The total number of cases attributable to exposure to particulate matter (where a linear dose-response is assumed) can be calculated as:

$$E=AF \times B \times P \quad \text{… Equation 4}$$

Where:
B = baseline incidence of a given health effect (eg mortality rate per person per year)
P = relevant exposed population

The above approach (while presented slightly differently) is consistent with that presented in Australia (Burgers & Walsh 2002), US (OEHHA 2002; USEPA 2005, 2010) and Europe (Martuzzi et al. 2002; Sjoberg et al. 2009). Where a linear dose-response is assumed (as is the case in this assessment), the calculations are equivalent to the following:

The calculation of an increased incidence (ie number of cases) of a particular health endpoint is not relevant to a specific individual, rather this is relevant to a statistically relevant population. This calculation has been undertaken for populations within the suburbs surrounding the proposed project. When considering the potential impact of the project on the population, the calculation has been undertaken using the following:

- Equation 1 has been used to calculate a relative risk. The relative risk has been calculated for a population weighted annual average incremental increase in $PM_{2.5}$ concentrations. The population weighted average has been calculated on the basis of the smallest statistical division provided by the Australian Bureau of Statistics within a suburb (i.e. mesh blocks – which are small blocks that cover an area of approximately 30 urban residences). For each mesh block in a suburb the average incremental increase in $PM_{2.5}$ concentration has been calculated and multiplied by the population living in the mesh block (data available from the ABS for the 2011 census year). The weighted average has been calculated by summing these calculations for each mesh block in a suburb and dividing by the total population in the suburb (i.e. in all the mesh block).
- Equation 3 has been used to calculate an attributable fraction.
- Equation 4 has been used to calculate the increased number of cases associated with the incremental $PM_{2.5}$ impact evaluated. The calculation is undertaken utilising the baseline incidence data relevant for the endpoint considered and the population (for the relevant age groups) present in the suburb.

The above approach can be simplified (mathematically, where the incremental change in particulate concentration is low, less than 1 µg/m^3) as follows:

$$E=\beta \times B \times \sum_{mesh} (\Delta X_{mesh} \times P_{mesh}) \quad \text{… Equation 5}$$

Where:
β = slope coefficient relevant to the per cent change in response to a 1 µg/m^3 change in particulate matter exposure (as per **Table 5-1**)
B = baseline incidence of a given health effect per person (eg annual mortality rate)
ΔX_{mesh} = change (increment) in PM_{10} or $PM_{2.5}$ exposure concentration in µg/m^3 as an average within a small area defined as a mesh block (from the ABS – where many mesh blocks make up a suburb)
P_{mesh} = population (residential – based on data form the ABS) within each small mesh block

An additional risk can then be calculated as:

$$Risk=\beta \times \Delta X \times B \quad \text{… Equation 6}$$

Where:
β = slope coefficient relevant to the per cent change in response to a 1 µg/m^3 change in particulate matter exposure (as per **Table 5-1**)
ΔX = change (increment) in PM_{10} or $PM_{2.5}$ exposure concentration in µg/m^3 relevant to the project at the point of exposure
B = baseline incidence of a given health effect per person (eg annual mortality rate)

This calculation provides an annual risk for individuals exposed to increased PM emissions from the project at specific locations (such as the maximum, or at specific sensitive receiver locations).

For the assessment of potential lung cancer risks associated with exposure to diesel particulate matter, a non-threshold cancer risk is calculated. Non-threshold carcinogenic risks are estimated as the incremental probability of an individual developing cancer over a lifetime as a result of exposure to a potential non-threshold carcinogen. The numerical estimate of excess lifetime cancer risk is calculated as follows for inhalation exposures (USEPA 2009a):

Carcinogenic Risk (inhalation) = Exposure Concentration in Air x Inhalation Unit Risk

5.3.2 Quantification of short-and long-term effects

The concentration-response functions adopted for the assessment of exposure are derived from long and short-term studies and relate to short or long-term effects endpoints (eg change in incidence from daily changes in particulate matter, or chronic incidence from long-term exposures to particulate matter).

Long-term or chronic effects are assessed on the basis of the identified exposure-response function and annual average particulate matter concentrations. These then allow the calculation of a chronic incidence of the assessed health endpoint.

Short-term effects are also assessed on the basis of an exposure-response function that is expressed as a percentage change in endpoint per µg/m^3 change in particulate matter exposure. For short-term effects, the calculations relate to daily increases in particulate matter exposures and changes in daily effects endpoints. While it may be possible to measure daily incidence of the

evaluated health endpoints in a large population study specifically designed to include such data, it is not common to collect such data in hospitals nor are effects measurable in smaller communities. Instead these calculations relate to a parameter that is measurable, such as annual incidence of hospitalisations, mortality or lung cancer risks. The calculation of an annual incidence or additional risk can be undertaken using two approaches (Ostro 2004; USEPA 2010):

1. Calculate the daily incidence or risk at each receiver location over every 24-hour period of the year (based on the modelled incremental 24-hour average concentration for each day of the year and daily baseline incidence data) and then sum the daily incidence/risk to get the annual risk; or
2. Calculate the annual incidence/risk based on the incremental annual average concentration at each receiver (and using annual baseline incidence data).

In the absence of a threshold, and assuming a linear concentration-response function (as is the case in this assessment), these two approaches result in the same outcome mathematically (calculated incidence or risk). Given that it is much simpler computationally to calculate the incidence (for each receiver) based on the incremental annual average, compared with calculating effects on each day of the year and then summing, this is the preferred calculation method. It is the recommended method outlined by the WHO (Ostro 2004).

The use of the simpler approach, based on annual average particulate matter concentrations should not be taken as implying or suggesting that the calculation is quantifying the effects of long-term exposure.

Hence for the calculations presented in this technical working paper, for both long-term and short-term effects, annual average concentrations of particulate matter have been utilised.

5.3.3 Population exposed

The population exposed to emissions derived from the operation of the project are located in areas close to the southern and northern interchanges (as discussed further in **Section 3**).

The AQIA has identified the maximum predicted level in proximity to the ventilation facilities as well as the potential impacts within the local suburbs surrounding the project. In addition data is available from the AQIA on potential impacts at a number of sensitive receivers identified within the local community as listed in **Table 3-1** and **Table 3-2**.

The calculations presented for an increased annual risk is not dependent on the population exposed. However the calculations undertaken for the increased incidence (or number of cases) in the population exposed. This calculation is undertaken on a population level as outlined in **Section 5.3.1**.

5.3.4 Baseline incidence

The baseline incidence of the key health endpoints considered in this assessment has been derived from health statistics relevant to the area evaluated. As discussed in **Section 3.4.3** the baseline incidence of the key health endpoints addressed in this assessment are based on data for NSW. This data is considered to overestimate the incidence of these health endpoints in the smaller populations of interest in this project (refer to discussion in **Section 3.4.3**), however, in the absence of relevant and reliable data for the populations of interest the NSW data is considered to be appropriate.

5.3.5 Calculated health impacts – Southern and northern ventilation facilities alone

Incremental risk calculations

On the basis of the approach outlined above, and for the key health endpoints considered in relation to exposure to $PM_{2.5}$ and PM_{10} (derived from the project), incremental risks have been calculated for scenarios 2a (2019) and 2b (2029) based on data from the AQIA. The calculations have been undertaken for the maximum predicted concentrations as well as concentrations predicted at each of the sensitive receivers.

Table 5-2 and **Table 5-3** present a summary of the predicted increased annual risks relevant to the primary health indicators addressed in this assessment, for scenarios 2a (2019) and 2b (2029).

The calculations are not presented in these tables for all the individual sensitive receivers (but are presented in **Appendix B**) as the health endpoints are not considered to be relevant for the receiver evaluated, eg hospitalisations for people aged 65 years and over is not a relevant health endpoint for evaluating impacts at a childcare centre or school.

Table 5-4 to **Table 5-5** present a summary of the predicted increased annual risks relevant to the secondary health indicators, for scenarios 2a (2019) and 2b (2029). Detailed calculations of these health impacts are presented in **Appendix B**.

The calculations presented in these tables are considered accurate to one significant figure only due to the level of uncertainty within all aspects of the assessment presented.

Increased incidence of health effects

Based on analysis of the potential health impacts on the population adjacent to the northern and southern ends of the project based on the ventilation facilities alone, the calculated increased population incidence, or number of cases, for the primary health endpoints associated with PM2.5 exposure are summarised in **Table 5-6**. These calculated values are considered accurate to one significant figure only due to the level of uncertainty within all aspects of the assessment presented.

Calculations are presented in **Appendix C**, including calculations for the secondary endpoints (where the calculated increased incidence is similar to and lower than presented for the primary health endpoints).

Diesel particulate matter

The calculated incremental lifetime risk of cancer associated with potential exposure to diesel particulate matter (assuming 100 per cent of the $PM_{2.5}$ derived from the tunnel is diesel particulate matter), at the maximum impacted location is calculated to be $5x10^{-6}$ (scenario 2a, 2019)) and $3x10^{-6}$ (scenario 2b, 2029) for the southern interchange and $4x10^{-6}$ (scenario 2a, 2019) and $4x10^{-6}$ (scenario 2b, 2029) for the northern interchange.

5.3.6 Assessment of all project impacts

The calculations presented in **Sections 5.3.1** to **5.3.5** are associated with impacts of predicted emissions of particulate matter on the local community from the operation of the ventilation facilities at the southern and northern interchanges alone. The calculations presented do not take into account changes (primarily) reductions in emissions (and concentrations of particulate matter) that would occur along the existing road corridor of Pennant Hills Road (and associated feeder roads) as a result of the project. Impacts associated with the project would not only involve an increase in concentrations of $PM_{2.5}$ and PM_{10} in areas adjacent to the northern and southern interchanges, but also decreases in concentrations along Pennant Hills Road from the Hills M2 Motorway to the M1 Pacific Motorway (due to the reduction in traffic using this section of road).

To evaluate all the impacts from the proposed project (increases and decreases) the air modelling conducted for the various project scenarios have been combined as follows:

- Step 1: Modelling conducted to evaluate emissions from the southern and northern ventilation stacks (scenarios 2a and 2b) has been combined with modelling of emissions for the predicted reduced number of vehicles proposed Pennant Hills Road for the years 2019 and 2029.
- Step 2: Scenario 1 has modelled emissions and impacts along Pennant Hills Road (and feeder roads) if the project does not go ahead for the years 2019 and 2029.
- Step 3: Impacts form the overall project have been calculated by overlaying (subtracting or adding) impacts form the project (Step 1) with the impacts that would have occurred if the project did not go ahead (Step 2).

The incremental change in annual average $PM_{2.5}$ concentrations in the community adjacent to the whole project has been calculated on the basis of the above approach. **Figure 5-1 and Figure 5-2** present plots of the predicted change in annual average concentration in the project area for the years 2019 and 2029. The plots (and associated calculations) show that concentrations of $PM_{2.5}$ within the community adjacent to Pennant Hills Road are predicted to be lower with the completion of the tunnel. This is because the project is expected to improve traffic flows along Pennant Hills Road, which would be expected to improve air quality along that road corridor. There are some areas at the northern and southern ends of the proposed tunnel where an increase is predicted. It is noted that the increased impacts predicted are lower than the reduction in impacts along the corridor of Pennant Hills Road.

To provide some measure of the overall health impact of the whole project on the population (adjacent to the southern and northern interchanges and along Pennant Hills Road) the change in risk (increase or decrease) for the primary health endpoints have been calculated based on the population weighted average change in $PM_{2.5}$ concentration (annual average) for each suburb (or

part of a suburb relevant to the road corridor) and the total population. In addition the total population incidence has been calculated for all the suburbs combined. The calculated risks and population incidence calculated for 2019 and 2029 (for Scenario 2) are presented in **Table 5-7**. Values presented as a negative (-) are associated with a decreased risk (and decrease in incidence, cases per year over the whole population) while values presented as positive are associated with an increase in risk. Calculations for these health endpoints as well as the relevant secondary health endpoints are included in **Appendix D**.

Where the whole project is considered in relation to health impacts associated with $PM_{2.5}$, the following can be concluded from the calculations undertaken:

- There are some small increases in population risk for some suburbs located around the southern interchange and southern end of Pennant Hills Road. The increased risks calculated are all less than or equal to $1.5x10^{-6}$, which are considered to be negligible.
- For most of the suburbs located adjacent to Pennant Hills Road, and adjacent to the northern interchange the overall population risk decreases. The decreased levels of risk in these areas range from $1.7x10^{-7}$ to $4.2x10^{-5}$. The decreased risks are more significant than the increases noted above.
- The change in incidence of the primary health endpoints on the whole population, located adjacent to the southern and northern interchanges as well as along Pennant Hills Road is a decrease. The change in incidence is less than 1 so it is considered to be small (and not likely to be measurable within the populations). However the change does indicate the potential for a decrease in the incidence of $PM_{2.5}$ related health effects within the population located along the corridor.

Table 5-2 Summary of calculated incremental risks for primary health indicators: Exposure to $PM_{2.5}$ – Southern ventilation facility only

Scenario:	Scenario 2a (2019)			Scenario 2b (2029)		
Particulate fraction:	**PM2.5**	**PM2.5**	**PM2.5**	**PM2.5**	**PM2.5**	**PM2.5**
Health endpoint:	**Mortality – All Causes,** Long-term, ≥ 30 years	**Hospitalisations – Cardiovascular,** Short-term, ≥ 65 years	**Hospitalisations – Respiratory,** Short-term, ≥ 65 years	**Mortality – All Causes,** Long-term, ≥ 30 years	**Hospitalisations – Cardiovascular,** Short-term, ≥ 65 years	**Hospitalisations – Respiratory,** Short-term, ≥ 65 years
Baseline incidence:	1087 per 100,000	23352 per 100,000	8807 per 100,000	1087 per 100,000	23352 per 100,000	8807 per 100,000
Location	**Risk**	**Risk**	**Risk**	**Risk**	**Risk**	**Risk**
Southern Interchange only						
Maximum	$7X10^{-6}$	$2X10^{-5}$	$4X10^{-6}$	$8X10^{-6}$	$2X10^{-5}$	$5X10^{-6}$
Maximum for sensitive receivers in surrounding suburbs, and suburb average (residential)						
Carlingford						
Childcare	$9X10^{-7}$			$1X10^{-6}$		
Schools	$1X10^{-6}$			$1X10^{-6}$		
Community	$2X10^{-6}$	$5X10^{-6}$	$1X10^{-6}$	$2X10^{-6}$	$7X10^{-6}$	$1X10^{-6}$
Residential*	$2X10^{-6}$	$5X10^{-6}$	$1X10^{-6}$	$2X10^{-6}$	$6X10^{-6}$	$1X10^{-6}$
West Pennant Hills						
Childcare	$6X10^{-7}$			$7X10^{-7}$		
Aged Care	$5X10^{-7}$	$2X10^{-6}$	$3X10^{-7}$	$6X10^{-7}$	$2X10^{-6}$	$3X10^{-7}$
School	$2X10^{-6}$			$2X10^{-6}$		
Community	$2X10^{-6}$	$5X10^{-6}$	$9X10^{-7}$	$2X10^{-6}$	$5X10^{-6}$	$1X10^{-6}$
Residential*	$1X10^{-6}$	$3X10^{-6}$	$6X10^{-7}$	$1X10^{-6}$	$4X10^{-6}$	$7X10^{-7}$
Beecroft						
Childcare	$2X10^{-6}$			$2X10^{-6}$		
Aged Care	$2X10^{-6}$	$5X10^{-6}$	$1X10^{-6}$	$2X10^{-6}$	$6X10^{-6}$	$1X10^{-6}$
School	$1X10^{-6}$			$1X10^{-6}$		
Community	$2X10^{-6}$	$5X10^{-6}$	$1X10^{-6}$	$2X10^{-6}$	$7X10^{-6}$	$1X10^{-6}$
Residential*	$1X10^{-6}$	$4X10^{-6}$	$7X10^{-7}$	$2X10^{-6}$	$5X10^{-6}$	$9X10^{-7}$
North Rocks						
School	$3X10^{-7}$			$4X10^{-7}$		
Residential*	$3X10^{-7}$	$9X10^{-7}$	$2X10^{-7}$	$4X10^{-7}$	$1X10^{-6}$	$2X10^{-7}$
Epping						
School and Residential*	$2X10^{-7}$	$7X10^{-7}$	$1X10^{-7}$	$3X10^{-7}$	$8X10^{-7}$	$2X10^{-7}$

*Residential calculations are based on the average exposures in each suburb

Table 5-3 Summary of calculated incremental risks for primary health indicators: Exposure to $PM_{2.5}$ – Northern ventilation facility only

Scenario:	Scenario 2a (2019)			Scenario 2b (2029)		
Particulate fraction:	**PM2.5**	**PM2.5**	**PM2.5**	**PM2.5**	**PM2.5**	**PM2.5**
Health endpoint:	**Mortality – All Causes,** Long-term, ≥ 30 years	**Hospitalisations – Cardiovascular,** Short-term, ≥ 65 years	**Hospitalisations – Respiratory,** Short-term, ≥ 65 years	**Mortality – All Causes,** Long-term, ≥ 30 years	**Hospitalisations – Cardiovascular,** Short-term, ≥ 65 years	**Hospitalisations – Respiratory,** Short-term, ≥ 65 years
Baseline incidence:	1087 per 100,000	23352 per 100,000	8807 per 100,000	1087 per 100,000	23352 per 100,000	8807 per 100,000
Location	**Risk**	**Risk**	**Risk**	**Risk**	**Risk**	**Risk**
Northern Interchange only						
Maximum	$5X10^{-6}$	$2X10^{-5}$	$3X10^{-6}$	$7X10^{-6}$	$2X10^{-5}$	$4X10^{-6}$
Maximum for sensitive receivers in surrounding suburbs, and suburb average (residential)						
Wahroonga**						
Childcare	$3X10^{-6}$			$3X10^{-6}$		
Aged Care	$3X10^{-6}$	$1X10^{-5}$	$2X10^{-6}$	$4X10^{-6}$	$1X10^{-5}$	$2X10^{-6}$
School	$3X10^{-6}$			$4X10^{-6}$		
Hospital	$2X10^{-6}$	$5X10^{-6}$	$1X10^{-6}$	$2X10^{-6}$	$6X10^{-6}$	$1X10^{-6}$
Residential*	$2X10^{-6}$	$6X10^{-6}$	$1X10^{-6}$	$2X10^{-6}$	$7X10^{-6}$	$1X10^{-6}$
North Wahroonga						
Residential*	$2X10^{-6}$	$5X10^{-6}$	$1X10^{-6}$	$2X10^{-6}$	$6X10^{-6}$	$1X10^{-6}$
Waitara						
Childcare	$3X10^{-6}$			$3X10^{-6}$		
Aged Care	$2X10^{-6}$	$5X10^{-6}$	$9X10^{-7}$	$2X10^{-6}$	$5X10^{-6}$	$1X10^{-6}$
School	$3X10^{-6}$			$4X10^{-6}$		
Residential*	$2X10^{-6}$	$6X10^{-6}$	$1X10^{-6}$	$2X10^{-6}$	$7X10^{-6}$	$1X10^{-6}$
Hornsby						
Childcare	$2X10^{-6}$			$2X10^{-6}$		
Aged Care	$3X10^{-6}$	$7X10^{-6}$	$1X10^{-6}$	$3X10^{-6}$	$9X10^{-6}$	$2X10^{-6}$
School	$1X10^{-6}$			$1X10^{-6}$		
Hospital	$2X10^{-6}$	$6X10^{-6}$	$1X10^{-6}$	$2X10^{-6}$	$7X10^{-6}$	$1X10^{-6}$
Residential*	$2X10^{-6}$	$4X10^{-6}$	$9X10^{-7}$	$2X10^{-6}$	$5X10^{-6}$	$1X10^{-6}$
Normanhurst						
Childcare	$1X10^{-6}$			$1X10^{-6}$		
Aged Care	$1X10^{-6}$	$4X10^{-6}$	$7X10^{-7}$	$1X10^{-6}$	$4X10^{-6}$	$8X10^{-7}$
School	$1X10^{-6}$			$1X10^{-6}$		
Residential*	$1X10^{-6}$	$3X10^{-6}$	$6X10^{-7}$	$1X10^{-6}$	$4X10^{-6}$	$7X10^{-7}$

*Residential calculations are based on the average exposures in each suburb, ** The one receiver (school) located within the adjacent suburb Warrawee has been included in the calculations for Wahroonga

Table 5-4 Summary of calculated incremental risks for secondary health indicators: Exposure to $PM_{2.5}$ and PM_{10} – Southern ventilation facility only

Scenario:	Scenario 2a (2019)					Scenario 2b (2029)				
Particulate fraction:	**PM10**	**PM2.5**	**PM2.5**	**PM2.5**	**PM2.5**	**PM10**	**PM2.5**	**PM2.5**	**PM2.5**	**PM2.5**
Health endpoint:	**Mortality - All Causes,** Short-Term, All ages	**Mortality - All Causes,** Short-Term, All ages	**Mortality – Cardiopulmonary** Long-term, ≥ 30 years	**Mortality – Cardiovascular** Short-Term, All ages	**Mortality – Respiratory,** Short-Term, All ages	**Mortality - All Causes,** Short-Term, All ages	**Mortality - All Causes,** Short-Term, All ages	**Mortality – Cardiopulmonary** Long-term, ≥ 30 years	**Mortality – Cardiovascular** Short-Term, All ages	**Mortality – Respiratory,** Short-Term, All ages
Baseline incidence:	670 per 100,000	670 per 100,000	490 per 100,000	164 per 100,000	57 per 100,000	670 per 100,000	670 per 100,000	490 per 100,000	164 per 100,000	57 per 100,000
Location	**Risk**	**Risk**	**Risk**	**Risk**	**Risk**	**Risk**	**Risk**	**Risk**	**Risk**	**Risk**
Southern Interchange only										
Maximum	$5X10^{-7}$	$7X10^{-7}$	$7X10^{-6}$	$2X10^{-7}$	$1X10^{-7}$	$5X10^{-7}$	$8X10^{-7}$	$8X10^{-6}$	$2X10^{-7}$	$1X10^{-7}$
Maximum for sensitive receivers in surrounding suburbs, and suburb average (residential)										
Carlingford										
Childcare	$6X10^{-8}$	$9X10^{-8}$	$9X10^{-7}$	$2X10^{-8}$	$2X10^{-8}$	$7X10^{-8}$	$1X10^{-7}$	$1X10^{-6}$	$3X10^{-8}$	$2X10^{-8}$
Schools	$8X10^{-8}$	$1X10^{-7}$	$1X10^{-6}$	$3X10^{-8}$	$2X10^{-8}$	$9X10^{-8}$	$1X10^{-7}$	$1X10^{-6}$	$4X10^{-8}$	$2X10^{-8}$
Community	$1X10^{-7}$	$2X10^{-7}$	$2X10^{-6}$	$4X10^{-8}$	$3X10^{-8}$	$2X10^{-7}$	$2X10^{-7}$	$2X10^{-6}$	$6X10^{-8}$	$4X10^{-8}$
Residential*	$1X10^{-7}$	$2X10^{-7}$	$2X10^{-6}$	$4X10^{-8}$	$3X10^{-8}$	$1X10^{-7}$	$2X10^{-7}$	$2X10^{-6}$	$5X10^{-8}$	$4X10^{-8}$
West Pennant Hills										
Childcare	$4X10^{-8}$	$6X10^{-8}$	$6X10^{-7}$	$2X10^{-8}$	$1X10^{-8}$	$5X10^{-8}$	$7X10^{-8}$	$7X10^{-7}$	$2X10^{-8}$	$1X10^{-8}$
Aged Care	$4X10^{-8}$	$5X10^{-8}$	$5X10^{-7}$	$1X10^{-8}$	$9X10^{-9}$	$4X10^{-8}$	$6X10^{-8}$	$6X10^{-7}$	$2X10^{-8}$	$1X10^{-8}$
School	$1X10^{-7}$	$2X10^{-7}$	$2X10^{-6}$	$4X10^{-8}$	$3X10^{-8}$	$1X10^{-7}$	$2X10^{-7}$	$2X10^{-6}$	$4X10^{-8}$	$3X10^{-8}$
Community	$1X10^{-7}$	$2X10^{-7}$	$2X10^{-6}$	$4X10^{-8}$	$3X10^{-8}$	$1X10^{-7}$	$2X10^{-7}$	$2X10^{-6}$	$5X10^{-8}$	$3X10^{-8}$
Residential*	$7X10^{-8}$	$1X10^{-7}$	$1X10^{-6}$	$3X10^{-8}$	$2X10^{-8}$	$8X10^{-8}$	$1X10^{-7}$	$1X10^{-6}$	$3X10^{-8}$	$2X10^{-8}$
Beecroft										
Childcare	$1X10^{-7}$	$2X10^{-7}$	$2X10^{-6}$	$4X10^{-8}$	$3X10^{-8}$	$1X10^{-7}$	$2X10^{-7}$	$2X10^{-6}$	$5X10^{-8}$	$4X10^{-8}$
Aged Care	$1X10^{-7}$	$2X10^{-7}$	$2X10^{-6}$	$4X10^{-8}$	$3X10^{-8}$	$1X10^{-7}$	$2X10^{-7}$	$2X10^{-6}$	$5X10^{-8}$	$4X10^{-8}$
School	$7X10^{-8}$	$1X10^{-7}$	$1X10^{-6}$	$3X10^{-8}$	$2X10^{-8}$	$8X10^{-8}$	$1X10^{-7}$	$1X10^{-6}$	$3X10^{-8}$	$2X10^{-8}$
Community	$1X10^{-7}$	$2X10^{-7}$	$2X10^{-6}$	$4X10^{-8}$	$3X10^{-8}$	$2X10^{-7}$	$2X10^{-7}$	$2X10^{-6}$	$6X10^{-8}$	$4X10^{-8}$
Residential*	$9X10^{-8}$	$1X10^{-7}$	$1X10^{-6}$	$3X10^{-8}$	$2X10^{-8}$	$1X10^{-7}$	$2X10^{-7}$	$2X10^{-6}$	$4X10^{-8}$	$3X10^{-8}$
North Rocks										
School	$2X10^{-8}$	$3X10^{-8}$	$3X10^{-7}$	$9X10^{-9}$	$6X10^{-9}$	$3X10^{-8}$	$4X10^{-8}$	$4X10^{-7}$	$1X10^{-8}$	$7X10^{-9}$
Residential*	$2X10^{-8}$	$3X10^{-8}$	$3X10^{-7}$	$7X10^{-9}$	$5X10^{-9}$	$2X10^{-8}$	$4X10^{-8}$	$4X10^{-7}$	$9X10^{-9}$	$6X10^{-9}$
Epping										
School and Residential*	$2X10^{-8}$	$2X10^{-8}$	$2X10^{-7}$	$6X10^{-9}$	$4X10^{-9}$	$2X10^{-8}$	$3X10^{-8}$	$3X10^{-7}$	$7X10^{-9}$	$5X10^{-9}$

*Residential calculations are based on the average exposures in each suburb

Table 5-5 Summary of calculated incremental risks for secondary health indicators: Exposure to $PM_{2.5}$ and PM_{10} – Northern ventilation facility only

Scenario:	Scenario 2a (2019)					Scenario 2b (2029)				
Particulate fraction:	**PM10**	**PM2.5**	**PM2.5**	**PM2.5**	**PM2.5**	**PM10**	**PM2.5**	**PM2.5**	**PM2.5**	**PM2.5**
Health endpoint:	**Mortality - All Causes,** Short-Term, All ages	**Mortality - All Causes,** Short-Term, All ages	**Mortality – Cardiopulmonary** Long-term, ≥ 30 years	**Mortality – Cardiovascular** Short-Term, All ages	**Mortality – Respiratory,** Short-Term, All ages	**Mortality - All Causes,** Short-Term, All ages	**Mortality - All Causes,** Short-Term, All ages	**Mortality – Cardiopulmonary** Long-term, ≥ 30 years	**Mortality – Cardiovascular** Short-Term, All ages	**Mortality – Respiratory,** Short-Term, All ages
Baseline incidence:	670 per 100,000	670 per 100,000	490 per 100,000	164 per 100,000	57 per 100,000	670 per 100,000	670 per 100,000	490 per 100,000	164 per 100,000	57 per 100,000
Location	**Risk**	**Risk**	**Risk**	**Risk**	**Risk**	**Risk**	**Risk**	**Risk**	**Risk**	**Risk**
Northern Interchange only										
Maximum	$3X10^{-7}$	$5X10^{-7}$	$5X10^{-6}$	$1X10^{-7}$	$9X10^{-8}$	$4X10^{-7}$	$7X10^{-7}$	$7X10^{-6}$	$2X10^{-7}$	$1X10^{-7}$
Maximum for sensitive receivers in surrounding suburbs, and suburb average (residential)										
Wahroonga**										
Childcare	$2X10^{-7}$	$3X10^{-7}$	$3X10^{-6}$	$7X10^{-8}$	$5X10^{-8}$	$2X10^{-7}$	$3X10^{-7}$	$3X10^{-6}$	$9X10^{-8}$	$6X10^{-8}$
Aged Care	$2X10^{-7}$	$3X10^{-7}$	$3X10^{-6}$	$8X10^{-8}$	$6X10^{-8}$	$3X10^{-7}$	$4X10^{-7}$	$4X10^{-6}$	$1X10^{-7}$	$7X10^{-8}$
School	$2X10^{-7}$	$3X10^{-7}$	$3X10^{-6}$	$8X10^{-8}$	$6X10^{-8}$	$3X10^{-7}$	$4X10^{-7}$	$4X10^{-6}$	$1X10^{-7}$	$7X10^{-8}$
Hospital	$1X10^{-7}$	$2X10^{-7}$	$2X10^{-6}$	$4X10^{-8}$	$3X10^{-8}$	$1X10^{-7}$	$2X10^{-7}$	$2X10^{-6}$	$5X10^{-8}$	$3X10^{-8}$
Residential*	$1X10^{-7}$	$2X10^{-7}$	$2X10^{-6}$	$5X10^{-8}$	$3X10^{-8}$	$2X10^{-7}$	$2X10^{-7}$	$2X10^{-6}$	$6X10^{-8}$	$4X10^{-8}$
North Wahroonga										
Residential*	$1X10^{-7}$	$2X10^{-7}$	$2X10^{-6}$	$5X10^{-8}$	$3X10^{-8}$	$1X10^{-7}$	$2X10^{-7}$	$2X10^{-6}$	$5X10^{-8}$	$4X10^{-8}$
Waitara										
Childcare	$2X10^{-7}$	$3X10^{-7}$	$3X10^{-6}$	$7X10^{-8}$	$5X10^{-8}$	$2X10^{-7}$	$3X10^{-7}$	$3X10^{-6}$	$8X10^{-8}$	$6X10^{-8}$
Aged Care	$1X10^{-7}$	$2X10^{-7}$	$2X10^{-6}$	$4X10^{-8}$	$3X10^{-8}$	$1X10^{-7}$	$2X10^{-7}$	$2X10^{-6}$	$5X10^{-8}$	$3X10^{-8}$
School	$2X10^{-7}$	$3X10^{-7}$	$3X10^{-6}$	$8X10^{-8}$	$6X10^{-8}$	$3X10^{-7}$	$4X10^{-7}$	$4X10^{-6}$	$1X10^{-7}$	$7X10^{-8}$
Residential*	$1X10^{-7}$	$2X10^{-7}$	$2X10^{-6}$	$5X10^{-8}$	$3X10^{-8}$	$2X10^{-7}$	$2X10^{-7}$	$2X10^{-6}$	$6X10^{-8}$	$4X10^{-8}$
Hornsby										
Childcare	$1X10^{-7}$	$2X10^{-7}$	$2X10^{-6}$	$5X10^{-8}$	$3X10^{-8}$	$2X10^{-7}$	$2X10^{-7}$	$2X10^{-6}$	$6X10^{-8}$	$4X10^{-8}$
Aged Care	$2X10^{-7}$	$3X10^{-7}$	$3X10^{-6}$	$6X10^{-8}$	$4X10^{-8}$	$2X10^{-7}$	$3X10^{-7}$	$3X10^{-6}$	$7X10^{-8}$	$5X10^{-8}$
School	$6X10^{-8}$	$1X10^{-7}$	$1X10^{-6}$	$2X10^{-8}$	$2X10^{-8}$	$7X10^{-8}$	$1X10^{-7}$	$1X10^{-6}$	$3X10^{-8}$	$2X10^{-8}$
Hospital	$1X10^{-7}$	$2X10^{-7}$	$2X10^{-6}$	$5X10^{-8}$	$4X10^{-8}$	$2X10^{-7}$	$2X10^{-7}$	$2X10^{-6}$	$6X10^{-8}$	$4X10^{-8}$
Residential*	$1X10^{-7}$	$2X10^{-7}$	$2X10^{-6}$	$4X10^{-8}$	$3X10^{-8}$	$1X10^{-7}$	$2X10^{-7}$	$2X10^{-6}$	$4X10^{-8}$	$3X10^{-8}$
Normanhurst										
Childcare	$6X10^{-8}$	$1X10^{-7}$	$1X10^{-6}$	$2X10^{-8}$	$2X10^{-8}$	$7X10^{-8}$	$1X10^{-7}$	$1X10^{-6}$	$3X10^{-8}$	$2X10^{-8}$
Aged Care	$9X10^{-8}$	$1X10^{-7}$	$1X10^{-6}$	$3X10^{-8}$	$2X10^{-8}$	$1X10^{-7}$	$1X10^{-7}$	$1X10^{-6}$	$4X10^{-8}$	$3X10^{-8}$
School	$8X10^{-8}$	$1X10^{-7}$	$1X10^{-6}$	$3X10^{-8}$	$2X10^{-8}$	$9X10^{-8}$	$1X10^{-7}$	$1X10^{-6}$	$4X10^{-8}$	$2X10^{-8}$
Residential*	$7X10^{-8}$	$1X10^{-7}$	$1X10^{-6}$	$3X10^{-8}$	$2X10^{-8}$	$9X10^{-8}$	$1X10^{-7}$	$1X10^{-6}$	$3X10^{-8}$	$2X10^{-8}$

*Residential calculations are based on the average exposures in each suburb, ** The one receiver (school) located within the adjacent suburb Warrawee has been included in the calculations for Wahroonga

Table 5-6 Summary of calculated increased population incidence (additional cases per year): Exposure to $PM_{2.5}$ – Primary indicators for southern and northern ventilation facilities only*

Health Endpoint:	Mortality - All Causes, Long-term		Hospitalisations – Cardiovascular, Short-term		Hospitalisations - Respiratory, Short-term	
Age Group:	≥ 30 years		≥ 65 years		≥ 65 years	
Baseline Incidence:	1087 per 100,000		23352 per 100,000		8807 per 100,000	
	Scenario 2a - 2019	**Scenario 2b - 2029**	**Scenario 2a - 2019**	**Scenario 2b - 2029**	**Scenario 2a - 2019**	**Scenario 2b - 2029**
Southern interchange only: Suburbs						
Carlingford	0.007	0.008	0.005	0.006	0.001	0.001
West Pennant Hills	0.008	0.009	0.005	0.005	0.001	0.001
Beecroft	0.006	0.007	0.005	0.006	0.001	0.001
North Rocks	0.001	0.001	0.0009	0.001	0.0002	0.0002
Epping	0.004	0.005	0.003	0.003	0.0005	0.0006
Total over all suburbs	**0.03**	**0.03**	**0.02**	**0.02**	**0.004**	**0.004**
Northern Interchange only: Suburbs						
Wahroonga	0.01	0.02	0.01	0.01	0.002	0.003
North Wahroonga	0.001	0.001	0.001	0.001	0.0001	0.0002
Warrawee	0.001	0.001	0.0008	0.0009	0.0001	0.0002
Waitara	0.005	0.006	0.003	0.004	0.0007	0.0008
Hornsby	0.009	0.01	0.005	0.006	0.001	0.001
Normanhurst	0.003	0.003	0.002	0.003	0.0004	0.0005
Total over all suburbs:	**0.03**	**0.04**	**0.02**	**0.03**	**0.005**	**0.005**

* The calculations presented in this table are for incremental impacts from the southern and northern interchanges only. The impact of the whole project needs to be considered in conjunction with changes to emissions and exposures along the Pennant Hills Road corridor, presented in **Table 5-7**.

