

NorthConnex

Building for the future



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

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

Building for the future



Technical working paper: Air quality

Technical Working Paper: Air Quality

NorthConnex

Client: Roads and Maritime Services

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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 (PM₁₀ and PM_{2.5}), nitrogen dioxide (NO₂), 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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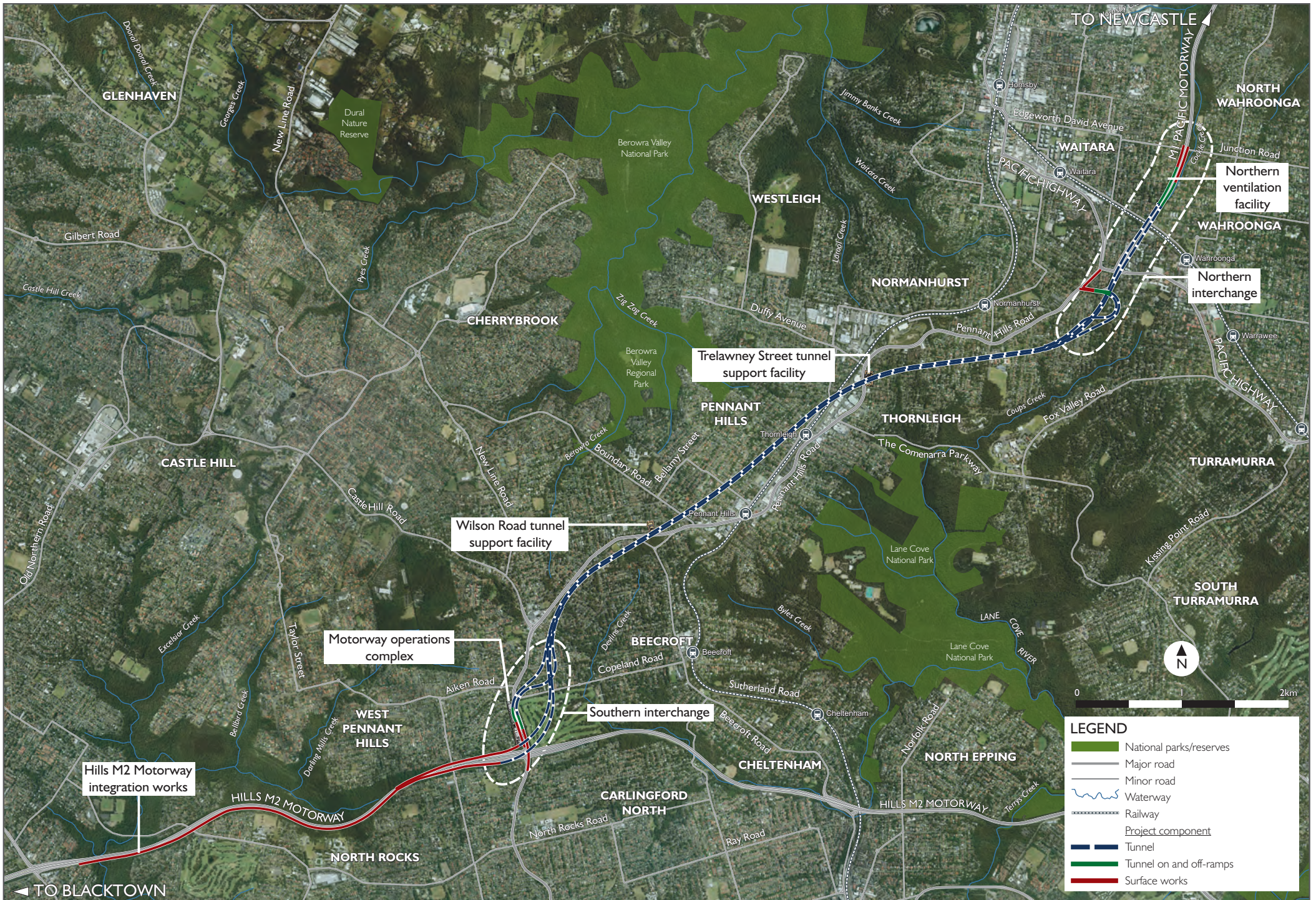


Figure 1 The project

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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 PM₁₀ and PM_{2.5} values, consideration of impacts from dispersal of TSP, CO, NO₂ 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.

