

NorthConnex

Building for the future



Volume I



Environmental Impact Statement

Submissions and Preferred Infrastructure Report
Chapters 1 - 4

November 2014

Roads and Maritime Services

NorthConnex

Submissions and preferred infrastructure report

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Appendices

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Appendix B	Wind roses

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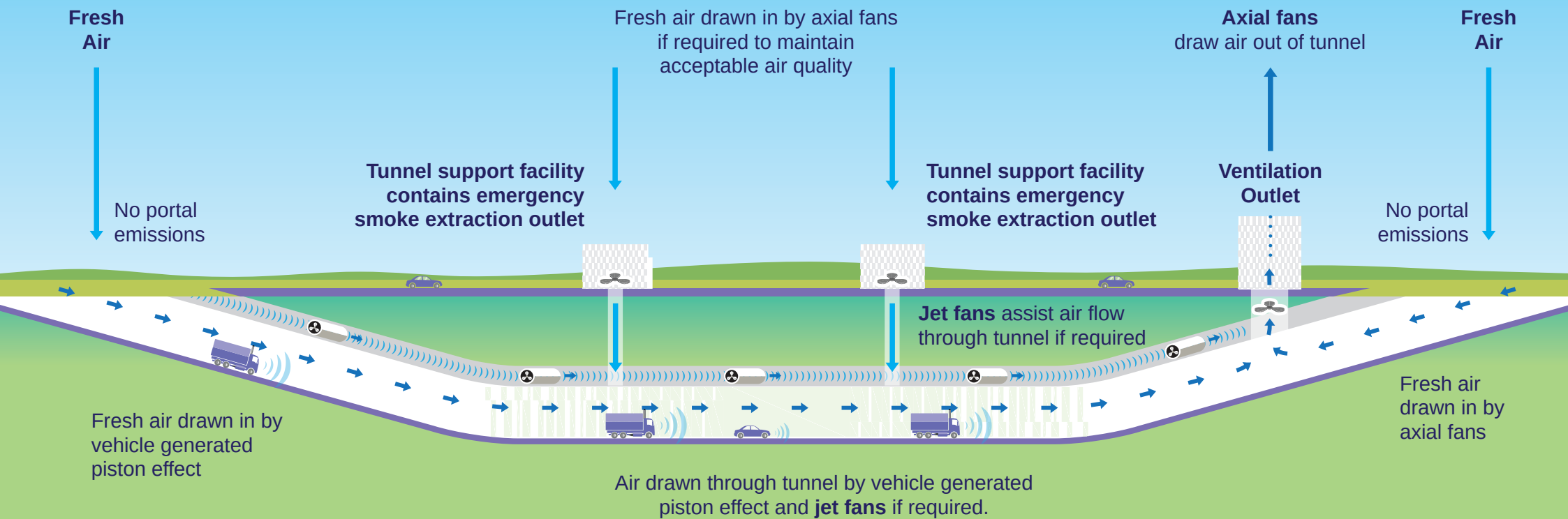
Glossary of terms and abbreviations

This section provides a list of terms and abbreviations used in this document.

A diagram showing the key components of the project is provided on the following page to assist in understanding and interpreting components of the project and its ventilation system.

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Motorway Tunnel Ventilation



Key

-  Axial fans
-  Fresh air
-  Jet fans
-  Air flow

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Term	Meaning
$\mu\text{g}/\text{m}^3$	Micrograms per cubic metre
A	
AADT	Average annual daily traffic. The total volume of traffic passing a roadside observation point over a period of a year, divided by the number of days per year. It is calculated from mechanically obtained axle counts.
Aboriginal cultural heritage	The tangible (objects) and intangible (dreaming stories, songlines, places) cultural practices and traditions associated with past and present day Aboriginal communities.
Aboriginal object	Any deposit, object or material evidence (not being a handicraft made for sale), including Aboriginal remains, relating to the Aboriginal habitation of NSW.
Acute noise levels	Road traffic noise levels received at private dwellings that are predicted to be greater than $65\text{dB(A)}L_{\text{eq}(15\text{hr})}$ (day) and $60\text{dB(A)}L_{\text{eq}(9\text{hr})}$ (night), as presented in Practice Note IV of the Environmental Noise Management Manual (RTA, 2001).
AHD	Australian Height Datum. The standard reference level used to express the relative height of various features. A height given in metres AHD is essentially the height above sea level. Mean sea level is set as zero elevation.
Airshed	Part of the atmosphere that shares a common flow of air and that is exposed to similar influences.
Alignment	The geometric layout (eg of a road tunnel) in plan (horizontal) and elevation (vertical).
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.
Ancillary	A subordinate part or element.
ANZECC	Australian and New Zealand Environment and Conservation Council
Aquatic ecology	Flora and fauna that live in or on water for all or a substantial part of the life span (generally restricted to fresh/ inland waters).
Aquifer	Geologic formation, group of formations, or part of a formation capable of transmitting and yielding quantities of water.
Archaeology	The scientific study of human history, particularly the relics and cultural remains of the distant past.
ARI	Average recurrence interval. Used to describe the frequency or probability of floods occurring. (eg a 100 year ARI flood is a flood that occurs or is exceeded on average once every 100 years (100:1)).
Arterial roads	The main or trunk roads of the State road network.
Asphalt	A dense, continuously graded mixture of coarse and fine aggregates, mineral filler and bitumen usually produced hot in a mixing plant.
Axial fans	Fans typically used within the ventilation facility or tunnel support facility that pull air into or out of the main alignment tunnel.
B	
Background noise level	The ambient sound-pressure noise level in the absence of the sound under investigation exceeded for 90 per cent of the measurement period. Normally equated to the average minimum A-weighted sound pressure level.

Term	Meaning
Blasting	The use of explosives for excavating rock, demolition and other purposes.
Bore	A cylindrical drill hole sunk into the ground from which water is pumped for use or monitoring.
Borehole	A hole produced in the ground by drilling for the investigation and assessment of soil and rock profiles.
Bund	A small embankment designed to retain water.
C	
Cadastral	Showing the extent and ownership of land (generally on a map).
CALPUFF	An advanced air dispersion model.
Carriageway	The portion of a roadway used by vehicles including shoulders and ancillary lanes.
Catchment	The area from which a surface watercourse or a groundwater system derives its water.
CO	Carbon monoxide.
CO ₂	Carbon dioxide.
CO _{2-e}	Carbon dioxide equivalent.
Compound site	Facilities used to support the operation of a construction site including (but not limited to) site offices, workshops, delivery areas, storage areas, staff vehicle parking, materials, plant and equipment.
Concentration (air quality)	Vehicles emit pollutants to the air, which are transported and diluted resulting in a volume of pollutant per volume of ambient air. Ambient air quality goals are expressed in terms of concentrations, which are measured in parts per million or micrograms per cubic metre.
Constructability	The ease with which structures can be built.
Construction footprint	The area required to construct the project, including underground components, above ground components and temporary ancillary construction facilities.
CSIRO	Commonwealth Scientific and Industrial Research Organisation.
CTMP	Construction Traffic Management Plan
Cumulative impacts	Impacts that, when considered together, have different and/or more substantial impacts than a single impact considered alone.
Cut	The material excavated from a cutting.
Cutting	Formation resulting from the construction of the road below existing ground level – the material is cut out or excavated.
D	
dB(A)	Decibels using the A-weighted scale measured according to the frequency of the human ear.
DEC	NSW Department of Environment and Conservation (now OEH and the EPA).
DECC	NSW Department of Environment and Climate Change (formerly DEC and now OEH and EPA).
DECCW	NSW Department of Environment, Climate Change and Water (formerly DEC, DECC and now OEH and the EPA).
Decibel	A scale unit used in the comparison of powers and levels of sound energy. Used for measuring noise.
Dewatering	The removal of water from solid material or soil by wet classification, centrifugation, filtration or similar solid-liquid separation processes.

Term	Meaning
DGRs	Director-General's Requirements. Requirements and specifications for an environmental impact statement prepared by the Secretary (formerly the Director-General) of the Department of Planning and Environment under section 115Y of the <i>Environmental Planning and Assessment Act 1979</i> .
Drainage	Natural or artificial means for the interception and removal of surface or subsurface water.
E	
Earthworks	All operations involved in loosening, excavating, placing, shaping and compacting soil or rock.
Ecosystem	A functional unit of energy transfer and nutrient cycling in a given place. It includes all relationships within the biotic community and between the biotic components of the system.
Emergency smoke extraction facility	A facility that is designed to maintain air quality in the tunnels in the unlikely event of an emergency. As a secondary feature, these facilities would also supply fresh air the tunnels during low speed, congested traffic conditions.
Emission factor	The rate of pollutants emitted in the exhaust of a vehicle, depending on the type of vehicles and the conditions under which it is driven.
EPA	NSW Environment Protection Authority.
F	
Fill	The material placed in an embankment.
Footprint	The extent of impact that a development makes on the land.
Fragmentation	The breaking up of continuous sections of ecosystems or landscape features.
Frequency (sound)	Similar to the pitch of a musical note in sound pressure fluctuations of cycles per second (Hertz). Most sounds comprise a composite of frequencies of varying sound-pressure levels in the range of 20 Hertz to 20,000 Hertz.
G	
Grade	The degree of inclination of a road or slope.
Grade separation	The separations of road, rail or other traffic so that crossing movements at intersections are at different levels. Opposite to 'at grade'.
Greenhouse gas (GHG)	Greenhouse gases are those gases which reduce the loss of heat from the earth's atmosphere by absorbing infrared radiation. Six greenhouse gases are recognised by the Kyoto Protocol: Carbon dioxide (CO ₂), Methane (CH ₄), nitrous oxide (N ₂ O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF ₆). The emissions of greenhouse gases are reported in carbon dioxide equivalents (see above).
Groundwater	Water that is held in the rocks and soil beneath the earth's surface.
H	
ha	Hectare. Equivalent to 10,000 m ² .
Habitat	The place where a species, population or ecological community lives (whether permanently, periodically or occasionally). Habitats are measurable and can be described by their flora and physical components.
Heavy vehicle	A vehicle is classified as a Class 3 vehicle (a two axle truck) or larger, in accordance with the Austroads Vehicle Classification System.

Term	Meaning
Hills M2 Motorway integration works	The works to join the project to the Hills M2 Motorway extending from the southern interchange to Windsor Road interchange
Hydrocarbon	Any organic compound — gaseous, liquid or solid — consisting only of carbon and hydrogen.
Hydrogeology	The science of the distribution and movement of groundwater.
Hydrology	The study of rainfall and surface water runoff processes.
I	
Interchange	A grade separation of two or more roads with one or more interconnecting carriageways.
Integration works	Works to join existing roads to the project.
ISEPP	<i>State Environmental Planning Policy (Infrastructure) 2007.</i>
L	
Landscape character	The aggregate of built, natural and cultural aspects that make up an area and provide a sense of place. Includes all aspects of a tract of land – built, planted and natural topographical and ecological features.
LEP	Local Environmental Plan.
Light vehicle	A vehicle is classified as a Class 2 vehicle or smaller, in accordance with the Austroads Vehicle Classification System.
Local road	A road or street used primarily for access to abutting properties.
Longitudinal ventilation	The method of tunnel ventilation in which air is drawn along the carriageway of the tunnel, typically in the direction of traffic flow.
Lot	A parcel of land defined by measurement as a lot in a deposited plan (DP) or as a Crown portion or allotment.
M	
Macroinvertebrates	Macroinvertebrates are fauna with no backbone that can be seen with the naked eye (ie without the aid of a microscope or magnifying glass). Aquatic macroinvertebrates are those that spend all or part of their life cycles in water.
Macrophytes	Macrophytes are aquatic plants that can be seen with the naked eye. They can grow below, within or on top of the water.
Main alignment tunnels	The two underground tunnels forming the principal carriageways of the project.
Micrometre	One millionth of a metre (abbreviation μm).
Motorway	Fast, high volume controlled access roads. May be tolled or untolled.
Motorway control centre	A centre with facilities necessary for the monitoring, maintenance and control of tunnel services. Also known as a tunnel control centre facility.
Motorway operations complex	The combined facility near the southern interchange comprising the motorway control centre, workshops, the water treatment plant and the southern ventilation facility.
Mt	Million tonnes.
N	
Northern interchange	The connections of the project with the M1 Pacific Motorway (formerly known as the F3 Freeway) and Pennant Hills Road.
Northern ventilation facility	A component of the ventilation system located near the northern portal of the project for the extraction of in-tunnel air from the northbound tunnel.
NO _x	Oxides of nitrogen.
NO ₂	Nitrogen dioxide.

Term	Meaning
NSW	New South Wales
O	
O ₃	Ozone
OEH	NSW Office of Environment and Heritage.
P	
PACHCI	Procedure for Aboriginal Cultural Heritage Consultation and Investigation (Roads and Maritime Services, 2011).
PCU	Passenger car unit. A standard, consistent basis for accounting for the amount of space taken up by different size vehicles.
Peak oil	The predicted time when oil extraction reaches its maximum, after which oil extraction is anticipated to decline.
pH	A measure of acidity or alkalinity of a solution, numerically equal to 7 for neutral solution, increasing with increasing alkalinity and decreasing with increasing acidity. Originally stood for the words potential of hydrogen.
PIARC	Permanent International Association of Road Congresses.
Piezometer	Device used to measure the pressure of groundwater, or static pressure of a liquid.
Piston effect	Air flow in a tunnel that is generated by, and in the direction of, moving vehicles.
PM	Particulate matter.
PM _{2.5}	Particulate matter less than 2.5 micrometres in diameter.
PM ₁₀	Particulate matter less than 10 micrometres in diameter.
Pollutant	Any measured concentration of solid or liquid matter that is not naturally present in the environment.
Portal	Where a tunnel emerges to the surface, being the entrance or exit of the main alignment tunnels, off-ramps or on-ramps.
(The) project	The NorthConnex project.
Q	
Quarry	An open pit from which stone, sand, gravel or fill is taken.
R	
Receiver	An environmental modelling term used to describe a map reference point where the impact is predicted. A sensitive receiver is a home, work place, school or other place where people spend some time.
Revegetation	To revegetate an area by direct seeding with non-native species or cover crops and / or native species using manual or mechanical means such as hydromulching, strawmulching and tractor seeding.
RNP	NSW Road Noise Policy (DECCW, 2011).
Roads and Maritime	Roads and Maritime Services of New South Wales.
RTA	Roads and Traffic Authority of NSW (now Roads and Maritime Services).
Runoff	That part of the rainfall on a catchment which flows as surface discharge past a specified point.
S	
Sediment	Material, both mineral and organic, that is being or has been moved from its site of origin by the action of wind, water or gravity and comes to rest either above or below water level.
Sediment/ sedimentation basins	An area where runoff water is ponded to allow sediment to be deposited.
Sedimentation	Deposition of sediment usually by water.

Term	Meaning
Sensitive receiver	A sensitive receiver, such as a residence, work place, school or other place where people spend some time. An elevated sensitive receiver is a point above ground level.
Site establishment works	Preliminary works carried out prior to the commencement of construction, including installation of environmental controls, demolition of existing structures, vegetation clearing and establishment of temporary construction facilities.
Shotcrete	Concrete applied to a surface through a pressure hose.
Shoulder	The portion of the carriageway beyond the traffic lanes adjacent to and flush with the surface of the pavement.
Southern interchange	The connections of the project with the Hills M2 Motorway and Pennant Hills Road.
Southern ventilation facility	A component of the ventilation system located near the southern portal of the project for the extraction of in-tunnel air from the southbound tunnel.
Spoil	Surplus excavated material.
SPTs	Standards Penetration Tests
Surface water	Water flowing or held in streams, rivers and other wetlands in the landscape.
T	
Terrestrial	Living or growing on land (ie a terrestrial plant or animal).
Threatened	As defined under the <i>Threatened Species Conservation Act 1994</i> , a species, population or ecological community that is likely to become extinct or is in immediate danger of extinction.
Tie-in works	The works to join the project to existing roads, such as the M1 Pacific Motorway.
U	
Urban design	The process and product of designing human settlements, and their supporting infrastructure, in urban and rural environments.
V	
Ventilation facility	Facilities for the mechanical removal of air from the main alignment tunnels, or mechanical introduction of air into the tunnels.
Ventilation offtake	The component of the ventilation system that connects the main alignment tunnel to the ventilation facility, and through which tunnel air is drawn prior to discharge via the ventilation outlet.
Ventilation outlet	Part of the tunnel's ventilation system within the ventilation facility which contains axial fans to expel air from within the tunnels into the atmosphere.
W	
Water table	The surface of saturation in an unconfined aquifer at which the pressure of the water is equal to that of the atmosphere.
Waterway	Any flowing stream of water, whether natural or artificially regulated (not necessarily permanent).
Z	
Zoning	Zoning regulates land use within an environmental planning instrument (usually by different colour codes on a map accompanying a local environmental plan). Land use tables set out the various purposes for which land may or may not be used or developed in each zone.

Executive Summary

The NSW Government's State Infrastructure Strategy, State Plan and Long Term Master Plan identify the NorthConnex project as a priority to deliver improvements to the State's urban road network.

The proposed motorway includes a nine-kilometre tunnel linking Sydney's north to the Orbital road network and forms part of the National Highway route. It would provide a vital link for commuters and freight operators between the M1 Pacific Motorway at Wahroonga and the Hills M2 Motorway at West Pennant Hills. The project would deliver a high standard motorway to integrate with the regional transport network, keeping Sydney and the NSW economy moving. It would also improve road safety, noise and air pollution and ease congestion along Pennant Hills Road.

The NorthConnex project is a public private partnership with the NSW and Federal governments, Transurban and the M7 Westlink Shareholders (the Project Sponsors).

Project Benefits

The NorthConnex project is designed to:

- ✓ Provide the missing link in Sydney's motorway network and the National Land Transport Network between the M1 Pacific Motorway and the Sydney Orbital road network
- ✓ Save up to 15 minutes of travel time on opening compared to using Pennant Hills Road
- ✓ Bypass 21 sets of traffic lights along Pennant Hills Road
- ✓ Improve productivity and efficiency of intrastate and interstate freight movements through travel time savings and reduced operating costs
- ✓ Improve safety of motorists, cyclists and pedestrians on Pennant Hills Road through the reduction of around 5,000 heavy vehicles every day.
- ✓ Improve local amenities and connectivity for people living, working and travelling along Pennant Hills Road
- ✓ Provide opportunities for future public transport improvements and the reinvigoration of the Pennant Hills Road corridor.

Environmental Impact Statement

The NorthConnex environmental impact statement was placed on public exhibition from 15 July to 12 September 2014. During this extended 60 day period, the community, interest groups, local councils and relevant Government departments, were invited to provide submissions on the proposal for consideration by the Department of Planning and Environment as part of the planning process.

Interested parties were also invited to attend a number of information forums, meetings, displays and the community information centre where specialists in air quality, health assessment, tunnel design, noise and other project specifics were available to answer inquiries and record feedback.

A total of 1,518 submissions from 1,251 stakeholders were received by the Department of Planning and Environment. Five submissions were from government agencies and three from local government. Of the submissions received, 672 submissions (44 per cent) were anonymous and 605 (40 per cent) were standardised form letters. Each submission was read carefully and issues extracted for detailed consideration. **Chapter 7** and **Chapter 8** of this report present the issues raised in submissions and corresponding responses.

The subjects most commonly raised related to:

- Operational air quality.
- Project development and alternatives.
- Health impact.
- Planning and statutory requirements.
- Construction traffic impact.
- Consultation.
- Urban design, landscape character and visual impact.

Air quality was the issue most frequently raised in submissions, indicating that despite the effort given to assess and address this issue in the environmental impact statement the community remained concerned. Accordingly significant additional effort has been made during the preparation of this Submissions and Preferred Infrastructure Report to address this issue.

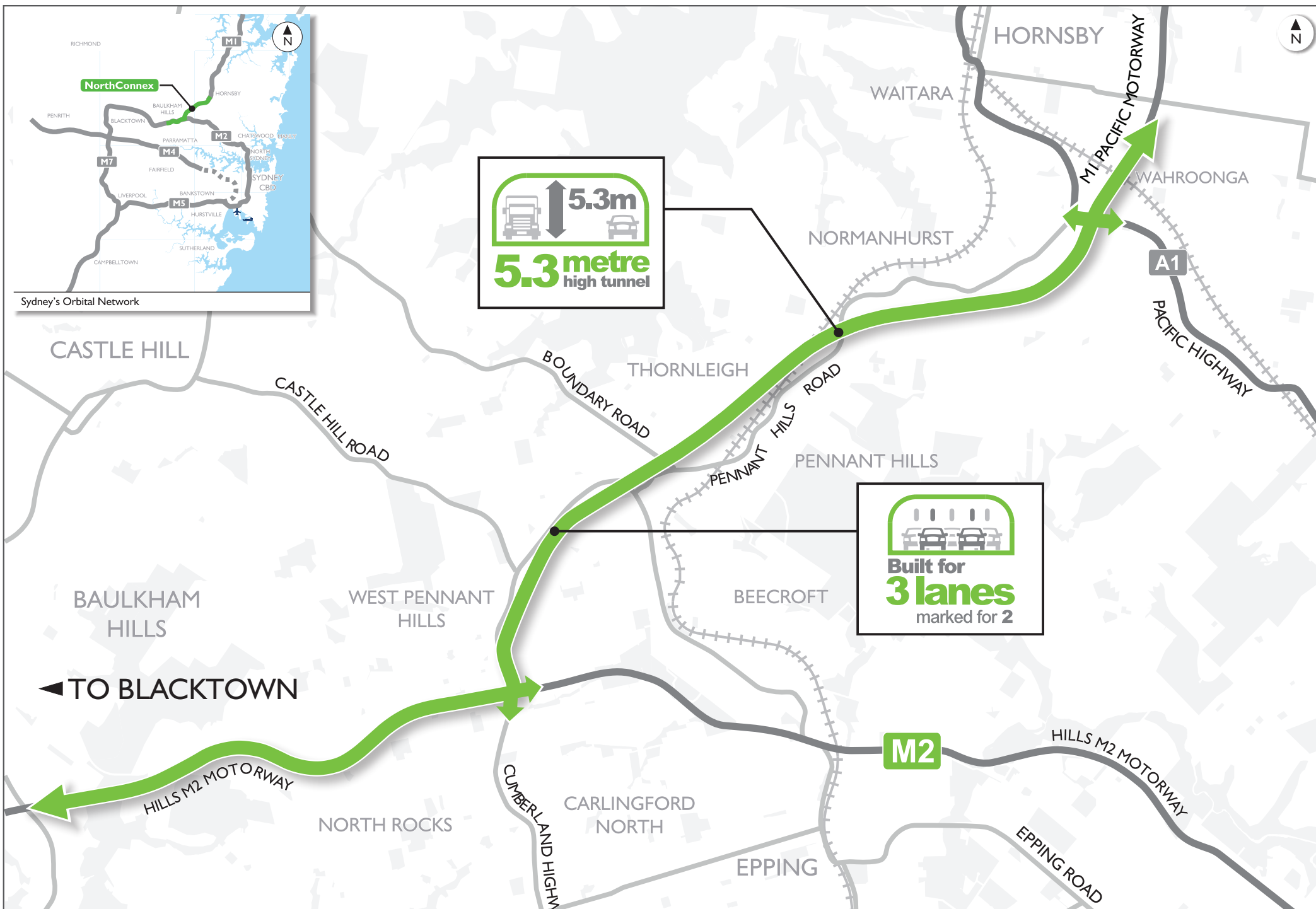
The air quality assessment prepared for the NorthConnex environmental impact statement demonstrated effective performance of the proposed tunnel ventilation system and ventilation outlets. It explains the effect on local air quality and demonstrates there will be an overall net improvement in air quality across the Pennant Hills Road corridor.

The predicted increase around each of the ventilation outlets, for all health outcomes including diesel emissions, would be very small and undetectable.

The air quality assessment also predicted a reduction in the health impacts along Pennant Hills Road due to the decrease in air pollution as a result of traffic, particularly heavy vehicles, using the tunnel.

The assessment considered the potential impact on the general population, as well as more sensitive members of the community including children, the elderly and those with existing respiratory issues.

For the first time for a road project in NSW, a comprehensive health risk assessment was also carried out in accordance with the *Environmental Health Risk Assessment: Guidelines for assessing human health risks from environmental hazards* (enHealth, 2012) and published as part of the environmental impact statement.



Linking Sydney's Orbital road network

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From a health risk perspective, taking into account the total population affected by both increases and decreases in vehicle emissions (refer to Section 7.4 of the environmental impact statement) it has been calculated that the NorthConnex project would have a net health benefit.

The health risk assessment is conservative (potential benefits are under-predicted) as it was limited to air quality and did not include the expected improvement in health from a reduction in road incidents and fewer injuries/fatalities as a result of the NorthConnex project. In a recent NRMA survey, Pennant Hills Road is the second worst road in New South Wales, experiencing around 360 crashes per year. Drivers would be five times less likely to be involved in a crash and about four times less likely to be involved in an injury crash using the NorthConnex project instead of Pennant Hills Road.

Submissions and Preferred Infrastructure Report

To prepare this Submissions and Preferred Infrastructure Report, Roads and Maritime has reviewed all submissions and prepared clarifications and responses to the issues raised. A range of amendments to the project have also been identified to reduce environmental impacts and address stakeholder and community concerns.

This information is set out in this Submissions and Preferred Infrastructure Report in the following format.

- Introduction - **Chapter 1**.
- Clarifications in response to issues raised in respect of air quality are documented in **Chapter 2** and **Chapter 3**.
- Clarifications in response to other issues are addressed in **Chapter 4**.
- A summary of community involvement is outlined in **Chapter 5**.
- A summary of submissions received is provided in **Chapter 6**.
- Issues raised in submissions from government, councils, peak groups and advisory organisations, schools, churches, hospitals and age care facilities and members of parliament are addressed in **Chapter 7**.
- Issues raised in community submissions are addressed in **Chapter 8**.
- Changes made to the project (since exhibition of the environmental impact statement) to reduce environmental impacts are described and assessed in **Chapter 9**.
- An updated summary of mitigation measures is provided in **Chapter 10**.
- Conclusions – **Chapter 11**.

Of particular note is **Chapter 2** which presents the reorganisation and consolidation of relevant material regarding air quality contained in Section 7.2 and Appendix G of the environmental impact statement. It comprehensively explains the air quality impact assessment for the project, including a description of the inputs, methodology and assumptions. Further detail has been provided where relevant to respond to specific issues raised in submissions on the environmental impact statement.

Changes to the project since exhibition of the EIS

As recognised in submissions made by key government agencies, all feasible and reasonable mitigation measures to reduce exposures to vehicle emissions within the tunnels and surrounding environment need to be identified and applied to the NorthConnex project.

This requirement is supported and further consideration of reasonable and feasible measures has been undertaken (refer to **Section 3.2** of this report). This has included an analysis of ventilation design alternatives considering:

- Ventilation outlet height.
- Ventilation outlet locations.
- Additional ventilation outlets.
- Ventilation flow rates.
- Air treatment systems (ie filtration).

This further analysis identified it was feasible to increase the height of the southern and the northern ventilation outlets by five metres. This would make both outlets 20 metres in height, measured from Pennant Hills Road and Bareena Avenue respectively.

It is therefore proposed to change the project design to increase the height of the southern and the northern ventilation outlets by five metres. This would optimise the performance of the outlets while maintaining the efficiency of the in-tunnel ventilation system.

The following additional changes to the project are also proposed to reduce environmental impacts and respond to community concerns:

- Amendments to the construction haulage routes for the southern interchange (C5), Trelawney Street (C7) and northern interchange (C9) compounds to reduce heavy vehicle impacts on local residential streets.
- An increase in bus movements at the Pioneer Avenue compound (C8), to minimise potential construction worker traffic and parking impacts on the surrounding road network.
- Additional property acquisition near the Wilson Road compound (C6), to improve the safety of access arrangements.
- Inclusion of a laydown area at the Junction Road compound (C11), to improve construction phase management and to minimise the requirement for out of hours deliveries to the site.

Descriptions and assessments of these changes to the project are provided in **Chapter 9** of this report.

Clarifications in response to submissions

Air quality and modelling

Submissions queried the veracity of assumptions and inputs applied to the air dispersion modelling, including background air quality, local topography, local meteorology, and the implications of drawing background concentrations of pollution into the tunnels. Clarification was also sought on whether the overall vehicle emissions would be reduced with the project or whether the NorthConnex project transferred emissions to areas around the outlets.

Chapter 2 of this report provides clarifications and interpretative discussion of the air quality impact assessment presented in the environmental impact statement. Information about the methodology, assumptions and inputs into the assessment are provided in a single, consolidated location.

The key areas of information, clarification and analysis are summarised below:

- **Background air quality data** - Air quality across Sydney is variable throughout the year and largely similar at different regional monitoring locations. While it is desirable to have site-specific background air quality data for an air quality impact assessment, it is rare that sufficient local data is available. An accepted alternative is the use of data from a monitoring location, demonstrated as representative of local conditions.

In the case of the NorthConnex project, **Section 2.11** of this report presents further analysis of the background air quality data used in the air quality impact assessment, obtained from the Office of Environment and Heritage. This information has been validated using three local monitoring stations along the project corridor. The analysis demonstrates the data was appropriate for use as an alternative to site specific data, in accordance with the *Approved Methods for the Modelling and Assessment of Air Pollutants in New South Wales* (DEC, 2005).

- **Topographical data** – Additional analysis has been carried out to compare the topographic data used in the meteorological and air dispersion modelling for the NorthConnex project, with high resolution 'LiDAR' topographic data (remote sensing technology that measures distance by illuminating a target laser and analysing the reflected light) collected along the project corridor. This analysis confirms the terrain data used in the assessment reflects local terrain conditions. Analysis using a screening level air dispersion model suggests the topographic data used in the assessment of the NorthConnex project may have produced slightly conservative estimates (over estimates) of air quality impacts.
- **Meteorological data** – Submissions questioned whether the regional meteorological data appropriately represented localised weather conditions. The analysis of the air quality dispersion modelling meteorological data demonstrates peak air quality impacts will occur under moderate wind conditions rather than calm or still days. Therefore if there were more calm and low wind days around the outlets than predicted in the modelling, this would lead to less impact than currently estimated. A review and comparison of data from local amateur weather stations has also been completed. Hence the current modelling represents a realistic and conservative approach.
- **Vehicle emissions at portals** - Additional modelling has been carried out to account for background pollution being drawn into the tunnel entry portals. The

additional modelling has demonstrated a negligible change in predicted air quality (refer to **Table 2-46** in **Section 2.8.3** of this report).

- **Overall reduction in emissions** as a result of the NorthConnex project - By providing a free-flowing motorway alternative to Pennant Hills Road, the NorthConnex project would reduce the total amount of vehicle emissions discharged into the atmosphere. Avoiding stop-start traffic congestion along Pennant Hills Road, it is estimated a heavy vehicle would emit 80 per cent less carbon monoxide, 70 per cent less oxides of nitrogen and 70 per cent less particulate matter (as PM₁₀). This demonstrates the NorthConnex project would reduce the quantity of emissions being generated along the Pennant Hills Road corridor.
- **Reduced emissions and improved dispersion** – the NorthConnex project would lead to improved air quality outcomes along the Pennant Hills Road corridor. This is achieved by reducing overall travel times along the motorway. The project would manage and disperse vehicle emissions in a controlled manner through a well-designed ventilation system and effective ventilation outlets. Rather than vehicle emissions being emitted at ground level with limited dispersion, the ventilation outlets would ensure effective atmospheric dispersion by discharge at high speeds (at up to about 70 km/h from the ventilation outlets).

Project design and scope

A number of submissions were seeking clarifications of the project design and scope.

This report provides minor clarifications of project design and scope issues. This includes the location of the ventilation off-take for the southern ventilation outlet. The offtake is a separate tunnel used to transport the air and emissions from the southbound tunnel to the ventilation outlet located in the motorway operations complex. Its purpose and location has now been clarified both in this report and through community consultation material and events.

Traffic forecasting

A number of submissions questioned whether the environmental impact statement had considered the impact if forecast traffic numbers have been underestimated.

Section 2.5.1 and Section 2.7.3 of this report provide further information and clarification to demonstrate that:

- The modelling of air quality and the design of the ventilation system was carried out using predicted traffic figures and a worst case scenario, which was described in the environmental impact statement as 'design analysis A'.
- There is a significant difference between forecast NorthConnex daily traffic volumes to the worst case traffic volumes (design analysis A). This provides an allowance for incidents, traffic mix and increased traffic. The graph on the following page shows the level of passenger car units (PCU) at different times of the day. A comparison of the forecast traffic against the worst case traffic figure (design analysis A) shows there is a significant margin of conservatism (a factor of more than two).
- The traffic scenario and air quality impacts using the traffic figures in design analysis A are very unlikely to eventuate.

- The performance of the ventilation system has been assessed and verified against the worst case traffic figures (design analysis A), based on a full tunnel using a range of vehicles speeds (80, 60, and 40 km/h) and stationary traffic. In all cases the in-tunnel air quality design criteria would be met by the proposed ventilation system.
- The air quality impact assessment presented in the environmental impact statement considers expected air quality performance based on forecast traffic volumes, as well as the design analysis A traffic figures. In both cases the project meets ambient air quality criteria.

In summary, this approach demonstrates that even if the NorthConnex project had more than twice the expected daily traffic volume than anticipated, the tunnel ventilation system would operate effectively and meet in-tunnel and out-of-tunnel air quality criteria.

In-tunnel air quality

A number of submissions questioned whether the tunnel ventilation system would achieve appropriate in-tunnel air quality.

The key to ensuring an effective, efficient and safe tunnel is the establishment of appropriate design criteria for in-tunnel air quality conditions. The ventilation system for the NorthConnex project has been designed and would be operated to meet the in-tunnel air quality criteria.

In-tunnel criteria are generally expressed in maximum concentration levels for a period of time. The expected travel time through the NorthConnex tunnels would be around seven minutes under normal operation at 80 km/h, nine minutes at 60 km/h and 14 minutes at 40 km/h.

The ventilation system would be automatically controlled using “real time” traffic data covering both vehicle mix and speed, and feedback from air quality sensors in the tunnel, to ensure in-tunnel conditions are managed effectively in accordance with the agreed criteria. Further, there would be specific ventilation modes developed to manage breakdown, congested and emergency situations.

Ventilation design

Submissions made by key government agencies state all feasible and reasonable mitigation measures be identified and applied to reduce exposure to vehicle emissions within the tunnels and surrounding environment. Community submissions have raised concerns about in-tunnel air treatment (filtration), ventilation outlet heights and ventilation outlet locations.

A key mitigation measure to reduce human exposure to vehicle emissions is to design the tunnel infrastructure to minimise the creation of emissions by vehicles using it. Emission quantities will vary depending on traffic mix, quantity, speed and gradient. Roads with free-flowing traffic in and out of the tunnel, together with flat grades, will create the least amount of emissions.

The NorthConnex design provisions to mitigate emissions within the tunnel include:

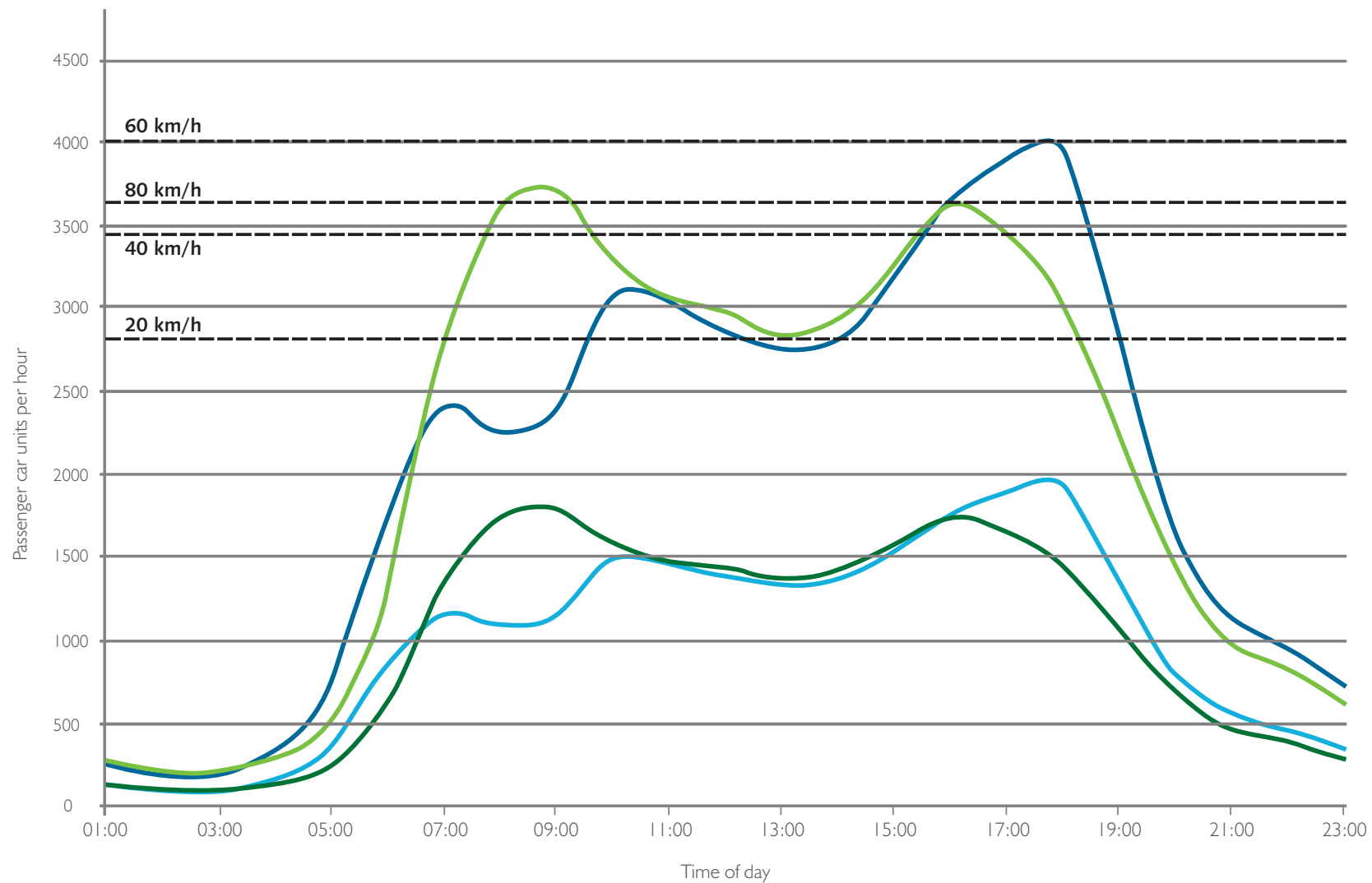
- **Minimal gradients** - The NorthConnex tunnels would be very flat (around eight kilometres with a grade of around 1.5 per cent south to north), with short entry and exit ramps of around four per cent. By way of comparison, the M5 East tunnel has a grade of up to eight per cent on the western exit, which causes trucks to slow down and increase emissions. The NorthConnex project alignment, with motorway-to-motorway connections at both ends, ensures efficient operation of vehicles in the tunnel and minimises emissions generated. This results in significantly less emissions than equivalent vehicles using Pennant Hills Road.
- **Large tunnel cross-section** – the NorthConnex project has a very large tunnel cross-sectional area. This allows a greater air flow along the tunnel.
- **Low air velocity** - Good engineering practice for longitudinally ventilated tunnels, is to limit maximum air velocity to 10 metres per second (m/s) (36 km/h). For the NorthConnex project, the maximum air volume vertically exhausted from the tunnel is 700m³/s. Of this maximum air flow volume, 600m³/s is drawn along the full length of the tunnel from the entrance portal with a further 100m³/s drawn in from the adjacent exit portal. The 100 m³/s ensures the zero portal emissions criterion is met. Therefore, air velocities along the tunnel resulting from the 600m³/s flow will be around 8 m/s (29 km/h) – well within the maximum limit.
- **Increased height** - The significantly higher NorthConnex tunnel, 5.3 metres versus the 4.6 metres in the M5 East, also minimises the risk of overheight incidents blocking the tunnel, ensuring free-flowing traffic is not disrupted by oversized heavy vehicles. Evidence of this is Westlink M7 Motorway which has a minimum overpass bridge headroom of 5.3 metres.
- **Smoky vehicle cameras** – These would be installed to automatically detect vehicles with excessive exhaust smoke, with penalties applying to offenders. A similar initiative is in place for the M5 East tunnel and has resulted in a reduction of smoky vehicles using the tunnel.

Analysis of alternatives to further improve air quality

In addition to the infrastructure provisions, an analysis of ventilation design alternatives has been carried out (refer to **Section 3.2** of this report), as summarised below:

Ventilation outlet heights - Further analysis was carried out to assess the implications of increasing the ventilation outlets by two, five, 10 or 15 metres. The analysis considered the change in the ventilation outlet performance and the impacts to the community.

It found that increasing the height by five metres would improve performance while not unduly increasing adverse visual impact. This is a feasible and reasonable means of optimising the dispersion of emissions while maintaining performance of the in-tunnel ventilation system.



Design analysis A (PCU) relative to traffic design capacity

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The project scope has therefore been amended to include this increase with further assessment of environmental impacts presented in **Section 9.2** of this report.

Ventilation outlet locations – Relocating the outlet, as demonstrated through the additional analysis of environmental impacts including air quality, health, visual amenity, land and cost, offers no significant improvement in environmental outcomes, notably in relation to out-of-tunnel air quality. Given this, the additional environmental impact, property acquisition requirements and engineering constraints are not considered appropriate.

Additional ventilation outlets – These would improve in-tunnel and ambient air quality outcomes but would introduce significant additional environmental and land use impacts that would outweigh any minor air quality benefits.

Ventilation flow rates – The average in-tunnel air quality levels for particulate matter and nitrogen dioxide are well within acceptable limits for both free-flowing and slow moving traffic. There is an opportunity to further improve the in-tunnel air quality levels by drawing additional air into the tunnel through the tunnel support facilities at Trelawney Street and Wilson Road. This operation would be adopted to optimise in-tunnel air quality to ensure the proposed design criteria is met at all times.

Air treatment systems – Filtration can be used to reduce particulate matter and with more recent technology, nitrogen dioxide levels if acceptable in-tunnel or external air quality criteria cannot be met by conventional ventilation systems.

The NorthConnex project has carried out analysis of the environmental, land use, engineering and cost implications of a filtration treatment system (refer to **Section 3.2** of this report). The analysis of the availability, sustainability and efficiency of such technology (refer to **Section 3.1** of this report) has been completed. The conclusions are:

- Most tunnels achieve acceptable air quality criteria without filtration. Less than one per cent of tunnels in the world use filtration to reduce particulate matter or nitrogen dioxide levels to maintain acceptable in-tunnel or external air quality. No tunnels in Australia use filtration to meet their air quality criteria.
- In some international tunnels where filtration systems are installed they are seldom used.
- According to a CETU Study (2010), there are around 60 tunnels with filtration worldwide, eight are in Norway (where there are more than 900 road tunnels) and 45 are in Japan (where there are 8,000 tunnels).
- In Norway, filtration systems are required for the high dust concentration related to the use of studded tyres and large amounts of sand and salt dispersed in winter.
- In Japan, they are required to address the high number of diesel powered cars, the high percentage of heavy vehicles and poor local air quality.
- Other tunnels with filtration systems in Spain, Italy, France, Austria, Vietnam and South Korea, have specific local conditions that have to be managed, including poor external air quality, poor fleet and local geographical conditions.
- In Australia, there was a trial system in the M5 East Motorway that was not found to be effective. This trial was not on the outlets, it was used to manage air being recycled between the westbound and eastbound tunnels, and in-tunnel air quality.

- The technology around tunnel air filtering systems for nitrogen dioxide is relatively new and any benefit has yet to be sufficiently measured.
- The majority of tunnel air filtration systems are primarily “to improve visibility in the tunnels where visibility is affected by particulate pollution, or to minimise the need for fresh air renewal in very long tunnels. These systems are rarely used solely for environmental purposes” (CETU 2010).
- NorthConnex in-tunnel air quality levels, which are comparable to best practice and accepted elsewhere in Australia and throughout the world, would be achieved without filtration. As the conventional ventilation system is effective, there would be little benefit in providing an in-tunnel filtration system.
- If in-tunnel air quality levels could not be achieved with the proposed NorthConnex ventilation system, the most effective solution would be the introduction of additional ventilation outlets and additional air supply locations. This is a proven solution and more sustainable and reliable than tunnel filtration systems.
- Incorporating filtration to the ventilation outlets would have negligible benefit and require a significant increase in the size of the tunnel facilities to accommodate the equipment. It would result in increased project size, community footprint, and capital cost. The energy usage would be substantial and does not represent a sustainable approach. Further, the air leaving the outlet is not highly concentrated with pollutants (as demonstrated by the air quality assessment) since it must be of a quality to be acceptable for tunnel users. Any predicted impact on local air quality is very small even without a filtration system.

In summary, the provision of a tunnel filtration system does not represent a feasible and reasonable mitigation measure and is not being proposed.

Tunnel safety

The air quality forum held on 29 July 2014, and submissions received from the community queried the impact of an in-tunnel fire as a concern.

Section 2.7.2 of this report provides a more detailed analysis of the potential for in-tunnel fire incidents, including consideration of incident rates in other road tunnels. It demonstrates the likelihood of an in-tunnel fire incident is very low, taking into account the design of the project, exclusion of dangerous goods traffic from the tunnel and the use of emergency infrastructure and response procedures. It also discusses the low consequence of in-tunnel fires and how these potential consequences would be further reduced through the emergency management systems included in the project design. The outlets would be designed to meet the requirements of AS1668 with respect to ensuring the safe and effective dispersion of smoke in the event of a fire.

In summary, the likelihood of significant fire incidents in the tunnel is low. In the rare event of a significant fire incident, smoke would be ‘scrubbed’ by the in-tunnel fire suppression deluge system before effective dispersion via the tunnel support systems. The risk to human health is at worse, no higher than uncontrolled dispersion of smoke from a fire incident on the surface.

Noise and vibration

Further project design development around the southern interchange near Coral Tree Drive, has identified the need for more consideration of noise mitigation measures for residents in this area. **Section 4.4** of this report presents additional analysis of operational traffic noise impacts for residents along Coral Tree Drive, and identifies:

- The need for a two-noise barrier configuration next to the connection between the NorthConnex project and the Hills M2 Motorway.
- An additional six properties in addition to those identified in the environmental impact statement who would be eligible for consideration of at-property acoustic treatments.

Ongoing consultation with the Department of Planning and Environment as part of the assessment for the NorthConnex project, and concerns raised in several submissions have identified the need for more details of the construction noise mitigation and management measures to be presented.

Section 4.5 of this report provides more information and includes:

- Details of predicted noise impact around construction sites, including the level of noise impact and the number of residents potentially affected by the impact.
- Site and property specific noise mitigation and management commitments, taking into account the predicted level of noise impact. These mitigation and management measures have been modelled on similar approaches taken for the North West Rail Link and the Hills M2 Motorway upgrade projects.

Operational air quality

In addition to the clarification of air dispersion modelling presented in **Chapter 2** of this report, several submissions, including those from the key government agencies, have raised concerns relating to the air quality impact assessment. Many relate to testing the sensitivity of the air quality impact assessment to changes in modelling assumptions, including:

- Traffic forecasts.
- Vehicle fleet and fuel mix.
- Vehicle speed in the tunnel, including congested conditions.

The environmental impact statement considered forecast traffic scenarios in 2019 and 2029, as well as a worst-case traffic scenario based on the maximum traffic design capacity of the main tunnels ('Design Analysis A'). Further information is provided in relation to forecast traffic volumes and Design Analysis A as part of the response to the submission from the Environmental Protection Authority (EPA) (refer to **Section 7.1** of this report). This information demonstrates and confirms the range of conceivable potential traffic volumes that may use the tunnels has been considered in the EIS, and acceptable environmental outcomes would be achieved.

Clarifications of assumptions around the vehicle fleet and fuel mix have been provided in response to concerns raised in the submissions from the EPA and Kuring-gai Council. In particular, further analysis has been carried out around potential

changes in the petrol-diesel mix of the vehicle fleet. This analysis demonstrated changes in petrol-diesel mix assumptions would have a minor impact on in-tunnel and ambient air quality. This analysis is considered to be conservative since it does not take into account future declines in vehicle fleet emissions from 2020, including the proposed introduction of Euro 6 standards for heavy-duty diesel engines in Australia from 2017.

As a consequence, a more conservative set of assumptions around petrol-diesel mix have been applied to the additional air dispersion modelling done for the five metre height increases of the southern and northern ventilation outlets (refer to **Section 9.2** of this report).

Further discussion has been provided in **Section 2.5** to demonstrate the NorthConnex project has been designed to operate as a free-flowing motorway connection with an average traffic speed of 80 km/h. The likelihood of low traffic speeds (40 km/h or less) or congested traffic conditions have been minimised through project design and operational measures and procedures. These operational strategies would be implemented as part of the design development phase to ensure in-tunnel air quality is managed within acceptable levels in the unlikely event of a drop in traffic speed or congestion in the tunnel.

Project development and alternatives

Concerns raised in relation to the project development and alternatives included strategic planning and evolution of the project.

Further discussion of scope and findings of the F3 to Sydney Orbital Link Study (SKM, 2004) and the subsequent Pearlman Review of that report is provided in the relevant parts of **Section 8.1** and **Section 8.2** of this report.

Planning and statutory requirements

Submissions have queried the scope and level of detail of the assessments presented in the environmental impact statement, particularly, compliance with the environmental assessment requirements issued by the Secretary of the Department of Planning and Environment.

Where relevant in **Chapter 7** and **Chapter 8** of this report, further discussion and demonstration of the adequacy of the environmental impact statement has been provided, with reference to the Secretary's environmental assessment requirements and current impact assessment guidelines and policies. In each case, the environmental impact statement has been demonstrated an appropriate, robust and conservative assessment of the potential impacts of the NorthConnex project during construction and operation.

Further statutory concerns raised in public submissions include the duration of the public exhibition period and declaration of the project as critical State Significant Infrastructure.

A discussion of these matters is provided in **Chapter 8** of this report, noting these matters are the responsibility of the Department of Planning and Environment, or otherwise dictated by the requirements of the *Environmental Planning and Assessment Act 1979*.

Construction traffic impact

The major construction traffic issue raised in submissions related to the potential impact of heavy vehicles on the surrounding road network. Of particular concern was the use of local residential streets for heavy vehicle movements.

In response, heavy vehicle access routes during construction have been reviewed and revised. This has principally focused on those construction sites where the use of local residential streets was originally contemplated:

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

Construction traffic access arrangements at these sites have been changed to avoid the need to use local residential streets. As a result, construction traffic and noise impacts are expected to improve. Further information about these changes is presented in **Section 9.4** of this report.

Consultation

Submissions have raised various concerns relating to community consultation, particularly the adequacy and extent of consultation activities during development of the project and preparation of the environmental impact statement. Submissions suggested the level of consultation had not been sufficient.

Chapter 5 of this report provides a detailed summary of community and stakeholder consultation carried out in relation to the NorthConnex project. This summary demonstrates that the outcomes of consultation activities were used to inform the project and its assessment in a meaningful way.

Urban design, landscape character and visual amenity

Key concerns raised in submissions in relation to urban design, landscape character and visual amenity, principally relate to the appearance of operational infrastructure (including the ventilation outlets, motorway operations complex and tunnel support facilities at Wilson Road and Trelawney Street). Concerns relating to landscaping in and around these sites, and along the Hills M2 Motorway and M1 Pacific Motorway were also raised.

As identified in the environmental impact statement and in **Section 8.13** of this report, further consideration of urban design and landscaping would be done as part of the detailed design for the NorthConnex project. It is recognised minimising the visual impacts and optimising integration into the surrounding landscape will be an important focus.

The Technical Working Paper: Urban Design (Appendix I of the environmental impact statement) provides urban design and landscape plans for the NorthConnex project. These will be further developed as part of detailed design and documented in an

Urban Design and Landscape Plan. As identified in the Community Communication Framework (Appendix D of the environmental impact statement), the Urban Design and Landscape Plan would be developed in consultation with the community and relevant local councils.

Land use and property impacts

Key concerns raised in submissions relating to land use and property impacts included property acquisition, compensation and property values.

As detailed in the environmental impact statement and in **Section 8.20** of this report, the need for acquisition of properties has been minimised. A key feature of the NorthConnex project has been a design and construction methodology that requires relatively little space, is largely within the existing road corridor, and as a consequence, has a relatively low level of property acquisitions compared to other road projects. All properties directly affected are subject to acquisition and compensation in accordance with the *Land Acquisition (Just Terms Compensation) Act 1991*. Discussions with affected property owners in relation to acquisition arrangements started when the project was announced on 16 March 2014.

Compensation or acquisition of other properties not directly affected by the project is not proposed, based on the demonstration in the environmental impact statement that the potential impacts would be within acceptable limits.

Section 8.20 of this report provides further information on the potential impacts of major infrastructure projects on property prices and recent residential property sales activity along the project. Based on this information and the demonstration of acceptable environmental and land use impact presented in the environmental impact statement, there is no technical basis or evidence of negative changes in property values as a result of the project.

Social and economic impacts

Concerns relating to social and economic impacts have principally focused on dust, traffic and noise generated during construction and operation. These concerns are discussed broadly in **Section 8.15** of this report, and in specific detail in relevant (air, noise, traffic) sections of the report. The environmental impact statement and this report have demonstrated amenity impacts can be mitigated and managed within acceptable limits. As a consequence, social and economic impact is anticipated to be minimal.

As presented in the environmental impact statement, the NorthConnex project is expected to lead to significant social and economic improvements along the Pennant Hills Road corridor during operation as a result of reduced congestion and improvements to travel time, air quality, noise, and road safety. The project is also expected to provide wider economic benefits through its contribution to improving the efficient movement of freight in NSW.

Next steps

All stakeholders and members of the community who made a submission on the NorthConnex environmental impact statement (if contact details have not been withheld) will receive a letter to confirm the release of the report and details of where they can find a response to their submission. The project team will also provide information on the project website (www.northconnex.com.au) and distribute a community update to inform the local community.

The Department of Planning and Environment will assess this project, including information provided in the environmental impact statement, concerns raised in submissions and responses provided in this report and the proposed changes to the project to reduce environmental impacts described and assessed in the preferred infrastructure report.

The Department will then make a recommendation to the Minister for Planning, who will make a decision on whether to approve the project and any conditions applied if the project is approved.

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1 Introduction

1.1 The project

Roads and Maritime Services (Roads and Maritime) proposes to construct and operate a tolled motorway, known as the NorthConnex project, linking the M1 Pacific Motorway at Wahroonga to the Hills M2 Motorway at Carlingford in northern Sydney (the project). The project would deliver a high standard motorway that integrates with the regional transport network.

The NorthConnex project comprises the following key features:

- 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 that includes operation and maintenance facilities.
- Two tunnel support facilities incorporating emergency smoke extraction outlets and substations.
- 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.

The regional context of the project is shown in **Figure 1-1**. An overview of the project in the local context is shown in **Figure 1-2**. A detailed description of the project is available in Chapter 5 of the NorthConnex project environmental impact statement.

1.2 Statutory context

On 25 October 2013 the NorthConnex project was declared by the Minister for Planning to be State significant infrastructure and critical State significant infrastructure under sections 115U (4) and 115V of the *Environmental Planning and Assessment Act 1979*. Roads and Maritime is seeking approval for the project under Part 5.1 of that Act.

In accordance with the requirements of the *Environmental Planning and Assessment Act 1979*, an environmental impact statement was prepared to assess the potential impacts of the project. This was submitted to the Department of Planning and Environment in July 2014 and placed on public exhibition for a period of sixty days.

1.3 Purpose of the document

During the exhibition of the environmental impact statement, 1,518 submissions were made. The Secretary (formerly the Director-General) of the Department of Planning and Environment provided copies of the submissions to Roads and Maritime.

In accordance with section 115Z of the *Environmental Planning and Assessment Act 1979*, the Secretary required Roads and Maritime to respond to the issues raised in these submissions in a submissions report. The Secretary also advised that if there are any proposed changes to the project to minimise its environmental impact or to address issues raised in submissions, a preferred infrastructure report would be required. This NorthConnex Submissions and Preferred Infrastructure Report document has been prepared to fulfil both of these requirements.

This report presents the following information:

- A number of clarifications to information presented in the environmental impact statement in relation to air quality (**Chapter 2**).
- Further discussion of in-tunnel air treatment technologies and a review of feasible and reasonable ventilation design options and alternatives to minimise in-tunnel and ambient exposures to vehicle emissions (**Chapter 3**).
- A number of clarifications to information presented in the environmental impact statement in relation to the scope and design of the project, and noise issues (**Chapter 4**).
- Details of the community involvement activities carried out for the project during the public exhibition period (**Chapter 5**).
- A summary of the submissions received during the public exhibition period (**Chapter 6**).
- Responses to the issues raised in submissions received from government agencies and local councils (**Chapter 7**).
- Responses to the issues raised in submissions received from the local community (**Chapter 8**).
- Changes made to the project as presented in the environmental impact statement to further minimise its environmental impact and / or in response to issues raised in submissions (**Chapter 9**).
- A revised summary of mitigation measures, to those presented in the EIS, which have been updated to reflect responses to issues raised in submissions and changes made to the project (**Chapter 10**).

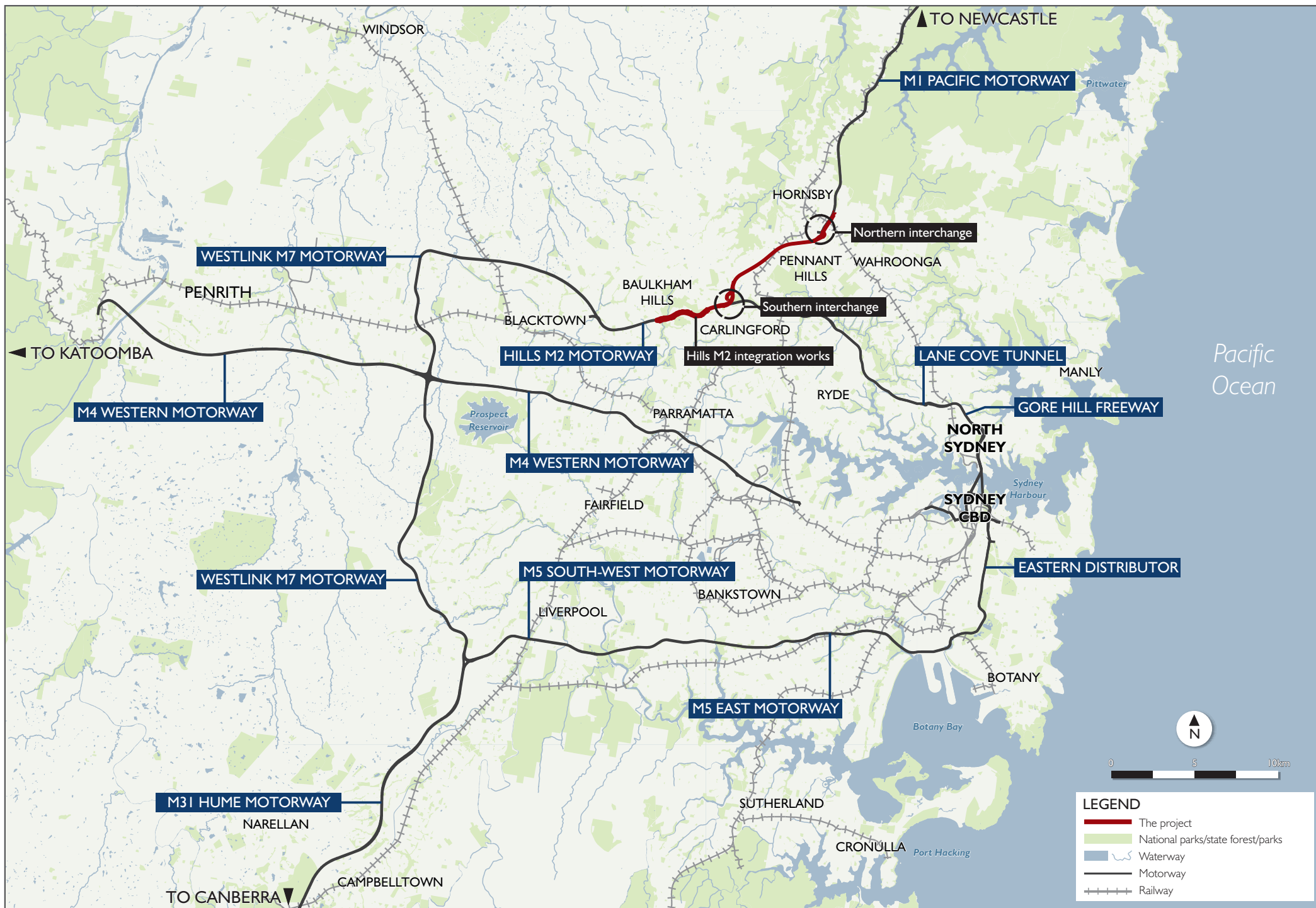


Figure 1-1 Regional context of the project

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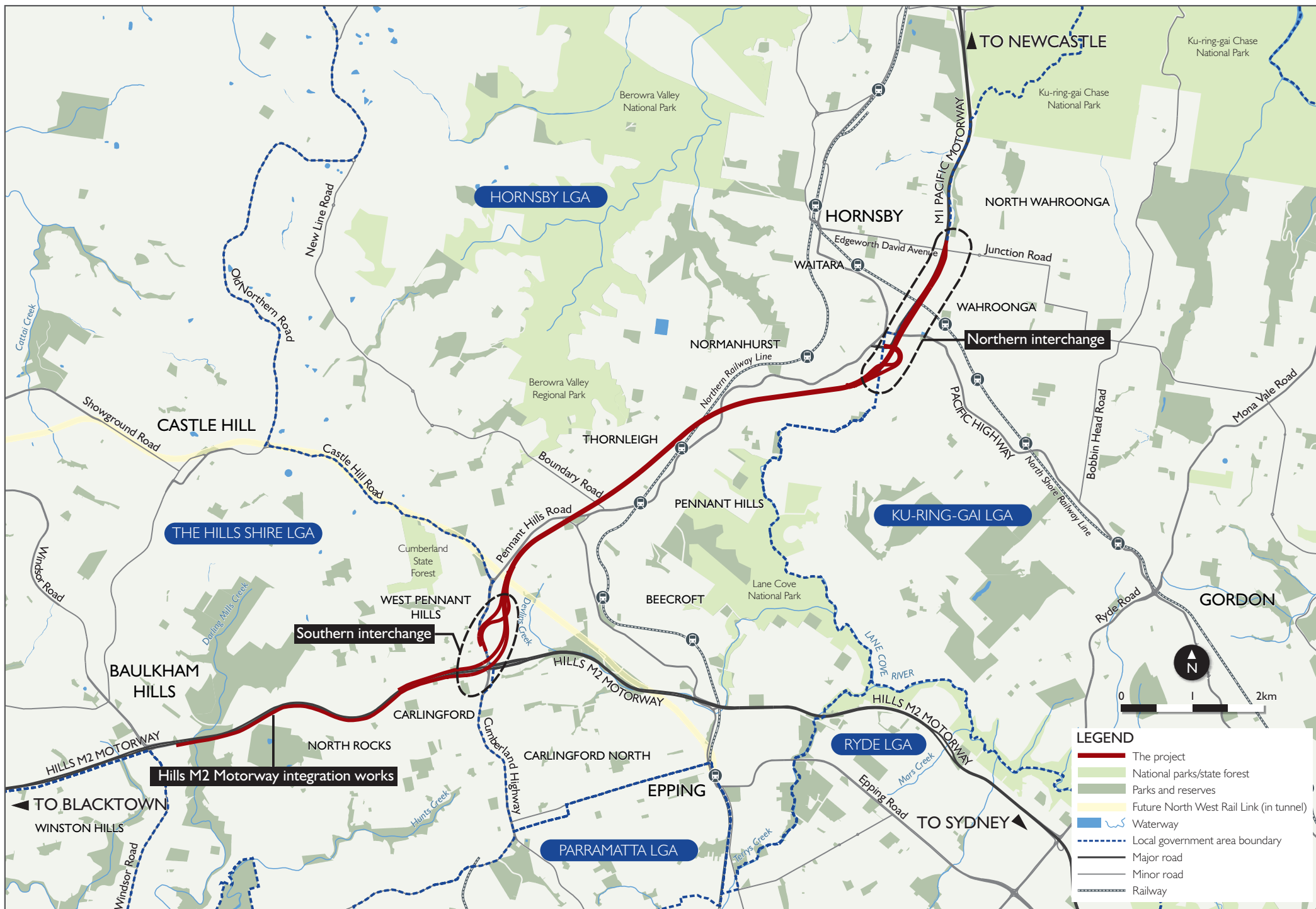


Figure 1-2 Local context of the project

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2 Clarifications – Air quality

This chapter presents the reorganisation and consolidation of relevant material regarding air quality previously contained in Section 7.2 and Appendix G of the environmental impact statement. In particular, it seeks to explain in a clear and consolidated way, the air quality impact assessment for the project, including a description of the inputs, methodology and assumptions. Further detail has been provided where relevant to respond to specific issues raised in submissions on the environmental impact statement. Additional sensitivity testing of modelling assumptions has also been included.

Chapter 3 of this report includes discussion of ventilation design options and alternatives and an assessment of feasible and reasonable measures that could be applied to the project to further reduce in-tunnel and ambient exposures to vehicle emissions.

Chapter 9 of this report details several changes that have been made to the project in order to further reduce environmental impacts. These changes include increasing the height of the northern and southern ventilation outlets by five metres.

2.1 Purpose of this chapter

The reorganisation and consolidation of relevant air quality information previously presented in the environmental impact statement in this chapter aims to:

- Address the criticism in some submissions about the presentation, clarity and robustness of the air quality impact assessment presented in the environmental impact statement.
- Reproduce the air quality impact assessment methodology originally presented in the technical working paper: air quality for the NorthConnex project, with clarifications of methodology, assumptions and inputs where relevant.
- Include further information around methodology, assumptions and inputs in response to specific issues raised in submissions on the environmental impact statement, including issues raised by the Environment Protection Authority, NSW Health and other community members and stakeholders.
- Provide further sensitivity testing of modelling assumptions to demonstrate the robust and conservative nature of the air quality impact assessment, consistent with typical environmental impact assessment practice and policy in New South Wales.
- Indicate where methodology, assumptions and inputs have been updated as part of the further air quality impact assessment conducted for an increase in ventilation outlet heights by five metres (refer to **Section 9.2** of this report).
- Provide a single, consolidated description and explanation of the methodology, assumptions and inputs into the air quality impact assessment for the NorthConnex project.

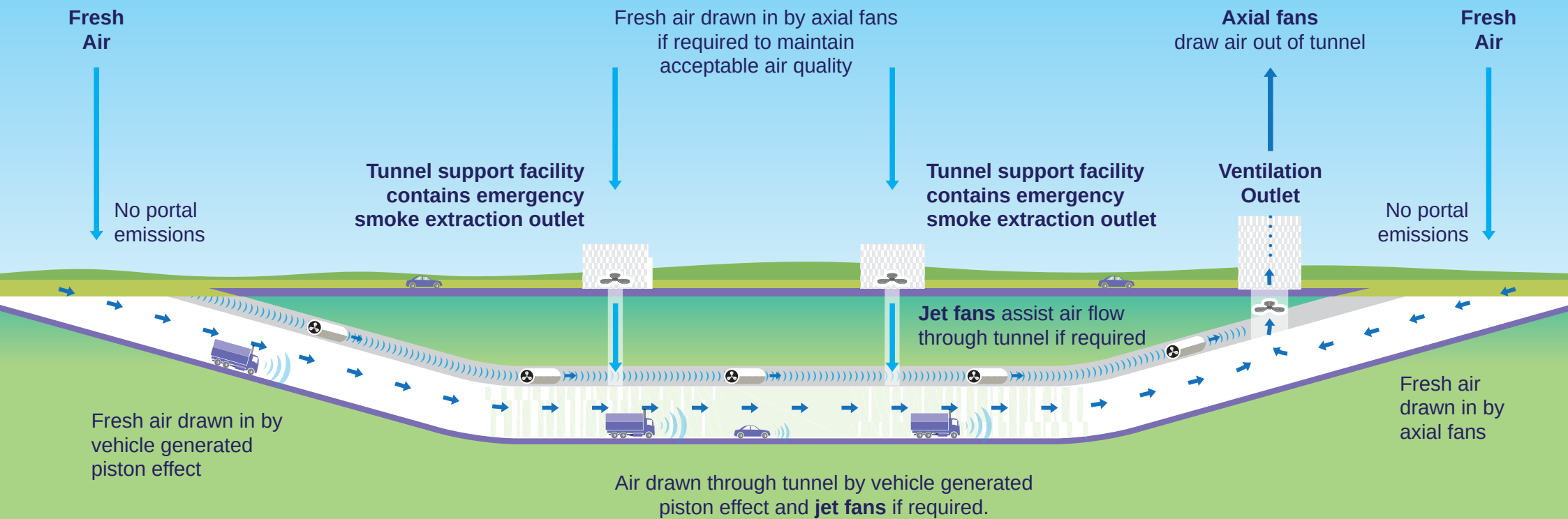
2.2 Chapter outline

This chapter includes information and discussion in relation to:

- The purpose of this chapter (refer to **Section 2.1**).
- Changes since the exhibition of the environmental impact statement (refer to **Section 2.3**).
- The components of the project relevant to air quality (refer to **Section 2.4**).
- The ventilation system design criteria that have been applied to the project (refer to **Section 2.5**).
- The assessment philosophy and approach to conservatism in the air quality impact assessment (refer to **Section 2.6**).
- Traffic volumes and assessment scenarios (refer to **Section 2.7**).
- The methodology used to calculate the emissions inventories for the project (refer to **Section 2.8**).
- In-tunnel air quality (refer to **Section 2.9**).
- Meteorological data and modelling (refer to **Section 2.10**).
- Ambient air quality (refer to **Section 2.11**).
- Local and regional terrain (refer to **Section 2.12**).
- Dispersion modelling (refer to **Section 2.13**).
- Post-processing of dispersion modelling outputs (refer to **Section 2.14**).
- The operational air quality impact assessment of the project (refer to **Section 2.15**).
- Construction air quality (refer to **Section 2.16**).

A diagram illustrating the key components of the project ventilation system is provided on the following page to assist in interpreting the text in **Section 2.4** and **Section 2.5**.

Motorway Tunnel Ventilation



Key

-  Axial fans
-  Fresh air
-  Jet fans
-  Air flow

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2.3 Changes since the exhibition of the environmental impact statement

This chapter principally reflects the methodology, assumptions and inputs applied to the air quality impact assessment presented in the environmental impact statement, with further discussion and clarification of the methodology, assumptions and inputs where required to respond to issues raised in submissions. This further discussion and clarification has been provided as supplementary information and has not altered the approach taken to the modelling and assessment of air quality impacts as presented in the environmental impact statement.

In response to issues raised in submissions, and as detailed further in **Section 3.2** of this report, a review of ventilation options and alternatives has been conducted to identify feasible and reasonable measures to further minimise in-tunnel and ambient exposures to vehicle emissions. This review has concluded that an increase in the height of the northern and southern ventilation outlets by five metres is both feasible and reasonable. Accordingly, the height of both ventilation outlets has been increased by five metres (refer to **Section 9.2** of this report).

Increasing the height of the ventilation outlets has necessitated further operational air quality modelling and impact assessment. This has provided an opportunity to update some aspects of the air quality impact assessment methodology, assumptions and inputs to take into consideration comments received in response to the exhibition of the environmental impact statement. Broadly, these updates have included:

- Increasing the resolution of the receiver grid applied around each ventilation outlet (ie reduced receiver spacing) (refer to **Section 2.13.1**).
- Applying higher resolution topographic data (refer to **Section 2.12**).
- Revising future projections of vehicle fleet fuel mix, to reflect an increased use of diesel fuel in the future) (refer to **Section 2.7**).
- Amending the ozone limiting method equation to take into account a $\text{NO}_2:\text{NO}_x$ ratio of 16 per cent, as recommended by the Environment Protection Authority (refer to **Section 2.14**).

Further detail of each of these updates in methodology, assumptions and inputs has been included in this chapter, where relevant.

2.4 Project description

Chapter 5 of the environmental impact statement provides description and details of the project.

In response to issues raised in public submissions and to further reduce the environmental impacts of the project, a series of amendments to the project have been made. Details of these amendments are provided in **Chapter 9** of this report.

The key amendment relevant to air quality is the increases in the northern and southern ventilation outlet heights by five metres. An impact assessment of this amendment for both the northern and southern ventilation outlets is provided in **Section 9.2** of this report, including the outcomes of air quality modelling using the methodology, assumptions and inputs detailed in this chapter.

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

2.4.1 Road grade and tunnel design

The main alignment tunnels would have an absolute maximum grade of four per cent to maintain consistent traffic speeds and to minimise emissions.

The main alignment tunnels would be a minimum of 10.5 metres in width and a minimum of 5.3 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.

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 conducted.

2.4.2 Ventilation system and facilities

The tunnel ventilation system would be operated to maintain appropriate air quality during both normal operation and emergency conditions (refer to **Section 2.5** for a discussion of ventilation system design criteria).

During operation, the ventilation system would draw fresh air into the tunnels via the entry portals 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 energy 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 additional energy consumption to operate tunnel jet fans to draw air through the tunnels and to transport the exhaust air from the tunnel to the ventilation outlets. This approach provides ongoing environmental and cost benefits through the reduction in energy consumption and greenhouse gas emissions during tunnel operation.

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

The project has been designed to have no portal emissions under normal operating conditions. Portal emissions 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 (on average less than once per year), 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 2-1**.

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

Table 2-1 Key ventilation system components

Component	Description
Jet fans	• Jet fans would be mounted in pairs, with each pair separated by a distance of around 90 metres. • A total of around 65 jet fans would be installed in the northbound tunnel and ramps and around 60 jet fans in the southbound tunnel and ramps. • Jet fans would be located throughout the tunnel and would operate as required to maintain in tunnel air quality requirements.
Emergency smoke extraction outlets	• Each tunnel support facility would have a minimum exhaust capacity of around 400 cubic metres per second to generate a net flow of around five metres per second along the tunnel (equivalent to 18 kilometres per hour). • 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 may be used to supply additional fresh air to the tunnels if necessary to maintain acceptable in-tunnel air quality.
Ventilation facilities	• Two ventilation outlets would be required – one near each of the northern and southern main alignment tunnel portals. • Each ventilation outlet would have a maximum exhaust capacity of around 700 cubic metres per second. • The ventilation outlets would be serviced by five horizontally-mounted axial fans, each with an exhaust capacity of around 175 cubic metres per second. • Total ventilation requirements could be achieved with four fans, with the fifth fan on standby. During normal operation, however, all five fans would likely be operated at reduced capacity. • The ventilation facilities would maintain exit velocities from around 13 m/s to around 19 m/s under normal operating conditions. • The southern ventilation facility would have an outlet at around 20 metres in height, and a building height of seven metres when measured from Pennant Hills Road (note that the total height of the ventilation has been increased by five metres from the 15 metre height considered in the environmental impact statement. This change in ventilation outlet height is considered in more detail in Section 9.2). • The northern ventilation facility would have an outlet at around 20 metres in height and a building height of around seven metres when measured from the neighbouring land (note that the total height of the ventilation has been increased by five metres from the 15 metre height considered in the environmental impact statement. This change in ventilation outlet height is considered in more detail in Section 9.2).

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 into the tunnel from the entry portals and moved 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 the atmosphere.

For the tunnel off-ramps, air would be drawn from the portal 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 to prevent portal emissions during normal and slow speed/ congested traffic conditions.

Air from within the tunnels, containing vehicle emissions, would be extracted from the tunnels prior to reaching the exit portals. Tunnel air would be removed 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/ congested traffic conditions

The piston effect of vehicle movements would be less pronounced during low speed traffic conditions. Under these conditions, the tunnel jet fans would be used as required to assist air flow. 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 to draw in fresh air. The operation of axial fans in the ventilation facilities would be increased as required 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.

During smoke control, air would be extracted from the tunnel and transferred by operation of the jet fans to the closest emergency smoke extraction outlet, ventilation facility or portal. The smoke would then be discharged from the facility to the atmosphere.

The emergency smoke extraction outlets are expected to operate in smoke extraction mode infrequently and only during an emergency. Such operation would be for a short duration while emergency services and tunnel fire and life safety systems bring the situation under control. Further information about the potential for and management of in-tunnel fire events is provided in **Section 2.7.2**.

These facilities would also operate as required to supply fresh air the tunnels during low speed traffic conditions (discussed above).

2.5 Ventilation system design criteria

The project's ventilation system has been designed to achieve specified in-tunnel air quality outcomes for traffic volumes up to and including the maximum traffic throughput capacity of the project's main alignment tunnels. The ventilation system design criteria are provided in Table 7-95 of the environmental impact statement and are reproduced below. **Table 2-2** provides additional explanatory comments to provide context to the likely operational mode of the project relative to average traffic speeds and ventilation system design criteria.

Table 2-2 Ventilation system design criteria

Average traffic speed (km/h)	Operational mode	CO design criteria (15 minute)	NO ₂ design criteria (15 minute)	Visibility (extinction coefficient)
80	Normal traffic conditions. Vehicles are moving freely with no congestion effects	50 ppm (57.5 mg/m ³)	0.5 ppm (0.94 mg/m ³)	<0.005 m ⁻¹
60		50 ppm (57.5 mg/m ³)	0.5 ppm (0.94 mg/m ³)	<0.005 m ⁻¹
40	Congested traffic conditions. Vehicles have slowed as a result of traffic congestion, caused by a vehicle accident or incident. Congestion management measures would be implemented as average traffic speeds fall towards 40 km/h.	60 ppm (69 mg/m ³)	0.8 ppm (1.51 mg/m ³)	<0.005 m ⁻¹
0 to 20	Significantly congested traffic conditions. Vehicles have slowed significantly as a result of traffic congestion, caused by a vehicle accident or incident. Congestion management measures would be in place.	87 ppm (100 mg/m ³)	1.0 ppm (1.88 mg/m ³)	<0.005 m ⁻¹

In applying the ventilation system design criteria outlined in **Table 2-2**:

- The carbon monoxide (CO) ventilation design criterion has been applied as **a 15-minute exposure standard** for a motorist using the project tunnels (with no allowance made for the mitigating effects of closing vehicle windows or recirculating vehicle air). For likely average traffic speeds through the main alignment tunnels, in-tunnel exposure durations would be less than 15 minutes, and as such, exposure to ambient air before and/ or after travel through a main alignment tunnel has also been taken into account when assessing motorist exposures. In the case of CO, ambient air has been assumed to be 5 ppm CO (5.73 mg/m^3 or equivalently $5,730 \text{ } \mu\text{g/m}^3$), which is higher than monitored background air quality data (refer to **Section 2.11**). For an example of a motorist travelling at an average speed of 80 kilometres per hour (ie an in-tunnel journey of around 6.75 minutes), the motorist's exposure to CO would be:
 - Around 6.75 minutes within the main alignment tunnel, with gradually increasing in-tunnel concentrations of CO from the tunnel entry portal to the ventilation offtake near the tunnel exit portal. The concentrations of CO experienced by the motorist within the main alignment tunnel would depend on the traffic volumes/ traffic mix at the time of the tunnel journey.
 - The remaining 8.25 minutes (to total 15 minutes) with exposure to ambient air, being assumed to be a constant 5 ppm (5.73 mg/m^3 or equivalently $5,730 \text{ } \mu\text{g/m}^3$) for the design and sizing of the ventilation system.
- The nitrogen dioxide (NO_2) ventilation design criterion has also been applied as **a 15-minute exposure standard**, and assessed in a similar way as outlined above for CO. For the purpose of taking into account background air quality, exposures prior to and following a journey through the project tunnels has been assumed to occur at 1 ppm NO_x (1.88 mg/m^3 or equivalently $1,880 \text{ } \mu\text{g/m}^3$). Comparison with the monitored background air quality data (refer to **Section 2.11**) shows that this assumption overestimates likely ambient concentrations of NO_x .
- The visibility design criterion has been applied as **an in-tunnel air quality standard**, applicable at all locations along the project tunnels, irrespective of potential motorist exposures.

As noted above, background concentrations of CO and NO_x outside the project tunnels have been assumed to be constant and above monitored background values. This is a conservative assumption because a higher assumed exposure to CO and NO_x outside the project tunnels means that a motorist must be exposed to lower concentrations in the project tunnels (than if a lower background concentration outside the project tunnels had been assumed) in order for the ventilation design criteria to be met (as exposure standards). This approach will have led to a slight over-design in the ventilation system capacity to maintain lower-than-required in-tunnel concentrations of CO and NO_x . This slight over-design provides additional latent ventilation capacity in the event that it is ever required and is considered to be a prudent approach to the design and management of a road tunnel ventilation system.

2.5.1 Design capacity of the project's ventilation system

The total number of vehicles (measured as a standard passenger car unit) that can pass a fixed point in a motorway lane per hour is dependent on the average speed of traffic. 'Passenger car units' is a standard, consistent basis for measuring the 'space' taken up by different size vehicles. For example:

- A standard passenger vehicle is one passenger car unit.
- An articulated truck is 2.9 passenger car units.
- A truck and dog is two passenger car units.

This relationship between the theoretical motorway lane 'throughput capacity' and average traffic speed is illustrated in **Figure 2-1**. The figure shows that:

- A maximum motorway lane capacity of 2,000 passenger car units per lane per hour is achievable at an average traffic speed of 60 km/h. This means that 2,000 passenger car units could pass a fixed monitoring point on a motorway lane every hour if traffic is travelling at 60 km/h.
- At an average traffic speed of 80 km/h per hour, a greater stopping distance is required between vehicles. Because of this, only 1,740 passenger car units would pass the same fixed point on a motorway lane per hour.
- At an average speed of 40 km/h, a shorter stopping is required between vehicles, but the vehicles are moving more slowly. Because of this, only 1,849 passenger car units would pass the same fixed point on a motorway lane per hour. For 20 km/h, this figure would drop further to only 1,419 passenger car units per hour.

For the two lane configuration of each of the project's main alignment tunnels, this means that for a fixed point, the following maximum vehicle throughputs could be accommodated:

- A maximum of 3,480 passenger car units per hour (two lanes) at 80 km/h.
- A maximum of 4,000 passenger car units per hour (two lanes) at 60 km/h.
- A maximum of 3,698 passenger car units per hour (two lanes) at 40 km/h.

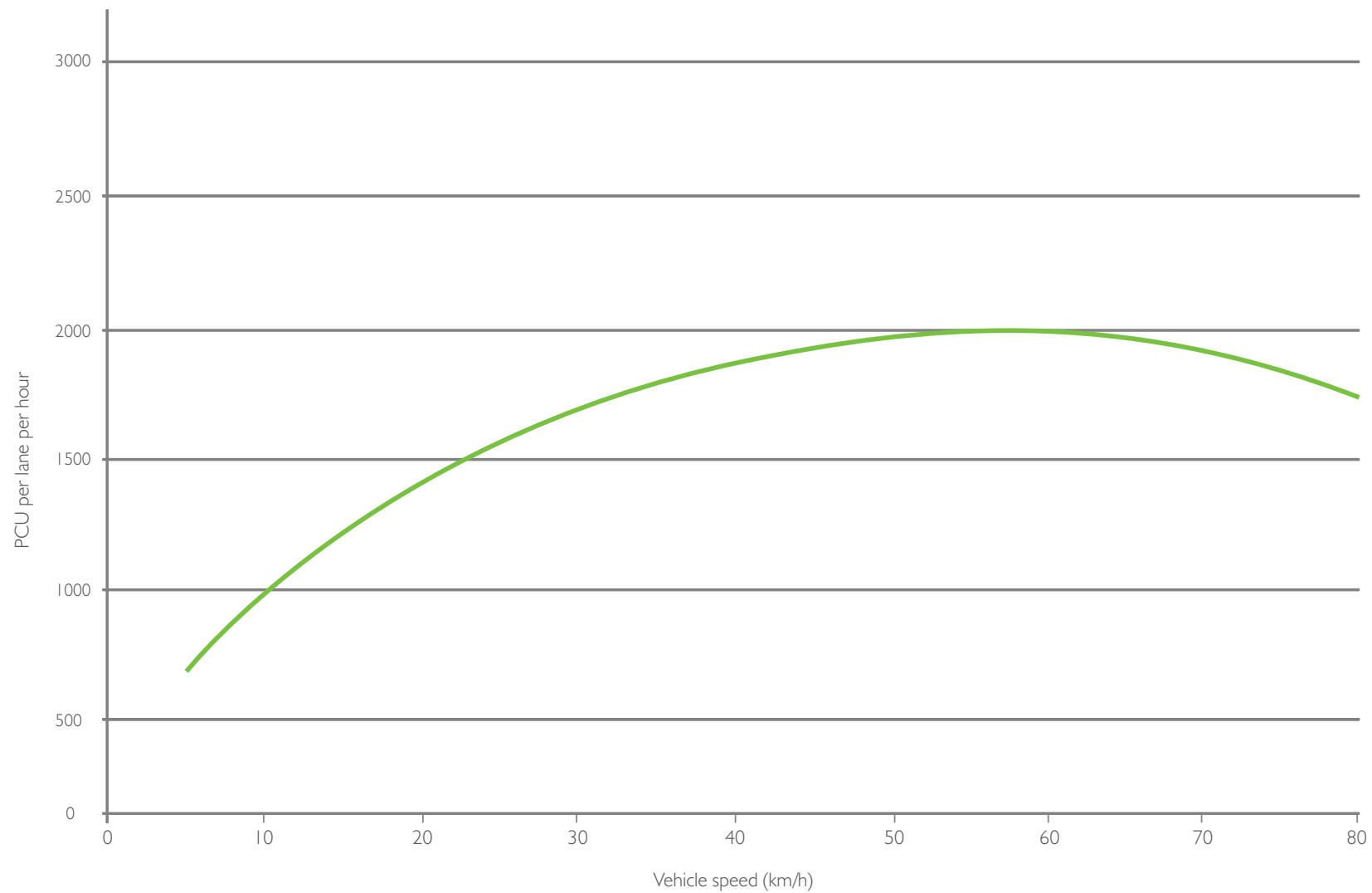


Figure 2-1 Relationship between motorway lane capacity and average traffic speed

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By virtue of the physical capacity of a motorway lane to allow traffic to pass, the 'worst case' in-tunnel vehicle emissions scenarios for the project would occur whenever the maximum throughput of traffic is experienced at the relevant average traffic speed, as listed above. As part of the ventilation design process for the project, these 'worst case' vehicle emissions scenarios have been analysed and the ventilation system sized to provide sufficient air flow to ensure that in-tunnel concentrations of emissions do not exceed the design criteria specified in **Table 2-2**.

Table 2-3 summarises calculated in tunnel air quality (ventilation design calculations) at the ventilation offtake and at the tunnel mid point for the northbound and southbound main alignment tunnels for the maximum physical throughput capacity at each nominated average traffic speed.

The values shown in the table are in-tunnel concentrations at the relevant point (as distinct from motorist exposures). Therefore some of the concentrations listed in the table at the ventilation offtake are higher in magnitude than the ventilation system design criteria. The project ventilation would nonetheless comply with the ventilation system design criteria when factors including averaging period and the distinction between exposure standards and in-tunnel concentrations are taken into account.

The calculations conducted for the values presented in **Table 2-3** are:

- Based on the theoretical maximum physical throughput capacity of the main alignment tunnels at average traffic speeds of 80 km/h, 60 km/h and 40 km/h.
- Based on the project's ventilation design to achieve these criteria.
- Independent of year (as they are based in the maximum traffic throughput of a motorway lane), but have conservatively applied the Permanent International Association of Road Congresses (2012) emission factors for 2019 (rather than lower emissions factors for a later year). Emissions from vehicles after this year are expected to be no worse than in 2019, and likely to improve over time, based on current trends, with improved vehicle and fuel efficiency.

As noted in the environmental impact statement, vehicle throughput would be actively managed once traffic speeds fall to 40 km/h or lower in order to manage motorist exposure levels and to maintain in-tunnel air quality within acceptable limits

It is proposed to develop a proactive and adaptive management approach to ensure that ventilation design criteria are not exceeded in the project tunnels. This approach would be developed during the detailed design phase of the project, and implemented from the commencement of operation.

Table 2-3 Summary of road tunnel design and operational criteria (visibility)

Average traffic speed	Carbon monoxide			Nitrogen dioxide			Visibility (PM ₁₀)		
	Design criterion (15-minute)	Maximum concentration at tunnel mid point	Maximum concentration at ventilation offtake	Design criterion (15-minute)	Maximum concentration at tunnel mid point	Maximum concentration at ventilation offtake	Design criterion	Maximum concentration at tunnel mid point	Maximum concentration at ventilation offtake
Northbound main alignment tunnel									
80 km/h	50 ppm (57.3 mg/m³)	8.4 ppm (9.6 mg/m ³)	11.8 ppm (13.5 mg/m ³)	0.5 ppm (0.94 mg/m³)	0.40 ppm (0.75 mg/m ³)	0.78 ppm (1.47 mg/m ³)	<0.005 m⁻¹ (1.06 mg/m³)	0.0026 m ⁻¹ (0.55 mg/m ³)	0.0045 m ⁻¹ (0.96 mg/m ³)
60 km/h	50 ppm (57.3 mg/m³)	8.9 ppm (10.2 mg/m ³)	12.8 ppm (14.7 mg/m ³)	0.5 ppm (0.94 mg/m³)	0.43 ppm (0.81 mg/m ³)	0.84 ppm (1.58 mg/m ³)	<0.005 m⁻¹ (1.06 mg/m³)	0.0029 m ⁻¹ (0.62 mg/m ³)	0.0050 m ⁻¹ (1.06 mg/m ³)
40 km/h	60 ppm (68.7 mg/m³)	10.1 ppm (11.6 mg/m ³)	13.1 ppm (15.0 mg/m ³)	0.8 ppm (1.51 mg/m³)	0.51 ppm (0.96 mg/m ³)	0.83 ppm (1.56 mg/m ³)	<0.005 m⁻¹ (1.06 mg/m³)	0.0034 m ⁻¹ (0.72 mg/m ³)	0.0050 m ⁻¹ (1.06 mg/m ³)
Southbound main alignment tunnel									
80 km/h	50 ppm (57.3 mg/m³)	7.2 ppm (8.2 mg/m ³)	10.0 ppm (11.5 mg/m ³)	0.5 ppm (0.94 mg/m³)	0.21 ppm (0.40 mg/m ³)	0.48 ppm (0.90 mg/m ³)	<0.005 m⁻¹ (1.06 mg/m³)	0.0021 m ⁻¹ (0.45 mg/m ³)	0.0039 m ⁻¹ (0.83 mg/m ³)
60 km/h	50 ppm (57.3 mg/m³)	8.3 ppm (9.5 mg/m ³)	12.0 ppm (13.7 mg/m ³)	0.5 ppm (0.94 mg/m³)	0.27 ppm (0.51 mg/m ³)	0.61 ppm (1.14 mg/m ³)	<0.005 m⁻¹ (1.06 mg/m³)	0.0027 m ⁻¹ (0.57 mg/m ³)	0.0050 m ⁻¹ (1.06 mg/m ³)
40 km/h	60 ppm (68.7 mg/m³)	10.2 ppm (11.7 mg/m ³)	12.9 ppm (14.8 mg/m ³)	0.8 ppm (1.51 mg/m³)	0.43 ppm (0.80 mg/m ³)	0.69 ppm (1.30 mg/m ³)	<0.005 m⁻¹ (1.06 mg/m³)	0.0035 m ⁻¹ (0.68 mg/m ³)	0.0050 m ⁻¹ (1.06 mg/m ³)

Note: in-tunnel air quality should be considered and assessed at the tunnel mid point. The maximum concentration at the ventilation offtake is relevant to and has been considered in the assessment of ambient air quality.

2.5.2 Compliance with design criteria and operational monitoring

Application of the ventilation design criteria listed in **Table 2-2** as operational performance criteria would be impractical because of the nature of some of those criteria as 15-minute average motorist exposure standards. To apply exposure standards as operational performance criteria would:

- Require knowledge of motorist exposures while outside the project tunnels (to account for a full 15 minute exposure in cases where tunnel travel times are less than 15 minutes).
- Require knowledge of exposure mitigation and its efficacy, such as the implications of closing vehicle windows (if they exist) and recirculating air.
- Involve a calculation with several inputs, which is less desirable than continuous monitoring for comparison to an in-tunnel concentration standard.

As a consequence, it is proposed that in-tunnel concentration limits be set to ensure acceptable in-tunnel air quality and as compliance standards for operation of the project. It is proposed that these in-tunnel concentration limits be set as a time-based average, measurable at the mid point of the main alignment tunnels. While in practice concentration limits could be developed and applied to any location within the project tunnels, the tunnel mid point is considered most practical and useful as an indication of average conditions along the tunnel length and well placed to provide tunnel operators with a practical measure of tunnel performance.

Table 2-3 indicates expected maximum in-tunnel concentrations (as an hourly average based on maximum theoretical traffic throughput) at the mid points of the project tunnels and the maximum in-tunnel concentrations at the ventilation offtakes.

2.6 Assessment philosophy and conservatism

2.6.1 Approach taken to the assessment

The air quality impact assessments conducted for the NorthConnex project, as presented in the environmental impact statement and in this report, have been pursued with a deliberate intention to provide a conservative assessment of potential impacts during construction and operation. In this context, the concept of a 'conservative assessment' has been applied through the selection and application of assessment methodologies, assumptions and inputs that would tend to overestimate the likely environmental impacts of the project. This approach is not unusual, and a similar philosophy has been historically applied to other major infrastructure and other development proposals in New South Wales.

In applying a conservative approach to the assessment of air quality and other impacts from the project, the intention has been to err on the side of overestimating likely impacts without unreasonably exaggerating or otherwise skewing the predictions. By demonstrating that a conservative overestimate of impacts is acceptable, it can be confidently predicted that actual impacts likely to be experienced in reality would also lie within acceptable limits.

A reasonable level of conservatism in the air quality impact assessment is desirable for the following reasons:

- It assists in accommodating some uncertainty in the series of assumptions and inputs into the overall environmental impact assessment. The various models and assessments conducted for the project build on each other in many areas (for example, the traffic forecast model, which informs the air quality impact assessment, which in turn informs the human health risk assessment), and each model/ assessment includes its own suite of assumptions and inputs. By selecting assumptions and inputs in each assessment that would produce a conservative outcome from the relevant model/ assessment, the uncertainty in each assumption/ input and the risk that changes in an assumption/ input may significantly affect the outcomes of the relevant assessment(s) are largely mitigated. That is, if assumed conditions or assessment inputs are different in reality, it is more likely than not that the net effect of different conditions would remain within the conservative assessment outcomes pursued through the environmental impact assessment process.
- It provides a broader 'environmental impact envelope' within which the detailed design of the project can be finalised and within which the project can be implemented. It is undesirable for the extent of potential environmental impacts from the project to be too narrowly defined at this point in the development of the project design, noting that there remains scope for the design of the project to be refined prior to implementation. A conservative assessment approach provides flexibility for ongoing design refinements within an approved environmental envelope (subject to approval of the project and conditions of approval that may be applied by the Minister for Planning), and reduces the risk that additional environmental impact assessments would be required for each minor design refinement between approval of the project and its final implementation.

However, it is recognised that conservatism in the air quality impact assessment may lead to some potentially undesirable outcomes that need to be mitigated and managed, such as:

- Risk of overstatement of potential air quality impacts and associated human health risks, which may contribute to concerns by the local community and other stakeholders about the impacts of the project. The potential community and stakeholder concern raised in submissions has led to additional effort to clearly explain the level of conservatism in the assessment and to provide interpretation and context for conservative results that have been presented. Full details of community and stakeholder engagement activities are provided in **Chapter 5** of this report.
- Overstatement of potential air quality impacts and associated human health risks may also lead to additional or more stringent conditions of approval than necessary, including in relation to mitigation, monitoring and management of air quality. The mitigation, monitoring and management measures required and proposed for the project in light of predicted air quality and other impacts have been reviewed and confirmed as feasible and reasonable.
- Overstatement of vehicle contributions to local air quality may similarly lead to overstating the benefit where vehicle emissions are reduced by project (along surface roads, such as Pennant Hills Road). These benefits have been reviewed and appropriately qualified.

2.6.2 Assumptions and conservatism

The assumptions applied to the air quality impact assessment for the project that have the most influence on the outcomes of the assessment are discussed in this section. This discussion is provided to clarify the level of uncertainty and conservatism in the assessment (and consequently, the total conservatism in the predicted air quality impacts of the project). A full summary of key assumptions and conservatism is provided in **Table 2-4** at the end of this section.

Emission factors

The air quality impact assessment has been based on emission factors published by the Permanent International Association of Road Congresses (PIARC), which were used to calculate emissions from vehicles within the project tunnels and on surface roads. Details of these calculations are provided in **Section 2.8**, including inherent conservatism in the PIARC emissions factors where relevant.

Key areas of uncertainty and conservatism in PIARC emissions factors can be summarised as follows:

- The PIARC emission factors were developed for the purpose of tunnel ventilation design, and as such have been developed to include a design safety margin.
- A recent study conducted on the Lane Cove Tunnel (PEL, September 2014) (refer to **Section 2.8.1**) included an analysis of in-tunnel air quality calculated using PIARC emission factors and in-tunnel air quality monitoring data. This analysis indicated that for the conditions in the Lane Cove Tunnel, the PIARC emission factors overestimated CO by 1.3 to 1.7 times, NO_x by 1.6 to 1.8 times, and PM_{2.5} by 2.8 to 4.4 times.
- PIARC provides adjustment factors up to the year 2020 to account for expected continuous improvement in engine technologies and emissions. As this assessment considered traffic in the years 2019 and 2029, the 2020 adjustment factors were conservatively used for predicting traffic emissions in the 2029 case. That is, the air quality impact assessment has not factored in any improvement in vehicle efficiencies or fuel standards beyond 2020.

Background air quality

The approach taken to determine background air quality in and around the project is detailed in **Section 2.11**.

Sufficient air quality monitoring data in proximity to the project's ventilation outlets was not available for the air quality impact assessment for the project and as such an alternative method has been applied to gain representative ambient background air quality values. The method, in summary, was that hourly monitoring data from Lindfield and Prospect monitoring stations (operated by the Office of Environment and Heritage) were combined and the highest monitored concentration of each pollutant on an hourly basis was selected as part of the background (ambient) air quality data set for the assessment. The use of the highest monitored concentrations compared to simply the data from a single nearest station, as is common practice for assessments in NSW, resulted in a total average for all pollutants above the average from either individual station.

A review of ambient monitoring data against the monitoring data collected from monitoring stations installed along the project corridor has been conducted and is provided in **Section 2.11** (for the period January 2014 to August 2014, inclusive). The review shows a good correlation between the two sets of data, with the monitoring data from the stations operated by the Office of Environment and Heritage trending towards the upper end of the project monitoring data (ie the data used in the air quality impact assessment tends to be at the higher end of observed air quality along the project corridor). The review confirms that the ambient background data used in the assessment is likely to be consistent with local pollution trends in the project area and is appropriate for use in the assessment.

Surface road contributions

Section 2.14.1 of this report details how project contributions, background contributions and cumulative concentrations of air pollutants have been calculated. In broad terms, the approach taken in the air quality impact assessment for the project applied the following definitions:

- 'Project contributions' have been taken to be those changes in air quality directly attributable to the operation of the project's ventilation outlets.
- 'Background contributions' have been taken to be all other air quality contributions, including pollutant levels in ambient air in the region and contributions from surface roads (which includes both increases and decreases in road contributions as an indirect consequence of operation of the project). The approach to determining 'background contributions' for the purpose of the air quality impact assessments is detailed further below.
- 'Cumulative concentrations' have been taken to be the sum of the project contribution and the background contribution for a particular receiver location.

An alternative approach to calculating and assigning project and background air quality contributions is also analysed in **Section 2.14.1**. This alternative approach includes changes in air quality as a result in changes to surface traffic as part of the 'project contribution' rather than the 'background contribution' (as was done in the air quality assessment for the project).

