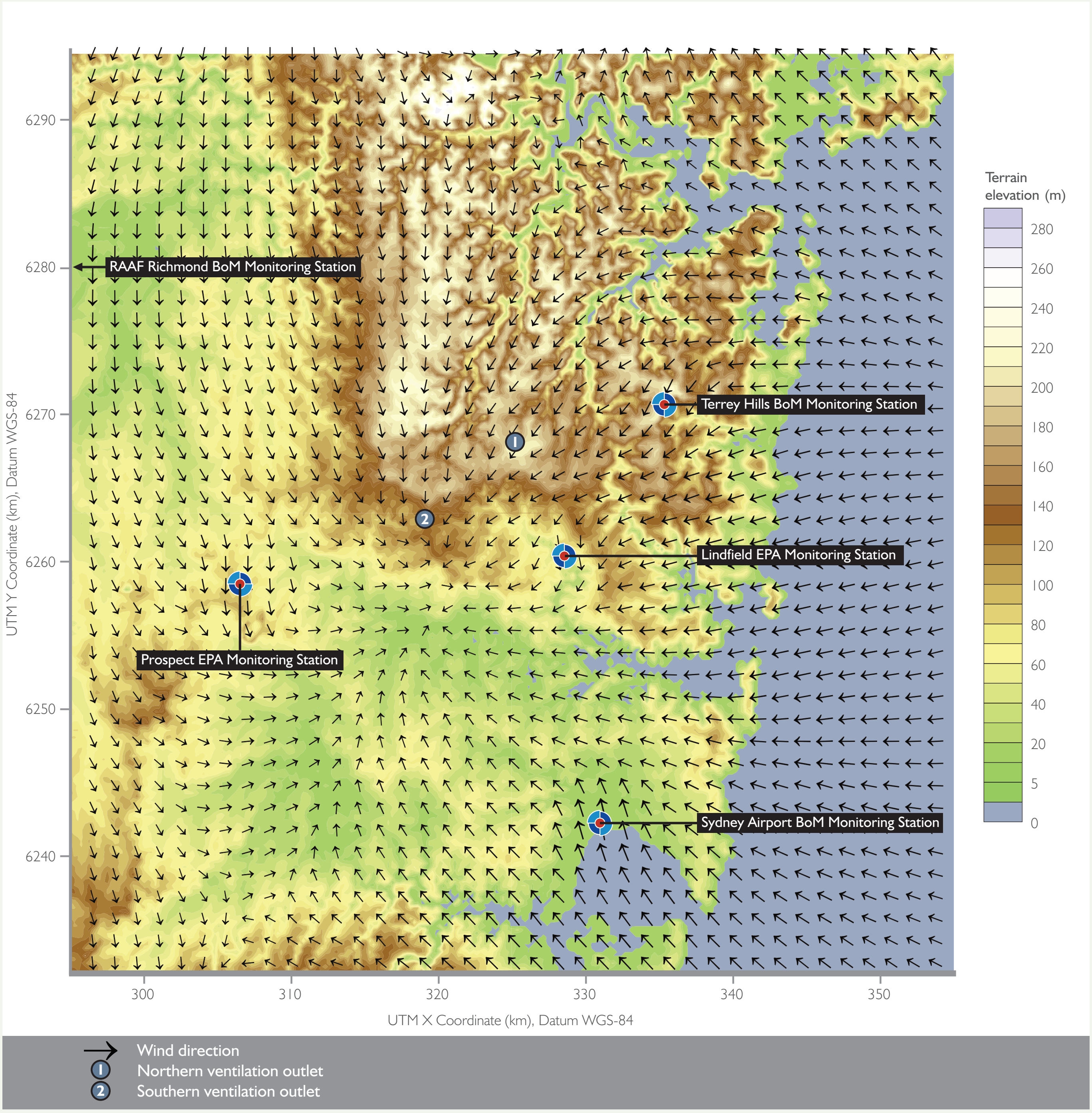

Figure 2-35 Wind flow field at hour 09:00 on day 337 (10 metres)