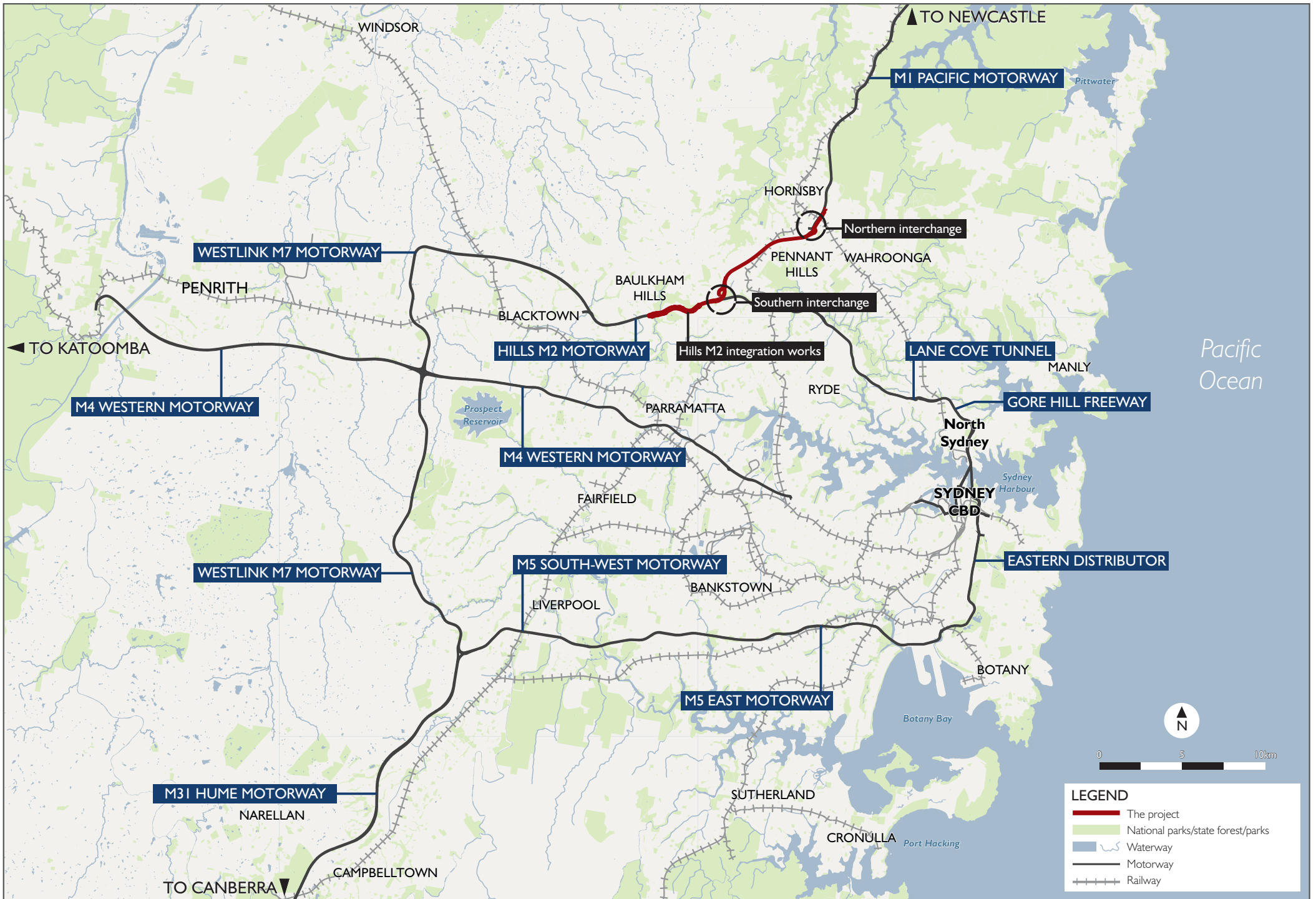


Figure 2 Regional context of the project

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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 PM₁₀ 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/m³ for diesel vehicle exhaust emissions

from cars. This represents approximately 95 per cent of the PM₁₀ emission rate of 2.1 kg/m³. 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/m³ for PM_{2.5}; this represents approximately 93 per cent of the PM₁₀ factor of 0.067 kg/m³. 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 PM₁₀ 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 NO₂), while diesel engines emit around 90 per cent NO. In the presence of ozone (O₃), which occurs naturally in the atmosphere, the NO oxidises to NO₂, 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 NO₂ (Bluett et al., 2008).

VOCs are emitted both from the vehicle exhausts and from the fuel tank (breathing losses) as the fuel heats¹. 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 direction². 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 | <ul style="list-style-type: none"> - 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 | <ul style="list-style-type: none"> - 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 | <ul style="list-style-type: none"> - 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 PM₁₀ criteria do, however, occur in Sydney, primarily as a result of bushfires and dust storms. The Air NEPM sets a national standard for PM₁₀ of 50 micrograms per cubic metre ($\mu\text{g}/\text{m}^3$) 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 PM₁₀ 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.

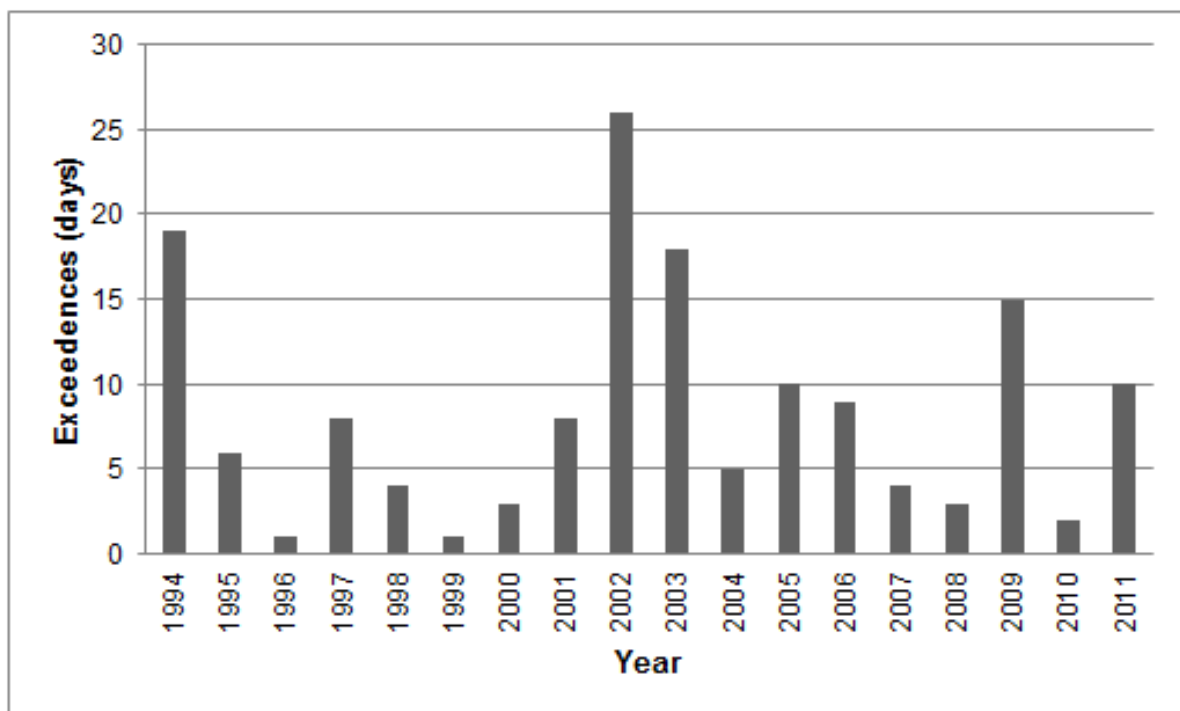


Figure 3 24 hour PM₁₀ exceedences: Sydney, 1994 – 2011 (source: EPA, 2012)

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 PM₁₀ 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 PM₁₀ concentrations using a PM₁₀ 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 PM₁₀ 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 PM₁₀ 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 PM₁₀ 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 PM₁₀ 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.

