two to protect susceptible people (i.e. asthmatic children) was applied to the LOAEL (NEPC 1998). On this basis the NEPC (and Environment Protection Authority) acute guideline is protective of adverse health effects in all individuals, including sensitive individuals.

Table 4-1 presents a summary of the maximum (for all locations modelled over the years 2009-2011) predicted cumulative 1-hour average concentration of nitrogen dioxide for scenarios 2a (2019) and 2b (2029) relevant for expected emissions from the project.

Table 4-1 Review of potential acute health impacts – nitrogen dioxide (NO_2)

Location and scenario	Maximum 1-hour average concentration of NO_2 (µg/m³)
Southern interchange	
- Scenario 2a (2019)	165
- Scenario 2b (2029)	167
Northern interchange	
- Scenario 2a (2019)	151
- Scenario 2b (2029)	159
Acute health based guideline	**246**

All the concentrations of nitrogen dioxide presented in the above table are well below the acute NEPC guideline of 246 µg/m³. Hence there are no adverse health effects expected in relation to acute exposures to nitrogen dioxide in the local area surrounding the project. Hence no further detailed assessment of these exposures is warranted.

Assessment of chronic exposures:

The NEPC ambient air quality guideline for the assessment of chronic (long-term or lifetime) exposures to nitrogen dioxide relates to the maximum predicted total (cumulative) annual average concentration in air. The guideline of 62 µg/m³ (or 30 ppbv) is based on a lowest observed adverse effect level (LOAEL) of the order of 40 – 80 ppbv (around 75-150 µg/m³) during early and middle childhood years which can lead to the development of recurrent upper and lower respiratory tract symptoms, such as recurrent 'colds', a productive cough and an increased incidence of respiratory infection with resultant absenteeism from school. An uncertainty factor of two was applied to the LOAEL to account for susceptible people within the population resulting in a guideline of 20-40 ppbv (38-75 µg/m³) (NEPC 1998). On this basis the NEPC (and OEH) chronic guideline is protective of adverse health effects in all individuals, including sensitive individuals.

Table 4-2 presents a summary of the maximum (for all locations modelled over the years 2009-2011) predicted cumulative annual average concentration of nitrogen dioxide for scenarios 2a (2019) and 2b (2029) relevant for expected emissions from the project.

Table 4-2 Review of potential chronic health impacts – Nitrogen dioxide (NO_2)

Location and scenario	Maximum annual average concentration of NO_2 (µg/m^3)
Southern interchange	
- Scenario 2a (2019)	42.4
- Scenario 2b (2029)	42.8
Northern interchange	
- Scenario 2a (2019)	38.7
- Scenario 2b (2029)	39.9
Chronic health based guideline	**62**

All the concentrations of nitrogen dioxide presented in the above table are well below the chronic NEPC guideline of 62 µg/m^3. Hence there are no adverse health effects expected in relation to chronic exposures to nitrogen dioxide in the local area surrounding the project.

As the assessment of potential acute and chronic health impacts are addressed in the guidelines adopted (and considered above), and no predicted impacts exceed these guidelines, no further detailed assessment of these exposures is warranted.

4.2.2 Carbon monoxide

Motor vehicles are the dominant source of carbon monoxide in air (DECCW 2009). Adverse health effects of exposure to carbon monoxide are linked with carboxyhaemoglobin (COHb) in blood. In addition, association between exposure to carbon monoxide and cardiovascular hospital admissions and mortality, especially in the elderly for cardiac failure, myocardial infarction and ischemic heart disease; and some birth outcomes (such as low birth weights) have been identified (NEPC 2010).

Guidelines are available in Australia from NEPC (NEPC 2003) and NSW EPA (OEH) that are based on the protection of adverse health effects associated with carbon monoxide. Review of these guidelines by NEPC (2010) identified additional supporting studies[6] for the evaluation of potential adverse health effects and indicated that these should be considered in the current review of the National Ambient Air Quality NEPM (no interim or finalisation date available). The air guidelines currently available from NEPC are consistent with health based guidelines currently available from the WHO (2005) and the USEPA (2011[7], specifically listed to be protective of exposures by

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[6] Many of the more current studies are epidemiology studies that relate to a mix of urban air pollutants (including particulate matter) where it is more complex to determine the effects that can be attributed to carbon monoxide exposure only.

[7] Most recent review of the Primary National Ambient Air Quality Standards for Carbon Monoxide published by the USEPA in the Federal Register Volume 76, No. 169, 2011, available from: http://www.gpo.gov/fdsys/pkg/FR-2011-08-31/html/2011-21359.htm

sensitive populations including asthmatics, children and the elderly). On this basis the current NEPC guidelines are considered appropriate for the assessment of potential health impacts associated with the project.

The NEPC ambient air quality guideline for the assessment of exposures to carbon monoxide has considered LOAEL (lowest observed adverse effect level) and NOAELs (no observed adverse effect level) associated with a range of health effects in healthy adults, people with ischemic heart disease and foetal effects. In relation to these data, a guideline level of carbon monoxide of nine ppmv (or 10 mg/m^3 or 10 000 µg/m^3) over an 8-hour period was considered to provide protection (for both acute and chronic health effects) for most members of the population. An additional 1.5 fold uncertainty factor to protect more susceptible groups in the population was included. On this basis the NEPC (and the Environment Protection Authority) guideline is protective of adverse health effects in all individuals, including sensitive individuals.

The Environment Protection Authority have also established a guideline for 15-minute average (100 mg/m^3) and 1-hour average (30 mg/m^3) concentrations of carbon monoxide in ambient air. These guidelines are based on criteria established by the WHO (WHO 2000b) using the same data used by the NEPC to establish the guideline (above) with extrapolation to different periods of exposure on the basis of known physiological variables that affect carbon monoxide uptake.

Table 4-3 presents a summary of the maximum (for all locations modelled over the years 2009-2011) predicted cumulative 1-hour average and 8-hour average concentrations of carbon monoxide for scenarios 2a (2019) and 2b (2029) relevant for expected emissions from the project.

Table 4-3 Review of potential acute and chronic health impacts – Carbon monoxide (CO)

Location and scenario	Maximum 1-hour average concentration of CO (µg/m^3)	Maximum 8-hour average concentration of CO (µg/m^3)
Southern interchange		
- Scenario 2a (2019)	3695	2635
- Scenario 2b (2029)	3715	2660
Northern interchange		
- Scenario 2a (2019)	3712	2634
- Scenario 2b (2029)	3732	2656
Relevant health based guideline	**30 000**	**10 000**

All the concentrations of carbon monoxide presented in the above table are well below the relevant health based guidelines. Hence there are no adverse health effects expected in relation to exposures (acute and chronic) to carbon monoxide in the local area surrounding the project.

As the assessment of potential acute and chronic health impacts are addressed in the guidelines adopted (and considered above), and no predicted impacts exceed these guidelines, no further detailed assessment of these exposures is warranted

4.3 Review of volatile organic compounds and polycyclic aromatic hydrocarbons

4.3.1 General

The AQIA has considered emissions of volatile organic compounds and polycyclic aromatic hydrocarbons to air from the project. Both volatile organic compounds and polycyclic aromatic hydrocarbons refer to a group of compounds with a mix of different proportions and toxicities. It is the individual compounds within the group that are of importance for evaluating adverse health effects. The composition of individual compounds in the volatile organic compounds and polycyclic aromatic hydrocarbons evaluated will vary depending on the source of the emissions. Hence it is important that the key individual compounds present in emissions considered for this project are speciated (i.e. identified and quantified as a percentage of the total volatile organic compounds or total polycyclic aromatic hydrocarbons) to ensure that potential impacts associated with exposure to these compounds can be adequately assessed.

Volatile organic compounds in air in Sydney (OEH 2012) are primarily derived from domestic/commercial sources (54 per cent) with on-road vehicles contributing around 24 per cent, industrial emissions eight per cent with the remainder from off-road mobile sources and other commercial sources.

Volatile organic compounds and polycyclic aromatic hydrocarbons from the project are associated with emissions from vehicles assumed to be using the tunnel (and approaches). The makeup of the volatile organic compounds and polycyclic aromatic hydrocarbons emissions would depend on the mix of vehicles considered as these pollutants will be emitted in different proportions from petrol and diesel powered vehicles. In addition the age and the fuel used by the vehicle fleet would affect these emissions.

The proportion of passenger vehicles, light duty vehicles and heavy goods vehicles in 2013 has been considered in the AQIA as follows:

- Of the total vehicle fleet using the tunnel the proportion that will be heavy goods vehicles is estimated to be:
  - 2019: 27.8 per cent to 28.6 per cent (maximum assumed for calculations).
  - 2029: 24.5 per cent to 25.2 per cent (maximum assumed for calculations).
- The remaining vehicles using the tunnel comprise 83.4 per cent passenger vehicles and 16.6 per cent light duty vehicles.
- All the heavy goods vehicles are assumed to be diesel powered.
- Passenger vehicles are assumed to comprise 92.1 per cent petrol and 7.9 per cent diesel powered vehicles. Conservatively, none are assumed to be hybrid, electric or LPG (where emissions would be lower than from petrol or diesel vehicles).
- Light duty vehicles are assumed to comprise 50.1 per cent petrol and 49.9 per cent diesel powered vehicles.

4.3.2 Volatile organic compounds

Volatile organic compounds have been modelled in the AQIA based on emissions from all vehicles considered. The proportion of each of the individual volatile organic compounds that may be present in the air is then estimated based on the assumed composition of the vehicle fleet and the type of fuel used. Most of the VOC emissions comprise a range of hydrocarbons that are of low toxicity (such as methane, ethylene, ethane, butenes, butanes, pentenes, pentanes, heptanes etc) (EPA 2012). From a toxicity perspective the key volatile organic compounds that have been considered for the vehicle emissions are BTX, 1,3-butadiene, acetaldehyde and formaldehyde (consistent with those identified and targeted in studies conducted in Australia on vehicle emissions (DEH 2003; EPA 2012).

The proportion of each of the key volatile organic compounds considered are derived from the 2008 Calendar Year Air Emissions Inventory for the Greater Metropolitan Region in NSW (EPA 2012), for the vehicle fleet assessed in the AQIA (as summarised above). In relation to passenger vehicles it has been assumed that sixty per cent[8] of fuel used is E10. It is assumed that the composition of volatile organic compounds in vehicle emissions remains the same over time, and does not improve (lower) with improved vehicle emissions technology.

Table 4-4 presents a summary of volatile organic compounds speciation profile considered for the different vehicle types considered in the project as well as the weighted mass fraction for these volatile organic compounds considered for the project in 2019 and 2029.

Table 4-4 Volatile organic compounds speciation profile for vehicle emissions

VOC	Mass fraction (per cent VOC)					Mass Faction for Vehicle Fleet in Project (%VOC)	
	Passenger Vehicles		Light duty vehicles		Heavy goods vehicles	2019	2029
	No Ethanol	E10	Petrol	Diesel*	Diesel		
1,3-butadiene	1.27	1.2	1.27	0.4	0.4	0.91	1.0
acetaldehyde	0.46	1.3	0.46	3.81	3.81	2.1	1.6
benzene	4.96	4.54	4.96	1.07	1.07	3.3	3.8
formaldehyde	1.46	1.82	1.46	9.86	9.86	4.9	3.9
xylenes	7.6	7.22	7.6	0.38	0.38	4.6	5.5
toluene	9.18	8.79	9.18	0.47	0.47	5.6	6.7

Volatile organic compounds speciation from EPA (2012)
* speciation for diesel emissions also adopted for diesel passenger vehicles

[8] The value of 60 per cent of ethanol in total fuel volume sales was adopted as the target for petrol sold in NSW as outlined in the *Biofuels Act 2007*.

4.3.3 Polycyclic aromatic hydrocarbons

Polycyclic aromatic hydrocarbons have been considered in the AQIA as key pollutants that may be derived from diesel powered heavy goods vehicles. The presence of polycyclic aromatic hydrocarbons in diesel exhaust has been found to be more a function of the polycyclic aromatic hydrocarbon content of the fuel than of engine technology. For a given refinery and crude oil, diesel fuel polycyclic aromatic hydrocarbon levels correlate with total aromatic content and T90 (distillation temperature where 90 per cent of the fuel is evaporated). Representative data on aromatic content for diesel fuels in Australia are limited, however, emissions tests have been conducted on a range of light and heavy vehicles under different traffic congestion conditions (DEH 2003). The data presented from these emissions tests is assumed to include fuels commonly used in Australia and are considered to provide an indication of the likely proportions of individual polycyclic aromatic hydrocarbons in diesel exhaust.

The polycyclic aromatic hydrocarbons reported in diesel exhaust by DEH (DEH 2003) comprise the 16 most commonly reported (and highest proportion) polycyclic aromatic hydrocarbons present in exhaust. The data available from this study is quite dated (from vehicles manufactured from 1990 to 1996) and use of this data is likely to provide an overestimation of polycyclic aromatic hydrocarbon polycyclic aromatic hydrocarbon emissions from current (and future) diesel vehicles. The evaluation of potential health impacts associated with exposure to polycyclic aromatic hydrocarbons from the project requires consideration of the 16 individual polycyclic aromatic hydrocarbons, present at the highest levels in exhaust and which have the most information on chronic health effects.

The toxicity of individual polycyclic aromatic hydrocarbons varies significantly, with some considered to be carcinogenic while others are not carcinogenic. For the carcinogenic polycyclic aromatic hydrocarbons, these are commonly assessed as a group with the total carcinogenic polycyclic aromatic hydrocarbon concentration calculated using weighting factors that relate the toxicity of individual carcinogenic polycyclic aromatic hydrocarbons to the most well studied polycyclic aromatic hydrocarbon, benzo(a)pyrene. For the carcinogenic polycyclic aromatic hydrocarbons the weighting factors presented by CCME (CCME 2010) have been adopted. Other polycyclic aromatic hydrocarbons that are not carcinogenic have been considered separately.

On the basis of this approach the speciation of individual polycyclic aromatic hydrocarbons (as per cent of total polycyclic aromatic hydrocarbons) has been calculated based on the data from DEH (2003). The data presented relates to emissions that occur during two traffic scenarios (termed segments):

- Segment 1 – congested urban traffic which comprises stop/start traffic flow. This data has been used to be representative of the worst-case situation of heavy congested traffic in the tunnel.
- Segment 4 – highway or freeway traffic which comprises moving traffic. This data is considered more representative of the continuous flow traffic expected in the tunnel.

Table 4-5 presents a summary of the polycyclic aromatic hydrocarbon speciation profile considered in this assessment for the above traffic conditions.

Table 4-5 Polycyclic aromatic hydrocarbon speciation profile for diesel vehicle emissions

Individual PAH	Fraction of total PAH emissions (% PAHs)	
	Congested traffic (worst-case) – Used to evaluate emissions for design analysis A (refer to Appendix E)	Highway/freeway (steady traffic flow) – Used to evaluate emissions for scenarios 2a and 2b
Non-carcinogenic PAHs		
Naphthalene	70	65.7
Acenaphthalene	4.9	5.4
Acenaphthene	2	1.4
Fluorene	5	6.9
Phenanthrene	3.4	13.7
Anthracene	0.49	1.1
Fluoranthene	0.45	0.8
Pyrene	0.71	1.4
Carcinogenic PAHs		
Benzo(a)pyrene TEQ	4.6	0.9

4.3.4 Review of health impacts

The predicted (incremental) concentration of individual volatile organic compounds and polycyclic aromatic hydrocarbons associated with the project (based on the speciation as outlined above) have been reviewed against published peer-reviewed health based guidelines that are relevant to acute and chronic exposures (where relevant). The health based guidelines adopted (identified on the basis of guidance from enHealth 2012) are relevant to exposures that may occur to all members of the general public (including sensitive individuals) with no adverse health effects. The guidelines available relate to the duration of exposure and the nature of the health effects considered where:

- Acute guidelines are based on exposures that may occur for a short period of time (typically between an hour or up to 14 days). These guidelines are available to assess peak exposures (based on the modelled 1-hour maximum concentration) that may be associated with volatile organic compounds in the air;
- Chronic guidelines are based on exposures that may occur all day, every day for a lifetime. These guidelines are available to assess long-term exposures (based on the modelled annual average concentration) that may be associated with volatile organic compounds and polycyclic aromatic hydrocarbons in the air.

Table 4-6 and **Table 4-7** present a summary of the maximum predicted 1-hour or annual average concentration with comparison against acute (**Table 4-6**) and chronic (**Table 4-7**) health based guidelines. The table also presents a Hazard Index (HI) which is the ratio of the maximum predicted concentration to the guideline. Each individual HI is added up to obtain a total HI for all the volatile organic compounds and polycyclic aromatic hydrocarbons considered. The total HI is a sum of the potential hazards associated with all the volatile organic compounds and polycyclic aromatic hydrocarbons together assuming the health effects are additive, and is evaluated as follows:

- A total HI ≤ 1 means that all the maximum predicted concentrations are below the health based guidelines and there are no additive health impacts of concern.
- A total HI > 1 means that the predicted concentrations (for at least one individual compound) are above the health based guidelines, or that there are at least a few individual volatile organic compounds or polycyclic aromatic hydrocarbons where the maximum predicted

concentrations are close to the health based guidelines such that there is the potential for the presence of all these together (as a sum) to result in adverse health effects.

The following evaluation is based on the maximum predicted (incremental) concentration in air for scenarios 2a (2019) and 2b (2029) as modelled in the AQIA.

Concentrations in other areas of the surrounding community would be lower and hence the tables present a worst-case evaluation only.

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Table 4-6 Evaluation of potential acute impacts in local area

Key VOC	Proportion of total VOCs (%)* 2019	Proportion of total VOCs (%)* 2029	Health based acute guideline, and basis (µg/m³)	Scenario 2a (operational emissions - 2019) Northern interchange Max Conc. (µg/m³)	Scenario 2a Northern interchange HI	Scenario 2a Southern interchange Max Conc. (µg/m³)	Scenario 2a Southern interchange HI	Scenario 2b (operational emissions - 2029) Northern interchange Max Conc. (µg/m³)	Scenario 2b Northern interchange HI	Scenario 2b Southern interchange Max Conc. (µg/m³)	Scenario 2b Southern interchange HI
				Maximum predicted 1-hour average concentration from project** and calculated HI for each scenario and interchange							
			Total VOCs	**4.1**		**3.7**		**5.4**		**7.4**	
Benzene	3.3	3.8	**29[A1] to 170[T1]** (lower value adopted) A1: Acute guideline (1hr to 14 day exposure), based on immunological effects in mice. T1: Acute 1 hour health based guideline, based on depressed peripheral lymphocytes and depressed mitogen-induced blastogenesis (mice study)	0.13	0.0046	0.12	0.0042	0.20	0.0070	0.20	0.0070
Toluene	5.6	6.7	**4500[T2]** Acute 1 hour health based guideline, based on eye and nose irritation, increased occurrence of headache and intoxication in human male volunteers	0.23	0.000051	0.21	0.000047	0.36	0.000080	0.36	0.000080
Xylenes	4.6	5.5	**2200[T3]** Acute 1 hour health based guideline, based on mild respiratory effects and subjective symptoms of neurotoxicity in human volunteers	0.19	0.000086	0.17	0.000079	0.30	0.00013	0.30	0.00013
1,3-Butadiene	0.9	1.0	**660[O1]** Acute 1 hour health based guideline, based on developmental effects	0.037	0.000056	0.034	0.000051	0.054	0.000082	0.054	0.000082
Formaldehyde	4.9	3.9	**15[T4]** Acute 1 hour health based guideline, based on eye and nose irritation in human volunteers	0.20	0.013	0.18	0.012	0.21	0.014	0.206	0.014

Key VOC	Proportion of total VOCs (%)*		Health based acute guideline, and basis (µg/m^3)	Maximum predicted 1-hour average concentration from project** and calculated HI for each scenario and interchange							
				Scenario 2a (operational emissions - 2019)				Scenario 2b (operational emissions - 2029)			
				Northern interchange		Southern interchange		Northern interchange		Southern interchange	
	2019	2029		Max Conc. (µg/m^3)	HI	Max Conc. (µg/m^3)	HI	Max Conc. (µg/m^3)	HI	Max Conc. (µg/m^3)	HI
Acetaldehyde	2.1	1.6	**470**[O2] Acute 1 hour health based guideline, based on effects on sensory irritation, bronchoconstriction, eye redness and swelling	0.083	0.00018	0.076	0.00016	0.088	0.00019	0.087	0.00019
			Total HI		**0.018**		**0.017**		**0.021**		**0.021**

Notes:

*	Percentage of each individual volatile organic compound is based on a weighted average of emissions from the range of vehicle types proposed to be used on the project in 2019 and 2029 (refer to discussion above table)
**	Concentrations presented for the 1 hour average are the predicted incremental 99.9th percentile concentrations (as provided from the AQIA)
A1:	Acute inhalation guideline (for exposures from 1 hour to 14 days) from review by ATSDR 2008 for benzene
T1:	TCEQ 2007, Benzene, Development Support Document. Texas Commission of Environmental Quality, 1 hour average guideline value (include additional 3.3 fold safety factor). This acute guideline is lower than that derived by the OEHHA (based on older studies)
T2:	TCEQ 2008, Toluene, Development Support Document. Texas Commission of Environmental Quality, 1 hour average guideline value (include additional 3.3 fold safety factor)
T3:	TCEQ 2009, Xylenes, Development Support Document. Texas Commission of Environmental Quality, 1 hour average guideline value (include additional 3.3 fold safety factor)
T4:	TCEQ 2008, Formaldehyde, Development Support Document. Texas Commission of Environmental Quality, 1 hour average guideline value (include additional 3.3 fold safety factor). This guideline is noted to be lower than the acute guideline available from the WHO (2000a, 2010) of 100 µg/m^3 for formaldehyde
O1:	OEHHA 2013, Acute (1 hour average) guideline derived by the California Office of Environmental Health Hazard Assessment. The guideline developed is lower than developed by TCEQ (2008) based on the same critical study
O2:	OEHHA 2008, Acute (1 hour average) guideline derived by the California Office of Environmental Health Hazard Assessment

Table 4-7 Evaluation of potential chronic impacts in local area

Key VOC	Proportion of total VOCs* (%)		Health based chronic guideline and basis (µg/m^3)	Maximum predicted annual average concentration from project** and calculated HI for each scenario and interchange							
				Scenario 2a (operational emissions - 2019)				Scenario 2b (operational emissions - 2029)			
				Northern interchange		Southern interchange		Northern interchange		Southern interchange	
				Max Conc. (µg/m^3)	HI	Max Conc. (µg/m^3)	HI	Max Conc. (µg/m^3)	HI	Max Conc. (µg/m^3)	HI
	2019	**2029**	**Total VOCs**	**0.11**		**0.11**		**0.14**		**0.13**	
Benzene	3.3	3.8	**1.7**[W1] Benzene is classified as a known human carcinogen by IARC. Chronic guideline based on excess risk of leukaemia	0.0035	0.0020	0.0037	0.0022	0.0052	0.0030	0.0049	0.0029
Toluene	5.6	6.7	**5000**[U1] Chronic guideline based on neurological effects in an occupational study (converted to public health value using safety factors)	0.0059	1.2X10^{-6}	0.0063	1.3X10^{-6}	0.0092	1.8X10^{-6}	0.0087	1.7X10^{-6}
Xylenes	4.6	5.5	**220**[A1] Chronic guideline based on mild subjective respiratory and neurological symptoms in an occupational study (converted to public health value using safety factors)	0.0049	0.000022	0.0052	0.000023	0.0076	0.000034	0.0072	0.000033
1,3-Butadiene	0.9	1.0	**0.3**[U2] 1,3-Butadiene is classified by IARC as a probable human carcinogen. Chronic air guideline based on an excess risk of leukaemia	0.00095	0.0032	0.00101	0.0034	0.00138	0.0046	0.00131	0.0044
Formaldehyde	4.9	3.9	**3.3**[T1] Formaldehyde is classified by IARC as carcinogenic to humans. The guideline developed is based on the protection of all adverse effects including cancer and non-cancer (including short term effects)	0.0051	0.0015	0.0054	0.0016	0.0053	0.00160	0.0050	0.00152
Acetaldehyde	2.1	1.6	**9**[U3] Chronic guideline based on nasal effects (in a rat study) (converted to a public health value using safety factors)	0.0022	0.00024	0.0023	0.00025	0.0022	0.00025	0.0021	0.00024

Key VOC	Proportion of total VOCs* (%)	Health based chronic guideline and basis (µg/m³)		Maximum predicted annual average concentration from project** and calculated HI for each scenario and interchange							
				Scenario 2a (operational emissions - 2019)				Scenario 2b (operational emissions - 2029)			
				Northern interchange		Southern interchange		Northern interchange		Southern interchange	
				Max Conc. (µg/m³)	HI	Max Conc. (µg/m³)	HI	Max Conc. (µg/m³)	HI	Max Conc. (µg/m³)	HI
			Total PAHs	**$1.9X10^{-5}$**		**$2.1X10^{-5}$**		**$2.3X10^{-5}$**		**$2.1X10^{-5}$**	
Naphthalene	65.7	**3**[U4] Chronic guideline based on nasal effects (in a mouse study) (converted to a public health value using safety factors)		$1.3X10^{-5}$	$4.2X10^{-6}$	$1.4X10^{-5}$	$4.5X10^{-6}$	$1.5X10^{-5}$	$5.0X10^{-6}$	$1.4X10^{-5}$	$4.6X10^{-6}$
Acenaphthylene	5.4	200[U5S]	Refer to notes for ref U5	$1.0X10^{-6}$	$5.2X10^{-9}$	$1.1X10^{-6}$	$5.6X10^{-9}$	$1.2X10^{-6}$	$6.1X10^{-9}$	$1.1X10^{-6}$	$5.7X10^{-9}$
Acenaphthene	1.4	200[U5]		$2.7X10^{-7}$	$1.3X10^{-9}$	$2.9X10^{-7}$	$1.4X10^{-9}$	$3.2X10^{-7}$	$1.6X10^{-9}$	$2.9X10^{-7}$	$1.5X10^{-9}$
Fluorene	6.9	140[U5]		$1.3X10^{-6}$	$9.5X10^{-9}$	$1.4X10^{-6}$	$1.0X10^{-8}$	$1.6X10^{-6}$	$1.1X10^{-8}$	$1.4X10^{-6}$	$1.0X10^{-8}$
Phenanthrene	13.7	140[U5S]		$2.6X10^{-6}$	$1.9X10^{-8}$	$2.8X10^{-6}$	$2.0X10^{-8}$	$3.1X10^{-6}$	$2.2X10^{-8}$	$2.9X10^{-6}$	$2.1X10^{-8}$
Anthracene	1.1	100[U5]		$2.1X10^{-7}$	$2.1X10^{-9}$	$2.3X10^{-7}$	$2.3X10^{-9}$	$2.5X10^{-7}$	$2.5X10^{-9}$	$2.3X10^{-7}$	$2.3X10^{-9}$
Fluoranthene	0.8	140[U5]		$1.5X10^{-7}$	$1.1X10^{-9}$	$1.6X10^{-7}$	$1.2X10^{-9}$	$1.8X10^{-7}$	$1.3X10^{-9}$	$1.7X10^{-7}$	$1.2X10^{-9}$
Pyrene	1.4	100[U5]		$2.7X10^{-7}$	$2.7X10^{-9}$	$2.9X10^{-7}$	$2.9X10^{-9}$	$3.2X10^{-7}$	$3.2X10^{-9}$	$2.9X10^{-7}$	$2.9X10^{-9}$
Benzo(a)pyrene TEQ	0.9	**0.00012**[W2] BaP is classified by IARC as a known human carcinogen, which relates to BaP as well as all the other carcinogenic PAHs assessed as a BaP toxicity equivalent value. The chronic guideline is based on protection from lung cancer for an occupational study		$1.7X10^{-7}$	0.00144	$1.9X10^{-7}$	0.00155	$2.0X10^{-7}$	0.0017	$1.9X10^{-7}$	0.0016
			Total HI (VOCs + PAHs)		**0.0085**		**0.0090**		**0.011**		**0.011**

Notes:

*	Percentage of each individual volatile organic compounds and polycyclic aromatic hydrocarbons is based on a weighted average of emissions from the range of vehicle types proposed to be used on the project in 2019 and 2029, and for normal traffic flow or congested traffic flow (refer to discussion above table)
**	Concentrations presented for the annual average are as provided from the AQIA
A	Polycyclic aromatic hydrocarbon speciation data for normal traffic conditions – utilised in the assessment of scenarios 2a and 2b
W1:	WHO 2000 Air Quality Guidelines, value for benzene is based on non-threshold carcinogenic effects (excess lifetime risk of leukaemia). Guideline value based on incremental cancer risk of $1x10^{-5}$, consistent with guidance provided by NEPM (1999 amended 2013) and enHealth (2012)
W2:	WHO 2010 Guidelines for Indoor Air Quality, value for BaP is based on non-threshold carcinogenic effects from occupational study of coke workers (lung cancer is critical effect). Guideline value based on incremental cancer risk of $1x10^{-5}$, consistent with guidance provided by NEPM (1999 amended 2013) and enHealth (2012)
T1:	TCEQ 2008, Formaldehyde, Development Support Document. Texas Commission of Environmental Quality. The air guideline is derived on the basis of irritation of the eyes and airway discomfort in humans, with review of carcinogenic and other non-carcinogenic effects found to be adequately protected by this guideline. The guideline is more conservative than derived by the WHO (2010)
A1:	ATSDR 2007, Toxicological Profile for Xylene, chronic inhalation guideline derived is the most current robust evaluation
U1:	USEPA evaluation for toluene (most recently reviewed in 2005). This is the most current evaluation of effects associated with chronic inhalation exposure to toluene and is consistent with the value used to derive the NEPM (1999 amended 2013) health based guidelines
U2:	USEPA evaluation of 1,3-butadiene (most recently updated in 2002) with the chronic guideline adopted as the lower from the evaluation of non-threshold carcinogenic effects and non-cancer effects. This is the most conservative evaluation of this compound. A more recent review by TCEQ (2013) on the basis of the same critical studies as well as more current studies resulted in a higher chronic air guideline value.
U3:	USEPA evaluation of acetaldehyde (most recently updated in 1991). The guideline established is lower than more recent reviews undertaken by the WHO (2000) and the Californian OEHHA where less conservative evaluations are presented.
U4:	USEPA evaluation of naphthalene (most recently updated in 1998). The guideline established is and is consistent with the value used to derive the NEPM (1999 amended 2013) health based guidelines
U5:	Guideline available from the USEPA. Chronic guidelines for non-carcinogenic polycyclic aromatic hydrocarbons are based on criteria derived from oral studies (for critical effects on the liver, kidney and haematology) which are then converted to an inhalation value (relevant for the protection of public health, including the use of safety factors) for use in this assessment. The value presented in the above table has been converted from an acceptable dose in mg/kg/day to an acceptable air concentration assuming a body weight of 70kg and inhalation of 20 m^3/day (as per (USEPA 2009a))
U5S:	No guideline available for individual polycyclic aromatic hydrocarbon, hence a surrogate compound has been used for the purpose of screening. The surrogate compound is a polycyclic aromatic hydrocarbon of similar structure and toxicity. In relation to the surrogates adopted in this evaluation, acenaphthene has been adopted as a surrogate for acenaphthylene, fluoranthene has been adopted as a surrogate for phenanthrene

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Review of the acute assessment presented in **Table 4-6** indicates that during expected operation of the tunnel (in 2019 and 2029) the maximum short-duration peak (1 hour average) concentrations of volatile organic compounds (assessed as the key individual volatile organic compounds and as a sum of all the individual volatile organic compounds) in air surrounding the northern and southern interchanges are well below the relevant acute health based guidelines. The maximum HI calculated for acute exposure to the volatile organic compounds is 0.021, well below the target HI of 1 (around 50 times lower than the target HI). On this basis no further detailed assessment of the peak emissions of volatile organic compounds from the project is warranted.

Review of the chronic assessment presented in **Table 4-7** indicates that during expected operation of the tunnel (in 2019 and 2029) the maximum long-term average (annual average) concentrations of volatile organic compounds and polycyclic aromatic hydrocarbons (assessed as the key individual volatile organic compound and polycyclic aromatic hydrocarbon compounds and as a sum of all the individual volatile organic compounds and polycyclic aromatic hydrocarbons) in air surrounding the northern and southern interchanges are well below the relevant long-term (chronic) health based guidelines. These are guidelines that are based on the protection of public health for inhalation exposures all day (24 hours), every day (365 days per year) for a lifetime (at least 70 years). The maximum HI calculated for exposure to the volatile organic compounds and polycyclic aromatic hydrocarbons is 0.011, well below the target HI of 1 (around 90 times lower than the target HI). On this basis no further detailed assessment of the emissions of individual volatile organic compounds and polycyclic aromatic hydrocarbons from the project is warranted.

4.4 Review of particulate matter

4.4.1 General

Particulate matter (PM) is a widespread air pollutant with a mixture of physical and chemical characteristics that vary by location (and source). Unlike many other pollutants, particulates comprise a broad class of diverse materials and substances, with varying morphological, chemical, physical and thermodynamic properties, with sizes that vary from <0.005 µm to >100 µm. Particulates can be derived from natural sources such as crustal dust (soil), pollen and moulds, and other sources that include combustion and industrial processes. Secondary particulate matter is formed via atmospheric reactions of primary gaseous emissions. The gases that are the most significant contributors to secondary particulates include nitrogen oxides, ammonia, sulfur oxides, and certain organic gases (derived from vehicle exhaust, combustion sources, agricultural, industrial and biogenic emissions).

Numerous epidemiological studies[9] have reported significant positive associations between particulate air pollution and adverse health outcomes, in particular mortality as well as a range of adverse cardiovascular and respiratory effects.

4.4.2 Particulate size and composition

The potential for particulate matter to result in adverse health effects is dependent on the size and composition of the particulate matter.

The size of particulates is important as it determines how far from an emission source the particulates may be present in air (with larger particulates settling out close to the source and smaller particles remaining airborne for greater distances) and also the potential for adverse effects to occur as a result of exposure.

The common measures of particulate matter that are considered in the assessment of air quality and health risks are:

- **Total suspended particulates (TSP):** This refers to all particulates with an equivalent aerodynamic particle[10] size below 50 microns (µm) in diameter[11]. It is a fairly gross indicator of the presence of dust with a wide range of sizes. Larger particles (termed “inspirable”, comprise particles around 10 microns (µm) and larger) are more of a nuisance as they will deposit out of the air (measured as deposited dust) close to the source and, if inhaled, are mostly trapped in the upper respiratory system[12] and do not reach the lungs. Finer particles (smaller than 10 µm, termed “respirable”) tend to be transported further from the source and are of more concern with respect to human health as these particles can penetrate into the lungs. Hence not all of the dust characterised as total suspended particulates is relevant for the assessment of health impacts, and total suspended particulates as a measure of impact, has not been further evaluated in this assessment. The assessment has only focused on particulates of a size where significant associations have been identified between exposure and adverse health effects.

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[9] Epidemiology is the study of diseases in populations. Epidemiological evidence can only show that this risk factor is associated (correlated) with a higher incidence of disease in the population exposed to that risk factor. The higher the correlation the more certain the association. Causation (i.e. that a specific risk factor actually causes a disease) cannot be proven with only epidemiological studies. For causation to be determined a range of other studies need to be considered in conjunction with the epidemiology studies.

[10] The term equivalent aerodynamic particle is used to reference the particle to a particle of spherical shape and particle of density 1 g/cm^3

[11] The size, diameter, of dust particles is measured in micrometers (microns, µm).

[12] The upper respiratory tract comprises the mouth, nose, throat and trachea. Larger particles are mostly trapped by the cilia and mucosa and swept to the back of the throat and swallowed.

- **PM_{10}, particulate matter below 10 µm in diameter, $PM_{2.5}$, particulate matter below 2.5 µm in diameter and PM_1, particulate matter below 0.1 µm in diameter (termed ultrafine particles):** These particles are small and have the potential to penetrate beyond the body's natural clearance mechanisms of cilia and mucous in the nose and upper respiratory system, with smaller particles able to further penetrate into the lower respiratory tract[13] and lungs. Once in the lungs adverse health effects may result (OEHHA 2002). It is well accepted nationally and internationally that monitoring for PM_{10} is a good method of determining the community's exposure to potentially harmful dust (regardless of the source) and is most commonly measured in local and regional air quality monitoring programs. Smaller particulates such as $PM_{2.5}$ and PM_1, however, are of most significance with respect to evaluating health effects as a higher proportion of these particles penetrate deep into the lungs. Urban air, that has a significant contribution from combustion sources, tends to have a significant proportion of $PM_{2.5}$ and PM_1 in ambient air.

Evaluation of size alone as a single factor in determining the potential for particulate toxicity and is difficult since the potential health effects are not independent of chemical composition. There are certain particulate size fractions that tend to contain certain chemical components, such as metals in fine particulates (<$PM_{2.5}$) and crustal materials (like soil) in the coarse mode (PM_{10} or larger). In addition, different sources of particulates have the potential to result in the presence of other pollutants in addition to particulate matter. For example combustion sources, prevalent in urban areas, result in the emission of particulate matter (more dominated by $PM_{2.5}$) as well as gaseous pollutants (ozone, nitrogen dioxide, carbon monoxide and sulfur dioxide).

There is strong evidence to conclude (USEPA 2012; WHO 2003, 2013b) that fine particles (< 2.5 µm, $PM_{2.5}$) are more hazardous than larger ones (coarse particles), primarily on the basis of studies conducted in urban air environments where there is a higher proportion (as a percentage of all particulates) of fine particulates and other gaseous pollutants present from fuel combustion sources, as compared to particulates derived from crustal origins. Toxicological and controlled human exposure studies indicate that primary particles generated from fossil fuel combustion processes may be a significant contributor to adverse health outcomes with several physical, biological and chemical characteristics of particles found to elicit cardiopulmonary responses. Amongst the characteristics found to be contributing to toxicity in epidemiological and controlled exposure studies are high organic carbon content, metal content, presence of polycyclic aromatic hydrocarbons, presence of other organic components or endotoxins and both small (< 2.5 µm) and extremely small size (< 1 µm) (USEPA 2009b; WHO 2003, 2006a).

[13] The lower respiratory tract comprises the smaller bronchioles and alveoli, the area of the lungs where gaseous exchange takes place. The alveoli have a very large surface area and absorption of gases occurs rapidly with subsequent transport to the blood and the rest of the body. Small particles can reach these areas, be dissolved by fluids and absorbed.

A significant amount of research, primarily from large epidemiology studies, has been conducted on the health effects of particulates with causal effects relationships identified for exposure to $PM_{2.5}$ (acting alone or in conjunction with other pollutants) (USEPA 2012). A more limited body of evidence suggests an association between exposure to larger particles, PM_{10} and adverse health effects (USEPA 2009b; WHO 2003). The health effects identified from these studies has been specifically related to $PM_{2.5}$ or PM_{10} as these are the most commonly adopted robust and widespread measures of particulate matter available in urban air environments.

A recent study of potential health effects associated with exposure to fine and ultrafine particulates in a heavy polluted city in China[14] (Meng et al. 2013), where data were specifically collected to characterise many bands of fine, very fine and ultrafine particulates (not normally measured in ambient air), identified that fine and very fine particulates (PM_1, but more specifically the sizes 0.25-0.50 µm) were significantly associated with total and cardiovascular mortality, but not respiratory mortality. Effect estimates increased with decreasing particle size. This suggests PM_1 may be associated with more significant health effects (particularly in relation to cardiovascular effects). A number of other studies have also identified that exposure to fine and ultrafine particulates (measured as PM_1 or $PM_{0.1}$) are associated with more significant effects than the coarse particulates (NEPC 2010). However, it was not clear whether observed effects were due to particle size alone or to chemical characteristics, in that the ultrafine particles would have a relatively larger surface area per unit mass for potential adsorption of other chemicals than would the larger size particulates.

In urban air environments, where most of the epidemiology studies have been undertaken, PM_1 comprises a significant proportion of $PM_{2.5}$. Measurements indicate that the ratio of PM_1:$PM_{2.5}$ is around 0.8-0.9 in Europe (Gomiščžek et al. 2004) (showing results similar to other European urban areas) with data from Australia (Keywood et al. 1999) suggesting a ratio of around 0.72. Data from Italy (Giugliano et al. 2005) suggests that within tunnels the fraction of $PM_{2.5}$ that is also PM_1 is slightly higher than in open air areas, but consistent with that reported in Europe. As the primary source of both PM_1 and $PM_{2.5}$ in urban air are combustion (traffic) emissions, the ratio of PM_1:$PM_{2.5}$ has been observed to be relatively stable throughout the year within urban air environments. For this project (where vehicle emissions are being assessed, the ratio of PM_1:$PM_{2.5}$ is expected to remain stable. Hence the use of exposure response relationships established for $PM_{2.5}$ from large epidemiology studies conducted in urban air environments (such as Europe and the US, as adopted in this assessment), these relationships will have also accounted for the presence of PM_1 and the health effects associated with exposure to these fine particulates.

A more detailed review of epidemiology and air monitoring data in Europe determined that monitoring PM_1 would not significantly add to the information content of data obtained on $PM_{2.5}$ (Gomiščžek et al. 2004).

[14] Authors of the paper note that the level of particulate pollution, and the likely composition, in cities in developing countries such as China differ from developed countries where many of the health effect relationships for exposure to particulate matter have been identified.

In relation to ultrafine particles (particles that are ≤100 nm, or ≤0.1 µm in diameter) the current science has been recently evaluated (HEI 2013), where the following is noted in relation to exposure and health effects:

- The key source of ultrafine particulates is vehicle emissions.
- Assessing exposure to ultrafine particulates is more challenging as the concentrations are much more variable (spatially) than measures of $PM_{2.5}$ and concentrations of ultrafine particulates are not routinely measured in urban areas.
- Available studies in animals and humans have identified a range of adverse health effects associated with exposure to ultrafine particulates, however the studies do not show that short-term exposure to ultrafine particulates have effects that are significantly different from those associated with exposure to $PM_{2.5}$.
- Epidemiology studies conducted in relation to exposure to ultrafine particulates have shown inconsistent (but suggestive) evidence of adverse effects associated with short-term exposure.
- The current body of evidence does not support strong and consistent conclusions of independent effects of ultrafine particulates on human health.