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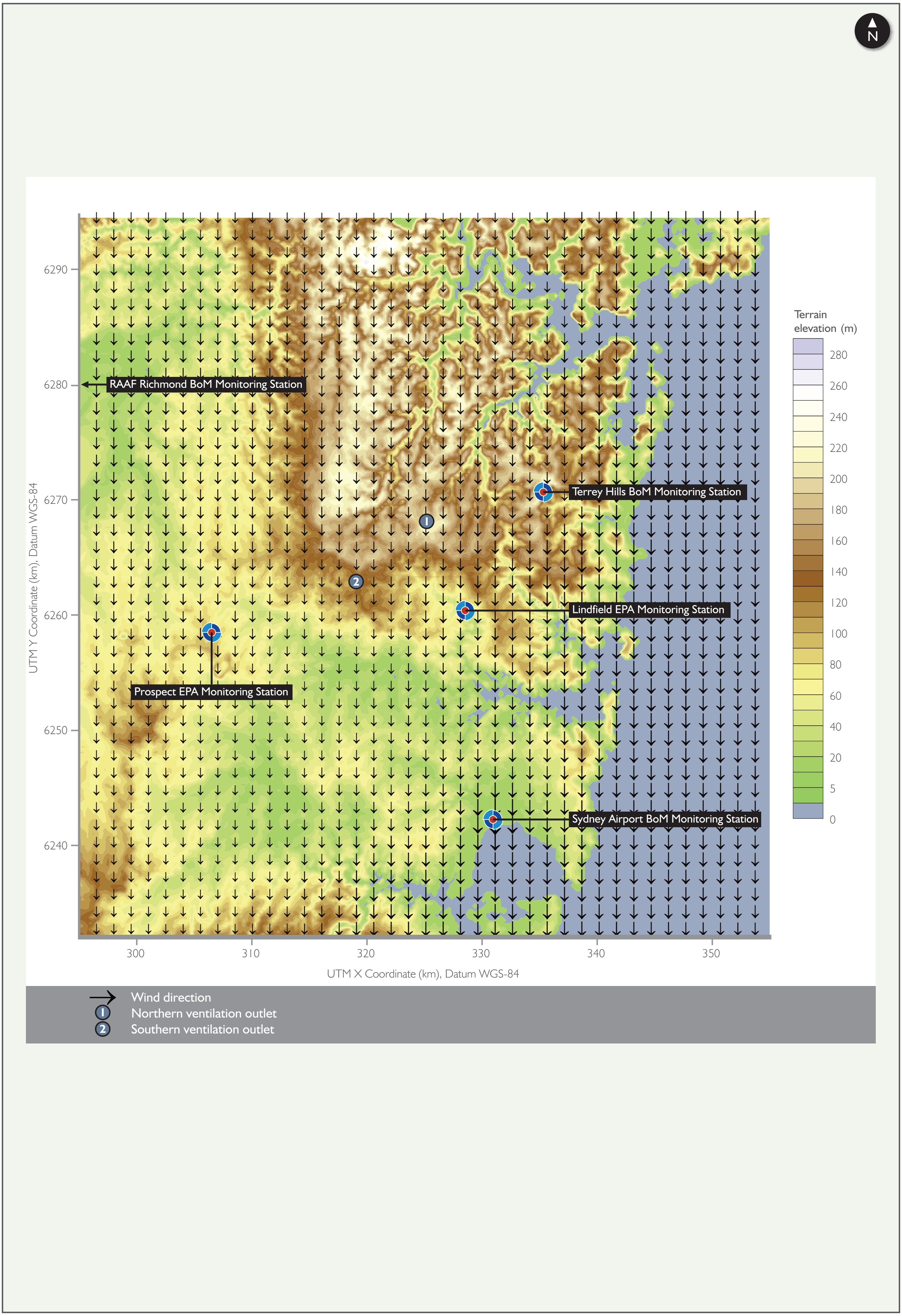

Figure 2-36 Wind flow field at hour 10:00 on day 337 (10 metres)