An assessment of the two methodologies for a series of receiver locations has been conducted (refer to **Section 2.14.1**). The assessment demonstrates that for most of the time (more than 99.95 per cent of the time when considering maximum cumulative concentrations of NO₂ (one hour) and PM₁₀ (24 hour)), the methodology applied in the environmental impact statement and in this report calculates higher predicted cumulative impacts (project and background contributions) than the alternative method. This analysis also confirms that the air quality impact assessments for the project are over-estimating cumulative air quality impacts.

Traffic forecasts and assessment scenarios

In addition to assessing air quality impacts under forecast traffic volumes in 2019 and 2029, the environmental impact statement includes an assessment of a 'worst case' scenario (design analysis A). Details of scenarios that have been assessed for the project, and an explanation of how design analysis A represents a credible worst case scenario are provided in **Section 2.7.3**.

One of the key assumptions applied as part of design analysis A is that the theoretical maximum traffic throughput capacity of the project will be reached during the peak hour. The theoretical maximum traffic throughput capacity (4,000 passenger car units per hour) is around 2.1 times the peak forecast traffic volumes in 2019 and around 1.6 times the peak forecast traffic volumes in 2029. This means that actual traffic volumes would need to be around 110 per cent higher than traffic forecasts in 2019 or around 60 per cent higher than traffic in forecasts in 2029. Based on traffic forecasts using the Cube strategic model, the triggers that may lead to this level of variance in traffic volumes (demography, land use, major additions to the road network, traffic generating developments) are not expected within the timeframes considered as part of the assessment of the project.

The environmental impact statement demonstrates that design analysis A would comply with applicable ambient air quality criteria and advisory reporting standards. The analysis presented in **Section 2.5** also demonstrates that the project's ventilation system has been designed to achieve specified in-tunnel air quality criteria at the maximum traffic throughput capacity of the main alignment tunnels (as has been assumed in the peak hour for design analysis A).

Dispersion modelling

Discussion of modelling packages used in the air quality impact assessment is provided in **Section 2.13**.

The atmosphere is a complex, physical system, and the movement of air in a given location is dependent on a number of variables, including temperature, topography and land use, as well as larger-scale synoptic processes. Dispersion modelling is a method of simulating the movement of air pollutants in the atmosphere using mathematical equations. The model equations necessarily involve the current understanding of the complex environmental interactions and chemical reaction processes involved, available input data, processing time and data storage limitations. The model configuration particularly affects model predictions during certain meteorological conditions and source emission types. For example, the prediction of pollutant dispersion under low wind speed conditions (typically defined as those less than 1 m/s) or for low-level, non-buoyant sources, is problematic for most dispersion models. To accommodate these effects, the model is configured to provide conservative estimates of pollutant concentrations at particular locations. While the models, when used appropriately and with high quality input data, can provide very good indications of the scale of pollutant concentrations and the likely locations of the maximum concentrations occurring, their outputs should not be considered to be representative of exact pollutant concentrations at any given location or point in time.

Summary of assumptions and conservatism

The key methods and assumptions for the air quality impact assessment are summarised in **Table 2-4**, and discussed in more detail in the relevant following sections of this report.

Table 2-4 Summary of key methods and assumptions applied to the air quality impact assessment

Issue	Comment
General method	The air quality modelling and impact assessment were conducted in accordance with relevant guidance documents (DEC, 2005; Barclay and Scire, 2011).
Emissions inventory	
Project contribution	The project contribution has been considered to be ventilation outlet emissions only. Surface road emissions have been included as background pollutant concentrations. A review of a comparison method applying the impact from change in traffic as project contribution has been completed (refer to Section 2.14.1).
Portal emissions	The assessment has been conducted assuming zero emissions from the tunnel portals; that is, all vehicle emissions have been assumed to be vented via the tunnel ventilation outlets near the end of each tunnel.
Outlet heights	The ventilation emission points had been assumed to be 15 metres above ground (for the assessment presented in the environmental impact statement). These have been increased by five metres (to 20 metres) as part of this report in response to issues raised in submissions and based on an analysis of feasible and reasonable measures to minimise exposures to vehicle emissions (refer to Section 3.2).
Volumetric flow rates	Volumetric flow rates (VFRs) were initially calculated for each hourly predicted traffic flow rates. This volumetric flow rate was then assigned to one of the “VSO Running Levels”, which defined the conditions under which the ventilation stations will be operated. The running level above the predicted volumetric flow rate was adopted for each hour. Rates were based on a minimum VFR of 300 Nm ³ /s which would correspond with periods of the lowest traffic volumes in the project tunnels and a maximum design capacity of 700 Nm ³ /s (four fans operating at a maximum capacity of 175 Nm ³ /s each).
Hourly varying emission rates	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 volumetric flows to reflect the expected traffic volumes.
Emission factors source	PIARC emission factors have been used for particulate matter, NO _x and CO. As these factors have been development or the purpose of ventilation design, they include engineering safety factors (ie they overestimate likely emissions). The emission factors published in the National Pollutant Inventory (NPI) (DEWHA, 2008) have also been used to estimate emissions of other pollutants (refer to Section 2.8).
PIARC adjustment factors	PIARC adjustment factors for 2019 and 2020 have been used to estimate emissions for 2019 and 2029 modelling scenarios (refer to Section 2.8). Adjustment factors are only available up to 2020 – the use of 2020 factors for 2029 is expected to result in overestimation of 2029 emissions and resultant ground level pollutant concentrations due to expected improvements in vehicle emissions over time (EPA, 2012b).

Issue	Comment
Particulate matter ratio (PM ₁₀ :PM _{2.5})	The NPI provides emission factors for a variety of different vehicle types and fuels. The ratios of PM ₁₀ to PM _{2.5} emissions have been calculated for the various vehicle types assessed (refer to Section 2.8). The ratios for cars and light duty vehicles (LDVs) have been averaged to provide an average ratio of PM _{2.5} to PM ₁₀ for non-heavy duty vehicles (HDVs) (0.93). This ratio has then been multiplied by the PM ₁₀ emissions calculated using the PIARC emission factors to estimate PM _{2.5} emission rates. A similar process has been followed for HDVs, where the ratio of PM _{2.5} to PM ₁₀ was calculated to be 0.95.
VOCs and PAHs emission factors	Emissions of VOCs and PAHs have been similarly calculated using the carbon monoxide emission rates (refer to Section 2.8). The ratios of NPI emission factors for these pollutants and carbon monoxide have been 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.
Traffic forecast data	The forecast traffic volumes presented in the Technical Working Paper: Traffic and Transport (Appendix E of the environmental impact statement) have been used in the air quality impact assessment.
Fleet distribution – general	The current Australian fleet distribution relating to the number of diesel-powered passenger vehicles and the fleet mix (proportion of LDV to HDV) data have been obtained from the motor vehicle census prepared by the Australian Bureau of Statistics (ABS, 2013). This data has been compared with vehicle registration data from Roads and Maritime Services and confirmed to be representative of the NSW vehicle fleet (refer to Section 2.8). Diesel-engine passenger cars have been shown to make up approximately eight per cent of the current Australian fleet, and this value has been 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 the assessment presented in the environmental impact statement. The current ratio of petrol to diesel vehicles (2013) has therefore been used for both 2019 and 2029 in the assessment presented in the environmental impact statement. Emissions from passenger cars /LDVs have been calculated separately for all pollutants, and then summed with the emissions from HDVs to provide total pollutant emission rates. As part of this report, the heights of the project's ventilation outlets have been increased by five metres. Further air quality impact assessment for this amendment to the project has applied updated assumptions around petrol/ diesel fuel mix. In particular, the growth in diesel-fuelled vehicle has been extrapolated to 2019 and 2029 (refer to Section 2.8), rather than assuming a constant petrol/ diesel distribution to identify sensitivity to changes in fuel mix in the future.

Issue	Comment
Fleet distribution – heavy vehicles	The percentage of heavy vehicles in the total traffic volumes using the project tunnels has been forecast to be around 28 per cent in 2019 and around 25 per cent in 2029. These traffic forecasts for the project have assumed that 95 per cent of through heavy vehicles travelling along the Pennant Hills Road corridor would be directed into the project tunnels with the implementation of regulatory measures (to require heavy vehicles to use the tunnels). A sensitivity analysis has been conducted of the implications should the proportion of heavy vehicles increase by 10 per cent (refer to Section 2.9.2 and Table 2-48).
Fleet distribution – proportion of diesel vehicles	As stated above, the fleet distribution has been sourced from ABS data. The environmental impact statement fleet distribution applied the 2013 composition to the 2019 and 2029 assessment scenarios, while in this report a linear extrapolation from 2008 and 2013 ABS data has been applied to determine the fleet mix in 2019 and 2029. This extrapolation resulted in a future increase in diesel vehicles. Refer to Section 2.8 for more details.
Surface road particulate matter calculations	Surface road dispersion modelled has employed the CAL3QHCR model, which doesn't include PM _{2.5} as a modelling species. To address this issue, the concentrations of PM ₁₀ calculated by the CAL3QHCR model have been multiplied by 0.95 (the maximum ratio of PM _{2.5} to PM ₁₀ calculated for the project tunnel emissions (refer to Section 2.8) to estimate PM _{2.5} concentrations at each receiver location.
Tunnel emissions calculation - parameters	Predicted pollutant emissions from vehicles within the project tunnels have been calculated taking into account the number of vehicles each hour, the speed and the fleet composition (refer to Section 2.8). The vertical design alignment of the tunnel has also been taken into account, and each main alignment tunnel has been split into a series of sections to calculate the differing emissions resulting from gradient changes along the lengths of the tunnels. Gradient data for the emission calculations have been obtained from the design documents.
Tunnel emission calculation	It has been assumed that there are no portal emissions. The total tunnel emissions have been calculated based on the sum of each tunnel section's emissions, factoring in the length of each section, the time taken for vehicles in the tunnel to pass through each section, the density of vehicles in the tunnel and the respective gradients. Hourly emission rates in grams per second have been generated for the identified pollutants of concern for each individual tunnel for the expected traffic flows in the assessment years 2019 and 2029.
Portal in-take air	Pollutant loads in portal intake air was not considered in the environmental impact statement dispersion modelling. A screening assessment has been undertaken as part of this report and demonstrates that pollutant loads in portal intake air do not significantly alter the outcomes of the air quality impact assessment.
Variable exit temperature	Variable temperatures have been calculated using average seasonal temperature differences between the Lane Cove Tunnel emissions and ambient air. The hourly seasonal average temperature differences have then been applied to the temperature data predicted for the project's ambient environment to calculate the estimated temperatures of emissions from the ventilation outlets.
Exit diameter of the	The air dispersion modelling has assumed time-varying ventilation outlet diameters to maintain required discharge velocity.

Issue	Comment
ventilation outlets	
Forecast traffic data	Twenty-four hour Annual Average Weekday Traffic (AAWT) flows have been used in the air quality assessment. The use of 24 hour AAWT data, rather than the use of 24 hour Annual Average Daily Traffic (AADT), is considered to be a conservative approach in the assessment as AAWT data only take into account the weekday traffic volumes, which are typically busier than weekend traffic volumes. Traffic forecasts have assumed that 95 per cent of heavy vehicles travelling along the Pennant Hills Road corridor would utilise the project tunnels, and have accommodate anticipated growth in heavy vehicle numbers.
Pollutant concentrations	
NO ₂ calculation – ozone limiting method	The Ozone Limiting Method (OLM) endorsed for use in the Approved Methods for the Modelling and Assessment of Air Pollutants in New South Wales (DEC, 2005a) has been used to calculate the conversion of NO_x to NO₂. The air quality impact assessment presented in the environmental impact statement has applied the OLM equation using the equation published in the Approved Methods guideline (refer to Section 2.14.2). Based on further advice from the Environment Protection Authority in its submission on the environmental impact statement, the published OLM equation has been modified to reflect a NO₂:NO_x ratio in vehicle exhaust of 16 per cent (on average). The amended OLM equation has been applied to the further modelling and assessment of the increased ventilation outlet height (refer to Section 2.15.1).
VOC calculation	The total VOC concentrations have been 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 human health risk assessment for the project. For passenger cars, sixty per cent of fuel used has been assumed to be E10. This percentage represents the target for petrol sold in New South Wales under the <i>Biofuels Act 2007</i> . For the purpose of this speciation, the composition of VOCs in vehicle emissions has been assumed to remain the same over time. The mass fraction percentages have been multiplied by the 99.9th percentile predicted total VOC ground level concentrations.
PAHs and VOCs - background	For PAHs and VOCs, cumulative assessment using background data is not required by the Approved Methods for the Modelling and Assessment of Air Pollutants in New South Wales (DEC, 2005a). Furthermore, background data are not available to conduct a cumulative assessment of these pollutants.
Contemporaneous assessment	A contemporaneous assessment 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 than simply adding the two maximum values.

Issue	Comment
Background data	
Background data source	Pollutant concentrations measured at Prospect and Lindfield were taken to be indicative of ambient pollutant concentrations throughout the project area. For PM ₁₀ , PM _{2.5} and NO ₂ , the ambient concentrations were determined by taking the maximum of the concentrations predicted by CAL3QHCR and those measured by the Office of Environment and Heritage at its Lindfield and Prospect monitoring stations. This was done for each receiver for each hour modelled. Data from the Office of Environment and Heritage monitoring stations has been compared with data collected from the ambient monitoring stations installed along Pennant Hills Road and this is discussed in Section 2.11.3 .
Background PM ₁₀ to PM _{2.5} ratio	As PM _{2.5} is not monitored at either the Lindfield or Prospect monitoring stations, PM _{2.5} concentrations have been estimated from the monitored PM ₁₀ concentrations using a PM ₁₀ to PM _{2.5} ratio calculated from Sydney monitoring stations that recorded both particulate matter fractions. Monitoring data from Liverpool, Chullora, Earlwood and Richmond for the period 2009 to 2011 have been used. The PM ₁₀ to PM _{2.5} ratios have been calculated for each of the monitoring stations for each hour of the day. These ratios have then been averaged across the monitoring stations for each hour of the day, and the maximum of those averages has been adopted as the conversion ratio for the assessment, which was 0.35. This ratio has been applied to the combined PM ₁₀ monitoring data from Lindfield/Prospect to estimate hourly PM _{2.5} concentrations. Based on experience, the ratio is typically between 0.3 and 0.4, so this value is considered to be acceptable.
Meteorological Data	
Data source	Meteorological data have been 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 Office of Environment and Heritage. These measured data have been used in conjunction with MM5 prognostic model data (refer to Section 2.10).
Modelled time period	The dispersion modelling has been conducted for a three year period (January 2009 – December 2011).
Terrain/land use	
Terrain data source	NASA SRTM three arc-second (or around 90 metre resolution) data has been used for the terrain data in the environmental impact statement (refer to Section 2.12). The further modelling and assessment of the increased ventilation outlet height (refer to Section 2.15.1) has used 5m resolution Land and Property Information (LPI) data.
Land use data source	Land use data within the study area has been derived from the Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES).

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2.7 Traffic volumes and assessment scenarios

2.7.1 Forecast traffic volumes

Full details of traffic forecasts and the assessment of potential traffic impacts of the project are included in Section 7.1 of the environmental impact statement and the Technical Working Paper: Traffic and Transport (Appendix E of the environmental impact statement). Outputs from those assessments relevant to the operational air quality impact assessment are summarised in this section.

Forecast traffic data for the project, including the project tunnels and the surrounding surface road network, has been generated through a strategic transport model of Sydney's major road network using the Cube Voyager software platform. Cube is the most widely used software package in the world for transport planning.

The Cube model used to develop traffic forecast data for the NorthConnex project has taken into account factors including existing and future land use, anticipated changes to the major road network, existing and future travel demands, existing and future tolling structures, and motorist behaviours. Further details of these assumptions and inputs are provided in Section 5.2 of the Technical Working Paper: Traffic and Transport (Appendix E of the environmental impact statement).

It is relevant to note that the Cube model has taken into account factors that are outside the scope of the NorthConnex project, and as a consequence, not all forecast changes in traffic on the surface road network are necessarily fully or partially a consequence of the project itself. Importantly, anticipated potential changes in the tolling structure applicable to the Westlink M7 Motorway have been taken into account in traffic forecasts across the surface road network. These potential changes in tolling structure are outside the scope of the NorthConnex project, and are not subject to assessment under the *Environmental Planning and Assessment Act 1979* because the Westlink M7 Motorway would continue to operate within the terms of its existing planning and environmental approvals. Notwithstanding, traffic forecasts presented in the Technical Working Paper: Traffic and Transport (Appendix E of the environmental impact statement) show changes in the distribution of traffic on the surface road network as a result of changes to the Westlink M7 Motorway tolling structure which are independent of any effect attributable to the NorthConnex project itself.

With respect to potential traffic changes on the surface road network, it is also important to recognise that a key objective of the project has been to ensure that there is no deterioration in the performance of the surface road network. That is, design and construct tenderers were directed to design the project in a manner that minimised adverse impacts (ie significant increases in traffic volumes) on the surface road network as a consequence of the project. This outcome has been achieved, and traffic forecasts for the surface road network presented in the Technical Working Paper: Traffic and Transport (Appendix E of the environmental impact statement) and summarised in the following sections, show few areas of increased traffic volumes and no deterioration in road network performance when considering measures such as level of service. This is also reflected in the limited need for surface road network enhancements to accommodate the project.

Traffic forecasts for 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 main alignment tunnel for the opening year of the tunnel and 10 years after opening (2019 and 2029, respectively), are shown graphically in **Figure 2-2** and **Figure 2-3**. The figures illustrate the forecast increase in traffic flows between 2019 and 2029 assessment years for the northbound and southbound tunnels.

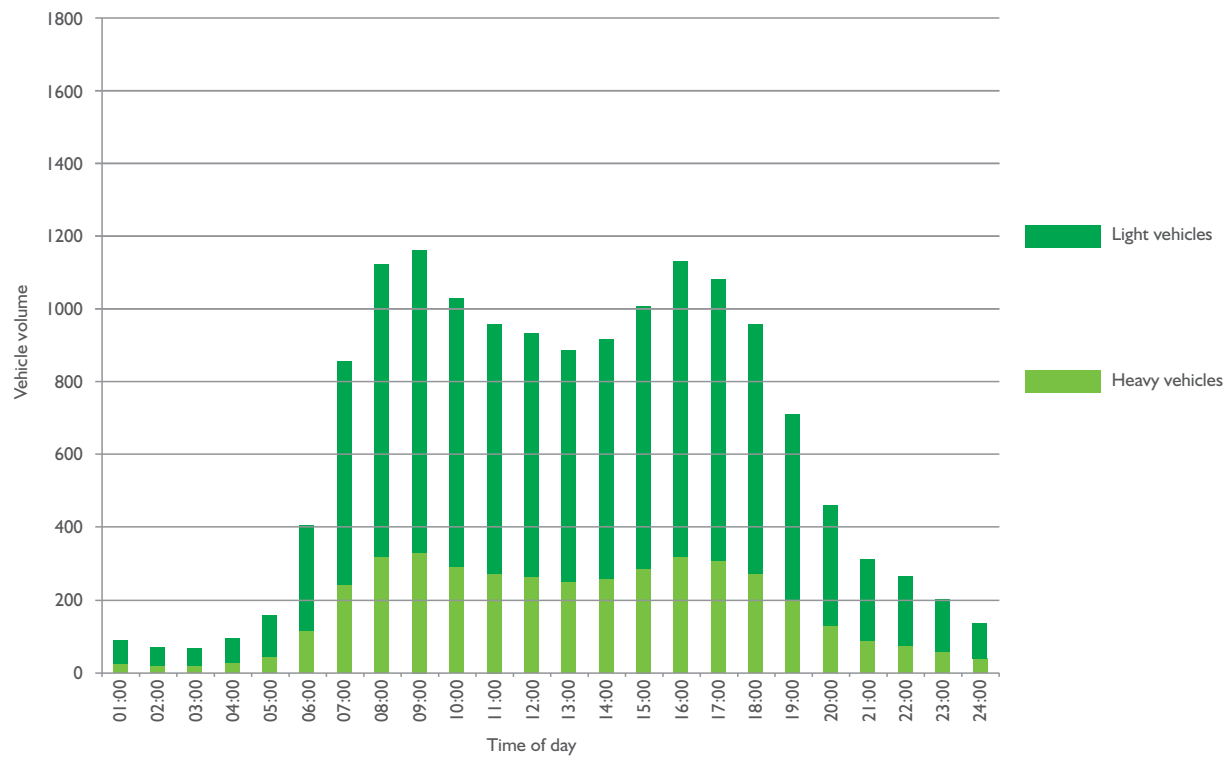
For 2019, the predicted percentage of heavy vehicles varied hourly, and ranged from 28.0 per cent to 28.5 percent for the northbound tunnel and from 27.8 per cent to 28.6 per cent in the southbound tunnel.

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

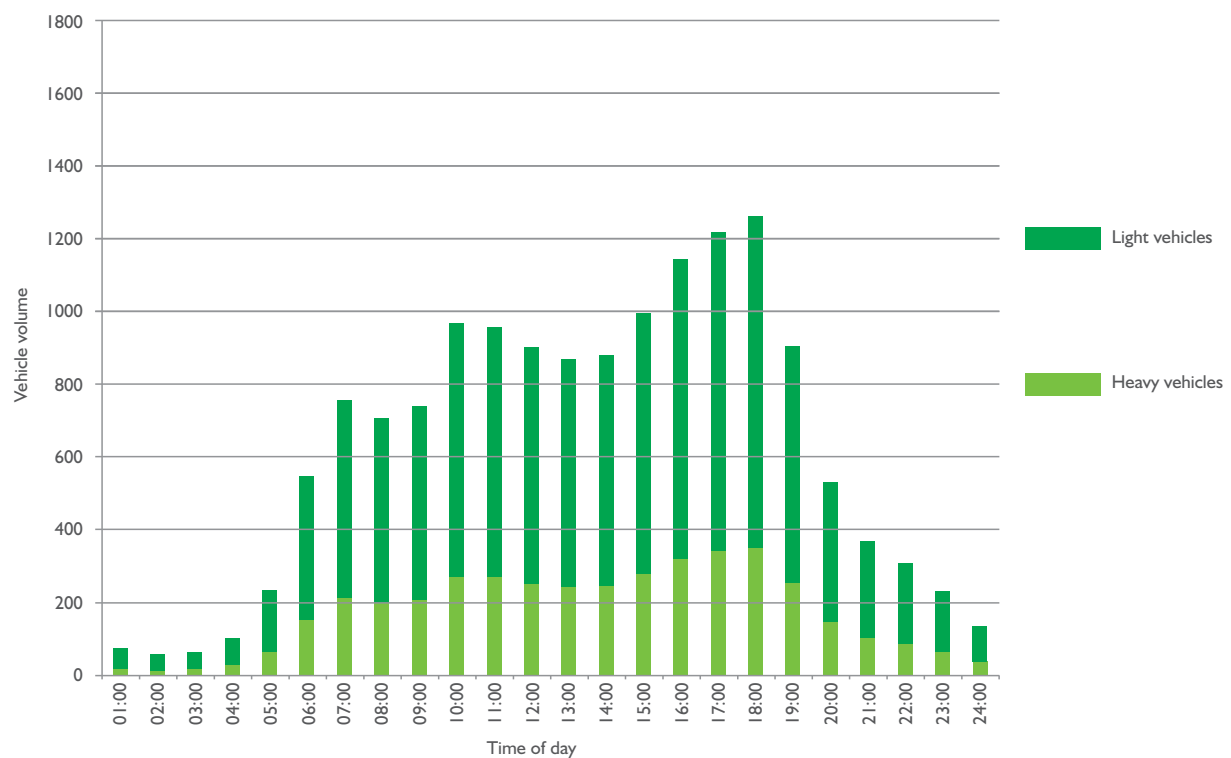
These traffic forecasts for the project have assumed that 95 per cent of through heavy vehicles travelling along the Pennant Hills Road corridor would be directed into the project tunnels with the implementation of regulatory measures (to require heavy vehicles to use the tunnels). There is therefore a very low potential for heavy vehicles using the project to exceed these heavy vehicle percentages.

Forecast traffic data have been consistently presented in the environmental impact statement and associated technical specialist studies through figures such as **Figure 2-2** and **Figure 2-3**, rather than detailed tables of forecast traffic numbers, based on the commercial sensitivities of this information. If required, actual forecast traffic numbers can be provided to relevant regulatory agencies for internal assessment purposes.

A significant investment is proposed in the NorthConnex project. The commercial viability of this investment is dependent on forecast traffic volumes expected to use the project being reasonable and realistic. Because of this, the Cube model and its outputs have been interrogated in detail to confirm that the project is viable prior to seeking design and construct tenders or lodging an application for environmental planning approval.



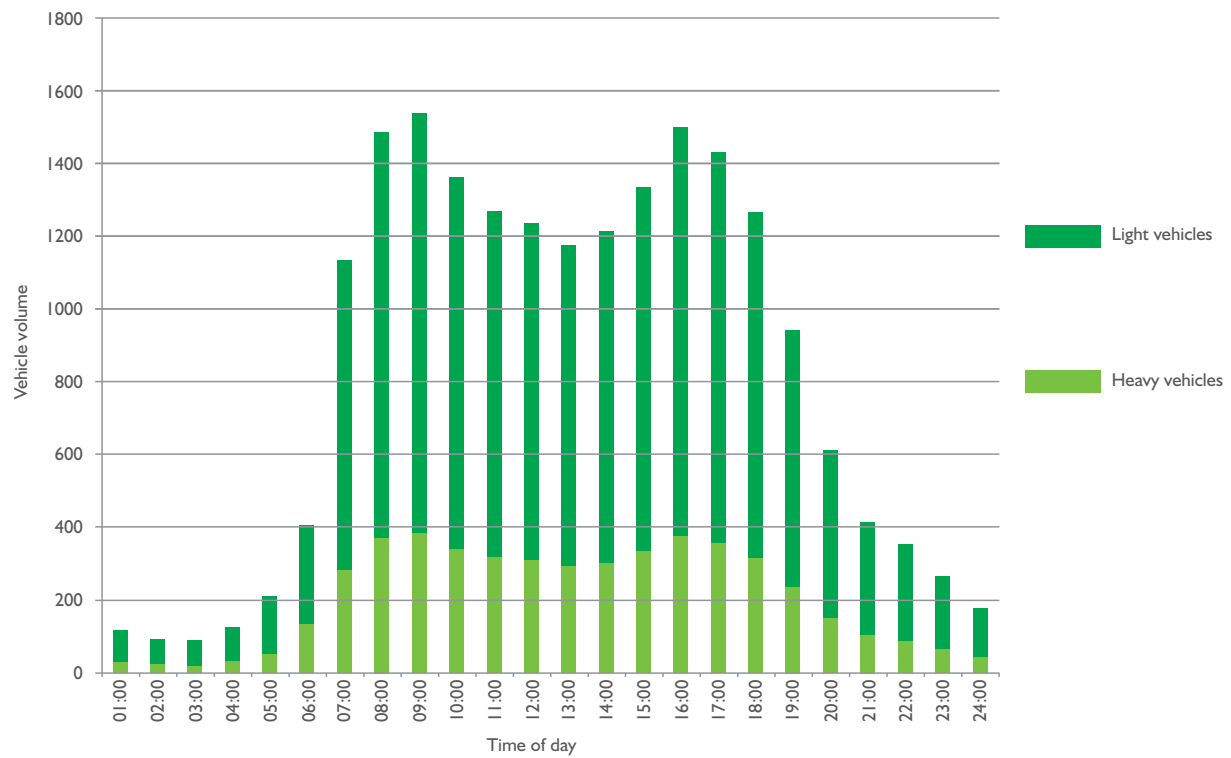
SOUTHBOUND - 2019



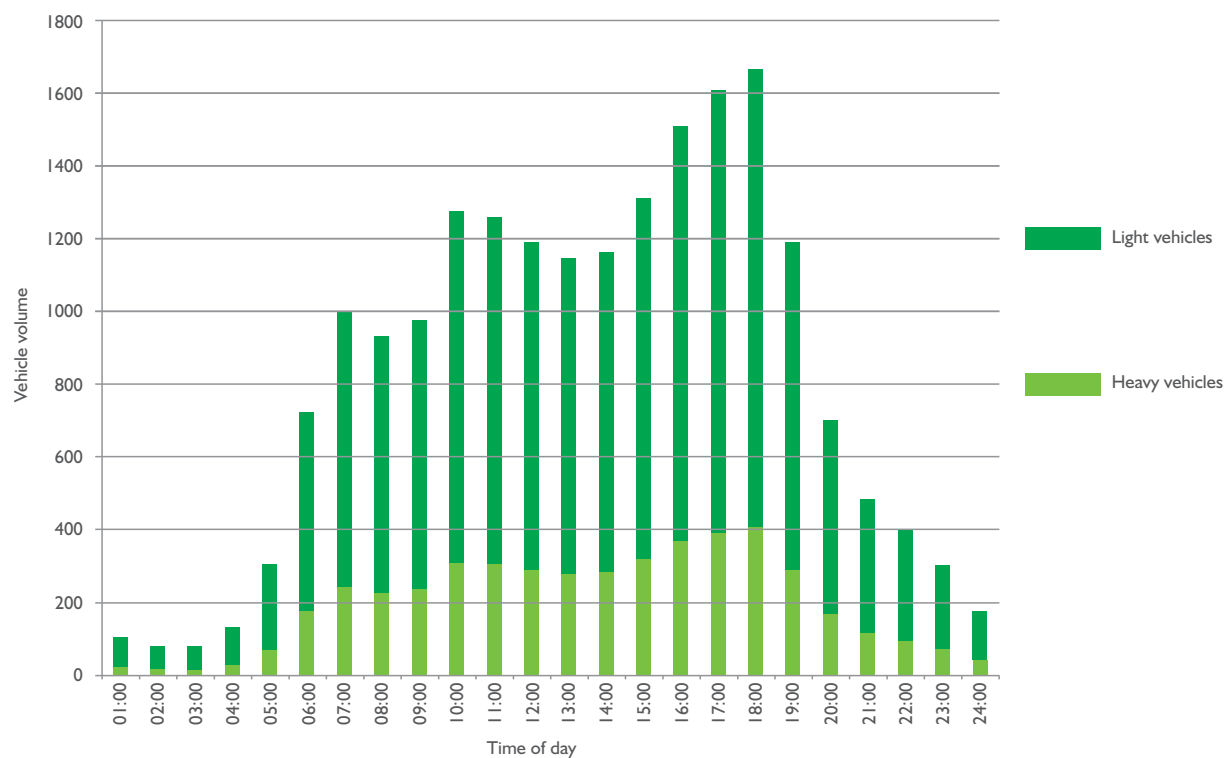
NORTHBOUND - 2019

Figure 2-2 2019 hourly traffic flows

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SOUTHBOUND - 2029



NORTHBOUND - 2029

Figure 2-3 2029 hourly traffic flows

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Traffic forecasts for the surface road network

Section 7.1 of the environmental impact statement and the Technical Working Paper: Traffic and Transport (Appendix E of the environmental impact statement) present the outcomes of traffic forecasts for surface roads around the project. The section summarises data relevant to the air quality impact assessment.

The project would affect traffic volumes, and associated vehicle emissions, along the following surface roads:

- Major roads connecting to and around the project, including:
 - Direct impacts on the Hills M2 Motorway, through road capacity changes associated with the Hills M2 Motorway integration works, and indirectly through induced and redistributed traffic flows.
 - Direct impacts on the M1 Pacific Motorway through road capacity changes associated with the M1 Pacific Motorway tie-in works, and indirectly through induced and redistributed traffic flows.
- Direct impacts on Pennant Hills Road, through road capacity changes associated with roadworks at Pearces Corner, and indirectly by providing an alternative traffic route through the corridor.
- Other major arterial roads in the region, indirectly through induced and redistributed traffic flows. This includes the Pacific Highway, which connects to the project via Pennant Hills Road and/ or the M1 Pacific Motorway.

While there is potential for the project to contribute to changes in traffic flows along local streets during operation, these potential changes are considered minor in nature and in the context of traffic changes on the surrounding major arterial road network.

The following sections summarise the forecast changes in surface traffic volumes as a result of the project in 2019 and 2029. Data is presented for total vehicles, as well as for light vehicles and heavy vehicles. To assist in interpretation of traffic data, the change in surface traffic volumes has been expressed as a percentage and visually highlighted as summarised in **Table 2-5**.

Table 2-5 Shading for forecast changes in surface traffic

Increases in traffic	Decreases in traffic
Less than one per cent increase	Less than one per cent increase
From one to 10 per cent increase	From one to 10 percent decrease
From 10 to 50 per cent increase	From 10 to 50 per cent decrease
More than 50 per cent increase	More than 50 per cent decrease

Note that the traffic data presented in this section is summarised (refer to the Technical Working Paper: Traffic and Transport for the full traffic data set and impact assessment), nor does it represent all of the data used for the assessment of air quality changes associated with surface roads (refer to **Section 2.8.3** of this report). The traffic data presented in this section are intended to provide context to the extent and relative magnitude of changes in surface traffic as a result of the project, and as a consequence the extent and relative magnitude of changes in traffic-related air quality. This context has been used to define and justify the scope of the air quality impact assessment as it relates to surface traffic changes (refer to **Section 2.7.2** of this report).

Major roads connecting to the project

Major roads connecting to the project include the Hills M2 Motorway, the M1 Pacific Motorway, Pennant Hills Road and the Pacific Highway near the intersection with Pennant Hills Road and the M1 Pacific Motorway. Traffic forecasts on these major connecting roads are summarised in **Table 2-6**, **Table 2-7**, **Table 2-8** and **Table 2-9** respectively. Data is shown for the peak hours in 2019 and 2029, with a breakdown by vehicle type (total vehicles, light vehicles and heavy vehicles) and calculated change in vehicle numbers (as a percentage change).

The data in the tables show that:

- For the Hills M2 Motorway:
 - In 2019, there is forecast to be a slight reduction in traffic volumes in the AM peak (generally less than six per cent) and a moderate increase in the PM peak (generally up to around 15 per cent). The most pronounced changes are forecast in heavy vehicle numbers to the east of Pennant Hills Road, which are forecast to fall by around 39 per cent (westbound, AM peak) and 25 per cent (eastbound PM peak). The most significant increase in heavy vehicles is forecast to occur in the eastbound direction in the PM peak (around 21 per cent increase).
 - In 2029, there is forecast to be a slight increase in total vehicles and light vehicle numbers in the AM peak (less than 10 per cent), with the exception of the westbound direction east of Pennant Hills Road which shows a forecast decrease in vehicle numbers (both light and heavy vehicles). A similar trend is shown in the PM peak traffic forecasts (increases in total and light vehicle numbers up to around 20 per cent), with the exception of the eastbound direction east of Pennant Hills Road, which shows a slight decrease (around seven per cent). The most significant changes in vehicle numbers can be seen in heavy vehicles, and particularly during the AM peak. During the AM peak in an eastbound direction, and during the PM peak in both an eastbound and westbound direction, heavy vehicles numbers are forecast to increase. The westbound direction in the AM peak is forecast to experience a significant reduction in heavy vehicle numbers (around 60 per cent reduction east of Pennant Hills Road, and around 25 per cent west of Pennant Hills Road).
- For the M1 Pacific Motorway:
 - There is generally negligible change in vehicle numbers in both peaks in 2019 and 2029. This outcome is not unexpected given the design of the project and the location of the M1 Pacific Motorway in the broader road network. The M1 Pacific Motorway is the principal route connecting the Central Coast, Newcastle and the north of New South Wales to Sydney, with no other practical alternative. All traffic travelling between Sydney and the north currently uses the motorway, and will continue to do so in the future. The NorthConnex project connects to the end of the M1 Pacific Motorway, and does not create new entry/ exit points along the motorway north of Sydney (other than the connection to the end of the motorway). Traffic forecasts show a very small redistribution of traffic on the M1 Pacific Motorway in 2019 associated with the new interchange connection, and no change in 2029.

- For Pennant Hills Road:
 - Traffic forecasts indicate an almost comprehensive reduction in traffic volumes along Pennant Hills Road in the AM and PM peaks in 2019 and 2029. The most significant reductions are apparent in heavy vehicle numbers which in many cases show a forecast drop of around 50 to 80 per cent.
 - The key exception is the southern portion of Pennant Hills Road, where traffic is forecast to be redistributed as a consequence of access/ egress arrangements for the project. The most pronounced change in traffic can be seen in heavy vehicles traveling northbound on Pennant Hills Road between North Rocks Road and the Hills M2 Motorway (ie south of the southern interchange) in the PM peak. Forecast increases in heavy vehicle numbers in this area are around 120 to 180 per cent. In relative terms these forecast changes are significant, however, the absolute numbers of heavy vehicles (less than 200 in the PM peak) are low.
- For the Pacific Highway near the connection with the project:
 - In 2019, traffic volumes are generally forecast to decrease (by up to 20 per cent) in the AM peak. The exception is northbound east of the M1 Motorway (ie traffic from the Pacific Highway travelling towards the project) where a moderate increase in total vehicles is anticipated (up to 10 per cent). Heavy vehicle numbers are forecast to increase by around 30 per cent, but this is a consequence of the relative change (from 120 to 160 heavy vehicles in the peak hour) rather than a significant absolute heavy vehicle volume. Forecast changes in traffic are more pronounced in the PM peak, with reductions in total vehicles of up to around 60 per cent in the southbound direction north of Pennant Hills Road and increases in total vehicles of up to around seven per cent in the southbound direction east of the M1 Pacific Motorway. Forecast significant increases in heavy vehicle numbers (up to around 170 per cent in the northbound direction north of Pennant Hills Road) are the result of a significant relative change in vehicle numbers (from 30 to 80 in the PM peak) rather than indicating a significant increase in the absolute number of vehicles
 - In 2029, forecast traffic in the AM peak is anticipated to fall north of Pennant Hills Road (by up to around 10 per cent for total and light vehicle counts) and increase to the east of the M1 Pacific Motorway (by around 10 per cent for total vehicle numbers). The most significant change is forecast to occur in heavy vehicle numbers east of the M1 Pacific Motorway, where increases of around 30 to 50 per cent are forecast. In the PM peak, traffic volumes are forecast to increase in most cases (by up to around 15 per cent for total and light vehicle numbers) with the exception of southbound north of Pennant Hills Road where traffic numbers are forecast to fall by a similar degree. The most significant relative change is anticipated in heavy vehicles northbound north of Pennant Hills Road and southbound east of the M1 Pacific Motorway (by around 230 per cent and 100 per cent, respectively).

Table 2-6 Hills M2 Motorway – forecast peak hour traffic (mid block) with and without the project in 2019 and 2029

Road	Total vehicles			Light vehicles			Heavy vehicles		
	Without project	With project	% change because of project	Without project	With project	% change because of project	Without project	With project	% change because of project
2019 AM peak									
Hills M2 Motorway (east of Pennant Hills Road) eastbound	4,530	4,280	-5.5%	4,190	3,960	-5.5%	340	320	-5.9%
Hills M2 Motorway (east of Pennant Hills Road) westbound	2,200	2,190	-0.5%	2,020	2,080	+3.0%	180	110	-38.9%
Hills M2 Motorway (west of Pennant Hills Road) eastbound	4,730	4,550	-3.8%	4,250	4,090	-3.8%	480	460	-4.2%
Hills M2 Motorway (west of Pennant Hills Road) westbound	2,990	3,030	+1.3%	2,730	2,760	+1.1%	260	270	+3.8%
2019 PM peak									
Hills M2 Motorway (east of Pennant Hills Road) eastbound	2,790	2,510	-10.0%	2,590	2,360	-8.9%	200	150	-25.0%
Hills M2 Motorway (east of Pennant Hills Road) westbound	4,620	4,820	+4.3%	4,290	4,540	+5.8%	330	280	-15.2%
Hills M2 Motorway (west of Pennant Hills Road) eastbound	3,430	3,650	+6.4%	3,140	3,300	+5.1%	290	350	+20.7%

Road	Total vehicles			Light vehicles			Heavy vehicles		
	Without project	With project	% change because of project	Without project	With project	% change because of project	Without project	With project	% change because of project
Hills M2 Motorway (west of Pennant Hills Road) westbound	4,570	5,180	+13.3%	4,120	4,700	+14.1%	450	480	+6.7%
2029 AM peak									
Hills M2 Motorway (east of Pennant Hills Road) eastbound	4,690	4,830	+3.0%	4,490	4,540	+1.1%	200	290	+45.0%
Hills M2 Motorway (east of Pennant Hills Road) westbound	2,470	2,160	-12.6%	2,140	2,020	-5.6%	330	140	-57.6%
Hills M2 Motorway (west of Pennant Hills Road) eastbound	5,150	5,440	+5.6%	4,860	4,970	+2.3%	290	470	+62.1%
Hills M2 Motorway (west of Pennant Hills Road) westbound	3,480	3,510	+0.9%	3,030	3,170	+4.6%	450	340	-24.4%
2029 PM peak									
Hills M2 Motorway (east of Pennant Hills Road) eastbound	3,040	2,850	-6.3%	2,840	2,640	-7.0%	200	210	+5.0%
Hills M2 Motorway (east of Pennant Hills Road) westbound	5,030	5,710	+13.5%	4,700	5,320	+13.2%	330	390	+18.2%

Road	Total vehicles			Light vehicles			Heavy vehicles		
	Without project	With project	% change because of project	Without project	With project	% change because of project	Without project	With project	% change because of project
Hills M2 Motorway (west of Pennant Hills Road) eastbound	3,880	4,400	+13.4%	3,520	3,930	+11.6%	360	470	+30.6%
Hills M2 Motorway (west of Pennant Hills Road) westbound	5,020	5,980	+19.1%	4,530	5,480	+21.0%	490	500	+2.0%

Table 2-7 M1 Pacific Motorway – forecast peak hour traffic (mid block) with and without the project in 2019 and 2029

Road	Total vehicles			Light vehicles			Heavy vehicles		
	Without project	With project	% change because of project	Without project	With project	% change because of project	Without project	With project	% change because of project
2019 AM peak									
M1 Pacific Motorway between Ku-ring-gai Chase Road and Windy Banks interchange northbound	1,850	1,820	-1.6%	1,580	1,550	-1.9%	270	270	0%
M1 Pacific Motorway between Ku-ring-gai Chase Road and Windy Banks interchange southbound	4,210	4,160	-1.2%	3,920	3,860	-1.5%	290	300	+3.4%
2019 PM peak									
M1 Pacific Motorway between Ku-ring-gai Chase Road and Windy Banks interchange northbound	4,330	4,240	-2.1%	4,060	3,960	-2.5%	270	280	+3.7%
M1 Pacific Motorway between Ku-ring-gai Chase Road and Windy Banks interchange southbound	2,230	2,230	0%	2,000	1,980	-10.0%	230	250	+8.7%

Road	Total vehicles			Light vehicles			Heavy vehicles		
	Without project	With project	% change because of project	Without project	With project	% change because of project	Without project	With project	% change because of project
2029 AM peak									
M1 Pacific Motorway between Ku-ring-gai Chase Road and Windy Banks interchange northbound	1,930	1,930	0%	1,610	1,610	0%	320	320	0%
M1 Pacific Motorway between Ku-ring-gai Chase Road and Windy Banks interchange southbound	4,980	4,980	0%	4,620	4,620	0%	360	360	0%
2029 PM peak									
M1 Pacific Motorway between Ku-ring-gai Chase Road and Windy Banks interchange northbound	4,920	4,920	0%	4,580	4,580	0%	340	340	0%
M1 Pacific Motorway between Ku-ring-gai Chase Road and Windy Banks interchange southbound	2,340	2,340	0%	2,030	2,030	0%	310	310	0%

Table 2-8 Pennant Hills Road – forecast peak hour traffic (mid block) with and without the project in 2019 and 2029

Road	Total vehicles			Light vehicles			Heavy vehicles		
	Without project	With project	% change because of project	Without project	With project	% change because of project	Without project	With project	% change because of project
2019 AM peak									
Pennant Hills Road, North Rocks Road to Hills M2 Motorway, northbound	1,770	1,770	0%	1,590	1,610	+1.3%	180	160	-11.1%
Pennant Hills Road, North Rocks Road to Hills M2 Motorway, southbound	2,450	2,390	-2.4%	2,320	2,240	-3.4%	130	150	+15.4%
Pennant Hills Road, Hills M2 Motorway to Castle Hill Road, northbound	2,680	2,330	-13.1%	2,330	2,140	-8.2%	350	190	-45.7%
Pennant Hills Road, Hills M2 Motorway to Castle Hill Road, southbound	3,470	3,080	-11.2%	3,220	2,990	-7.1%	250	90	-64.0%
Pennant Hills Road, Castle Hill Road to Beecroft Road, northbound	2,830	2,610	-7.8%	2,540	2,470	-2.8%	290	140	-51.7%
Pennant Hills Road, Castle Hill Road to Beecroft Road, southbound	2,410	2,150	-10.8%	2,200	2,080	-5.4%	210	70	-66.7%
Pennant Hills	3,770	3,430	-9.0%	3,430	3,260	-5.0%	340	170	-50.0%

Road	Total vehicles			Light vehicles			Heavy vehicles		
	Without project	With project	% change because of project	Without project	With project	% change because of project	Without project	With project	% change because of project
Road, Beecroft Road to Comenarra Parkway, northbound									
Pennant Hills Road, Beecroft Road to Comenarra Parkway, southbound	3,590	3,240	-9.7%	3,380	3,130	-7.4%	210	110	-47.6%
Pennant Hills Road, Comenarra Parkway to Pacific Highway, northbound	2,430	2,240	-7.8%	2,140	2,100	-1.9%	290	140	-51.7%
Pennant Hills Road, Comenarra Parkway to Pacific Highway, southbound	2,610	2,170	-16.9%	2,340	2,100	-10.3%	270	70	-74.1%
2019 PM peak									
Pennant Hills Road, North Rocks Road to Hills M2 Motorway, northbound	2,130	1,760	-17.4%	2,080	1,620	-22.1%	50	140	+180%
Pennant Hills Road, North Rocks Road to Hills M2 Motorway, southbound	2,120	1,890	-10.8%	1,980	1,730	-12.6%	140	160	+14.3%

Road	Total vehicles			Light vehicles			Heavy vehicles		
	Without project	With project	% change because of project	Without project	With project	% change because of project	Without project	With project	% change because of project
Pennant Hills Road, Hills M2 Motorway to Castle Hill Road, northbound	3,830	3,490	-8.8%	3,640	3,420	-6.0%	190	70	-63.2%
Pennant Hills Road, Hills M2 Motorway to Castle Hill Road, southbound	3,280	2,830	-13.7%	2,970	2,660	-10.4%	310	170	-45.2%
Pennant Hills Road, Castle Hill Road to Beecroft Road, northbound	2,610	2,190	-16.1%	2,450	2,170	-11.4%	160	20	-87.5%
Pennant Hills Road, Castle Hill Road to Beecroft Road, southbound	2,540	2,220	-12.6%	2,250	2,090	-7.1%	290	130	-55.2%
Pennant Hills Road, Beecroft Road to Comenarra Parkway, northbound	3,870	3,560	-8.0%	3,690	3,530	-4.3%	180	30	-83.3%
Pennant Hills Road, Beecroft Road to Comenarra Parkway, southbound	3,160	2,600	-17.7%	2,830	2,480	-12.4%	330	120	-63.6%
Pennant Hills Road, Comenarra	3,060	2,760	-9.8%	2,890	2,650	-8.3%	170	110	-35.3%

Road	Total vehicles			Light vehicles			Heavy vehicles		
	Without project	With project	% change because of project	Without project	With project	% change because of project	Without project	With project	% change because of project
Parkway to Pacific Highway, northbound									
Pennant Hills Road, Comenarra Parkway to Pacific Highway, southbound	3,280	1,830	-44.2%	2,970	1,750	-41.1%	310	80	-41.9%
2029 AM peak									
Pennant Hills Road, North Rocks Road to Hills M2 Motorway, northbound	2,050	2,090	+2.0%	1,810	1,900	+5.0%	240	190	-20.8%
Pennant Hills Road, North Rocks Road to Hills M2 Motorway, southbound	3,010	2,750	-8.6%	2,840	2,560	-9.9%	170	190	+11.8%
Pennant Hills Road, Hills M2 Motorway to Castle Hill Road, northbound	2,870	2,460	-14.3%	2,470	2,220	-10.1%	400	240	-40.0%
Pennant Hills Road, Hills M2 Motorway to Castle Hill Road, southbound	3,940	3,640	-7.6%	3,620	3,490	-3.6%	320	150	-53.1%
Pennant Hills Road, Castle Hill Road to Beecroft	3,070	2,740	-10.7%	2,750	2,570	-6.5%	320	170	-46.9%

Road	Total vehicles			Light vehicles			Heavy vehicles		
	Without project	With project	% change because of project	Without project	With project	% change because of project	Without project	With project	% change because of project
Road, northbound									
Pennant Hills Road, Castle Hill Road to Beecroft Road, southbound	2,630	2,330	-11.4%	2,370	2,230	-5.9%	260	100	-61.5%
Pennant Hills Road, Beecroft Road to Comenarra Parkway, northbound	4,180	3,720	-11.0%	3,750	3,470	-7.5%	430	250	-41.9%
Pennant Hills Road, Beecroft Road to Comenarra Parkway, southbound	4,210	3,710	-11.9%	3,930	3,620	-7.9%	280	90	-67.9%
Pennant Hills Road, Comenarra Parkway to Pacific Highway, northbound	2,630	2,490	-5.3%	2,290	2,310	+0.9%	340	180	-47.1%
Pennant Hills Road, Comenarra Parkway to Pacific Highway, southbound	3,000	2,550	-15.0%	2,690	2,430	-9.7%	310	120	-61.3%
2029 PM peak									
Pennant Hills Road, North Rocks Road to Hills M2 Motorway,	2,480	2,150	-13.3%	2,420	2,020	-16.5%	60	130	+116.7%

Road	Total vehicles			Light vehicles			Heavy vehicles		
	Without project	With project	% change because of project	Without project	With project	% change because of project	Without project	With project	% change because of project
northbound									
Pennant Hills Road, North Rocks Road to Hills M2 Motorway, southbound	2,500	2,530	+1.2%	2,280	2,340	+2.6%	220	190	-13.6%
Pennant Hills Road, Hills M2 Motorway to Castle Hill Road, northbound	4,290	3,840	-10.5%	4,050	3,720	-8.1%	240	120	-50.0%
Pennant Hills Road, Hills M2 Motorway to Castle Hill Road, southbound	2,990	3,140	+5.0%	2,620	2,950	+12.6%	370	190	-48.6%
Pennant Hills Road, Castle Hill Road to Beecroft Road, northbound	2,730	2,350	-13.9%	2,560	2,290	-10.5%	170	60	-64.7%
Pennant Hills Road, Castle Hill Road to Beecroft Road, southbound	2,740	2,470	-9.9%	2,400	2,270	-5.4%	340	200	-41.2%
Pennant Hills Road, Beecroft Road to Comenarra Parkway, northbound	4,320	3,930	-9.0%	4,080	3,870	-5.1%	240	60	-75.0%
Pennant Hills Road, Beecroft	3,400	2,810	-17.4%	2,990	2,620	-12.4%	410	190	-53.7%

Road	Total vehicles			Light vehicles			Heavy vehicles		
	Without project	With project	% change because of project	Without project	With project	% change because of project	Without project	With project	% change because of project
Road to Comenarra Parkway, southbound									
Pennant Hills Road, Comenarra Parkway to Pacific Highway, northbound	3,370	3,080	-8.6%	3,140	2,940	-6.4%	230	140	-39.1%
Pennant Hills Road, Comenarra Parkway to Pacific Highway, southbound	3,680	2,030	-44.8%	3,300	1,880	-43.0%	380	150	-60.5%

Table 2-9 Pacific Highway – forecast peak hour traffic (mid block) with and without the project in 2019 and 2029

Road	Total vehicles			Light vehicles			Heavy vehicles		
	Without project	With project	% change because of project	Without project	With project	% change because of project	Without project	With project	% change because of project
2019 AM peak									
Pacific Highway, north of Pennant Hills Road, northbound	1,570	1,420	-9.6%	1,470	1,340	-8.8%	100	80	-20.0%
Pacific Highway, north of Pennant Hills Road, southbound	1,230	1,000	-18.7%	1,150	920	-20.0%	80	80	0%
Pacific Highway, east of M1 Pacific Motorway, northbound	1,720	1,890	+9.9%	1,600	1,730	+8.1%	120	160	+33.3%
Pacific Highway, east of M1 Pacific Motorway, southbound	3,170	3,060	-3.5%	3,000	2,900	-3.3%	170	160	-5.9%
2019 PM peak									
Pacific Highway, north of Pennant Hills Road, northbound	1,330	1,360	+2.3%	1,300	1,280	-1.5%	30	80	+166.7%
Pacific Highway, north of Pennant Hills Road, southbound	4,270	1,680	-60.7%	4,200	1,630	-61.2%	70	50	-28.6%
Pacific Highway, east of M1 Pacific Motorway, northbound	3,110	3,050	-1.9%	3,030	2,970	-2.0%	80	80	0%

Road	Total vehicles			Light vehicles			Heavy vehicles		
	Without project	With project	% change because of project	Without project	With project	% change because of project	Without project	With project	% change because of project
Pacific Highway, east of M1 Pacific Motorway, southbound	1,850	1,980	+7.0%	1,790	1,880	+5.0%	60	100	+66.7%
2029 AM peak									
Pacific Highway, north of Pennant Hills Road, northbound	1,650	1,590	-3.6%	1,570	1,500	-4.7%	80	90	+12.5%
Pacific Highway, north of Pennant Hills Road, southbound	1,290	1,140	-11.6%	1,200	1,050	-12.5%	90	90	0%
Pacific Highway, east of M1 Pacific Motorway, northbound	1,960	2,170	+10.7%	1,800	1,950	+8.3%	160	220	+37.5%
Pacific Highway, east of M1 Pacific Motorway, southbound	3,370	3,390	+0.6%	3,240	3,190	-1.5%	130	200	+53.8%
2029 PM peak									
Pacific Highway, north of Pennant Hills Road, northbound	1,330	1,500	+12.8%	1,300	1,400	+7.7%	30	100	+233.3%
Pacific Highway, north of Pennant Hills Road, southbound	1,700	1,560	-8.2%	1,630	1,500	-8.0%	70	60	-14.3%
Pacific Highway, east of M1 Pacific	3,110	3,290	+5.8%	3,030	3,200	+5.6%	80	90	+12.5%

Road	Total vehicles			Light vehicles			Heavy vehicles		
	Without project	With project	% change because of project	Without project	With project	% change because of project	Without project	With project	% change because of project
Motorway, northbound									
Pacific Highway, east of M1 Pacific Motorway, southbound	1,850	2,110	+14.1%	1,790	1,990	+11.2%	60	120	+100.0%

Other major roads in the area

Traffic data for other major roads around the project corridor are provided in **Table 2-10**. Given the volumes of traffic on these roads and/ or the minor level of traffic volume changes as a consequence of the project, traffic data have been provided as daily traffic volumes (annual weekly daily traffic (AWDT)).

Table 2-10 shows that the relative change in traffic volume (either increase or decrease) would in most cases be less than 10 per cent (and frequently less than five per cent) as a consequence of the project.

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Table 2-10 Other major roads – forecast average weekly daily traffic (mid block) with and without the project in 2019 and 2029

Road	Total vehicles			Light vehicles			Heavy vehicles		
	Without project	With project	% change because of project	Without project	With project	% change because of project	Without project	With project	% change because of project
2019									
Pacific Highway, Pennant Hills Road to Woolcott Avenue, northbound	17,700	17,950	+1.41%	16,650	16,800	+0.90%	1,050	1,150	+9.52%
Pacific Highway, Pennant Hills Road to Woolcott Avenue, southbound	21,000	19,850	-5.48%	20,450	19,400	-5.13%	550	450	-18.18%
Pacific Highway, M1 Pacific Motorway interchange to Redleaf Avenue, northbound	36,450	36,950	+1.37%	33,550	34,200	+1.94%	2,900	2,750	-5.17%
Pacific Highway, M1 Pacific Motorway interchange to Redleaf Avenue, southbound	39,350	40,350	+2.54%	34,800	35,300	+1.44%	4,550	5,050	+10.99%
Pacific Highway, North of Bobbin Head Road, northbound	36,550	33,700	-7.80%	33,700	30,950	-8.16%	2,850	2,750	-3.51%
Pacific Highway, North of Bobbin Head Road,	32,100	29,250	-8.88%	28,150	25,550	-9.24%	3,950	3,700	-6.33%

Road	Total vehicles			Light vehicles			Heavy vehicles		
	Without project	With project	% change because of project	Without project	With project	% change because of project	Without project	With project	% change because of project
southbound									
Castle Hill Road, New Line Road to Edward Bennett Drive, eastbound	19,100	17,800	-6.81%	18,350	17,250	-5.99%	750	550	-26.67%
Castle Hill Road, New Line Road to Edward Bennett Drive, westbound	16,650	14,650	-12.01%	15,900	14,950	-5.97%	750	700	-6.67%
Boundary Road, North of Pennant Hills Road, eastbound	18,650	16,200	-13.14%	17,550	15,150	-13.68%	1,100	1,050	-4.55%
Boundary Road, North of Pennant Hills Road, westbound	12,200	13,050	+6.97%	11,100	11,850	+6.76%	1,100	1,200	+9.09%
Beecroft Road, Hills M2 Motorway interchange to Cheltenham Road, northbound	25,900	27,000	+4.25%	24,600	25,550	+3.86%	1,300	1,450	+11.54%
Beecroft Road, Hills M2 Motorway interchange to Cheltenham Road, southbound	19,400	20,250	+4.38%	18,600	19,350	+4.03%	800	900	+12.50%
Beecroft Road, South of Hills M2 Motorway, northbound	23,500	23,850	+1.49%	22,400	22,600	+0.89%	1,100	1,250	+13.64%
Beecroft Road,	16,000	15,750	-1.56%	15,550	15,300	-1.61%	450	450	0%

Road	Total vehicles			Light vehicles			Heavy vehicles		
	Without project	With project	% change because of project	Without project	With project	% change because of project	Without project	With project	% change because of project
South of Hills M2 Motorway, southbound									
North Rocks Road, West of Pennant Hills Road, eastbound	18,100	18,050	-0.28%	16,900	16,850	-0.30%	1,200	1,200	0%
North Rocks Road, West of Pennant Hills Road, westbound	14,600	14,150	+3.08%	13,950	13,250	-5.02%	650	900	+38.46%
Carlingford Road, East of Pennant Hills Road, eastbound	14,700	14,400	-2.04%	14,250	13,950	-2.11%	450	450	0%
Carlingford Road, East of Pennant Hills Road, westbound	22,050	21,450	-2.72%	21,300	20,700	-2.82%	750	750	0%
Lane Cove Road, South of Hills M2 Motorway, northbound	32,350	29,600	-8.50%	29,700	27,050	-8.92%	2,650	2,550	-3.77%
Lane Cove Road, South of Hills M2 Motorway, southbound	27,950	25,950	-7.16%	25,500	23,650	-7.25%	2,450	2,300	-6.12%
Epping Road, West of Delhi Road, northbound	49,400	47,150	-4.55%	45,950	43,650	-5.01%	3,450	3,500	+1.45%
Epping Road, West of Delhi Road,	33,750	32,750	-2.96%	31,450	30,400	-3.34%	2,300	2,350	+2.17%

Road	Total vehicles			Light vehicles			Heavy vehicles		
	Without project	With project	% change because of project	Without project	With project	% change because of project	Without project	With project	% change because of project
southbound									
Pennant Hills Road, Marsden Road to Carlingford Road, northbound	31,500	30,850	-2.06%	28,250	27,550	-2.48%	3,250	3,300	+1.54%
Pennant Hills Road, Marsden Road to Carlingford Road, southbound	42,950	41,700	-2.91%	37,700	36,000	-4.51%	5,250	5,700	+8.57%
Emert Street, North of Great Western Highway, northbound	27,150	25,900	-4.60%	24,450	23,000	-5.93%	2,700	2,900	+7.41%
Emert Street, North of Great Western Highway, southbound	34,000	32,600	-4.12%	30,550	28,700	-6.06%	3,450	3,900	+13.04%
2029									
Pacific Highway, Pennant Hills Road to Woolcott Avenue, northbound	23,000	22,800	-0.87%	21,800	21,350	-2.06%	1,200	1,450	+20.83%
Pacific Highway, Pennant Hills Road to Woolcott Avenue, southbound	23,000	19,500	-15.22%	22,350	18,950	-15.21%	650	550	-15.38%
Pacific Highway, M1 Pacific	40,700	41,350	+1.60%	37,100	37,900	+2.16%	3,600	3,450	-4.17%

Road	Total vehicles			Light vehicles			Heavy vehicles		
	Without project	With project	% change because of project	Without project	With project	% change because of project	Without project	With project	% change because of project
Motorway interchange to Redleaf Avenue, northbound									
Pacific Highway, M1 Pacific Motorway interchange to Redleaf Avenue, southbound	43,450	43,900	+1.04%	38,000	38,200	+0.53%	5,450	5,900	+8.26%
Pacific Highway, North of Bobbin Head Road, northbound	38,600	36,800	-4.66%	35,150	33,450	-4.84%	3,450	3,350	-2.90%
Pacific Highway, North of Bobbin Head Road, southbound	34,750	31,650	-8.92%	29,950	27,350	-8.68%	4,800	4,300	-10.42%
Castle Hill Road, New Line Road to Edward Bennett Drive, eastbound	21,950	21,100	-3.87%	21,000	20,300	-3.33%	950	800	-15.79%
Castle Hill Road, New Line Road to Edward Bennett Drive, westbound	19,300	19,150	-0.78%	18,250	18,150	-0.55%	1,050	1,000	-4.76%
Boundary Road, North of Pennant Hills Road, eastbound	20,800	19,250	-7.45%	19,400	18,000	-7.22%	1,400	1,250	-10.71%
Boundary Road, North of Pennant	13,100	14,200	+8.40%	11,700	12,650	+8.12%	1,400	1,550	+10.71%

Road	Total vehicles			Light vehicles			Heavy vehicles		
	Without project	With project	% change because of project	Without project	With project	% change because of project	Without project	With project	% change because of project
Hills Road, westbound									
Beecroft Road, Hills M2 Motorway interchange to Cheltenham Road, northbound	28,600	31,100	+8.74%	26,750	28,950	+8.22%	1,850	2,050	+10.81%
Beecroft Road, Hills M2 Motorway interchange to Cheltenham Road, southbound	20,750	22,900	+10.36%	19,750	21,750	+10.13%	1,000	1,150	+15.00%
Beecroft Road, South of Hills M2 Motorway, northbound	25,350	26,600	+4.93%	23,750	24,850	+4.63%	1,600	1,750	+9.38%
Beecroft Road, South of Hills M2 Motorway, southbound	16,300	16,600	+1.84%	15,700	16,000	+1.91%	600	600	0%
North Rocks Road, West of Pennant Hills Road, eastbound	18,550	18,650	+0.54%	17,350	17,400	+0.29%	1,200	1,250	+4.17%
North Rocks Road, West of Pennant Hills Road, westbound	14,950	14,900	-0.33%	14,250	13,750	-3.51%	700	1,150	+64.29%
Carlingford Road, East of Pennant Hills Road, eastbound	16,550	16,550	0%	15,950	16,000	+0.31%	600	550	-8.33%

Road	Total vehicles			Light vehicles			Heavy vehicles		
	Without project	With project	% change because of project	Without project	With project	% change because of project	Without project	With project	% change because of project
Carlingford Road, East of Pennant Hills Road, westbound	24,050	24,100	+0.21%	23,150	23,250	+0.43%	900	850	-5.56%
Lane Cove Road, South of Hills M2 Motorway, northbound	36,800	34,800	-5.43%	33,550	31,700	-5.51%	3,250	3,100	-4.62%
Lane Cove Road, South of Hills M2 Motorway, southbound	33,000	31,400	-4.85%	29,700	28,500	-4.04%	3,300	2,900	-12.12%
Epping Road, West of Delhi Road, northbound	55,450	54,550	-1.62%	51,300	50,300	-1.95%	4,150	4,250	+2.41%
Epping Road, West of Delhi Road, southbound	36,900	36,850	-0.14%	34,100	34,050	-0.15%	2,800	2,800	0%
Pennant Hills Road, Marsden Road to Carlingford Road, northbound	33,900	34,100	+0.59%	30,350	30,450	+0.33%	3,550	3,650	+2.82%
Pennant Hills Road, Marsden Road to Carlingford Road, southbound	45,200	45,150	-0.11%	39,700	38,950	-1.89%	5,500	6,200	+2.73%
Emert Street, North of Great Western Highway, northbound	32,100	32,050	-0.16%	29,050	28,600	-1.55%	3,050	3,450	+13.11%

Road	Total vehicles			Light vehicles			Heavy vehicles		
	Without project	With project	% change because of project	Without project	With project	% change because of project	Without project	With project	% change because of project
Emert Street, North of Great Western Highway, southbound	38,350	38,600	+0.65%	34,350	33,900	-1.31%	4,000	4,700	+17.50%

2.7.2 Scope of the operational air quality impact assessment

The project has been reviewed to identify potential air emissions sources during operation of the project. As part of the review, consideration has been given to the significance of the particular emissions source, and whether it may be directly or indirectly associated with the project. Emissions sources relevant to the operation of the project include:

- Emissions from the project tunnels, through the northern and southern ventilation outlets, under normal operating conditions.
- Changes in air quality associated with changes in surface traffic.
- Emissions from the project during emergency operations.

Air emissions from the project tunnels (normal operation)

The air quality impact assessments for the project have included consideration of emissions from the northern and southern ventilation outlets during normal operations. No other emissions would occur from the project tunnels.

The project has been designed to operate without portal emissions. Approval is currently not being sought to allow portal emissions, and the air quality impact assessment has therefore not included consideration of portals as an emissions source. If portal emissions are contemplated in the future, such as if vehicle emissions reduce or the number of electric or low emission vehicles increase, an appropriate air quality impact assessment would be conducted at that time.

Air emissions from surface roads

Based on a review of forecast surface traffic changes in 2019 and 2029, including the data presented in **Section 2.7.1** of this report, the extent of surface roads considered as part of the air quality impact assessment has been delineated as shown in **Figure 2-4**. The surface roads shown in **Figure 2-4** are considered to be those along which changes in traffic flows as a consequence of the project are likely to be material to the air quality impact assessment. While there is potential for changes in traffic volumes and distribution beyond this boundary, the likely effect of these changes in the context of the air quality implications of the project would be minimal and not sufficient to materially affect the outcomes of the air quality impact assessment.

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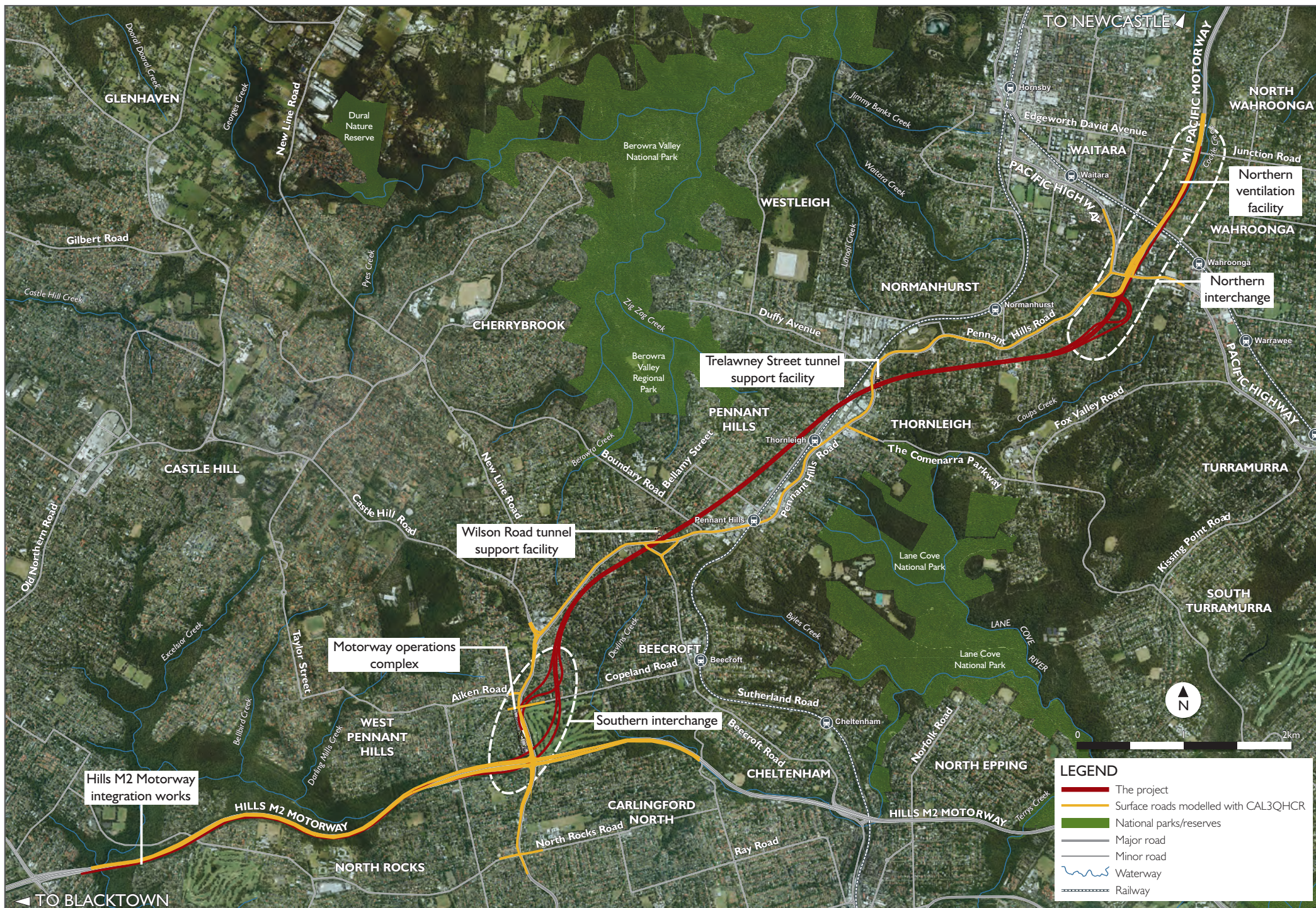


Figure 2-4 Surface roads modelled with CAL3QHCR

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Air emissions from the project tunnels (emergency operation)

The air quality impact assessment for the NorthConnex project has been conducted for a series of credible construction and operational scenarios. An appropriate level of conservatism has been applied to these scenarios to give regulatory authorities, the community and other stakeholders confidence in the veracity and robustness of the air quality impact assessment (refer to **Section 2.6**).

A detailed, quantitative assessment has not been conducted for scenarios including force majeure events, very low risk (ie very low likelihood and/ or very low consequence) incidents or other outcomes that are either not realistically or credibly foreseeable during the normal operation of the project. This is consistent with the approach taken for the assessment of other major infrastructure and developments in New South Wales, including major surface road and tunnel projects, rail infrastructure, ports and airports. These types of developments consider the risk of an emergency or unexpected event occurring (such as a major road crash, a train derailment, or an aircraft crash), but do not provide a detailed, quantified assessment of the potential environmental impacts of such an event occurring. Instead, the focus in these cases is ensuring that feasible and reasonable measures are applied to the particular development to minimise the likelihood and the consequence of emergency events.

It is also important to note that any smoke that may be generated during a tunnel fire would be controlled, contained within the tunnel and ventilated at elevated velocity using the tunnel ventilation system. Ventilation of smoke generated by a surface fire (for example on Pennant Hills Road) would not be controlled and would be emitted at ground level.

In the case of the NorthConnex project, detailed consideration has been given to the project design to ensure that feasible and reasonable design, operation and incident management measures are provided to minimise the risk of an incident and the flow-on impacts to motorists, the environment, the local community and project infrastructure. These measures have been developed in consultation with Fire and Rescue NSW, and this consultation would continue during the detailed design and implementation phases. Key aspects of the project's safety and emergency management design include:

- A unidirectional, non-contraflow design to avoid the potential for head-on collisions.
- Prohibition of dangerous goods carriage through the project tunnels.
- A higher and wider design than other domestic tunnels, to minimise the potential for vehicle strike and to provide some capacity for vehicle manoeuvrability to avoid in-tunnel incidents.
- An emergency lane and shoulder/ breakdown lane to allow emergency vehicle access or to provide a safe location for vehicle breakdowns away from the main traffic carriageway.
- Fire resistant design and project elements to minimise the risk of fire escalation and to protect project infrastructure until fire suppression and/ or emergency services bring a fire event under control.
- Automatic linear heat, smoke detection and alarm systems.
- Closed circuit television monitoring of in-tunnel conditions.
- A public address emergency warning system.

- An automatic and manually-operated deluge system capable of delivering 10 millimetres of water per minute in a minimum 60 metre length of traffic lanes with full coverage for a full kerb to kerb tunnel width.
- Dual supply fire hydrants at 60 metre intervals, with fire hydrant boosters at each tunnel portal.
- Emergency/ fire cabinet points at 60 metre intervals, including dry extinguishers, hydrants/ hoses, power outlets and emergency telephones.
- A tunnel ventilation system capable of limiting the extent of smoke zones within the tunnels, and extracting smoke and tunnel air at high temperature.
- Two vehicular cross passages near the Wilson Road and Trelawney Street sites, to allow for emergency vehicle access.
- Evacuation cross passages located at 120 metre intervals along the main alignment tunnels, and disabled persons egress capability.
- Directional sounding exit signs and illuminated egress exit signs.
- Operational measures to minimise and manage congested traffic conditions, to ensure acceptable in-tunnel air quality and to minimise the risk of congestion-related incidents.

These and other measures have been developed having regard to relevant guidelines published by the Permanent International Association of Road Congresses (PIARC), the National Fire Protection Association and Australian Standards.

There is limited data available to quantify the likelihood of an in-tunnel fire occurring other than to extrapolate from existing information which broadly indicates that the likelihood is very low. This is principally due to a number of key factors:

- There are relatively few road tunnels compared to surface road infrastructure. This has historically limited the ability to develop statistically significant datasets.
- There are relatively few regulatory authorities that actively collect and/ or share in-tunnel fire data, or which have done so over a sufficient period of time to draw meaningful conclusions from the data.
- Much of the non-Australian data that is available is not strictly transferable to an Australian context. Much of the available data, for example, relates to European road tunnels in alpine areas, or road tunnels in Europe or North America which carry dangerous goods cargoes. Much of the data also relates to tunnel incidents dating back to 1950 to 1980, and involves tunnels which have not been designed to modern standards.

A French study of 26 tunnels (PIARC, 1999) for example, identified a likelihood of one to two fires involving passenger vehicles and up to eight fires in heavy vehicles (without dangerous goods) for every 100 million vehicle kilometres. Of the fires involving heavy vehicles, only one per 100 million vehicle kilometres resulted in tunnel damage, and between 0.1 and 0.3 per 100 million vehicle kilometres were considered by French authorities to be very serious. Most of these fire incidents were minor in nature and were recorded in alpine areas, where road grades tended to increase the risk of overheating in motors and brakes.

PIARC (1999) also quotes experience from Germany and Switzerland, which suggests that as a proportion of all breakdowns and accidents in tunnels, fire events

are rare. Data from Germany and Switzerland suggests that in those countries, only about one in 100 to 500 breakdowns involves a fire, and about one in 10 to 20 accidents involves a fire.

A survey undertaken by the United States Transportation Research Board published in 2011, includes in-tunnel fire incident data collected from 15 agencies worldwide, reporting on a total of 319 tunnels. Of the 29 tunnels considered in the United States, it was reported that 14 of these experienced fire incidences one to two times per year, while 11 of the tunnels reported no fires. Tunnels within the responsibility of the Port Authority of New York and New Jersey reported higher fire incident rates of two to five per year, explained by the relatively high volumes of traffic in tunnels such as the Clifford Milburn Holland Tunnel (linking Manhattan with Jersey City). Two of the agencies surveyed outside the United States reported tunnel fire frequencies of one to two per year.

A summary of available tunnel fire incident data for Australia is provided in **Table 2-11**. Australian tunnels need to be distinguished from other international tunnels because:

- Australian tunnels are typically more modern than international tunnels. They are therefore, on average, more likely to include modern traffic safety and emergency management systems than some of their international counterparts.
- Longer, more trafficked Australian tunnels typically have deluge fire suppression systems installed. These systems have until recently not been used in European and North American road tunnels.
- The carriage of dangerous goods is prohibited in Australian tunnels.
- Australian tunnels are located in urban environments, and tunnel designs generally avoid challenging grade or geometric constraints that are encountered in other areas, such as in the alpine areas of Europe.

Based on available data, it is possible to calculate an historical tunnel fire frequency on a vehicle-kilometre basis for two of the Australian tunnels listed in **Table 2-11**:

- For the Lane Cove Tunnel, historical fire frequency has been around 0.61 fires per 100 million vehicle-kilometres (all vehicles).
- For the CityLink Tunnels, historical fire frequency has been around 0.51 fires per 100 million vehicle-kilometres (all vehicles).

Based on traffic forecasts, the NorthConnex project is anticipated to experience around 100 million vehicle kilometres in 2019 and around 130 million vehicle kilometres in 2029. Applying similar tunnel fire frequencies to forecast traffic volumes for the NorthConnex project indicates:

- An expected annual tunnel fire frequency of 0.50 to 0.60 is expected in 2019 (equivalent to one fire incident every 1.6 to two years).
- An expected annual tunnel fire frequency of 0.67 to 0.80 is expected in 2029 (equivalent to one fire incident every 1.3 to 1.5 years).

These values are comparable to observed annual tunnel fire incident rates for other Australian tunnels presented in **Table 2-11**, which range from around 0.06 to 0.93 per year, or around 0.5 to one per 100 million vehicle kilometres.

Table 2-11 Other major roads – forecast peak hour traffic (mid block) with and without the project in 2019 and 2029

Tunnel	Length	Opened to traffic	Comments on fire incidents	Traffic volumes	Incident frequency
Sydney Harbour Tunnel	Two tunnels, each 2.7 km	August 1992	Around 10 fires since opening (around 0.45 per year). A recent heavy vehicle fire (February 2013) led to closure of the tunnel (and reopened within one hour), operation of the deluge system and fire brigade response. The fire started in the vehicle's battery.	Around 80,000 vehicles per day Around 86 million vehicle kilometres per annum	0.5 per 100 million vehicle kilometres
M5 East Motorway Tunnel	Two tunnels, each 4 km	December 2001	Around 72 fire and smoke/ fume incidents between 2002 and 2009, although this includes non-fire incidents (ie vehicle exhaust/ fume events are included in this figure). A recent heavy vehicle fire (August 2012) led to closure of the tunnel (and reopened within two hours), operation of the deluge system and fire brigade response.	Around 90,000 vehicles per day Around 130 million vehicle kilometres per annum	Insufficient data
M2 Motorway Tunnel (Norfolk Tunnel)	Two tunnels, each 0.5 km	May 1997	One heavy vehicle fire since opening (around 0.06 per year). The fire (September 2013) led to closure of the tunnel (and reopened in three hours), operation of the deluge system and fire brigade response. The fire started in the vehicle's engine compartment.	Around 50,000 vehicles per day Around nine million vehicle kilometres per annum	0.7 per 100 million vehicle kilometres
Cross City Tunnel	Two tunnels, each 2.1 km	August 2005	Two fires recorded since the tunnel was opened in 2005 (around 0.22 per year). Of these fire incidents, one required the	Around 30,000 vehicles per day Around 23 million kilometres per annum	1.0 per 100 million vehicle kilometres

Tunnel	Length	Opened to traffic	Comments on fire incidents	Traffic volumes	Incident frequency
			operation of the deluge system. The second fire was extinguished without the need for deluge.		
CityLink Tunnels (Burnley Tunnel and Domain Tunnel)	Burnley Tunnel – two tunnels each 3.4 km Domain Tunnel – two tunnels each 1.6 km	December 2000	A total of 13 fires recorded since the tunnels were opened in late 2000 (around 0.93 per year). Of these fires, seven related to vehicle fires where there vehicle was driven through and exited the tunnels without incident. Three of the fires required use of the deluge system and the remaining three fires required use of extinguishers. The most significant fire to occur was a result of a major car/ truck collision in the Burnley Tunnel in 2007. This incident resulted in three fatalities and required closure of the tunnel for four days.	Around 55,000 (Burnley) and 45,000 (Domain) vehicles per day Around 94 million vehicle kilometres per annum (combined)	0.5 per 100 million vehicle kilometres (fires within the tunnel only)
Lane Cove Tunnel	Two tunnels, each 3.6 km	March 2007	A total of three fires recorded since the tunnels were opened in 2007 (around 0.43 per year). All of these fires required use of the deluge system.	Around 66,000 vehicles per day Around 87 million vehicle kilometres per annum	0.5 per 100 million vehicle kilometres

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Not all tunnel fires will be significant in scale or consequence to the extent of requiring use of the emergency smoke extraction facilities. Based on available data from Australian tunnels, fires will in most cases be addressed through hand-held extinguishes and in some cases through the operation of tunnel deluge systems. With the exception of major in-tunnel incidents, such as was the case with the Burnley Tunnel fire in 2007, most fire incidents are rapidly brought under control with minimal or limited disruption to normal tunnel operations. A similar outcome is expected for the NorthConnex tunnels.

Fire incidents are only likely to occur as a result of vehicle malfunction (such as motor or brake overheating) or in the event of a major collision leading to the release and ignition of fuel. The NorthConnex project has been designed to minimise the potential for both of these potential initiating events by:

- Reduced tunnel grades to minimise the potential for motor and brake overheating, and development and implementation of management measures to effectively handle congested traffic conditions to minimise the need for a stop-start or slow speed traffic scenario.
- Higher and wider tunnels to provide greater flexibility and manoeuvrability for motorists to avoid potential collisions, with provision of an emergency breakdown lane to separate broken down vehicles from the live traffic lanes. A major contributing factor to the Burnley Tunnel fire in 2007 was a broken down heavy vehicle parked in a live traffic lane (with traffic diversions into other traffic lanes around the incident) with a blown tyre. Removal of the heavy vehicle from live traffic may have assisted in avoiding or reducing the severity of the incident.

In the event that a fire is initiated, a heat detection and closed circuit television system are available to either automatically trigger or to prompt manual engagement of the tunnel's deluge system. Hand-held extinguishers, fire hose and fire reels would also be provided at regular intervals along the project tunnels.

Significant volumes of smoke are only likely to be generated during major fire incidents (involving large volumes of fuel, such as in the case of multi-vehicle accidents) and where fire management measures do not rapidly extinguish the fire. The NorthConnex project has been designed to minimise the risk of these two events simultaneously occurring. Even where a major fire occurs, and is subject to the deluge system operating but not extinguishing the fire, the operation of the deluge is likely to bring the fire under control (ie reduce the spread of the fire and reduces smoke production) and to reduce some of the in-tunnel smoke load through the wet scrubbing action of the deluge. Where this occurs, Fire and Rescue NSW would extinguish the fire through the use of the project's fire hydrant systems.

It is also relevant to compare in-tunnel fires with the potential for similar surface events to occur, for example along Pennant Hills Road. The potential for a fire in the NorthConnex tunnels is likely to be similar to, and potentially lower than, a fire on Pennant Hills Road on a vehicle-kilometre basis because:

- A vehicle malfunction (such as motor or brake overheating) is equally likely to occur in a tunnel as it is on the surface. Potential malfunction on the surface may in fact be higher due to the congested stop-start nature of Pennant Hills Road compared with the free-flowing motorway standard NorthConnex tunnels.
- Vehicle accident rates would be lower in the free-flowing motorway standard NorthConnex tunnels compared with Pennant Hills Road, as demonstrated in Section 7.1 and Appendix E of the environmental impact statement.

The key differences between a fire on Pennant Hills Road and a fire in the NorthConnex tunnels would be:

- Smoke that may be generated during a tunnel fire would be controlled, contained within the tunnel and ventilation at elevated velocity using the tunnel ventilation system. Ventilation of smoke generated by a surface fire would not be controlled.
- A fire in the NorthConnex tunnels would be actively managed through the deluge system and hand-held extinguishers and fire hoses/ fire reels prior to attendance by emergency services. These facilities are not available on Pennant Hills Road.
- A response to a fire in the NorthConnex tunnels would be automatic in the case of the deluge system or could be manually operated if required. This level of detection and response would be more rapid than a response to a surface fire. The emergency service notification period for an incident on Pennant Hills Road is likely to be longer.
- The rapid response to an in-tunnel fire, and particularly the use of the deluge system, would act to reduce the severity of the incident and the potential generation of smoke. Smoke generated by a surface road fire would not be mitigated until fire control was initiated by emergency services (or potentially an immediate attendee in some cases).

These factors taken together highlight that the smoke generation in the unlikely event of a major incident in the NorthConnex tunnels would be minimised and ventilated in a controlled manner. The heat of the smoke/ in-tunnel air and the velocity with which it is discharged is likely to result in better dispersion and lower impacts than would be experienced during a surface road fire (under current or future conditions).

If a fire incident does occur, the emergency smoke extraction system would exhaust tunnel air vertically at high velocity. The smoke would therefore be dispersed at a high elevation over a broad area. The smoke would likely still be at an elevated temperature despite possibly being cooled by the tunnel deluge system. This elevated temperature would contribute to enhanced buoyancy of the discharge plume and improved dispersion.

The key point is that ventilation of smoke during an in-tunnel fire is managed to minimise the potential for exposure to external receivers, and therefore minimise the potential consequence for local amenity and human health. As with normal operation of the project's ventilation outlets, operation of the emergency smoke extraction facilities would eject smoke vertically at high speed which would separate the emission plume from local ground level receivers.

2.7.3 Assessment scenarios

The following scenarios have been developed and quantitatively assessed for operation of the project:

- The 'do nothing' scenario – assessment of air quality in 2019 and 2029, assuming that the project does not proceed.
- The project assuming forecast traffic volumes in 2019 and 2029.
- A breakdown scenario in the project tunnels.
- A 'worst case' air quality impact scenario (design analysis A).
- A regulatory scenario to assist regulatory authorities in their consideration of potential discharge concentration limits for the project (design analysis B).

The approach taken to calculate the emissions inventories for each of these scenarios is provided in **Section 2.8**, including discharge mass emission rates and concentrations.

The 'do nothing' scenarios (Scenario 1a and 1b)

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 (refer to **Section 2.13**) and expected future traffic volumes for the existing road network for 2019 and 2029 (Scenarios 1a and 1b, respectively).

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. The set-up of these models is discussed in **Section 2.13**.

The forecast traffic volume scenarios (Scenario 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.

Further details of the calculation of the emissions inventory for this scenario are provided in **Section 2.8**.

The 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 has taken into account an upper vehicle limit of 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 has taken into account an upper vehicle limit of 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 breakdown 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 breakdown scenario and was carried forward for more detailed assessment.

Some submissions received in response to the environmental impact statement sought further details of how the number of vehicles involved in breakdown scenario A was calculated (511 vehicles in total). Details of this calculation are provided below.

Vehicles contributing emissions during the breakdown scenario would be a combination of:

- Vehicles in the tunnel at the time of the breakdown that are prevented from leaving the tunnel due to the breakdown blockage near the tunnel exit.
- Additional vehicles that enter the tunnel in the ten minutes following the breakdown and before the tunnel is closed to additional traffic.

At the time of the breakdown, it has been assumed that average vehicle speeds drop rapidly from 80 km/h to 20 km/h until traffic banks back to the maximum traffic throughput capacity of the main alignment tunnel at 20 km/h. The maximum throughput capacity of a main alignment tunnel is around 2,800 passenger car units (refer to **Section 2.5.1**) at this speed. Based on the distribution of vehicle types as forecast in 2019:

- Passenger vehicles would comprise 72 per cent of vehicles in the tunnel. Passenger vehicles are one passenger car unit each.
- Heavy vehicles would comprise around 28 per cent of vehicles in the tunnel. Consistent with the assumption made in the traffic impact assessment for the project, heavy vehicles have been assumed to be 2.9 passenger car units each.

Taking this distribution of vehicles into account, 2,800 passenger car units would be around 1,316 passenger vehicles and around 512 heavy vehicles (a total of 1,828 vehicles per hour).

For a nine kilometre long tunnel, 1,828 vehicles per hour would equate to 205.7 vehicles (ie $(9\text{km})/(80\text{ km/h}) \times 1,828\text{ vph} = 205.7\text{ vehicles}$).

For the ten minutes following the breakdown a further 305.7 vehicles would enter the tunnel (ie $(1/6) \times 1,828\text{ vph} = 305.7\text{ vehicles}$).

Combined, the 205.7 vehicles in the tunnel at the time of the breakdown and the 305.7 vehicles enter in the ten minutes following the breakdown, would sum to 510.4 vehicles. This figure has been rounded to 511 vehicles for the purpose of the air quality impact assessment.

The worst case scenario (design analysis A)

Consideration of 'worst case'

When considering a 'worst case' air quality scenario for the project, it is relevant to take into account two principal factors:

- The average speed of vehicles travelling through the tunnels, because lower average traffic speeds equate to more emissions. That is, traffic using the project tunnels will generate greater emissions at 40 km/ h than at 80 km/ h.
- The total volume of vehicles travelling through the tunnels, because more vehicles broadly equates to more emissions (the implications of changes in vehicle fleet and fuel mix are discussed in **Section 2.8**).

The data presented in **Section 2.5.2** of this report indicate that maximum traffic throughput capacity, traffic travelling at 40 km/ h would generate higher in-tunnel concentrations of vehicle emissions than for comparable scenarios at 60 km/h and 80 km/ h.

The project has been designed to operate with two motorway standard traffic lanes in each direction (northbound and southbound). The design capacity of a motorway standard traffic lane is 2,000 passenger car units per hour under free flowing traffic conditions (60 km/h), which is equivalent to 4,000 passenger car units per hour for each of the main alignment tunnels. As discussed in **Section 2.4.2** and shown in **Figure 2-1**, the two lane configuration of each main alignment tunnel has a design throughput capacity of vehicles (as passenger car units) at different average traffic speeds:

- A maximum of 3,480 passenger car units per hour (two lanes) at 80 km/h.
- A maximum of 4,000 passenger car units per hour (two lanes) at 60 km/h.
- A maximum of 3,698 passenger car units per hour (two lanes) at 40 km/h.

There are two potential scenarios that may lead to a decrease in average traffic speed through the main alignment tunnels:

- The patronage of the project exceeds the maximum theoretical design throughput capacity of the project tunnels (as listed above), generating congested traffic conditions and a reduction in average traffic speed.
- An incident in the tunnel(s) or downstream of the tunnel temporarily reduces the capacity of the tunnel (for example by blocking a lane, slowing traffic as a motorist reaction to the incident or causing a downstream obstruction that leads to traffic queuing).

Both of these scenarios have a low probability of occurrence based on the design and forecast performance of the project. As discussed in **Section 2.5.2**, the maximum theoretical traffic throughput of each main alignment tunnel is 4,000 passenger car units per hour. This is around 2.1 times the peak forecast traffic volumes in 2019 and around 1.6 times the peak forecast traffic volumes in 2029. This means that actual traffic volumes would need to be around 110 per cent higher than traffic forecasts in 2019 or around 60 per cent higher than traffic in forecasts in 2029. Based on traffic forecasts using the Cube strategic model, the triggers that may lead to this level of variance in traffic volumes (demography, land use, major additions to the road network, traffic generating developments) are not expected within the timeframes considered as part of the assessment of the project.

An incident in the project tunnels or downstream could involve:

- A minor incident, such as a vehicle breakdown.
- A major incident, such as a vehicle crash or fire.

Incidents in the project tunnels or downstream would be unlikely events. In the case of a major incident:

- Vehicle crashes on a motorway standard road have been estimated to occur at around 19.9 per 100 million vehicle kilometres (refer to the Technical Working Paper: Traffic and Transport in the environmental impact statement). This is equivalent to project 23 vehicle crashes in the project tunnels in 2029 (or around one every 15 days). This includes all crash types (fatal and injury).
- As discussed in **Section 2.7.2**, the frequency of fires in the project tunnels in 2029 has been estimated at 0.67 to 0.80 in 2029 (equivalent to one fire incident every 1.3 to 1.5 years).

The potential for incidents within the project tunnels would be actively monitored and managed. The project would be equipped with an automatic video incident detection (AVID) system. AVID is a close circuit television (CCTV) system but has the additional capability of detecting and actively alerting tunnel operators to incidents within the tunnel as they occur. The AVID system has the ability to detect a range of tunnel incidents including stopped vehicles, pedestrians or the presence of smoke in the project tunnels.

The AVID system would quickly alert the tunnel operators to an incident in the project tunnels, so that they can implement the appropriate incident management plan. For example, in the event of a stopped vehicle, the operators can quickly identify its location and respond by implementing a traffic management plan and increasing the level of ventilation if required. It would also assist them to address the driver through the public address system or motorist emergency telephone.

Unlike surface roads, road tunnels are constantly managed from a central control room with an operations team to ensure that action can be taken quickly and effectively in the event of an alarm or incident. With respect to the emergency devices such as the deluge system, these would be automatically operated in the event of an incident.

Where there is a major incident such as a crash which results in the tunnel being blocked, the relevant tunnel would be closed and vehicles diverted to surface roads. The closed tunnel would only be reopened once the incident is cleared. This action would be taken quickly (response time would be in minutes from alert) to minimise the number of vehicles in the tunnel.

In the event of a fire incident the whole tunnel in both directions would be closed and vehicles diverted to surface roads until the incident has been dealt with.

The low frequency of incidents, the design of the project and proactive monitoring and management of incidents means that the potential for extended periods of low average traffic speeds (around 40 km/ h or less) is very low. In the event that an incident, such as a breakdown or crash occurs, management measures would be in place to rapidly move any obstruction from the operational traffic lanes into the relevant breakdown lane, and to manage the entry of additional vehicles into the project tunnels so that congested traffic

conditions do not eventuate (or are not exacerbated by continued traffic entry into the tunnels).

This approach is expected to resolve most incidents within the order of an hour or less. While there may be an increase in vehicle emissions in the project tunnels during this time if average traffic speeds drop, the ventilation system would be managed to maintain acceptable in-tunnel air quality. The potential implications for ambient air quality are unlikely to be material for any more than a short duration and at a low frequency. For these reasons, it is not considered appropriate to develop a low average traffic speed scenario (around 40 km/ h) as a worst-case scenario of the air quality impact assessment.

Design analysis A

Design analysis A has assumed that the maximum theoretical design capacity of 4,000 passenger car units in a main alignment tunnel would be reached during the peak hour. It is extremely unlikely that the maximum design capacity would be experienced for an entire 24-hour period, with traffic volumes likely to ebb and flow during the day around peak periods. A realistic traffic scenario for design analysis A was therefore established by:

- Comparing the maximum theoretical design capacity of each main alignment tunnel (4,000 passenger car units) with the expected peak hour traffic volumes in 2019, which were around 1,790 passenger car units in the southbound main alignment tunnel (morning peak) and around 1,930 passenger car units in the northbound main alignment tunnel (afternoon peak).
- Noting that the theoretical design capacity was around a factor of 2.1 times the maximum forecast peak in 2019 (ie 4,000 is around 2.1 times 1,930).
- Scaling the forecast traffic flows for 2019 by a factor of 2.1 for each hour of the day, to obtain the traffic flows used for design analysis A.

An equally valid approach would have been to use forecast traffic volumes in 2029 to derive design analysis A. However, given that the relative diurnal flows of traffic would be similar in 2019 and 2029 (refer to the shape of the diurnal flow curves in Figure 5-2), and scaling would be to the same maximum (4,000 passenger car units), there would be no significant difference in outcomes if traffic forecasts for 2029 had been used instead of data from 2019.

The total daily traffic volumes for design analysis A have therefore been established at around 48,000 passenger car units in each main alignment tunnel. This is considered to be a reasonable and realistic estimate of a worst case scenario (albeit highly unlikely) for operation of the project.

Figure 2-5 shows traffic volumes for design analysis A relative to the base traffic forecasts for 2019 and the maximum traffic design capacity of the southbound and northbound main alignment tunnels. The figure shows that the peak hour traffic volumes for design analysis A could only be accommodated through the project's main alignment tunnels under free flowing traffic conditions (60 km/ h to 80 km/h). Congested traffic conditions in the project tunnels (40 km/ h or less) would require a commensurate reduction in traffic volumes below the design analysis A peak hour figures, based on the physical capacity of the project tunnel lanes.

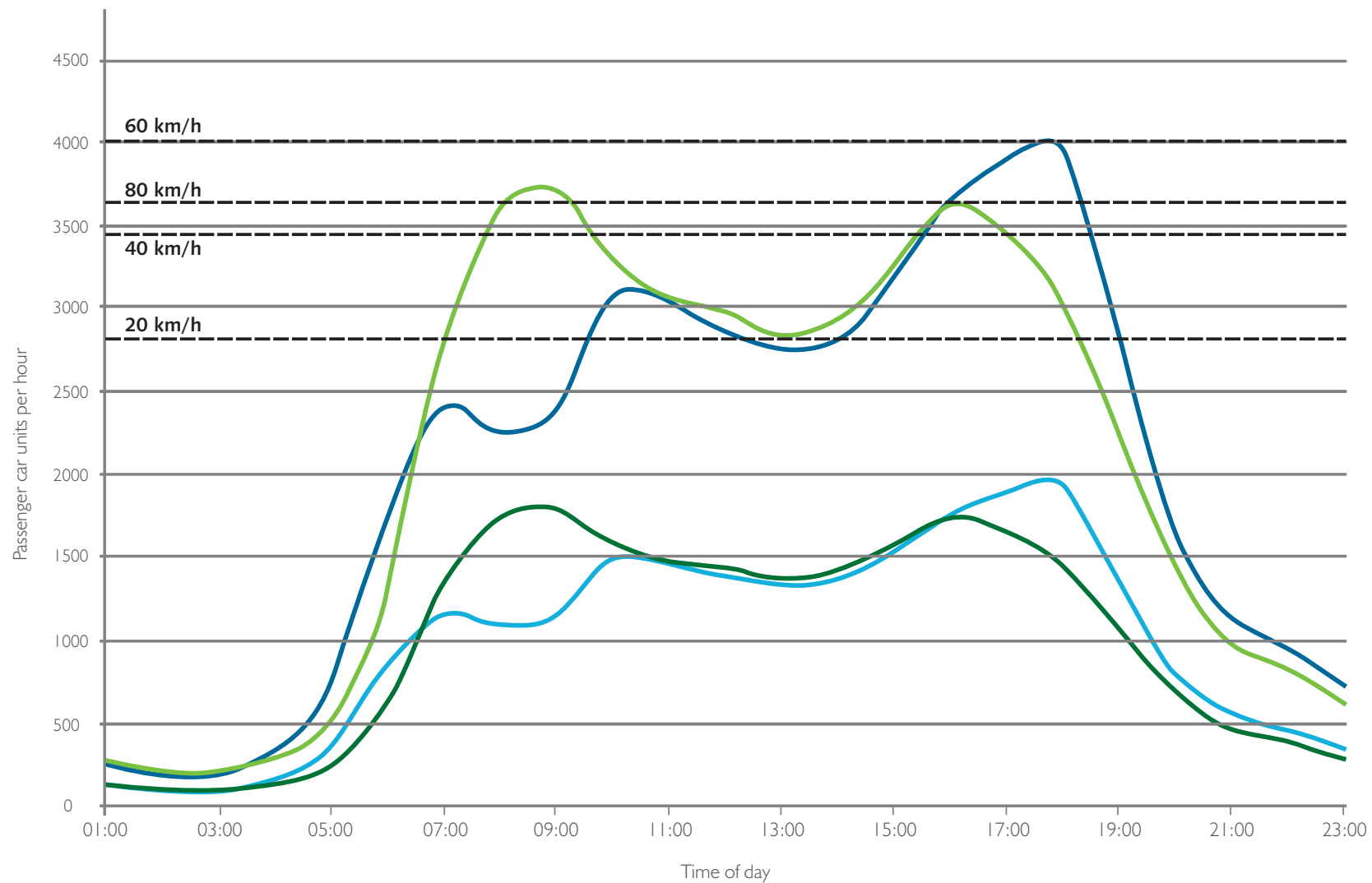


Figure 2-5 Design analysis A (PCU) relative to traffic design capacity

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The regulatory scenario (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 are not considered in further detail in this chapter (refer to Appendix G of the Technical Working Paper: Air Quality in the environmental impact statement for further information).