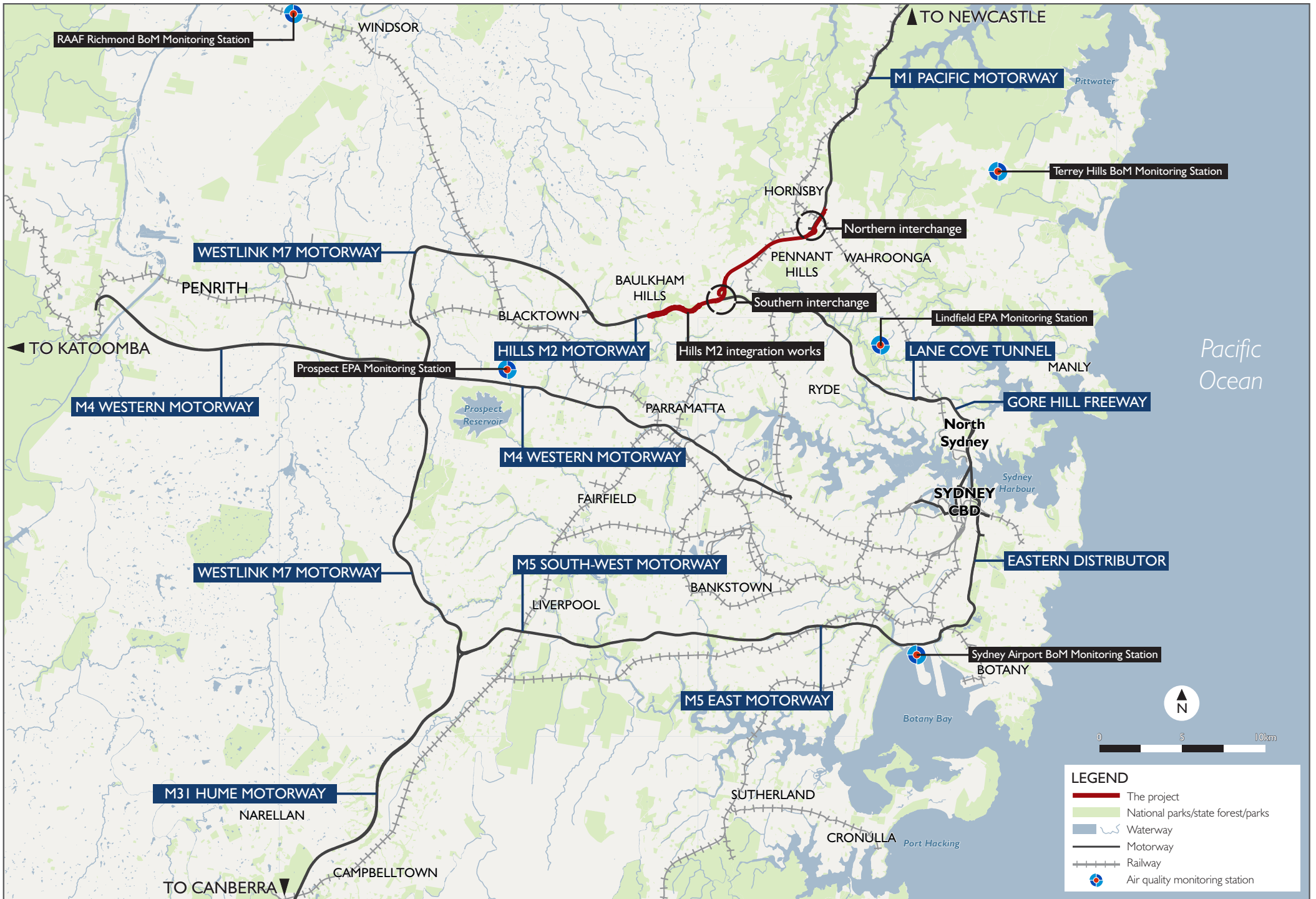


Figure 4 Regional air quality monitoring stations

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The PM₁₀ 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 PM₁₀ concentration between 2009 and 2011 of 222 µg/m³. Nine exceedences of the criterion were recorded in 2009.

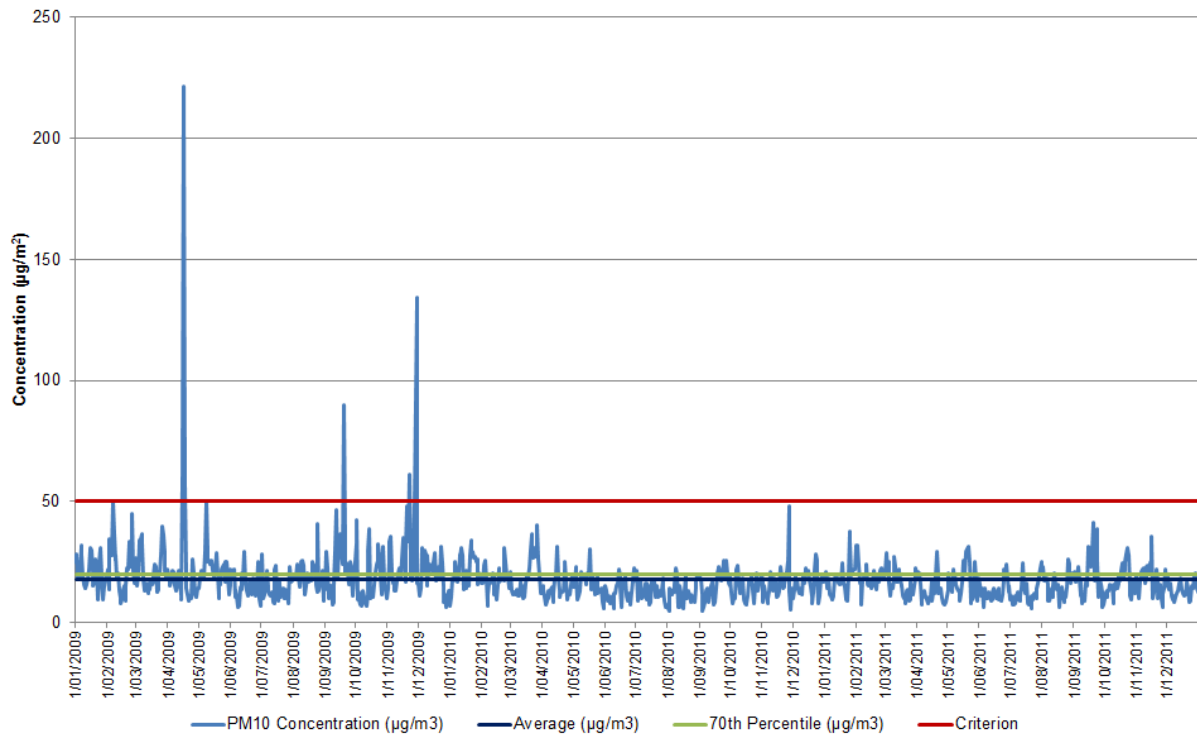


Chart 1 Combined OEH 24 hour PM₁₀ concentrations, 2009 - 2011

Table 3 Combined OEH monitoring data from Lindfield and Prospect – 24 hour average PM₁₀ (µg/m³) – 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.