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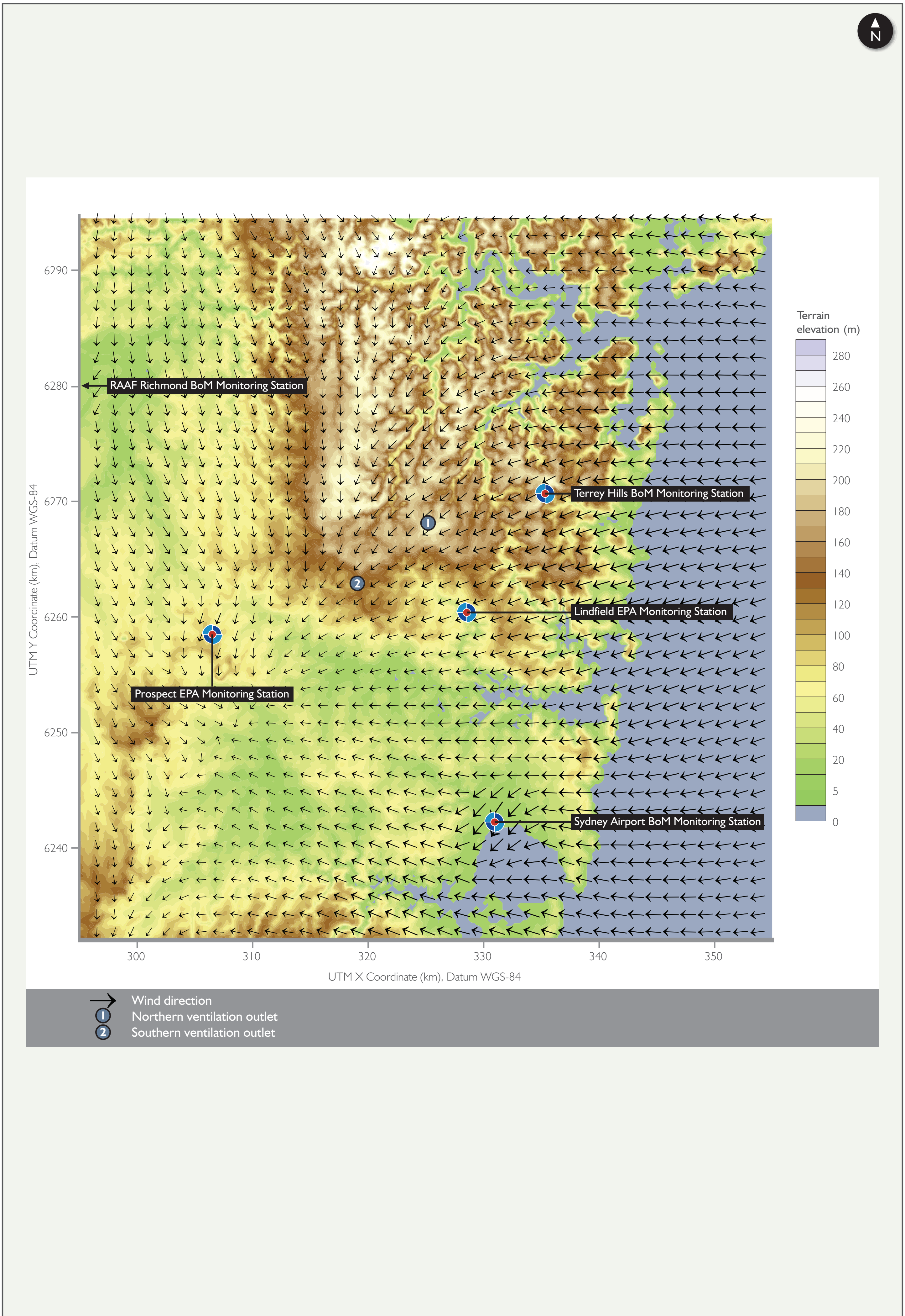

Figure 2-37 Wind flow field at hour 11:00 on day 337 (10 metres)

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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 µg/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. <u>For each of the plots shown in **Figure 2-38**, the single outlier data point is hour 8 on day 337</u>.

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).