2.8 Emissions inventories

This section details how emissions inventories have been calculated as inputs into the air quality impact assessments for the project. It includes:

- Details of the emission factors used in the assessment (refer to **Section 2.8.1**).
- An explanation of how the emissions inventory for the project tunnels was calculated, including testing of the sensitivity of key assumption (refer to **Section 2.8.2**).
- An explanation of how the emissions inventory for the surface road modelling was calculated (refer to **Section 2.8.3**).

2.8.1 Emission factors

The air quality impact assessment has applied emission factors published by the Permanent International Association of Road Congresses (PIARC) (2012), and specifically those published for Australia.

The PIARC emission factors have been used to calculate emissions of particulate matter, NO_x and CO from vehicles within the tunnel and on the surface roads. As the tunnel ventilation designers used the PIARC emission factors for the design of project's ventilation system, it was considered desirable for the air quality assessment to be consistent with the tunnel design in terms of predicted emissions and transferability of ventilation and air quality information between the ventilation design and the environmental impact statement. This was considered particularly important for transparency and consistency, where it was considered more appropriate to be consistent in use of emission factors and overestimate emissions rather than to use different emission factors for the tunnel ventilation design and the air quality impact assessment. To ensure consistency of approach across all aspects of the project, PIARC emission factors were also applied to surface roads.

PIARC (2012) provides Australian-specific emissions based on fleet distribution data and emission standards relevant to Australia. As noted in Section 4.2.8.1 of the Technical Working Paper: Air Quality, 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 – as such, a safety margin is added to the emission factors such that, if these emission factors are used for developing emission inventories for dispersion modelling purposes, the estimated emissions are likely to be higher than would be expected in practice. The use of conservative emission factors results in higher predicted pollutant concentrations for in-tunnel and ambient receivers than would be predicted using less conservative emissions estimates.

A recent study (PEL, September 2014) comparing the PIARC emission rates to pollutant concentrations measured in the ventilation outlets of the Lane Cove Tunnel by Pacific Environment Limited (2014) determined that the PIARC emission factors overestimated emissions of CO by 1.3 to 1.7 times, emissions of NO_x by 1.6 to 1.8 times, and PM_{2.5} by 2.8 to 4.4 times. While it is noted that the Lane Cove Tunnel has different dimensions and ventilation characteristics than the proposed NorthConnex project, the results of the Pacific Environment Limited study provide an indication of the potential scale of the overestimation of emissions when using the PIARC emission factors (compared to the NSW vehicle fleet using the Lane Cove Tunnel). Given these data, it could be expected that the actual contributions to pollutant concentrations at sensitive receiver locations could be 1.6 to 1.8 times lower for NO_x and 2.8 to 4.4 times lower for PM_{2.5} than predicted in the air quality impact assessment for the project (based on the contribution from the project's ventilation outlets).

It should be noted that the use of PIARC emission factors in tunnel assessments has much precedence. Recent studies making use of the PIARC emission factors include the East West Link in Melbourne, where the Victorian EPA reviewed the emission factors and considered them to be appropriate, the Brisbane Northern Link Project, and the Brisbane Airport Link Project.

The PIARC emission factors have been designed to determine the minimum air requirement needed to ensure adequate in-tunnel air quality and visibility thresholds under normal operating conditions, which include high traffic loads and frequently congested traffic. The report detailing the PIARC emission factors indicates that “Vehicle speeds around 10 km/h and stopped traffic typically define the normal ventilation capacity requirements.” As such, the PIARC emission factors do accommodate congested traffic conditions. While the emission factors have been specifically designed to calculate emissions in road tunnels rather than emissions from surface roads, the conservatism built into the emission factors is considered to be adequate for providing conservative estimates of emissions from surface roads, even under stop-start conditions such as experience on Pennant Hills Road. The surface road modelling conducted for the project assessed vehicle speeds between 30 and 100 kilometres per hour.

2.8.2 Project tunnel emissions inventories

This section details how the emissions inventories for the project tunnels have been calculated, including:

- Traffic fleet and fuel mix assumptions.
- Tunnel characteristics.
- Tunnel ventilation rates.
- Vehicle emission rates.
- Particulate matter and other emissions.
- Details of the calculation emissions inventories used in the air quality impact assessment.
- Analysis of the implications of air drawn into the project tunnels on the air quality impact assessment.

Traffic fleet and fuel mix assumptions

The raw outputs from the Cube strategic traffic model provided for the 2019 and 2029 forecast traffic years, and the derived 'design analysis A' were expressed in terms of total vehicles per hour for each hour of the day. Heavy vehicle numbers, as a percentage of total vehicles in each hour of the day were also provided.

In order to calculate vehicle emissions within the project tunnels, total light vehicles and heavy vehicles needed to be differentiated further based on vehicle type and fuel type. For this, data available from the Australian Bureau of Statistics was used (the Australian Bureau of Statistics – Motor Vehicle Census (31 January 2013)). These data are summarised in **Table 2-12**.

Table 2-12 Vehicle fleet composition (ABS, 2013)

Vehicle type	Petrol (total)	Diesel	Other	All
Passenger vehicles				
Passenger vehicles	11,616,025	1,029,561	354,435	13,000,021
Campervans	17,635	34,164	2,302	54,101
Motorcycles	744,518	0	214	744,732
Light duty vehicles				
Light commercial vehicles	1,300,490	1,281,381	135,802	2,717,673
Non-freight vehicles	3,159	19,338	489	22,986
Heavy vehicles				
Light rigid trucks	9,116	120,044	1,987	131,147
Heavy rigid trucks	17,172	307,340	1,486	325,998
Articulated trucks	1,332	89,416	156	90,904
Buses	17,802	71,081	4,151	93,034

Since preparing the environmental impact statement, the data in **Table 2-12** have been compared with registration records held by Roads and Maritime (as at 31 March 2014). At a vehicle category level, these two data sets are similar, as shown in **Table 2-13**. Roads and Maritime registration records show a slightly higher percentage of light duty vehicles in the fleet mix than the ABS (2013) data. For the purpose of this comparison, all Roads and Maritime registration data as at 31 March 2014 has been included with the exception of heavy and light trailers (which do not include an engine) and heavy and light plant (which are not expected to regularly use roads as part of the New South Wales vehicle fleet, and for most of the time would be located off road).

Table 2-13 Comparison of ABS (2013) and RMS (2014) fleet data

Vehicle category	ABS (2013)	RMS (2014)
Passenger cars	80.3%	79.8%
Light duty vehicles	16.0%	17.8%
Heavy vehicles	3.7%	2.4%

For the purpose of the environmental impact statement, 'light vehicles' included passenger vehicles and light duty vehicles (as distinct from heavy vehicles). When considering only light vehicles, the ABS (2013) shows contribution of 83.4 per cent from passenger vehicles and a 16.6 per cent contribution from light duty vehicles. This shows a good correlation with:

- Roads and Maritime registration records, which show a contribution of 81.8 per cent from passenger vehicles and a contribution of 18.2 per cent from light duty vehicles.
- The default values published by the Permanent International Association of Road Congresses, which include 84 per cent passenger vehicles and 16 per cent light duty vehicles.
- Data quoted in the submission received from the Environment Protection Authority, which indicate that 18 to 20 per cent of light vehicles are light duty vehicles.

Vehicles listed in the ABS (2013) data set as 'other' fuel were redistributed into 'petrol' or 'diesel' categories. The redistribution maintained the relative percentages of petrol and diesel fuelled vehicles for each vehicle type. For example, where petrol fuelled passenger cars were four times the number of diesel fuelled passenger cars, 'other' fuelled passenger cars reallocated to petrol or diesel categories to maintain this ratio. This approach is conservative, as 'other' fuelled vehicles include 'cleaner' burning fuels, such as liquefied petroleum gas.

This process yielded the breakdown in vehicle categories by fuel type summarised in **Table 2-14**. It is important to note that as part of the air quality impact assessment, all heavy vehicles were assumed to be diesel fuelled, despite the data presented in **Table 2-14**. This is a conservative assumption, as it will lead to an over estimation of key pollutants include NO_x and particulate matter for these vehicles.

Table 2-14 Summary of fuel type (ABS, 2013)

Vehicle type	Petrol	Diesel
Passenger vehicles (cars)	92.1%	7.9%
Light duty vehicles	50.1%	49.9%
Heavy vehicles	7.2%	92.8%

Based on feedback received from the Environment Protection Authority, a similar process has been applied to Roads and Maritime registration data (ie re-distribution of 'other' fuelled vehicles). The vehicle fleet distribution as a function of fuel for Roads and Maritime registrations is summarised in **Table 2-15**. The table shows that:

- ABS (2013) and RMS (2014) fleet data are similar for passenger vehicles and light duty vehicles.
- ABS (2013) data slightly underestimates the proportion of diesel fuelled passenger vehicles relative to RMS (2014) data (7.9 per cent versus 9.9 per cent).
- ABS (2013) data slightly overestimates the proportion of diesel fuelled light duty vehicles relative to RMS (2014) data (49.9 per cent versus 46.5 per cent).
- On balance, the ABS (2013) is a reasonable representation of the New South Wales vehicle fleet fuel mix in 2013.

Table 2-15 shows a significant variance in fuel type for heavy vehicles between the ABS (2013) data and Roads and Maritime registration data. However, because all heavy vehicles were assumed to be diesel fuelled for the purpose of the air quality impact assessment in the environmental impact statement, this variance is not a relevant issue.

Table 2-15 Registered NSW vehicle fleet by fuel type (RMS, 2014)

Vehicle Type	Petrol (number)	Diesel (number)	Petrol	Diesel
Passenger vehicles (cars)	3,816,820	418,906	90.1%	9.9%
Passenger vehicles	2,801,586	94,621	96.7%	3.3%
Off-road vehicles	808,316	324,222	71.4%	28.6%
Motor cycles	191,953	61	99.9%	<0.1%
Scooters	14,964	2	99.9%	<0.1%
Light duty vehicles	355,182	334,829	51.5%	48.5%
People movers	63,801	7,592	89.4%	10.6%
Small buses	8,857	9,476	48.3%	51.7%
Mobile homes	3,367	4,502	42.8%	57.2%
Light trucks	279,037	313,256	47.1%	52.9%
Other vehicles	119	2	98.3%	1.7%
Heavy vehicles	1,946	120,331	1.6%	98.4%
Buses	232	12,744	1.8%	98.2%
Heavy trucks	1,640	88,951	1.8%	98.2%
Prime movers	74	18,636	0.4%	99.6%

Because the emission factors for Australian heavy vehicles published by the Permanent International Association of Road Congresses (2012) are based on an average mass of 23 tonnes, an analysis of heavy vehicle fleet mass has been conducted to confirm the suitability of those emission factors for use (without amendment). The calculation to estimate average heavy vehicle mass based on ABS data (2013) is presented in **Table 2-16**. Based on a broader range of heavy vehicle masses that could be expected in each heavy vehicle category, the average mass of the heavy vehicle fleet would be around nine to 25 tonnes. Based on this, the emission factors for Australian heavy vehicles published by the Permanent International Association of Road Congresses (2012) for an average 23 tonne heavy vehicle fleet are considered reasonable.

This takes into account the fact that the heavy vehicle fleet is unlikely to comprise all vehicles at their respective maximum mass. Further, it also takes into account that the average mass of heavy vehicles across Sydney in 2013, as measured at Roads and Maritime weigh-in-motion sites, was 16.6 tonnes. Taking into account that a slightly heavier fleet mix may use the NorthConnex project because of its location along a major road freight corridor, emission rates based on an average mass of 23 tonnes is reasonable.

By way of sensitivity analysis, these calculations have been tested by:

- Removing buses from the calculation. This would alter the range of average heavy vehicle mass to 7.90 tonnes to 26.49 tonnes.
- Altering the proportion of B double vehicles in the fleet mix. With no B doubles, the average heavy vehicle mass would be from 8.93 tonnes to 22.85 tonnes. With only B doubles in the articulated trucks category, the average mass would be from 11.06 tonnes to 25.4 tonnes.

Heavy vehicles as a percentage of total traffic volumes have been forecast to be around 28 per cent in 2019 and around 25 per cent in 2029.

Table 2-16 Average heavy vehicle mass (based on ABS (2013))

Heavy vehicle type	Number of vehicles (ABS, 2013)	Mass range	Mass of vehicle type
Light rigid trucks	131,147	4.5 tonnes	0.590 million tonnes
Heavy rigid trucks	325,998	4.5 tonnes to 26 tonnes	1.467 million tonnes to 8.476 million tonnes
Articulated trucks	90,904	25 tonnes to 42 tonnes 40 tonnes to 60 tonnes (B doubles)	2.272 million tonnes to 5.454 million tonnes
Buses	93,034	15 tonnes to 19 tonnes	1.396 million tonnes to 1.768 million tonnes
Total	641,083	5.725 million tonnes to 16.288 million tonnes	
Average		8.93 tonnes to 25.4 tonnes per vehicle	

In its submission, the Environment Protection Authority questioned the assumption in the air quality impact statement that the petrol-diesel fuel mix estimated in 2013 (based on ABS data) would remain constant into the future. Other submissions also raised questions in relation to this and related matters.

On review, it is acknowledged that this assumption was not conservative. To test the sensitivity of the air quality assessment to this assumption, the mix of fuel types derived for 2013 (refer to **Table 2-14**) has been extrapolated based on an assumed constant linear trend in fuel types between the 2008 and 2013 data published by the Australian Bureau of Statistics. For example, between 2008 and 2013, the Australian Bureau of Statistics recorded a 104 per cent increase in diesel fuelled passenger vehicles but only a six per cent increase in petrol fuelled passenger vehicles over the same period.

Extrapolating changes in fuel mix in this manner has generated the fuel mix estimates in **Table 2-17** and **Table 2-18**, for 2019 and 2029, respectively.

Table 2-17 Summary of fuel type (2019)

Vehicle type	Petrol	Diesel
Cars	85.1%	14.9%
Light duty vehicles	34.4%	65.6%
Heavy vehicles	5.1%	94.9%

Table 2-18 Summary of fuel type (2029)

Vehicle type	Petrol	Diesel
Cars	77.1%	22.9%
Light duty vehicles	20.8%	79.2%
Heavy vehicles	2.6%	97.4%

This anticipated growth has been calculated through linear extrapolation of trends in diesel fuelled vehicles between 2008 and 2013 (based on ABS data). This extrapolation is summarised in **Table 2-19**.

Table 2-19 Extrapolated fuel mix by vehicle type (based on ABS (2008, 2013))

Vehicle type	Petrol				Diesel			
	2008	2013	2019	2029	2008	2013	2019	2029
Passenger vehicles	95.6%	92.1%	85.1%	77.1%	4.4%	7.9%	14.9%	22.9%
Light duty vehicles	63.6%	50.1%	34.4%	20.8%	36.4%	49.9%	65.6%	79.2%
Heavy vehicles	9.9%	7.2%	5.1%	2.6%	90.1%	92.8%	94.9%	97.4%

Notwithstanding the above, all air quality impact assessments conducted for the project have assumed that all heavy vehicles are diesel fuelled.

These changes in fuel mix (in 2019 and 2029) have been carried through the emissions inventory calculated for the project, and which was used as an input in the air quality impact assessment. Changes in the mass emission rate (g/s) of pollutants at the project's ventilation outlets as a consequence of these changes in fuel mix assumptions are summarised in **Table 2-20**. The table shows that with the change in fuel mix assumptions:

- Mass emission rates, and consequently ambient air quality impacts, would decrease for carbon monoxide (CO), polycyclic aromatic hydrocarbons (PAHs) and total volatile organic compounds (VOCs).
- Mass emission rates for oxides of nitrogen (NO_x) and particulate matter (PM₁₀ and PM_{2.5}) would increase marginally – around one to two per cent in 2019, and around two to four per cent in 2029. This is because NO_x and particulate matter emissions are dominated by contributions from heavy vehicles, so changes in fuel mix assumptions for passenger cars has little effect.

Table 2-20 Effect of changes in fuel mix assumptions (change in mass emission rate)

Pollutant	Change to 2019 emissions	Change to 2029 emissions
CO	-3.2% to -3.4%	-6.8% to -7.3%
NO _x	+1.1% to +1.3%	+2.9% to +3.3%
PM ₁₀	+1.2% to +1.8%	+2.7% to + 3.9%
PM _{2.5}	+1.2% to +1.7%	+2.6% to +3.9%
PAHs	-0.4% to -0.4%	-1.0% to -1.1%
Total VOCs	-2.3% to -2.5%	-5.2% to -5.5%

These changes in mass emission rates would not significantly affect the outcomes of the air quality impact assessment presented in the environmental impact statement, and would have only a minor impact on modelled ground level concentrations of these pollutants.

Updated fuel mix assumptions have been reflected in the additional air dispersion modelling conducted for the five metre increase in ventilation outlet heights (refer to **Section 2.15** and **Section 9.2** of this report). The fuel mix has been assumed to be the extrapolated values above in 2019 and 2029.

As noted above, the percentage of heavy vehicles in the total traffic volumes using the project tunnels has been forecast to be around 28 per cent in 2019 and around 25 per cent in 2029. These traffic forecasts for the project have assumed that 95 per cent of through heavy vehicles travelling along the Pennant Hills Road corridor would be directed into the project tunnels with the implementation of regulatory measures (to require heavy vehicles to use the tunnels). There is therefore a very low potential for heavy vehicles using the project to exceed these heavy vehicle percentages.

Tunnel characteristics

Because the emission factors published by the Permanent International Association of Road Congresses (2012) are a function of road gradient, an analysis of the design of the main alignment tunnels was conducted. The analysis involved dividing each main alignment into segments between points where the road gradient changed, and calculating the gradient for that segment. Where the gradient was not an integer multiple of two (the published emission factors are available in multiples of two per cent gradient) professional judgement was used to determine an appropriately conservative gradient for the assessment. A summary of tunnel dimensions applied to the calculation of the emissions inventory is presented in **Table 2-21**.

Table 2-21 Tunnel dimensions applied to the emissions inventory

Measure	Tunnel segment					
	1	2	3	4	5	6
Northbound main alignment tunnel						
Chainage start (m)	1001.9	1230.4	2141.8	7846.8	8465.8	9776.7
Chainage end (m)	1230.4	2141.8	7846.8	8465.8	9776.7	10026.8
Length of segment (m)	228.5	911.3	5705.0	618.9	1310.9	250.2
Elevation start (m)	119.6	111.0	74.6	144.3	147.4	160.5
Elevation end (m)	111.0	74.6	144.3	147.4	160.5	170.5
Calculated gradient (%)	-3.75	-4.00	+1.22	+0.50	+1.00	+4.00
Applied gradient (%)	-4.00	-4.00	+2.00	0.00	0.00	+4.00
Southbound main alignment tunnel						
Chainage start (m)	9943.7	9576.0	8464.5	7819.8	2201.5	1148.0
Chainage end (m)	9576.0	8464.5	7819.8	2201.5	1148.0	688.2
Length of segment (m)	367.8	1111.5	644.7	5618.2	1053.6	459.8
Elevation start (m)	173.3	158.6	147.4	144.3	75.4	89.1
Elevation end (m)	158.6	147.4	144.2	75.4	89.1	107.5
Calculated gradient (%)	-4.00	-1.01	-0.49	-1.23	+1.30	+4.00
Applied gradient (%)	-4.00	0.00	0.00	-2.00	+2.00	+4.00

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Ventilation rates

The ventilation system for the project has been designed to achieve specified in-tunnel air quality criteria based on the maximum traffic throughput capacity of the main alignment tunnels at various average traffic speeds. These design criteria and the process applied to design the ventilation system and to ensure sufficient ventilation capacity are discussed in **Section 2.4.2**.

The project's ventilation system has a maximum capacity of 700 m³/s (per ventilation outlet), and is anticipated to operate at around 300 m³/s under low traffic volume conditions. The ventilation flow rate through the main alignment tunnels would be managed to ensure acceptable in-tunnel air quality, and would operationally be considered a function of total traffic volumes and the composition of traffic within the tunnels (particularly heavy vehicles).

Although ventilation would be directly managed to ensure acceptable in-tunnel air quality, ventilation flows would be indirectly a function of traffic volumes at any particular time, and the percentage of heavy vehicles in the traffic flows. The ventilation flow rates applied to the air quality impact assessment, based on the design of the project's ventilation system, as summarised in **Table 2-22**. The ventilation flow rates are based on an average traffic speed of 80 km/ h for the forecast traffic scenarios in 2019 and 2029.

In the case of 'design analysis A', traffic volumes are based on the design throughput capacity of two motorway lanes travelling at different speeds. Since there is more traffic throughput at 60km/ h in the case of 'design analysis A', requiring more ventilation than traffic at 80km/h, the ventilation flow rates during these peak hours are based on an average traffic speed of 60 km/h rather than 80km/h. Further discussion of the traffic throughput capacity of motorway lanes at different speeds is provided in **Section 2.4.2**.

Table 2-22 Applied ventilation flow rates

Time of day	Ventilation flow rate (m ³ /s)		
	Forecast traffic 2019	Forecast traffic 2019	Design analysis A
01:00	300	300	380
02:00	300	300	380
03:00	300	300	380
04:00	300	300	380
05:00	380	380	460
06:00	460	460	540
07:00	540	620	700
08:00	620	620	620
09:00	620	620	620
10:00	620	620	620
11:00	540	620	700
12:00	540	620	700
13:00	540	620	700
14:00	540	620	700
15:00	540	620	620
16:00	620	620	620
17:00	620	620	620
18:00	540	620	700
19:00	540	540	620
20:00	460	460	620
21:00	380	460	540
22:00	380	460	460
23:00	380	380	460
00:00	380	380	380

Emission rates

Emission rates published by the Permanent International Association of Road Congresses (PIARC) have been applied in the calculation of the project's emissions inventory. The emissions rates that were used are specific to Australia, and take into account vehicle type (passenger car, light duty vehicle or heavy vehicle), fuel (petrol or diesel) and road gradient.

To account for improvements in vehicle and fuel efficiency over time, the emission factors are published for a base year (2010) with future emission factors then applied to determine emission rates for future years. Future emission factors have been published up to 2020. For the purpose of the air quality impact assessment, emission factors were scaled to 2019 for the 2019 forecast traffic scenario, but only to 2020 for the 2029 forecast traffic scenario. This is a conservative assumption, as it makes no allowance for around nine years of potential improvements in vehicle and fuel efficiencies for the 2029 forecast traffic scenario.

Emission rates for 'design analysis A' were taken as the 2019 emissions factors. This is also a conservative assumption because the traffic volumes contemplated by this scenario are very unlikely to occur when the project is anticipated to open in 2019, and vehicle and fuel efficiencies would improve beyond that date.

Base emission rates (2010) relevant to the project for a range of vehicle speeds are provided in **Table 2-23** (for passenger cars), **Table 2-24** (for light duty vehicles) and **Table 2-25** (for heavy vehicles). Full emission factors are provided in Road Tunnels: Vehicle Emissions and Air Demand for Ventilation (PIARC, 2012).

Table 2-23 Base emission rates for passenger cars (2010)

Speed	Gradient				
	-4%	-2%	0%	+2%	+4%
Carbon monoxide – petrol					
20 km/h	58.2 g/h	66 g/h	73.7 g/h	84.8 g/h	97.3 g/h
40 km/h	64.4 g/h	81.8 g/h	106.1 g/h	136.1 g/h	177.3 g/h
60 km/h	66.5 g/h	93.9 g/h	132.8 g/h	191.4 g/h	274.1 g/h
80 km/h	65.9 g/h	99.7 g/h	161 g/h	262.8 g/h	408.1 g/h
Carbon monoxide – diesel					
20 km/h	9.6 g/h	9.8 g/h	11 g/h	11.9 g/h	11.2 g/h
40 km/h	9.6 g/h	10.1 g/h	12 g/h	12.4 g/h	13.3 g/h
60 km/h	9.6 g/h	10.2 g/h	11.2 g/h	13.2 g/h	8.8 g/h
80 km/h	9.6 g/h	11.4 g/h	12.2 g/h	8.8 g/h	7.9 g/h
Oxides of nitrogen – petrol					
20 km/h	6.3 g/h	6.5 g/h	10.4 g/h	12.4 g/h	17.6 g/h
40 km/h	6.3 g/h	8.4 g/h	13.4 g/h	23.9 g/h	30.2 g/h
60 km/h	6.3 g/h	9.6 g/h	20.3 g/h	31 g/h	37.2 g/h
80 km/h	6.3 g/h	13.3 g/h	30 g/h	38.1 g/h	53.7 g/h
Oxides of nitrogen – diesel					
20 km/h	8 g/h	9.1 g/h	19.1 g/h	25.8 g/h	31.5 g/h
40 km/h	8 g/h	12.2 g/h	26.7 g/h	38.9 g/h	55.9 g/h
60 km/h	8 g/h	13 g/h	31.9 g/h	56.3 g/h	84.2 g/h
80 km/h	8 g/h	22.1 g/h	48.4 g/h	84.2 g/h	124 g/h
Opacity – diesel					
20 km/h	2.3 m ² /h	2.8 m ² /h	8.2 m ² /h	12.6 m ² /h	16.8 m ² /h
40 km/h	2.3 m ² /h	4.3 m ² /h	13.3 m ² /h	20.6 m ² /h	28.7 m ² /h
60 km/h	2.3 m ² /h	4.7 m ² /h	17 m ² /h	28.8 m ² /h	40.5 m ² /h
80 km/h	2.3 m ² /h	10.1 m ² /h	25.3 m ² /h	40.5 m ² /h	55.2 m ² /h

Table 2-24 Base emission rates for light duty vehicles (2010)

Speed	Gradient				
	-4%	-2%	0%	+2%	+4%
Carbon monoxide – petrol/ diesel					
20 km/h	34.8 g/h	53.3 g/h	108.4 g/h	96.9 g/h	53.9 g/h
40 km/h	34.8 g/h	85.9 g/h	72.8 g/h	66.2 g/h	148.6 g/h
60 km/h	34.8 g/h	115 g/h	56.5 g/h	179.4 g/h	393.2 g/h
80 km/h	34.8 g/h	130 g/h	181.4 g/h	474.8 g/h	758.9 g/h
Oxides of nitrogen – petrol/ diesel					
20 km/h	9.3 g/h	14.1 g/h	32.2 g/h	35.3 g/h	37 g/h
40 km/h	9.3 g/h	24.1 g/h	30.8 g/h	33.6 g/h	55.9 g/h
60 km/h	9.3 g/h	34.8 g/h	30.2 g/h	63.6 g/h	103.3 g/h
80 km/h	9.3 g/h	35.7 g/h	64 g/h	87.1 g/h	169.5 g/h
Opacity – diesel					
20 km/h	1.2 m ² /h	2.2 m ² /h	5.6 m ² /h	8.4 m ² /h	11.2 m ² /h
40 km/h	1.2 m ² /h	4.1 m ² /h	9.6 m ² /h	14.5 m ² /h	19.7 m ² /h
60 km/h	1.2 m ² /h	6 m ² /h	13.6 m ² /h	21.3 m ² /h	28.8 m ² /h
80 km/h	1.2 m ² /h	11.4 m ² /h	21.4 m ² /h	31.3 m ² /h	41.2 m ² /h

Table 2-25 Base emission rates for heavy vehicles (2010)

Speed	Gradient				
	-4%	-2%	0%	+2%	+4%
Carbon monoxide – diesel					
20 km/h	31.4 g/h	55 g/h	67.6 g/h	76 g/h	90.2 g/h
40 km/h	29.6 g/h	62.1 g/h	75.4 g/h	97.9 g/h	129.4 g/h
60 km/h	23.5 g/h	56.2 g/h	82.1 g/h	127 g/h	167.4 g/h
80 km/h	20.3 g/h	56.9 g/h	98.9 g/h	156.3 g/h	212.2 g/h
Oxides of nitrogen – diesel					
20 km/h	52.8 g/h	151.1 g/h	217.2 g/h	305.3 g/h	432.3 g/h
40 km/h	48.8 g/h	183.3 g/h	295.1 g/h	493.2 g/h	751.3 g/h
60 km/h	33.3 g/h	154.6 g/h	357.7 g/h	727.7 g/h	1079.6 g/h
80 km/h	28 g/h	163.5 g/h	499.4 g/h	987.2 g/h	1445.3 g/h
Opacity – diesel					
20 km/h	25.9 m ² /h	36.4 m ² /h	49.5 m ² /h	61.1 m ² /h	73.5 m ² /h
40 km/h	24.4 m ² /h	45.7 m ² /h	59.9 m ² /h	80.1 m ² /h	109.9 m ² /h
60 km/h	20.6 m ² /h	42.9 m ² /h	66.6 m ² /h	107.4 m ² /h	147.4 m ² /h
80 km/h	16.7 m ² /h	42.9 m ² /h	80.7 m ² /h	136.6 m ² /h	190.6 m ² /h

Future emission factors published by the Permanent International Association of Road Congresses (2012) are available for the years 2015 and 2020. For 2019, a linear interpolation has been applied to the published factors. Future emission factors applied in calculation of the emissions inventory for the project are summarised in **Table 2-26**.

These future emission factors have been applied to the base emission rates (2010) in the tables above to generate:

- Future emission rates in 2019 (refer to **Table 2-27** to **Table 2-29**).
- Future emission rates in 2029 (refer to **Table 2-30** to **Table 2-32**).

Table 2-26 Future emission factors

Year	CO Petrol	Diesel	NO _x Petrol	Diesel	Opacity Diesel
Passenger cars					
2010	1	1	1	1	1
2015	0.59	0.67	0.55	0.84	0.64
2019	0.45	0.48	0.36	0.66	0.42
2020	0.42	0.43	0.31	0.61	0.37
Light duty vehicles					
2010	1	1	1	1	1
2015	0.69	0.72	0.72	0.72	0.64
2019	0.55	0.53	0.53	0.53	0.46
2020	0.51	0.48	0.48	0.48	0.41
Heavy vehicles					
2010	-	1	-	1	1
2015	-	0.73	-	0.74	0.73
2019	-	0.55	-	0.56	0.54
2020	-	0.50	-	0.52	0.49

Table 2-27 Future emission rates for passenger cars (2019)

Speed	Gradient				
	-4%	-2%	0%	+2%	+4%
Carbon monoxide – petrol					
20 km/h	26.4 g/h	30.0 g/h	33.5 g/h	38.5 g/h	44.2 g/h
40 km/h	29.2 g/h	37.1 g/h	48.2 g/h	61.8 g/h	80.5 g/h
60 km/h	30.2 g/h	42.6 g/h	60.3 g/h	86.9 g/h	124.4 g/h
80 km/h	29.9 g/h	45.3 g/h	73.1 g/h	119.3 g/h	185.3 g/h
Carbon monoxide – diesel					
20 km/h	4.59 g/h	4.68 g/h	5.26 g/h	5.69 g/h	5.35 g/h
40 km/h	4.59 g/h	4.83 g/h	5.74 g/h	5.93 g/h	6.36 g/h
60 km/h	4.59 g/h	4.88 g/h	5.35 g/h	6.31 g/h	4.21 g/h
80 km/h	4.59 g/h	5.45 g/h	5.83 g/h	4.21 g/h	3.78 g/h
Oxides of nitrogen – petrol					
20 km/h	2.26 g/h	2.33 g/h	3.72 g/h	4.44 g/h	6.30 g/h
40 km/h	2.26 g/h	3.01 g/h	4.80 g/h	8.56 g/h	10.81 g/h
60 km/h	2.26 g/h	3.44 g/h	7.27 g/h	11.10 g/h	13.32 g/h
80 km/h	2.26 g/h	4.76 g/h	10.74 g/h	13.64 g/h	19.22 g/h
Oxides of nitrogen – diesel					
20 km/h	5.25 g/h	5.97 g/h	12.53 g/h	16.92 g/h	20.66 g/h
40 km/h	5.25 g/h	8.00 g/h	17.52 g/h	25.52 g/h	36.67 g/h
60 km/h	5.25 g/h	8.53 g/h	20.93 g/h	36.93 g/h	55.24 g/h
80 km/h	5.25 g/h	14.50 g/h	31.75 g/h	55.24 g/h	81.34 g/h
Opacity – diesel					
20 km/h	0.98 m ² /h	1.19 m ² /h	3.48 m ² /h	5.34 m ² /h	7.12 m ² /h
40 km/h	0.98 m ² /h	1.82 m ² /h	5.64 m ² /h	8.73 m ² /h	12.170 m ² /h
60 km/h	0.98 m ² /h	2.00 m ² /h	7.21 m ² /h	12.21 m ² /h	17.17 m ² /h
80 km/h	0.98 m ² /h	4.28 m ² /h	10.73 m ² /h	17.17 m ² /h	23.41 m ² /h

Table 2-28 Future emission rates for light duty vehicles (2019)

Speed	Gradient				
	-4%	-2%	0%	+2%	+4%
Carbon monoxide – petrol/ diesel					
20 km/h	19.0 g/h	29.1 g/h	59.2 g/h	52.9 g/h	29.4 g/h
40 km/h	19.0 g/h	46.9 g/h	39.7 g/h	36.1 g/h	81.1 g/h
60 km/h	19.0 g/h	62.8 g/h	30.8 g/h	98.0 g/h	214.7 g/h
80 km/h	19.0 g/h	71.0 g/h	99.0 g/h	259.2 g/h	414.4 g/h
Oxides of nitrogen – petrol/ diesel					
20 km/h	4.9 g/h	7.4 g/h	17.0 g/h	18.6 g/h	19.5 g/h
40 km/h	4.9 g/h	12.7 g/h	16.3 g/h	17.7 g/h	29.5 g/h
60 km/h	4.9 g/h	18.4 g/h	15.9 g/h	33.6 g/h	54.5 g/h
80 km/h	4.9 g/h	18.8 g/h	33.8 g/h	46.0 g/h	89.5 g/h
Opacity – diesel					
20 km/h	0.5 m ² /h	1.0 m ² /h	2.6 m ² /h	3.8 m ² /h	5.1 m ² /h
40 km/h	0.5 m ² /h	1.9 m ² /h	4.4 m ² /h	6.6 m ² /h	9.0 m ² /h
60 km/h	0.5 m ² /h	2.7 m ² /h	6.2 m ² /h	9.7 m ² /h	13.1 m ² /h
80 km/h	0.5 m ² /h	5.2 m ² /h	9.8 m ² /h	14.3 m ² /h	18.8 m ² /h

Table 2-29 Future emission rates for heavy vehicles (2019)

Speed	Gradient				
	-4%	-2%	0%	+2%	+4%
Carbon monoxide – diesel					
20 km/h	17.14 g/h	30.03 g/h	36.91 g/h	41.50 g/h	49.25 g/h
40 km/h	16.16 g/h	33.91 g/h	41.17 g/h	53.45 g/h	70.65 g/h
60 km/h	12.83 g/h	30.69 g/h	44.83 g/h	69.34 g/h	91.40 g/h
80 km/h	11.08 g/h	31.07 g/h	54.00 g/h	85.34 g/h	115.86 g/h
Oxides of nitrogen – diesel					
20 km/h	29.8 g/h	85.2 g/h	122.5 g/h	172.2 g/h	243.8 g/h
40 km/h	27.5 g/h	103.4 g/h	166.4 g/h	278.2 g/h	423.7 g/h
60 km/h	18.8 g/h	87.2 g/h	201.7 g/h	410.4 g/h	608.9 g/h
80 km/h	15.8 g/h	92.2 g/h	281.7 g/h	556.8 g/h	815.1 g/h
Opacity – diesel					
20 km/h	13.9 m ² /h	19.6 m ² /h	26.6 m ² /h	32.9 m ² /h	39.5 m ² /h
40 km/h	13.1 m ² /h	24.6 m ² /h	32.2 m ² /h	43.1 m ² /h	59.1 m ² /h
60 km/h	11.1 m ² /h	23.1 m ² /h	35.8 m ² /h	57.8 m ² /h	79.3 m ² /h
80 km/h	9.0 m ² /h	23.1 m ² /h	43.4 m ² /h	73.5 m ² /h	102.5 m ² /h

Table 2-30 Future emission rates for passenger cars (2029)

Speed	Gradient				
	-4%	-2%	0%	+2%	+4%
Carbon monoxide – petrol					
20 km/h	24.4 g/h	27.7 g/h	31.0 g/h	35.6 g/h	40.9 g/h
40 km/h	27.0 g/h	34.4 g/h	44.6 g/h	57.2 g/h	74.5 g/h
60 km/h	27.9 g/h	39.4 g/h	55.8 g/h	80.4 g/h	115.1 g/h
80 km/h	27.7 g/h	41.9 g/h	67.6 g/h	110.4 g/h	171.4 g/h
Carbon monoxide – diesel					
20 km/h	4.13 g/h	4.21 g/h	4.73 g/h	5.12 g/h	4.82 g/h
40 km/h	4.13 g/h	4.34 g/h	5.16 g/h	5.33 g/h	5.72 g/h
60 km/h	4.13 g/h	4.39 g/h	4.82 g/h	5.68 g/h	3.78 g/h
80 km/h	4.13 g/h	4.90 g/h	5.25 g/h	3.78 g/h	3.40 g/h
Oxides of nitrogen – petrol					
20 km/h	1.95 g/h	2.02 g/h	3.22 g/h	3.84 g/h	5.46 g/h
40 km/h	1.95 g/h	2.60 g/h	4.15 g/h	7.41 g/h	9.36 g/h
60 km/h	1.95 g/h	2.98 g/h	6.29 g/h	9.61 g/h	11.53 g/h
80 km/h	1.95 g/h	4.12 g/h	9.30 g/h	11.81 g/h	16.65 g/h
Oxides of nitrogen – diesel					
20 km/h	4.88 g/h	5.55 g/h	11.65 g/h	15.74 g/h	19.22 g/h
40 km/h	4.88 g/h	7.44 g/h	16.29 g/h	23.73 g/h	34.10 g/h
60 km/h	4.88 g/h	7.93 g/h	19.46 g/h	34.34 g/h	51.36 g/h
80 km/h	4.88 g/h	13.48 g/h	29.52 g/h	51.36 g/h	75.64 g/h
Opacity – diesel					
20 km/h	0.85 m ² /h	1.04 m ² /h	3.03 m ² /h	4.66 m ² /h	6.22 m ² /h
40 km/h	0.85 m ² /h	1.59 m ² /h	4.92 m ² /h	7.62 m ² /h	10.62 m ² /h
60 km/h	0.85 m ² /h	1.74 m ² /h	6.29 m ² /h	10.66 m ² /h	14.99 m ² /h
80 km/h	0.85 m ² /h	3.74 m ² /h	9.36 m ² /h	14.99 m ² /h	20.42 m ² /h

Table 2-31 Future emission rates for light duty vehicles (2029)

Speed	Gradient				
	-4%	-2%	0%	+2%	+4%
Carbon monoxide – petrol/ diesel					
20 km/h	17.7 g/h	27.2 g/h	55.3 g/h	49.4 g/h	27.5 g/h
40 km/h	17.7 g/h	43.8 g/h	37.1 g/h	33.8 g/h	75.8 g/h
60 km/h	17.7 g/h	58.7 g/h	28.8 g/h	91.5 g/h	200.5 g/h
80 km/h	17.7 g/h	66.3 g/h	92.5 g/h	242.1 g/h	387.0 g/h
Oxides of nitrogen – petrol/ diesel					
20 km/h	4.5 g/h	6.8 g/h	15.5 g/h	16.9 g/h	17.8 g/h
40 km/h	4.5 g/h	11.6 g/h	14.8 g/h	16.1 g/h	26.8 g/h
60 km/h	4.5 g/h	16.7 g/h	14.5 g/h	30.5 g/h	49.6 g/h
80 km/h	4.5 g/h	17.1 g/h	30.7 g/h	41.8 g/h	81.4 g/h
Opacity – diesel					
20 km/h	0.5 m ² /h	0.9 m ² /h	2.3 m ² /h	3.4 m ² /h	4.6 m ² /h
40 km/h	0.5 m ² /h	1.7 m ² /h	3.9 m ² /h	5.9 m ² /h	8.1 m ² /h
60 km/h	0.5 m ² /h	2.5 m ² /h	5.6 m ² /h	8.7 m ² /h	11.8 m ² /h
80 km/h	0.5 m ² /h	4.7 m ² /h	8.8 m ² /h	12.8 m ² /h	16.9 m ² /h

Table 2-32 Future emission rates for heavy vehicles (2029)

Speed	Gradient				
	-4%	-2%	0%	+2%	+4%
Carbon monoxide – diesel					
20 km/h	15.7 g/h	27.5 g/h	33.8 g/h	38.0 g/h	45.1 g/h
40 km/h	14.8 g/h	31.1 g/h	37.7 g/h	49.0 g/h	64.7 g/h
60 km/h	11.8 g/h	28.1 g/h	41.1 g/h	63.5 g/h	83.7 g/h
80 km/h	10.2 g/h	28.5 g/h	49.5 g/h	78.2 g/h	106.1 g/h
Oxides of nitrogen – diesel					
20 km/h	27.5 g/h	78.6 g/h	112.9 g/h	158.8 g/h	224.8 g/h
40 km/h	25.4 g/h	95.3 g/h	153.5 g/h	256.5 g/h	390.7 g/h
60 km/h	17.3 g/h	80.4 g/h	186.0 g/h	378.4 g/h	561.4 g/h
80 km/h	14.6 g/h	85.0 g/h	259.7 g/h	513.3 g/h	751.6 g/h
Opacity – diesel					
20 km/h	12.7 m ² /h	17.8 m ² /h	24.3 m ² /h	29.9 m ² /h	36.0 m ² /h
40 km/h	12.0 m ² /h	22.4 m ² /h	29.4 m ² /h	39.2 m ² /h	53.9 m ² /h
60 km/h	10.1 m ² /h	21.0 m ² /h	32.6 m ² /h	52.6 m ² /h	72.2 m ² /h
80 km/h	8.2 m ² /h	21.0 m ² /h	39.5 m ² /h	66.9 m ² /h	93.4 m ² /h

Particulate matter emissions

Emissions of particulate matter come from two sources:

- Exhaust emissions generated by the combustion of fuel in vehicles.
- Non-exhaust emissions, generated by brake and tyre wear, and re-entrainment of particulate matter from the road surface.

In the case of exhaust emissions, the opacity emission rates listed in **Table 2-27** to **Table 2-32** of this report have been converted to particulate matter (PM₁₀) emissions based on the correlations published by the Permanent International Association of Road Congresses (2012).

Opacity in m²/h has been converted to an equivalent vehicle mass emission rate for PM₁₀ based on:

$$1 \text{ g/h} = 4.7 \text{ m}^2/\text{h} \quad (\text{PIARC, 2012})$$

It should be noted that the Permanent International Association of Road Congresses deals with particulate matter in terms of opacity (extinction coefficients). At the time of preparing the air quality impact assessment, it was unclear from the PIARC publications (2012) whether opacity factors were based on PM₁₀ or PM_{2.5}. For the purpose of the air quality impact assessment, it was assumed that opacity as referred to by PIARC included the full PM₁₀ fraction.

As part of preparing this report, it has been clarified with a contributor to the PIARC document that opacity is in fact based on the PM_{2.5} fraction. This clarification if carried through the air quality impact assessment for the project will result in around a five per cent variance in PM_{2.5} and PM₁₀ mass emission rates from the project (ventilation outlet and surface road assessments). Given the low predicted impacts of the project, and conservatism in other areas of the assessment, a variance of five percent in particulate matter mass emission rates is considered minor and would not affect the outcomes of the air quality impact assessment (in terms of compliance with applicable air quality standards).

The PM_{2.5} fraction has been determined through comparison of PM₁₀ and PM_{2.5} emission rates from the National Pollutant Inventory (NPI) for combustion engines (2008). The ratio of PM_{2.5} to PM₁₀ in exhaust emissions applied to the emissions inventory is summarised in **Table 2-33**. Note that the NPI emission factors are expressed in kilograms per cubic metre (kg/m³) of fuel consumed. Because they are only used below to calculate PM_{2.5}:PM₁₀ ratios, there is no need to convert these emission factors into a grams per hour (g/h) basis (as has been used elsewhere in this report and the environmental impact statement).

In the case of heavy vehicles, the ratio of PM_{2.5} to PM₁₀ has been calculated with National Pollutant Inventory data for different categories of heavy vehicles, and then calculated as a weighted average for the whole heavy vehicle group. Weightings have been applied based on the relative proportion of each heavy vehicle category based on ABS (2013) data, as summarised in **Table 2-34**.

These emission ratios have been applied to calculated exhaust emissions of PM₁₀ to determine exhaust emissions of PM_{2.5}.

Table 2-33 Ratio of PM_{2.5} to PM₁₀ for passenger cars and light duty vehicles

Particulate matter fraction	Emission factor (kg/m³ fuel)	Ratio (PM _{2.5} :PM ₁₀)
Passenger cars – petrol		
PM ₁₀	0.067 kg/m³	0.9254
PM _{2.5}	0.062 kg/m³	
Passenger cars – diesel		
PM ₁₀	2.1 kg/m³	0.9524
PM _{2.5}	2 kg/m³	
Light duty vehicles – petrol		
PM ₁₀	0.072 kg/m³	0.9306
PM _{2.5}	0.067 kg/m³	
Light duty vehicles - diesel		
PM ₁₀	2.4 kg/m³	0.9583
PM _{2.5}	2.3 kg/m³	

Table 2-34 Ratio of PM_{2.5} to PM₁₀ for heavy vehicles

Particulate matter fraction	Emission factor (kg/m ³ fuel)	Ratio (PM _{2.5} :PM ₁₀) for heavy vehicle category	Percentage of total heavy vehicles	Ratio (PM _{2.5} :PM ₁₀) for all heavy vehicles
Medium goods vehicle				0.9510
PM ₁₀	2.3 kg/m ³	0.9565	20.46%	
PM _{2.5}	2.2 kg/m ³			
Heavy goods vehicle				
PM ₁₀	1.8 kg/m ³	0.9444	50.85%	
PM _{2.5}	1.7 kg/m ³			
Very heavy goods vehicle				
PM ₁₀	1.2 kg/m ³	0.9167	14.18%	
PM _{2.5}	1.1 kg/m ³			
Buses				
PM ₁₀	2.1 kg/m ³	1.000	14.51%	
PM _{2.5}	2.1 kg/m ³			

Note that while it may appear from the table above that heavy vehicles emit less particulate matter than passenger cars (compare, for example, a PM₁₀ emission factor for a diesel fuelled car at 2.1 kg/m³ compared with the same figure for a very heavy goods vehicle of only 1.2 kg/m³), the emission factors presented above are expressed in terms of total mass of particulate matter per cubic metre of fuel consumed. Heavy vehicles use more fuel per kilometre than passenger cars, so while they may emit less mass of particulate matter per

cubic metre of fuel, they emit a greater total amount of particulate matter because of a much higher amount of fuel used per kilometre than passenger cars.

The Permanent International Association of Road Congresses (2012) provides emission factors for non-exhaust $PM_{2.5}$, as summarised in **Table 2-35**. These emission factors have been added to the emission factors for exhaust emissions to determine a total $PM_{2.5}$ emission factor for the purpose of calculating the project's emissions inventory. Unlike exhaust emissions, non-exhaust emission factors have been applied consistently over time with no assumed improvement in the future. To determine non-exhaust PM_{10} emissions, the same $PM_{2.5}:PM_{10}$ ratios as outlined above have been applied.

Table 2-35 Non-exhaust $PM_{2.5}$ emission factors

Speed	Non-exhaust emission factors ($PM_{2.5}$)	
	Passenger cars/ light duty vehicles	Heavy vehicles
20 km/h	0.56 g/h	2.08 g/h
40 km/h	1.12 g/h	4.16 g/h
60 km/h	1.68 g/h	6.24 g/h
80 km/h	2.24 g/h	8.32 g/h

Other emissions

Data from the National Pollutant Inventory (NPI) for combustion engines (2008) has been used to determine the emission factors for other hydrocarbon pollutants. These other pollutants have been calculated based on their ratio relative to the emission factor for carbon monoxide, as summarised in **Table 2-36** for passenger and light duty vehicles, and **Table 2-37** for heavy vehicles.

Table 2-36 Ratio of hydrocarbons to CO for passenger cars and light duty vehicles

Pollutant	Emission factor	Ratio of pollutant: CO
Passenger cars – petrol		
CO	37 kg/m ³	-
Polycyclic aromatic hydrocarbons (PAHs)	5.2×10^{-6} kg/m ³	1.41×10^{-7}
Total volatile organic compounds (VOCs)	2.5 kg/m ³	0.0676
Passenger cars – diesel		
CO	10 kg/m ³	-
Polycyclic aromatic hydrocarbons (PAHs)	3.2×10^{-4} kg/m ³	3.2×10^{-5}
Total volatile organic compounds (VOCs)	0.82	0.082
Light duty vehicles – petrol		
CO	87 kg/m ³	-
Polycyclic aromatic hydrocarbons (PAHs)	1.8×10^{-5} kg/m ³	2.07×10^{-7}
Total volatile organic compounds (VOCs)	8.5 kg/m ³	0.0977
Light duty vehicles – diesel		
CO	19 kg/m ³	-
Polycyclic aromatic hydrocarbons (PAHs)	1.6×10^{-4} kg/m ³	8.42×10^{-6}
Total volatile organic compounds (VOCs)	0.42 kg/m ³	0.0221

Table 2-37 Ratio of hydrocarbons to CO for heavy vehicles

Pollutant	Emission factor	Ratio of pollutant: CO for heavy vehicle category	Percentage of total heavy vehicles	Ratio of pollutant: CO for all heavy vehicles
Medium goods vehicle				PAHs: 8.143 x 10 ⁻⁵ VOCs: 0.21
CO	12 kg/m ³	-	20.46%	
Polycyclic aromatic hydrocarbons	8.4 x 10 ⁻⁴ kg/m ³	7.0 x 10 ⁻⁵		
Total volatile organic compounds	2.1 kg/m ³	0.175		
Heavy goods vehicle				
CO	6.8 kg/m ³	-	50.85%	
Polycyclic aromatic hydrocarbons	7.1 x 10 ⁻⁴ kg/m ³	1.04 x 10 ⁻⁴		
Total volatile organic compounds	1.8 kg/m ³	0.2647		
Very heavy goods vehicle				
CO	8.5 kg/m ³	-	14.18%	
Polycyclic aromatic hydrocarbons	4.0 x 10 ⁻⁴ kg/m ³	4.71 x 10 ⁻⁵		
Total volatile organic compounds	1.0 kg/m ³	0.1176		
Buses				
CO	9.1 kg/m ³	-	14.51%	
Polycyclic aromatic hydrocarbons	4.6 x 10 ⁻⁴ kg/m ³	5.05 x 10 ⁻⁵		
Total volatile organic compounds	1.2 kg/m ³	0.1318		

Calculated emissions inventories

This section includes:

- Updated emissions inventories used in the air quality impact assessment presented in this report (to reflect an increase in ventilation outlet heights by five metres). As discussed in **Section 2.3**, some amendments have been made to assumptions and inputs used in the air quality impact assessment for the project since public exhibition of the environmental impact statement. One of these amendments (future fuel mix) has altered the emissions inventories for the project, as detailed below.
- Clarification of the emissions inventory presented in the environmental impact statement for forecast traffic flow scenarios in 2019 and 2029 (scenario 2a and scenario 2b).

Updated emissions inventories

As discussed in **Section 2.3** and detailed in the relevant sections in this chapter, four amendments have been made to the assumptions and inputs into the air quality impact assessment for the project:

- Increasing the resolution of the receiver grid applied around each ventilation outlet (ie reduced receiver spacing) (refer to **Section 2.13.1**).
- Applying higher resolution topographic data (refer to **Section 2.12**).
- Revising future projections of vehicle fleet fuel mix, to reflect an increased use of diesel fuel in the future) (refer to **Section 2.7**).
- Amending the ozone limiting method equation to take into account a NO₂:NO_x ratio of 16 per cent, as recommended by the Environment Protection Authority (refer to **Section 2.14**).

Of these amendments, the revision of future projections of vehicle fuel mix has affected the emissions inventories for the air quality impact assessment scenarios. The updated emissions inventories are provided in this section. With the exception of the clarification in the following section of this report, the emissions inventories applied to the air quality impact assessment presented in the environmental impact statement have not been reproduced in this report because those emissions inventories have now been superseded by the inventories provided in this report.

Emission inventories for the air quality impact assessment scenarios are provided in the following tables. Flow rates and pollutant concentrations have been expressed in terms of normal cubic metres per second (Nm^3/s) at 0°C , one atmosphere of pressure and dry conditions.

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Table 2-38 Emissions inventory – forecast traffic volumes 2019 (scenario 2a)

Time of day	Flowrate (Nm ³ /s)	CO g/s	CO mg/m ³	NO _x g/s	NO _x mg/m ³	PM ₁₀ g/s	PM ₁₀ mg/m ³	PM _{2.5} g/s	PM _{2.5} mg/m ³	PAHs g/s	PAHs mg/m ³	VOCs g/s	VOCs mg/m ³
Southbound													
01:00	300	0.171	0.570	0.197	0.655	0.018	0.061	0.017	0.057	0.000003	0.000011	0.0172	0.0572
02:00	300	0.134	0.447	0.155	0.518	0.014	0.048	0.014	0.045	0.000003	0.000008	0.0135	0.0450
03:00	300	0.129	0.431	0.148	0.492	0.014	0.046	0.013	0.043	0.000002	0.000008	0.0129	0.0431
04:00	300	0.181	0.603	0.212	0.707	0.020	0.065	0.019	0.062	0.000003	0.000012	0.0183	0.0610
05:00	380	0.307	0.807	0.359	0.945	0.033	0.087	0.031	0.082	0.000006	0.000016	0.0310	0.0815
06:00	460	0.786	1.709	0.915	1.990	0.085	0.184	0.080	0.174	0.000015	0.000033	0.0793	0.1723
07:00	540	1.659	3.073	1.929	3.572	0.178	0.331	0.169	0.312	0.000032	0.000059	0.1672	0.3097
08:00	620	2.176	3.509	2.526	4.075	0.234	0.377	0.221	0.356	0.000041	0.000067	0.2192	0.3535
09:00	620	2.253	3.634	2.616	4.220	0.242	0.391	0.229	0.369	0.000043	0.000069	0.2270	0.3661
10:00	620	1.995	3.217	2.321	3.743	0.215	0.346	0.203	0.327	0.000038	0.000061	0.2011	0.3243
11:00	540	1.857	3.439	2.158	3.996	0.200	0.370	0.189	0.349	0.000035	0.000066	0.1871	0.3466
12:00	540	1.809	3.349	2.101	3.891	0.194	0.360	0.184	0.340	0.000034	0.000064	0.1822	0.3375
13:00	540	1.721	3.188	2.002	3.708	0.185	0.343	0.175	0.324	0.000033	0.000061	0.1735	0.3213
14:00	540	1.778	3.293	2.068	3.829	0.191	0.354	0.181	0.335	0.000034	0.000063	0.1792	0.3319
15:00	540	1.954	3.619	2.272	4.208	0.210	0.389	0.199	0.368	0.000037	0.000069	0.1970	0.3648
16:00	620	2.196	3.542	2.551	4.114	0.236	0.381	0.223	0.360	0.000042	0.000067	0.2212	0.3568
17:00	620	2.097	3.382	2.436	3.929	0.225	0.364	0.213	0.344	0.000040	0.000064	0.2113	0.3408
18:00	540	1.855	3.436	2.158	3.996	0.200	0.370	0.189	0.349	0.000035	0.000066	0.1870	0.3463
19:00	540	1.378	2.551	1.602	2.967	0.148	0.274	0.140	0.259	0.000026	0.000049	0.1389	0.2572
20:00	460	0.895	1.946	1.039	2.258	0.096	0.209	0.091	0.197	0.000017	0.000037	0.0902	0.1960
21:00	380	0.605	1.592	0.703	1.850	0.065	0.171	0.061	0.162	0.000012	0.000030	0.0610	0.1605
22:00	380	0.515	1.354	0.597	1.571	0.055	0.145	0.052	0.137	0.000010	0.000026	0.0518	0.1364
23:00	380	0.389	1.024	0.450	1.184	0.042	0.110	0.039	0.104	0.000007	0.000019	0.0391	0.1030
24:00	380	0.260	0.684	0.302	0.796	0.028	0.074	0.026	0.070	0.000005	0.000013	0.0262	0.0689
Northbound													
01:00	300	0.240	0.800	0.348	1.161	0.020	0.068	0.019	0.064	0.000005	0.000015	0.0241	0.0803
02:00	300	0.184	0.614	0.269	0.897	0.016	0.053	0.015	0.050	0.000003	0.000012	0.0185	0.0618
03:00	300	0.187	0.623	0.269	0.898	0.016	0.053	0.015	0.050	0.000003	0.000012	0.0187	0.0624
04:00	300	0.306	1.019	0.443	1.478	0.026	0.087	0.025	0.082	0.000006	0.000019	0.0307	0.1022
05:00	380	0.697	1.835	0.999	2.630	0.059	0.155	0.056	0.146	0.000013	0.000034	0.0697	0.1834
06:00	460	1.642	3.570	2.362	5.136	0.139	0.302	0.131	0.286	0.000031	0.000067	0.1643	0.3572

07:00	540	2.261	4.187	3.251	6.020	0.191	0.354	0.181	0.335	0.000042	0.000078	0.2262	0.4189
08:00	620	2.117	3.920	3.044	5.638	0.179	0.332	0.169	0.314	0.000039	0.000073	0.2118	0.3922
09:00	620	2.215	4.103	3.187	5.902	0.188	0.347	0.177	0.328	0.000041	0.000077	0.2217	0.4105
10:00	620	2.895	5.362	4.156	7.696	0.245	0.453	0.231	0.428	0.000054	0.000100	0.2895	0.5361
11:00	540	2.857	5.291	4.107	7.606	0.242	0.448	0.229	0.423	0.000053	0.000099	0.2858	0.5293
12:00	540	2.696	4.992	3.870	7.167	0.228	0.422	0.215	0.399	0.000050	0.000093	0.2696	0.4992
13:00	540	2.602	4.819	3.742	6.930	0.220	0.408	0.208	0.386	0.000049	0.000090	0.2603	0.4821
14:00	540	2.635	4.879	3.790	7.018	0.223	0.413	0.211	0.390	0.000049	0.000091	0.2636	0.4882
15:00	540	2.976	5.511	4.281	7.928	0.252	0.466	0.238	0.441	0.000055	0.000103	0.2978	0.5514
16:00	620	3.421	5.517	4.916	7.929	0.289	0.467	0.274	0.441	0.000064	0.000103	0.3422	0.5519
17:00	620	3.646	5.880	5.234	8.442	0.308	0.497	0.291	0.470	0.000068	0.000109	0.3646	0.5880
18:00	540	3.774	6.088	5.424	8.748	0.319	0.515	0.302	0.487	0.000070	0.000113	0.3775	0.6089
19:00	540	2.701	5.001	3.885	7.194	0.229	0.423	0.216	0.400	0.000050	0.000093	0.2702	0.5004
20:00	460	1.592	3.460	2.284	4.965	0.134	0.292	0.127	0.276	0.000030	0.000064	0.1591	0.3460
21:00	380	1.104	2.400	1.586	3.448	0.093	0.203	0.088	0.192	0.000021	0.000045	0.1104	0.2400
22:00	380	0.917	2.413	1.316	3.464	0.078	0.204	0.073	0.193	0.000017	0.000045	0.0917	0.2413
23:00	380	0.692	1.821	0.998	2.628	0.059	0.155	0.056	0.146	0.000013	0.000034	0.0693	0.1824
24:00	380	0.404	1.063	0.586	1.542	0.034	0.091	0.033	0.086	0.000008	0.000020	0.0405	0.1067

Table 2-39 Emissions inventory – forecast traffic volumes 2029 (scenario 2b)

Time of day	Flowrate (Nm ³ /s)	CO g/s	CO mg/m ³	NO _x g/s	NO _x mg/m ³	PM ₁₀ g/s	PM ₁₀ mg/m ³	PM _{2.5} g/s	PM _{2.5} mg/m ³	PAHs g/s	PAHs mg/m ³	VOCs g/s	VOCs mg/m ³
Southbound													
01:00	300	0.204	0.680	0.220	0.734	0.022	0.074	0.021	0.069	0.000004	0.000012	0.0199	0.0664
02:00	300	0.160	0.533	0.174	0.580	0.017	0.058	0.016	0.055	0.000003	0.000009	0.0156	0.0521
03:00	300	0.154	0.514	0.165	0.552	0.017	0.055	0.016	0.052	0.000003	0.000009	0.0150	0.0500
04:00	300	0.216	0.719	0.237	0.792	0.024	0.079	0.022	0.074	0.000004	0.000013	0.0212	0.0706
05:00	380	0.366	0.962	0.402	1.058	0.040	0.105	0.038	0.100	0.000006	0.000017	0.0359	0.0944
06:00	460	0.937	2.037	1.025	2.228	0.102	0.222	0.097	0.210	0.000016	0.000035	0.0918	0.1996
07:00	620	1.979	3.191	2.160	3.484	0.216	0.348	0.204	0.328	0.000034	0.000055	0.1937	0.3125
08:00	620	2.594	4.184	2.829	4.563	0.283	0.456	0.267	0.430	0.000045	0.000073	0.2539	0.4096
09:00	620	2.686	4.333	2.930	4.725	0.293	0.472	0.276	0.446	0.000047	0.000075	0.2629	0.4241
10:00	620	2.378	3.836	2.599	4.192	0.260	0.419	0.245	0.395	0.000041	0.000067	0.2329	0.3757
11:00	620	2.214	3.572	2.417	3.898	0.241	0.389	0.228	0.367	0.000038	0.000062	0.2168	0.3497
12:00	620	2.156	3.478	2.353	3.795	0.235	0.379	0.222	0.358	0.000037	0.000060	0.2111	0.3405
13:00	620	2.052	3.310	2.242	3.616	0.224	0.361	0.211	0.341	0.000036	0.000058	0.2010	0.3242
14:00	620	2.120	3.420	2.316	3.735	0.231	0.373	0.218	0.352	0.000037	0.000059	0.2076	0.3349
15:00	620	2.330	3.758	2.544	4.104	0.254	0.410	0.240	0.387	0.000041	0.000065	0.2282	0.3680
16:00	620	2.618	4.223	2.856	4.607	0.285	0.460	0.269	0.434	0.000045	0.000073	0.2563	0.4134
17:00	620	2.500	4.033	2.728	4.400	0.273	0.440	0.257	0.415	0.000043	0.000070	0.2448	0.3948
18:00	620	2.212	3.568	2.416	3.897	0.241	0.389	0.228	0.367	0.000038	0.000062	0.2166	0.3494
19:00	540	1.643	3.042	1.794	3.322	0.179	0.332	0.169	0.313	0.000029	0.000053	0.1609	0.2979
20:00	460	1.067	2.320	1.163	2.528	0.116	0.253	0.110	0.238	0.000019	0.000040	0.1044	0.2271
21:00	460	0.721	1.568	0.787	1.711	0.079	0.171	0.074	0.161	0.000013	0.000027	0.0706	0.1536
22:00	460	0.614	1.334	0.669	1.453	0.067	0.145	0.063	0.137	0.000011	0.000023	0.0600	0.1305
23:00	380	0.464	1.221	0.504	1.326	0.050	0.133	0.048	0.125	0.000008	0.000021	0.0453	0.1193
24:00	380	0.310	0.815	0.339	0.891	0.034	0.089	0.032	0.084	0.000005	0.000014	0.0303	0.0798
Northbound													
01:00	300	0.286	0.954	0.384	1.279	0.024	0.081	0.023	0.076	0.000005	0.000016	0.0278	0.0928
02:00	300	0.220	0.733	0.296	0.987	0.019	0.062	0.018	0.059	0.000004	0.000013	0.0214	0.0714
03:00	300	0.223	0.744	0.297	0.990	0.019	0.063	0.018	0.059	0.000004	0.000013	0.0216	0.0722
04:00	380	0.365	0.960	0.488	1.285	0.031	0.081	0.029	0.077	0.000006	0.000016	0.0354	0.0933
05:00	380	0.833	2.191	1.102	2.899	0.070	0.184	0.066	0.173	0.000014	0.000037	0.0806	0.2122

06:00	540	1.960	3.630	2.603	4.821	0.165	0.305	0.156	0.288	0.000033	0.000061	0.1901	0.3519
07:00	540	2.699	4.999	3.582	6.634	0.227	0.420	0.214	0.397	0.000045	0.000084	0.2616	0.4845
08:00	540	2.527	4.680	3.355	6.213	0.212	0.393	0.201	0.371	0.000042	0.000079	0.2450	0.4537
09:00	540	2.645	4.898	3.512	6.504	0.222	0.412	0.210	0.389	0.000044	0.000082	0.2564	0.4748
10:00	620	3.457	5.575	4.580	7.387	0.290	0.468	0.274	0.442	0.000058	0.000093	0.3349	0.5402
11:00	620	3.411	5.502	4.526	7.300	0.287	0.462	0.271	0.436	0.000057	0.000092	0.3306	0.5333
12:00	620	3.218	5.191	4.265	6.879	0.270	0.436	0.255	0.411	0.000054	0.000087	0.3118	0.5029
13:00	620	3.106	5.010	4.124	6.651	0.261	0.421	0.246	0.398	0.000052	0.000084	0.3011	0.4857
14:00	620	3.146	5.073	4.176	6.736	0.264	0.426	0.250	0.403	0.000053	0.000085	0.3049	0.4918
15:00	620	3.553	5.730	4.718	7.609	0.299	0.482	0.282	0.455	0.000060	0.000096	0.3444	0.5555
16:00	620	4.084	6.587	5.417	8.738	0.343	0.553	0.324	0.522	0.000069	0.000111	0.3958	0.6384
17:00	620	4.352	7.020	5.768	9.304	0.365	0.589	0.345	0.556	0.000073	0.000118	0.4217	0.6802
18:00	620	4.506	7.268	5.977	9.640	0.378	0.610	0.357	0.576	0.000076	0.000122	0.4367	0.7044
19:00	620	3.224	5.200	4.281	6.904	0.271	0.437	0.256	0.413	0.000054	0.000087	0.3126	0.5041
20:00	540	1.900	3.519	2.517	4.662	0.159	0.295	0.151	0.279	0.000032	0.000059	0.1841	0.3409
21:00	460	1.318	2.865	1.748	3.799	0.111	0.241	0.104	0.227	0.000022	0.000048	0.1277	0.2777
22:00	460	1.095	2.380	1.451	3.154	0.092	0.200	0.087	0.189	0.000018	0.000040	0.1061	0.2306
23:00	380	0.826	2.174	1.100	2.895	0.070	0.183	0.066	0.173	0.000014	0.000037	0.0802	0.2110
24:00	380	0.482	1.269	0.645	1.699	0.041	0.107	0.038	0.101	0.000008	0.000022	0.0469	0.1233

Table 2-40 Emissions inventory – worst case scenario (design analysis A)

Time of day	Flowrate (Nm ³ /s)	CO g/s	CO mg/m ³	NO _x g/s	NO _x mg/m ³	PM ₁₀ g/s	PM ₁₀ mg/m ³	PM _{2.5} g/s	PM _{2.5} mg/m ³	PAHs g/s	PAHs mg/m ³	VOCs g/s	VOCs mg/m ³
Southbound													
01:00	380	0.383	1.009	0.441	1.160	0.041	0.108	0.039	0.102	0.000007	0.000019	0.0385	0.1013
02:00	380	0.301	0.791	0.348	0.917	0.032	0.085	0.030	0.080	0.000006	0.000015	0.0303	0.0797
03:00	380	0.290	0.762	0.331	0.871	0.031	0.081	0.029	0.076	0.000005	0.000014	0.0290	0.0764
04:00	380	0.406	1.068	0.476	1.252	0.044	0.116	0.041	0.109	0.000008	0.000021	0.0410	0.1079
05:00	460	0.687	1.494	0.805	1.750	0.074	0.162	0.070	0.153	0.000013	0.000029	0.0695	0.1510
06:00	540	1.762	3.263	2.052	3.799	0.190	0.351	0.179	0.332	0.000034	0.000062	0.1777	0.3291
07:00	700	3.720	5.314	4.324	6.178	0.400	0.572	0.378	0.540	0.000071	0.000101	0.3749	0.5356
08:00	620	5.139	8.289	5.889	9.498	0.550	0.887	0.520	0.838	0.000109	0.000175	0.5361	0.8646
09:00	620	5.321	8.582	6.098	9.836	0.569	0.918	0.538	0.868	0.000113	0.000182	0.5551	0.8953
10:00	620	4.711	7.599	5.410	8.726	0.505	0.814	0.477	0.770	0.000100	0.000161	0.4919	0.7933
11:00	700	4.163	5.948	4.838	6.911	0.448	0.640	0.423	0.604	0.000079	0.000113	0.4195	0.5994
12:00	700	4.055	5.792	4.710	6.729	0.436	0.623	0.412	0.588	0.000077	0.000110	0.4085	0.5836
13:00	700	3.859	5.513	4.489	6.413	0.415	0.593	0.392	0.560	0.000074	0.000105	0.3890	0.5557
14:00	700	3.987	5.695	4.636	6.622	0.429	0.613	0.405	0.579	0.000076	0.000109	0.4018	0.5740
15:00	620	4.616	7.446	5.297	8.543	0.494	0.797	0.467	0.754	0.000098	0.000158	0.4818	0.7771
16:00	620	5.187	8.365	5.946	9.590	0.555	0.895	0.525	0.846	0.000110	0.000177	0.5411	0.8728
17:00	620	4.953	7.989	5.679	9.159	0.530	0.855	0.501	0.808	0.000105	0.000169	0.5168	0.8335
18:00	700	4.160	5.942	4.837	6.910	0.448	0.639	0.423	0.604	0.000079	0.000113	0.4193	0.5989
19:00	620	3.089	4.982	3.591	5.793	0.332	0.536	0.314	0.506	0.000059	0.000095	0.3113	0.5021
20:00	620	2.007	3.237	2.328	3.755	0.216	0.348	0.204	0.328	0.000038	0.000062	0.2021	0.3260
21:00	540	1.357	2.512	1.576	2.919	0.146	0.270	0.138	0.255	0.000026	0.000048	0.1367	0.2531
22:00	460	1.154	2.508	1.338	2.909	0.124	0.269	0.117	0.254	0.000022	0.000048	0.1162	0.2526
23:00	460	0.872	1.896	1.009	2.193	0.093	0.203	0.088	0.192	0.000017	0.000036	0.0877	0.1907
24:00	380	0.582	1.533	0.678	1.784	0.063	0.165	0.059	0.156	0.000011	0.000029	0.0587	0.1545
Northbound													
01:00	380	0.497	1.308	0.722	1.899	0.042	0.112	0.040	0.105	0.000009	0.000025	0.0499	0.1313
02:00	380	0.382	1.005	0.557	1.466	0.033	0.086	0.031	0.081	0.000007	0.000019	0.0384	0.1010
03:00	380	0.387	1.019	0.558	1.469	0.033	0.086	0.031	0.082	0.000007	0.000019	0.0388	0.1020
04:00	380	0.633	1.666	0.919	2.417	0.054	0.142	0.051	0.134	0.000012	0.000031	0.0635	0.1672
05:00	460	1.445	3.141	2.071	4.502	0.122	0.265	0.115	0.251	0.000027	0.000058	0.1444	0.3139
06:00	620	3.402	5.487	4.895	7.895	0.288	0.465	0.272	0.439	0.000063	0.000102	0.3404	0.5491

07:00	620	4.684	7.556	6.735	10.863	0.396	0.639	0.375	0.604	0.000087	0.000141	0.4687	0.7559
08:00	620	4.386	7.074	6.308	10.174	0.371	0.599	0.351	0.566	0.000082	0.000132	0.4388	0.7078
09:00	620	4.590	7.404	6.603	10.650	0.389	0.627	0.367	0.592	0.000086	0.000138	0.4593	0.7408
10:00	700	5.999	8.569	8.610	12.300	0.507	0.724	0.479	0.685	0.000112	0.000159	0.5998	0.8569
11:00	700	5.920	8.457	8.509	12.156	0.501	0.715	0.473	0.676	0.000110	0.000158	0.5922	0.8460
12:00	700	5.585	7.979	8.018	11.455	0.472	0.674	0.446	0.638	0.000104	0.000148	0.5585	0.7978
13:00	700	5.391	7.701	7.753	11.076	0.456	0.652	0.431	0.616	0.000100	0.000144	0.5394	0.7706
14:00	700	5.459	7.799	7.852	11.217	0.462	0.660	0.437	0.624	0.000102	0.000145	0.5462	0.7803
15:00	700	6.166	8.808	8.870	12.671	0.522	0.746	0.493	0.705	0.000115	0.000164	0.6169	0.8813
16:00	620	6.346	10.236	9.982	16.100	0.614	0.990	0.580	0.936	0.000141	0.000228	0.6737	1.0866
17:00	700	6.763	9.662	10.627	15.182	0.654	0.934	0.618	0.883	0.000150	0.000215	0.7177	1.0253
18:00	700	7.002	10.003	11.012	15.732	0.677	0.967	0.640	0.915	0.000156	0.000223	0.7433	1.0619
19:00	700	5.595	7.993	8.049	11.498	0.474	0.677	0.448	0.640	0.000104	0.000149	0.5598	0.7998
20:00	620	3.298	5.319	4.732	7.633	0.279	0.449	0.263	0.425	0.000061	0.000099	0.3297	0.5318
21:00	540	2.287	4.236	3.286	6.085	0.193	0.358	0.183	0.339	0.000043	0.000079	0.2288	0.4237
22:00	460	1.900	4.131	2.728	5.929	0.161	0.349	0.152	0.330	0.000035	0.000077	0.1900	0.4130
23:00	460	1.434	3.117	2.069	4.497	0.122	0.264	0.115	0.250	0.000027	0.000058	0.1436	0.3122
24:00	380	0.837	2.203	1.214	3.195	0.071	0.188	0.067	0.177	0.000016	0.000041	0.0840	0.2210

Table 2-41 Emissions inventory – regulatory scenario 2019 (design analysis B 2019)

Time of day	Flowrate (Nm ³ /s)	CO g/s	CO mg/m ³	NO _x g/s	NO _x mg/m ³	PM ₁₀ g/s	PM ₁₀ mg/m ³	PM _{2.5} g/s	PM _{2.5} mg/m ³	PAHs g/s	PAHs mg/m ³	VOCs g/s	VOCs mg/m ³
Southbound													
01:00	300	1.090	3.634	1.266	4.220	0.117	0.391	0.111	0.369	0.000021	0.000069	0.1098	0.3661
02:00	300	1.090	3.634	1.266	4.220	0.117	0.391	0.111	0.369	0.000021	0.000069	0.1098	0.3661
03:00	300	1.090	3.634	1.266	4.220	0.117	0.391	0.111	0.369	0.000021	0.000069	0.1098	0.3661
04:00	300	1.090	3.634	1.266	4.220	0.117	0.391	0.111	0.369	0.000021	0.000069	0.1098	0.3661
05:00	380	1.381	3.634	1.603	4.220	0.148	0.391	0.140	0.369	0.000026	0.000069	0.1391	0.3661
06:00	460	1.671	3.634	1.941	4.220	0.180	0.391	0.170	0.369	0.000032	0.000069	0.1684	0.3661
07:00	540	1.962	3.634	2.279	4.220	0.211	0.391	0.199	0.369	0.000037	0.000069	0.1977	0.3661
08:00	620	2.253	3.634	2.616	4.220	0.242	0.391	0.229	0.369	0.000043	0.000069	0.2270	0.3661
09:00	620	2.253	3.634	2.616	4.220	0.242	0.391	0.229	0.369	0.000043	0.000069	0.2270	0.3661
10:00	620	2.253	3.634	2.616	4.220	0.242	0.391	0.229	0.369	0.000043	0.000069	0.2270	0.3661
11:00	540	1.962	3.634	2.279	4.220	0.211	0.391	0.199	0.369	0.000037	0.000069	0.1977	0.3661
12:00	540	1.962	3.634	2.279	4.220	0.211	0.391	0.199	0.369	0.000037	0.000069	0.1977	0.3661
13:00	540	1.962	3.634	2.279	4.220	0.211	0.391	0.199	0.369	0.000037	0.000069	0.1977	0.3661
14:00	540	1.962	3.634	2.279	4.220	0.211	0.391	0.199	0.369	0.000037	0.000069	0.1977	0.3661
15:00	540	2.253	3.634	2.616	4.220	0.242	0.391	0.229	0.369	0.000043	0.000069	0.2270	0.3661
16:00	620	2.253	3.634	2.616	4.220	0.242	0.391	0.229	0.369	0.000043	0.000069	0.2270	0.3661
17:00	620	2.253	3.634	2.616	4.220	0.242	0.391	0.229	0.369	0.000043	0.000069	0.2270	0.3661
18:00	540	1.962	3.634	2.279	4.220	0.211	0.391	0.199	0.369	0.000037	0.000069	0.1977	0.3661
19:00	540	1.962	3.634	2.279	4.220	0.211	0.391	0.199	0.369	0.000037	0.000069	0.1977	0.3661
20:00	460	1.671	3.634	1.941	4.220	0.180	0.391	0.170	0.369	0.000032	0.000069	0.1684	0.3661
21:00	380	1.671	3.634	1.941	4.220	0.180	0.391	0.170	0.369	0.000032	0.000069	0.1684	0.3661
22:00	380	1.381	3.634	1.603	4.220	0.148	0.391	0.140	0.369	0.000026	0.000069	0.1391	0.3661
23:00	380	1.381	3.634	1.603	4.220	0.148	0.391	0.140	0.369	0.000026	0.000069	0.1391	0.3661
24:00	380	1.381	3.634	1.603	4.220	0.148	0.391	0.140	0.369	0.000026	0.000069	0.1391	0.3661
Northbound													
01:00	300	1.826	6.088	2.624	8.748	0.154	0.515	0.146	0.487	0.000034	0.000113	0.1827	0.6089
02:00	300	1.826	6.088	2.624	8.748	0.154	0.515	0.146	0.487	0.000034	0.000113	0.1827	0.6089
03:00	300	1.826	6.088	2.624	8.748	0.154	0.515	0.146	0.487	0.000034	0.000113	0.1827	0.6089
04:00	300	1.826	6.088	2.624	8.748	0.154	0.515	0.146	0.487	0.000034	0.000113	0.1827	0.6089
05:00	380	2.313	6.088	3.324	8.748	0.196	0.515	0.185	0.487	0.000043	0.000113	0.2314	0.6089
06:00	460	2.800	6.088	4.024	8.748	0.237	0.515	0.224	0.487	0.000052	0.000113	0.2801	0.6089

07:00	540	3.287	6.088	4.724	8.748	0.278	0.515	0.263	0.487	0.000061	0.000113	0.3288	0.6089
08:00	540	3.287	6.088	4.724	8.748	0.278	0.515	0.263	0.487	0.000061	0.000113	0.3288	0.6089
09:00	540	3.287	6.088	4.724	8.748	0.278	0.515	0.263	0.487	0.000061	0.000113	0.3288	0.6089
10:00	540	3.287	6.088	4.724	8.748	0.278	0.515	0.263	0.487	0.000061	0.000113	0.3288	0.6089
11:00	540	3.287	6.088	4.724	8.748	0.278	0.515	0.263	0.487	0.000061	0.000113	0.3288	0.6089
12:00	540	3.287	6.088	4.724	8.748	0.278	0.515	0.263	0.487	0.000061	0.000113	0.3288	0.6089
13:00	540	3.287	6.088	4.724	8.748	0.278	0.515	0.263	0.487	0.000061	0.000113	0.3288	0.6089
14:00	540	3.287	6.088	4.724	8.748	0.278	0.515	0.263	0.487	0.000061	0.000113	0.3288	0.6089
15:00	540	3.287	6.088	4.724	8.748	0.278	0.515	0.263	0.487	0.000061	0.000113	0.3288	0.6089
16:00	620	3.774	6.088	5.424	8.748	0.319	0.515	0.302	0.487	0.000070	0.000113	0.3775	0.6089
17:00	620	3.774	6.088	5.424	8.748	0.319	0.515	0.302	0.487	0.000070	0.000113	0.3775	0.6089
18:00	620	3.774	6.088	5.424	8.748	0.319	0.515	0.302	0.487	0.000070	0.000113	0.3775	0.6089
19:00	540	3.287	6.088	4.724	8.748	0.278	0.515	0.263	0.487	0.000061	0.000113	0.3288	0.6089
20:00	460	2.800	6.088	4.024	8.748	0.237	0.515	0.224	0.487	0.000052	0.000113	0.2801	0.6089
21:00	460	2.800	6.088	4.024	8.748	0.237	0.515	0.224	0.487	0.000052	0.000113	0.2801	0.6089
22:00	380	2.313	6.088	3.324	8.748	0.196	0.515	0.185	0.487	0.000043	0.000113	0.2314	0.6089
23:00	380	2.313	6.088	3.324	8.748	0.196	0.515	0.185	0.487	0.000043	0.000113	0.2314	0.6089
24:00	380	2.313	6.088	3.324	8.748	0.196	0.515	0.185	0.487	0.000043	0.000113	0.2314	0.6089

Table 2-42 Emissions inventory – regulatory scenario 2029 (design analysis B 2029)

Time of day	Flowrate (Nm ³ /s)	CO g/s	CO mg/m ³	NO _x g/s	NO _x mg/m ³	PM ₁₀ g/s	PM ₁₀ mg/m ³	PM _{2.5} g/s	PM _{2.5} mg/m ³	PAHs g/s	PAHs mg/m ³	VOCs g/s	VOCs mg/m ³
Southbound													
01:00	300	1.300	4.333	1.418	4.725	0.142	0.472	0.134	0.446	0.000023	0.000075	0.1272	0.4241
02:00	300	1.300	4.333	1.418	4.725	0.142	0.472	0.134	0.446	0.000023	0.000075	0.1272	0.4241
03:00	300	1.300	4.333	1.418	4.725	0.142	0.472	0.134	0.446	0.000023	0.000075	0.1272	0.4241
04:00	300	1.300	4.333	1.418	4.725	0.142	0.472	0.134	0.446	0.000023	0.000075	0.1272	0.4241
05:00	380	1.646	4.333	1.796	4.725	0.179	0.472	0.169	0.446	0.000029	0.000075	0.1612	0.4241
06:00	460	1.993	4.333	2.174	4.725	0.217	0.472	0.205	0.446	0.000035	0.000075	0.1951	0.4241
07:00	620	2.686	4.333	2.930	4.725	0.293	0.472	0.276	0.446	0.000047	0.000075	0.2629	0.4241
08:00	620	2.686	4.333	2.930	4.725	0.293	0.472	0.276	0.446	0.000047	0.000075	0.2629	0.4241
09:00	620	2.686	4.333	2.930	4.725	0.293	0.472	0.276	0.446	0.000047	0.000075	0.2629	0.4241
10:00	620	2.686	4.333	2.930	4.725	0.293	0.472	0.276	0.446	0.000047	0.000075	0.2629	0.4241
11:00	620	2.686	4.333	2.930	4.725	0.293	0.472	0.276	0.446	0.000047	0.000075	0.2629	0.4241
12:00	620	2.686	4.333	2.930	4.725	0.293	0.472	0.276	0.446	0.000047	0.000075	0.2629	0.4241
13:00	620	2.686	4.333	2.930	4.725	0.293	0.472	0.276	0.446	0.000047	0.000075	0.2629	0.4241
14:00	620	2.686	4.333	2.930	4.725	0.293	0.472	0.276	0.446	0.000047	0.000075	0.2629	0.4241
15:00	620	2.686	4.333	2.930	4.725	0.293	0.472	0.276	0.446	0.000047	0.000075	0.2629	0.4241
16:00	620	2.686	4.333	2.930	4.725	0.293	0.472	0.276	0.446	0.000047	0.000075	0.2629	0.4241
17:00	620	2.686	4.333	2.930	4.725	0.293	0.472	0.276	0.446	0.000047	0.000075	0.2629	0.4241
18:00	620	2.686	4.333	2.930	4.725	0.293	0.472	0.276	0.446	0.000047	0.000075	0.2629	0.4241
19:00	540	2.340	4.333	2.552	4.725	0.255	0.472	0.241	0.446	0.000041	0.000075	0.2290	0.4241
20:00	460	1.993	4.333	2.174	4.725	0.217	0.472	0.205	0.446	0.000035	0.000075	0.1951	0.4241
21:00	460	1.993	4.333	2.174	4.725	0.217	0.472	0.205	0.446	0.000035	0.000075	0.1951	0.4241
22:00	460	1.993	4.333	2.174	4.725	0.217	0.472	0.205	0.446	0.000035	0.000075	0.1951	0.4241
23:00	380	1.646	4.333	1.796	4.725	0.179	0.472	0.169	0.446	0.000029	0.000075	0.1612	0.4241
24:00	380	1.646	4.333	1.796	4.725	0.179	0.472	0.169	0.446	0.000029	0.000075	0.1612	0.4241
Northbound													
01:00	300	2.180	7.268	2.892	9.640	0.183	0.610	0.173	0.576	0.000037	0.000122	0.2113	0.7044
02:00	300	2.180	7.268	2.892	9.640	0.183	0.610	0.173	0.576	0.000037	0.000122	0.2113	0.7044
03:00	300	2.180	7.268	2.892	9.640	0.183	0.610	0.173	0.576	0.000037	0.000122	0.2113	0.7044
04:00	380	2.762	7.268	3.663	9.640	0.232	0.610	0.219	0.576	0.000046	0.000122	0.2677	0.7044
05:00	380	2.762	7.268	3.663	9.640	0.232	0.610	0.219	0.576	0.000046	0.000122	0.2677	0.7044

06:00	540	3.925	7.268	5.206	9.640	0.330	0.610	0.311	0.576	0.000066	0.000122	0.3804	0.7044
07:00	540	3.925	7.268	5.206	9.640	0.330	0.610	0.311	0.576	0.000066	0.000122	0.3804	0.7044
08:00	540	3.925	7.268	5.206	9.640	0.330	0.610	0.311	0.576	0.000066	0.000122	0.3804	0.7044
09:00	540	3.925	7.268	5.206	9.640	0.330	0.610	0.311	0.576	0.000066	0.000122	0.3804	0.7044
10:00	620	4.506	7.268	5.977	9.640	0.378	0.610	0.357	0.576	0.000076	0.000122	0.4367	0.7044
11:00	620	4.506	7.268	5.977	9.640	0.378	0.610	0.357	0.576	0.000076	0.000122	0.4367	0.7044
12:00	620	4.506	7.268	5.977	9.640	0.378	0.610	0.357	0.576	0.000076	0.000122	0.4367	0.7044
13:00	620	4.506	7.268	5.977	9.640	0.378	0.610	0.357	0.576	0.000076	0.000122	0.4367	0.7044
14:00	620	4.506	7.268	5.977	9.640	0.378	0.610	0.357	0.576	0.000076	0.000122	0.4367	0.7044
15:00	620	4.506	7.268	5.977	9.640	0.378	0.610	0.357	0.576	0.000076	0.000122	0.4367	0.7044
16:00	620	4.506	7.268	5.977	9.640	0.378	0.610	0.357	0.576	0.000076	0.000122	0.4367	0.7044
17:00	620	4.506	7.268	5.977	9.640	0.378	0.610	0.357	0.576	0.000076	0.000122	0.4367	0.7044
18:00	620	4.506	7.268	5.977	9.640	0.378	0.610	0.357	0.576	0.000076	0.000122	0.4367	0.7044
19:00	620	4.506	7.268	5.977	9.640	0.378	0.610	0.357	0.576	0.000076	0.000122	0.4367	0.7044
20:00	540	3.925	7.268	5.206	9.640	0.330	0.610	0.311	0.576	0.000066	0.000122	0.3804	0.7044
21:00	460	3.343	7.268	4.434	9.640	0.281	0.610	0.265	0.576	0.000056	0.000122	0.3240	0.7044
22:00	460	3.343	7.268	4.434	9.640	0.281	0.610	0.265	0.576	0.000056	0.000122	0.3240	0.7044
23:00	380	2.762	7.268	3.663	9.640	0.232	0.610	0.219	0.576	0.000046	0.000122	0.2677	0.7044
24:00	380	2.762	7.268	3.663	9.640	0.232	0.610	0.219	0.576	0.000046	0.000122	0.2677	0.7044

The emissions inventory calculated for the assessed breakdown scenario is summarised in **Table 2-43** for key pollutants. The percentage of these mass emission rates relative to the maximum mass emission rates for the forecast traffic flow scenario in 2029 (refer to Table is also listed. The breakdown scenario has not been assessed further because it would be well within the forecast traffic flow scenario in 2029. Because acceptable ambient air quality outcome have been demonstrated for that scenario (refer to **Section 2.15**), then the breakdown would also have acceptable ambient air quality impacts.

Table 2-43 Emissions inventory – breakdown scenario

Pollutant	Mass emission rate
Carbon monoxide (CO)	3.5 g/s (77.8%)
Nitrogen oxides (NO _x)	4.1 g/s (68.6%)
Particulate matter (PM ₁₀)	0.27 g/s (71.4%)

Clarification of environmental impact statement emissions inventories

The air quality impact assessment presented in Section 7.3 of the environmental impact statement and the associated Technical Working Paper: Air Quality have been reviewed and confirmed as complete and correct based on the assumptions and inputs that were applied. This includes the ventilation outlet emission rates used in the air dispersion modelling as part of the air quality impact assessment in the environmental impact statement.

However, the tables of data presented in Appendix H of the Technical Working Paper: Air Quality do not represent the data used in the air dispersion modelling.

The summary of ventilation outlet emission rates presented in **Table 2-44** and **Table 2-45** present the actual data as used in the air dispersion modelling included in the environmental impact statement. This data replaces the information in Appendix H of the Technical Working Paper: Air Quality (contained in Appendix G of the environmental impact statement).

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Table 2-44 EIS emissions inventory – forecast traffic volumes 2019 (scenario 2a)

Time of day	Flowrate (Nm ³ /s)	CO (g/s)	NO _x (g/s)	PM ₁₀ (g/s)	PM _{2.5} (g/s)	PAHs (g/s)	VOCs (g/s)
Southbound							
01:00	300	0.177	0.194	0.018	0.017	0.0176	0.000003
02:00	300	0.139	0.153	0.014	0.013	0.0138	0.000003
03:00	300	0.134	0.146	0.014	0.013	0.0133	0.000002
04:00	300	0.187	0.210	0.019	0.018	0.0187	0.000003
05:00	380	0.317	0.355	0.033	0.031	0.0318	0.000006
06:00	460	0.813	0.904	0.084	0.079	0.0812	0.000015
07:00	540	1.717	1.905	0.176	0.167	0.1714	0.000032
08:00	620	2.252	2.494	0.231	0.218	0.2247	0.000042
09:00	620	2.331	2.583	0.239	0.226	0.2327	0.000043
10:00	620	2.064	2.292	0.212	0.200	0.2061	0.000038
11:00	540	1.922	2.131	0.197	0.186	0.1918	0.000036
12:00	540	1.872	2.074	0.192	0.181	0.1868	0.000035
13:00	540	1.781	1.977	0.183	0.173	0.1779	0.000033
14:00	540	1.840	2.042	0.189	0.179	0.1837	0.000034
15:00	540	2.022	2.244	0.208	0.196	0.2019	0.000037
16:00	620	2.272	2.518	0.233	0.220	0.2268	0.000042
17:00	620	2.170	2.405	0.223	0.210	0.2166	0.000040
18:00	540	1.920	2.131	0.197	0.186	0.1917	0.000036
19:00	540	1.426	1.582	0.146	0.138	0.1423	0.000026
20:00	460	0.926	1.025	0.095	0.090	0.0924	0.000017
21:00	380	0.626	0.694	0.064	0.061	0.0625	0.000012
22:00	380	0.533	0.589	0.055	0.052	0.0531	0.000010
23:00	380	0.403	0.444	0.041	0.039	0.0401	0.000007
24:00	380	0.269	0.299	0.028	0.026	0.0268	0.000005
Northbound							
01:00	300	0.248	0.344	0.020	0.0190	0.025	0.000005
02:00	300	0.190	0.266	0.016	0.0147	0.019	0.000004
03:00	300	0.193	0.266	0.016	0.0147	0.019	0.000004
04:00	300	0.316	0.438	0.026	0.0242	0.031	0.000006
05:00	380	0.720	0.988	0.058	0.0547	0.071	0.000013
06:00	460	1.696	2.336	0.137	0.1292	0.168	0.000031
07:00	540	2.336	3.214	0.188	0.1778	0.232	0.000042

08:00	620	2.187	3.010	0.176	0.1665	0.217	0.000040
09:00	620	2.289	3.151	0.184	0.1743	0.227	0.000041
10:00	620	2.991	4.108	0.240	0.2273	0.296	0.000054
11:00	540	2.952	4.061	0.238	0.2246	0.293	0.000053
12:00	540	2.785	3.826	0.224	0.2117	0.276	0.000050
13:00	540	2.688	3.700	0.216	0.2046	0.267	0.000049
14:00	540	2.722	3.747	0.219	0.2072	0.270	0.000049
15:00	540	3.074	4.233	0.248	0.2341	0.305	0.000056
16:00	620	3.534	4.860	0.284	0.2689	0.350	0.000064
17:00	620	3.766	5.175	0.303	0.2863	0.373	0.000068
18:00	540	3.899	5.362	0.314	0.2966	0.387	0.000071
19:00	540	2.790	3.841	0.225	0.2124	0.277	0.000051
20:00	460	1.644	2.258	0.132	0.1250	0.163	0.000030
21:00	380	1.141	1.568	0.092	0.0867	0.113	0.000021
22:00	380	0.947	1.302	0.076	0.0720	0.094	0.000017
23:00	380	0.715	0.987	0.058	0.0546	0.071	0.000013
24:00	380	0.417	0.579	0.034	0.0320	0.042	0.000008

Table 2-45 EIS emissions inventory – forecast traffic volumes 2029 (scenario 2b)

Time of day	Flowrate (Nm ³ /s)	CO (g/s)	NO _x (g/s)	PM ₁₀ (g/s)	PM _{2.5} (g/s)	PAHs (g/s)	VOCs (g/s)
Southbound							
01:00	300	0.220	0.213	0.021	0.020	0.021	0.000004
02:00	300	0.172	0.169	0.017	0.016	0.017	0.000003
03:00	300	0.166	0.160	0.016	0.015	0.016	0.000003
04:00	300	0.233	0.230	0.023	0.022	0.022	0.000004
05:00	380	0.394	0.389	0.039	0.037	0.038	0.000006
06:00	460	1.010	0.993	0.100	0.094	0.097	0.000016
07:00	620	2.133	2.092	0.210	0.198	0.205	0.000035
08:00	620	2.797	2.740	0.275	0.260	0.269	0.000046
09:00	620	2.896	2.837	0.285	0.269	0.278	0.000047
10:00	620	2.564	2.517	0.253	0.239	0.246	0.000042
11:00	620	2.388	2.341	0.235	0.222	0.229	0.000039
12:00	620	2.325	2.279	0.229	0.216	0.223	0.000038
13:00	620	2.213	2.172	0.218	0.206	0.213	0.000036
14:00	620	2.286	2.243	0.225	0.213	0.220	0.000037
15:00	620	2.512	2.464	0.247	0.234	0.241	0.000041
16:00	620	2.823	2.766	0.278	0.262	0.271	0.000046
17:00	620	2.696	2.642	0.265	0.251	0.259	0.000044
18:00	620	2.385	2.340	0.235	0.222	0.229	0.000039
19:00	540	1.771	1.737	0.174	0.165	0.170	0.000029
20:00	460	1.151	1.126	0.113	0.107	0.111	0.000019
21:00	460	0.778	0.762	0.077	0.072	0.075	0.000013
22:00	460	0.662	0.647	0.065	0.061	0.064	0.000011
23:00	380	0.500	0.488	0.049	0.046	0.048	0.000008
24:00	380	0.334	0.328	0.033	0.031	0.032	0.000005
Northbound							
01:00	300	0.307	0.373	0.023	0.022	0.029	0.000005
02:00	300	0.236	0.288	0.018	0.017	0.023	0.000004
03:00	300	0.240	0.288	0.018	0.017	0.023	0.000004
04:00	380	0.392	0.475	0.030	0.028	0.037	0.000006
05:00	380	0.894	1.070	0.067	0.063	0.085	0.000014
06:00	540	2.105	2.529	0.159	0.150	0.201	0.000033
07:00	540	2.898	3.480	0.218	0.206	0.276	0.000046

08:00	540	2.714	3.259	0.204	0.193	0.259	0.000043
09:00	540	2.840	3.411	0.214	0.202	0.271	0.000045
10:00	620	3.712	4.448	0.279	0.264	0.353	0.000059
11:00	620	3.663	4.396	0.276	0.261	0.349	0.000058
12:00	620	3.456	4.143	0.260	0.246	0.329	0.000055
13:00	620	3.335	4.006	0.251	0.237	0.318	0.000053
14:00	620	3.377	4.056	0.254	0.240	0.322	0.000053
15:00	620	3.815	4.582	0.287	0.271	0.363	0.000060
16:00	620	4.385	5.262	0.330	0.312	0.418	0.000069
17:00	620	4.673	5.603	0.351	0.332	0.445	0.000074
18:00	620	4.838	5.805	0.364	0.344	0.461	0.000076
19:00	620	3.462	4.158	0.261	0.246	0.330	0.000055
20:00	540	2.040	2.445	0.153	0.145	0.194	0.000032
21:00	460	1.415	1.698	0.106	0.101	0.135	0.000022
22:00	460	1.176	1.409	0.088	0.084	0.112	0.000019
23:00	380	0.887	1.069	0.067	0.063	0.085	0.000014
24:00	380	0.518	0.627	0.039	0.037	0.049	0.000008

Ambient air drawn into project tunnels

The pollutant load of ambient air drawn into the project tunnels has a relatively minor influence on pollutant loads of in-tunnel air quality. This includes air drawn into the tunnel via the entry portals (through the piston effect of vehicles entering the tunnel) and via mechanically assisted ventilation (by fans either within the tunnels or within the emergency smoke extraction facilities under certain conditions).

It is recognised that any air drawn into the project tunnels will carry with it a certain level of background pollution, and that the concentration of this pollution will vary over time depending on conditions external to the project tunnels. To demonstrate the effect of drawing ambient pollution into the project tunnels, the air quality model used for the NorthConnex project has been used to consider the implications of this additional pollutant load on the ambient air quality impacts of the project. The model has been run assuming that background pollution at each main alignment tunnel entry portal is added to the emissions inventory within the project tunnels before discharge from the project's ventilation outlets.

This analysis has considered one meteorological year (2009) and has assumed that air within the road corridor near the entry portal is drawn into the main alignment tunnel. Pollutant loads drawn into the entry portal have been modelled for each hour of the day, over an entire year. For the purpose of this analysis, 'background air' has been taken as the predicted background concentration (refer to **Section 2.14.1** of this report) of pollutants predicted at the closest receiver location to the relevant tunnel entry portal (ie the higher of the CAL3QHCR prediction or monitored ambient data from the Prospect/ Lindfield monitoring stations).

Table 2-46 summarises the maximum ground level concentration from either the northern or southern ventilation outlet (whichever concentration is higher) as presented in the environmental impact statement, and then with the addition of background pollutant loads assuming introduction through the main alignment tunnel entry portals. The table shows that with inclusion of ambient pollution drawn into the main alignment tunnels via the entry portals, the predicted ground level concentrations of relevant pollutants increase by a negligible amount compared with the modelling outcomes presented in the environmental impact statement. When compared with relevant ambient air quality criteria and advisory reporting standards, the predicted air quality impacts of the NorthConnex project remain very low at the most affected locations.