When assessing health impacts from fine particulates, the robust associations of effects (that are based on large epidemiology studies primarily from the US and Europe) have been determined on the basis of $PM_{2.5}$, as $PM_{2.5}$ is what is commonly measured in urban air. No robust associations (that can be used in a quantitative assessment) are available for PM_1 and the current science is inconclusive in relation to ultrafine particulates. The associations developed for $PM_{2.5}$ would include a significant contribution from PM_1 (as $PM_{2.5}$ comprises a significant proportion of PM_1) and hence health effects observed for PM_1 would be captured in the studies that have been conducted on the basis of $PM_{2.5}$. It is important that the quantitative evaluation of potential health impacts adopts robust health effects associations and utilises particulate matter measures that are collected in the urban air environment. Hence the further assessment of exposure to fine particulate matter has focused on particulates reported/evaluated as $PM_{2.5}$.

4.4.3 Health effects

Health effects that have been associated with exposure to PM_{10} and $PM_{2.5}$ relate to exposure over both the short term (hours or days where effects may occur on the same day or after a day or two) and long term (months or years) and include (Anderson et al. 2004; NEPC 2010; OEHHA 2002; USEPA 2009b; WHO 2003, 2013b):

- Respiratory and cardiovascular morbidity, such as aggravation of asthma, respiratory symptoms and an increase in hospital admissions.
- Mortality from all causes, and specifically cardiovascular and respiratory diseases and from lung cancer.

There is good evidence of the effects of short-term exposure to PM_{10} on respiratory health, but for mortality and cardiovascular effects the evidence of effects for PM_{10} exposure is weaker. For these health effects $PM_{2.5}$ (particles in the 2.5–10 µm range) is a stronger risk factor (particles in the 2.5–10 µm range).

In short-term studies (based on 24-hour particulate levels), groups with pre-existing respiratory, lung or heart disease, as well as elderly people were more susceptible to the morbidity and mortality effects of ambient particulate matter exposure (Esworthy 2013; WHO 2013b). In longer term studies it has been suggested that the socially disadvantaged and poorly educated populations respond more strongly in terms of mortality (Esworthy 2013; WHO 2003, 2013b).

Based on the available studies, there is no evidence of a safe level of exposure or a threshold below which no adverse health effects occur (NEPC 2010; WHO 2013b).

Additional discussion on health effects associated with exposure to $PM_{2.5}$ and PM_{10} is presented in **Section 5.1**, including quantitative associations (exposure-response relationships) between exposure and the most significant health effects.

At present, at the population level, there is not enough evidence to identify differences in the effects of particles with different chemical compositions or emanating from various sources (NEPC 2010; WHO 2013b). The evidence for the hazardous nature of combustion-related particulate matter (from both mobile and stationary sources that dominate urban air where most of the epidemiological studies are conducted) is more consistent than that for particulate matter from other sources, and dominate the epidemiological studies used to develop relationships between exposure and adverse health effects. This is the relevant source of particulate matter for this project.

Particulates that are derived from specific sources, such as diesel emissions, are known to comprise other compounds such as volatile organic compounds and polycyclic aromatic hydrocarbons that are known to also be associated with adverse health effects. The presence of these other compounds has been addressed separately however the presence of these (and likely other compounds) compounds and other co-pollutants (also derived from combustion sources) adds to the complexity of utilising data form urban air epidemiological studies for assessing health effects from particulate matter.

Recently, outdoor air pollution has been classified by the International Agency for Research on Cancer (IARC 2013) as carcinogenic (Group 1) to humans based on sufficient evidence that exposure to outdoor air pollution causes lung cancer. Particulate matter, a major component of outdoor air pollution, was evaluated separately and also classified as carcinogenic to humans (Group 1).

In 2012, IARC evaluated exhaust from diesel engines (consisting mostly of particulate matter) and classified these emissions as carcinogenic (Group 1) to humans.

4.4.4 Initial assessment of potential health issues from exposure to particulate matter

For many of the key health effects associated with exposures to PM_{10} and $PM_{2.5}$ the exposure-response relationship is linear (where there is no threshold below which no adverse effects have been identified) (NEPC 2010). This means that any exposure to particulate matter has the potential to be associated with an effect. Guidelines have been established in Australia (and internationally) to determine a level at which cumulative exposure (ie exposure to particulates from all sources) are likely to minimise the potential for adverse impacts in a population. The available guidelines are discussed and further considered below.

However as there is no threshold for adverse effects it is also important that any incremental exposure to particulate matter derived from the project is also assessed. The more detailed evaluation of incremental impacts associated with the project is presented in **Section 5**.

Guidelines

Air quality goals for PM_{10}, and advisory goal for $PM_{2.5}$, have been established by NEPC (NEPC 2002, 2003) that are based on the protection of human health and well-being. The goals apply to average or regional exposures by populations from all sources, not to localised “hot-spot” areas such as locations near industry, busy roads or mining. They are intended to be compared against ambient air monitoring data collected from appropriately sited regional monitoring stations.

In addition, the assessment of impacts from any development requires consideration of air quality goals/guidelines that are outlined in the Environment Protection Authority’s "Approved Methods for the Modelling and Assessment of Air Pollutants in NSW" (DEC 2005a). The guidelines are primarily derived from the NEPC, with the exception of an annual average PM_{10} guideline which is derived from older goals adopted by the Environment Protection Authority (EPA 1998). The air quality goals relate to total particulate matter burden in the air and not just the particulate matter from the project, hence use of these criteria requires consideration of background levels of particulate matter and other local sources. Similar to the NEPC criteria, these guidelines do not apply to localised “hot-spot” areas such as locations near industry, busy roads or mining. However, in the absence of alternative measures, Environment Protection Authority does apply these criteria to assess the potential for impacts to arise at such locations, particularly for new projects.

Table 4-8 presents a summary of the current NEPC and Environment Protection Authority’s air quality goals and guidelines for particulate matter. These guidelines are for cumulative impacts and should also be considered in conjunction with incremental impact calculations presented in **Section 5**.

Table 4-8 Air quality goals for particulates

Pollutant	Averaging period	Criteria	Reference
PM_{10}	24-hour	50 µg/m^3 Maximum of 5 days exceedance per year	(DEC 2005a; NEPC 2003)
	Annual	30 µg/m^3	(DEC 2005a)
$PM_{2.5}$	24-hour	25 µg/m^3	Advisory goal [15] (NEPC 2003)
	Annual	8 µg/m^3	

[15] The $PM_{2.5}$ criteria established by the National Environment Protection Council are advisory goals. The goals have been derived on the basis of available health based information that relates exposure to $PM_{2.5}$ to adverse health effects. However, as $PM_{2.5}$ had not been routinely monitored in the community at the time when the criteria were being considered, existing urban (and regional) levels were not known, and the ability to meet the advisory goals could not be determined in individual states. Hence these criteria were not established as standards as defined in the National Environment Protection Council Act 1994. The relevance of any exceedance of these goals will be fully assessed once a sufficient database of monitoring data is available. They are, however, goals that are based on the protection of population health.

In relation to the current NEPC PM_{10} guideline, the following is noted (NEPC 1998, 2010):

- The guideline was derived through a review of appropriate health studies by a technical review panel of the NEPC where short-term exposure-response relationships for PM_{10} and mortality and morbidity health endpoints were considered.
- Mortality health impacts were identified as the most significant and were the primary basis for the development of the guideline.
- On the basis of the available data for key air sheds in Australia, the imposition of a criterion of 50 µg/m^3 was based on analysis of the number of premature deaths that would be avoided and associated cost savings to the health system (using data from the US). The development of the goal is not based on any acceptable level of risk.
- The acceptable number of exceedances per year is not based on an assessment of health, rather it is based on review of existing air quality in urban areas and identifying a number of exceedances that are consistent with these existing areas.
- The assessment undertaken considered exposures and issues relevant to urban air environments that are expected to also be managed through the PM_{10} guideline. These issues included emissions from vehicles and wood heaters.
- Review of the air goals in 2010 did not identify that there was a need to revise the PM_{10} guideline.

A similar approach has been adopted by NEPC (Burgers & Walsh 2002; NEPC 2002) in relation to the derivation of the $PM_{2.5}$ air quality goals, with specific studies related to $PM_{2.5}$ and mortality and morbidity indicators considered.

Table 4-9 presents a comparison of the NEPC guidelines with those established (following more recent reviews) by the WHO (WHO 2005a), the EU and the USEPA (2012). The goals established by the NEPC for $PM_{2.5}$ (and adopted in this assessment) are similar to but slightly more conservative (health protective) than those provided by the WHO, EU and the USEPA. The NEPC and NSW OEH PM_{10} guidelines are also similar to those established by the WHO and EU, however the guidelines are significantly lower than the 24-hour average guideline available from the USEPA.

The air quality guidelines for $PM_{2.5}$ and PM_{10} relate to total concentrations in the air (from all sources including the project). The background air quality data that has been used in the AQIA for this project includes a number of days that have been affected by occasional dust storms and bushfires. These extreme events result in exceedance of the NEPM guidelines (particularly in 2009). Hence, review of the 24-hour average, and the annual average, cumulative concentration is complex as it involves evaluating the incremental impact of the project on a background data set that includes these events. Detailed review of the 24-hour average and annual average concentrations associated with the operation of the project are presented in the AQIA. The review concluded that emissions from the project do not predict any additional exceedances of the NEPM criteria.

Table 4-9 Comparison of particulate matter air quality goals

Pollutant	Averaging period	Criteria/Guidelines/Goals			
		NEPC and NSW OEH	WHO (2005)	EU #	USEPA (2012)
PM_{10}	24-hour	**50 µg/m^3** Maximum of 5 days exceedance per year	**50 µg/m^3**	**50 µg/m^3** as limit value with 35 exceedances permitted each year	**150 µg/m^3** (not to be exceeded more than once per year on average over 3 years)
	Annual	**30 µg/m^3**	**20* µg/m^3**	**40 µg/m^3** as limit value	NA
$PM_{2.5}$	24-hour	**25 µg/m^3** (goal)	**25 µg/m^3**	NA	**35 µg/m^3** (98th percentile, averaged over 3 years)
	Annual	**8 µg/m^3** (goal)	**10* µg/m^3**	**25 µg/m^3** as target value from 2010 and limit value from 2015. **20 µg/m^3** as a 3 year average (average exposure indicator) from 2015 with requirements for ongoing percentage reduction and target of **18 µg/m^3** as 3 year average by 2020	**12 µg/m^3** (annual mean averaged over 3 years)

Current EU Air Quality Standards available from http://ec.europa.eu/environment/air/quality/standards.htm

* The WHO Air Quality guidelines are based on the lowest levels at which total, cardiopulmonary and lung cancer mortality have been shown to increase with more than 95% confidence in response to $PM_{2.5}$ in the ACS study (Pope et al. 2002). The use of $PM_{2.5}$ guideline is preferred (WHO 2005a).

Incremental Impacts of particulate matter

As there is no safe level for particulate matter in ambient air, the incremental impact of $PM_{2.5}$ and PM_{10} emissions to air from the project have been evaluated in more detail, as presented in **Section 5**.

The predicted incremental concentrations of $PM_{2.5}$ and PM_{10} are very low with:

- the maximum 24-hour average $PM_{2.5}$ incremental impact = 1.3-2 µg/m^3
- the maximum 24-hour average PM_{10} incremental impact = 1.4-2.1 µg/m^3
- the maximum annual average $PM_{2.5}$ incremental impact = 0.11-0.13 µg/m^3
- the maximum annual average PM_{10} incremental impact = 0.11-0.13 µg/m^3

To provide some context to the level of $PM_{2.5}$ predicted from the project, the maximum predicted 24 hour average $PM_{2.5}$ concentration has been compared with published (measured) levels of $PM_{2.5}$ in air during a range of common daily activities. This comparison is illustrated in

Figure 4-1.

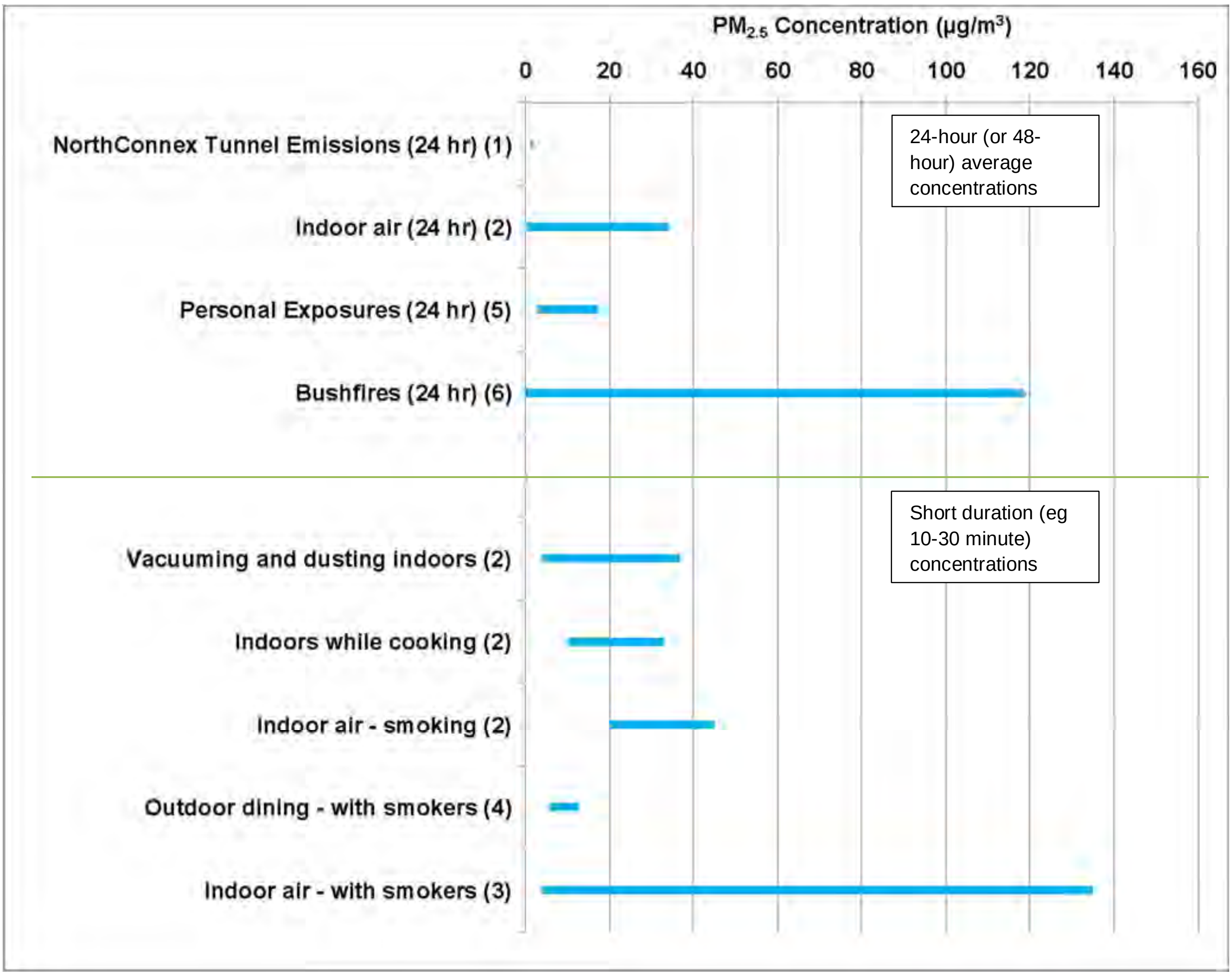

Figure 4-1 Comparison of incremental (above background) PM2.5 concentrations from range of events and activities

Notes for Figure 4-1:

1 – Maximum predicted incremental $PM_{2.5}$ impacts for project (from either northern or southern interchanges) for scenarios 2a or 2b.

2 – Data for range of indoor activities for homes in Brisbane (Morawska, Moore & Ristovski 2004). Range for 24 hour average concentrations is similar to but lower than reported in other studies in Australia (CAWCR 2010). The peak $PM_{2.5}$ concentrations in the kitchen during cooking have been reported to be significantly higher than present in the graph above, with levels up to 745 **µg/m^3** (He et al. 2004). The range reported for cooking activities in Australia are similar to the range reported in other countries (Abdullahi, Delgado-Saborit & Harrison 2013).

3 – Data for $PM_{2.5}$ levels in indoor venues in Western Australia (Stafford, Daube & Franklin 2010).

4 – Data for $PM_{2.5}$ in 69 outdoor dining areas in Melbourne (Cameron et al. 2010).

5 – Personal exposures throughout a day that include cooking, cleaning, burning of candles and other activities undertaken throughout the day (increment presented is the 25th to 75th percentile above the median background) (Sorensen et al. 2005).

6 – Data for 24 hour measurements of $PM_{2.5}$ that include bushfire events in Sydney (Burgers & Walsh 2002). Significantly higher peak concentrations of $PM_{2.5}$ (>500 µg/m^3) are often reported when bushfires are present (CSIRO 2008).

Section 5. Detailed assessment of exposure to particulate matter

5.1 Summary of adverse health effects

Adverse health effects associated with exposure to particulate matter have been well studied and reviewed by Australian and International agencies. Most of the studies and reviews have focused on population-based epidemiological studies in large urban areas in North America, Europe and Australia, where there have been clear associations determined between health effects and exposure to $PM_{2.5}$ and to a lesser extent, PM_{10}. These studies are complemented by findings from other key investigations conducted in relation to the characteristics of inhaled particles; deposition and clearance of particles in the respiratory tract; animal and cellular toxicity studies; and studies on inhalation toxicity by human volunteers (NEPC 2010).

Particulate matter has been linked to adverse health effects after both short-term exposure (days to weeks) and long-term exposure (months to years). The health effects associated with exposure to particulate matter vary widely (with the respiratory and cardiovascular systems most affected) and include mortality and morbidity effects.

In relation to mortality: for short-term exposures in a population this relates to the increase in the number of deaths due to existing (underlying) respiratory or cardiovascular disease; for long-term exposures in a population this relates to mortality rates over a lifetime, where long-term exposure is considered to accelerate the progression of disease or even initiate disease.

In relation to morbidity effects, this refers to a wide range of health indicators used to define illness that have been associated with (or caused by) exposure to particulate matter. In relation to exposure to particulate matter, effects are primarily related to the respiratory and cardiovascular system and include (Morawska, Moore & Ristovski 2004; USEPA 2009b):

- Aggravation of existing respiratory and cardiovascular disease (as indicated by increased hospital admissions and emergency room visits).
- Changes in cardiovascular risk factors such as blood pressure.
- Changes in lung function and increased respiratory symptoms (including asthma).
- Changes to lung tissues and structure.
- Altered respiratory defence mechanisms.

These effects are commonly used as measures of population exposure to particulate matter in community epidemiological studies (from which most of the available data in relation to health effects is derived), and are more often grouped (through the use of hospital codes) into the general categories of cardiovascular morbidity/effects and respiratory morbidity/effects. The available studies provide evidence for increased susceptibility for various populations, particularly older populations, children and those with underlying health conditions (USEPA 2009b).

There is consensus in the available studies and detailed reviews that exposure to fine particulates, $PM_{2.5}$, is associated with (and causal to) cardiovascular and respiratory effects and mortality (all causes) (USEPA 2012). Similar relationships have also been determined for PM_{10} , however, the supporting studies do not show relationships as clear as shown with $PM_{2.5}$ (USEPA 2012).

There are a number of other studies that have been undertaken where other health effects have been evaluated. These studies are suggestive (but do not show effects as clearly as the effects noted above) of an association between exposure to $PM_{2.5}$ and reproductive and developmental effects as well as cancer, mutagenicity and genotoxicity (USEPA 2012). IARC (2013) has classified particulate matter as carcinogenic to human based on data relevant to lung cancer.

Other studies have been reviewed to determine relationships/associations between particulate matter exposure (either PM_{10} or $PM_{2.5}$) and a wide range of other health effects and health measures including mortality (for different age groups), chronic bronchitis, medication use by adults and children with asthma, respiratory symptoms (including cough), restricted work days, work days lost, school absence and restricted activity days (Anderson et al. 2004; EC 2011; Ostro 2004; WHO 2006a). While these relationships/associations have been identified the exposure-response relationships established are not as strong as those discussed above. Also the available baseline data does not include information for many of these health effects which means it is not possible to undertake a quantitative assessment.

The detailed assessment of potential health effects associated with exposure to emissions associated with the project has focused on health effects and exposure-response relationships[16] that are robust and relate to $PM_{2.5}$, being the more important particulate fraction size relevant for emissions from combustion sources. These health effects (or endpoints) have been identified and agreed with NSW Health and include the following:

- Primary health endpoints:
  - Long-term exposure to $PM_{2.5}$ on all-cause mortality (≥ 30 years of age).
  - Short-term exposure on the rate of hospitalisation with cardiovascular and respiratory disease (≥ 65 years of age).
- Secondary health endpoints (to supplement the primary assessment):
  - Long-term exposure to $PM_{2.5}$ on cardiopulmonary mortality (≥ 30 years of age).
  - Short-term exposure to $PM_{2.5}$ on mortality (all causes, cardiovascular and respiratory, all ages).
  - Short-term exposure to PM_{10} on mortality (all causes and all ages).

5.2 Exposure-response relationships

5.2.1 Mortality and morbidity health endpoints

A quantitative assessment of risk for these endpoints uses a mathematical relationship between an exposure concentration (ie concentration in air) and a response (namely a health effect). This relationship is termed an exposure-response relationship and is relevant to the range of health effects (or endpoints) identified as relevant (to the nature of the emissions assessed) and robust (refer to **Section 5.1**). An exposure-response relationship can have a threshold, where there is a safe level of exposure, below which there are no adverse effects; or the relationship can have no

[16] An exposure-response relationship is a quantitative relationship between an exposure concentration of particulate matter in air (what is inhaled) and the health effect evaluated.

threshold (and is regarded as linear) where there is some potential for adverse effects at any level of exposure.

In relation to the health effects associated with exposure to particulate matter, no threshold has been identified. Non-threshold exposure-response relationships have been identified for the primary and secondary health endpoints considered in this assessment.

A range of exposure-response relationships are available from the many studies that have been undertaken and published. Review of the available studies has been undertaken in Australia for the purpose of developing the NEPC Air Quality Guidelines (Burgers & Walsh 2002; NEPC 2002, 2010), where a range of health endpoints and exposure-response relationships were identified and evaluated. Similar exposure-response relationships have been considered in the development and review of air guidelines established by the WHO (WHO 2005a) and the USEPA (USEPA 2012). These organisations have identified which of the available relationships that have been identified are the most robust.

The exposure-response relationships adopted in this assessment have been identified on the basis of the studies considered in the development of the NEPC Air Quality Guidelines as well as updated supporting studies published in the literature.

The assessment of potential risks associated with exposure to particulate matter involves the calculation of a relative risk (RR). For the purpose of this assessment the shape of the exposure response function used to calculate the relative risk is assumed to be linear[17]. The calculation of a relative risk based on the change in relative risk exposure concentration from baseline/existing (ie based on incremental impacts from the project) can be calculated on the basis of the following equation (Ostro 2004):

$$RR = exp[\beta(X-X_0)] \qquad \text{…Equation 1}$$

Where:

$X-X_0$ = the change in particulate matter concentration to which the population is exposed (µg/m^3)

β = regression/slope coefficient, or the slope of the exposure-response function which can also be expressed as the per cent change in response per 1 µg/m^3 increase in particulate matter exposure.

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[17] Some reviews have identified that a log-linear exposure response function may be more relevant for some of the health endpoints considered in this assessment. Review of outcomes where a log-linear exposure-response function has been adopted (Ostro 2004) for $PM_{2.5}$ identified that the log-linear relationship calculated slightly higher relative risks compared with the linear relationship within the range 10-30 µg/m^3,(relevant for evaluating potential impacts associated with air quality goals or guidelines) but lower relative risks below and above this range. For this assessment (where impacts from a particular project are being evaluated) the impacts assessed relate to concentrations of $PM_{2.5}$ that are well below 10 µg/m^3 and hence use of the linear relationship is expected to provide a more conservative estimate of relative risk.

Based on this equation, where the published studies have derived relative risk values that are associated with a 10 µg/m^3 increase in particulate matter exposure (as presented in **Table 5-**1), the β coefficient can be calculated using the following equation:

$$\beta = \frac{\ln(RR)}{10} \qquad \text{… Equation 2}$$

Where:

RR = relative risk for the relevant health endpoint as published and listed in **Table 5-1** (µg/m^3)

10 = increase in particulate matter concentration associated with the RR (all the RR presented in **Table 5-1** are associated with a 10 µg/m^3 increase in particulate matter exposure).

Table 5-1 presents a summary of the health endpoints considered in this assessment, the relevant health impact functions (from the referenced published studies) and the associated β value relevant to the calculation of a relative risk.

The health impact functions presented in this table have been discussed and agreed with NSW Health as the most current and appropriate for the quantification of potential health effects for the health endpoints considered in this assessment.

Table 5-1 Adopted health impact functions and exposure-responses relationships

Health endpoint	Exposure period	Age group	Published relative risk [95% confidence interval] per 10 µg/m³	Adopted β coefficient (as %) for 1 µg/m³ increase in PM	Reference
Primary assessment health endpoints					
PM2.5: Mortality, all causes	Long-term	≥30yrs	1.06 [1.04-1.08]	0.0058 (0.58%)	Relationship derived for all follow-up time periods to the year 2000 (for approx. 500 000 participants in the US) with adjustment for seven ecologic (neighbourhood level) covariates (Krewski et al. 2009). This study is an extension (additional follow-up and exposure data) of the work undertaken by Pope (2002), is consistent with the findings from California (1999-2002) (Ostro et al. 2006) and is more conservative than the relationships identified in a more recent Australian and New Zealand study (EPHC 2010).
PM2.5: Cardiovascular hospital admissions	Short-term	≥65yrs	1.008 [1.0059-1.011]	0.0008 (0.08%)	Relationship established for all data and all seasons from US data for 1999 to 2005 for lag 0 (exposure on same-day)(strongest effect identified) (Bell, M. L. 2012; Bell, Michelle L. et al. 2008)
PM2.5: Respiratory hospital admissions	Short-term	≥65yrs	1.0041 [1.0009-1.0074]	0.00041 (0.041%)	Relationship established for all data and all seasons from US data for 1999 to 2005 for lag 2 (exposure 2 days previous)(strongest effect identified) (Bell, M. L. 2012; Bell, Michelle L. et al. 2008)
Secondary assessment health endpoints					
PM10: Mortality, all causes	Short-term	All ages*	1.006 [1.004-1.008]	0.0006 (0.06%)	Based on analysis of data from European studies from 33 cities and includes panel studies of symptomatic children (asthmatics, chronic respiratory conditions) (Anderson et al. 2004)
PM2.5: Mortality, all causes	Short-term	All ages*	1.0094 [1.0065-1.0122]	0.00094 (0.094%)	Relationship established from study of data from 47 US cities for the years 1999 to 2005 (Zanobetti & Schwartz 2009)
PM2.5: Cardiopulmonary Mortality	Long-term	≥30yrs	1.14 [1.11-1.17]	0.013 (1.3%)	Relationship derived for all follow-up time periods to the year 2000 (for approx. 500 000 participants in the US) with adjustment for seven ecologic (neighbourhood level) covariates (Krewski et al. 2009).
PM2.5: Cardiovascular mortality	Short-term	All ages*	1.0097 [1.0051-1.0143]	0.00097 (0.097%)	Relationship established from study of data from 47 US cities for the years 1999 to 2005 (Zanobetti & Schwartz 2009)
PM2.5: Respiratory mortality (including lung cancer)	Short-term	All ages*	1.0192 [1.0108-1.0278]	0.0019 (0.19%)	Relationship established from study of data from 47 US cities for the years 1999 to 2005 (Zanobetti & Schwartz 2009)

* Relationships established for all ages, including young children and the elderly

5.2.2 Exposure to diesel particulate matter

In addition to the above exposure-response relationships, potential exposure to diesel particulate matter (DPM) derived from the project has been evaluated.

Diesel exhaust (DE) is emitted from “on-road” diesel engines (vehicle engines) and can be formed from the gaseous compounds emitted by diesel engines (secondary particulate matter). After emission from the exhaust pipe, diesel exhaust undergoes dilution and chemical and physical transformations in the atmosphere, as well as dispersion and transport in the atmosphere. The atmospheric lifetime for some compounds present in diesel exhaust ranges from hours to days.

Data from the USEPA (USEPA 2002) indicates that diesel exhaust as measured as diesel particulate matter made up about six per cent of the total ambient/urban air $PM_{2.5}$. In this project, emissions to air from the operation of the tunnel include a significant proportion of diesel powered vehicles (100 per cent of the HGVs and 49.9 per cent of the LDVs). Available evidence indicates that there are human health hazards associated with exposure to diesel particulate matter. The hazards include acute exposure-related symptoms, chronic exposure related non-cancer respiratory effects, and lung cancer.

In relation to non-carcinogenic effects, acute or short-term (eg episodic) exposure to diesel particulate matter can cause acute irritation (eg eye, throat, bronchial), neurophysiological symptoms (eg light-headedness, nausea), and respiratory symptoms (cough, phlegm). There also is evidence for an immunologic effect–exacerbation of allergenic responses to known allergens and asthma-like symptoms. Chronic effects include respiratory effects. The review of these effects (USEPA 2002) identified a threshold concentration for the assessment of chronic non-carcinogenic effects. The review conducted by the USEPA also concluded that exposures to diesel particulate matter also consider $PM_{2.5}$ goals (as these also address the presence of diesel particulate matter in urban air environments). The review found that the diesel particulate matter chronic guideline will also be met if the $PM_{2.5}$ guideline was met. Review of exposure to $PM_{2.5}$ has been assessed separately in relation to the current ambient air guidelines (refer to **Section 4.4.4**) where cumulative impacts of $PM_{2.5}$ for the project have been found to comply with the NEPC $PM_{2.5}$ advisory goal. Hence non-carcinogenic effects associated with exposure to diesel particulate matter are not considered to be of concern.

Review of exposures to diesel particulate matter (USEPA 2002) identified that such exposures are “likely to be carcinogenic to humans by inhalation”. A more recent review by IARC (Attfield et al. 2012; IARC 2012; Silverman et al. 2012) classified diesel engine exhaust as carcinogenic to humans (Group 1) based on sufficient evidence that exposure is associated with an increased risk for lung cancer. In addition, outdoor air pollution and particulate matter (that includes diesel particulate matter) have been classified by IARC as carcinogenic to humans based on sufficient evidence of lung cancer.

Many of the organic compounds present in diesel exhaust are known to have mutagenic and carcinogenic properties and hence it is appropriate that a non-threshold approach is considered for the quantification of lung-cancer endpoints.

In relation to quantifying carcinogenic risks associated with exposure to diesel exhaust, the USEPA (USEPA 2002) has not established a non-threshold value (due to uncertainties identified in the available data).

WHO has used data from studies in rats to estimate unit risk values for cancer (WHO 1996). Using four different studies where lung cancer was the cancer endpoint, WHO calculated a range of 1.6×10^{-5} to 7.1×10^{-5} per µg/m^3 (mean value of 3.4×10^{-5} per µg/m^3). This would suggest that an increase in lifetime exposure to diesel particulate matter between 0.14 and 0.625 µg/m^3 could result in a one in one hundred thousand excess risk of cancer.

The California Environmental Protection Agency has proposed a unit lifetime cancer risk of 3.0×10^{-4} per µg/m^3 diesel particulate matter (OEHHA 1998). This was derived from data on exposed workers and based on evidence that suggested unit risks between 1.5×10^{-4} and 15×10^{-4} per µg/m^3. This would suggest that an increase in lifetime exposure to diesel particulate matter of 0.033 µg/m^3 could result in a one in one hundred thousand excess risk of cancer. This estimate has been widely criticised as overestimating the risk and hence has not been considered in this assessment.

On the basis of the above, the WHO cancer unit risk value (mean value of 3.4×10^{-5} per µg/m^3) has been used to evaluate potential excess lifetime risks associated with incremental impacts from diesel particulate matter exposures. Diesel particulate matter has not been specifically modelled in the AQIA; rather diesel particulate matter is part of the $PM_{2.5}$ assessment. For the purpose of this assessment it has been conservatively assumed that 100 per cent of the incremental $PM_{2.5}$ (from the project only) is derived from diesel sources. This is conservative as not all the vehicles using the tunnel (and emitting $PM_{2.5}$) would be diesel powered (as currently there is a mix of petrol, diesel, LPG and hybrid-electric powered vehicles with the proportion of alternative fuels rising in the future).

5.3 Particulate impact assessment

5.3.1 Quantification of impact and risk

The assessment of health impacts for a particular population associated with exposure to particulate matter has been undertaken utilising the methodology presented by the WHO (Ostro 2004)[18] where the exposure-response relationships (presented in **Section 5.2**) have been directly considered on the basis of the approach outlined below.

The calculation of changes in health endpoints associated with exposure to particulate matter as outlined by the WHO (Ostro 2004) has considered the following four elements:

- Estimates of the changes in particulate matter exposure levels (ie incremental impacts) due to the project for the relevant modelled scenarios (as provided by the AQIA);
- Estimates of the number of people exposed to particulate matter at a given location (ie population data, refer to **Section 3.3**);
- Baseline incidence of the key health endpoints that are relevant to the population exposed (refer to **Section 3.4**); and
- Exposure-response relationships expressed as a percentage change in health endpoint per µg/m^3 change in particulate matter exposure (refer to **Section 5.2**), where a relative risk (RR) is determined (refer to Equation 1).

From the above, the increased incidence of a health endpoint corresponding to a particular change in particulate matter concentrations can be calculated using the following:

The attributable fraction/portion (AF) of health effects from air pollution, or impact factor, can be calculated from the relative risk (calculated for the incremental change in particulate matter considered as per Equation 1) as:

$$AF=\frac{RR-1}{RR} \quad \text{… Equation 3}$$

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[18] For regional guidance, such as that provided for Europe by the WHO (WHO 2006a, Health risks or particulate matter from long-range transboundary air pollution) regional background incidence data for relevant health endpoints are combined with exposure-response functions to present an impact function, which is expressed as the number/change in incidence/new cases per 100,000 population exposed per µg/m^3 change in particulate matter exposure. These impact functions are simpler to use than the approach adopted in this assessment, however in utilising this approach it is assumed that the baseline incidence of the health effects is consistent throughout the whole population (as used in the studies) and is specifically applicable to the sub-population group being evaluated. For the assessment of exposures in the areas evaluated surrounding the project it is more relevant to utilise local data in relation to baseline incidence rather than assume that the population is similar to that in Europe (where these relationships are derived).

The total number of cases attributable to exposure to particulate matter (where a linear dose-response is assumed) can be calculated as:

$$E = AF \times B \times P \quad \text{... Equation 4}$$

Where:
B = baseline incidence of a given health effect (eg mortality rate per person per year)
P = relevant exposed population

The above approach (while presented slightly differently) is consistent with that presented in Australia (Burgers & Walsh 2002), US (OEHHA 2002; USEPA 2005, 2010) and Europe (Martuzzi et al. 2002; Sjoberg et al. 2009). Where a linear dose-response is assumed (as is the case in this assessment), the calculations are equivalent to the following:

The calculation of an increased incidence (ie number of cases) of a particular health endpoint is not relevant to a specific individual, rather this is relevant to a statistically relevant population. This calculation has been undertaken for populations within the suburbs surrounding the proposed project. When considering the potential impact of the project on the population, the calculation has been undertaken using the following:

- Equation 1 has been used to calculate a relative risk. The relative risk has been calculated for a population weighted annual average incremental increase in $PM_{2.5}$ concentrations. The population weighted average has been calculated on the basis of the smallest statistical division provided by the Australian Bureau of Statistics within a suburb (i.e. mesh blocks – which are small blocks that cover an area of approximately 30 urban residences). For each mesh block in a suburb the average incremental increase in $PM_{2.5}$ concentration has been calculated and multiplied by the population living in the mesh block (data available from the ABS for the 2011 census year). The weighted average has been calculated by summing these calculations for each mesh block in a suburb and dividing by the total population in the suburb (i.e. in all the mesh block).
- Equation 3 has been used to calculate an attributable fraction.
- Equation 4 has been used to calculate the increased number of cases associated with the incremental $PM_{2.5}$ impact evaluated. The calculation is undertaken utilising the baseline incidence data relevant for the endpoint considered and the population (for the relevant age groups) present in the suburb.

The above approach can be simplified (mathematically, where the incremental change in particulate concentration is low, less than 1 µg/m^3) as follows:

$$E=\beta \times B \times \sum_{mesh} (\Delta X_{mesh} \times P_{mesh})$$ … Equation 5

Where:
β = slope coefficient relevant to the per cent change in response to a 1 µg/m^3 change in particulate matter exposure (as per **Table 5-1**)
B = baseline incidence of a given health effect per person (eg annual mortality rate)
ΔX_{mesh} = change (increment) in PM_{10} or $PM_{2.5}$ exposure concentration in µg/m^3 as an average within a small area defined as a mesh block (from the ABS – where many mesh blocks make up a suburb)
P_{mesh} = population (residential – based on data form the ABS) within each small mesh block

An additional risk can then be calculated as:

$$Risk=\beta \times \Delta X \times B$$ … Equation 6

Where:
β = slope coefficient relevant to the per cent change in response to a 1 µg/m^3 change in particulate matter exposure (as per **Table 5-1**)
ΔX = change (increment) in PM_{10} or $PM_{2.5}$ exposure concentration in µg/m^3 relevant to the project at the point of exposure
B = baseline incidence of a given health effect per person (eg annual mortality rate)

This calculation provides an annual risk for individuals exposed to increased PM emissions from the project at specific locations (such as the maximum, or at specific sensitive receiver locations).

For the assessment of potential lung cancer risks associated with exposure to diesel particulate matter, a non-threshold cancer risk is calculated. Non-threshold carcinogenic risks are estimated as the incremental probability of an individual developing cancer over a lifetime as a result of exposure to a potential non-threshold carcinogen. The numerical estimate of excess lifetime cancer risk is calculated as follows for inhalation exposures (USEPA 2009a):

Carcinogenic Risk (inhalation) = Exposure Concentration in Air x Inhalation Unit Risk

5.3.2 Quantification of short-and long-term effects

The concentration-response functions adopted for the assessment of exposure are derived from long and short-term studies and relate to short or long-term effects endpoints (eg change in incidence from daily changes in particulate matter, or chronic incidence from long-term exposures to particulate matter).

Long-term or chronic effects are assessed on the basis of the identified exposure-response function and annual average particulate matter concentrations. These then allow the calculation of a chronic incidence of the assessed health endpoint.

Short-term effects are also assessed on the basis of an exposure-response function that is expressed as a percentage change in endpoint per µg/m^3 change in particulate matter exposure. For short-term effects, the calculations relate to daily increases in particulate matter exposures and changes in daily effects endpoints. While it may be possible to measure daily incidence of the evaluated health endpoints in a large population study specifically designed to include such data, it is not common to collect such data in hospitals nor are effects measurable in smaller communities. Instead these calculations relate to a parameter that is measurable, such as annual incidence of hospitalisations, mortality or lung cancer risks. The calculation of an annual incidence or additional risk can be undertaken using two approaches (Ostro 2004; USEPA 2010):

1. Calculate the daily incidence or risk at each receiver location over every 24-hour period of the year (based on the modelled incremental 24-hour average concentration for each day of the year and daily baseline incidence data) and then sum the daily incidence/risk to get the annual risk; or
2. Calculate the annual incidence/risk based on the incremental annual average concentration at each receiver (and using annual baseline incidence data).

In the absence of a threshold, and assuming a linear concentration-response function (as is the case in this assessment), these two approaches result in the same outcome mathematically (calculated incidence or risk). Given that it is much simpler computationally to calculate the incidence (for each receiver) based on the incremental annual average, compared with calculating effects on each day of the year and then summing, this is the preferred calculation method. It is the recommended method outlined by the WHO (Ostro 2004).

The use of the simpler approach, based on annual average particulate matter concentrations should not be taken as implying or suggesting that the calculation is quantifying the effects of long-term exposure.

Hence for the calculations presented in this technical working paper, for both long-term and short-term effects, annual average concentrations of particulate matter have been utilised.

5.3.3 Population exposed

The population exposed to emissions derived from the operation of the project are located in areas close to the southern and northern interchanges (as discussed further in **Section 3**).

The AQIA has identified the maximum predicted level in proximity to the ventilation facilities as well as the potential impacts within the local suburbs surrounding the project. In addition data is available from the AQIA on potential impacts at a number of sensitive receivers identified within the local community as listed in **Table 3-1** and **Table 3-2**.

The calculations presented for an increased annual risk is not dependent on the population exposed. However the calculations undertaken for the increased incidence (or number of cases) in the population exposed. This calculation is undertaken on a population level as outlined in **Section 5.3.1**.

5.3.4 Baseline incidence

The baseline incidence of the key health endpoints considered in this assessment has been derived from health statistics relevant to the area evaluated. As discussed in **Section 3.4.3** the baseline incidence of the key health endpoints addressed in this assessment are based on data for NSW. This data is considered to overestimate the incidence of these health endpoints in the smaller populations of interest in this project (refer to discussion in **Section 3.4.3**), however, in the absence of relevant and reliable data for the populations of interest the NSW data is considered to be appropriate.

5.3.5 Calculated health impacts – Southern and northern ventilation facilities alone

Incremental risk calculations

On the basis of the approach outlined above, and for the key health endpoints considered in relation to exposure to $PM_{2.5}$ and PM_{10} (derived from the project), incremental risks have been calculated for scenarios 2a (2019) and 2b (2029) based on data from the AQIA. The calculations have been undertaken for the maximum predicted concentrations as well as concentrations predicted at each of the sensitive receivers.