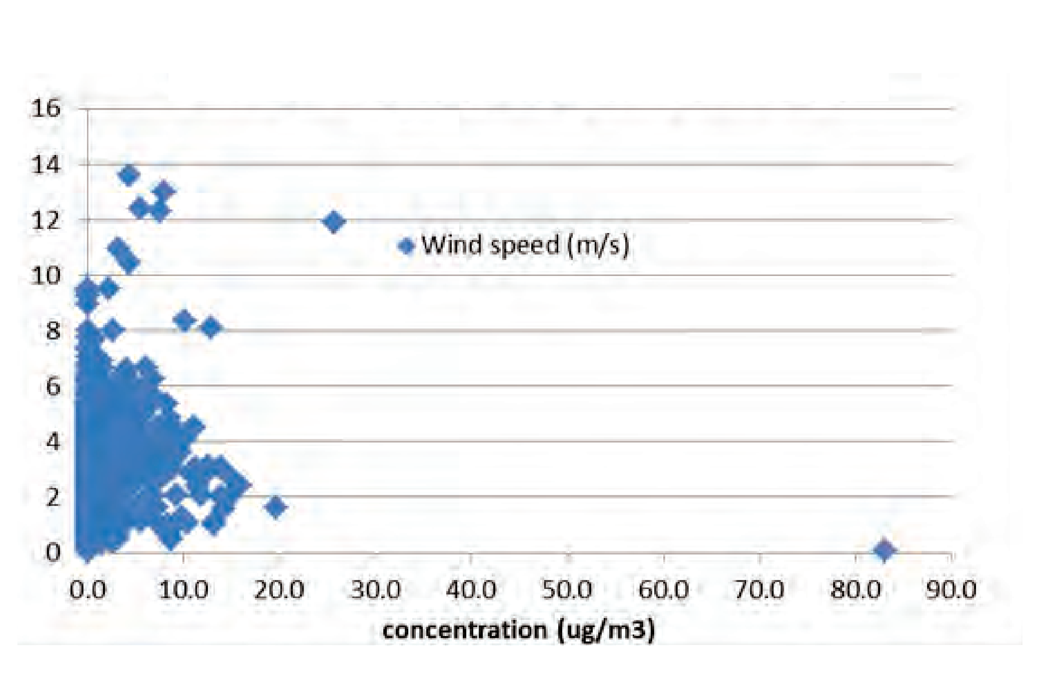
The dispersion modelling for the **SPIR15** and **SPIR20** scenarios (ie to assess the change in ventilation outlet heights by five metres) has generated results that, taking into account the effects of rare meteorological events, are consistent with expected trends. This includes a general reduction 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

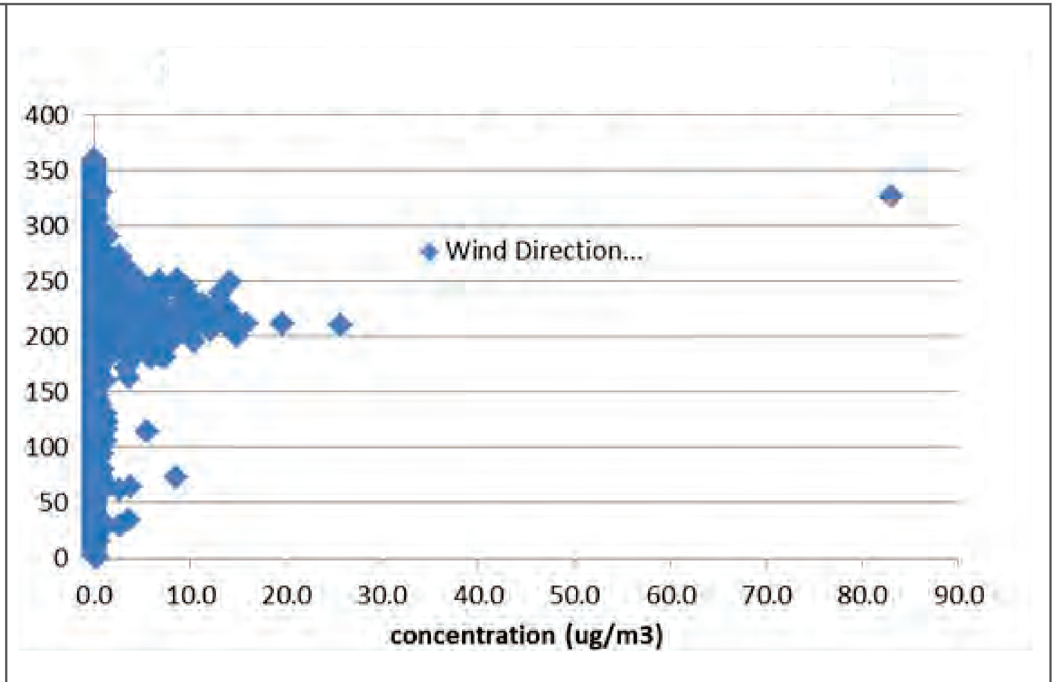
The modelling results and analysis presented in this section demonstrate that the potential impacts of the project would comply with applicable ambient air quality criteria and advisory reporting standards, and in most cases by a significant degree.