Table 2-46 Expected effect of background pollution (portal intake) on ground level concentrations from ventilation outlet emissions

Pollutant (averaging period)	Environmental impact statement		With addition of background air drawn into tunnels	
	Concentration ($\mu\text{g}/\text{m}^3$)	Percentage of air quality criteria/ advisory standard	Concentration ($\mu\text{g}/\text{m}^3$)	Percentage of air quality criteria/ advisory standard
NO ₂ (annual average)	1.4 $\mu\text{g}/\text{m}^3$	2.3%	1.4 $\mu\text{g}/\text{m}^3$	2.3%
NO ₂ (one-hour maximum)	68.9 $\mu\text{g}/\text{m}^3$	28.0%	69.7 $\mu\text{g}/\text{m}^3$	28.3%
PM ₁₀ (annual average)	0.11 $\mu\text{g}/\text{m}^3$	0.37%	0.12 $\mu\text{g}/\text{m}^3$	0.40%
PM ₁₀ (24-hour maximum)	1.4 $\mu\text{g}/\text{m}^3$	2.8%	1.8 $\mu\text{g}/\text{m}^3$	3.6%
PM _{2.5} (annual average)	0.11 $\mu\text{g}/\text{m}^3$	1.38%	0.11 $\mu\text{g}/\text{m}^3$	1.38%
PM _{2.5} (24-hour maximum)	1.3 $\mu\text{g}/\text{m}^3$	5.2%	1.4 $\mu\text{g}/\text{m}^3$	5.6%

2.8.3 Surface road emissions inventories

Surface road emissions inventories have been calculated in the same manner as for tunnel emissions inventories. This has include both exhaust and non-exhaust emission sources.

2.9 In-tunnel air quality

This section includes information and discussion of:

- The design and intended operation of the project's ventilation system to maintain acceptable in-tunnel air quality.
- In-tunnel air quality concentrations for the air quality impact assessment scenarios.
- Discussion of the variability of in-tunnel air quality and averaging periods.

2.9.1 Design and intended operation of the ventilation system

Section 2.5.1 of this report details the approach applied to the design of the project's ventilation system, including the design criteria that have been applied. **Table 2-3** in that section details the maximum in-tunnel concentrations that could be expected based on the design of the project's ventilation system and assuming operation at the maximum traffic throughput capacity of the main alignment tunnels at different average traffic speeds. These concentrations represent the maximum concentrations that are considered physically possible given the project's design. These maximum concentrations are also considered to be highly conservative and unlikely to be reached in practice for several reasons, the most significant being:

- The inherent conservatism in the emission factors published by the Permanent International Association of Road Congresses (2012) on which the calculation of in-tunnel air quality has been based.

- The assumption underpinning the concentrations in **Table 2-3**, that the main alignment tunnels would be completely full at each of the average traffic velocities that were considered (ie operation at the maximum throughput capacity of the tunnels). As discussed in **Section 2.7.3**, operation at this traffic throughput is considered unlikely in the foreseeable future and would be well above forecast traffic volumes.

The project has been designed and has committed to achieving the ventilation design criteria specified in **Table 2-2**. The project would also be operated to achieve in-tunnel air quality conditions that may be specified in conditions of approval for the project, if applied by the Minister for Planning.

A detailed ventilation control strategy would be developed during the detailed design phase and implemented during operation of the project to ensure that acceptable in-tunnel air quality is maintained. The control strategy would be developed to include three distinct operational modes:

- **Normal operation** for the management and control of in-tunnel air quality under all traffic scenarios, including fluid free flowing traffic conditions and congestion.
- **Breakdown mode** where a breakdown has caused the tunnel to be blocked or severely restricted.
- **Emergency operation** for the management and control of smoke in the event of a fire, for the safe egress of occupants and access for emergency services.

During normal operation, the project's ventilation system would automatically operate and adjust the ventilation flow rates within the tunnel and at the ventilation outlets to maintain in-tunnel air quality within acceptable limits.

The ventilation system would have a fixed number of ventilation levels which would generally correspond with the number of exhaust fans (at the ventilation outlets) in combination with the supply fans (within the main alignment tunnels and ramps) in the system. For example, a 'level 1' operation may involve the operation of one exhaust fan, and a 'level 5' operation may involve the operation of four exhaust fans. The number of ventilation levels and fan operating combinations would be determined during the detailed design of the project.

Jet fans ('supply fans') in the main alignment tunnels and ramps would operate to maintain longitudinal ventilation and to balance air flow in each tunnel section, such that in-tunnel air quality is maintained within acceptable limits.

The following key inputs would be used to determine the level of ventilation required at any given time and for any given traffic scenario:

- **Time of day** – The ventilation system would activate the level of ventilation required based on the time of day, increasing the level of ventilation in the tunnel in the lead up to peak hours, and reducing the level at off peak times such as during the night.
- **Traffic speed and density** – Vehicle detectors located within the roadway of the project tunnels and approaches would provide real-time input for traffic speed and traffic density in the project tunnels. This combination of vehicle speed and number of vehicles per hour would be used to select and confirm the level of ventilation required, possibly increasing above the level estimated by the 'time of day' schedule, if necessary. The combination of traffic speed, density and ventilation level would be pre-programmed into the ventilation system using an algorithm to ensure that acceptable in-tunnel air quality is maintained to prevent emissions from the project's portals.
- **Data from in-tunnel air quality monitoring sensors** - Air quality monitoring sensors would be located throughout the project tunnels to identify and provide a complete

understanding of in-tunnel air quality during operation. As a minimum, these sensors would provide continuous monitoring for carbon monoxide, nitrogen dioxide, visibility and in-tunnel air flow.

If the air quality monitoring sensors detect that vehicle emissions concentrations are approaching the pre-set limits (ie actions triggers below maximum allowable in-tunnel air quality criteria to provide an 'early warning' and action system), feedback would be given to the ventilation system to increase the ventilation rate to the next ventilation level. This would continue in order to maintain in-tunnel air quality and to ensure compliance with the air quality criteria is always achieved.

- **Incident detection** – The project would be equipped with an automatic video incident detection (AVID) system. AVID is a close circuit television (CCTV) system but has the additional capability of detecting and actively alerting tunnel operators to incidents within the tunnel as they occur. The AVID system has the ability to detect a range of tunnel incidents including stopped vehicles, pedestrians or the presence of smoke in the project tunnels.

The AVID system would quickly alert the tunnel operators to an incident in the project tunnels, so that they can implement the appropriate incident management plan. For example, in the event of a stopped vehicle, the operators can quickly identify its location and respond by implementing a traffic management plan and increasing the level of ventilation if required. It would also assist them to address the driver through the public address system or motorist emergency telephone.

Unlike surface roads, road tunnels are constantly managed from a central control room with an operations team to ensure that action can be taken quickly and effectively in the event of an alarm or incident. With respect to the emergency devices such as the deluge system, these would be automatically operated in the event of an incident.

Where there is a major incident such as a crash which results in the tunnel being blocked, the relevant tunnel would be closed and vehicles diverted to surface roads. The close tunnel would only be reopened once the incident is cleared. This action would be taken quickly (response time would be in minutes from alert) to minimise the number of vehicles in the tunnel.

In the event of a fire incident the whole tunnel in both directions would be closed and vehicles diverted to surface roads until the incident has been dealt with.

- **Traffic and ventilation management** - It is envisaged that congested, slow moving traffic conditions would be rare in the project. However, where average traffic speeds drop below 40km/h, the tunnel operators would have the ability to implement traffic management procedures as a further means to manage vehicle emissions and air quality within the tunnel, in conjunction with the tunnel ventilation system.

Subject to the conditions of approval that may be applied to the project by the Minister for Planning, the NorthConnex project would regularly report (real time) on the performance and compliance with the air quality criteria. This would include in-tunnel air quality, air discharged from the ventilation outlets and ambient air external to the project tunnels.

In-tunnel air quality reporting would provide a direct clear comparison between the actual monitored air quality exposure within the tunnel against the maximum allowable air quality criteria to demonstrate that compliance is achieved at all times.

2.9.2 In-tunnel air quality for air quality impact assessment scenarios

Because emissions have been calculated for each hour of the day in several segments along each main alignment tunnel, it has been possible to use this data to calculate expected in-tunnel concentrations of vehicle emissions. This has been achieved by applying the ventilation flow rate applicable to the particular hour and traffic volume to the emissions calculated in each segment of each main alignment tunnel. Concentrations of pollutants at

any point in each main alignment tunnel have been calculated by adding emissions from all tunnel segments up to the point of interest (ie all emissions from the tunnel entry portal up to the point at which the concentration has been calculated).

To provide a more accessible series of concentration data for in-tunnel air quality, calculated concentrations of pollutants within each tunnel segment have been linearly interpolated to provide concentrations at each kilometre along the main alignment tunnels. The outcomes of this process are provided:

- In **Table 2-47** for forecast traffic volumes in 2019 and 2029 (peak hours) for each main alignment tunnel. Data presented in the table shows:
 - The in-tunnel air quality profiles as presented in the environmental impact statement.
 - The in-tunnel air quality profiles based on updated fuel mix assumptions in 2019 and 2029 (refer to **Section 2.8**) and maintain a NO₂:NO_x ratio of 10 per cent, as recommended by PIARC.
 - The in-tunnel air quality profiles based on updated fuel mix assumptions in 2019 and 2029 (refer to **Section 2.8**) and amending the NO₂:NO_x ratio to 16 per cent, as suggested by the Environment Protection Authority in its submission on the environmental impact statement.

Further discussion of the NO₂:NO_x ratio in the project tunnels is provided in **Section 2.14.2**, including an analysis of experience in other road tunnels and the approach proposed to be taken to management of in-tunnel NO₂ concentrations during operation of the project.

- In **Table 2-48** for a heavy vehicle sensitivity analysis, which assumes a 10 per cent increase in heavy vehicle numbers (ie an increase in heavy vehicle percentage of total traffic in 2019 from 28 per cent to 31 per cent and in 2029 from 25 per cent to 27.5 per cent). **Table 2-48** includes consideration of a NO₂:NO_x ratio of 10 per cent and also 16 per cent.

As discussed in **Section 2.7.1** of this report, detail traffic forecasting has been conducted for the project. A significant investment is proposed in the NorthConnex project. The commercial viability of this investment is dependent on forecast traffic volumes expected to use the project being reasonable and realistic. Because of this, the Cube model and its outputs have been interrogated in detail to confirm that the project is viable prior to seeking design and construct tenders or lodging an application for environmental planning approval. The forecast heavy vehicles volumes for the project (28 per cent of total traffic in 2019 and 25 per cent of total traffic in 2029) are considered realistic with low risk of significant variance in these forecasts.

These traffic forecasts for the project have assumed that 95 per cent of through heavy vehicles travelling along the Pennant Hills Road corridor would be directed into the project tunnels with the implementation of regulatory measures (to require heavy vehicles to use the tunnels). There is therefore a very low potential for heavy vehicles using the project to exceed these heavy vehicle percentages.

When considering and interpreting this in-tunnel air quality information, it is important to recognise that this information:

- Presents an estimated maximum concentration at a particular point in each main alignment tunnel within the relevant one hour period (refer to the following section of this report, which discusses variability of in-tunnel air quality and averaging periods).
- Presents a concentration, rather than an exposure for a motorist passing through the main alignment tunnel. To determine an exposure, concentrations along the entire length of the main alignment tunnel need to be considered within the time period during which the motorist's journey occurs (ie around seven minutes at 80 km/h). Where comparisons are to be made for exposure averaging periods greater than the tunnel journey time, then account also needs to be made of the concentration of the relevant pollutant to which the motorist would be exposure prior to/ following the journey (ie ambient air).
- The concentrations (and consequently the exposures that may be calculated from them) do not take into account reductions that may be achieved by closing vehicle windows and recirculating air.
- In-tunnel concentrations have not taken into account additional 'fresh' air that may be drawn into the main alignment tunnels via the exit portal and tunnel ramps (in order to maintain zero portal emission conditions). This air would have the effect of diluting in-tunnel vehicle emissions.
- Based on the variability of background air quality over time, in-tunnel concentrations of pollutants have not included contributions from air drawn into the main alignment tunnels. When considering in-tunnel air quality and motorist exposures, allowance would need to be made for contributions from ambient air. Pollutant loads in ambient air drawn into the main alignment tunnels would affect in-tunnel air quality in the early sections of each main alignment tunnel, before contributions from vehicles within the main alignment tunnels become the dominant contributor to in-tunnel concentrations of vehicle emissions.

Table 2-47 Calculated in-tunnel air quality for forecast traffic volumes (2019 and 2029) (project contribution) – main alignment tunnels during peak hours

Black – design as presented in the EIS

Blue – design including updates to fuel mix and no change to ratio of NO₂ to NO_x (10%)

Red – design including updates to fuel mix and ratio of NO₂ to NO_x (16%)

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	0.772	1.06	1.34	1.62	1.90	2.17	2.58	3.45
	0.348	0.812	1.12	1.41	1.70	2.00	2.28	2.71	3.63
NO ₂	0.039	0.098	0.124	0.144	0.165	0.186	0.206	0.250	0.374
	0.044	0.111	0.140	0.162	0.186	0.210	0.232	0.282	0.422
	0.070	0.177	0.224	0.260	0.298	0.336	0.372	0.451	0.675
PM ₁₀	0.039	0.084	0.122	0.158	0.193	0.229	0.265	0.307	0.377
	0.040	0.087	0.127	0.164	0.200	0.238	0.275	0.318	0.391
PM _{2.5}	0.037	0.080	0.115	0.149	0.183	0.217	0.251	0.290	0.347
	0.039	0.085	0.122	0.158	0.195	0.231	0.267	0.308	0.369
Southbound main alignment tunnel at 9 am (2029)									
CO	0.411	0.956	1.32	1.67	2.01	2.35	2.70	3.20	4.29
	0.415	0.965	1.33	1.69	2.03	2.37	2.73	3.23	4.33
NO ₂	0.043	0.108	0.136	0.159	0.182	0.204	0.227	0.276	0.411
	0.049	0.124	0.156	0.183	0.209	0.235	0.261	0.317	0.473
	0.079	0.199	0.250	0.292	0.335	0.375	0.418	0.508	0.756
PM ₁₀	0.047	0.101	0.145	0.189	0.232	0.275	0.319	0.369	0.439
	0.051	0.109	0.156	0.203	0.249	0.296	0.343	0.397	0.472
PM _{2.5}	0.046	0.095	0.137	0.178	0.219	0.260	0.301	0.348	0.414
	0.050	0.102	0.148	0.192	0.236	0.280	0.324	0.375	0.446
Northbound main alignment tunnel at 6 pm (2019)									
CO	0.156	0.911	1.76	2.62	3.47	4.32	5.12	5.59	6.26
	0.152	0.890	1.71	2.55	3.38	4.20	4.98	5.44	6.09

NO ₂	0.005	0.110	0.231	0.352	0.473	0.594	0.707	0.771	0.860
	0.005	0.112	0.235	0.358	0.481	0.604	0.719	0.784	0.875
	0.008	0.179	0.376	0.573	0.770	0.97	1.15	1.26	1.40
PM ₁₀	0.032	0.090	0.153	0.215	0.278	0.340	0.401	0.450	0.504
	0.033	0.092	0.156	0.220	0.284	0.347	0.410	0.460	0.515
PM _{2.5}	0.030	0.085	0.144	0.203	0.263	0.322	0.379	0.425	0.477
	0.031	0.087	0.147	0.207	0.269	0.329	0.387	0.434	0.487
Northbound main alignment tunnel at 6 pm (2029)									
CO	0.195	1.13	2.19	3.25	4.31	5.37	6.35	6.94	7.76
	0.183	1.06	2.05	3.04	4.04	5.03	5.95	6.50	7.27
NO ₂	0.005	0.119	0.250	0.381	0.512	0.643	0.765	0.834	0.932
	0.005	0.123	0.258	0.393	0.529	0.664	0.790	0.861	0.963
	0.008	0.197	0.413	0.630	0.846	1.06	1.26	1.38	1.54
PM ₁₀	0.039	0.106	0.178	0.250	0.323	0.395	0.464	0.521	0.585
	0.041	0.111	0.186	0.261	0.337	0.412	0.484	0.543	0.61
PM _{2.5}	0.037	0.100	0.169	0.237	0.305	0.373	0.439	0.497	0.553
	0.039	0.104	0.176	0.247	0.318	0.389	0.457	0.518	0.576

Table 2-48 Calculated in-tunnel air quality – heavy vehicle sensitivity analysis

Blue – design including updates to fuel mix and no change to ratio of NO₂ to NO_x (10%). Heavy vehicles are assumed to be 28 per cent of total traffic in 2019 and 25 per cent in 2029

Green – design including updates to fuel mix and no change to ratio of NO₂ to NO_x (10%). Heavy vehicles are assumed to be 31 per cent of total traffic in 2029 and 27.5 per cent in 2029

Orange – design including updates to fuel mix and a ratio of NO₂ to NO_x (16%). Heavy vehicles are assumed to be 31 per cent of total traffic in 2029 and 27.5 per cent in 2029

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	0.348	0.812	1.12	1.41	1.70	2.00	2.28	2.71	3.63
	0.345	0.806	1.11	1.40	1.69	1.98	2.26	2.69	3.60
NO ₂	0.044	0.111	0.140	0.162	0.186	0.210	0.232	0.282	0.422
	0.047	0.119	0.151	0.175	0.201	0.226	0.251	0.304	0.455
	0.075	0.190	0.242	0.280	0.322	0.362	0.402	0.486	0.728
PM ₁₀	0.040	0.087	0.127	0.164	0.200	0.238	0.275	0.318	0.391
	0.043	0.092	0.133	0.173	0.211	0.250	0.290	0.336	0.412
PM _{2.5}	0.039	0.085	0.122	0.158	0.195	0.231	0.267	0.308	0.369
	0.042	0.090	0.129	0.167	0.206	0.244	0.282	0.326	0.390
Southbound main alignment tunnel at 9 am (2029)									
CO	0.415	0.965	1.33	1.69	2.03	2.37	2.73	3.23	4.33
	0.412	0.958	1.32	1.67	2.01	2.36	2.71	3.21	4.30
NO ₂	0.049	0.124	0.156	0.183	0.209	0.235	0.261	0.317	0.473
	0.053	0.134	0.169	0.197	0.226	0.253	0.282	0.342	0.510
	0.085	0.214	0.270	0.315	0.362	0.405	0.451	0.547	0.816
PM ₁₀	0.051	0.109	0.156	0.203	0.249	0.296	0.343	0.397	0.472
	0.053	0.115	0.164	0.214	0.263	0.312	0.362	0.419	0.498
PM _{2.5}	0.050	0.102	0.148	0.192	0.236	0.280	0.324	0.375	0.446
	0.052	0.108	0.156	0.202	0.249	0.295	0.342	0.395	0.470
Northbound main alignment tunnel at 6 pm (2019)									
CO	0.152	0.890	1.71	2.55	3.38	4.20	4.98	5.44	6.09

	0.170	1.01	1.94	2.89	3.83	4.77	5.65	6.17	6.91
NO ₂	0.005	0.112	0.235	0.358	0.481	0.604	0.719	0.784	0.875
	0.006	0.139	0.293	0.446	0.600	0.753	0.896	0.977	1.09
	0.010	0.222	0.469	0.714	0.960	1.20	1.43	1.56	1.74
PM ₁₀	0.033	0.092	0.156	0.220	0.284	0.347	0.410	0.460	0.515
	0.040	0.113	0.191	0.269	0.348	0.425	0.501	0.563	0.630
PM _{2.5}	0.031	0.087	0.147	0.207	0.269	0.329	0.387	0.434	0.487
	0.037	0.106	0.180	0.254	0.329	0.402	0.474	0.531	0.596
Northbound main alignment tunnel at 6 pm (2029)									
CO	0.183	1.06	2.05	3.04	4.04	5.03	5.95	6.50	7.27
	0.181	1.05	2.03	3.01	3.99	4.98	5.88	6.43	7.19
NO ₂	0.005	0.123	0.258	0.393	0.529	0.664	0.790	0.861	0.963
	0.006	0.135	0.284	0.433	0.582	0.731	0.870	0.949	1.06
	0.010	0.216	0.454	0.693	0.931	1.17	1.39	1.52	1.70
PM ₁₀	0.041	0.111	0.186	0.261	0.337	0.412	0.484	0.543	0.61
	0.043	0.118	0.198	0.279	0.360	0.440	0.517	0.581	0.652
PM _{2.5}	0.039	0.104	0.176	0.247	0.318	0.389	0.457	0.518	0.576
	0.041	0.111	0.188	0.264	0.340	0.415	0.489	0.554	0.616

2.9.3 Variability of in-tunnel air quality

The data presented in **Section 2.9.2** have been calculated for peak hour traffic volumes in main alignment tunnel. The concentrations presented in the tables in that section have therefore been calculated on an hourly average basis. A similar approach has been taken for in-tunnel air quality calculations presented in the environmental impact statement.

Air quality within road tunnels is likely to be variable, with the concentration of a particular pollutant at a particular point dependent on the conditions at that point and at a specified time. For example, air quality at a particular point would be different depending on whether a passenger vehicle or a heavy was travelling past that point. Further, the size of vehicles (passenger vehicles or larger heavy vehicles) as well as the number and distribution of vehicles within a particular time period will affect the spatial distribution and mixing of pollutants within the road tunnel. In practice, these effects are seen as variable short term changes in pollutant concentrations around an hourly average (or other averaging period value).

Because motorist journeys through a road tunnel are usually shorter than one hour duration (around 6.75 minutes at 80 km/h through the NorthConnex main alignment tunnels), it is useful to understand the short term variability in in-tunnel pollutant concentrations to gain an appreciation for the range of concentrations that may be experienced by a motorist. It is also useful to understand the likely scale of this variability because exposure standards (where they exist) and in-tunnel air quality criteria are often expressed for shorter averaging periods – often 15 minutes or 30 minutes.

To gain an appreciation of this variability, carbon monoxide monitoring data from the M5 East Motorway tunnels has been analysed for the period April 2013 until December 2013. In-tunnel monitoring data has been used to compared 15-minute average CO concentrations with the one-hour average concentrations calculated from that data. The intention of this comparison was to understand how much higher a 15-minute average concentration may be when compared with an hourly average.

Analysis of the in-tunnel CO monitoring data from the M5 East Motorway indicates that:

- For all of the monitoring data:
 - The maximum 15-minute average CO concentrations were around 18 per cent to 24 per cent higher than the simultaneous hourly average concentrations.
 - The minimum 15-minute average CO concentrations were around zero and 25 per cent below the simultaneous hourly average concentrations.
- For monitoring data in the AM peak (8am to 10am):
 - The maximum 15-minute average CO concentrations were around seven per cent to 15 per cent higher than the simultaneous hourly average concentrations.
 - The minimum 15-minute average CO concentrations were around five per cent to seven per cent below the simultaneous hourly average concentrations.
- For monitoring data in the PM peak (5pm to 7pm):
 - The maximum 15-minute average CO concentrations were around six per cent to 13 per cent higher than the simultaneous hourly average concentrations.
 - The minimum 15-minute average CO concentrations were around five per cent to eight per cent below the simultaneous hourly average concentrations.

2.10 Meteorological data and modelling

This section provides information and discussion of:

- How the MM5 and CALMET models have been set up and used to model meteorology in and around the project.
- Validation of the CALMET model outputs.

2.10.1 Set up of the MM5 and CALMET models

General approach

An advanced diagnostic meteorological model (CALMET) was used to establish local meteorological conditions over a grid around the project corridor measuring 60 kilometres by 62.5 kilometres. The CALMET model constructs three dimensional wind and temperature fields starting from base meteorological data, topography and land use information.

The CALMET model used meteorological inputs from the MM5 prognostic meteorological model (the Fifth-Generation Penn State/ NCAR Mesoscale Model), which is a regional scale model used to create weather forecasts and climate projections. To ensure that the MM5 model generated meteorological data that was representative of actual conditions, the outputs from the MM5 model were compared with and calibrated against actual monitoring data from five existing meteorological monitoring stations across Sydney: at Lindfield, Terrey Hills, Richmond, Prospect and the Sydney Kingsford Smith Airport.

Prognostic meteorological data from MM5 were used to define the meteorological parameters for the upper air levels (which are required by the CALPUFF model but are not measured at most Bureau of Meteorology and Office of Environment and Heritage monitoring stations) and to provide the initial wind field information at the surface level.

CALMET then used the Bureau of Meteorology and Office of Environment and Heritage meteorological monitoring station data to modify those initial wind fields to be more representative of actual measured conditions.

Meteorological modelling using MM5 and CALMET, within inputs from meteorological monitoring data is a two-step process:

- In the first step, the CALMET model uses the meteorological monitoring data and the MM5 prognostic data to develop a flow field across the entire modelling domain. In this first step, the surface meteorological monitoring stations 'assist' in nudging the MM5 data towards their solution.
- In the second step, fine scale terrain and land use inputs are introduced (across the CALMET model model), with these inputs used to further nudge the initial wind field generated based on the MM5 and meteorological monitoring data.

The CALMET/ MM5 model can be run very well without meteorological monitoring, but meteorological monitoring data ensures a more robust numerical data output.

Meteorological parameters have been modified in CALMET based on the data recorded by the Bureau of Meteorology and Office of Environment and Heritage meteorological monitoring stations, terrain and land use data to produce site-representative wind fields, which were used by the CALPUFF model to predict pollutant movements in the atmosphere. Examples of these wind fields are shown in **Figure 2-6** and **Figure 2-7** for onshore and offshore wind flows, respectively.

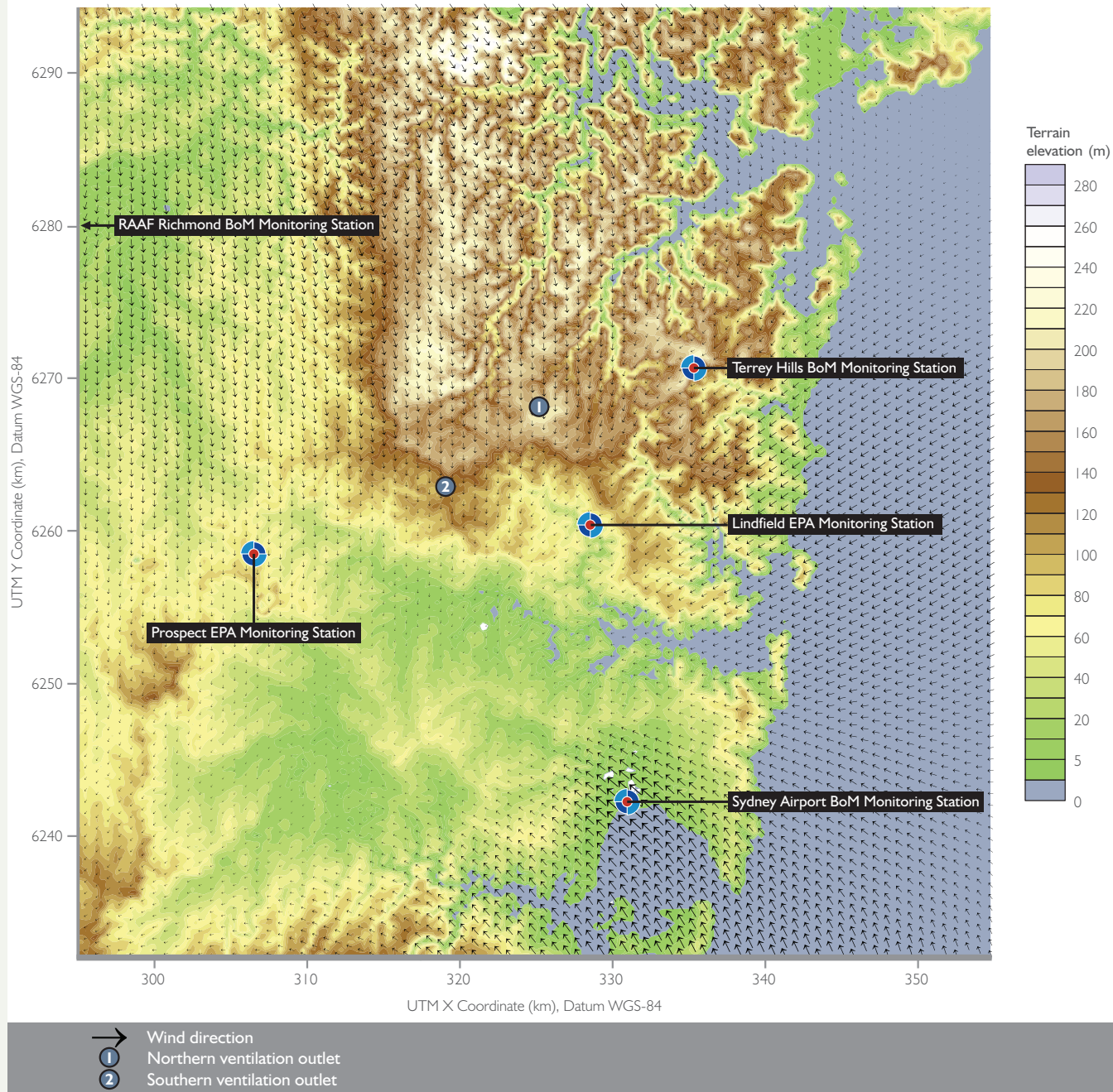


Figure 2-6 Example wind field (onshore flow, October 2011, 4:00am)

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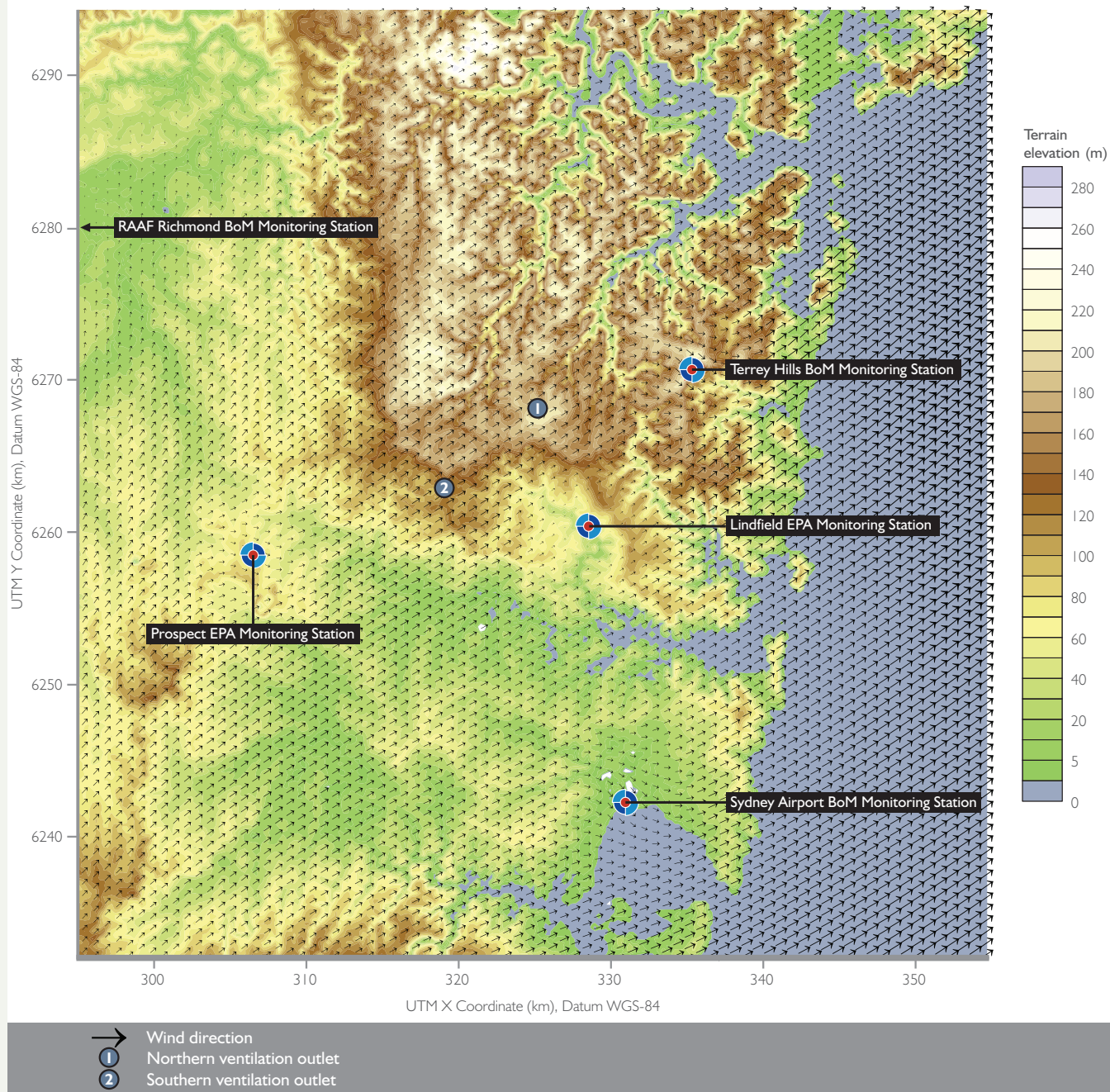


Figure 2-7 Example wind field (offshore flow, October 2011, 4:00am)

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CALMET and MM5 model parameters

The model input parameters used in the CALMET model and the MM5 model are summarised in **Table 2-49** and **Table 2-50**, respectively.

The seven critical parameters of the CALMET model and their values used in the air quality impact assessment for the project are:

- TERRAD – six kilometres.
- RMAX1 – four kilometres.
- RMAX2 – not used as prognostic data were used to determine the temperature field above 20 metres.
- R1 – 2.5 kilometres.
- R2 – not used as prognostic data were used to determine the temperature field above 20 metres.
- IEXTRP – no extrapolation was done.
- BIAS – no bias was done.

It should also be noted that ten vertical levels were used in CALMET, defined as the levels between 0, 20, 40, 80, 160, 320, 700, 1300, 1700, 2300 and 3000 metres above ground level. Cloud cover and cloud ceiling height were determined from the prognostic data (MM5).

The values described above have been chosen consistent with the guidance provided in in Generic Guidance and Optimum Model Settings for the CALPUFF Modeling System for Inclusion into the 'Approved Methods for the Modeling and Assessment of Air Pollutants in NSW, Australia' (OEH, 2011). The final parameters used in the air quality impact assessment, as listed above, were determined following an iterative process of investigation of the effects of different values on the resultant wind fields. This iterative process considered parameters in the following ranges:

- TERRAD values between four kilometres and 10 kilometres.
- RMAX1 values between one kilometre and eight kilometres.
- R1 values between one kilometre and six kilometres.
- IEXTRP switched both on and off. For this air quality impact assessment, it was switched off due to confidence in the MM5 data in determining the initial guess wind fields.

Table 2-49 CALMET model input parameters

Parameter	Input
Meteorological grid domain	60 kilometres x 62.5 kilometres
Meteorological grid resolution	250 metre resolution (240 x 250 grid cells)
Reference grid coordinate of southwest corner	295.000 E, 6232.000 S
Cell face heights in vertical grid	0, 20, 40, 80, 160, 320, 700, 1300, 1700, 2300 and 3000 m
Years of analysis	2009, 2010 and 2011
Simulation length	3 years (62,280 hours/1,095 days)
Surface meteorological stations	CALMET Hybrid Mode: Run using a combination of MM5 gridded numerical data supplemented by data from five surface meteorological stations operated by BOM and OEH (described below). Lindfield OEH Monitoring Station Hourly data: Temperature, precipitation, humidity, wind speed and wind direction. MGA Coordinates (km): 328.711 E, 6260.391 S Terry Hills BOM Monitoring Station (Station No. 066059) Hourly data: Temperature, precipitation, humidity, wind speed and wind direction. MGA Coordinates (km): 335.509 E, 6270.714 S Richmond RAAF BOM Monitoring Station (Station No. 067105) Hourly data: Temperature, precipitation, humidity, pressure, wind speed and wind direction. MGA Coordinates (km): 293.651 E, 6279.933 S Prospect OEH Monitoring Station Hourly data: Temperature, precipitation, humidity, wind speed and wind direction. MGA Coordinates (km): 306.745 E, 6258.646 S Sydney Airport BOM Monitoring Station (Station No. 066307) Hourly data: Temperature, precipitation, humidity, pressure, wind speed and wind direction. MGA Coordinates (km): 331.173 E, 6242.272 S
Upper air meteorological station	No upper air stations. The three-dimensional gridded prognostic data from MM5 were used as the initial guess wind-field for CALMET.
Terrain data	For the assessment presented in the environmental impact statement, terrain elevations were extracted from the NASA Shuttle Radar Topography Mission data set (SRTM 90 metre, 3-arc sec). Terrain data has been updated as part of the air quality impact assessments presented in this report (refer to Section 2.12). Terrain data have been re-extracted using five metre resolution Land and Property Information (LPI) data. The elevations of the discrete receivers and the ventilation outlet locations have been identified using this revised data.

Table 2-50 MM5 model input parameters

Parameter	Input
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.

2.10.2 Wind data from the Sydney airport

For the purpose of the air quality impact assessment presented in the environmental impact statement, the three years of data from the Bureau of Meteorology Sydney Airport station used as inputs in the meteorological modelling were compared to the long term (30 year) statistics from this site in order to show the suitability of these years for the assessment (Section 4.2.4 of the Technical Working Paper: Air Quality in the environmental impact statement).

Sydney Airport data were used in this analysis as this monitoring location it is one of several key surface meteorological stations used in the meteorological modelling. Monthly summaries of temperature, relative humidity and wind speed were provided for 9 am and 3 pm conditions. The data used in the modelling (2009 – 2011) were different to the long term (30 year) average data from Sydney Airport. This difference is attributed to the anemometer at the monitoring station (Potts, Monypenny & Middleton, 1997).

From 1939 to 1994, wind reports at the airport were taken from a Dines pressure-tube anemometer. The Dines anemometer, which was sited in a number of different locations during its operational period, was replaced by a Synchrotac anemometer in August 1994. The new anemometer, which is the new Bureau of Meteorology standard wind vane and rotating cup anemometer, was sited in a location that is more exposed to winds from all directions.

Before its decommissioning, operational staff at the airport indicated concern that the anemometer was recording wind speeds lower than those reported by pilots or indicated by other anemometers on site and wind socks. Since the upgrade, higher average wind speeds have been recorded at the site. These higher wind speeds affect the modelling data since

the modelling period occurred after the replacement of the anemometer, and, as such, the wind speeds during modelling period were higher than the 30 year average data.

The effect of the anemometer replacement is illustrated in **Figure 2-8**, which shows the 3 pm average wind speeds for the old and new anemometers and the 30 year average. As can be seen, the average wind speed for the period 1995 – 2011 was higher than the 30 year average. The 3 pm annual average wind speed for the modelling period (2009 – 2011) was 7.3 m/s, which closely aligns with the 16 year average (1995 – 2011) of 7.2 m/s shown in **Figure 2-8**.

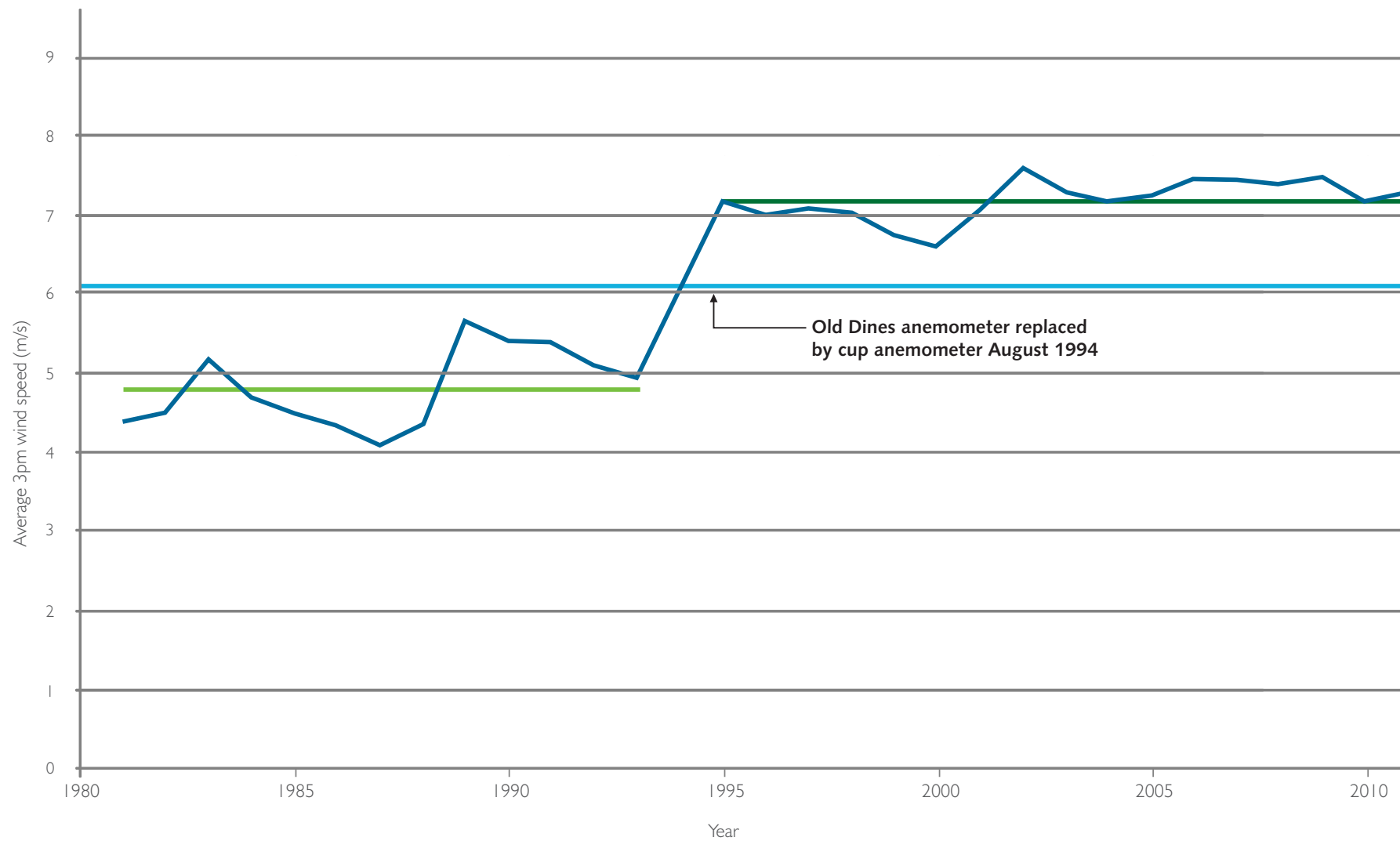


Figure 2-8 Effect of anemometer replacement at Sydney Airport

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2.10.3 Validation of the CALMET and MM5 models

The outputs of the CALMET and MM5 models have been validated using observed meteorological data from the Earlwood meteorological monitoring station operated by the Office of Environment and Heritage. Data from this station has not been previously used in the CALMET or MM5 modelling.

The outputs of the CALMET and MM5 models have been validated by comparing the results from the model at the Earlwood site, with actual monitoring data from that station.

A comparison of the wind directions and speeds of the CALMET monitoring data extracted for the suburb of Earlwood (generated using MM5 prognostic data and surface monitoring stations) (referred to as modelled) and data from the Earlwood monitoring station is provided in **Appendix B**, in the form of seasonal and annual wind roses.

From the comparison of CALMET/ MM5 generated wind roses and wind roses based on monitoring data at the Earlwood monitoring stations, the following observations can be made:

- The annual average comparison shows that the general spread of wind directions is generally uniform for all years, although the monitoring data from the Earlwood station does show a stronger portion of winds from the west north-west. The modelled data also shows relatively higher wind speeds.
- The summer data shows a strong correlation between wind trends, both showing a strong proportion of north east to south winds. These winds are likely to represent sea breezes. The modelled data shows generally stronger wind conditions.
- The autumn data correlation is not as strong as the other seasons, although still shows similar trends between data sets. The observed data shows lower wind conditions with a marginal west north-west and east south-east axis. The modelled data shows more winds from the south east to west south-west. Both data sets show minor winds from the north-west to east quadrants.
- The winter shows a good correlation between data sets, with winds predominantly blowing between the south west and north west, with minor winds from the other directions. As seen in the annual comparison, the monitoring data has a stronger portion of winds from the west north-west.
- The spring data shows a good correlation, with winds prevalent from most wind directions from both data sets. Again, the modelled data shows generally stronger wind conditions.

The comparison of the observed to modelled data shows a reasonable correlation between the data sets, although the modelled data tends to predict higher winds and may underestimate winds blowing from the west south-west. In general, the data shows a good correlation and is considered appropriate for the use in the air quality impact assessment.

2.10.4 Calm and low wind speed conditions

Based on the observation that modelled meteorology generally produced less frequent calm and low wind speeds than monitoring data (refer to the validation of the CALMET and MM5 models, above), and in response to concerns raised in public submissions, further analysis of calm and low wind speed conditions has been conducted.

The CALMET data used in the air quality modelling have been analysed to determine the frequency of calm and light wind conditions. Data at the northern ventilation outlet is presented here, although it is highlighted that analysis of data for the southern ventilation outlet produces essentially the same observations.

For the 2009 meteorological modelling year, there were 81 calm wind periods (hours) present in the CALMET file for the northern ventilation outlet, representing 0.9 per cent of the modelling period. For 2010 and 2011, there were 65 and 44 calm periods respectively.

Low wind speeds between zero and one metre per second have been predicted for approximately three per cent of 2009 and 2011 and 3.4 per cent of 2010. Low wind speeds between one and 2.5 metres per second occurred for approximately 36 per cent of 2009 and 2011 and 38 per cent of 2010.

It is well known that prognostic meteorological data typically under-predict the number of calm events. Actual meteorological conditions at the ventilation outlet sites would be expected to have a slightly greater number of low wind speed classes and fewer stronger winds. It should be noted, however, that apart from a single peak concentration of NO₂ that occurred during a calm period, the highest pollutant concentrations from the project's ventilation outlets have been predicted to occur during high wind speeds (refer to analysis of this issue below). As such, the meteorological data are considered adequate for this assessment.

Figure 2-9 and **Figure 2-10** show the frequency and distribution of calm and low wind speeds at the northern ventilation outlet for the zero to one metre per second wind speed band, and the one to 2.5 metres per second wind speed band. These data have been generated by the CALMET and MM5 models used for the air quality impact assessment.

Wind speeds less than one metre per second are relatively consistent across all wind directions, but are more common in the west-southwesterly direction and least frequent in the easterly direction. Winds between one and 2.5 metres per second most commonly occur in the southerly and westerly directions and least commonly in the northerly directions. It can be seen from **Figure 2-9** and **Figure 2-10** that low wind speed conditions are distributed across all the directions/ receiver locations.

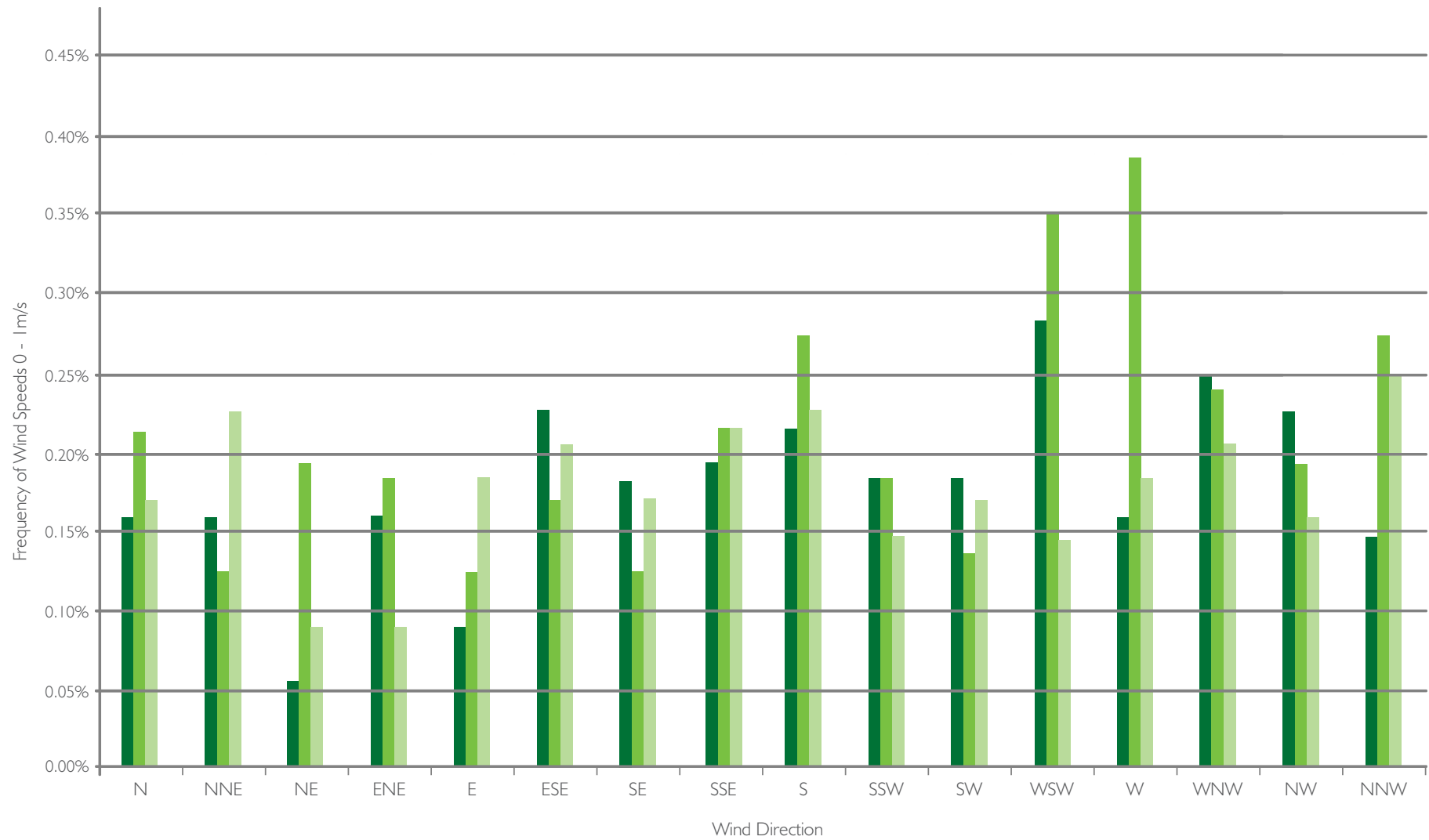


Figure 2-9 Winter low wind frequency and distribution

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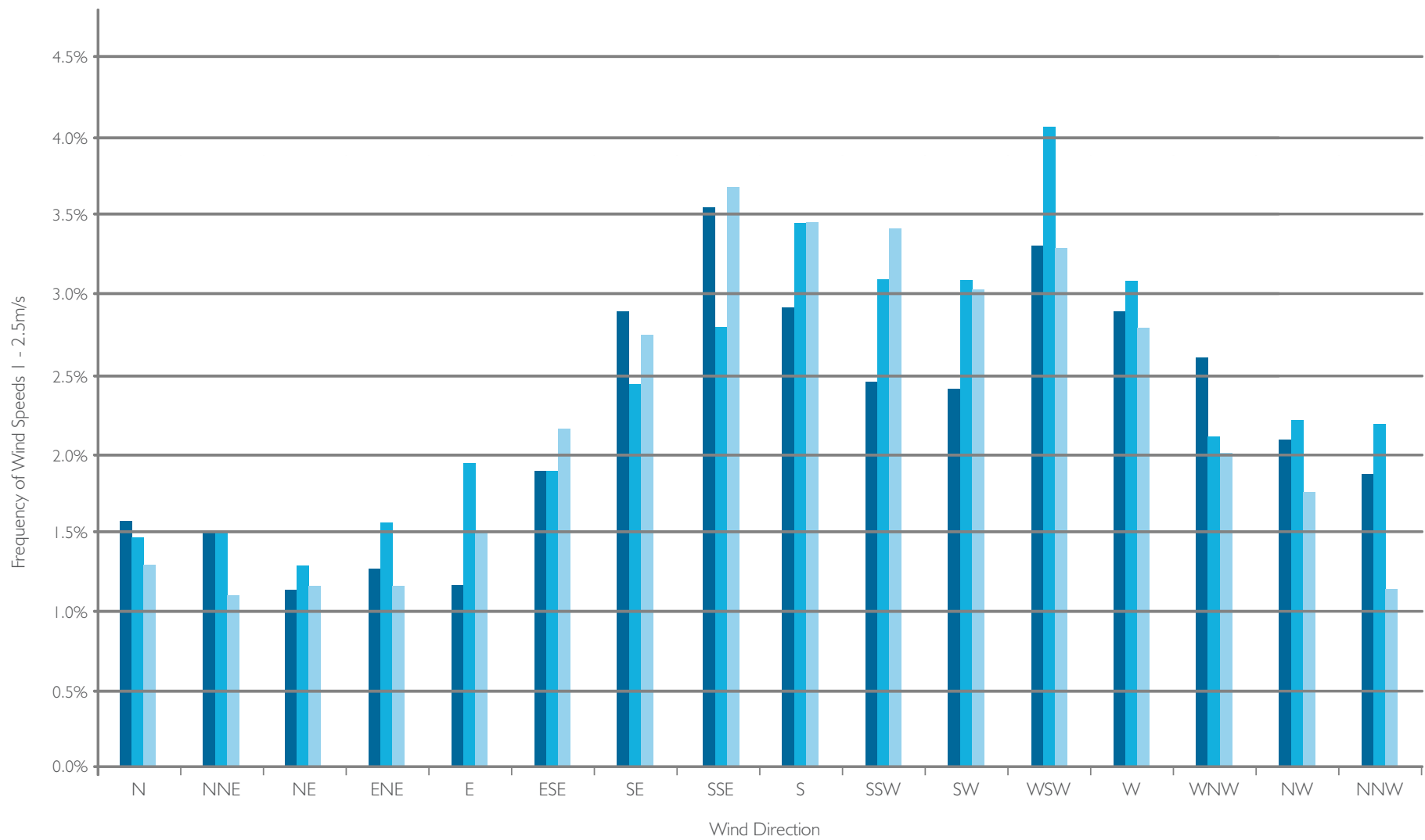


Figure 2-10 Summer low wind frequency and distribution

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2.10.5 Sensitivity to calm and low wind speed conditions

To test the sensitivity of the air quality impact assessment to changes in the percentage of calm meteorological conditions, further analysis of dispersion modelling results has been carried out. This analysis has considered predicted maximum and second highest ground level concentrations of oxides of nitrogen (NO_x) as a function of wind speed.

Concentrations of NO_x at ground level around the northern ventilation outlet under forecast traffic volumes in 2019 have been analysed. The northern ventilation outlet has been considered based on predictions in the environmental impact statement that maximum ground level concentrations would be higher than around the southern ventilation outlet. Ground level concentrations have been analysed for the most affected location, based on the 2009 meteorological modelling year (during which the maximum impacts were predicted to occur).

Table 2-51 summarises the maximum, the second highest and the average NO_x concentration around the northern ventilation outlet by wind speed. The number of modelled hours at the relevant wind speeds is also listed.

Table 2-51 shows that the predicted peak concentration of NO_x would occur under calm conditions. However, comparison of this value with the second highest prediction under calm conditions highlights a significant difference in concentrations, which suggests that the peak NO_x concentration occurred during a single hour during which a rare combination of meteorological conditions was experienced. This rare combination of meteorological conditions is discussed further in **Section 2.15.2** as part of the analysis of predicted air quality impacts. The unusually high maximum NO_x concentration under calm condition has also skewed the average value.

The maximum NO_x concentration for the single hour under calm conditions is also significantly higher than all other ground level concentrations predicted through the air dispersion modelling, reinforcing the conclusion that this value is more likely to be an unusual, infrequent outcome rather than an outcome characteristic of typical calm conditions. This is supported by the further analysis conducted in response to issues raised by the Environment Protection Authority (refer to **Section 7.1.1.3** of this report) that identifies a single unusual hour of meteorological data (out of three years of data used in the air quality impact assessment) that has contributed to a distinct and elevated (but very rare) air quality impact.

With the exception of the single elevated NO_x prediction, **Table 2-51** shows that:

- NO_x concentrations under calm conditions and light wind conditions (up to 1 m/s) are very low. NO_x concentrations under these conditions are lower than predicted concentrations under higher wind speeds.
- The wind speeds with the highest NO_x concentrations when considering maximum and second highest predicted values lie within the range 1 m/s to 5 m/s.
- Annual average ground level concentrations of NO_x are highest at high wind speeds (more than 5 m/s).

On this basis, peak ground level air quality impacts are not expected to occur under calm and light wind conditions. Peak ground level concentrations are expected to occur when winds are between 1 m/s and 5 m/s (3.6 to 18 km/h). These wind speeds are well represented in the meteorological monitoring data used in the air quality impact assessment of the project (around 90 per cent of the time based on modelled hours of wind speeds summarised in **Table 2-51**).

To the extent that calm and light winds may have been underestimated in the meteorological modelling for the project, this is likely to have led to an overestimate of air quality impacts (based on an overestimate of higher wind conditions). The air quality impact assessment and the meteorological modelling conducted for the project is therefore conservative (ie over predicted).

Table 2-51 Correlation between peak NO_x concentration and wind speed

Scalar wind speed (m/s)	Predicted NO _x concentration (one hour) (µg/m ³)			Number of modelled hours of wind speed
	Maximum	Second highest	Average	
0 to 0.5	119.0*	14.8	2.9	49
0.5 to 1	16.3	6.6	0.3	208
1 to 2	42.5	34.9	0.5	1,293
2 to 3	38.1	37.7	0.2	3,941
3 to 5	35.6	34.7	0.7	2,657
5 to 7	29.2	24.7	1.1	521
7 to 9	32.9	28.5	1.3	69
>9	79.2	23.0	7.4	22

* One hour in three years of modelling (refer to discussion in Section 2.15.2).

2.10.6 Local meteorological monitoring data

This section includes information and discussion of:

- Quality requirements for meteorological monitoring.
- Community meteorological monitoring data.
- Meteorological monitoring data from the monitoring stations installed along the project corridor.

Quality requirements for meteorological data

Meteorological data used in the air quality impact assessment for the project were sourced from meteorological stations operated by the Bureau of Meteorology (BoM) and the New South Wales Office of Environment and Heritage (NSW OEH). All stations from which data were sourced are operated in accordance with Australian Standard AS 3580.14-2011 Meteorological Monitoring for ambient air quality monitoring applications. The purpose of this standard is to ensure that meteorological parameters are accurately defined and representative of the wider area.

Location of instruments is critical for the measurement of meteorological parameters. The Australian Standard stipulates that wind should be measured at 10 metres above ground level, and must be at a distance of at least 10 times the height of all obstructions (trees, buildings etc.) within a defined distance. This is because obstructions may influence measured wind by -50% to +100% in speed and more than 90° in direction when compared with wind representative of the wider area.

The Australian Standard also sets a schedule for critical performance checks and calibrations to ensure that instrumentation is in operable condition and measurements are within specified tolerances. It is also critical that data recorded during calibration or maintenance procedures are removed from the final validated data set. This is because meteorological data cannot be accurately validated unless correct calibration, maintenance and checks are performed on the instrumentation at regular intervals.

Non-conformance to the Australian Standard may result in meteorological data that significantly deviates from actual conditions. If such data are used as input in an air dispersion model, predictions made with the model may also deviate significantly from reality. As such, the Environment Protection Authority requires meteorological equipment used for the collection of data used in dispersion modelling to be established, sited, operated and maintained in accordance with Australian Standards

The National Association of Testing Authorities (NATA) is the authority responsible for the accreditation of laboratories, inspection bodies, calibration services, technical operators, producers of certified reference materials and proficiency testing scheme providers throughout Australia.

The NorthConnex project monitoring stations are all operated to NATA standards by experienced industry specialists. Monitoring stations operated by the Office of Environment and Heritage are also to NATA standards.

Community meteorological monitoring data

Several submissions received in response to the exhibition of the environmental impact statement made reference to a community meteorological monitoring station in Wahroonga.

Reasonable endeavours have been made to identify the location of this meteorological monitoring station, but without success. Efforts to locate the monitoring station have included:

- Attendance at the location of the Wahroonga monitoring station site (at the coordinates listed on the Weather Underground website (<http://www.wunderground.com/personal-weather-station/dashboard?ID=INEWSOUT355#history>) (-33.712, 151.139)). This location is within Cherrywood Reserve, located on land between Cherrywood Avenue and Bunyana Avenue, Wahroonga. No evidence of a monitoring station could be identified at this location.
- Doorknocks of properties around the listed location of the monitoring station. None of the local residents who were spoken to were aware of or knew the location of a local meteorological monitoring station.

Based on the coordinates listed on the Weather Underground website, the Wahroonga monitoring station appears to be located in an area surrounded by medium density residential development and a large number of mature trees. Based on this and the lack of visibility of a monitoring station tower during attendance at the site, it is considered likely that the station is not sited in accordance with AS 3580.14-2011 due to the number of obstacles (trees) within a short distance of the listed location of the station. The presence of obstacles can significantly affect wind readings, and it is likely that data from this station will not be representative of the winds in the wider local area.

Despite uncertainty over the quality of data from community meteorological monitoring stations in the area, the data that is available on the Wunderground website from several of those stations has nonetheless been analysed. Community weather stations in the vicinity of the northern ventilation outlet have been identified at Wahroonga, Asquith, Florence Cotton Reserve, Normanhurst, Turrumurra and St Ives. Due to differences in the types of data collected at the stations and limitations on website data availability, the only data that could be compared between the community stations and the project monitoring station at James Park were average wind speed and average temperature.

The average temperature data recorded at community monitoring stations between January and August 2014 are shown in **Figure 2-11**. In contrast to the wind speed data discussed below, there was a high degree of consistency in average temperatures measured at each of the community weather stations and the project monitoring station at James Park. The average temperatures recorded at James Park were typically within one degree of the average temperatures from the community weather stations. This is not unexpected because temperature is not as dependent on location as wind speed in the area of investigation.

The average wind speed data collected between January 2014 and August 2014 are shown in **Figure 2-12**. It should be noted that, due to the inconsistent formatting of monthly data on the community weather station website, the available monitoring station data does not correspond exactly to calendar months. The data has, however, been investigated in a manner that provides a summary of each stations interpretation of the conditions within the month.

As shown in **Figure 2-12**, the average wind speeds measured at the project monitoring station at James Park were consistently higher than the wind speeds measured at each of the community weather stations. The highest wind speeds at community weather stations were recorded at Florence Cotton Reserve and Asquith. There is, however, great variability between the average wind speeds measured at the community weather stations. As such, it can be concluded that wind conditions within the area of investigation are likely to be heavily influenced by near field obstructions, further strengthening the likelihood that the community stations are not sited in accordance with AS 3580.14-2011, so that their wind measurements reflect very local conditions and not, for example, those in the vicinity of the ventilation outlets. Therefore in accordance with Environment Protection Authority requirements, the community stations cannot be used in the dispersion modelling assessment.

The Wahrenonga community monitoring station available on the Weather Underground website is identified as the closest community monitoring station to the northern ventilation outlet. The site is located around 2.2 kilometres to the east of the ventilation outlet.

A high-level comparison has been undertaken to attempt to identify any trends and similarities between data collected at the Wahrenonga community monitoring station and the James Park project monitoring station.

The James Park project monitoring station is operated as part of the NorthConnex project by a NATA certified and experienced company. The collected data is processed through a vigorous validation procedure prior to being released. The station is compliant with Australian Standard AS 3580.14-2011 Meteorological Monitoring for ambient air quality monitoring applications. The site is located within an open park area, approximately 1.1 kilometres from the northern ventilation outlet.

The Wahrenonga station data is only available from May 2014 and the validated James Park project station data from January to August 2014. As such the review is limited to the period from May 2014 to August 2014.

Monitoring data for the entire May to August period, 9am and 3pm at the James Park monitoring station show a predominant wind direction from the west with minor winds from all other directions, and an average wind vector of 261 degrees. Winds were predominantly from the west at 9am and from the west and south east at 3pm.

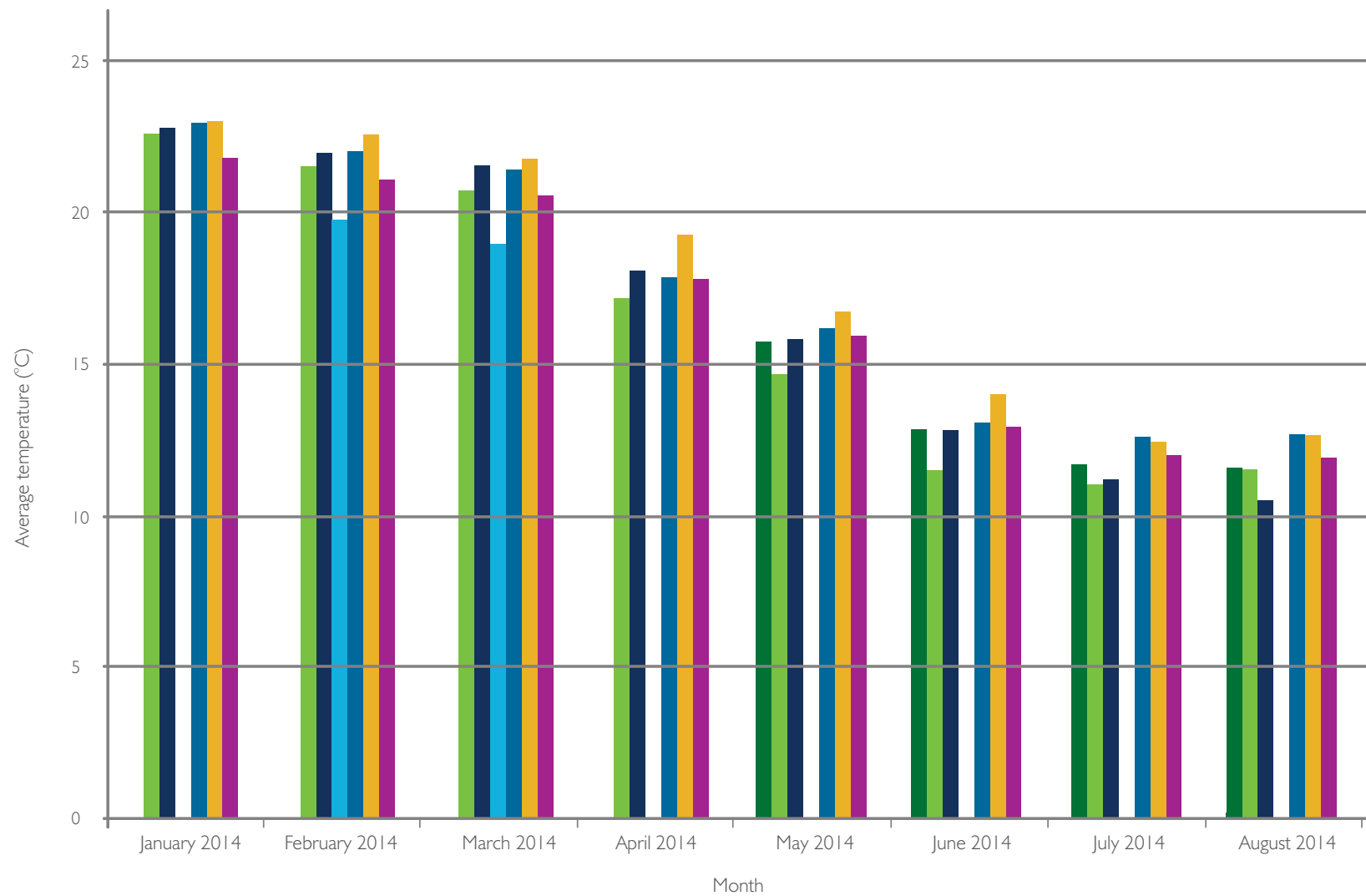


Figure 2-11 Temperature data from community monitoring stations

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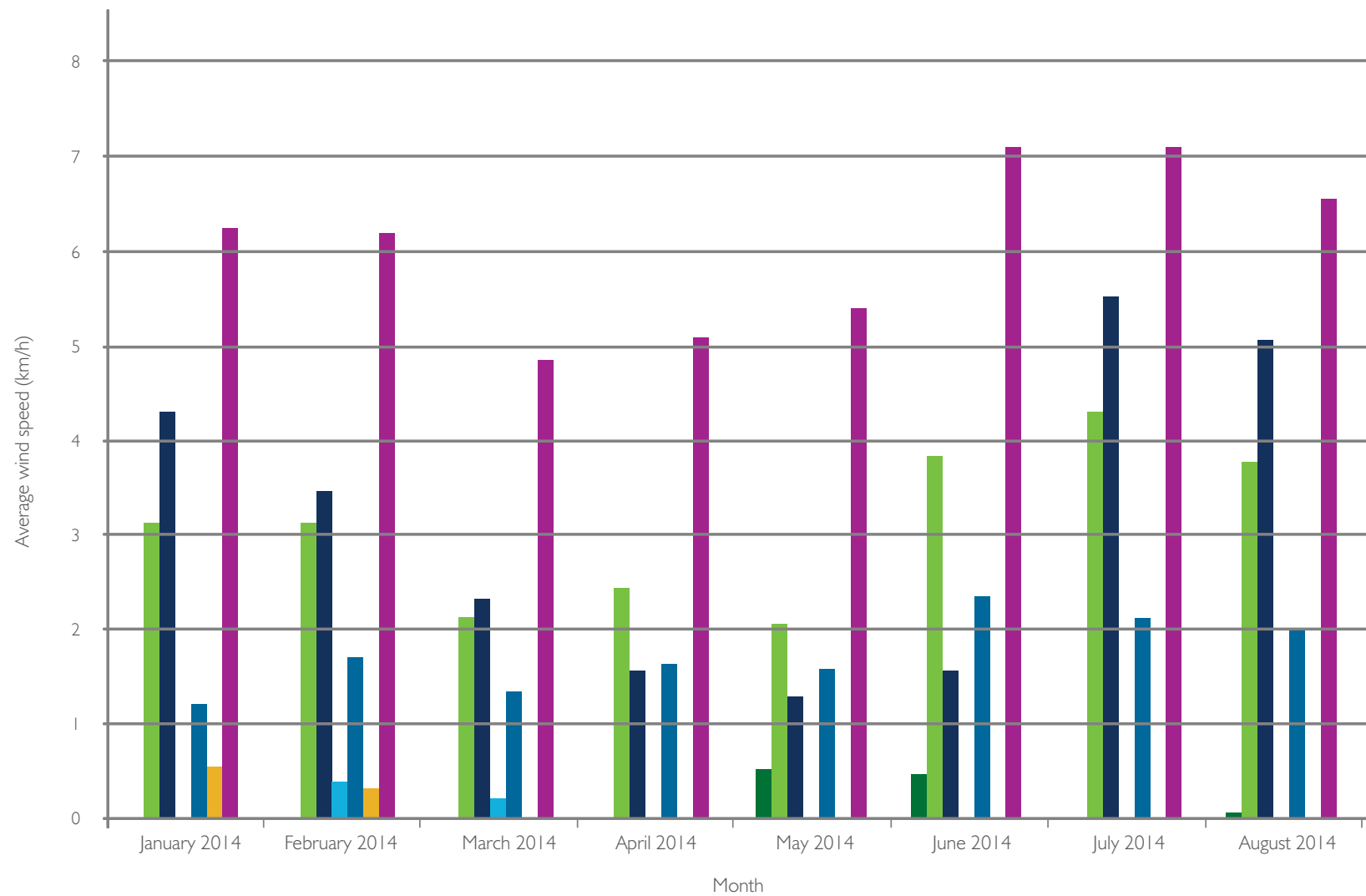


Figure 2-12 Wind speed data from community monitoring stations

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The Wahroonga data show winds predominately from the north, with an average wind vector of 357 degrees. Winds were predominantly from the north west at 9am and from the west and south at 3pm. During periods of inconsistent and missing data within the Wahroonga dataset the wind direction typically defaulted to a northerly direction. This default to a northerly direction in low to zero wind speed conditions consequently introduced a high likelihood of a northerly bias into the monitoring data that is probably inconsistent with actual conditions.

The two data sets do not seem to correlate wind direction well for the entire period or 9am wind roses. They do show some, albeit low, correlation for the 3pm wind rose with both showing a higher proportion of westerly data and some scatter to the south and south east.

The calm percentage (wind speeds less than 0.5 m/s) for the May to August period for James Park was nine per cent compared to 90 per cent for Wahroonga. The data show that the maximum hourly average wind speed for the James Park data was 8.5 m/s while for the Wahroonga data it was 2.0 m/s. The wind speed trends show no real correlation between datasets. The James Park data show a more typical trend with decreasing wind counts as wind speed increases. The Wahroonga data shows the majority of the wind speed range is calm, with no wind counts greater than 2 m/s.

It should be noted that there was a great deal of inconsistent and missing data from the community weather stations as well as inconsistent averaging periods and data that appeared to be invalid in accordance with AS 3580.14-2011. The Wahroonga monitoring station, for example, was estimated to have a data capture rate of about 50%. It has an average wind speed of zero kilometres per hour for the month of July compared to 7.1 kilometres per hour at James Park. The Wahroonga station data shows 30 out of 31 days as having a zero kilometre per hour reading for this month. It is highly unlikely that the Wahroonga station had no measurable winds for 96 per cent of the month; it is more likely that the station's measuring sensitivity is not appropriate, the stall speed is too high, the station was malfunctioning and recording zero, or that the station siting is not appropriate. During these periods of inconsistent and data missing the wind direction typically defaults to a northerly direction. This default to a northerly direction in low to zero wind speed conditions consequently introduced a high likelihood of a northerly bias into the monitoring data that is probably inconsistent with actual conditions.

Based on the analysis above, it is concluded that the Wahroonga data set does not represent the winds in the project area but rather just those in the very close vicinity of the measuring instrument, i.e. it is not sited in accordance with AS 3580.14-2011. Furthermore, there appear to be significant uncertainties in the recorded wind speeds (far too many calms, probably due to high start/stall speeds) and wind directions (due to the default to north when the wind speed was measured to be zero).

Project meteorological monitoring data

As discussed in the environmental impact statement and earlier in this report, a series of five monitoring stations have been installed and operated along the project corridor since late 2013. The monitoring stations have collected background air quality and meteorological data.

Two of the monitoring stations – at James Park, Hornsby and at Rainbow Farm Reserve, Carlingford – are the closest project monitoring stations to the northern and southern ventilation outlets, respectively. The Rainbow Farm Reserve monitoring station is located reasonably close to the site for the southern ventilation outlet, and is representative of local meteorological conditions. The James Park site is further distanced from the northern ventilation site, but is nonetheless reasonably representative of local meteorological conditions.

Both the James Park and the Rainbow Farm Reserve monitoring stations record temperature, relative humidity, wind direction and wind speed. At the time of conducting the air quality impact assessment presented in the environmental impact statement, data were available from:

- The Rainbow Farm Reserve monitoring station from 16 January 2014 to 30 April 2014.
- The James Park data monitoring station from 3 December 2013 to 31 May 2014.

An initial review and comparison of meteorological data (wind speed, direction and frequency) has been conducted based on CALMET data used in the air dispersion modelling for the project and monitored data from each of the Rainbow Farm Reserve and James Park monitoring stations. From this comparison, the CALMET data shows a greater range in wind directions than project monitoring data. A higher percentage of calm conditions and very low wind speeds have also been recorded at the project monitoring stations than have been predicted in the CALMET data. This is consistent with the broader discussion about calm and low wind conditions presented earlier in this section.

Observations that can be made from the comparison of CALMET and project monitoring data include:

- The Rainbow Farm Reserve data shows a relatively high proportion of wind from the north-west, which are not similarly reflected in the CALMET data. Most of the Rainbow Farm Reserve data shows winds from the south-west to the north. In comparison, most of the CALMET data shows wind from the west-southwest to the south-southeast.
- The James Park meteorological data and the CALMET meteorological data are similar in terms of wind direction. However, the CALMET data show a greater spread of wind directions.

Overall, the CALMET data shows higher wind speeds and a lower percentage of calm conditions than recorded at James Park or at Rainbow Farm Reserve.

It is important to note the following regarding the James Park and Rainbow Farm Reserve meteorological monitoring data:

- Missing data – A substantial amount of data are missing for the monitoring period (more than 20 per cent of data are missing from James Park and < 20 per cent for Rainbow Farm Reserve).
- Interference– Based on the expected wind patterns and the measured winds at Rainbow Farm Reserve, there appears to be some interference by the large trees located to the west of the Rainbow Farm Reserve monitoring station (despite the station being located in accordance with AS3580.14-2011). Winds from the west are usually the dominant flow for the region, but were rarely recorded by this monitoring station.
- Wind speed - The measured wind speeds at Rainbow Farm Reserve and James Park are unusually low. At Rainbow Farm Reserve, more than 38 per cent of all measured wind speeds fell between 0.5 and 1 m/s (1.8 to 3.6 km/h). At James Park, 30 per cent of the winds were less than 1 m/s (3.6 km/h) and 48 per cent of the winds were between 1 and 3.3 m/s (11.8 km/h). The fastest wind speed recorded at both Rainbow Farm Reserve and James Park was 5.4 m/s (19.4 km/h).

Based on available data from project monitoring stations and the limitations referred to above, a conclusive comparison between project monitoring station data and CALMET data is not possible. However, there is sufficient information to form a general view that there is likely to be a higher percentage of calm and very low wind conditions experienced around the northern and southern ventilation outlets than reflected in the CALMET meteorological data.

The tendency for calm conditions to be under predicted by the CALMET meteorological is recognised, and typically taken into account when analysing and interpreting related air dispersion modelling predictions. As part of this analysis and interpretation, it is important to recognise that plume behaviour is influenced by two significant factors:

- Plume velocity and buoyancy, which drive the vertical component of a plume, pushing it into the atmosphere. Some of this upward energy will contribute to dispersion of the plume as it rises.
- Ambient winds, which drive the horizontal or lateral component of plume, pushing it away from a straight vertical ascent. Energy from ambient winds will contribute to dispersion of the plume.

The balance between the vertical and horizontal forces affecting a plume will determine how high it rises before 'bending' from its vertical ascent, and the degree to which the plume 'bends'. Under high winds, a plume is more likely to be dominated by a horizontal component, leading to early plume 'bending' and increased horizontal dispersion. In the case of calm or very light winds, a plume is likely to ascend much higher before being affected by significant horizontal dispersion. Depending on the specific situation, it is therefore often moderate winds, rather than high wind speeds or calm conditions that are of particular interest when considering peak ground level air quality impacts.

In the case of the NorthConnex project, a preliminary analysis suggests that the plumes could rise up to around 100 metres above each of the ventilation outlets in calm conditions. Under high wind conditions, the plumes are expected to rise by up to around 30 metres above the ventilation outlets before being significantly affected by the horizontal component of ambient winds. This would suggest that calm conditions and low wind speeds may not be the limiting factor when assessing the potential peak air quality impacts of the project. This issue is considered further in the analysis in the following section.

2.11 Ambient air quality

This section provides information and discussion of:

- The approach taken to selecting background (ambient) air quality data for use in the air quality impact assessment for the project.
- Consideration of the representativeness of background air quality data having regard to local data collected from project monitoring stations.

2.11.1 Approach taken for the project

The air quality impact assessment for the project has been carried out in accordance with the Approved Methods for the Modelling and Assessment of Air Pollutants in New South Wales (DEC, 2005a) (the Approved Methods guidelines). This involved preparing a dispersion model with site-specific background air quality data and meteorological data inputs.

The Approved Methods guidelines require a minimum of one year of background air quality data and meteorological data in the dispersion model. The NorthConnex dispersion model has used three years of background air quality and meteorological data, to provide a more rigorous and comprehensive analysis of potential air dispersion scenarios.

The Approved Methods guidelines recognise that it is ideal to gather background air quality monitoring data from the site of a proposed development. The Approved Methods guidelines recognise that it is 'extremely rare' for one year of background air quality monitoring data to be available. Where it is available, the Approved Methods guidelines recommend that data be sourced from a location as close as possible to the proposed development site where the sources of air pollution resemble the existing sources at the proposed development site.

At the time of conducting the air quality impact assessment for the project, background air quality and meteorological data was available from:

- Several years of background air quality and meteorological data available from an existing network of monitoring stations operated by the Office of Environment and Heritage and the Australian Bureau of Meteorology across the Sydney Metropolitan Area. There are 15 monitoring stations in the Sydney region (including the Southern Highlands), the two nearest monitoring stations to the project being Prospect and Lindfield.
- Around four months of background air quality and meteorological data from five monitoring stations installed along the NorthConnex project corridor. The two road monitoring stations were positioned close to Pennant Hills Road (to monitor air quality for receivers significantly affected by traffic emissions along the Pennant Hills Road corridor) and the three ambient monitoring stations were positioned away from Pennant Hills Road (to monitor air quality for receivers away from and not significantly affected by traffic emissions along the Pennant Hills Road corridor, or from other major road sources). Air quality and meteorological data have continued to be collected from these monitoring stations, with data up to and including August 2014 available at the time of preparation of this report (around nine months of data in total).

The background air quality and meteorological data from the Office of Environment and Heritage and the Australian Bureau of Meteorology was identified as satisfying the requirements of the Approved Methods guidelines. The first requirement is satisfied because more than a year's worth of data was available and the sources of air pollution resemble existing sources in the project area. Relevantly, areas around Lindfield and Prospect exhibit similar land use patterns and development types as exists along the project corridor, with principal sources of air pollution similar in scale and nature.

For the second requirement of the Approved Methods guidelines, the background air quality data from the Office of Environment and Heritage monitoring stations has been compared with data collected from the ambient monitoring stations installed along the Pennant Hills Road corridor to determine whether it is representative of background air quality around the NorthConnex project. These data are presented in **Table 2-52**.

Receivers in proximity to Pennant Hills Road and other major roads are recognised as likely to experience higher levels of background air pollution compared to receivers further removed from those major roads. This can be seen by comparing the data presented in **Table 2-52**, from the project road monitoring stations (located close to Pennant Hills Road), with the data from the project ambient monitoring stations (located away from Pennant Hills Road). In all cases, concentrations of relevant air pollutants are markedly higher at monitoring stations close to Pennant Hills Road.

To adequately account for the influence of vehicle emissions along Pennant Hills Road and other major roads, background air quality along major road corridors was modelled at more than 6,900 locations using an advance dispersion model (CAL3QHCR) developed for application to linear sources such as roads. Full details of this modelling are provided in the Technical Paper: Air Quality (Appendix G to the environmental impact statement).

The results of this air quality modelling were compared to the background air quality measured for receivers away from the influence of vehicle emissions from major roads (ie data from existing monitoring stations). Where the major road air quality modelling results were higher than background air quality data, the modelled background air quality results were applied rather than background air quality data from monitoring stations.

In relation to cumulative pollutant concentrations, Table 7-97 of the environmental impact statement provides the peak cumulative concentration of all assessed pollutants (ie the project contribution plus the background concentration).

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Table 2-52 Background air quality monitoring data

Pollutant (averaging period)	Statistic	Project road monitoring stations (December 2013 – August 2014)		Project ambient monitoring stations (December 2013 – August 2014)			OEH monitoring stations – Prospect and Lindfield		
		Observatory Park	Brickpit Park	Headen Sports Park	Rainbow Farm Reserve	James Park	Year 1	Year 2	Year 3
PM ₁₀ (24-hour) (µg/m ³)	Maximum	50	47	40	35	41	222	48	42
	95 th percentile	32	29	26	22	25	36	27	28
	Average	20	18	14	13	16	21	16	16
PM _{2.5} (24-hour) (µg/m ³)	Maximum	38	32	30	29	27	78	17	15
	95 th percentile	20	17	16	16	15	13	10	10
	Average	12	9	10	8	9	7	6	6
NO ₂ (1-hour) (µg/m ³)	Maximum	155	109	90	107	87	100	81	75
	95 th percentile	89	62	44	58	48	47	49	47
	Average	42	29	17	26	18	22	23	22
CO (1-hour) (µg/m ³)	Maximum	2,251	1,373	2,205	1,884	1,693	3,625	3,250	2,875
	95 th percentile	1,138	678	577	789	514	1,125	1,000	1,000
	Average	453	314	216	302	214	451	419	419
O ₃ (1-hour) (µg/m ³)	Maximum	119	162	156	154	173	218	204	247
	95 th percentile	49	61	68	61	67	86	76	71
	Average	19	28	35	26	35	36	32	32

Project NO₂, CO and O₃ values have been converted to µg/m³ @ 0°C, using the conversion factors in Section 12, Table 12.1 of the Approved Methods for the Modelling and Assessment of Air Pollutants in New South Wales (DEC, 2005a)

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2.11.2 Approach to particulate matter concentrations (PM_{2.5})

PM_{2.5} concentrations are not monitored at the Lindfield or Prospect monitoring stations. In order to estimate ambient PM_{2.5} concentrations, 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 air quality impact assessment presented in the environmental impact statement, which was 0.35. This ratio was applied to the combined PM₁₀ monitoring data from Lindfield/Prospect to estimate hourly PM_{2.5} concentrations.

This assumption has been revisited since publication of the environmental impact statement to test whether it is reasonable. A sensitivity analysis has been conducted, which considers whether a higher ratio (0.50 PM_{2.5} to PM₁₀) would significantly alter the outcomes of the air quality impact assessment (in terms of the acceptability or otherwise of predicted ground level concentrations of PM_{2.5})

Five receiver locations with predicted elevated PM_{2.5} concentrations (as identified from the modelling and assessment presented in the environmental impact statement) have been selected for analysis. All of these receiver locations had background pollutant contributions based on ambient (OEH) monitoring data (rather than from outputs from the CAL3QHCR model for roadside receiver locations). The background (ambient) concentration of PM_{2.5} at each of these receiver locations was amended to reflect PM_{2.5} as 50 per cent of PM₁₀ and compared with the approach taken in the environmental impact statement (ie PM_{2.5} as 35 per cent of PM₁₀).

The results of this comparison are presented in **Table 2-53**. The results are based on the forecast traffic volume scenario in 2019.

The results of the analysis of the five receiver locations with elevated PM_{2.5} concentrations shows that while the cumulative concentrations increase for PM_{2.5}, no additional exceedances of the advisory reporting standard (that is, exceedances in addition to those present in the background) are expected when the data are considered contemporaneously. The increased PM_{2.5} background concentrations are due to the higher PM_{2.5} ratio which, when applied to the ambient monitoring data from Prospect/ Lindfield, result in five additional exceedances in 2009. As the exceedances are related to the background concentrations and not project contributions, however, these additional exceedances are not an issue of concern for compliance for the project.

Table 2-53 Comparison of cumulative PM_{2.5} concentrations (35% and 50% PM_{2.5})

Pollutant	Background Calculation Method	Statistic	Receiver location				
			1	2	3	4	5
PM _{2.5} (24 hour)	35% PM _{2.5} to PM ₁₀ ratio	Maximum (µg/m ³)	77.6	77.6	77.6	77.6	77.6
		Average	7.5	7.5	7.5	7.5	7.5
		Number of exceedances of advisory reporting standard	4	4	4	4	4
	50% PM _{2.5} to PM ₁₀ ratio	Maximum value	110.8	110.8	110.8	110.8	110.8
		Average value	10.6	10.6	10.6	10.6	10.6
		Number of exceedances of advisory reporting standard	9	9	9	9	9

2.11.3 Representativeness of background air quality data

To demonstrate the representativeness of the Lindfield/ Prospect monitoring for conditions along the project corridor, data from those monitoring stations has been compared with data collected the project ambient monitoring stations (Rainbow Park Reserve, James Park and Headen Park). The analysis has compared data between January 2014 and August 2014 contemporaneously (data collected at the same time at each monitoring station has been compared).

The monitoring data from the project monitoring stations at Brickpit Park and Observatory Park is affected by surface road emissions (due to the proximity of Pennant Hills Road) and has been used separately to validate surface road dispersion modelling (refer to **Section 2.13.3**).

Figure 2-13 and **Figure 2-14** show this comparison for NO₂ (one hour average) and PM₁₀ (24 hour average).

The data shown from the monitoring stations at Prospect and Lindfield represent the maximum concentrations recorded at either Prospect or Lindfield for each monitoring period. This approach has been taken to be consistent with the methodology applied to the air quality impact assessment for the project.

For one hour average NO₂, the project monitoring data and the maximum Prospect/ Lindfield data (refer to **Figure 2-13**) follow the same general trends. The Prospect/ Lindfield monitoring data follows the most similar in trend to the Rainbow Park data, while the Headen Park data are typically much lower than the data recorded at the other monitoring stations. Overall, the maximum Prospect/ Lindfield data are considered to be representative of NO₂ levels in the project area, and slightly higher than data collected from monitoring stations along the project corridor in most cases.

For 24 hour average PM₁₀, the data from the three project monitoring stations typically follow the same trends (refer **Figure 2-14**). The project monitoring data shows a high degree of agreement with the maximum Prospect/ Lindfield data, with the maximum Prospect/ Lindfield data generally being higher than the project monitoring data. The peak value of the Prospect/ Lindfield data is higher than the project monitoring data. As such, the data indicate that the Prospect/ Lindfield maximum data represent a conservative estimate of ambient PM₁₀ levels in the project area.

As the Prospect/ Lindfield data are currently similar to the project monitoring data, and there are no known reasons to assume that significant differences might have occurred between the project area and the Prospect/ Lindfield monitoring locations in the recent past (since 2009), the use of the maximum Prospect/ Lindfield data for ambient pollutant concentrations in the dispersion modelling undertaken for the environmental impact statement and in this report, measured between 2009 and 2011, is considered to be appropriate.

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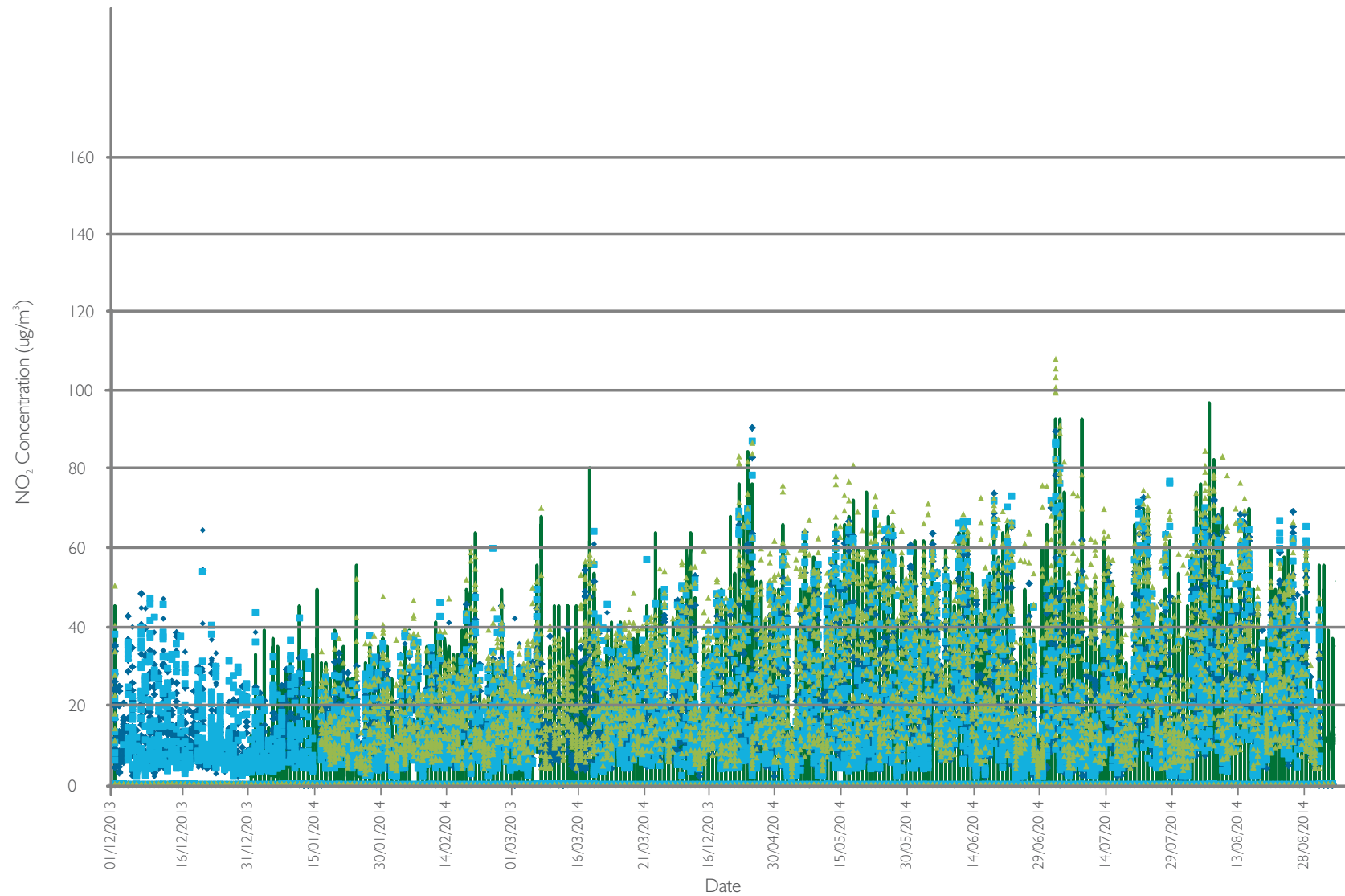


Figure 2-13 24 hour NO₂ concentrations (ug/m³) - January to August 2014

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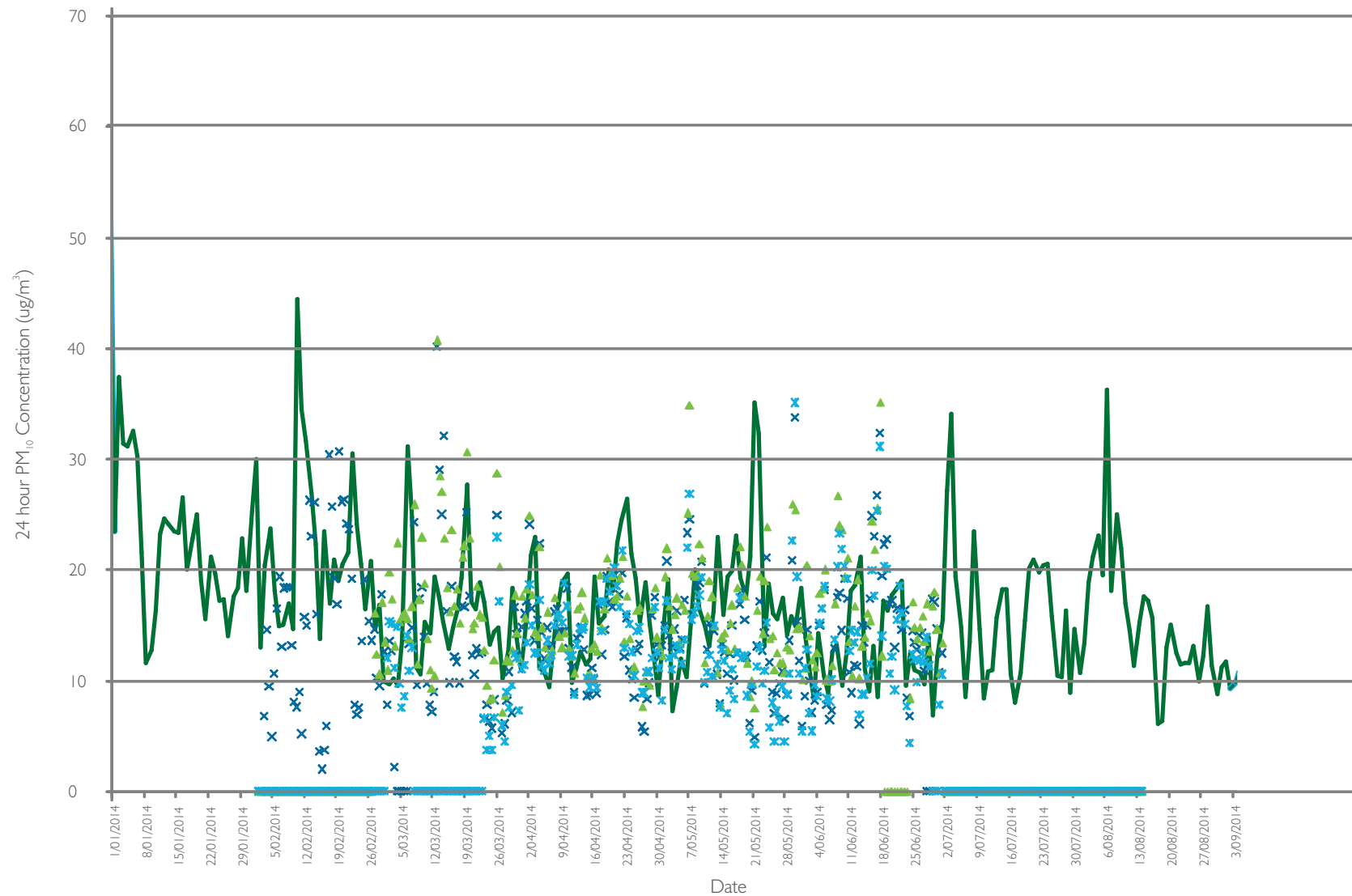


Figure 2-14 24 hour PM₁₀ concentrations (ug/m³) - January to August 2014

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2.12 Local and regional terrain

This section provides information and discussion in relation to:

- Local and regional terrain data used in the air quality impact assessment.
- A sensitivity analysis to test the terrain data that has been used.

2.12.1 Terrain data used in the air quality impact assessment

The air quality impact assessment for the project (as presented in the environmental impact statement) has relied on topographic data from the Shuttle Radar Topography Mission (SRTM), which utilised a modified radar system on board the Space Shuttle Endeavour to gather topographic data across almost all of the Earth. The SRTM was an international project directed by the United States National Geospatial-Intelligence Agency (NGA) and the National Aeronautics and Space Administration (NASA).

The SRTM topographic data has been used in the air quality impact assessment in two key areas:

- In the meteorological modelling using the CALMET model (refer to **Section 2.10**).
- In the air dispersion modelling using the CALPUFF model (refer to **Section 2.13**).

SRTM topographic data has been used for the air quality impact assessment presented in the environmental impact statement at a resolution of approximately 90 metres.

The CALMET meteorological model has been with a model grid resolution of 250 metres. The terrain height in the CALMET meteorological model has been determined based on an interpolated average of all the terrain heights that fall within the corresponding SRTM topographic data cells. That is, within each 250 metre by 250 metre CALMET model grid cell, there are at least four 90 metre by 90 metre SRTM topographic data cells which have been used to determine terrain height.

In the case of the CALPUFF air dispersion model, a finer resolution modelling grid has been used with defined receiver locations. The terrain elevations for each receiver location, and for the northern and southern ventilation outlet emission sources, have been separately interpolated from the 90 metre resolution SRTM topographic data in the same manner as for the CALMET model terrain data. If a receiver location fell between two horizontally displaced 90 metre terrain height locations, the CALPUFF model could either interpolate between the two heights or take the peak between the two. In the case of the air dispersion modelling carried out for the project, the more conservative approach of taking the peak terrain value for these receivers have been applied. This approach will tend to overestimate the height of the receiver relative to the ventilation outlet height, leading to a more conservative (overestimate) of ground level concentrations of emissions.

The approach taken to terrain assumptions and the use of topographic data in the air quality impact assessment for the project is consistent with Generic Guidance and Optimum Model Settings for the CALPUFF Modelling System for Inclusion into the Approved Methods for the Modelling and Assessments of Air Pollutants in NSW, Australia (OEH, 2011). This guideline states that *'the SRTM data is recommended*

for all applications conducted in NSW, Australia', and makes specific reference to the use of 90 metre SRTM data.

2.12.2 Sensitivity analysis of terrain data

Some of the submissions received in response to the exhibition of the environmental impact statement for the project have questioned the accuracy and reliability of SRTM topographic data.

All empirical data sets have an associated degree of uncertainty or error, typically as a result of the accuracy of the data gathering equipment and/ or the measurement methodology. The accuracy of SRTM topographic data has been assessed in An Assessment of the SRTM Topographic Products (Rodríguez et al, undated). The Rodríguez et al report compares topographic elevations from the SRTM with data gathered at 'ground control points' (GCPs) via a global positioning system (GPS) across a series of transects on each continent. Ground control points were generally accurate to around 0.5 metres.

With respect to SRTM data for Australia, the Rodríguez et al report identified that:

- The SRTM data has a mean error of 1.8 metres, with a standard deviation of 3.5 metres. The 90% absolute error in the data set for all of Australia was identified as 6.0 metres (refer to Table 2.1 in the Rodríguez et al report).
- The SRTM data was slightly more likely to overestimate topographic height than to underestimate it (refer to Figure 2.1 of the Rodríguez et al report).