What do the population incidence numbers mean in Tables 5-6 and 5-7:
When only the northern and southern ventilation facilities are considered an increased annual incidence between 0.0001 and 0.04 has been calculated as presented in **Table 5-6**.
An increased annual incidence of 0.001 in a suburb (eg North Wahroonga or North Rocks) means that the population would need to live in the same homes in this suburb for 1000 years for 1 extra case (of the health indicator assessed) to occur in the population.
An increased annual incidence of 0.04 in a number of suburbs (eg all suburbs assessed adjacent to the northern interchange) means that the entire population would need to live in the same homes in this area for 25 years for 1 extra case (of the health indicator assessed) to occur in the population.

When the whole project is assessed, presented in **Table 5-7**, an overall decrease in annual incidence between 0.03 and 0.3 has been calculated for the whole population.
A decrease in annual incidence of 0.3 (for the whole population considered) means that the whole population would need to live at the same homes in this area for 3 years for 1 less case (of the health indicators assessed) to occur within this population.

Table 5-7 Summary of calculated risk (for each suburb) and total population incidence (cases per year)* – Exposure to $PM_{2.5}$ for whole project (southern and northern ventilation facilities and changes to Pennant Hills Road) – Primary Indicators

Health Endpoint:	**Mortality - All Causes, Long-term**		**Hospitalisations – Cardiovascular, Short-term**		**Hospitalisations - Respiratory, Short-term**	
Age Group:	≥ 30 years		≥ 65 years		≥ 65 years	
Baseline Incidence:	1087 per 100,000		23352 per 100,000		8807 per 100,000	
	2019	**2029**	**2019**	**2029**	**2019**	**2029**
Increased population annual risk/incidence – whole project						
Carlingford - risk	$4.7X10^{-7}$	$4.9X10^{-7}$	$1.4X10^{-6}$	$1.5X10^{-6}$	$2.7X10^{-7}$	$2.8X10^{-7}$
- population incidence	0.005	0.005	0.004	0.004	0.0007	0.0007
North Rocks - risk	$1.7X10^{-7}$	$1.8X10^{-7}$	$5.0X10^{-7}$	$5.4X10^{-7}$	$9.8X10^{-8}$	$1.0X10^{-7}$
- population incidence	0.0006	0.0006	0.0004	0.0005	0.00008	0.00009
Epping/North Epping - risk	$2.3X10^{-7}$	$2.5X10^{-7}$	$6.9X10^{-7}$	$7.4X10^{-7}$	$1.3X10^{-7}$	$1.4X10^{-7}$
- population incidence	0.001	0.001	0.0009	0.001	0.0002	0.0002
Decreased population annual risk/incidence – whole project						
West Pennant Hills - risk	$-2.0X10^{-6}$	$-2.5X10^{-6}$	$-5.9X10^{-6}$	$-7.4X10^{-6}$	$-1.1X10^{-6}$	$-1.4X10^{-6}$
- population incidence	-0.01	-0.02	-0.009	-0.01	-0.002	-0.002
Pennant Hills/Cheltenham - risk	$-1.2X10^{-5}$	$-1.2X10^{-5}$	$-3.7X10^{-5}$	$-3.6X10^{-5}$	$-7.1X10^{-6}$	$-7.0X10^{-6}$
- population incidence	-0.1	-0.1	-0.09	-0.09	-0.02	-0.02
Wahroonga/Warrawee - risk	$-3.0X10^{-7}$	$-1.2X10^{-6}$	$-9.0X10^{-7}$	$-3.6X10^{-6}$	$-1.7X10^{-7}$	$-7.0X10^{-7}$
- population incidence	-0.003	-0.01	-0.003	-0.01	-0.0005	-0.002
Hornsby/Waitara - risk	$-5.1X10^{-7}$	$-7.3X10^{-7}$	$-1.5X10^{-6}$	$-2.2X10^{-6}$	$-2.9X10^{-7}$	$-4.2X10^{-7}$
- population incidence	-0.006	-0.008	-0.003	-0.004	-0.0006	-0.0008
Normanhurst/Thornleigh/Westleigh - risk	$-1.3X10^{-5}$	$-1.4X10^{-5}$	$-4.0X10^{-5}$	$-4.2X10^{-5}$	$-7.7X10^{-6}$	$-8.0X10^{-6}$
- population incidence	-0.09	-0.1	-0.08	-0.09	-0.02	-0.02
Total change (decrease) in annual risk – whole population	**$-3X10^{-5}$**	**$-3X10^{-5}$**	**$-8X10^{-5}$**	**$-9X10^{-5}$**	**$-2X10^{-5}$**	**$-2X10^{-5}$**
Total change (decrease) in annual incidence (cases per year) – whole population:	**-0.2**	**-0.3**	**-0.2**	**-0.2**	**-0.03**	**-0.04**

*Calculations presented are based on the maximum modelled annual average $PM_{2.5}$ concentrations (increase or decrease) for the emission years modelled and the meteorological data considered. The concentrations utilised in the calculations are the population weighted concentrations for each suburb (or part of suburb).

(blank page)

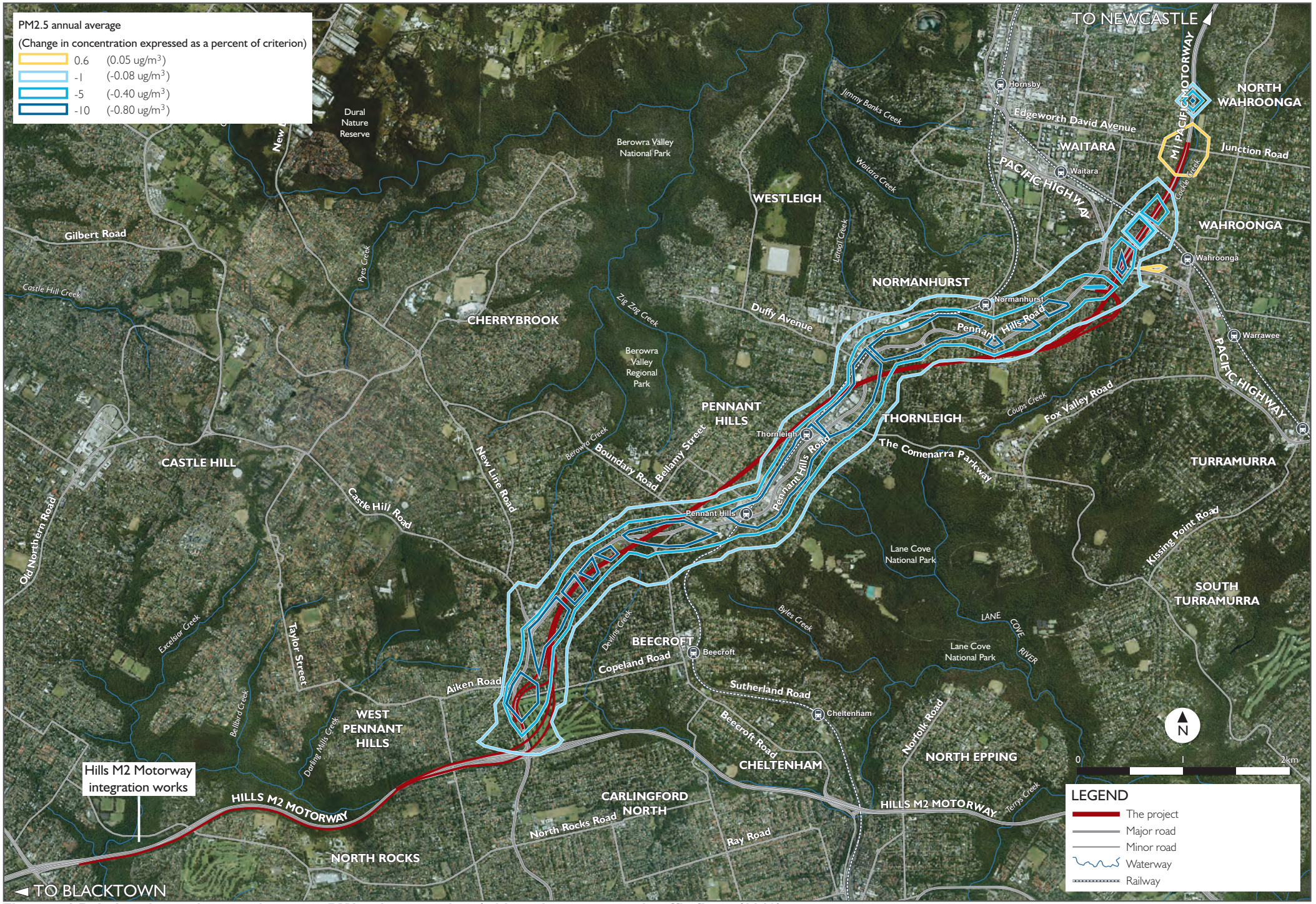


Figure 5-1 Relative change in annual average PM2.5 due to project (with project - expected traffic flows (2019)

(blank page)

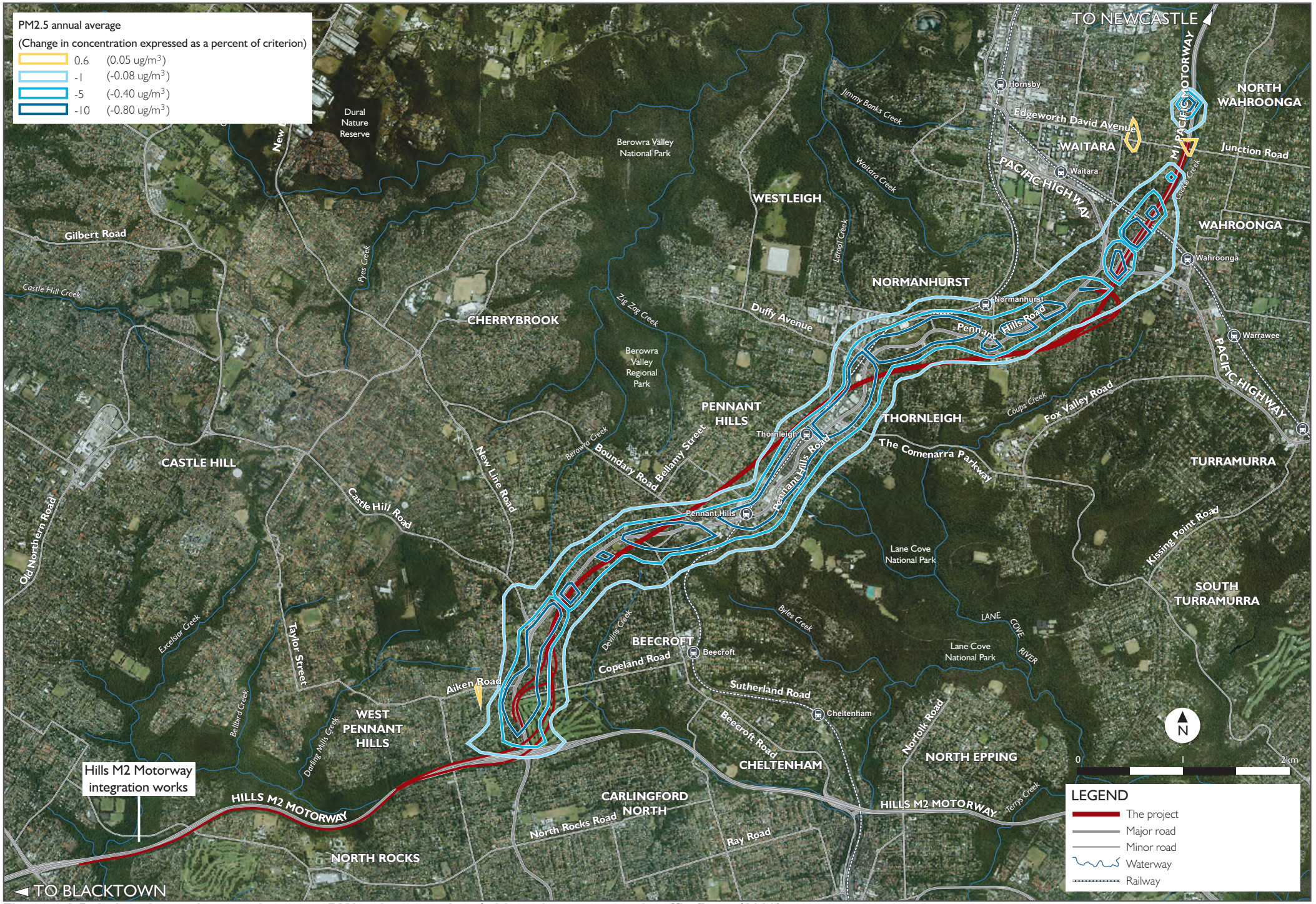


Figure 5-2 Relative change in annual average PM2.5 due to project (with project - expected traffic flows (2029)

(blank page)

5.4 Acceptability of health risk impacts

5.4.1 General

Based on the assessment outlined and presented in **Sections 5.1** to **5.3**, potential health impacts associated with the project have been assessed on the basis of two calculations:

1. Calculation of an annual risk for each health endpoint. This is an incremental risk over and above the baseline risk (or incidence) of the effect occurring for any member of the population, where exposed to the particulate matter concentration estimated.
2. Calculation of an increased incidence of the health effect occurring within the population exposed. This calculates the increased number of cases (mortality or hospitalisations) that may occur for the population assumed to be exposed to the particulate matter concentration estimated.

To determine if the calculated annual risk or increased incidence within a population associated with particulate matter impacts from the project may be considered to be acceptable a number of factors need to be considered. These are further discussed in the following sections.

5.4.2 Acceptable risk levels

General

The acceptability of an additional population risk is the subject of some discussion as there are currently no guidelines available in Australia, or internationally, in relation to an acceptable level of population risk associated with exposure to particulate matter. More specifically there are no guidelines available that relate to an acceptable level of risk for a small population (associated with impacts from a specific activity or project) compared with risks that are relevant to whole urban populations (that are considered when deriving guidelines). The following provides additional discussion in relation to evaluating calculated risk levels.

> "*The solution to developing better criteria for environmental contaminants is not to adopt arbitrary thresholds of 'acceptable risk' in an attempt to manage the public's perception of risk, or develop oversimplified tools for enforcement or risk assessment. Rather, the solution is to standardize the process by which risks are assessed, and to undertake efforts to narrow the gap between the public's understanding of actual vs. perceived risk. A more educated public with regard to the actual sources of known risks to health, environmental or otherwise, will greatly facilitate the regulatory agencies' ability to prioritize their efforts and standards to reduce overall risks to public health*." (Kelly 1991).

Most human activities that have contributed to economic progress present also some disadvantages, including risks of different kinds that adversely affect human health. These risks include air or water pollution due to industrial activities (coal power generation, chemical plants, and transportation), food contaminants (pesticide residues, additives), and soil contamination (hazardous waste). Despite all possible efforts to reduce these threats, it is clear that the zero risk objective is unobtainable or simply not necessary for human and environmental protection and that a certain level of risk in a given situation is deemed "acceptable" as the effects are so small as to be

negligible or undetectable. Risk managers need to cope with some residual risks and thus must adopt some measure of an acceptable risk.

Much has been written about how to determine the acceptability of risk. The general consensus in the literature is that "acceptability" of a risk is a judgment decision properly made by those exposed to the hazard or their designated health officials. It is not a scientifically derived value or a decision made by outsiders to the process. Acceptability is based on many factors, such as the number of people exposed, the consequences of the risk, the degree of control over exposure, and many other factors.

The USEPA (Hoffman 1988) "*surveyed a range of health risks that our society faces*" and reviewed acceptable-risk standards of government and independent institutions. The survey found that "*No fixed level of risk could be identified as acceptable in all cases and under all regulatory programs*...," and that: "...*the acceptability of risk is a relative concept and involves consideration of different factors*". Considerations may include:

- The certainty and severity of the risk.
- The reversibility of the health effect.
- The knowledge or familiarity of the risk.
- Whether the risk is voluntarily accepted or involuntarily imposed.
- Whether individuals are compensated for their exposure to the risk.
- The advantages of the activity.
- The risks and advantages for any alternatives.

To regulate a technology in a logically defensible way, one must consider all its consequences, i.e. both risks and benefits.

10^{-6} as an 'acceptable' risk level?

The concept of $1x10^{-6}$ (10^{-6}) was originally an arbitrary number, finalised by the U.S. Food and Drug Administration (FDA) in 1977 as a screening level of "essentially zero" or *de minimus* risk. The term *de minimus* is an abbreviation of the legal concept, "*de minimus non curat lex*: the law does not concern itself with trifles." In other words, 10^{-6} was developed as a level of risk below which risk was considered a "trifle" and not of concern in a legal case.

This concept was traced back to a 1961 proposal by two scientists from the National Cancer Institute regarding methods to determine "safety" levels in carcinogenicity testing. The FDA applied the concept in risk assessment in its efforts to deal with diethylstilboestrol as a growth promoter in cattle. The threshold of one-in-a-million risk of developing cancer was established as a screening level to determine what carcinogenic animal drug residues merited further regulatory consideration. In the FDA legislation, the regulators specifically stated that this level of "essentially zero" was not to be interpreted as equal to an acceptable level of residues in meat products. Since then, the use of risk assessment and 10^{-6} (or variations thereof) have been greatly expanded to almost all areas of chemical regulation, to the point where today one-in-a-million (10^{-6}) risk means different things to different regulatory agencies in different countries. What the FDA intended to be a lower regulatory level of "zero risk" below which no consideration would be given as to risk to human health, for many regulators it somehow came to be considered a maximum or target level of "acceptable" risk (Kelly 1991).

When evaluating human health risks, the quantification of risk can involve the calculation of an increased lifetime chance of cancer (as is calculated for diesel particulate matter in this assessment) or an increased probability of some adverse health effect (or disease) occurring, over and above the baseline incidence of that health effect/disease in the community (as is calculated for exposure to particulate matter).

In the context of human health risks, 10^{-6} is a shorthand description for an increased chance of 0.000001 in 1 (one chance in a million) of developing a specific adverse health effect due to exposure (over a lifetime or a shorter duration as relevant for particulate matter) to a substance. The number 10^{-5} represents 1 chance in 100,000, and so on.

Where cancer may be considered, lifetime exposure to a substance associated with a cancer risk of $1x10^{-6}$ would increase an individual's current chances of developing cancer from all causes (which is 40 per cent, or 0.4 – the background incidence of cancer in a lifetime) from 0.4 to 0.400001, an increase of 0.00025 per cent.

For other health indicators considered in this assessment, such as cardiovascular hospitalisations for people aged 65 years and older (for example), an increased risk of 10^{-6} (one chance in a million) would increase an individual's (aged 65 years and older) chance of hospitalisation for cardiovascular disease (above the baseline incidence of 23 per cent, or 0.23) from 0.23 to 0.230001, an increase of 0.00043 per cent.

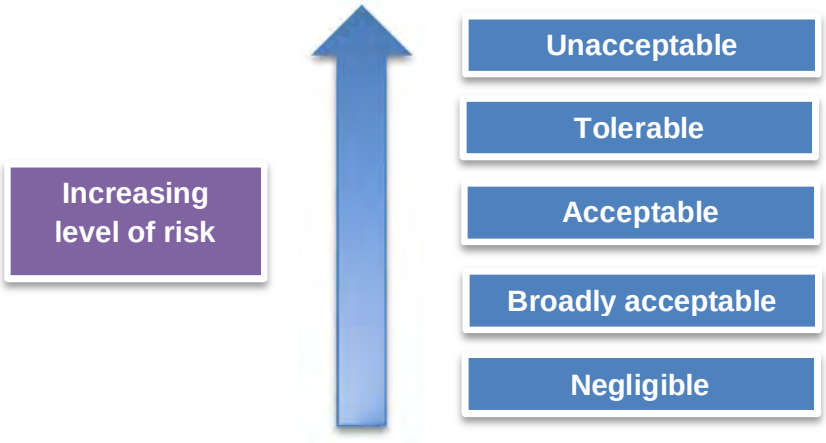
To provide more context in relation to the concept of a one in a million risk, the following presents a range of everyday life occurrences. The activity and the time spent undertaking the activity that is associated with reaching a risk of one in a million for mortality are listed below (Higson 1989; NSW Planning 2011).

- Motor vehicle accident – 2.5 days spent driving a motor vehicle to reach one in a million chance of having an accident that causes mortality (death).
- Home accidents – 3.3 days spent within a residence to reach a one in a million chance of having an accident at home that causes mortality.
- Pedestrian accident (being struck by vehicles) – 10 days spent walking along roads to reach a one in a million chance of being struck by a vehicle that causes mortality.
- Train accident – 12 days spent travelling on a train to reach a one in a million chance of being involved in an accident that causes mortality.
- Falling down stairs[1] – 66 days spent requiring the use of stairs in day-to-day activities to reach a one in a million chance of being involved in a fall that causes mortality.
- Falling objects – 121 days spent in day-to-day activities to reach a one in a million chance of being hit by a falling object that causes mortality.

This risk level should also be considered in the context that everyone has a cumulative risk of death that ultimately must equal one and the annual risk of death for most of one's life is about one in 1000.

[1] Mortality risks as presented by: http://www.riskcomm.com/visualaids/riskscale/datasources.php

While various terms have been applied, it is clear that the two ends of what is a spectrum of risk are the “negligible” level and the “unacceptable" level. Risk levels intermediate between these are frequently adopted by regulators with varying terms often used to describe the levels. When considering a risk derived for an environmental impact it is important to consider that the level of risk that may be considered acceptable will lie somewhere between what is negligible and unacceptable, as illustrated below.



The calculated individual lifetime risk of death or illness due to an exposure to a range of different environmental hazards covers many orders of magnitude, ranging from well less than 10^{-6} to levels of 10^{-3} and higher (in some situations). However, most figures for an acceptable or a tolerable risk range between 10^{-6} to 10^{-4}, used for either one year of exposure or a whole life exposure. It is noteworthy that 10^{-6} as a criterion for "acceptable risk" has not been applied to all sources of exposure or all agents that pose risk to public health.

A review of the evolution of 10^{-6} reveals that *perception* of risk is a major determinant of the circumstances under which this criterion is used. The risk level 10^{-6} is not consistently applied to all environmental legislation. Rather, it seems to be applied according to the general perception of the risk associated with the source being regulated and where the risk is being regulated (with different levels selected in different countries for the same sources).

A review of acceptable risk levels at the USEPA (Schoeny 2008) points out that risk assessors can identify risks and possibly calculate their value but cannot determine what is acceptable. Acceptability is a value judgment that varies with type of risk, culture, voluntariness and many other factors. Acceptability may be set by convention or law. The review also states that the USEPA aims for risk levels between 10^{-6} and 10^{-4} for risks calculated to be linear at low dose, while for other endpoints, not thought to be linear at low dose, the risk is compared to Reference Dose/Concentrations or guideline levels. The USEPA typically uses a target reference risk range of 10^{-4} to 10^{-6} for carcinogens in drinking water, which is in line with World Health Organization (WHO) guidelines for drinking water quality which, where practical, base guideline values for genotoxic carcinogens on the upper bound estimate of an excess lifetime cancer risk of 10^{-5}.

There are many different ways to define acceptable risk and each way gives different weight to the views of different stakeholders in the debate. No definition of 'acceptable' will be acceptable to all stakeholders. Resolving such issues, therefore, becomes a political (in the widest sense) rather than a strictly health process.

The following is a list of standpoints that could be used as a basis for determining when a risk is acceptable or, perhaps, tolerable.

The WHO (Fewtrell & Bartram 2001) address standards related to water quality. They offer the following guidelines for determining acceptable risk. A risk is acceptable when:

- It falls below an arbitrary defined probability.
- It falls below some level that is already tolerated.
- It falls below an arbitrary defined attributable fraction of total disease burden in the community.
- The cost of reducing the risk would exceed the costs saved.
- The cost of reducing the risk would exceed the costs saved when the 'costs of suffering' are also factored in.
- The opportunity costs would be better spent on other, more pressing, public health problems.
- Public health professionals say it is acceptable.
- The general public say it is acceptable (or more likely, do not say it is not).
- Politicians say it is acceptable.

In everyday life individual risks are rarely considered in isolation. It could be argued that a sensible approach would be to consider health risks in terms of the total disease burden of a community and to define acceptability in terms of it falling below an arbitrary defined level. A problem with this approach is that the current burden of disease attributable to a single factor, such as air pollution, may not be a good indicator of the potential reductions available from improving other environmental health factors. For diseases such as cardiovascular disease where causes are multifactorial, reducing the disease burden by one route may have little impact on the overall burden of disease.

Overall

It is not possible to provide a rigid definition of acceptable risk due to the complex and context-driven nature of the challenge. It is possible to propose some general guidelines as to what might be an acceptable risk for specific development projects.

If the level of 10^{-6} (one chance in a million) were retained as a level of increased risk that would be considered as a negligible risk in the community, then the level of risk that could be considered to be tolerable would lie between this level and an upper level that is considered to be unacceptable.

While there is no guidance available on what level of risk is considered to be unacceptable in the community, a level of 10^{-4} for increased risk (one chance in 10,000) has been generally adopted by health authorities as a point where risk is considered to be unacceptable in the development of drinking water guidelines (that impact on whole populations) (for exposure to carcinogens as well as for annual risks of disease (Fewtrell & Bartram 2001)) and in the evaluation of exposures from pollutants in air (DEC 2005b).

Between an increased risk level considered negligible (10^{-6}) and unacceptable (10^{-4}) lie risks that may be considered to be tolerable or even acceptable. Tolerable risks are those that can be tolerated (and where the best available, and most appropriate, technology has been implemented to minimise exposure) in order to realise some benefit.

In a societal context, risks are inevitable and any new development will be accompanied by risks which are not amenable or economically feasible to reduce below a certain level. It is not good policy to impose an arbitrary risk level to such developments without consideration of the myriad factors that should be brought into play to determine what is 'tolerable'.

When considering the impacts associated with this project, it is important to note that there are a range of benefits associated with the project (refer to **Section 2.5**) and the design of the project has incorporated measures to minimise exposures to traffic-related emissions in the local areas (as outlined in Chapter 5 of the environmental impact statement). Hence for this project the calculated risks have been considered to be tolerable when in the range of 10^{-6} and 10^{-4} of increased risk and where the increased incidence of the health impacts are considered to be insignificant (refer to discussion in **Section 5.4.3**).

5.4.3 Determination of significance of incremental impacts

The assessment of potential health impacts associated with emissions to air from the project has not only calculated an increased annual risk, relevant to the health endpoints considered, but also an increased incidence, ie the additional number of cases, of the adverse effects occurring within the population potentially exposed. The calculated increased incidence need to be considered in terms of what may be significant.

In relation to the increased impact of PM_{10} and $PM_{2.5}$ concentrations, the AQIA predicted increased concentrations in the local community of around 0.1 µg/m^3 as an annual average and 1.3 µg/m^3 to 2.1 µg/m^3 as a 24-hour average. These increases would not be detectable above the variability in daily PM_{10} and $PM_{2.5}$ measurements and are at or below the reported precision of the equipment that is used to measure PM_{10} and $PM_{2.5}$ (reported to vary from five per cent to 15 per cent depending on the equipment used, eg for the most common equipment used for measuring ambient $PM_{2.5}$ concentrations the precision of the data is ± 1 µg/m^3).

In relation to the calculated increased incidence of an adverse health effect occurring in a population, the following is noted for the primary health indicators (based on statistics available from NSW Health):

- In relation to mortality (all causes), the health statistics available show that for the year 2010 – 2011 the variability in all admissions data reported (based on the 95 per cent confidence interval for data reported in northern Sydney) is around ± two per cent. This is the variability in the data reported in one year. Each year the mortality rate also varies with around three per cent variability reported in the mortality rate (number reported for all causes) between 2009/10 and 2010/11. Based on the baseline incidence of mortality considered in this assessment a variability of two to three per cent equates to a variability of around one case per year (where the maximum impacts are considered). Hence any estimation of mortality in the population less than one case per year could not be detected (above normal variability) in the health statistics.