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.

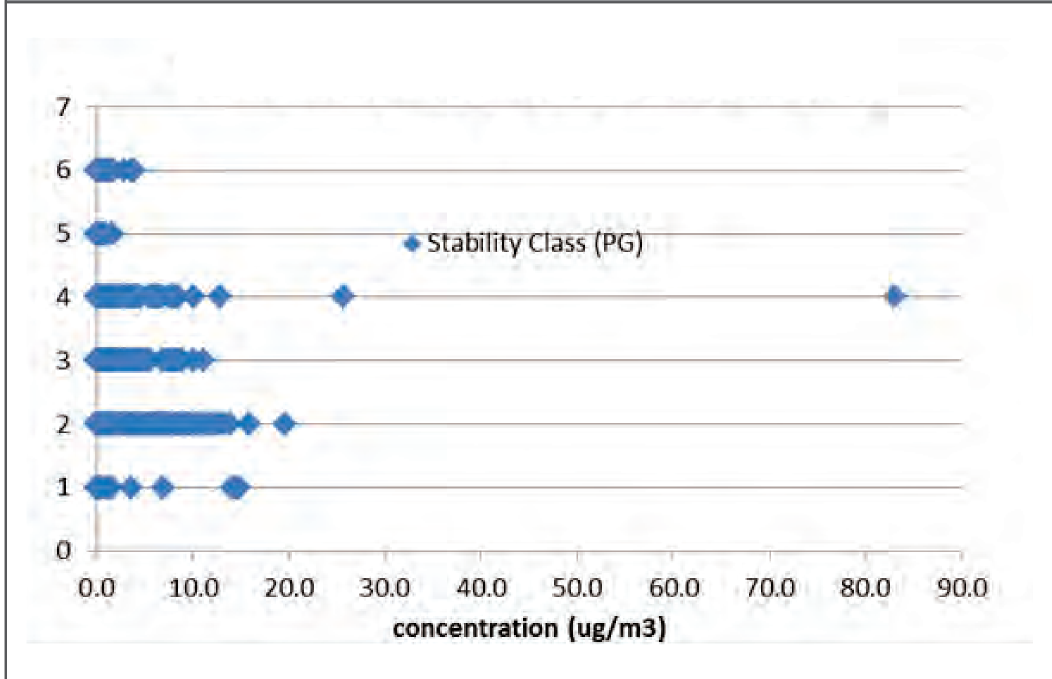
Through the air quality modelling and analysis conducted for the project, two rare and infrequent meteorological conditions have been identified as the cause of a very small number of incidents of elevated ground level concentrations. The analysis presented in this section demonstrates that the conditions 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.