These findings support the conclusion that the SRTM data is accurate with relatively low error magnitudes on average. Where errors do occur, they are more likely to overestimate the height of topography which, in the case of air quality dispersion modelling such as presented in the NorthConnex project, poses a greater risk of assessing elevated and more highly impacted receivers, rather than the converse. That is, there is a risk that SRTM data has overestimated the height of receiver locations around the ventilation outlets, which would have led to an overestimation of potential impacts at those locations.

To test the sensitivity of terrain data and assumptions in the air quality impact assessment, a screening level air dispersion model and assessment has been conducted for the northern ventilation outlet (as an example, with comparable results anticipated for the southern ventilation outlet). This screening level assessment considered:

- Terrain inputs based on SRTM topographic data, consistent with the approach taken in the environmental impact statement.
- Terrain inputs based on LiDAR topographic data measured along the project corridor.

LiDAR topographic data with resolution of one metre (and accuracy of ± 150 millimetres) was collected along the project corridor in August 2013. The data was collected for the purpose of informing the engineering design of the project, and provides an accurate, high resolution and recent topographic data set. The LiDAR data was only collected along the project corridor, and was therefore not sufficient for use across the broader modelling domain considered as part of the air quality impact assessment. It is, however, useful in testing the sensitivity of the air dispersion

modelling of the project to topographic data and assumptions around the project's ventilation outlets.

A discrete receiver grid has been established using the one metre resolution LiDAR topographic data with a grid spacing of 150 metres, to match the grid spacing applied to the air quality assessment for the project. All other modelling inputs and assumptions, including source parameters (ventilation outlet height, emissions inventory, flow rates etc) and meteorology (one year of data) have not been altered from the inputs presented in the environmental impact statement.

Table 2-54 presents the outcomes of the screening level assessment based on terrain inputs based on SRTM 90 metre resolution topographic data and the LiDAR one metre resolution topographic data. The table presents ground level concentrations at the most affected receiver location based on forecast traffic data in 2019.

Table 2-54 shows that using the higher resolution LiDAR data produces lower predicted air quality impacts for all modelled pollutants. By corollary, this indicates that the air dispersion modelling presented in the environmental impact statement and employing SRTM 90 metre resolution data (as interpolated using the approach summarised above) is likely to have conservatively overestimated potential air quality impacts. Based on the screening level assessment using LiDAR data, the predicted air quality impacts (and associated human health risks) presented in the environmental impact statement may be overstated by around 10 to 20 per cent.

Table 2-54 Comparison of data sets

Pollutant (averaging period)	EIS design (90 metre SRTM)	LiDAR data (one metre)	Percentage change relative to EIS design
NO _x (one hour average)	119.0 µg/m ³	109.9 µg/m ³	-7.6%
NO _x (annual average)	1.29 µg/m ³	1.09 µg/m ³	-15.5%
PM ₁₀ (24 hour average)	0.94 µg/m ³	0.84 µg/m ³	-10.6%
PM ₁₀ (annual average)	0.08 µg/m ³	0.06 µg/m ³	-25.0%
PM _{2.5} (24 hour average)	0.88 µg/m ³	0.79 µg/m ³	-10.2%
PM _{2.5} (annual average)	0.07 µg/m ³	0.06 µg/m ³	-14.3%

As part of the further air quality impact assessment conducted for the submissions and preferred infrastructure report (to assess an increase in height of the northern and southern ventilation outlets by five metres), the assumptions and inputs relating to terrain have been reviewed.

The assumptions and inputs relating to terrain have been reviewed in light of submissions that suggested the 90 metre SRTM topographic data used to determine the receiver grid elevations may be too coarse or may not reflect local conditions. In response, the terrain data have been re-extracted using five metre resolution Land and Property Information (LPI) data. The elevations of the discrete receivers and the ventilation outlet locations have been identified using this revised data.

Section 2.15 of this report details the outcomes of the further air quality modelling taking into account this updated assumption/ input data.

2.13 Dispersion modelling

This section provides information and explanatory discussion relevant to the air dispersion modelling for the project, including:

- The receiver grid considered in the air quality impact assessment.
- Set up of the CALPUFF model for dispersion modelling from the ventilation outlets.
- Set up of the CAL3QHCR model for dispersion modelling from surface roads.

2.13.1 Receiver location grids

The CALMET meteorological modelling conducted in the air quality impact assessment employed a 60 kilometre by 62.5 kilometre modelling domain, with 250 metre resolution.

The CALPUFF air dispersion modelling conducted in the air quality impact assessment employed a 17 kilometre by 10 kilometre modelling domain. A 250 metre grid spacing was used to match the CALPUFF model with the CALMET model. Within that 250 metre grid spacing, finer modelling grids were applied for the purpose of modelling ground level concentrations of air emissions for relevant receivers.

Relevant receivers for the purpose of the air dispersion modelling, which were indicative locations rather than specific individual premises, were determined through the use of variable grid sizes depending on distance from a project ventilation outlet or a major road (Pennant Hills Road, the Hills M2 Motorway or the M1 Pacific Motorway).

As indicated in Section 4.2.6 of the environmental impact statement, a high density receiver grid of 150 metre spacing was applied to a five kilometre by five kilometre area around each of the project ventilation outlets. Outside this area (more than 2.5 kilometres from each ventilation outlet) a receiver grid with 300 metre spacing was applied.

For receivers along major road corridors, receiver locations were spaced at 10 metres, 35 metres, 105 metres, 160 metres and 225 metres from the road centreline.

In total, 6,919 receiver locations were considered in the air quality impact assessment. Figure 8 in the Technical Working Paper: Air Quality shows the receiver locations considered in the assessment.

The resolution of the receiver grids applied as part of the air quality impact was developed having regard to the guidance document Generic Guidance and Optimum Model Settings for the CALPUFF Modelling System for Inclusion into the Approved Methods for the Modelling and Assessment of Air Pollutants in NSW, Australia (OEH, 2011). One of the authors of that document, who is an internationally-recognised meteorological and air dispersion modelling specialist, peer reviewed and endorsed the CALMET and CALPUFF parameters used in the air quality assessment for the project. This included the receiver grid resolution.

As noted in Generic Guidance and Optimum Model Settings for the CALPUFF Modelling System for Inclusion into the Approved Methods for the Modelling and Assessment of Air Pollutants in NSW, Australia (OEH, 2011), the best receiver grid

spacing for each modelling project is dependent on the size of the modelling domain and the complexity of the terrain within the domain. The guidance document states that typical CALMET applications should include between 100 and 300 grid cells in both the x and y directions (OEH, 2011, page 18). Furthermore, it states that near-field applications may require modelling grid spacings of about 250 metres, while grid spacings of 150 metres may be required to resolve dominant terrain features (OEH, 2011, page 18).

Modelling domains and receiver grid resolutions for the air quality impact assessment have been developed consistent with the direction provided in the abovementioned guidance document. The CALMET meteorological modelling domain had 240 by 250 cells with a 250 metre spacing, while the CALPUFF air dispersion modelling domain had a grid spacing of 150 metres around the ventilation outlets to accommodate near-field effects. The terrain around the ventilation outlets is undulating, but was not considered to be complex with dominant terrain features. Based on advice provided in the guidance document (OEH, 2011), the project location and the project scale, the meteorological and air dispersion modelling grids were considered appropriate.

In addition the base receiver grids applied to the air quality impact assessment, a further 60 receiver locations were included in the air quality modelling. These receiver locations were health sensitive sites, including schools, hospitals, aged care and nursery care centres. Air quality modelling outcomes for these 60 locations were used to inform specific health risk assessments for those locations as part of the broader human health risk assessment presented in Section 7.4 and Appendix H of the environmental impact statement.

Although a 150 metre grid spacing around the project ventilation outlets is considered to be appropriate, a further screening level analysis has been conducted to demonstrate the potential effect of a reduced grid spacing. The screening level assessment has been based on:

- A 150 metre and a 25 metre receiver grid around the northern ventilation outlet.
- Forecast traffic flows in 2019.
- One year of meteorological data.
- Annual and 24 hour average PM_{2.5} concentrations.

Table 2-55 summarises the outcomes of the screening level assessment. It presents the maximum value modelled in the domain around the northern ventilation outlet, as well as the average value across the modelling domain. The table shows that:

- On average across the modelling domain around the northern ventilation outlet, a 25 metre grid spacing produces a slightly higher 24 hour average and annual average value PM_{2.5} concentration. However, the increase in the average value across the modelling domain is less than 0.5% of the advisory reporting standard in both cases.
- The peak 24 hour average and annual average PM_{2.5} concentrations are both higher with a 150 metre grid spacing than with the application of a 25 metre spacing. In the case of the 24 hour average, the relative difference is two percent of the advisory reporting standard. The difference in the annual average is less, at only 0.13%.

This demonstrates that the difference in the modelling domain grid spacing has a negligible impact on predicted ground level concentrations, on average. However, the use of a 150 metre grid spacing in the air quality impact assessment for the project is likely to have led to an overestimation of impacts at the most affected receiver location. This overestimation is negligible in the case of the annual average PM_{2.5} concentration, but up to two percent of the advisory reporting standard for the 24 hour average. This supports the conclusion that a 150 metre grid spacing is appropriate, and may in fact be conservative for shorter duration averaging periods.

Table 2-55 Comparison of 150 metre and 25 metre receiver grid spacings

Pollutant	Statistic	Ground level concentrations and percentage of advisory standard				Relative change (% of standard)
		150 metre grid	% of standard	25 metre grid	% of standard	
PM _{2.5} (24 hour average)	Average across domain	0.21 µg/m ³	0.84%	0.33 µg/m ³	1.32%	+0.48%
	Peak value	1.21 µg/m ³	4.84%	0.71 µg/m ³	2.84%	-2.0%
PM _{2.5} (annual average)	Average across domain	0.014 µg/m ³	0.18%	0.026 µg/m ³	0.33%	+0.15%
	Peak value	0.075 µg/m ³	0.94%	0.065 µg/m ³	0.81%	-0.13%

Notwithstanding the analysis above, the receiver grid has been revised and an updated grid spacing has been applied to the air quality impact assessment of the five metre increase in height at the northern and southern ventilation outlets. The receiver grid has been recalculated for the following spacings:

- 25 metre spacing for an area of 500 metres by 500 metres centred on each ventilation outlet.
- 50 metre spacing for an area of 1,000 metres by 1,000 metres centred on each ventilation outlet.
- 100 metre spacing for an area of 4,000 metres by 4,000 metres centred on each ventilation outlet.

2.13.2 Ventilation outlet modelling (CALPUFF)

This section provides information and discussion of:

- How the CALPUFF model has been set up and used to model dispersion from the project's ventilation outlets.
- Validation studies of the CALPUFF model.

Set up of the CALPUFF model

This section summarises the parameters applied to the CALPUFF model.

CALPUFF model parameters

CALPUFF model parameters, as applied to the air quality impact assessment presented in the environmental impact statement and as used for the assessments in this report are provided in **Table 2-56**.

Table 2-56 CALPUFF model input parameters

Parameter	Input
Modelling domain	Modelling domain of around 15 kilometres by 10 kilometres. MGA SW Coordinates (km): 315.300 E, 6260.500 S MGA NE Coordinates (km): 330.600 E, 6270.701 S
Modelling grid resolution	250 metre grid resolution as per the CALMET meteorological model.
Number of receivers	All grid resolutions provided above were modelled as discrete receiver locations (i.e. no gridded receivers) to account for varying grid resolution over the modelling domain. A total of 6,919 discrete receiver locations resulted from the modelling grids, including 3,332 receivers along the project corridor.
Dispersion algorithm	Turbulence-based coefficients
Hours modelled	26,280 hours (1,095 days) (8,760 hours per year)
Meteorological modelling period	1 January 2009 – 31 December 2011

Building wake effects

Potential building wake effects have been taken into account in the CALPUFF modelling. Assumptions and parameters adopted in this regard include:

- Northern ventilation outlet parameters (refer to **Table 2-57**).
- Southern ventilation outlet parameters (refer to **Table 2-58**).
- Parameters for other structures around the ventilation outlets (refer to **Table 2-59**).

Building wakes have been calculated using the PRIME algorithm.

Table 2-57 Northern ventilation outlet parameters

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

Table 2-58 Southern ventilation outlet parameters

Parameter	Value	Reference	Comments and assumptions
Outlet location	319,233 m E, 6,262,984 m S (MGA 56)	F3M2-5000-DR-UD-0516	Estimated from plan.
Outlet height	15 metres	F3M2-5000-DR-SK-UD-0525	Outlet 15 metres above adjacent land taken from plan
Outlet diameter	Hourly variable	F3M2-440-DR-US-0100.	Based on outlet opening area of 46 m ² .
Outlet temperature	Hourly variable	CALMET.DAT Files	Hourly temperature data assumed to be equal to ambient temperature with a correction. Temperature data were extracted from CALMET output at 319.244 metres East, 6,262,993 metres South (MGA 56). Ventilation outlet temperature differentials were added to outlet parameters to better replicate the expected hotter air leaving the

Parameter	Value	Reference	Comments and assumptions
			ventilation outlets than the ambient air conditions.
Outlet velocity	Hourly variable	Not applicable	Hourly velocities were calculated based on the hourly volumetric flow rates.
Building wakes	Variable	F3M2-5000-DR-UD-0516 F3M2-5000-DR-SK-UD-0510 F3M2-5000-DR-SK-UD-0508 F3M2-5000-DR-UD-DU-0513 F3M2-5000-DR-SK-UD-0525	Building dimensions from the southern ventilation station (VS01), water tank, covered service yard, workshop and Motorway Control Centre (MCC) were estimated from plans and input into the BPIP to estimate building wake effects on the southern outlet. Building parameters used to calculate building wakes are presented in the following table.

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Table 2-59 Building parameters used to calculated building wakes

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

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Validation studies of the CALPUFF model

Dispersion modelling from the project ventilation outlets utilised the CALPUFF suite of models which have been approved for use in NSW by the Environment Protection Authority and internationally by bodies such as the United States Environmental Protection Agency. The CALPUFF model is an advanced Gaussian modelling system for the simulation of atmospheric dispersion. It was first developed in the late 1980s and issued for use in 1990. Since that time, it has continued to be refined and updated, and continues to be an internationally-recognised air dispersion model.

The United States Environmental Protection Agency has designated CALPUFF as a 'Guideline Model' which means that it has undergone an extensive, multi-year (15 years) model assessment and evaluation process, including:

- Evaluation of the model performance relative to real-life observations.
- Requirements for model documentation, access and computer codes.
- An open, public review process involving public hearings.
- Formal peer review by committees created by the United States Environmental Protection Agency, professional organisations such as the United States Air and Waste Management Association (AWMA), and private sector industry groups such as the American Petroleum Institute (API), the United States Utility Air Regulatory Group (UARG) and the United States Electric Power Research Institute (EPRI).

The CALPUFF model has been accepted for use in several international jurisdictions, including Australia, Canada, Chile, Iceland, Italy, New Zealand, Saudi Arabia and the United States of America (among others).

The CALPUFF model has been evaluated against most well-known classic data sets, including in relation to long-range transport, short to intermediate-range transport and offshore/ coastal data sets. Some key evaluation and verification studies based on monitored, real-life data include:

- The Lovett Power Station Study (New York) which compared modelled and monitored concentrations of sulfur dioxide from the power station ventilation outlet for the CALPUFF, CTDMPUS and RTDM models. The study demonstrated that the CALPUFF model most accurately reflected actual monitoring data, and in most cases over-estimated ambient concentrations.
- The European Tracer Experiment (ETEX), which evaluated the performance of five models based on experimental release and monitoring of a perfluoromethylcyclohexane (PMCH) tracer. Of the five models that were evaluated, the combination of the CALPUFF model with MM5 meteorological data (as was used to model and assess the NorthConnex project) was identified as most accurately reflecting behaviour of the PMCH tracer in the atmosphere.
- The Kincaid Data Set, which compared modelled and monitored concentrations of a sulfur hexafluoride (SF₆) tracer using the CALPUFF and the AERMOD models. The study demonstrated that the CALPUFF model most accurately reflected monitored tracer concentrations in the atmosphere, and in most cases over-estimated the actual ambient concentrations (within 10 kilometres of the source).

On the basis of extensive evaluation studies and adoption of the model by several international jurisdictions, including within New South Wales, the CALPUFF model and modelling approach taken for the NorthConnex project are considered to be robust and appropriate.

2.13.3 Surface road modelling (CAL3QHCR)

This section provides information and discussion of:

- How the CAL3QHCR model has been set up and used to model dispersion from surface roads.
- Validation of the CAL3QHCR model outputs.

Set up of the CAL3QHCR model

The assessment of surface road air quality contributions has been conducted using the CALROADs modelling suite incorporating the CAL3QHCR model. A series of 'roadway links' or lengths of road have been assessed (refer to **Section 2.7.2**), each of which assumed that a certain number of vehicles were travelling along the roadway emitting pollution according to the vehicle fleet mix and traffic forecasts. The resultant pollutant concentrations have been predicted at receiver locations positioned perpendicular to the roadway links at distances up to 200 metres from the road centreline.

As part of the development of the overall modelling environment for the project, there was a need to define the background pollutant concentrations along the roadway at each of the receiver locations. The methodology adopted for the environmental impact statement assumed that the concentration at each receiver location was the maximum of the existing ambient pollution levels (as defined by the monitoring data from the Prospect and Lindfield monitoring stations) or modelled pollution levels from the CAL3QHCR model. The rationale for this methodology was that receiver locations close to surface roads would experience air quality dominated by surface road contributions (ie predicted with the CAL3QHCR) and receiver locations further away would experience air quality similar to ambient conditions, without the influence of surface roads.

The adopted methodology resulted in a spatially consistent background monitoring pattern with little to no spatial variation in pollution concentrations as the pollution moved away from the road. It is acknowledged that, in practice, the pollution would be expected to decrease rapidly in the area immediately adjacent to the surface road, and then decrease more slowly away from the surface road edge.

Validation of the CAL3QHCR model

Since publication of the environmental impact statement, the CAL3QHCR modelling has been reviewed to determine the extent to which it accurately reflects surface road air quality impacts, particular at very close distances. To clearly characterise the potential air quality conditions close to the edge of the road (within 30 metres of the road centreline) an analysis of the project monitoring data from Brickpit Park and Observatory has been conducted. Both of these monitoring stations have been established for the project, in proximity to Pennant Hills Road, to assess air quality conditions in areas influenced by emissions from Pennant Hills Road.

Monitoring data from Brickpit Park and Observatory Park have been compared with modelling results from CAL3QHCR at those locations. Monitoring data have been compared with outputs from the CAL3QHCR under forecast traffic volumes in 2019 (without the project). As discussed in the Technical Working Paper: Traffic and Transport, Pennant Hills Road is currently heavily congested and operating at or above its design capacity in many areas. As a consequence, there has been no appreciable growth in traffic volumes along Pennant Hills Road in recent years and this trend is anticipated to continue in the future without implementation of the project. Because traffic growth is being constrained by having largely reached its maximum capacity, it is considered reasonable to compare CAL3QHCR model outputs in 2019 with monitoring data from 2014.

Figure 2-15 and **Figure 2-16** compare CAL3QHCR model outputs and monitoring data for NO₂ (one hour) at Brickpit Park and Observatory Park, respectively. A similar analysis has been conducted for PM_{2.5} (24 hour), and is shown in **Figure 2-17** and **Figure 2-18** for Brickpit Park and Observatory Park, respectively

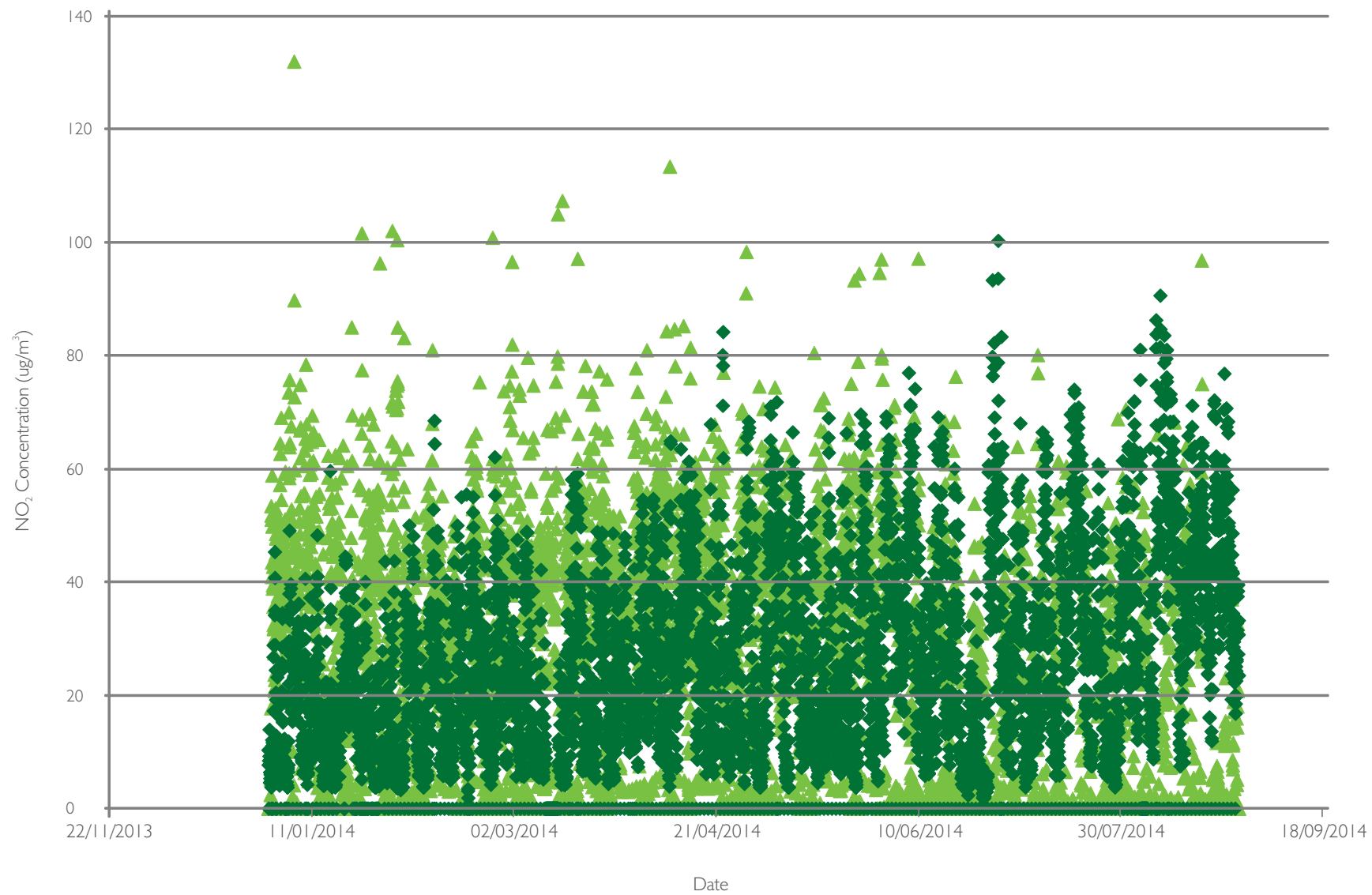
Figure 2-17 and **Figure 2-18** show that the concentrations of PM_{2.5} predicted by the CAL3QHCR model at the Brickpit Park and Observatory Park monitoring station locations are lower than monitored PM_{2.5} concentrations. Particulate matter emissions in the area around Pennant Hills Road would not be expected to be solely due to vehicle traffic along Pennant Hills Road, but road emissions would be expected to represent a substantial proportion of the measured particulate matter concentrations. The predicted PM_{2.5} concentrations at Brickpit Park from the CAL3QHCR model are, on average, 53 per cent below the monitored values, while the Observatory Park model outputs are on average 29 per cent of the monitored concentrations.

Figure 2-15 and **Figure 2-16** show that CAL3QHCR NO₂ model outputs are lower than monitoring data, but more closely reflect monitoring data than in the case of PM_{2.5}.

These comparisons results demonstrate that the surface road modelling predictions do not account for 100 per cent of the background pollutant concentrations measured at the Brickpit Park and Observatory Park monitoring stations.

To determine whether the CAL3QHCR model accurately predicts pollutant concentrations close to surface roads, monitoring data from roadside monitoring stations (Brickpit Park and Observatory Park) have been compared with ambient monitoring data (from the project monitoring station at Headen Sports Park). The objective of this analysis was to provide an indication of the relative contribution of the surface roads to monitored pollutant concentrations – that is, the difference between Headen Sports Park (away from major surface roads) and Brickpit Park and Observatory Park (close to Pennant Hills Road). The difference between monitored concentrations of pollutants at these locations has been used to provide an indication of the level of monitored pollutants that may be contributed by Pennant Hills Road.

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◆ Measured NO₂ (ug/m³)
 ▲ CALROADs NO₂ (ug/m³)

Figure 2-15 CAL3QHCR validation - Brickpit Park NO₂ (1 hour)

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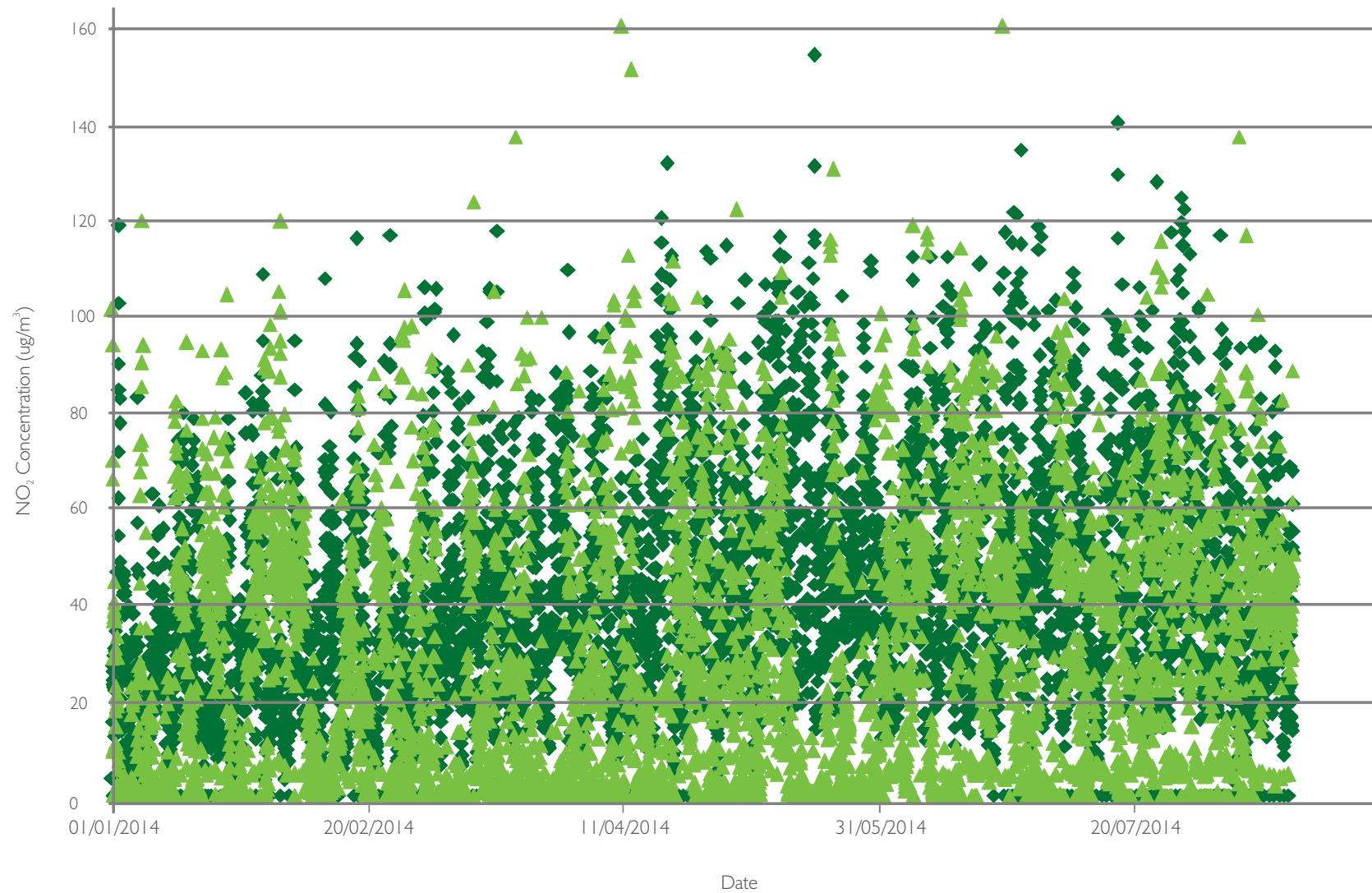


Figure 2-16 CAL3QHCR validation - Observatory Park NO₂ (1 hour)

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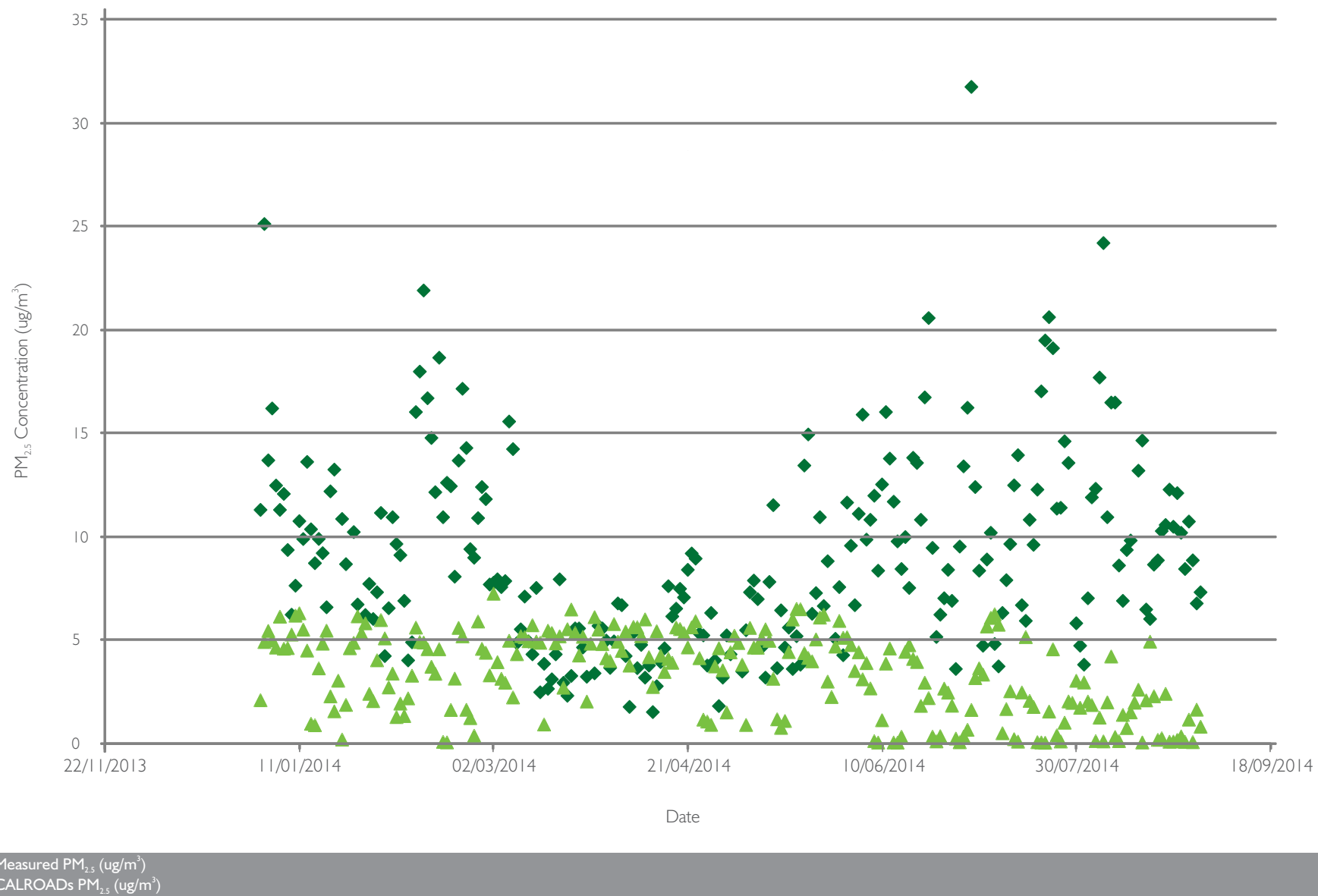
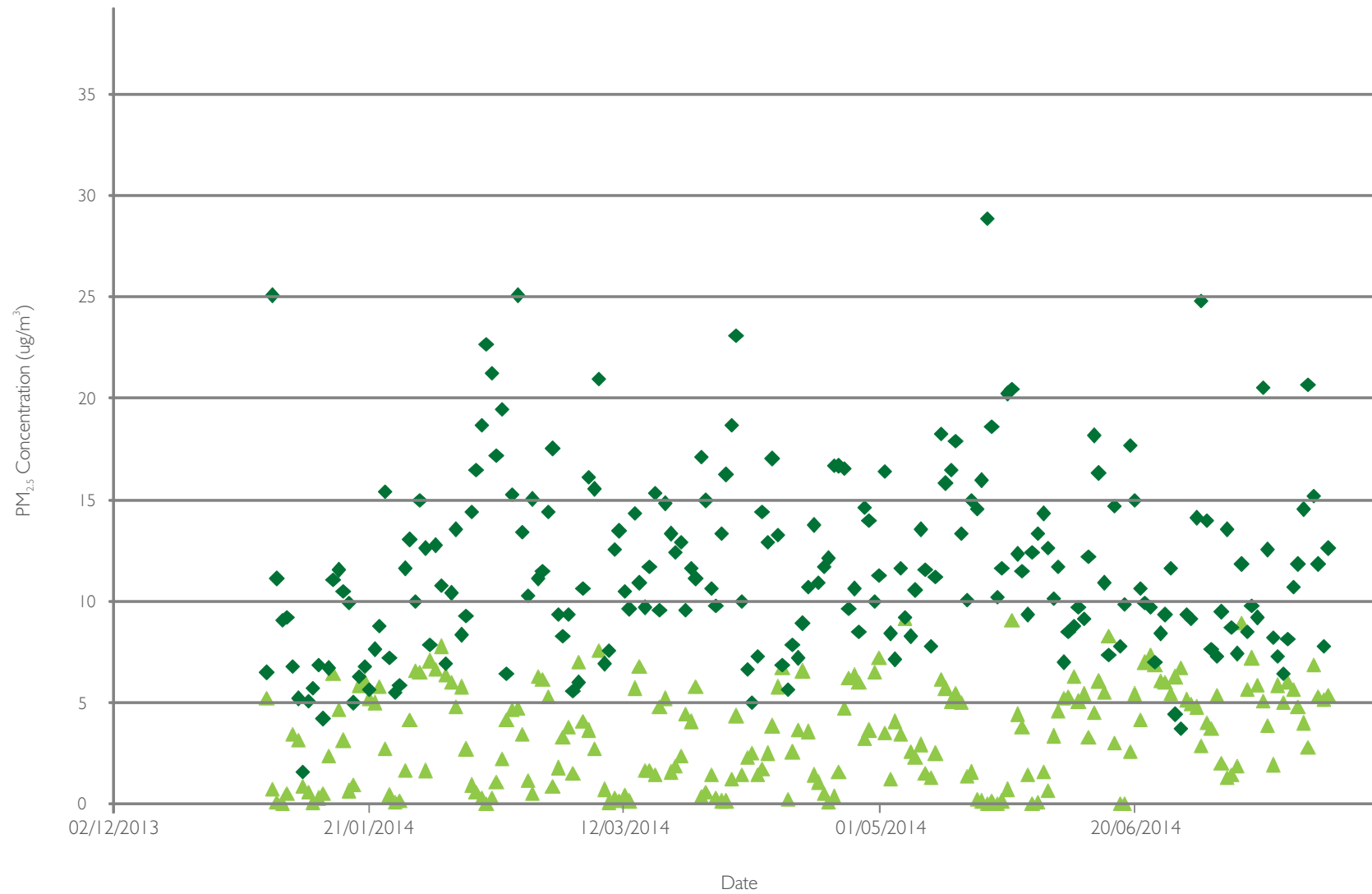


Figure 2-17 CAL3QHCR validation - Brickpit Park PM_{2.5} (24 hour)

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- ◆ Measured PM_{2.5} (ug/m³)
- ▲ CALROADs PM_{2.5} (ug/m³)

Figure 2-18 CAL3QHCR validation - Observatory Park PM_{2.5} (24 hour)

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This analysis considers three different values:

- **Modelled road contribution** – being the CAL3QHCR model output at the relevant location (Brickpit Park or Observatory Park).
- **Monitored roadside background** – being the monitored pollutant concentration at the relevant roadside monitoring location (Brickpit Park or Observatory Park).
- **Monitored ambient background** – being the monitored pollutant concentration at the Headen Sports Park monitoring station.

Because CAL3QHCR modelling relates to 2019 and monitoring data is available for 2014, a contemporaneous evaluation of values is not possible. As such, average values for each data set have been analysed and compared. Comparison of average values is intended to provide a high level analysis only, and provides an indication of relative differences rather than a definitive, absolute measure of the difference between the data sets.

Contributions from Pennant Hills Road have been estimated by subtracting Headen Sports Park average values from average values at Observatory Park (refer to **Table 2-60**) and Brickpit Park (refer to **Table 2-61**).

Table 2-60 Estimated surface road contribution (Observatory Park)

Pollutant	Monitored roadside background (Observatory Park) ($\mu\text{g}/\text{m}^3$)	Monitored ambient background (Headen Sports Park) ($\mu\text{g}/\text{m}^3$)	Estimated road contribution ($\mu\text{g}/\text{m}^3$)
Average PM ₁₀ (24 hour)	19.9	14.5	5.4
Average PM _{2.5} (24 hour)	11.7	10.4	1.3
Average NO ₂ (one hour)	43.1	17.9	25.2

Table 2-61 Estimated surface road contribution (Brickpit Park)

Pollutant	Monitored roadside background (Brickpit Park) ($\mu\text{g}/\text{m}^3$)	Monitored ambient background (Headen Sports Park) ($\mu\text{g}/\text{m}^3$)	Estimated road contribution ($\mu\text{g}/\text{m}^3$)
Average PM ₁₀ (24 hour)	17.9	14.5	3.4
Average PM _{2.5} (24 hour)	9.0	10.4	-1.4
Average NO ₂ (one hour)	24.8	17.9	6.9

Table 2-60 and **Table 2-61** show a marked difference between the estimated road contributions at Observatory Park and at Brickpit Park (with the latter showing lower estimated values). The potential reasons for this difference have been considered through visual analysis of the locations of the Observatory and Brickpit Park monitoring sites.

Both monitoring stations are located close to the road edge, with the Observatory Park monitoring station sited marginally closer to the road edge than at Brickpit Park. A solid retaining wall (around one metre in height) is located between the Brickpit Park monitoring station and Pennant Hills Road. This solid barrier may be affecting the flow of air between Pennant Hills Road and the Brickpit Park monitoring station, and may be leading to the formation of down-wind wakes (ie away from the road). These effects and presence of the retaining wall may be resulting in lower concentrations of pollutants being recorded at the Brickpit Park monitoring station (compared to what may be recorded in the absence of the effects of the retaining wall).

In comparison, visual analysis of the Observatory Park monitoring station site shows no similar structures or factors that may affected concentrations of monitored pollutants.

On this basis, monitoring data from Observatory Park has been used as the basis for further analysis, noting that it is more likely to represent a higher quality monitoring data set.

The estimated road contribution using data from the Observatory Park monitoring station (refer to **Table 2-60**) can be compared to the monitoring results from the CAL3QHCR model at this location. This comparison is presented in **Table 2-62** below. The table shows that there is good agreement between CAL3QHCR model predictions and estimated road contributions for NO₂. Model predictions are slightly higher than monitored data (estimated road contribution) for PM_{2.5} and slightly lower in the case of PM₁₀.

Table 2-62 Comparison of CAL3QHCR model predictions and estimated road contributions at Observatory Park

Pollutant	CAL3QHCR model predictions at Observatory Park (µg/m ³)	Estimated road contribution (µg/m ³) at Observatory Park
Average PM ₁₀ (24 hour)	3.6	5.4
Average PM _{2.5} (24 hour)	3.4	1.3
Average NO ₂ (one hour)	25.5	25.2

The outcome of this analysis is that the contributions of surface road pollution to background air quality for receivers close to surface roads (within about 30 metres) may not have been fully reflected in the cumulative concentrations calculated and presented in the environmental impact statement.

To test the effect of additional surface road pollution contributions for receivers close to surface roads, cumulative concentrations of pollutants have been compared for:

- The EIS scenario – as presented in the environmental impact statement, which assumed background air quality was the higher of CAL3QHCR model outputs or ambient monitoring data from Prospect/ Lindfield monitoring stations.
- The higher roadside scenario – which has added a further increment to background air quality data to account for higher pollutant concentrations near roads. The applied increments are:
 - PM_{10} – $5.4 \mu\text{g}/\text{m}^3$ (24 hour).
 - $PM_{2.5}$ – $1.3 \mu\text{g}/\text{m}^3$ (24 hour).
 - NO_2 – $25.2 \mu\text{g}/\text{m}^3$ (one hour)

These two scenarios have been considered for the five receiver locations predicted to experience the highest project contribution (ie highest contribution from operation of the project's ventilation outlets). The five receivers have been identified from the 2019 forecast traffic scenario using the 2009 meteorological data set.

It is relevant to note that for the five identified receiver locations for this analysis, all five had background contributions equal to ambient monitoring data from the Prospect/ Lindfield monitoring stations (rather than CAL3QHCR model outputs) for the air quality impact assessment presented in the environmental impact statement. All five receivers are close to surface roads around the northern ventilation outlet.

Comparison of cumulative concentration (project contribution plus background contribution) results for the two background calculation methods – the EIS method and the higher roadside method – is provided in **Table 2-63**. The table shows the effect of increasing background pollutant concentrations to take into account elevated surface road contributions for receiver locations close to roads (within about 30 metres) (the higher roadside method). The background concentration at each receiver location has been calculated contemporaneously.

Table 2-63 shows that neither the EIS method nor the higher roadside method lead to an exceedance of the applicable NO_2 criterion ($246 \mu\text{g}/\text{m}^3$) at any of the assessed receiver locations.

In the case of PM_{10} and $PM_{2.5}$ exceedances of the applicable ambient air quality criterion/ advisory reporting standard are predicted for both the EIS method and the higher roadside method. Importantly, the higher roadside method leads to no additional exceedances of the criterion/ standard for $PM_{2.5}$ and four additional exceedances for PM_{10} .

This analysis shows that applying the higher roadside method does not alter the outcomes of the air quality impact assessment (in terms of cumulative concentration compliance with applicable air quality criteria), although adopting this approach for roadside receivers would increase the magnitude of predicted cumulative concentrations. It is important to recognise that this is a high level analysis and only applicable to receiver locations close to roads (within around 30 metres). It should not be applied further across the modelling domain for receiver locations away from the influence of surface roads.

Table 2-63 Cumulative air quality concentrations at roadside receivers

Pollutant	Background contribution calculation method	Statistic	Receiver location (ranked, 1 = highest, 5 = 5th highest project contribution)				
			1	2	3	4	5
NO ₂ (one hour)	EIS method	Maximum value	133.7	133.4	131.9	130.5	128.3
		Average value	23.2	23.1	22.7	22.7	23.2
	Higher background method	Maximum value	158.9	158.6	157.1	155.7	153.5
		Average value	48.4	48.3	47.9	47.9	48.4
PM ₁₀ (24 hour)	EIS method	Maximum value	221.6	221.6	221.6	221.6	221.6
		Average value	21.3	21.2	21.2	21.2	21.3
		Number of exceedances of criterion	9	9	9	9	9
	Higher background method	Maximum value	227.1	227.0	227.0	227.0	227.0
		Average value	26.7	26.6	26.6	26.6	26.7
		Number of exceedances of criterion	13	13	13	13	13
PM _{2.5} (24 hour)	EIS method	Maximum value	77.59	77.57	77.57	77.56	77.56
		Average value	8.5	7.9	8.6	8.2	7.5
		Number of exceedances of advisory standard	4	4	4	4	4
	Higher background method	Maximum value	78.9	78.9	78.9	78.9	78.9
		Average value	9.8	9.2	9.9	9.5	8.8
		Number of exceedances of advisory standard	4	4	4	4	4

2.14 Post-processing of model outputs

The section provides information and explanatory discussion in relation to:

- Calculation of cumulative impacts and consideration of background air quality (refer to **Section 2.14.1**).
- Atmospheric conversion of oxides of nitrogen to nitrogen dioxide (refer to **Section 2.14.2**).

2.14.1 Cumulative impacts – consideration of background air quality

This section includes information and explanatory discussion relating to:

- The methodology used to consider the project, background and cumulative air quality contributions in the air quality impact assessment conducted for the project and presented in the environmental impact statement.
- A sensitivity analysis comparing the methodology adopted for the project (as presented in the environmental impact statement) with an alternative methodology, developed through different definitions and allocations of project, background and cumulative air quality contributions.

Approach taken for the project

The primary focus of the air quality impact assessments conducted for the project has been understanding the implications of the project's ventilation outlets for local air quality during operation.

As discussed in **Section 2.7.1** of this report, the project will also contribute to changes in traffic on surface roads which may also contribute to changes in air quality. These changes may result through a combination of direct changes to surface infrastructure (such as the Hills M2 Motorway integration works, the M1 Pacific Motorway tie-in works and the minor upgrade works at Pearces Corner) and as an indirect consequence of redistribution of surface traffic. Where direct changes to surface infrastructure are not proposed, changes in traffic volumes as a consequence of the project remain within the design capacity of the affected roads and generally represent a maintenance or improvement in current performance of those roads.

For the purpose of the air quality impact assessments conducted for the project, the following characterisation of changes in air quality have been applied:

- 'Project contributions' have been taken to be those changes in air quality directly attributable to the operation of the project's ventilation outlets.
- 'Background contributions' have been taken to be all other air quality contributions, including pollutant levels in ambient air in the region and contributions from surface roads (which includes both increases and decreases in road contributions as an indirect consequence of operation of the project). The approach to determining 'background contributions' for the purpose of the air quality impact assessments is detailed further below.
- 'Cumulative concentrations' have been taken to be the sum of the project contribution (from the ventilation outlets) and the background contribution (from

surface road modelling or ambient monitoring data) for a particular receiver location.

The air quality impact assessments for the project have taken the background contribution for a particular receiver as being the higher of either:

- The ambient concentration of a particular pollutant established through monitoring data collected by the Office of Environment and Heritage (refer to **Section 2.8** of this report); or
- The modelled pollutant concentration for a receiver location obtained from modelling air quality along major roads in the area using the CAL3QHCR model (refer to **Section 2.13.3** of this report).

The intention of this approach is to recognise that receiver locations along major roads are likely to experience air quality that is significantly affected by contributions from vehicles travelling along that road.

The project corridor is in an area that is not a major hub of industry or manufacturing facilities, and a review of the National Pollutant Inventory (NPI) indicates that there are very few sites within or around the project corridor that are required to report their emissions (i.e. major pollutant emitters). In contrast, receiver locations away from the influence of major roads are likely to experience similar air quality, consistent with the suburban nature of developments around the project corridor. **Section 2.11** of this report provides further discussion of the ambient air quality.

An alternative approach and sensitivity analysis

It is acknowledged that alternative approaches to the definition of 'project contributions' and 'background contributions' and the calculation of 'cumulative concentrations' could have been adopted for the project.

Different jurisdictions within Australian and internationally adopt different approaches to this issue.

An alternative approach involves the addition of three components to calculate a cumulative concentration by considering the sum of:

- Contributions from the project's ventilation outlets.
- Contributions from surface roads (which may be positive or negative, depending on the influence of the project on surface traffic distribution).
- Contributions from ambient air quality, such as is monitoring at ambient air quality monitoring stations.

A comparison of this three component alternative approach, compared to the two component approach used in the assessment of the project (as presented in the environmental impact statement), has been conducted to review the sensitivity of the assessment results to the selected methodology adopted.

Figure 2-19 shows the difference in approach between the methodology applied to the project (the project methodology) and this alternative approach (the alternative methodology). **Table 2-61** also summarises the components that are included in each aspect of the cumulative concentration calculation for the two assessment approaches.

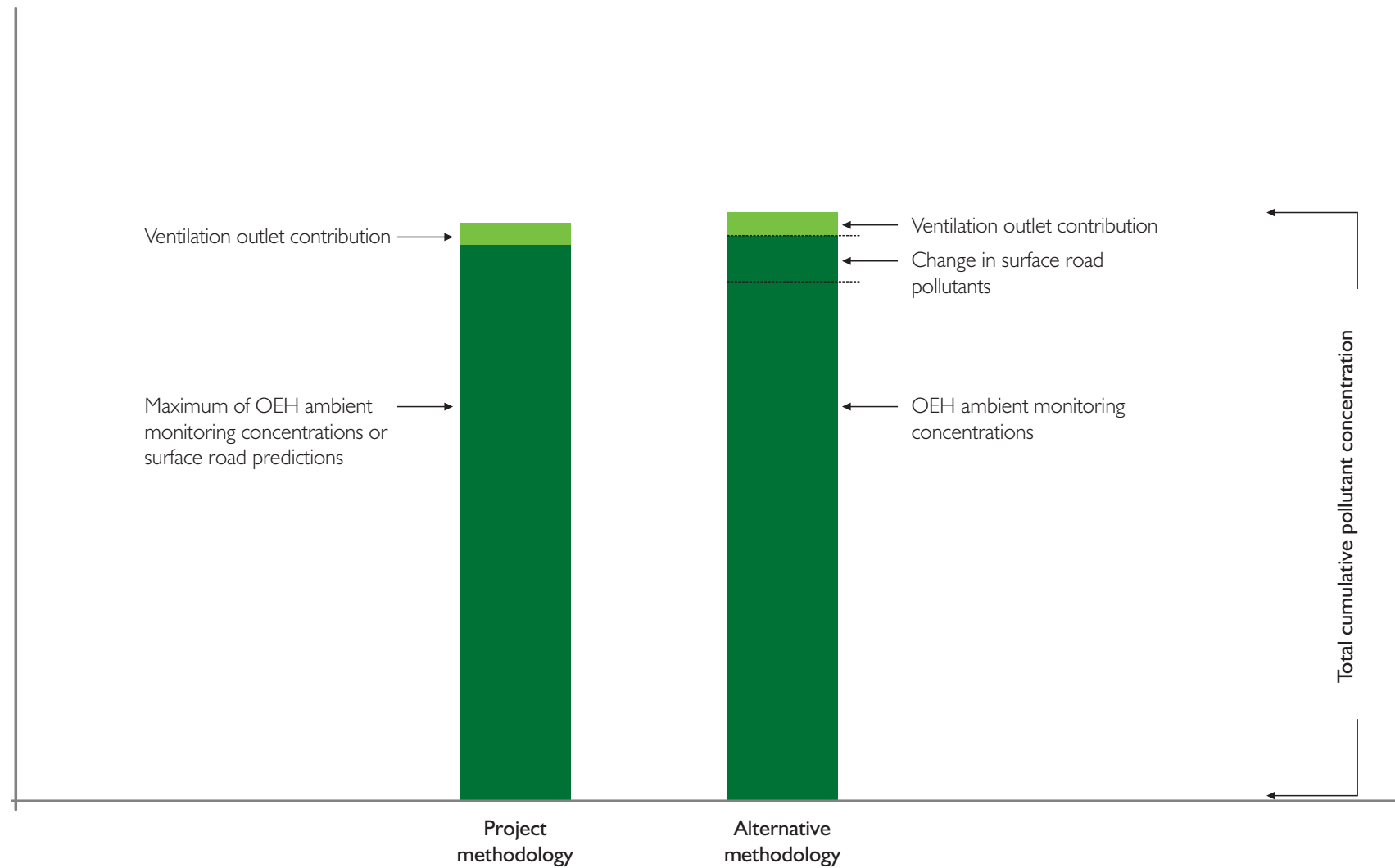


Figure 2-19 Comparison of project methodology and alternative methodology

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Table 2-64 Comparison of project contribution and cumulative concentration calculation methods

Component	Ventilation outlet contribution	Modelled surface road contribution			Ambient air quality monitoring data
		Without project (2019/ 2029)	With project (2019/ 2029)	Difference between 'with project' and 'without project' (2019/ 2029)	
Project methodology					
Project contribution	✓				
Background contribution			✓	← maximum of →	✓
Cumulative concentration	✓		✓	← →	✓
Alternative methodology					
Project contribution	✓			✓	
Background contribution					✓
Cumulative concentration	✓			✓	✓

The project methodology and the alternative methodology differ in two key respects:

- Assignment of surface traffic contributions. In the case of the project methodology, contributions from surface roads are allocated to background air quality rather than to project contributions. The alternative methodology assigns changes in surface road contributions (between the 'with project' and without project' scenarios) as a component of the project contribution (these surface road contributions may be positive or negative, depending on how the project affects surface traffic volumes).
- Both methodologies attempt to avoid 'double counting' surface road contributions to background air quality (which may result, for example, from adding monitored ambient air quality and contributions from surface roads). The project methodology endeavours to avoid this by taking the maximum value of either the monitored ambient air quality or the modelled surface road contributions. The alternative methodology takes a difference approach, and adds the change in surface road contributions (rather than the total surface road contributions from either the 'with project' or 'without project' scenarios) to the monitored ambient air quality.

The implications of the project methodology and the alternative methodology for the outcomes of the air quality impact assessments for the project have been tested by applying both approaches to three transects across the project corridor. A summary of the transects is provided in **Table 2-65**. The transects have been considered under forecast traffic volumes in 2019, with a summary of relevant traffic data at each transect provided in **Table 2-66**.

Table 2-65 Summary of assessed transects

Transect	Location	Forecast traffic
Northern	This transect is located across the M1 Pacific Motorway, north of the northern ventilation outlet and the northern portals (refer to Figure 2-20). It is positioned in a location that would be influenced by traffic entering and exiting the northern portals, and within the area affected by the northern ventilation outlet.	Total traffic volumes at this location are forecast to be higher with the project than without it. Heavy vehicle volumes at this location are forecast to be higher with the project than without it (refer to Table 2-66).
Central	This transect is located across Pennant Hills Road, south of Brickpit Park (around the mid point of the project) (refer to Figure 2-21). It is positioned in a location that is beyond the influence of the southern and northern ventilation outlets.	Total traffic volumes at this location are forecast to be lower with the project than without it. Heavy vehicle volumes at this location are forecast to be lower with the project than without it (refer to Table 2-66).
Southern	This transect is located across the Hills M2 Motorway, to the west of the southern interchange (refer to Figure 2-22). It is positioned in a location that would reflect traffic volumes on the motorway, including traffic entering and exiting the southern portals. The transect has been positioned to the west of the southern interchange to avoid the complexity of traffic movements through the interchange. The transect lies in an area beyond the immediate effects of the southern ventilation outlet.	Total traffic volumes at this location are forecast to be higher with the project than without it. Heavy vehicle volumes at this location are forecast to be lower with the project than without it (refer to Table 2-66). Importantly, heavy vehicles in this location are forecast to be lower in 2019 only, with an increase forecast in 2029. If the 2029 were to be considered, the result would be comparable to the northern transect, at which both total vehicles and heavy vehicles are forecast to increase.

The distinction made in the table above in relation to total traffic volumes and heavy vehicle volumes is important because heavy vehicles have a greater contribution to emissions than passenger vehicles. Where total vehicle numbers are forecast to increase, the total change in surface road emissions may not necessarily also increase if the forecast decreases in heavy vehicle numbers are sufficient to offset the increase in emissions from passenger vehicles. The effect of heavy vehicle volume changes (whether an increase or a decrease) will be more pronounced where the change in total traffic volumes are relatively small (ie where there is little change in passenger vehicle volumes between 'without project' and 'with project' scenarios, the effect of changes in heavy vehicle volumes will be more obvious).

Taking into account traffic forecasts, as summarised in **Table 2-66**, the forecast changes in traffic volumes could be expected to result in:

- At the northern transect – an increase in surface road emissions from the ‘without project’ to the ‘with project’ scenarios because total traffic volumes and heavy vehicle volume are both forecast to increase.
- At the central transect – a decrease in surface road emissions from the ‘without project’ to the ‘with project’ scenario, because total traffic volumes and heavy vehicle volume are both forecast to decrease.
- At the southern transect – either a decrease or an increase in surface road emissions from the ‘without project’ to the ‘with project’ scenario. Whether surface road emissions will decrease or increase will depend on the relative change in total vehicle numbers and heavy vehicle numbers (ie which change has a greater influence on total surface road emissions).

Along each transect, receiver locations have been identified to give a sense of air quality impacts in areas that are likely to be dominated by adjacent surface roads, and receiver locations further away (ie those areas more likely to be characterised by ambient air quality conditions away from the influence of surface roads). The locations of the three transects and the assessed receiver locations are shown in **Figure 2-20** (northern transect), **Figure 2-21** (central transect) and **Figure 2-22** (southern transect).

Each of the receiver locations has been assessed for PM₁₀ and NO₂ as project contributions, background contributions and cumulative concentrations using the project methodology and the alternative methodology. The assessment has been based on:

- Forecast traffic volumes in 2019 (Scenario 2a).
- One year of meteorological data (the 2009 meteorological year).

The results of this analysis are presented in the following sections.

Note that the discussion above and the following analysis is a simplification of a complex model that has a number of factors influencing results (such as traffic volumes, traffic mix, meteorology and topography). An important area of potential ‘interference’ for the transects that have been assessed is the possibility of changes within nearby road links. These changes may alter the modelled outcomes at each transect depending on wind conditions (ie transfer of additional pollutant loads from a nearby road link to the transect being assessed). This potential for interference has been addressed through the location of the transects away from any potential interference where practicable. This was practicable for the central transect and the southern transect, but not the northern transect which has a high potential to be influenced by nearby road links.

Table 2-66 Forecast traffic by transect

	Total vehicles (AADT)	Heavy vehicles (%)	Heavy vehicles (number)	Light vehicles (%)	Light vehicles (number)	NO_x emissions (g/vehicle kilometre)	PM₁₀ emissions (g/vehicle kilometre)
Northern transect							
Without project	92,541	13.3	12,339	86.7	80,203	0.56	0.34
With project	103,161	12.1	12,458	87.9	90,703	0.60	0.37
Central transect							
Without project	66,864	15.2	10,164	84.8	56,699	0.66	0.45
With project	53,681	6.6	3,528	93.4	50,153	0.39	0.22
Southern transect							
Without project	101,756	14.0	14,278	86.0	87,478	0.80	0.09
With project	103,166	13.0	13,419	87.0	89,747	0.75	0.09

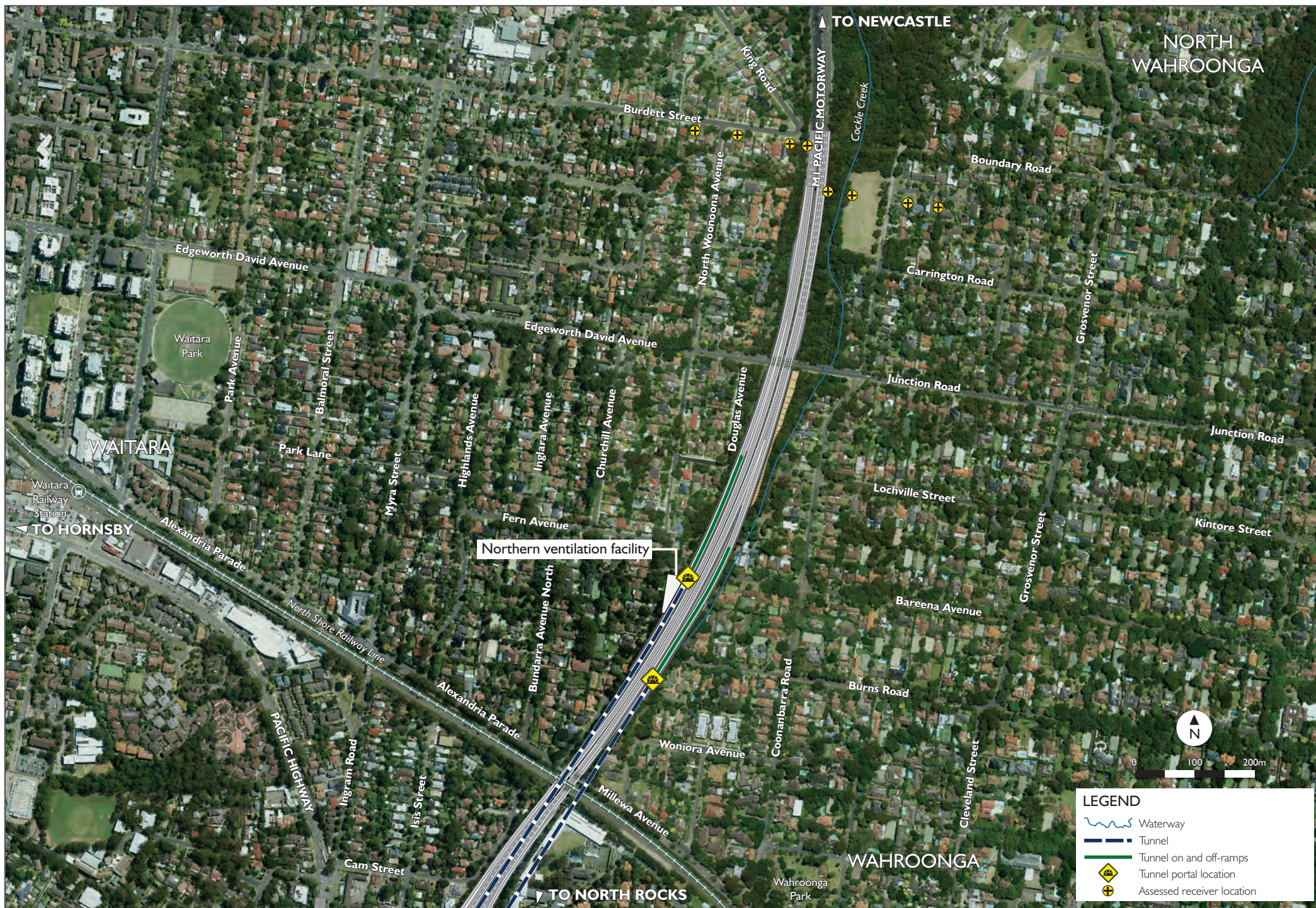


Figure 2-20 Northern assessment transects

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Figure 2-21 Central assessment transects

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Figure 2-22 Southern assessment transects

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NO₂ data comparison

Figure 2-23, **Figure 2-24** and **Figure 2-25** show the predicted surface road air quality contributions for the northern, central and southern transects, respectively. The figures show CAL3QHCR outputs under forecast traffic volumes at each transect (in 2019) for the 'without project' and the 'with project' scenarios.

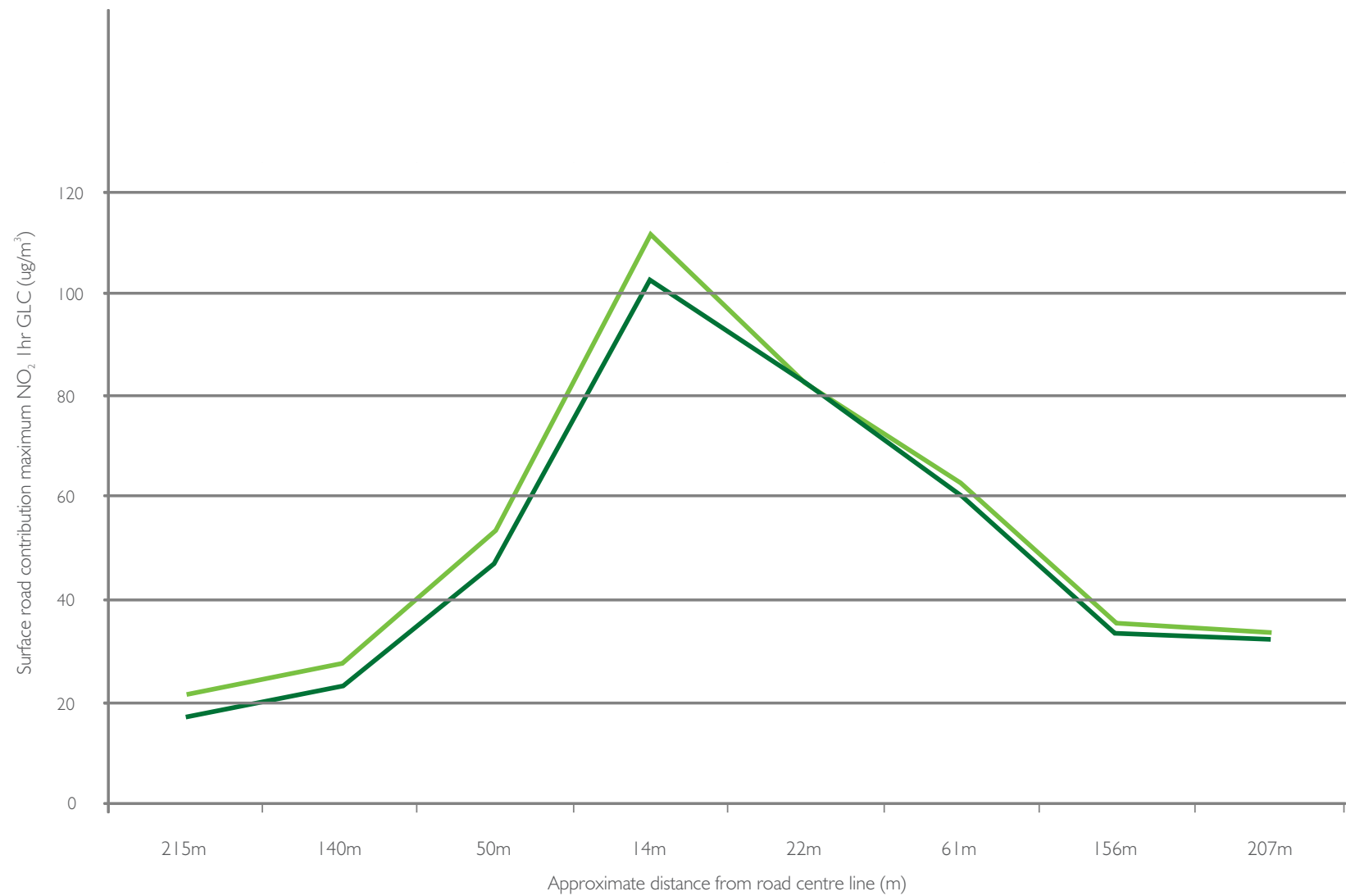
With the exception of the northern transect (**Figure 2-23**), changes in air quality reflect expected changes from the 'without project' and the 'with project' scenarios based on analysis of changes in traffic:

- For the central transect, total traffic volumes are forecast to decrease and heavy vehicle volumes are forecast to decrease. **Figure 2-24** shows a reduction in surface road emissions from the 'without project' to the 'with project' scenarios.
- For the southern transect, total traffic volumes are forecast to increase but heavy vehicles volumes are forecast to decrease (in 2019). **Figure 2-25** shows that taking these two changes into account, there is minimal overall change between the 'without project' and the 'with project' scenarios.

In the case of the northern transect, total vehicle volumes and heavy vehicle volumes are forecast to increase. On this basis, surface road emissions are anticipated to increase at this location from the 'without project' to the 'with project' scenario. However, **Figure 2-23** shows minimal difference between the scenarios and less than would be expected based on forecast increases in traffic.

Further investigation of this issue indicates that the unexpected results for surface road emissions at the northern transect are the result of interference from other road links in the area. That is, the unexpected result is a modelling artefact with the results presented in **Figure 2-23** not purely representing predictions for the M1 Pacific Motorway, but also reflecting the effects of other roads in the area. It is relevant to note that the CAL3QHCR includes a road link around 100 to 150 metres to the south east of the northern transect. Winds from the south east towards the northern transect are likely to have contributed emissions from that road link to the northern transect results. Based on meteorological data used in the air quality impact assessment for the project, winds around the northern ventilation outlet (close to the northern transect) show a predominance of winds from the east (from north-northeast to south-southeast), particularly during the summer.

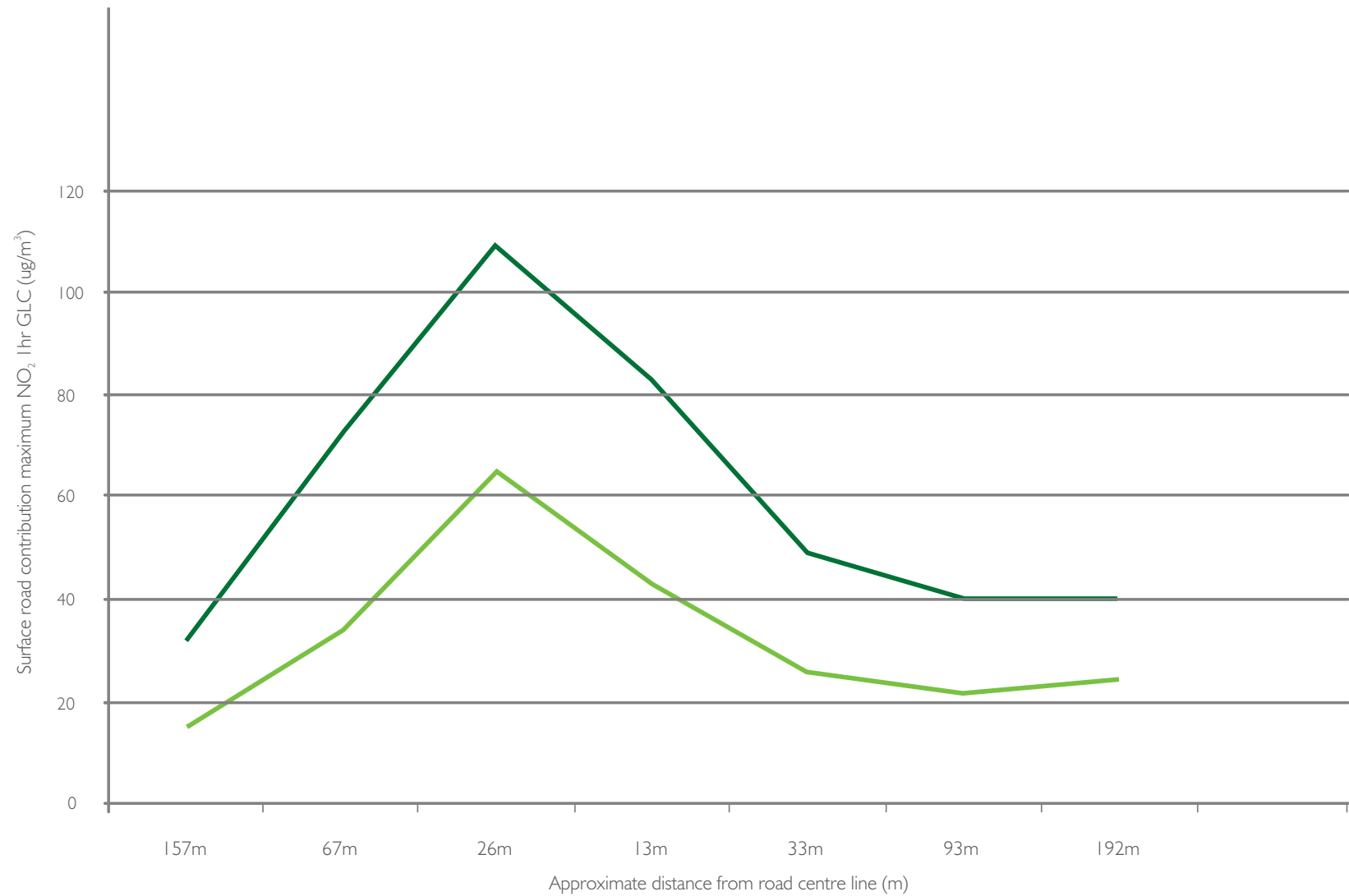
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With project
Without project

Figure 2-23 Transect 1 (northern) maximum NO₂ receptor results

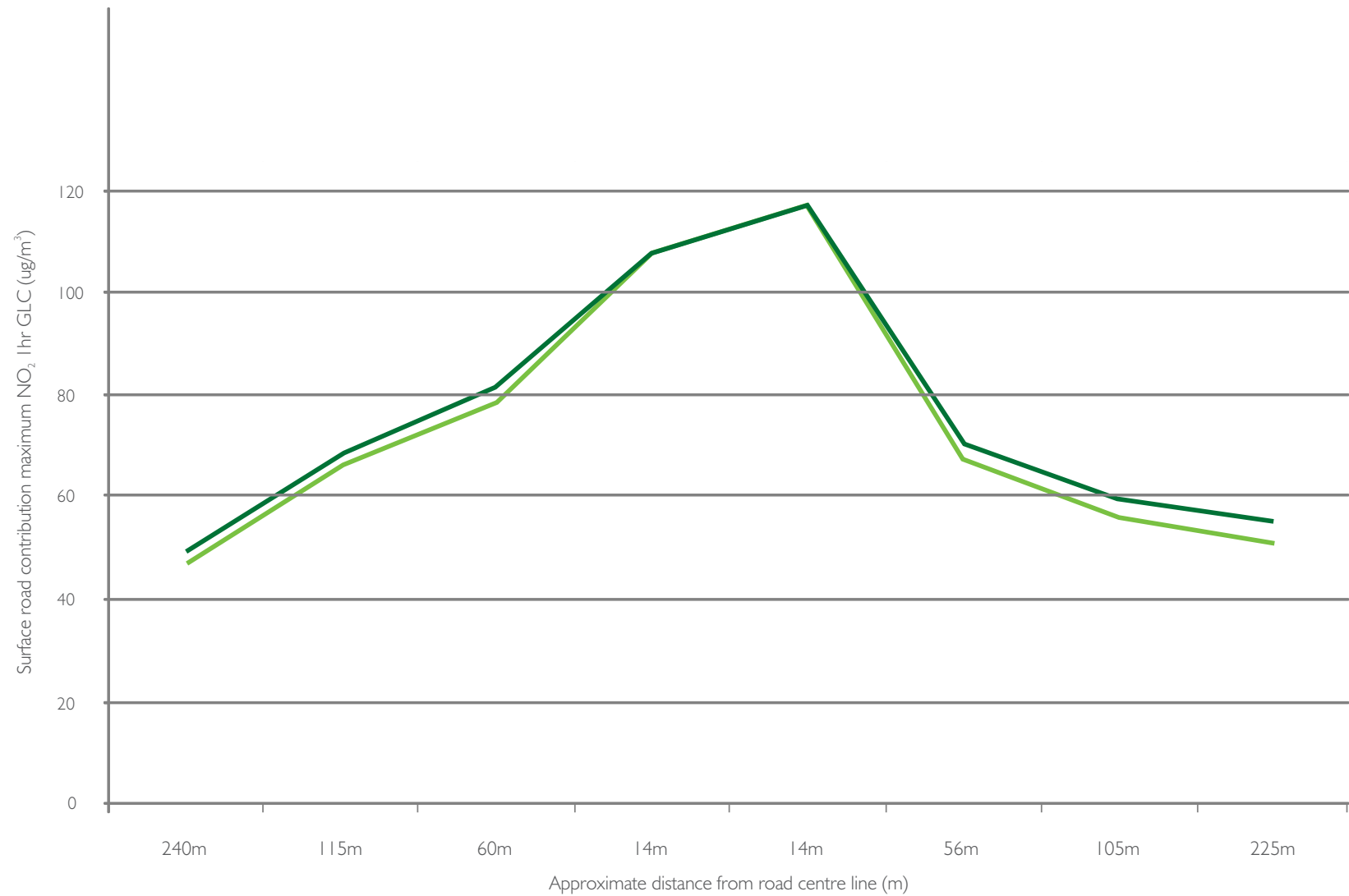
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With project
Without project

Figure 2-24 Transect 2 (middle) maximum NO₂ receptor results

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With project
Without project

Figure 2-25 Transect 3 (southern) maximum NO₂ receptor results

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The outputs from the CAL3QHCR modelling shown in the preceding figures have been used to calculate project contributions, background contributions and cumulative concentrations at each transect and receiver location. The project methodology and the alternative methodology have been applied, as detailed earlier in this section.

Table 2-67, **Table 2-68** and **Table 2-69** show the background contribution, the project contribution and the cumulative concentration of NO₂ for selected receiver locations calculated using the project methodology and the alternative methodology.

It should be noted that the minimum and maximum background and project contributions provided in the tables cannot be added to calculate the cumulative pollutant concentrations. This is because the cumulative concentrations have been calculated contemporaneously – that is, the background and project contributions have been paired in time. The maximum background concentrations did not occur at the same time as the maximum project contributions occurred, so the maximum cumulative concentration does not represent the maximum project contribution summed with the maximum background concentration. The same issue is present for the minimum data but, as the minimum project contributions are 0 µg/m³ at some receivers, the issue is not as apparent. With the average data, the background and project averages have been calculated and, as such, have no temporal association. The background and project averages can therefore be added together to determine cumulative concentrations.

Concentrations of NO₂ have been calculated from total nitrogen oxide concentrations using the ozone limiting method (refer to **Section 2.14.2**) and results are therefore affected by ambient concentrations of ozone.

Comparing the project methodology and the alternative methodology, the tables show that:

- The project methodology results in background NO₂ contributions that are equal to or higher than the background NO₂ contributions calculated using the alternative methodology. Where the project methodology results in the background contribution being higher than the alternative methodology, this indicates that the CAL3QHCR surface road modelling results are higher than the ambient monitoring data (Lindfield/ Prospect data set) at the relevant receiver location.
- The project methodology results in project NO₂ contributions that are higher than the minimum and average project contributions calculated using the alternative methodology. In the case of the maximum project NO₂ contributions, the project methodology and the alternative methodology show almost identical results at the southern and central transects. There are differences with the two methodologies evident in the results at the northern transect, with the alternative methodology producing slightly higher concentrations close to the road and the project methodology producing slightly higher concentrations further away from the road.
- The project methodology results in cumulative NO₂ concentrations that are higher than the minimum and average project contributions calculated using the alternative methodology. In the case of maximum cumulative concentrations the two methodologies produce identical results away from the road, while the project methodology produces higher cumulative concentrations for receivers close to the road.

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Table 2-67 Background contribution of NO₂ (one hour average) for selected receivers (µg/m³)

Project methodology – the maximum of OEH monitoring data or CAL3QHCR surface road model output (2019 and 2029 surface traffic)

Alternative methodology – OEH monitoring data

		Southern transect							
		240m	115m	60m	14m	14 m	56 m	105 m	225 m
Minimum value	Project methodology	1.9	1.9	1.9	1.9	1.9	0.9	0.9	0.9
	Alternative methodology	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
Average valve	Project methodology	22.4	23.5	25.4	33.6	33.4	24.5	23.1	22.3
	Alternative methodology	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0
Maximum value	Project methodology	99.6	99.6	99.6	108.1	117.9	99.6	99.6	99.6
	Alternative methodology	99.6	99.6	99.6	99.6	99.6	99.6	99.6	99.6
		Central transect							
		157 m	67 m	26 m	13m	33 m	93 m	192 m	
Minimum value	Project methodology	1.9	1.9	1.9	0.9	0.9	0.9	0.9	
	Alternative methodology	0.9	0.9	0.9	0.9	0.9	0.9	0.9	
Average valve	Project methodology	22.0	22.3	24.1	23.5	22.3	22.0	22.0	
	Alternative methodology	22.0	22.0	22.0	22.0	22.0	22.0	22.0	
Maximum value	Project methodology	99.6	99.6	99.6	99.6	99.6	99.6	99.6	
	Alternative methodology	99.6	99.6	99.6	99.6	99.6	99.6	99.6	
		Northern transect							
		215 m	140 m	50 m	14 m	22 m	61 m	156 m	207 m
Minimum value	Project methodology	1.9	1.9	1.9	1.9	0.9	0.9	0.9	0.9
	Alternative methodology	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
Average valve	Project methodology	22.0	22.1	23.3	29.1	25.6	22.9	22.2	22.1
	Alternative methodology	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0

Maximum value	Project methodology	99.6	99.6	99.6	112.0	99.6	99.6	99.6	99.6
	Alternative methodology	99.6	99.6	99.6	99.6	99.6	99.6	99.6	99.6

Table 2-68 Project contribution of NO₂ (one hour average) for selected receivers (µg/m³)

Project methodology – contributions from the project's ventilation outlets only

Alternative methodology – contributions from the project's ventilation outlets plus the change in surface road contributions (difference between the 'with project' and 'without project' scenarios)

		Southern transect							
		240m	115m	60m	14m	14 m	56 m	105 m	225 m
Minimum value	Project methodology	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Alternative methodology	-2.9	-3.5	-3.7	-4.6	-5.1	-5.4	-4.9	-4.8
Average valve	Project methodology	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Alternative methodology	-0.2	-0.2	-0.3	-0.2	-0.3	-0.2	-0.2	-0.1
Maximum value	Project methodology	6.1	4.2	4.8	5.1	5.0	5.0	5.0	5.2
	Alternative methodology	3.9	4.2	4.8	5.1	5.0	4.9	5.0	5.2
		Central transect							
		157 m	67 m	26 m	13m	33 m	93 m	192 m	
Minimum value	Project methodology	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
	Alternative methodology	-17.3	-38.5	-53.0	-44.1	-26.4	-19.0	-19.3	
Average valve	Project methodology	0.1	0.1	0.1	0.1	0.1	0.1	0.1	
	Alternative methodology	-1.3	-2.5	-4.1	-5.1	-3.9	-2.3	-1.5	
Maximum value	Project methodology	16.6	14.9	13.4	11.6	10.6	10.7	10.5	
	Alternative methodology	16.4	13.8	13.4	11.6	10.6	10.7	10.5	
		Northern transect							
		215 m	140 m	50 m	14 m	22 m	61 m	156 m	207 m
Minimum value	Project methodology	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Alternative methodology	-3.5	-3.7	-3.9	0.0	0.0	0.0	-0.5	-1.0
Average valve	Project methodology	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4
	Alternative methodology	0.5	0.61	0.9	2.2	1.1	0.83	0.6	0.6

Maximum value	Project methodology	23.4	24.9	25.2	24.7	23.9	24.7	21.8	27.4
	Alternative methodology	23.0	23.8	25.5	31.5	27.2	26.4	22.0	27.3

Table 2-69 Cumulative concentration of NO₂ (one hour average) for selected receivers (µg/m³)

Project methodology – project contribution added to background contribution

Alternative methodology – project contribution added to background contribution

		Southern transect							
		240m	115m	60m	14m	14 m	56 m	105 m	225 m
Minimum value	Project methodology	1.9	1.9	1.9	1.9	1.9	0.9	0.9	0.9
	Alternative methodology	0.5	0.2	-0.1	-0.7	-1.7	-0.4	-0.1	0.0
Average valve	Project methodology	22.4	23.6	25.4	33.6	33.4	24.5	23.2	22.4
	Alternative methodology	21.8	21.7	21.7	21.8	21.7	21.7	21.8	21.8
Maximum value	Project methodology	99.6	99.6	99.6	108.1	119.2	99.6	99.6	99.6
	Alternative methodology	99.6	99.6	99.6	98.8	99.6	98.8	99.1	99.3
		Central transect							
		157 m	67 m	26 m	13m	33 m	93 m	192 m	
Minimum value	Project methodology	1.9	1.9	1.9	0.9	0.9	0.9	0.9	
	Alternative methodology	-11.9	-25.4	-38.7	-32.8	-18.1	-15.2	-15.5	
Average valve	Project methodology	22.1	22.4	24.2	23.6	22.4	22.1	22.1	
	Alternative methodology	20.7	19.5	17.8	16.8	18.1	19.6	20.4	
Maximum value	Project methodology	99.6	99.6	99.6	99.6	99.6	99.6	99.6	
	Alternative methodology	99.6	99.6	98.4	88.3	91.1	95.7	97.0	
		Northern transect							
		215 m	140 m	50 m	14 m	22 m	61 m	156 m	207 m
Minimum value	Project methodology	1.9	1.9	1.9	1.9	0.9	0.9	0.9	0.9
	Alternative methodology	0.7	0.6	0.6	0.9	1.1	0.9	0.9	0.9
Average valve	Project methodology	22.5	22.6	23.7	29.5	25.9	23.3	22.6	22.5
	Alternative methodology	22.5	22.6	22.9	24.2	23.1	22.8	22.5	22.5

Maximum value	Project methodology	99.6	99.6	99.6	112.0	99.6	99.6	99.6	99.6
	Alternative methodology	99.6	99.6	99.6	100.0	99.7	99.6	99.6	99.6

PM₁₀ data comparison

Figure 2-26, **Figure 2-27** and **Figure 2-28** show the predicted surface road air quality contributions for the northern, central and southern transects, respectively. The figures show CAL3QHCR outputs under forecast traffic volumes at each transect (in 2019) for the 'without project' and the 'with project' scenarios.

With the exception of the northern transect (**Figure 2-26**), changes in air quality reflect expected changes from the 'without project' and the 'with project' scenarios based on analysis of changes in traffic:

- For the central transect, total traffic volumes are forecast to decrease and heavy vehicle volumes are forecast to decrease. **Figure 2-27** shows a reduction in surface road emissions from the 'without project' to the 'with project' scenarios.
- For the southern transect, total traffic volumes are forecast to increase but heavy vehicles volumes are forecast to decrease (in 2019). **Figure 2-28** shows that taking these two changes into account, there is minimal overall change between the 'without project' and the 'with project' scenarios.

Although **Figure 2-26** shows an increase in surface road emissions from the 'without project' to the 'with project' scenarios, the increase is not as great as may be anticipated based on forecast increases in traffic volumes (in 2019). Analysis of the CAL2QHCR model indicates that a similar influence from nearby road links is affected model results at the northern transect as discussed in relation to NO₂. The key difference, and the reason for there being a more pronounced difference in 'without project' and 'with project' scenarios for PM₁₀ when compared with NO₂, is the effect of the ozone limiting method (for calculation of NO₂ concentrations). Application of the ozone limiting method tends to 'buffer' changes in total oxides of nitrogen based on the availability of ozone.

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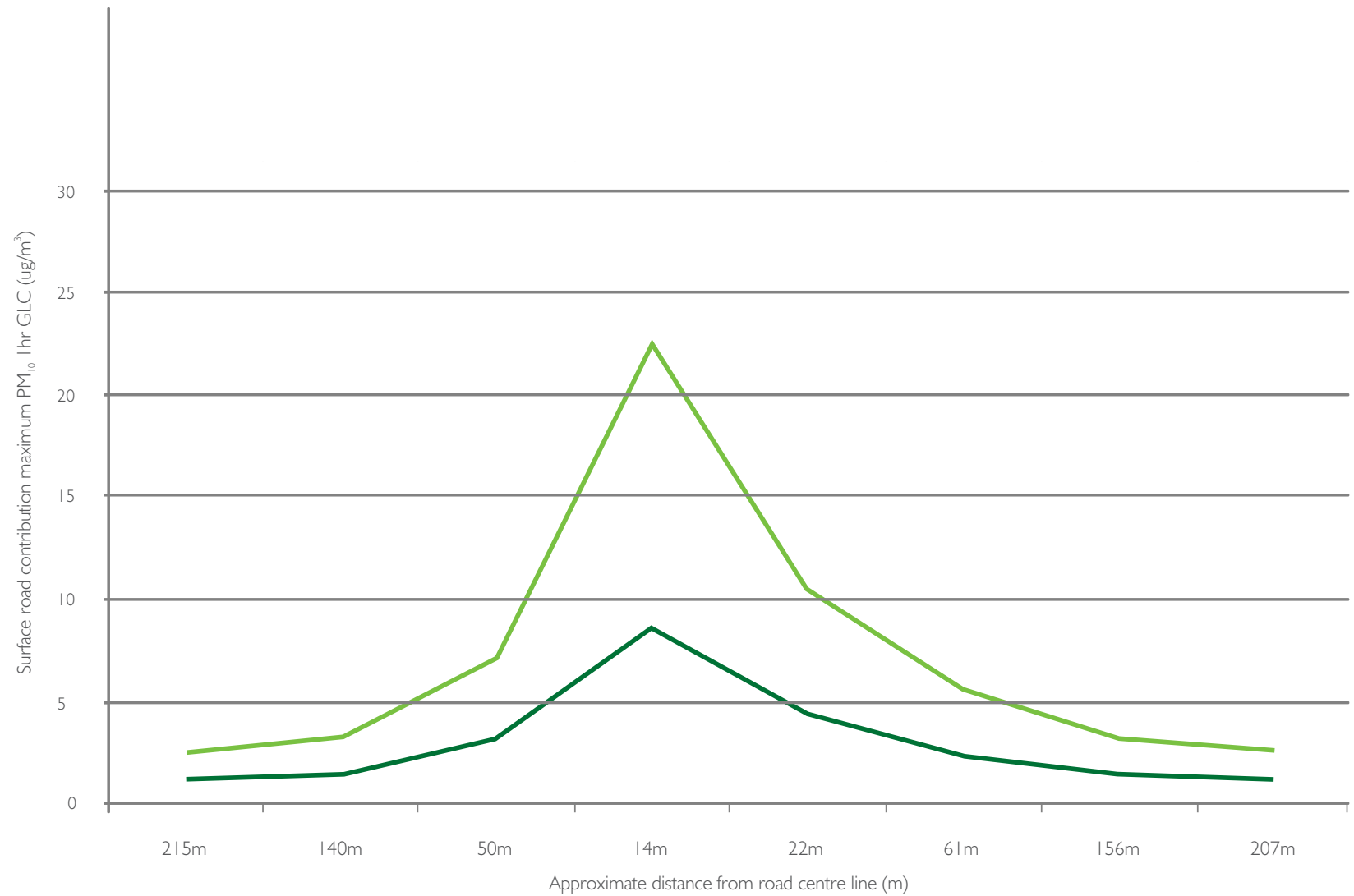
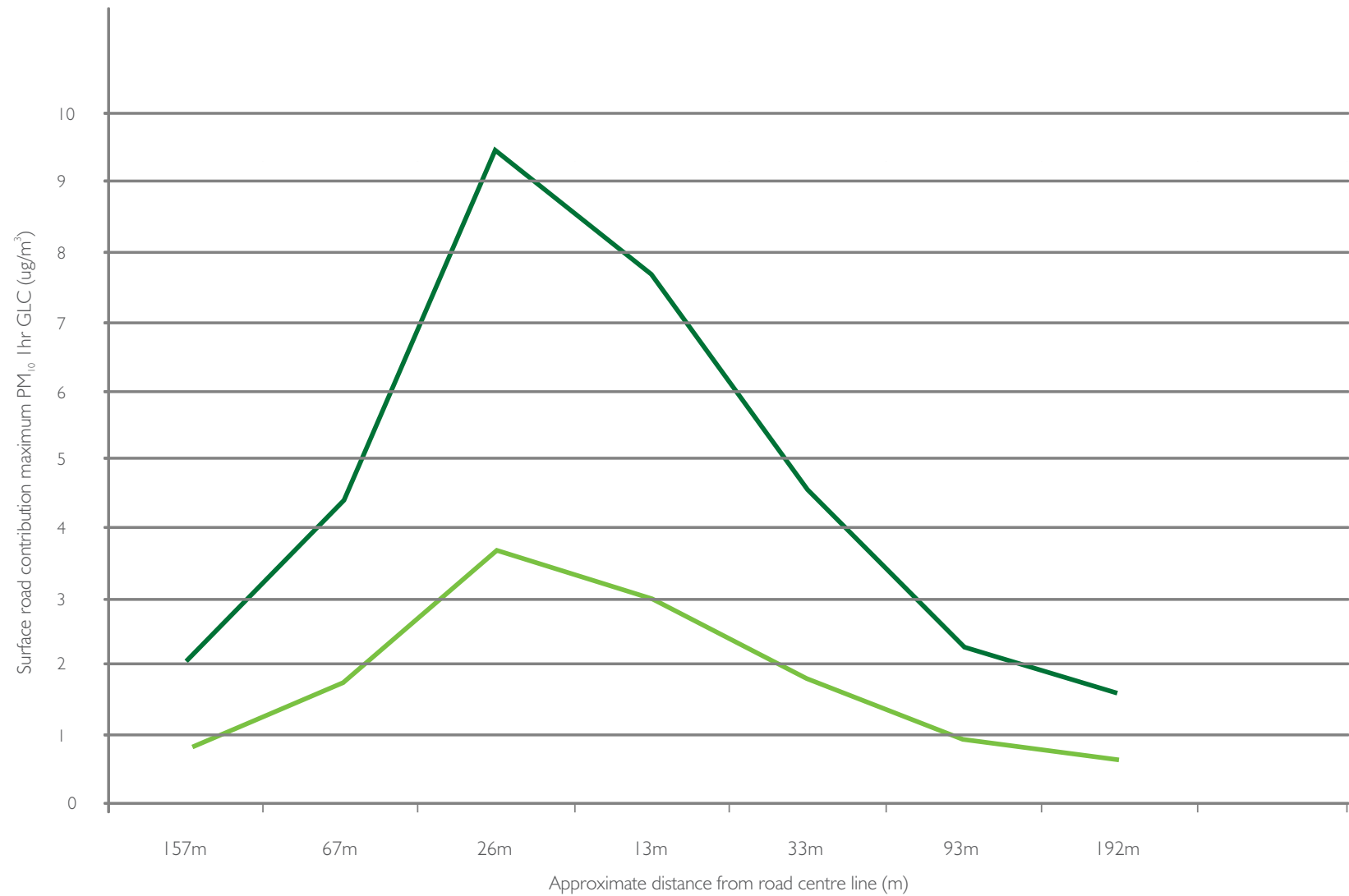


Figure 2-26 Transect 1 (northern) maximum PM₁₀ receptor results

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With project
Without project

Figure 2-27 Transect 2 (middle) maximum PM₁₀ receptor results

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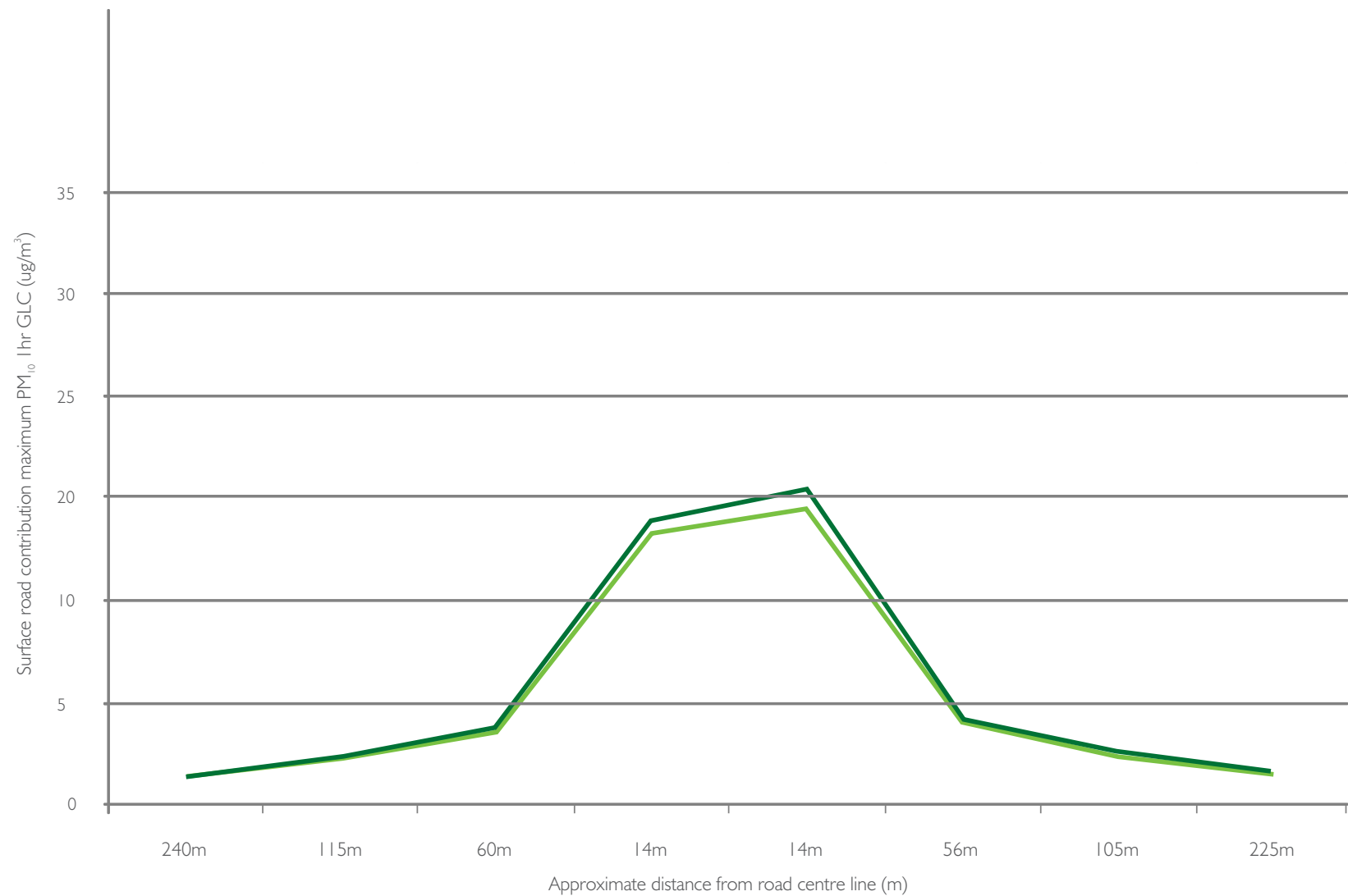


Figure 2-28 Transect 3 (southern) maximum PM_{10} receptor results

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The outputs from the CAL3QHCR modelling shown in the preceding figures have been used to calculate project contributions, background contributions and cumulative concentrations at each transect and receiver location. The project methodology and the alternative methodology have been applied, as detailed earlier in this section.

Table 2-70, Table 2-71 and Table 2-72 show the background contribution, the project contribution and the cumulative concentration of PM₁₀ for selected receiver locations calculated using the project methodology and the alternative methodology.

As noted earlier in relation to NO₂ concentrations, background and project contributions provided in the tables cannot be added to calculate the cumulative pollutant concentrations. This is because the cumulative concentrations have been calculated contemporaneously.

Comparing the project methodology and the alternative methodology, the tables show that:

- The project methodology and the alternative methodology result in identical background PM₁₀ contribution values. This is because in the case of the project methodology, the ambient monitoring data (from OEH monitoring stations) is higher than then CAL3QHCR surface road model outputs for PM₁₀ at each of the receiver locations that were assessed.
- The project methodology results in project PM₁₀ contributions that are higher than the minimum and average project contributions calculated using the alternative methodology. In the case of the maximum project PM₁₀ contributions, the project methodology and the alternative methodology show almost identical results at the southern and central transects. There are differences with the two methodologies evident in the results at the northern transect, with the alternative methodology producing higher concentrations close to the road and the project methodology producing similar or slightly higher concentrations further away from the road.
- The project methodology results in cumulative PM₁₀ concentrations that are higher than the minimum and average project contributions calculated using the alternative methodology. In the case of maximum cumulative concentrations the two methodologies produce similar results, with differences of no more than a few µg/m³.