Table 5-2 and **Table 5-3** present a summary of the predicted increased annual risks relevant to the primary health indicators addressed in this assessment, for scenarios 2a (2019) and 2b (2029).

The calculations are not presented in these tables for all the individual sensitive receivers (but are presented in **Appendix B**) as the health endpoints are not considered to be relevant for the receiver evaluated, eg hospitalisations for people aged 65 years and over is not a relevant health endpoint for evaluating impacts at a childcare centre or school.

Table 5-4 to **Table 5-5** present a summary of the predicted increased annual risks relevant to the secondary health indicators, for scenarios 2a (2019) and 2b (2029). Detailed calculations of these health impacts are presented in **Appendix B**.

The calculations presented in these tables are considered accurate to one significant figure only due to the level of uncertainty within all aspects of the assessment presented.

Increased incidence of health effects

Based on analysis of the potential health impacts on the population adjacent to the northern and southern ends of the project based on the ventilation facilities alone, the calculated increased population incidence, or number of cases, for the primary health endpoints associated with PM2.5 exposure are summarised in **Table 5-6**. These calculated values are considered accurate to one significant figure only due to the level of uncertainty within all aspects of the assessment presented.

Calculations are presented in **Appendix C**, including calculations for the secondary endpoints (where the calculated increased incidence is similar to and lower than presented for the primary health endpoints).

Diesel particulate matter

The calculated incremental lifetime risk of cancer associated with potential exposure to diesel particulate matter (assuming 100 per cent of the $PM_{2.5}$ derived from the tunnel is diesel particulate matter), at the maximum impacted location is calculated to be $5x10^{-6}$ (scenario 2a, 2019)) and $3x10^{-6}$ (scenario 2b, 2029) for the southern interchange and $4x10^{-6}$ (scenario 2a, 2019) and $4x10^{-6}$ (scenario 2b, 2029) for the northern interchange.

5.3.6 Assessment of all project impacts

The calculations presented in **Sections 5.3.1** to **5.3.5** are associated with impacts of predicted emissions of particulate matter on the local community from the operation of the ventilation facilities at the southern and northern interchanges alone. The calculations presented do not take into account changes (primarily) reductions in emissions (and concentrations of particulate matter) that would occur along the existing road corridor of Pennant Hills Road (and associated feeder roads) as a result of the project. Impacts associated with the project would not only involve an increase in concentrations of $PM_{2.5}$ and PM_{10} in areas adjacent to the northern and southern interchanges, but also decreases in concentrations along Pennant Hills Road from the Hills M2 Motorway to the M1 Pacific Motorway (due to the reduction in traffic using this section of road).

To evaluate all the impacts from the proposed project (increases and decreases) the air modelling conducted for the various project scenarios have been combined as follows:

- Step 1: Modelling conducted to evaluate emissions from the southern and northern ventilation stacks (scenarios 2a and 2b) has been combined with modelling of emissions for the predicted reduced number of vehicles proposed Pennant Hills Road for the years 2019 and 2029.
- Step 2: Scenario 1 has modelled emissions and impacts along Pennant Hills Road (and feeder roads) if the project does not go ahead for the years 2019 and 2029.
- Step 3: Impacts form the overall project have been calculated by overlaying (subtracting or adding) impacts form the project (Step 1) with the impacts that would have occurred if the project did not go ahead (Step 2).

The incremental change in annual average $PM_{2.5}$ concentrations in the community adjacent to the whole project has been calculated on the basis of the above approach. **Figure 5-1 and Figure 5-2** present plots of the predicted change in annual average concentration in the project area for the years 2019 and 2029. The plots (and associated calculations) show that concentrations of $PM_{2.5}$ within the community adjacent to Pennant Hills Road are predicted to be lower with the completion of the tunnel. This is because the project is expected to improve traffic flows along Pennant Hills Road, which would be expected to improve air quality along that road corridor. There are some areas at the northern and southern ends of the proposed tunnel where an increase is predicted. It is noted that the increased impacts predicted are lower than the reduction in impacts along the corridor of Pennant Hills Road.

To provide some measure of the overall health impact of the whole project on the population (adjacent to the southern and northern interchanges and along Pennant Hills Road) the change in risk (increase or decrease) for the primary health endpoints have been calculated based on the population weighted average change in $PM_{2.5}$ concentration (annual average) for each suburb (or part of a suburb relevant to the road corridor) and the total population. In addition the total population incidence has been calculated for all the suburbs combined. The calculated risks and population incidence calculated for 2019 and 2029 (for Scenario 2) are presented in **Table 5-7**. Values presented as a negative (-) are associated with a decreased risk (and decrease in incidence, cases per year over the whole population) while values presented as positive are associated with an increase in risk. Calculations for these health endpoints as well as the relevant secondary health endpoints are included in **Appendix D**.

Where the whole project is considered in relation to health impacts associated with $PM_{2.5}$, the following can be concluded from the calculations undertaken:

- There are some small increases in population risk for some suburbs located around the southern interchange and southern end of Pennant Hills Road. The increased risks calculated are all less than or equal to $1.5x10^{-6}$, which are considered to be negligible.
- For most of the suburbs located adjacent to Pennant Hills Road, and adjacent to the northern interchange the overall population risk decreases. The decreased levels of risk in these areas range from $1.7x10^{-7}$ to $4.2x10^{-5}$. The decreased risks are more significant than the increases noted above.
- The change in incidence of the primary health endpoints on the whole population, located adjacent to the southern and northern interchanges as well as along Pennant Hills Road is a decrease. The change in incidence is less than 1 so it is considered to be small (and not likely to be measurable within the populations). However the change does indicate the potential for a decrease in the incidence of $PM_{2.5}$ related health effects within the population located along the corridor.

Table 5-2 Summary of calculated incremental risks for primary health indicators: Exposure to $PM_{2.5}$ – Southern ventilation facility only

Scenario:	Scenario 2a (2019)			Scenario 2b (2029)		
Particulate fraction:	**PM2.5**	**PM2.5**	**PM2.5**	**PM2.5**	**PM2.5**	**PM2.5**
Health endpoint:	**Mortality – All Causes,** Long-term, ≥ 30 years	**Hospitalisations – Cardiovascular,** Short-term, ≥ 65 years	**Hospitalisations – Respiratory,** Short-term, ≥ 65 years	**Mortality – All Causes,** Long-term, ≥ 30 years	**Hospitalisations – Cardiovascular,** Short-term, ≥ 65 years	**Hospitalisations – Respiratory,** Short-term, ≥ 65 years
Baseline incidence:	1087 per 100,000	23352 per 100,000	8807 per 100,000	1087 per 100,000	23352 per 100,000	8807 per 100,000
Location	**Risk**	**Risk**	**Risk**	**Risk**	**Risk**	**Risk**
Southern Interchange only						
Maximum	$7X10^{-6}$	$2X10^{-5}$	$4X10^{-6}$	$8X10^{-6}$	$2X10^{-5}$	$5X10^{-6}$
Maximum for sensitive receivers in surrounding suburbs, and suburb average (residential)						
Carlingford						
Childcare	$9X10^{-7}$			$1X10^{-6}$		
Schools	$1X10^{-6}$			$1X10^{-6}$		
Community	$2X10^{-6}$	$5X10^{-6}$	$1X10^{-6}$	$2X10^{-6}$	$7X10^{-6}$	$1X10^{-6}$
Residential*	$2X10^{-6}$	$5X10^{-6}$	$1X10^{-6}$	$2X10^{-6}$	$6X10^{-6}$	$1X10^{-6}$
West Pennant Hills						
Childcare	$6X10^{-7}$			$7X10^{-7}$		
Aged Care	$5X10^{-7}$	$2X10^{-6}$	$3X10^{-7}$	$6X10^{-7}$	$2X10^{-6}$	$3X10^{-7}$
School	$2X10^{-6}$			$2X10^{-6}$		
Community	$2X10^{-6}$	$5X10^{-6}$	$9X10^{-7}$	$2X10^{-6}$	$5X10^{-6}$	$1X10^{-6}$
Residential*	$1X10^{-6}$	$3X10^{-6}$	$6X10^{-7}$	$1X10^{-6}$	$4X10^{-6}$	$7X10^{-7}$
Beecroft						
Childcare	$2X10^{-6}$			$2X10^{-6}$		
Aged Care	$2X10^{-6}$	$5X10^{-6}$	$1X10^{-6}$	$2X10^{-6}$	$6X10^{-6}$	$1X10^{-6}$
School	$1X10^{-6}$			$1X10^{-6}$		
Community	$2X10^{-6}$	$5X10^{-6}$	$1X10^{-6}$	$2X10^{-6}$	$7X10^{-6}$	$1X10^{-6}$
Residential*	$1X10^{-6}$	$4X10^{-6}$	$7X10^{-7}$	$2X10^{-6}$	$5X10^{-6}$	$9X10^{-7}$
North Rocks						
School	$3X10^{-7}$			$4X10^{-7}$		
Residential*	$3X10^{-7}$	$9X10^{-7}$	$2X10^{-7}$	$4X10^{-7}$	$1X10^{-6}$	$2X10^{-7}$
Epping						
School and Residential*	$2X10^{-7}$	$7X10^{-7}$	$1X10^{-7}$	$3X10^{-7}$	$8X10^{-7}$	$2X10^{-7}$

*Residential calculations are based on the average exposures in each suburb

Table 5-3 Summary of calculated incremental risks for primary health indicators: Exposure to $PM_{2.5}$ – Northern ventilation facility only

Scenario:	Scenario 2a (2019)			Scenario 2b (2029)		
Particulate fraction:	**PM2.5**	**PM2.5**	**PM2.5**	**PM2.5**	**PM2.5**	**PM2.5**
Health endpoint:	**Mortality – All Causes,** Long-term, ≥ 30 years	**Hospitalisations – Cardiovascular,** Short-term, ≥ 65 years	**Hospitalisations – Respiratory,** Short-term, ≥ 65 years	**Mortality – All Causes,** Long-term, ≥ 30 years	**Hospitalisations – Cardiovascular,** Short-term, ≥ 65 years	**Hospitalisations – Respiratory,** Short-term, ≥ 65 years
Baseline incidence:	1087 per 100,000	23352 per 100,000	8807 per 100,000	1087 per 100,000	23352 per 100,000	8807 per 100,000
Location	**Risk**	**Risk**	**Risk**	**Risk**	**Risk**	**Risk**
Northern Interchange only						
Maximum	$5X10^{-6}$	$2X10^{-5}$	$3X10^{-6}$	$7X10^{-6}$	$2X10^{-5}$	$4X10^{-6}$
Maximum for sensitive receivers in surrounding suburbs, and suburb average (residential)						
Wahroonga**						
Childcare	$3X10^{-6}$			$3X10^{-6}$		
Aged Care	$3X10^{-6}$	$1X10^{-5}$	$2X10^{-6}$	$4X10^{-6}$	$1X10^{-5}$	$2X10^{-6}$
School	$3X10^{-6}$			$4X10^{-6}$		
Hospital	$2X10^{-6}$	$5X10^{-6}$	$1X10^{-6}$	$2X10^{-6}$	$6X10^{-6}$	$1X10^{-6}$
Residential*	$2X10^{-6}$	$6X10^{-6}$	$1X10^{-6}$	$2X10^{-6}$	$7X10^{-6}$	$1X10^{-6}$
North Wahroonga						
Residential*	$2X10^{-6}$	$5X10^{-6}$	$1X10^{-6}$	$2X10^{-6}$	$6X10^{-6}$	$1X10^{-6}$
Waitara						
Childcare	$3X10^{-6}$			$3X10^{-6}$		
Aged Care	$2X10^{-6}$	$5X10^{-6}$	$9X10^{-7}$	$2X10^{-6}$	$5X10^{-6}$	$1X10^{-6}$
School	$3X10^{-6}$			$4X10^{-6}$		
Residential*	$2X10^{-6}$	$6X10^{-6}$	$1X10^{-6}$	$2X10^{-6}$	$7X10^{-6}$	$1X10^{-6}$
Hornsby						
Childcare	$2X10^{-6}$			$2X10^{-6}$		
Aged Care	$3X10^{-6}$	$7X10^{-6}$	$1X10^{-6}$	$3X10^{-6}$	$9X10^{-6}$	$2X10^{-6}$
School	$1X10^{-6}$			$1X10^{-6}$		
Hospital	$2X10^{-6}$	$6X10^{-6}$	$1X10^{-6}$	$2X10^{-6}$	$7X10^{-6}$	$1X10^{-6}$
Residential*	$2X10^{-6}$	$4X10^{-6}$	$9X10^{-7}$	$2X10^{-6}$	$5X10^{-6}$	$1X10^{-6}$
Normanhurst						
Childcare	$1X10^{-6}$			$1X10^{-6}$		
Aged Care	$1X10^{-6}$	$4X10^{-6}$	$7X10^{-7}$	$1X10^{-6}$	$4X10^{-6}$	$8X10^{-7}$
School	$1X10^{-6}$			$1X10^{-6}$		
Residential*	$1X10^{-6}$	$3X10^{-6}$	$6X10^{-7}$	$1X10^{-6}$	$4X10^{-6}$	$7X10^{-7}$

*Residential calculations are based on the average exposures in each suburb, ** The one receiver (school) located within the adjacent suburb Warrawee has been included in the calculations for Wahroonga

Table 5-4 Summary of calculated incremental risks for secondary health indicators: Exposure to $PM_{2.5}$ and PM_{10} – Southern ventilation facility only

Scenario:	Scenario 2a (2019)					Scenario 2b (2029)				
Particulate fraction:	**PM10**	**PM2.5**	**PM2.5**	**PM2.5**	**PM2.5**	**PM10**	**PM2.5**	**PM2.5**	**PM2.5**	**PM2.5**
Health endpoint:	**Mortality - All Causes,** Short-Term, All ages	**Mortality - All Causes,** Short-Term, All ages	**Mortality – Cardiopulmonary** Long-term, ≥ 30 years	**Mortality – Cardiovascular** Short-Term, All ages	**Mortality – Respiratory,** Short-Term, All ages	**Mortality - All Causes,** Short-Term, All ages	**Mortality - All Causes,** Short-Term, All ages	**Mortality – Cardiopulmonary** Long-term, ≥ 30 years	**Mortality – Cardiovascular** Short-Term, All ages	**Mortality – Respiratory,** Short-Term, All ages
Baseline incidence:	670 per 100,000	670 per 100,000	490 per 100,000	164 per 100,000	57 per 100,000	670 per 100,000	670 per 100,000	490 per 100,000	164 per 100,000	57 per 100,000
Location	**Risk**	**Risk**	**Risk**	**Risk**	**Risk**	**Risk**	**Risk**	**Risk**	**Risk**	**Risk**
Southern Interchange only										
Maximum	5×10^{-7}	7×10^{-7}	7×10^{-6}	2×10^{-7}	1×10^{-7}	5×10^{-7}	8×10^{-7}	8×10^{-6}	2×10^{-7}	1×10^{-7}
Maximum for sensitive receivers in surrounding suburbs, and suburb average (residential)										
Carlingford										
Childcare	6×10^{-8}	9×10^{-8}	9×10^{-7}	2×10^{-8}	2×10^{-8}	7×10^{-8}	1×10^{-7}	1×10^{-6}	3×10^{-8}	2×10^{-8}
Schools	8×10^{-8}	1×10^{-7}	1×10^{-6}	3×10^{-8}	2×10^{-8}	9×10^{-8}	1×10^{-7}	1×10^{-6}	4×10^{-8}	2×10^{-8}
Community	1×10^{-7}	2×10^{-7}	2×10^{-6}	4×10^{-8}	3×10^{-8}	2×10^{-7}	2×10^{-7}	2×10^{-6}	6×10^{-8}	4×10^{-8}
Residential*	1×10^{-7}	2×10^{-7}	2×10^{-6}	4×10^{-8}	3×10^{-8}	1×10^{-7}	2×10^{-7}	2×10^{-6}	5×10^{-8}	4×10^{-8}
West Pennant Hills										
Childcare	4×10^{-8}	6×10^{-8}	6×10^{-7}	2×10^{-8}	1×10^{-8}	5×10^{-8}	7×10^{-8}	7×10^{-7}	2×10^{-8}	1×10^{-8}
Aged Care	4×10^{-8}	5×10^{-8}	5×10^{-7}	1×10^{-8}	9×10^{-9}	4×10^{-8}	6×10^{-8}	6×10^{-7}	2×10^{-8}	1×10^{-8}
School	1×10^{-7}	2×10^{-7}	2×10^{-6}	4×10^{-8}	3×10^{-8}	1×10^{-7}	2×10^{-7}	2×10^{-6}	4×10^{-8}	3×10^{-8}
Community	1×10^{-7}	2×10^{-7}	2×10^{-6}	4×10^{-8}	3×10^{-8}	1×10^{-7}	2×10^{-7}	2×10^{-6}	5×10^{-8}	3×10^{-8}
Residential*	7×10^{-8}	1×10^{-7}	1×10^{-6}	3×10^{-8}	2×10^{-8}	8×10^{-8}	1×10^{-7}	1×10^{-6}	3×10^{-8}	2×10^{-8}
Beecroft										
Childcare	1×10^{-7}	2×10^{-7}	2×10^{-6}	4×10^{-8}	3×10^{-8}	1×10^{-7}	2×10^{-7}	2×10^{-6}	5×10^{-8}	4×10^{-8}
Aged Care	1×10^{-7}	2×10^{-7}	2×10^{-6}	4×10^{-8}	3×10^{-8}	1×10^{-7}	2×10^{-7}	2×10^{-6}	5×10^{-8}	4×10^{-8}
School	7×10^{-8}	1×10^{-7}	1×10^{-6}	3×10^{-8}	2×10^{-8}	8×10^{-8}	1×10^{-7}	1×10^{-6}	3×10^{-8}	2×10^{-8}
Community	1×10^{-7}	2×10^{-7}	2×10^{-6}	4×10^{-8}	3×10^{-8}	2×10^{-7}	2×10^{-7}	2×10^{-6}	6×10^{-8}	4×10^{-8}
Residential*	9×10^{-8}	1×10^{-7}	1×10^{-6}	3×10^{-8}	2×10^{-8}	1×10^{-7}	2×10^{-7}	2×10^{-6}	4×10^{-8}	3×10^{-8}
North Rocks										
School	2×10^{-8}	3×10^{-8}	3×10^{-7}	9×10^{-9}	6×10^{-9}	3×10^{-8}	4×10^{-8}	4×10^{-7}	1×10^{-8}	7×10^{-9}
Residential*	2×10^{-8}	3×10^{-8}	3×10^{-7}	7×10^{-9}	5×10^{-9}	2×10^{-8}	4×10^{-8}	4×10^{-7}	9×10^{-9}	6×10^{-9}
Epping										
School and Residential*	2×10^{-8}	2×10^{-8}	2×10^{-7}	6×10^{-9}	4×10^{-9}	2×10^{-8}	3×10^{-8}	3×10^{-7}	7×10^{-9}	5×10^{-9}

*Residential calculations are based on the average exposures in each suburb

Table 5-5 Summary of calculated incremental risks for secondary health indicators: Exposure to $PM_{2.5}$ and PM_{10} – Northern ventilation facility only

Scenario:	Scenario 2a (2019)					Scenario 2b (2029)				
Particulate fraction:	PM10	PM2.5	PM2.5	PM2.5	PM2.5	PM10	PM2.5	PM2.5	PM2.5	PM2.5
Health endpoint:	Mortality - All Causes, Short-Term, All ages	Mortality - All Causes, Short-Term, All ages	Mortality – Cardiopulmonary Long-term, ≥ 30 years	Mortality – Cardiovascular Short-Term, All ages	Mortality – Respiratory, Short-Term, All ages	Mortality - All Causes, Short-Term, All ages	Mortality - All Causes, Short-Term, All ages	Mortality – Cardiopulmonary Long-term, ≥ 30 years	Mortality – Cardiovascular Short-Term, All ages	Mortality – Respiratory, Short-Term, All ages
Baseline incidence:	670 per 100,000	670 per 100,000	490 per 100,000	164 per 100,000	57 per 100,000	670 per 100,000	670 per 100,000	490 per 100,000	164 per 100,000	57 per 100,000
Location	**Risk**	**Risk**	**Risk**	**Risk**	**Risk**	**Risk**	**Risk**	**Risk**	**Risk**	**Risk**
Northern Interchange only										
Maximum	$3X10^{-7}$	$5X10^{-7}$	$5X10^{-6}$	$1X10^{-7}$	$9X10^{-8}$	$4X10^{-7}$	$7X10^{-7}$	$7X10^{-6}$	$2X10^{-7}$	$1X10^{-7}$
Maximum for sensitive receivers in surrounding suburbs, and suburb average (residential)										
Wahroonga**										
Childcare	$2X10^{-7}$	$3X10^{-7}$	$3X10^{-6}$	$7X10^{-8}$	$5X10^{-8}$	$2X10^{-7}$	$3X10^{-7}$	$3X10^{-6}$	$9X10^{-8}$	$6X10^{-8}$
Aged Care	$2X10^{-7}$	$3X10^{-7}$	$3X10^{-6}$	$8X10^{-8}$	$6X10^{-8}$	$3X10^{-7}$	$4X10^{-7}$	$4X10^{-6}$	$1X10^{-7}$	$7X10^{-8}$
School	$2X10^{-7}$	$3X10^{-7}$	$3X10^{-6}$	$8X10^{-8}$	$6X10^{-8}$	$3X10^{-7}$	$4X10^{-7}$	$4X10^{-6}$	$1X10^{-7}$	$7X10^{-8}$
Hospital	$1X10^{-7}$	$2X10^{-7}$	$2X10^{-6}$	$4X10^{-8}$	$3X10^{-8}$	$1X10^{-7}$	$2X10^{-7}$	$2X10^{-6}$	$5X10^{-8}$	$3X10^{-8}$
Residential*	$1X10^{-7}$	$2X10^{-7}$	$2X10^{-6}$	$5X10^{-8}$	$3X10^{-8}$	$2X10^{-7}$	$2X10^{-7}$	$2X10^{-6}$	$6X10^{-8}$	$4X10^{-8}$
North Wahroonga										
Residential*	$1X10^{-7}$	$2X10^{-7}$	$2X10^{-6}$	$5X10^{-8}$	$3X10^{-8}$	$1X10^{-7}$	$2X10^{-7}$	$2X10^{-6}$	$5X10^{-8}$	$4X10^{-8}$
Waitara										
Childcare	$2X10^{-7}$	$3X10^{-7}$	$3X10^{-6}$	$7X10^{-8}$	$5X10^{-8}$	$2X10^{-7}$	$3X10^{-7}$	$3X10^{-6}$	$8X10^{-8}$	$6X10^{-8}$
Aged Care	$1X10^{-7}$	$2X10^{-7}$	$2X10^{-6}$	$4X10^{-8}$	$3X10^{-8}$	$1X10^{-7}$	$2X10^{-7}$	$2X10^{-6}$	$5X10^{-8}$	$3X10^{-8}$
School	$2X10^{-7}$	$3X10^{-7}$	$3X10^{-6}$	$8X10^{-8}$	$6X10^{-8}$	$3X10^{-7}$	$4X10^{-7}$	$4X10^{-6}$	$1X10^{-7}$	$7X10^{-8}$
Residential*	$1X10^{-7}$	$2X10^{-7}$	$2X10^{-6}$	$5X10^{-8}$	$3X10^{-8}$	$2X10^{-7}$	$2X10^{-7}$	$2X10^{-6}$	$6X10^{-8}$	$4X10^{-8}$
Hornsby										
Childcare	$1X10^{-7}$	$2X10^{-7}$	$2X10^{-6}$	$5X10^{-8}$	$3X10^{-8}$	$2X10^{-7}$	$2X10^{-7}$	$2X10^{-6}$	$6X10^{-8}$	$4X10^{-8}$
Aged Care	$2X10^{-7}$	$3X10^{-7}$	$3X10^{-6}$	$6X10^{-8}$	$4X10^{-8}$	$2X10^{-7}$	$3X10^{-7}$	$3X10^{-6}$	$7X10^{-8}$	$5X10^{-8}$
School	$6X10^{-8}$	$1X10^{-7}$	$1X10^{-6}$	$2X10^{-8}$	$2X10^{-8}$	$7X10^{-8}$	$1X10^{-7}$	$1X10^{-6}$	$3X10^{-8}$	$2X10^{-8}$
Hospital	$1X10^{-7}$	$2X10^{-7}$	$2X10^{-6}$	$5X10^{-8}$	$4X10^{-8}$	$2X10^{-7}$	$2X10^{-7}$	$2X10^{-6}$	$6X10^{-8}$	$4X10^{-8}$
Residential*	$1X10^{-7}$	$2X10^{-7}$	$2X10^{-6}$	$4X10^{-8}$	$3X10^{-8}$	$1X10^{-7}$	$2X10^{-7}$	$2X10^{-6}$	$4X10^{-8}$	$3X10^{-8}$
Normanhurst										
Childcare	$6X10^{-8}$	$1X10^{-7}$	$1X10^{-6}$	$2X10^{-8}$	$2X10^{-8}$	$7X10^{-8}$	$1X10^{-7}$	$1X10^{-6}$	$3X10^{-8}$	$2X10^{-8}$
Aged Care	$9X10^{-8}$	$1X10^{-7}$	$1X10^{-6}$	$3X10^{-8}$	$2X10^{-8}$	$1X10^{-7}$	$1X10^{-7}$	$1X10^{-6}$	$4X10^{-8}$	$3X10^{-8}$
School	$8X10^{-8}$	$1X10^{-7}$	$1X10^{-6}$	$3X10^{-8}$	$2X10^{-8}$	$9X10^{-8}$	$1X10^{-7}$	$1X10^{-6}$	$4X10^{-8}$	$2X10^{-8}$
Residential*	$7X10^{-8}$	$1X10^{-7}$	$1X10^{-6}$	$3X10^{-8}$	$2X10^{-8}$	$9X10^{-8}$	$1X10^{-7}$	$1X10^{-6}$	$3X10^{-8}$	$2X10^{-8}$

*Residential calculations are based on the average exposures in each suburb, ** The one receiver (school) located within the adjacent suburb Warrawee has been included in the calculations for Wahroonga

Table 5-6 Summary of calculated increased population incidence (additional cases per year): Exposure to $PM_{2.5}$ – Primary indicators for southern and northern ventilation facilities only*

Health Endpoint:	Mortality - All Causes, Long-term		Hospitalisations – Cardiovascular, Short-term		Hospitalisations - Respiratory, Short-term	
Age Group:	≥ 30 years		≥ 65 years		≥ 65 years	
Baseline Incidence:	1087 per 100,000		23352 per 100,000		8807 per 100,000	
	Scenario 2a - 2019	**Scenario 2b - 2029**	**Scenario 2a - 2019**	**Scenario 2b - 2029**	**Scenario 2a - 2019**	**Scenario 2b - 2029**
Southern interchange only: Suburbs						
Carlingford	0.007	0.008	0.005	0.006	0.001	0.001
West Pennant Hills	0.008	0.009	0.005	0.005	0.001	0.001
Beecroft	0.006	0.007	0.005	0.006	0.001	0.001
North Rocks	0.001	0.001	0.0009	0.001	0.0002	0.0002
Epping	0.004	0.005	0.003	0.003	0.0005	0.0006
Total over all suburbs	**0.03**	**0.03**	**0.02**	**0.02**	**0.004**	**0.004**
Northern Interchange only: Suburbs						
Wahroonga	0.01	0.02	0.01	0.01	0.002	0.003
North Wahroonga	0.001	0.001	0.001	0.001	0.0001	0.0002
Warrawee	0.001	0.001	0.0008	0.0009	0.0001	0.0002
Waitara	0.005	0.006	0.003	0.004	0.0007	0.0008
Hornsby	0.009	0.01	0.005	0.006	0.001	0.001
Normanhurst	0.003	0.003	0.002	0.003	0.0004	0.0005
Total over all suburbs:	**0.03**	**0.04**	**0.02**	**0.03**	**0.005**	**0.005**

* The calculations presented in this table are for incremental impacts from the southern and northern interchanges only. The impact of the whole project needs to be considered in conjunction with changes to emissions and exposures along the Pennant Hills Road corridor, presented in **Table 5-7**.

What do the population incidence numbers mean in Tables 5-6 and 5-7:
When only the northern and southern ventilation facilities are considered an increased annual incidence between 0.0001 and 0.04 has been calculated as presented in **Table 5-6**.
An increased annual incidence of 0.001 in a suburb (eg North Wahroonga or North Rocks) means that the population would need to live in the same homes in this suburb for 1000 years for 1 extra case (of the health indicator assessed) to occur in the population.
An increased annual incidence of 0.04 in a number of suburbs (eg all suburbs assessed adjacent to the northern interchange) means that the entire population would need to live in the same homes in this area for 25 years for 1 extra case (of the health indicator assessed) to occur in the population.

When the whole project is assessed, presented in **Table 5-7**, an overall decrease in annual incidence between 0.03 and 0.3 has been calculated for the whole population.
A decrease in annual incidence of 0.3 (for the whole population considered) means that the whole population would need to live at the same homes in this area for 3 years for 1 less case (of the health indicators assessed) to occur within this population.

Table 5-7 Summary of calculated risk (for each suburb) and total population incidence (cases per year)* – Exposure to $PM_{2.5}$ for whole project (southern and northern ventilation facilities and changes to Pennant Hills Road) – Primary Indicators

Health Endpoint:	**Mortality - All Causes, Long-term**		**Hospitalisations – Cardiovascular, Short-term**		**Hospitalisations - Respiratory, Short-term**	
Age Group:	≥ 30 years		≥ 65 years		≥ 65 years	
Baseline Incidence:	1087 per 100,000		23352 per 100,000		8807 per 100,000	
	2019	**2029**	**2019**	**2029**	**2019**	**2029**
Increased population annual risk/incidence – whole project						
Carlingford - risk	$4.7X10^{-7}$	$4.9X10^{-7}$	$1.4X10^{-6}$	$1.5X10^{-6}$	$2.7X10^{-7}$	$2.8X10^{-7}$
- population incidence	0.005	0.005	0.004	0.004	0.0007	0.0007
North Rocks - risk	$1.7X10^{-7}$	$1.8X10^{-7}$	$5.0X10^{-7}$	$5.4X10^{-7}$	$9.8X10^{-8}$	$1.0X10^{-7}$
- population incidence	0.0006	0.0006	0.0004	0.0005	0.00008	0.00009
Epping/North Epping - risk	$2.3X10^{-7}$	$2.5X10^{-7}$	$6.9X10^{-7}$	$7.4X10^{-7}$	$1.3X10^{-7}$	$1.4X10^{-7}$
- population incidence	0.001	0.001	0.0009	0.001	0.0002	0.0002
Decreased population annual risk/incidence – whole project						
West Pennant Hills - risk	$-2.0X10^{-6}$	$-2.5X10^{-6}$	$-5.9X10^{-6}$	$-7.4X10^{-6}$	$-1.1X10^{-6}$	$-1.4X10^{-6}$
- population incidence	-0.01	-0.02	-0.009	-0.01	-0.002	-0.002
Pennant Hills/Cheltenham - risk	$-1.2X10^{-5}$	$-1.2X10^{-5}$	$-3.7X10^{-5}$	$-3.6X10^{-5}$	$-7.1X10^{-6}$	$-7.0X10^{-6}$
- population incidence	-0.1	-0.1	-0.09	-0.09	-0.02	-0.02
Wahroonga/Warrawee - risk	$-3.0X10^{-7}$	$-1.2X10^{-6}$	$-9.0X10^{-7}$	$-3.6X10^{-6}$	$-1.7X10^{-7}$	$-7.0X10^{-7}$
- population incidence	-0.003	-0.01	-0.003	-0.01	-0.0005	-0.002
Hornsby/Waitara - risk	$-5.1X10^{-7}$	$-7.3X10^{-7}$	$-1.5X10^{-6}$	$-2.2X10^{-6}$	$-2.9X10^{-7}$	$-4.2X10^{-7}$
- population incidence	-0.006	-0.008	-0.003	-0.004	-0.0006	-0.0008
Normanhurst/Thornleigh/Westleigh - risk	$-1.3X10^{-5}$	$-1.4X10^{-5}$	$-4.0X10^{-5}$	$-4.2X10^{-5}$	$-7.7X10^{-6}$	$-8.0X10^{-6}$
- population incidence	-0.09	-0.1	-0.08	-0.09	-0.02	-0.02
Total change (decrease) in annual risk – whole population	$-3X10^{-5}$	$-3X10^{-5}$	$-8X10^{-5}$	$-9X10^{-5}$	$-2X10^{-5}$	$-2X10^{-5}$
Total change (decrease) in annual incidence (cases per year) – whole population:	**-0.2**	**-0.3**	**-0.2**	**-0.2**	**-0.03**	**-0.04**

*Calculations presented are based on the maximum modelled annual average $PM_{2.5}$ concentrations (increase or decrease) for the emission years modelled and the meteorological data considered. The concentrations utilised in the calculations are the population weighted concentrations for each suburb (or part of suburb).

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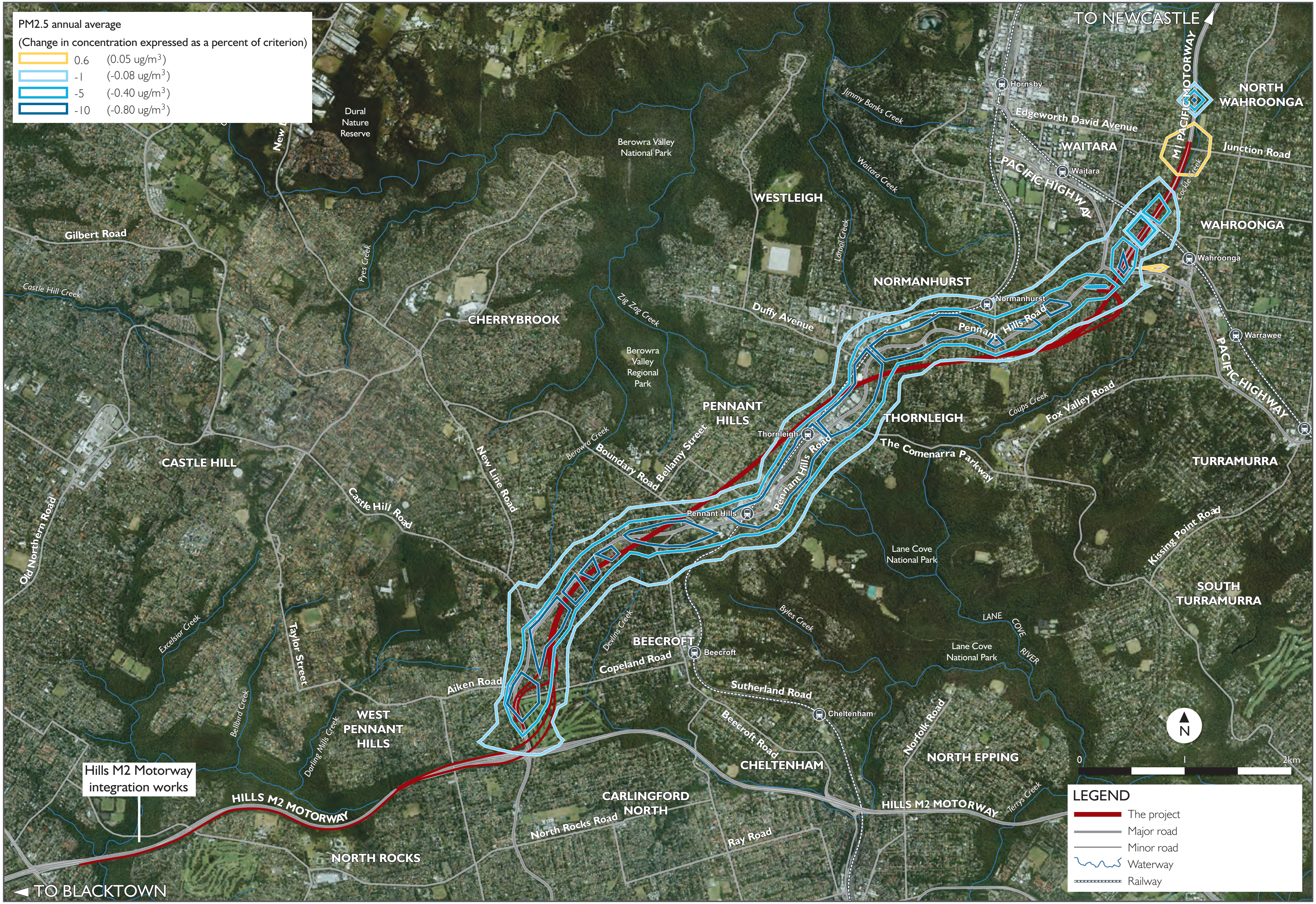

Figure 5-1 Relative change in annual average PM2.5 due to project (with project - expected traffic flows (2019)

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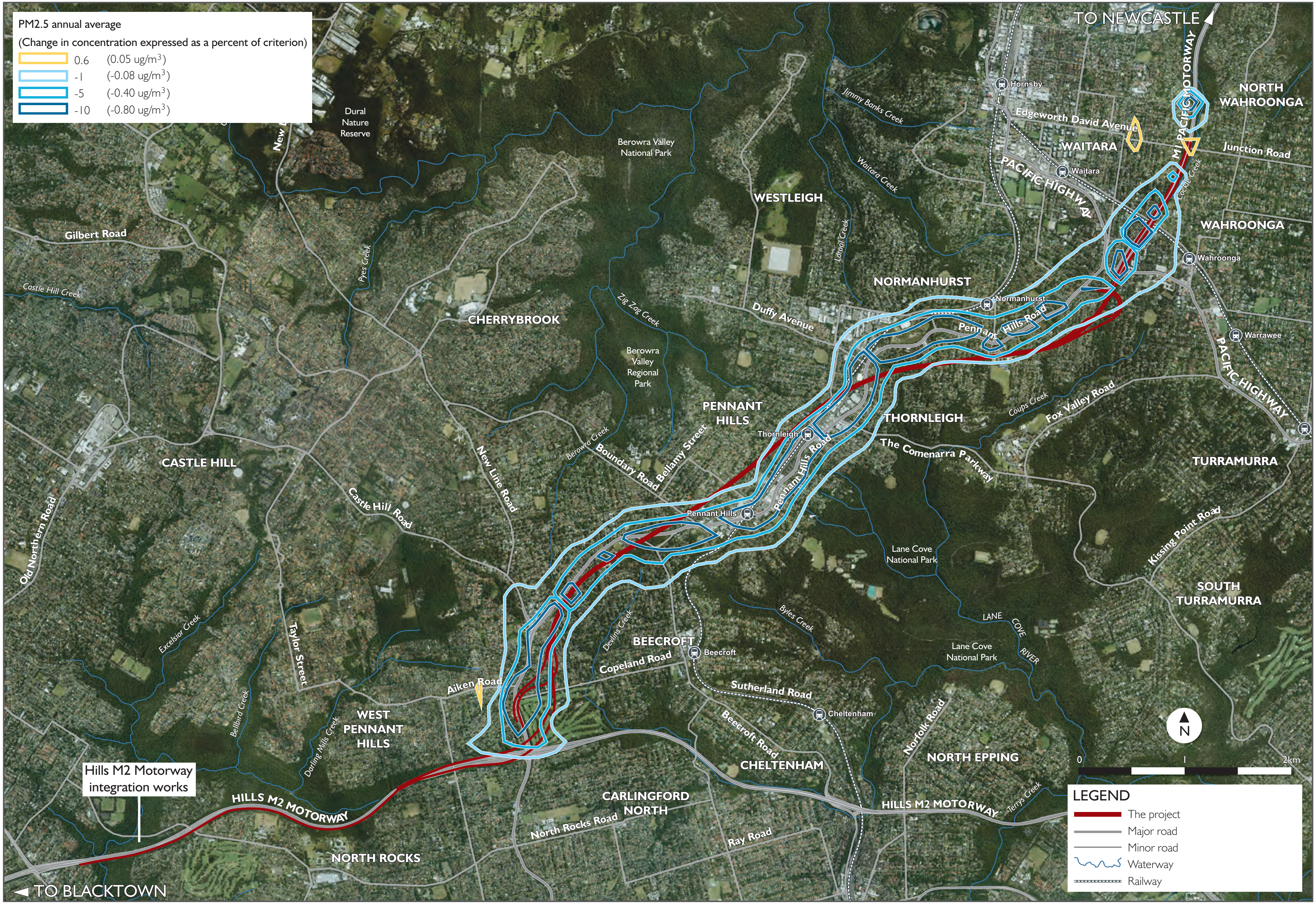

Figure 5-2 Relative change in annual average PM2.5 due to project (with project - expected traffic flows (2029)

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5.4 Acceptability of health risk impacts

5.4.1 General

Based on the assessment outlined and presented in **Sections 5.1** to **5.3**, potential health impacts associated with the project have been assessed on the basis of two calculations:

1. Calculation of an annual risk for each health endpoint. This is an incremental risk over and above the baseline risk (or incidence) of the effect occurring for any member of the population, where exposed to the particulate matter concentration estimated.
2. Calculation of an increased incidence of the health effect occurring within the population exposed. This calculates the increased number of cases (mortality or hospitalisations) that may occur for the population assumed to be exposed to the particulate matter concentration estimated.

To determine if the calculated annual risk or increased incidence within a population associated with particulate matter impacts from the project may be considered to be acceptable a number of factors need to be considered. These are further discussed in the following sections.

5.4.2 Acceptable risk levels

General

The acceptability of an additional population risk is the subject of some discussion as there are currently no guidelines available in Australia, or internationally, in relation to an acceptable level of population risk associated with exposure to particulate matter. More specifically there are no guidelines available that relate to an acceptable level of risk for a small population (associated with impacts from a specific activity or project) compared with risks that are relevant to whole urban populations (that are considered when deriving guidelines). The following provides additional discussion in relation to evaluating calculated risk levels.