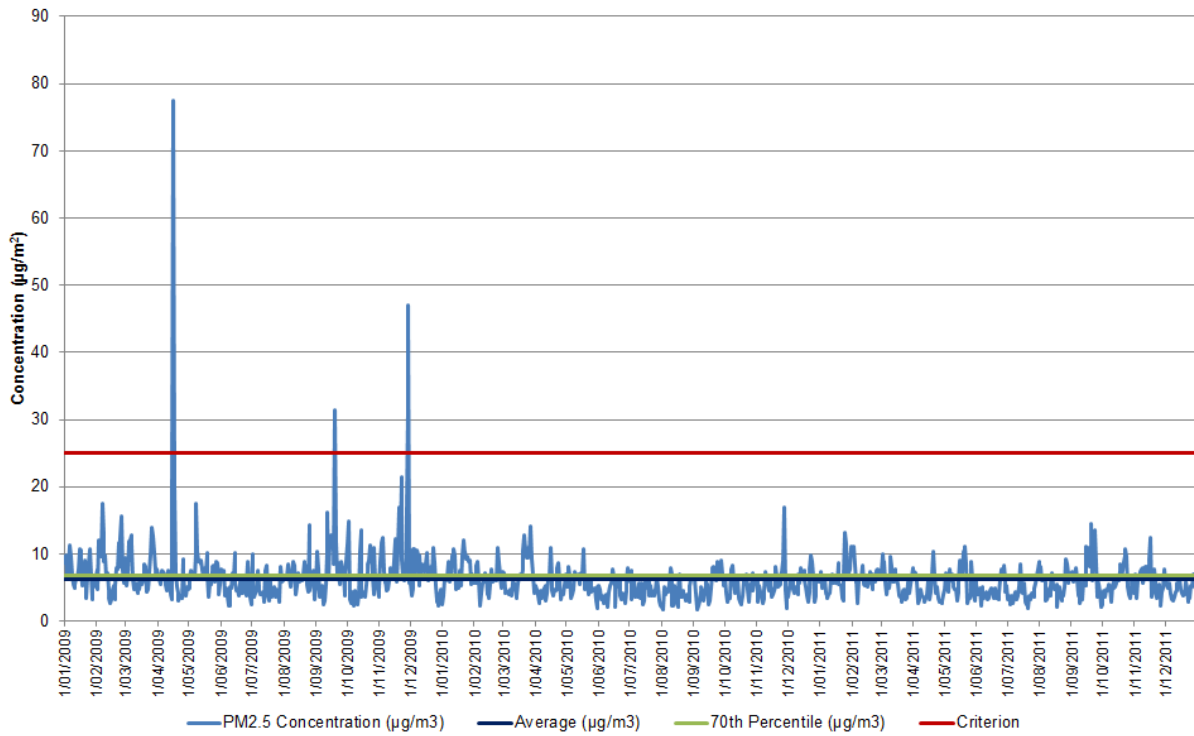


Chart 2 Estimated OEH 24 hour PM_{2.5} concentrations, 2009 - 2011

Table 4 Estimated concentrations from combined OEH monitoring data from Lindfield and Prospect – 24 hour average PM_{2.5} (µg/m³) – 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 µg/m ³) | 4 | 4 | 0 | 0 |

The NO₂ 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 NO₂, are summarised in **Table 6**.

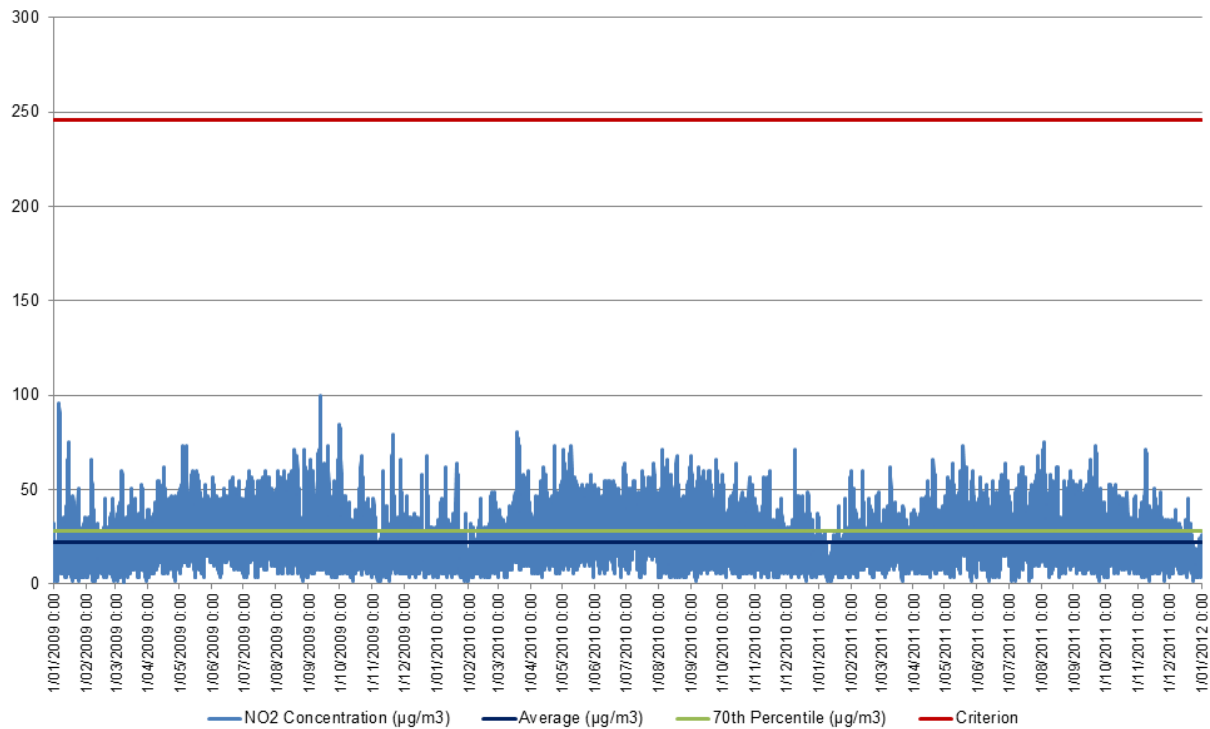


Chart 3 Combined OEH 24 hour NO₂ concentrations, 2009 - 2011

Table 5 Combined OEH monitoring data from Lindfield and Prospect – one hour average NO₂ (µg/m³) – 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 µg/m ³) | 0 | 0 | 0 | 0 |

Table 6 Combined OEH monitoring data from Lindfield and Prospect – one hour average O₃ (µg/m³) – 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 ($\mu\text{g}/\text{m}^3$) – 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 ($\mu\text{g}/\text{m}^3$) – 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 | 33°43'26.6"S 151 °4'44.42"E | 176 | 20/11/13 | Ambient |
| James Park | 33°42'2.59"S 151 °6'48.46"E | 177 | 03/12/13 | Ambient |
| Observatory Park | 33°44'25.29"S 151 °3'49.81"E | 193 | 05/12/13 | Road |
| Brickpit Park | 33°43'25.12"S 151 °5'23.76"E | 235 | 13/12/13 | Road |
| Rainbow Farm Reserve | 33°45'38.83"S 151 °2'40.25"E | 112 | 16/1/14 | Ambient |

Table 10 Monitoring parameters of the project monitoring stations and standards

| Parameter measured | Relevant standard |
|---------------------------------------|-------------------------|
| NO, NO ₂ , NO _x | 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**.