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Table 2-70 Background contribution of PM₁₀ (24 hour average) for selected receivers (µg/m³)

Project methodology – the maximum of OEH monitoring data or CAL3QHCR surface road model output (2019 and 2029 surface traffic)

Alternative methodology – OEH monitoring data

		Southern transect							
		240m	115m	60m	14m	14 m	56 m	105 m	225 m
Minimum value	Project methodology	6.3	6.3	6.3	6.7	6.3	6.3	6.3	6.3
	Alternative methodology	6.3	6.3	6.3	6.3	6.3	6.3	6.3	6.3
Average value	Project methodology	21.2	21.2	21.2	21.3	21.2	21.2	21.2	21.2
	Alternative methodology	21.2	21.2	21.2	21.2	21.2	21.2	21.2	21.2
Maximum value	Project methodology	221.6	221.6	221.6	221.6	221.6	221.6	221.6	221.6
	Alternative methodology	221.6	221.6	221.6	221.6	221.6	221.6	221.6	221.6
		Central transect							
		157 m	67 m	26 m	13m	33 m	93 m	192 m	
Minimum value	Project methodology	6.3	6.3	6.3	6.3	6.3	6.3	6.3	
	Alternative methodology	6.3	6.3	6.3	6.3	6.3	6.3	6.3	
Average value	Project methodology	21.2	21.2	21.2	21.2	21.2	21.2	21.2	
	Alternative methodology	21.2	21.2	21.2	21.2	21.2	21.2	21.2	
Maximum value	Project methodology	221.6	221.6	221.6	221.6	221.6	221.6	221.6	
	Alternative methodology	221.6	221.6	221.6	221.6	221.6	221.6	221.6	
		Northern transect							
		215 m	140 m	50 m	14 m	22 m	61 m	156 m	207 m
Minimum value	Project methodology	6.3	6.3	6.3	6.3	6.3	6.3	6.3	6.3
	Alternative methodology	6.3	6.3	6.3	6.3	6.3	6.3	6.3	6.3
Average	Project methodology	21.2	21.2	21.2	21.4	21.2	21.2	21.2	21.2

valve	Alternative methodology	21.2	21.2	21.2	21.2	21.2	21.2	21.2	21.2
Maximum value	Project methodology	221.6	221.6	221.6	221.6	221.6	221.6	221.6	221.6
	Alternative methodology	221.6	221.6	221.6	221.6	221.6	221.6	221.6	221.6

Table 2-71 Project contribution of PM₁₀ (24 hour average) for selected receivers (µg/m³)

Project methodology – contributions from the project's ventilation outlets only

Alternative methodology – contributions from the project's ventilation outlets plus the change in surface road contributions (difference between the 'with project' and 'without project' scenarios)

		Southern transect							
		240m	115m	60m	14m	14 m	56 m	105 m	225 m
Minimum value	Project methodology	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Alternative methodology	-0.12	-0.15	-0.24	-0.81	-1.10	-0.32	-0.26	-0.21
Average value	Project methodology	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Alternative methodology	-0.04	-0.07	-0.11	-0.41	-0.46	-0.09	-0.06	-0.04
Maximum value	Project methodology	0.06	0.06	0.06	0.07	0.06	0.06	0.07	0.08
	Alternative methodology	0.00	0.00	0.00	-0.09	-0.13	0.00	0.00	0.01
		Central transect							
		157 m	67 m	26 m	13m	33 m	93 m	192 m	
Minimum value	Project methodology	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
	Alternative methodology	-1.22	-2.69	-5.73	-4.61	-2.74	-1.37	-0.87	
Average value	Project methodology	0.01	0.01	0.01	0.01	0.01	0.01	0.01	
	Alternative methodology	-0.31	-0.66	-1.81	-2.18	-1.23	-0.64	-0.42	
Maximum value	Project methodology	0.09	0.09	0.08	0.07	0.07	0.08	0.08	
	Alternative methodology	0.02	0.00	0.00	0.00	0.00	0.00	0.00	
		Northern transect							
		215 m	140 m	50 m	14 m	22 m	61 m	156 m	207 m
Minimum value	Project methodology	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Alternative methodology	-1.02	-1.40	-3.13	-8.24	-4.34	-2.23	-1.29	-1.09
Average	Project methodology	0.03	0.03	0.03	0.02	0.02	0.02	0.03	0.03

valve	Alternative methodology	0.29	0.40	0.95	2.38	-0.43	-0.19	-0.09	-0.07
Maximum value	Project methodology	0.31	0.29	0.50	0.50	0.39	0.24	0.35	0.39
	Alternative methodology	2.39	3.20	6.98	19.91	8.85	4.14	2.87	2.34

Table 2-72 Cumulative concentration of PM₁₀ (24 hour average) for selected receivers (µg/m³)

Project methodology – project contribution added to background contribution

Alternative methodology – project contribution added to background contribution

		Southern transect							
		240m	115m	60m	14m	14 m	56 m	105 m	225 m
Minimum value	Project methodology	6.3	6.3	6.3	6.7	6.3	6.3	6.3	6.3
	Alternative methodology	6.2	6.2	6.1	5.8	5.8	6.3	6.3	6.3
Average value	Project methodology	21.2	21.2	21.2	21.3	21.3	21.2	21.2	21.2
	Alternative methodology	21.1	21.1	21.1	20.8	20.7	21.1	21.1	21.1
Maximum value	Project methodology	221.6	221.6	221.6	221.6	221.6	221.6	221.6	221.6
	Alternative methodology	221.5	221.4	221.3	220.8	221.2	221.5	221.6	221.6
		Central transect							
		157 m	67 m	26 m	13m	33 m	93 m	192 m	
Minimum value	Project methodology	6.3	6.3	6.3	6.3	6.3	6.3	6.3	
	Alternative methodology	5.3	4.4	2.0	3.3	4.6	5.6	6.0	
Average value	Project methodology	21.2	21.2	21.2	21.2	21.2	21.2	21.2	
	Alternative methodology	20.9	20.5	19.4	19.0	19.9	20.5	20.8	
Maximum value	Project methodology	221.6	221.6	221.6	221.6	221.6	221.6	221.6	
	Alternative methodology	221.5	221.5	220.8	217.4	219.4	220.5	220.8	
		Northern transect							
		215 m	140 m	50 m	14 m	22 m	61 m	156 m	207 m
Minimum value	Project methodology	6.4	6.4	6.4	6.3	6.3	6.3	6.3	6.3
	Alternative methodology	5.8	5.5	4.4	-1.7	3.4	5.0	5.7	5.9
Average	Project methodology	21.2	21.2	21.2	21.4	21.2	21.2	21.2	21.2

valve	Alternative methodology	21.5	21.6	22.1	23.6	20.7	21.0	21.1	21.1
Maximum value	Project methodology	221.6	221.6	221.6	221.6	221.6	221.6	221.6	221.7
	Alternative methodology	222.4	222.8	224.3	222.5	217.3	219.4	220.4	220.6

Comparison of the methodologies

This comparison of the project methodology and the alternative methodology shows that:

- The alternative methodology and the project methodology result in similar cumulative NO₂ concentrations in areas away from the influence of surface roads. Close to surface roads, however, the project methodology results in higher cumulative NO₂ concentrations.
- The project methodology and the alternative methodology result in similar cumulative PM₁₀ concentrations, both close to and away from surface roads. Based on the receiver locations assessed, the difference between the two methodologies is no more than around 3 µg/m³ (and typically much less).
- The alternative methodology provides for a more comprehensive and transparent account of all air quality changes resulting from implementation of the project – both positive and negative. The alternative methodology is also more likely to better reflect the expected air quality benefits of the project. In contrast, the project methodology is more focused on identifying and quantifying potential adverse air quality outcomes (rather than benefits), particularly those associated with the operation of the project's ventilation outlets.
- One drawback of the alternative methodology may be that air quality improvements may mask adverse air quality outcomes in some areas. While this may be more representative of the likely cumulative outcome in practice, it is not desirable if the principal focus of the air quality impact assessment is to clearly and conservatively identify adverse impacts.

In interpreting air quality modelling results for the project, it is important to note that the project contributions that have been reported are focused on emissions from the project's ventilation outlets. The project will also result in changes to surface road emissions, and for the purpose of assessing the NorthConnex project, these changes have been taken into account as part of the background contribution component of the air quality calculations.

2.14.2 Atmospheric reactions – oxides of nitrogen

This section outlines:

- The approach taken to estimate the atmospheric conversion of nitrogen oxides (NO_x) to NO₂ after emission from the project's ventilation outlets.
- An analysis of the conservatism in the approach taken.
- Further consideration of the ratio of NO₂ to NO_x in emissions from vehicles.

Approach taken to the estimation of NO₂ formation in the atmosphere

In the atmosphere, nitrogen oxide (NO) is oxidised to nitrogen dioxide (NO₂) in the presence of ozone (O₃). The mechanics of this reaction in the atmosphere can be complex, but there are several methods to estimate the extent of conversion of NO to NO₂, with varying levels of conservatism.

The Approved Methods for the Modelling and Assessment of Air Pollutants in New South Wales (DEC, 2005) endorses three methods for estimating the generation of the NO₂ (from the simplest approach to the more detailed approach):

- Method 1 – assume 100% conversion of NO to NO₂.
- Method 2 – assume that conversion of NO to NO₂ is limited by the ambient concentration of ozone (the ozone limiting method).
- Method – assume that conversion of NO to NO₂ is represented by the empirical equation developed by Janssen et al (1988).

If methods other than those above are proposed to be applied to an air quality impact assessment, the proposed method must be first discussed and agreed with the Environment Protection Authority.

Based on the loads of nitrogen oxides likely to be emitted from the project (as a major component of vehicle emissions), Method 1 is considered likely to unreasonably overestimate the ground level NO₂ concentrations attributable to the project. Method 1 is only typically used for minor sources of nitrogen oxides where only a simplistic assessment is required to demonstrate compliance with ambient air quality criteria. The NorthConnex project is not such a project.

Method 3 involves the application of an empirical relationship developed by Janssen et al (1988). This empirical relationship is based on distance from the source, ozone concentration, wind speed and season. It was developed for the conversion of NO to NO₂ in plumes emitted from power stations. Power stations typically have tall emission sources (typically greater than 50 metres in height), and, subsequently, pollutants travel long distances downwind (tens of kilometres). As the air quality impact assessment for the NorthConnex project considered ventilation outlets 15 metres in height, and receivers within metres of emission sources, the Janssen et al empirical relationship is not considered appropriate.

Method 2, which involves the application of the ozone limiting method has been applied to the project to determine the extent of formation of NO₂ from nitrogen oxides emitted from the project. The ozone limiting methods applies the following equation:

$$[\text{NO}_2]_{\text{project increment}} = 0.1[\text{NO}_x]_{\text{prediction}} + \text{MIN}\{0.9[\text{NO}_x]_{\text{prediction}} \text{ or } (46/48)[\text{O}_3]_{\text{background}}\}$$

Where:

$[\text{NO}_2]_{\text{project increment}}$ is the project contribution to ambient NO₂ concentrations at ground level.

$[\text{NO}_x]_{\text{prediction}}$ is the predicted concentration of NO_x from the project at ground level.

$[\text{O}_3]_{\text{background}}$ is the background concentration of ozone.

A Level 2 (contemporaneous) assessment has been conducted using the ozone limiting method which:

- Combined the predicted ground level concentration of total nitrogen oxides (NO_x) in each modelled hour with the background (ambient) ozone concentration for the same hour using the equation above.
- Added the resultant ground level concentration of NO₂ from the project to the background (ambient) concentration of NO₂ for the relevant hour (to obtain a total cumulative NO₂ concentration).

As part of this approach, the project contribution of nitrogen oxides ([NO₂]_{project increment}) has been taken as the contribution from the project's ventilation outlets only (refer to **Section 2.14.1** in relation to the treatment of project and background contributions). The background concentration of nitrogen dioxide added to the contribution from the project's ventilation outlets has been taken as the higher of the ambient air quality data or the outputs from the CAL3QHCR model (for major surface road contributions) as detailed in **Section 2.14.1**.

Conservatism in the ozone limiting method

The ozone limiting method endorsed in the Approved Methods for the Modelling and Assessment of Air Pollutants in New South Wales (DEC, 2005) was taken from the US Environmental Protection Agency ozone limiting method, originally developed by Cole and Summerhays (1979) and Tikvart (1996). The method assumes that all the available ozone in the atmosphere will react with NO in the plume until either all the O₃ or all the NO is used up. The approach is known to be conservative. Some of the reasons for its conservatism are listed below:

- The ozone limiting method assumes that the atmospheric reaction is instant, whereas in reality the reaction takes place over a number of hours.
- The actual reactions of NO to NO₂ occur in proportion to the moles of each reactant rather than in proportion to the concentration assumed by the ozone limiting method. At constant volume, one part per million of a gas is proportional to one mole of a gas. This assumption is not valid in the open atmosphere, as there is a virtually unlimited amount of O₃ available for reaction. As plumes expand downwind, more O₃ is available for reaction, and even lower concentrations of O₃ can react with NO in the plume.
- The ozone limiting method is further complicated as some of the NO_x is already converted to NO₂ upstream in the plume before it reaches the receiver.
- Studies have shown that the NO_x emission rates are extremely important with respect to the rate of conversion to NO₂. The size of the plume is not affected by the NO_x emission rate, which means that there is the same amount of O₃ available for chemical conversion regardless of the NO_x emission rate. Larger NO_x emission rates lead to lower predicted ratios of NO₂/NO_x. Maximum impacts that occur at receivers located further away have high predicted NO₂/NO_x ratios. Further emissions emitted into stable (narrow) plumes will have less conversion to NO₂ compared to those emissions emitted into less stable (wider) plumes. The ozone limiting method does not take the NO_x emission rate or plume size into consideration.
- The ozone limiting method can only be used on one plume at a time. The US Environmental Protection Agency states that the ozone limiting should be used with a 'plume-by-plume' approach. This is a significant limitation to a facility with many different plumes. The ozone limiting will therefore be very conservative for near field NO₂ impacts for large multi plume sources. The ozone limiting may not be conservative for single plumes downwind, where low concentrations of O₃ can still react with the plume.

The ozone limiting is expected to be conservative during daylight hours when the photochemical equilibrium reverses the oxidation of NO by O₃. It is also expected to be conservative during stable and night conditions when both NO₂ and O₃ are removed by reaction with vegetation and other surfaces.

Ratio of NO₂ to NO_x in vehicle emissions

The ozone limiting method equation as outlined above assumes that 10 per cent of nitrogen oxides (NO_x) are present as nitrogen dioxide (NO₂). This means that there is an inherent assumption in the ozone limiting method equation as stated that the ratio of NO₂ to NO_x at the point of emission (in this case, at the vehicle exhaust) will be 10 per cent.

In its submission in response to the environmental impact statement, the Environment Protection Authority noted that the total New South Wales fleet average NO₂ emission fraction ranges between 15 per cent and 17 per cent of total NO_x. The Environment Protection Authority therefore suggested that a NO₂ to NO_x ratio of 16 per cent would be more appropriate (rather than the 10 per cent assumed in the ozone limiting method equation outlined above).

Implications for ambient air quality

Based on advice from the Environment Protection Authority, the ozone limiting method equation has been amended to reflect a 16 per cent NO₂ to NO_x ratio of 16 per cent as follows:

$$[\text{NO}_2]_{\text{project increment}} = 0.16[\text{NO}_x]_{\text{prediction}} + \text{MIN}\{0.84[\text{NO}_x]_{\text{prediction}} \text{ or } (46/48)[\text{O}_3]_{\text{background}}\}$$

A sensitivity analysis has been conducted to determine the potential effect of the amended ozone limiting method equation (as corrected above) on predicted ground level concentrations of NO₂. Ground level concentrations of NO₂ have been calculated for a series of NO_x and O₃ concentrations (up to around the NO₂ one hour average criterion of 246 µg/m³) using the ozone limiting method equation for both 10 per cent NO₂:NO_x and 16 per cent NO₂:NO_x at the point of discharge. These calculations are summarised in **Table 2-73**. Shaded cells indicate situations in which O₃ concentration is the limiting factor for NO₂ generation.

For context, background O₃ concentrations applied to the air quality impact assessment are broadly summarised in **Section 2.11** and include:

- Maximum concentrations around 200 µg/m³ to 250 µg/m³.
- 95th percentile concentrations around 70 µg/m³ to 90 µg/m³.
- Average concentrations around 30 µg/m³ to 35 µg/m³.

Table 2-73 Comparison of ozone limiting method equation calculations

		Ozone concentration (one hour) ($\mu\text{g}/\text{m}^3$)					
		0	50	100	150	200	250
Total NO_x concentration (one hour) ($\mu\text{g}/\text{m}^3$)	50	Amended ozone limiting method equation (16% NO_2)					
	100	8.0	50	50	50	50	50
	150	16.0	63.9	100	100	100	100
	200	24.0	71.9	119.8	150	150	150
	250	32.0	79.9	127.8	175.8	200	200
	250	40.0	87.9	135.8	183.8	231.7	250
	50	Original ozone limiting method equation (10% NO_2)					
	100	5.0	50	50	50	50	50
	150	10.0	57.9	100	100	100	100
	200	15.0	62.9	110.8	150	150	150
	250	20.0	67.9	115.8	163.8	200	200
	250	25.0	72.9	120.8	168.8	216.7	250

Comparing the calculations presented in **Table 2-73**, the percentage change in predicted ground level NO_2 concentrations has been determined, as summarised in **Table 2-74**. The percentage values shown indicate the extent to which a 16 per cent $\text{NO}_2:\text{NO}_x$ ratio exceeds a 10 per cent $\text{NO}_2:\text{NO}_x$ ratio in terms of ground level NO_2 concentrations. The table indicates that:

- For situations where the NO_x concentration is limiting, rather than the O_3 concentration, there would be no difference in the air quality assessment outcomes for NO_2 based on differences in the ozone limiting method equation.
- The maximum difference resulting from amendment of the ozone limiting method equation is 60 per cent. This would occur when no O_3 is present which, although it may occur, is unlikely. Differences approaching 60 per cent would occur at low O_3 concentrations. However, under these conditions total NO_2 concentrations at ground level would be low (as indicated in **Table 2-74**) and would be dominated by the contribution of NO_2 at the point of discharge, rather than NO_2 generated through atmospheric conversion.
- Based on the air dispersion modelling present in the environmental impact statement, the project is expected to typically contribute peak ground level concentrations around $50 \mu\text{g}/\text{m}^3$ to $150 \mu\text{g}/\text{m}^3$. With most background air quality data indicating typical O_3 concentrations up to $100 \mu\text{g}/\text{m}^3$, the net effect of the amended ozone limiting method equation is expected to be around 10 to 15 per cent (as a change in ground level concentration).

Table 2-74 Percentage difference between ozone limiting method equations

		Ozone concentration (one hour) ($\mu\text{g}/\text{m}^3$)					
		0	50	100	150	200	250
Total NO_x concentration (one hour) ($\mu\text{g}/\text{m}^3$)	50	60.0%	0%	0%	0%	0%	0%
	100	60.0%	10.4%	0%	0%	0%	0%
	150	60.0%	14.3%	8.1%	0%	0%	0%
	200	60.0%	17.8%	10.4%	7.3%	0%	0%
	250	60.0%	20.6%	12.4%	8.9%	6.9%	0%

As part of the further air quality impact assessment conducted for the submissions and preferred infrastructure report (to assess an increase in height of the northern and southern ventilation outlets by five metres), the ozone limiting method equation has been updated to reflect a NO_2 to NO_x ratio in vehicle emissions of 16 per cent.

Implications for in-tunnel air quality

The issue of in-tunnel concentrations of NO_2 is complex, noting that NO_2 concentrations within a road tunnel are a function of traffic volumes and vehicle/ fuel mix, vehicle emissions (as NO_x and as NO_2) and background pollutant levels drawn into the tunnel, the extent of dilution provided by background air, ventilation flow rates and in-tunnel air residence times, and the amount of ozone present. The significance of each of these factors will depend on the specific context of the road tunnel under consideration. However, broad observations about the proportions of NO_x and NO_2 in typical emissions from an entire vehicle fleet therefore do not necessarily reflect or approximate conditions that may be experience within a road tunnel.

When considering NO_2 concentrations within the NorthConnex project tunnels, and particularly the percentage of NO_x present as NO_2 , it is important to take into account:

- The design of the tunnel ventilation system, including ventilation design criteria.
- Factors affecting the NO_x : NO_2 ratio.
- Historical data on NO_x : NO_2 ratios in other Australian and international road tunnels.
- Management of in-tunnel air quality.

Tunnel ventilation design

The project's ventilation system has been designed to meet specified design criteria under a range of average traffic speeds and tunnel operational scenarios. These ventilation design criteria are discussed in **Section 2.5**. As is typically the case with engineering design, a reasonable level of design conservatism has been applied to provide additional operational capacity if required.

The design of the project's ventilation system has been based on, among other things, guidance published by the Permanent International Association of Road Congresses (2012), which has been developed from extensive international experience in road tunnel design and operation. The guidance published by the Permanent International Association of Road

Congresses is inherently conservative to ensure a robust approach to the design of road tunnel ventilation systems. The data relied on as part of the design of the project's ventilation system has used emission factors relevant to the Australian vehicle fleet (including for CO, NO_x and opacity) and takes into account vehicle types (passenger vehicles, light duty vehicles and heavy goods vehicles) as well as fuel type (petrol and diesel).

The total rate of NO_x emissions generated by the combined fleet composition expected to travel through the project has been calculated for forecast traffic volumes and for a worst case traffic scenario (design analysis A) over a diurnal cycle. This includes peak traffic periods for the northbound and southbound main alignment tunnels, which would correlate with peak in-tunnel vehicle emissions.

Consistent with the advice published by the Permanent International Association of Road Congresses (2012), the calculation of in-tunnel air quality has assumed that 10 per cent of NO_x within the project tunnels would be present as NO₂. Calculated NO₂ concentrations within the main alignment tunnels have been used to appropriately design the project's ventilation system, including sizing of ventilation fans, to achieve the ventilation design criteria summarised in **Section 2.5** under all conditions. The limiting design factor in this case is the maximum traffic design capacity of the main alignment tunnels, should it be achieved in the future (as distinct from forecast traffic volumes). This approach means that the project's ventilation system would have additional capacity to manage in-tunnel air quality above what would ordinarily be required for forecast traffic volumes.

Factors affecting the NO_x:NO₂ ratio

The ratio of NO₂:NO_x varies based on a range of factors, predominately the percentage of diesel vehicles within a road tunnel, the length of the tunnel, and operation of the ventilation system.

Heavy goods vehicles generate significantly higher NO₂ emissions as a proportion of total NO_x, and will often be higher than 10 per cent. In comparison, petrol fuelled passenger vehicles generate considerably less NO₂ as a proportion of NO_x. Short tunnels generally experience higher ratios of NO₂:NO_x.

The Permanent International Association of Road Congresses (2012) states that:

'While in previous years NO_x from combustion processes contained mostly NO (90 to 95% of the NO_x), the implementation of diesel vehicle exhaust gas after-treatment systems (oxygenation catalyst, DPF1, SCR2 systems) tend to significantly increase the primary emitted NO₂ percentages.

In many European road tunnels, NO₂ can be around 20 to 30% of NO_x concentrations, which strongly depends on the share of diesel vehicles with exhaust gas after-treatment systems in the vehicle fleet and on the residence time of the NO_x in the tunnel air.'

Although the percentage of diesel passenger vehicles in New South Wales is rising, the percentage of diesel vehicles forecast to use the NorthConnex project is considerably lower than experienced in international road tunnels, particularly those in Europe. Taking this into account, the assumption of 10 per cent NO₂:NO_x is considered to be reasonable and sufficient for the design of the project's ventilation system, including sizing ventilation fans and maximum capacity, to accommodate a worst case traffic scenario. In doing so, additional capacity has been provided if required under forecast traffic scenarios.

Historical NO_x:NO₂ ratio data

Two studies have looked at the NO₂:NO_x ratios in Australian tunnels. One study, conducted by Holmes Air Science on the M5 East Motorway in 2004 showed values for the NO₂:NO_x ratio in that tunnel of around five to six per cent. The second study, conducted on the Lane Cove Tunnel, found a median NO₂:NO_x ratio of around seven per cent.

Several other studies have been conducted on international road tunnels. **Table 2-75** summarises the findings of these studies in relation to NO₂:NO_x ratios. It is important to note that the majority of these road tunnels do not actively and directly monitor in-tunnel concentrations of NO₂.

Table 2-75 supports the selection of a NO₂:NO_x ratio of 10 per cent as appropriate for design of the project's ventilation system under worst case traffic conditions.

Table 2-75 Reported NO₂:NO_x ratios in international road tunnels (O'Gorman and Gehrke, 2014)

Tunnel	Reported NO ₂ :NO _x ratio	Source
La Croix Rousse, France (1.8 kilometres, bi-directional)	Average: 7.3% to 9.2 % Daily peak: 8.7% to 9.6% Ratios of 20% have been measured during low NO _x periods (off peak)	Permanent International Association of Road Congresses (2000)
Careybeckx, Netherlands (1.6 kilometre, twin tube)	Average: 5%	De Fre, Bruynseraede and Kretzshmer (1994)
Tate's Cairn, Hong Kong (4 kilometre, twin tube) Tai Lam (3.7 kilometre, twin tube)	Average: 6% Peaks in areas of high ozone: 20%	Yao et al (2005)
Hatfield, United Kingdom (1.1 kilometres, twin tube) Bell Common, United Kingdom (500 metres, twin tube)	Peak in areas of high ozone: 25% Near exit portals: 12% to 14%	Boulter, McCrae and Green (2007)
M5 East Motorway, Australia (4 kilometres, twin tube)	Average: 5% to 6%	National Health and Medical Research Council (2008)
Laerdal, Norway (24.5 kilometres, bi-directional) Fodnes, Norway (6.6 kilometres, bi-directional) Knappe, Norway (2.5 kilometres, twin tube)	Range: 10% to 30% Typical: 20%	Norwegian Public Roads Administration (2013)
Lane Cove Tunnel, Australia	Median: 7%	O'Gorman et al (2009)

Management of in-tunnel air quality

The actual ratio of $\text{NO}_2:\text{NO}_x$ within the project tunnels is expected to fluctuate throughout the day. During off peak hours when traffic volumes are low and times when there is a higher percentage of heavy vehicles within the tunnels, the ratio of $\text{NO}_2:\text{NO}_x$ may increase above 10 per cent. Although the ratio of $\text{NO}_2:\text{NO}_x$ may increase during these periods, the total NO_x load would be considerably lower than during peak traffic periods.

Under all circumstances, the NorthConnex tunnels would continue to operate within the stipulated design criteria for NO_2 . Air quality within the tunnels would be continuously monitored and the ventilation rate would be adjusted in response to traffic flows and real-time measurements for NO_2 concentrations taken within the project tunnels. This would maintain a safe environment for the tunnel users.

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2.15 Operational impact assessment

As discussed in **Section 2.3** of this report, two key amendments have occurred that have affected the outcomes of the air quality impact as presented in the environmental impact statement:

- The height of the northern and southern ventilation outlets have been increased by five metres as a result of further consideration of feasible and reasonable measures that could be applied to the project to reduce in-tunnel and ambient exposures to vehicle emissions (refer to **Section 3.2** for this analysis). This amendment has been included in the preferred infrastructure report component of this document, provided in **Chapter 9**.
- Amendments have been made to four assumptions and inputs into the air quality impact assessment of the project. These amendments have been discussed in the relevant parts of this chapter and are summarised in **Table 2-76**.

Table 2-76 Changes to dispersion model inputs

Assumption or input	Change made to the assessment approach
Receiver grid spacing of 150 metres may be too coarse.	The receiver grid has been recalculated for the following refined spacings: • 25 metre spacing for an area of 500 metres by 500 metres centred on each ventilation outlet. • 50 metre spacing for an area of 1,000 metres by 1,000 metres centred on each ventilation outlet. • 100 metre spacing for an area of 4,000 metres by 4,000 metres centred on each ventilation outlet.
The 90 metre SRTM topographic data used to determine the receiver grid elevations may be too coarse or may not reflect local conditions.	The topographic data have been re-extracted using five metre resolution Land and Property Information (LPI) data. The elevations of the discrete receivers and the ventilation outlet locations have been identified using this revised data.
Vehicle fleet composition data was based on 2013 Australia Bureau of Statistics data. This may potentially underestimate the future percentage of diesel vehicles as sales trends show an increase in diesel passenger vehicles.	2008 and 2013 Australian Bureau of Statistics data have been used to extrapolate predicted fleet compositions for 2019 and 2029. The data have then been used when calculating vehicle emissions to inform the project's emissions inventory. The emission rates in the air quality dispersion model have been adjusted accordingly.
Ozone limiting method (OLM) equation does not reflect the ratio of NO ₂ :NO _x identified from the NSW vehicle fleet by the Environment Protection Authority.	The ozone limiting method calculation has been amended to reflect an initial NO ₂ :NO _x ratio of 16 per cent.

The results of further air quality modelling, taking into account the increase in ventilation outlet heights and the amended assumptions summarised in **Table 2-76** are detailed in **Section 2.15.1**.

2.15.1 Air quality modelling results (increased ventilation outlet height)

Table 2-77 summarises the outcomes of the revised air quality dispersion modelling, under forecast traffic volumes in 2019 and 2029, and for 'design analysis A' (the worst case traffic scenario). Modelling outputs are presented as project contributions (without the addition of background pollutant concentrations), for direct comparison with modelling outcomes for the original ventilation outlet heights (as presented in the environmental impact statement).

Table 2-78 presents the outcomes of the air quality modelling included in the environmental impact statement and compares them with the outcomes of the revised air quality dispersion modelling. As expected with an increase in ventilation outlet height, most ground level concentrations of emissions would decrease by a significant percentage (up to 60 per cent reduction in some cases), although it is recognised that the concentrations were originally very low and remain very low. However, counterintuitively, some peak ground level concentrations of emissions are predicted to increase, despite the increase in ventilation outlet heights. This would only occur for one hour in three years and is still within the applicable impact assessment criteria.

When compared to the concentrations presented in the environmental impact statement, the increase in ventilation outlet heights by five metres generally results in a decrease in ground level concentrations. For the forecast traffic volumes, these decreases are:

- Annual average PM₁₀ and PM_{2.5} concentrations, up to 60 per cent at the southern ventilation outlet and up to 41 per cent at the northern ventilation outlet.
- Annual average nitrogen dioxide concentrations, up to 31 per cent at the southern ventilation outlet and up to 55 per cent at the northern ventilation outlet.
- Eight hour maximum carbon monoxide concentrations, up to 48 per cent at the southern ventilation outlet and up to 16 per cent at the northern ventilation outlet.
- Total volatile organic compounds, up to 56 per cent at the southern ventilation outlet and up to 35 per cent at the northern ventilation outlet.
- Polycyclic aromatic hydrocarbons, up to 56 per cent at the southern ventilation outlet and up to 34 per cent at the northern ventilation outlet.

There is, however, an increase in some pollutants for some averaging periods. Based on a more detailed review of modelling outputs, these increases occur very rarely (around one event for the three years of modelling data). **Section 2.15.2** analyses the very rare meteorological events that lead to infrequent increases in ground level concentrations of pollutants, and demonstrates that these events do not represent typical meteorological conditions.

Table 2-77 Revised predicted air quality outcomes for project operation in 2019, 2029 and design analysis A (increased ventilation outlet heights)

Pollutant	Averaging period	Value	Predicted maximum project contributions (µg/m³)						Impact assessment criteria/ standards (µg/m³)
			With project – forecast traffic in 2019		With project – forecast traffic in 2029		Design analysis A		
			Northern ventilation outlet	Southern ventilation outlet	Northern ventilation outlet	Southern ventilation outlet	Northern ventilation outlet	Southern ventilation outlet	
PM ₁₀	24 hour maximum	Peak project contribution	1.02	0.65	1.28	1.18	1.80	1.93	50
		% of criterion	2.0%	1.3%	2.6%	2.4%	3.6%	3.9%	-
	Annual average	Peak project contribution	0.05	0.05	0.08	0.06	0.12	0.11	30
		% of criterion	0.2%	0.2%	0.3%	0.2%	0.4%	0.4%	-
PM _{2.5}	24 hour maximum	Peak project contribution	0.96	0.62	1.20	1.13	1.70	1.82	25
		% of reporting standard	2.5%	4.8%	4.5%	6.8%	7.3%	2.5%	-
	Annual average	Peak project contribution	0.05	0.04	0.08	0.05	0.11	0.11	8
		% of reporting standard	0.6%	0.5%	1.0%	0.7%	1.4%	1.3%	-
NO ₂	1 hour maximum	Peak project contribution	54.3	69.0	58.3	76.0	70.4	91.8	246
		% of criterion	22.1%	28.0%	23.7%	30.9%	28.6%	37.3%	-
	Annual average	Peak project contribution	0.6	0.8	0.8	1.3	1.3	1.8	62
		% of criterion	1.0%	1.3%	1.3%	2.0%	2.1%	2.9%	-
CO	1 hour maximum	Peak project contribution	181.8	48.4	217.5	57.9	172.0	114.5	100,000
		% of criterion	0.18%	0.05%	0.22%	0.06%	0.17%	0.11%	-

PollutantAveraging period		Value	Predicted maximum project contributions (µg/m³)						
			With project – forecast traffic in 2019		With project – forecast traffic in 2029		Design analysis A		Impact assessment criteria/ standards (µg/m³)
			Northern ventilation outlet	Southern ventilation outlet	Northern ventilation outlet	Southern ventilation outlet	Northern ventilation outlet	Southern ventilation outlet	
	8 hour maximum	Peak project contribution	36.0	17.2	45.5	31.5	59.0	51.5	30,000
		% of criterion	0.12%	0.06%	0.15%	0.10%	0.20%	0.17%	-
Total VOC	1 hour 99.9th percentile	Peak project contribution	2.6	1.7	3.5	2.3	5.4	4.2	29*
		% of criterion	9.1%	5.8%	12.2%	8.0%	18.5%	14.6%	-
PAHs	1 hour 99.9th percentile	Peak project contribution	0.0005	0.0003	0.0006	0.0004	0.0011	0.0008	0.4**
		% of criterion	0.12%	0.08%	0.15%	0.10%	0.27%	0.21%	-
* as benzo(a)pyrene		** as benzene							

Table 2-78 Comparison of revised air quality modelling results against EIS modelling results

Pollutant	Averaging period	Design	Predicted maximum project contributions (µg/m³)						Impact assessment criteria (µg/m³)
			With project – forecast traffic in 2019		With project – forecast traffic in 2029		Design analysis A		
			Northern ventilation outlet	Southern ventilation outlet	Northern ventilation outlet	Southern ventilation outlet	Northern ventilation outlet	Southern ventilation outlet	
PM ₁₀	24 hour maximum	+5 metre ventilation outlet	1.02*	0.65	1.28	1.18	1.80	1.93	50
		EIS predictions	0.95	1.39	1.37	2.14	2.23	3.13	
		% change	7%*	-53%	-7%	-45%	-19%	-38%	
	Annual average	+5 metre ventilation outlet	0.05	0.05	0.08	0.06	0.12	0.11	30
		EIS predictions	0.09	0.11	0.11	0.13	0.17	0.26	
		% change	-41%	-60%	-25%	-58%	-32%	-57%	
PM _{2.5}	24 hour maximum	+5 metre ventilation outlet	0.96*	0.62	1.20	1.13	1.70	1.82	25
		EIS predictions	0.90	1.34	1.30	2.01	2.11	2.97	
		% change	7%*	-54%	-7%	-44%	-19%	-39%	
	Annual average	+5 metre ventilation outlet	0.05	0.04	0.08	0.05	0.11	0.11	8
		EIS predictions	0.08	0.11	0.10	0.13	0.16	0.25	
		% change	-41%	-60%	-25%	-59%	-31%	-57%	
NO ₂	1 hour maximum	+5 metre ventilation outlet	54.3	69.0**	58.3	76.0**	70.4	91.8	246
		EIS predictions	68.9	61.8	74.6	65.0	114.8	98.2	
		% change	-21%	12%**	-22%	17%**	-39%	-7%	

Pollutant	Averaging period	Design	Predicted maximum project contributions (µg/m³)						Impact assessment criteria (µg/m³)	
			With project – forecast traffic in 2019		With project – forecast traffic in 2029		Design analysis A			
			Northern ventilation outlet	Southern ventilation outlet	Northern ventilation outlet	Southern ventilation outlet	Northern ventilation outlet	Southern ventilation outlet		
CO	Annual average	+5 metre ventilation outlet	0.6	0.8	0.8	1.3	1.3	1.8	62	
		EIS predictions	1.4	1.2	1.7	1.4	2.5	2.4		
		% change	-55%	-31%	-53%	-10%	-47%	-24%		
	1 hour maximum	+5 metre ventilation outlet	181.8**	48.4	217.5**	57.9	172.0	114.5	100,000	
		EIS predictions	86.6	70.1	107.4	90.3	179.3	166.7		
		% change	110%**	-31%	103%**	-36%	-4%	-31%		
		8 hour maximum	+5 metre ventilation outlet	36.0**	17.2	45.5	31.5	59.0	51.5	30,000
			EIS predictions	32.4	33.1	54.2	57.9	80.3	81.7	
			% change	11%**	-48%	-16%	-46%	-27%	-37%	
Total VOC	1 hour 99.9th percentile	+5 metre ventilation outlet	2.63	1.67	3.53	2.33	5.35	4.24	29***	
		EIS predictions	4.07	3.72	5.38	5.36	7.40	8.96		
		% change	-35%	-55%	-35%	-56%	-28%	-53%		
PAHs	1 hour 99.9th percentile	+5 metre ventilation outlet	0.0005	0.0003	0.0006	0.0004	0.0011	0.0008	0.4****	
		EIS predictions	0.0007	0.0007	0.0009	0.0009	0.0015	0.0018		
		% change	-34%	-54%	-31%	-56%	-28%	-53%		
* Occurs 1 day in three years		** Occurs 1 hour in three years *** as benzo(a)pyrene **** as benzene								

2.15.2 Further analysis of air quality modelling results (increased ventilation outlet height)

This section presents a more detailed analysis and explanation of the factors that have contributed to the counterintuitive results presented in **Section 2.15.1**. In particular the combination of an increase in ventilation outlet heights and the amended model assumptions and inputs that have generated a set of predicted project contributions to ambient air which results in an overall significant reduction in air quality impacts from operation of the project (albeit from an already low base).

A high level review of dispersion modelling outputs suggests that where ground level concentrations of pollutants have increased as a result of increasing the ventilation outlet heights, this is the result of a very small number of events that have affected the predicted peak concentrations for these pollutants. The frequency of these events is around once in the three years of modelling data.

For the purpose of this further analysis, predicted air quality impacts under forecast traffic volumes in 2019 have been considered. It is relevant to note that the factors that may have contributed to the counterintuitive air quality assessment results are common to all of the air quality impact assessment scenarios (ie the meteorological dataset, the amended modelling assumptions and inputs and the increased ventilation outlet heights). Therefore, this analysis is independent of the air quality impact assessment scenario that is considered, with similar conclusions likely to be drawn from analysis of other assessment scenarios.

Contextualisation of the issue(s)

The air quality modelling results presented in **Section 2.15.1** of this report show changes in predicted peak ground level concentrations (project contributions only) that differ from those presented in the environmental impact statement. Changes in predicted ground level concentrations are expected based on changes made to the modelling assumptions and inputs and the increased ventilation outlet heights.

Because each of these factors (ie changes in modelling assumptions and the increase in ventilation outlet heights) will affect predicted ground level concentrations in different ways, modelling results have been considered for three scenarios:

- **EIS15** – this scenario is identical to the assessment presented in the environmental impact statement (EIS). It includes ventilation outlets at 15 metres and no changes to modelling assumptions and inputs.
- **SPIR15** – this scenario only incorporates changes to modelling assumptions and inputs detailed in this submissions and preferred infrastructure report (SPIR). It includes ventilation outlets at 15 metres (ie no increase in ventilation outlet height).
- **SPIR20** – this scenario incorporates both the changes to the modelling assumptions and inputs and the increase in ventilation outlet heights detailed in this submissions and preferred infrastructure report (SPIR). It includes ventilation outlets at 15 metres.

Table 2-78 in **Section 2.15.1** summarises the change in predicted ground level concentrations between the environmental impact statement (**EIS15**) and the project presented in this report (**SPIR20**).

The expectation for an increase in outlet height would be that ground level concentrations would decrease. However, some peak ground level concentrations of pollutants have been modelled to increase for short term average periods. Analysis of the modelling outputs indicates that these increased peak ground level concentrations are the result of rare events that appear in the modelling outputs at a frequency of around one event in the whole three years of modelling data.

A potentially contributing factor to these unexpected results is the amended modelling inputs and assumptions that have been detailed in this chapter and applied to updated air quality modelling:

- Increasing the resolution of the receiver grid applied around each ventilation outlet (ie reduced receiver spacing) (refer to **Section 2.13.1**).
- Applying higher resolution topographic data (refer to **Section 2.12**).
- Revising future projections of vehicle fleet fuel mix, to reflect an increased use of diesel fuel in the future) (refer to **Section 2.7**).
- Amending the ozone limiting method equation to take into account a NO₂:NO_x ratio of 16 per cent, as recommended by the Environment Protection Authority (refer to **Section 2.14**).

To test whether some or all of these amended assumptions and inputs are a significant contributor to the unexpected ground level concentration results, the **SPiR15** scenario has been modelled. This scenario includes the amended assumptions and inputs, but retains 15 metre high ventilation outlets. By modelling the **SPiR15** scenario, a base line can be established against which to assess only the increase in ventilation height (noting that the **SPiR15** and **SPiR20** include the same amended assumptions and inputs, with the only difference between them being ventilation outlet height).

Table 2-79 summarises the outcomes of modelling **SPiR15** for forecast traffic flows in 2019, and compares these results with the **EIS15** results. The data in the table showing the relative change in ground level concentrations are solely attributable to amended modelling assumptions and inputs (as this is the only difference between **EIS15** and **SPiR15**).

Table 2-79 shows the following:

- For all pollutants and averaging times (with the exception of one hour average NO₂ at the southern ventilation outlet), the **SPiR15** scenario shows lower predicted project contributions than the **EIS15** scenario.
- The reductions in predicted project contributions (designated in green shading in the table) ranged from four per cent to 44 per cent.
- Overall, these observations support the conclusion that amendments to modelling assumptions and inputs are not the cause of increased ground level concentrations when considering the increase in ventilation outlet heights (the **SPiR20** scenario).

Table 2-79 Comparison of EIS15 and SPIR15 results (relative change)

Pollutant	Averaging period	Scenario	Predicted maximum project contribution ($\mu\text{g}/\text{m}^3$)	
			Northern ventilation outlet	Southern ventilation outlet
PM ₁₀	24 hour maximum	EIS15	0.94	1.2
		SPIR15	0.76	0.91
		Change (SPIR15 relative to EIS15)	-19%	-27%
	Annual average	EIS15	0.08	0.08
		SPIR15	0.06	0.05
		Change (SPIR15 relative to EIS15)	-19%	-43%
PM _{2.5}	24 hour maximum	EIS15	0.88	1.21
		SPIR15	0.72	0.86
		Change (SPIR15 relative to EIS15)	-18%	-29%
	Annual average	EIS15	0.07	0.07
		SPIR15	0.06	0.04
		Change (SPIR15 relative to EIS15)	-19%	-43%
NO ₂	One hour maximum	EIS15	68.9	61.8
		SPIR15	58.7	76.4
		Change (SPIR15 relative to EIS15)	-15%	+24%
	Annual average	EIS15	1.4	1.2
		SPIR15	0.7	1.0
		Change (SPIR15 relative to EIS15)	-53%	-15%
CO	One hour average	EIS15	86.6	70.1
		SPIR15	83.0	43.2
		Change (SPIR15 relative to EIS15)	-4%	-38%
	Eight hour average	EIS15	32.4	27.3
		SPIR15	22.2	16.8
		Change (SPIR15 relative to EIS15)	-32%	-38%
Total VOCs	One hour, 99.9 th percentile	EIS15	3.46	3.45
		SPIR15	3.24	1.91
		Change (SPIR15 relative to EIS15)	-6%	-44%
PAHs	One hour, 99.9 th percentile	EIS15	0.0006	0.0006
		SPIR15	0.0006	0.0004
		Change (SPIR15 relative to EIS15)	-4%	-44%

Analysis of the **SPIR15** scenario indicates that changes to modelling assumptions and inputs are not the cause of the predicted increase in ground level concentrations relative to the **EIS15** scenario (as summarised in **Table 2-78**). It should be noted that the increase in NO₂ concentrations an artefact of the application of the ozone limiting method. The effect of the ozone limiting method is analysed and explained later in this section.

To clarify the implications of increasing ventilation outlet heights in isolation, modelling results for **SPIR15** and **SPIR20** have been compared. Both of these scenarios include amended modelling assumptions and inputs, and the only difference between the two is ventilation outlet height. The comparison of modelling results for these two scenarios under forecast traffic flows in 2019 is presented in **Table 2-80**.

- All longer term averaging periods show a decrease in ground level concentrations with an increase in ventilation outlet height.
- All percentile pollutant concentrations (total VOCs and PAH) show a decrease in the ground level pollutant concentrations with an increase in ventilation outlet height.
- Short term averaging periods for CO (one and eight hour averages) show an increase in maximum ground level concentrations whilst the peak short term averaging periods for NO₂ (one hour average) show a decrease in ground level concentrations.
- Short term particulate concentrations (24 hour average) show an increase in concentrations for the northern ventilation outlet and a decrease in concentrations for the southern ventilation outlet.

Based on these observations, it has been identified that the cause of the unexpected air quality outcomes modelled for an increase in ventilation outlet heights is likely to be:

- An infrequent and/ or shorter-term or short duration issue, because it appears to affect short term averaging period concentrations more than longer term averages.
- Affecting the northern and southern ventilation outlets in different ways (despite both ventilation outlets being the same height).

The following sections analyse and explain the reasons for the unexpected modelling outcomes and demonstrate that they are caused by rare and infrequent meteorological conditions. These rare meteorological conditions and infrequent peak ground level concentrations of pollutants would not typically occur during operation of the project.

Table 2-80 Comparison of SPIR15 and SPIR20 results (relative change)

Pollutant	Averaging period	Scenario	Predicted maximum project contribution ($\mu\text{g}/\text{m}^3$)	
			Northern ventilation outlet	Southern ventilation outlet
PM ₁₀	24 hour maximum	SPIR15	0.76	0.91
		SPIR20	1.00	0.60
		Change (SPIR20 relative to SPIR15)	+32%	-34%
	Annual average	SPIR15	0.06	0.05
		SPIR20	0.04	0.03
		Change (SPIR20 relative to SPIR15)	-31%	-29%
PM _{2.5}	24 hour maximum	SPIR15	0.72	0.86
		SPIR20	0.96	0.60
		Change (SPIR20 relative to SPIR15)	+33%	-30%
	Annual average	SPIR15	0.06	0.04
		SPIR20	0.04	0.03
		Change (SPIR20 relative to SPIR15)	-30%	-29%
NO ₂	One hour maximum	SPIR15	58.7	76.4
		SPIR20	54.3	69.0
		Change (SPIR20 relative to SPIR15)	-7%	-10%
	Annual average	SPIR15	0.7	1.0
		SPIR20	0.5	0.7
		Change (SPIR20 relative to SPIR15)	-30%	-31%
CO	One hour average	SPIR15	83.0	43.2
		SPIR20	181.8	48.4
		Change (SPIR20 relative to SPIR15)	+119%	+12%
	Eight hour average	SPIR15	22.2	16.8
		SPIR20	36.0	17.2
		Change (SPIR20 relative to SPIR15)	+62%	+2%
Total VOCs	One hour, 99.9 th percentile	SPIR15	3.24	1.91
		SPIR20	2.2	1.5
		Change (SPIR20 relative to SPIR15)	-32%	-22%
PAHs	One hour, 99.9 th percentile	SPIR15	0.0006	0.0004
		SPIR20	0.0004	0.0003
		Change (SPIR20 relative to SPIR15)	-31%	-22%

Short term NO₂ and CO concentrations

Why do the short term NO₂ and CO average concentrations not follow the same trend for 15 metre and 20 metre ventilation outlet heights?

The dispersion modelling for CO and the NO₂ are handled in different ways.

Both the NO_x and CO emissions data are entered into the dispersion model and predicted ambient concentrations are generated for the different averaging periods. In the case of NO_x only, these predicted ambient concentrations are further processed following the dispersion modelling to take into account conversion of NO_x to NO₂ (via the ozone limiting method in the case of this assessment).

Based on the different processing requirements for the NO₂ and CO data, a comparison of the trends between NO₂ and CO data is not considered valid. A more valid comparison is the analysis of the CO data and the NO_x data prior to post-dispersion model processing of the NO_x predictions (to calculate NO₂ concentrations). This analysis has been conducted and is presented in **Table 2-81**.

Table 2-81 shows that:

- The NO_x concentrations increase for the one hour average data between the **SPiR15** scenario and the **SPiR20** scenario.
- The short term average trends are now similar for NO_x and CO predictions with the only difference in the trends being that the northern ventilation outlet results show a higher increase than for the southern ventilation.

This analysis indicates that NO_x and CO are being affected in a similar way, and that it is the application of the ozone limiting method during the post-dispersion model processing that is obscuring the similarity of this relationship.

Table 2-81 Comparison of SPiR15 and SPiR20 CO and NO_x results (relative change)

Pollutant	Averaging period	Scenario	Predicted maximum project contribution (µg/m ³)	
			Northern ventilation outlet	Southern ventilation outlet
NO _x	One hour maximum	SPiR15	119.3	50.3
		SPiR20	261.4	56.4
		Change (SPiR20 relative to SPiR15)	+119%	+12%
	Annual average	SPiR15	1.04	0.49
		SPiR20	0.72	0.35
		Change (SPiR20 relative to SPiR15)	-31%	-30%
CO	One hour average	SPiR15	83.0	43.2
		SPiR20	181.8	48.4
		Change (SPiR20 relative to SPiR15)	+119%	+12%
	Eight hour average	SPiR15	22.2	16.8
		SPiR20	36.0	17.2
		Change (SPiR20 relative to SPiR15)	+62%	+2%

Short term pollutant concentrations increasing with ventilation outlet height

Why do short term pollutant concentrations increase with an increase in ventilation outlet height?

The data presented in **Table 2-80** show peak short term average concentrations increasing with ventilation outlet height. The key exception to this trend is the percentile pollutants (PAHs and total VOCs) which show a reduction in ground level concentration with increased ventilation outlet height. It is important to note that the concentrations of the percentile pollutants are calculated after excluding the eight highest predicted concentrations. A similar trend is also not evident in annual average concentrations, which all show a decrease in ground level concentration with an increase in ventilation outlet height.

These observations suggest that there may be a short term and infrequent meteorological condition leading to unexpected increases in ground level concentrations with increased ventilation outlet height.

To consider this in more detail, the 10 highest predicted concentrations at the three most affected receiver locations have been analysed for both **SPIR15** and **SPIR20** scenarios. Hourly data for the full 2009 modelling year has been analysed, with data ranked by magnitude of predicted ground level concentration. The resultant ranked data is provided in **Table 2-83 (SPIR15)** and **Table 2-84 (SPIR20)**.

Comparing the data in **Table 2-82** and **Table 2-83** makes it apparent that a small number of individual events (single hours) are leading to an increase in peak one hour average concentrations of CO with an increase in ventilation outlet height. These individual events have been shaded in **Table 2-82** and **Table 2-83**.

Analysis of the data in **Table 2-82** and **Table 2-83** indicates that for:

- A 15 metre ventilation outlet height (**SPIR15**):
 - The peak CO (one hour) concentration is predicted to be $83.03 \mu\text{g}/\text{m}^3$. The highest impact occurs at 8:00 on day 357.
 - The second highest CO (one hour) concentration is predicted to be $25.71 \mu\text{g}/\text{m}^3$, which is 69 per cent lower than the peak concentration.
- A 20 metre ventilation outlet height (**SPIR20**):
 - The peak CO (one hour) concentration is predicted to be $181.84 \mu\text{g}/\text{m}^3$. The highest impact occurs at 17:00 on day 45.
 - The second highest CO (one hour) concentration is predicted to be $52.65 \mu\text{g}/\text{m}^3$, which is 71 per cent lower than the peak concentration.

Other trends that can be observed from the data in **Table 2-82** and **Table 2-83** include:

- The peak CO (one hour average) concentration for the **SPIR15** scenario, whilst elevated, remains below the predicted air quality impacts presented in the environmental impact statement. The conclusions reached with respect to the acceptability of the predicted air quality impacts presented in the environmental impact statement therefore remain valid and applicable for the **SPIR15** scenario.
- The hour in which the peak concentration for the **SPIR15** scenario modelling occurs is 8:00 on day 337. With the increase in outlet height for the **SPIR20**

scenario, hour 8:00 on day 337 represents the second highest concentration. If the same hour on the same day is compared (ie 8:00 on day 337 at receiver location 337), the increase in ventilation outlet height would decrease the concentration of CO (one hour) from 83.03 $\mu\text{g}/\text{m}^3$ to 52.65 $\mu\text{g}/\text{m}^3$ (ie a 63 per cent reduction as a result of the increased ventilation height).

Analysis of the meteorological data contributing to the results in **Table 2-82** and **Table 2-83** indicates that for both the SPIR15 and SPIR20 scenarios, elevated ground level concentrations are the result of a very small number of meteorological conditions. These rare and infrequent meteorological conditions are considered in more detail in the following sections of this report.

Table 2-82 Ranked CO concentrations (SPIR15) for the three most affected receiver locations

Rank	Receiver location 3286			Receiver location 3284			Receiver location 3258		
	Day	Hour	Concentration ($\mu\text{g}/\text{m}^3$)	Day	Hour	Concentration ($\mu\text{g}/\text{m}^3$)	Day	Hour	Concentration ($\mu\text{g}/\text{m}^3$)
1	337	8:00	83.03	337	8:00	82.58	337	8:00	81.85
2	45	17:00	25.71	45	17:00	26.13	45	17:00	21.65
3	353	9:00	19.62	353	9:00	19.97	353	9:00	19.18
4	65	10:00	15.85	65	11:00	17.10	65	11:00	17.63
5	65	11:00	14.93	65	10:00	16.04	65	10:00	16.44
6	59	11:00	14.58	230	12:00	14.06	248	11:00	15.25
7	319	10:00	14.19	248	11:00	13.43	230	12:00	14.73
8	347	10:00	13.83	59	11:00	13.22	45	16:00	14.36
9	230	12:00	13.80	244	12:00	12.11	325	9:00	13.82
10	244	12:00	13.18	248	10:00	12.04	290	10:00	13.33

Table 2-83 Ranked CO concentrations (SPIR20) for the three most affected receiver locations

Rank	Receiver location 3286			Receiver location 3284			Receiver location 3258		
	Day	Hour	Concentration ($\mu\text{g}/\text{m}^3$)	Day	Hour	Concentration ($\mu\text{g}/\text{m}^3$)	Day	Hour	Concentration ($\mu\text{g}/\text{m}^3$)
1	45	17:00	181.84	45	17:00	129.28	45	17:00	121.97
2	337	8:00	52.65	337	8:00	64.91	45	16:00	91.48
3	45	16:00	32.41	45	21:00	30.51	337	8:00	60.34
4	45	21:00	26.05	45	20:00	22.41	45	20:00	18.52
5	45	20:00	20.60	45	22:00	21.99	45	21:00	8.86
6	45	22:00	18.24	46	17:00	20.27	249	8:00	8.43
7	249	8:00	7.53	45	16:00	13.84	45	22:00	6.06
8	45	23:00	6.47	45	23:00	10.65	343	8:00	5.36
9	343	9:00	4.84	46	15:00	10.47	338	13:00	5.34
10	343	8:00	4.36	45	18:00	8.30	353	10:00	5.31

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Differences in PM₁₀ and PM_{2.5} at different ventilation outlets

Why does the short term average PM₁₀ and PM_{2.5} data increase at the northern ventilation outlet, but not at the southern ventilation outlet?

Table 2-80 shows that with an increase in ventilation outlet height, 24-hour average concentrations of particulate matter (PM₁₀ and PM_{2.5}) increase at the northern ventilation outlet, but decrease at the southern ventilation outlet.

Analysis of the data for the two ventilation outlets shows that the peak PM₁₀ and PM_{2.5} concentrations at the northern ventilation outlet both occur on day 45. The same effect is not seen in data for the southern ventilation outlet.

The meteorological conditions leading to the peak particulate matter concentrations at the northern ventilation outlet are characterised by high wind speeds which lead to outlet tip downwash on day 45 of the modelling. This situation is a very unusual occurrence in the meteorology and is not considered to be representative of normal meteorological conditions in the area surrounding the northern ventilation outlet. In this case, the difference in air quality outcomes at the northern and southern ventilation outlets is a consequence of infrequent meteorological conditions (refer to the following sections of this report for discussion of these conditions).

Meteorological conditions as a potential cause

What are the rare and infrequent meteorological conditions that result in elevated ground level concentrations?

Based on the summary presented in **Table 2-82** and **Table 2-83**, day 337 and day 45 have been identified as most frequently experiencing elevated ground level concentrations. Wind conditions on those days, and for the times at and around those identified in **Table 2-82** and **Table 2-83** are summarised in the table below.

Table 2-84 Wind conditions leading up to and during predicted peak ground level concentrations

Day 337		Day 45	
Hour of day	Scalar wind speed (m/s)	Hour of day	Scalar wind speed (m/s)
6:00	1.9	14:00	2.8
7:00	0.8	15:00	4.3
8:00	0.1	16:00	9.5
9:00	1.2	17:00	11.9
10:00	1.8	18:00	13.6

Given predicted increases in short term average ground level concentrations with increased ventilation outlet height, and the relatively high wind speeds identified on day 45 in the table above, outlet tip downwash has been identified as a potential cause of unexpectedly high ground level concentrations. Outlet tip downwash can occur when the ratio between the outlet discharge velocity and ambient wind speed at the outlet height is less than 1.5.

To explore the potential for outlet tip downwash further, the hours of interest (from 15:00 to 23:00) on day 45 have been analysed for the northern ventilation outlet. For these hours, the ratio of outlet discharge velocity to ambient wind speed has been plotted and is shown in **Figure 2-29**. The figure shows that the ratio of outlet discharge velocity to ambient wind speed is less than 1.5 for all hours analysed, suggesting that outlet tip downwash is likely to be a key contributing factor to elevated short term ground level concentrations during these times.

This hypothesis has been tested qualitatively by plotting the locations of the three most affected receiver locations for the **SPiR15** and **SPiR20** scenarios (for the northern ventilation outlet). These receiver locations are shown in **Figure 2-30**. All six locations lie within the road reserve of the M1 Pacific Motorway and do not impact on surrounding residential receivers.

Ordinarily an increase in the height of a ventilation outlet is expected to move the location of peak ground level impacts away from the ventilation outlet (ie discharge at a greater height increases the length of time before the peak effects of a plume are experienced at ground level). **Figure 2-30** shows that the converse is true around the northern ventilation outlet, with the most affected receiver locations for the **SPiR20** scenario being located closer to the northern ventilation outlet than for the **SPiR15** scenario. This suggests that under certain conditions, the discharge plume is reaching ground level faster than anticipated, which is consistent with the effects of outlet tip downwash.

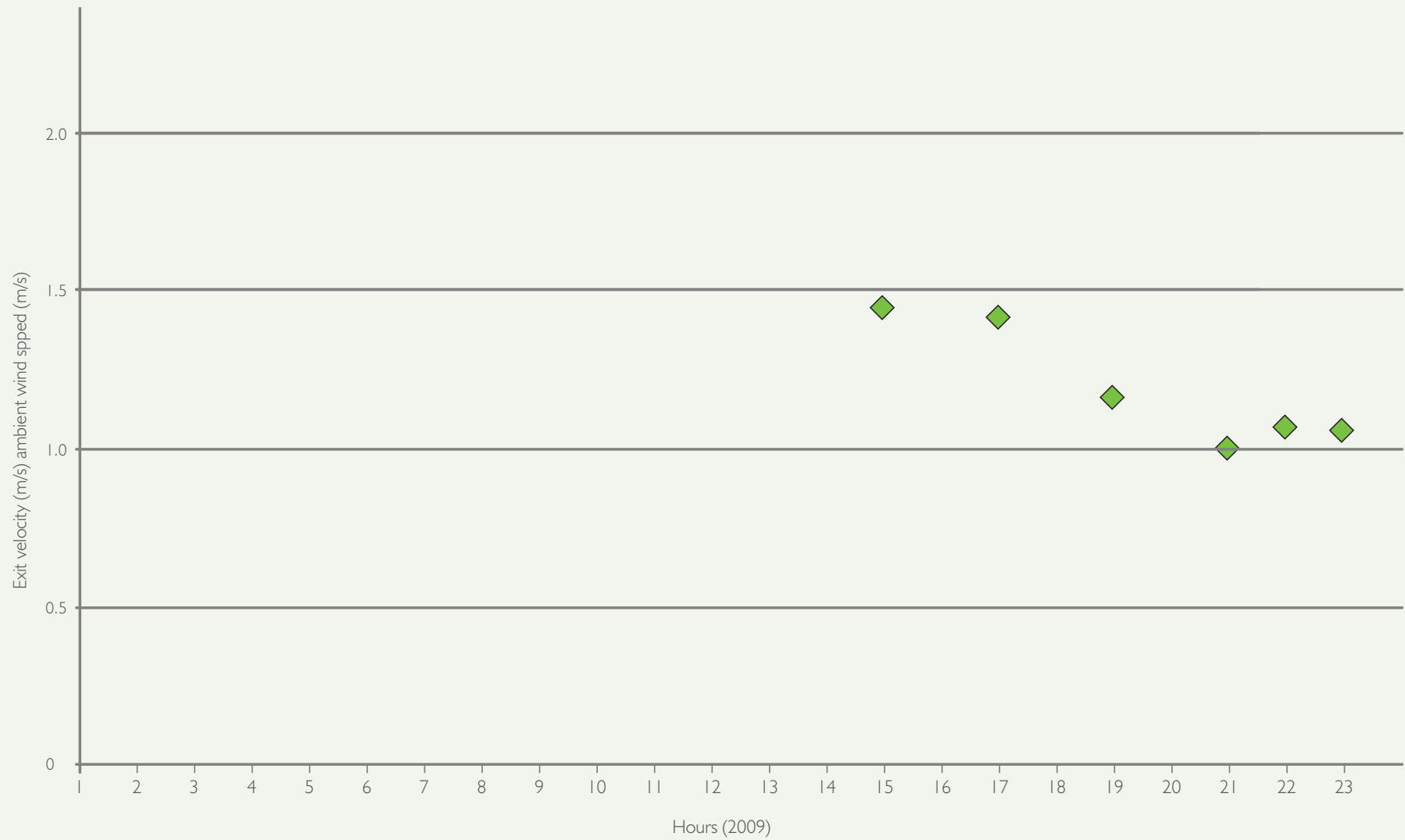


Figure 2-29 Ratio of discharge velocity to wind velocity on day 45 (hour 15:00 to hour 23:00)

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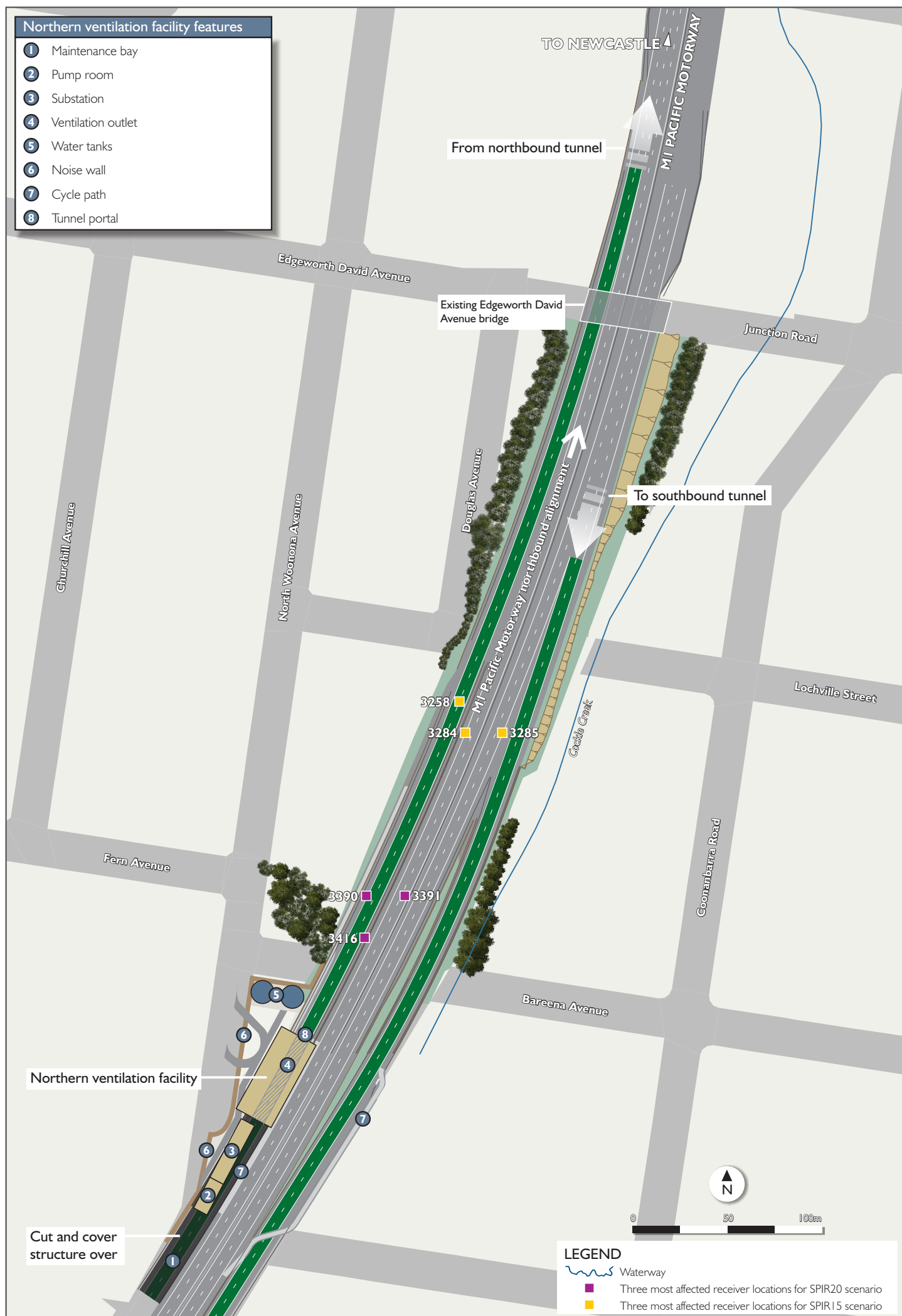


Figure 2-30 Three most affected receiver locations for SPIR15 and SPIR20

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The reality of meteorological conditions

Are the identified rare and infrequent meteorological conditions that result in elevated ground level concentrations real?

Further consideration has been given to rare and infrequent meteorological identified as contributing elevated ground level concentrations for short term averaging periods, and in particular:

- Hour 17:00 on day 45.
- Hour 8:00 on day 337.

Meteorological conditions at these times have been analysed to established whether they could plausibly occur in practice.

Hour 17:00 on day 45

Wind flow fields for hour 17:00 on day 45 are shown in **Figure 2-31** (at 10 metres), **Figure 2-32** (at 30 metres) and **Figure 2-33** (at 60 metres).

Based on the analysis of the wind field figures there does not appear to be anything erroneous or unrealistic with the meteorology. The day in question appears to be a windy day with winds at the northern ventilation outlet of 2.8 m/s at hour 14:00, 4.3 m/s at hour 15:00, 9.5 m/s at hour 16:00, 11.9 m/s at hour 17:00 and 13.6 m/s at hour 18:00. The wind speeds increase significantly with height. There is neutral stability so convective velocity is not responsible for the observed elevated ground level concentrations at these times.

In short, the meteorology on day 45 appears plausible and there is no reason to consider it as erroneous or unrealistic.

Hour 8:00 on day 337

Wind flow fields for hours around the hour of interest (ie before and after hour 8:00 on day 337) are shown in **Figure 2-34** (hour 7:00), **Figure 2-35** (hour 9:00), **Figure 2-36** (hour 10:00) and **Figure 2-37** (hour 11:00). Each of these wind fields is shown at 10 metres.

Based on analysis of these wind fields, the peak prediction CO concentrations (one hour average) at the northern ventilation outlet at hour 8:00 on day 337 (3 December 2009) is the result of the switch in flow from nocturnal offshore flow to onshore flow at that hour. The diurnal pattern of sea breeze giving way to land breeze happens every morning and evening. A series of spatial wind field plots from 7:00 to 11:00 shows relatively moderate onshore flow at Sydney airport and supported by MM5 data over the ocean, whilst inland stations at Terrey Hills and Lindfield show offshore flow consistent with the decaying land breeze. At 8:00 the interface between the land and sea breeze lies over the northern ventilation outlet and tunnel portals. The meteorology at the northern ventilation outlet and tunnel portals experiences a significant switch in meteorological conditions around this time.

Given the likelihood of wind shifts in the area around the project corridor, it is considered likely that these conditions would occur regularly. The potential implications of regular occurrence of these conditions are considered further in the following section. Despite these conditions potentially producing elevated ground level concentrations, the concentrations themselves are considered acceptable (in the context of the overall air quality impacts being lower than the environmental impact statement predictions which were considered acceptable).

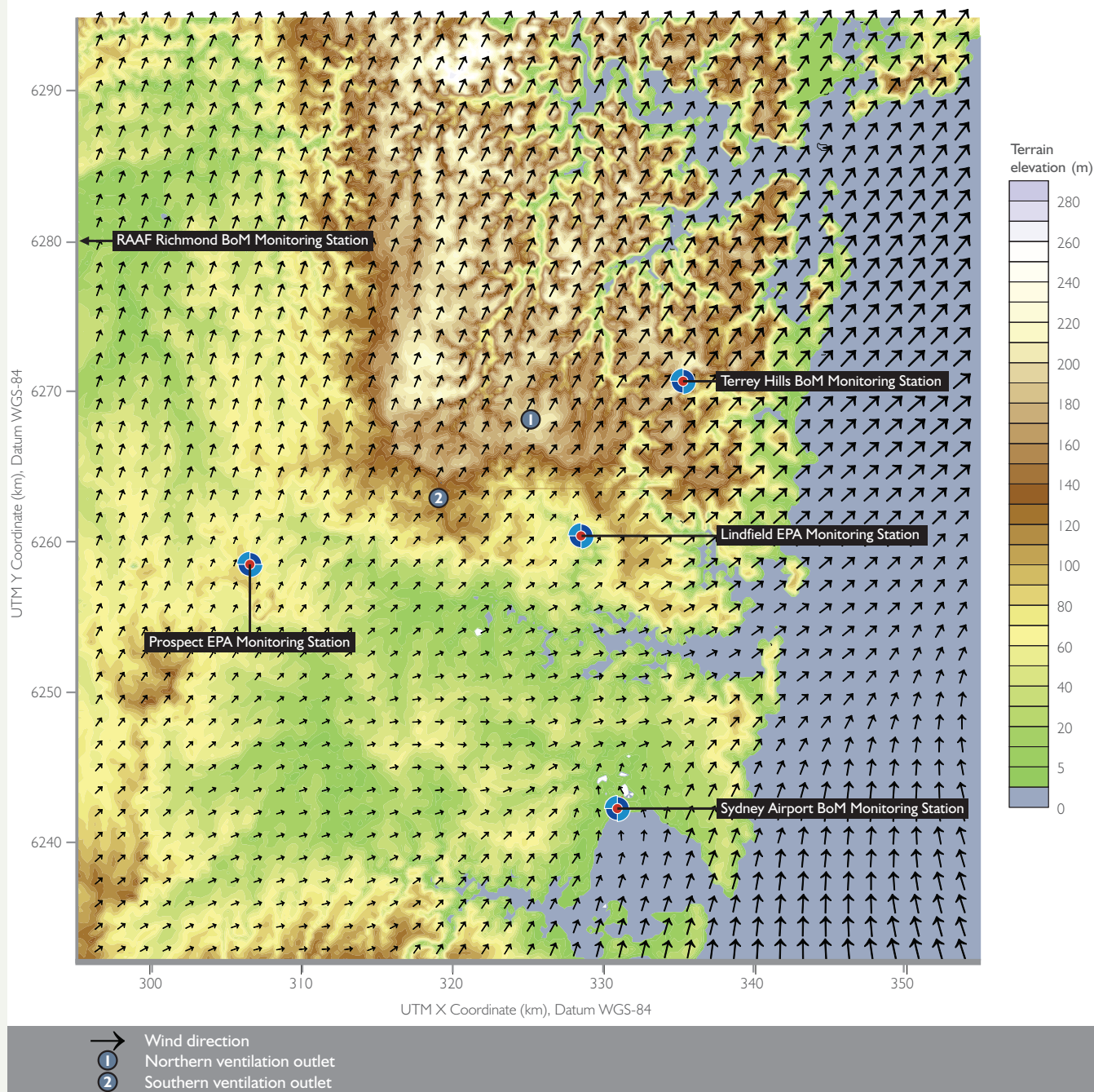


Figure 2-31 Wind flow field at hour 17:00 on day 45 (10 metres)

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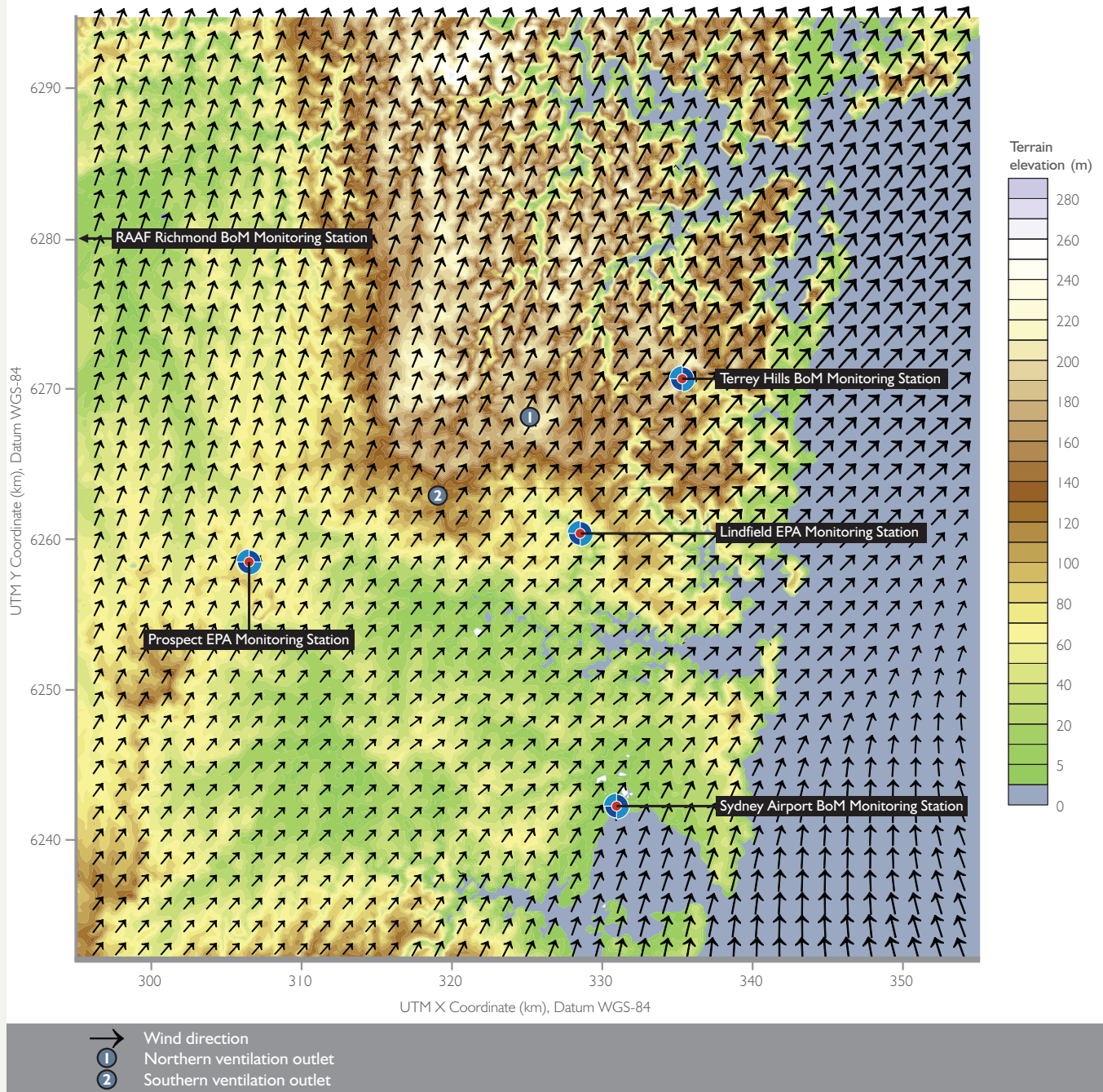


Figure 2-32 Wind flow field at hour 17:00 on day 45 (30 metres)

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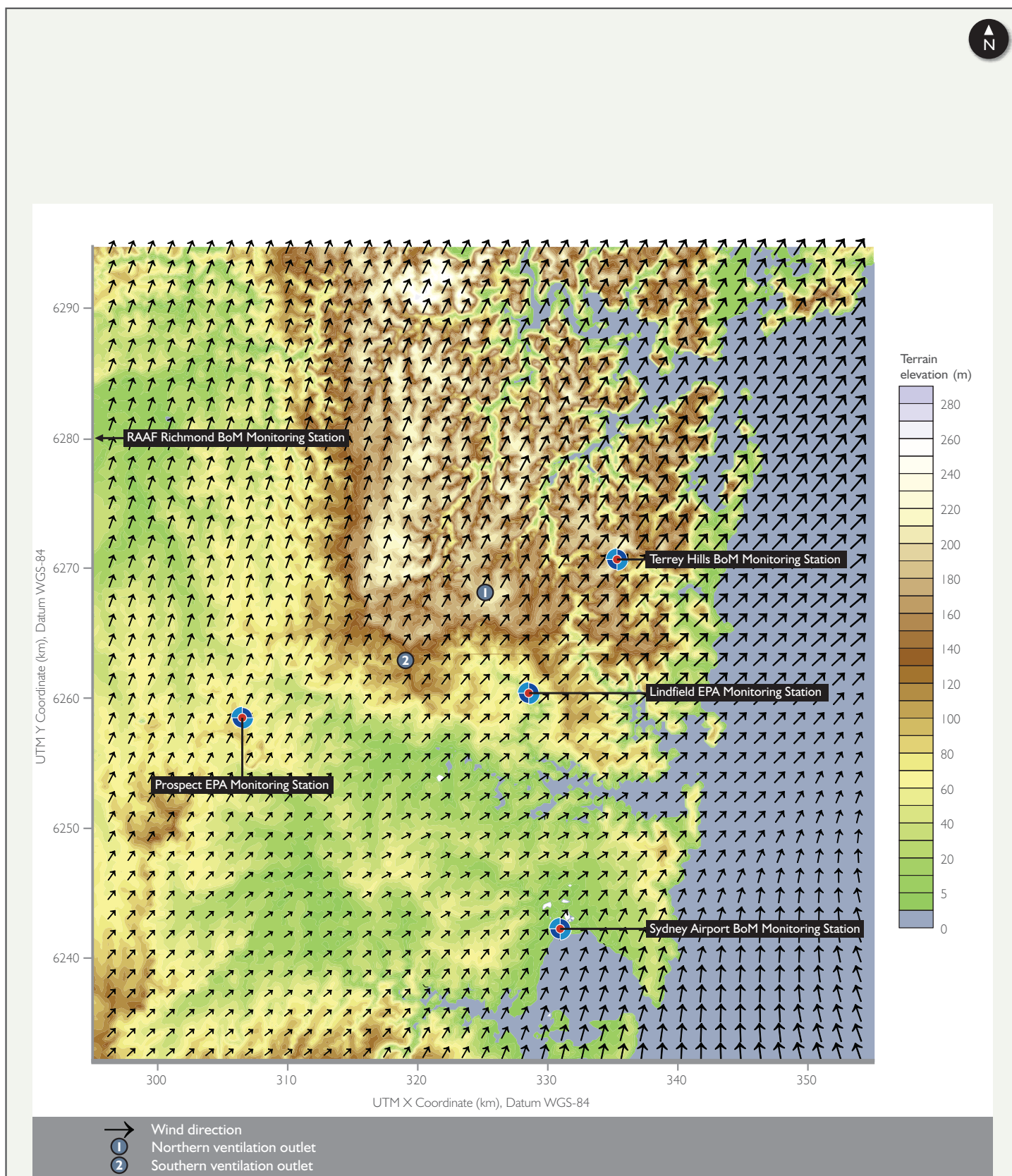


Figure 2-33 Wind flow field at hour 17:00 on day 45 (60 metres)

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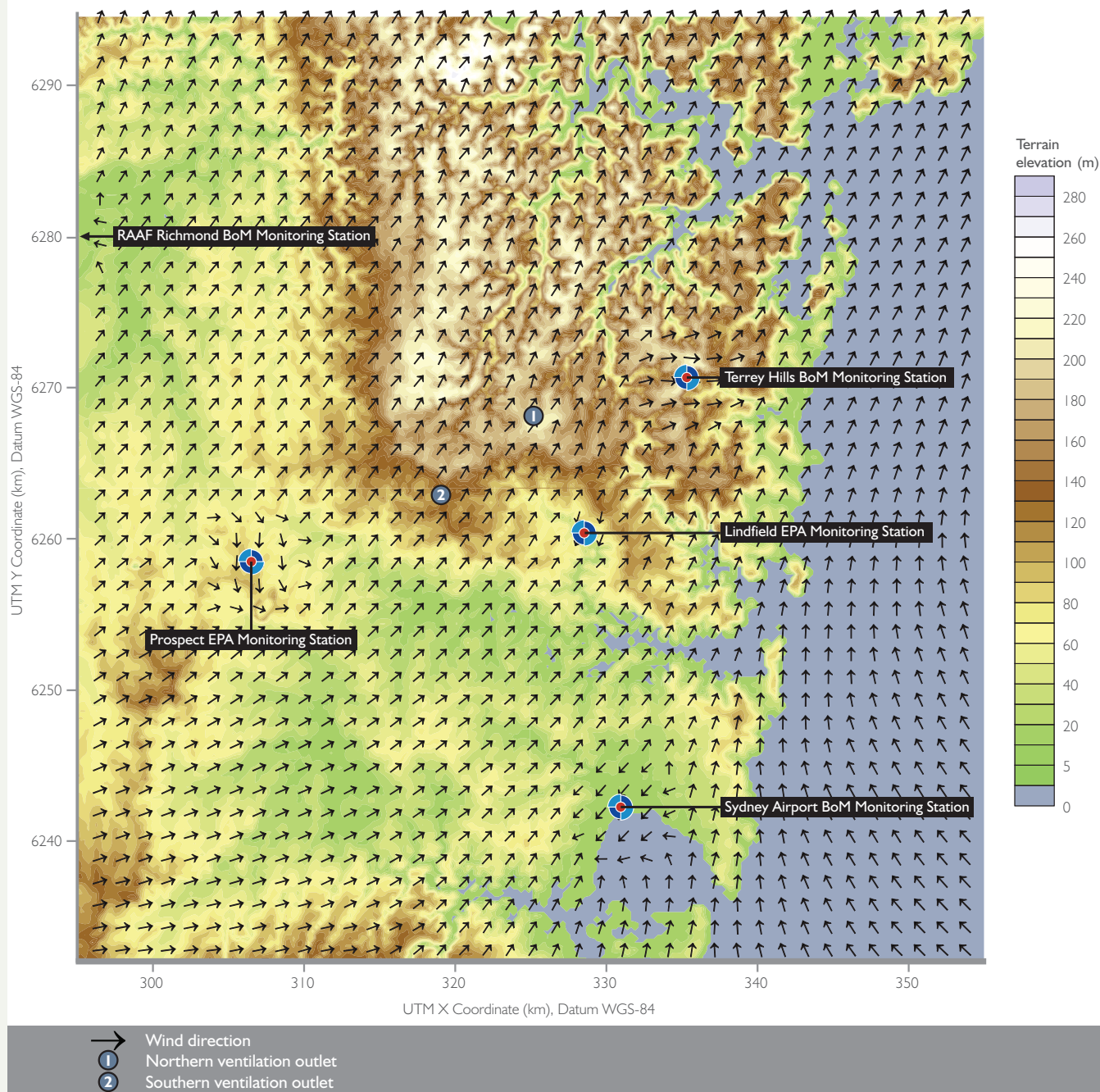


Figure 2-34 Wind flow field at hour 07:00 on day 337 (10 metres)

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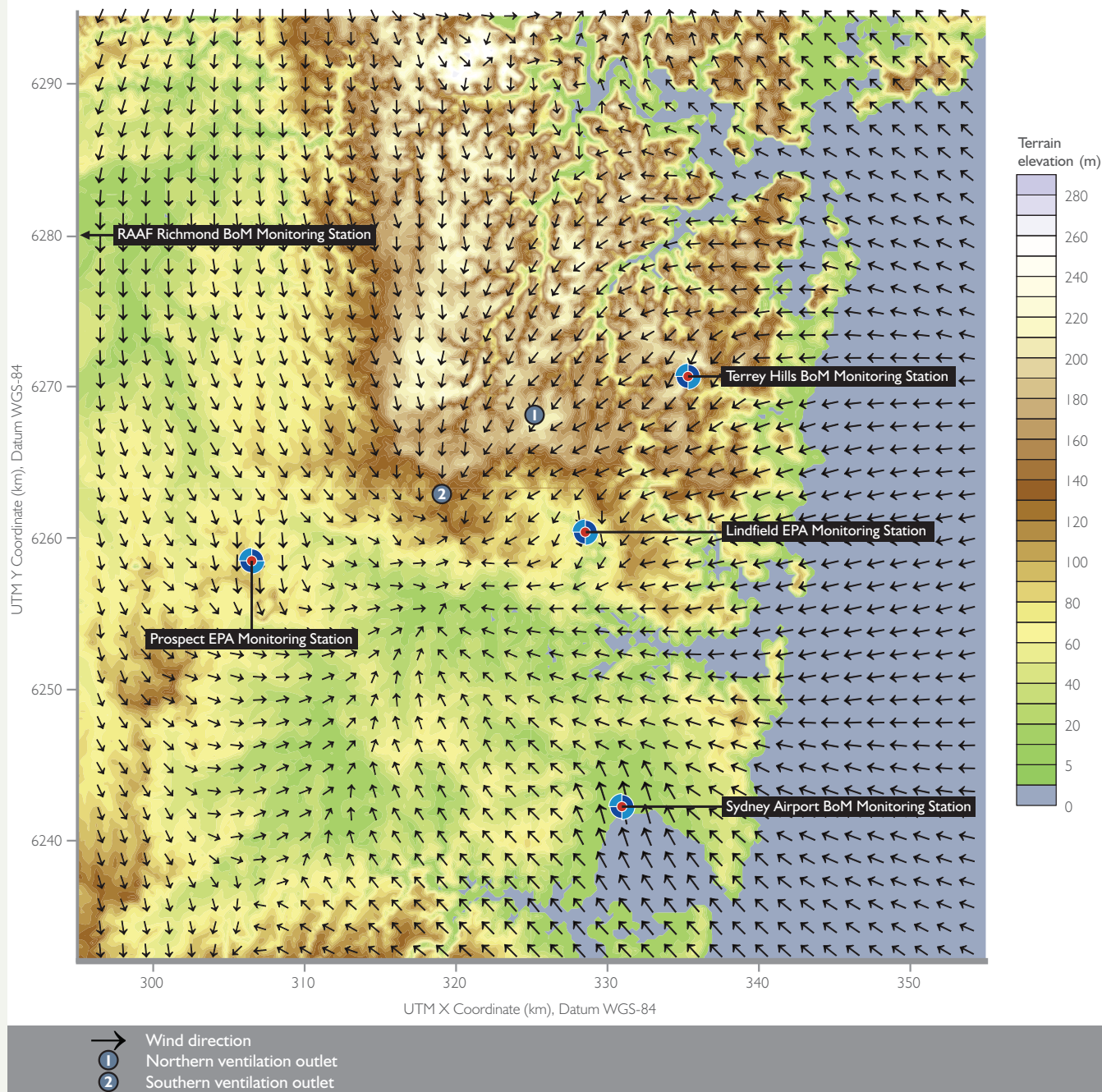


Figure 2-35 Wind flow field at hour 09:00 on day 337 (10 metres)

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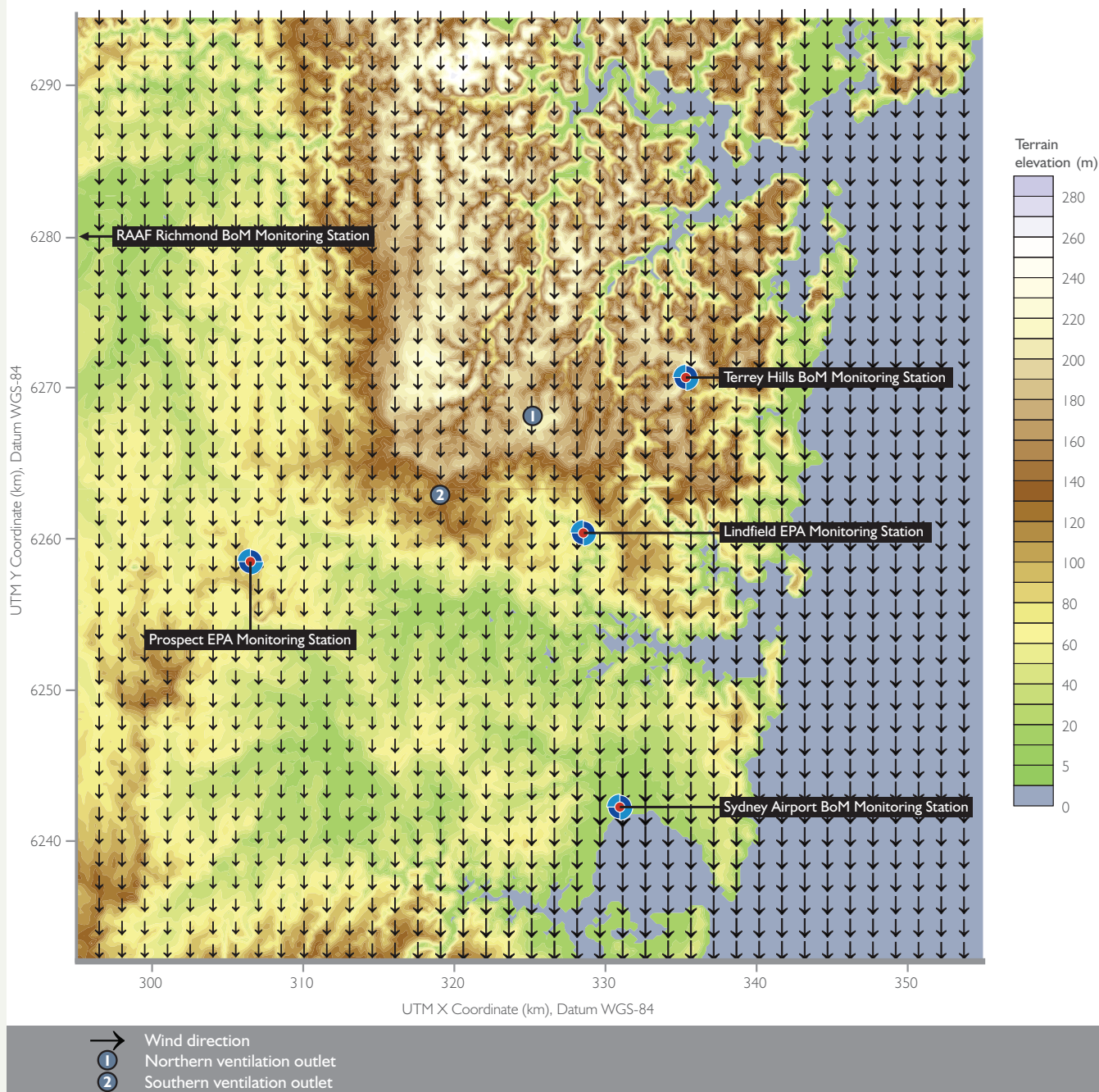


Figure 2-36 Wind flow field at hour 10:00 on day 337 (10 metres)

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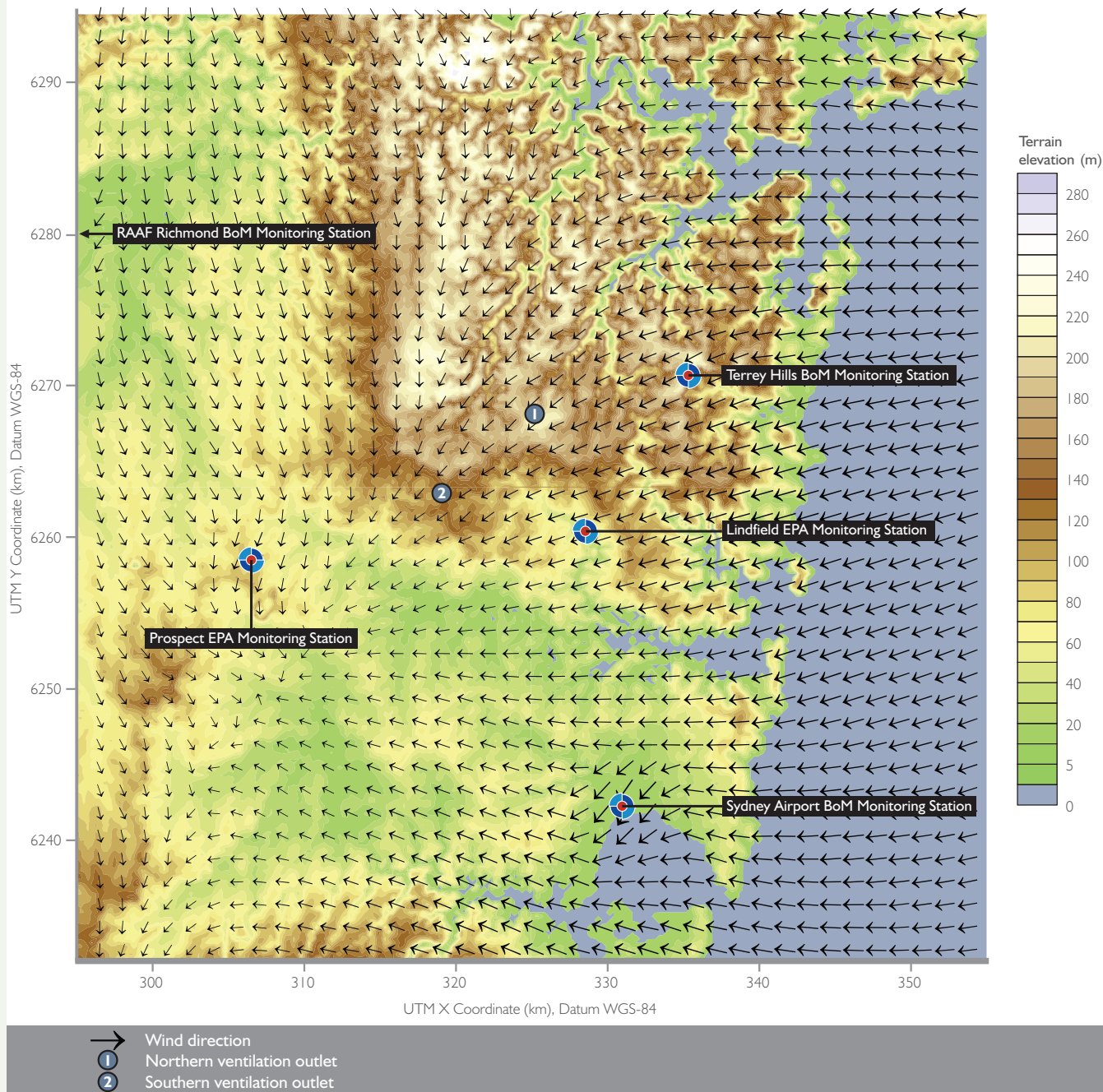


Figure 2-37 Wind flow field at hour 11:00 on day 337 (10 metres)

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Frequency of meteorological conditions

How often do the identified rare and infrequent meteorological conditions that result in elevated ground level concentrations occur?

Hour 17:00 on day 45 (outlet tip downwash)

As a result of observations made in relation to day 45 and potential for outlet tip downwash, an analysis has been conducted to identify the number of hours during the modelling period (2009 to 2011) during which outlet tip downwash may be anticipated to occur at the northern and southern ventilation outlets. **Table 2-85** and **Table 2-86** list times when outlet tip downwash is expected to occur at the northern and southern ventilation outlet, respect. Note that all occurrences were identified in the 2009 meteorological data, with no events in either 2010 or 2011.

Table 2-85 Outlet tip downwash occurrences at the northern ventilation outlet

Year	Day	Hour	Ratio of discharge velocity to wind speed
2009	266	15	1.4
2009	270	15	1.4
2009	45	17	1.4
2009	45	19	1.2
2009	45	20	1.5
2009	45	21	1.0
2009	45	22	1.1
2009	45	23	1.1

Table 2-86 Outlet tip downwash occurrences at the southern ventilation outlet

Year	Day	Hour	Ratio of discharge velocity to wind speed
2009	266	9	1.4
2009	184	14	1.4
2009	266	14	1.3
2009	270	14	1.4
2009	266	15	1.4
2009	270	15	1.4
2009	45	19	1.2
2009	45	20	1.5
2009	45	21	1.0
2009	45	22	1.1
2009	45	23	1.1

There were no meteorological conditions which suggest the potential for outlet tip downwash in 2010 or 2011 and only the potential for a small number of hours on three days for the northern ventilation outlet (of which only one period resulted in elevated ground level concentrations – day 45). Only a small number of hours on four days at the southern ventilation outlet in 2009 were identified (at times no elevated ground level concentrations have been predicted).

The potential frequency of outlet tip downwash conditions leading to elevated ground level concentrations is therefore concluded to be very rare.

Hour 8:00 on day 337 (wind shifts)

Day 337 meteorological conditions have been further analysed and the conditions under which peak concentrations occur are characterised by the following set of events:

- 180 degree wind direction change during the hour as offshore land breeze gives way to the onshore sea breeze.
- Wind speed reduction around the maximum hour.
- Mixing height reduction accompanied by a vertical velocity reduction and change in stability class from unstable to neutral at the hour that the maximum concentration was recorded.

The meteorological event responsible for the peak concentration is a naturally occurring part of the diurnal cycle of flow in the region. These characteristics are typically ascribed to the shift between off-shore flow during the night which gives way to on-shore winds in the morning. The sea land breeze cycle is likely to occur every single day of the year.

However, although this meteorological event occurs mostly every day, there is no other hour in the entire year (2009) or in 2010 or 2011 that produces a peak concentration at this time of the day or at the interchange between the land and sea breeze. Certainly the meteorological events leading up to the peak event are not unusual and it can only be concluded that it is the combination of the massive wind direction change, a reduction in the stability class, mixing height and wind speed that caused the predicted concentration peak which is a factor of two higher than the next highest concentration.

A more detailed analysis of the meteorological data against the concentration data for a full year period was undertaken to demonstrate that the peak concentration of day 337 ($81 \mu\text{g}/\text{m}^3$) is an outlier of an otherwise normal data distribution. The plots shown in **Figure 2-38** are hourly meteorological and concentration data from the northern ventilation outlet the entire year 2009 meteorological year. The plots represent the concentration of CO plotted against corresponding wind speed, wind direction, atmospheric stability class and mixing height. For each of the plots shown in **Figure 2-38**, the single outlier data point is hour 8 on day 337.

The modelling results shown in **Figure 2-38** clearly show that the single result recorded on hour 8:00, day 337 does not fit the normal distribution of data observed for all other meteorological conditions and can clearly be considered to be an outlier. The offshore-onshore breeze is a daily occurrence and yet no other hour at the time of the land sea breeze interface produces a concentration of any significance, therefore it can be confidently concluded that this hour is an outlier and not a normal by-product of this sort of event.

The above analysis is a simplistic analysis which draws broad conclusions about a highly complex meteorological situation. The broad trends and graphs above have been selected to attempt to demonstrate that the predicted concentration is not a typical effect and whilst it could be considered to be a calm condition (due to low wind speeds alone) wind speed is clearly not the only factor influencing the result. On this basis, it is not considered accurate to characterise these meteorological conditions as an effect caused by calm conditions rather it is a unique combination of modelled assumptions resulting in a single predicted data point well above the rest of the data predicted for the remaining 8,759 hours of the year. **It would therefore be considered acceptable to omit this data (hour 8:00 on day 337) from the analysis.**

Summary of outcomes

The analysis presented in this section has identified a number of factors affecting predicted short term average concentrations of emissions around the northern and southern ventilation outlets. These include rare and infrequent meteorological conditions leading to outlet tip downwash, and conditions associated with onshore-offshore winds.