> "*The solution to developing better criteria for environmental contaminants is not to adopt arbitrary thresholds of 'acceptable risk' in an attempt to manage the public's perception of risk, or develop oversimplified tools for enforcement or risk assessment. Rather, the solution is to standardize the process by which risks are assessed, and to undertake efforts to narrow the gap between the public's understanding of actual vs. perceived risk. A more educated public with regard to the actual sources of known risks to health, environmental or otherwise, will greatly facilitate the regulatory agencies' ability to prioritize their efforts and standards to reduce overall risks to public health*." (Kelly 1991).

Most human activities that have contributed to economic progress present also some disadvantages, including risks of different kinds that adversely affect human health. These risks include air or water pollution due to industrial activities (coal power generation, chemical plants, and transportation), food contaminants (pesticide residues, additives), and soil contamination (hazardous waste). Despite all possible efforts to reduce these threats, it is clear that the zero risk objective is unobtainable or simply not necessary for human and environmental protection and that a certain level of risk in a given situation is deemed "acceptable" as the effects are so small as to be negligible or undetectable. Risk managers need to cope with some residual risks and thus must adopt some measure of an acceptable risk.

Much has been written about how to determine the acceptability of risk. The general consensus in the literature is that "acceptability" of a risk is a judgment decision properly made by those exposed to the hazard or their designated health officials. It is not a scientifically derived value or a decision made by outsiders to the process. Acceptability is based on many factors, such as the number of people exposed, the consequences of the risk, the degree of control over exposure, and many other factors.

The USEPA (Hoffman 1988) "*surveyed a range of health risks that our society faces*" and reviewed acceptable-risk standards of government and independent institutions. The survey found that "*No fixed level of risk could be identified as acceptable in all cases and under all regulatory programs*...," and that: "...*the acceptability of risk is a relative concept and involves consideration of different factors*". Considerations may include:

- The certainty and severity of the risk.
- The reversibility of the health effect.
- The knowledge or familiarity of the risk.
- Whether the risk is voluntarily accepted or involuntarily imposed.
- Whether individuals are compensated for their exposure to the risk.
- The advantages of the activity.
- The risks and advantages for any alternatives.

To regulate a technology in a logically defensible way, one must consider all its consequences, i.e. both risks and benefits.

10^{-6} as an 'acceptable' risk level?

The concept of 1×10^{-6} (10^{-6}) was originally an arbitrary number, finalised by the U.S. Food and Drug Administration (FDA) in 1977 as a screening level of "essentially zero" or *de minimus* risk. The term *de minimus* is an abbreviation of the legal concept, "*de minimus non curat lex*: the law does not concern itself with trifles." In other words, 10^{-6} was developed as a level of risk below which risk was considered a "trifle" and not of concern in a legal case.

This concept was traced back to a 1961 proposal by two scientists from the National Cancer Institute regarding methods to determine "safety" levels in carcinogenicity testing. The FDA applied the concept in risk assessment in its efforts to deal with diethylstilboestrol as a growth promoter in cattle. The threshold of one-in-a-million risk of developing cancer was established as a screening level to determine what carcinogenic animal drug residues merited further regulatory consideration. In the FDA legislation, the regulators specifically stated that this level of "essentially zero" was not to be interpreted as equal to an acceptable level of residues in meat products. Since then, the use of risk assessment and 10^{-6} (or variations thereof) have been greatly expanded to almost all areas of chemical regulation, to the point where today one-in-a-million (10^{-6}) risk means different things to different regulatory agencies in different countries. What the FDA intended to be a lower regulatory level of "zero risk" below which no consideration would be given as to risk to human health, for many regulators it somehow came to be considered a maximum or target level of "acceptable" risk (Kelly 1991).

When evaluating human health risks, the quantification of risk can involve the calculation of an increased lifetime chance of cancer (as is calculated for diesel particulate matter in this assessment) or an increased probability of some adverse health effect (or disease) occurring, over and above the baseline incidence of that health effect/disease in the community (as is calculated for exposure to particulate matter).

In the context of human health risks, 10^{-6} is a shorthand description for an increased chance of 0.000001 in 1 (one chance in a million) of developing a specific adverse health effect due to exposure (over a lifetime or a shorter duration as relevant for particulate matter) to a substance. The number 10^{-5} represents 1 chance in 100,000, and so on.

Where cancer may be considered, lifetime exposure to a substance associated with a cancer risk of 1×10^{-6} would increase an individual's current chances of developing cancer from all causes (which is 40 per cent, or 0.4 – the background incidence of cancer in a lifetime) from 0.4 to 0.400001, an increase of 0.00025 per cent.

For other health indicators considered in this assessment, such as cardiovascular hospitalisations for people aged 65 years and older (for example), an increased risk of 10^{-6} (one chance in a million) would increase an individual's (aged 65 years and older) chance of hospitalisation for cardiovascular disease (above the baseline incidence of 23 per cent, or 0.23) from 0.23 to 0.230001, an increase of 0.00043 per cent.

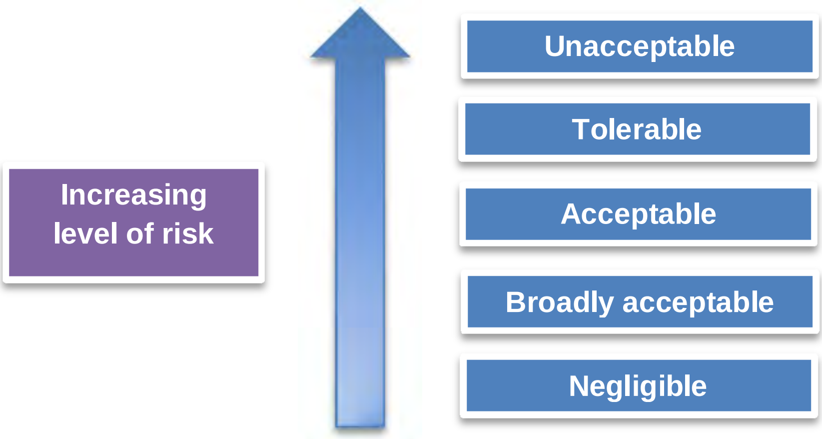
To provide more context in relation to the concept of a one in a million risk, the following presents a range of everyday life occurrences. The activity and the time spent undertaking the activity that is associated with reaching a risk of one in a million for mortality are listed below (Higson 1989; NSW Planning 2011).

- Motor vehicle accident – 2.5 days spent driving a motor vehicle to reach one in a million chance of having an accident that causes mortality (death).
- Home accidents – 3.3 days spent within a residence to reach a one in a million chance of having an accident at home that causes mortality.
- Pedestrian accident (being struck by vehicles) – 10 days spent walking along roads to reach a one in a million chance of being struck by a vehicle that causes mortality.
- Train accident – 12 days spent travelling on a train to reach a one in a million chance of being involved in an accident that causes mortality.
- Falling down stairs[1] – 66 days spent requiring the use of stairs in day-to-day activities to reach a one in a million chance of being involved in a fall that causes mortality.
- Falling objects – 121 days spent in day-to-day activities to reach a one in a million chance of being hit by a falling object that causes mortality.

This risk level should also be considered in the context that everyone has a cumulative risk of death that ultimately must equal one and the annual risk of death for most of one's life is about one in 1000.

[1] Mortality risks as presented by: http://www.riskcomm.com/visualaids/riskscale/datasources.php

While various terms have been applied, it is clear that the two ends of what is a spectrum of risk are the “negligible” level and the “unacceptable" level. Risk levels intermediate between these are frequently adopted by regulators with varying terms often used to describe the levels. When considering a risk derived for an environmental impact it is important to consider that the level of risk that may be considered acceptable will lie somewhere between what is negligible and unacceptable, as illustrated below.



The calculated individual lifetime risk of death or illness due to an exposure to a range of different environmental hazards covers many orders of magnitude, ranging from well less than 10^{-6} to levels of 10^{-3} and higher (in some situations). However, most figures for an acceptable or a tolerable risk range between 10^{-6} to 10^{-4}, used for either one year of exposure or a whole life exposure. It is noteworthy that 10^{-6} as a criterion for "acceptable risk" has not been applied to all sources of exposure or all agents that pose risk to public health.

A review of the evolution of 10^{-6} reveals that *perception* of risk is a major determinant of the circumstances under which this criterion is used. The risk level 10^{-6} is not consistently applied to all environmental legislation. Rather, it seems to be applied according to the general perception of the risk associated with the source being regulated and where the risk is being regulated (with different levels selected in different countries for the same sources).

A review of acceptable risk levels at the USEPA (Schoeny 2008) points out that risk assessors can identify risks and possibly calculate their value but cannot determine what is acceptable. Acceptability is a value judgment that varies with type of risk, culture, voluntariness and many other factors. Acceptability may be set by convention or law. The review also states that the USEPA aims for risk levels between 10^{-6} and 10^{-4} for risks calculated to be linear at low dose, while for other endpoints, not thought to be linear at low dose, the risk is compared to Reference Dose/Concentrations or guideline levels. The USEPA typically uses a target reference risk range of 10^{-4} to 10^{-6} for carcinogens in drinking water, which is in line with World Health Organization (WHO) guidelines for drinking water quality which, where practical, base guideline values for genotoxic carcinogens on the upper bound estimate of an excess lifetime cancer risk of 10^{-5}.

There are many different ways to define acceptable risk and each way gives different weight to the views of different stakeholders in the debate. No definition of 'acceptable' will be acceptable to all stakeholders. Resolving such issues, therefore, becomes a political (in the widest sense) rather than a strictly health process.

The following is a list of standpoints that could be used as a basis for determining when a risk is acceptable or, perhaps, tolerable.

The WHO (Fewtrell & Bartram 2001) address standards related to water quality. They offer the following guidelines for determining acceptable risk. A risk is acceptable when:

- It falls below an arbitrary defined probability.
- It falls below some level that is already tolerated.
- It falls below an arbitrary defined attributable fraction of total disease burden in the community.
- The cost of reducing the risk would exceed the costs saved.
- The cost of reducing the risk would exceed the costs saved when the 'costs of suffering' are also factored in.
- The opportunity costs would be better spent on other, more pressing, public health problems.
- Public health professionals say it is acceptable.
- The general public say it is acceptable (or more likely, do not say it is not).
- Politicians say it is acceptable.

In everyday life individual risks are rarely considered in isolation. It could be argued that a sensible approach would be to consider health risks in terms of the total disease burden of a community and to define acceptability in terms of it falling below an arbitrary defined level. A problem with this approach is that the current burden of disease attributable to a single factor, such as air pollution, may not be a good indicator of the potential reductions available from improving other environmental health factors. For diseases such as cardiovascular disease where causes are multifactorial, reducing the disease burden by one route may have little impact on the overall burden of disease.

Overall

It is not possible to provide a rigid definition of acceptable risk due to the complex and context-driven nature of the challenge. It is possible to propose some general guidelines as to what might be an acceptable risk for specific development projects.

If the level of 10^{-6} (one chance in a million) were retained as a level of increased risk that would be considered as a negligible risk in the community, then the level of risk that could be considered to be tolerable would lie between this level and an upper level that is considered to be unacceptable.

While there is no guidance available on what level of risk is considered to be unacceptable in the community, a level of 10^{-4} for increased risk (one chance in 10,000) has been generally adopted by health authorities as a point where risk is considered to be unacceptable in the development of drinking water guidelines (that impact on whole populations) (for exposure to carcinogens as well as for annual risks of disease (Fewtrell & Bartram 2001)) and in the evaluation of exposures from pollutants in air (DEC 2005b).

Between an increased risk level considered negligible (10^{-6}) and unacceptable (10^{-4}) lie risks that may be considered to be tolerable or even acceptable. Tolerable risks are those that can be tolerated (and where the best available, and most appropriate, technology has been implemented to minimise exposure) in order to realise some benefit.

In a societal context, risks are inevitable and any new development will be accompanied by risks which are not amenable or economically feasible to reduce below a certain level. It is not good policy to impose an arbitrary risk level to such developments without consideration of the myriad factors that should be brought into play to determine what is 'tolerable'.

When considering the impacts associated with this project, it is important to note that there are a range of benefits associated with the project (refer to **Section 2.5**) and the design of the project has incorporated measures to minimise exposures to traffic-related emissions in the local areas (as outlined in Chapter 5 of the environmental impact statement). Hence for this project the calculated risks have been considered to be tolerable when in the range of 10^{-6} and 10^{-4} of increased risk and where the increased incidence of the health impacts are considered to be insignificant (refer to discussion in **Section 5.4.3**).

5.4.3 Determination of significance of incremental impacts

The assessment of potential health impacts associated with emissions to air from the project has not only calculated an increased annual risk, relevant to the health endpoints considered, but also an increased incidence, ie the additional number of cases, of the adverse effects occurring within the population potentially exposed. The calculated increased incidence need to be considered in terms of what may be significant.

In relation to the increased impact of PM_{10} and $PM_{2.5}$ concentrations, the AQIA predicted increased concentrations in the local community of around 0.1 µg/m^3 as an annual average and 1.3 µg/m^3 to 2.1 µg/m^3 as a 24-hour average. These increases would not be detectable above the variability in daily PM_{10} and $PM_{2.5}$ measurements and are at or below the reported precision of the equipment that is used to measure PM_{10} and $PM_{2.5}$ (reported to vary from five per cent to 15 per cent depending on the equipment used, eg for the most common equipment used for measuring ambient $PM_{2.5}$ concentrations the precision of the data is ± 1 µg/m^3).

In relation to the calculated increased incidence of an adverse health effect occurring in a population, the following is noted for the primary health indicators (based on statistics available from NSW Health):

- In relation to mortality (all causes), the health statistics available show that for the year 2010 – 2011 the variability in all admissions data reported (based on the 95 per cent confidence interval for data reported in northern Sydney) is around ± two per cent. This is the variability in the data reported in one year. Each year the mortality rate also varies with around three per cent variability reported in the mortality rate (number reported for all causes) between 2009/10 and 2010/11. Based on the baseline incidence of mortality considered in this assessment a variability of two to three per cent equates to a variability of around one case per year (where the maximum impacts are considered). Hence any estimation of mortality in the population less than one case per year could not be detected (above normal variability) in the health statistics.

- In relation to cardiovascular disease hospitalisations, the health statistics available show that for the year 2011 – 2012 the variability in all admissions data reported (based on the 95 percent confidence interval for data reported in northern Sydney) is around ± 1.5 percent. This is the variability in the data reported in one year. Each year the rate of hospitalisations (all ages) also varies with around three per cent variability reported in the number of hospitalisations for people aged 65 years and older between 2010/11 and 2011/12. Based on the baseline incidence of cardiovascular hospitalisations considered in this assessment for individuals aged 65 years and older a variability of 1.5 per cent equates to a variability of around 40 cases per year (where the maximum impacts are considered). Hence any estimation of increased incidence of cardiovascular hospitalisations in the population aged 65 years and older less than 40 cases per year could not be detected (above normal variability) in the health statistics.
- In relation to respiratory disease hospitalisations, the health statistics available show that for the year 2011 – 2012 the variability in all admissions data reported (based on the 95 percent confidence interval for data reported in northern Sydney) is around ± 1.5 percent. This is the variability in the data reported in one year. Each year the rate of hospitalisations (all ages) also varies with around three-four per cent variability reported in the number of hospitalisations (all ages) between 2010/11 and 2011/12. Based on the baseline incidence of respiratory hospitalisations considered in this assessment for individuals aged 65 years and older a variability of 1.5 per cent equates to a variability of around 17 cases per year (where the maximum impacts are considered). Hence any estimation of increased incidence of cardiovascular hospitalisations in the population aged 65 years and older less than 17 cases per year could not be detected (above normal variability) in the health statistics.

Where changes arising from an individual project are well below one case per year and are not detectable in the normal fluctuations in health statistics such impacts are considered to be negligible.

5.5 Discussion of potential health impacts from the project

5.5.1 General

The assessment presented in this section has focused on the quantification of health impacts associated with exposure primarily to $PM_{2.5}$ (as the source of the emissions is derived from vehicle emission), but also to PM_{10}. Incremental annual risk and increased incidence for a range of primary and secondary health indicators associated with exposure to $PM_{2.5}$ and PM_{10} have been calculated and are presented in **Section 5.3.5**.

The assessment of health impacts addresses impacts that may occur to all members of the community including young children, the elderly and individuals with pre-existing health conditions. The exposure-response relationships are based on effects identified in large urban communities and while some of the health indicators used have focused on age groups where the exposure-response relationships are the most robust, there are a number of health indicators that address all ages of the population. Hence the calculations undertaken, and the discussion presented in this section are relevant to all the individual receivers assessed (as listed in **Section 3.2**) including young children attending day-care and schools in the area, the elderly in aged care, individuals with health conditions at hospital facilities or in the community and all members of the public living in the area. A more specific assessment of the impact of the project on asthma in young children has been presented separately in **Section 5.7.2**.

The following discussion relates to a review of the calculated health impacts within the context of the discussion presented in **Section 5.4**.

5.5.2 Primary health indicators

In relation to the primary health indicators considered in relation to exposure to $PM_{2.5}$ derived from the project, the following can be noted:

- For the assessment of **mortality** from all causes (for people aged 30 years and over) the following has been calculated (for scenarios 2a (2019) and 2b (2029)):
    - The increased annual risks (mortality) are calculated to be:
        - $5x10^{-6}$ to $8x10^{-6}$ for the maximum project impact locations adjacent to the southern and northern interchanges; and
        - $\leq 5x10^{-6}$ for the individual sensitive receivers located in the community surrounding the southern and northern interchanges.
    - The increased annual incidence within the local population is calculated to be 0.04 for the population around the northern interchange and 0.03 for the population around the southern interchange.

    Based on the discussion presented in **Section 5.4.2**, the calculated risks are within the range of tolerable risks associated with impacts from a specific project.

    With further consideration of the calculated increased population incidence of mortality as discussed in **Section 5.4.3**, the calculated increased risks are considered to be negligible.

- For the assessment of **cardiovascular hospitalisations** (for people aged 65 years and over) the following has been calculated (for scenarios 2a (2019) and 2b (2029)):
    - The increased annual risks (cardiovascular hospitalisations) are calculated to be:
        - $2x10^{-5}$ for the maximum project impact locations adjacent to the southern and northern interchanges; and
        - $\leq 2x10^{-5}$ for the individual sensitive receiver located in the community surrounding the southern and northern interchanges.
    - The increased annual incidence within the local population is calculated to be 0.03 for the population around the northern interchange and 0.02 for the population around the southern interchange.

    Based on the discussion presented in **Section 5.4.2**, the calculated risks are within the range of tolerable risks associated with impacts from a specific project. With further consideration of the calculated increased incidence of cardiovascular hospitalisations as discussed in **Section 5.4.3**, the calculated increased risks are considered to be negligible.

- For the assessment of **respiratory hospitalisations** (for people aged 65 years and over) the following has been calculated (for scenarios 2a (2019) and 2b (2029)):

  - The increased annual risks (respiratory hospitalisations) are calculated to be:
    - $3x10^{-6}$ to $5x10^{-6}$ for the maximum project impact locations adjacent to the southern and northern interchanges; and
    - $\leq 3x10^{-6}$ for the individual sensitive receivers located in the community surrounding the southern and northern interchanges.
  - The increased annual incidence within the local population is calculated to be 0.005 for the population around the northern interchange and 0.004 for the population around the southern interchange.

  Based on the discussion presented in **Section 5.4.2**, the calculated risks are within the range of tolerable risks associated with impacts from a specific project. With further consideration of the calculated increased incidence of respiratory hospitalisations as discussed in **Section 5.4.3**, the calculated increased risks are considered to be negligible.

5.5.3 Secondary health indicators

In relation to the secondary health indicators considered in relation to exposure to $PM_{2.5}$ and PM_{10} derived from the project:

- For the assessment of **mortality** from all causes (all ages) and from cardiopulmonary (ages 30 years and over), cardiovascular (all ages) and respiratory disease (all ages) the following has been calculated (for scenarios 2a (2019) and 2b (2029)):

  - The increased annual risks are calculated to be:
    - $9x10^{-8}$ to $8x10^{-6}$ for the maximum project impact locations adjacent to the southern and northern interchanges; and
    - $\leq 5x10^{-6}$ for the individual sensitive receivers located in the community surrounding the southern and northern interchanges.

  Based on the discussion presented in **Section 5.4.2**, these risks are negligible for some health indicators with the reminder within the range of tolerable risks associated with impacts from a specific project.

5.6 Qualitative assessment of other key issues

5.6.1 In-tunnel exposures

Concentrations of carbon monoxide, oxides of nitrogen, total volatile organic compounds, total polycyclic aromatic hydrocarbons, $PM_{2.5}$ and PM_{10} have been estimated within the tunnel itself during normal operations (scenarios 2a (2019) and 2b (2029)). Concentrations in the tunnel vary depending on:

- Time of day. Pollutant concentrations within the main alignment tunnels have been estimated to vary by a factor of up to nine times (depending on the particular pollutant and location within the main alignment tunnels) from periods of low traffic to peak traffic.

- Location within the main alignment tunnels. Concentrations of pollutants would gradually increase from the tunnel portals to around the offtake to the ventilation outlets. Average exposure for a motorist would be around half of the maximum concentration within a main alignment tunnel.

The assessment of potential exposures that may occur in the tunnel has been undertaken with consideration of these factors. In addition the following has also been considered:

- The time spent within the tunnel would be limited, taking around six minutes to travel the full distance of the tunnel (when travelling at 80 kilometres per hour). During peak times the time of travel may be slightly longer depending on the speed of traffic flow in the tunnel. As the concentrations are not the same in all parts of the tunnel, with concentrations increasing with distance from the start, the amount of time exposed to the maximum concentration would be much lower (around one to two minutes). The average exposure through the whole tunnel would be lower than, approximately half, the maximum (at the end of the tunnel).
- The concentration of pollutants within the vehicle itself, particularly where all windows are closed when inside the tunnel, as most vehicles have filters on the air intake. Where the air conditioning/ventilation in the car is set to recirculation this would limit the contribution of air derived from within the tunnel to the air within the vehicle. Measurements conducted by NSW Health in relation to the M5 East Tunnel (NSW Health 2003) identified that closing car windows and switching the ventilation to recirculation can reduce exposures by approximately 70-75 per cent for carbon monoxide and nitrogen dioxide, 80 per cent for fine particulates and 50 per cent for volatile organic compounds.

In-tunnel emissions were also estimated using internationally-recognised vehicle emission factors prepared by the World Road Association (PIARC, 2012), which provide Australian-specific emissions based on fleet distribution data and emission standards relevant to Australia. PIARC emission factors were developed for the purpose of defining the minimum air flows required to achieve adequate air quality within road tunnels rather than for the purpose of developing emissions inventories, so a safety margin is added to the emission factors within PIARC. This is expected to result in conservative emissions estimates when used for inventory purposes. A review of the emissions inventory for this project has been provided to Pacific Environment Limited for peer review, which included a comparison using the NSW Environment Protection Authority's published emission factors. This was conducted to assess the conservatism of the PIARC emission factors and its reasonableness for use. The outcome of the review concluded that the emissions inventory adopted was conservative, particularly in the case of PM_{10} and $PM_{2.5}$ (where concentrations from PIARC were found to be twice as high as estimated from the NSW Environment Protection Authority). Further detail on the emissions inventory, and the findings of the Pacific Environment review, can be found in technical working paper: air quality (AECOM, 2014).

The following provides further discussion on the range of concentrations predicted within the tunnel.

Carbon monoxide

Figure 5-3 presents the predicted hourly concentration of carbon monoxide in the northbound and southbound tunnels at different distances from the start of the tunnel, for different times of the day, for scenario 2a (2019) and scenario 2b (2029).

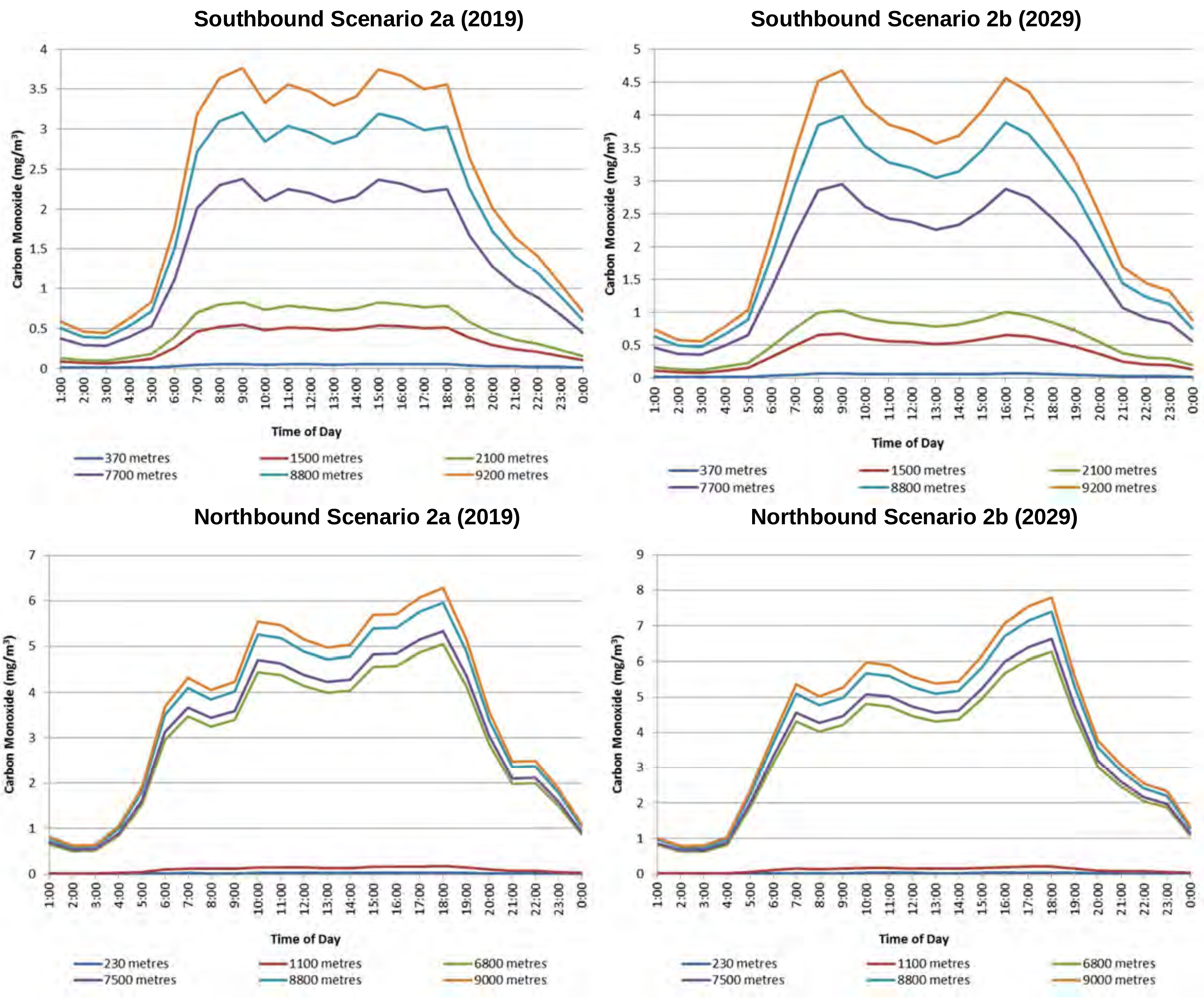


Figure 5-3: Predicted in-tunnel concentrations of Carbon Monoxide

Review of **Figure 5-3** indicates the following:

- The concentrations predicted in the project tunnel are <1 mg/m^3 at the start of the tunnel increasing to levels of 2 to 4.6 mg/m^3 towards the end of the southbound tunnel during the peak times and middle of the day and 4 to 8 mg/m^3 towards the end of the northbound tunnel during the peak times and middle of the day;
- Based on the maximum in-tunnel concentrations estimated, average exposure for a motorist using the southbound tunnel in peak periods[19] is estimated to be approximately 2 mg/m^3 for a duration of approximately six minutes with windows open and 0.6 mg/m^3 with windows closed and ventilation set to recirculation mode.
- Based on the maximum in-tunnel concentrations estimated, average exposure for a motorist using the northbound tunnel in peak periods is estimated to be approximately 4 mg/m^3 for a duration of approximately six minutes with windows open and 1.2 mg/m^3 with windows closed and ventilation set to recirculation mode.
- The NHMRC (2008) has published measured concentrations of carbon monoxide from a range of tunnels in Sydney and around the world. The measured concentrations come from a number of different studies where the averaging time for the collection of the data varies significantly. This makes it difficult to directly compare the range of reported concentrations with the concentrations predicted in this assessment (ie not comparing data reported over similar averaging/exposure periods). While noting this difficulty in comparing the data, the a range of average concentrations of carbon monoxide have been reported from 6 to 44 mg/m^3 (NHMRC 2008).
- The maximum concentration (8 mg/m^3), and likely average concentration (half the maximum, or around 4 mg/m^3) predicted in the project tunnel is lower than the WHO guidelines[20] for 15-minute exposures of 100 mg/m^3, and 30-minute exposures of 57 mg/m^3.
- These concentrations are also lower than the USEPA guidelines for in-tunnel exposures that range from 40 mg/m^3 for 45-60 minute exposures to 138 mg/m^3 for peak period for traffic (<15 mins) (NHMRC 2008).

[19] Refer to the technical working paper: air quality (AECOM, 2014) for more details in relation to concentrations estimated in the tunnel in peak periods (at each kilometre through the tunnel).

[20] The guidelines are presented in ppmv by the referenced organisation. These concentrations have been converted to mg/m^3 for use in this report based on the molecular weight of the compound and standard temperature and pressure.

Nitrogen dioxide

Figure 5-4 presents the predicted hourly concentration of nitrogen dioxide in the northbound and southbound tunnels at different distances from the start of the tunnel, for different times of the day, for scenario 2a (2019) and scenario 2b (2029). The non-linearity of nitrogen oxides chemistry in road tunnels makes the estimation of the potential levels of nitrogen dioxide in the tunnel complex. Regardless of the complexities, the concentration of nitrogen dioxide has been estimated assuming that 10 per cent of the total nitrogen oxides comprise nitrogen dioxide (PIARC 2012).

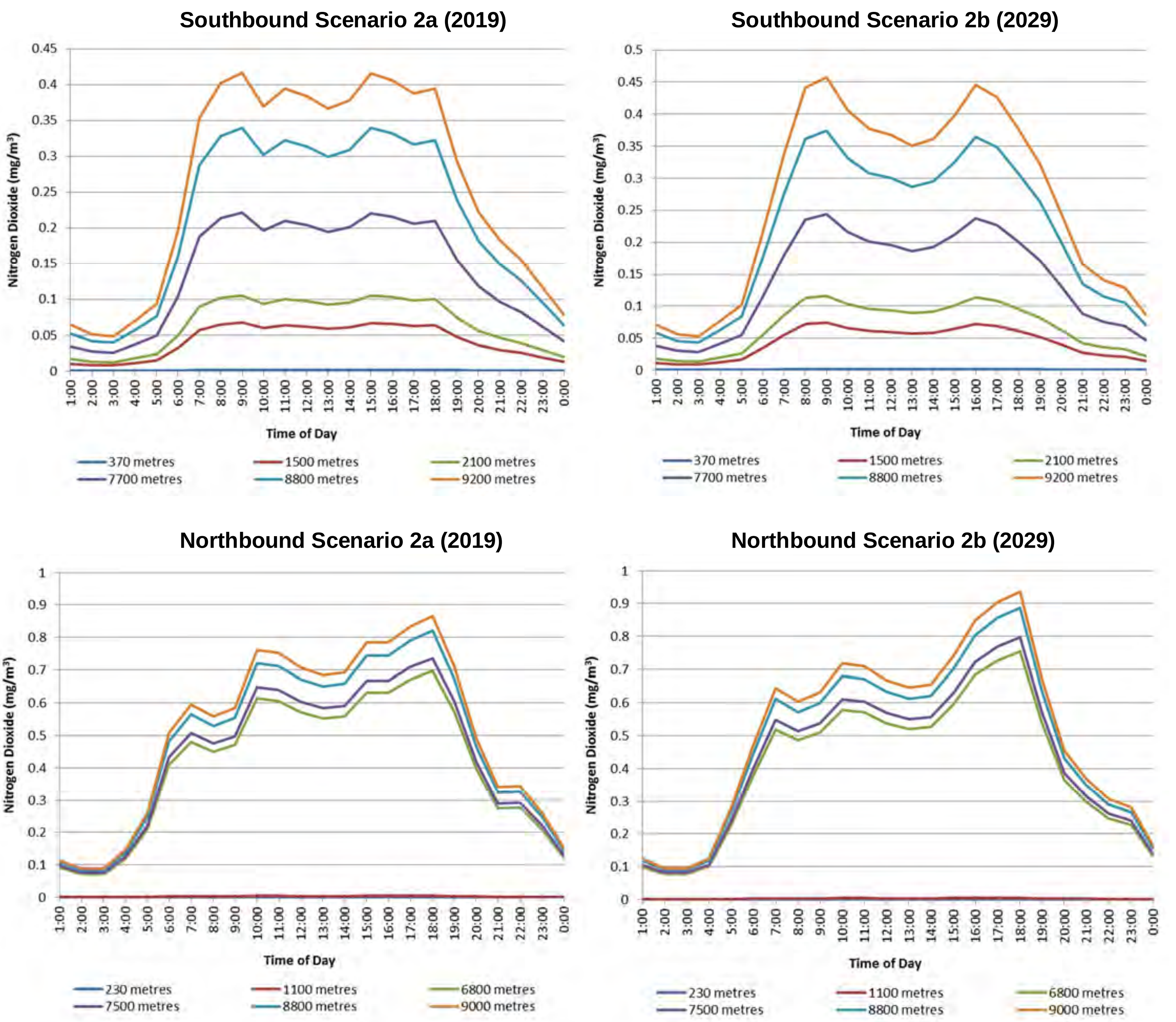


Figure 5-4: Predicted in-tunnel concentrations of Nitrogen Dioxide

Review of **Figure 5-4** indicates the following:

- The hourly concentrations predicted in the project tunnel are <0.1 mg/m^3 at the start of the tunnel increasing to levels of approximately 0.2 to 0.4 mg/m^3 towards the end of the southbound tunnel during the peak times and middle of the day and 0.4 to <1 mg/m^3 towards the end of the northbound tunnel during the peak times and middle of the day;
- Based on the maximum in-tunnel concentrations estimated, average exposure for a motorist using the southbound tunnel in peak periods[21] is estimated to be approximately 0.2 mg/m^3 for a duration of approximately six minutes with windows open and 0.06 mg/m^3 with windows closed and ventilation set to recirculation mode.
- Based on the maximum in-tunnel concentrations estimated, average exposure for a motorist using the northbound tunnel in peak periods is estimated to be approximately 0.5 mg/m^3 for a duration of approximately six minutes with windows open and 0.15 mg/m^3 with windows closed and ventilation set to recirculation mode.
- The NHMRC (2008) has published measured concentrations of nitrogen dioxide from a range of tunnels in Sydney and around the world. The measured concentrations come from a number of different studies where the averaging time for the collection of the data varies significantly. This makes it difficult to directly compare the range of reported concentrations with the concentrations predicted in this assessment (ie not comparing data reported over similar averaging/exposure periods). While noting this difficulty in comparing the data, the NHMRC (2008) have reported a range of average concentrations of nitrogen dioxide in tunnels that range from 0.09 to 0.5 mg/m^3 with levels up to 0.75 mg/m^3 reported during peak periods. These levels are based on data with averaging times that vary from 30 seconds during travel through a tunnel, six minute averages, to long term data with (unspecified averaging times). At the downstream end of a tunnel (where exposure is very short, ie minutes) levels up to 1.5 mg/m^3 have been reported.
- There are very few studies that have evaluated health effects associated with very short duration exposures to nitrogen dioxide. A study conducted in Stockholm (Svartengren et al. 2000) involved exposing 20 adults with mild asthma to air quality inside a car in a tunnel for 30 minutes, where levels of nitrogen dioxide ranged from 0.2 to 0.462 mg/m^3 (noting exposure to particulate matter and other pollutants inside the tunnel occurred at the same time). The study showed an increase in bronchial response to allergens several hours after exposure for individuals with allergic asthma. These results are similar to other studies where individuals with mild asthma were exposed to 0.5 mg/m^3 nitrogen dioxide for 30 minutes (Barck et al. 2002; Strand et al. 1998), a range of concentrations from 0 to 1 mg/m^3 for 30 minutes (Bylin et al. 1988) or for 15 minutes on one day and then repeated twice in the following day (Barck et al. 2005), followed by an allergen inhalation challenge. None of the available studies have considered individuals with moderate or severe asthma. The data suggest that exposure to elevated concentrations of nitrogen dioxide in a

[21] Refer to the technical working paper: air quality (AECOM, 2014) for more details in relation to concentrations estimated in the tunnel in peak periods (at each kilometre through the tunnel).

congested tunnel is associated with an increased risk of adverse effects for those with asthma (NHMRC 2008).

- There are no guidelines in Australia for levels of nitrogen dioxide in tunnels. Guidelines[22] for in-tunnel levels of nitrogen dioxide are available from Belgium (0.9 mg/m^3 for exposures <20 minutes), France (0.75 mg/m^3 for a 15 minute average exposure period), Norway (Norwegian Public Road Admiration (NPRA) guidelines of 1.4 mg/m^3 at the tunnel midpoint and 2.8 mg/m^3 at the tunnel ends, based on a 15-minute average) and Sweden (where the WHO guideline of 0.2 mg/m^3 for a 1-hour average exposure has been adopted). The PIARC has proposed a level of 1.9 mg/m^3 (as a threshold limit for healthy people). The average expected exposures in peak periods discussed above are lower than the available short term (15-minute to 20-minute average) guidelines.

[22] The guidelines are presented in ppmv by the referenced organisation. These concentrations have been converted to mg/m^3 for use in this report based on the molecular weight of the compound and standard temperature and pressure.

Fine Particulates ($PM_{2.5}$)

Figure 5-5 presents the predicted hourly concentration of $PM_{2.5}$ in the northbound and southbound tunnels at different distances from the start of the tunnel, for different times of the day, for scenario 2a (2019) and scenario 2b (2029). Given the key source of the particulates within the tunnel is from combustion emissions, the focus of this review is on fine particulates as $PM_{2.5}$.

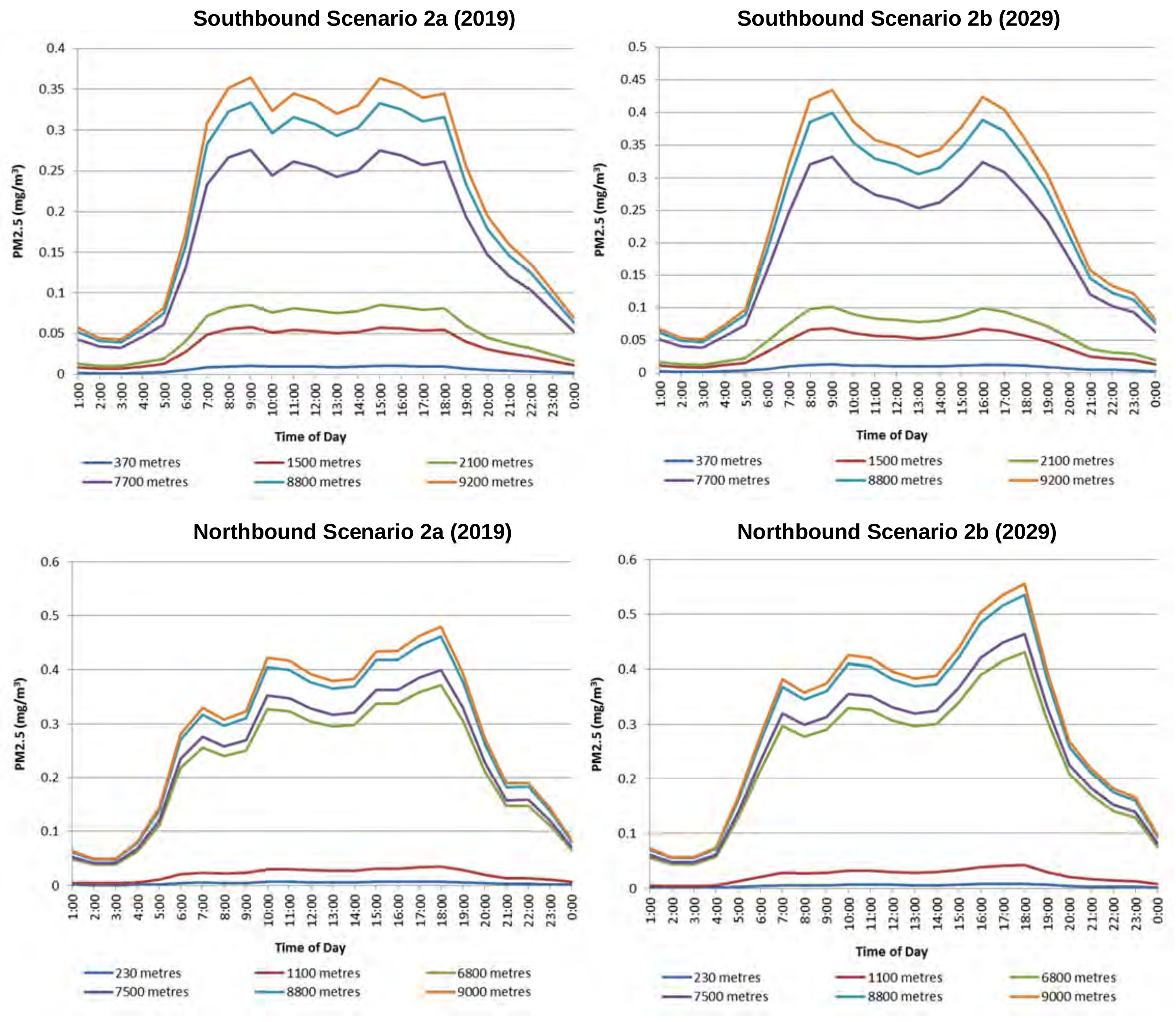


Figure 5-5: Predicted in-tunnel concentrations of fine particulates ($PM_{2.5}$)

Review of **Figure 5-5** indicates the following:

- The in-tunnel concentrations for the project have been estimated based on the predicted traffic volume using the tunnel and emission factors from PIARC. These emission factors (when compared with those published by the NSW Environment Protection Authority) are conservative particularly in relation to the assessment of particulate matter (PM_{10} and $PM_{2.5}$) (refer to technical working paper: air quality (AECOM, 2014)).
- The hourly concentrations predicted in the project tunnel are <0.1 mg/m^3 at the start of the tunnel increasing to levels of around 0.25 to 0.35 mg/m^3 towards the end of the southbound tunnel during the peak times and middle of the day and 0.25 to 0.55 mg/m^3 towards the end of the northbound tunnel during the peak times and middle of the day.
- Based on the maximum in-tunnel concentrations estimated, average exposure for a motorist using the southbound tunnel in peak periods[23] is estimated to be approximately 0.2 mg/m^3 for a duration of approximately six minutes with windows open and 0.04 mg/m^3 with windows closed and ventilation set to recirculation mode.
- Based on the maximum in-tunnel concentrations estimated, average exposure for a motorist using the northbound tunnel in peak periods is estimated to be approximately 0.3 mg/m^3 for a duration of approximately six minutes with windows open and 0.06 mg/m^3 with windows closed and ventilation set to recirculation mode.
- The NHMRC (2008) has published measured concentrations of particulates (as $PM_{2.5}$ and PM_{10}) from a range of tunnels in Sydney and around the world. The measured concentrations come from a number of different studies where the sampling methodology and averaging time for the collection of the data varies significantly. This makes it difficult to directly compare the range of reported concentrations with the concentrations predicted in this assessment (ie not comparing data reported over similar averaging/exposure periods). While noting this difficulty in comparing the data, the range of average concentrations of $PM_{2.5}$ reported typically range from around 0.03 to 0.343 mg/m^3 (AMOG 2012; NHMRC 2008). These levels are based on data with averaging times that vary from one hour averages, peak hour averages, daytime averages to 24-hour averages.
- The exposure-response relationships for particulate matter that have been established on the basis of adverse health effects from short-term exposures relate to changes in the health effects associated with variability in 24-hour average concentrations of $PM_{2.5}$ in urban air. They do not relate to much shorter variations in $PM_{2.5}$ exposure that may occur within a 24-hour period, where there may be exposures over a few minutes to higher levels of $PM_{2.5}$. No guidelines are currently available for assessing potential health effects that may occur as a result of exposures to particulates that may occur for minutes (or even an hour).
- Recent review (WHO 2013a) of available studies in relation to short-duration (less than 24-hour) exposures to particulates indicates the following:
    - Epidemiological and clinical studies have demonstrated that sub-daily exposures to elevated levels of particulate matter can lead to adverse physiological changes in the

[23] Refer to the technical working paper: air quality (AECOM, 2014) for more details in relation to concentrations estimated in the tunnel in peak periods (at each kilometre through the tunnel).

respiratory and cardiovascular system, in particular exacerbation of existing disease. This is generally consistent with the outcome of studies reviewed and considered by the USEPA (USEPA 2009b).