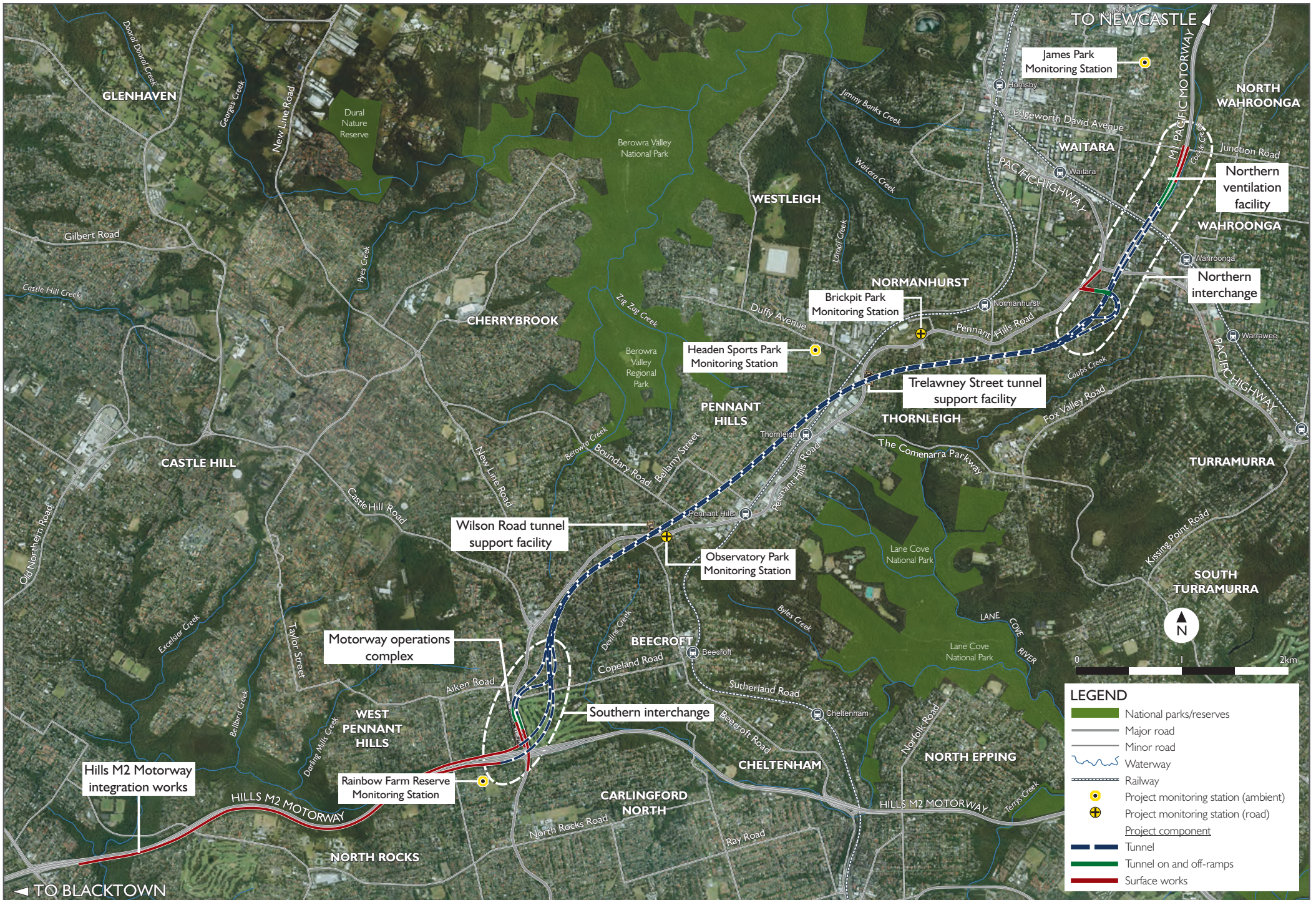


Figure 5 Local air quality monitoring stations

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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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intentionally.

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. |
| | 2029 | | This scenario is referenced as scenario 1. |
| 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 |
| | 2029 | | This scenario is referenced as 'with project – expected traffic flows 2019' (scenario 2a) and 'with project – expected traffic flows 2029' (scenario 2b). |
| 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.