- In relation to cardiovascular disease hospitalisations, the health statistics available show that for the year 2011 – 2012 the variability in all admissions data reported (based on the 95 percent confidence interval for data reported in northern Sydney) is around ± 1.5 percent. This is the variability in the data reported in one year. Each year the rate of hospitalisations (all ages) also varies with around three per cent variability reported in the number of hospitalisations for people aged 65 years and older between 2010/11 and 2011/12. Based on the baseline incidence of cardiovascular hospitalisations considered in this assessment for individuals aged 65 years and older a variability of 1.5 per cent equates to a variability of around 40 cases per year (where the maximum impacts are considered). Hence any estimation of increased incidence of cardiovascular hospitalisations in the population aged 65 years and older less than 40 cases per year could not be detected (above normal variability) in the health statistics.
- In relation to respiratory disease hospitalisations, the health statistics available show that for the year 2011 – 2012 the variability in all admissions data reported (based on the 95 percent confidence interval for data reported in northern Sydney) is around ± 1.5 percent. This is the variability in the data reported in one year. Each year the rate of hospitalisations (all ages) also varies with around three-four per cent variability reported in the number of hospitalisations (all ages) between 2010/11 and 2011/12. Based on the baseline incidence of respiratory hospitalisations considered in this assessment for individuals aged 65 years and older a variability of 1.5 per cent equates to a variability of around 17 cases per year (where the maximum impacts are considered). Hence any estimation of increased incidence of cardiovascular hospitalisations in the population aged 65 years and older less than 17 cases per year could not be detected (above normal variability) in the health statistics.

Where changes arising from an individual project are well below one case per year and are not detectable in the normal fluctuations in health statistics such impacts are considered to be negligible.

5.5 Discussion of potential health impacts from the project

5.5.1 General

The assessment presented in this section has focused on the quantification of health impacts associated with exposure primarily to $PM_{2.5}$ (as the source of the emissions is derived from vehicle emission), but also to PM_{10}. Incremental annual risk and increased incidence for a range of primary and secondary health indicators associated with exposure to $PM_{2.5}$ and PM_{10} have been calculated and are presented in **Section 5.3.5**.

The assessment of health impacts addresses impacts that may occur to all members of the community including young children, the elderly and individuals with pre-existing health conditions. The exposure-response relationships are based on effects identified in large urban communities and while some of the health indicators used have focused on age groups where the exposure-response relationships are the most robust, there are a number of health indicators that address all ages of the population. Hence the calculations undertaken, and the discussion presented in this section are relevant to all the individual receivers assessed (as listed in **Section 3.2**) including young children attending day-care and schools in the area, the elderly in aged care, individuals with health conditions at hospital facilities or in the community and all members of the public living in the area. A

more specific assessment of the impact of the project on asthma in young children has been presented separately in **Section 5.7.2**.

The following discussion relates to a review of the calculated health impacts within the context of the discussion presented in **Section 5.4**.

5.5.2 Primary health indicators

In relation to the primary health indicators considered in relation to exposure to $PM_{2.5}$ derived from the project, the following can be noted:

- For the assessment of **mortality** from all causes (for people aged 30 years and over) the following has been calculated (for scenarios 2a (2019) and 2b (2029)):
    - The increased annual risks (mortality) are calculated to be:
        - $5x10^{-6}$ to $8x10^{-6}$ for the maximum project impact locations adjacent to the southern and northern interchanges; and
        - $\leq 5x10^{-6}$ for the individual sensitive receivers located in the community surrounding the southern and northern interchanges.
    - The increased annual incidence within the local population is calculated to be 0.04 for the population around the northern interchange and 0.03 for the population around the southern interchange.

      Based on the discussion presented in **Section 5.4.2**, the calculated risks are within the range of tolerable risks associated with impacts from a specific project.

      With further consideration of the calculated increased population incidence of mortality as discussed in **Section 5.4.3**, the calculated increased risks are considered to be negligible.
- For the assessment of **cardiovascular hospitalisations** (for people aged 65 years and over) the following has been calculated (for scenarios 2a (2019) and 2b (2029)):
    - The increased annual risks (cardiovascular hospitalisations) are calculated to be:
        - $2x10^{-5}$ for the maximum project impact locations adjacent to the southern and northern interchanges; and
        - $\leq 2x10^{-5}$ for the individual sensitive receiver located in the community surrounding the southern and northern interchanges.
    - The increased annual incidence within the local population is calculated to be 0.03 for the population around the northern interchange and 0.02 for the population around the southern interchange.

      Based on the discussion presented in **Section 5.4.2**, the calculated risks are within the range of tolerable risks associated with impacts from a specific project. With further consideration of the calculated increased incidence of cardiovascular hospitalisations as discussed in **Section 5.4.3**, the calculated increased risks are considered to be negligible.

- For the assessment of **respiratory hospitalisations** (for people aged 65 years and over) the following has been calculated (for scenarios 2a (2019) and 2b (2029)):

    - The increased annual risks (respiratory hospitalisations) are calculated to be:
        - $3x10^{-6}$ to $5x10^{-6}$ for the maximum project impact locations adjacent to the southern and northern interchanges; and
        - $\leq 3x10^{-6}$ for the individual sensitive receivers located in the community surrounding the southern and northern interchanges.
    - The increased annual incidence within the local population is calculated to be 0.005 for the population around the northern interchange and 0.004 for the population around the southern interchange.

      Based on the discussion presented in **Section 5.4.2**, the calculated risks are within the range of tolerable risks associated with impacts from a specific project. With further consideration of the calculated increased incidence of respiratory hospitalisations as discussed in **Section 5.4.3**, the calculated increased risks are considered to be negligible.

5.5.3 Secondary health indicators

In relation to the secondary health indicators considered in relation to exposure to $PM_{2.5}$ and PM_{10} derived from the project:

- For the assessment of **mortality** from all causes (all ages) and from cardiopulmonary (ages 30 years and over), cardiovascular (all ages) and respiratory disease (all ages) the following has been calculated (for scenarios 2a (2019) and 2b (2029)):

    - The increased annual risks are calculated to be:
        - $9x10^{-8}$ to $8x10^{-6}$ for the maximum project impact locations adjacent to the southern and northern interchanges; and
        - $\leq 5x10^{-6}$ for the individual sensitive receivers located in the community surrounding the southern and northern interchanges.

      Based on the discussion presented in **Section 5.4.2**, these risks are negligible for some health indicators with the reminder within the range of tolerable risks associated with impacts from a specific project.

5.6 Qualitative assessment of other key issues

5.6.1 In-tunnel exposures

Concentrations of carbon monoxide, oxides of nitrogen, total volatile organic compounds, total polycyclic aromatic hydrocarbons, $PM_{2.5}$ and PM_{10} have been estimated within the tunnel itself during normal operations (scenarios 2a (2019) and 2b (2029)). Concentrations in the tunnel vary depending on:

- Time of day. Pollutant concentrations within the main alignment tunnels have been estimated to vary by a factor of up to nine times (depending on the particular pollutant and location within the main alignment tunnels) from periods of low traffic to peak traffic.

- Location within the main alignment tunnels. Concentrations of pollutants would gradually increase from the tunnel portals to around the offtake to the ventilation outlets. Average exposure for a motorist would be around half of the maximum concentration within a main alignment tunnel.

The assessment of potential exposures that may occur in the tunnel has been undertaken with consideration of these factors. In addition the following has also been considered:

- The time spent within the tunnel would be limited, taking around six minutes to travel the full distance of the tunnel (when travelling at 80 kilometres per hour). During peak times the time of travel may be slightly longer depending on the speed of traffic flow in the tunnel. As the concentrations are not the same in all parts of the tunnel, with concentrations increasing with distance from the start, the amount of time exposed to the maximum concentration would be much lower (around one to two minutes). The average exposure through the whole tunnel would be lower than, approximately half, the maximum (at the end of the tunnel).
- The concentration of pollutants within the vehicle itself, particularly where all windows are closed when inside the tunnel, as most vehicles have filters on the air intake. Where the air conditioning/ventilation in the car is set to recirculation this would limit the contribution of air derived from within the tunnel to the air within the vehicle. Measurements conducted by NSW Health in relation to the M5 East Tunnel (NSW Health 2003) identified that closing car windows and switching the ventilation to recirculation can reduce exposures by approximately 70-75 per cent for carbon monoxide and nitrogen dioxide, 80 per cent for fine particulates and 50 per cent for volatile organic compounds.

In-tunnel emissions were also estimated using internationally-recognised vehicle emission factors prepared by the World Road Association (PIARC, 2012), which provide Australian-specific emissions based on fleet distribution data and emission standards relevant to Australia. PIARC emission factors were developed for the purpose of defining the minimum air flows required to achieve adequate air quality within road tunnels rather than for the purpose of developing emissions inventories, so a safety margin is added to the emission factors within PIARC. This is expected to result in conservative emissions estimates when used for inventory purposes. A review of the emissions inventory for this project has been provided to Pacific Environment Limited for peer review, which included a comparison using the NSW Environment Protection Authority's published emission factors. This was conducted to assess the conservatism of the PIARC emission factors and its reasonableness for use. The outcome of the review concluded that the emissions inventory adopted was conservative, particularly in the case of PM_{10} and $PM_{2.5}$ (where concentrations from PIARC were found to be twice as high as estimated from the NSW Environment Protection Authority). Further detail on the emissions inventory, and the findings of the Pacific Environment review, can be found in technical working paper: air quality (AECOM, 2014).

The following provides further discussion on the range of concentrations predicted within the tunnel.

Carbon monoxide

Figure 5-3 presents the predicted hourly concentration of carbon monoxide in the northbound and southbound tunnels at different distances from the start of the tunnel, for different times of the day, for scenario 2a (2019) and scenario 2b (2029).

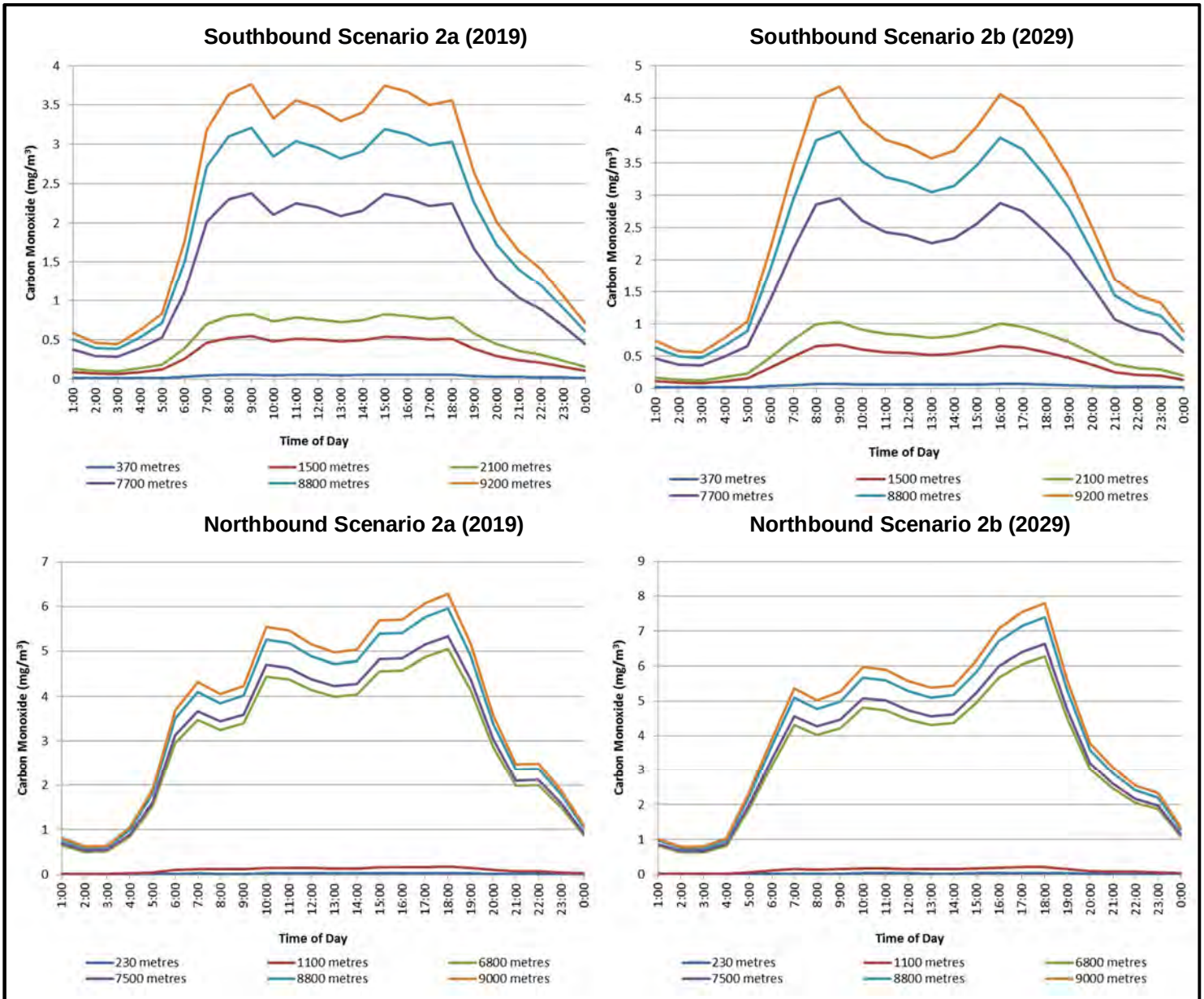


Figure 5-3: Predicted in-tunnel concentrations of Carbon Monoxide

Review of **Figure 5-3** indicates the following:

- The concentrations predicted in the project tunnel are <1 mg/m^3 at the start of the tunnel increasing to levels of 2 to 4.6 mg/m^3 towards the end of the southbound tunnel during the peak times and middle of the day and 4 to 8 mg/m^3 towards the end of the northbound tunnel during the peak times and middle of the day;
- Based on the maximum in-tunnel concentrations estimated, average exposure for a motorist using the southbound tunnel in peak periods[19] is estimated to be approximately 2 mg/m^3 for a duration of approximately six minutes with windows open and 0.6 mg/m^3 with windows closed and ventilation set to recirculation mode.
- Based on the maximum in-tunnel concentrations estimated, average exposure for a motorist using the northbound tunnel in peak periods is estimated to be approximately 4 mg/m^3 for a duration of approximately six minutes with windows open and 1.2 mg/m^3 with windows closed and ventilation set to recirculation mode.
- The NHMRC (2008) has published measured concentrations of carbon monoxide from a range of tunnels in Sydney and around the world. The measured concentrations come from a number of different studies where the averaging time for the collection of the data varies significantly. This makes it difficult to directly compare the range of reported concentrations with the concentrations predicted in this assessment (ie not comparing data reported over similar averaging/exposure periods). While noting this difficulty in comparing the data, the a range of average concentrations of carbon monoxide have been reported from 6 to 44 mg/m^3 (NHMRC 2008).
- The maximum concentration (8 mg/m^3), and likely average concentration (half the maximum, or around 4 mg/m^3) predicted in the project tunnel is lower than the WHO guidelines[20] for 15-minute exposures of 100 mg/m^3, and 30-minute exposures of 57 mg/m^3.
- These concentrations are also lower than the USEPA guidelines for in-tunnel exposures that range from 40 mg/m^3 for 45-60 minute exposures to 138 mg/m^3 for peak period for traffic (<15 mins) (NHMRC 2008).

[19] Refer to the technical working paper: air quality (AECOM, 2014) for more details in relation to concentrations estimated in the tunnel in peak periods (at each kilometre through the tunnel).

[20] The guidelines are presented in ppmv by the referenced organisation. These concentrations have been converted to mg/m^3 for use in this report based on the molecular weight of the compound and standard temperature and pressure.

Nitrogen dioxide

Figure 5-4 presents the predicted hourly concentration of nitrogen dioxide in the northbound and southbound tunnels at different distances from the start of the tunnel, for different times of the day, for scenario 2a (2019) and scenario 2b (2029). The non-linearity of nitrogen oxides chemistry in road tunnels makes the estimation of the potential levels of nitrogen dioxide in the tunnel complex. Regardless of the complexities, the concentration of nitrogen dioxide has been estimated assuming that 10 per cent of the total nitrogen oxides comprise nitrogen dioxide (PIARC 2012).

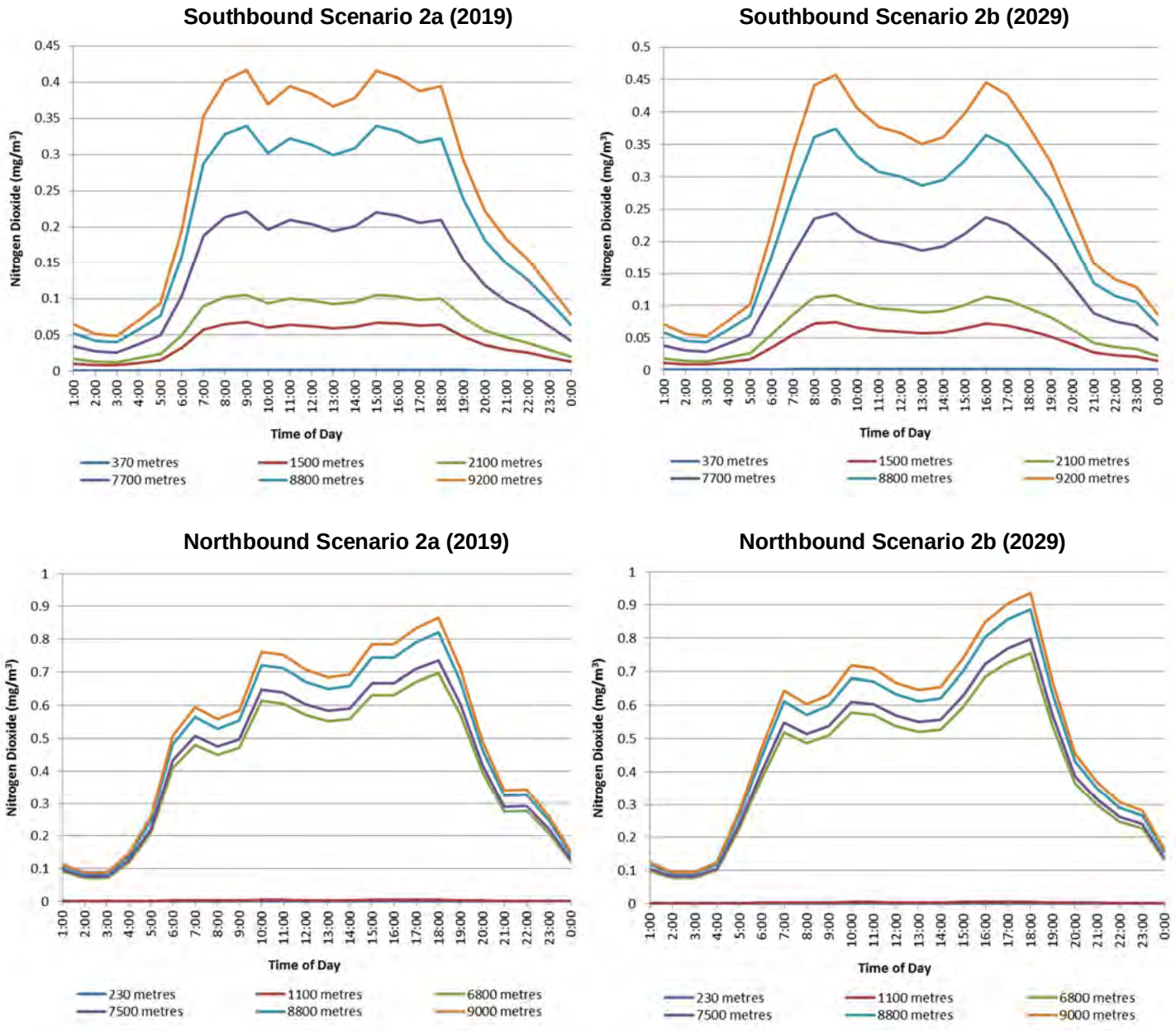


Figure 5-4: Predicted in-tunnel concentrations of Nitrogen Dioxide

Review of **Figure 5-4** indicates the following:

- The hourly concentrations predicted in the project tunnel are <0.1 mg/m^3 at the start of the tunnel increasing to levels of approximately 0.2 to 0.4 mg/m^3 towards the end of the southbound tunnel during the peak times and middle of the day and 0.4 to <1 mg/m^3 towards the end of the northbound tunnel during the peak times and middle of the day;
- Based on the maximum in-tunnel concentrations estimated, average exposure for a motorist using the southbound tunnel in peak periods[21] is estimated to be approximately 0.2 mg/m^3 for a duration of approximately six minutes with windows open and 0.06 mg/m^3 with windows closed and ventilation set to recirculation mode.
- Based on the maximum in-tunnel concentrations estimated, average exposure for a motorist using the northbound tunnel in peak periods is estimated to be approximately 0.5 mg/m^3 for a duration of approximately six minutes with windows open and 0.15 mg/m^3 with windows closed and ventilation set to recirculation mode.
- The NHMRC (2008) has published measured concentrations of nitrogen dioxide from a range of tunnels in Sydney and around the world. The measured concentrations come from a number of different studies where the averaging time for the collection of the data varies significantly. This makes it difficult to directly compare the range of reported concentrations with the concentrations predicted in this assessment (ie not comparing data reported over similar averaging/exposure periods). While noting this difficulty in comparing the data, the NHMRC (2008) have reported a range of average concentrations of nitrogen dioxide in tunnels that range from 0.09 to 0.5 mg/m^3 with levels up to 0.75 mg/m^3 reported during peak periods. These levels are based on data with averaging times that vary from 30 seconds during travel through a tunnel, six minute averages, to long term data with (unspecified averaging times). At the downstream end of a tunnel (where exposure is very short, ie minutes) levels up to 1.5 mg/m^3 have been reported.
- There are very few studies that have evaluated health effects associated with very short duration exposures to nitrogen dioxide. A study conducted in Stockholm (Svartengren et al. 2000) involved exposing 20 adults with mild asthma to air quality inside a car in a tunnel for 30 minutes, where levels of nitrogen dioxide ranged from 0.2 to 0.462 mg/m^3 (noting exposure to particulate matter and other pollutants inside the tunnel occurred at the same time). The study showed an increase in bronchial response to allergens several hours after exposure for individuals with allergic asthma. These results are similar to other studies where individuals with mild asthma were exposed to 0.5 mg/m^3 nitrogen dioxide for 30 minutes (Barck et al. 2002; Strand et al. 1998), a range of concentrations from 0 to 1 mg/m^3 for 30 minutes (Bylin et al. 1988) or for 15 minutes on one day and then repeated twice in the following day (Barck et al. 2005), followed by an allergen inhalation challenge. None of the available studies have considered individuals with moderate or severe asthma. The data suggest that exposure to elevated concentrations of nitrogen dioxide in a

[21] Refer to the technical working paper: air quality (AECOM, 2014) for more details in relation to concentrations estimated in the tunnel in peak periods (at each kilometre through the tunnel).

congested tunnel is associated with an increased risk of adverse effects for those with asthma (NHMRC 2008).

- There are no guidelines in Australia for levels of nitrogen dioxide in tunnels. Guidelines [22] for in-tunnel levels of nitrogen dioxide are available from Belgium (0.9 mg/m^3 for exposures <20 minutes), France (0.75 mg/m^3 for a 15 minute average exposure period), Norway (Norwegian Public Road Admiration (NPRA) guidelines of 1.4 mg/m^3 at the tunnel midpoint and 2.8 mg/m^3 at the tunnel ends, based on a 15-minute average) and Sweden (where the WHO guideline of 0.2 mg/m^3 for a 1-hour average exposure has been adopted). The PIARC has proposed a level of 1.9 mg/m^3 (as a threshold limit for healthy people). The average expected exposures in peak periods discussed above are lower than the available short term (15-minute to 20-minute average) guidelines.

[22] The guidelines are presented in ppmv by the referenced organisation. These concentrations have been converted to mg/m^3 for use in this report based on the molecular weight of the compound and standard temperature and pressure.

Fine Particulates ($PM_{2.5}$)

Figure 5-5 presents the predicted hourly concentration of $PM_{2.5}$ in the northbound and southbound tunnels at different distances from the start of the tunnel, for different times of the day, for scenario 2a (2019) and scenario 2b (2029). Given the key source of the particulates within the tunnel is from combustion emissions, the focus of this review is on fine particulates as $PM_{2.5}$.

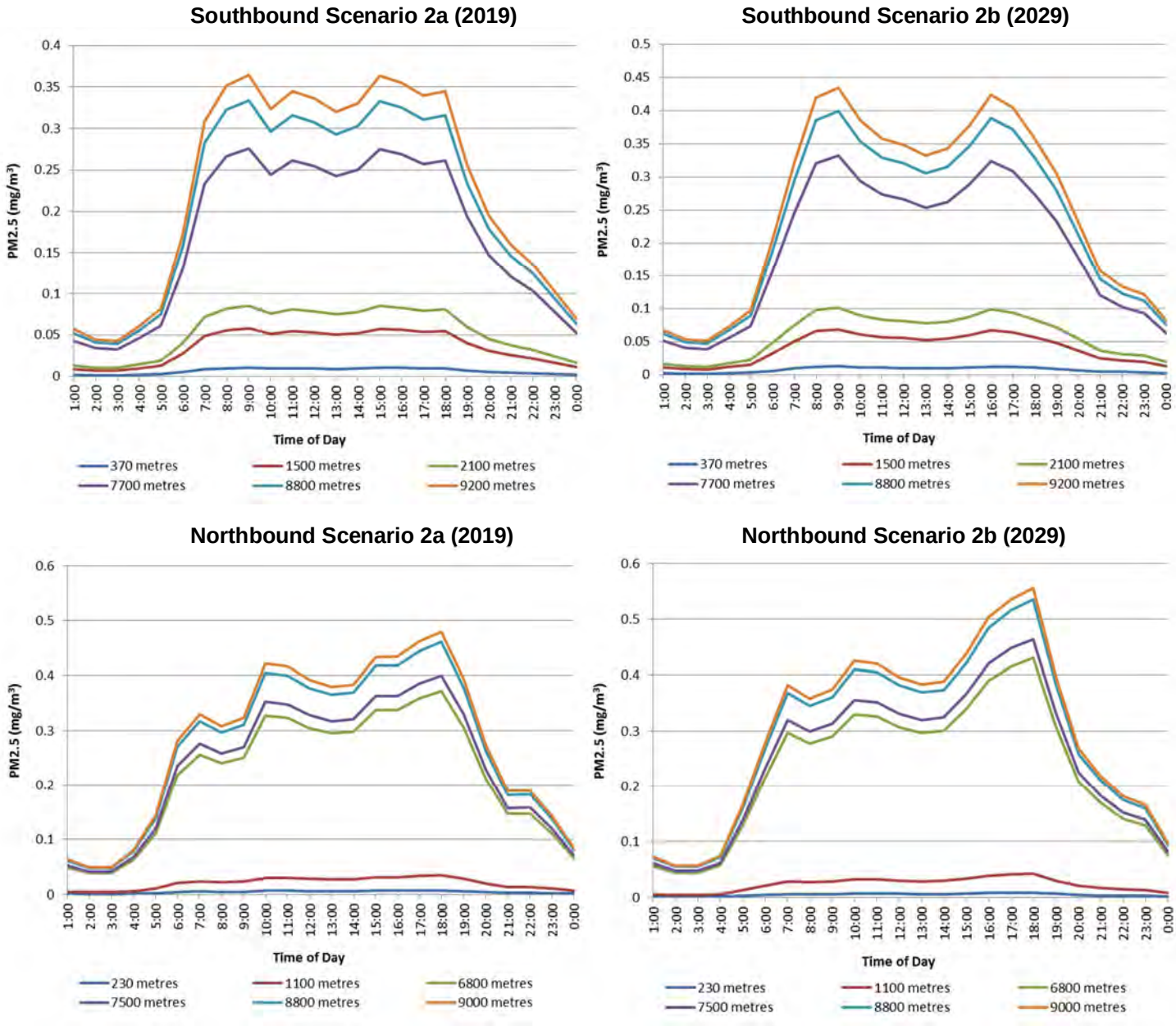


Figure 5-5: Predicted in-tunnel concentrations of fine particulates ($PM_{2.5}$)

Review of **Figure 5-5** indicates the following:

- The in-tunnel concentrations for the project have been estimated based on the predicted traffic volume using the tunnel and emission factors from PIARC. These emission factors (when compared with those published by the NSW Environment Protection Authority) are conservative particularly in relation to the assessment of particulate matter (PM_{10} and $PM_{2.5}$) (refer to technical working paper: air quality (AECOM, 2014)).
- The hourly concentrations predicted in the project tunnel are <0.1 mg/m^3 at the start of the tunnel increasing to levels of around 0.25 to 0.35 mg/m^3 towards the end of the southbound tunnel during the peak times and middle of the day and 0.25 to 0.55 mg/m^3 towards the end of the northbound tunnel during the peak times and middle of the day.
- Based on the maximum in-tunnel concentrations estimated, average exposure for a motorist using the southbound tunnel in peak periods[23] is estimated to be approximately 0.2 mg/m^3 for a duration of approximately six minutes with windows open and 0.04 mg/m^3 with windows closed and ventilation set to recirculation mode.
- Based on the maximum in-tunnel concentrations estimated, average exposure for a motorist using the northbound tunnel in peak periods is estimated to be approximately 0.3 mg/m^3 for a duration of approximately six minutes with windows open and 0.06 mg/m^3 with windows closed and ventilation set to recirculation mode.
- The NHMRC (2008) has published measured concentrations of particulates (as $PM_{2.5}$ and PM_{10}) from a range of tunnels in Sydney and around the world. The measured concentrations come from a number of different studies where the sampling methodology and averaging time for the collection of the data varies significantly. This makes it difficult to directly compare the range of reported concentrations with the concentrations predicted in this assessment (ie not comparing data reported over similar averaging/exposure periods). While noting this difficulty in comparing the data, the range of average concentrations of $PM_{2.5}$ reported typically range from around 0.03 to 0.343 mg/m^3 (AMOG 2012; NHMRC 2008). These levels are based on data with averaging times that vary from one hour averages, peak hour averages, daytime averages to 24-hour averages.
- The exposure-response relationships for particulate matter that have been established on the basis of adverse health effects from short-term exposures relate to changes in the health effects associated with variability in 24-hour average concentrations of $PM_{2.5}$ in urban air. They do not relate to much shorter variations in $PM_{2.5}$ exposure that may occur within a 24-hour period, where there may be exposures over a few minutes to higher levels of $PM_{2.5}$. No guidelines are currently available for assessing potential health effects that may occur as a result of exposures to particulates that may occur for minutes (or even an hour).
- Recent review (WHO 2013a) of available studies in relation to short-duration (less than 24-hour) exposures to particulates indicates the following:
    - Epidemiological and clinical studies have demonstrated that sub-daily exposures to elevated levels of particulate matter can lead to adverse physiological changes in the

[23] Refer to the technical working paper: air quality (AECOM, 2014) for more details in relation to concentrations estimated in the tunnel in peak periods (at each kilometre through the tunnel).

respiratory and cardiovascular system, in particular exacerbation of existing disease. This is generally consistent with the outcome of studies reviewed and considered by the USEPA (USEPA 2009b).

- The studies available do not cover a range of exposure concentrations, nor do they adequately address other variables such as co-pollutants (gases) or repeated short-duration exposures.
- The studies have not determined if a 1 hour exposure would lead to a different response than a similar dose spread over 24-hours, or if an exposure-response can be determined.
- Exposures that occur during the use of various transportation methods (such as in-vehicles) have been found to contribute to and affect 24-hour personal exposures.

The urban epidemiology studies (upon which exposure-response relationships are based and have been used in this assessment) utilise health data for adverse health effects from an urban population, where the urban population will have been exposed to ambient levels of particulate matter (as measured by air monitoring stations) as well as fluctuations that occur throughout the day during various daily activities including in-vehicle exposures (and others such as cooking). These large urban studies have related health effects to regional ambient (urban) air concentrations. They have not measured daily (or longer term) personal exposures to particulate matter, but such fluctuations would occur within the population exposed and would be expected to be accounted for within the health data considered in the epidemiology studies. Specific health effects from the short duration variations in particulate exposures throughout any specific day cannot be determined from these studies. It is therefore important to consider if exposures to $PM_{2.5}$ in the project tunnel would be consistent with other tunnels or in-vehicle exposures (during commuting in an urban environment).