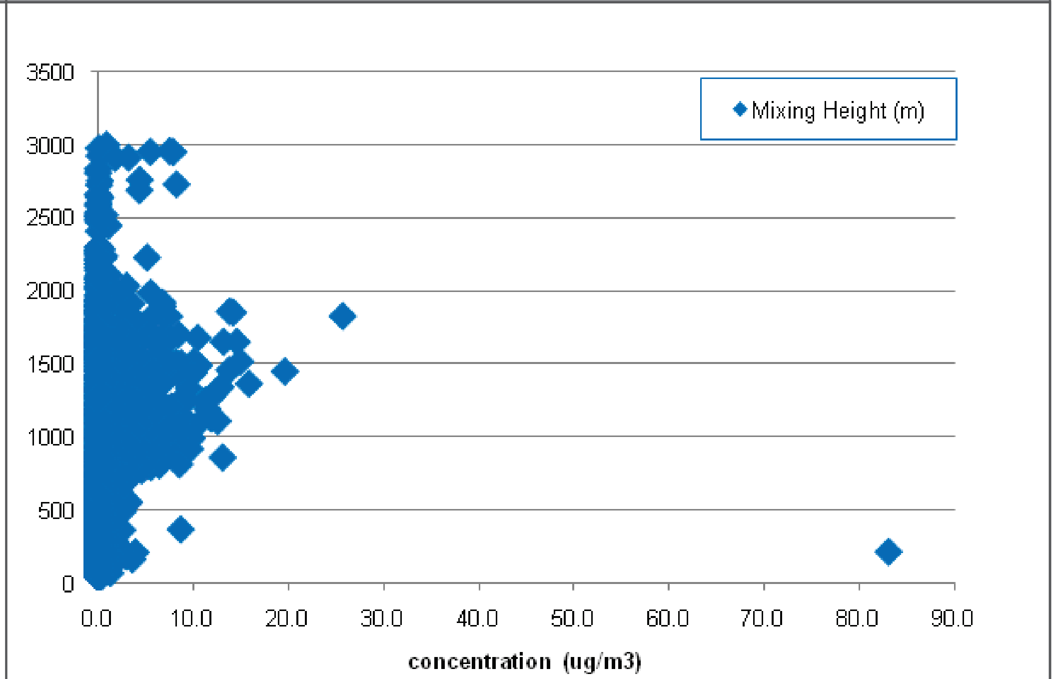
Concentration vs wind speed. The maximum outlier peak hourly concentrations of JDay 337 and JDay 45 are shown.



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

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

Worksite or area	Typical activities with potential to generate air emissions
	main alignment tunnels, • Removal, storage and transport of around 1,024,350 m^3 of spoil from construction activities from the northern interchange compound. • General civil works. • Paving. • Exhaust emissions from the operation of construction vehicles and plant. • Decommissioning and removal of construction-related buildings and plant. • Construction of permanent operational ancillary facilities at the Bareena Avenue compound. • Surface site rehabilitation and restoration.

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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 (PM_{10} 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 PM_{10} of all road vehicles on a volume-of-fuel-used basis; buses emit the greatest level of nitrogen oxides (NO_X); petrol-fueld 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 PM_{10} and $PM_{2.5}$ are very similar.

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

All plant and equipment used during construction would comply with the emissions concentration limits outlined in the *Protection of the Environment Operations (Clean Air) Regulation 2010*. As such, vehicular and plant emissions arising from the civil construction works are 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, PM_{10} and $PM_{2.5}$. The highest levels of particulates were generated from vehicle movements on unpaved roads and wind erosion of material stockpiles; these activities are similar to those associated with the proposed excavation works. As such, these activities would be expected to be primary potential emission sources for the proposed construction works.

The NPI specifies control efficiencies for various management and mitigation measures. As shown in **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 though the air quality environmental management plan to mitigate any odour emissions from the groundwater treatment plants or stockpiles, should they arise.
Disturbed areas would be stabilised as soon as practicable to prevent or minimise windblown dust.
Cutting of materials such as concrete slabs or bricks would be undertaken in a manner that minimises the generation of dust where possible, such as wetting of the cutting face.
Controls, such as rumble grids or wheel wash facilities, would be implemented to minimise the tracking of dirt onto public roads.
Hardstand areas and surrounding public roads would be cleaned, as required.
Speed limits would be posted and observed by all construction vehicles on the construction site.
All loaded haulage trucks would be covered at all times on public roads and on site where there is a risk of release of dust or other materials.
Haul trucks and plant equipment would be switched off when not in operation for periods of greater than 15 minutes.
Construction plant, vehicles and machinery would be maintained in good working order and in accordance with manufacturers' specifications.
Monitoring
A formal dust observation program would be implemented during construction, involving daily reviews of weather forecasts, observations of meteorological conditions and on site dust generation. This would inform mitigation measures or alterations to construction activities to be implemented during unfavourable weather conditions (such as dry weather and strong winds).