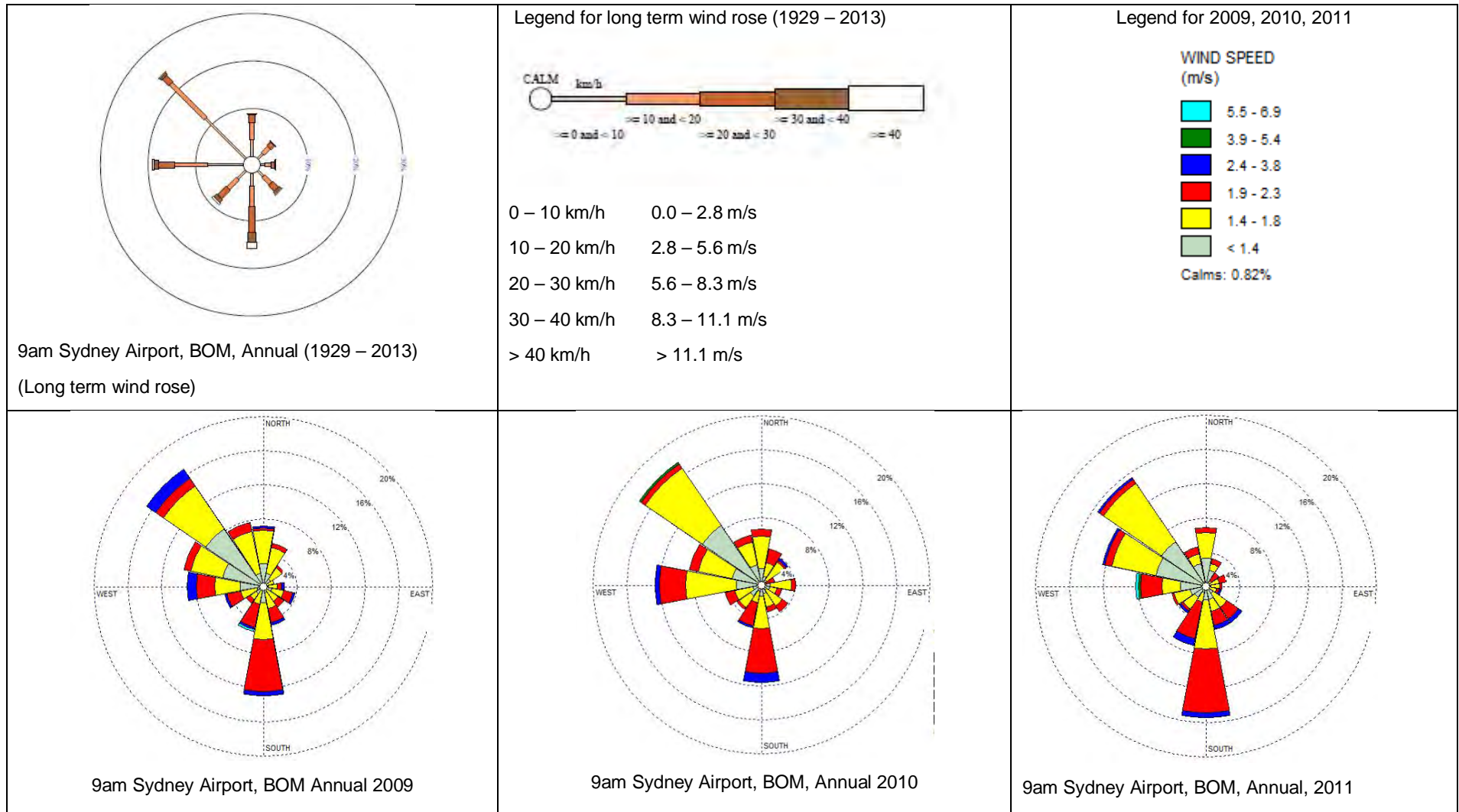


Figure 6 Comparison of long term (1929 – 2013) data and data from the modelling period (2009 – 2011) from Sydney Airport - 9 am

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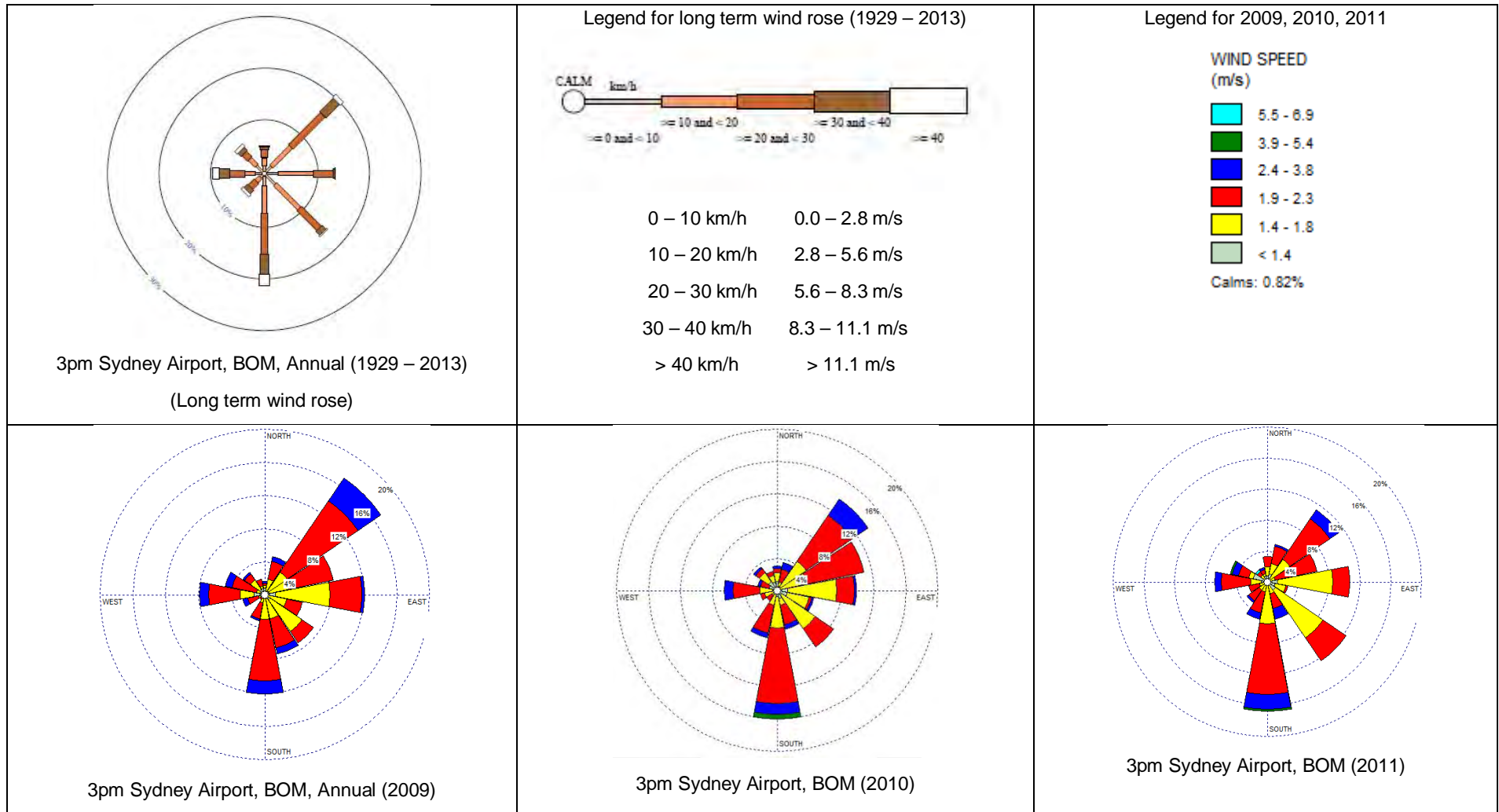


Figure 7 Comparison of long term (1929 – 2013) data and data from the modelling period (2009 – 2011) from Sydney Airport – 3 pm