- Exposure to particulate matter within vehicles varies with the intensity of the traffic, the age of the vehicle the choice of ventilation used within the vehicle and the type of fuel used (Knibbs, de Dear & Morawska 2010). Levels of $PM_{2.5}$ reported in vehicles in Europe (ETC 2013) vary from 0.022 to 0.085 mg/m^3 for passenger cars and 0.026 to 0.13 mg/m^3 for bus travel.
- Levels of $PM_{2.5}$ that have been measured within cars while commuting in Sydney (where tunnel travel was not part of the study) range from 0.009 to 0.045 mg/m^3 (NSW Health 2004).
- Keeping windows closed and switching ventilation to recirculation has been shown to reduce exposures inside the vehicle by up to 80 per cent (NSW Health 2003). While noting no guidelines are availability for very short duration exposures, this would further reduce exposure to motorists.

Polycyclic aromatic hydrocarbons

- The hourly concentrations of total polycyclic aromatic hydrocarbons predicted in the project tunnel are <0.00001 mg/m^3 at the start of the tunnel increasing to levels of approximately 0.00007 mg/m^3 towards the end of the southbound tunnel during the peak times and middle of the day and 0.0001 mg/m^3 towards the end of the northbound tunnel during the peak times and middle of the day;

- Based on the maximum in-tunnel concentrations estimated, average exposure for a motorist using the southbound tunnel in peak periods is estimated to be approximately 0.00003 mg/m^3 for total polycyclic aromatic hydrocarbons and 0.3 ng/m^3 for carcinogenic polycyclic aromatic hydrocarbons (as a BaP TEQ where speciated as outlined in **Section 0**) for a duration of approximately six minutes with windows open (lower with the windows closed and on recirculation).
- Based on the maximum in-tunnel concentrations estimated, average exposure for a motorist using the northbound tunnel in peak periods is estimated to be approximately 0.00016 mg/m^3 for total polycyclic aromatic hydrocarbons and 1.4 ng/m^3 for carcinogenic polycyclic aromatic hydrocarbons (as a BaP TEQ where speciated as outlined in **Section 0**) for a duration of approximately six minutes with windows open (lower with the windows closed and on recirculation).
- While difficult to directly compare due to a wide range of averaging times for the different studies (varying from hours to 24-hour averages), the concentrations of carcinogenic polycyclic aromatic hydrocarbons in other tunnels (in Sydney and around the world) have been reported to range from 0.9 to 11.8 ng/m^3 (NHMRC 2008).
- There are no short-term peak guidelines for exposure to polycyclic aromatic hydrocarbons (as the health effects associated with these compounds relates to chorionic exposures only) that would be relevant for assessing the very short duration of time likely to be spent within the tunnel. However it is noted that the calculated incremental carcinogenic risks for a very short duration exposure (of minutes) to carcinogenic PAHs at the maximum levels reported would be less than 1x10^{-6} and would be considered to be negligible.

Volatile organic compounds

- The hourly concentrations of total volatile organic compounds predicted in the project tunnel are <0.1 mg/m^3 at the start of the tunnel increasing to levels of approximately 0.38 mg/m^3 towards the end of the southbound tunnel during the peak times and middle of the day and 0.7 mg/m^3 towards the end of the northbound tunnel during the peak times and middle of the day;
- Based on the maximum in-tunnel concentrations estimated for total volatile organic compounds, average exposure for a motorist using the southbound tunnel in peak periods[24] is estimated to be approximately 0.2 mg/m^3 for a duration of approximately six minutes with windows open and 0.1 mg/m^3 with windows closed and ventilation set to recirculation mode.
- Based on the maximum in-tunnel concentrations estimated for total volatile organic compounds, average exposure for a motorist using the northbound tunnel in peak periods is estimated to be approximately 0.4 mg/m^3 for a duration of approximately six minutes with windows open and 0.2 mg/m^3 with windows closed and ventilation set to recirculation mode.
- The peak period exposure concentrations for the total volatile organic compound concentrations are higher than assessed previously in relation to acute exposures (refer to **Section 4.2**). Utilising the approach adopted for speciating individual VOCs (as outlined in

[24] Refer to the technical working paper: air quality (AECOM, 2014) for more details in relation to concentrations estimated in the tunnel in peak periods (at each kilometre through the tunnel).

Section 4.2), assuming windows are down, taking into account a 6 minute exposure period (compared with 60 minute average guidelines) and the acute (60 minute, or hourly average) health based criteria presented in **Table 4-6**, all potential exposure concentrations of individual volatile organic compounds (and all compounds together) are below the acute guidelines. Hence no adverse health effects are expected for the short duration of exposure to volatile organic compounds in the tunnel.

- Where speciated out to individual VOCs (as per **Section 4.2**) the maximum hourly average peak period exposure concentration (windows down) of benzene is estimated to be 0.01 mg/m^3, toluene is estimated to be 0.02 mg/m^3 and formaldehyde is estimated to be 0.02 mg/m^3.
- The average concentrations reported in other tunnels in Sydney and around the world for benzene, toluene and formaldehyde (NHMRC 2008) range from:
    - For benzene - 0.008 to 0.33 mg/m^3.
    - For toluene - 0.03 to 0.63 mg/m^3
    - For formaldehyde - 0.013 to 0.056 mg/m^3.

  The reported levels vary based on differing averaging times (varying from hours to 24-hour averages) and sample locations in the tunnels (NHMRC 2008).
- The concentrations predicted are also consistent with (and slightly lower than) the levels measured within cars (NSW Health 2004) (during commuting in Sydney, where tunnel travel was not part of the study) for benzene (mean ranged from 0.04 to 0.07 mg/m^3) and toluene (mean ranged from 0.1 to 0.2 mg/m^3). Hence exposure to these VOCs during use of the tunnel is not expected to be different to the exposure that would occur within a car during normal commuting within Sydney.

Overall Assessment

In-tunnel concentrations have been estimated based on the predicted traffic volume using the tunnel and emission factors from PIARC. These emission factors (when compared with those published by the NSW Environment Protection Authority) are conservative particularly in relation to the assessment of particulate matter (PM_{10} and $PM_{2.5}$).

The duration of exposure to vehicle emissions within the project tunnel is limited (minutes, rather than hours, only) and where guidelines are available for short duration exposures in tunnels, the likely exposure concentrations (representative of the average concentrations from start to end) are generally within or below these guidelines. Short-duration exposure guidelines are not available for nitrogen dioxide or particulate matter (assessed as $PM_{2.5}$). In relation to nitrogen dioxide exposures studies are available that suggest in situations of congested traffic (including delayed traffic in a tunnel) there is an increased risk of adverse health effects amongst individuals with asthma. Particulate matter exposures within the tunnel are estimated to be similar to those expected within other vehicle tunnels, are of limited duration (minutes) and are consistent with expected variability of exposure to $PM_{2.5}$ throughout any day where a range of activities are undertaken.

For regular users of tunnels in Sydney, and regular commuters in heavy traffic, repeated short duration exposures to elevated concentrations of pollutants from vehicle emissions would contribute to a higher level of overall (daily) exposure and may be associated with increased risks for asthmatics. Drivers who regularly use tunnels or drive in congested traffic in Sydney can minimise exposure to vehicle emissions by keeping windows up and air conditioning on recirculation when in

tunnels or heavy traffic conditions. Keeping windows closed and switching ventilation to recirculation has been shown to reduce exposures inside the vehicle by up to 80 per cent.

5.6.2 Impact of project on asthma

A common concern in relation to exposure to particulate matter relates to the potential for impacts on children with asthma. The available studies that have evaluated the potential impact of exposure to particulate matter with asthma indicators (hospital visits and medication use) are more limited, and considered to be less robust (showing less statistical significance); however they have shown the presence of potential adverse effects (and relationship) for particulates, particularly $PM_{2.5}$ in the range 9.7 µg/m^3 to 30 µg/m^3 (USEPA 2012).

Background $PM_{2.5}$ concentrations exceed the current levels of $PM_{2.5}$ in ambient air in Sydney, and exceed the predicted cumulative (background plus incremental) concentrations of $PM_{2.5}$ for this project. Hence any use of relationships established for levels of exposure in excess of what is being considered in this assessment should be done with caution. Due to this limitation, along with the issue that much of the necessary baseline data is limited in availability, the outcomes of any assessment of particulate matter exposures and asthma are only considered to be qualitative.

Review by the WHO in the report “Effects of Air Pollution on Children's Health and Development” (WHO 2005b) concluded that the evidence on asthma and air pollution is sufficient to suggest a causal link between air pollution, in particular where living in proximity to traffic, and aggravation of asthma. One way of measuring aggravation of asthma is through the monitoring the use of bronchodilators (also known as asthma relievers).

The most of the available studies in relation to increased medication use for these relievers and exposure to particulate matter relate to PM_{10}. This is mainly due to the nature of the available studies where coarse particulate matter levels were measured in air rather than the finer $PM_{2.5}$. In this study it is recognised that most of the PM_{10} impacts predicted comprise significant levels of $PM_{2.5}$ due to the source being vehicle emissions.

Review of available data by the WHO (Anderson et al. 2004), as summarised for Europe (EC 2011) identified relative risk of a 0.4 per cent (95 per cent confidence interval:-1.7 per cent to 2.6 per cent) increase in bronchodilator days per 10 µg/m^3 increase in PM_{10} for children aged 5 – 15 years. Based on this study a β coefficient of 0.0004 can be determined and applied for the age group 5 – 14 years considered in this assessment (age group where data on asthma use and population are available). This relationship was established following analysis of data from studies conducted in Europe, including panel studies of children with existing asthma symptoms.

To calculate the change in annual incidence, or change in use of medication each year for the population of concern in this assessment, additional information is required as follows:

- Changes in concentration of PM_{10} (annual average):
    - The assessment presented has considered the impact of the ventilation facilities alone as well as the project as a whole (where changes in exposures occur as a result of the ventilation facilities as well as the change in use of Pennant Hills Road).

- For this assessment the change in PM_{10} concentration, as a population weighted change in concentration, in the suburbs of West Pennant Hills (southern end) and Wahroonga (northern end) has been considered.
- The change in PM_{10} population weighted concentration (maximum change for the years 2019 and 2029) for these suburbs is as follows:
  - West Pennant Hills = 0.02 µg/m^3 for the southern ventilation facility alone
    = - 0.04 µg/m^3 (ie decreased concentration) for the whole project
  - Wahroonga = 0.03 µg/m^3 for the northern ventilation facility alone
    = - 0.02 µg/m^3 (ie decreased concentration) for the whole project

- Population exposed: It is assumed that the number of children currently with asthma is 15.4 per cent of the total population of children. The per cent of children with asthma is based on the NSW rate of current asthma reported by NSW Health[25] for children aged 2 – 15 years for 2012. This rate has been adopted for assessing children aged 5 – 14 years.
- It is too conservative to assume that 100 per cent of the children aged 5 – 14 years in the whole of the Hornsby South statistical area is present at the location of maximum incremental PM_{10} impacts. For this calculation the number of children aged 5 – 14 years present in West Pennant Hills (2103 children) and Wahroonga (2462 children) have been considered. If 15.4 per cent of the children in these areas have asthma, this results in 324 children in West Pennant Hills and 379 children in Wahroonga with asthma.
- Based on data from Australia (assumed to be relevant to Northern Sydney) for 2002 – 2004, the rate of daily use of reliever medications by children aged 5 – 14 years was 7.2 per cent (ACAM 2007). This incidence is multiplied by 365 to obtain the annual incidence of asthma medication use, ie 0.072 x 365 = 26.28.
- Based on the above the number of additional days per year of bronchodilator use by children associated with the incremental PM_{10} concentration predicted is calculated to be:
  - West Pennant Hills, additional days of bronchodilator use
    = 0.07 days per year for southern ventilation facilities only
    = - 0.1 days per year for whole project – ie a decrease in number of days per year.

  - Wahroonga, additional days of bronchodilator use
    = 0.1 days per year for northern ventilation facilities only
    = -0.08 days per year for whole project – ie a decrease in number of days per year.

Where the project is considered as a whole an overall decrease in the number of days of bronchodilator use by young children is predicted. It is noted that the estimated change in bronchodilator is very low and would not be measurable within the local community.

[25] NSW Health Statistics for current asthma in children aged 2-15 years. The rate for NSW of 15.4 per cent is equivalent to that reported for Northern Sydney (15.3 per cent). Data available from http://www.healthstats.nsw.gov.au/

5.7 Uncertainties

5.7.1 Particulate concentrations

The modelling of particulate impacts involves the use of a number of assumptions in relation to the operation of the project and activities that result in the emission of dust to air. In addition the determining the dispersion of particulate matter from the ventilation facility outlets to the surrounding environment has utilised air dispersion models. While the approach adopted in the AQIA utilised published peer-reviewed emission estimation techniques, the currently available site-specific data on the operation of the project, site-specific meteorology and terrain data and approved models for the quantification of impacts in the surrounding areas, the overall approach adopted is generally conservative to ensure that where uncertainties are present, the impact is overestimated.

5.7.2 Assessment of the effects of exposure to particulate matter

The available scientific information provides a sufficient basis for determining that exposure to particulate matter (particularly $PM_{2.5}$ and smaller) is associated with adverse health effects in a population. The data is insufficient to provide a thorough understanding of all of the potential toxic properties of particulates to which humans may be exposed. Over time it is expected that many of the current uncertainties will be refined with the collection of additional data, however some uncertainty will be inherent in any estimate. The influence of the uncertainties may be either positive or negative.

Overall, however, the epidemiological and toxicological data on which the assessment presented in this technical working paper are based on current and robust for the assessment of risks to human health associated with the potential exposure to particulate matter from combustion sources. When drawing conclusions in relation to the assessment presented, the following also need to be considered.

Exposure-response function

The choice of exposure-response functions for the quantification of potential health impacts is important. For mortality health endpoints, many of the exposure-mortality functions have been replicated throughout the world. While many of these have shown consistent outcomes, the calculated relative risk estimates for these studies do vary. This is illustrated by **Figure 5-6** to **Figure 5-8** that show the variability in the relative risk estimates calculated in published studies for the US (and Canadian) population that are relevant to the primary health endpoints considered in this assessment (USEPA 2012). A similar variability is observed where additional studies from Europe, Asia and Australia/New Zealand are considered.

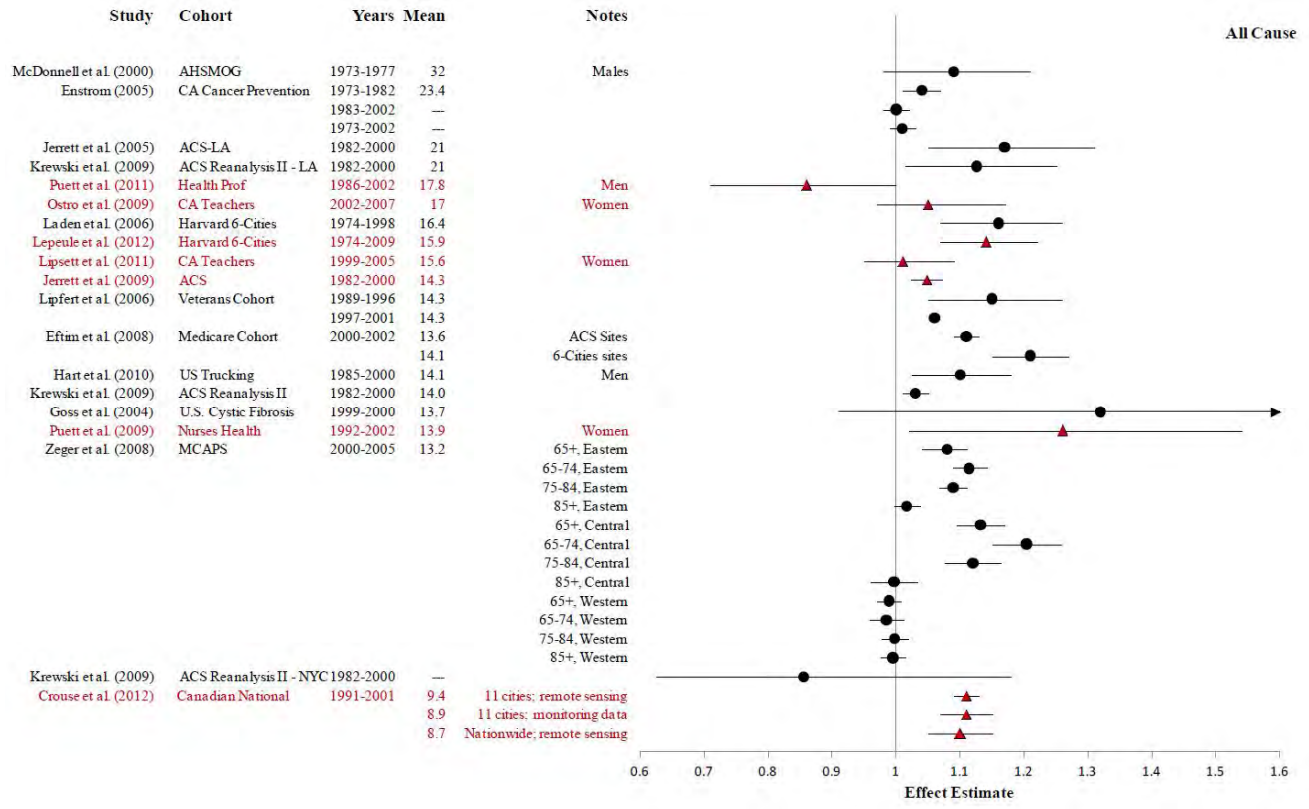


Figure 5-6 All-cause mortality relative risk estimates for long-term exposure to $PM_{2.5}$ (USEPA 2012, note studies in red are those completed since 2009)

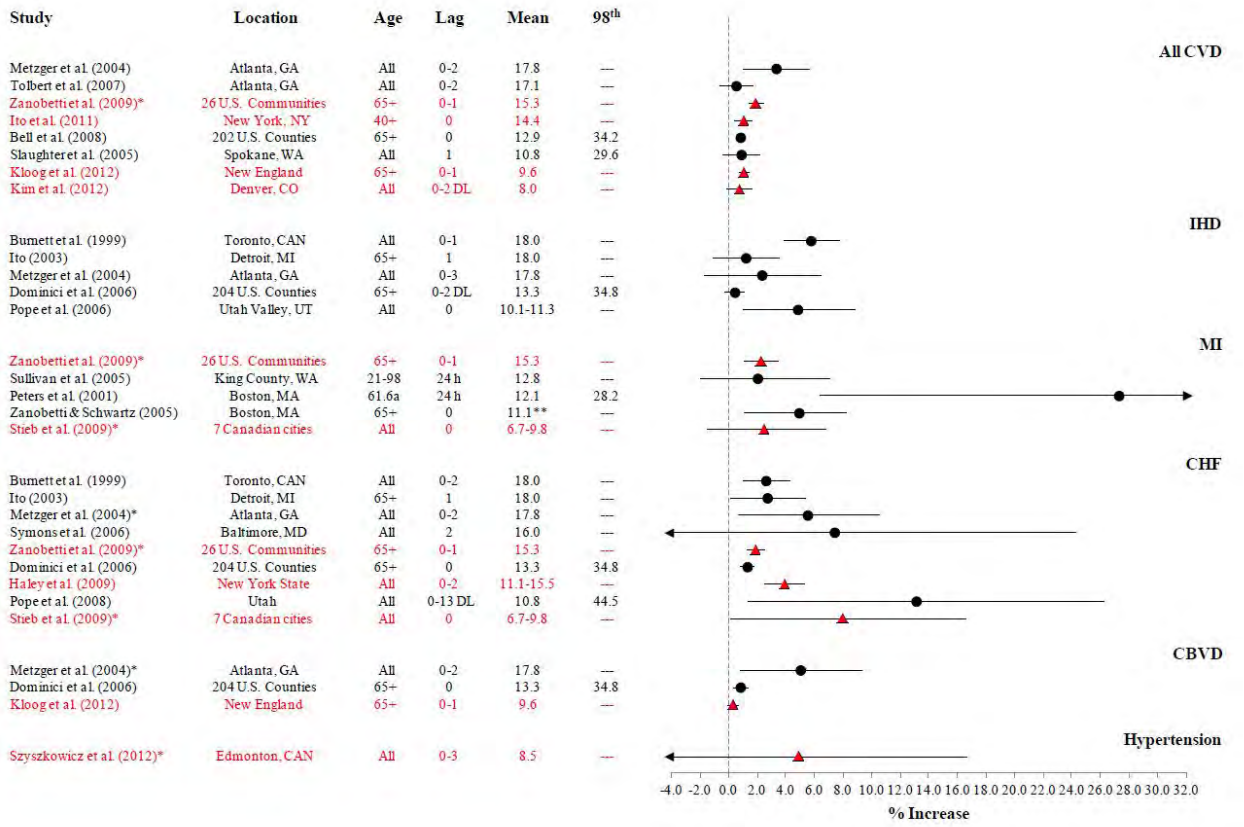


Figure 5-7 Per cent increase in cardiovascular-related hospital admissions for a 10 µg/m^3 increase in short-term (24-hour average) exposure to $PM_{2.5}$ (USEPA 2012, note studies in red are those completed since 2009)

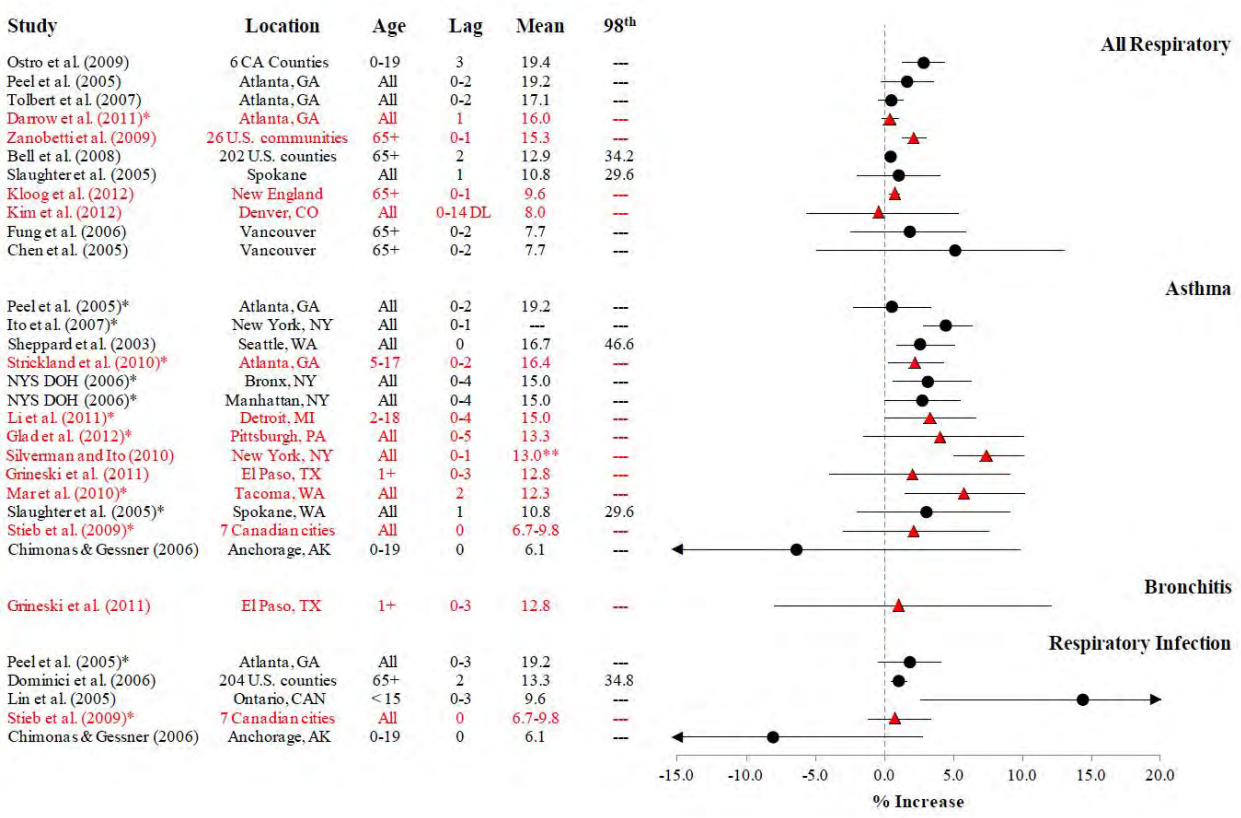


Figure 5-8 Per cent increase in respiratory-related hospital admissions for a 10 µg/m^3 increase in short-term (24-hour average) exposure to $PM_{2.5}$ (USEPA 2012, note studies in red are those completed since 2009)

The above figures illustrate the variability inherent in the studies used to estimate exposure-response functions. The variability is expected to reflect the local and regional variability in the characteristics of particulate matter to which the population is exposed.

Based on the available data, and the detailed reviews undertaken by organisations such as the USEPA (USEPA 2010, 2012) and WHO (WHO 2003, 2006b, 2006a) and discussions with NSW Health, the adopted exposure-response estimates are considered to be current, robust and relevant to the characterisation of impacts form PM.

Shape of exposure-response function

The shape of the exposure-response function and whether there is a threshold for some of the effects endpoints remains an uncertainty. Reviews of the currently available data (that includes studies that show effects at low concentrations) have not shown evidence of a threshold. However, as these conclusions are based on epidemiological studies, discerning the characteristics of the particulates responsible for these effects and the observed shape of the dose-response relationship is complex. For example, it is not possible to determine if the observed no threshold response is relevant to exposure to particulates from all sources, or whether it relates to particulates from combustion sources only. Most studies have demonstrated that there is a linear relationship

between relative risk and ambient concentration however for long-term exposure-related mortality a log-linear relationship is more plausible and should be considered where there is the potential for exposure to very high concentrations of pollution. In this assessment the impact considered is a localised impact with low level incremental increases in concentration. At low levels the assumption of a linear relationship is considered appropriate.

Co-pollutants

It is likely that some of the health effects observed relate to both particulate matter and other related/correlated pollutants. Many of the pollutants evaluated come from a common source (eg fuel combustion) hence the use of only particulate matter as an index for the mix of pollutants is reasonable but conservative, particularly where there are multiple sources, or the scenario being evaluated is not from a source type that is likely to have dominated the studies underlying the relative risk values used in the risk assessment.

Selected health outcomes

The assessment of risk has utilised exposure-response functions and relative risk values that relate to the more significant health endpoints where the most significant and robust positive associations have been identified. The approach does not include all possible subsets of effects that have been considered in various published studies. However, the assessment undertaken has considered the health endpoints/outcomes that incorporate many of the subsets, and has utilised the most current and robust relationships.

Application of exposure-response functions to small populations

The exposure-response functions have been developed on the basis of epidemiological studies from large urban populations where associations have been determined between health effects (health endpoints) and changes in ambient (regional) particulate levels. Typically these exposure response functions are applied to large populations for the purpose of establishing/reviewing air guidelines or reviewing potential impacts of regional air quality issues on large populations. When applied to small populations (less than larger urban centres such as the whole of greater Sydney) the uncertainty increases.

In addition it is noted that the exposure-response functions relate changes in health endpoints with changes in regional air quality measurements. They do not relate to specific local sources (which occur within a regional airshed), or daily variability in exposure that may occur as a result of various different activities that may occur in any one day.

Diesel particulate matter evaluation

The health hazard conclusions associated with exposure to diesel particulate matter are based on studies that are dominated by exhaust emissions from diesel engines built prior to the mid-1990s. With current engine use including some new and many older engines (engines typically stay in service for a long time), the health hazard conclusions, in general, are likely to be applicable to engines currently in use. However as new and cleaner diesel engines, together with different diesel fuels, replace a substantial number of existing engines; the general applicability of the health hazard conclusions may require further evaluation. The NEPC (NEPC 2009) has established a program to reduce diesel emissions from the Australian heavy vehicle fleet. This is expected to lower the potential for all diesel emissions over time.

(blank)

Section 6. Review of noise and vibration impacts

6.1 Overview of the noise and vibration assessment

6.1.1 General

This section presents a summary of the technical working paper: noise and vibration (AECOM, 2014) (NVTP) that relates to construction and operational impacts for noise and vibration associated with the project. The assessment has been reviewed to determine if the predicted impacts have the potential to affect the health of the surrounding community, and if impacts are predicted, if they can be effectively mitigated.

The NVTP provides a more detailed evaluation of all the activities, and the duration of those activities, associated with construction and operation of the proposed tunnel that may give rise to noise or vibration impacts in the surrounding community.

In general the existing noise environment in the areas surrounding the project is dominated by existing road traffic noise. To undertake the noise assessment required for the project, the existing background noise quality is required as the guidelines that relate to noise impacts from a specific project are based on levels allowable above background (refer to **Section 6.1.2** for further detail). Background noise levels were measured at 23 locations throughout the study area. The measured noise levels were used with consideration of the existing road traffic flows to calibrate the operational noise model and also to establish construction noise management levels relevant for the project.

Noise levels that are measured, or modelled, refer to noise levels over a specified period of time and are presented as L_{A1}, L_{A10}, L_{A90}, L_{Amax} and L_{Aeq} levels of the noise environment. The L_{A1}, L_{A10} and L_{A90} levels are the levels exceeded for one percent, 10 per cent and 90 per cent of the sample period respectively. The L_{Amax} is indicative of maximum noise levels due to individual noise events. The L_{A90} is taken as the rating background noise level (RBL). The L_{Aeq} is the energy averaged noise level over a defined period.

The background noise levels in each of the 23 monitoring locations varies, depending on the location of each of these relative to existing noise sources (in particular major roadways). Background noise levels were established for the day (7am to 6pm, varying from 41 to 59 dB(A)), evening (6pm to 10pm, varying from 38 to 54 dB(A)) and night-time (10pm to 7am, varying from 30 to 45 dB(A)) periods (as $L_{A90,\ 15\ minute}$).

6.1.2 Noise assessment criteria

Noise issues in NSW are managed by the NSW Environment Protection Authority. They have prepared a number of guidance documents with regard to the types of noise that are considered in relation to construction and operation of the project. The NSW Industrial Noise Policy (Environment Protection Authority, 2000), the NSW Road Noise Policy (RNP) (Department of Environment, Climate Change and Water, 2011), and the Interim Construction Noise Guideline (ICNG) (Department of Environment and Climate Change, 2009) are all relevant to the assessment of noise generated by this project. In all these policies there is discussion of the need to balance the economic and social benefits of activities that may generate noise with the protection of the

community from the adverse effects of noise. The noise assessment criteria adopted relate to levels of noise that can be tolerated or permitted above background before some adverse effect (annoyance, discomfort, sleep disturbance or complaints) occurs.

For the assessment of noise impacts from the project a range of guidelines and criteria have been adopted:

Construction noise

General

The ICNG has been adopted for the assessment of noise during construction works. In relation to these guidelines, noise impacts from the project are predicted at sensitive receivers and compared with the criteria, referred to as management levels, outlined in the ICNG. Where an exceedance occurs the guidelines advises that the proponent apply all feasible and reasonable work practices to minimise impacts. The management levels are based on levels of noise above background that may result in reactions (or complaints) by the community. The levels are based on some reaction (noise affected) and a strong reaction (highly noise affected).

Levels of noise allowable outside standard work hours, particularly at night, are lower. The ICNG recommended that where construction works are planned to extend over more than two consecutive nights a sleep disturbance assessment is required to be undertaken. Based on the available information on the levels of noise that result in sleep disturbance, a maximum internal noise level below 50-55 dB(A) is considered unlikely to cause awakening. The project has considered that a closed window provides up to 10 dB(A) attenuation of noise, and hence an upper limit of outside noise of 65 dB(A) has been adopted for the assessment of sleep disturbance.

The assessment of noise impacts during construction has been undertaken based on 16 noise catchment areas (assumed to have background noise levels consistent with the background noise monitoring location within that catchment area)

Ground-borne noise

Noise from activities such as tunnelling are assessed on the basis of criteria outlined in the ICNG for the day-time and night-time. These criteria are based on amenity and sleep disturbance when people are at home.

Vibration criteria

Guidelines for vibration from construction activities that are based on structural damage and human comfort (as tactile vibration or regenerated noise) have been adopted in the assessment. The structural damage guidelines adopted are the German Standard DIN 4150 (as there are no Australian Standards available).

In relation to human comfort, intermittent vibration has been evaluated on the basis of the Environment Protection Authority guideline Assessing Vibration: A Technical Guideline (Department of Environment and Conservation, 2006), which is based on vibration dose values (VDV). The criteria for VDV are based on the potential for annoyance (based on the level of vibration over the assessment period). Guidelines for continuous and impulsive vibration are dependent on the time of day and the activity taking place. The criteria established for these vibration types are based on the potential for adverse comment (complaint) and disturbance to building occupants.