  - The studies available do not cover a range of exposure concentrations, nor do they adequately address other variables such as co-pollutants (gases) or repeated short-duration exposures.
  - The studies have not determined if a 1 hour exposure would lead to a different response than a similar dose spread over 24-hours, or if an exposure-response can be determined.
  - Exposures that occur during the use of various transportation methods (such as in-vehicles) have been found to contribute to and affect 24-hour personal exposures.

The urban epidemiology studies (upon which exposure-response relationships are based and have been used in this assessment) utilise health data for adverse health effects from an urban population, where the urban population will have been exposed to ambient levels of particulate matter (as measured by air monitoring stations) as well as fluctuations that occur throughout the day during various daily activities including in-vehicle exposures (and others such as cooking). These large urban studies have related health effects to regional ambient (urban) air concentrations. They have not measured daily (or longer term) personal exposures to particulate matter, but such fluctuations would occur within the population exposed and would be expected to be accounted for within the health data considered in the epidemiology studies. Specific health effects from the short duration variations in particulate exposures throughout any specific day cannot be determined from these studies. It is therefore important to consider if exposures to $PM_{2.5}$ in the project tunnel would be consistent with other tunnels or in-vehicle exposures (during commuting in an urban environment).

- Exposure to particulate matter within vehicles varies with the intensity of the traffic, the age of the vehicle the choice of ventilation used within the vehicle and the type of fuel used (Knibbs, de Dear & Morawska 2010). Levels of $PM_{2.5}$ reported in vehicles in Europe (ETC 2013) vary from 0.022 to 0.085 mg/m^3 for passenger cars and 0.026 to 0.13 mg/m^3 for bus travel.
- Levels of $PM_{2.5}$ that have been measured within cars while commuting in Sydney (where tunnel travel was not part of the study) range from 0.009 to 0.045 mg/m^3 (NSW Health 2004).
- Keeping windows closed and switching ventilation to recirculation has been shown to reduce exposures inside the vehicle by up to 80 per cent (NSW Health 2003). While noting no guidelines are availability for very short duration exposures, this would further reduce exposure to motorists.

Polycyclic aromatic hydrocarbons

- The hourly concentrations of total polycyclic aromatic hydrocarbons predicted in the project tunnel are <0.00001 mg/m^3 at the start of the tunnel increasing to levels of approximately 0.00007 mg/m^3 towards the end of the southbound tunnel during the peak times and middle of the day and 0.0001 mg/m^3 towards the end of the northbound tunnel during the peak times and middle of the day;

- Based on the maximum in-tunnel concentrations estimated, average exposure for a motorist using the southbound tunnel in peak periods is estimated to be approximately 0.00003 mg/m^3 for total polycyclic aromatic hydrocarbons and 0.3 ng/m^3 for carcinogenic polycyclic aromatic hydrocarbons (as a BaP TEQ where speciated as outlined in **Section 0**) for a duration of approximately six minutes with windows open (lower with the windows closed and on recirculation).
- Based on the maximum in-tunnel concentrations estimated, average exposure for a motorist using the northbound tunnel in peak periods is estimated to be approximately 0.00016 mg/m^3 for total polycyclic aromatic hydrocarbons and 1.4 ng/m^3 for carcinogenic polycyclic aromatic hydrocarbons (as a BaP TEQ where speciated as outlined in **Section 0**) for a duration of approximately six minutes with windows open (lower with the windows closed and on recirculation).
- While difficult to directly compare due to a wide range of averaging times for the different studies (varying from hours to 24-hour averages), the concentrations of carcinogenic polycyclic aromatic hydrocarbons in other tunnels (in Sydney and around the world) have been reported to range from 0.9 to 11.8 ng/m^3 (NHMRC 2008).
- There are no short-term peak guidelines for exposure to polycyclic aromatic hydrocarbons (as the health effects associated with these compounds relates to chorionic exposures only) that would be relevant for assessing the very short duration of time likely to be spent within the tunnel. However it is noted that the calculated incremental carcinogenic risks for a very short duration exposure (of minutes) to carcinogenic PAHs at the maximum levels reported would be less than $1x10^{-6}$ and would be considered to be negligible.

Volatile organic compounds

- The hourly concentrations of total volatile organic compounds predicted in the project tunnel are <0.1 mg/m^3 at the start of the tunnel increasing to levels of approximately 0.38 mg/m^3 towards the end of the southbound tunnel during the peak times and middle of the day and 0.7 mg/m^3 towards the end of the northbound tunnel during the peak times and middle of the day;
- Based on the maximum in-tunnel concentrations estimated for total volatile organic compounds, average exposure for a motorist using the southbound tunnel in peak periods[24] is estimated to be approximately 0.2 mg/m^3 for a duration of approximately six minutes with windows open and 0.1 mg/m^3 with windows closed and ventilation set to recirculation mode.
- Based on the maximum in-tunnel concentrations estimated for total volatile organic compounds, average exposure for a motorist using the northbound tunnel in peak periods is estimated to be approximately 0.4 mg/m^3 for a duration of approximately six minutes with windows open and 0.2 mg/m^3 with windows closed and ventilation set to recirculation mode.
- The peak period exposure concentrations for the total volatile organic compound concentrations are higher than assessed previously in relation to acute exposures (refer to **Section 4.2**). Utilising the approach adopted for speciating individual VOCs (as outlined in

[24] Refer to the technical working paper: air quality (AECOM, 2014) for more details in relation to concentrations estimated in the tunnel in peak periods (at each kilometre through the tunnel).

Section 4.2), assuming windows are down, taking into account a 6 minute exposure period (compared with 60 minute average guidelines) and the acute (60 minute, or hourly average) health based criteria presented in **Table 4-6**, all potential exposure concentrations of individual volatile organic compounds (and all compounds together) are below the acute guidelines. Hence no adverse health effects are expected for the short duration of exposure to volatile organic compounds in the tunnel.

- Where speciated out to individual VOCs (as per **Section 4.2**) the maximum hourly average peak period exposure concentration (windows down) of benzene is estimated to be 0.01 mg/m^3, toluene is estimated to be 0.02 mg/m^3 and formaldehyde is estimated to be 0.02 mg/m^3.
- The average concentrations reported in other tunnels in Sydney and around the world for benzene, toluene and formaldehyde (NHMRC 2008) range from:
  - For benzene - 0.008 to 0.33 mg/m^3.
  - For toluene - 0.03 to 0.63 mg/m^3
  - For formaldehyde - 0.013 to 0.056 mg/m^3.

  The reported levels vary based on differing averaging times (varying from hours to 24-hour averages) and sample locations in the tunnels (NHMRC 2008).
- The concentrations predicted are also consistent with (and slightly lower than) the levels measured within cars (NSW Health 2004) (during commuting in Sydney, where tunnel travel was not part of the study) for benzene (mean ranged from 0.04 to 0.07 mg/m^3) and toluene (mean ranged from 0.1 to 0.2 mg/m^3). Hence exposure to these VOCs during use of the tunnel is not expected to be different to the exposure that would occur within a car during normal commuting within Sydney.

Overall Assessment

In-tunnel concentrations have been estimated based on the predicted traffic volume using the tunnel and emission factors from PIARC. These emission factors (when compared with those published by the NSW Environment Protection Authority) are conservative particularly in relation to the assessment of particulate matter (PM_{10} and $PM_{2.5}$).

The duration of exposure to vehicle emissions within the project tunnel is limited (minutes, rather than hours, only) and where guidelines are available for short duration exposures in tunnels, the likely exposure concentrations (representative of the average concentrations from start to end) are generally within or below these guidelines. Short-duration exposure guidelines are not available for nitrogen dioxide or particulate matter (assessed as $PM_{2.5}$). In relation to nitrogen dioxide exposures studies are available that suggest in situations of congested traffic (including delayed traffic in a tunnel) there is an increased risk of adverse health effects amongst individuals with asthma. Particulate matter exposures within the tunnel are estimated to be similar to those expected within other vehicle tunnels, are of limited duration (minutes) and are consistent with expected variability of exposure to $PM_{2.5}$ throughout any day where a range of activities are undertaken.

For regular users of tunnels in Sydney, and regular commuters in heavy traffic, repeated short duration exposures to elevated concentrations of pollutants from vehicle emissions would contribute to a higher level of overall (daily) exposure and may be associated with increased risks for asthmatics. Drivers who regularly use tunnels or drive in congested traffic in Sydney can minimise exposure to vehicle emissions by keeping windows up and air conditioning on recirculation when in tunnels or heavy traffic conditions. Keeping windows closed and switching ventilation to recirculation has been shown to reduce exposures inside the vehicle by up to 80 per cent.

5.6.2 Impact of project on asthma

A common concern in relation to exposure to particulate matter relates to the potential for impacts on children with asthma. The available studies that have evaluated the potential impact of exposure to particulate matter with asthma indicators (hospital visits and medication use) are more limited, and considered to be less robust (showing less statistical significance); however they have shown the presence of potential adverse effects (and relationship) for particulates, particularly $PM_{2.5}$ in the range 9.7 µg/m^3 to 30 µg/m^3 (USEPA 2012).

Background $PM_{2.5}$ concentrations exceed the current levels of $PM_{2.5}$ in ambient air in Sydney, and exceed the predicted cumulative (background plus incremental) concentrations of $PM_{2.5}$ for this project. Hence any use of relationships established for levels of exposure in excess of what is being considered in this assessment should be done with caution. Due to this limitation, along with the issue that much of the necessary baseline data is limited in availability, the outcomes of any assessment of particulate matter exposures and asthma are only considered to be qualitative.

Review by the WHO in the report "Effects of Air Pollution on Children's Health and Development" (WHO 2005b) concluded that the evidence on asthma and air pollution is sufficient to suggest a causal link between air pollution, in particular where living in proximity to traffic, and aggravation of asthma. One way of measuring aggravation of asthma is through the monitoring the use of bronchodilators (also known as asthma relievers).

The most of the available studies in relation to increased medication use for these relievers and exposure to particulate matter relate to PM_{10}. This is mainly due to the nature of the available studies where coarse particulate matter levels were measured in air rather than the finer $PM_{2.5}$. In this study it is recognised that most of the PM_{10} impacts predicted comprise significant levels of $PM_{2.5}$ due to the source being vehicle emissions.

Review of available data by the WHO (Anderson et al. 2004), as summarised for Europe (EC 2011) identified relative risk of a 0.4 per cent (95 per cent confidence interval:-1.7 per cent to 2.6 per cent) increase in bronchodilator days per 10 µg/m^3 increase in PM_{10} for children aged 5 – 15 years. Based on this study a β coefficient of 0.0004 can be determined and applied for the age group 5 – 14 years considered in this assessment (age group where data on asthma use and population are available). This relationship was established following analysis of data from studies conducted in Europe, including panel studies of children with existing asthma symptoms.

To calculate the change in annual incidence, or change in use of medication each year for the population of concern in this assessment, additional information is required as follows:

- Changes in concentration of PM_{10} (annual average):
    - The assessment presented has considered the impact of the ventilation facilities alone as well as the project as a whole (where changes in exposures occur as a result of the ventilation facilities as well as the change in use of Pennant Hills Road).

- For this assessment the change in PM_{10} concentration, as a population weighted change in concentration, in the suburbs of West Pennant Hills (southern end) and Wahroonga (northern end) has been considered.
- The change in PM_{10} population weighted concentration (maximum change for the years 2019 and 2029) for these suburbs is as follows:
    - West Pennant Hills = 0.02 µg/m^3 for the southern ventilation facility alone
      = - 0.04 µg/m^3 (ie decreased concentration) for the whole project
    - Wahroonga = 0.03 µg/m^3 for the northern ventilation facility alone
      = - 0.02 µg/m^3 (ie decreased concentration) for the whole project

- Population exposed: It is assumed that the number of children currently with asthma is 15.4 per cent of the total population of children. The per cent of children with asthma is based on the NSW rate of current asthma reported by NSW Health[25] for children aged 2 – 15 years for 2012. This rate has been adopted for assessing children aged 5 – 14 years.
- It is too conservative to assume that 100 per cent of the children aged 5 – 14 years in the whole of the Hornsby South statistical area is present at the location of maximum incremental PM_{10} impacts. For this calculation the number of children aged 5 – 14 years present in West Pennant Hills (2103 children) and Wahroonga (2462 children) have been considered. If 15.4 per cent of the children in these areas have asthma, this results in 324 children in West Pennant Hills and 379 children in Wahroonga with asthma.
- Based on data from Australia (assumed to be relevant to Northern Sydney) for 2002 – 2004, the rate of daily use of reliever medications by children aged 5 – 14 years was 7.2 per cent (ACAM 2007). This incidence is multiplied by 365 to obtain the annual incidence of asthma medication use, ie 0.072 x 365 = 26.28.
- Based on the above the number of additional days per year of bronchodilator use by children associated with the incremental PM_{10} concentration predicted is calculated to be:
    - West Pennant Hills, additional days of bronchodilator use
      = 0.07 days per year for southern ventilation facilities only
      = - 0.1 days per year for whole project – ie a decrease in number of days per year.

    - Wahroonga, additional days of bronchodilator use
      = 0.1 days per year for northern ventilation facilities only
      = -0.08 days per year for whole project – ie a decrease in number of days per year.

Where the project is considered as a whole an overall decrease in the number of days of bronchodilator use by young children is predicted. It is noted that the estimated change in bronchodilator is very low and would not be measurable within the local community.

[25] NSW Health Statistics for current asthma in children aged 2-15 years. The rate for NSW of 15.4 per cent is equivalent to that reported for Northern Sydney (15.3 per cent). Data available from http://www.healthstats.nsw.gov.au/

5.7 Uncertainties

5.7.1 Particulate concentrations

The modelling of particulate impacts involves the use of a number of assumptions in relation to the operation of the project and activities that result in the emission of dust to air. In addition the determining the dispersion of particulate matter from the ventilation facility outlets to the surrounding environment has utilised air dispersion models. While the approach adopted in the AQIA utilised published peer-reviewed emission estimation techniques, the currently available site-specific data on the operation of the project, site-specific meteorology and terrain data and approved models for the quantification of impacts in the surrounding areas, the overall approach adopted is generally conservative to ensure that where uncertainties are present, the impact is overestimated.

5.7.2 Assessment of the effects of exposure to particulate matter

The available scientific information provides a sufficient basis for determining that exposure to particulate matter (particularly $PM_{2.5}$ and smaller) is associated with adverse health effects in a population. The data is insufficient to provide a thorough understanding of all of the potential toxic properties of particulates to which humans may be exposed. Over time it is expected that many of the current uncertainties will be refined with the collection of additional data, however some uncertainty will be inherent in any estimate. The influence of the uncertainties may be either positive or negative.

Overall, however, the epidemiological and toxicological data on which the assessment presented in this technical working paper are based on current and robust for the assessment of risks to human health associated with the potential exposure to particulate matter from combustion sources. When drawing conclusions in relation to the assessment presented, the following also need to be considered.

Exposure-response function

The choice of exposure-response functions for the quantification of potential health impacts is important. For mortality health endpoints, many of the exposure-mortality functions have been replicated throughout the world. While many of these have shown consistent outcomes, the calculated relative risk estimates for these studies do vary. This is illustrated by **Figure 5-6** to **Figure 5-8** that show the variability in the relative risk estimates calculated in published studies for the US (and Canadian) population that are relevant to the primary health endpoints considered in this assessment (USEPA 2012). A similar variability is observed where additional studies from Europe, Asia and Australia/New Zealand are considered.

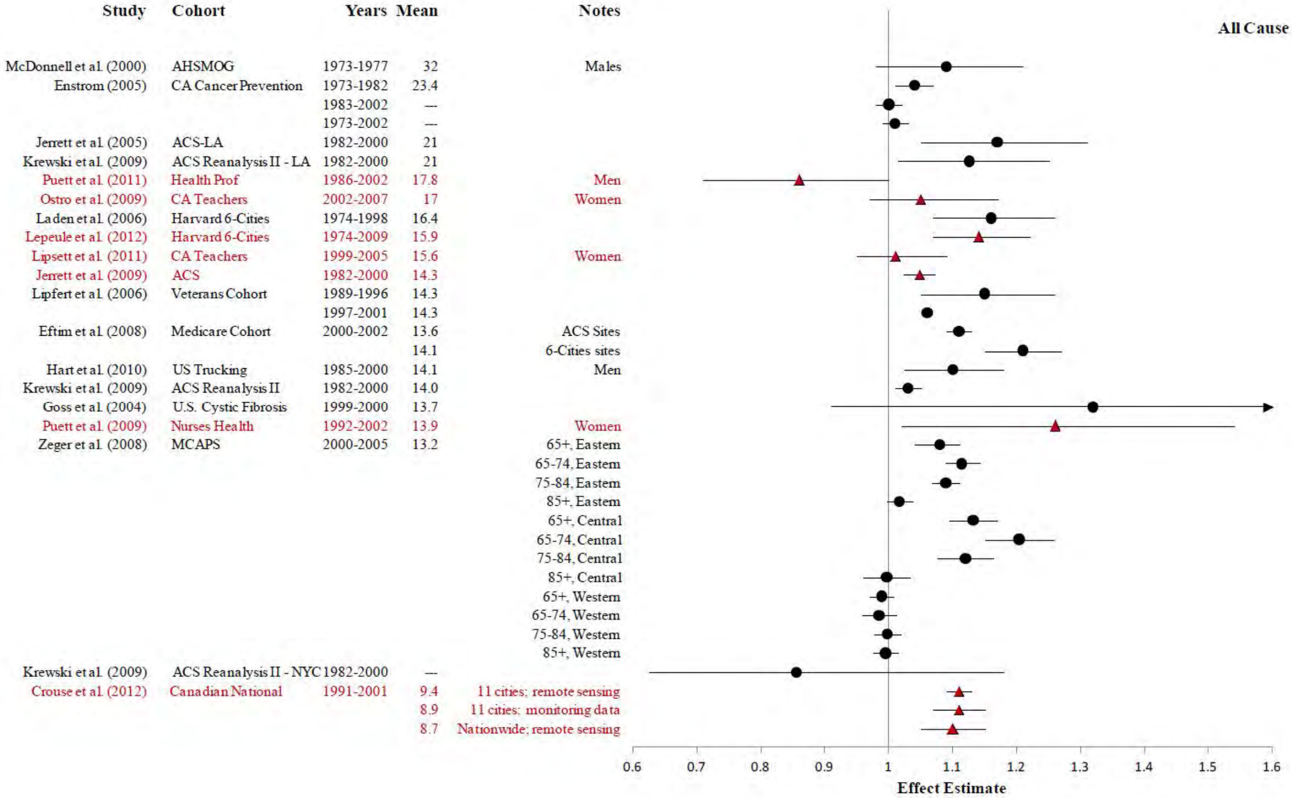


Figure 5-6 All-cause mortality relative risk estimates for long-term exposure to $PM_{2.5}$ (USEPA 2012, note studies in red are those completed since 2009)

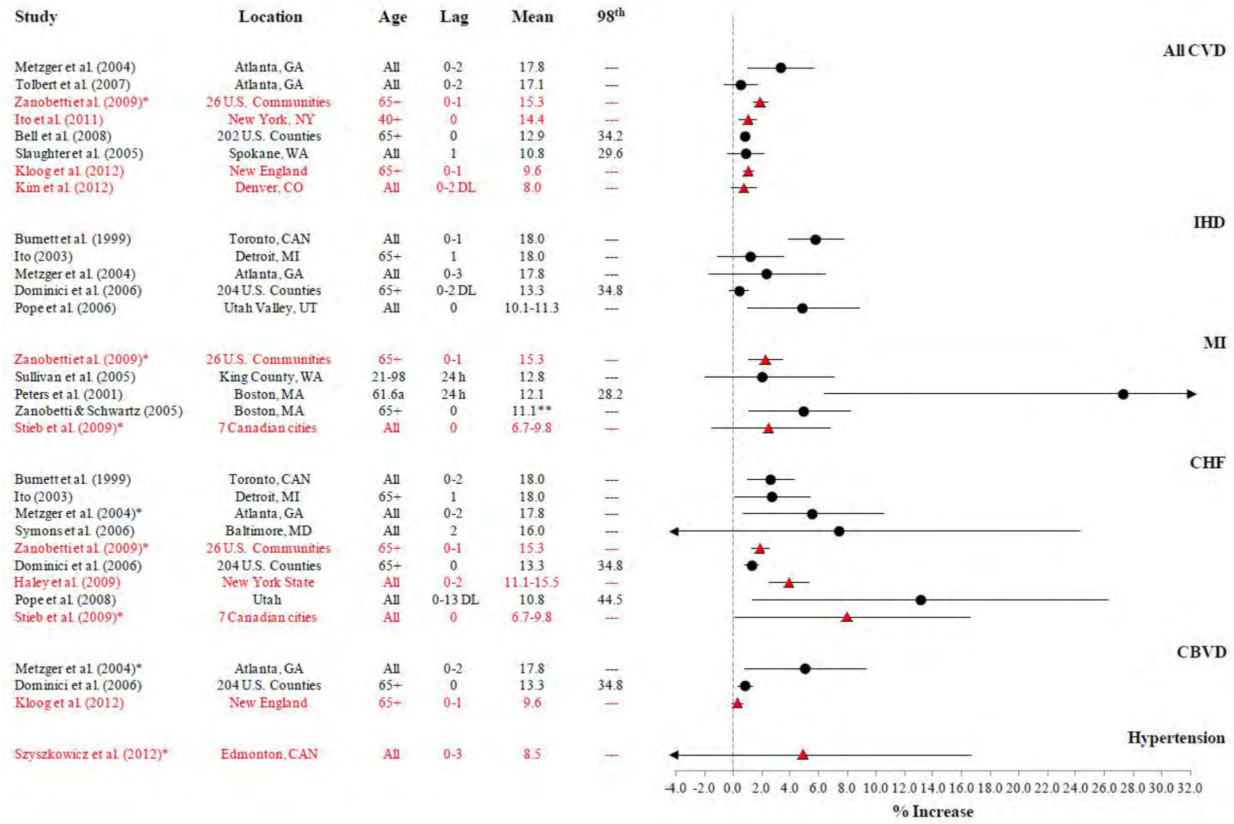


Figure 5-7 Per cent increase in cardiovascular-related hospital admissions for a 10 µg/m^3 increase in short-term (24-hour average) exposure to $PM_{2.5}$ (USEPA 2012, note studies in red are those completed since 2009)

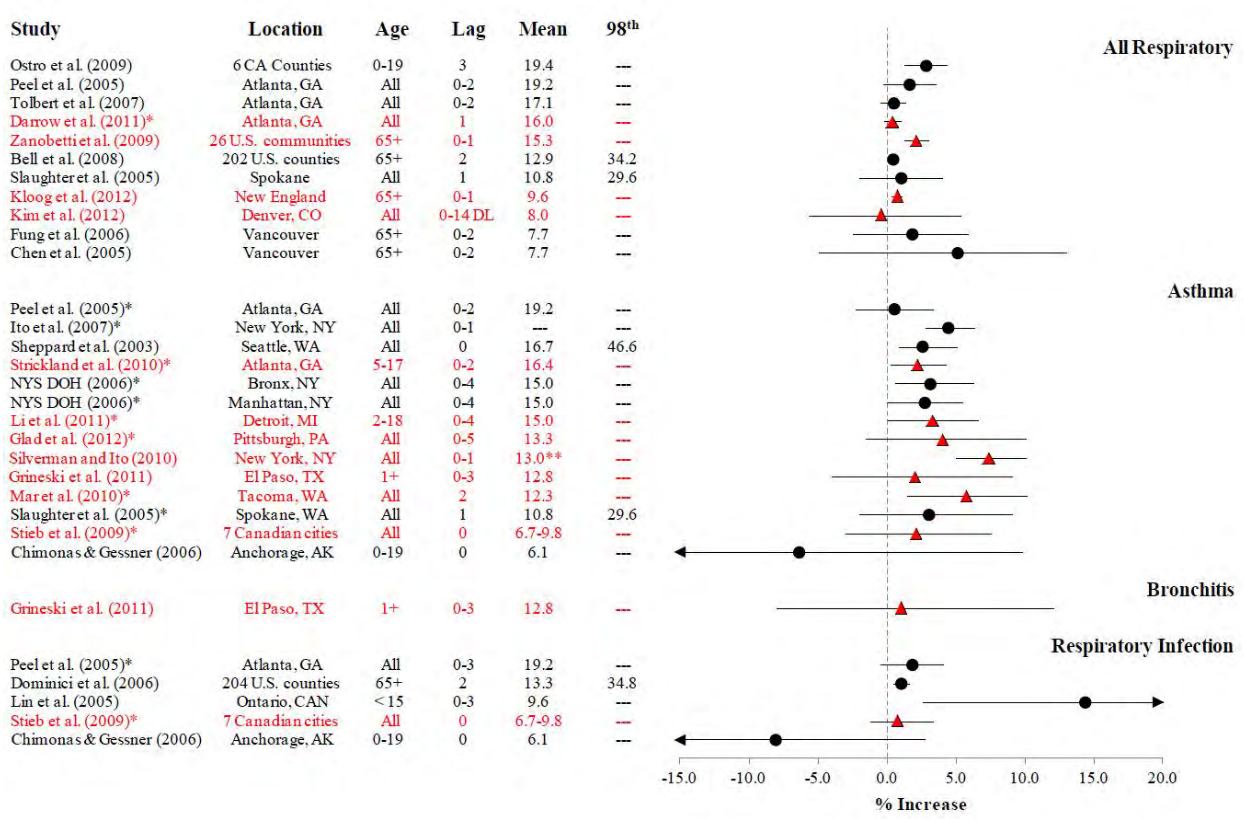


Figure 5-8 Per cent increase in respiratory-related hospital admissions for a 10 µg/m^3 increase in short-term (24-hour average) exposure to $PM_{2.5}$ (USEPA 2012, note studies in red are those completed since 2009)

The above figures illustrate the variability inherent in the studies used to estimate exposure-response functions. The variability is expected to reflect the local and regional variability in the characteristics of particulate matter to which the population is exposed.

Based on the available data, and the detailed reviews undertaken by organisations such as the USEPA (USEPA 2010, 2012) and WHO (WHO 2003, 2006b, 2006a) and discussions with NSW Health, the adopted exposure-response estimates are considered to be current, robust and relevant to the characterisation of impacts form PM.

Shape of exposure-response function

The shape of the exposure-response function and whether there is a threshold for some of the effects endpoints remains an uncertainty. Reviews of the currently available data (that includes studies that show effects at low concentrations) have not shown evidence of a threshold. However, as these conclusions are based on epidemiological studies, discerning the characteristics of the particulates responsible for these effects and the observed shape of the dose-response relationship is complex. For example, it is not possible to determine if the observed no threshold response is relevant to exposure to particulates from all sources, or whether it relates to particulates from combustion sources only. Most studies have demonstrated that there is a linear relationship between relative risk and ambient concentration however for long-term exposure-related mortality a log-linear relationship is more plausible and should be considered where there is the potential for exposure to very high concentrations of pollution. In this assessment the impact considered is a localised impact with low level incremental increases in concentration. At low levels the assumption of a linear relationship is considered appropriate.

Co-pollutants

It is likely that some of the health effects observed relate to both particulate matter and other related/correlated pollutants. Many of the pollutants evaluated come from a common source (eg fuel combustion) hence the use of only particulate matter as an index for the mix of pollutants is reasonable but conservative, particularly where there are multiple sources, or the scenario being evaluated is not from a source type that is likely to have dominated the studies underlying the relative risk values used in the risk assessment.

Selected health outcomes

The assessment of risk has utilised exposure-response functions and relative risk values that relate to the more significant health endpoints where the most significant and robust positive associations have been identified. The approach does not include all possible subsets of effects that have been considered in various published studies. However, the assessment undertaken has considered the health endpoints/outcomes that incorporate many of the subsets, and has utilised the most current and robust relationships.

Application of exposure-response functions to small populations

The exposure-response functions have been developed on the basis of epidemiological studies from large urban populations where associations have been determined between health effects (health endpoints) and changes in ambient (regional) particulate levels. Typically these exposure response functions are applied to large populations for the purpose of establishing/reviewing air guidelines or reviewing potential impacts of regional air quality issues on large populations. When applied to small populations (less than larger urban centres such as the whole of greater Sydney) the uncertainty increases.

In addition it is noted that the exposure-response functions relate changes in health endpoints with changes in regional air quality measurements. They do not relate to specific local sources (which occur within a regional airshed), or daily variability in exposure that may occur as a result of various different activities that may occur in any one day.

Diesel particulate matter evaluation

The health hazard conclusions associated with exposure to diesel particulate matter are based on studies that are dominated by exhaust emissions from diesel engines built prior to the mid-1990s. With current engine use including some new and many older engines (engines typically stay in service for a long time), the health hazard conclusions, in general, are likely to be applicable to engines currently in use. However as new and cleaner diesel engines, together with different diesel fuels, replace a substantial number of existing engines; the general applicability of the health hazard conclusions may require further evaluation. The NEPC (NEPC 2009) has established a program to reduce diesel emissions from the Australian heavy vehicle fleet. This is expected to lower the potential for all diesel emissions over time.

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Section 6. Review of noise and vibration impacts

6.1 Overview of the noise and vibration assessment

6.1.1 General

This section presents a summary of the technical working paper: noise and vibration (AECOM, 2014) (NVTP) that relates to construction and operational impacts for noise and vibration associated with the project. The assessment has been reviewed to determine if the predicted impacts have the potential to affect the health of the surrounding community, and if impacts are predicted, if they can be effectively mitigated.

The NVTP provides a more detailed evaluation of all the activities, and the duration of those activities, associated with construction and operation of the proposed tunnel that may give rise to noise or vibration impacts in the surrounding community.

In general the existing noise environment in the areas surrounding the project is dominated by existing road traffic noise. To undertake the noise assessment required for the project, the existing background noise quality is required as the guidelines that relate to noise impacts from a specific project are based on levels allowable above background (refer to **Section 6.1.2** for further detail). Background noise levels were measured at 23 locations throughout the study area. The measured noise levels were used with consideration of the existing road traffic flows to calibrate the operational noise model and also to establish construction noise management levels relevant for the project.

Noise levels that are measured, or modelled, refer to noise levels over a specified period of time and are presented as L_{A1}, L_{A10}, L_{A90}, L_{Amax} and L_{Aeq} levels of the noise environment. The L_{A1}, L_{A10} and L_{A90} levels are the levels exceeded for one percent, 10 per cent and 90 per cent of the sample period respectively. The L_{Amax} is indicative of maximum noise levels due to individual noise events. The L_{A90} is taken as the rating background noise level (RBL). The L_{Aeq} is the energy averaged noise level over a defined period.

The background noise levels in each of the 23 monitoring locations varies, depending on the location of each of these relative to existing noise sources (in particular major roadways). Background noise levels were established for the day (7am to 6pm, varying from 41 to 59 dB(A)), evening (6pm to 10pm, varying from 38 to 54 dB(A)) and night-time (10pm to 7am, varying from 30 to 45 dB(A)) periods (as $L_{A90,\ 15\ minute}$).

6.1.2 Noise assessment criteria

Noise issues in NSW are managed by the NSW Environment Protection Authority. They have prepared a number of guidance documents with regard to the types of noise that are considered in relation to construction and operation of the project. The NSW Industrial Noise Policy (Environment Protection Authority, 2000), the NSW Road Noise Policy (RNP) (Department of Environment, Climate Change and Water, 2011), and the Interim Construction Noise Guideline (ICNG) (Department of Environment and Climate Change, 2009) are all relevant to the assessment of noise generated by this project. In all these policies there is discussion of the need to balance the economic and social benefits of activities that may generate noise with the protection of the community from the adverse effects of noise. The noise assessment criteria adopted relate to levels of noise that can be tolerated or permitted above background before some adverse effect (annoyance, discomfort, sleep disturbance or complaints) occurs.

For the assessment of noise impacts from the project a range of guidelines and criteria have been adopted:

Construction noise

General

The ICNG has been adopted for the assessment of noise during construction works. In relation to these guidelines, noise impacts from the project are predicted at sensitive receivers and compared with the criteria, referred to as management levels, outlined in the ICNG. Where an exceedance occurs the guidelines advises that the proponent apply all feasible and reasonable work practices to minimise impacts. The management levels are based on levels of noise above background that may result in reactions (or complaints) by the community. The levels are based on some reaction (noise affected) and a strong reaction (highly noise affected).

Levels of noise allowable outside standard work hours, particularly at night, are lower. The ICNG recommended that where construction works are planned to extend over more than two consecutive nights a sleep disturbance assessment is required to be undertaken. Based on the available information on the levels of noise that result in sleep disturbance, a maximum internal noise level below 50-55 dB(A) is considered unlikely to cause awakening. The project has considered that a closed window provides up to 10 dB(A) attenuation of noise, and hence an upper limit of outside noise of 65 dB(A) has been adopted for the assessment of sleep disturbance.

The assessment of noise impacts during construction has been undertaken based on 16 noise catchment areas (assumed to have background noise levels consistent with the background noise monitoring location within that catchment area)

Ground-borne noise

Noise from activities such as tunnelling are assessed on the basis of criteria outlined in the ICNG for the day-time and night-time. These criteria are based on amenity and sleep disturbance when people are at home.

Vibration criteria

Guidelines for vibration from construction activities that are based on structural damage and human comfort (as tactile vibration or regenerated noise) have been adopted in the assessment. The structural damage guidelines adopted are the German Standard DIN 4150 (as there are no Australian Standards available).

In relation to human comfort, intermittent vibration has been evaluated on the basis of the Environment Protection Authority guideline Assessing Vibration: A Technical Guideline (Department of Environment and Conservation, 2006), which is based on vibration dose values (VDV). The criteria for VDV are based on the potential for annoyance (based on the level of vibration over the assessment period). Guidelines for continuous and impulsive vibration are dependent on the time of day and the activity taking place. The criteria established for these vibration types are based on the potential for adverse comment (complaint) and disturbance to building occupants.

Blasting

Construction blasting has been assessed for air blast and ground vibration, which have the potential to result in discomfort as well as damage to structure and services. Guidelines adopted for the assessment of these effects are from ANZECC and Australian Standards. The ANZECC guidelines are based on minimising annoyance and discomfort to persons at sensitive locations caused by blasting. The guidelines also have recommendations that can be implemented to minimise impacts of blasting at sensitive receivers. The guidelines presented in the Australian Standards are consistent with those presented in the ANZECC guidelines but also specifically address structural damage issues.

Blasting activities, if required, will only occur underground and are proposed to be managed such that the criteria are not exceeded.

Operational Noise

Operational noise impacts have been evaluated on the basis of the EPA's RNP, with additional guidance and criteria provided within Roads and Maritime's Environmental Noise Management Manual (ENMM) (Roads and Traffic Authority, 2001). This requires consideration of the following:

- Whether the road is in a new or existing road corridor.
- Whether the receivers have an existing road traffic noise exposure. A receiver is subject to existing road traffic noise exposure if the existing noise levels exceed a daytime $L_{Aeq(15hour)}$ of 55 dB(A) or a night-time $L_{Aeq(9hour)}$ of 50 dB(A).
- Whether the road would introduce road traffic noise from a new direction compared with the existing road traffic noise exposure.

The road noise considered in the assessment has considered receivers along the Hill M2 Motorway, M1 Pacific Highway, Pacific Highway and Pennant Hills Road as receivers subject to existing road noise. The operation of the tunnel itself, while it is a new road, would have the road noise attenuated by the tunnel. Receivers adjacent to the southern and northern portals are located within the existing road corridor.

Within the RNP, the criteria have been developed to provide protection inside and immediately around permanent residences and at schools, hospitals and other sensitive land uses close to roads. The criteria are based on a level where 90 per cent of residents should not be highly annoyed by the noise from traffic.

In addition to the RNP criteria, the ENMM identifies a category of highly affected noise sensitive receivers, which are termed as 'acute' receivers. Where receivers experience noise levels that would be greater than or equal to $L_{Aeq(15hour)}$ 65 dB(A) and $L_{Aeq(9hour)}$ of 60 dB(A) as a result of existing or future road traffic noise, they would be classified as 'acute'. In these instances, noise mitigation in accordance with practice note IV of the ENMM would be necessary.

In addition guidelines are available for assessing noise impacts from fixed facilities (that would include the ventilation facilities at the southern and northern interchanges) that are based on the following:

- To assess the potential for disturbance (referred to as an intrusive criterion). This criteria is based on existing noise levels measured as RBL ($L_{A90,\ 15\text{-minute}}$, dB(A)) at sensitive receivers (adjusted to account for potentially annoying noise characteristics). This criterion applies to the assessment of residential areas only; and
- To manage noise amenity relevant to specific land uses (referred to as an amenity criterion). This criterion is designed to preserve noise amenity of the land use and protect against noise impacts such as community annoyance and speech interference. The criterion is based on existing ambient and background noise levels ($L_{Aeq,\ 15\text{-minute}}$) at receivers not affected by industrial noise. This criterion applies to all land uses considered in the assessment.

6.2 Impacts during construction

6.2.1 Noise impacts

Noise during construction has focused on the following key works:

- Hills M2 integration works.
- Main tunnel alignment works.
- Development of the southern interchange and northern interchange.
- Works inside ancillary construction compounds, ranging from site establishment to the construction of permanent operational ancillary facilities, where relevant.

During standard working hours the assessment has identified a number of sensitive receivers in the community adjacent to the southern interchange and the Hills M2 Motorway integration works, northern interchange and M1 Pacific Highway tie-in works where the Noise Management Limits (NMLs) are exceeded with a smaller number of receivers identified as highly affected noise receivers. During some activities receivers adjacent to the Wilson Road compound, Trelawney Street compound, northern interchange compound, Bareena Avenue compound and the Pioneer Avenue compound also exceed the NMLs with some considered to be highly noise affected.

Out of hours works have also been evaluated with a number of sensitive receivers located in the community surrounding the southern interchange and the Hills M2 Motorway integration works, southern interchange compound, Wilson Road compound, Trelawney Street compound and northern interchange compound where the Noise Management Limits (NMLs) are exceeded. A small number of receivers have been identified as highly noise affected along the Hills M2 Motorway integration works.

A number of sensitive receivers have been identified where ground-borne noise levels exceed the adopted criterion during the evening and night-time.

A number of sensitive receivers have been identified in areas surrounding the M2 Hills Motorway integration works (bridgeworks), southern interchange compound, Wilson Road compound, Trelawney Street compound and Northern interchange compound where the criteria for sleep disturbance is exceeded.

Review of the impact of construction road traffic on noise levels has identified that the predicted increased during the morning and afternoon peak periods (less than 2 dB) meets the recommended noise goal. Exceedances of the recommended noise goal have been predicted during night-time periods, and the use of local roads by heavy vehicles during night-time periods would be reviewed during construction planning.