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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 (°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 (°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 (°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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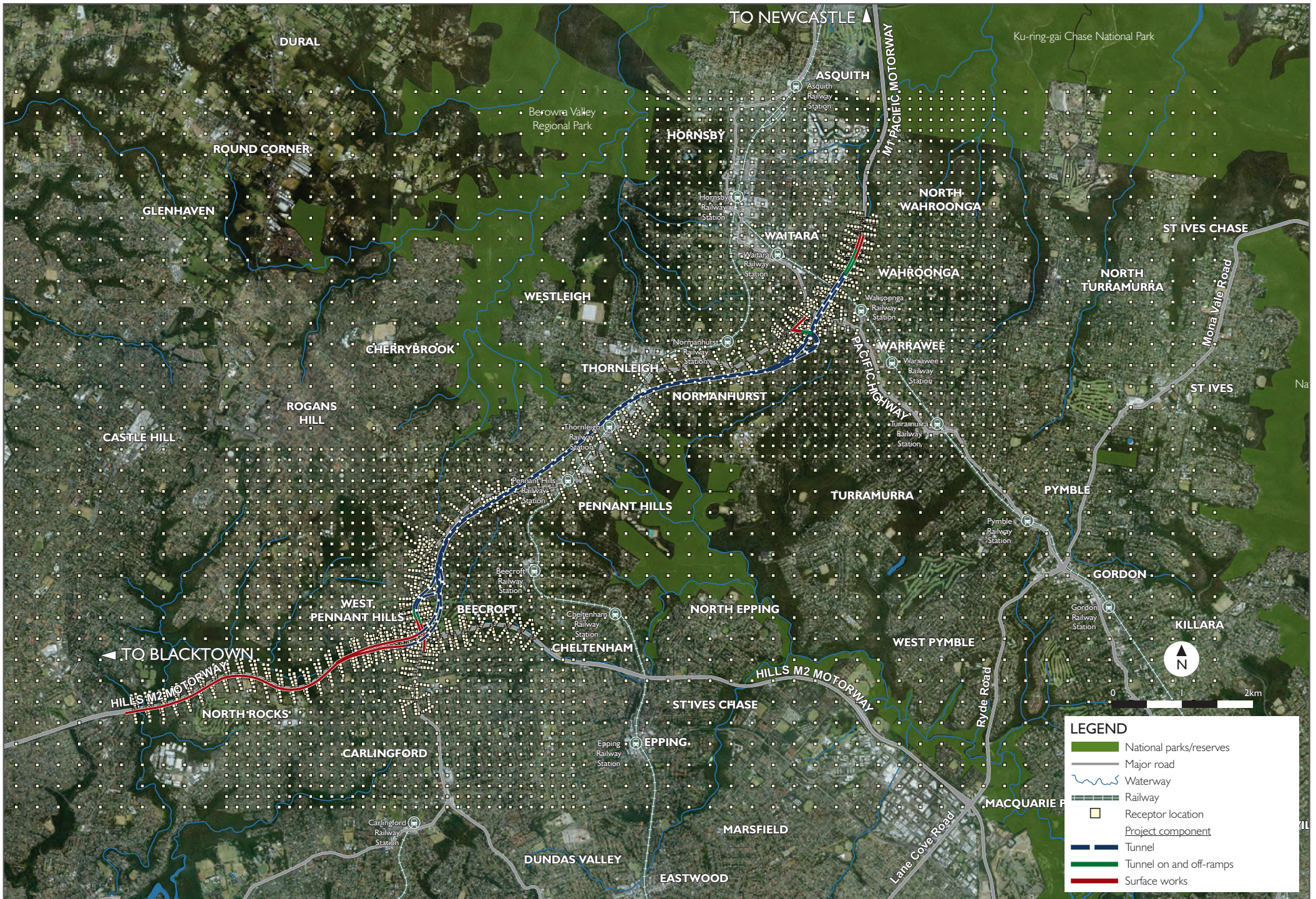


Figure 8 Receiver locations

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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 | <p>CALMET Hybrid Mode: Run using a combination of MM5 gridded numerical data supplemented by data from five surface meteorological stations operated by BOM and OEH (described below).</p> <p>Lindfield OEH Monitoring Station <i>Hourly data:</i> Temperature, precipitation, humidity, wind speed and wind direction. <i>MGA Coordinates (km):</i> 328.711 E, 6260.391 S</p> <p>Terry Hills BOM Monitoring Station (Station No. 066059) <i>Hourly data:</i> Temperature, precipitation, humidity, wind speed and wind direction. <i>MGA Coordinates (km):</i> 335.509 E, 6270.714 S</p> <p>Richmond RAAF BOM Monitoring Station (Station No. 067105) <i>Hourly data:</i> Temperature, precipitation, humidity, pressure, wind speed and wind direction. <i>MGA Coordinates (km):</i> 293.651 E, 6279.933 S</p> <p>Prospect OEH Monitoring Station <i>Hourly data:</i> Temperature, precipitation, humidity, wind speed and wind direction. <i>MGA Coordinates (km):</i> 306.745 E, 6258.646 S</p> <p>Sydney Airport BOM Monitoring Station (Station No. 066307) <i>Hourly data:</i> Temperature, precipitation, humidity, pressure, wind speed and wind direction. <i>MGA Coordinates (km):</i> 331.173 E, 6242.272 S</p> |
| 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. <i>MGA SW Coordinates (km): 315.300 E, 6260.500 S</i> <i>MGA NE Coordinates (km): 330.600 E, 6270.701 S</i> |
| 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 PM₁₀, 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 assessment⁴. 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 (PM₁₀) (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 PM₁₀ 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.

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 PM₁₀ 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 PM₁₀ for non-HDVs (0.93); this ratio was then multiplied by the PM₁₀ 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 PM₁₀ emissions for non-HDVs. A similar process was followed for HDVs, where the ratio of PM_{2.5} to PM₁₀ 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. PM₁₀ 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 PM₁₀ 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, NO₂, PM₁₀ 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, NO₂ and PM₁₀). 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 PM₁₀ and less than half in the case of PM_{2.5}. This may be a consequence of assumptions around the ratio of PM₁₀/PM_{2.5} in vehicle exhaust. High concentrations of PM₁₀ 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 PM₁₀ 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: NO₂ 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 concentrations (mg/m ³) (peak hour) | | | | | | | | | |
|---|---|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|
| Pollutant | 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 concentrations (mg/m ³) (peak hour) | | | | | | | | | |
|---|---|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|
| Pollutant | 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: NO₂ 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 PM₁₀ estimated by the CAL3QHCR model were multiplied by 0.95 (the maximum ratio of PM_{2.5} to PM₁₀ 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 per cent 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.