Blasting

Construction blasting has been assessed for air blast and ground vibration, which have the potential to result in discomfort as well as damage to structure and services. Guidelines adopted for the assessment of these effects are from ANZECC and Australian Standards. The ANZECC guidelines are based on minimising annoyance and discomfort to persons at sensitive locations caused by blasting. The guidelines also have recommendations that can be implemented to minimise impacts of blasting at sensitive receivers. The guidelines presented in the Australian Standards are consistent with those presented in the ANZECC guidelines but also specifically address structural damage issues.

Blasting activities, if required, will only occur underground and are proposed to be managed such that the criteria are not exceeded.

Operational Noise

Operational noise impacts have been evaluated on the basis of the EPA's RNP, with additional guidance and criteria provided within Roads and Maritime's Environmental Noise Management Manual (ENMM) (Roads and Traffic Authority, 2001). This requires consideration of the following:

- Whether the road is in a new or existing road corridor.
- Whether the receivers have an existing road traffic noise exposure. A receiver is subject to existing road traffic noise exposure if the existing noise levels exceed a daytime $L_{Aeq(15hour)}$ of 55 dB(A) or a night-time $L_{Aeq(9hour)}$ of 50 dB(A).
- Whether the road would introduce road traffic noise from a new direction compared with the existing road traffic noise exposure.

The road noise considered in the assessment has considered receivers along the Hill M2 Motorway, M1 Pacific Highway, Pacific Highway and Pennant Hills Road as receivers subject to existing road noise. The operation of the tunnel itself, while it is a new road, would have the road noise attenuated by the tunnel. Receivers adjacent to the southern and northern portals are located within the existing road corridor.

Within the RNP, the criteria have been developed to provide protection inside and immediately around permanent residences and at schools, hospitals and other sensitive land uses close to roads. The criteria are based on a level where 90 per cent of residents should not be highly annoyed by the noise from traffic.

In addition to the RNP criteria, the ENMM identifies a category of highly affected noise sensitive receivers, which are termed as 'acute' receivers. Where receivers experience noise levels that

would be greater than or equal to $L_{Aeq(15hour)}$ 65 dB(A) and $L_{Aeq(9hour)}$ of 60 dB(A) as a result of existing or future road traffic noise, they would be classified as 'acute'. In these instances, noise mitigation in accordance with practice note IV of the ENMM would be necessary.

In addition guidelines are available for assessing noise impacts from fixed facilities (that would include the ventilation facilities at the southern and northern interchanges) that are based on the following:

- To assess the potential for disturbance (referred to as an intrusive criterion). This criteria is based on existing noise levels measured as RBL ($L_{A90,\ 15\text{-}minute}$, dB(A)) at sensitive receivers (adjusted to account for potentially annoying noise characteristics). This criterion applies to the assessment of residential areas only; and
- To manage noise amenity relevant to specific land uses (referred to as an amenity criterion). This criterion is designed to preserve noise amenity of the land use and protect against noise impacts such as community annoyance and speech interference. The criterion is based on existing ambient and background noise levels ($L_{Aeq,\ 15\text{-}minute}$) at receivers not affected by industrial noise. This criterion applies to all land uses considered in the assessment.

6.2 Impacts during construction

6.2.1 Noise impacts

Noise during construction has focused on the following key works:

- Hills M2 integration works.
- Main tunnel alignment works.
- Development of the southern interchange and northern interchange.
- Works inside ancillary construction compounds, ranging from site establishment to the construction of permanent operational ancillary facilities, where relevant.

During standard working hours the assessment has identified a number of sensitive receivers in the community adjacent to the southern interchange and the Hills M2 Motorway integration works, northern interchange and M1 Pacific Highway tie-in works where the Noise Management Limits (NMLs) are exceeded with a smaller number of receivers identified as highly affected noise receivers. During some activities receivers adjacent to the Wilson Road compound, Trelawney Street compound, northern interchange compound, Bareena Avenue compound and the Pioneer Avenue compound also exceed the NMLs with some considered to be highly noise affected.

Out of hours works have also been evaluated with a number of sensitive receivers located in the community surrounding the southern interchange and the Hills M2 Motorway integration works, southern interchange compound, Wilson Road compound, Trelawney Street compound and northern interchange compound where the Noise Management Limits (NMLs) are exceeded. A small number of receivers have been identified as highly noise affected along the Hills M2 Motorway integration works.

A number of sensitive receivers have been identified where ground-borne noise levels exceed the adopted criterion during the evening and night-time.

A number of sensitive receivers have been identified in areas surrounding the M2 Hills Motorway integration works (bridgeworks), southern interchange compound, Wilson Road compound, Trelawney Street compound and Northern interchange compound where the criteria for sleep disturbance is exceeded.

Review of the impact of construction road traffic on noise levels has identified that the predicted increased during the morning and afternoon peak periods (less than 2 dB) meets the recommended noise goal. Exceedances of the recommended noise goal have been predicted during night-time periods, and the use of local roads by heavy vehicles during night-time periods would be reviewed during construction planning.

As a result of the assessment undertaken for noise during construction works, specific mitigation should be proposed for each construction activity where required before construction begins in the form of a Construction Noise and Vibration Management Plan. The Construction Noise and Vibration Management Plan will also need to consider any cumulative noise impacts in the surrounding community from other major works being undertaken in the area, including the Epping to Thornleigh Third Track and the North West Rail Link. Details of the Construction Noise and Vibration Management Plan (addressing management and mitigation measures as well as requirements for noise monitoring) are outlined in the NVTP.

The issues associated with construction fatigue for receivers located adjacent to the M2 Hills Motorway (where major construction works have only just been completed) were identified and these issues would be required to be managed through community consultation.

6.2.2 Vibration impacts

A range of management measures have been identified to monitor and manage vibration impacts associated with surface works. During tunnelling operations a number of sensitive receivers were identified where the night-time vibration criteria (preferred criteria based on human comfort [not structural damage]) were exceeded. No predicted vibration levels exceeded the maximum criteria for these works which are related to structural damage.

Impacts associated with vibration are to be addressed, mitigated or managed, using measured to be outlined in the Construction Noise and Vibration Management Plan.

6.3 Noise impacts during operation

In relation to noise impacts from the operation of the project the assessment identified the following:

- Southern interchange and Hills M2 Motorway integration:
  - Noise impacts have been identified at a number of sensitive receiver locations associated with road traffic noise.
  - During the design year (Year 2029), a total of 134 receivers exceed the $L_{Aeq(15hour)}$ daytime noise criteria of 60 dB(A). A total of 264 receivers exceed the $L_{Aeq(9hour)}$ noise criteria of 55 dB(A) during the night-time period.
  - Of these sensitive receivers, 47 receivers would be eligible for consideration for noise mitigation. Of the 47 receivers, 46 receivers have been identified as acute. However, these receivers would be considered to be acute in the absence of the project. Additional noise mitigation is also identified for Early Childhood Intervention Australia in North Rocks.
  - For this project, all road design and traffic management options have been considered. A low-noise pavement in the form of stone-mastic asphalt has been included in the design. Noise barriers already partially line both sides of the Hills M2 Motorway corridor. Further mitigation in the form of increased height noise barriers and architectural treatment on individual homes is recommended to achieve compliance with the applicable noise goals. A list of properties that require additional architectural treatment (such as upgraded windows and doors) is provided in the technical working paper.

- Northern interchange:
  - Noise impacts have been identified at a number of receiver locations associated with road traffic noise.
  - During the design year (Year 2029), a total of 106 receivers exceed the $L_{Aeq(15hour)}$ daytime noise criteria of 60 dB(A). A total of 184 receivers exceed the $L_{Aeq(9hour)}$ noise criteria of 55 dB(A) during the night-time period.
  - Of these sensitive receivers, 82 receivers would be eligible for consideration for noise mitigation. Of the 82 receivers, 69 receivers have been identified as acute. The majority of these receivers would be identified as acute in the absence of the project. Additional noise mitigation is also identified for St Pauls Church on Pearces Corner, Wahroonga.
  - For this project, all road design and traffic management options have been explored. Low-noise pavements have been included in the design. Noise barriers already line both sides of the M1 Pacific Motorway road corridor. Further mitigation in the form of increased height noise barriers and architectural treatment on individual homes is recommended to achieve compliance with the applicable noise goals. A list of properties that require additional architectural treatment (such as upgraded windows and doors) is provided in the technical working paper.

6.4 Health outcomes relevant to noise

Environmental noise has been identified (I-INCE 2011; WHO 2011) as a growing concern in the growth of urban areas because it has negative effects on quality of life and well-being and it has the potential for causing harmful physiological health effects. With increasingly urbanised societies impacts of noise have the potential to increase within the community.

Deciding on the most effective noise management option in a specific situation is not just a matter of defining noise control actions to achieve the lowest noise levels or meeting arbitrarily chosen criteria for exposure to noise. The goal should be to achieve the best available compromise between the benefits to society of reduced exposure to community noise versus the costs and technical feasibility of achieving the desired exposure levels. On the one hand there are the rights of the community to enjoy an acceptably quiet and healthy environment. On the other are the needs of the society for a new or upgraded facilities, industries, roads, recreation opportunities, etc, all of which typically produce more community noise (I-INCE 2011; WHO 2011).

Sound is a natural phenomenon that only becomes noise when it has some undesirable effect on people or animals. Unlike chemical pollution, noise energy does not accumulate either in the body or in the environment but it can have both short-term and long-term adverse effects on people. These health effects include (WHO 1999, 2011):

- Sleep disturbance.
- Annoyance.
- Hearing impairment.
- Interference with speech and other daily activities.
- Children's school performance (through effects on memory and concentration).
- Cardiovascular health.

Other effects for which evidence of health impacts exists, but for which the evidence is weaker, include:

- Effects on mental health (usually in the form of exacerbation of existing issues for vulnerable populations rather than direct effects).
- Effects on the performance of cognitive tasks.
- Some evidence of indirect effects such as impacts on the immune system.

Often, annoyance is the major consideration because it reflects the community's dislike of noise and their concerns about the full range of potential negative effects.

There are many possible reasons for noise annoyance in different situations. Noise can interfere with speech communication or other desired activities. Noise can contribute to sleep disturbance, which can obviously be very annoying and has the potential to lead to long-term health effects. Sometimes noise is just perceived as being inappropriate in a particular setting without there being any objectively measurable effect at all. In this respect, the context in which sound becomes noise can be more important than the sound level itself.

Different individuals have different sensitivities to different types of noise and this reflects differences in expectations and attitudes more than it reflects any differences in underlying auditory physiology. A noise level that is perceived as reasonable by one person in one context (for example

in their kitchen when preparing a meal) may be considered completely unacceptable by that same person in another context (for example in their bedroom when they are trying to sleep). In this case the annoyance relates, in part, to the intrusion from the noise. Similarly a noise level, which is considered to be completely unacceptable by one person, may be of little consequence to another even if they are in essentially the same room. In this case the annoyance depends almost entirely on the personal preferences, lifestyles and attitudes of the listeners concerned.

It is against this background that regulators in various communities have established sound level criteria above which noise is deemed to be unacceptable and below which it is deemed to be acceptable. Any assessment of noise impacts needs to consider the relevant criteria established for a new or existing (or upgraded) facility or activity. Where there are impacts in excess of these guidelines an assessment of noise mitigation is required to be undertaken.

In relation to the project, potential noise impacts have been assessed against Australian (more specifically New South Wales) criteria that have been established on the basis of the relationship between noise and health impacts. The criteria developed for use in the assessment for control of noise come from policy documents developed by the NSW Government including the NSW Industrial Noise Policy, the NSW Interim Construction Noise Policy, and the NSW Road Noise Policy. All of these policies are based on the health effects of noise, and are based on guidance and reviews published in the following:

- World Health Organisation- Guidelines on Community Noise – Health effects of noise (WHO 1999).
- World Health Organisation – Night Noise Guidelines for Europe (WHO 2009).
- Environmental Health Council of Australia - The health effects of environmental noise – other than hearing loss (enHealth 2004).

Various attempts have been made to assess the effect (measured by average reported annoyance, sleep disturbance or a similar type of effect) from community noise (measured by long term average sound levels) to develop exposure-response relationships. As individual reactions to noise are so varied, these studies need large sample sizes to obtain reasonable correlation between the noise exposure and the response. Any dose-response relationship determined from large studies over a range of communities and cultures will not necessarily represent the reaction of individuals or small communities. These exposure-response relationships are of value for macro-scale (ie whole urban environment scale) strategic assessment purposes where individual differences are not important, however they are not useful when considering potential impacts to a small population located close to a specific project/activity. Hence these macro-scale relationships cannot be applied (in any meaningful way) in this assessment.

As guidelines/criteria are available for construction and operational noise impacts associated with this project, that are based on the protection of health (including annoyance), the assessment of potential health impacts has focused on whether the guidelines/criteria established can be met. Noise levels that do not comply with these guidelines/criteria would have the potential to have negative health outcomes for the community adjacent to the Hills M2 Motorway integration works, southern interchange and northern interchange.

Currently, the worst case assessment predicts that noise criteria would be exceeded at a number of properties in these areas without additional noise mitigation measures.

Construction

During construction it is important that proposed measures for mitigation, management and monitoring be included and detailed in the Construction Noise and Vibration Management Plan. Measures that have been recommended to mitigate the construction noise impact at adjacent sensitive receivers include:

- Completion of a construction noise and vibration management plan
- Community consultation
- Appropriate selection and maintenance of equipment
- Use of noise barriers
- Scheduling of work for less sensitive time periods
- Situating plant in less noise sensitive locations
- Training of construction site workers
- Construction traffic management
- Noise monitoring
- Respite offers, and
- Alternative accommodation.

Feasible and reasonable mitigation measures would be detailed within the construction noise and vibration management plan to manage predicted noise levels at sensitive receivers. Consultation with the affected community would also occur prior to and during construction

Operations

During operation of the project within much of the community surrounding the project, predicted noise impacts meet the criteria established that are based on the protection of health. There are some properties where additional mitigation measures (that include the use of low noise road pavement, replacement and improvement of noise barriers and implementation of architectural treatments on individual homes) are required to ensure that noise impacts are reduced where feasible and reasonable to meet the established criteria/guidelines. The recommended mitigation measures would ensure that the levels of road traffic noise experienced by residents would be reduced as low as is feasible and reasonable. The requirements and the form of noise mitigation would be confirmed when assessed against the detailed design.

For a number of individual properties architectural treatment has been identified to mitigate noise impacts indoors, so that the noise criteria can be met. While these mitigation measures are required to ensure that the environment where people spend most of the day is not associated with adverse health impacts it does assume that residents take up these measures and where they do, they keep external windows and doors shut and have minimal use of outdoor areas.

In urban areas particularly where noise is dominated by road traffic noise, access to outdoor green-space areas that are not (perceived to be) impacted by noise (eg where there is a quiet side of a specific property or there is access to a quiet green space areas close to the residential home) have been found to significantly affect well-being and lower levels of stress (Gidlöf-Gunnarsson &

Öhrström 2007). Impacts on the use and enjoyment of outdoor areas due to increased noise may result in increased levels of stress at individual properties.

Where specific residents/properties do not take up the recommended architectural treatments to mitigate noise indoors there is the potential for noise levels at these properties to exceed the relevant guidelines/criteria. In these situations there is the potential for adverse health effects, particularly annoyance and sleep disturbance, to occur.

Community consultation will be an important part of the process in addressing noise impacts for the project as there are a number of individual homes where architectural treatment is required to enable the noise criteria to be met, and minimise the potential for adverse health effects associated with the project.

Section 7. Conclusions

An assessment of health impacts associated with emissions to air as well as noise and vibration resulting from the construction and operation of the project has been undertaken.

In relation to impacts to air quality, potential health impacts have been evaluated on the basis of appropriate health based guidelines (that are protective of public health), or, in the case of exposure to $PM_{2.5}$ and PM_{10} conducting a detailed assessment of the impact of the emissions on key community health indicators. All predicted concentrations of carbon monoxide, nitrogen dioxide, key individual volatile organic compounds and polycyclic aromatic hydrocarbons are below health based guidelines. For the assessment of potential impacts of $PM_{2.5}$ and PM_{10} from the operation of the tunnel, potential health impacts are low and essentially negligible in proximity to the ventilation outlets. Overall, taking a significant number of vehicles, in particular trucks off the existing road corridor along Pennant Hills Road, and managing emissions via the tunnel ventilation system, would lead to a net benefit to health within the community.

In relation to noise and vibration, potential impacts during construction and operation have been considered. During construction potential impacts of noise and vibration on the local community can be managed and/or mitigated through the implementation of a range of measures. For construction noise and vibration, these management and mitigation measures (including the requirement for noise monitoring) are to be outlined in detail within the Construction Noise and Vibration Management Plan.

During operation of the project a number of individual homes located adjacent to the northern interchange as well as the southern interchange and the Hills M2 Motorway integration works where noise impacts, in excess of the health based guidelines adopted, have been identified. The recommended mitigation measures would ensure that the levels of road traffic noise experienced by residents would be reduced as low as feasible and reasonable. The requirements and the form of operational noise mitigation would be confirmed when assessed against the detailed design. This would include consideration of the feasibility of noise barriers with consideration to engineering considerations, and the outcomes of consultation with the affected community

(blank)

Section 8. References

Project Reports:

AECOM, 2014. Technical Working Paper: Air Quality – NorthConnex. AECOM Australia Pty Ltd.

AECOM, 2014. Technical Working Paper: Noise and Vibration – NorthConnex. AECOM Australia Pty Ltd.

Other References:

Abdullahi, KL, Delgado-Saborit, JM & Harrison, RM 2013, 'Emissions and indoor concentrations of particulate matter and its specific chemical components from cooking: A review', *Atmospheric environment,* vol. 71, pp. 260-294.

ACAM 2007, *Patterns of asthma medication use in Australia*, Australian Centre for Asthma Monitoring, Australian Institute of Health and Welfare, Canberra.

AMOG 2012, *M5 East Tunnel Filtration Trial Evaluation Program - Review of Operational Performance, Independent Review Role M5 East Air Filtration Project, prepared for Roads and Maritime Services*.

Anderson, CH, Atkinson, RW, Peacock, JL, Marston, L & Konstantinou, K 2004, *Meta-analysis of time-series studies and panel studies of Particulate Matter (PM) and Ozone (O3), Report of a WHO task group*, World Health Organisation.

Attfield, MD, Schleiff, PL, Lubin, JH, Blair, A, Stewart, PA, Vermeulen, R, Coble, JB & Silverman, DT 2012, 'The Diesel Exhaust in Miners study: a cohort mortality study with emphasis on lung cancer', *Journal of the National Cancer Institute,* vol. 104, no. 11, Jun 6, pp. 869-883.

Barck, C, Sandstrom, T, Lundahl, J, Hallden, G, Svartengren, M, Strand, V, Rak, S & Bylin, G 2002, 'Ambient level of NO2 augments the inflammatory response to inhaled allergen in asthmatics', *Respiratory medicine,* vol. 96, no. 11, Nov, pp. 907-917.

Barck, C, Lundahl, J, Hallden, G & Bylin, G 2005, 'Brief exposures to NO2 augment the allergic inflammation in asthmatics', *Environmental research,* vol. 97, no. 1, Jan, pp. 58-66.

Bell, ML, Ebisu, K, Peng, RD, Walker, J, Samet, JM, Zeger, SL & Dominici, F 2008, 'Seasonal and Regional Short-term Effects of Fine Particles on Hospital Admissions in 202 US Counties, 1999–2005', *American Journal of Epidemiology,* vol. 168, no. 11, December 1, 2008, pp. 1301-1310.

Bell, ML 2012, 'Assessment of the health impacts of particulate matter characteristics', *Research report*, no. 161, Jan, pp. 5-38.

Burgers, M & Walsh, S 2002, *Exposure Assessment and Risk Characterisation for the Development of a PM2.5 Standard*, NEPC. viewed September 2002,

Bylin, G, Hedenstierna, G, Lindvall, T & Sundin, B 1988, 'Ambient nitrogen dioxide concentrations increase bronchial responsiveness in subjects with mild asthma', *The European respiratory journal : official journal of the European Society for Clinical Respiratory Physiology,* vol. 1, no. 7, Jul, pp. 606-612.

Cameron, M, Brennan, E, Durkin, S, Borland, R, Travers, MJ, Hyland, A, Spittal, MJ & Wakefield, MA 2010, 'Secondhand smoke exposure (PM2.5) in outdoor dining areas and its correlates', *Tob Control,* vol. 19, no. 1, Feb, pp. 19-23.

CAWCR 2010, *Indoor Air Project, Part 1: Main Report, Indoor Air in Typical Australian Dwellings, A report to the, Air Quality Section, Environment Standards Branch, Department of the Environment, Water, Heritage and the Arts*, The Centre for Australian Weather and Climate Research, Partnership between CSIRO and Bureau of Meteorology.

CCME 2010, *Canadian Soil Quality Guidelines, Carcinogenic and Other Polycyclic Aromatic Hydrocarbons (PAHs) (Environmental and Human Health Effects), Scientific Criteria Document (revised)*, Quebec.

CSIRO 2008, *Particles, Ozone and Air Toxic Levels in Rural Communities during Prescribed Burning Seasons*, CSIRO Marine and Atmospheric Research.

DEC 2005a, *Approved Methods for the Modelling and Assessment of Air Pollutants in NSW*, NSW Department of Environment and Conservation.

DEC 2005b, *Approved Methods for the Modelling and Assessment of Air Pollutants in New South Wales*, Department of Environment and Conservation NSW (DEC),

DEH 2003, *Technical Report No. 1: Toxic Emissions from Diesel Vehicles in Australia*, Environment Australia.

EC 2011, *Final report on risk functions used in the case studies*, Health and Environment Integrated Methodology and Toolbox for Scenario Development (HEIMTSA).

enHealth 2001, *Health Impact Assessment Guidelines*, Commonwealth Department of Health and Aged Care.

enHealth 2004, *The health effects of environmental noise – other than hearing loss*, enHealth Council, Department of Health and Ageing.

enHealth 2012a, *Environmental Health Risk Assessment, Guidelines for assessing human health risks from environmental hazards*, Commonwealth of Australia, Canberra.

enHealth 2012b, *Australian Exposure Factors Guide*, Commonwealth of Australia, Canberra.

EPA 1998, *Action for Air: The NSW Government's 25-Year Air Quality Management Plan*, NSW Environment Protection Authority.

EPA 2012, *Air Emissions Inventory for the Greater Metropolitan Region in New South Wales, 2008 Calendar Year, On-Road Mobile Emissions:Results*, NSW Environment Protection Authority, Sydney.

EPHC 2010, *Expansion of the multi-city mortality and morbidity study, Final Report*, Environment Protection and Heritage Council.

Esworthy, R 2013, *Air Quality: EPA's 2013 Changes to the Particulate Matter (PM) Standard*, Congressional Research Service.

ETC 2013, *Assessment of population exposure to air pollution during commuting in European cities, ETC/ACM Technical Paper 2013/2*, European Topic Centre on Air Pollution and Climate Change Mitigation.

Fewtrell, L & Bartram, J 2001, *Water quality: Guidelines, standards and health, Assessment of risk and risk management for water-related infectious disease*, WHO. <http://www.who.int/water_sanitation_health/dwq/whoiwa/en/>.

Gidlöf-Gunnarsson, A & Öhrström, E 2007, 'Noise and well-being in urban residential environments: The potential role of perceived availability to nearby green areas', *Landscape and Urban Planning,* vol. 83, no. 2–3, pp. 115-126.

Giugliano, M, Lonati, G, Butelli, P, Romele, L, Tardivo, R & Grosso, M 2005, 'Fine particulate (PM2.5–PM1) at urban sites with different traffic exposure', *Atmospheric environment,* vol. 39, no. 13, pp. 2421-2431.

Gomišček, B, Hauck, H, Stopper, S & Preining, O 2004, 'Spatial and temporal variations of PM1, PM2.5, PM10 and particle number concentration during the AUPHEP—project', *Atmospheric environment,* vol. 38, no. 24, pp. 3917-3934.

He, C, Morawska, L, Hitchins, J & Gilbert, D 2004, 'Contribution from indoor sources to particle number and mass concentrations in residential houses', *Atmospheric environment,* vol. 38, no. 21, pp. 3405-3415.

HEI 2013, *Understanding the Health Effects of Ambient Ultrafine Particles, HEI Review Panel on Ultrafine Particles, HEI Perspectives 3*, Health Effects Institute, Boston.

Higson, DJ 1989, *Risks to Individuals in NSW and in Australia as a Whole*, Nuclear Science Bureau,

Hoffman, HJ 1988, *Survey of risks : Memorandum to the docket, Memorandum to the docket: OAQPS 79-3, Part 1*, EPA, Washington D.C.

I-INCE 2011, *Guidelines for Community Noise Impact Assessment and Mitigation, I-INCE Publication Number: 11-1*, I-INCE Technical Study Group on Community Noise: Environmental Noise Impact Assessment and Mitigation.

IARC 2012, *IARC: Diesel Engine Exhaust Carcinogenic*, World Health Organisation.

Kelly, KE 1991, 'The Myth of 10-6 as a Definition of Acceptable Risk', *84th Annual Meeting, Air & Waste Management Association* Air & Waste Management Association.

Keywood, MD, Ayers, GP, Gras, JL, Gillett, RW & Cohen, DD 1999, 'Relationships between size segregated mass concentration data and ultrafine particle number concentrations in urban areas', *Atmospheric environment,* vol. 33, no. 18, pp. 2907-2913.

Knibbs, LD, de Dear, RJ & Morawska, L 2010, 'Effect of cabin ventilation rate on ultrafine particle exposure inside automobiles', *Environmental science & technology,* vol. 44, no. 9, May 1, pp. 3546-3551.

Krewski, D, Jerrett, M, Burnett, RT, Ma, R, Hughes, E, Shi, Y, Turner, MC, Pope, CA, 3rd, Thurston, G, Calle, EE, Thun, MJ, Beckerman, B, DeLuca, P, Finkelstein, N, Ito, K, Moore, DK, Newbold, KB, Ramsay, T, Ross, Z, Shin, H & Tempalski, B 2009, 'Extended follow-up and spatial analysis of the American Cancer Society study linking particulate air pollution and mortality', *Research report*, no. 140, May, pp. 5-114; discussion 115-136.

Martuzzi, M, Galasso, C, Ostro, B, Forastiere, F & Bertollini, R 2002, *Health Impact Assessment of Air Pollution in the Eight Major Italian Cities*, World Health Organisation, Europe.

Meng, X, Ma, Y, Chen, R, Zhou, Z, Chen, B & Kan, H 2013, 'Size-fractionated particle number concentrations and daily mortality in a Chinese city', *Environmental health perspectives,* vol. 121, no. 10, Oct, pp. 1174-1178.

Morawska, L, Moore, MR & Ristovski, ZD 2004, *Health Impacts of Ultrafine Particles, Desktop Literature Review and Analysis*, Australian Government, Department of the Environment and Heritage.

NEPC 1998, *National Environment Protection (Ambient Air Quality) Measure - Revised Impact Statement*, National Environment Protection Council.

NEPC 1999 amended 2013, *National Environment Protection (Assessment of Site Contamination) Measure Schedule B8 Guideline on Community Engagement and Risk Communication*, National Environment Protection Council,

NEPC 2002, *National Environment Protection (Ambient Air Quality) Measure, Impact Statement for PM2.5 Variation Setting a PM2.5 Standard in Australia*, National Environment Protection Council.

NEPC 2003, *National Environment Protection (Ambient Air Quality) Measure*, National Environment Protection Council.

NEPC 2009, *National Environment Protection (Diesel Vehicle Emissions) Measure*, NEPC Service Corporation,

NEPC 2010, *Review of the National Environment Protection (Ambient Air Quality) Measure, Discussion Paper, Air Quality Standards*, National Environmental Protection Council.

NHMRC 2008, *Air Quality in and Around Traffic Tunnels, Systematic Literature Review*, National Health and Medical Research Council.

NSW Health 2003, *M5 East Tunnels Air Quality Monitoring Project*, South Eastern Sudney Public Health Unit & NSW Department of Health.

NSW Health 2004, *Comparison of personal exposures to air pollutants by commuting mode in Sydney, BTEX & NO_2*, NSW Department of Health, Sydney.

NSW Planning 2011, *Risk Criteria for Land Use Safety Planning, Hazardous Industry Planning Advisory Paper No 4*, Sydney.

OEHHA 1998, *Proposed Identification of Diesel Exhaust as a Toxic Air Contaminant. Appendix III, Part B: Health Risk Assessment for Diesel Exhaust*, Office of Environmental Health Hazard Assessment, Air Toxicology and Epidemiology Section.

OEHHA 2002, *Staff Report: Public Hearing to Consider Amendments to the Ambient Air Quality Standards for Particulate Matter and Sulfates*, Office of Environmental Health Hazard Assessment.

Ostro, B 2004, *Outdoor Air Pollution: Assessing the environmental burden of disease at national and local levels.*, World Health Organisation.

Ostro, B, Broadwin, R, Green, S, Feng, WY & Lipsett, M 2006, 'Fine particulate air pollution and mortality in nine California counties: results from CALFINE', *Environmental health perspectives,* vol. 114, no. 1, Jan, pp. 29-33.

Pope, CA, 3rd, Burnett, RT, Thun, MJ, Calle, EE, Krewski, D, Ito, K & Thurston, GD 2002, 'Lung cancer, cardiopulmonary mortality, and long-term exposure to fine particulate air pollution', *JAMA : the journal of the American Medical Association,* vol. 287, no. 9, Mar 6, pp. 1132-1141.

Schoeny, R 2008, 'Acceptable Risk Levels at EPA', in U.S Department of the Interior, BoR (ed), *Workshop on Tolerable Risk Evaluation*. <http://www.usbr.gov/ssle/damsafety/jointventures/tolerablerisk/07Schoeny.pdf>.

Silverman, DT, Samanic, CM, Lubin, JH, Blair, AE, Stewart, PA, Vermeulen, R, Coble, JB, Rothman, N, Schleiff, PL, Travis, WD, Ziegler, RG, Wacholder, S & Attfield, MD 2012, 'The Diesel Exhaust in Miners study: a nested case-control study of lung cancer and diesel exhaust', *Journal of the National Cancer Institute,* vol. 104, no. 11, Jun 6, pp. 855-868.

Sjoberg, K, Haeger-Eugensson, M, Forsberg, B, Astrom, S, Hellsten, S, Larsson, K, Bjork, A & Blomgren, H 2009, *Quantification of population exposure to PM2.5 and PM10 in Sweden 2005*, Swedish Environmental Research Institute.

Sorensen, M, Loft, S, Andersen, HV, Raaschou-Nielsen, O, Skovgaard, LT, Knudsen, LE, Nielsen, IV & Hertel, O 2005, 'Personal exposure to PM2.5, black smoke and NO2 in Copenhagen: relationship to bedroom and outdoor concentrations covering seasonal variation', *Journal of exposure analysis and environmental epidemiology,* vol. 15, no. 5, Sep, pp. 413-422.

Stafford, J, Daube, M & Franklin, P 2010, 'Second hand smoke in alfresco areas', *Health Promot J Austr,* vol. 21, no. 2, Aug, pp. 99-105.

Strand, V, Svartengren, M, Rak, S, Barck, C & Bylin, G 1998, 'Repeated exposure to an ambient level of NO2 enhances asthmatic response to a nonsymptomatic allergen dose', *The European respiratory journal : official journal of the European Society for Clinical Respiratory Physiology,* vol. 12, no. 1, Jul, pp. 6-12.

Svartengren, M, Strand, V, Bylin, G, Jarup, L & Pershagen, G 2000, 'Short-term exposure to air pollution in a road tunnel enhances the asthmatic response to allergen', *The European respiratory journal : official journal of the European Society for Clinical Respiratory Physiology,* vol. 15, no. 4, Apr, pp. 716-724.

USEPA 2002, *Health Assessment Document For Diesel Engine Exhaust*, United States Environmental Protection Agency.

USEPA 2005, *Particulate Matter Health Risk Assessment For Selected Urban Areas*, U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards.

USEPA 2009a, *Risk Assessment Guidance for Superfund, Volume I: Human Health Evaluation Manual, (Part F, Supplemental Guidance for Inhalation Risk Assessment)*, United States Environmental Protection Agency, Washington, D.C.