Based on the results provided, the increase in ventilation outlet heights results in an overall decrease in concentrations with the exception of a very small number of hours that are characterised by outlet tip downwash conditions. These downwash conditions are not common and can be considered a rare event and not likely to result in regular ongoing elevated pollutant concentrations. The analysis presented above also demonstrates that although onshore-offshore wind switch occur regularly, the frequency of these conditions leading to an elevated ground level concentration is very low (so as to be an extreme outlier in the data set).

The dispersion modelling for the **SPIR15** and **SPIR20** scenarios (ie to assess the change in ventilation outlet heights by five metres) has generated results that, taking into account the effects of rare meteorological events, are consistent with expected trends. This includes a general reduction in ground level concentrations with an increase in ventilation height. This comparison demonstrates that the air quality modelling is appropriately predicting plume dispersion and that an increase in ventilation outlet heights by five metres (from 15 metres to 20 metres) significantly improves ambient air quality performance.

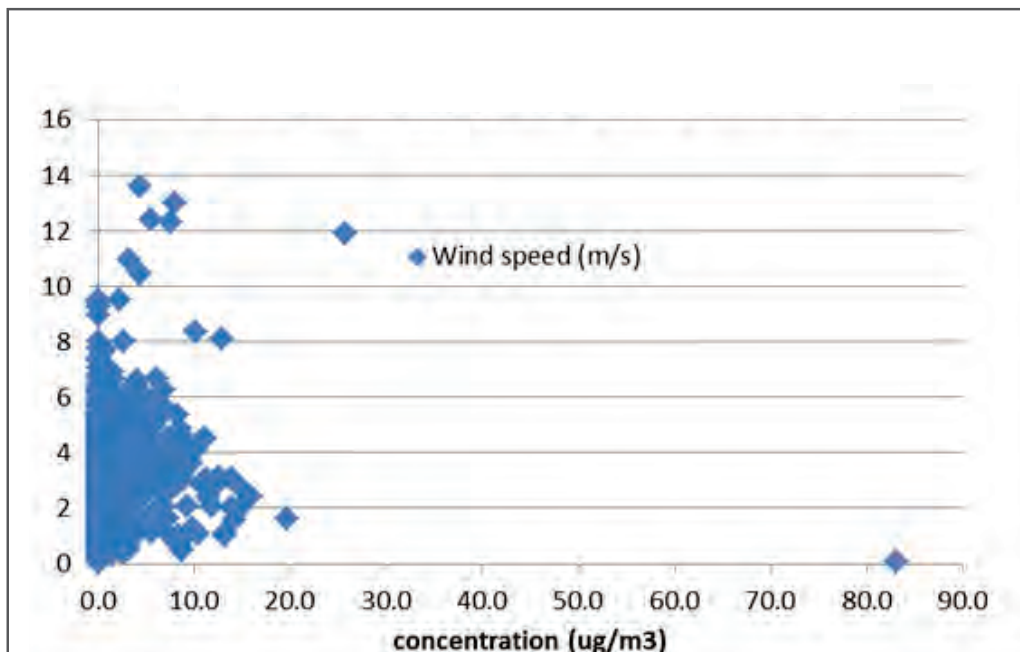
2.15.3 Conclusions

The modelling results and analysis presented in this section demonstrate that the potential impacts of the project would comply with applicable ambient air quality criteria and advisory reporting standards, and in most cases by a significant degree.

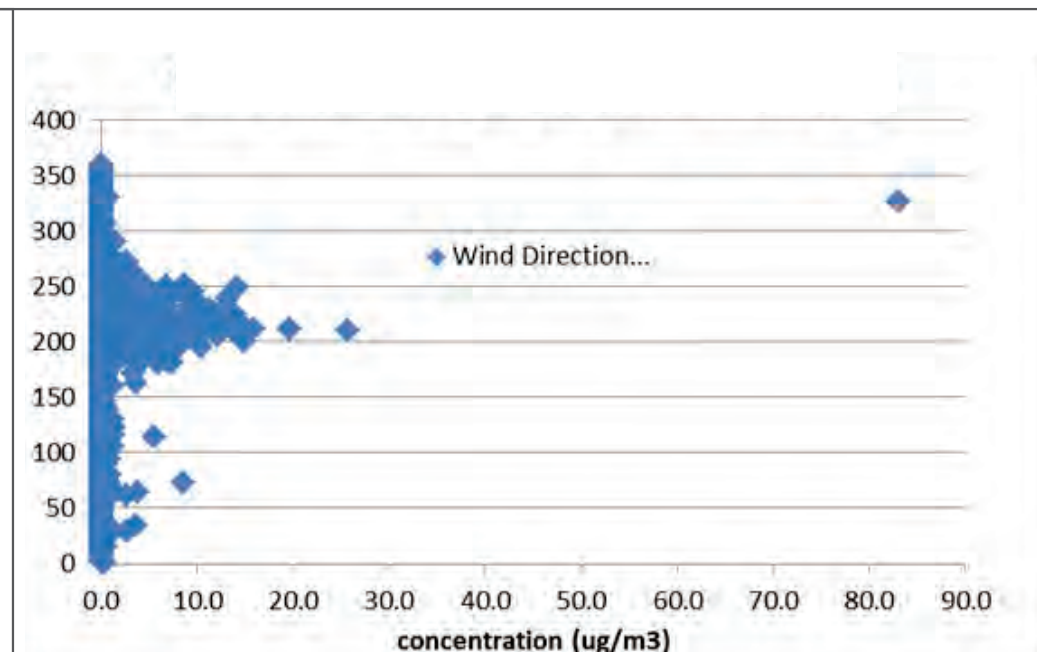
By increasing the height of the southern and northern ventilation outlets by five metres, the potential ambient air quality impacts of the project have been reduced even further than predicted in the environmental impact statement.

Through the air quality modelling and analysis conducted for the project, two rare and infrequent meteorological conditions have been identified as the cause of a very small number of incidents of elevated ground level concentrations. The analysis presented in this section demonstrates that the conditions potentially leading to outlet tip downwash are rare and would not typically occur during operation of the project. In the case of onshore-offshore wind switch, although this phenomenon is expected to occur regularly, analysis of the meteorological and modelling data from the air

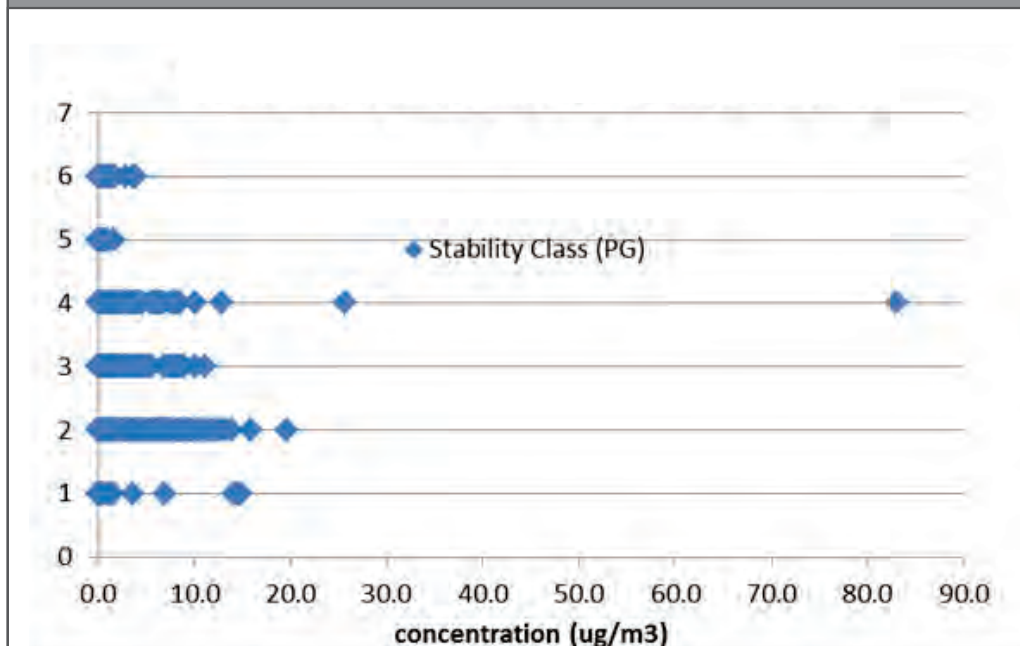
quality impact assessment demonstrates that the potential for this phenomenon to lead to elevated ground level impacts is very low. Based on analysis of data from the air quality impact assessment, this event has been identified as an extreme outlier in the data set.



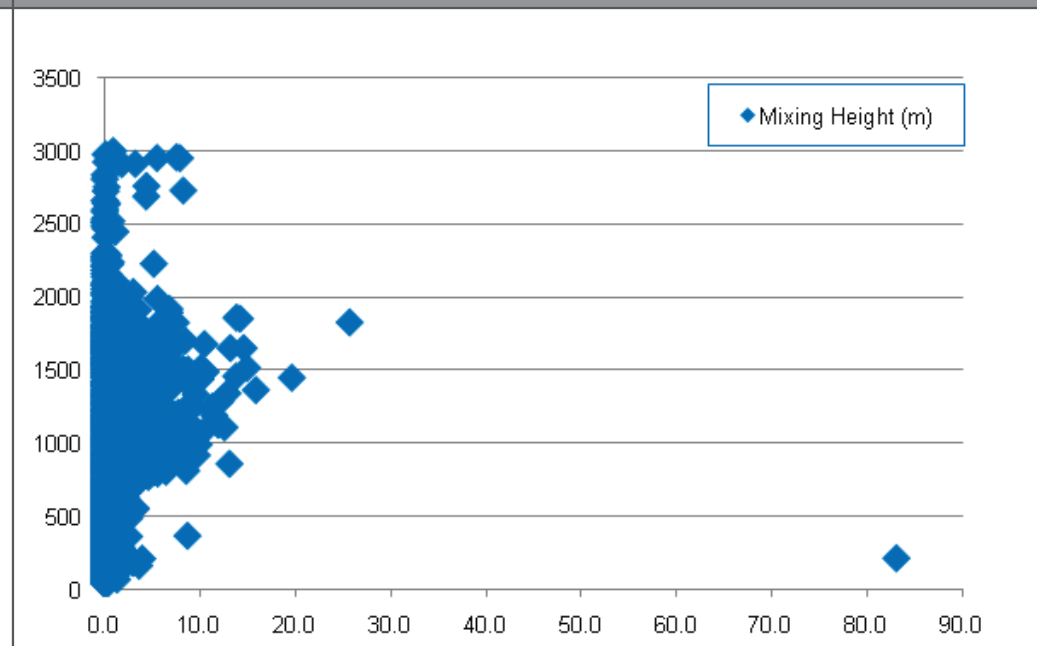
Concentration vs wind speed. The maximum outlier peak hourly concentrations of JDay 337 and JDay 45 are shown.



Concentration vs wind direction



Concentration vs stability class



Concentration vs mixing height

Figure 2-38 CO concentration data analysis for varying meteorological parameters

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2.16 Construction air quality

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

- 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.

Details of construction activities can be found in Chapter 5 of the environmental impact statement. Aspects relevant to the consideration of air quality impacts during construction are summarised below.

2.16.1 Overview of relevant construction activities

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

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

then identified to reduce the likelihood of the works adversely affecting local air quality and receivers.

Table 2-87 provides a high level summary of construction activities with potential air quality implications, based on construction site.

2.16.2 Tunnel excavation

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

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

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

Table 2-87 High level construction activities associated with emissions to air

Worksite or area	Typical activities with potential to generate air emissions
Hills M2 Motorway integration works	• Establishment of work areas. • Earthworks associated the formation of the finished design levels for the additional lane, cuttings and embankments. • Bridge construction works, including piling. • General civil works. • Spoil handling and management, estimated at around 39,800 m³ of spoil. • Paving. • Exhaust emissions from the operation of construction vehicles and plant. • Surface site rehabilitation and restoration.
Windsor Road compound (C1), Darling Mills Creek compound (C2), Barclay Road compound (C3) and Yale Close compound (C4)	• Establishment of work sites. • Exhaust emissions from the operation of construction vehicles and plant. • Surface site rehabilitation and restoration.
Southern interchange and southern interchange compound (C5)	• Establishment of work areas, including vegetation removal and building demolition. • Earthworks associated with the formation of finished design levels, cuttings, cut-and-cover sections (including tunnel structures), and the excavation of decline ramps, main alignment tunnels, and shafts. • General civil works, including retaining walls. • Removal, storage and transport of around 613,900 m³ of spoil from construction activities. • Paving. • Exhaust emissions from the operation of construction vehicles and plant. • Construction of permanent operational ancillary facilities. • Surface site rehabilitation and restoration.

Worksite or area	Typical activities with potential to generate air emissions
Wilson Road compound (C6)	- Establishment of work site, including building demolition and vegetation clearance. - Earthworks associated with the formation of the finished design levels for the site and the excavation of the decline to the main alignment tunnels. - Removal, storage and transport of around 441,950 m³ of spoil from tunnelling activities. - Exhaust emissions from the operation of construction vehicles and plant. - Decommissioning and removal of construction-related buildings and plant. - Construction of permanent operational ancillary facilities. - Surface site rehabilitation and restoration.
Trelawney Street compound (C7)	- Establishment of work site, including building demolition and vegetation clearance. - Earthworks associated with the formation of the finished design levels for the site and the excavation of the decline to the main alignment tunnels. - Removal, storage and transport of around 492,200 m³ of spoil from tunnelling activities. - Exhaust emissions from the operation of construction vehicles and plant. - Decommissioning and removal of construction-related buildings and plant. - Construction of permanent operational ancillary facilities. - Surface site rehabilitation and restoration.
Pioneer Avenue compound (C8)	- Establishment of work site, including building demolition. - Construction of temporary structures, and paving for car parking areas. - Decommissioning and removal of construction-related buildings. - Surface site rehabilitation and restoration. - Exhaust emissions from the vehicles.
Northern interchange, the northern interchange compound (C9), Bareena Avenue compound (C10) and Junction Road compound (C11).	- Establishment of work areas, including vegetation removal and building demolition. - Earthworks associated with the formation of the finished design levels for the interchange, cuttings, cut-and-cover sections (including tunnel structures), and the excavation of on-ramps and off-ramps, shafts and the

Worksite or area	Typical activities with potential to generate air emissions
	main alignment tunnels, • Removal, storage and transport of around 1,024,350 m³ of spoil from construction activities from the northern interchange compound. • General civil works. • Paving. • Exhaust emissions from the operation of construction vehicles and plant. • Decommissioning and removal of construction-related buildings and plant. • Construction of permanent operational ancillary facilities at the Bareena Avenue compound. • Surface site rehabilitation and restoration.

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

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

2.16.3 Construction program

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

Table 2-88 Indicative construction program

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

2.16.4 Construction plant and equipment

During construction, standard items of plant and equipment commonly used in road and tunnel construction would be used, including gantry cranes, fans, excavators, compressors, loaders, road sweepers, water carts, pumps, excavators, concrete agitators and dump trucks.

The following table provides a list of plant and equipment expected to be used at different worksites during construction of the project. Separate lists are provided for plant and equipment used on the surface and underground.

Table 2-89 Indicative construction plant and equipment

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

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

2.16.5 Spoil and waste disposal

The project would generate around 2.6 million cubic metres of spoil from dive and tunnel excavation. Tunnel spoil generated by road headers would generally be transported from the tunnelling face to the extraction shaft sites via trucks operating within the tunnels. Where excavation occurs close to the extraction shaft, the spoil material would be transferred directly from the road headers to the shaft for removal from the tunnels. Small quantities of excavated spoil would remain in the tunnels for short periods of time.

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

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

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

Spoil generation and disposal activities would occur throughout the majority of the four year construction period. A number of suitable sites have been identified for spoil disposal, with the final disposal location(s) to be determined during detailed design and construction planning.

2.16.6 Construction vehicles

Construction vehicles required for the project are summarised in **Table 2-90**. The indicative vehicle numbers listed below represent those expected to be required for the excavation phase, as this phase has the highest vehicle numbers of all the working phases. Vehicle numbers associated with the fit out phases are expected to be substantially lower.

Table 2-90 Indicative construction vehicle numbers

Site	Daily heavy vehicles	Daily light vehicles
Windsor Road compound (C1)	20	85
Darling Mills compound (C2)	50	20
Barclay Road compound (C3)	50	52
Yale Close compound (C4)	50	20
Southern interchange (C5)	740	165
Wilson Road compound (C6)	600	100
Trelawney Street compound (C7)	570	100
Pioneer Avenue compound (C8)	12	650
Northern interchange (C9)	720	100
Bareena Avenue compound (C10)	20	25
Junction Road compound (C11)	5*	100

* Note: this figure takes into account amendments made to the Junction Road compound (C11) to include laydown activities, as detailed in Section 9.5 of this report.

2.16.7 Construction emission sources

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

Plant and equipment associated with excavating, handling or moving material (such as road headers, excavators, jack hammers and piling rigs) generate particulate matter emissions. Particulate matter is also emitted through wind erosion from exposed, unsealed and unvegetated areas and uncovered stockpiles. Diesel and petroleum-powered plant and equipment are sources of pollutants such as particulates (PM₁₀ and PM_{2.5}), nitrogen dioxide, carbon dioxide and volatile organic compounds (VOCs) through their exhaust (combustion) emissions. Electrically-powered plant and equipment do not generate combustion emissions at the construction site.

The most substantial particulate emissions potentially generated by the construction works are those associated with surface earthworks, material stockpiles, wind erosion and wheel-generated dust from vehicles on unsealed roads.

Off-road plant and equipment can generate substantial emissions of oxides of nitrogen and lesser amounts of carbon monoxide, particulates and VOCs. Passenger vehicles are also a source of these emissions. All emissions from construction activities would be closely managed and are expected to be confined to the local area surrounding the emission points, with no lasting effects on local air quality.

2.16.8 Construction motor vehicles and plant

The main sources of emissions from heavy vehicles, mobile excavation machinery and stationary combustion plants would be related to diesel combustion. Construction plant would generally be diesel-powered and would emit gaseous and particulate matter into the air. Road headers would be driven by mains power and would therefore not contribute to site based emissions at construction sites following connection of mains power (refer to **Section 4.1**).

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

The NPI (2008) provides emission factors for road transport vehicles (cars, light and heavy goods vehicles and buses used on either sealed roads or on well-formed unsealed roads) and industrial (off-road) vehicles, such as heavy earth moving and construction equipment and a range of miscellaneous vehicles such as forklifts. According to these factors, diesel light goods vehicles emit the greatest amount of PM₁₀ of all road vehicles on a volume-of-fuel-used basis; buses emit the greatest level of nitrogen oxides (NO_x); petrol-fuelled light goods vehicles (LGVs) emit the greatest level of total VOCs; and petrol cars have the highest emissions of benzene and 1,3-butadiene. Within each vehicle category, emissions of PM₁₀ and PM_{2.5} are very similar.

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

All plant and equipment used during construction would comply with the emissions concentration limits outlined in the *Protection of the Environment Operations (Clean Air) Regulation 2010*. As such, vehicular and plant emissions arising from the civil construction works are unlikely to have a substantial effect on the surrounding air quality.

Emissions would be minimised through application of standard environmental management measures including switching engines off when not in use, maintaining vehicles in accordance with manufacturers' specifications, using fuel efficient vehicles and efficient construction planning to minimise the number of trips.

2.16.9 Earth moving, excavation and demolition

The construction activities commonly requiring earth moving, excavation and demolition include:

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

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

Katestone (2011) prepared a best practice guide for the management of mining emissions, which was based on the results of environmental audits conducted for coal mines within the Greater Metropolitan Region. The different mining activities were ranked according to their emission levels of TSP, PM₁₀ and PM_{2.5}. The highest levels of particulates were generated from vehicle movements on unpaved roads and wind erosion of material stockpiles; these activities are similar to those associated with the proposed excavation works. As such, these activities would be expected to be primary potential emission sources for the proposed construction works.

The NPI specifies control efficiencies for various management and mitigation measures. As shown in **Table 2-91**, the most effective mitigation strategy for wheel-generated dust is the sealing of roads, followed by watering at a rate of greater than two litres per square metre per hour. For wind erosion of stockpiles, total enclosure is considered to reduce 99 per cent of emissions. For this project, the majority of haul truck travel would be undertaken on sealed roads, and the stockpiles of material excavated from the tunnels would be stored within acoustic sheds in the majority of case. These actions would substantially mitigate emissions associated with the construction works.

Table 2-91 Estimated control factors for various mining operations (NPI, 2012c)

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

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

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

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

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

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

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

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

2.16.10 Construction water treatment

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

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

2.16.11 Construction air quality management

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

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

Table 2-92 Proposed construction air quality management and mitigation measures

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

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3 Clarifications – Ventilation system design

This chapter includes clarifications and discussion of design options and alternatives for the project's ventilation system. In particular, it provides information in relation to:

- The availability and effectiveness of in-tunnel air treatment systems (refer to **Section 3.1**).
- Ventilation system design options and alternatives, and an analysis of feasible and reasonable measures that could be applied to the project to minimise in-tunnel and ambient exposures to vehicle emissions.

3.1 Availability and effectiveness of in-tunnel air treatment systems

Many of the submissions received in response to the public exhibition of the environmental impact statement have raised questions about treatment of in-tunnel air, including the use of filtration technology. Some of these submissions argue that filtration technology should be applied to the NorthConnex project, while others provide broader comments on the availability and efficacy of in-tunnel air treatment technologies (with a particular focus on filtration technologies).

Submissions received from the Environment Protection Authority and NSW Health, as well as other submissions, have expressed a view that all feasible and reasonable measures should be applied to the project to minimise in-tunnel and ambient exposures to vehicle emissions. This principle is supported, and further analysis of ventilation design options and alternatives to achieve this outcome is presented in **Section 3.1** of this report.

This clarification provides information about the availability and effectiveness of in-tunnel air treatment technologies, to provide a basis for responding to issues raised in submissions and to inform the analysis of ventilation design options and alternatives presented in **Section 3.1** of this report.

3.1.1 Availability of in-tunnel air treatment technologies

There are currently two types of air treatment technologies relevant to the management of in-tunnel air:

- Technologies that remove particulate matter from in-tunnel air.
- Technologies that remove gaseous pollutants (principally nitrogen dioxide) from in-tunnel air.

Particulate matter treatment technologies

Particulate matter filtration removes suspended particulate matter from the airflow drawn into the treatment system. Nearly all particulate matter filtration systems are based on the principle of 'electrostatic precipitation'. It is a process that is applied to a range of industries and that has been adopted for use in a limited number of in-tunnel air filtration installations.

Electrostatic precipitation for road tunnels has been progressively developed since the first installation in Japan in 1979. The electrostatic precipitation process involves:

- Charging suspended particles in the airflow with an electric charge.
- Passing the air containing the charged suspended particles over electrode plates with an opposite charge, thereby depositing the particles on the plates.

The operation of an electrostatic precipitator is similar to the effect of static electricity on certain materials, which once charged with static electricity, attract dust or other oppositely charged objects.

Electrostatic precipitators do not collect all particulate matter.

The efficiency and effectiveness at which an electrostatic precipitator system will function varies according to the:

- Speed of the airflow through the electrostatic precipitator.
- Type and size of particles in the airflow.
- Concentration of particulate matter in the airflow.

According to The Treatment of Air in Road Tunnels study by the Centre d'Études des Tunnels (CETU, 2010), the effectiveness of road tunnel particulate matter filtration systems is in the range 80 to 90 per cent reduction in the mass concentration of particulate matter.

The CETU study also confirms that such air treatment systems demonstrate higher performance when treating higher concentrations of particulate matter. It is for this reason that electrostatic precipitators are often used in industries where high concentrations of particulate matter need to be managed and treated (eg in coal fired power generation).

By comparison, the concentration of particulate matter experienced in most road tunnels is much lower than in industries where electrostatic precipitators are used. Because electrostatic precipitators operate more effectively at higher concentrations of particulate matter, their removal efficiencies when applied to road tunnels are considerably less than experienced in other industrial applications.

Electrostatic precipitators are also more efficient when treating larger particle sizes, and less efficient when treating smaller particle sizes. This difference relates to the area on the particles that is available to carry an electrostatic charge – larger particles can carry a higher charge and are therefore more likely to be strongly attracted to electrode plates compared with smaller particles.

Austrian experience from in-situ data from the Plabutsch tunnel indicates that the treatment of particulate matter has the efficiencies summarised in **Table 3-1**. This data, provided by a manufacturer of electrostatic precipitation equipment, indicates that smaller particles are less likely to be removed than larger particles.

Table 3-1 Efficiency of particulate matter removal by particle size

Particle size	Content by weight	Removal efficiency
< 2.5 µm	30%	54% to 91%
2.5 µm to 10 µm	60%	94% to 99%
>10 µm	10%	>99%

Filter maintenance and regeneration are important factors for particulate matter filtration as they determine the long term efficiency of the filtration equipment. Over time, particulate matter builds up in the filter and requires removal. Excess accumulation of particulate matter will reduce the efficiency of the filtration process.

Filter regeneration may be either wet (water jet) or dry (air jet). Both methods aim to separate particulate matter from the filter and would be applied, for example, for a one hour cycle every five days for a fully operating road tunnel air treatment plant. Appropriate measures will need to be in place for the collection, handling and disposal of the waste stream from the filter regeneration process.

Gaseous filtration technologies

While there are a number of pollutant gases that are emitted by motor vehicles, nitrogen dioxide is the principal gas that is targeted in existing air cleansing (gaseous filtration) systems for road tunnels. These systems employ a denitrification process.

Denitrification system performance is dependent on the in-tunnel air first being treated with an electrostatic precipitator to remove particulate matter. Higher loads of particulate matter will adversely affect the performance of denitrification systems.

Denitrification treatment technologies involve the collection and chemical reaction of nitrogen dioxide to a form that can be collected and removed from the road tunnel in a manageable waste stream.

As at 2010, there were only five road tunnel denitrification treatment systems worldwide (CETU, 2010). The systems in use are essentially trial systems using the following technologies:

- Activated carbon treated with potassium hydroxide.
- Adsorption methods where nitrogen dioxide is physically adsorbed into pellets.
- Photocatalytic de-nitrification using titanium oxide under ultraviolet light to activate oxygen and break down the nitrogen dioxide to form acids, including nitric acid.

Other trial systems not installed in road tunnels include bio-filtration, and cold plasma techniques to convert gases to less harmful gas compounds.

The small number of denitrification system installations and the varying technologies used has yielded very limited data on the performance of these systems. The limited data that is available is not sufficient to adequately evaluate the overall performance of denitrification systems. Furthermore, the denitrification technologies are not yet sufficiently mature to have converged on a single leading efficient methodology, whereas there is more general consensus of the use of electrostatic precipitation for removal of particulate matter removal. There is little available, validated data which demonstrates the effectiveness of gaseous filtration systems.

3.1.2 International experience

Around the world, there are relatively few road tunnels with installed filtration systems. Where in-tunnel treatment technologies have been applied to road tunnels, these technologies have focused on the management and treatment of particulate matter.

A review of the use of the international electrostatic precipitators and denitrification technologies by country is provided below.

Japan

Japan has about 8,000 road tunnels comprising a total length of 2,500 kilometres. The 2010 CETU study lists 46 road tunnels (around 0.6 per cent of all Japanese road tunnels) where particulate matter filtration is installed or was being installed at the time of that report.

The use of particulate matter filtration in Japanese tunnels is mainly to improve in-tunnel visibility. The stated objective for the installation of particulate matter filtration as identified by the 2010 CETU study for each of the Japanese road tunnels employing particulate matter filtration is summarised in **Table 3-2**. The table shows that 28 Japanese road tunnels employ particulate matter filtration to manage in-tunnel visibility (as the principal or contributing reason for installing the technology). A total of 21 tunnels base the installation of particulate matter filtration (as the principal or contributing reason) on management of discharge air quality (from the road tunnel ventilation outlets or tunnel portals).

Table 3-2 Japanese road tunnels with filtration – reported objective of particulate matter filtration

Objective for particle filtration	Number of Japanese road tunnels
Improve in-tunnel visibility	21
Improve in-tunnel visibility and exhaust air	7
Improve exhaust air	14
No stated objective	4
Total	46

Where particulate matter filtration technology is installed to manage in-tunnel visibility, this is typically as a result of a high percentage of diesel powered vehicles and a very high percentage of heavy goods vehicles using the road tunnel.

Most of the Japanese tunnels with particulate matter filtration are less than five kilometres long. Operating hours for the filtration systems vary widely, from five hours per month, up to 24 hours per day for some urban tunnels.

The longest of the tunnels with particulate matter filtration (and the longest tunnel in Japan) is the Kan-Etsu Tunnel at around 11 kilometres (between the Gunma and Niigata Prefectures). The Kan-Etsu Tunnel operates entirely with portal emissions and does not include vertical ventilation outlets. The particulate matter filtration system is reported to operate about 20 per cent of the time at the north portal, and three per cent of the time at the south portal.

The next longest, the Tokyo Bay Tunnel at 9.6 kilometres long has a ceiling bypass particulate matter filtration system which operates around 12 to 13 hours per year (only 0.15 per cent of the time). The filtration system in the Tokyo Bay Tunnel has been installed and operates to manage in-tunnel visibility, which can deteriorate during periods of high traffic volumes given the gradient of the tunnel. The location the tunnel under Tokyo Bay makes the use of an intermediate ventilation outlet to manage in-tunnel air quality impractical, and a particulate matter filtration system has been installed as an alternative means to manage in-tunnel air quality (visibility).

As confirmed in the CETU report (2010), both denitrification and particulate matter filtration systems have been installed at the Central Circular Route (Chuo-Kanjo-Shinjuku) in Tokyo since 2007. Data published on the website of the Tokyo Metropolitan Expressway Company claims a minimum 90 per cent NO₂ reduction and a minimum 80 per cent particulate matter reduction for these installations. It is understood that there is a small number (perhaps two) other installations of denitrification technology in Japan, in addition to the extension of the central Tokyo road tunnel network (Shinagawa Tunnel) which is currently in construction.

Norway

Norway has around 1,000 road tunnels of which only eight (around 0.8 per cent of all Norwegian tunnels) have a particulate matter filtration system installed. Two of these tunnels, the Festning Tunnel (in Oslo) and the Bragernes Tunnel (in Drammen), installed filtration principally to improve emissions to the environment.

Norway also has specific challenges in terms of in-tunnel visibility. Visibility is deteriorated significantly in Norwegian tunnels when studded tyres are used (required due to icy conditions) which increases abrasion with the road surface and, consequently, the suspension of particulate matter resulting from this abrasion. Road tunnels in warmer climates, where studded tyres are not required (such as in Sydney) do not have this issue.

The Festning Tunnel passes beneath central Oslo. It is 1.8 kilometres long and carries 60,000 vehicles per day. It is understood that the filtration system installed in this tunnel is no longer in operation (RTA, 2001).

The Bragernes Tunnel is an unusual 'corkscrew tunnel' with significant grade. It is 3.2 kilometres long and carries 20,000 vehicles per day. The tunnel climbs 150 metres over its length.

The Laerdal Tunnel is the longest road tunnel in the world at 24.5 kilometres, and the longest with an in-tunnel air treatment system. The tunnel only carries 1,000 vehicles per day, and the principal purpose of the particulate matter filtration system is to improve visibility within the tunnel, as the tunnel is deep underground with no opportunity to introduce additional fresh air along its length. It is understood that the filtration system within this tunnel is no longer operational.

The Laerdal Tunnel was also equipped with an absorption denitrification filtration system. However, A Guide to Optimising the Air Quality Impact upon the Environment (PIARC, 2008) confirms that both filtration systems within this tunnel do not operate as traffic volumes have never approached forecast levels. With improving fuel quality, vehicle efficiencies and lowering emissions rates, the systems are unlikely to ever be used.

Norway also has specific challenges in terms of in-tunnel visibility. Visibility deteriorates significantly in Norwegian tunnels due to the use of studded tyres (required due to icy conditions) which increases abrasion with the road surface and, consequently, the suspension of particulate matter resulting from this abrasion. Sydney tunnels do not have this issue.

Spain

The M-30 Orbital Motorway circles the central districts of Madrid. It is the innermost ring road, with a length is 32.5 kilometres. It has at least three lanes in each direction, supplemented in some parts by two or three lane auxiliary roads. It connects to the main Spanish radial national roads that start in Madrid.

From 2005 to 2008, major upgrading works took place, and now a significant portion of the southern part runs underground. The M-30 Orbital Motorway is essentially a number of independent tunnels and surface roads. They are the longest urban motorway tunnels in Europe, with sections of more than six kilometres in length and three to six lanes in each direction.

Overall there are 22 particulate matter filtration systems and four denitrification systems installed by four different manufacturers. These were initially operated for 20 hours per day. The 2010 CETU study identifies that they now only operate for a few hours each week.

France

The Mont Blanc Tunnel was retrofitted with a particulate matter filtration system around 2010. The tunnel is a two lane bi-directional tunnel 11.6 kilometres long and originally constructed in 1965. It has a relatively small cross sectional area. The objective of the particulate matter filtration system is to contribute to various local initiatives aimed at improving air quality in the Chamonix Valley (CETU, 2010).

Italy

Italy reportedly has the greatest number of tunnels in the world, however, only one tunnel (the 'Le Vigne' tunnel in Cesene) has a particulate matter filter system installed. This tunnel is 1.6 kilometres in length and is located in a heavily populated area which is particularly sensitive to air emission from the tunnel portals. The objective of the particulate matter filtration system for this tunnel is to reduce the emission levels from the tunnel portals.

Italy has experimented with photocatalytic denitrification at the relatively short (350m) bi-directional Umberto Tunnel in Rome. However, the CETU report (201) suggests that health concerns related to the photocatalytic agent (titanium oxide) appear to have limited its use. Titanium oxide dust has been identified by the International Agency for Research on Cancer as a possible carcinogen.

Germany and Austria

One tunnel in Germany and two tunnels in Austria currently have small scale particulate matter filtration systems installed. These systems have been installed by filtration system manufacturers to trial and develop their systems.

South Korea and Vietnam

Five tunnels in South Korea and one tunnel in Vietnam have particulate matter filtration systems installed. The 2010 CETU study identifies that in these two countries, the systems are mainly used to provide adequate in-tunnel visibility where there are constraints on the intake of fresh air into the tunnels (as an alternative means of managing in-tunnel visibility).

Australia

In Australia, there was a trial in-tunnel air treatment system including particulate matter filtration and denitrification technologies carried out on the M5 East Motorway tunnels. Based on that trial, the in-tunnel air treatment system was not found to be effective.

The trial was used to manage in-tunnel air being recycled between the westbound and eastbound tunnels, rather than in relation to in-tunnel air being emitted from the ventilation outlet for the tunnels. The principal focus of the trial was on management of in-tunnel air quality, rather than improvement in the quality of in-tunnel air emitted to the environment.

Hong Kong

Design and construct contracts have been awarded for the Central Wan Chai Bypass in Hong Kong. It is understood that both denitrification and particulate matter filtration systems are to be installed in this tunnel. This is a 3.7 kilometre twin tunnel with three lanes of traffic in each direction. It is due to open in 2017.

3.1.3 Summary

Particle matter filtration has been used in a very small number of tunnels across the world, and in some cases has been reported to have an efficiency of around 80 per cent to 90 per cent. The technology has also been reported to be less efficient for smaller particle sizes and lower particulate matter concentrations. The majority of the installed systems in Japan and Norway have improved in-tunnel visibility in response to specific local conditions including the use of studded tyres and a very high proportion of diesel and heavy vehicles. These conditions are not present for the NorthConnex project.

Of the small number of systems that have been installed, the majority of these have been subsequently switched off or are currently being operated infrequently (in some cases only a few hours per year in response to unusual or infrequent conditions, and/ or ongoing maintenance requirements). Where the operation of in-tunnel air treatment systems have been discontinued or reduced, the reasons have been that

- The technology has proved to be less effective than predicted.
- The forecast traffic volumes have not eventuated.
- Reductions in vehicle emissions.

As a result of these reasons, the high ongoing operational costs of the technology have not been justified.

The CETU 2010 study identifies that conventional ventilation techniques (such as well designed ventilation outlets and effective management of in-tunnel ventilation rates) should be explored before consideration of in-tunnel air treatment options. For the NorthConnex project, these options have been explored in **Section 3.2** of this report.

3.2 Alternative ventilation design configurations

Submissions, including those made by the Environment Protection Authority, by NSW Health and by the local community, have raised issues relating to the design of the project's ventilation system. Key issues raised in these submissions include:

- Whether the design of the project's ventilation system has taken into account all feasible and reasonable measures to reduce concentrations of pollutants in the project's tunnel, and to reduce the impacts of the project on local air quality.
- Whether the design of the project's ventilation system has taken into account alternatives, including different locations and configurations of ventilation outlets.

A series of ventilation options and alternatives have been considered in the context of potential changes in impacts relative to the NorthConnex project as currently presented in the environmental impact statement. The assessment of ventilation options and alternatives scenarios is provided in the following section.

3.2.1 Options and alternatives

The design of the project's ventilation system has been reviewed in light of potential options and alternatives, including:

- **Scenario 1** –increasing the ventilation outlet height for the ventilation outlet locations presented in the environmental impact statement. The following increases in height of the southern and northern ventilation outlets have been considered:
 - Two metres (ventilation discharge at 17 metres).
 - Five metres (ventilation discharge at 20 metres).
 - Ten metres (ventilation discharge at 25 metres).
 - Fifteen metres (ventilation discharge at 30 metres).
- **Scenario 2** – relocation of the northern and southern ventilation outlets to alternative locations nominated in public submissions. These scenarios have considered:
 - Relocation of the northern ventilation outlet to a site in the Asquith Industrial Estate.
 - Relocation of the southern ventilation outlet into the south-western corner of the Pennant Hills Golf Course.
- **Scenario 3** – provision of additional ventilation outlets along the main alignment tunnels. This scenario has considered:
 - A new ventilation outlet around the mid point of the main alignment tunnels.
 - Conversion of the emergency smoke extraction facilities at Wilson Road and Trelawney Street into ventilation outlets.
- **Scenario 4** – changes to the ventilation flow rates within the project tunnels.
- **Scenario 5** – further consideration of measures to reduce the load of pollutants within or discharged from the project. This has included consideration of 'filtration' for particulate matter and nitrogen dioxide.

Each of these scenarios has been assessed to an appropriate level to allow comparison with the impacts predicted for the NorthConnex project in the environmental impact statement. In most cases this has involved qualitative or semi-quantitative/ simplified assessments for the purpose of a comparative screening. A comprehensive assessment equivalent to the detail required for an environmental impact statement has not been conducted.

For each of the scenarios, the following has been assessed:

1. **Changes in ambient air quality impacts.** Where a particular scenario involves changes to ambient air quality impacts, additional air dispersion modelling has been conducted for the purpose of comparison with predictions presented in the environmental impact statement. This air dispersion modelling has been conducted at a 'screening level' to determine a broad estimate of relative change in impacts, which has involved:
 - Assessment of nitrogen dioxide (NO₂), PM₁₀ and PM_{2.5} on an annual average basis.
 - Assessment of project incremental changes in ambient air quality, without the addition of background air quality concentrations.
 - Forecast traffic data in 2019 has been used as the basis for modelling and comparative assessment. As the assessment is comparative (ie considering the relative changes between scenarios), the selection of a forecast traffic data set is arbitrary.
 - Assessment using one year of metrological data (the 2009 meteorological year).
 - Ventilation outlets have been assumed to be the same design as presented in the environmental impact statement, with the exception in height increases or changes in location. Other parameters, including traffic forecasts and emissions inventories have remained unchanged. With the exception of Scenario 4 (ventilation flow rates), discharge parameters for the ventilation outlets have also remained unchanged.
 - Model parameters, such as topography and meteorology have remained unchanged from the modelling presented in the environmental impact statement. A simpler 150 metre receiver grid resolution has been applied, with no additional roadside receiver locations included.
2. **Changes in concentrations of in-tunnel air pollutants.** For scenarios involving additional ventilation outlets, discharge volumes have been assumed to be replaced with ambient air at the point of discharge (ie an additional air intake is provided at each intermediate ventilation outlet location to replace the same volume of air as discharged from that outlet). In the case of Scenario 2 (relocation of existing ventilation outlets), the ventilation outlets have been assumed to be moved with no extension of the main alignment tunnels and therefore no change in in-tunnel emissions inventories.
3. **Implications for human health.** Potential changes in human health effects have been estimated based on expected change in ground level concentrations of PM_{2.5} (as the principal driver of human health impacts). This approach has therefore inherently assumed that a similar population is exposed for each scenario when compared with the assessment presented in the environmental impact statement.
4. **Changes in other potential environmental and land use impacts** (other than in-tunnel and ambient air quality, and human health). A review of each scenario has been conducted to identify potential changes in environmental and land use impacts.

5. **Engineering practicality/ achievability and constructability.** The complexity of the engineering requirements for each scenario has been qualitatively reviewed.
6. **Cost.** Capital and operating cost for each scenario have been estimated.

The following sections outline the assessment of each scenario against the above matters. A summary of the outcomes of the assessments is provided at the end of the analysis of all scenarios.

3.2.2 Scenario 1 – Changes in ventilation outlet height

Potential changes in the heights of the northern and southern ventilation outlets have been considered at increments of +2 metres, +5 metres, +10 metres and +15 metres. All other aspects of the northern and southern ventilation outlets remained unchanged for this analysis.

Ambient air quality

Table 3-3 and **Table 3-4** summarise the outcomes of air dispersion modelling for different discharge heights at the northern ventilation outlet and the southern ventilation outlet, respectively. The table presents the maximum ground level concentration (annual average) for each pollutant based on the ventilation outlet design presented in the environmental impact statement, compared with the outcomes for each different ventilation outlet height. Ground level concentrations are for the contribution of the project only, based on forecast traffic in 2019.

Note that the values in listed in the tables have been gained using a simplified screening assessment to allow for rapid modelling and comparison of predicted air quality impacts, and have not been generated for detailed assessment or regulatory purposes. The results are therefore not directly comparable with those presented in Table 7-97 of the environmental impact statement. The modelling outcomes in Table 7-97 of the environmental impact statement are based on three years of meteorological data (2009, 2010 and 2011 meteorological years), whereas the tables below are based on only one year of meteorological data (the 2009 meteorological year). The modelling data presented below should therefore only be used for the purpose of comparing relative levels of impacts between alternatives, rather than as a substitute for a more detailed assessment using a larger meteorological data set (as is presented in the environmental impact statement).

Table 3-3 Effect of ventilation outlet height changes – northern ventilation outlet

Parameter	EIS design ¹	+2 metres	+5 metres	+10 metres	+15 metres
PM ₁₀ (annual average) (µg/m ³)	0.057	0.054	0.042	0.036	0.031
Percentage of criterion (30 µg/m ³)	0.19%	0.18%	0.14%	0.12%	0.10%
PM _{2.5} (annual average) (µg/m ³)	0.054	0.051	0.040	0.034	0.029
Percentage of advisory reporting standard (8 µg/m ³)	0.68%	0.64%	0.50%	0.43%	0.36%
NO ₂ (annual average) (µg/m ³)	0.96	0.90	0.71	0.60	0.52
Percentage of criterion (62 µg/m ³)	1.54%	1.45%	1.15%	0.97%	0.84%

¹ This data represent the outcomes of applying the project design in the environmental impact to the screening assessment approach, rather than a reproduction of results from the environmental impact statement.

Table 3-4 Effect of ventilation outlet height changes – southern ventilation outlet

Parameter	EIS design ¹	+2 metres	+5 metres	+10 metres	+15 metres
PM ₁₀ (annual average) (µg/m ³)	0.046	0.043	0.033	0.027	0.024
Percentage of criterion (30 µg/m ³)	0.15%	0.14%	0.11%	0.09%	0.08%
PM _{2.5} (annual average) (µg/m ³)	0.044	0.041	0.031	0.026	0.023
Percentage of advisory reporting standard (8 µg/m ³)	0.55%	0.51%	0.39%	0.33%	0.29%
NO ₂ (annual average) (µg/m ³)	0.51	0.47	0.36	0.30	0.26
Percentage of criterion (62 µg/m ³)	0.81%	0.76%	0.58%	0.48%	0.42%

¹ This data represent the outcomes of applying the project design in the environmental impact to the screening assessment approach, rather than a reproduction of results from the environmental impact statement.

Table 3-3 and **Table 3-4** show a decrease in ground level concentrations of PM₁₀, PM_{2.5} and NO₂ with increasing ventilation outlet height. In all cases predicted contributions from the project remain well below applicable criteria and advisory reporting standards (less than one percent). In absolute terms, these decreases are very small. In relative terms, however, decreases in ground level concentrations would significantly decrease over the 15 metre range considered, including:

- With an increase in height of two metres, maximum annual average concentrations would decrease by around five to eight per cent compared with a 15 metre ventilation outlet height.
- With an increase in height of five metres, maximum annual average concentrations would decrease by around 26 to 30 per cent compared with a 15 metre ventilation outlet height.
- With an increase in height of 10 metres, maximum annual average concentrations would decrease by around 37 to 41 per cent compared with a 15 metre ventilation outlet height.
- With an increase in height of 15 metres, maximum annual average concentrations would decrease by around 46 to 49 per cent compared with a 15 metre ventilation outlet height.

Figure 3-1 and **Figure 3-2** illustrate the relative effect of height increases at the northern and southern ventilation outlets, respectively, compared with applicable ambient air quality criteria and advisory reporting standards. The figures show:

- Some reduction with an increase in ventilation outlet height by two metres.
- A marked reduction with an increase in ventilation outlet height by five metres.
- Some continued reduction with increases in ventilation outlet height by 10 and 15 metres, but the trend in reductions tapers off. Predicted reductions from the first five metre increase in height are generally greater than subsequent five metre increments (ie greater reductions are expected by increasing ventilation outlets from 15 to 20 metres, than from 20 metres to 25 metres, or from 25 metres to 30 metres).

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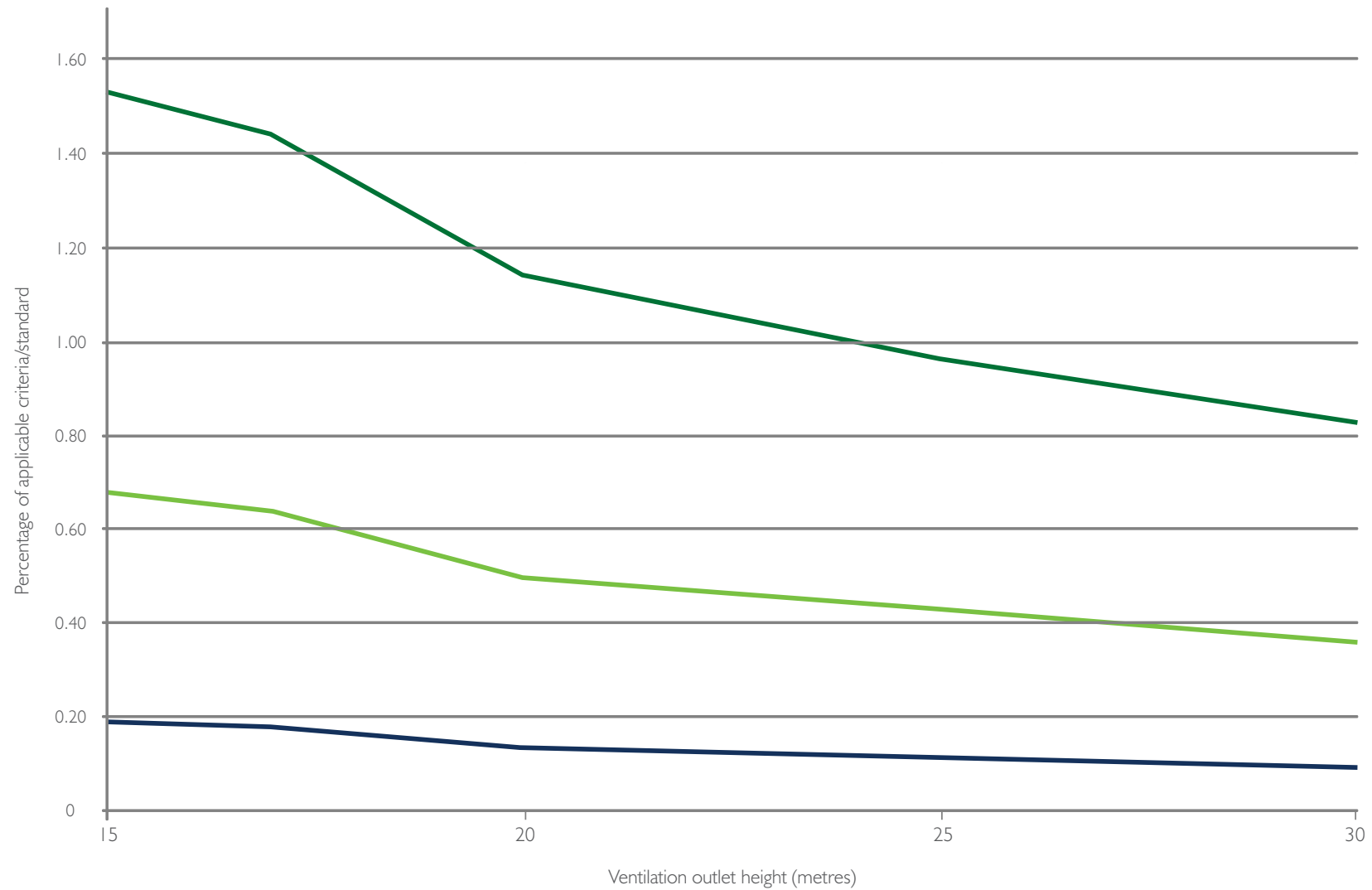


Figure 3-1 Effect of northern ventilation height on annual average concentrations

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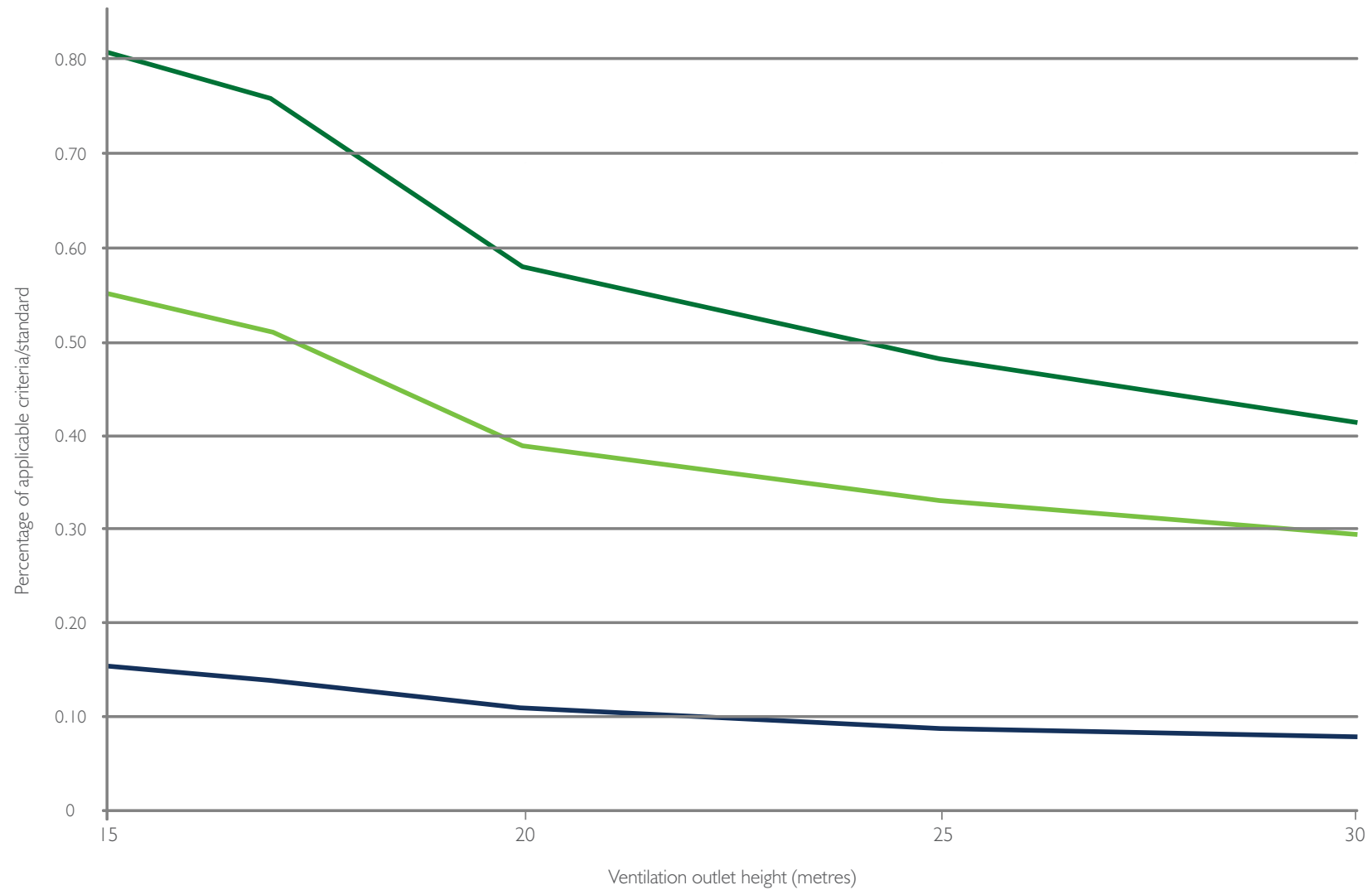


Figure 3-2 Effect of southern ventilation height on annual average concentrations

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In-tunnel air quality

Changes in the height of the ventilation outlets would not affect in-tunnel air quality.

Human health risks

Human health risks associated with emissions from the project's ventilation outlets are principally a function of exposure to PM_{2.5}. Changes in human health risks as a consequence of potentially increasing the height of the ventilation outlets would therefore be similar to the predicted reductions in annual average PM_{2.5} concentrations.

Table 3-15 summarises estimated increases in incidence of primary health indicators as a function of ventilation outlet height, and includes a comparison with the same data presented in the environmental impact statement for 15 metre ventilation outlets. The table shows a gradual decrease in values with increased ventilation outlet height. The most significant change for both ventilation outlets occurs around the +5 metre scenario (noting that further increases in height would decrease incident rates, but to a lesser degree).

Table 3-5 Estimated increases in incidence of primary health effects (per year) – increased ventilation outlet heights

Primary health indicator	Baseline incidence per year (per 100,000)	Normal incidence variability (cases per year)	EIS (2019)	+2 metres	+5 metres	+10 metres	+15 metres
Northern interchange							
Mortality from all causes (≥ 30 years of age)	1,087	1	0.03	0.028	0.022	0.019	0.016
Rate of hospitalisation with cardiovascular disease (≥ 65 years of age)	23,352	40	0.02	0.019	0.015	0.013	0.011
Rate of hospitalisation with respiratory disease (≥ 65 years of age)	8,807	17	0.005	0.0047	0.0037	0.0031	0.0027
Southern interchange							
Mortality from all causes (≥ 30 years of age)	1,087	1	0.03	0.028	0.021	0.018	0.016
Rate of hospitalisation with cardiovascular disease (≥ 65 years of age)	23,352	40	0.02	0.019	0.014	0.012	0.010
Rate of hospitalisation with respiratory disease (≥ 65 years of age)	8,807	17	0.004	0.0037	0.0028	0.0024	0.0021

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Other environmental and land use impacts

Relevant environmental and land use impacts (other than air quality and human health risks) for potential increases in ventilation outlet height are presented in **Table 3-6**.

Table 3-6 Assessment of other environmental and land use impacts – increased ventilation outlet heights

Environmental and land use impacts	Assessment
Visual amenity impacts	Figure 3-3 and Figure 3-4 show the visual envelope maps for potential increased heights at the northern and southern ventilation outlets, respectively. With respect to the northern ventilation outlet, Figure 3-3 shows a marked increase in the visual envelope for an increase of two metres in height, relative to the assessment presented in the environmental impact statement. This is particularly the case for residential receivers to the west of the M1 Pacific Motorway. An increase of five metres in the height of the ventilation outlet generates a marginal additional impact above the two metre height increase scenario. Both the 10 and 15 metre height increase scenarios for the northern ventilation outlet introduce significant additional areas of affected receivers, most notably further afield to the west of the M1 Pacific Motorway, and more significantly due to their proximity to the ventilation outlet, a long band of visual receivers immediately to the east of the M1 Pacific Motorway. For the southern ventilation outlet, Figure 3-4 shows a slight increase in the visual catchment area with an additional two metres of height. There would be a further slight increase in visual catchment with an increase of five metres, including new areas of affected receivers to the north-east, generally beyond 500 metres from the site. Increases of 10 and 15 metres show a significant step change in the scale and extent of the visual catchment, particularly for nearer field receivers (closer than 500 metres), to the east of the southern ventilation outlet.
Noise and vibration impacts	Further consideration may need to be given the scale and duty of fans utilised in the northern and southern ventilation outlets, particularly to overcome increased pressure drops associated with the increased height of the ventilation outlets. This would be particularly the case for greater increases in height. The operational noise impact assessment summarised in Table 7-82 of the environmental impact statement demonstrates that the northern ventilation outlet would operate well within applicable operational noise criteria. On this basis, there is unlikely to be significant operational noise impacts as a result of increased ventilation outlet height (even if increased ventilation fan noise becomes a relevant factor). In contrast, the southern ventilation outlet (combined with the effects of the southern portals) is currently predicted to be close to, but not exceeding, the applicable operational noise criteria. Table 7-82 of the environmental impact statement indicates that noise from this site would be 40 dB(A) during neutral weather conditions, and 41 dB(A) during adverse weather conditions

	when measured at the nearest residential receiver (compared with a criterion of 41 dB(A)). If increased ventilation fan noise becomes a relevant factor, further consideration of noise mitigation (at-source) may be required (such as selection of fans with specified sound power levels and/ or acoustic treatment of the ventilation facility). For the purpose of this assessment, it has been assumed that such mitigation would either not be required, or would be available and considered to be feasible and reasonable.
Land acquisition	Additional land acquisition is unlikely for any of the ventilation outlet height increase options, beyond that already presented in the environmental impact statement.
Land use impacts	Potential land use impacts beyond those already assessed in the environmental impact statement are unlikely.
Construction impacts	Increased height at one or both of the northern and southern ventilation facilities is unlikely to alter the construction phase impacts assessment for those sites in the environmental impact statement.

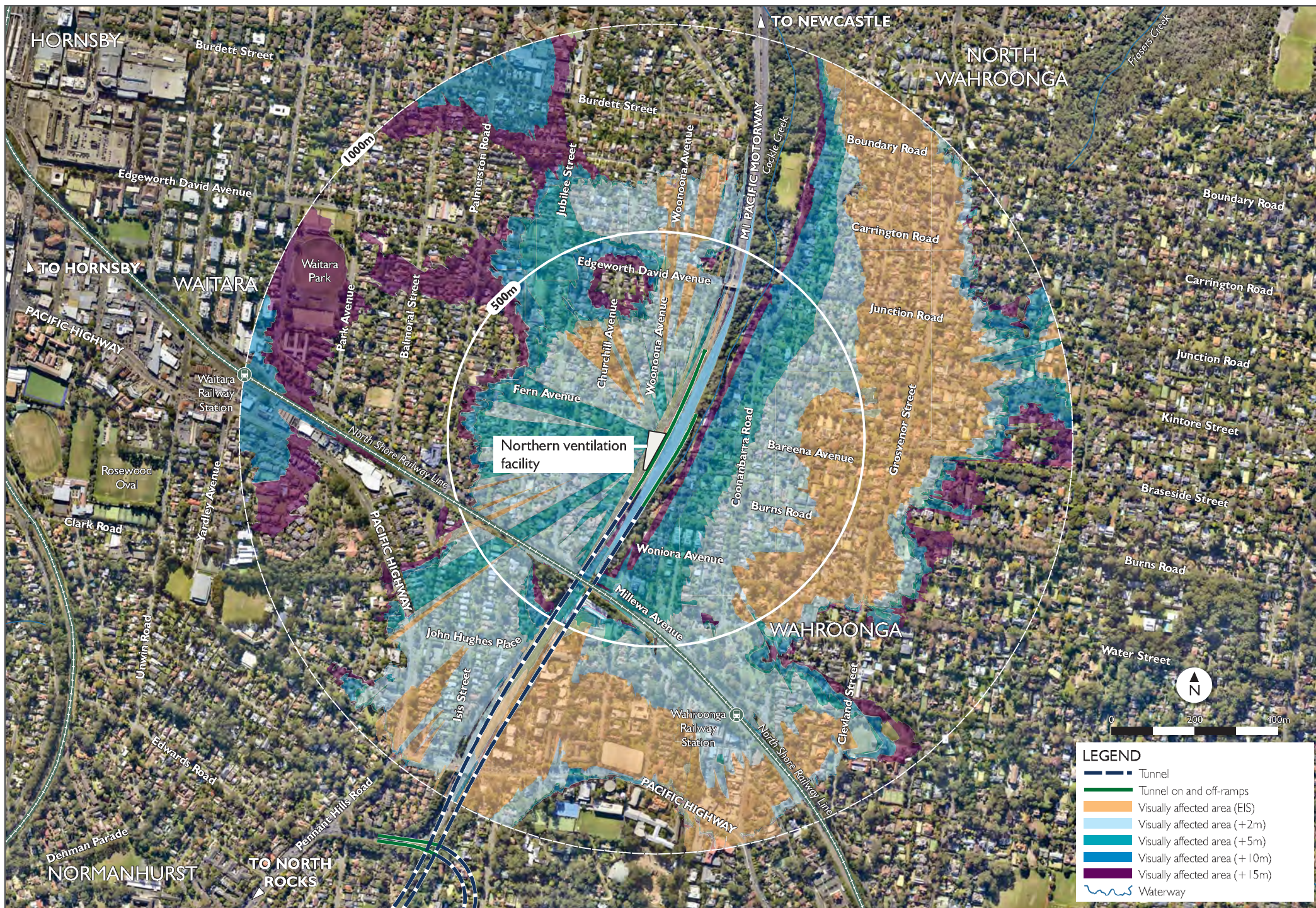


Figure 3-3 Increased northern ventilation facility visual envelope map

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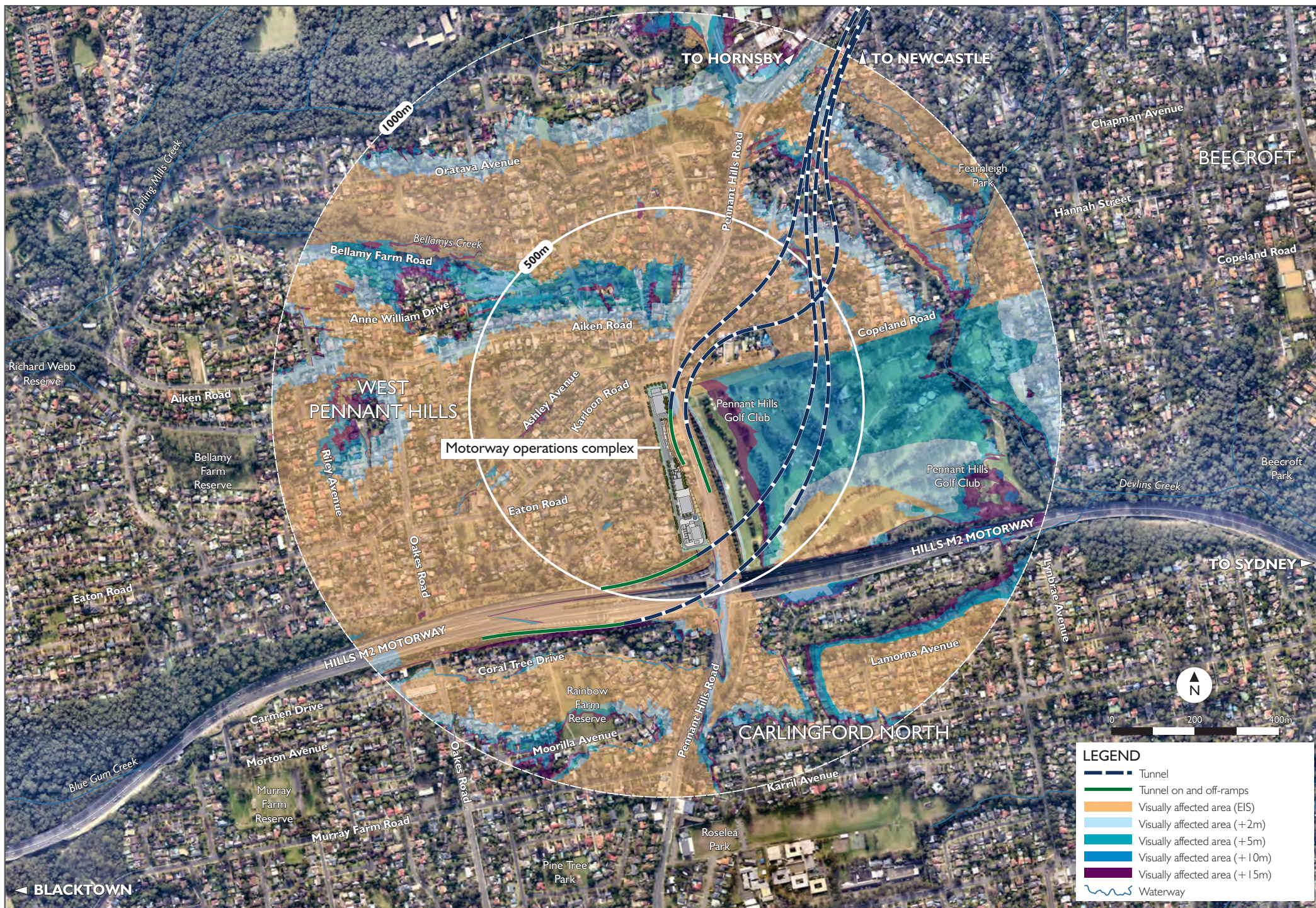


Figure 3-4 Increased southern ventilation outlet visual envelope map

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Engineering considerations

Addition of extra height to the southern and northern ventilation outlets is unlikely to raise significant engineering issues for the height increases considered. Some further design consideration and verification for the ventilation system, particularly in relation to increased pressure drops across the ventilation outlet, may be required. These issues are unlikely to be a significant impediment to any of the height increase scenarios.

Capital and operating costs

Estimated additional capital and operating costs associated with increases in the heights of the southern and northern ventilation outlets are summarised in **Table 3-7**. These costs are incremental additions above the cost of the project as presented in the environmental impact statement, and assume that any change in ventilation outlet height would be applied to both the southern and northern ventilation outlets. If the height of only one ventilation outlet is altered, the costs summarised in **Table 3-7** would be halved.

While there is likely to be a change in operating costs for different ventilation outlet heights (as a result of increased pressure drops across higher ventilation outlets and associated with maintenance of higher outlets), these costs are anticipated to be negligible relative to the operating costs of 15 metre ventilation outlets.

Table 3-7 Estimated increase in capital and operating costs for increased ventilation outlet heights

Relative increase in ventilation outlet height	Increase in project capital cost	Increase in project operating cost
+2 metres	\$0.7 million	Negligible
+5 metres	\$2 million	Negligible
+10 metres	\$5 million	Negligible
+15 metres	\$8 million	Negligible

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3.2.3 Scenario 2 – Relocation of northern and southern ventilation outlets

Potential relocation of the northern and southern ventilation outlets has been considered. For the northern ventilation outlet, relocation to the Asquith Industrial Estate has been considered based on several submissions from the local community raising this as an option. The assessed location of a relocated northern ventilation outlet in the Asquith Industrial Estate is shown in **Figure 3-5**. More detailed micro-siting of the ventilation facility would be required, however, the assessed locations provide representative scenarios involving ventilation outlet locations that are:

- On land zoned for industrial purposes.
- On a site that is not currently developed.
- Broadly equidistant from surrounding residential receivers.

It has been assumed that the tunnel air from the project's main alignment tunnels could be transferred to the relocated northern ventilation outlet for handling and discharge. No changes in the length or configuration of the project's main alignment tunnels have been assumed, to provide a consistent basis for comparison with the project as assessed in the environmental impact statement. The relocated outlet has been assumed to be identical in design, configuration and operation as the northern ventilation outlet described in the environmental impact statement.

For the southern ventilation outlet, relocation to the Pennant Hills Golf Course has been considered based on several submissions from the local community raising this option as preferable to the proposed location of the ventilation outlet. The assessed location of a relocated southern ventilation outlet in the Pennant Hills Golf Course is shown in **Figure 3-6**. The assessment presented in the following sections of this report would apply equally to land adjacent to the golf course, noting for example, the parcel of land next to the south west corner of the golf course which is owned by Roads and Maritime.

The relocated outlet has been positioned in the south west corner of the golf course with the aim of minimising potential disruption to the current configuration and operation of the golf course, and to maintain the ventilation outlet as close to the southbound main alignment tunnel exit portal as possible. The relocated outlet has been assumed to be identical in design, configuration and operation as the southern ventilation outlet described in the environmental impact statement.

Ambient air quality

Table 3-8 and **Table 3-9** summarise the outcomes of air dispersion modelling for the relocated northern ventilation outlet (Asquith Industrial Estate) and the southern ventilation outlet (Pennant Hills Golf Course), respectively. The tables show the maximum annual average predicted around the relocated ventilation outlets, compared with the maximum values for the northern and southern ventilation outlets in the locations identified in the environmental impact statement.

Table 3-8 Effect of relocating the northern ventilation outlet – Asquith Industrial Estate

Parameter	EIS design ¹	Asquith Industrial Estate
PM ₁₀ (annual average) (µg/m ³)	0.057	0.097
Percentage of criterion (30 µg/m ³)	0.19%	0.32%
PM _{2.5} (annual average) (µg/m ³)	0.054	0.092
Percentage of advisory reporting standard (8 µg/m ³)	0.68%	1.15%
NO ₂ (annual average) (µg/m ³)	0.96	1.70
Percentage of criterion (62 µg/m ³)	1.55%	2.74%

¹ This data represent the outcomes of applying the project design in the environmental impact to the screening assessment approach, rather than a reproduction of results from the environmental impact statement.

Table 3-9 Effect of relocating the southern ventilation outlet – Pennant Hills Golf Course

Parameter	EIS design ¹	Pennant Hills Golf Course
PM ₁₀ (annual average) (µg/m ³)	0.046	0.037
Percentage of criterion (30 µg/m ³)	0.15%	0.12%
PM _{2.5} (annual average) (µg/m ³)	0.044	0.035
Percentage of advisory reporting standard (8 µg/m ³)	0.55%	0.44%
NO ₂ (annual average) (µg/m ³)	0.51	0.41
Percentage of criterion (62 µg/m ³)	0.82%	0.66%

¹ This data represent the outcomes of applying the project design in the environmental impact to the screening assessment approach, rather than a reproduction of results from the environmental impact statement.

Table 3-8 shows a predicted increase in maximum annual average concentrations of PM₁₀, PM_{2.5} and NO₂ as a result of relocating the northern ventilation outlet to the Asquith Industrial Area. The contributions of the relocated northern ventilation outlet to surrounding air quality would nonetheless remain within applicable ambient air quality criteria and advisory reporting standards. From an analysis of the air dispersion modelling outcomes, the principal reason for an increase in ground level concentrations is the topography in and around the Asquith Industrial Estate.

The air dispersion modelling also shows that the maximum annual average concentration is expected to occur within the Asquith Industrial Estate. Air quality impacts at surrounding residential receivers are predicted to be equivalent to those presented in the environmental impact statement for receivers around the currently proposed location of the northern ventilation outlet. While relocation of the northern ventilation outlet would increase maximum annual average impacts, these increased impacts would be confined to the industrial estate, with residential receivers experiencing negligible change (either positive or negative) relative to the predicted air quality impacts to residential receivers presented in the environmental impact statement.

Table 3-19 shows an approximate 20 per cent reduction in maximum annual average ground level concentrations around the relocated southern ventilation outlet relative the assessment presented in the environmental impact statement. Notwithstanding a relative decrease in air quality impacts, the predicted ground level concentrations associated with the operation of the southern ventilation outlet in its current proposed location and in its potentially relocated position in the Pennant Hills Golf Course are both very low absolute values (and both well within applicable ambient air quality criteria and advisory reporting standards). As with the potentially relocated northern ventilation outlet, the principal driver for changes in air quality impacts around the potentially relocated southern ventilation outlet is topography. Maximum annual average concentrations around the potentially relocated ventilation outlet remain within residential areas, although the distribution of predicted impacts is shifted in an easterly direction commensurate with the shift in the southern ventilation outlet location.



Figure 3-5 Indicative location of alternative northern ventilation outlet

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Figure 3-6 Indicative location of alternative southern ventilation outlet

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In-tunnel air quality

Changes in the locations of the ventilation outlets would not affect in-tunnel air quality.

Human health risks

A fully quantified human health risk assessment has not been conducted for the relocation of the northern and southern ventilation outlets. However, it has been possible to form the following broad qualitative conclusions about the potential human health implications of relocating the ventilation outlets:

- Peak annual average PM_{2.5} concentrations remain the same for residential receivers around the northern ventilation outlet relocated to the Asquith Industrial Estate, as for residential receivers around the northern ventilation outlet in its currently proposed location. The distribution of PM_{2.5} (annual average) is greater around the relocated northern ventilation outlet than around the outlet at its currently proposed location, however, a significant proportion of the affected area is currently used for industrial land uses or is currently not occupied. On balance, the human health impacts associated with the relocated northern ventilation outlet are expected to be comparable, and potentially marginally lower, than predicted for the current location of the northern ventilation outlet and presented in the environmental impact statement.
- Peak annual average PM_{2.5} concentrations are lower and less widely distributed around the southern ventilation outlet relocated to the Pennant Hills Golf Course, compared with the predicted outcomes for the currently proposed location of the southern ventilation outlet. This reduction in predicted air quality impacts and the reduced area of potentially affected residential receivers (principally within the golf course), means that the relocated southern ventilation outlet in the Pennant Hills Golf Course would have slightly lower human health impacts than presented in the environmental impact statement.

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Other environmental and land use impacts

Relevant environmental and land use impacts (other than air quality and human health risks) for potential increases in ventilation outlet height are presented in **Table 3-10**.

Table 3-10 Assessment of other environmental and land use impacts – relocated northern and southern ventilation outlets

Environmental and land use impacts	Assessment
Visual amenity impacts	Northern ventilation outlet Based on its relocation away from sensitive visual receivers, proximity to an existing industrial facility, adjacent areas of native vegetation and local topography, the location of the northern ventilation outlet in the Asquith Industrial Estate is likely to have reduced visual impacts relative to the assessed outcomes in the environmental impact statement. Southern ventilation outlet Relocating the southern ventilation outlet into the Pennant Hills Golf Course (or immediately adjacent to it) is likely to significantly increase visual impacts because of: • The visual (landscape, topographic) prominence of the golf course, particularly the south west corner. • Disaggregation of the currently proposed motorway operations complex which forms a single coherent visual unit. Relocation of the southern ventilation outlet would spread this visual element and introduce a new, isolated structure (the southern ventilation outlet) which is out of context with its immediate surrounds and disassociated from the remainder of the motorway operations complex.
Noise and vibration impacts	Northern ventilation outlet The northern ventilation outlet has been assessed in the environmental impact statement as comfortably complying with applicable operational noise criteria. Compliance is likely to extend even further through relocation of the northern ventilation outlet to the Asquith Industrial Estate, further away from residential receivers. Southern ventilation outlet The southern ventilation outlet (combined with the effects of the southern portals) is currently predicted to be close to, but not exceeding, the applicable operational noise criteria. This includes an operational noise impact of - 40 dB(A) during neutral weather conditions, and 41 dB(A) during adverse weather conditions when measured at the nearest residential receiver (compared with a criterion of 41 dB(A)). The major of this noise impact relates to noise from the southern portals, with a relatively low contribution from the southern ventilation outlet (comparable to operational noise predictions for the northern ventilation outlet). Relocation of the southern ventilation outlet to the Pennant Hills Golf Course, or adjacent to the golf course, would therefore result in some reductions in operational noise, albeit small.

Land acquisition	Northern ventilation outlet Relocation of the northern ventilation outlet would require acquisition of land, which is expected to be slightly greater in area than the currently proposed location of the outlet. This is because the current outlet location relies partly on land within the M1 Pacific Motorway corridor, which is already owned by Roads and Maritime. Depending on the solution used to transfer in-tunnel air to the relocated ventilation outlet, stratum acquisition and potentially surface acquisition, would be required between the main alignment tunnels and the relocated ventilation outlet. Land acquisition requirements would be partially offset by removal of the need to acquire some land at the currently proposed site for the northern ventilation outlet. However, land at the currently proposed location of the northern ventilation outlet would nonetheless still need to be acquired to accommodate facilities such as the fire suppression water tanks. Southern ventilation outlet Part of the Pennant Hills Golf Course would need to be acquired for relocation of the southern ventilation outlet in this area. This would not be offset by a reduction in land acquisition at the currently proposed location for the outlet, noting that the land in that location is currently owned by Roads and Maritime and would continue as the motorway operations complex.
Land use impacts	Northern ventilation outlet The relocated northern ventilation outlet would occupy industrially-zoned land. Subject to appropriate site selection, loss of this industrial land is unlikely to be significant given the context of the broader industrial estate. Southern ventilation outlet Relocation of the southern ventilation outlet is likely to lead to potentially significant disruption of the Pennant Hills Golf Course requiring reconfiguration of facilities/ operations, and disruption during construction.
Construction impacts	Northern ventilation outlet Overall, relocation of the northern ventilation outlet is likely to increase construction impacts relative to the activities assessed in the environmental impact statement. This is because of the significant length of additional ventilation tunnel required to connect the project's main alignment tunnels with the relocation northern ventilation outlet. Southern ventilation outlet Relocation of the southern ventilation outlet is unlikely to reduce construction impacts associated with the southern interchange compound (C5) or construction of the motorway operations complex, given that the ventilation outlet is only one relatively small component of those works. In contrast, relocation of the southern ventilation outlet to the Pennant Hills Golf Course or adjacent to it is likely to spread construction impacts, and introduce new amenity impacts to users of the golf course.

Engineering considerations

Relocation of the northern ventilation outlet to the Asquith Industrial Estate is likely introduce significant additional engineering challenges based on the distance of that site from the main alignment tunnels. This would include additional complexity associated with the construction of a relatively long ventilation connection to the relocated ventilation outlet, and the increased design requirements of the project's ventilation system to manage pressure losses over this distance.

Based on a preliminary review, relocation of the southern ventilation outlet into the Pennant Hills Golf Course has been identified as a potentially feasible option, with expected benefits in terms of air quality impacts. As such, a more detailed engineering assessment of this potential option has been conducted.

Conceptually, relocation of the southern ventilation outlet would potentially involve construction of the ventilation outlet within or around a small section of land owned by Roads and Maritime at the corner of the Pennant Hills Golf Course, adjacent to the Pennant Hills Road/ Hills M2 Motorway. The parcel of land is 297 m² and is located on a steep embankment, between the golf course and the Hills M2 Motorway/ Pennant Hills Road retaining walls.

The main extraction fans and main ventilation building would need to remain in their current proposed location as part of the motorway operations complex. This is because the land available is too small to house, construct or maintain the whole ventilation facility. However, the potential to construct and maintain just an exhaust structure at this location has been considered. This would require a ventilation tunnel to be constructed from the main facility, (under Pennant Hills Road) and then a shaft to be sunk at the relocated ventilation outlet site.

A constructability review of this option has identified four key issues

- Land acquisition requirements for construction.
- Land acquisition for permanent access.
- Anchors to existing retaining walls.

Land acquisition for construction

The site is on a steep embankment and bounded by an arterial road intersection on its frontage and a golf course to its rear. A significant challenge is having room to safely construct the works and the ability to safely access it, both from a temporary and permanent access perspective.

For construction equipment to operate on the site, substantial levelling would be required to create a platform for piling rigs and excavators to operate. A level platform of approximately 15 metres by 20 metres for would be required for this purpose. A platform of this size would require temporary batters to extend beyond the actual lot size into the golf course. This would require additional private land to be acquired from the golf course.

Further land would need to be acquired to enable the remainder of the construction works, notably the shaft sinking operation. The land would need to be large enough to set up and operate concrete pumps and cranes etc.

The site would be required to be serviced by light vehicles, spoil disposal trucks, and general construction delivery trucks for materials such as concrete, reinforcing, formwork and

scaffold. To allow these vehicles to enter and exit the site, access tracks would be required to be constructed. These tracks would have to be suitable for emergency access during construction and would be required to be all weather, (ie road base and seal).

The access tracks would be required to be constructed within the golf course land, due to the steepness of the site and the unsuitable level change from Pennant Hills Road. This would require further private land acquisition and removal of a significant amount of additional trees and vegetation.

It is anticipated that the option of constructing the ventilation facility from Pennant Hills Road would require substantial lane closures. The traffic volumes dictate that daytime closures would not be feasible, as the adjacent intersection would be significantly affected. Adopting road closures only at night or weekends would not provide enough access to practically construct the works within a reasonable timeframe.

Land acquisition for permanent access

In addition to the construction access issues there would need to be a permanent access arrangement for maintenance. Permanent access from Pennant Hills Road would not be feasible due to traffic volumes and topographical issues. A permanent access would likely have to be created through the golf course, similar to that for the construction access.

Anchors to existing retaining walls

It is envisaged the ventilation facility and any related retaining walls would be required to be founded on bored concrete piles. It is anticipated that the ventilation shaft, piled retaining structures and temporary excavations required would interact with the existing anchors retaining the Hills M2 Motorway vertical shotcrete walls. These anchors would require modification to accommodate the interactions, which will be very challenging given the lack of space, traffic and safety implications.

Capital and operating costs

Estimated additional capital and operating costs associated with relocating the southern and northern ventilation outlets are summarised **Table 3-11**. These costs are presented individually for relocation of the southern and northern ventilation outlets. If both ventilation outlets were to be relocated, the costs would be the total of the values presented in **Table 3-11**.

Additional capital and operating costs associated with relocation of the northern ventilation outlet to the Asquith Industrial Estate are largely the result of the significant length of ventilation tunnel that would need to be constructed and operated between the project tunnels and the relocated ventilation outlet.

Some additional capital cost is likely to be incurred with a relocation of the southern ventilation outlet to the Pennant Hills Golf Course, based on the increased engineering complexity at this location. Additional operating costs are likely to be negligible.

Table 3-11 Estimated increase in capital and operating costs for relocation of ventilation outlets

Ventilation outlet relocation	Increase in project capital cost	Increase in project operating cost
Relocation of the northern ventilation outlet to the Asquith Industrial Estate	\$450 million to \$500 million, subject to further design development	\$2 million per annum
Relocation of the southern ventilation outlet to the Pennant Hills Golf Course	\$30 million to \$35 million, subject to further design development	Negligible

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3.2.4 Scenario 3 – Addition of intermediate ventilation outlet(s)

Two variations involving the inclusion of an intermediate ventilation outlet(s) between the currently proposed locations of the northern and southern ventilation outlets:

- A ventilation outlet at around the mid point along the main alignment tunnels. The general location of a potential mid point ventilation outlet is shown in **Figure 3-7**, although more detailed consideration of siting would need to be conducted if this option were to be pursued. The mid point ventilation outlet would be the same design and operated in the same manner as the northern and southern ventilation outlets, and would receive half of the in-tunnel air it would handle from each of the main alignment tunnels. It has been assumed that fresh air would be re-introduced into the main alignment tunnels to balance the volume of in-tunnel air removed from each.
- Conversion of the currently proposed Wilson Road and Trelawney Street emergency smoke extraction facilities to also function as operational ventilation outlets. It has been assumed that both sites would be the same design and operated in the same manner as the northern and southern ventilation outlets. The Wilson Road ventilation outlet would service the southbound main alignment tunnel, while the Trelawney Street ventilation outlet would service the northbound main alignment tunnel.

Ambient air quality

Table 3-12 and **Table 3-13** summarise the outcomes of air dispersion modelling for the provision of an intermediate ventilation outlet(s). For the purpose of comparison with the assessment presented in the environmental impact statement, maximum annual average concentrations of NO₂, PM₁₀ and PM_{2.5} have been identified around each ventilation outlet location (northern ventilation outlet, southern ventilation outlet, mid point ventilation outlet, Wilson Road ventilation outlet and Trelawney Street ventilation outlet). For potential intermediate ventilation outlet locations, these maximum annual average concentrations have been identified from the air dispersion modelling presented in the environmental impact statement, taking into account the effects of the currently proposed ventilation outlets only (ie not taking into account changes in emissions along Pennant Hills Road – reductions as a result of vehicles diverting to Pennant Hills Road into the project tunnels).

Table 3-12 and **Table 3-13** show that:

- With the addition of a mid point ventilation outlet:
 - Air quality impacts around the northern and southern ventilation outlets would reduce by around 20 per cent relative to the levels predicted and assessed in the environmental impact statement.
 - Air quality impact impacts around the mid point ventilation outlet would be around 2.5 times the particulate matter levels predicted and assessed in the environmental impact statement, and around three times the predicted NO₂ levels. Although these relative increases are significant in magnitude, the maximum annual average concentrations predicted around the mid point ventilation outlet are around the same as predicted around the southern ventilation outlet and slightly less than predicted around the northern ventilation outlet.
 - All predicted impacts would remain well within applicable ambient air quality criteria and advisory reporting standards, and in most cases less than one per cent of these criteria and standards. The exception is NO₂ around the northern ventilation outlet, which would remain slightly above one per cent of the applicable criterion.

- With the conversion of the Wilson Road and Trelawney Street sites to ventilation outlets:
 - Air quality impacts around the northern and southern ventilation outlets would reduce by around 50 per cent relative to the levels predicted and assessed in the environmental impact statement.
 - Air quality impacts around the Wilson Road ventilation outlet would be slightly higher (around 10 to 30 per cent higher) than predicted for operation of the project as presented in the environmental impact statement.
 - Air quality impacts around the Trelawney Street ventilation outlet would be significantly higher (around 60 to 120 per cent higher) than predicted for operation of the project as presented in the environmental impact statement. However, in absolute terms, maximum annual average concentrations predicted around the Trelawney Street ventilation outlet would be similar to those predicted around the Wilson Road ventilation outlet.
 - Air quality impacts around all four ventilation outlets are similar in magnitude.

Table 3-12 Effect of installing a mid point ventilation outlet

Parameter	EIS design ¹	With mid point ventilation outlet
Northern ventilation outlet		
PM ₁₀ (annual average) (µg/m ³)	0.057	0.046
Percentage of criterion (30 µg/m ³)	0.19%	0.15%
PM _{2.5} (annual average) (µg/m ³)	0.054	0.044
Percentage of advisory reporting standard (8 µg/m ³)	0.68%	0.55%
NO ₂ (annual average) (µg/m ³)	0.96	0.77
Percentage of criterion (62 µg/m ³)	1.54%	1.23%
Mid point ventilation outlet		
PM ₁₀ (annual average) (µg/m ³)	0.014	0.035
Percentage of criterion (30 µg/m ³)	0.05%	0.12%
PM _{2.5} (annual average) (µg/m ³)	0.013	0.033
Percentage of advisory reporting standard (8 µg/m ³)	0.16%	0.41%
NO ₂ (annual average) (µg/m ³)	0.158	0.483
Percentage of criterion (62 µg/m ³)	0.25%	0.78%
Southern ventilation outlet		
PM ₁₀ (annual average) (µg/m ³)	0.046	0.037
Percentage of criterion (30 µg/m ³)	0.15%	0.12%
PM _{2.5} (annual average) (µg/m ³)	0.044	0.035
Percentage of advisory reporting standard (8 µg/m ³)	0.55%	0.44%
NO ₂ (annual average) (µg/m ³)	0.51	0.41
Percentage of criterion (62 µg/m ³)	0.81%	0.65%

¹ This data represent the outcomes of applying the project design in the environmental impact to the screening assessment approach, rather than a reproduction of results from the environmental impact statement.

Table 3-13 Effect of converting Wilson Road and Trelawney Street into ventilation outlets

Parameter	EIS design ¹	With Wilson Road and Trelawney Street ventilation outlets
Northern ventilation outlet		
PM ₁₀ (annual average) (µg/m ³)	0.057	0.029
Percentage of criterion (30 µg/m ³)	0.19%	0.10%
PM _{2.5} (annual average) (µg/m ³)	0.054	0.028
Percentage of advisory reporting standard (8 µg/m ³)	0.68%	0.35%
NO ₂ (annual average) (µg/m ³)	0.96	0.467
Percentage of criterion (62 µg/m ³)	1.54%	0.75%
Wilson Road ventilation outlet		
PM ₁₀ (annual average) (µg/m ³)	0.025	0.029
Percentage of criterion (30 µg/m ³)	0.08%	0.10%
PM _{2.5} (annual average) (µg/m ³)	0.023	0.028
Percentage of advisory reporting standard (8 µg/m ³)	0.29%	0.35%
NO ₂ (annual average) (µg/m ³)	0.276	0.346
Percentage of criterion (62 µg/m ³)	0.45%	0.56%
Trelawney Street ventilation outlet		
PM ₁₀ (annual average) (µg/m ³)	0.013	0.029
Percentage of criterion (30 µg/m ³)	0.04%	0.10%
PM _{2.5} (annual average) (µg/m ³)	0.013	0.027
Percentage of advisory reporting standard (8 µg/m ³)	0.16%	0.34%
NO ₂ (annual average) (µg/m ³)	0.202	0.325
Percentage of criterion (62 µg/m ³)	0.33%	0.52%
Southern ventilation outlet		
PM ₁₀ (annual average) (µg/m ³)	0.046	0.024
Percentage of criterion (30 µg/m ³)	0.15%	0.08%
PM _{2.5} (annual average) (µg/m ³)	0.044	0.023
Percentage of advisory reporting standard (8 µg/m ³)	0.55%	0.29%
NO ₂ (annual average) (µg/m ³)	0.51	0.373
Percentage of criterion (62 µg/m ³)	0.81%	0.60%

¹ This data represent the outcomes of applying the project design in the environmental impact to the screening assessment approach, rather than a reproduction of results from the environmental impact statement.

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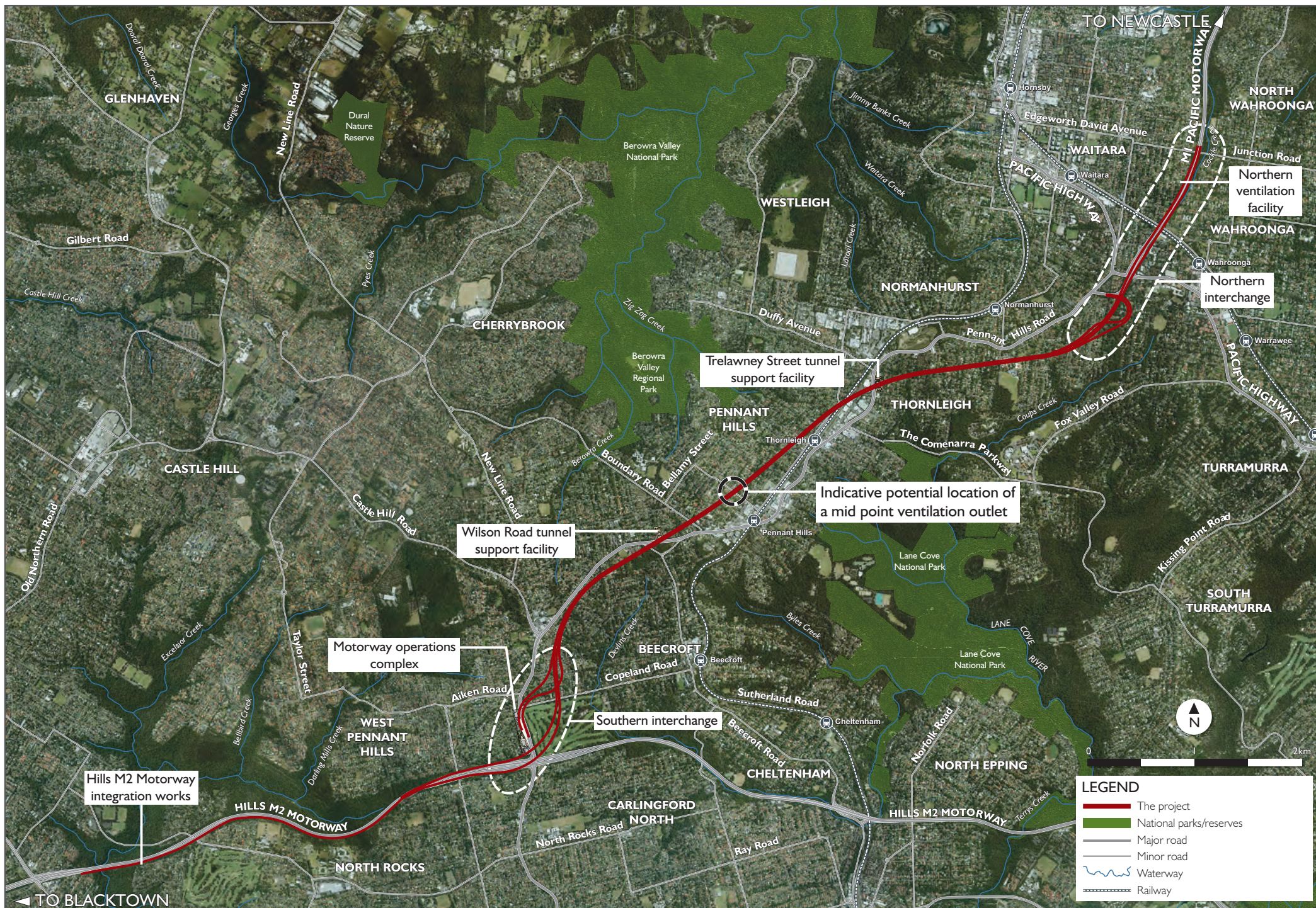


Figure 3-7 indicative location of a mid point ventilation outlet

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In-tunnel air quality

Table 3-14 summarises the calculated in-tunnel concentrations of NO₂, PM₁₀ and PM_{2.5} under scenarios including installation of additional intermediate ventilation outlets. This data has been developed for direct comparison with Table 7-101 in the environmental impact statement, and is based on the same assumptions and calculation methodology (refer to **Chapter 2** of this report for further discussion of this methodology and interpretation of outputs). The table shows only in-tunnel pollutant concentrations for each main alignment tunnel in the relevant peak hour in 2019 and 2029 (ie a worst-case in-tunnel air quality scenario based on forecast traffic flows).

Table 3-14 shows that:

- With the installation of a mid point ventilation outlet, in-tunnel pollutant concentrations remain the same for the first half of the two main alignment tunnels as presented in the environmental impact statement. At the mid point, in-tunnel concentrations would drop to around half of the predictions made in the environmental impact statement, with removal of half of the in-tunnel air from each main alignment tunnel and replacement with an equivalent volume of ambient air. The in-tunnel pollutant concentration profile for the second half of each main alignment tunnel would then continue consistent with the trend in data presented in the environmental impact statement.
- With the conversion of the Wilson Road and Trelawney Street sites, in-tunnel pollutant concentrations would remain the same for the first two thirds of the two main alignment tunnels as presented in the environmental impact statement. At the two thirds point, in-tunnel concentrations would drop to zero contributions from in-tunnel air (ie in-tunnel air at this location would be entirely drawn from the ambient environment). The in-tunnel pollutant concentration profile for the last one third of each main alignment tunnel would then continue consistent with the trend in data presented in the environmental impact statement.
- Conversion of the Wilson Road and Trelawney Street sites has a greater impact on reducing peak in-tunnel concentrations of pollutants than the addition of a mid point ventilation outlet.

Human health risks

A quantified human health risk assessment has not been conducted for the provision of an intermediate ventilation outlet(s). However, it has been possible to form broad qualitative conclusions about the potential human health implications of an intermediate ventilation outlet(s) assuming that all ventilation outlets operate in a similar manner (consistent with the operation of the ventilation outlets in the environmental impact statement) and assuming a generally consistent composition and distribution of affected populations around each of the ventilation outlet locations.

Potential changes in human health risks relative to those presented in the environmental impact statement are expected to be:

- With the addition of a mid point ventilation outlet:
 - Human health risks for populations around the northern and southern ventilation outlets would be around 20 per cent lower than the risks presented in the environmental impact statement (based on predicted reductions in PM_{2.5} annual average concentrations).
 - Human health risks for the population around the mid point ventilation outlet would be similar to those around the southern ventilation outlet (around 20 cent

lower than the human health risks presented in the environmental impact statement).

- Peak adverse human health risks associated with operation of the project would be slightly reduced when considering the project as a whole. The total population likely to be affected by health risk impacts would however be increased.
- With the conversion of the Wilson Road and Trelawney Street sites to ventilation outlets:
 - Human health risks for populations around the northern and southern ventilation outlets would be around 50 per cent lower than the risks presented in the environmental impact statement (based on predicted reductions in PM_{2.5} annual average concentrations).
 - Human health risks for populations around the Wilson Road and Trelawney Street ventilation outlets would be around 50 per cent lower than the human health risks predicted for the northern and southern ventilation outlets in the environmental impact statement).
 - Peak adverse human health risks associated with operation of the project would be markedly reduced when considering the project as a whole. The total population likely to be affected by health risk impacts would however be increased.

Table 3-14 Calculated in-tunnel air quality with additional ventilation outlets – main alignment tunnels during peak hours

Black – design as presented in the EIS including updates to fuel mix and no change to ratio of NO₂ to NO_x (10%)

Red – design including a mid point ventilation outlet

Blue – design including conversion of Wilson Road and Trelawney Street sites

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)									
NO ₂ *	0.044	0.111	0.140	0.162	0.186	0.210	0.232	0.282	0.422
	0.044	0.111	0.140	0.162	0.099	0.123	0.145	0.195	0.335
	0.044	0.111	0.140	0.162	0.186	0.210	0.022	0.072	0.212
PM ₁₀	0.040	0.087	0.127	0.164	0.200	0.238	0.275	0.318	0.391
	0.040	0.087	0.127	0.164	0.109	0.147	0.184	0.227	0.300
	0.040	0.087	0.127	0.164	0.200	0.238	0.037	0.080	0.153
PM _{2.5}	0.039	0.085	0.122	0.158	0.195	0.231	0.267	0.308	0.369
	0.039	0.085	0.122	0.158	0.107	0.143	0.179	0.220	0.281
	0.039	0.085	0.122	0.158	0.195	0.231	0.036	0.077	0.138
Southbound main alignment tunnel at 9 am (2029)									
NO ₂ *	0.049	0.124	0.156	0.183	0.209	0.235	0.261	0.317	0.473
	0.049	0.124	0.156	0.183	0.111	0.137	0.163	0.219	0.375
	0.049	0.124	0.156	0.183	0.209	0.235	0.026	0.082	0.238
PM ₁₀	0.051	0.109	0.156	0.203	0.249	0.296	0.343	0.397	0.472
	0.051	0.109	0.156	0.203	0.136	0.183	0.230	0.284	0.359
	0.051	0.109	0.156	0.203	0.249	0.296	0.047	0.101	0.176
PM _{2.5}	0.050	0.102	0.148	0.192	0.236	0.28	0.324	0.375	0.446
	0.050	0.102	0.148	0.192	0.129	0.173	0.217	0.268	0.339
	0.050	0.102	0.148	0.192	0.236	0.28	0.044	0.095	0.166
Northbound main alignment tunnel at 6 pm (2019)									
NO ₂ *	0.005	0.112	0.235	0.358	0.481	0.604	0.719	0.784	0.875
	0.005	0.112	0.235	0.358	0.271	0.394	0.509	0.574	0.665
	0.005	0.112	0.235	0.358	0.481	0.604	0.115	0.180	0.271
PM ₁₀	0.033	0.092	0.156	0.220	0.284	0.347	0.410	0.460	0.515
	0.033	0.092	0.156	0.220	0.158	0.221	0.284	0.334	0.389
	0.033	0.092	0.156	0.220	0.284	0.347	0.063	0.113	0.168

PM _{2.5}	0.031	0.087	0.147	0.207	0.269	0.329	0.387	0.434	0.487
	0.031	0.087	0.147	0.207	0.150	0.210	0.268	0.315	0.368
	0.031	0.087	0.147	0.207	0.269	0.329	0.058	0.105	0.158
Northbound main alignment tunnel at 6 pm (2029)									
NO ₂ *	0.005	0.123	0.258	0.393	0.529	0.664	0.790	0.861	0.963
	0.005	0.123	0.258	0.393	0.299	0.434	0.560	0.631	0.733
	0.005	0.123	0.258	0.393	0.529	0.664	0.126	0.197	0.299
PM ₁₀	0.041	0.111	0.186	0.261	0.337	0.412	0.484	0.543	0.610
	0.041	0.111	0.186	0.261	0.188	0.263	0.335	0.394	0.461
	0.041	0.111	0.186	0.261	0.337	0.412	0.072	0.131	0.198
PM _{2.5}	0.039	0.104	0.176	0.247	0.318	0.389	0.457	0.518	0.576
	0.039	0.104	0.176	0.247	0.177	0.248	0.316	0.377	0.435
	0.039	0.104	0.176	0.247	0.318	0.389	0.068	0.129	0.187

*Note: NO₂ has been assumed to be 10% of total nitrogen oxides, consistent with PIARC (2012)

Other environmental and land use impacts

Relevant environmental and land use impacts (other than air quality and human health risks) for potential increases in ventilation outlet height are presented in **Table 3-15**.