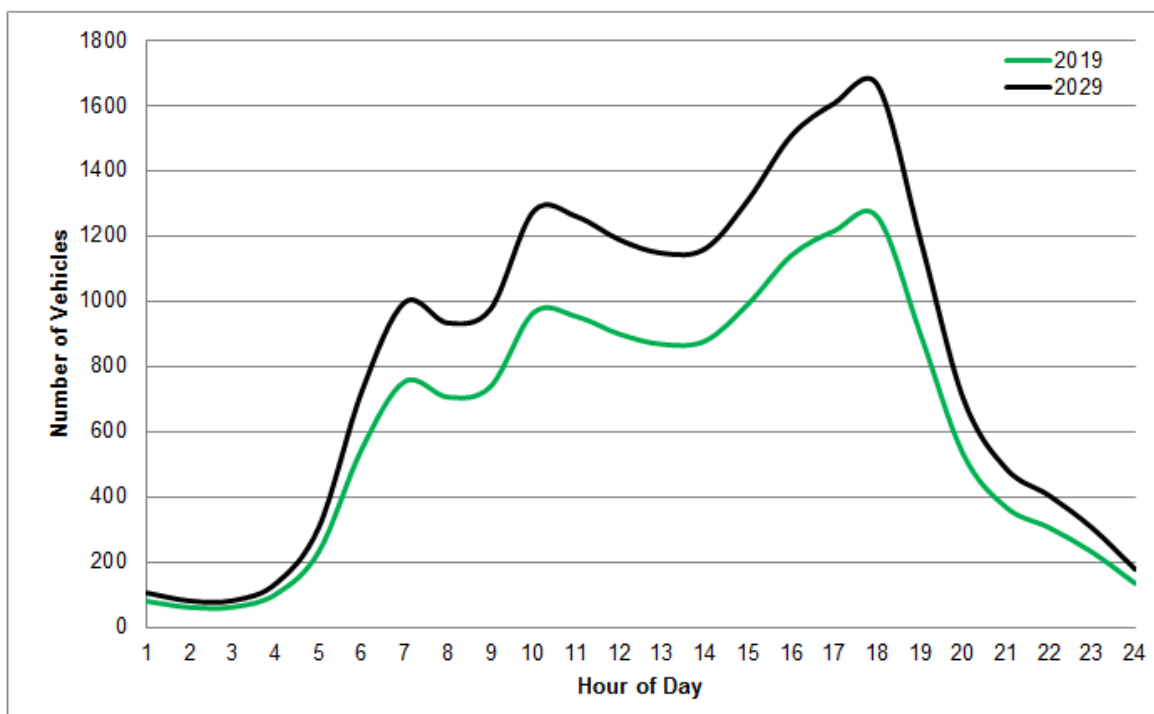


Figure 9 Predicted tunnel traffic flows – northbound

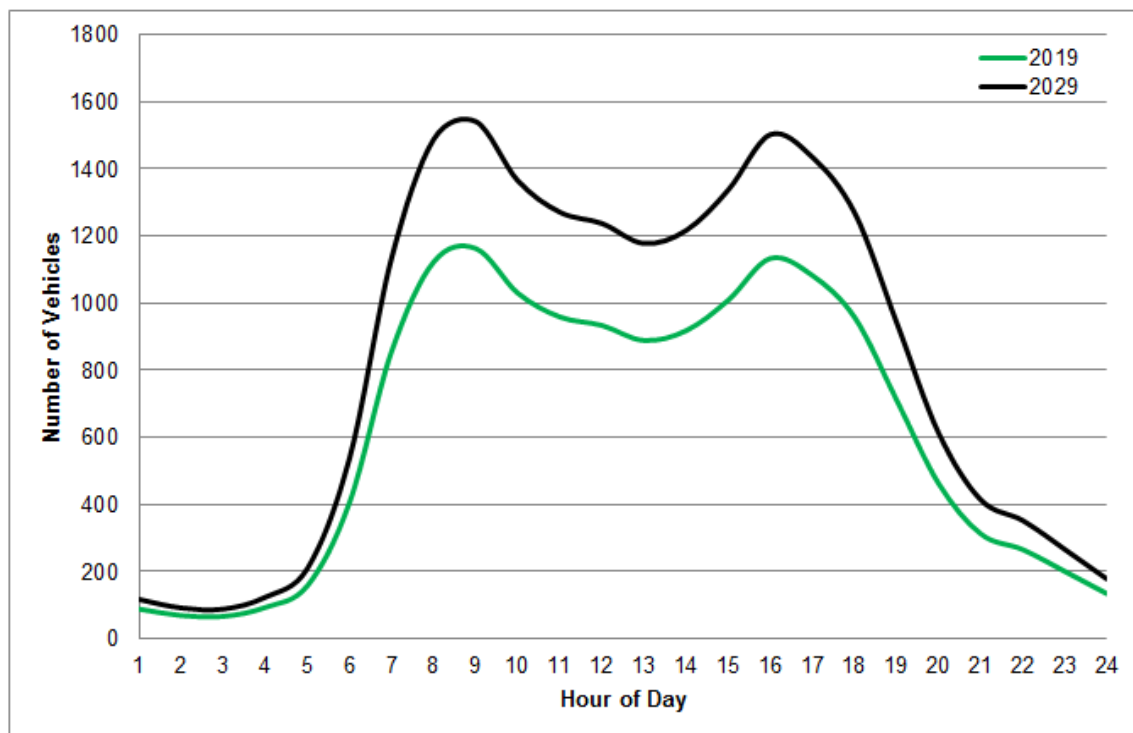


Figure 10 Predicted tunnel traffic flows – southbound

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 NO₂ and VOCs, additional analysis of the model outputs was required. For PM₁₀, PM_{2.5}, NO₂ 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 NO₂

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 (NO₂). 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 NO₂. The conversion of NO to NO₂ 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 NO₂ and then further to other higher oxides of nitrogen.

The USEPA's Ozone Limiting Method (OLM) was used to predict ground-level concentrations of NO₂. The OLM is based on the assumption that approximately 10 per cent of the initial NO_x emissions are emitted as NO₂. If the ozone (O₃) concentration is greater than 90 per cent of the predicted NO_x concentrations, all the NO_x is assumed to be converted to NO₂, otherwise NO₂ concentrations are predicted using the equation:

$$\text{NO}_2 = 46/48 \times \text{O}_3 + 0.1 \times \text{NO}_x$$

This method assumes instant conversion of NO to NO₂ 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 NO₂ 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 NO₂ concentrations include during daylight hours when the photochemical equilibrium reverses the oxidation of NO by O₃, and during stable and night conditions when both NO₂ and O₃ 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 cent⁵ 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 PM₁₀, PM_{2.5}, NO₂ 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 PM₁₀, PM_{2.5} and NO₂, 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 PM₁₀, PM_{2.5} and NO₂) 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 PM₁₀ data were typically less than the PM₁₀ concentrations measured by the OEH, while the NO₂ 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 PM₁₀ and NO₂ measured at the project road monitoring stations were typically well below the pollutant concentrations predicted by the road modelling.

PM₁₀ and NO_x

The ambient pollutant data for PM₁₀ 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 PM₁₀ 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 PM₁₀ and NO₂ 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 (PM₁₀ and NO₂) 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 PM₁₀ 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 PM₁₀ 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 PM₁₀ monitoring data from Lindfield/Prospect to estimate hourly PM_{2.5} concentrations. That is, the maximum hourly concentrations of PM₁₀ 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 µg/m³ for 1 hour CO and 2,601 µg/m³ for 8 hour CO).

Table 23 Maximum carbon monoxide concentrations – CAL3QHCR predictions compared to Prospect monitoring data (µg/m³)

| 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 PM₁₀, PM_{2.5} and NO₂, 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 PM₁₀, PM_{2.5} and NO₂ 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 PM₁₀ and PM_{2.5} were recorded in the background pollutant data. NO₂ was also assessed contemporaneously, as the EPA's basic level conversion of NO_x to NO₂ (Level 1, Method 2 - maximum predicted NO₂ concentration with maximum NO₂ 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 PM₁₀, NO₂ 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 (µg/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 ($\mu\text{g}/\text{m}^3$) | 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 PM₁₀, PM_{2.5} and NO₂ 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 PM₁₀ 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 PM₁₀; the NSW EPA criterion for this averaging period is higher than the WHO guideline of 20 $\mu\text{g}/\text{m}^3$.
- 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 NO₂, 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 PM₁₀, PM_{2.5} and NO₂

| Pollutant | Averaging Period | Guidelines/ assessment criteria ($\mu\text{g}/\text{m}^3$) | | |
|-------------------|------------------|--|---------------|---------------|
| | | 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), PM₁₀ 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.