As a result of the assessment undertaken for noise during construction works, specific mitigation should be proposed for each construction activity where required before construction begins in the form of a Construction Noise and Vibration Management Plan. The Construction Noise and Vibration Management Plan will also need to consider any cumulative noise impacts in the surrounding community from other major works being undertaken in the area, including the Epping to Thornleigh Third Track and the North West Rail Link. Details of the Construction Noise and Vibration Management Plan (addressing management and mitigation measures as well as requirements for noise monitoring) are outlined in the NVTP.

The issues associated with construction fatigue for receivers located adjacent to the M2 Hills Motorway (where major construction works have only just been completed) were identified and these issues would be required to be managed through community consultation.

6.2.2 Vibration impacts

A range of management measures have been identified to monitor and manage vibration impacts associated with surface works. During tunnelling operations a number of sensitive receivers were identified where the night-time vibration criteria (preferred criteria based on human comfort [not structural damage]) were exceeded. No predicted vibration levels exceeded the maximum criteria for these works which are related to structural damage.

Impacts associated with vibration are to be addressed, mitigated or managed, using measured to be outlined in the Construction Noise and Vibration Management Plan.

6.3 Noise impacts during operation

In relation to noise impacts from the operation of the project the assessment identified the following:

- Southern interchange and Hills M2 Motorway integration:
  - Noise impacts have been identified at a number of sensitive receiver locations associated with road traffic noise.
  - During the design year (Year 2029), a total of 134 receivers exceed the $L_{Aeq(15hour)}$ daytime noise criteria of 60 dB(A). A total of 264 receivers exceed the $L_{Aeq(9hour)}$ noise criteria of 55 dB(A) during the night-time period.
  - Of these sensitive receivers, 47 receivers would be eligible for consideration for noise mitigation. Of the 47 receivers, 46 receivers have been identified as acute. However, these receivers would be considered to be acute in the absence of the project. Additional noise mitigation is also identified for Early Childhood Intervention Australia in North Rocks.
  - For this project, all road design and traffic management options have been considered. A low-noise pavement in the form of stone-mastic asphalt has been included in the design. Noise barriers already partially line both sides of the Hills M2 Motorway corridor. Further mitigation in the form of increased height noise barriers and architectural treatment on individual homes is recommended to achieve compliance with the applicable noise goals. A list of properties that require additional architectural treatment (such as upgraded windows and doors) is provided in the technical working paper.

- Northern interchange:
  - Noise impacts have been identified at a number of receiver locations associated with road traffic noise.
  - During the design year (Year 2029), a total of 106 receivers exceed the $L_{Aeq(15hour)}$ daytime noise criteria of 60 dB(A). A total of 184 receivers exceed the $L_{Aeq(9hour)}$ noise criteria of 55 dB(A) during the night-time period.
  - Of these sensitive receivers, 82 receivers would be eligible for consideration for noise mitigation. Of the 82 receivers, 69 receivers have been identified as acute. The majority of these receivers would be identified as acute in the absence of the project. Additional noise mitigation is also identified for St Pauls Church on Pearces Corner, Wahroonga.
  - For this project, all road design and traffic management options have been explored. Low-noise pavements have been included in the design. Noise barriers already line both sides of the M1 Pacific Motorway road corridor. Further mitigation in the form of increased height noise barriers and architectural treatment on individual homes is recommended to achieve compliance with the applicable noise goals. A list of properties that require additional architectural treatment (such as upgraded windows and doors) is provided in the technical working paper.

6.4 Health outcomes relevant to noise

Environmental noise has been identified (I-INCE 2011; WHO 2011) as a growing concern in the growth of urban areas because it has negative effects on quality of life and well-being and it has the potential for causing harmful physiological health effects. With increasingly urbanised societies impacts of noise have the potential to increase within the community.

Deciding on the most effective noise management option in a specific situation is not just a matter of defining noise control actions to achieve the lowest noise levels or meeting arbitrarily chosen criteria for exposure to noise. The goal should be to achieve the best available compromise between the benefits to society of reduced exposure to community noise versus the costs and technical feasibility of achieving the desired exposure levels. On the one hand there are the rights of the community to enjoy an acceptably quiet and healthy environment. On the other are the needs of the society for a new or upgraded facilities, industries, roads, recreation opportunities, etc, all of which typically produce more community noise (I-INCE 2011; WHO 2011).

Sound is a natural phenomenon that only becomes noise when it has some undesirable effect on people or animals. Unlike chemical pollution, noise energy does not accumulate either in the body or in the environment but it can have both short-term and long-term adverse effects on people. These health effects include (WHO 1999, 2011):

- Sleep disturbance.
- Annoyance.
- Hearing impairment.
- Interference with speech and other daily activities.
- Children's school performance (through effects on memory and concentration).
- Cardiovascular health.

Other effects for which evidence of health impacts exists, but for which the evidence is weaker, include:

- Effects on mental health (usually in the form of exacerbation of existing issues for vulnerable populations rather than direct effects).
- Effects on the performance of cognitive tasks.
- Some evidence of indirect effects such as impacts on the immune system.

Often, annoyance is the major consideration because it reflects the community's dislike of noise and their concerns about the full range of potential negative effects.

There are many possible reasons for noise annoyance in different situations. Noise can interfere with speech communication or other desired activities. Noise can contribute to sleep disturbance, which can obviously be very annoying and has the potential to lead to long-term health effects. Sometimes noise is just perceived as being inappropriate in a particular setting without there being any objectively measurable effect at all. In this respect, the context in which sound becomes noise can be more important than the sound level itself.

Different individuals have different sensitivities to different types of noise and this reflects differences in expectations and attitudes more than it reflects any differences in underlying auditory physiology. A noise level that is perceived as reasonable by one person in one context (for example in their kitchen when preparing a meal) may be considered completely unacceptable by that same person in another context (for example in their bedroom when they are trying to sleep). In this case the annoyance relates, in part, to the intrusion from the noise. Similarly a noise level, which is considered to be completely unacceptable by one person, may be of little consequence to another even if they are in essentially the same room. In this case the annoyance depends almost entirely on the personal preferences, lifestyles and attitudes of the listeners concerned.

It is against this background that regulators in various communities have established sound level criteria above which noise is deemed to be unacceptable and below which it is deemed to be acceptable. Any assessment of noise impacts needs to consider the relevant criteria established for a new or existing (or upgraded) facility or activity. Where there are impacts in excess of these guidelines an assessment of noise mitigation is required to be undertaken.

In relation to the project, potential noise impacts have been assessed against Australian (more specifically New South Wales) criteria that have been established on the basis of the relationship between noise and health impacts. The criteria developed for use in the assessment for control of noise come from policy documents developed by the NSW Government including the NSW Industrial Noise Policy, the NSW Interim Construction Noise Policy, and the NSW Road Noise Policy. All of these policies are based on the health effects of noise, and are based on guidance and reviews published in the following:

- World Health Organisation- Guidelines on Community Noise – Health effects of noise (WHO 1999).
- World Health Organisation – Night Noise Guidelines for Europe (WHO 2009).
- Environmental Health Council of Australia - The health effects of environmental noise – other than hearing loss (enHealth 2004).

Various attempts have been made to assess the effect (measured by average reported annoyance, sleep disturbance or a similar type of effect) from community noise (measured by long term average sound levels) to develop exposure-response relationships. As individual reactions to noise are so varied, these studies need large sample sizes to obtain reasonable correlation between the noise exposure and the response. Any dose-response relationship determined from large studies over a range of communities and cultures will not necessarily represent the reaction of individuals or small communities. These exposure-response relationships are of value for macro-scale (ie whole urban environment scale) strategic assessment purposes where individual differences are not important, however they are not useful when considering potential impacts to a small population located close to a specific project/activity. Hence these macro-scale relationships cannot be applied (in any meaningful way) in this assessment.

As guidelines/criteria are available for construction and operational noise impacts associated with this project, that are based on the protection of health (including annoyance), the assessment of potential health impacts has focused on whether the guidelines/criteria established can be met. Noise levels that do not comply with these guidelines/criteria would have the potential to have negative health outcomes for the community adjacent to the Hills M2 Motorway integration works, southern interchange and northern interchange.

Currently, the worst case assessment predicts that noise criteria would be exceeded at a number of properties in these areas without additional noise mitigation measures.

Construction

During construction it is important that proposed measures for mitigation, management and monitoring be included and detailed in the Construction Noise and Vibration Management Plan. Measures that have been recommended to mitigate the construction noise impact at adjacent sensitive receivers include:

- Completion of a construction noise and vibration management plan
- Community consultation
- Appropriate selection and maintenance of equipment
- Use of noise barriers
- Scheduling of work for less sensitive time periods
- Situating plant in less noise sensitive locations
- Training of construction site workers
- Construction traffic management
- Noise monitoring
- Respite offers, and
- Alternative accommodation.

Feasible and reasonable mitigation measures would be detailed within the construction noise and vibration management plan to manage predicted noise levels at sensitive receivers. Consultation with the affected community would also occur prior to and during construction

Operations

During operation of the project within much of the community surrounding the project, predicted noise impacts meet the criteria established that are based on the protection of health. There are some properties where additional mitigation measures (that include the use of low noise road pavement, replacement and improvement of noise barriers and implementation of architectural treatments on individual homes) are required to ensure that noise impacts are reduced where feasible and reasonable to meet the established criteria/guidelines. The recommended mitigation measures would ensure that the levels of road traffic noise experienced by residents would be reduced as low as is feasible and reasonable. The requirements and the form of noise mitigation would be confirmed when assessed against the detailed design.

For a number of individual properties architectural treatment has been identified to mitigate noise impacts indoors, so that the noise criteria can be met. While these mitigation measures are required to ensure that the environment where people spend most of the day is not associated with adverse health impacts it does assume that residents take up these measures and where they do, they keep external windows and doors shut and have minimal use of outdoor areas.

In urban areas particularly where noise is dominated by road traffic noise, access to outdoor green-space areas that are not (perceived to be) impacted by noise (eg where there is a quiet side of a specific property or there is access to a quiet green space areas close to the residential home) have been found to significantly affect well-being and lower levels of stress (Gidlöf-Gunnarsson &

Öhrström 2007). Impacts on the use and enjoyment of outdoor areas due to increased noise may result in increased levels of stress at individual properties.

Where specific residents/properties do not take up the recommended architectural treatments to mitigate noise indoors there is the potential for noise levels at these properties to exceed the relevant guidelines/criteria. In these situations there is the potential for adverse health effects, particularly annoyance and sleep disturbance, to occur.

Community consultation will be an important part of the process in addressing noise impacts for the project as there are a number of individual homes where architectural treatment is required to enable the noise criteria to be met, and minimise the potential for adverse health effects associated with the project.

Section 7. Conclusions

An assessment of health impacts associated with emissions to air as well as noise and vibration resulting from the construction and operation of the project has been undertaken.

In relation to impacts to air quality, potential health impacts have been evaluated on the basis of appropriate health based guidelines (that are protective of public health), or, in the case of exposure to $PM_{2.5}$ and PM_{10} conducting a detailed assessment of the impact of the emissions on key community health indicators. All predicted concentrations of carbon monoxide, nitrogen dioxide, key individual volatile organic compounds and polycyclic aromatic hydrocarbons are below health based guidelines. For the assessment of potential impacts of $PM_{2.5}$ and PM_{10} from the operation of the tunnel, potential health impacts are low and essentially negligible in proximity to the ventilation outlets. Overall, taking a significant number of vehicles, in particular trucks off the existing road corridor along Pennant Hills Road, and managing emissions via the tunnel ventilation system, would lead to a net benefit to health within the community.

In relation to noise and vibration, potential impacts during construction and operation have been considered. During construction potential impacts of noise and vibration on the local community can be managed and/or mitigated through the implementation of a range of measures. For construction noise and vibration, these management and mitigation measures (including the requirement for noise monitoring) are to be outlined in detail within the Construction Noise and Vibration Management Plan.

During operation of the project a number of individual homes located adjacent to the northern interchange as well as the southern interchange and the Hills M2 Motorway integration works where noise impacts, in excess of the health based guidelines adopted, have been identified. The recommended mitigation measures would ensure that the levels of road traffic noise experienced by residents would be reduced as low as feasible and reasonable. The requirements and the form of operational noise mitigation would be confirmed when assessed against the detailed design. This would include consideration of the feasibility of noise barriers with consideration to engineering considerations, and the outcomes of consultation with the affected community

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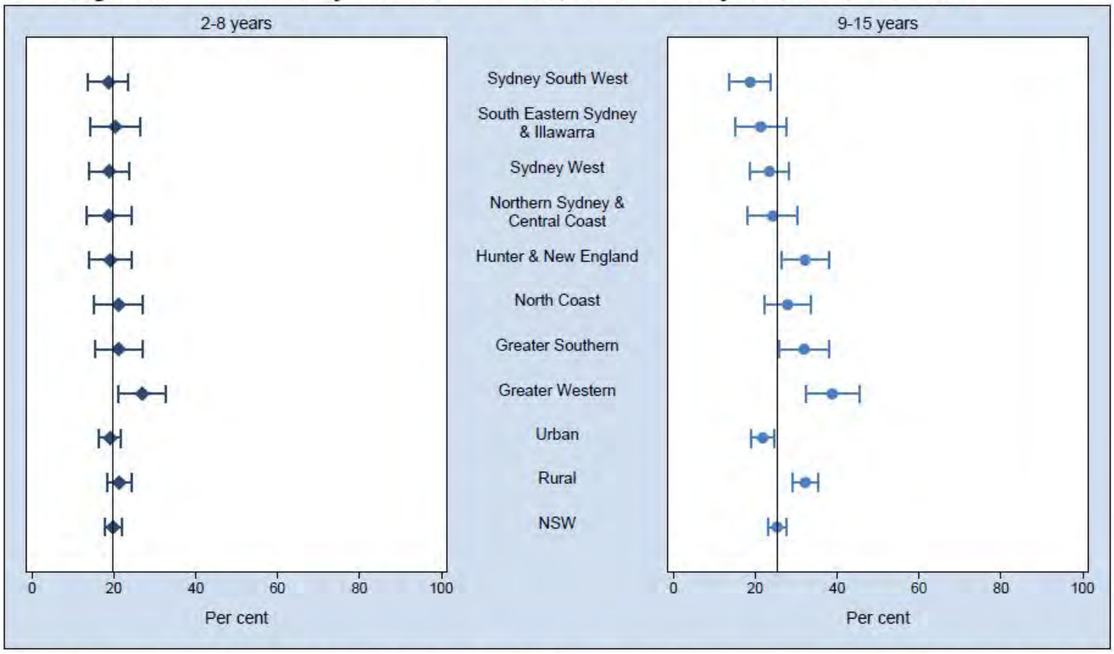
Appendix A Summary of existing asthma health statistics

A1 Asthma in children

The following graphs are reproduced from the NSW Population Health Survey, 2006 – 2006 Report on child health published by NSW Health (2008).

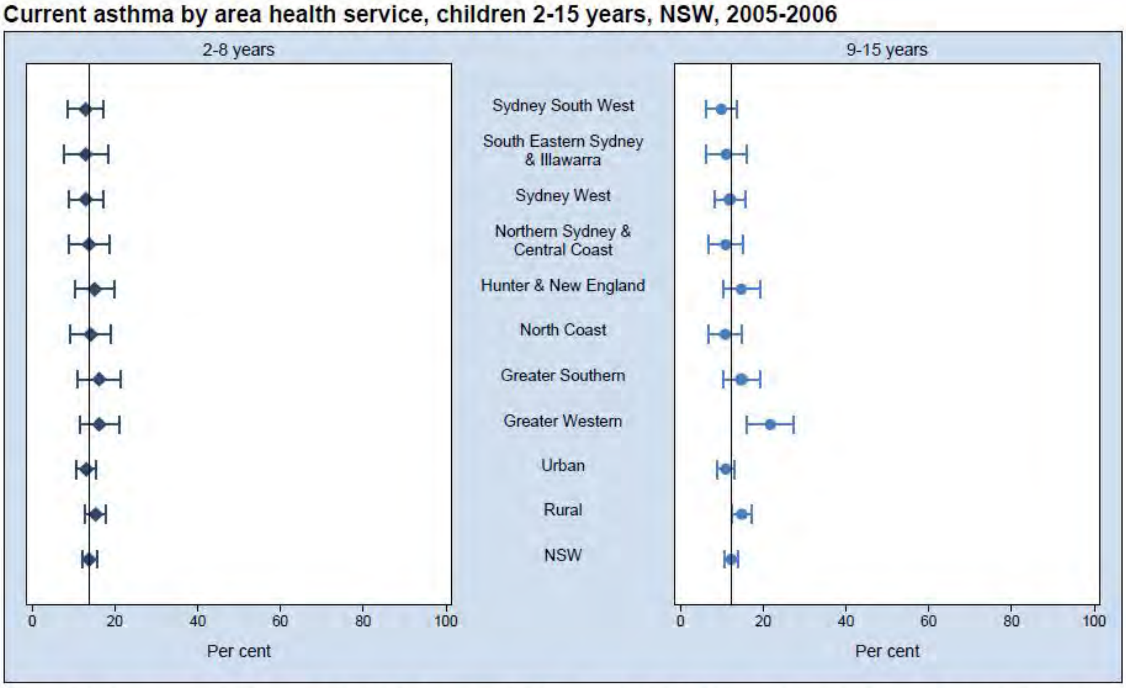
Ever diagnosed with asthma by area health service, children 2-15 years, NSW, 2005-2006



Note: Estimates are based on 3,938 respondents in NSW. For this indicator 11 (0.28%) were not stated (Don't know or Refused) in NSW. The indicator includes those children who have ever been told by a doctor or hospital that they have asthma. The question used to define the indicator was: Has child ever been told by a doctor or hospital heor she has asthma?

Source: New South Wales Population Health Survey 2006 (HOIST). Centre for Epidemiology and Research, NSW Department of Health.

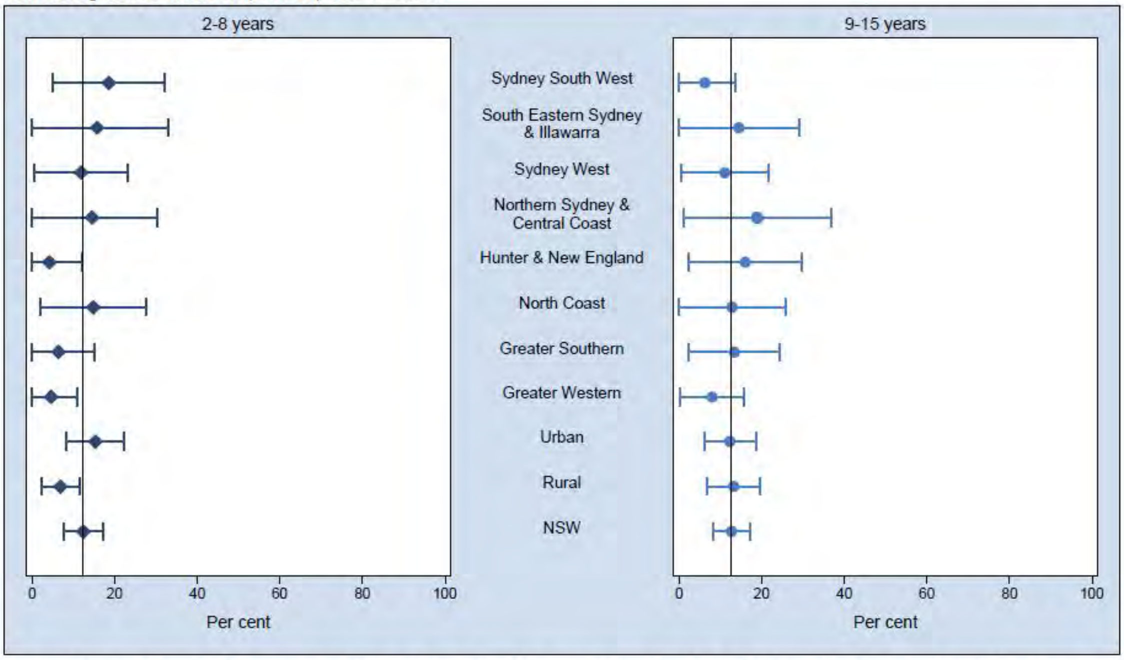
Current asthma by area health service, children 2-15 years, NSW, 2005-2006



Note: Estimates are based on 3,937 respondents in NSW. For this indicator 12 (0.30%) were not stated (Don't know or Refused) in NSW. The indicator includes those children with symptoms of asthma or who had treatment for asthma in the last 12 months. The questions used to define the indicator were: Has child ever been told by a doctor or hospital he or she has asthma? Has child had symptoms of asthma or treatment for asthma in the last 12 months?

Source: New South Wales Population Health Survey 2006 (HOIST). Centre for Epidemiology and Research, NSW Department of Health.

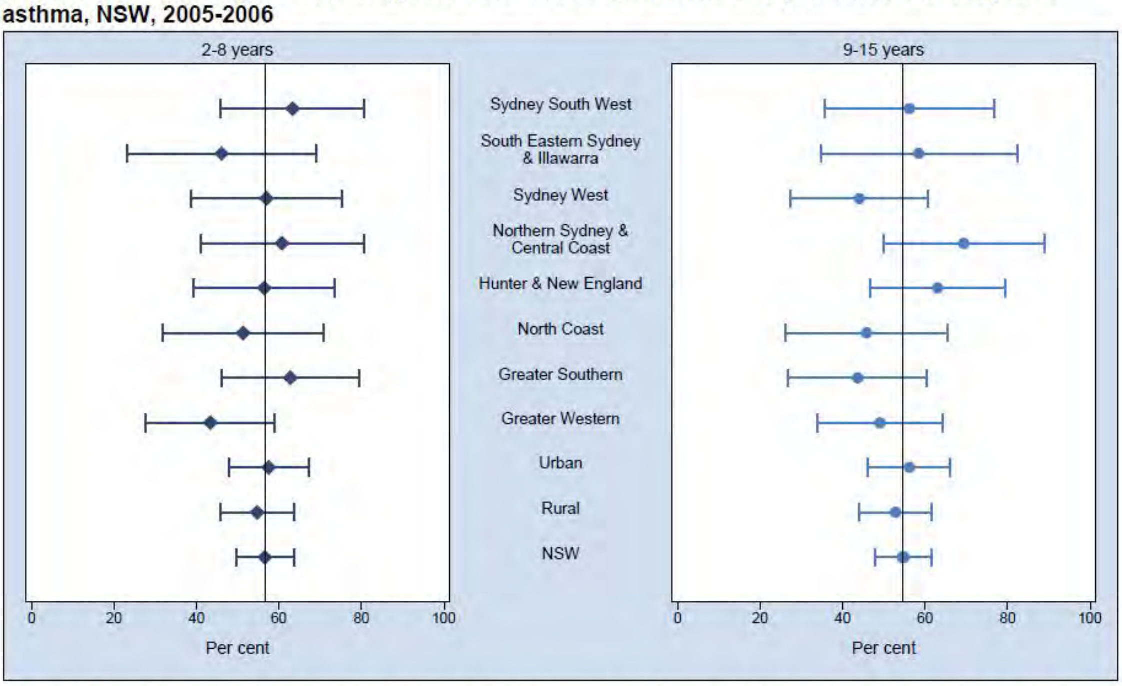
Moderate to extreme interference with daily activities by area health service, children 2-15 years who currently have asthma, NSW, 2005-2006



Note: Estimates are based on 536 respondents in NSW. For this indicator 3 (0.56%) were not stated (Don't know or Refused) in NSW. The indicator includes those children whose asthma interfered with their ability to manage day-to-day activities moderately, quite a lot, or extremely in the last 4 weeks. The questions used to define the indicator were: Have you ever been told by a doctor or hospital you have asthma? Have you had symptoms of asthma or taken treatment for asthma in the last 12 months? During the last 4 weeks, did your asthma interfere with your ability to manage your day to day activities? and Did it interfere with these activities: A little bit, Moderately, Quite a lot, or Extremely?

Source: New South Wales Population Health Survey 2006 (HOIST). Centre for Epidemiology and Research, NSW Department of Health.

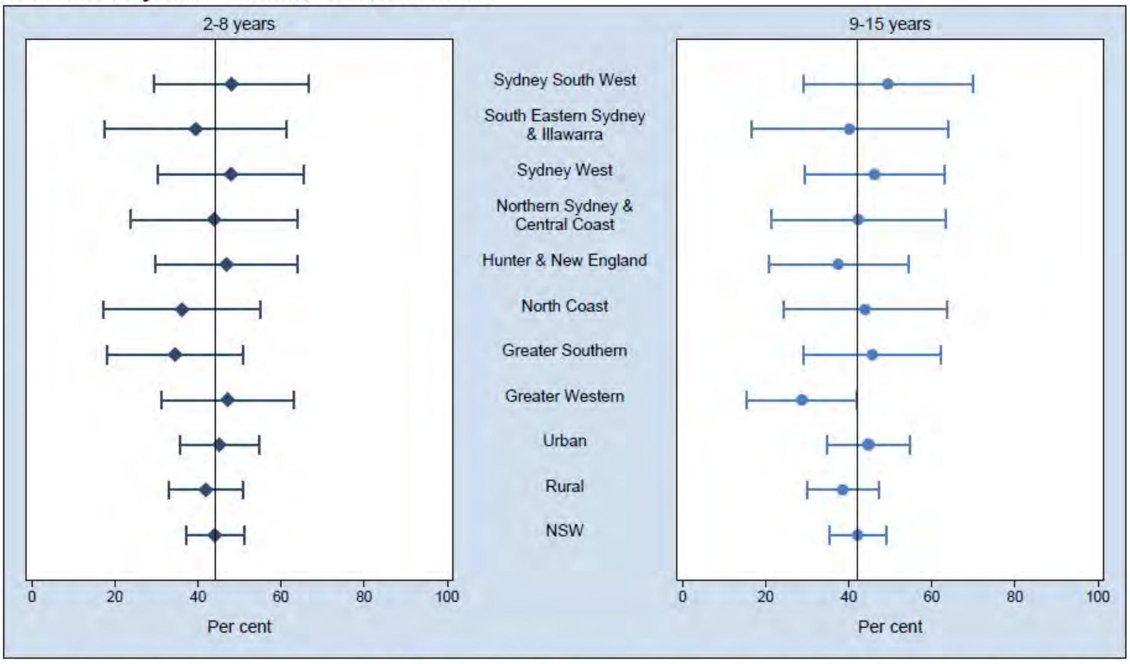
Written asthma management plan by area health service, children 2-15 years who currently have asthma, NSW, 2005-2006



Note: Estimates are based on 536 respondents in NSW. For this indicator 3 (0.56%) were not stated (Don't know or Refused) in NSW. The indicator includes those who have current asthma and who have a written asthma management plan. The questions used to define the indicator were: Has child ever been told by a doctor that he or she has asthma? Does child currently have asthma? Does child have a written asthma management plan from his or her doctor on how to treat their asthma?

Source: New South Wales Population Health Survey 2006 (HOIST). Centre for Epidemiology and Research, NSW Department of Health.

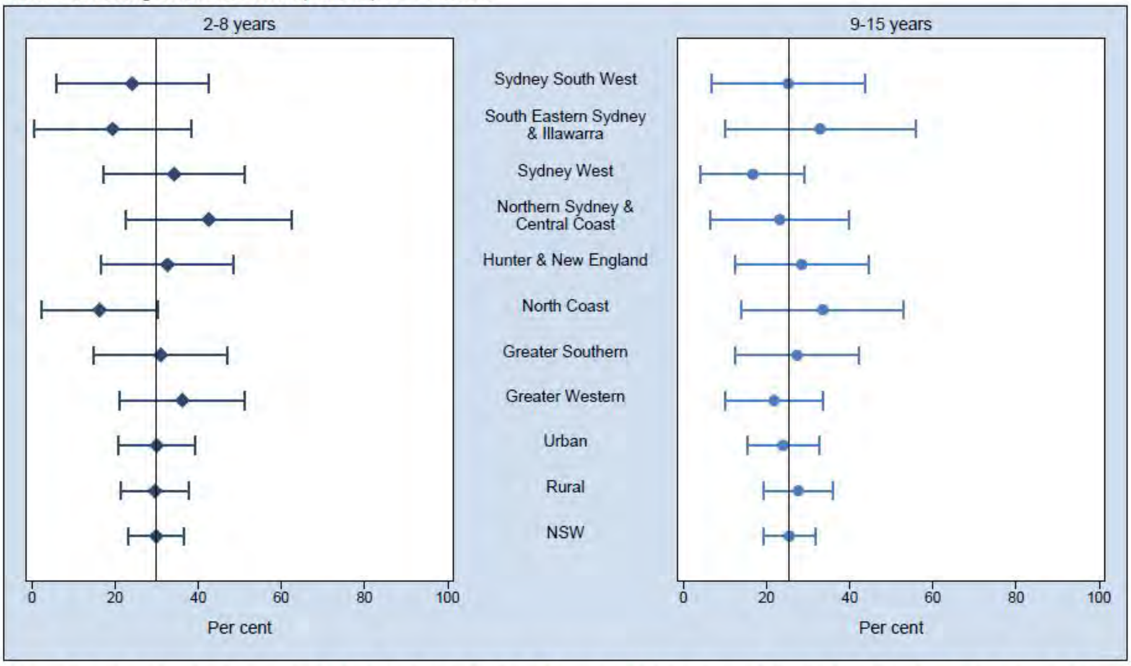
Asthma reliever medications used in the last 12 months by area health service, children 2-15 years who currently have asthma, NSW, 2005-2006



Note: Estimates are based on 544 respondents in NSW. For this indicator 12 (2.16%) were not stated (Don't know or Refused) in NSW. The indicator includes those who have used reliever medication for asthma in the last 12 months. The questions used to define the indicator were: Has child ever been told by a doctor or hospital he or she has asthma? Has child had symptoms of asthma or treatment for asthma in the last 12 months? What are the names or brands of all the medications child took for asthma in the last 12 months? Reliever medications include short-acting beta-agonists (Salbutamol, Ventolin, Asmol, Bricanyl, short-acting anti-cholinergics (Atrovent), combined inhaled steroid and long-acting beta agonists (Seretide and Symbicort), and long acting beta agonists (Symbicort and Seretide).

Source: New South Wales Population Health Survey 2006 (HOIST). Centre for Epidemiology and Research, NSW Department of Health.

Asthma preventer medications used in the last 12 months by area health service, children 2-15 years who currently have asthma, NSW, 2005-2006



Note: Estimates are based on 544 respondents in NSW. For this indicator 12 (2.16%) were not stated (Don't know or Refused) in NSW. The indicator includes those who have used preventer medication for asthma in the last 12 months. The questions used to define the indicator were: Has child ever been told by a doctor or hospital he or she has asthma? Has child had symptoms of asthma or treatment for asthma in the last 12 months? What are the names or brands of all the medications child took for asthma in the last 12 months? Preventer medications include combined inhaled steroids and long acting beta agonists (Seretide and Symbicort), inhaled corticosteroids (Pulmicort, Flixotide, Qvar; and Alvesco), leukotriene receptor antagonists (Singulair and Accolate), oral steroids (Prednisone), and cromones (Intal, Intal Forte, and Tilade).

Source: New South Wales Population Health Survey 2006 (HOIST). Centre for Epidemiology and Research, NSW Department of Health.

Appendix B $PM_{2.5}$ and PM_{10} calculations for primary and secondary health indicators

Quantification of Effects - PM2.5 and PM10, Scenario 2a 2019
Southern Interchange

Particulate Fraction:	**PM2.5**	**PM2.5**	**PM2.5**	**PM10**	**PM2.5**	**PM2.5**	**PM2.5**	**PM2.5**	**Incremental Risk - DPM**
Endpoint:	**Mortality - All Causes**	**Hospitalisations - Cardiovascular**	**Hospitalisations - Respiratory**	**Mortality - All Causes**	**Mortality - All Causes**	**Mortality - Cardiopulmonary**	**Mortality - Cardiovascular**	**Mortality - Respiratory**	
Effect Exposure Duration:	Long-term	Short-term	Short-term	Short-Term	Short-Term	Long-term	Short-Term	Short-Term	(based on WHO)
Age Group:	≥ 30 years	≥ 65 years	≥ 65 years	All ages	All ages	≥ 30 years	All ages	All ages	Unit Risk
β (change in effect per 1 μg/m³ PM) (as per Table 5-1)	0.0058	0.0008	0.00041	0.0006	0.00094	0.013	0.00097	0.0019	
Baseline Incidence (per 100,000) (as per Table 3-5)	1087	23352	8807	670	670	490	164	57	
Baseline Incidence (per person)	0.01087	0.23352	0.08807	0.0067	0.0067	0.0049	0.00164	0.00057	

Receptor		Increase in Annual Average PM10 Concentration (μg/m³)	Increase in Annual Average PM2.5 Concentration (μg/m³)	Risk (Equation 6)	Risk (Equation 6)	Risk (Equation 6)	Risk (Equation 6)	Risk (Equation 6)	Risk (Equation 6)	Risk (Equation 6)	Risk (Equation 6)	Risk
Maximum Receptor												
Southern Interchange		**0.11**	**0.11**	**6.8E-06**	**2.0E-05**	**3.9E-06**	**4.6E-07**	**6.8E-07**	**6.9E-06**	**1.7E-07**	**1.2E-07**	**3.7E-06**
Sensitive Receptors												
Carlingford												
Shine Preschool	Childcare	0.014	0.014	8.7E-07	2.6E-06	5.0E-07	5.8E-08	8.7E-08	8.8E-07	2.2E-08	1.5E-08	4.7E-07
Murray Farm Public School	Schools	0.014	0.014	8.6E-07	2.6E-06	5.0E-07	5.8E-08	8.6E-08	8.7E-07	2.2E-08	1.5E-08	4.7E-07
St Gerards Primary School	Schools	0.016	0.016	9.8E-07	2.9E-06	5.6E-07	6.5E-08	9.8E-08	9.9E-07	2.5E-08	1.7E-08	5.3E-07
Roselea Primary School	Schools	0.019	0.019	1.2E-06	3.5E-06	6.7E-07	7.8E-08	1.2E-07	1.2E-06	2.9E-08	2.0E-08	6.3E-07
Carlingford High School	Schools	0.019	0.019	1.2E-06	3.5E-06	6.7E-07	7.8E-08	1.2E-07	1.2E-06	2.9E-08	2.0E-08	6.3E-07
Colin Place Out of School Care	Schools	0.012	0.011	7.1E-07	2.1E-06	4.1E-07	4.7E-08	7.1E-08	7.2E-07	1.8E-08	1.2E-08	3.8E-07
Roselea Community Centre	Community	0.018	0.017	1.1E-06	3.3E-06	6.3E-07	7.3E-08	1.1E-07	1.1E-06	2.8E-08	1.9E-08	5.9E-07
Pennant Hills Golf Course	Community	0.029	0.027	1.7E-06	5.1E-06	9.9E-07	1.2E-07	1.7E-07	1.7E-06	4.3E-08	3.0E-08	9.3E-07
Average Residential	**includes max**	**0.028**	**0.027**	**1.7E-06**	**5.1E-06**	**9.8E-07**	**1.1E-07**	**1.7E-07**	**1.7E-06**	**4.3E-08**	**2.9E-08**	**9.2E-07**
West Pennant Hills												
Bird House Early Learning Centre	Childcare	0.010	0.010	6.3E-07	1.9E-06	3.6E-07	4.2E-08	6.3E-08	6.4E-07	1.6E-08	1.1E-08	3.4E-07
Southern Cross Nordby Village	Aged Care	0.009	0.009	5.4E-07	1.6E-06	3.1E-07	3.6E-08	5.4E-08	5.4E-07	1.4E-08	9.2E-09	2.9E-07
West Pennant Hills Public School	Schools	0.027	0.026	1.6E-06	4.9E-06	9.4E-07	1.1E-07	1.6E-07	1.7E-06	4.1E-08	2.8E-08	8.8E-07
West Pennant Hills Community Church	Community	0.026	0.025	1.6E-06	4.7E-06	9.0E-07	1.1E-07	1.6E-07	1.6E-06	4.0E-08	2.7E-08	8.5E-07
Average Residential		**0.018**	**0.017**	**1.1E-06**	**3.2E-06**	**6.3E-07**	**7.3E-08**	**1.1E-07**	**1.1E-06**	**2.8E-08**	**1.9E-08**	**5.9E-07**
Beecroft												
Thinking Hats Early Learning Centre and Twinklestar Childcare	Childcare	0.015	0.014	8.8E-07	2.6E-06	5.0E-07	5.9E-08	8.8E-08	8.9E-07	2.2E-08	1.5E-08	4.7E-07
Beecroft Long Day & Early Learning Centre	Childcare	0.028	0.027	1.7E-06	5.1E-06	9.8E-07	1.1E-07	1.7E-07	1.7E-06	4.3E-08	2.9E-08	9.2E-07
Twilight Aged Care: Jamieson House	Aged Care	0.029	0.028	1.8E-06	5.2E-06	1.0E-06	1.2E-07	1.8E-07	1.8E-06	4.4E-08	3.0E-08	9.5E-07
Beecroft Nursing Home	Aged Care	0.011	0.010	6.5E-07	1.9E-06	3.7E-07	4.3E-08	6.4E-08	6.5E-07	1.6E-08	1.1E-08	3.5E-07
Beecroft Primary School	Schools	0.017	0.017	1.0E-06	3.1E-06	6.0E-07	7.0E-08	1.0E-07	1.1E-06	2.6E-08	1.8E-08	5.6E-07
Pennant Hills Golf Course	Community	0.029	0.027	1.7E-06	5.1E-06	9.9E-07	1.2E-07	1.7E-07	1.7E-06	4.3E-08	3.0E-08	9.3E-07
Average Residential		**0.021**	**0.021**	**1.3E-06**	**3.8E-06**	**7.4E-07**	**8.6E-08**	**1.3E-07**	**1.3E-06**	**3.3E-08**	**2.2E-08**	**7.0E-07**
North Rocks												
North Rocks Public School	Schools	0.0056	0.0053	3.4E-07	1.0E-06	1.9E-07	2.3E-08	3.4E-08	3.4E-07	8.5E-09	5.8E-09	1.8E-07
Muirfield High School	Schools	0.0043	0.0041	2.6E-07	7.6E-07	1.5E-07	1.7E-08	2.6E-08	2.6E-07	6.5E-09	4.4E-09	1.4E-07
Average Residential		**0.0049**	**0.0047**	**3.0E-07**	**8.8E-07**	**1.7E-07**	**2.0E-08**	**3.0E-08**	**3.0E-07**	**7.5E-09**	**5.1E-09**	**1.6E-07**
Epping												
Arden Anglican School	Schools	0.0038	0.0036	2.3E-07	6.8E-07	1.3E-07	1.5E-08	2.3E-08	2.3E-07	5.8E-09	3.9E-09	1.2E-07
Average Residential		**0.0038**	**0.0036**	**2.3E-07**	**6.8E-07**	**1.3E-07**	**1.5E-08**	**2.3E-08**	**2.3E-07**	**5.8E-09**	**3.9E-09**	**1.2E-07**

Quantification of Effects - PM2.5 and PM10, Scenario 2b 2029
Southern Interchange

Particulate Fraction:	PM2.5	PM2.5	PM2.5	PM10	PM2.5	PM2.5	PM2.5	PM2.5	Incremental Risk - DPM
Endpoint:	Mortality - All Causes	Hospitalisations - Cardiovascular	Hospitalisations - Respiratory	Mortality - All Causes	Mortality - All Causes	Mortality - Cardiopulmonary	Mortality - Cardiovascular	Mortality - Respiratory	
Effect Exposure Duration:	Long-term	Short-term	Short-term	Short-Term	Short-Term	Long-term	Short-Term	Short-Term	(based on WHO)
Age Group:	≥ 30 years	≥ 65 years	≥ 65 years	All ages	All ages	≥ 30 years	All ages	All ages	Unit Risk
β (change in effect per 1 µg/m^3 PM) (as per Table 5-1)	0.0058	0.0008	0.00041	0.0006	0.00094	0.013	0.00097	0.0019	
Baseline Incidence (per 100,000) (as per Table 3-5)	1087	23352	8807	670	670	490	164	57	
Baseline Incidence (per person)	0.01087	0.23352	0.08807	0.0067	0.0067	0.0049	0.00164	0.00057	