USEPA 2009b, *Integrated Science Assessment for Particulate Matter*, United States Environmental Protection Agency. <http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=216546#Download>.

USEPA 2010, *Quantitative Health Risk Assessment for Particulate Matter*, Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency.

USEPA 2012, *Provisional Assessment of Recent Studies on Health Effects of Particulate Matter Exposure*, National Center for Environmental Assessment RTP Division, Office of Research and Development, U.S. Environmental Protection Agency.

WHO 1996, *Diesel Fuel and Exhaust Emissions*, Environmental Health Criteria 171, World Health Organisation.

WHO 1999, *Guidelines for Community Noise*, World Health Organisation, Geneva.

WHO 2000a, *WHO air quality guidelines for Europe, 2nd edition, 2000 (CD ROM version)*, World Health Organisation.

WHO 2000b, *Guidelines for Air Quality*, World Health Organisation, Geneva.

WHO 2003, *Health Aspects of Air Pollution with Particulate Matter, Ozone and Nitrogen Dioxide, Report on a WHO Working Group*, World Health Organisation.

WHO 2005a, *WHO air quality guidelines global update 2005, Report on a Working Group meeting, Bonn, Germany, 18-20 October 2005*, World Health Organisation.

WHO 2005b, *Effects of Air Pollution on Children's Health and Development, A Review of the Evidence*, World Health Organisation, Special Programme on Health and Environment, European Centre for Environment and Health.

WHO 2006a, *Health risks or particulate matter from long-range transboundary air pollution*, World Health Organisation Regional Office for Europe.

WHO 2006b, *WHO Air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide, Global Update, Summary of risk assessment*, World Health Organisation.

WHO 2009, *Night Noise Guidelines for Europe* World Health Organisation Regional Office for Europe.

WHO 2011, *Burden of disease from environmental noise, Quantification of healthy life years lost in Europe*, World Health Organisation and JRC European Commission.

WHO 2013a, *Review of evidence on health aspects of air pollution - REVIHAAP Project, Technical Report*, World Health Organization, Regional Office for Europe.

WHO 2013b, *Health Effects of Particulate Matter, Policy implications for countries in eastern Europe, Caucasus and central Asia*, WHO Regional Office for Europe.

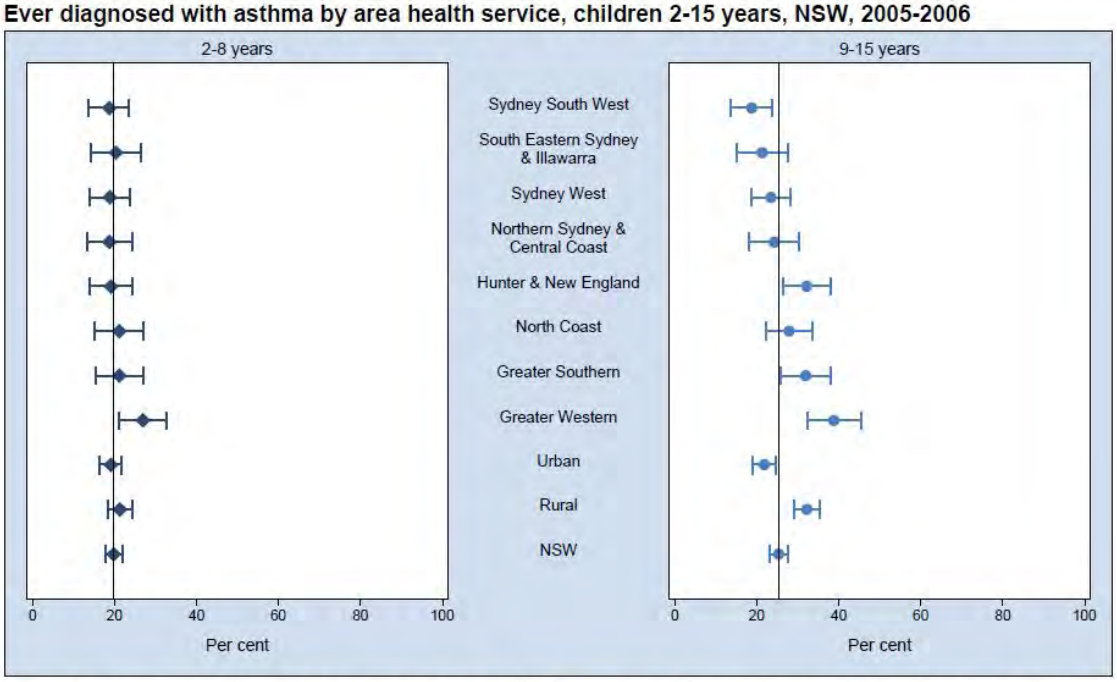
Zanobetti, A & Schwartz, J 2009, 'The effect of fine and coarse particulate air pollution on mortality: a national analysis', *Environmental health perspectives,* vol. 117, no. 6, Jun, pp. 898-903.

Appendix A Summary of existing asthma health statistics

A1 Asthma in children

The following graphs are reproduced from the NSW Population Health Survey, 2006 – 2006 Report on child health published by NSW Health (2008).

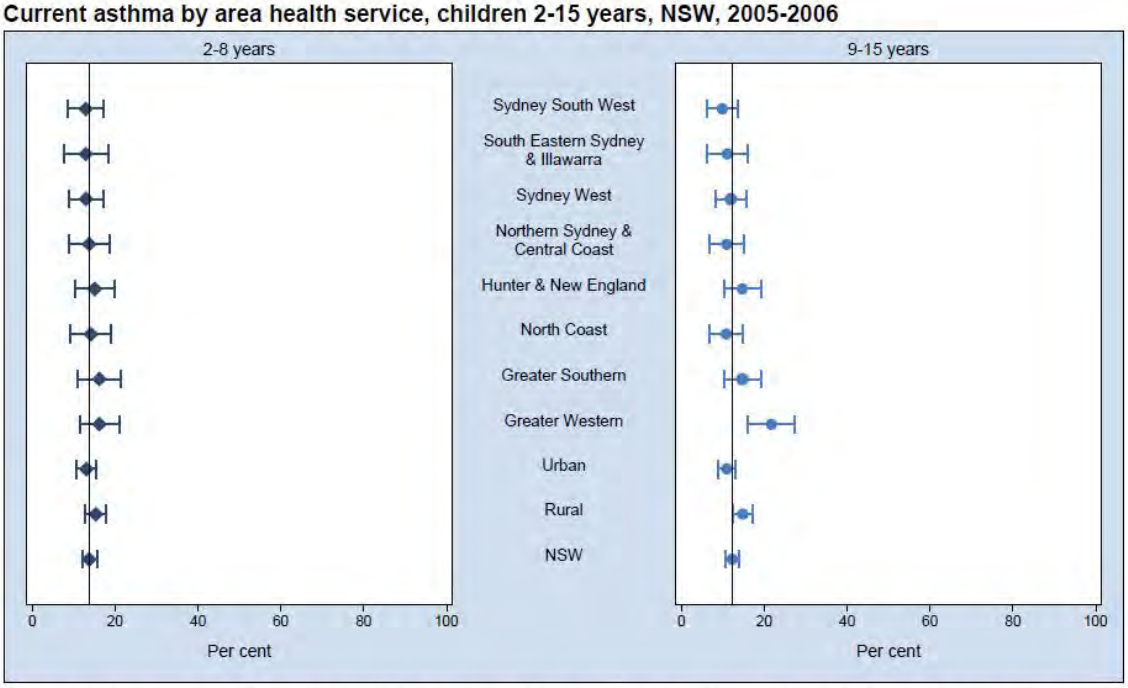
Ever diagnosed with asthma by area health service, children 2-15 years, NSW, 2005-2006



Note: Estimates are based on 3,938 respondents in NSW. For this indicator 11 (0.28%) were not stated (Don't know or Refused) in NSW. The indicator includes those children who have ever been told by a doctor or hospital that they have asthma. The question used to define the indicator was: Has child ever been told by a doctor or hospital heor she has asthma?

Source: New South Wales Population Health Survey 2006 (HOIST). Centre for Epidemiology and Research, NSW Department of Health.

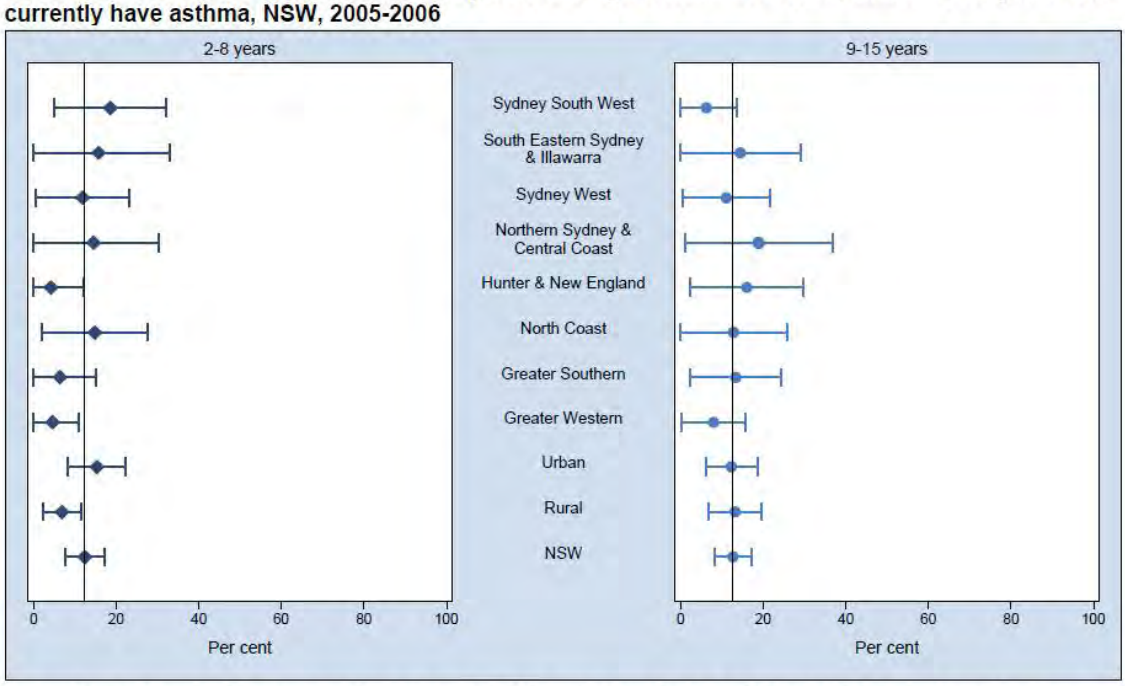
Current asthma by area health service, children 2-15 years, NSW, 2005-2006



Note: Estimates are based on 3,937 respondents in NSW. For this indicator 12 (0.30%) were not stated (Don't know or Refused) in NSW. The indicator includes those children with symptoms of asthma or who had treatment for asthma in the last 12 months. The questions used to define the indicator were: Has child ever been told by a doctor or hospital he or she has asthma? Has child had symptoms of asthma or treatment for asthma in the last 12 months?

Source: New South Wales Population Health Survey 2006 (HOIST). Centre for Epidemiology and Research, NSW Department of Health.

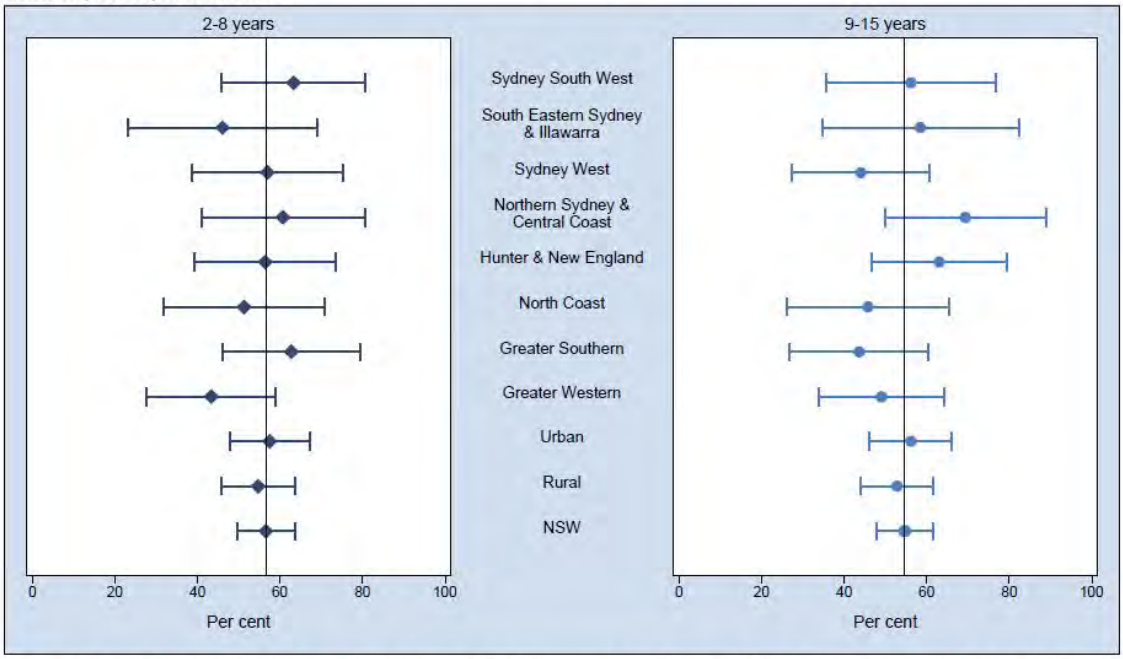
Moderate to extreme interference with daily activities by area health service, children 2-15 years who currently have asthma, NSW, 2005-2006



Note: Estimates are based on 536 respondents in NSW. For this indicator 3 (0.56%) were not stated (Don't know or Refused) in NSW. The indicator includes those children whose asthma interfered with their ability to manage day-to-day activities moderately, quite a lot, or extremely in the last 4 weeks. The questions used to define the indicator were: Have you ever been told by a doctor or hospital you have asthma? Have you had symptoms of asthma or taken treatment for asthma in the last 12 months? During the last 4 weeks, did your asthma interfere with your ability to manage your day to day activities? and Did it interfere with these activities: A little bit, Moderately, Quite a lot, or Extremely?

Source: New South Wales Population Health Survey 2006 (HOIST). Centre for Epidemiology and Research, NSW Department of Health.

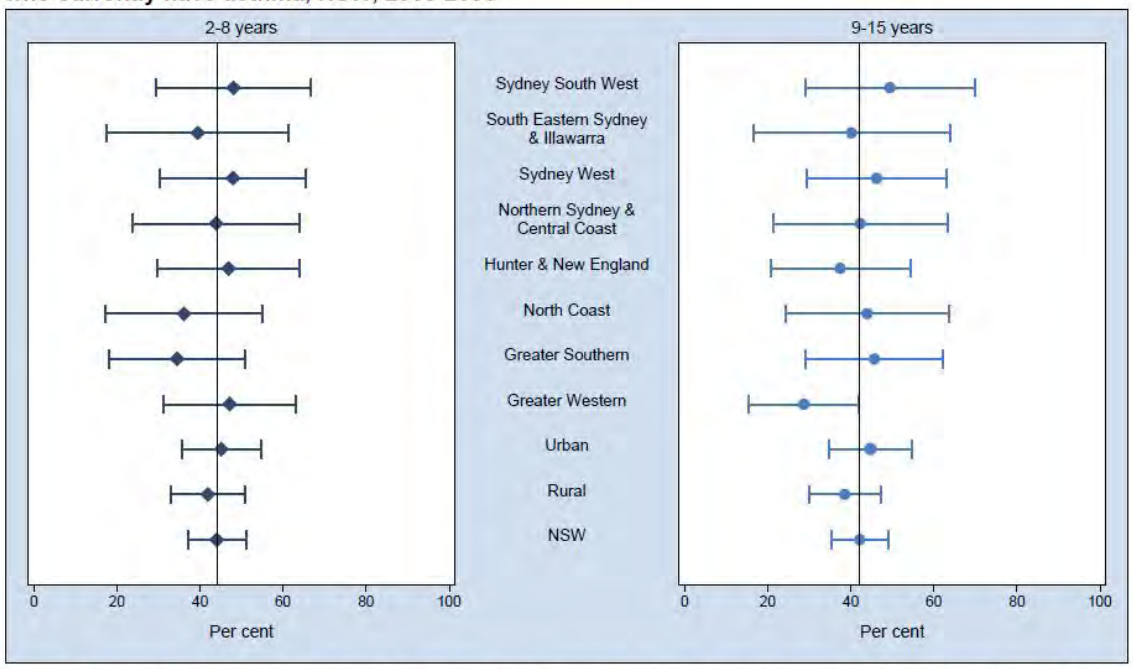
Written asthma management plan by area health service, children 2-15 years who currently have asthma, NSW, 2005-2006



Note: Estimates are based on 536 respondents in NSW. For this indicator 3 (0.56%) were not stated (Don't know or Refused) in NSW. The indicator includes those who have current asthma and who have a written asthma management plan. The questions used to define the indicator were: Has child ever been told by a doctor that he or she has asthma? Does child currently have asthma? Does child have a written asthma management plan from his or her doctor on how to treat their asthma?

Source: New South Wales Population Health Survey 2006 (HOIST). Centre for Epidemiology and Research, NSW Department of Health.

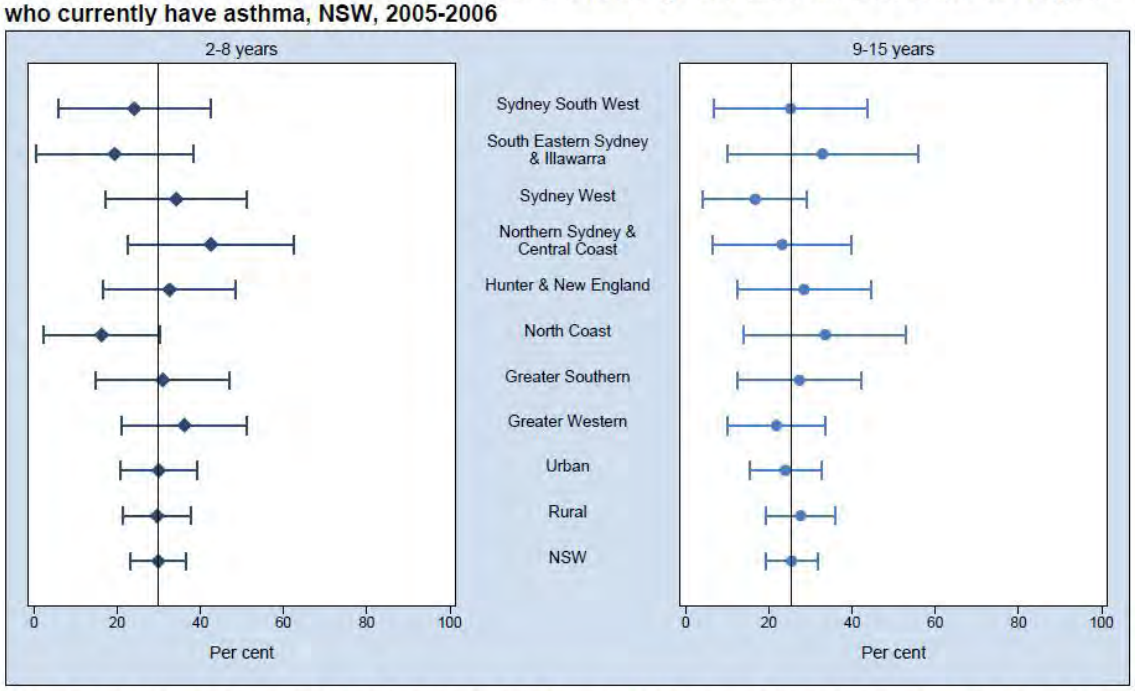
Asthma reliever medications used in the last 12 months by area health service, children 2-15 years who currently have asthma, NSW, 2005-2006



Note: Estimates are based on 544 respondents in NSW. For this indicator 12 (2.16%) were not stated (Don't know or Refused) in NSW. The indicator includes those who have used reliever medication for asthma in the last 12 months. The questions used to define the indicator were: Has child ever been told by a doctor or hospital he or she has asthma? Has child had symptoms of asthma or treatment for asthma in the last 12 months? What are the names or brands of all the medications child took for asthma in the last 12 months? Reliever medications include short-acting beta-agonists (Salbutamol, Ventolin, Asmol, Bricanyl, short-acting anti-cholinergics (Atrovent), combined inhaled steroid and long-acting beta agonists (Seretide and Symbicort), and long acting beta agonists (Symbicort and Seretide).

Source: New South Wales Population Health Survey 2006 (HOIST). Centre for Epidemiology and Research, NSW Department of Health.

Asthma preventer medications used in the last 12 months by area health service, children 2-15 years who currently have asthma, NSW, 2005-2006



Note: Estimates are based on 544 respondents in NSW. For this indicator 12 (2.16%) were not stated (Don't know or Refused) in NSW. The indicator includes those who have used preventer medication for asthma in the last 12 months. The questions used to define the indicator were: Has child ever been told by a doctor or hospital he or she has asthma? Has child had symptoms of asthma or treatment for asthma in the last 12 months? What are the names or brands of all the medications child took for asthma in the last 12 months? Preventer medications include combined inhaled steroids and long acting beta agonists (Seretide and Symbicort), inhaled corticosteroids (Pulmicort, Flixotide, Qvar; and Alvesco), leukotriene receptor antagonists (Singulair and Accolate), oral steroids (Prednisone), and cromones (Intal, Intal Forte, and Tilade).

Source: New South Wales Population Health Survey 2006 (HOIST). Centre for Epidemiology and Research, NSW Department of Health.

Appendix B $PM_{2.5}$ and PM_{10} calculations for primary and secondary health indicators

Quantification of Effects - PM2.5 and PM10, Scenario 2a 2019
Southern Interchange

Particulate Fraction:	PM2.5	PM2.5	PM2.5	PM10	PM2.5	PM2.5	PM2.5	PM2.5	
Endpoint:	Mortality - All Causes	Hospitalisations - Cardiovascular	Hospitalisations - Respiratory	Mortality - All Causes	Mortality - All Causes	Mortality - Cardiopulmonary	Mortality - Cardiovascular	Mortality - Respiratory	Incremental Risk - DPM
Effect Exposure Duration:	Long-term	Short-term	Short-term	Short-Term	Short-Term	Long-term	Short-Term	Short-Term	(based on WHO)
Age Group:	≥ 30 years	≥ 65 years	≥ 65 years	All ages	All ages	≥ 30 years	All ages	All ages	Unit Risk
β (change in effect per 1 µg/m^3 PM) (as per Table 5-1)	0.0058	0.0008	0.00041	0.0006	0.00094	0.013	0.00097	0.0019	
Baseline Incidence (per 100,000) (as per Table 3-5)	1087	23352	8807	670	670	490	164	57	
Baseline Incidence (per person)	0.01087	0.23352	0.08807	0.0067	0.0067	0.0049	0.00164	0.00057	

Receptor		Increase in Annual Average PM10 Concentration (µg/m^3)	Increase in Annual Average PM2.5 Concentration (µg/m^3)	Risk (Equation 6)	Risk (Equation 6)	Risk (Equation 6)	Risk (Equation 6)	Risk (Equation 6)	Risk (Equation 6)	Risk (Equation 6)	Risk (Equation 6)	Risk
Maximum Receptor												
Southern Interchange		**0.11**	**0.11**	**6.8E-06**	**2.0E-05**	**3.9E-06**	**4.6E-07**	**6.8E-07**	**6.9E-06**	**1.7E-07**	**1.2E-07**	**3.7E-06**
Sensitive Receptors												
Carlingford												
Shine Preschool	Childcare	0.014	0.014	8.7E-07	2.6E-06	5.0E-07	5.8E-08	8.7E-08	8.8E-07	2.2E-08	1.5E-08	4.7E-07
Murray Farm Public School	Schools	0.014	0.014	8.6E-07	2.6E-06	5.0E-07	5.8E-08	8.6E-08	8.7E-07	2.2E-08	1.5E-08	4.7E-07
St Gerards Primary School	Schools	0.016	0.016	9.8E-07	2.9E-06	5.6E-07	6.5E-08	9.8E-08	9.9E-07	2.5E-08	1.7E-08	5.3E-07
Roselea Primary School	Schools	0.019	0.019	1.2E-06	3.5E-06	6.7E-07	7.8E-08	1.2E-07	1.2E-06	2.9E-08	2.0E-08	6.3E-07
Carlingford High School	Schools	0.019	0.019	1.2E-06	3.5E-06	6.7E-07	7.8E-08	1.2E-07	1.2E-06	2.9E-08	2.0E-08	6.3E-07
Colin Place Out of School Care	Schools	0.012	0.011	7.1E-07	2.1E-06	4.1E-07	4.7E-08	7.1E-08	7.2E-07	1.8E-08	1.2E-08	3.8E-07
Roselea Community Centre	Community	0.018	0.017	1.1E-06	3.3E-06	6.3E-07	7.3E-08	1.1E-07	1.1E-06	2.8E-08	1.9E-08	5.9E-07
Pennant Hills Golf Course	Community	0.029	0.027	1.7E-06	5.1E-06	9.9E-07	1.2E-07	1.7E-07	1.7E-06	4.3E-08	3.0E-08	9.3E-07
Average Residential	**includes max**	**0.028**	**0.027**	**1.7E-06**	**5.1E-06**	**9.8E-07**	**1.1E-07**	**1.7E-07**	**1.7E-06**	**4.3E-08**	**2.9E-08**	**9.2E-07**
West Pennant Hills												
Bird House Early Learning Centre	Childcare	0.010	0.010	6.3E-07	1.9E-06	3.6E-07	4.2E-08	6.3E-08	6.4E-07	1.6E-08	1.1E-08	3.4E-07
Southern Cross Nordby Village	Aged Care	0.009	0.009	5.4E-07	1.6E-06	3.1E-07	3.6E-08	5.4E-08	5.4E-07	1.4E-08	9.2E-09	2.9E-07
West Pennant Hills Public School	Schools	0.027	0.026	1.6E-06	4.9E-06	9.4E-07	1.1E-07	1.6E-07	1.7E-06	4.1E-08	2.8E-08	8.8E-07
West Pennant Hills Community Church	Community	0.026	0.025	1.6E-06	4.7E-06	9.0E-07	1.1E-07	1.6E-07	1.6E-06	4.0E-08	2.7E-08	8.5E-07
Average Residential		**0.018**	**0.017**	**1.1E-06**	**3.2E-06**	**6.3E-07**	**7.3E-08**	**1.1E-07**	**1.1E-06**	**2.8E-08**	**1.9E-08**	**5.9E-07**
Beecroft												
Thinking Hats Early Learning Centre and Twinklestar Childcare	Childcare	0.015	0.014	8.8E-07	2.6E-06	5.0E-07	5.9E-08	8.8E-08	8.9E-07	2.2E-08	1.5E-08	4.7E-07
Beecroft Long Day & Early Learning Centre	Childcare	0.028	0.027	1.7E-06	5.1E-06	9.8E-07	1.1E-07	1.7E-07	1.7E-06	4.3E-08	2.9E-08	9.2E-07
Twilight Aged Care: Jamieson House	Aged Care	0.029	0.028	1.8E-06	5.2E-06	1.0E-06	1.2E-07	1.8E-07	1.8E-06	4.4E-08	3.0E-08	9.5E-07
Beecroft Nursing Home	Aged Care	0.011	0.010	6.5E-07	1.9E-06	3.7E-07	4.3E-08	6.4E-08	6.5E-07	1.6E-08	1.1E-08	3.5E-07
Beecroft Primary School	Schools	0.017	0.017	1.0E-06	3.1E-06	6.0E-07	7.0E-08	1.0E-07	1.1E-06	2.6E-08	1.8E-08	5.6E-07
Pennant Hills Golf Course	Community	0.029	0.027	1.7E-06	5.1E-06	9.9E-07	1.2E-07	1.7E-07	1.7E-06	4.3E-08	3.0E-08	9.3E-07
Average Residential		**0.021**	**0.021**	**1.3E-06**	**3.8E-06**	**7.4E-07**	**8.6E-08**	**1.3E-07**	**1.3E-06**	**3.3E-08**	**2.2E-08**	**7.0E-07**
North Rocks												
North Rocks Public School	Schools	0.0056	0.0053	3.4E-07	1.0E-06	1.9E-07	2.3E-08	3.4E-08	3.4E-07	8.5E-09	5.8E-09	1.8E-07
Muirfield High School	Schools	0.0043	0.0041	2.6E-07	7.6E-07	1.5E-07	1.7E-08	2.6E-08	2.6E-07	6.5E-09	4.4E-09	1.4E-07
Average Residential		**0.0049**	**0.0047**	**3.0E-07**	**8.8E-07**	**1.7E-07**	**2.0E-08**	**3.0E-08**	**3.0E-07**	**7.5E-09**	**5.1E-09**	**1.6E-07**
Epping												
Arden Anglican School	Schools	0.0038	0.0036	2.3E-07	6.8E-07	1.3E-07	1.5E-08	2.3E-08	2.3E-07	5.8E-09	3.9E-09	1.2E-07
Average Residential		**0.0038**	**0.0036**	**2.3E-07**	**6.8E-07**	**1.3E-07**	**1.5E-08**	**2.3E-08**	**2.3E-07**	**5.8E-09**	**3.9E-09**	**1.2E-07**

Quantification of Effects - PM2.5 and PM10, Scenario 2b 2029
Southern Interchange

Particulate Fraction:	PM2.5	PM2.5	PM2.5	PM10	PM2.5	PM2.5	PM2.5	PM2.5	Incremental Risk - DPM
Endpoint:	Mortality - All Causes	Hospitalisations - Cardiovascular	Hospitalisations - Respiratory	Mortality - All Causes	Mortality - All Causes	Mortality - Cardiopulmonary	Mortality - Cardiovascular	Mortality - Respiratory	
Effect Exposure Duration:	Long-term	Short-term	Short-term	Short-Term	Short-Term	Long-term	Short-Term	Short-Term	(based on WHO)
Age Group:	≥ 30 years	≥ 65 years	≥ 65 years	All ages	All ages	≥ 30 years	All ages	All ages	Unit Risk
β (change in effect per 1 µg/m^3 PM) (as per Table 5-1)	0.0058	0.0008	0.00041	0.0006	0.00094	0.013	0.00097	0.0019	
Baseline Incidence (per 100,000) (as per Table 3-5)	1087	23352	8807	670	670	490	164	57	
Baseline Incidence (per person)	0.01087	0.23352	0.08807	0.0067	0.0067	0.0049	0.00164	0.00057	