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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 denitrifcation 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 NO_2 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 denitrifcation 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 (NO_2), PM_{10} 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 PM_{10}, $PM_{2.5}$ and NO_2 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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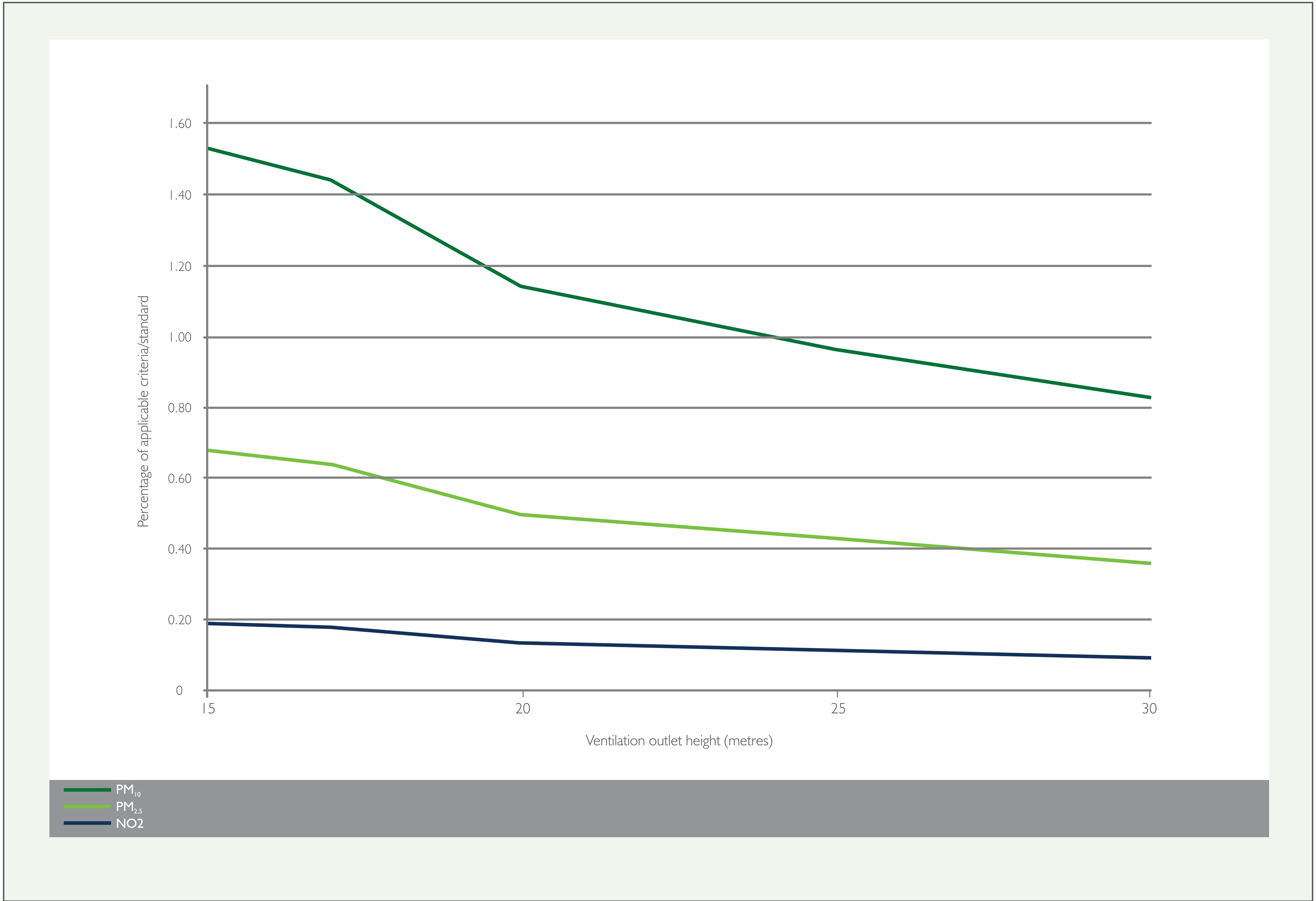