Receptor		Increase in Annual Average PM10 Concentration (µg/m^3)	Increase in Annual Average PM2.5 Concentration (µg/m^3)	Risk (Equation 6)	Risk (Equation 6)	Risk (Equation 6)	Risk (Equation 6)	Risk (Equation 6)	Risk (Equation 6)	Risk (Equation 6)	Risk (Equation 6)	Risk
Maximum Receptor												
Southern Interchange		**0.13**	**0.13**	**8.0E-06**	**2.4E-05**	**4.6E-06**	**5.3E-07**	**7.9E-07**	**8.0E-06**	**2.0E-07**	**1.4E-07**	**4.3E-06**
Sensitive Receptors												
Carlingford												
Shine Preschool	Childcare	0.017	0.016	1.0E-06	3.1E-06	5.9E-07	7.0E-08	1.0E-07	1.0E-06	2.6E-08	1.8E-08	5.6E-07
Murray Farm Public School	Schools	0.017	0.016	1.0E-06	3.0E-06	5.9E-07	6.9E-08	1.0E-07	1.0E-06	2.6E-08	1.8E-08	5.5E-07
St Gerards Primary School	Schools	0.020	0.019	1.2E-06	3.5E-06	6.7E-07	8.0E-08	1.2E-07	1.2E-06	3.0E-08	2.0E-08	6.3E-07
Roselea Primary School	Schools	0.023	0.022	1.4E-06	4.1E-06	8.0E-07	9.4E-08	1.4E-07	1.4E-06	3.5E-08	2.4E-08	7.5E-07
Carlingford High School	Schools	0.024	0.022	1.4E-06	4.1E-06	8.0E-07	9.5E-08	1.4E-07	1.4E-06	3.5E-08	2.4E-08	7.5E-07
Colin Place Out of School Care	Schools	0.014	0.013	8.4E-07	2.5E-06	4.8E-07	5.7E-08	8.4E-08	8.5E-07	2.1E-08	1.4E-08	4.5E-07
Roselea Community Centre	Community	0.022	0.021	1.3E-06	3.9E-06	7.6E-07	9.0E-08	1.3E-07	1.3E-06	3.3E-08	2.3E-08	7.1E-07
Pennant Hills Golf Course	Community	0.040	0.038	2.4E-06	7.1E-06	1.4E-06	1.6E-07	2.4E-07	2.4E-06	6.0E-08	4.1E-08	1.3E-06
Average Residential	**includes max**	**0.035**	**0.033**	**2.1E-06**	**6.1E-06**	**1.2E-06**	**1.4E-07**	**2.1E-07**	**2.1E-06**	**5.2E-08**	**3.5E-08**	**1.1E-06**
West Pennant Hills												
Bird House Early Learning Centre	Childcare	0.011	0.011	6.7E-07	2.0E-06	3.8E-07	4.5E-08	6.7E-08	6.7E-07	1.7E-08	1.1E-08	3.6E-07
Southern Cross Nordby Village	Aged Care	0.010	0.009	6.0E-07	1.8E-06	3.4E-07	4.1E-08	6.0E-08	6.0E-07	1.5E-08	1.0E-08	3.2E-07
West Pennant Hills Public School	Schools	0.029	0.027	1.7E-06	5.1E-06	9.9E-07	1.2E-07	1.7E-07	1.7E-06	4.4E-08	3.0E-08	9.3E-07
West Pennant Hills Community Church	Community	0.031	0.029	1.8E-06	5.4E-06	1.0E-06	1.2E-07	1.8E-07	1.8E-06	4.6E-08	3.1E-08	9.8E-07
Average Residential		**0.020**	**0.019**	**1.2E-06**	**3.6E-06**	**6.9E-07**	**8.2E-08**	**1.2E-07**	**1.2E-06**	**3.0E-08**	**2.1E-08**	**6.5E-07**
Beecroft												
Thinking Hats Early Learning Centre and Twinklestar Childcare	Childcare	0.017	0.016	1.0E-06	3.1E-06	5.9E-07	7.0E-08	1.0E-07	1.0E-06	2.6E-08	1.8E-08	5.6E-07
Beecroft Long Day & Early Learning Centre	Childcare	0.035	0.033	2.1E-06	6.1E-06	1.2E-06	1.4E-07	2.1E-07	2.1E-06	5.2E-08	3.5E-08	1.1E-06
Twilight Aged Care: Jamieson House	Aged Care	0.036	0.033	2.1E-06	6.2E-06	1.2E-06	1.4E-07	2.1E-07	2.1E-06	5.3E-08	3.6E-08	1.1E-06
Beecroft Nursing Home	Aged Care	0.013	0.012	7.6E-07	2.3E-06	4.4E-07	5.2E-08	7.6E-08	7.7E-07	1.9E-08	1.3E-08	4.1E-07
Beecroft Primary School	Schools	0.020	0.019	1.2E-06	3.5E-06	6.8E-07	8.1E-08	1.2E-07	1.2E-06	3.0E-08	2.0E-08	6.4E-07
Pennant Hills Golf Course	Community	0.040	0.038	2.4E-06	7.1E-06	1.4E-06	1.6E-07	2.4E-07	2.4E-06	6.0E-08	4.1E-08	1.3E-06
Average Residential		**0.027**	**0.025**	**1.6E-06**	**4.7E-06**	**9.1E-07**	**1.1E-07**	**1.6E-07**	**1.6E-06**	**4.0E-08**	**2.7E-08**	**8.6E-07**
North Rocks												
North Rocks Public School	Schools	0.0067	0.0063	4.0E-07	1.2E-06	2.3E-07	2.7E-08	4.0E-08	4.0E-07	1.0E-08	6.8E-09	2.1E-07
Muirfield High School	Schools	0.0051	0.0048	3.1E-07	9.0E-07	1.7E-07	2.1E-08	3.0E-08	3.1E-07	7.7E-09	5.2E-09	1.6E-07
Average Residential		**0.0059**	**0.0056**	**3.5E-07**	**1.0E-06**	**2.0E-07**	**2.4E-08**	**3.5E-08**	**3.6E-07**	**8.9E-09**	**6.0E-09**	**1.9E-07**
Epping												
Arden Anglican School	Schools	0.0046	0.0043	2.7E-07	8.1E-07	1.6E-07	1.9E-08	2.7E-08	2.8E-07	6.9E-09	4.7E-09	1.5E-07
Average Residential		**0.0046**	**0.0043**	**2.7E-07**	**8.1E-07**	**1.6E-07**	**1.9E-08**	**2.7E-08**	**2.8E-07**	**6.9E-09**	**4.7E-09**	**1.5E-07**

Quantification of Effects - PM2.5 and PM10, Scenario 2a 2019
Northern Interchange

Particulate Fraction:	**PM2.5**	**PM2.5**	**PM2.5**	**PM10**	**PM2.5**	**PM2.5**	**PM2.5**	**PM2.5**	**Incremental Risk -DPM**
Endpoint:	**Mortality - All Causes**	**Hospitalisations - Cardiovascular**	**Hospitalisations - Respiratory**	**Mortality - All Causes**	**Mortality - All Causes**	**Mortality - Cardiopulmonary**	**Mortality - Cardiovascular**	**Mortality - Respiratory**	
Effect Exposure Duration:	Long-term	Short-term	Short-term	Short-Term	Short-Term	Long-term	Short-Term	Short-Term	(based on WHO)
Age Group:	≥ 30 years	≥ 65 years	≥ 65 years	All ages	All ages	≥ 30 years	All ages	All ages	Unit Risk
β (change in effect per 1 µg/m^3 PM) (as per Table 5-1)	0.0058	0.0008	0.00041	0.0006	0.00094	0.013	0.00097	0.0019	
Baseline Incidence (per 100,000) (as per Table 3-5)	1087	23352	8807	670	670	490	164	57	
Baseline Incidence (per person)	0.01087	0.23352	0.08807	0.0067	0.0067	0.0049	0.00164	0.00057	

Receptor		Increase in Annual Average PM10 Concentration (µg/m^3)	Increase in Annual Average PM2.5 Concentration (µg/m^3)	Risk (Equation 6)	Risk (Equation 6)	Risk (Equation 6)	Risk (Equation 6)	Risk (Equation 6)	Risk (Equation 6)	Risk (Equation 6)	Risk (Equation 6)	Risk
Maximum Receptor												
Northern Interchange		**0.09**	**0.08**	**5.1E-06**	**1.5E-05**	**2.9E-06**	**3.4E-07**	**5.1E-07**	**5.2E-06**	**1.3E-07**	**8.8E-08**	**2.8E-06**
Sensitive Receptors												
Wahroonga												
KU Wahroonga	Childcare	0.035	0.033	2.1E-06	6.2E-06	1.2E-06	1.4E-07	2.1E-07	2.1E-06	5.3E-08	3.6E-08	1.1E-06
Next Generation Child Care	Childcare	0.049	0.047	2.9E-06	8.7E-06	1.7E-06	2.0E-07	2.9E-07	3.0E-06	7.4E-08	5.1E-08	1.6E-06
Peter Rabbit Community Preschool	Childcare	0.036	0.034	2.2E-06	6.4E-06	1.2E-06	1.4E-07	2.2E-07	2.2E-06	5.5E-08	3.7E-08	1.2E-06
Wahroonga Long Day Care	Childcare	0.019	0.018	1.1E-06	3.4E-06	6.5E-07	7.6E-08	1.1E-07	1.2E-06	2.9E-08	2.0E-08	6.2E-07
Wahroonga Beehive Pre-School	Childcare	0.015	0.014	8.8E-07	2.6E-06	5.0E-07	5.9E-08	8.8E-08	8.9E-07	2.2E-08	1.5E-08	4.7E-07
Little Learning School Wahroonga	Childcare	0.038	0.036	2.3E-06	6.8E-06	1.3E-06	1.5E-07	2.3E-07	2.3E-06	5.8E-08	3.9E-08	1.2E-06
Pymble Turramurra Kindergarten	Childcare	0.008	0.008	5.0E-07	1.5E-06	2.8E-07	3.3E-08	5.0E-08	5.0E-07	1.3E-08	8.5E-09	2.7E-07
The Woniora Care	Aged Care	0.044	0.042	2.6E-06	7.8E-06	1.5E-06	1.8E-07	2.6E-07	2.7E-06	6.7E-08	4.5E-08	1.4E-06
Tallwoods Centre	Aged Care	0.046	0.044	2.8E-06	8.2E-06	1.6E-06	1.9E-07	2.8E-07	2.8E-06	7.0E-08	4.8E-08	1.5E-06
B'nai B'rith Retirement Village	Aged Care	0.055	0.052	3.3E-06	9.7E-06	1.9E-06	2.2E-07	3.3E-07	3.3E-06	8.2E-08	5.6E-08	1.8E-06
Wahroonga Nursing Home	Aged Care	0.044	0.042	2.6E-06	7.8E-06	1.5E-06	1.8E-07	2.6E-07	2.7E-06	6.6E-08	4.5E-08	1.4E-06
Netherby Aged Care	Aged Care	0.042	0.040	2.5E-06	7.4E-06	1.4E-06	1.7E-07	2.5E-07	2.5E-06	6.3E-08	4.3E-08	1.4E-06
Wahroonga Waldorf Apartments	Aged Care	0.042	0.040	2.5E-06	7.4E-06	1.4E-06	1.7E-07	2.5E-07	2.5E-06	6.3E-08	4.3E-08	1.4E-06
Thomas & Rosetta Aged Care Facility	Aged Care	0.023	0.021	1.4E-06	4.0E-06	7.7E-07	9.1E-08	1.3E-07	1.4E-06	3.4E-08	2.3E-08	7.3E-07
Redleaf Serviced Apartments/Aged Care	Aged Care	0.023	0.021	1.4E-06	4.0E-06	7.7E-07	9.1E-08	1.3E-07	1.4E-06	3.4E-08	2.3E-08	7.3E-07
UPA of NSW Ltd	Aged Care	0.023	0.021	1.4E-06	4.0E-06	7.8E-07	9.1E-08	1.4E-07	1.4E-06	3.4E-08	2.3E-08	7.3E-07
Waitara Public School	Schools	0.054	0.051	3.2E-06	9.6E-06	1.9E-06	2.2E-07	3.2E-07	3.3E-06	8.2E-08	5.6E-08	1.7E-06
Wahroonga Preparatory School	Schools	0.042	0.040	2.5E-06	7.5E-06	1.4E-06	1.7E-07	2.5E-07	2.5E-06	6.4E-08	4.3E-08	1.4E-06
Wahroonga Public School	Schools	0.023	0.021	1.4E-06	4.0E-06	7.7E-07	9.1E-08	1.4E-07	1.4E-06	3.4E-08	2.3E-08	7.3E-07
Abbotsleigh	Schools	0.025	0.023	1.5E-06	4.4E-06	8.5E-07	1.0E-07	1.5E-07	1.5E-06	3.7E-08	2.5E-08	8.0E-07
Abbotsleigh Junior School and Early Learning Centre	Schools	0.012	0.012	7.4E-07	2.2E-06	4.2E-07	4.9E-08	7.4E-08	7.4E-07	1.9E-08	1.3E-08	4.0E-07
Knox Grammar	Schools	0.020	0.019	1.2E-06	3.6E-06	6.9E-07	8.1E-08	1.2E-07	1.2E-06	3.0E-08	2.1E-08	6.5E-07
Knox Preparatory School	Schools	0.039	0.037	2.3E-06	6.9E-06	1.3E-06	1.6E-07	2.3E-07	2.4E-06	5.9E-08	4.0E-08	1.3E-06
St Lucys School	Schools	0.042	0.039	2.5E-06	7.3E-06	1.4E-06	1.7E-07	2.5E-07	2.5E-06	6.2E-08	4.2E-08	1.3E-06
Prouille Catholic College	Schools	0.047	0.044	2.8E-06	8.2E-06	1.6E-06	1.9E-07	2.8E-07	2.8E-06	7.0E-08	4.8E-08	1.5E-06
Prouille Catholic Primary School	Schools	0.044	0.042	2.6E-06	7.8E-06	1.5E-06	1.8E-07	2.6E-07	2.7E-06	6.6E-08	4.5E-08	1.4E-06
St Leos	Schools	0.025	0.024	1.5E-06	4.5E-06	8.7E-07	1.0E-07	1.5E-07	1.5E-06	3.8E-08	2.6E-08	8.2E-07
St Edmund's School for Blind and Visually Impaire	Schools	0.024	0.022	1.4E-06	4.2E-06	8.1E-07	9.6E-08	1.4E-07	1.4E-06	3.6E-08	2.4E-08	7.6E-07
Warrawee Public School	Schools	0.011	0.011	6.8E-07	2.0E-06	3.9E-07	4.6E-08	6.8E-08	6.9E-07	1.7E-08	1.2E-08	3.7E-07
Retaval School	Schools	0.011	0.011	6.8E-07	2.0E-06	3.9E-07	4.6E-08	6.8E-08	6.9E-07	1.7E-08	1.2E-08	3.7E-07
Neringah Hospital (hope Healthcare)	Hospital	0.030	0.028	1.8E-06	5.2E-06	1.0E-06	1.2E-07	1.8E-07	1.8E-06	4.5E-08	3.0E-08	9.5E-07
Average Residential	**includes max**	**0.034**	**0.032**	**2.0E-06**	**6.0E-06**	**1.2E-06**	**1.4E-07**	**2.0E-07**	**2.0E-06**	**5.1E-08**	**3.5E-08**	**1.1E-06**
North Wahroonga												
Residential (Suburb Receptor)	**Residential**	**0.030**	**0.029**	**1.8E-06**	**5.4E-06**	**1.0E-06**	**1.2E-07**	**1.8E-07**	**1.8E-06**	**4.6E-08**	**3.1E-08**	**9.7E-07**
Waitara												
Balamara Preschool	Childcare	0.048	0.045	2.9E-06	8.5E-06	1.6E-06	1.9E-07	2.9E-07	2.9E-06	7.2E-08	4.9E-08	1.5E-06
Waitara Family Centre	Childcare	0.021	0.020	1.2E-06	3.7E-06	7.1E-07	8.3E-08	1.2E-07	1.3E-06	3.1E-08	2.1E-08	6.7E-07
Twinkle Tots Cottage	Childcare	0.029	0.027	1.7E-06	5.1E-06	9.9E-07	1.2E-07	1.7E-07	1.7E-06	4.4E-08	3.0E-08	9.3E-07
The Grange	Aged Care	0.026	0.025	1.6E-06	4.7E-06	9.0E-07	1.1E-07	1.6E-07	1.6E-06	4.0E-08	2.7E-08	8.5E-07
Waitara Public School	Schools	0.054	0.051	3.2E-06	9.6E-06	1.9E-06	2.2E-07	3.2E-07	3.3E-06	8.2E-08	5.6E-08	1.7E-06
Our Lady of the Rosary Primary School	Schools	0.021	0.020	1.3E-06	3.8E-06	7.4E-07	8.6E-08	1.3E-07	1.3E-06	3.3E-08	2.2E-08	7.0E-07
Average Residential		**0.033**	**0.032**	**2.0E-06**	**5.9E-06**	**1.1E-06**	**1.3E-07**	**2.0E-07**	**2.0E-06**	**5.0E-08**	**3.4E-08**	**1.1E-06**
Hornsby												
Bumble Bees Early Learning Centre	Childcare	0.023	0.022	1.4E-06	4.1E-06	7.9E-07	9.3E-08	1.4E-07	1.4E-06	3.5E-08	2.4E-08	7.5E-07
Kids Academy Hornsby	Childcare	0.024	0.023	1.4E-06	4.2E-06	8.2E-07	9.6E-08	1.4E-07	1.4E-06	3.6E-08	2.5E-08	7.7E-07
Explore & Develop Waitara	Childcare	0.034	0.032	2.0E-06	6.0E-06	1.2E-06	1.4E-07	2.0E-07	2.1E-06	5.1E-08	3.5E-08	1.1E-06
Little Learning School Hornsby	Childcare	0.034	0.032	2.0E-06	6.0E-06	1.2E-06	1.4E-07	2.0E-07	2.1E-06	5.1E-08	3.5E-08	1.1E-06
Bright Horizons Early Learning Centre	Childcare	0.034	0.032	2.0E-06	6.0E-06	1.2E-06	1.4E-07	2.0E-07	2.1E-06	5.1E-08	3.5E-08	1.1E-06
Belvedere Aged Care	Aged Care	0.042	0.040	2.5E-06	7.4E-06	1.4E-06	1.7E-07	2.5E-07	2.5E-06	6.3E-08	4.3E-08	1.4E-06
Hornsby Girls High School	Schools	0.016	0.015	9.6E-07	2.9E-06	5.5E-07	6.5E-08	9.6E-08	9.7E-07	2.4E-08	1.7E-08	5.2E-07
Barker College	Schools	0.014	0.013	8.4E-07	2.5E-06	4.8E-07	5.6E-08	8.4E-08	8.5E-07	2.1E-08	1.4E-08	4.5E-07
Hornsby South Public School	Schools	0.010	0.010	6.2E-07	1.8E-06	3.6E-07	4.2E-08	6.2E-08	6.3E-07	1.6E-08	1.1E-08	3.4E-07
Clarke Road School	Schools	0.010	0.010	6.2E-07	1.8E-06	3.6E-07	4.2E-08	6.2E-08	6.3E-07	1.6E-08	1.1E-08	3.4E-07
Hornsby Hospital (and childcare centre)	Hospital	0.034	0.032	2.0E-06	6.1E-06	1.2E-06	1.4E-07	2.0E-07	2.1E-06	5.2E-08	3.5E-08	1.1E-06
Average Residential		**0.025**	**0.024**	**1.5E-06**	**4.5E-06**	**8.6E-07**	**1.0E-07**	**1.5E-07**	**1.5E-06**	**3.8E-08**	**2.6E-08**	**8.1E-07**
Normanhurst												
Normanhurst Child Care Centre	Childcare	0.016	0.015	9.5E-07	2.8E-06	5.5E-07	6.3E-08	9.5E-08	9.6E-07	2.4E-08	1.6E-08	5.1E-07
Bowden Brae Retirement Village	Aged Care	0.021	0.020	1.3E-06	3.8E-06	7.4E-07	8.6E-08	1.3E-07	1.3E-06	3.3E-08	2.2E-08	7.0E-07
Greenwood Aged Care	Aged Care	0.020	0.019	1.2E-06	3.5E-06	6.8E-07	8.0E-08	1.2E-07	1.2E-06	3.0E-08	2.1E-08	6.4E-07
Normanhurst Boys High School	Schools	0.020	0.019	1.2E-06	3.5E-06	6.9E-07	8.0E-08	1.2E-07	1.2E-06	3.0E-08	2.1E-08	6.5E-07
Normanhurst Public School	Schools	0.016	0.015	9.4E-07	2.8E-06	5.4E-07	6.2E-08	9.4E-08	9.5E-07	2.4E-08	1.6E-08	5.1E-07
Average Residential		**0.018**	**0.018**	**1.1E-06**	**3.3E-06**	**6.4E-07**	**7.4E-08**	**1.1E-07**	**1.1E-06**	**2.8E-08**	**1.9E-08**	**6.0E-07**

Quantification of Effects - PM2.5 and PM10, Scenario 2b 2029
Northern Interchange

Particulate Fraction:	**PM2.5**	**PM2.5**	**PM2.5**	**PM10**	**PM2.5**	**PM2.5**	**PM2.5**	**PM2.5**	**Incremental Risk -DPM**
Endpoint:	**Mortality - All Causes**	**Hospitalisations - Cardiovascular**	**Hospitalisations - Respiratory**	**Mortality - All Causes**	**Mortality - All Causes**	**Mortality - Cardiopulmonary**	**Mortality - Cardiovascular**	**Mortality - Respiratory**	
Effect Exposure Duration:	Long-term	Short-term	Short-term	Short-Term	Short-Term	Long-term	Short-Term	Short-Term	(based on WHO)
Age Group:	≥ 30 years	≥ 65 years	≥ 65 years	All ages	All ages	≥ 30 years	All ages	All ages	Unit Risk
β (change in effect per 1 μg/m³ PM) (as per Table 5-1)	0.0058	0.0008	0.00041	0.0006	0.00094	0.013	0.00097	0.0019	
Baseline Incidence (per 100,000) (as per Table 3-5)	1087	23352	8807	670	670	490	164	57	
Baseline Incidence (per person)	0.01087	0.23352	0.08807	0.0067	0.0067	0.0049	0.00164	0.00057	

Receptor		Increase in Annual Average PM10 Concentration (μg/m³)	Increase in Annual Average PM2.5 Concentration (μg/m³)	Risk (Equation 6)	Risk (Equation 6)	Risk (Equation 6)	Risk (Equation 6)	Risk (Equation 6)	Risk (Equation 6)	Risk (Equation 6)	Risk (Equation 6)	Risk
Maximum Receptor												
Northern Interchange		**0.11**	**0.10**	**6.5E-06**	**1.9E-05**	**3.7E-06**	**4.4E-07**	**6.5E-07**	**6.6E-06**	**1.6E-07**	**1.1E-07**	**3.5E-06**
Sensitive Receptors												
Wahroonga												
KU Wahroonga	Childcare	0.041	0.039	2.5E-06	7.3E-06	1.4E-06	1.7E-07	2.5E-07	2.5E-06	6.2E-08	4.2E-08	1.3E-06
Next Generation Child Care	Childcare	0.058	0.055	3.5E-06	1.0E-05	2.0E-06	2.3E-07	3.5E-07	3.5E-06	8.7E-08	5.9E-08	1.9E-06
Peter Rabbit Community Preschool	Childcare	0.041	0.039	2.5E-06	7.3E-06	1.4E-06	1.7E-07	2.5E-07	2.5E-06	6.2E-08	4.2E-08	1.3E-06
Wahroonga Long Day Care	Childcare	0.022	0.021	1.3E-06	3.9E-06	7.5E-07	8.8E-08	1.3E-07	1.3E-06	3.3E-08	2.2E-08	7.0E-07
Wahroonga Beehive Pre-School	Childcare	0.017	0.016	1.0E-06	3.0E-06	5.8E-07	6.8E-08	1.0E-07	1.0E-06	2.5E-08	1.7E-08	5.4E-07
Little Learning School Wahroonga	Childcare	0.044	0.042	2.7E-06	7.9E-06	1.5E-06	1.8E-07	2.6E-07	2.7E-06	6.7E-08	4.6E-08	1.4E-06
Pymble Turramurra Kindergarten	Childcare	0.010	0.009	5.7E-07	1.7E-06	3.3E-07	3.9E-08	5.7E-08	5.8E-07	1.4E-08	9.9E-09	3.1E-07
The Woniora Care	Aged Care	0.059	0.056	3.5E-06	1.0E-05	2.0E-06	2.4E-07	3.5E-07	3.6E-06	8.9E-08	6.0E-08	1.9E-06
Tallwoods Centre	Aged Care	0.054	0.052	3.2E-06	9.6E-06	1.9E-06	2.2E-07	3.2E-07	3.3E-06	8.2E-08	5.6E-08	1.8E-06
B'nai B'rith Retirement Village	Aged Care	0.065	0.061	3.9E-06	1.1E-05	2.2E-06	2.6E-07	3.9E-07	3.9E-06	9.7E-08	6.6E-08	2.1E-06
Wahroonga Nursing Home	Aged Care	0.051	0.048	3.1E-06	9.0E-06	1.7E-06	2.1E-07	3.1E-07	3.1E-06	7.7E-08	5.2E-08	1.6E-06
Netherby Aged Care	Aged Care	0.049	0.046	2.9E-06	8.6E-06	1.7E-06	2.0E-07	2.9E-07	2.9E-06	7.3E-08	5.0E-08	1.6E-06
Wahroonga Waldorf Apartments	Aged Care	0.049	0.046	2.9E-06	8.6E-06	1.7E-06	2.0E-07	2.9E-07	2.9E-06	7.3E-08	5.0E-08	1.6E-06
Thomas & Rosetta Aged Care Facility	Aged Care	0.026	0.025	1.6E-06	4.6E-06	8.9E-07	1.0E-07	1.6E-07	1.6E-06	3.9E-08	2.7E-08	8.4E-07
Redleaf Serviced Apartments/Aged Care	Aged Care	0.026	0.025	1.6E-06	4.6E-06	8.9E-07	1.0E-07	1.6E-07	1.6E-06	3.9E-08	2.7E-08	8.4E-07
UPA of NSW Ltd	Aged Care	0.026	0.025	1.6E-06	4.6E-06	8.9E-07	1.1E-07	1.6E-07	1.6E-06	3.9E-08	2.7E-08	8.4E-07
Waitara Public School	Schools	0.065	0.061	3.8E-06	1.1E-05	2.2E-06	2.6E-07	3.8E-07	3.9E-06	9.7E-08	6.6E-08	2.1E-06
Wahroonga Preparatory School	Schools	0.049	0.046	2.9E-06	8.7E-06	1.7E-06	2.0E-07	2.9E-07	3.0E-06	7.4E-08	5.0E-08	1.6E-06
Wahroonga Public School	Schools	0.026	0.024	1.5E-06	4.6E-06	8.8E-07	1.0E-07	1.5E-07	1.6E-06	3.9E-08	2.6E-08	8.3E-07
Abbotsleigh	Schools	0.029	0.027	1.7E-06	5.0E-06	9.7E-07	1.1E-07	1.7E-07	1.7E-06	4.3E-08	2.9E-08	9.1E-07
Abbotsleigh Junior School and Early Learning Centre	Schools	0.022	0.020	1.3E-06	3.8E-06	7.3E-07	8.6E-08	1.3E-07	1.3E-06	3.2E-08	2.2E-08	6.8E-07
Knox Grammar	Schools	0.023	0.022	1.4E-06	4.1E-06	7.9E-07	9.3E-08	1.4E-07	1.4E-06	3.5E-08	2.4E-08	7.5E-07
Knox Preparatory School	Schools	0.044	0.042	2.6E-06	7.8E-06	1.5E-06	1.8E-07	2.6E-07	2.7E-06	6.7E-08	4.5E-08	1.4E-06
St Lucys School	Schools	0.047	0.044	2.8E-06	8.3E-06	1.6E-06	1.9E-07	2.8E-07	2.8E-06	7.1E-08	4.8E-08	1.5E-06
Prouille Catholic College	Schools	0.053	0.050	3.1E-06	9.3E-06	1.8E-06	2.1E-07	3.1E-07	3.2E-06	7.9E-08	5.4E-08	1.7E-06
Prouille Catholic Primary School	Schools	0.050	0.047	3.0E-06	8.8E-06	1.7E-06	2.0E-07	3.0E-07	3.0E-06	7.5E-08	5.1E-08	1.6E-06
St Leos	Schools	0.029	0.028	1.8E-06	5.2E-06	1.0E-06	1.2E-07	1.8E-07	1.8E-06	4.4E-08	3.0E-08	9.5E-07
St Edmund's School for Blind and Visually Impaire	Schools	0.027	0.026	1.6E-06	4.8E-06	9.2E-07	1.1E-07	1.6E-07	1.6E-06	4.1E-08	2.8E-08	8.7E-07
Warrawee Public School	Schools	0.013	0.012	7.9E-07	2.3E-06	4.5E-07	5.3E-08	7.9E-08	8.0E-07	2.0E-08	1.4E-08	4.2E-07
Retaval School	Schools	0.013	0.013	7.9E-07	2.4E-06	4.5E-07	5.4E-08	7.9E-08	8.0E-07	2.0E-08	1.4E-08	4.3E-07
Neringah Hospital (hope Healthcare)	Hospital	0.034	0.032	2.0E-06	6.0E-06	1.2E-06	1.4E-07	2.0E-07	2.0E-06	5.1E-08	3.5E-08	1.1E-06
Average Residential	**includes max**	**0.040**	**0.038**	**2.4E-06**	**7.0E-06**	**1.4E-06**	**1.6E-07**	**2.4E-07**	**2.4E-06**	**6.0E-08**	**4.1E-08**	**1.3E-06**
North Wahroonga												
Residential (Suburb Receptor)	**Residential**	**0.035**	**0.033**	**2.1E-06**	**6.2E-06**	**1.2E-06**	**1.4E-07**	**2.1E-07**	**2.1E-06**	**5.2E-08**	**3.6E-08**	**1.1E-06**
Waitara												
Balamara Preschool	Childcare	0.056	0.053	3.4E-06	1.0E-05	1.9E-06	2.3E-07	3.4E-07	3.4E-06	8.5E-08	5.8E-08	1.8E-06
Waitara Family Centre	Childcare	0.024	0.023	1.4E-06	4.3E-06	8.2E-07	9.7E-08	1.4E-07	1.5E-06	3.6E-08	2.5E-08	7.8E-07
Twinkle Tots Cottage	Childcare	0.034	0.032	2.0E-06	5.9E-06	1.1E-06	1.4E-07	2.0E-07	2.0E-06	5.1E-08	3.4E-08	1.1E-06
The Grange	Aged Care	0.031	0.029	1.8E-06	5.4E-06	1.1E-06	1.2E-07	1.8E-07	1.9E-06	4.6E-08	3.2E-08	9.9E-07
Waitara Public School	Schools	0.065	0.061	3.8E-06	1.1E-05	2.2E-06	2.6E-07	3.8E-07	3.9E-06	9.7E-08	6.6E-08	2.1E-06
Our Lady of the Rosary Primary School	Schools	0.025	0.024	1.5E-06	4.4E-06	8.6E-07	1.0E-07	1.5E-07	1.5E-06	3.8E-08	2.6E-08	8.1E-07
Average Residential		**0.039**	**0.037**	**2.3E-06**	**6.9E-06**	**1.3E-06**	**1.6E-07**	**2.3E-07**	**2.4E-06**	**5.9E-08**	**4.0E-08**	**1.3E-06**
Hornsby												
Bumble Bees Early Learning Centre	Childcare	0.027	0.025	1.6E-06	4.7E-06	9.1E-07	1.1E-07	1.6E-07	1.6E-06	4.0E-08	2.7E-08	8.6E-07
Kids Academy Hornsby	Childcare	0.028	0.026	1.7E-06	4.9E-06	9.5E-07	1.1E-07	1.7E-07	1.7E-06	4.2E-08	2.8E-08	8.9E-07
Explore & Develop Waitara	Childcare	0.040	0.037	2.4E-06	7.0E-06	1.4E-06	1.6E-07	2.4E-07	2.4E-06	6.0E-08	4.1E-08	1.3E-06
Little Learning School Hornsby	Childcare	0.040	0.037	2.4E-06	7.0E-06	1.4E-06	1.6E-07	2.4E-07	2.4E-06	6.0E-08	4.1E-08	1.3E-06
Bright Horizons Early Learning Centre	Childcare	0.040	0.037	2.4E-06	7.0E-06	1.4E-06	1.6E-07	2.4E-07	2.4E-06	6.0E-08	4.1E-08	1.3E-06
Belvedere Aged Care	Aged Care	0.049	0.046	2.9E-06	8.6E-06	1.7E-06	2.0E-07	2.9E-07	2.9E-06	7.3E-08	5.0E-08	1.6E-06
Hornsby Girls High School	Schools	0.018	0.017	1.1E-06	3.3E-06	6.3E-07	7.4E-08	1.1E-07	1.1E-06	2.8E-08	1.9E-08	5.9E-07
Barker College	Schools	0.016	0.015	9.7E-07	2.9E-06	5.6E-07	6.5E-08	9.7E-08	9.8E-07	2.5E-08	1.7E-08	5.2E-07
Hornsby South Public School	Schools	0.012	0.011	7.2E-07	2.1E-06	4.1E-07	4.9E-08	7.2E-08	7.3E-07	1.8E-08	1.2E-08	3.9E-07
Clarke Road School	Schools	0.012	0.011	7.2E-07	2.1E-06	4.1E-07	4.9E-08	7.2E-08	7.3E-07	1.8E-08	1.2E-08	3.9E-07
Hornsby Hospital (and childcare centre)	Hospital	0.040	0.038	2.4E-06	7.0E-06	1.4E-06	1.6E-07	2.4E-07	2.4E-06	6.0E-08	4.1E-08	1.3E-06
Average Residential		**0.029**	**0.028**	**1.7E-06**	**5.2E-06**	**1.0E-06**	**1.2E-07**	**1.7E-07**	**1.8E-06**	**4.4E-08**	**3.0E-08**	**9.4E-07**
Normanhurst												
Normanhurst Child Care Centre	Childcare	0.019	0.018	1.1E-06	3.3E-06	6.4E-07	7.5E-08	1.1E-07	1.1E-06	2.8E-08	1.9E-08	6.0E-07
Bowden Brae Retirement Village	Aged Care	0.025	0.023	1.5E-06	4.4E-06	8.5E-07	1.0E-07	1.5E-07	1.5E-06	3.7E-08	2.5E-08	8.0E-07
Greenwood Aged Care	Aged Care	0.023	0.022	1.4E-06	4.0E-06	7.8E-07	9.2E-08	1.4E-07	1.4E-06	3.4E-08	2.3E-08	7.4E-07
Normanhurst Boys High School	Schools	0.023	0.022	1.4E-06	4.1E-06	8.0E-07	9.4E-08	1.4E-07	1.4E-06	3.5E-08	2.4E-08	7.5E-07
Normanhurst Public School	Schools	0.018	0.017	1.1E-06	3.2E-06	6.3E-07	7.4E-08	1.1E-07	1.1E-06	2.8E-08	1.9E-08	5.9E-07
Average Residential		**0.022**	**0.020**	**1.3E-06**	**3.8E-06**	**7.4E-07**	**8.7E-08**	**1.3E-07**	**1.3E-06**	**3.2E-08**	**2.2E-08**	**6.9E-07**

Appendix C Calculation of population incidence for exposure to $PM_{2.5}$ (scenarios 2a and 2b)

Assessment of Increased Incidence - PM2.5, Scenario 2a 2019
Southern Interchange

	Primary Indicators			Secondary Indicators			
Health Endpoint:	**Mortality - All Causes, Long-term**	**Hospitalisations - Cardiovascular, Short-term**	**Hospitalisations - Respiratory, Short-term**	**Mortality - All Causes, Short-term**	**Mortality - Cardiopulmonary, Long-term**	**Mortality - Cardiovascular, Short-term**	**Mortality - Respiratory, Short-term**
Age Group:	≥ 30 years	≥ 65 years	≥ 65 years	All ages	≥ 30 years	All ages	All ages
β (change in effect per 1 μg/m³ PM) (as per Table 5-1)	0.0058	0.0008	0.00041	0.00094	0.013	0.00097	0.0019
Baseline Incidence (per 100,000) (as per Table 3-5)	1087	23352	8807	670	490	164	57
Baseline Incidence (per person)	0.01087	0.23352	0.08807	0.0067	0.0049	0.00164	0.00057
Carlingford							
Total Population:	21570	21570	21570	21570	21570	21570	21570
% population in assessment age-group:	63%	16%	16%	100%	63%	100%	100%
Population weighted Δx (μg/m³):	0.008	0.008	0.008	0.008	0.008	0.008	0.008
Relative Risk:	1.0000474	1.0000065	1.0000033	1.0000077	1.0001062	1.0000079	1.0000155
Attributable fraction (AF):	4.7E-05	6.5E-06	3.3E-06	7.7E-06	1.1E-04	7.9E-06	1.6E-05
Increased number of cases in population:	0.007	0.005	0.001	0.00111	0.0071	0.00028	0.00019
West Pennant Hills							
Total Population:	15967	15967	15967	15967	15967	15967	15967
% population in assessment age-group:	61%	12%	12%	100%	61%	100%	100%
Population weighted Δx (μg/m³):	0.014	0.014	0.014	0.014	0.014	0.014	0.014
Relative Risk:	1.000079	1.000011	1.000006	1.000013	1.000177	1.000013	1.000026
Attributable fraction (AF):	7.9E-05	1.1E-05	5.6E-06	1.3E-05	1.8E-04	1.3E-05	2.6E-05
Increased number of cases in population:	0.008	0.005	0.001	0.0014	0.008	0.00035	0.00024
Beecroft							
Total Population:	8836	8836	8836	8836	8836	8836	8836
% population in assessment age-group:	63%	19%	19%	100%	63%	100%	100%
Population weighted Δx (μg/m³):	0.017	0.017	0.017	0.017	0.017	0.017	0.017
Relative Risk:	1.000096	1.000013	1.000007	1.000016	1.000215	1.000016	1.000031
Attributable fraction (AF):	9.6E-05	1.3E-05	6.8E-06	1.6E-05	2.2E-04	1.6E-05	3.1E-05
Increased number of cases in population:	0.0058	0.0051	0.0010	0.0009	0.0059	0.00023	0.00016
North Rocks							
Total Population:	7625	7625	7625	7625	7625	7625	7625
% population in assessment age-group:	64%	16%	16%	100%	64%	100%	100%
Population weighted Δx (μg/m³):	0.004	0.004	0.004	0.004	0.004	0.004	0.004
Relative Risk:	1.0000224	1.0000031	1.0000016	1.0000036	1.0000501	1.0000037	1.0000073
Attributable fraction (AF):	2.2E-05	3.1E-06	1.6E-06	3.6E-06	5.0E-05	3.7E-06	7.3E-06
Increased number of cases in population:	0.0012	0.00089	0.00017	0.00019	0.00120	0.000047	0.000032
Epping							
Total Population:	20227	20227	20227	20227	20227	20227	20227
% population in assessment age-group:	60%	13%	13%	100%	60%	100%	100%
Population weighted Δx (μg/m³):	0.005	0.005	0.005	0.005	0.005	0.005	0.005
Relative Risk:	1.0000310	1.0000043	1.0000022	1.0000050	1.0000695	1.0000052	1.0000102
Attributable fraction (AF):	3.1E-05	4.3E-06	2.2E-06	5.0E-06	6.9E-05	5.2E-06	1.0E-05
Increased number of cases in population:	0.0041	0.0027	0.00052	0.00068	0.0041	0.000172	0.000117
Total for all suburbs	**0.026**	**0.019**	**0.0037**	**0.0043**	**0.027**	**0.0011**	**0.00073**

Assessment of Increased Incidence - PM2.5, Scenario 2b 2029
Southern Interchange

	Primary Indicators			Secondary Indicators			
Health Endpoint:	**Mortality - All Causes, Long-term**	**Hospitalisations - Cardiovascular, Short-term**	**Hospitalisations - Respiratory, Short-term**	**Mortality - All Causes, Short-term**	**Mortality - Cardiopulmonary, Long-term**	**Mortality - Cardiovascular, Short-term**	**Mortality - Respiratory, Short-term**
Age Group:	≥ 30 years	≥ 65 years	≥ 65 years	All ages	≥ 30 years	All ages	All ages
β (change in effect per 1 µg/m^3 PM) (as per Table 5-1)	0.0058	0.0008	0.00041	0.00094	0.013	0.00097	0.0019
Baseline Incidence (per 100,000) (as per Table 3-5)	1087	23352	8807	670	490	164	57
Baseline Incidence (per person)	0.01087	0.23352	0.08807	0.0067	0.0049	0.00164	0.00057
Carlingford							
Total Population:	21570	21570	21570	21570	21570	21570	21570
% population in assessment age-group:	63%	16%	16%	100%	63%	100%	100%
Population weighted Δx (µg/m^3):	0.010	0.010	0.010	0.010	0.010	0.010	0.010
Relative Risk:	1.0000565	1.0000078	1.0000040	1.0000092	1.0001266	1.0000094	1.0000185
Attributable fraction (AF):	5.6E-05	7.8E-06	4.0E-06	9.2E-06	1.3E-04	9.4E-06	1.8E-05
Increased number of cases in population:	0.0083	0.0063	0.0012	0.00132	0.0084	0.00033	0.00023
West Pennant Hills							
Total Population:	15967	15967	15967	15967	15967	15967	15967
% population in assessment age-group:	61%	12%	12%	100%	61%	100%	100%
Population weighted Δx (µg/m^3):	0.014	0.014	0.014	0.014	0.014	0.014	0.014
Relative Risk:	1.000082	1.000011	1.000006	1.000013	1.000185	1.000014	1.000027
Attributable fraction (AF):	8.2E-05	1.1E-05	5.8E-06	1.3E-05	1.8E-04	1.4E-05	2.7E-05
Increased number of cases in population:	0.0087	0.0053	0.0010	0.0014	0.009	0.00036	0.00025
Beecroft							
Total Population:	8836	8836	8836	8836	8836	8836	8836
% population in assessment age-group:	63%	19%	19%	100%	63%	100%	100%
Population weighted Δx (µg/m^3):	0.020	0.020	0.020	0.020	0.020	0.020	0.020
Relative Risk:	1.000115	1.000016	1.000008	1.000019	1.000257	1.000019	1.000038
Attributable fraction (AF):	1.1E-04	1.6E-05	8.1E-06	1.9E-05	2.6E-04	1.9E-05	3.8E-05
Increased number of cases in population:	0.0069	0.0060	0.0012	0.0011	0.0070	0.00028	0.00019
North Rocks							
Total Population:	7625	7625	7625	7625	7625	7625	7625
% population in assessment age-group:	64%	16%	16%	100%	64%	100%	100%
Population weighted Δx (µg/m^3):	0.005	0.005	0.005	0.005	0.005	0.005	0.005
Relative Risk:	1.0000264	1.0000036	1.0000019	1.0000043	1.0000592	1.0000044	1.0000087
Attributable fraction (AF):	2.6E-05	3.6E-06	1.9E-06	4.3E-06	5.9E-05	4.4E-06	8.7E-06
Increased number of cases in population:	0.0014	0.0011	0.00020	0.00022	0.00142	0.000055	0.000038
Epping							
Total Population:	20227	20227	20227	20227	20227	20227	20227
% population in assessment age-group:	60%	13%	13%	100%	60%	100%	100%
Population weighted Δx (µg/m^3):	0.006	0.006	0.006	0.006	0.006	0.006	0.006
Relative Risk:	1.0000366	1.0000051	1.0000026	1.0000059	1.0000821	1.0000061	1.0000120
Attributable fraction (AF):	3.7E-05	5.1E-06	2.6E-06	5.9E-06	8.2E-05	6.1E-06	1.2E-05
Increased number of cases in population:	0.0048	0.0032	0.00061	0.00080	0.0049	0.000203	0.000138
Total for all suburbs	**0.030**	**0.022**	**0.0042**	**0.0049**	**0.031**	**0.0012**	**0.00084**