Table 3-15 Assessment of other environmental and land use impacts – provision of intermediate ventilation outlets

Environmental and land use impacts	Assessment
Visual amenity impacts	Mid point ventilation outlet As an exact site for a potential mid point ventilation outlet has not been identified at this time, a visual envelope map has not been produced. However, potential visual impacts on the area surrounding the site are likely to be similar in extent to those considered for the Wilson Road and Trelawney Street ventilation outlets (refer below). With respect to near field visual impacts, the installation of a mid point ventilation outlet is likely to introduce additional impacts over and above those presented in the environmental impact statement. This is due to the location of an additional ventilation outlet in an urban residential context. Wilson Road and Trelawney Street ventilation outlets Figure 3-8 and Figure 3-9 show the visual envelope maps for potential increased heights (addition of ventilation outlets) at the Wilson Road and Trelawney Street sites, respectively. With respect to the Wilson Road ventilation outlet, Figure 3-8 shows a moderate increase in potential visual impacts relative to the visual envelope map provided as Figure 7-53 of the environmental impact statement. It shows that the addition of a 15 metre high ventilation outlet to the five metre Wilson Road facility extends some of the potential near field (less than 500 metre) impacts, with a distinct increase in potentially affected receivers between 500 metres and 1,000 metres to the north east of the site. For consideration in the context of the ventilation outlet height increases discussed under Scenario 1 above, Figure 3-8 also shows the potential extent of visual impacts for a 17 metre, 20 metre, 25 metre and 30 metre ventilation outlet in this location. Key areas of increased impacts at these higher ventilation outlet configurations include areas to the west of the site (500 metres to 1,000 metres) and relatively limited areas to the east (also at 500 metres to 1,000 metres).

	For the Trelawney Street ventilation outlet, Figure 3-9 shows a significant increase in areas potentially visually affected by the Trelawney Street with the addition of a 15 metre ventilation outlet. Compared with Figure 7-56 of the environmental impact statement, the additional of a ventilation outlet extends potential visual impacts over a significant area to the west of the site. Figure 3-9 also shows the potential extent of visual impacts for higher ventilation outlets on the Trelawney Street site. It shows relatively small increases in affected areas over and above the potential impacts of a 15 metre ventilation outlet.
Noise and vibration impacts	Mid point ventilation outlet Based on the operational noise assessment presented in the environmental impact statement for the northern and southern ventilation outlets, it is expected that a ventilation outlet at a mid point location could be designed to achieve acceptable noise outcomes (as derived in accordance with the NSW Industrial Noise Policy (EPA, 2000)). However, further consideration may need to be given to the noise performance of an additional air intake at this location, noting that this has not been previously considered as part of the project (because continuous air intakes are not required with the current project design). Wilson Road and Trelawney Street ventilation outlets Based on the operational noise assessment presented in the environmental impact statement for the northern and southern ventilation outlets, it is expected that ventilation outlets at Wilson Road and Trelawney Street could be designed to achieve acceptable noise outcomes (as derived in accordance with the NSW Industrial Noise Policy (EPA, 2000)). However, further consideration may need to be given to the noise performance of the additional continuous air intakes at these locations, noting that these have not been previously considered as part of the project (because continuous air intakes are not required with the current project design).
Land acquisition	Mid point ventilation outlet Significant additional land acquisition, over and above the requirements of the currently proposed project, are likely to be required for a mid point ventilation outlet. Land acquisition would be required for the ventilation outlet as well as air intake infrastructure, which together is expected to require a larger area than the current northern and southern ventilation outlet footprints. Wilson Road and Trelawney Street ventilation outlets Additional land acquisition may be required at the Wilson Road and Trelawney Street sites to accommodate the inclusion of a ventilation outlet in each of these locations. It has been assumed that infrastructure to allow for air intake at these sites would be similar to the currently proposed emergency smoke extraction facilities on these sites.
Land use impacts	Mid point ventilation outlet Introduction of a mid point ventilation outlet is likely to generate additional land use impacts, noting that most of the land around the mid point of the main alignment tunnels is currently zoned for and developed as urban residential development.

	Wilson Road and Trelawney Street ventilation outlets The potential for additional land use impacts at the Wilson Road and Trelawney Street site beyond those identified and assessed in the environmental impact statement is limited. There may be marginal increases in these impacts if additional land acquisition is required at these locations.
Construction impacts	Mid point ventilation outlet Construction of a mid point ventilation outlet would introduce new construction impacts at a site previously not identified for disturbance in the environmental impact statement. The extent of potential construction impacts would depend on whether this site is also used for tunnel support activities. Notwithstanding, the addition of construction impacts a new site within a residential context is likely to be a significant increase above the impacts already assessed in the environmental impact statement. Wilson Road and Trelawney Street ventilation outlets There is likely to be only a marginal increase in construction impacts at the Wilson Road and Trelawney Street sites if ventilation outlets were to be constructed at these locations. This is based on the two sites already being proposed as major construction sites and tunnelling support sites.

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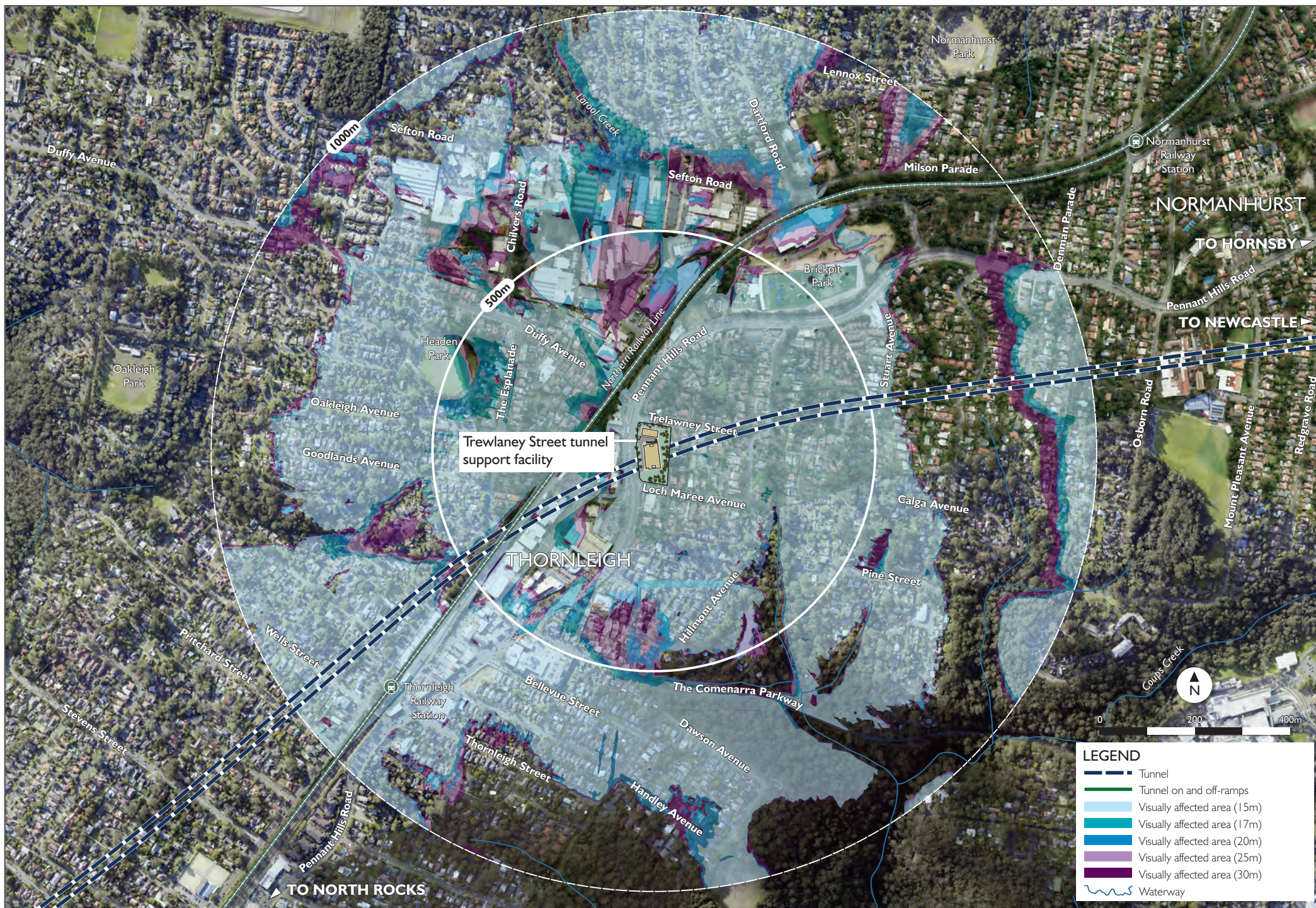


Figure 3-9 Trelwney Street ventilation outlet visual envelope map

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Engineering considerations

The construction of additional ventilation outlets is unlikely to introduce new engineering challenges, subject to further design consideration, noting that ventilation outlet designs have already been considered for the northern and southern ventilation outlets. However, additional engineering complexity would be introduced with the need to provide air intakes at the intermediate ventilation outlet sites, in addition to the other project infrastructure required at those locations (eg separation of the shaft for ventilation outlet air and air intake).

Capital and operating costs

Estimated additional capital and operating costs associated with intermediate ventilation outlets are summarised **Table 3-16**. Costs have been listed for individual intermediate ventilation outlet locations (ie the conversion of the Wilson Road and Trelawney Street tunnel support sites have been listed separately).

Additional operating costs for each of the intermediate ventilation outlet options are largely the result of electricity costs.

Table 3-16 Estimated increase in capital and operating costs for intermediate ventilation outlets

Intermediate ventilation outlet location	Increase in project capital cost	Increase in project operating cost
Provision of a mid point ventilation outlet	\$100 million to \$150 million, subject to further design development	\$3.5 million per annum, depending on ventilation flow rates
Conversion of the Wilson Road tunnel support facility	\$20 million to \$60 million, subject to further design development	\$3.5 million per annum, depending on ventilation flow rates
Conversion of the Trelawney Street tunnel support facility	\$20 million to \$50 million, subject to further design development	\$3.5 million per annum, depending on ventilation flow rates

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3.2.5 Scenario 4 – Changes in ventilation flow rates

The project's ventilation system has been designed to achieve specified in-tunnel air quality outcomes for traffic volumes up to and including the maximum traffic throughput capacity of the project's main alignment tunnels. The ventilation system design criteria are provided in Table 7-95 of the environmental impact statement and are reproduced below. Further details of these criteria, including how they have been applied to the design of the project's ventilation system are provided in **Section 2.5** of this report.

Table 3-17 Ventilation system design criteria

Average traffic speed (km/h)	Operational mode	CO design criteria (15 minute)	NO ₂ design criteria (15 minute)	Visibility (extinction coefficient)
80	Normal traffic conditions. Vehicles are moving freely with no congestion effects	50 ppm (57.5 mg/m ³)	0.5 ppm (0.94 mg/m ³)	<0.005 m ⁻¹
60		50 ppm (57.5 mg/m ³)	0.5 ppm (0.94 mg/m ³)	<0.005 m ⁻¹
40	Congested traffic conditions. Vehicles have slowed as a result of traffic congestion, caused by a vehicle accident or incident. Congestion management measures would be implemented as average traffic speeds fall towards 40 km/h.	60 ppm (69 mg/m ³)	0.8 ppm (1.51 mg/m ³)	<0.005 m ⁻¹
0 to 20	Significantly congested traffic conditions. Vehicles have slowed significantly as a result of traffic congestion, caused by a vehicle accident or incident. Congestion management measures would be in place.	87 ppm (100 mg/m ³)	1.0 ppm (1.88 mg/m ³)	<0.005 m ⁻¹

In-tunnel exposures to vehicle emissions could be changed through the design and operation of the project's ventilation system in one of three ways:

- Increasing the capacity of the project's ventilation system.
- Applying more stringent ventilation design criteria to the ventilation system design.
- Operating the ventilation system at increased flow rates within the existing design capacity of the project.
- Changing the configuration of the ventilation system (for example, to a transverse or semi-transverse system, rather than longitudinal ventilation).

Changing design criteria/ increasing ventilation capacity

The last two of the options listed above would essentially be the same. As discussed above, the project's ventilation system has been designed to achieve the in-tunnel air quality outcomes summarised in **Table 3-17**. A change to these criteria would necessitate a change in project design to provide additional ventilation capacity. Because the ventilation design criteria are comparable to or better than other road tunnels around the world, there is no reasonable justification for applying more stringent criteria or requiring additional ventilation capacity to be provided in the project design.

Changing design criteria/ increasing ventilation capacity

Operating the project within its current ventilation design capacity, but at higher ventilation flow rates than have been applied to the ambient and in-tunnel air quality assessments presented in the environmental impact statement, is an option that is already available. The project has been design and has committed to achieving the ventilation design criteria specified in **Table 3-17**. The project would also be operated to achieve in-tunnel air quality conditions that may be specified in conditions of approval for the project, if applied by the Minister for Planning.

Because the ventilation design criteria are comparable to or better than other road tunnels around the world, there is no reasonable justification for operating the project's ventilation system at higher ventilation flow rates than necessary to achieve these criteria. Constantly or frequently operating the ventilation system at greater flow rates than necessary would introduce potentially significant operating costs based on increased energy requirements.

A detailed ventilation control strategy would be developed during the detailed design phase and implemented during operation of the project to ensure that acceptable in-tunnel air quality is maintained. The control strategy would be developed to include three distinct operational modes:

- **Normal operation** for the management and control of in-tunnel air quality under all traffic scenarios, including fluid free flowing traffic conditions and congestion.
- **Breakdown mode** where a breakdown has caused the tunnel to be blocked or severely restricted
- **Emergency operation** for the management and control of smoke in the event of a fire, for the safe egress of occupants and access for emergency services.

During normal operation, the project's ventilation system would automatically operate and adjust the ventilation flow rates within the tunnel and at the ventilation outlets to maintain in-tunnel air quality within acceptable limits.

The ventilation system would have a fixed number of ventilation levels which would generally correspond with the number of exhaust fans (at the ventilation outlets) in combination with the supply fans (within the main alignment tunnels and ramps) in the system. For example, a 'level 1' operation may involve the operation of one exhaust fan, and a 'level 5' operation may involve the operation of four exhaust fans. The number of ventilation levels and fan operating combinations would be determined during the detailed design of the project.

Jet fans ('supply fans') in the main alignment tunnels and ramps would operate to maintain longitudinal ventilation and to balance air flow in each tunnel section, such that in-tunnel air quality is maintained within acceptable limits.

The following key inputs will be used to determine the level of ventilation required at any given time and for any given traffic scenario:

- **Time of day** – The ventilation system would activate the level of ventilation required based on the time of day, increasing the level of ventilation in the tunnel in the lead up to peak hours, and reducing the level at off peak times such as during the night.
- **Traffic speed and density** – Vehicle detectors located within the roadway of the project tunnels and approaches would provide real-time input for traffic speed and traffic density in the project tunnels. This combination of vehicle speed and number of vehicles per hour would be used to select and confirm the level of ventilation required, possibly increasing above the level estimated by the 'time of day' schedule, if necessary. The combination of traffic speed, density and ventilation level would be pre-programmed into the ventilation system using an algorithm to ensure that acceptable in-tunnel air quality is maintained to prevent emissions from the project's portals.
- **Data from in-tunnel air quality monitoring sensors** - Air quality monitoring sensors would be located throughout the project tunnels to identify and provide a complete understanding of in-tunnel air quality during operation. As a minimum, these sensors would provide continuous monitoring for carbon monoxide, nitrogen dioxide, visibility and in-tunnel air flow.

If the air quality monitoring sensors detect that vehicle emissions concentrations are approaching the pre-set limits (ie actions triggers below maximum allowable in-tunnel air quality criteria to provide an 'early warning' and action system), feedback would be given to the ventilation system to increase the ventilation rate to the next ventilation level. This would continue in order to maintain in-tunnel air quality and to ensure compliance with the air quality criteria is always achieved.

- **Incident detection** – The project would be equipped with an automatic video incident detection (AVID) system. AVID is a close circuit television (CCTV) system but has the additional capability of detecting and actively alerting tunnel operators to incidents within the tunnel as they occur. The AVID system has the ability to detect a range of tunnel incidents including stopped vehicles, pedestrians or the presence of smoke in the project tunnels.

The AVID system would quickly alert the tunnel operators to an incident in the project tunnels, so that they can implement the appropriate incident management plan. For example, in the event of a stopped vehicle, the operators can quickly identify its location and respond by implementing a traffic management plan and increasing the level of ventilation if required. It would also assist them to address the driver through the public address system or motorist emergency telephone.

Unlike surface roads, road tunnels are constantly managed from a central control room with an operations team to ensure that action can be taken quickly and effectively in the event of an alarm or incident. With respect to the emergency devices such as the deluge system, these would be automatically operated in the event of an incident.

Where there is a major incident such as a crash which results in the tunnel being blocked, the relevant tunnel would be closed and vehicles diverted to surface roads. The close tunnel would only be reopened once the incident is cleared. This action would be taken quickly (response time would be in minutes from alert) to minimise the number of vehicles in the tunnel.

In the event of a fire incident the whole tunnel in both directions would be closed and vehicles diverted to surface roads until the incident has been dealt with.

- **Traffic and ventilation management** - It is envisaged that congested, slow moving traffic conditions would be rare in the project. However, where average traffic speeds drop below 40km/h, the tunnel operators would have the ability to implement traffic

management procedures as a further means to manage vehicle emissions and air quality within the tunnel, in conjunction with the tunnel ventilation system.

Subject to the conditions of approval that may be applied to the project by the Minister for Planning, the NorthConnex project would regularly report (real time) on the performance and compliance with the air quality criteria. This would include in-tunnel air quality, air discharged from the ventilation outlets and ambient air external to the project tunnels.

In-tunnel air quality reporting would provide a direct clear comparison between the actual monitored air quality exposure within the tunnel against the maximum allowable air quality criteria to demonstrate that compliance is achieved at all times.

Changing the configuration of the project's ventilation system

Broadly, there are four types of ventilation systems for road tunnels:

- Natural ventilation.
- Fully transverse mechanical ventilation.
- Semi-transverse mechanical ventilation.
- Longitudinal mechanical ventilation.

The NorthConnex project has been designed as a longitudinal mechanical ventilation system.

Natural ventilation

For short tunnels with low traffic volumes, natural ventilation is often sufficient. Natural ventilation relies on prevailing winds, a difference in air pressure between tunnel portals, and in some cases a slight convective, or 'chimney effect'. Where traffic flows are uni-directional, the piston effect generated by moving traffic also assists in tunnel ventilation. Naturally ventilated tunnels emit in-tunnel air from the tunnel portals. The majority of road tunnels around the world are naturally ventilated. Given the length of the NorthConnex project, natural ventilation would not be sufficient to maintain acceptable in-tunnel air quality.

Fully transverse mechanical ventilation

Fully transverse ventilation includes two ducts in addition to the main traffic tunnel. One duct brings in 'fresh' ambient air, which is supplied typically from below or near the base on the main traffic tunnel. The air passes vertically the main traffic tunnel before being extracted at or above the main traffic tunnel and passing into an exhaust duct. The exhaust duct carries in-tunnel air comprising vehicle emissions to a ventilation outlet(s). Fresh air is provided by the supply duct and removed by the exhaust duct at many locations along the main traffic tunnel (typically spaced at around 10 metre intervals)

The supply and exhaust ducts of a fully transverse ventilation system contribute a significant additional cross-sectional area to the road tunnel (potentially up to 50 per cent more). Additional ventilation capacity is typically required in fully transverse ventilation systems to offset the pressure loss across the many fresh air supply and exhaust offtake points. This additional ventilation capacity, and the fact that fully transverse ventilation systems do not take advantage of the piston effect generated by traffic, means that these types of ventilation systems are more capital intensive and more expensive to operate.

For the NorthConnex project, the extra excavation required to provide a fully transverse ventilation system would have a considerable impact on the cost and construction program for the project. It would also increase spoil management and disposal requirements by up to 50 per cent. A longer construction program with greater spoil handling requirements would increase impacts on local communities, particularly in relation to construction noise and construction traffic.

Fully transverse ventilation systems also typically include both supply and exhaust ventilation buildings. This requirement introduces additional surface disturbance and associated environmental and land use impacts.

Semi-transverse mechanical ventilation

Semi-transverse ventilation systems are similar to fully transverse systems, except that the main traffic tunnel is used as the exhaust duct (rather than constructing a separate exhaust duct). Fresh air is supplied to the main traffic tunnel via a supply duct with outlets at many locations along the tunnel. Semi transverse ventilation systems emit in-tunnel air from tunnel portals or dedicated ventilation outlets.

Semi transverse ventilation systems have similar, but not all, of the space and energy usage disadvantages of fully transverse systems. As the main traffic tunnel acts as the exhaust duct, the system is able to take advantage of some of the energy saving efficiency of using the piston effect of traffic flow. This is offset by supply air system inefficiencies as supply air needs to be distributed through a duct rather than using the full cross sectional area of the tunnel as is the case with a longitudinal system.

A semi-transverse ventilation solution is undesirable for the NorthConnex project for similar reasons as a fully transverse system.

Longitudinal mechanical ventilation

Longitudinal ventilation consists of jet fans mounted at a number of points along the tunnel length. Air is drawn in at one portal and is accelerated along the tunnel to exhaust at the other. For the majority of the world's tunnels that have longitudinal mechanical ventilation, tunnel air is exhausted via the tunnel portal. A minority of tunnels with longitudinal mechanical ventilation have vertical ventilation outlets which disperse the tunnel air vertically and at high velocity to ensure that pollutants are dispersed over a far wider area rather than allowing exhausting the emissions through the portal. Depending on traffic mix, gradient and length some tunnels have more than one ventilation outlet per tunnel.

In uni-directional tunnels, such as the NorthConnex project, the piston effect of traffic movement provides additional momentum to tunnel air pushing it toward the ventilation outlet point. As a result, this type of tunnel ventilation system is the most energy efficient method of mechanically ventilating road tunnels and has been adopted for the majority of road tunnels worldwide.

The use of a longitudinal system for NorthConnex has been adopted due to its high efficiency and proven performance on long uni-directional tunnels. Whilst very effective for normal operation, the longitudinal system is also very effective in controlling smoke in fire conditions.

3.2.6 Scenario 5 – Treatment of in-tunnel air or ventilation discharges

The application of in-tunnel air treatment technology involving particulate matter filtration has been considered for application to the project's main alignment tunnels. As outlined in **Section 3.1** of this report, de-nitrification technologies are still in the early stages of development, and have not been demonstrated at this time as viable at the scale and efficiency required for operational treatment of road tunnel air. For this reason, de-nitrification technologies have not been considered further for potential application to the NorthConnex project.

For the purpose of this analysis, it has been assumed that particulate matter filtration technology would be installed as part of the infrastructure at the Wilson Road and Trelawney Street tunnel support sites. Infrastructure at these sites would be augmented to provide sufficient ventilation capacity (through the ventilation shafts and ventilation fans) to operate the particulate matter filtration technology.

At each tunnel support facility, air would be drawn from the relevant main alignment tunnel and passed through a bank of electrostatic precipitators before being returned to the main alignment tunnel downstream of the air extraction point. Auxiliary plant would be required to support the particulate matter filtration facilities, including:

- A wash water treatment plant, to treat and manage an estimated 504 kL/ year of water per particulate matter filtration plant (ie a total of around 1,008 kL/ year assuming that a particulate matter filtration plant is installed in each main alignment tunnel).
- An electrical room housing high voltage generating panels associated with the electrostatic precipitators at each tunnel support site (Wilson Road and Trelawney Street).

The particulate matter filtration plants would be automated and would require minimal operator input.

For the purpose of this analysis and the conceptual design of the particulate matter filtration plants, it has been assumed that the following treatment outcomes would be achieved:

- An 80 per cent reduction in PM₁₀ at the point of treatment.
- An 80 per cent reduction in PM_{2.5} at the point of treatment.

As discussed in **Section 3.1** of this report, particulate matter filtration employing electrostatic precipitators may experience reduced treatment efficiency and effectiveness at lower particulate matter concentrations and for smaller particle sizes.

It is also important to recognise that a minimum flow rate of air through the main alignment tunnels needs to be maintained. Therefore, it is not possible to redirect and treat all of the air from the main alignment tunnels through the particulate matter filtration plant. Taking this into account, and based on the ventilation design and expected operation under forecast traffic flows, it is anticipated that up to around 75 percent of the volume of in-tunnel air could be redirected and treated at each of the tunnel support sites. Assuming an 80 per cent reduction in particulate matter load in the treated air, a net reduction in particulate matter of around 60 per cent could be expected (ie 80 per cent of 75 percent of the particulate matter load at the point of offtake for treatment).

Further design development and analysis would be required to optimise the project's ventilation design and operation, should particulate matter filtration be installed. However, for the purpose of this analysis, a net reduction in particulate matter of 60 per cent at the

Wilson Road and Trelawney Street tunnel support sites has been adopted as an indicative basis for comparison of ventilation design options and alternatives.

Ambient air quality

With a reduction in PM₁₀ and PM_{2.5} loads at the Wilson Road and Trelawney Street tunnel support facilities of around 60 percent, the reduction in mass emission rate at each ventilation outlet would be reduced as summarised in **Table 3-21** (refer to the following section of this report for a discussion of in-tunnel air quality). Data in the table is presented as the percentage of the relevant mass emission rates used in the air dispersion modelling included in the environmental impact statement.

Table 3-18 Relative reductions in mass emission rates at the ventilation outlets

Pollutant	Reduction in mass emission rate at the ventilation outlet (as a percentage of EIS mass emission rates)			
	2019 Southbound	2029 Southbound	2019 Northbound	2029 Northbound
PM ₁₀	62.3%	62.4%	59.5%	59.5%
PM _{2.5}	62.5%	62.3%	59.5%	59.5%

Changes in ambient air quality impacts from the project with the application of particulate matter filtration would be proportional to the change in mass emission rates from the project's ventilation outlets. Assuming that all other operational factors for the ventilation outlets remain the same, scaled ambient air impacts for the project based on the change in mass emission rates above, would be as summarised in **Table 3-22**. These scaled ambient air quality impacts assume continuous operation of the particulate matter filtration plants and constant particulate matter removal efficiencies.

Table 3-19 Scaled ambient air quality impacts

Parameter	EIS design ¹	With particulate matter filtration at Wilson Road and Trelawney Street
Northern ventilation outlet		
PM ₁₀ (annual average) (µg/m ³)	0.057	0.034
Percentage of criterion (30 µg/m ³)	0.19%	0.11%
PM _{2.5} (annual average) (µg/m ³)	0.054	0.032
Percentage of advisory reporting standard (8 µg/m ³)	0.68%	0.40%
NO ₂ (annual average) (µg/m ³)	0.96	0.96
Percentage of criterion (62 µg/m ³)	1.54%	1.54%
Southern ventilation outlet		
PM ₁₀ (annual average) (µg/m ³)	0.046	0.029
Percentage of criterion (30 µg/m ³)	0.15%	0.10%
PM _{2.5} (annual average) (µg/m ³)	0.044	0.027
Percentage of advisory reporting standard (8 µg/m ³)	0.55%	0.34%
NO ₂ (annual average) (µg/m ³)	0.51	0.51
Percentage of criterion (62 µg/m ³)	0.81%	0.81%

¹ This data represent the outcomes of applying the project design in the environmental impact to the screening assessment approach, rather than a reproduction of results from the environmental impact statement.

In-tunnel air quality

Table 3-23 summarises the calculated in-tunnel concentrations of NO₂, PM₁₀ and PM_{2.5} under scenarios including installation of particulate matter filtration at the Wilson Road and Trelawney Street tunnel support sites. This data has been developed for direct comparison with Table 7-101 in the environmental impact statement, and is based on the same assumptions and calculation methodology (refer to **Chapter 2** for further discussion of this methodology and interpretation of outputs). The table shows only in-tunnel pollutant concentrations for each main alignment tunnel in the relevant peak hour in 2019 and 2029 (ie a worst-case in-tunnel air quality scenario based on forecast traffic flows).

Table 3-23 shows that:

- Particulate matter filtration would not affect in-tunnel air quality for the first two thirds of each main alignment tunnel, based on the location of the filtration plants at the Wilson Road and Trelawney Street tunnel support facilities.
- In-tunnel concentrations of particulate matter would reduce by around 60 per cent at the point of filtration, based on an assumed particulate matter removal efficiency of 80 per cent, the design of the project's ventilation system and the need to maintain air flow through the main alignment tunnels (and therefore not treat all of the in-tunnel air).
- The net effect of particulate matter filtration, taking into account the assumptions about its efficiency and effectiveness, would be to reduce particulate matter concentrations to around 63 per cent at the southern ventilation intake and around 60 per cent at the northern ventilation intake in 2019 and 2029.
- These calculations may be significantly affected by how the project's ventilation system is operated, and by traffic volumes (noting the discussion in **Section 3.1** of this report about particulate matter removal efficiencies at different initial concentrations, and for different size particles).

Table 3-20 Indicative in-tunnel air quality with application of particulate matter filtration

Black – design as presented in the EIS including updates to fuel mix and no change to ratio of NO₂ to NO_x (10%)

Red – design including particulate matter filtration

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)									
NO ₂ *	0.044	0.111	0.14	0.162	0.186	0.210	0.232	0.282	0.422
	0.044	0.111	0.14	0.162	0.186	0.210	0.232	0.282	0.422
PM ₁₀	0.040	0.087	0.127	0.164	0.200	0.238	0.275	0.318	0.391
	0.040	0.087	0.127	0.164	0.200	0.095	0.132	0.175	0.248
PM _{2.5}	0.039	0.085	0.122	0.158	0.195	0.231	0.267	0.308	0.369
	0.039	0.085	0.122	0.158	0.195	0.092	0.128	0.169	0.230
Southbound main alignment tunnel at 9 am (2029)									
NO ₂ *	0.049	0.124	0.156	0.183	0.209	0.235	0.261	0.317	0.473
	0.049	0.124	0.156	0.183	0.209	0.235	0.261	0.317	0.473
PM ₁₀	0.051	0.109	0.156	0.203	0.249	0.296	0.343	0.397	0.472
	0.051	0.109	0.156	0.203	0.249	0.118	0.165	0.219	0.294
PM _{2.5}	0.050	0.102	0.148	0.192	0.236	0.280	0.324	0.375	0.446
	0.050	0.102	0.148	0.192	0.236	0.112	0.156	0.207	0.278
Northbound main alignment tunnel at 6 pm (2019)									
NO ₂ *	0.005	0.112	0.235	0.358	0.481	0.604	0.719	0.784	0.875
	0.005	0.112	0.235	0.358	0.481	0.604	0.719	0.784	0.875
PM ₁₀	0.033	0.092	0.156	0.220	0.284	0.347	0.410	0.46	0.515
	0.033	0.092	0.156	0.220	0.284	0.139	0.202	0.252	0.307
PM _{2.5}	0.031	0.087	0.147	0.207	0.269	0.329	0.387	0.434	0.487
	0.031	0.087	0.147	0.207	0.269	0.132	0.190	0.237	0.290
Northbound main alignment tunnel at 6 pm (2029)									
NO ₂ *	0.005	0.123	0.258	0.393	0.529	0.664	0.79	0.861	0.963
	0.005	0.123	0.258	0.393	0.529	0.664	0.79	0.861	0.963
PM ₁₀	0.041	0.111	0.186	0.261	0.337	0.412	0.484	0.543	0.610
	0.041	0.111	0.186	0.261	0.337	0.165	0.237	0.296	0.363

PM _{2.5}	0.039	0.104	0.176	0.247	0.318	0.389	0.457	0.518	0.576
	0.039	0.104	0.176	0.247	0.318	0.156	0.224	0.285	0.343

*Note: NO₂ has been assumed to be 10% of total nitrogen oxides, consistent with PIARC (2012)

Human health risks

Assuming that the particulate matter filtration plants operate continuously and constantly at the assumed removal efficiency, changes in human health impacts would be proportional to the predicted reductions in annual average PM_{2.5} concentrations (which would in turn be proportional to the change in mass emission rates from the project's ventilation outlets).

Table 3-24 summarises estimated increases in incidence of primary health indicators assuming the installation of particulate matter filtration plants, and includes equivalent data from the environmental impact statement without the use of filtration.

Table 3-21 Estimated increases in incidence of primary health effects (per year) – installation of particulate matter filtration

Primary health indicator	Baseline incidence per year (per 100,000)	Normal incidence variability (cases per year)	EIS (2019)	With particulate matter filtration
Northern interchange				
Mortality from all causes (≥ 30 years of age)	1,087	1	0.03	0.018
Rate of hospitalisation with cardiovascular disease (≥ 65 years of age)	23,352	40	0.02	0.012
Rate of hospitalisation with respiratory disease (≥ 65 years of age)	8,807	17	0.005	0.0030
Southern interchange				
Mortality from all causes (≥ 30 years of age)	1,087	1	0.03	0.019
Rate of hospitalisation with cardiovascular disease (≥ 65 years of age)	23,352	40	0.02	0.012
Rate of hospitalisation with respiratory disease (≥ 65 years of age)	8,807	17	0.004	0.0025

Other environmental and land use impacts

Relevant environmental and land use impacts (other than air quality and human health risks) for potential installation of particulate matter filtration plants at the Wilson Road and Trelawney Street tunnel support sites are presented in **Table 3-25**.

Table 3-22 Assessment of other environmental and land use impacts – installation of particulate matter filtration plants

Environmental and land use impacts	Assessment
Visual amenity impacts	An increase in the scale of the tunnel support facilities at Wilson Road and Trelawney Street sites to accommodate power supply and waste water management/ treatment systems would increase the bulk at these sites and associated visual impacts. Given that both sites are already proposed to be developed as tunnel support sites, only a minor additional deterioration in visual amenity would be anticipated.
Noise and vibration impacts	Both the Wilson Road and Trelawney Street tunnel support facilities are predicted to operate well below operational noise criteria. This, in addition to the ability to include appropriate noise attenuation in the design of additional surface infrastructure, would result in a negligible change in potential noise impacts relative to the assessment presented in the environmental impact statement.
Land acquisition	Subject to detailed design, surface infrastructure is anticipated to be able to be accommodated within the Wilson Road and Trelawney Street tunnel support facility sites, without the need for further land acquisition.
Land use impacts	Additional surface infrastructure at the Wilson Road and Trelawney Street sites is unlikely to increase land use impacts above those already presented and assessed in the environmental impact statement.
Construction impacts	Construction impacts are expected to be similar to those presented in the environmental impact statement, noting that construction at the Wilson Road and Trelawney Street sites is already proposed. Additional underground construction activities are unlikely to generate surface impacts.

Engineering considerations

Application of particulate matter filtration systems to the projects main alignment tunnels would increase the engineering design and operational complexity of the project. The ventilation system would be more complex, with a need to manage air flow rates through the main alignments as well as through in-tunnel offtake and re-entry infrastructure. Additional engineering is likely to be required to offset and manage the pressure drop across the filtration units.

Operationally, additional plant would be required, including the electrostatic precipitators, as well as the associated power supply and water management/ treatment systems.

Capital and operating costs

Estimated additional capital and operating costs associated with the installation of particulate matter filtration plans are summarised in **Table 3-26**. Costs include installation and operation of a filtration plant for each main alignment tunnel.

Operational costs including consumable materials, water supply and electricity. The cost of electricity required to operate the filtration plants is the major contributor to operational costs.

Table 3-23 Estimated increase in capital and operating costs for intermediate ventilation outlets

In-tunnel air treatment	Increase in project capital cost	Increase in project operating cost
Use of in-tunnel particulate matter filtration in both main alignment tunnels	\$125 million, subject to further design development	\$4 million per annum

3.2.7 Summary of scenario analysis

Each of the ventilation options and alternatives considered above has been qualitatively evaluated relative to the project presented and assessed in the environmental impact statement. The qualitative performance indicators presented in **Table 3-27** have been used to visually represent the relative performance of each option and alternative.

Table 3-28 summarises the outcomes of the qualitative comparative analysis of each option and alternative, in terms of ambient and in-tunnel air quality, human health risks, other environmental and land use impacts, engineering considerations and cost.

Scenario 4 (alternative ventilation designs) has not been evaluated in detail because, based on the discussion presented earlier in this section, none of the ventilation design alternatives (with the exception of the current project ventilation design) are considered feasible or viable for the NorthConnex project.

Table 3-24 Qualitative performance indicators

Symbol	Description
↑↑↑	An outcome that is significantly improved from the outcomes presented in the environmental impact statement for the project.
↑↑	An outcome that is moderately improved from the outcomes presented in the environmental impact statement for the project.
↑	An outcome that is slightly improved from the outcomes presented in the environmental impact statement for the project.
•	An outcome that is the same or broadly equivalent to the outcomes presented in the environmental impact statement for the project.
↓	An outcome that is slightly worsened from the outcomes presented in the environmental impact statement for the project.
↓↓	An outcome that is moderately worsened from the outcomes presented in the environmental impact statement for the project.
↓↓↓	An outcome that is significantly worsened from the outcomes presented in the environmental impact statement for the project.
!	An outcome that is unacceptable because it does not comply with applicable legislation, criteria or other project requirement.

In considering each of the ventilation options and alternatives, an analysis of whether each is feasible and reasonable has been conducted. In this context:

- 'Feasible' relates to engineering factors and whether the particular option can be built, or practically implemented.
- 'Reasonable' relates to whether, based on application of judgement and a balanced merit assessment, the benefits of the option outweigh its disbenefits, taking into account:
 - The degree to which the option reduces in-tunnel and ambient exposures to vehicle emissions.
 - The environmental and land use impacts of the option.
 - The cost and complexity of the option.

With the exception of significant changes to the project's ventilation design (Scenario 4) (for example, to a naturally, fully transverse or semi-transverse ventilation), all of the options considered in this analysis are feasible. A decision on whether to pursue any of the options is therefore a question of reasonableness.

Table 3-25 Comparative analysis of ventilation options and alternatives

Option/ alternative	Ambient air quality	In-tunnel air quality	Human health risks	Visual amenity impacts	Noise and vibration impacts	Land acquisition	Land use impacts	Construction impacts	Engineering	Cost
Scenario 1 – ventilation outlet height										
Northern ventilation outlet +2 metres	•	•	•	•	•	•	•	•	•	↓
Northern ventilation outlet +5 metres	↑	•	↑	↓	•	•	•	•	•	↓
Northern ventilation outlet +10 metres	↑	•	↑	↓↓	•	•	•	•	•	↓
Northern ventilation outlet +15 metres	↑	•	↑	↓↓	•	•	•	•	•	↓
Southern ventilation outlet +2 metres	•	•	•	•	•	•	•	•	•	↓
Southern ventilation outlet +5 metres	↑	•	↑	↓	•	•	•	•	•	↓
Southern ventilation outlet +10 metres	↑	•	↑	↓↓	•	•	•	•	•	↓
Southern ventilation outlet +15 metres	↑	•	↑	↓↓	•	•	•	•	•	↓
Scenario 2 – relocation of ventilation outlets										
Asquith Industrial Area (northern ventilation outlet)	•	•	•	↑	•	↓↓	•	↓↓	↓↓↓	↓↓↓
Pennant Hills Golf Course (southern ventilation outlet)	↑	•	↑	↓↓	•	↓↓	↓	↓	↓↓	↓↓
Scenario 3 – additional ventilation outlets										
Mid point ventilation outlet	↑	↑	↑	↓↓	•	↓↓	↓	↓↓	↓	↓↓
Conversion of Wilson Road and Trelawney Street facilities	↑	↑	↑	↓	•	↓	↓	↓	↓	↓↓
Scenario 5 – treatment of in-tunnel air										
Use of in-tunnel particulate matter filtration in both main alignment tunnels	↑	↑	↑	↓	•	•	•	•	↓↓	↓↓↓

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Scenario 1 – Increased ventilation outlet height

All increases in ventilation outlet would improve ambient air quality impacts and associated human health risks. The degree of improvement would increase with additional ventilation outlet height, with the greatest incremental improvement identified at around an additional five to ten metres. Height increases above this level show a decline in incremental benefit with increased height. Increasing the height of the project's ventilation outlets does not affect in-tunnel air quality.

The key environmental impact associated with increased ventilation outlet height is potential visual impacts. Based on an assessment of the visual envelope mapping, a five metre increase in ventilation outlet height has been identified as the threshold around which visual impacts would transition from acceptable and manageable, to levels that are considered unacceptable.

Based on the net improvement in ventilation performance with increased ventilation outlet height, the additional visual impacts associated with increases of 10 metres or more would not be acceptable.

On the basis of this analysis, ventilation outlet height increases up to five metres would be feasible and reasonable.

An increase in ventilation outlet heights of five metres (for both the southern and the northern ventilation outlets) has been adopted for the NorthConnex project. Further details of this project design changes, and a revised environmental impact assessment, are presented in **Section 9.2** of this report.

Scenario 2 – Relocation of the ventilation outlets

Relocation of the northern ventilation outlet into the Asquith Industrial Estate would provide no tangible air quality or human health benefit. It would also not reduce in-tunnel exposures to vehicle emissions. This option would introduce significant additional capital and operating costs. With respect to land acquisition and construction impacts, this option would have a greater impact than presented in the environmental impact statement for the project.

On the basis of this analysis, relocation of the northern ventilation outlet to the Asquith Industrial Estate is feasible, but not reasonable.

A screening level air quality impact assessment has identified that relocating the southern ventilation outlet into the Pennant Hills Golf Course, or land around the south west corner of the golf course, would reduce the air quality impacts of the project. However, slightly better improvements in air quality could be achieved by increasing the height of the ventilation outlet.

Relocation of the southern ventilation outlet would increase visual impacts through disaggregation and distribution of the built form. It would also require additional land acquisition, with potential flow on impacts with respect to the operation of the Pennant Hills Golf Course.

The relocation would increase engineering complexities, and increase construction related impacts.

On the basis of this analysis, relocation of the southern ventilation outlet to the Pennant Hills Golf Course (or adjacent land) would be feasible, but not reasonable.

Scenario 3 – Intermediate ventilation outlets

All intermediate ventilation outlet options would improve in-tunnel air quality. All options would also reduce ambient air quality impacts to varying degrees, and the associated human health risks. Broadly, the screening level assessment presented in this report indicates around a 20 per cent reduction in ambient air quality (particulate matter) impacts and human health risks with inclusion of a mid point ventilation outlet, and around 50 per cent reduction for conversion of the Trelawney Street and Wilson Road facilities. These predicted reductions are relative to already very low predicted impacts. It is recognised that these options would not reduce the total pollution load emitted by the project, but would redistribute it at a lower concentration across a larger population.

In terms of in-tunnel air quality, the installation of a mid point ventilation outlet would reduce maximum concentrations of in-tunnel pollutants by around 20 to 25 per cent. Conversion of the Wilson Road and Trelawney Street facilities would result in a reduction of around 50 to 70 per cent, depending on the pollutant, direction of travel and traffic forecast scenario (2019 or 2029).

A mid point ventilation outlet would introduce environmental and land use impacts that have not previously been contemplated, while conversion of the Wilson Road and Trelawney Street tunnel support facilities would increase environmental and land use impacts relative to those presented in the environmental impact statement. Based on submissions received in response to the public exhibition of the NorthConnex project, provision of intermediate ventilation outlets is unlikely to be received favourably by affected stakeholders.

Installation of intermediate ventilation outlets would require a fundamental redesign of the project, including construction and operational infrastructure, construction planning and urban design.

All intermediate ventilation outlet options would introduce moderate additional capital and operating costs. The ventilation design for a mid point ventilation outlet would introduce additional complexity into the ventilation design, particularly in relation to the introduction of additional air into the project tunnels to offset removal of in-tunnel air at the intermediate ventilation outlets, and management of ventilation flows within the tunnels around these points. Some additional ventilation design complexity would also be associated with reconfiguration of the Wilson Road and Trelawney Street tunnel support facilities to include concurrent air intake and ventilation emissions.

Although these options would result in a relative decrease in in-tunnel and ambient exposures to vehicle emissions, these reductions are considered low in absolute terms. Given the introduction of other undesirable environmental and land use impacts, and engineering complexity, improvements in in-tunnel and ambient air quality associated with these options are not considered sufficient to offset their undesirable implications.

On the basis of this analysis, an intermediate ventilation outlet(s) would be feasible, but not reasonable.

Scenario 4 – Ventilation flow rates

Changes in ventilation design to include natural, fully transverse or semi-transverse ventilation are not feasible or reasonable.

The ventilation design criteria are comparable to or better than other road tunnels around the world, and there is therefore no reasonable justification for applying more stringent criteria or requiring additional ventilation capacity to be provided in the project design.

Changes in ventilation design and/ or ventilation design criteria are feasible, but not reasonable.

Scenario 5 – In-tunnel air treatment

Installation of particulate matter filtration plants would reduce the load of particulate matter in the main alignment tunnels, with a consequential reduction in ambient air quality impacts and associated human health risks. The reductions in ambient air quality impacts and human health risks are comparable to the improvements identified for other options, including the addition of intermediate ventilation outlets and increases in ventilation outlet height. These other options would, however, not improve in-tunnel air quality (as would be the case with the installation of particulate matter filtration plants).

Based on the analysis presented in this report, assuming that the particulate matter removal efficiencies assumed would be achieved in practice, a reduction in particulate matter load at the ventilation offtakes of around 40 per cent could be achieved (ie a reduction to around 60 per cent of the particulate matter load that would be experienced if filtration technology were not installed). This reduction in particulate matter in the project tunnels is slightly better than with the installation of a mid point ventilation outlet (around 20 to 25 per cent reduction at the end of the project tunnels) and not quite as good as conversion of the Wilson Road and Trelawney Street site to ventilation outlets (around 50 to 70 per cent at the end of the project tunnels). Relevantly, in-tunnel filtration technology would only address particulate matter concentrations, rather than the full suite of pollutants that would be reduced with the installation of intermediate ventilation outlets. Based on in-tunnel air quality alone, this would suggest that an intermediate ventilation outlet may be preferable to in-tunnel filtration if the key intended outcome is a significant improvement in in-tunnel air quality. Other factors, including engineering practicality, cost and other environmental and land use impacts would however need to be factored into this consideration.

In-tunnel particulate matter filtration would increase some environmental impacts, including in relation to waste generation and waste water management/ treatment. The increased scale of surface infrastructure would increase the bulk of proposed tunnel support facilities, with some increases in visual impacts. The higher energy consumption would increase indirect greenhouse gas impacts and may increase air quality impacts at the generation source (depending on decision about the purchase of electricity). Compared with other ventilation design options that are anticipated to generate better in-tunnel and ambient air quality outcomes, installation of in-tunnel filtration is relatively costly both from a capital and operating expenditure perspective. As noted above, equivalent or better in-tunnel and ambient air quality outcomes may be achievable with one or more other ventilation design options (other than in-tunnel filtration) at lower cost and engineering complexity.

Additional engineering complexity would be introduced with the installation of in-tunnel filtration, particularly in terms of ventilation design and management. Electricity supply and wastewater management would be new components that would need to be accommodated within the project design.

In-tunnel particulate matter filtration would add significant additional capital and operating costs to the project.

In summary:

- Other ventilation design options would result in greater reductions in air quality and human health risks at significantly lower capital and operating cost.
- In-tunnel particulate matter filtration would reduce part of the load of in-tunnel vehicle emissions (ie only particulate matter, with other pollutants unaffected)
- The in-tunnel air quality criteria applied to the design of the project, which are comparable to best practice adopted and accepted elsewhere in Australia and throughout the world, would be achieved without particulate matter filtration. Therefore since the conventional ventilation system is effective, the benefit of providing an in-tunnel filtration system is considered negligible.
- If in-tunnel air quality levels could not be achieved with the proposed ventilation system, the most effective engineering solution would be the introduction of additional ventilation outlets and additional air supply. This is a proven solution, more sustainable and reliable than tunnel filtration systems. These alternatives would also be a more cost effective approach.

On the basis of this analysis, installation of particulate matter filtration would be feasible, but not reasonable.

4 Clarifications – Other issues

This chapter includes clarifications of issues other than in relation to air quality and ventilation system design, which have been addressed in **Chapter 2** and **Chapter 3** of this report, respectively.

The clarifications presented in this chapter relate to:

Project scope and design

- Use of generators to power road headers during the initial stages of construction before connection to main power supply (refer to **Section 4.1**).
- Location of the ventilation offtake from the southbound main alignment tunnel to the southern ventilation outlet (refer to **Section 4.2**).
- Use of the Darling Mills Creek construction compound (C2) for the temporary storage of construction materials (refer to **Section 4.3**).

Noise and vibration

- Operational noise barriers at the southern interchange near Coral Tree Drive (refer to **Section 4.4**).
- Construction noise mitigation and management measures (refer to **Section 4.5**).

4.1 Use of generators to power road headers prior to mains power connection

4.1.1 Description

The environmental impact statement discusses the power supply for road headers during the construction period in two principal locations:

- The construction air quality assessment in Section 7.3 of the environmental impact statement and the Technical Working Paper: Air Quality (Appendix G of the environmental impact statement) identify that *'road headers would be driven by mains power supply and would therefore not generate exhaust emissions'*.
- The project description in Section 5.3 of the environmental impact statement identifies that *'prior to the connection of mains power supply to the tunnel support sites, road headers would be powered by diesel generators'*.

To clarify this issue, the road headers would be powered by diesel generators prior to the connection of main power supply (ie before the mains supply for the construction plant and equipment is fully available). The approval through the relevant power supply authority and the construction of the power supply routes to the construction compounds would not be completed prior to the commencement of tunnelling works.

As such, there may be a period of construction where the power requirements for road headers would contribute to exhaust emissions. For the majority of the construction period, however, the road headers would be powered by mains power and would not generate exhaust emissions.

Diesel generators (four 1.25 MVA generators) powering the road headers would be used at:

- Southern interchange compound (C5).
- Northern interchange compound (C9).

There is also potential for generators to be required at the Wilson Road compound (C6) and the Trelawney Street compound (C7). However, at this stage project programming indicates that mains electricity supply may be available at these sites prior to the operation of road headers, in which case generators would not be required.

These generators would be located within the acoustic sheds at the four compounds to mitigate potential noise generation.

4.1.2 Environmental assessment

Potential construction air quality impacts have been assessed qualitatively in the environmental impact statement through a description of the proposed works, identification of plant and equipment and potential emissions sources. Proactive and reactive mitigation measures have been identified to reduce the potential for adverse impacts to local air quality and sensitive receivers.

The assessment has considered the potential for exhaust emissions from diesel powered plant and equipment and has identified a range of environmental management measures in order to reduce these potential impacts. These management measures would be also applied to the use of diesel generators to power the road headers before connection to mains power supply.

In addition to exhaust emissions, the use of diesel generators also has the potential to contribute to construction noise levels. The noise contributions from the use of diesel generators would be minor in the context of other noise sources during the early stages of construction and are not anticipated to increase predicted construction noise impacts beyond the levels presented in the environmental impact statement. Appropriate measures would be implemented such as acoustic screening of the generators to comply with the construction noise levels as described in section 7.2 of the environmental impact statement.

4.2 Southern ventilation offtake

4.2.1 Description

Submissions in response to the exhibition of the environmental impact statement and feedback received during community consultation have sought information on the location of the southern ventilation offtake. These submissions and feedback have identified that the ventilation offtake is not shown in figures in the environmental impact statement.

The ventilation offtake is a separate tunnel used to transport the in-tunnel air from the main alignment tunnel to the ventilation facility located at the southern end of the motorway operations complex.

The location of the ventilation offtake is shown in **Figure 4-1**. The ventilation offtake is around 150 metres long. The offtake is a separate tunnel used to transport the air and emissions from the southbound tunnel to the ventilation outlet located in the motorway operations complex. The large axial fans at the ventilation outlet draw the air from the project tunnels along the offtake tunnel. Similar arrangements are in place for tunnels like the Cross City Tunnel and Lane Cove Tunnel.

4.2.2 Environmental assessment

This clarification does not alter the environmental assessment or predicted impacts, as presented in the environmental impact statement.

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Figure 4-1 Southern ventilation off-take location

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4.3 Storage of materials at the Darling Mills Creek construction compound (C2)

4.3.1 Description

The Darling Mills Creek construction compound (C2) is described in the environmental impact statement as consisting of basic workforce amenities. These amenities would include toilets and a lunch room.

Ongoing design refinement and construction planning has identified the need for storage of construction materials at the Darling Mills Creek compound. Construction materials are to be securely stored under the bridge in the general vicinity of the workforce amenities. A revised indicated construction site layout for the Darling Mills Creek compound is shown in **Figure 4-2** (under the bridge across Darling Mills Creek).

4.3.2 Environmental assessment

This clarification does not alter the environmental assessment or predicted impacts, as presented in the environmental impact statement.

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Figure 4-2 Indicative Darling Mills Creek viaduct construction compound revised layout

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4.4 Positioning of noise barriers near Coral Tree Drive

4.4.1 Description

The operational noise impact assessment presented in Section 7.2 and Appendix F of the environmental impact statement was undertaken based on the height of existing noise barriers.

As part of the operational noise assessment, a noise barrier analysis was conducted. This analysis considered whether it was be feasible and reasonable to increase the height of existing noise barriers relative to their surveyed reduced level height, and the potential benefits of doing so based on anticipated road traffic noise levels at adjacent receiver locations.

The noise barrier analysis identified that the existing noise barrier located adjacent to the southern side of the Hills M2 Motorway and running parallel to Coral Tree Drive (NWM2WB08) should be maintained at its current height. This would result in maintaining a noise barrier in this location which is currently around 3.6 metres to six metres in height (above existing ground level).

In the vicinity of the noise barrier near Coral Tree Drive (NWM2WB08), the following works are required:

- Moving the existing on-ramp slightly to the north in order to facilitate the new motorway to motorway connection from the NorthConnex southbound tunnel to the Hills M2 Motorway westbound carriageway. The existing on-ramp from Pennant Hills Road would generally maintain its same elevation.
- A new tunnel portal and the NorthConnex southbound carriageway connecting to the Hills M2 Motorway westbound carriageway.

Due to the south to westbound motorway connection emerging from underground, there would be a significant change in elevation of the roadway in this location. The works in this area would require the existing ground level to be lowered.

The change in ground level in this area would mean that in order to maintain the height of the existing noise barrier (consistent with the reduced level of the top of the noise barrier), a new noise barrier would need to be installed at a height of more than 15 metres above the new lower ground level. A new noise barrier of this height is not considered feasible or reasonable, and would be likely to result in other impacts which are not desirable such as significant overshadowing, visual amenity implications and construction impacts to nearby receivers.

To resolve this issue, further consideration has been given to available feasible and reasonable noise mitigation measures for receivers in this location (along Coral Tree Drive). This has included further analysis of feasible and reasonable noise barrier heights, and consideration of eligibility for at-property acoustic treatments where relevant.

The assessment of feasible and reasonable noise barrier heights is provided in **Section 4.4.2** below. The assessment concludes that the following noise barriers should be provided:

- A six metre high noise barrier (NWM2WB08 North) on the re-aligned Pennant Hills Road to Hills M2 Motorway on-ramp.
- A new five-metre high noise barrier (NWM2WB08 South) adjacent to the on-ramp connecting the NorthConnex southbound tunnel to the Hills M2 Motorway westbound carriageway.

The assessment also identifies six properties eligible for consideration of at-property acoustic treatments. These properties are in addition to those already identified as eligible in the environmental impact statement. This is a preliminary assessment based on the current design of the project at this location. During detailed design, further work would be conducted to identify potential additional measures or alternatives to mitigate or avoid elevated noise impacts for the receivers along Coral Tree Drive

The locations of the re-alignment and new noise barriers, and the additional properties eligible for consideration of at-property acoustic treatments are shown in **Figure 4-7**.

4.4.2 Environmental assessment

Further assessment of potential noise mitigation measures, including noise barriers and potential at-property acoustic treatments, has been carried out for residential receivers around Coral Tree Drive in noise catchment area NCA10.

A comparison of noise reductions for a range of noise barrier heights has been carried out for noise barrier NWM2WB08, located adjacent to the Hills M2 Motorway and parallel to Coral Tree Drive. Separate assessments have been considered for the barrier on the realigned Pennant Hills Road on-ramp (NWM2WB08 North) and the new barrier adjacent to the on-ramp connecting the NorthConnex southbound tunnel to the Hills M2 Motorway westbound carriageway (NWM2WB08 South). The assessment has been conducted for the design year (2029).

NWM2WB08 North

Figure 4-3 shows the relationship between potential noise barrier height and reductions in road traffic noise (insertion loss) as well as predicted exceedance of the road traffic noise criterion at adjacent residential receivers.

Figure 4-4 shows the maximum insertion loss at any receiver and the maximum sound pressure level at any receiver. Over the varying barrier heights the specific receiver may not be the same, hence the decrease in insertion loss is not necessarily consistent with the maximum noise level.

The Environmental Noise Management Manual (RTA, 2001) requires assessment of noise barriers as follows:

- Identification of a 'target barrier', being the noise barrier which achieves compliance with applicable road traffic noise criteria at all receivers.
- Where the 'target barrier' is not feasible and/ or reasonable, identification of an 'assessed barrier', being the noise barrier which achieves the lowest feasible and reasonable road traffic noise levels at affected receivers. For an 'assessed barrier' to be considered reasonable, it must:
 - For noise barriers that are less than five metres high, have a minimum insertion loss (reduction in noise across the noise barrier) of around 5 dB(A) to be considered reasonable.
 - For noise barriers that are equal to or greater than five metres high, have a minimum insertion loss of around 10 dB(A) to be considered reasonable.

Notwithstanding the approach summarised above, Roads and Maritime has adopted a policy of not reducing the height of existing noise barriers, even if the target barrier and/ or the assessed barrier are less than the height of the existing barrier.

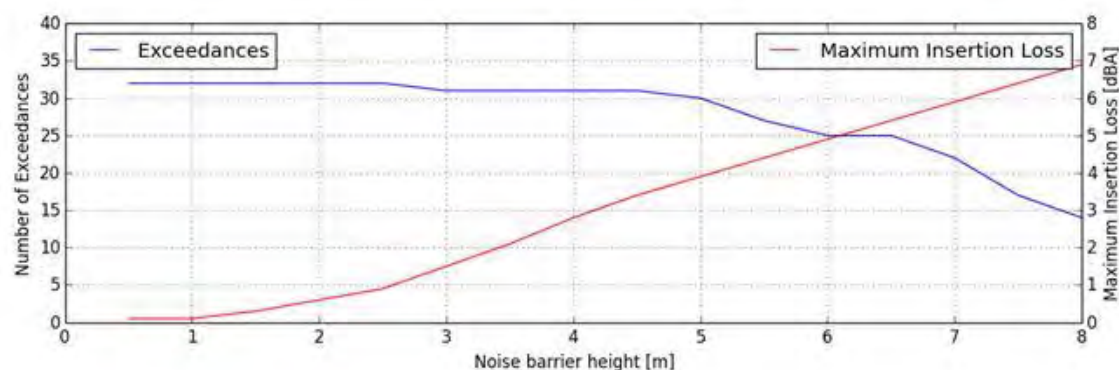


Figure 4-3 Maximum insertion loss and criterion exceedance as a function of noise barrier height (NWM2WB08 North)

Figure 4-3 shows that the 'target barrier' height is greater than eight metres (the point where exceedances of the applicable road traffic noise criteria fall to zero). The Environmental Noise Management Manual specifies that noise barriers greater than eight metres in height are not considered visually acceptable. Therefore, there is no feasible and reasonable target barrier for NWM2WB08 North.

In terms of a potential 'assessed barrier', **Figure 4-3** shows that:

- A 5 dB(A) insertion loss is achieved with a noise barrier height of around six metres.
- A 10 dB(A) insertion loss is achieved with a noise barrier height greater than eight metres.

At this location, a noise barrier would ordinarily not be considered viable based on the Environmental Noise Management Manual. However, considering a noise barrier currently exists in this location, Roads and Maritime policy is to provide a replacement barrier. Based on this policy, a noise barrier of six metres is considered viable as it meets the minimum insertion loss of 5 dB(A).

Potential noise barrier heights have also been assessed for reasonableness based on:

- Total noise benefit (TNB) – being the sum of the decibel reductions achieved (taking account of all road traffic noise sources) at all residential and other noise sensitive receivers.
- Total benefit per unit barrier area (TNBA) – being the ‘total noise benefit’ divided by the total area of the noise barrier.
- Marginal benefit value (MBV) – for a particular noise barrier height being the increase in total noise benefit (TNB) divided by the increase in the barrier height or area.

For this location, **Figure 4-4** illustrates the benefits of different noise barrier heights in terms of total noise benefit (TNB), total benefit per unit barrier area (TNBA) and marginal benefit value (MBV).

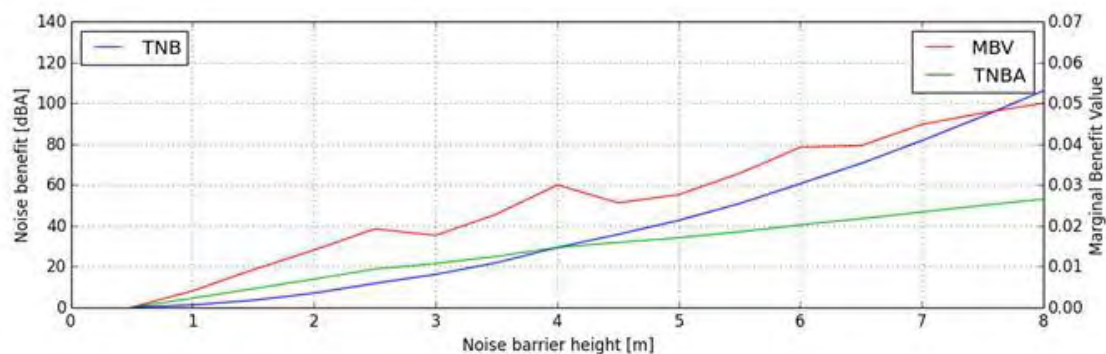


Figure 4-4 Potential noise benefits as a function of noise barrier height (NWM2WB08 North)

As shown in **Figure 4-4**, the marginal benefit value peaks at around four metres, then again at six metres and continues to rise beyond eight metres, while the total noise benefit per unit barrier area peaks at greater than eight metres. Of these values:

- A noise barrier greater than eight metres in high is not considered visually acceptable, and is therefore not considered reasonable.
- As identified above, a noise barrier five metres in height would not achieve the minimum insertion loss of 5 dB(A) specified by the Environmental Noise Management Manual.
- A noise barrier of six metres in height would achieve an insertion loss of 5 dB(A). Due to the unique circumstances of this noise barrier being a replacement for an existing barrier, a six metre barrier is considered to be appropriate.

Because there is no reasonable ‘target barrier’, the ‘assessed barrier’ with a height of six metres has been recommended for noise barrier NWM2WB08 North.

NWM2WB08 South

Figure 4-5 shows the relationship between potential noise barrier height and reductions in road traffic noise (insertion loss) as well as predicted exceedance of the road traffic noise criterion at adjacent residential receivers.

Figure 4-5 shows the maximum insertion loss at any receiver and the maximum sound pressure level at any receiver. Over the varying barrier heights the specific receiver may not be the same, hence the decrease in insertion loss is not necessarily consistent with the maximum noise level.

The Environmental Noise Management Manual (RTA, 2001) requires assessment of noise barriers as follows:

- Identification of a 'target barrier', being the noise barrier which achieves compliance with applicable road traffic noise criteria at all receivers.
- Where the 'target barrier' is not feasible and/ or reasonable, identification of an 'assessed barrier', being the noise barrier which achieves the lowest feasible and reasonable road traffic noise levels at affected receivers. For an 'assessed barrier' to be considered reasonable, it must:
 - For noise barriers that are less than five metres high, have a minimum insertion loss (reduction in noise across the noise barrier) of around 5 dB(A) to be considered reasonable.
 - For noise barriers that are equal to or greater than five metres high, have a minimum insertion loss of around 10 dB(A) to be considered reasonable.

Notwithstanding the approach summarised above, Roads and Maritime has adopted a policy of not reducing the height of existing noise barriers, even if the target barrier and/ or the assessed barrier are less than the height of the existing barrier.

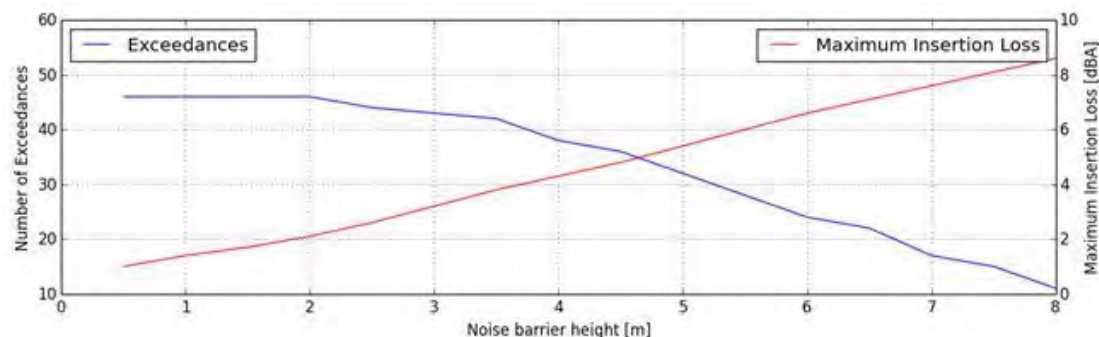


Figure 4-5 Maximum insertion loss and criterion exceedance as a function of noise barrier height (NWM2WB08 South)

Figure 4-5 shows that the ‘target barrier’ height is greater than eight metres (the point where exceedances of the applicable road traffic noise criteria fall to zero). The Environmental Noise Management Manual specifies that noise barriers greater than eight metres in height are not considered visually acceptable. Therefore, there is no feasible and reasonable target barrier for NWM2WB08 South.

In terms of a potential ‘assessed barrier’, **Figure 4-5** shows that:

- A 5 dB(A) insertion loss is achieved with a noise barrier height of around 4.5 metres.
- A 10 dB(A) insertion loss is achieved with a noise barrier height greater than eight metres.

At this location, a noise barrier around 4.5 metres to five metres high is therefore considered to be a viable ‘assessed barrier’ because it achieves the insertion loss required by the Environmental Noise Management Manual. A higher noise barrier (above five metres) is not considered viable because in order to achieve the insertion loss specified by the Environmental Noise Management Manual, the noise barrier would need to be eight metres in height, which is not considered visually acceptable.

Potential noise barrier heights have also been assessed for reasonableness based on:

- Total noise benefit (TNB) – being the sum of the decibel reductions achieved (taking account of all road traffic noise sources) at all residential and other noise sensitive receivers.
- Total benefit per unit barrier area (TNBA) – being the ‘total noise benefit’ divided by the total area of the noise barrier.
- Marginal benefit value (MBV) – for a particular noise barrier height being the increase in total noise benefit (TNB) divided by the increase in the barrier height or area.

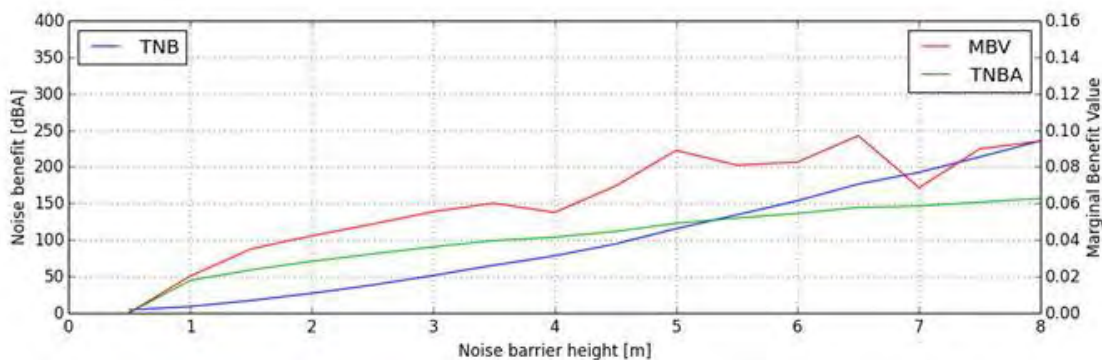


Figure 4-6 Potential noise benefits as a function of noise barrier height (NWM2WB08 South)

As shown in **Figure 4-6**, the marginal benefit value peaks at around five metres and around 6.5 metres, while the total noise benefit per unit barrier area peaks at greater than eight metres. Of these values:

- A noise barrier greater than eight metres in high is considered visually acceptable, and is therefore not considered reasonable.
- A noise barrier 6.5 metres in height does not achieve the minimum insertion loss of 10 dB(A) specified by the Environmental Noise Management Manual, and is therefore not considered reasonable.
- A noise barrier five metres in height would achieve the minimum insertion loss of 5 dB(A) specified by the Environmental Noise Management Manual. A noise barrier five metres in height is therefore considered to be reasonable and the 'assessed barrier' for (NWM2WB08 South).

Because there is no reasonable 'target barrier', the 'assessed barrier' with a height of five metres has been recommended for noise barrier NWM2WB08 South.

At-property acoustic treatment

Based on the consideration of noise barriers above, there is no combination of 'target barriers' in this location which would result in all receivers achieving compliance with the applicable traffic noise criteria. As such, further consideration has been given to the properties at this location eligible for consideration of at-property treatment. This assessment for both daytime and night-time noise levels is provided **Table 4-33** and **Table 4-34** respectively.

This assessment has identified an additional six properties which are eligible for consideration of at-property acoustic treatment. These properties are identified in **Figure 4-7**. It is noted that this assessment is based on the preferred tender design. Further consideration would be given to feasible and reasonable operational noise mitigation measures based on the detailed design of the project.

Additional considerations

By incorporating a six metre high noise barrier for the northern location and a five metre high noise barrier for the southern location noise levels would generally not appreciably increase from existing noise levels for nearby receivers. However there are six residual receivers that are predicted to experience noise level increases of more than 2 dB(A) as a result of the project. Noise levels at these receivers are predicted to increase by up to 3.1 dB(A) with the proposed design. The noise assessment above has shown that noise barriers greater than eight metres in height would be required to eliminate this noise increase via conventional means. Noise barriers of such a significant height are generally considered to be not feasible or reasonable due to the unacceptable visual impacts.

Extensive investigations have been undertaken by others into providing different capping formations on the top of noise barriers to improve the noise reduction performance. There have been many different configurations in noise barrier capping, however they reduce noise using the same mechanisms. The noise insertion loss is improved by affecting the diffraction path over the top of the barrier and sometimes providing additional absorption at the point of diffraction. While reductions of 5 dB(A) and greater have been reported in some instances, it is more likely that reductions of 1 dB(A) to 2 dB(A) would be achievable.

In this context, providing capping on the northern barrier adjacent to Coral Tree Drive has the potential to further reduce the predicted noise levels from the project. Further investigations should be undertaken at the detailed design stage of the project to ensure that all feasible and reasonable noise mitigation is provided to minimise the noise impact on receivers located on Coral Tree Drive.



Figure 4-7 Additional properties eligible for consideration of at-property acoustic treatment

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Table 4-1 Southern interchange and Hills M2 Motorway integration works – predicted daytime traffic noise levels (with NWM2WB08 North and South)

ID	Address	Usage	Criterion (dB(A))	Year of Opening (2019) L _{Aeq(15hour)} (dB(A))			Design Year (2029) L _{Aeq(15hour)} (dB(A))			Acute	Eligible
				No Build	Build	Increase	No Build	Build	Increase		
3759	27 Coral Tree Drive, Carlingford	Residential	60	57	60	3	58	61	3	No	Yes
3777	25 Coral Tree Drive, Carlingford	Residential	60	57	60	3.1	58	61	3.1	No	Yes
3793	23 Coral Tree Drive, Carlingford	Residential	60	58	61	2.9	59	62	2.9	No	Yes
3823	21 Coral Tree Drive, Carlingford	Residential	60	58	61	2.6	59	62	2.6	No	Yes
3842	22 Coral Tree Drive, Carlingford	Residential	60	58	61	3.1	59	62	3.1	No	Yes
3860	20 Coral Tree Drive, Carlingford	Residential	60	58	61	2.5	59	61	2.5	No	Yes

Table 4-2 Southern interchange and Hills M2 Motorway integration works – predicted night-time traffic noise levels (with NWM2WB08 North and South)

ID	Address	Usage	Criterion (dB(A))	Year of Opening (2019) L _{Aeq(15hour)} (dB(A))			Design Year (2029) L _{Aeq(15hour)} (dB(A))			Acute	Eligible
				No Build	Build	Increase	No Build	Build	Increase		
3759	27 Coral Tree Drive, Carlingford	Residential	55	55	57	2.1	56	58	2.1	No	Yes
3777	25 Coral Tree Drive, Carlingford	Residential	55	55	58	2.2	56	58	2.2	No	Yes
3793	23 Coral Tree Drive, Carlingford	Residential	55	56	58	2	57	59	2	No	Yes
3823	21 Coral Tree Drive, Carlingford	Residential	55	56	58	1.6	57	59	1.6	No	No
3842	22 Coral Tree Drive, Carlingford	Residential	55	56	58	2.2	57	59	2.2	No	Yes
3860	20 Coral Tree Drive, Carlingford	Residential	55	56	58	1.6	57	59	1.6	No	No

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4.5 Construction noise mitigation and management measures

4.5.1 Description

Potential construction noise impacts have been raised as a significant issue in submissions, particularly from local communities living close to construction sites. Submissions have also raised the need to apply all feasible and reasonable noise mitigation and management measures during the construction period.

To assist in consideration of potential construction noise issues, Table 7-60 to Table 7-77 of the environmental impact statement have been reproduced in the following pages of this report, and updated to include more detail about the magnitude and extent of potential noise impacts. The tables have been updated to list the number of receivers expected to receive construction noise between rating background levels (RBLs) (ie existing background noise) and noise management levels (NMLs) (ie the thresholds above which further consideration of feasible and reasonable noise mitigation measures is required). For those receivers expected to be affected by construction noise above noise management levels, receivers have been broken down into groups based on the extent of exceedance of the rating background levels in 10 dB(A) bands.

The construction noise assessment tables presented on the following pages are:

- For construction activities during standard construction hours:
 - **Table 4-36** summarises construction noise impacts from the Hills M2 Motorway integration work and southern interchange (cf. Table 7-60 in the environmental impact statement).
 - **Table 4-37** summarises construction noise impacts from the Coral Tree Drive switching station site (cf. Table 7-61 in the environmental impact statement).
 - **Table 4-38** summarises construction noise impacts from the Darling Mills Creek compound (C2) (cf Table 7-62 in the environmental impact statement).
 - **Table 4-39** summarises construction noise impacts from the Barclay Road compound (C3) (cf Table 7-63 in the environmental impact statement).
 - **Table 4-40** summarises construction noise impacts from the Yale Close compound (C4) (cf Table 7-64 in the environmental impact statement).
 - **Table 4-41** summarises construction noise impacts from the southern interchange compound (C5) (cf Table 7-65 in the environmental impact statement).
 - **Table 4-42** summarises construction noise impacts from the Wilson Road compound (C6) (cf Table 7-66 of the environmental impact statement).
 - **Table 4-43** summarises construction noise impacts from the Trelawney Street compound (C7) (cf Table 7-67 of the environmental impact statement).
 - **Table 4-44** summarises construction noise impacts from the Pioneer Avenue compound (C8) (cf Table 7-68 of the environmental impact statement).
 - **Table 4-45** summarises construction noise impacts from the northern interchange compound (C9) (cf Table 7-69 of the environmental impact statement).
 - **Table 4-46** summarises construction noise impacts from the Bareena Avenue compound (C10) (cf Table 7-70 of the environmental impact statement).

- **Table 4-47** summarises construction noise impacts from the Junction Road compound (C11) (cf Table 7-71 of the environmental impact statement). This table also includes updated construction noise impact assessment outcomes for additional laydown activities to be carried out at this site (refer to **Section 7.5** of this report).
- **Table 4-48** summarises construction noise impacts from the northern interchange and M1 Pacific Motorway tie-in works (cf Table 7-72 of the environmental impact statement).
- For nominated construction activities outside of standard construction hours:
 - **Table 4-49** summarises construction noise impacts from the Hills M2 Motorway integration bridgeworks (cf Table 7-33 of the environmental impact statement).
 - **Table 4-50** summarises construction noise impacts from tunnelling support sites (cf Table 7-74 of the environmental impact statement).
 - **Table 4-85** summarises ground-borne noise impacts from tunnelling activities (cf Table 7-75 of the environmental impact statement).
 - **Table 4-52** summarises sleep disturbance impacts from the Hills M2 Motorway integration bridgeworks (cf Table 7-76 of the environmental impact statement).
 - **Table 4-53** summarises sleep disturbance impacts from tunnelling support sites (cf Table 7-77 of the environmental impact statement).

Noise and vibration mitigation, monitoring and management measures to be applied to the project during construction and operation are summarised in Table 7-85 of the environmental impact statement. These measures apply to all aspects of the project, unless expressly stated otherwise (for example, in the case of site or activity specific measures).

During construction, a Construction Noise and Vibration Management Plan(s) would be developed and implemented for each construction site/ activity, or each group of construction sites/ activities. These plans would detail site/ activity specific mitigation measures, taking into account the number and sensitivity of potentially affected receivers, the nature and duration of relevant construction activities, and the availability of feasible and reasonable mitigation measures.

As a general guide, the approach taken during the construction of the North West Rail Link and the Hills M2 Motorway Upgrade would be adapted and applied to the NorthConnex project. This approach would require review of the predicted construction noise impacts summarised in **Table 4-36** to **Table 4-53** of this report, including any refinements to that assessment as a result of detailed design, and identification of receiver specific mitigation and management measures depending on the level of predicted construction noise impact relative to rating background levels (RBLs). Proposed receiver specific mitigation and management measures as a function of construction noise impact above rating background levels are summarised in **Table 4-35**.

Table 4-3 Proposed receiver specific construction noise mitigation and management measures

Predicted construction noise impact	Proposed receiver specific mitigation and management measures (refer to descriptions of measures provided after this table)
Airborne noise during standard construction hours (Table 2-66 to Table 2-78)	
For receivers affected by construction noise more than 0 dB(A) but less than 10 dB(A) above the applicable rating background level.	No additional receiver specific mitigation and management measures beyond those specified in Table 7-85 of the environmental impact statement.
For receivers affected by construction noise more than 10 dB(A) but less than 20 dB(A) above the applicable rating background level.	Letterbox drop
For receivers affected by construction noise more than 20 dB(A) but less than 30 dB(A) above the applicable rating background level.	Letterbox drop Noise monitoring
For receivers affected by construction noise more than 30 dB(A) above the applicable rating background level.	Letterbox drop Noise monitoring
Acutely affected receivers (equal to or more than 75 dB(A))	Letterbox drop Noise monitoring Respite periods
Airborne noise outside of standard construction hours (Table 2-79 and Table 2-80)	
For receivers affected by construction noise more than 0 dB(A) but less than 5 dB(A) above the applicable rating background level.	No additional receiver specific mitigation and management measures beyond those specified in Table 7-85 of the environmental impact statement.
For receivers affected by construction noise more than 5 dB(A) but less than 10 dB(A) above the applicable rating background level.	Letterbox drop
For receivers affected by construction noise more than 10 dB(A) but less than 20 dB(A) above the applicable rating background level.	Letterbox drop
For receivers affected by construction noise more than 20 dB(A) but less than 30 dB(A) above the applicable rating background level.	Letterbox drop Noise monitoring
For receivers affected by construction noise more than 30 dB(A) above the applicable rating background level.	Letterbox drop Noise monitoring Individual briefing Receiver specific notifications Receiver specific contact Respite periods Alternative accommodation
Acutely affected receivers (equal to or more than 75 dB(A))	Letterbox drop Noise monitoring Individual briefing

	Receiver specific notifications Receiver specific contact Respite periods Alternative accommodation
Ground-borne noise (Table 2-81)	
For receivers affected by ground-borne noise more than 0 dB(A) but less than 5 dB(A) above the evening ground-borne noise criterion.	No additional receiver specific mitigation and management measures beyond those specified in Table 7-85 of the environmental impact statement.
For receivers affected by ground-borne noise more than 5 dB(A) but less than 10 dB(A) above the evening ground-borne noise criterion.	Letterbox drop
For receivers affected by ground-borne noise more than 0 dB(A) but less than 5 dB(A) above the night time ground-borne noise criterion.	Letterbox drop Noise monitoring Receiver specific notifications
For receivers affected by ground-borne noise more than 5 dB(A) but less than 10 dB(A) above the night time ground-borne noise criterion.	Letterbox drop Noise monitoring Receiver specific notifications Receiver specific contact Alternative accommodation
Sleep disturbance impacts (Table 2-82 and Table 2-83)	
For receivers affected by sleep disturbance impacts more than 0 dB(A) but less than 10 dB(A) above the applicable sleep disturbance criterion.	Letterbox drop Receiver specific notifications Receiver specific contact Respite periods
For receivers affected by sleep disturbance impacts more than 10 dB(A) but less than 20 dB(A) above the applicable sleep disturbance criterion.	Letterbox drop Noise monitoring Individual briefing Receiver specific notifications Receiver specific contact Alternative accommodation
For receivers affected by sleep disturbance impacts above the awakening reaction criterion.	Letterbox drop Noise monitoring Individual briefing Receiver specific notifications Receiver specific contact Alternative accommodation

The receiver specific construction noise mitigation and management measures listed in **Table 4-35** would be developed and document in more detail during preparation of the Construction Noise and Vibration Management Plan(s). As a general guide, these measures are likely to include:

- **Letterbox drop** – notification of construction activities as part of periodic community updates distributed across areas surrounding construction activities.
- **Noise monitoring** – receiver or catchment specific noise monitoring used to confirm the construction noise performance of the project and to proactively inform, where relevant, review and update noise mitigation and management measures, and site construction practices.
- **Individual briefing** – offers of individual briefings about relevant construction activities and potential impacts with potentially affected receivers.
- **Receiver specific notifications** – individual correspondence to potentially affected receivers providing information on construction activities and potential impacts specific to the situation.
- **Receiver specific contact** – individual phone calls, emails or visits to potentially affected receivers providing information on construction activities and potential impacts specific to the situation.
- **Respite periods** – programming of feasible and reasonable respite periods for potentially affected receivers.
- **Alternative accommodation** – offers of reasonable alternative accommodation for receivers potentially affected by construction activities conducted at night (from 10 pm to 7 am). Alternative accommodation would be subject to consultation with the affected receiver and would take into account the duration and intensity of the potential impact.

4.5.2 Environmental assessment

This clarification does not alter the environmental assessment or predicted impacts, as presented in the environmental impact statement.

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Table 4-4 Construction noise – Hills M2 Motorway integration works and southern interchange (standard construction hours)

NCA	RBL (dB(A))	Number of receivers 0-10 dB(A) above RBL	NML	Number of receivers 10-20 dB(A) above RBL	Number of receivers 20-30 dB(A) above RBL	Number of receivers ≥ 30 dB(A) above RBL	Number of acutely affected receivers (≥75 dB(A))
Traffic management, set-up and line-marking							
NCA08	44	18	54	6	1	0	0
NCA10	44	210	54	87	17	0	0
NCA11	51	68	61	38	9	0	4
NCA12	39	134	49	73	30	5	0
NCA13	49	30	59	4	0	0	0
NCA14	53	48	63	16	0	0	0
NCA15	53	16	63	1	0	0	0
Total	-	524	-	225	57	5	4
Demolition							
NCA08	44	57	54	13	5	0	0
NCA10	44	245	54	93	12	2	2
NCA11	51	122	61	47	10	3	9
NCA12	39	200	49	103	40	17	6
NCA13	49	33	59	4	0	0	0
NCA14	53	42	63	19	5	0	2
NCA15	53	42	63	7	1	0	1
Total	-	741	-	286	73	22	20
Road widening							
NCA08	44	44	54	0	0	0	0
NCA10	44	153	54	83	12	2	2
NCA11	51	122	61	47	10	3	9
NCA12	39	153	49	69	21	9	2
NCA13	49	30	59	4	0	0	0
NCA14	53	39	63	18	5	0	2
Total	-	541	-	221	48	14	15
Bridgeworks							
NCA12	39	155	49	79	30	8	4
NCA13	49	19	59	6	2	0	0
NCA15	53	42	63	7	1	0	1
Total	-	216	-	92	33	8	5

NCA	RBL (dB(A))	Number of receivers 0-10 dB(A) above RBL	NML	Number of receivers 10-20 dB(A) above RBL	Number of receivers 20-30 dB(A) above RBL	Number of receivers ≥ 30 dB(A) above RBL	Number of acutely affected receivers (≥75 dB(A))
Intelligent Transport Systems works							
NCA08	44	18	54	10	3	0	0
NCA10	44	115	54	57	8	1	1
NCA11	51	63	61	32	8	1	7
NCA12	39	200	49	105	36	10	2
NCA13	49	22	59	6	0	0	0
NCA14	53	54	63	18	0	0	0
NCA15	53	13	63	5	0	0	0
Total	-	485	-	233	55	12	10
Earthworks, pavement and temporary median works							
NCA08	44	84	54	16	5	1	1
NCA09	44	16	54	2	0	0	0
NCA10	44	262	54	106	13	3	3
NCA11	51	145	61	56	11	5	9
NCA12	39	180	49	103	50	21	8
NCA13	49	45	59	14	1	0	0
NCA14	53	51	63	23	6	0	5
NCA15	53	51	63	8	1	0	1
Total	-	843	-	328	87	30	27
Re-surfacing asphalt works							
NCA08	44	76	54	18	6	0	0
NCA09	44	6	54	0	0	0	0
NCA10	44	193	54	105	41	1	1
NCA11	51	83	61	32	16	2	11
NCA12	39	157	49	86	39	16	2
NCA13	49	47	59	4	0	0	0
NCA14	53	78	63	26	0	0	0
NCA15	53	10	63	3	0	0	0
Total	-	650	-	274	102	19	14

Table 4-5 Construction noise – Coral Tree Drive switching station (standard construction hours)

NCA	RBL (dB(A))	Number of receivers 0-10 dB(A) above RBL	NML	Number of receivers 10-20 dB(A) above RBL	Number of receivers 20-30 dB(A) above RBL	Number of receivers ≥ 30 dB(A) above RBL	Number of acutely affected receivers (≥75 dB(A))
Site establishment and earthworks							
NCA08	44	3	54	0	0	0	0
NCA10	44	62	54	27	9	2	2
Total	-	65	-	27	9	2	2
Building construction works							
NCA08	44	51	54	17	0	0	0
NCA10	44	75	54	31	9	1	1
Total	-	126	-	31	9	1	1

Table 4-6 Construction noise – Darling Mills Creek compound (C2) (standard construction hours)

NCA	RBL (dB(A))	Number of receivers 0-10 dB(A) above RBL	NML	Number of receivers 10-20 dB(A) above RBL	Number of receivers 20-30 dB(A) above RBL	Number of receivers ≥ 30 dB(A) above RBL	Number of acutely affected receivers (≥75 dB(A))
Site establishment and earthworks							
NCA14	53	9	63	4	1	0	1
Total	-	9	-	4	1	0	1

Table 4-7 Construction noise – Barclay Road compound (C3) (standard construction hours)

NCA	RBL (dB(A))	Number of receivers 0-10 dB(A) above RBL	NML	Number of receivers 10-20 dB(A) above RBL	Number of receivers 20-30 dB(A) above RBL	Number of receivers ≥ 30 dB(A) above RBL	Number of acutely affected receivers (≥75 dB(A))
Site establishment and earthworks							
NCA13	49	24	59	3	0	0	1
Total	-	24	59	3	0	0	1

Table 4-8 Construction noise – Yale Close compound (C4) (standard construction hours)

NCA	RBL (dB(A))	Number of receivers 0-10 dB(A) above RBL	NML	Number of receivers 10-20 dB(A) above RBL	Number of receivers 20-30 dB(A) above RBL	Number of receivers ≥ 30 dB(A) above RBL	Number of acutely affected receivers (≥75 dB(A))
Site establishment and earthworks							
NCA12	39	103	49	54	21	4	3
Total	-	103	49	54	21	4	3

Table 4-9 Construction noise – Southern interchange compound (C5) (standard construction hours)

NCA	RBL (dB(A))	Number of receivers 0-10 dB(A) above RBL	NML	Number of receivers 10-20 dB(A) above RBL	Number of receivers 20-30 dB(A) above RBL	Number of receivers ≥ 30 dB(A) above RBL	Number of acutely affected receivers (≥75 dB(A))
Site establishment and earthworks							
NCA08	44	100	54	47	16	7	7
NCA10	44	64	54	25	12	14	14
Total	-	164	-	72	28	21	21
Tunnel support							
NCA08	44	51	54	17	0	0	0
NCA10	44	75	54	31	6	0	0
Total	-	126	-	48	6	0	0
Building construction							
NCA08	44	44	54	19	1	0	0
NCA10	44	42	54	17	0	0	0
Total	-	86	-	36	1	0	0
Ventilation shaft							
NCA08	44	8	54	0	0	0	0
NCA10	44	17	54	5	1	0	0
Total	-	25	-	5	1	0	0

Table 4-10 Construction noise – Wilson Road compound (C6) (standard construction hours)

NCA	RBL (dB(A))	Number of receivers 0-10 dB(A) above RBL	NML	Number of receivers 10-20 dB(A) above RBL	Number of receivers 20-30 dB(A) above RBL	Number of receivers ≥ 30 dB(A) above RBL	Number of acutely affected receivers (≥75 dB(A))
Site establishment and earthworks							
NCA07	41	265	51	122	41	22	18
Total	-	265	-	122	41	22	18
Tunnel support							
NCA07	41	154	51	73	22	1	0
Total	-	154	-	73	22	1	0
Building construction works							
NCA07	41	199	51	88	22	1	0
Total	-	199	-	88	22	1	0

Table 4-11 Construction noise – Trelawney Street compound (C7) (standard construction hours)

NCA	RBL (dB(A))	Number of receivers 0-10 dB(A) above RBL	NML	Number of receivers 10-20 dB(A) above RBL	Number of receivers 20-30 dB(A) above RBL	Number of receivers ≥ 30 dB(A) above RBL	Number of acutely affected receivers (≥75 dB(A))
Site establishment and earthworks							
NCA06	47	156	57	54	14	11	14
Total	-	156	-	54	14	11	14
Tunnel support							
NCA06	47	39	57	20	4	0	0
Total	-	39	-	20	4	0	0
Building construction works							
NCA06	47	60	57	26	2	2	3
Total	-	60	-	26	2	2	3

Table 4-12 Construction noise – Pioneer Avenue compound (C8) (standard construction hours)

NCA	RBL (dB(A))	Number of receivers 0-10 dB(A) above RBL	NML	Number of receivers 10-20 dB(A) above RBL	Number of receivers 20-30 dB(A) above RBL	Number of receivers ≥ 30 dB(A) above RBL	Number of acutely affected receivers (≥75 dB(A))
Site establishment and earthworks							
NCA06	47	27	57	9	0	0	0
Total	-	27	-	9	0	0	0

Table 4-13 Construction noise – Northern interchange compound (C9) (standard construction hours)

NCA	RBL (dB(A))	Number of receivers 0-10 dB(A) above RBL	NML	Number of receivers 10-20 dB(A) above RBL	Number of receivers 20-30 dB(A) above RBL	Number of receivers ≥ 30 dB(A) above RBL	Number of acutely affected receivers (≥75 dB(A))
Site establishment and earthworks							
NCA04	51	38	61	20	6	9	12
NCA05	41	42	51	25	0	0	0
Total	-	80	-	45	6	9	12
Tunnel support							
NCA04	51	28	61	12	1	0	0
NCA05	41	72	51	24	0	0	0
Total	-	100	-	36	1	0	0

Table 4-14 Construction noise – Bareena Avenue compound (C10) (standard construction hours)

NCA	RBL (dB(A))	Number of receivers 0-10 dB(A) above RBL	NML	Number of receivers 10-20 dB(A) above RBL	Number of receivers 20-30 dB(A) above RBL	Number of receivers ≥ 30 dB(A) above RBL	Number of acutely affected receivers (≥75 dB(A))
Site establishment and earthworks							
NCA02	56	58	66	19	0	1	9
NCA03	53	37	63	8	0	0	0
Total	-	95	-	27	0	1	9
Tunnel support							
NCA02	56	25	66	14	0	1	1
NCA03	53	13	63	5	0	0	0
Total	-	38	-	19	0	1	1
Ventilation shaft							
NCA02	56	37	66	12	0	1	1
NCA03	53	11	63	3	0	0	0
Total	-	48	-	15	0	1	1

Table 4-15 Construction noise – Junction Road compound (C11) (standard construction hours)

NCA	RBL (dB(A))	Number of receivers 0-10 dB(A) above RBL	NML	Number of receivers 10-20 dB(A) above RBL	Number of receivers 20-30 dB(A) above RBL	Number of receivers ≥ 30 dB(A) above RBL	Number of acutely affected receivers (≥75 dB(A))
Site establishment and earthworks							
NCA01	56	24	66	14	6	0	7
NCA02	56	6	66	2	0	0	0
Total	-	30	-	16	6	0	7
Laydown activities							
NCA01	56	3	66	0	0	0	0
NCA02	56	0	66	0	0	0	0
Total	-	0	-	0	0	0	0

Table 4-16 Construction noise – Northern interchange an M1 Pacific Motorway tie-in works (standard construction hours)

NCA	RBL (dB(A))	Number of receivers 0-10 dB(A) above RBL	NML	Number of receivers 10-20 dB(A) above RBL	Number of receivers 20-30 dB(A) above RBL	Number of receivers ≥ 30 dB(A) above RBL	Number of acutely affected receivers (≥75 dB(A))
Traffic management, set-up and line-marking							
NCA01	56	6	66	0	0	0	0
NCA02	43	19	53	9	6	0	8
NCA03	41	32	51	18	9	0	8
NCA04	41	62	51	47	29	8	27
NCA05	35	35	45	23	14	8	5
Total	-	154	-	97	58	16	48
Demolition							
NCA01	56	6	66	0	0	0	0
NCA02	43	20	53	12	7	3	10
NCA03	41	19	51	12	2	1	3
NCA04	41	42	51	24	10	3	8
NCA05	35	104	45	44	11	5	5
Total	-	191	-	92	30	12	26
Road widening							
NCA01	56	6	66	0	0	0	0
NCA02	43	20	53	12	7	3	10
NCA03	41	18	51	11	3	1	3
NCA04	41	42	51	24	10	3	8
NCA05	35	104	45	44	11	5	5
Total	-	190	-	91	31	12	26
Earthworks, pavement and temporary median works							
NCA01	56	8	66	0	0	0	0
NCA02	43	29	53	17	6	4	10
NCA03	41	30	51	21	11	5	15
NCA04	41	73	51	41	16	18	30
NCA05	35	135	45	55	12	6	5
Total	-	275	-	134	45	33	60
Re-surfacing asphalt works							
NCA01	56	14	66	0	0	0	0
NCA02	43	44	53	20	9	0	11

NCA	RBL (dB(A))	Number of receivers 0-10 dB(A) above RBL	NML	Number of receivers 10-20 dB(A) above RBL	Number of receivers 20-30 dB(A) above RBL	Number of receivers ≥ 30 dB(A) above RBL	Number of acutely affected receivers (≥75 dB(A))
NCA03	41	60	51	33	13	0	12
NCA04	41	136	51	61	21	16	26
NCA05	35	101	45	44	12	5	4
Total	-	355	-	158	55	21	53

Table 4-17 Construction noise – Hills M2 Motorway integration works (outside of standard construction hours)

NCA	RBL (dB(A))	Number of receivers 0-5 dB(A) above RBL	NML	Number of receivers 5-10 dB(A) above RBL	Number of receivers 10-20 dB(A) above RBL	Number of receivers 20-30 dB(A) above RBL	Number of receivers ≥ 30 dB(A) above RBL	Number of acutely affected receivers (≥75 dB(A))
Bridgeworks								
NCA11	37	21	42	13	8	0	0	0
NCA12	33	152	38	17	78	31	11	2
NCA13	33	152	38	36	57	7	2	0
NCA14	35	138	40	36	54	8	0	0
NCA15	38	98	43	17	54	7	1	0
Total	-	561	-	119	251	53	14	2

Table 4-18 Construction noise – tunnelling support (outside of standard construction hours)

NCA	RBL (dB(A))	Number of receivers 0- 5 dB(A) above RBL	NML	Number of receivers 5- 10 dB(A) above RBL	Number of receivers 10- 20 dB(A) above RBL	Number of receivers 20- 30 dB(A) above RBL	Number of receivers ≥ 30 dB(A) above RBL	Number of acutely affected receivers (≥75 dB(A))
Southern interchange compound								
NCA08	39	25	44	16	2	0	0	0
NCA10	36	30	41	19	15	1	0	0
Total	-	55	-	35	17	1	0	0
Wilson Road compound								
NCA07	30	243	35	8	94	14	3	0
Total	-	243	-	8	94	14	3	0
Trelawney Street compound								
NCA06	39	35	44	22	15	0	0	0
Total	-	35	-	22	15	0	0	0
Northern interchange compound								
NCA04	41	8	46	5	2	0	0	0
NCA05	35	2	40	1	0	0	0	0
Total	-	10	-	6	2	0	0	0

Table 4-19 Ground-borne noise assessment – tunnelling activities

Period	Criteria (dB(A))	Number of receivers 0-5 dB(A) above criteria	Number of receivers 5-10 dB(A) above criteria
Evening	40	28	0
Night	35	90	28

Table 4-20 Sleep disturbance – Hills M2 Motorway integration bridgeworks

NCA	Sleep disturbance criteria (dB(A))	Number of receivers 0-10 dB(A) above sleep disturbance criteria	Number of receivers 10-20 dB(A) above sleep disturbance criteria	Awakening reaction criteria (dB(A))	Number of receivers above awakening reaction criteria
NCA11	52	1	0	65	0
NCA12	48	75	36	65	3
NCA13	48	41	7	65	0
NCA14	50	49	2	65	0
NCA15	53	46	7	65	1
Total	-	212	52	-	4

Table 4-21 Sleep disturbance – tunnelling support sites

NCA	Sleep disturbance criteria (dB(A))	Number of receivers 0-10 dB(A) above sleep disturbance criteria	Number of receivers 10-20 dB(A) above sleep disturbance criteria	Awakening reaction criteria (dB(A))	Number of receivers above awakening reaction criteria
Southern interchange compound					
NCA08	54	5	0	65	0
NCA10	51	18	0	65	0
Total	-	23	0	-	0
Wilson Road compound					
NCA07	45	87	33	65	1
Total	-	87	33	-	1
Trelawney Street compound					
NCA06	54	22	2	65	1
Total	-	22	2	-	1
Northern interchange compound					
NCA04	56	5	0	65	0
Total	-	5	0	-	0

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