Figure 3-1 Effect of northern ventilation height on annual average concentrations

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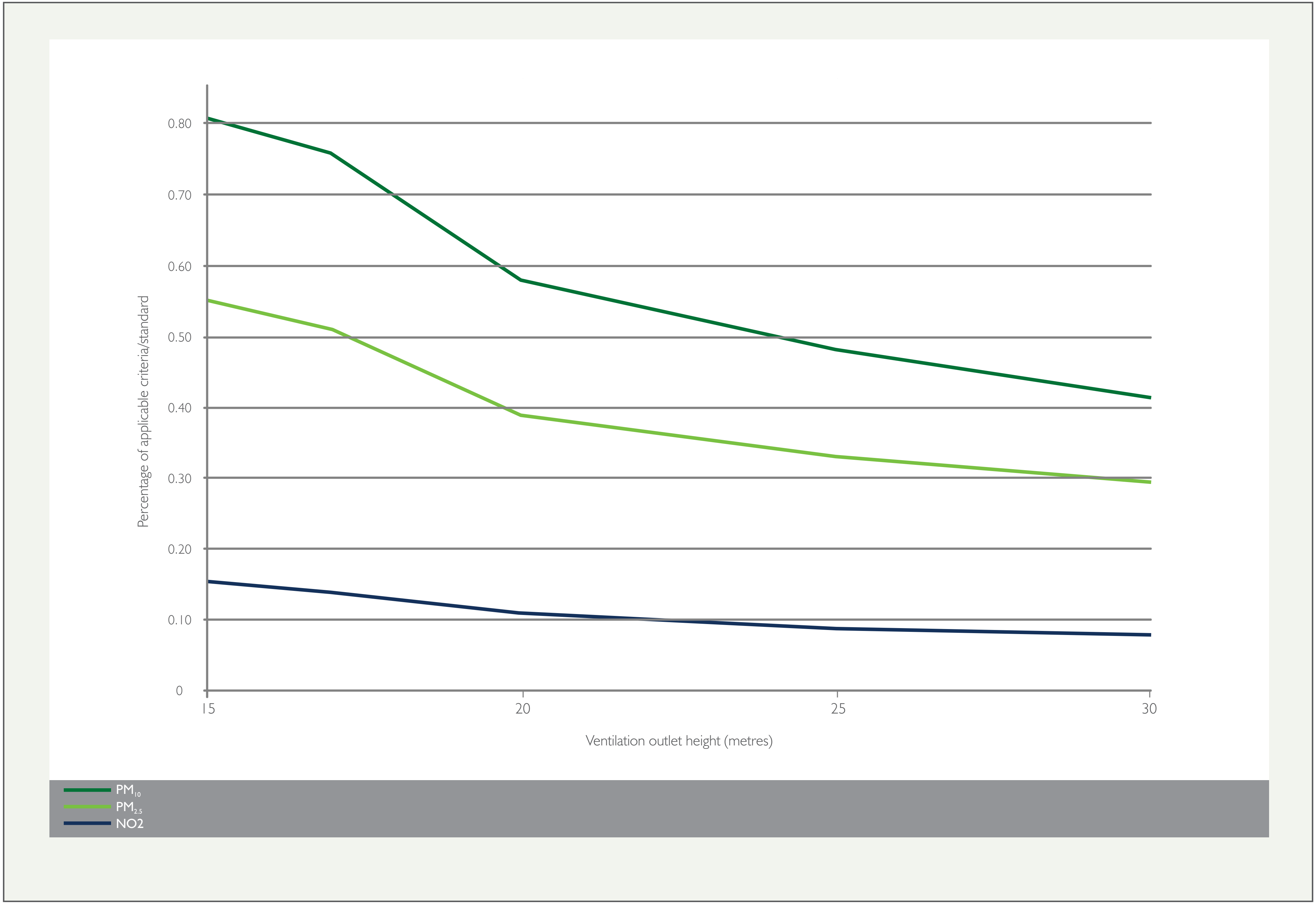

Figure 3-2 Effect of southern ventilation height on annual average concentrations

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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.