Receptor		Increase in Annual Average PM10 Concentration (µg/m^3)	Increase in Annual Average PM2.5 Concentration (µg/m^3)	Risk (Equation 6)	Risk (Equation 6)	Risk (Equation 6)	Risk (Equation 6)	Risk (Equation 6)	Risk (Equation 6)	Risk (Equation 6)	Risk (Equation 6)	Risk
Maximum Receptor												
Southern Interchange		**0.13**	**0.13**	**8.0E-06**	**2.4E-05**	**4.6E-06**	**5.3E-07**	**7.9E-07**	**8.0E-06**	**2.0E-07**	**1.4E-07**	**4.3E-06**
Sensitive Receptors												
Carlingford												
Shine Preschool	Childcare	0.017	0.016	1.0E-06	3.1E-06	5.9E-07	7.0E-08	1.0E-07	1.0E-06	2.6E-08	1.8E-08	5.6E-07
Murray Farm Public School	Schools	0.017	0.016	1.0E-06	3.0E-06	5.9E-07	6.9E-08	1.0E-07	1.0E-06	2.6E-08	1.8E-08	5.5E-07
St Gerards Primary School	Schools	0.020	0.019	1.2E-06	3.5E-06	6.7E-07	8.0E-08	1.2E-07	1.2E-06	3.0E-08	2.0E-08	6.3E-07
Roselea Primary School	Schools	0.023	0.022	1.4E-06	4.1E-06	8.0E-07	9.4E-08	1.4E-07	1.4E-06	3.5E-08	2.4E-08	7.5E-07
Carlingford High School	Schools	0.024	0.022	1.4E-06	4.1E-06	8.0E-07	9.5E-08	1.4E-07	1.4E-06	3.5E-08	2.4E-08	7.5E-07
Colin Place Out of School Care	Schools	0.014	0.013	8.4E-07	2.5E-06	4.8E-07	5.7E-08	8.4E-08	8.5E-07	2.1E-08	1.4E-08	4.5E-07
Roselea Community Centre	Community	0.022	0.021	1.3E-06	3.9E-06	7.6E-07	9.0E-08	1.3E-07	1.3E-06	3.3E-08	2.3E-08	7.1E-07
Pennant Hills Golf Course	Community	0.040	0.038	2.4E-06	7.1E-06	1.4E-06	1.6E-07	2.4E-07	2.4E-06	6.0E-08	4.1E-08	1.3E-06
Average Residential	**includes max**	**0.035**	**0.033**	**2.1E-06**	**6.1E-06**	**1.2E-06**	**1.4E-07**	**2.1E-07**	**2.1E-06**	**5.2E-08**	**3.5E-08**	**1.1E-06**
West Pennant Hills												
Bird House Early Learning Centre	Childcare	0.011	0.011	6.7E-07	2.0E-06	3.8E-07	4.5E-08	6.7E-08	6.7E-07	1.7E-08	1.1E-08	3.6E-07
Southern Cross Nordby Village	Aged Care	0.010	0.009	6.0E-07	1.8E-06	3.4E-07	4.1E-08	6.0E-08	6.0E-07	1.5E-08	1.0E-08	3.2E-07
West Pennant Hills Public School	Schools	0.029	0.027	1.7E-06	5.1E-06	9.9E-07	1.2E-07	1.7E-07	1.7E-06	4.4E-08	3.0E-08	9.3E-07
West Pennant Hills Community Church	Community	0.031	0.029	1.8E-06	5.4E-06	1.0E-06	1.2E-07	1.8E-07	1.8E-06	4.6E-08	3.1E-08	9.8E-07
Average Residential		**0.020**	**0.019**	**1.2E-06**	**3.6E-06**	**6.9E-07**	**8.2E-08**	**1.2E-07**	**1.2E-06**	**3.0E-08**	**2.1E-08**	**6.5E-07**
Beecroft												
Thinking Hats Early Learning Centre and Twinklestar Childcare	Childcare	0.017	0.016	1.0E-06	3.1E-06	5.9E-07	7.0E-08	1.0E-07	1.0E-06	2.6E-08	1.8E-08	5.6E-07
Beecroft Long Day & Early Learning Centre	Childcare	0.035	0.033	2.1E-06	6.1E-06	1.2E-06	1.4E-07	2.1E-07	2.1E-06	5.2E-08	3.5E-08	1.1E-06
Twilight Aged Care: Jamieson House	Aged Care	0.036	0.033	2.1E-06	6.2E-06	1.2E-06	1.4E-07	2.1E-07	2.1E-06	5.3E-08	3.6E-08	1.1E-06
Beecroft Nursing Home	Aged Care	0.013	0.012	7.6E-07	2.3E-06	4.4E-07	5.2E-08	7.6E-08	7.7E-07	1.9E-08	1.3E-08	4.1E-07
Beecroft Primary School	Schools	0.020	0.019	1.2E-06	3.5E-06	6.8E-07	8.1E-08	1.2E-07	1.2E-06	3.0E-08	2.0E-08	6.4E-07
Pennant Hills Golf Course	Community	0.040	0.038	2.4E-06	7.1E-06	1.4E-06	1.6E-07	2.4E-07	2.4E-06	6.0E-08	4.1E-08	1.3E-06
Average Residential		**0.027**	**0.025**	**1.6E-06**	**4.7E-06**	**9.1E-07**	**1.1E-07**	**1.6E-07**	**1.6E-06**	**4.0E-08**	**2.7E-08**	**8.6E-07**
North Rocks												
North Rocks Public School	Schools	0.0067	0.0063	4.0E-07	1.2E-06	2.3E-07	2.7E-08	4.0E-08	4.0E-07	1.0E-08	6.8E-09	2.1E-07
Muirfield High School	Schools	0.0051	0.0048	3.1E-07	9.0E-07	1.7E-07	2.1E-08	3.0E-08	3.1E-07	7.7E-09	5.2E-09	1.6E-07
Average Residential		**0.0059**	**0.0056**	**3.5E-07**	**1.0E-06**	**2.0E-07**	**2.4E-08**	**3.5E-08**	**3.6E-07**	**8.9E-09**	**6.0E-09**	**1.9E-07**
Epping												
Arden Anglican School	Schools	0.0046	0.0043	2.7E-07	8.1E-07	1.6E-07	1.9E-08	2.7E-08	2.8E-07	6.9E-09	4.7E-09	1.5E-07
Average Residential		**0.0046**	**0.0043**	**2.7E-07**	**8.1E-07**	**1.6E-07**	**1.9E-08**	**2.7E-08**	**2.8E-07**	**6.9E-09**	**4.7E-09**	**1.5E-07**

Quantification of Effects - PM2.5 and PM10, Scenario 2a 2019
Northern Interchange

Particulate Fraction:	PM2.5	PM2.5	PM2.5	PM10	PM2.5	PM2.5	PM2.5	PM2.5	Incremental Risk -DPM
Endpoint:	Mortality - All Causes	Hospitalisations - Cardiovascular	Hospitalisations - Respiratory	Mortality - All Causes	Mortality - All Causes	Mortality - Cardiopulmonary	Mortality - Cardiovascular	Mortality - Respiratory	
Effect Exposure Duration:	Long-term	Short-term	Short-term	Short-Term	Short-Term	Long-term	Short-Term	Short-Term	(based on WHO)
Age Group:	≥ 30 years	≥ 65 years	≥ 65 years	All ages	All ages	≥ 30 years	All ages	All ages	Unit Risk
β (change in effect per 1 µg/m³ PM) (as per Table 5-1)	0.0058	0.0008	0.00041	0.0006	0.00094	0.013	0.00097	0.0019	
Baseline Incidence (per 100,000) (as per Table 3-5)	1087	23352	8807	670	670	490	164	57	
Baseline Incidence (per person)	0.01087	0.23352	0.08807	0.0067	0.0067	0.0049	0.00164	0.00057	

Receptor		Increase in Annual Average PM10 Concentration (µg/m³)	Increase in Annual Average PM2.5 Concentration (µg/m³)	Risk (Equation 6)	Risk (Equation 6)	Risk (Equation 6)	Risk (Equation 6)	Risk (Equation 6)	Risk (Equation 6)	Risk (Equation 6)	Risk
Maximum Receptor											
Northern Interchange		**0.09**	**0.08**	**5.1E-06**	**1.5E-05**	**2.9E-06**	**3.4E-07**	**5.1E-07**	**5.2E-06**	**1.3E-07**	**8.8E-08**	**2.8E-06**
Sensitive Receptors												
Wahroonga												
KU Wahroonga	Childcare	0.035	0.033	2.1E-06	6.2E-06	1.2E-06	1.4E-07	2.1E-07	2.1E-06	5.3E-08	3.6E-08	1.1E-06
Next Generation Child Care	Childcare	0.049	0.047	2.9E-06	8.7E-06	1.7E-06	2.0E-07	2.9E-07	3.0E-06	7.4E-08	5.1E-08	1.6E-06
Peter Rabbit Community Preschool	Childcare	0.036	0.034	2.2E-06	6.4E-06	1.2E-06	1.4E-07	2.2E-07	2.2E-06	5.5E-08	3.7E-08	1.2E-06
Wahroonga Long Day Care	Childcare	0.019	0.018	1.1E-06	3.4E-06	6.5E-07	7.6E-08	1.1E-07	1.2E-06	2.9E-08	2.0E-08	6.2E-07
Wahroonga Beehive Pre-School	Childcare	0.015	0.014	8.8E-07	2.6E-06	5.0E-07	5.9E-08	8.8E-08	8.9E-07	2.2E-08	1.5E-08	4.7E-07
Little Learning School Wahroonga	Childcare	0.038	0.036	2.3E-06	6.8E-06	1.3E-06	1.5E-07	2.3E-07	2.3E-06	5.8E-08	3.9E-08	1.2E-06
Pymble Turramurra Kindergarten	Childcare	0.008	0.008	5.0E-07	1.5E-06	2.8E-07	3.3E-08	5.0E-08	5.0E-07	1.3E-08	8.5E-09	2.7E-07
The Woniora Care	Aged Care	0.044	0.042	2.6E-06	7.8E-06	1.5E-06	1.8E-07	2.6E-07	2.7E-06	6.7E-08	4.5E-08	1.4E-06
Tallwoods Centre	Aged Care	0.046	0.044	2.8E-06	8.2E-06	1.6E-06	1.9E-07	2.8E-07	2.8E-06	7.0E-08	4.8E-08	1.5E-06
B'nai B'rith Retirement Village	Aged Care	0.055	0.052	3.3E-06	9.7E-06	1.9E-06	2.2E-07	3.3E-07	3.3E-06	8.2E-08	5.6E-08	1.8E-06
Wahroonga Nursing Home	Aged Care	0.044	0.042	2.6E-06	7.8E-06	1.5E-06	1.8E-07	2.6E-07	2.7E-06	6.6E-08	4.5E-08	1.4E-06
Netherby Aged Care	Aged Care	0.042	0.040	2.5E-06	7.4E-06	1.4E-06	1.7E-07	2.5E-07	2.5E-06	6.3E-08	4.3E-08	1.4E-06
Wahroonga Waldorf Apartments	Aged Care	0.042	0.040	2.5E-06	7.4E-06	1.4E-06	1.7E-07	2.5E-07	2.5E-06	6.3E-08	4.3E-08	1.4E-06
Thomas & Rosetta Aged Care Facility	Aged Care	0.023	0.021	1.4E-06	4.0E-06	7.7E-07	9.1E-08	1.3E-07	1.4E-06	3.4E-08	2.3E-08	7.3E-07
Redleaf Serviced Apartments/Aged Care	Aged Care	0.023	0.021	1.4E-06	4.0E-06	7.7E-07	9.1E-08	1.3E-07	1.4E-06	3.4E-08	2.3E-08	7.3E-07
UPA of NSW Ltd	Aged Care	0.023	0.021	1.4E-06	4.0E-06	7.8E-07	9.1E-08	1.4E-07	1.4E-06	3.4E-08	2.3E-08	7.3E-07
Waitara Public School	Schools	0.054	0.051	3.2E-06	9.6E-06	1.9E-06	2.2E-07	3.2E-07	3.3E-06	8.2E-08	5.6E-08	1.7E-06
Wahroonga Preparatory School	Schools	0.042	0.040	2.5E-06	7.5E-06	1.4E-06	1.7E-07	2.5E-07	2.5E-06	6.4E-08	4.3E-08	1.4E-06
Wahroonga Public School	Schools	0.023	0.021	1.4E-06	4.0E-06	7.7E-07	9.1E-08	1.4E-07	1.4E-06	3.4E-08	2.3E-08	7.3E-07
Abbotsleigh	Schools	0.025	0.023	1.5E-06	4.4E-06	8.5E-07	1.0E-07	1.5E-07	1.5E-06	3.7E-08	2.5E-08	8.0E-07
Abbotsleigh Junior School and Early Learning Centre	Schools	0.012	0.012	7.4E-07	2.2E-06	4.2E-07	4.9E-08	7.4E-08	7.4E-07	1.9E-08	1.3E-08	4.0E-07
Knox Grammar	Schools	0.020	0.019	1.2E-06	3.6E-06	6.9E-07	8.1E-08	1.2E-07	1.2E-06	3.0E-08	2.1E-08	6.5E-07
Knox Preparatory School	Schools	0.039	0.037	2.3E-06	6.9E-06	1.3E-06	1.6E-07	2.3E-07	2.4E-06	5.9E-08	4.0E-08	1.3E-06
St Lucys School	Schools	0.042	0.039	2.5E-06	7.3E-06	1.4E-06	1.7E-07	2.5E-07	2.5E-06	6.2E-08	4.2E-08	1.3E-06
Prouille Catholic College	Schools	0.047	0.044	2.8E-06	8.2E-06	1.6E-06	1.9E-07	2.8E-07	2.8E-06	7.0E-08	4.8E-08	1.5E-06
Prouille Catholic Primary School	Schools	0.044	0.042	2.6E-06	7.8E-06	1.5E-06	1.8E-07	2.6E-07	2.7E-06	6.6E-08	4.5E-08	1.4E-06
St Leos	Schools	0.025	0.024	1.5E-06	4.5E-06	8.7E-07	1.0E-07	1.5E-07	1.5E-06	3.8E-08	2.6E-08	8.2E-07
St Edmund's School for Blind and Visually Impair	Schools	0.024	0.022	1.4E-06	4.2E-06	8.1E-07	9.6E-08	1.4E-07	1.4E-06	3.6E-08	2.4E-08	7.6E-07
Warrawee Public School	Schools	0.011	0.011	6.8E-07	2.0E-06	3.9E-07	4.6E-08	6.8E-08	6.9E-07	1.7E-08	1.2E-08	3.7E-07
Retaval School	Schools	0.011	0.011	6.8E-07	2.0E-06	3.9E-07	4.6E-08	6.8E-08	6.9E-07	1.7E-08	1.2E-08	3.7E-07
Neringah Hospital (hope Healthcare)	Hospital	0.030	0.028	1.8E-06	5.2E-06	1.0E-06	1.2E-07	1.8E-07	1.8E-06	4.5E-08	3.0E-08	9.5E-07
Average Residential	**includes max**	**0.034**	**0.032**	**2.0E-06**	**6.0E-06**	**1.2E-06**	**1.4E-07**	**2.0E-07**	**2.0E-06**	**5.1E-08**	**3.5E-08**	**1.1E-06**
North Wahroonga												
Residential (Suburb Receptor)	**Residential**	**0.030**	**0.029**	**1.8E-06**	**5.4E-06**	**1.0E-06**	**1.2E-07**	**1.8E-07**	**1.8E-06**	**4.6E-08**	**3.1E-08**	**9.7E-07**
Waitara												
Balamara Preschool	Childcare	0.048	0.045	2.9E-06	8.5E-06	1.6E-06	1.9E-07	2.9E-07	2.9E-06	7.2E-08	4.9E-08	1.5E-06
Waitara Family Centre	Childcare	0.021	0.020	1.2E-06	3.7E-06	7.1E-07	8.3E-08	1.2E-07	1.3E-06	3.1E-08	2.1E-08	6.7E-07
Twinkle Tots Cottage	Childcare	0.029	0.027	1.7E-06	5.1E-06	9.9E-07	1.2E-07	1.7E-07	1.7E-06	4.4E-08	3.0E-08	9.3E-07
The Grange	Aged Care	0.026	0.025	1.6E-06	4.7E-06	9.0E-07	1.1E-07	1.6E-07	1.6E-06	4.0E-08	2.7E-08	8.5E-07
Waitara Public School	Schools	0.054	0.051	3.2E-06	9.6E-06	1.9E-06	2.2E-07	3.2E-07	3.3E-06	8.2E-08	5.6E-08	1.7E-06
Our Lady of the Rosary Primary School	Schools	0.021	0.020	1.3E-06	3.8E-06	7.4E-07	8.6E-08	1.3E-07	1.3E-06	3.3E-08	2.2E-08	7.0E-07
Average Residential		**0.033**	**0.032**	**2.0E-06**	**5.9E-06**	**1.1E-06**	**1.3E-07**	**2.0E-07**	**2.0E-06**	**5.0E-08**	**3.4E-08**	**1.1E-06**
Hornsby												
Bumble Bees Early Learning Centre	Childcare	0.023	0.022	1.4E-06	4.1E-06	7.9E-07	9.3E-08	1.4E-07	1.4E-06	3.5E-08	2.4E-08	7.5E-07
Kids Academy Hornsby	Childcare	0.024	0.023	1.4E-06	4.2E-06	8.2E-07	9.6E-08	1.4E-07	1.4E-06	3.6E-08	2.5E-08	7.7E-07
Explore & Develop Waitara	Childcare	0.034	0.032	2.0E-06	6.0E-06	1.2E-06	1.4E-07	2.0E-07	2.1E-06	5.1E-08	3.5E-08	1.1E-06
Little Learning School Hornsby	Childcare	0.034	0.032	2.0E-06	6.0E-06	1.2E-06	1.4E-07	2.0E-07	2.1E-06	5.1E-08	3.5E-08	1.1E-06
Bright Horizons Early Learning Centre	Childcare	0.034	0.032	2.0E-06	6.0E-06	1.2E-06	1.4E-07	2.0E-07	2.1E-06	5.1E-08	3.5E-08	1.1E-06
Belvedere Aged Care	Aged Care	0.042	0.040	2.5E-06	7.4E-06	1.4E-06	1.7E-07	2.5E-07	2.5E-06	6.3E-08	4.3E-08	1.4E-06
Hornsby Girls High School	Schools	0.016	0.015	9.6E-07	2.9E-06	5.5E-07	6.5E-08	9.6E-08	9.7E-07	2.4E-08	1.7E-08	5.2E-07
Barker College	Schools	0.014	0.013	8.4E-07	2.5E-06	4.8E-07	5.6E-08	8.4E-08	8.5E-07	2.1E-08	1.4E-08	4.5E-07
Hornsby South Public School	Schools	0.010	0.010	6.2E-07	1.8E-06	3.6E-07	4.2E-08	6.2E-08	6.3E-07	1.6E-08	1.1E-08	3.4E-07
Clarke Road School	Schools	0.010	0.010	6.2E-07	1.8E-06	3.6E-07	4.2E-08	6.2E-08	6.3E-07	1.6E-08	1.1E-08	3.4E-07
Hornsby Hospital (and childcare centre)	Hospital	0.034	0.032	2.0E-06	6.1E-06	1.2E-06	1.4E-07	2.0E-07	2.1E-06	5.2E-08	3.5E-08	1.1E-06
Average Residential		**0.025**	**0.024**	**1.5E-06**	**4.5E-06**	**8.6E-07**	**1.0E-07**	**1.5E-07**	**1.5E-06**	**3.8E-08**	**2.6E-08**	**8.1E-07**
Normanhurst												
Normanhurst Child Care Centre	Childcare	0.016	0.015	9.5E-07	2.8E-06	5.5E-07	6.3E-08	9.5E-08	9.6E-07	2.4E-08	1.6E-08	5.1E-07
Bowden Brae Retirement Village	Aged Care	0.021	0.020	1.3E-06	3.8E-06	7.4E-07	8.6E-08	1.3E-07	1.3E-06	3.3E-08	2.2E-08	7.0E-07
Greenwood Aged Care	Aged Care	0.020	0.019	1.2E-06	3.5E-06	6.8E-07	8.0E-08	1.2E-07	1.2E-06	3.0E-08	2.1E-08	6.4E-07
Normanhurst Boys High School	Schools	0.020	0.019	1.2E-06	3.5E-06	6.9E-07	8.0E-08	1.2E-07	1.2E-06	3.0E-08	2.1E-08	6.5E-07
Normanhurst Public School	Schools	0.016	0.015	9.4E-07	2.8E-06	5.4E-07	6.2E-08	9.4E-08	9.5E-07	2.4E-08	1.6E-08	5.1E-07
Average Residential		**0.018**	**0.018**	**1.1E-06**	**3.3E-06**	**6.4E-07**	**7.4E-08**	**1.1E-07**	**1.1E-06**	**2.8E-08**	**1.9E-08**	**6.0E-07**

Quantification of Effects - PM2.5 and PM10, Scenario 2b 2029
Northern Interchange

Particulate Fraction:	PM2.5	PM2.5	PM2.5	PM10	PM2.5	PM2.5	PM2.5	PM2.5	Incremental Risk -DPM
Endpoint:	Mortality - All Causes	Hospitalisations - Cardiovascular	Hospitalisations - Respiratory	Mortality - All Causes	Mortality - All Causes	Mortality - Cardiopulmonary	Mortality - Cardiovascular	Mortality - Respiratory	
Effect Exposure Duration:	Long-term	Short-term	Short-term	Short-Term	Short-Term	Long-term	Short-Term	Short-Term	(based on WHO)
Age Group:	≥ 30 years	≥ 65 years	≥ 65 years	All ages	All ages	≥ 30 years	All ages	All ages	Unit Risk
β (change in effect per 1 µg/m³ PM) (as per Table 5-1)	0.0058	0.0008	0.00041	0.0006	0.00094	0.013	0.00097	0.0019	
Baseline Incidence (per 100,000) (as per Table 3-5)	1087	23352	8807	670	670	490	164	57	
Baseline Incidence (per person)	0.01087	0.23352	0.08807	0.0067	0.0067	0.0049	0.00164	0.00057	

Receptor		Increase in Annual Average PM10 Concentration (µg/m³)	Increase in Annual Average PM2.5 Concentration (µg/m³)	Risk (Equation 6)	Risk (Equation 6)	Risk (Equation 6)	Risk (Equation 6)	Risk (Equation 6)	Risk (Equation 6)	Risk (Equation 6)	Risk (Equation 6)	Risk
Maximum Receptor												
Northern Interchange		**0.11**	**0.10**	**6.5E-06**	**1.9E-05**	**3.7E-06**	**4.4E-07**	**6.5E-07**	**6.6E-06**	**1.6E-07**	**1.1E-07**	**3.5E-06**
Sensitive Receptors												
Wahroonga												
KU Wahroonga	Childcare	0.041	0.039	2.5E-06	7.3E-06	1.4E-06	1.7E-07	2.5E-07	2.5E-06	6.2E-08	4.2E-08	1.3E-06
Next Generation Child Care	Childcare	0.058	0.055	3.5E-06	1.0E-05	2.0E-06	2.3E-07	3.5E-07	3.5E-06	8.7E-08	5.9E-08	1.9E-06
Peter Rabbit Community Preschool	Childcare	0.041	0.039	2.5E-06	7.3E-06	1.4E-06	1.7E-07	2.5E-07	2.5E-06	6.2E-08	4.2E-08	1.3E-06
Wahroonga Long Day Care	Childcare	0.022	0.021	1.3E-06	3.9E-06	7.5E-07	8.8E-08	1.3E-07	1.3E-06	3.3E-08	2.2E-08	7.0E-07
Wahroonga Beehive Pre-School	Childcare	0.017	0.016	1.0E-06	3.0E-06	5.8E-07	6.8E-08	1.0E-07	1.0E-06	2.5E-08	1.7E-08	5.4E-07
Little Learning School Wahroonga	Childcare	0.044	0.042	2.7E-06	7.9E-06	1.5E-06	1.8E-07	2.6E-07	2.7E-06	6.7E-08	4.6E-08	1.4E-06
Pymble Turramurra Kindergarten	Childcare	0.010	0.009	5.7E-07	1.7E-06	3.3E-07	3.9E-08	5.7E-08	5.8E-07	1.4E-08	9.9E-09	3.1E-07
The Woniora Care	Aged Care	0.059	0.056	3.5E-06	1.0E-05	2.0E-06	2.4E-07	3.5E-07	3.6E-06	8.9E-08	6.0E-08	1.9E-06
Tallwoods Centre	Aged Care	0.054	0.052	3.2E-06	9.6E-06	1.9E-06	2.2E-07	3.2E-07	3.3E-06	8.2E-08	5.6E-08	1.8E-06
B'nai B'rith Retirement Village	Aged Care	0.065	0.061	3.9E-06	1.1E-05	2.2E-06	2.6E-07	3.9E-07	3.9E-06	9.7E-08	6.6E-08	2.1E-06
Wahroonga Nursing Home	Aged Care	0.051	0.048	3.1E-06	9.0E-06	1.7E-06	2.1E-07	3.1E-07	3.1E-06	7.7E-08	5.2E-08	1.6E-06
Netherby Aged Care	Aged Care	0.049	0.046	2.9E-06	8.6E-06	1.7E-06	2.0E-07	2.9E-07	2.9E-06	7.3E-08	5.0E-08	1.6E-06
Wahroonga Waldorf Apartments	Aged Care	0.049	0.046	2.9E-06	8.6E-06	1.7E-06	2.0E-07	2.9E-07	2.9E-06	7.3E-08	5.0E-08	1.6E-06
Thomas & Rosetta Aged Care Facility	Aged Care	0.026	0.025	1.6E-06	4.6E-06	8.9E-07	1.0E-07	1.6E-07	1.6E-06	3.9E-08	2.7E-08	8.4E-07
Redleaf Serviced Apartments/Aged Care	Aged Care	0.026	0.025	1.6E-06	4.6E-06	8.9E-07	1.0E-07	1.6E-07	1.6E-06	3.9E-08	2.7E-08	8.4E-07
UPA of NSW Ltd	Aged Care	0.026	0.025	1.6E-06	4.6E-06	8.9E-07	1.1E-07	1.6E-07	1.6E-06	3.9E-08	2.7E-08	8.4E-07
Waitara Public School	Schools	0.065	0.061	3.8E-06	1.1E-05	2.2E-06	2.6E-07	3.8E-07	3.9E-06	9.7E-08	6.6E-08	2.1E-06
Wahroonga Preparatory School	Schools	0.049	0.046	2.9E-06	8.7E-06	1.7E-06	2.0E-07	2.9E-07	3.0E-06	7.4E-08	5.0E-08	1.6E-06
Wahroonga Public School	Schools	0.026	0.024	1.5E-06	4.6E-06	8.8E-07	1.0E-07	1.5E-07	1.6E-06	3.9E-08	2.6E-08	8.3E-07
Abbotsleigh	Schools	0.029	0.027	1.7E-06	5.0E-06	9.7E-07	1.1E-07	1.7E-07	1.7E-06	4.3E-08	2.9E-08	9.1E-07
Abbotsleigh Junior School and Early Learning Centre	Schools	0.022	0.020	1.3E-06	3.8E-06	7.3E-07	8.6E-08	1.3E-07	1.3E-06	3.2E-08	2.2E-08	6.8E-07
Knox Grammar	Schools	0.023	0.022	1.4E-06	4.1E-06	7.9E-07	9.3E-08	1.4E-07	1.4E-06	3.5E-08	2.4E-08	7.5E-07
Knox Preparatory School	Schools	0.044	0.042	2.6E-06	7.8E-06	1.5E-06	1.8E-07	2.6E-07	2.7E-06	6.7E-08	4.5E-08	1.4E-06
St Lucys School	Schools	0.047	0.044	2.8E-06	8.3E-06	1.6E-06	1.9E-07	2.8E-07	2.8E-06	7.1E-08	4.8E-08	1.5E-06
Prouille Catholic College	Schools	0.053	0.050	3.1E-06	9.3E-06	1.8E-06	2.1E-07	3.1E-07	3.2E-06	7.9E-08	5.4E-08	1.7E-06
Prouille Catholic Primary School	Schools	0.050	0.047	3.0E-06	8.8E-06	1.7E-06	2.0E-07	3.0E-07	3.0E-06	7.5E-08	5.1E-08	1.6E-06
St Leos	Schools	0.029	0.028	1.8E-06	5.2E-06	1.0E-06	1.2E-07	1.8E-07	1.8E-06	4.4E-08	3.0E-08	9.5E-07
St Edmund's School for Blind and Visually Impair	Schools	0.027	0.026	1.6E-06	4.8E-06	9.2E-07	1.1E-07	1.6E-07	1.6E-06	4.1E-08	2.8E-08	8.7E-07
Warrawee Public School	Schools	0.013	0.012	7.9E-07	2.3E-06	4.5E-07	5.3E-08	7.9E-08	8.0E-07	2.0E-08	1.4E-08	4.2E-07
Retaval School	Schools	0.013	0.013	7.9E-07	2.4E-06	4.5E-07	5.4E-08	7.9E-08	8.0E-07	2.0E-08	1.4E-08	4.3E-07
Neringah Hospital (hope Healthcare)	Hospital	0.034	0.032	2.0E-06	6.0E-06	1.2E-06	1.4E-07	2.0E-07	2.0E-06	5.1E-08	3.5E-08	1.1E-06
Average Residential	**includes max**	**0.040**	**0.038**	**2.4E-06**	**7.0E-06**	**1.4E-06**	**1.6E-07**	**2.4E-07**	**2.4E-06**	**6.0E-08**	**4.1E-08**	**1.3E-06**
North Wahroonga												
Residential (Suburb Receptor)	**Residential**	**0.035**	**0.033**	**2.1E-06**	**6.2E-06**	**1.2E-06**	**1.4E-07**	**2.1E-07**	**2.1E-06**	**5.2E-08**	**3.6E-08**	**1.1E-06**
Waitara												
Balamara Preschool	Childcare	0.056	0.053	3.4E-06	1.0E-05	1.9E-06	2.3E-07	3.4E-07	3.4E-06	8.5E-08	5.8E-08	1.8E-06
Waitara Family Centre	Childcare	0.024	0.023	1.4E-06	4.3E-06	8.2E-07	9.7E-08	1.4E-07	1.5E-06	3.6E-08	2.5E-08	7.8E-07
Twinkle Tots Cottage	Childcare	0.034	0.032	2.0E-06	5.9E-06	1.1E-06	1.4E-07	2.0E-07	2.0E-06	5.1E-08	3.4E-08	1.1E-06
The Grange	Aged Care	0.031	0.029	1.8E-06	5.4E-06	1.1E-06	1.2E-07	1.8E-07	1.9E-06	4.6E-08	3.2E-08	9.9E-07
Waitara Public School	Schools	0.065	0.061	3.8E-06	1.1E-05	2.2E-06	2.6E-07	3.8E-07	3.9E-06	9.7E-08	6.6E-08	2.1E-06
Our Lady of the Rosary Primary School	Schools	0.025	0.024	1.5E-06	4.4E-06	8.6E-07	1.0E-07	1.5E-07	1.5E-06	3.8E-08	2.6E-08	8.1E-07
Average Residential		**0.039**	**0.037**	**2.3E-06**	**6.9E-06**	**1.3E-06**	**1.6E-07**	**2.3E-07**	**2.4E-06**	**5.9E-08**	**4.0E-08**	**1.3E-06**
Hornsby												
Bumble Bees Early Learning Centre	Childcare	0.027	0.025	1.6E-06	4.7E-06	9.1E-07	1.1E-07	1.6E-07	1.6E-06	4.0E-08	2.7E-08	8.6E-07
Kids Academy Hornsby	Childcare	0.028	0.026	1.7E-06	4.9E-06	9.5E-07	1.1E-07	1.7E-07	1.7E-06	4.2E-08	2.8E-08	8.9E-07
Explore & Develop Waitara	Childcare	0.040	0.037	2.4E-06	7.0E-06	1.4E-06	1.6E-07	2.4E-07	2.4E-06	6.0E-08	4.1E-08	1.3E-06
Little Learning School Hornsby	Childcare	0.040	0.037	2.4E-06	7.0E-06	1.4E-06	1.6E-07	2.4E-07	2.4E-06	6.0E-08	4.1E-08	1.3E-06
Bright Horizons Early Learning Centre	Childcare	0.040	0.037	2.4E-06	7.0E-06	1.4E-06	1.6E-07	2.4E-07	2.4E-06	6.0E-08	4.1E-08	1.3E-06
Belvedere Aged Care	Aged Care	0.049	0.046	2.9E-06	8.6E-06	1.7E-06	2.0E-07	2.9E-07	2.9E-06	7.3E-08	5.0E-08	1.6E-06
Hornsby Girls High School	Schools	0.018	0.017	1.1E-06	3.3E-06	6.3E-07	7.4E-08	1.1E-07	1.1E-06	2.8E-08	1.9E-08	5.9E-07
Barker College	Schools	0.016	0.015	9.7E-07	2.9E-06	5.6E-07	6.5E-08	9.7E-08	9.8E-07	2.5E-08	1.7E-08	5.2E-07
Hornsby South Public School	Schools	0.012	0.011	7.2E-07	2.1E-06	4.1E-07	4.9E-08	7.2E-08	7.3E-07	1.8E-08	1.2E-08	3.9E-07
Clarke Road School	Schools	0.012	0.011	7.2E-07	2.1E-06	4.1E-07	4.9E-08	7.2E-08	7.3E-07	1.8E-08	1.2E-08	3.9E-07
Hornsby Hospital (and childcare centre)	Hospital	0.040	0.038	2.4E-06	7.0E-06	1.4E-06	1.6E-07	2.4E-07	2.4E-06	6.0E-08	4.1E-08	1.3E-06
Average Residential		**0.029**	**0.028**	**1.7E-06**	**5.2E-06**	**1.0E-06**	**1.2E-07**	**1.7E-07**	**1.8E-06**	**4.4E-08**	**3.0E-08**	**9.4E-07**
Normanhurst												
Normanhurst Child Care Centre	Childcare	0.019	0.018	1.1E-06	3.3E-06	6.4E-07	7.5E-08	1.1E-07	1.1E-06	2.8E-08	1.9E-08	6.0E-07
Bowden Brae Retirement Village	Aged Care	0.025	0.023	1.5E-06	4.4E-06	8.5E-07	1.0E-07	1.5E-07	1.5E-06	3.7E-08	2.5E-08	8.0E-07
Greenwood Aged Care	Aged Care	0.023	0.022	1.4E-06	4.0E-06	7.8E-07	9.2E-08	1.4E-07	1.4E-06	3.4E-08	2.3E-08	7.4E-07
Normanhurst Boys High School	Schools	0.023	0.022	1.4E-06	4.1E-06	8.0E-07	9.4E-08	1.4E-07	1.4E-06	3.5E-08	2.4E-08	7.5E-07
Normanhurst Public School	Schools	0.018	0.017	1.1E-06	3.2E-06	6.3E-07	7.4E-08	1.1E-07	1.1E-06	2.8E-08	1.9E-08	5.9E-07
Average Residential		**0.022**	**0.020**	**1.3E-06**	**3.8E-06**	**7.4E-07**	**8.7E-08**	**1.3E-07**	**1.3E-06**	**3.2E-08**	**2.2E-08**	**6.9E-07**