Assessment of Increased Incidence - PM2.5, Scenario 2a 2019
Northern Interchange

	Primary Indicators			Secondary Indicators			
Health Endpoint:	Mortality - All Causes, Long-term	Hospitalisations - Cardiovascular, Short-term	Hospitalisations - Respiratory, Short-term	Mortality - All Causes, Short-term	Mortality - Cardiopulmonary, Long-term	Mortality - Cardiovascular, Short-term	Mortality - Respiratory, Short-term
Age Group:	≥ 30 years	≥ 65 years	≥ 65 years	All ages	≥ 30 years	All ages	All ages
β (change in effect per 1 μg/m^3 PM) (as per Table 5-1)	0.0058	0.0008	0.00041	0.00094	0.013	0.00097	0.0019
Baseline Incidence (per 100,000) (as per Table 3-5)	1087	23352	8807	670	490	164	57
Baseline Incidence (per person)	0.01087	0.23352	0.08807	0.0067	0.0049	0.00164	0.00057
Wahroonga:							
Total Population:	16726	16726	16726	16726	16726	16726	16726
% population in assessment age-group:	62%	18%	18%	100%	62%	100%	100%
Population weighted Δx (μg/m^3):	0.020	0.020	0.020	0.020	0.020	0.020	0.020
Relative Risk:	1.000117	1.000016	1.000008	1.000019	1.000263	1.000020	1.000038
Attributable fraction (AF):	1.2E-04	1.6E-05	8.3E-06	1.9E-05	2.6E-04	2.0E-05	3.8E-05
Increased number of cases in population:	0.013	0.011	0.0022	0.0021	0.013	0.00054	0.00037
North Wahroonga:							
Total Population:	1886	1886	1886	1886	1886	1886	1886
% population in assessment age-group:	63%	16%	16%	100%	63%	100%	100%
Population weighted Δx (μg/m^3):	0.017	0.017	0.017	0.017	0.017	0.017	0.017
Relative Risk:	1.000099	1.000014	1.000007	1.000016	1.000223	1.000017	1.000033
Attributable fraction (AF):	9.9E-05	1.4E-05	7.0E-06	1.6E-05	2.2E-04	1.7E-05	3.3E-05
Increased number of cases in population:	0.0013	0.0010	0.00019	0.00020	0.0013	0.000051	0.000035
Warrawee							
Total Population:	2912	2912	2912	2912	2912	2912	2912
% population in assessment age-group:	58%	14%	14%	100%	58%	100%	100%
Population weighted Δx (μg/m^3):	0.010	0.010	0.010	0.010	0.010	0.010	0.010
Relative Risk:	1.000060	1.000008	1.000004	1.000010	1.000134	1.000010	1.000020
Attributable fraction (AF):	6.0E-05	8.3E-06	4.2E-06	9.7E-06	1.3E-04	1.0E-05	2.0E-05
Increased number of cases in population:	0.0011	0.00077	0.00015	0.00019	0.0011	0.000048	0.000033
Waitara							
Total Population:	5370	5370	5370	5370	5370	5370	5370
% population in assessment age-group:	64%	15%	15%	100%	64%	100%	100%
Population weighted Δx (μg/m^3):	0.023	0.023	0.023	0.023	0.023	0.023	0.023
Relative Risk:	1.000136	1.000019	1.000010	1.000022	1.000304	1.000023	1.000044
Attributable fraction (AF):	1.4E-04	1.9E-05	9.6E-06	2.2E-05	3.0E-04	2.3E-05	4.4E-05
Increased number of cases in population:	0.0051	0.0035	0.00068	0.00079	0.0051	0.00020	0.00014
Hornsby							
Total Population:	19863	19863	19863	19863	19863	19863	19863
% population in assessment age-group:	62%	12%	12%	100%	62%	100%	100%
Population weighted Δx (μg/m^3):	0.011	0.011	0.011	0.011	0.011	0.011	0.011
Relative Risk:	1.000067	1.000009	1.000005	1.000011	1.000149	1.000011	1.000022
Attributable fraction (AF):	6.7E-05	9.2E-06	4.7E-06	1.1E-05	1.5E-04	1.1E-05	2.2E-05
Increased number of cases in population:	0.0089	0.0049	0.0010	0.0014	0.0090	0.00036	0.00025
Normanhurst							
Total Population:	5156	5156	5156	5156	5156	5156	5156
% population in assessment age-group:	61%	19%	19%	100%	61%	100%	100%
Population weighted Δx (μg/m^3):	0.013	0.013	0.013	0.013	0.013	0.013	0.013
Relative Risk:	1.000076	1.000010	1.000005	1.000012	1.000169	1.000013	1.000025
Attributable fraction (AF):	7.6E-05	1.0E-05	5.3E-06	1.2E-05	1.7E-04	1.3E-05	2.5E-05
Increased number of cases in population:	0.0026	0.0023	0.00045	0.00042	0.0026	0.00011	0.000073
Total - All Suburbs	**0.032**	**0.024**	**0.0046**	**0.0052**	**0.033**	**0.0013**	**0.0009**

Assessment of Increased Incidence - PM2.5, Scenario 2b 2029
Northern Interchange

	Primary Indicators			Secondary Indicators			
Health Endpoint:	**Mortality - All Causes, Long-term**	**Hospitalisations - Cardiovascular, Short-term**	**Hospitalisations - Respiratory, Short-term**	**Mortality - All Causes, Short-term**	**Mortality - Cardiopulmonary, Long-term**	**Mortality - Cardiovascular, Short-term**	**Mortality - Respiratory, Short-term**
Age Group:	≥ 30 years	≥ 65 years	≥ 65 years	All ages	≥ 30 years	All ages	All ages
β (change in effect per 1 μg/m³ PM) (as per Table 5-1)	0.0058	0.0008	0.00041	0.00094	0.013	0.00097	0.0019
Baseline Incidence (per 100,000) (as per Table 3-5)	1087	23352	8807	670	490	164	57
Baseline Incidence (per person)	0.01087	0.23352	0.08807	0.0067	0.0049	0.00164	0.00057
Wahroonga:							
Total Population:	16726	16726	16726	16726	16726	16726	16726
% population in assessment age-group:	62%	18%	18%	100%	62%	100%	100%
Population weighted Δx (μg/m³):	0.024	0.024	0.024	0.024	0.024	0.024	0.024
Relative Risk:	1.000139	1.000019	1.000010	1.000023	1.000312	1.000023	1.000046
Attributable fraction (AF):	1.4E-04	1.9E-05	9.8E-06	2.3E-05	3.1E-04	2.3E-05	4.6E-05
Increased number of cases in population:	0.016	0.013	0.0026	0.0025	0.016	0.00064	0.00043
North Wahroonga:							
Total Population:	1886	1886	1886	1886	1886	1886	1886
% population in assessment age-group:	63%	16%	16%	100%	63%	100%	100%
Population weighted Δx (μg/m³):	0.020	0.020	0.020	0.020	0.020	0.020	0.020
Relative Risk:	1.000114	1.000016	1.000008	1.000019	1.000256	1.000019	1.000037
Attributable fraction (AF):	1.1E-04	1.6E-05	8.1E-06	1.9E-05	2.6E-04	1.9E-05	3.7E-05
Increased number of cases in population:	0.0015	0.0011	0.00022	0.00023	0.0015	0.000059	0.000040
Warrawee							
Total Population:	2912	2912	2912	2912	2912	2912	2912
% population in assessment age-group:	58%	14%	14%	100%	58%	100%	100%
Population weighted Δx (μg/m³):	0.012	0.012	0.012	0.012	0.012	0.012	0.012
Relative Risk:	1.000069	1.000010	1.000005	1.000011	1.000155	1.000012	1.000023
Attributable fraction (AF):	6.9E-05	9.5E-06	4.9E-06	1.1E-05	1.5E-04	1.2E-05	2.3E-05
Increased number of cases in population:	0.0013	0.00088	0.00017	0.00022	0.0013	0.000055	0.000037
Waitara							
Total Population:	5370	5370	5370	5370	5370	5370	5370
% population in assessment age-group:	64%	15%	15%	100%	64%	100%	100%
Population weighted Δx (μg/m³):	0.027	0.027	0.027	0.027	0.027	0.027	0.027
Relative Risk:	1.000157	1.000022	1.000011	1.000025	1.000352	1.000026	1.000051
Attributable fraction (AF):	1.6E-04	2.2E-05	1.1E-05	2.5E-05	3.5E-04	2.6E-05	5.1E-05
Increased number of cases in population:	0.0059	0.0040	0.00078	0.00092	0.0059	0.00023	0.00016
Hornsby							
Total Population:	19863	19863	19863	19863	19863	19863	19863
% population in assessment age-group:	62%	12%	12%	100%	62%	100%	100%
Population weighted Δx (μg/m³):	0.013	0.013	0.013	0.013	0.013	0.013	0.013
Relative Risk:	1.000076	1.000010	1.000005	1.000012	1.000170	1.000013	1.000025
Attributable fraction (AF):	7.6E-05	1.0E-05	5.4E-06	1.2E-05	1.7E-04	1.3E-05	2.5E-05
Increased number of cases in population:	0.010	0.0056	0.0011	0.0016	0.0103	0.00041	0.00028
Normanhurst							
Total Population:	5156	5156	5156	5156	5156	5156	5156
% population in assessment age-group:	61%	19%	19%	100%	61%	100%	100%
Population weighted Δx (μg/m³):	0.015	0.015	0.015	0.015	0.015	0.015	0.015
Relative Risk:	1.000088	1.000012	1.000006	1.000014	1.000197	1.000015	1.000029
Attributable fraction (AF):	8.8E-05	1.2E-05	6.2E-06	1.4E-05	2.0E-04	1.5E-05	2.9E-05
Increased number of cases in population:	0.0030	0.0027	0.00052	0.00049	0.0030	0.00012	0.000085
Total - All Suburbs	**0.037**	**0.028**	**0.0053**	**0.0060**	**0.038**	**0.0015**	**0.0010**

Appendix D Calculations of Health Impacts for $PM_{2.5}$ concentrations changes – whole project including Pennant Hills Road

Assessment of Risk and Incidence - PM2.5 - Whole Project including PHR
Scenario 2a - 2019

	Primary Indicators			Secondary Indicators			
Health Endpoint:	**Mortality - All Causes, Long-term**	**Hospitalisations - Cardiovascular. Short-term**	**Hospitalisations - Respiratory, Short-term**	**Mortality - All Causes, Short-term**	**Mortality - Cardiopulmonary, Long-term**	**Mortality - Cardiovascular, Short-term**	**Mortality - Respiratory, Short-term**
Age Group:	≥ 30 years	≥ 65 years	≥ 65 years	All ages	≥ 30 years	All ages	All ages
β (change in effect per 1 µg/m^3 PM) (as per Table 5-1)	0.0058	0.0008	0.00041	0.00094	0.013	0.00097	0.0019
Baseline Incidence (per 100,000) (as per Table 3-5)	1087	23352	8807	670	490	164	57
Baseline Incidence (per person)	0.01087	0.23352	0.08807	0.0067	0.0049	0.00164	0.00057
Carlingford							
Total Population (part of suburb):	16292	16292	16292	16292	16292	16292	16292
% population in assessment age-group:	63%	16%	16%	100%	63%	100%	100%
Population weighted Δx (µg/m^3):	0.0074	0.0074	0.0074	0.0074	0.0074	0.0074	0.0074
Relative Risk:	1.0000428	1.0000059	1.0000030	1.0000069	1.0000960	1.0000072	1.0000140
Attributable fraction (AF):	4.3E-05	5.9E-06	3.0E-06	6.9E-06	9.6E-05	7.2E-06	1.4E-05
Increased number of cases in population:	0.0048	0.0036	0.00070	0.00076	0.0048	0.00019	0.00013
Risk:	4.7E-07	1.4E-06	2.7E-07	4.7E-08	4.7E-07	1.2E-08	8.0E-09
West Pennant Hills							
Total Population (part of suburb):	11882	11882	11882	11882	11882	11882	11882
% population in assessment age-group:	61%	12%	12%	100%	61%	100%	100%
Population weighted Δx (µg/m^3):	-0.0316	-0.0316	-0.0316	-0.0316	-0.0316	-0.0316	-0.0316
Relative Risk:	0.999817	0.999975	0.999987	0.999970	0.999590	0.999969	0.999940
Attributable fraction (AF):	-1.8E-04	-2.5E-05	-1.3E-05	-3.0E-05	-4.1E-04	-3.1E-05	-6.0E-05
Increased number of cases in population:	-0.0144	-0.0087	-0.0017	-0.0024	-0.015	-0.00060	-0.00041
Risk:	-2.0E-06	-5.9E-06	-1.1E-06	-2.0E-07	-2.0E-06	-5.0E-08	-3.4E-08
North Rocks							
Total Population (part of suburb):	5293	5293	5293	5293	5293	5293	5293
% population in assessment age-group:	64%	16%	16%	100%	64%	100%	100%
Population weighted Δx (µg/m^3):	0.0027	0.0027	0.0027	0.0027	0.0027	0.0027	0.0027
Relative Risk:	1.0000157	1.0000022	1.0000011	1.0000025	1.0000351	1.0000026	1.0000051
Attributable fraction (AF):	1.6E-05	2.2E-06	1.1E-06	2.5E-06	3.5E-05	2.6E-06	5.1E-06
Increased number of cases in population:	0.00058	0.00043	0.00008	0.00009	0.00058	0.000023	0.000015
Risk:	1.7E-07	5.0E-07	9.8E-08	1.7E-08	1.7E-07	4.3E-09	2.9E-09
Epping/North Epping							
Total Population (part of suburbs):	10146	10146	10146	10146	10146	10146	10146
% population in assessment age-group:	60%	13%	13%	100%	60%	100%	100%
Population weighted Δx (µg/m^3):	0.0037	0.0037	0.0037	0.0037	0.0037	0.0037	0.0037
Relative Risk:	1.0000215	1.0000030	1.0000015	1.0000035	1.0000482	1.0000036	1.0000070
Attributable fraction (AF):	2.1E-05	3.0E-06	1.5E-06	3.5E-06	4.8E-05	3.6E-06	7.0E-06
Increased number of cases in population:	0.0014	0.0009	0.00018	0.00024	0.0014	0.000060	0.000041
Risk:	2.3E-07	6.9E-07	1.3E-07	2.3E-08	2.4E-07	5.9E-09	4.0E-09
Pennant Hills/Cheltenham							
Total Population (part of suburbs):	15184	15184	15184	15184	15184	15184	15184
% population in assessment age-group:	74%	16%	16%	100%	74%	100%	100%
Population weighted Δx (µg/m^3):	-0.1957	-0.1957	-0.1957	-0.1957	-0.1957	-0.1957	-0.1957
Relative Risk:	0.9988653	0.9998434	0.9999197	0.9998160	0.9974585	0.9998101	0.9996282
Attributable fraction (AF):	-1.1E-03	-1.6E-04	-8.0E-05	-1.8E-04	-2.5E-03	-1.9E-04	-3.7E-04
Increased number of cases in population:	-0.1387	-0.0866	-0.01674	-0.01872	-0.1403	-0.004729	-0.003219
Risk:	-1.2E-05	-3.7E-05	-7.1E-06	-1.2E-06	-1.2E-05	-3.1E-07	-2.1E-07
Wahroonga/Warrawee:							
Total Population (part of suburb):	16284	16284	16284	16284	16284	16284	16284
% population in assessment age-group:	62%	18%	18%	100%	62%	100%	100%
Population weighted Δx (µg/m^3):	-0.0048	-0.0048	-0.0048	-0.0048	-0.0048	-0.0048	-0.0048
Relative Risk:	0.999972	0.999996	0.999998	0.999995	0.999937	0.999995	0.999991
Attributable fraction (AF):	-2.8E-05	-3.9E-06	-2.0E-06	-4.5E-06	-6.3E-05	-4.7E-06	-9.2E-06
Increased number of cases in population:	-0.003	-0.003	-0.0005	-0.0005	-0.003	-0.00013	-0.00009
Risk:	-3.0E-07	-9.0E-07	-1.7E-07	-3.0E-08	-3.1E-07	-7.7E-09	-5.2E-09
Hornsby/Waitara							
Total Population (part of suburbs):	17527	17527	17527	17527	17527	17527	17527
% population in assessment age-group:	62%	12%	12%	100%	62%	100%	100%
Population weighted Δx (µg/m^3):	-0.0081	-0.0081	-0.0081	-0.0081	-0.0081	-0.0081	-0.0081
Relative Risk:	0.999953	0.999993	0.999997	0.999992	0.999894	0.999992	0.999985
Attributable fraction (AF):	-4.7E-05	-6.5E-06	-3.3E-06	-7.7E-06	-1.1E-04	-7.9E-06	-1.5E-05
Increased number of cases in population:	-0.0056	-0.0031	-0.00060	-0.0009	-0.0056	-0.00023	-0.00015
Risk:	-5.1E-07	-1.5E-06	-2.9E-07	-5.1E-08	-5.2E-07	-1.3E-08	-8.8E-09
Normanhurst/Thornleigh/Westleigh							
Total Population (part of suburbs):	11181	11181	11181	11181	11181	11181	11181
% population in assessment age-group:	61%	19%	19%	100%	61%	100%	100%
Population weighted Δx (µg/m^3):	-0.2123	-0.2123	-0.2123	-0.2123	-0.2123	-0.2123	-0.2123
Relative Risk:	0.998769	0.999830	0.999913	0.999800	0.997244	0.999794	0.999597
Attributable fraction (AF):	-1.2E-03	-1.7E-04	-8.7E-05	-2.0E-04	-2.8E-03	-2.1E-04	-4.0E-04
Increased number of cases in population:	-0.0914	-0.0821	-0.01586	-0.01495	-0.0924	-0.00378	-0.002571
Risk:	-1.3E-05	-4.0E-05	-7.7E-06	-1.3E-06	-1.4E-05	-3.4E-07	-2.3E-07
Change in population risk for all suburbs	**-2.8E-05**	**-8.2E-05**	**-1.6E-05**	**-2.8E-06**	**-2.8E-05**	**-7.0E-07**	**-4.8E-07**
Change in incidence for all suburbs	**-0.246**	**-0.178**	**-0.034**	**-0.036**	**-0.249**	**-0.009**	**-0.006**

Assessment of Risk and Incidence - PM2.5 - Whole Project including PHR
Scenario 2b - 2029

	Primary Indicators			Secondary Indicators			
Health Endpoint:	**Mortality - All Causes, Long-term**	**Hospitalisations - Cardiovascular. Short-term**	**Hospitalisations - Respiratory, Short-term**	**Mortality - All Causes, Short-term**	**Mortality - Cardiopulmonary, Long-term**	**Mortality - Cardiovascular, Short-term**	**Mortality - Respiratory, Short-term**
Age Group:	≥ 30 years	≥ 65 years	≥ 65 years	All ages	≥ 30 years	All ages	All ages
β (change in effect per 1 µg/m^3 PM) (as per Table 5-1)	0.0058	0.0008	0.00041	0.00094	0.013	0.00097	0.0019
Baseline Incidence (per 100,000) (as per Table 3-5)	1087	23352	8807	670	490	164	57
Baseline Incidence (per person)	0.01087	0.23352	0.08807	0.0067	0.0049	0.00164	0.00057
Carlingford							
Total Population (part of suburb):	16292	16292	16292	16292	16292	16292	16292
% population in assessment age-group:	63%	16%	16%	100%	63%	100%	100%
Population weighted Δx (µg/m^3):	0.0078	0.0078	0.0078	0.0078	0.0078	0.0078	0.0078
Relative Risk:	1.0000453	1.0000062	1.0000032	1.0000073	1.0001015	1.0000076	1.0000148
Attributable fraction (AF):	4.5E-05	6.2E-06	3.2E-06	7.3E-06	1.0E-04	7.6E-06	1.5E-05
Increased number of cases in population:	0.0051	0.0038	0.00074	0.00080	0.0051	0.00020	0.00014
Risk:	4.9E-07	1.5E-06	2.8E-07	4.9E-08	5.0E-07	1.2E-08	8.5E-09
West Pennant Hills							
Total Population (part of suburb):	11882	11882	11882	11882	11882	11882	11882
% population in assessment age-group:	61%	12%	12%	100%	61%	100%	100%
Population weighted Δx (µg/m^3):	-0.0398	-0.0398	-0.0398	-0.0398	-0.0398	-0.0398	-0.0398
Relative Risk:	0.999769	0.999968	0.999984	0.999963	0.999483	0.999961	0.999924
Attributable fraction (AF):	-2.3E-04	-3.2E-05	-1.6E-05	-3.7E-05	-5.2E-04	-3.9E-05	-7.6E-05
Increased number of cases in population:	-0.0182	-0.0110	-0.0021	-0.0030	-0.018	-0.00075	-0.00051
Risk:	-2.5E-06	-7.4E-06	-1.4E-06	-2.5E-07	-2.5E-06	-6.3E-08	-4.3E-08
North Rocks							
Total Population (part of suburb):	5293	5293	5293	5293	5293	5293	5293
% population in assessment age-group:	64%	16%	16%	100%	64%	100%	100%
Population weighted Δx (µg/m^3):	0.0029	0.0029	0.0029	0.0029	0.0029	0.0029	0.0029
Relative Risk:	1.0000167	1.0000023	1.0000012	1.0000027	1.0000374	1.0000028	1.0000055
Attributable fraction (AF):	1.7E-05	2.3E-06	1.2E-06	2.7E-06	3.7E-05	2.8E-06	5.5E-06
Increased number of cases in population:	0.00061	0.00046	0.00009	0.00010	0.00062	0.000024	0.000016
Risk:	1.8E-07	5.4E-07	1.0E-07	1.8E-08	1.8E-07	4.6E-09	3.1E-09
Epping/North Epping							
Total Population (part of suburbs):	10146	10146	10146	10146	10146	10146	10146
% population in assessment age-group:	60%	13%	13%	100%	60%	100%	100%
Population weighted Δx (µg/m^3):	0.0040	0.0040	0.0040	0.0040	0.0040	0.0040	0.0040
Relative Risk:	1.0000230	1.0000032	1.0000016	1.0000037	1.0000516	1.0000039	1.0000075
Attributable fraction (AF):	2.3E-05	3.2E-06	1.6E-06	3.7E-06	5.2E-05	3.9E-06	7.5E-06
Increased number of cases in population:	0.0015	0.0010	0.00019	0.00025	0.0015	0.000064	0.000044
Risk:	2.5E-07	7.4E-07	1.4E-07	2.5E-08	2.5E-07	6.3E-09	4.3E-09
Pennant Hills/Cheltenham							
Total Population (part of suburbs):	15184	15184	15184	15184	15184	15184	15184
% population in assessment age-group:	74%	16%	16%	100%	74%	100%	100%
Population weighted Δx (µg/m^3):	-0.1950	-0.1950	-0.1950	-0.1950	-0.1950	-0.1950	-0.1950
Relative Risk:	0.9988695	0.9998440	0.9999200	0.9998167	0.9974679	0.9998108	0.9996295
Attributable fraction (AF):	-1.1E-03	-1.6E-04	-8.0E-05	-1.8E-04	-2.5E-03	-1.9E-04	-3.7E-04
Increased number of cases in population:	-0.1382	-0.0863	-0.01668	-0.01865	-0.1398	-0.004711	-0.003208
Risk:	-1.2E-05	-3.6E-05	-7.0E-06	-1.2E-06	-1.2E-05	-3.1E-07	-2.1E-07
Wahroonga/Warrawee:							
Total Population (part of suburb):	16284	16284	16284	16284	16284	16284	16284
% population in assessment age-group:	62%	18%	18%	100%	62%	100%	100%
Population weighted Δx (µg/m^3):	-0.0193	-0.0193	-0.0193	-0.0193	-0.0193	-0.0193	-0.0193
Relative Risk:	0.999888	0.999985	0.999992	0.999982	0.999749	0.999981	0.999963
Attributable fraction (AF):	-1.1E-04	-1.5E-05	-7.9E-06	-1.8E-05	-2.5E-04	-1.9E-05	-3.7E-05
Increased number of cases in population:	-0.012	-0.010	-0.0020	-0.0020	-0.012	-0.00050	-0.00034
Risk:	-1.2E-06	-3.6E-06	-7.0E-07	-1.2E-07	-1.2E-06	-3.1E-08	-2.1E-08
Hornsby/Waitara							
Total Population (part of suburbs):	17527	17527	17527	17527	17527	17527	17527
% population in assessment age-group:	62%	12%	12%	100%	62%	100%	100%
Population weighted Δx (µg/m^3):	-0.0116	-0.0116	-0.0116	-0.0116	-0.0116	-0.0116	-0.0116
Relative Risk:	0.999933	0.999991	0.999995	0.999989	0.999849	0.999989	0.999978
Attributable fraction (AF):	-6.7E-05	-9.3E-06	-4.8E-06	-1.1E-05	-1.5E-04	-1.1E-05	-2.2E-05
Increased number of cases in population:	-0.0080	-0.0044	-0.00085	-0.0013	-0.0080	-0.00032	-0.00022
Risk:	-7.3E-07	-2.2E-06	-4.2E-07	-7.3E-08	-7.4E-07	-1.8E-08	-1.3E-08
Normanhurst/Thornleigh/Westleigh							
Total Population (part of suburbs):	11181	11181	11181	11181	11181	11181	11181
% population in assessment age-group:	61%	19%	19%	100%	61%	100%	100%
Population weighted Δx (µg/m^3):	-0.2228	-0.2228	-0.2228	-0.2228	-0.2228	-0.2228	-0.2228
Relative Risk:	0.998709	0.999822	0.999909	0.999791	0.997108	0.999784	0.999577
Attributable fraction (AF):	-1.3E-03	-1.8E-04	-9.1E-05	-2.1E-04	-2.9E-03	-2.2E-04	-4.2E-04
Increased number of cases in population:	-0.0959	-0.0861	-0.01664	-0.01569	-0.0969	-0.00396	-0.002698
Risk:	-1.4E-05	-4.2E-05	-8.0E-06	-1.4E-06	-1.4E-05	-3.5E-07	-2.4E-07
Change in population risk for all suburbs	**-3.0E-05**	**-8.9E-05**	**-1.7E-05**	**-3.0E-06**	**-3.0E-05**	**-7.5E-07**	**-5.1E-07**
Change in incidence for all suburbs	**-0.265**	**-0.193**	**-0.037**	**-0.039**	**-0.268**	**-0.010**	**-0.007**

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Appendix E Calculations for design analysis A

E1 General

This appendix presents calculations relevant top predicted health impacts associated with design analysis A, the theoretical maximum peak hour traffic flow.

This design analysis has been conducted to ensure that the project's ventilation system is adequately sized to cater for tunnel full of traffic. It assumes that during peak hours, the maximum number of vehicles that can fit into the tunnel (4,000 passenger car units per two lane main alignment tunnel adjusted for speed). This design analysis represents the physical limit of the main alignment tunnels and is based on forecast traffic volumes that are unlikely to eventuate due to a range of factors.

The calculations presented are associated with the assessment of pollutants as presented in the main body of the report.

E2 Assessment of Key Pollutants

On the basis of the guidelines identified and outlined in **Section 4.2** of the main report the following can be noted in relation to potential exposures to nitrogen dioxide and carbon monoxide for design analysis A:

Nitrogen dioxide

- The maximum 1 hour average cumulative (background plus the project) concentration is predicted to be 182 µg/m^3, which is below the acute health based guideline of 246 µg/m^3.
- The maximum annual average cumulative (background plus project) concentration is predicted to be 42.6 µg/m^3, which is below the chronic health based guideline of 62 µg/m^3.

Carbon Monoxide

- The maximum 1 hour average cumulative (background plus the project) concentration is predicted to be 3 804 µg/m^3, which is below the acute health based guideline of 30 000 µg/m^3.
- The maximum 8-hour average cumulative (background plus project) concentration is predicted to be 2 684 µg/m^3, which is below the chronic health based guideline of 10 000 µg/m^3.

All the concentrations of nitrogen dioxide and carbon monoxide are well below the relevant health based guidelines. Hence there are no adverse health effects expected in relation to exposures (acute and chronic) to nitrogen dioxide or carbon monoxide in the local area surrounding the project.

E3 Assessment of Exposure to polycyclic aromatic hydrocarbons and volatile organic compounds

On the basis of the speciation of individual polycyclic aromatic hydrocarbons and volatile organic compounds, and the acute and chronic guidelines identified and outlined in **Section 4.3** of the main report the following has been calculated in relation to potential exposures to these compounds for this scenario:

Table E1 Evaluation of potential acute impacts in local area – design analysis A

Key VOC	Proportion of total VOCs (%)*		Health based acute guideline, and basis (µg/m^3)	Maximum predicted 1-hour average concentration from project** and calculated HI for each interchange			
				Northern interchange		Southern interchange	
	2019	2029		Max Conc. (µg/m^3)	HI	Max Conc. (µg/m^3)	HI
Total VOCs				**7.4**		**9.0**	
Benzene	3.3	3.8	**29[A1] to 170[T1]** (lower value adopted) A1: Acute guideline (1hr to 14 day exposure), based on immunological effects in mice. T1: Acute 1 hour health based guideline, based on depressed peripheral lymphocytes and depressed mitogen-induced blastogenesis (mice study)	0.24	0.0084	0.30	0.010
Toluene	5.6	6.7	**4500[T2]** Acute 1 hour health based guideline, based on eye and nose irritation, increased occurrence of headache and intoxication in human male volunteers	0.42	0.000093	0.51	0.00011
Xylenes	4.6	5.5	**2200[T3]** Acute 1 hour health based guideline, based on mild respiratory effects and subjective symptoms of neurotoxicity in human volunteers	0.34	0.00016	0.42	0.00019
1,3-Butadiene	0.9	1.0	**660[O1]** Acute 1 hour health based guideline, based on developmental effects	0.067	0.000102	0.081	0.00012
Formaldehyde	4.9	3.9	**15[T4]** Acute 1 hour health based guideline, based on eye and nose irritation in human volunteers	0.36	0.024	0.44	0.029
Acetaldehyde	2.1	1.6	**470[O2]** Acute 1 hour health based guideline, based on effects on sensory irritation, bronchoconstriction, eye redness and swelling	0.15	0.00032	0.18	0.00039
			Total HI		0.033		0.040

Notes:

*	Percentage of each individual volatile organic compound is based on a weighted average of emissions from the range of vehicle types proposed to be used on the project in 2019 and 2029 (refer to discussion above table)
**	Concentrations presented for the 1 hour average are the predicted incremental 99.9th percentile concentrations (as provided from the AQIA)
A1:	Acute inhalation guideline (for exposures from 1 hour to 14 days) from review by ATSDR 2008 for benzene
T1:	TCEQ 2007, Benzene, Development Support Document. Texas Commission of Environmental Quality, 1 hour average guideline value (include additional 3.3 fold safety factor). This acute guideline is lower than that derived by the OEHHA (based on older studies)
T2:	TCEQ 2008, Toluene, Development Support Document. Texas Commission of Environmental Quality, 1 hour average guideline value (include additional 3.3 fold safety factor)
T3:	TCEQ 2009, Xylenes, Development Support Document. Texas Commission of Environmental Quality, 1 hour average guideline value (include additional 3.3 fold safety factor)
T4:	TCEQ 2008, Formaldehyde, Development Support Document. Texas Commission of Environmental Quality, 1 hour average guideline value (include additional 3.3 fold safety factor). This guideline is noted to be lower than the acute guideline available from the WHO (2000a, 2010) of 100 µg/m^3 for formaldehyde
O1:	OEHHA 2013, Acute (1 hour average) guideline derived by the California Office of Environmental Health Hazard Assessment. The guideline developed is lower than developed by TCEQ (2008) based on the same critical study
O2:	OEHHA 2008, Acute (1 hour average) guideline derived by the California Office of Environmental Health Hazard Assessment

Table E2 Evaluation of potential chronic impacts in local area – design analysis A

Key VOC	Proportion of total VOCs* (%)		Health based chronic guideline and basis (µg/m^3)		Maximum predicted annual average concentration from project** and calculated HI for each interchange			
					Northern interchange		Southern interchange	
					Max Conc. (µg/m^3)	HI	Max Conc. (µg/m^3)	HI
	2019	2029	Total VOCs		0.20		0.21	
Benzene	3.3	3.8	**1.7**[W1] Benzene is classified as a known human carcinogen by IARC. Chronic guideline based on excess risk of leukaemia		0.0066	0.0039	0.0070	0.0041
Toluene	5.6	6.7	**5000**[U1] Chronic guideline based on neurological effects in an occupational study (converted to public health value using safety factors)		0.0113	$2.3X10^{-6}$	0.0120	$2.4X10^{-6}$
Xylenes	4.6	5.5	**220**[A1] Chronic guideline based on mild subjective respiratory and neurological symptoms in an occupational study (converted to public health value using safety factors)		0.0093	0.000042	0.0099	0.000045
1,3-Butadiene	0.9	1.0	**0.3**[U2] 1,3-Butadiene is classified by IARC as a probable human carcinogen. Chronic air guideline based on an excess risk of leukaemia		0.0018	0.0061	0.0019	0.0064
Formaldehyde	4.9	3.9	**3.3**[T1] Formaldehyde is classified by IARC as carcinogenic to humans. The guideline developed is based on the protection of all adverse effects including cancer and non-cancer (including short term effects)		0.0098	0.0030	0.010	0.0031
Acetaldehyde	2.1	1.6	**9**[U3] Chronic guideline based on nasal effects (in a rat study) (converted to a public health value using safety factors)		0.0041	0.00046	0.0044	0.00048
	B		Total PAHs		$3.8X10^{-5}$		$5.0X10^{-5}$	
Naphthalene	70		**3**[U4] Chronic guideline based on nasal effects (in a mouse study) (converted to a public health value using safety factors)		$2.7X10^{-5}$	$8.9X10^{-6}$	$3.5X10^{-5}$	$1.2X10^{-5}$
Acenaphthylene	4.9		200[U5S]	Refer to notes for ref U5	$1.9X10^{-6}$	$9.4X10^{-9}$	$2.5X10^{-6}$	$1.2X10^{-8}$
Acenaphthene	2.0		200[U5]		$7.7X10^{-7}$	$3.8X10^{-9}$	$1.0X10^{-6}$	$5.0X10^{-9}$
Fluorene	5.0		140[U5]		$1.9X10^{-6}$	$1.4X10^{-8}$	$2.5X10^{-6}$	$1.8X10^{-8}$
Phenanthrene	3.4		140[U5S]		$1.3X10^{-6}$	$9.3X10^{-9}$	$1.7X10^{-6}$	$1.2X10^{-8}$
Anthracene	0.49		100[U5]		$1.9X10^{-7}$	$1.9X10^{-9}$	$2.5X10^{-7}$	$2.5X10^{-9}$
Fluoranthene	0.45		140[U5]		$1.7X10^{-7}$	$1.2X10^{-9}$	$2.3X10^{-7}$	$1.6X10^{-9}$
Pyrene	0.71		100[U5]		$2.7X10^{-7}$	$2.7X10^{-9}$	$3.6X10^{-7}$	$3.6X10^{-9}$

Key VOC	Proportion of total VOCs* (%)	Health based chronic guideline and basis (µg/m³)	Maximum predicted annual average concentration from project** and calculated HI for each interchange			
			Northern interchange		Southern interchange	
			Max Conc. (µg/m³)	HI	Max Conc. (µg/m³)	HI
Benzo(a)pyrene TEQ	4.6	**0.00012**[W2] BaP is classified by IARC as a known human carcinogen, which relates to BaP as well as all the other carcinogenic PAHs assessed as a BaP toxicity equivalent value. The chronic guideline is based on protection from lung cancer for an occupational study	$1.8X10^{-6}$	0.015	$2.3X10^{-6}$	0.019
		Total HI (VOCs + PAHs)		**0.028**		**0.033**

Notes:

* Percentage of each individual volatile organic compounds and polycyclic aromatic hydrocarbons is based on a weighted average of emissions from the range of vehicle types proposed to be used on the project in 2019 and 2029, and for normal traffic flow or congested traffic flow (refer to discussion above table)

** Concentrations presented for the annual average are as provided from the AQIA

B Polycyclic aromatic hydrocarbon speciation data for congested traffic flow – utilised in the assessment of the worst-case emissions

W1: WHO 2000 Air Quality Guidelines, value for benzene is based on non-threshold carcinogenic effects (excess lifetime risk of leukaemia). Guideline value based on incremental cancer risk of $1x10^{-5}$, consistent with guidance provided by NEPM (1999 amended 2013) and enHealth (2012)

W2: WHO 2010 Guidelines for Indoor Air Quality, value for BaP is based on non-threshold carcinogenic effects from occupational study of coke workers (lung cancer is critical effect). Guideline value based on incremental cancer risk of $1x10^{-5}$, consistent with guidance provided by NEPM (1999 amended 2013) and enHealth (2012)

T1: TCEQ 2008, Formaldehyde, Development Support Document. Texas Commission of Environmental Quality. The air guideline is derived on the basis of irritation of the eyes and airway discomfort in humans, with review of carcinogenic and other non-carcinogenic effects found to be adequately protected by this guideline. The guideline is more conservative than derived by the WHO (2010)

A1: ATSDR 2007, Toxicological Profile for Xylene, chronic inhalation guideline derived is the most current robust evaluation

U1: USEPA evaluation for toluene (most recently reviewed in 2005). This is the most current evaluation of effects associated with chronic inhalation exposure to toluene and is consistent with the value used to derive the NEPM (1999 amended 2013) health based guidelines

U2: USEPA evaluation of 1,3-butadiene (most recently updated in 2002) with the chronic guideline adopted as the lower from the evaluation of non-threshold carcinogenic effects and non-cancer effects. This is the most conservative evaluation of this compound. A more recent review by TCEQ (2013) on the basis of the same critical studies as well as more current studies resulted in a higher chronic air guideline value.

U3: USEPA evaluation of acetaldehyde (most recently updated in 1991). The guideline established is lower than more recent reviews undertaken by the WHO (2000) and the Californian OEHHA where less conservative evaluations are presented.

U4: USEPA evaluation of naphthalene (most recently updated in 1998). The guideline established is and is consistent with the value used to derive the NEPM (1999 amended 2013) health based guidelines

U5: Guideline available from the USEPA. Chronic guidelines for non-carcinogenic polycyclic aromatic hydrocarbons are based on criteria derived from oral studies (for critical effects on the liver, kidney and haematology) which are then converted to an inhalation value (relevant for the protection of public health, including the use of safety factors) for use in this assessment. The value presented in the above table has been converted from an acceptable dose in mg/kg/day to an acceptable air concentration assuming a body weight of 70kg and inhalation of 20 m^3/day (as per (USEPA 2009a))

U5S: No guideline available for individual polycyclic aromatic hydrocarbon, hence a surrogate compound has been used for the purpose of screening. The surrogate compound is a polycyclic aromatic hydrocarbon of similar structure and toxicity. In relation to the surrogates adopted in this evaluation, acenaphthene has been adopted as a surrogate for acenaphthylene, fluoranthene has been adopted as a surrogate for phenanthrene

Review of the acute assessment indicates that during the design analysis A, the maximum short-duration peak (1 hour average) concentrations of volatile organic compounds (assessed as the key individual volatile organic compounds and as a sum of all the individual volatile organic compounds) in air surrounding the northern and southern interchanges are well below the relevant acute health based guidelines. The maximum HI calculated for acute exposure to the volatile organic compounds is 0.040, well below the target HI of 1 (around 25 times lower than the target HI).

Review of the chronic assessment indicates that during the design analysis A, the maximum long-term average (annual average) concentrations of volatile organic compounds and polycyclic aromatic hydrocarbons (assessed as the key individual volatile organic compound and polycyclic aromatic hydrocarbon compounds and as a sum of all the individual volatile organic compounds and polycyclic aromatic hydrocarbons) in air surrounding the northern and southern interchanges are well below the relevant long-term (chronic) health based guidelines. These are guidelines that are based on the protection of public health for inhalation exposures all day (24 hours), every day (365 days per year) for a lifetime (at least 70 years). The maximum HI calculated for exposure to the volatile organic compounds and polycyclic aromatic hydrocarbons is 0.033, well below the target HI of 1 (around 30 times lower than the target HI).

E4 Assessment of cumulative impacts from particulates

On the basis of the guidelines identified and outlined in **Section 4.4** of the main report and the detailed evaluation presented in the AQIA, the operation of the project is not predicted to result in any additional days of exceedance (over and above exceedances of the guidelines that occurs as a result of bushfires etc).

E5 Assessment of incremental impacts from particulates

On the basis of the approach outlined in **Section 5** of the main report the following can be noted in relation to potential incremental exposures to particulate matter (where a maximum annual average incremental increase in $PM_{2.5}$ = 0.16 µg/m^3 and 0.25 µg/m^3 for the northern and southern interchanges respectively) for design analysis A, for the primary health indicators:

- Mortality, all causes (≥30 years): calculated risk = 1×10^{-5} for the northern interchange and 1.6×10^{-5} for the southern interchanges.
- Cardiovascular hospitalisations (≥65 years): calculated risk = 3×10^{-5} for the northern interchange and 5×10^{-5} for the southern interchange.
- Respiratory hospitalisations (≥65 years): calculated risk = 6×10^{-6} for the northern interchange and 9×10^{-6} for the southern interchange.

The predicted increase in risk for these health endpoints remains within the range of tolerable risks identified and outlined in **Section 5.4** of the main report. This scenario is not considered likely to occur and if it were to occur it would not be every day of the year. Hence the calculations undertaken in relation to increased risk from the northern and southern interchanges do not change the assessment presented in the main report.

carbon neutral

australian made

recycled