Appendix C Calculation of population incidence for exposure to $PM_{2.5}$ (scenarios 2a and 2b)

Assessment of Increased Incidence - PM2.5, Scenario 2a 2019
Southern Interchange

	Primary Indicators			Secondary Indicators			
Health Endpoint:	**Mortality - All Causes, Long-term**	**Hospitalisations - Cardiovascular, Short-term**	**Hospitalisations - Respiratory, Short-term**	**Mortality - All Causes, Short-term**	**Mortality - Cardiopulmonary, Long-term**	**Mortality - Cardiovascular, Short-term**	**Mortality - Respiratory, Short-term**
Age Group:	≥ 30 years	≥ 65 years	≥ 65 years	All ages	≥ 30 years	All ages	All ages
β (change in effect per 1 µg/m^3 PM) (as per Table 5-1)	0.0058	0.0008	0.00041	0.00094	0.013	0.00097	0.0019
Baseline Incidence (per 100,000) (as per Table 3-5)	1087	23352	8807	670	490	164	57
Baseline Incidence (per person)	0.01087	0.23352	0.08807	0.0067	0.0049	0.00164	0.00057
Carlingford							
Total Population:	21570	21570	21570	21570	21570	21570	21570
% population in assessment age-group:	63%	16%	16%	100%	63%	100%	100%
Population weighted Δx (µg/m^3):	0.008	0.008	0.008	0.008	0.008	0.008	0.008
Relative Risk:	1.0000474	1.0000065	1.0000033	1.0000077	1.0001062	1.0000079	1.0000155
Attributable fraction (AF):	4.7E-05	6.5E-06	3.3E-06	7.7E-06	1.1E-04	7.9E-06	1.6E-05
Increased number of cases in population:	0.007	0.005	0.001	0.00111	0.0071	0.00028	0.00019
West Pennant Hills							
Total Population:	15967	15967	15967	15967	15967	15967	15967
% population in assessment age-group:	61%	12%	12%	100%	61%	100%	100%
Population weighted Δx (µg/m^3):	0.014	0.014	0.014	0.014	0.014	0.014	0.014
Relative Risk:	1.000079	1.000011	1.000006	1.000013	1.000177	1.000013	1.000026
Attributable fraction (AF):	7.9E-05	1.1E-05	5.6E-06	1.3E-05	1.8E-04	1.3E-05	2.6E-05
Increased number of cases in population:	0.008	0.005	0.001	0.0014	0.008	0.00035	0.00024
Beecroft							
Total Population:	8836	8836	8836	8836	8836	8836	8836
% population in assessment age-group:	63%	19%	19%	100%	63%	100%	100%
Population weighted Δx (µg/m^3):	0.017	0.017	0.017	0.017	0.017	0.017	0.017
Relative Risk:	1.000096	1.000013	1.000007	1.000016	1.000215	1.000016	1.000031
Attributable fraction (AF):	9.6E-05	1.3E-05	6.8E-06	1.6E-05	2.2E-04	1.6E-05	3.1E-05
Increased number of cases in population:	0.0058	0.0051	0.0010	0.0009	0.0059	0.00023	0.00016
North Rocks							
Total Population:	7625	7625	7625	7625	7625	7625	7625
% population in assessment age-group:	64%	16%	16%	100%	64%	100%	100%
Population weighted Δx (µg/m^3):	0.004	0.004	0.004	0.004	0.004	0.004	0.004
Relative Risk:	1.0000224	1.0000031	1.0000016	1.0000036	1.0000501	1.0000037	1.0000073
Attributable fraction (AF):	2.2E-05	3.1E-06	1.6E-06	3.6E-06	5.0E-05	3.7E-06	7.3E-06
Increased number of cases in population:	0.0012	0.00089	0.00017	0.00019	0.00120	0.000047	0.000032
Epping							
Total Population:	20227	20227	20227	20227	20227	20227	20227
% population in assessment age-group:	60%	13%	13%	100%	60%	100%	100%
Population weighted Δx (µg/m^3):	0.005	0.005	0.005	0.005	0.005	0.005	0.005
Relative Risk:	1.0000310	1.0000043	1.0000022	1.0000050	1.0000695	1.0000052	1.0000102
Attributable fraction (AF):	3.1E-05	4.3E-06	2.2E-06	5.0E-06	6.9E-05	5.2E-06	1.0E-05
Increased number of cases in population:	0.0041	0.0027	0.00052	0.00068	0.0041	0.000172	0.000117
Total for all suburbs	**0.026**	**0.019**	**0.0037**	**0.0043**	**0.027**	**0.0011**	**0.00073**

Assessment of Increased Incidence - PM2.5, Scenario 2b 2029
Southern Interchange

	Primary Indicators			Secondary Indicators			
Health Endpoint:	**Mortality - All Causes, Long-term**	**Hospitalisations - Cardiovascular, Short-term**	**Hospitalisations - Respiratory, Short-term**	**Mortality - All Causes, Short-term**	**Mortality - Cardiopulmonary, Long-term**	**Mortality - Cardiovascular, Short-term**	**Mortality - Respiratory, Short-term**
Age Group:	≥ 30 years	≥ 65 years	≥ 65 years	All ages	≥ 30 years	All ages	All ages
β (change in effect per 1 µg/m^3 PM) (as per Table 5-1)	0.0058	0.0008	0.00041	0.00094	0.013	0.00097	0.0019
Baseline Incidence (per 100,000) (as per Table 3-5)	1087	23352	8807	670	490	164	57
Baseline Incidence (per person)	0.01087	0.23352	0.08807	0.0067	0.0049	0.00164	0.00057
Carlingford							
Total Population:	21570	21570	21570	21570	21570	21570	21570
% population in assessment age-group:	63%	16%	16%	100%	63%	100%	100%
Population weighted Δx (µg/m^3):	0.010	0.010	0.010	0.010	0.010	0.010	0.010
Relative Risk:	1.0000565	1.0000078	1.0000040	1.0000092	1.0001266	1.0000094	1.0000185
Attributable fraction (AF):	5.6E-05	7.8E-06	4.0E-06	9.2E-06	1.3E-04	9.4E-06	1.8E-05
Increased number of cases in population:	0.0083	0.0063	0.0012	0.00132	0.0084	0.00033	0.00023
West Pennant Hills							
Total Population:	15967	15967	15967	15967	15967	15967	15967
% population in assessment age-group:	61%	12%	12%	100%	61%	100%	100%
Population weighted Δx (µg/m^3):	0.014	0.014	0.014	0.014	0.014	0.014	0.014
Relative Risk:	1.000082	1.000011	1.000006	1.000013	1.000185	1.000014	1.000027
Attributable fraction (AF):	8.2E-05	1.1E-05	5.8E-06	1.3E-05	1.8E-04	1.4E-05	2.7E-05
Increased number of cases in population:	0.0087	0.0053	0.0010	0.0014	0.009	0.00036	0.00025
Beecroft							
Total Population:	8836	8836	8836	8836	8836	8836	8836
% population in assessment age-group:	63%	19%	19%	100%	63%	100%	100%
Population weighted Δx (µg/m^3):	0.020	0.020	0.020	0.020	0.020	0.020	0.020
Relative Risk:	1.000115	1.000016	1.000008	1.000019	1.000257	1.000019	1.000038
Attributable fraction (AF):	1.1E-04	1.6E-05	8.1E-06	1.9E-05	2.6E-04	1.9E-05	3.8E-05
Increased number of cases in population:	0.0069	0.0060	0.0012	0.0011	0.0070	0.00028	0.00019
North Rocks							
Total Population:	7625	7625	7625	7625	7625	7625	7625
% population in assessment age-group:	64%	16%	16%	100%	64%	100%	100%
Population weighted Δx (µg/m^3):	0.005	0.005	0.005	0.005	0.005	0.005	0.005
Relative Risk:	1.0000264	1.0000036	1.0000019	1.0000043	1.0000592	1.0000044	1.0000087
Attributable fraction (AF):	2.6E-05	3.6E-06	1.9E-06	4.3E-06	5.9E-05	4.4E-06	8.7E-06
Increased number of cases in population:	0.0014	0.0011	0.00020	0.00022	0.00142	0.000055	0.000038
Epping							
Total Population:	20227	20227	20227	20227	20227	20227	20227
% population in assessment age-group:	60%	13%	13%	100%	60%	100%	100%
Population weighted Δx (µg/m^3):	0.006	0.006	0.006	0.006	0.006	0.006	0.006
Relative Risk:	1.0000366	1.0000051	1.0000026	1.0000059	1.0000821	1.0000061	1.0000120
Attributable fraction (AF):	3.7E-05	5.1E-06	2.6E-06	5.9E-06	8.2E-05	6.1E-06	1.2E-05
Increased number of cases in population:	0.0048	0.0032	0.00061	0.00080	0.0049	0.000203	0.000138
Total for all suburbs	**0.030**	**0.022**	**0.0042**	**0.0049**	**0.031**	**0.0012**	**0.00084**

Assessment of Increased Incidence - PM2.5, Scenario 2a 2019
Northern Interchange

	Primary Indicators			Secondary Indicators			
Health Endpoint:	**Mortality - All Causes, Long-term**	**Hospitalisations - Cardiovascular, Short-term**	**Hospitalisations - Respiratory, Short-term**	**Mortality - All Causes, Short-term**	**Mortality - Cardiopulmonary, Long-term**	**Mortality - Cardiovascular, Short-term**	**Mortality - Respiratory, Short-term**
Age Group:	≥ 30 years	≥ 65 years	≥ 65 years	All ages	≥ 30 years	All ages	All ages
β (change in effect per 1 µg/m^3 PM) (as per Table 5-1)	0.0058	0.0008	0.00041	0.00094	0.013	0.00097	0.0019
Baseline Incidence (per 100,000) (as per Table 3-5)	1087	23352	8807	670	490	164	57
Baseline Incidence (per person)	0.01087	0.23352	0.08807	0.0067	0.0049	0.00164	0.00057
Wahroonga:							
Total Population:	16726	16726	16726	16726	16726	16726	16726
% population in assessment age-group:	62%	18%	18%	100%	62%	100%	100%
Population weighted Δx (µg/m^3):	0.020	0.020	0.020	0.020	0.020	0.020	0.020
Relative Risk:	1.000117	1.000016	1.000008	1.000019	1.000263	1.000020	1.000038
Attributable fraction (AF):	1.2E-04	1.6E-05	8.3E-06	1.9E-05	2.6E-04	2.0E-05	3.8E-05
Increased number of cases in population:	0.013	0.011	0.0022	0.0021	0.013	0.00054	0.00037
North Wahroonga:							
Total Population:	1886	1886	1886	1886	1886	1886	1886
% population in assessment age-group:	63%	16%	16%	100%	63%	100%	100%
Population weighted Δx (µg/m^3):	0.017	0.017	0.017	0.017	0.017	0.017	0.017
Relative Risk:	1.000099	1.000014	1.000007	1.000016	1.000223	1.000017	1.000033
Attributable fraction (AF):	9.9E-05	1.4E-05	7.0E-06	1.6E-05	2.2E-04	1.7E-05	3.3E-05
Increased number of cases in population:	0.0013	0.0010	0.00019	0.00020	0.0013	0.000051	0.000035
Warrawee							
Total Population:	2912	2912	2912	2912	2912	2912	2912
% population in assessment age-group:	58%	14%	14%	100%	58%	100%	100%
Population weighted Δx (µg/m^3):	0.010	0.010	0.010	0.010	0.010	0.010	0.010
Relative Risk:	1.000060	1.000008	1.000004	1.000010	1.000134	1.000010	1.000020
Attributable fraction (AF):	6.0E-05	8.3E-06	4.2E-06	9.7E-06	1.3E-04	1.0E-05	2.0E-05
Increased number of cases in population:	0.0011	0.00077	0.00015	0.00019	0.0011	0.000048	0.000033
Waitara							
Total Population:	5370	5370	5370	5370	5370	5370	5370
% population in assessment age-group:	64%	15%	15%	100%	64%	100%	100%
Population weighted Δx (µg/m^3):	0.023	0.023	0.023	0.023	0.023	0.023	0.023
Relative Risk:	1.000136	1.000019	1.000010	1.000022	1.000304	1.000023	1.000044
Attributable fraction (AF):	1.4E-04	1.9E-05	9.6E-06	2.2E-05	3.0E-04	2.3E-05	4.4E-05
Increased number of cases in population:	0.0051	0.0035	0.00068	0.00079	0.0051	0.00020	0.00014
Hornsby							
Total Population:	19863	19863	19863	19863	19863	19863	19863
% population in assessment age-group:	62%	12%	12%	100%	62%	100%	100%
Population weighted Δx (µg/m^3):	0.011	0.011	0.011	0.011	0.011	0.011	0.011
Relative Risk:	1.000067	1.000009	1.000005	1.000011	1.000149	1.000011	1.000022
Attributable fraction (AF):	6.7E-05	9.2E-06	4.7E-06	1.1E-05	1.5E-04	1.1E-05	2.2E-05
Increased number of cases in population:	0.0089	0.0049	0.0010	0.0014	0.0090	0.00036	0.00025
Normanhurst							
Total Population:	5156	5156	5156	5156	5156	5156	5156
% population in assessment age-group:	61%	19%	19%	100%	61%	100%	100%
Population weighted Δx (µg/m^3):	0.013	0.013	0.013	0.013	0.013	0.013	0.013
Relative Risk:	1.000076	1.000010	1.000005	1.000012	1.000169	1.000013	1.000025
Attributable fraction (AF):	7.6E-05	1.0E-05	5.3E-06	1.2E-05	1.7E-04	1.3E-05	2.5E-05
Increased number of cases in population:	0.0026	0.0023	0.00045	0.00042	0.0026	0.00011	0.000073
Total - All Suburbs	**0.032**	**0.024**	**0.0046**	**0.0052**	**0.033**	**0.0013**	**0.0009**

Assessment of Increased Incidence - PM2.5, Scenario 2b 2029
Northern Interchange

	Primary Indicators			Secondary Indicators			
Health Endpoint:	**Mortality - All Causes, Long-term**	**Hospitalisations - Cardiovascular, Short-term**	**Hospitalisations - Respiratory, Short-term**	**Mortality - All Causes, Short-term**	**Mortality - Cardiopulmonary, Long-term**	**Mortality - Cardiovascular, Short-term**	**Mortality - Respiratory, Short-term**
Age Group:	≥ 30 years	≥ 65 years	≥ 65 years	All ages	≥ 30 years	All ages	All ages
β (change in effect per 1 µg/m^3 PM) (as per Table 5-1)	0.0058	0.0008	0.00041	0.00094	0.013	0.00097	0.0019
Baseline Incidence (per 100,000) (as per Table 3-5)	1087	23352	8807	670	490	164	57
Baseline Incidence (per person)	0.01087	0.23352	0.08807	0.0067	0.0049	0.00164	0.00057
Wahroonga:							
Total Population:	16726	16726	16726	16726	16726	16726	16726
% population in assessment age-group:	62%	18%	18%	100%	62%	100%	100%
Population weighted Δx (µg/m^3):	0.024	0.024	0.024	0.024	0.024	0.024	0.024
Relative Risk:	1.000139	1.000019	1.000010	1.000023	1.000312	1.000023	1.000046
Attributable fraction (AF):	1.4E-04	1.9E-05	9.8E-06	2.3E-05	3.1E-04	2.3E-05	4.6E-05
Increased number of cases in population:	0.016	0.013	0.0026	0.0025	0.016	0.00064	0.00043
North Wahroonga:							
Total Population:	1886	1886	1886	1886	1886	1886	1886
% population in assessment age-group:	63%	16%	16%	100%	63%	100%	100%
Population weighted Δx (µg/m^3):	0.020	0.020	0.020	0.020	0.020	0.020	0.020
Relative Risk:	1.000114	1.000016	1.000008	1.000019	1.000256	1.000019	1.000037
Attributable fraction (AF):	1.1E-04	1.6E-05	8.1E-06	1.9E-05	2.6E-04	1.9E-05	3.7E-05
Increased number of cases in population:	0.0015	0.0011	0.00022	0.00023	0.0015	0.000059	0.000040
Warrawee							
Total Population:	2912	2912	2912	2912	2912	2912	2912
% population in assessment age-group:	58%	14%	14%	100%	58%	100%	100%
Population weighted Δx (µg/m^3):	0.012	0.012	0.012	0.012	0.012	0.012	0.012
Relative Risk:	1.000069	1.000010	1.000005	1.000011	1.000155	1.000012	1.000023
Attributable fraction (AF):	6.9E-05	9.5E-06	4.9E-06	1.1E-05	1.5E-04	1.2E-05	2.3E-05
Increased number of cases in population:	0.0013	0.00088	0.00017	0.00022	0.0013	0.000055	0.000037
Waitara							
Total Population:	5370	5370	5370	5370	5370	5370	5370
% population in assessment age-group:	64%	15%	15%	100%	64%	100%	100%
Population weighted Δx (µg/m^3):	0.027	0.027	0.027	0.027	0.027	0.027	0.027
Relative Risk:	1.000157	1.000022	1.000011	1.000025	1.000352	1.000026	1.000051
Attributable fraction (AF):	1.6E-04	2.2E-05	1.1E-05	2.5E-05	3.5E-04	2.6E-05	5.1E-05
Increased number of cases in population:	0.0059	0.0040	0.00078	0.00092	0.0059	0.00023	0.00016
Hornsby							
Total Population:	19863	19863	19863	19863	19863	19863	19863
% population in assessment age-group:	62%	12%	12%	100%	62%	100%	100%
Population weighted Δx (µg/m^3):	0.013	0.013	0.013	0.013	0.013	0.013	0.013
Relative Risk:	1.000076	1.000010	1.000005	1.000012	1.000170	1.000013	1.000025
Attributable fraction (AF):	7.6E-05	1.0E-05	5.4E-06	1.2E-05	1.7E-04	1.3E-05	2.5E-05
Increased number of cases in population:	0.010	0.0056	0.0011	0.0016	0.0103	0.00041	0.00028
Normanhurst							
Total Population:	5156	5156	5156	5156	5156	5156	5156
% population in assessment age-group:	61%	19%	19%	100%	61%	100%	100%
Population weighted Δx (µg/m^3):	0.015	0.015	0.015	0.015	0.015	0.015	0.015
Relative Risk:	1.000088	1.000012	1.000006	1.000014	1.000197	1.000015	1.000029
Attributable fraction (AF):	8.8E-05	1.2E-05	6.2E-06	1.4E-05	2.0E-04	1.5E-05	2.9E-05
Increased number of cases in population:	0.0030	0.0027	0.00052	0.00049	0.0030	0.00012	0.000085
Total - All Suburbs	**0.037**	**0.028**	**0.0053**	**0.0060**	**0.038**	**0.0015**	**0.0010**

Appendix D Calculations of Health Impacts for $PM_{2.5}$ concentrations changes – whole project including Pennant Hills Road

Assessment of Risk and Incidence - PM2.5 - Whole Project including PHR
Scenario 2a - 2019

	Primary Indicators			Secondary Indicators			
Health Endpoint:	**Mortality - All Causes, Long-term**	**Hospitalisations - Cardiovascular. Short-term**	**Hospitalisations - Respiratory, Short-term**	**Mortality - All Causes, Short-term**	**Mortality - Cardiopulmonary, Long-term**	**Mortality - Cardiovascular, Short-term**	**Mortality - Respiratory, Short-term**
Age Group:	≥ 30 years	≥ 65 years	≥ 65 years	All ages	≥ 30 years	All ages	All ages
β (change in effect per 1 µg/m^3 PM) (as per Table 5-1)	0.0058	0.0008	0.00041	0.00094	0.013	0.00097	0.0019
Baseline Incidence (per 100,000) (as per Table 3-5)	1087	23352	8807	670	490	164	57
Baseline Incidence (per person)	0.01087	0.23352	0.08807	0.0067	0.0049	0.00164	0.00057
Carlingford							
Total Population (part of suburb):	16292	16292	16292	16292	16292	16292	16292
% population in assessment age-group:	63%	16%	16%	100%	63%	100%	100%
Population weighted Δx (µg/m^3):	0.0074	0.0074	0.0074	0.0074	0.0074	0.0074	0.0074
Relative Risk:	1.0000428	1.0000059	1.0000030	1.0000069	1.0000960	1.0000072	1.0000140
Attributable fraction (AF):	4.3E-05	5.9E-06	3.0E-06	6.9E-06	9.6E-05	7.2E-06	1.4E-05
Increased number of cases in population:	0.0048	0.0036	0.00070	0.00076	0.0048	0.00019	0.00013
Risk:	4.7E-07	1.4E-06	2.7E-07	4.7E-08	4.7E-07	1.2E-08	8.0E-09
West Pennant Hills							
Total Population (part of suburb):	11882	11882	11882	11882	11882	11882	11882
% population in assessment age-group:	61%	12%	12%	100%	61%	100%	100%
Population weighted Δx (µg/m^3):	-0.0316	-0.0316	-0.0316	-0.0316	-0.0316	-0.0316	-0.0316
Relative Risk:	0.999817	0.999975	0.999987	0.999970	0.999590	0.999969	0.999940
Attributable fraction (AF):	-1.8E-04	-2.5E-05	-1.3E-05	-3.0E-05	-4.1E-04	-3.1E-05	-6.0E-05
Increased number of cases in population:	-0.0144	-0.0087	-0.0017	-0.0024	-0.015	-0.00060	-0.00041
Risk:	-2.0E-06	-5.9E-06	-1.1E-06	-2.0E-07	-2.0E-06	-5.0E-08	-3.4E-08
North Rocks							
Total Population (part of suburb):	5293	5293	5293	5293	5293	5293	5293
% population in assessment age-group:	64%	16%	16%	100%	64%	100%	100%
Population weighted Δx (µg/m^3):	0.0027	0.0027	0.0027	0.0027	0.0027	0.0027	0.0027
Relative Risk:	1.0000157	1.0000022	1.0000011	1.0000025	1.0000351	1.0000026	1.0000051
Attributable fraction (AF):	1.6E-05	2.2E-06	1.1E-06	2.5E-06	3.5E-05	2.6E-06	5.1E-06
Increased number of cases in population:	0.00058	0.00043	0.00008	0.00009	0.00058	0.000023	0.000015
Risk:	1.7E-07	5.0E-07	9.8E-08	1.7E-08	1.7E-07	4.3E-09	2.9E-09
Epping/North Epping							
Total Population (part of suburbs):	10146	10146	10146	10146	10146	10146	10146
% population in assessment age-group:	60%	13%	13%	100%	60%	100%	100%
Population weighted Δx (µg/m^3):	0.0037	0.0037	0.0037	0.0037	0.0037	0.0037	0.0037
Relative Risk:	1.0000215	1.0000030	1.0000015	1.0000035	1.0000482	1.0000036	1.0000070
Attributable fraction (AF):	2.1E-05	3.0E-06	1.5E-06	3.5E-06	4.8E-05	3.6E-06	7.0E-06
Increased number of cases in population:	0.0014	0.0009	0.00018	0.00024	0.0014	0.000060	0.000041
Risk:	2.3E-07	6.9E-07	1.3E-07	2.3E-08	2.4E-07	5.9E-09	4.0E-09
Pennant Hills/Cheltenham							
Total Population (part of suburbs):	15184	15184	15184	15184	15184	15184	15184
% population in assessment age-group:	74%	16%	16%	100%	74%	100%	100%
Population weighted Δx (µg/m^3):	-0.1957	-0.1957	-0.1957	-0.1957	-0.1957	-0.1957	-0.1957
Relative Risk:	0.9988653	0.9998434	0.9999197	0.9998160	0.9974585	0.9998101	0.9996282
Attributable fraction (AF):	-1.1E-03	-1.6E-04	-8.0E-05	-1.8E-04	-2.5E-03	-1.9E-04	-3.7E-04
Increased number of cases in population:	-0.1387	-0.0866	-0.01674	-0.01872	-0.1403	-0.004729	-0.003219
Risk:	-1.2E-05	-3.7E-05	-7.1E-06	-1.2E-06	-1.2E-05	-3.1E-07	-2.1E-07
Wahroonga/Warrawee:							
Total Population (part of suburb):	16284	16284	16284	16284	16284	16284	16284
% population in assessment age-group:	62%	18%	18%	100%	62%	100%	100%
Population weighted Δx (µg/m^3):	-0.0048	-0.0048	-0.0048	-0.0048	-0.0048	-0.0048	-0.0048
Relative Risk:	0.999972	0.999996	0.999998	0.999995	0.999937	0.999995	0.999991
Attributable fraction (AF):	-2.8E-05	-3.9E-06	-2.0E-06	-4.5E-06	-6.3E-05	-4.7E-06	-9.2E-06
Increased number of cases in population:	-0.003	-0.003	-0.0005	-0.0005	-0.003	-0.00013	-0.00009
Risk:	-3.0E-07	-9.0E-07	-1.7E-07	-3.0E-08	-3.1E-07	-7.7E-09	-5.2E-09
Hornsby/Waitara							
Total Population (part of suburbs):	17527	17527	17527	17527	17527	17527	17527
% population in assessment age-group:	62%	12%	12%	100%	62%	100%	100%
Population weighted Δx (µg/m^3):	-0.0081	-0.0081	-0.0081	-0.0081	-0.0081	-0.0081	-0.0081
Relative Risk:	0.999953	0.999993	0.999997	0.999992	0.999894	0.999992	0.999985
Attributable fraction (AF):	-4.7E-05	-6.5E-06	-3.3E-06	-7.7E-06	-1.1E-04	-7.9E-06	-1.5E-05
Increased number of cases in population:	-0.0056	-0.0031	-0.00060	-0.0009	-0.0056	-0.00023	-0.00015
Risk:	-5.1E-07	-1.5E-06	-2.9E-07	-5.1E-08	-5.2E-07	-1.3E-08	-8.8E-09
Normanhurst/Thornleigh/Westleigh							
Total Population (part of suburbs):	11181	11181	11181	11181	11181	11181	11181
% population in assessment age-group:	61%	19%	19%	100%	61%	100%	100%
Population weighted Δx (µg/m^3):	-0.2123	-0.2123	-0.2123	-0.2123	-0.2123	-0.2123	-0.2123
Relative Risk:	0.998769	0.999830	0.999913	0.999800	0.997244	0.999794	0.999597
Attributable fraction (AF):	-1.2E-03	-1.7E-04	-8.7E-05	-2.0E-04	-2.8E-03	-2.1E-04	-4.0E-04
Increased number of cases in population:	-0.0914	-0.0821	-0.01586	-0.01495	-0.0924	-0.00378	-0.002571
Risk:	-1.3E-05	-4.0E-05	-7.7E-06	-1.3E-06	-1.4E-05	-3.4E-07	-2.3E-07
Change in population risk for all suburbs	**-2.8E-05**	**-8.2E-05**	**-1.6E-05**	**-2.8E-06**	**-2.8E-05**	**-7.0E-07**	**-4.8E-07**
Change in incidence for all suburbs	**-0.246**	**-0.178**	**-0.034**	**-0.036**	**-0.249**	**-0.009**	**-0.006**

Assessment of Risk and Incidence - PM2.5 - Whole Project including PHR
Scenario 2b - 2029

	Primary Indicators			Secondary Indicators			
Health Endpoint:	**Mortality - All Causes, Long-term**	**Hospitalisations - Cardiovascular. Short-term**	**Hospitalisations - Respiratory, Short-term**	**Mortality - All Causes, Short-term**	**Mortality - Cardiopulmonary, Long-term**	**Mortality - Cardiovascular, Short-term**	**Mortality - Respiratory, Short-term**
Age Group:	≥ 30 years	≥ 65 years	≥ 65 years	All ages	≥ 30 years	All ages	All ages
β (change in effect per 1 µg/m^3 PM) (as per Table 5-1)	0.0058	0.0008	0.00041	0.00094	0.013	0.00097	0.0019
Baseline Incidence (per 100,000) (as per Table 3-5)	1087	23352	8807	670	490	164	57
Baseline Incidence (per person)	0.01087	0.23352	0.08807	0.0067	0.0049	0.00164	0.00057
Carlingford							
Total Population (part of suburb):	16292	16292	16292	16292	16292	16292	16292
% population in assessment age-group:	63%	16%	16%	100%	63%	100%	100%
Population weighted Δx (µg/m^3):	0.0078	0.0078	0.0078	0.0078	0.0078	0.0078	0.0078
Relative Risk:	1.0000453	1.0000062	1.0000032	1.0000073	1.0001015	1.0000076	1.0000148
Attributable fraction (AF):	4.5E-05	6.2E-06	3.2E-06	7.3E-06	1.0E-04	7.6E-06	1.5E-05
Increased number of cases in population:	0.0051	0.0038	0.00074	0.00080	0.0051	0.00020	0.00014
Risk:	4.9E-07	1.5E-06	2.8E-07	4.9E-08	5.0E-07	1.2E-08	8.5E-09
West Pennant Hills							
Total Population (part of suburb):	11882	11882	11882	11882	11882	11882	11882
% population in assessment age-group:	61%	12%	12%	100%	61%	100%	100%
Population weighted Δx (µg/m^3):	-0.0398	-0.0398	-0.0398	-0.0398	-0.0398	-0.0398	-0.0398
Relative Risk:	0.999769	0.999968	0.999984	0.999963	0.999483	0.999961	0.999924
Attributable fraction (AF):	-2.3E-04	-3.2E-05	-1.6E-05	-3.7E-05	-5.2E-04	-3.9E-05	-7.6E-05
Increased number of cases in population:	-0.0182	-0.0110	-0.0021	-0.0030	-0.018	-0.00075	-0.00051
Risk:	-2.5E-06	-7.4E-06	-1.4E-06	-2.5E-07	-2.5E-06	-6.3E-08	-4.3E-08
North Rocks							
Total Population (part of suburb):	5293	5293	5293	5293	5293	5293	5293
% population in assessment age-group:	64%	16%	16%	100%	64%	100%	100%
Population weighted Δx (µg/m^3):	0.0029	0.0029	0.0029	0.0029	0.0029	0.0029	0.0029
Relative Risk:	1.0000167	1.0000023	1.0000012	1.0000027	1.0000374	1.0000028	1.0000055
Attributable fraction (AF):	1.7E-05	2.3E-06	1.2E-06	2.7E-06	3.7E-05	2.8E-06	5.5E-06
Increased number of cases in population:	0.00061	0.00046	0.00009	0.00010	0.00062	0.000024	0.000016
Risk:	1.8E-07	5.4E-07	1.0E-07	1.8E-08	1.8E-07	4.6E-09	3.1E-09
Epping/North Epping							
Total Population (part of suburbs):	10146	10146	10146	10146	10146	10146	10146
% population in assessment age-group:	60%	13%	13%	100%	60%	100%	100%
Population weighted Δx (µg/m^3):	0.0040	0.0040	0.0040	0.0040	0.0040	0.0040	0.0040
Relative Risk:	1.0000230	1.0000032	1.0000016	1.0000037	1.0000516	1.0000039	1.0000075
Attributable fraction (AF):	2.3E-05	3.2E-06	1.6E-06	3.7E-06	5.2E-05	3.9E-06	7.5E-06
Increased number of cases in population:	0.0015	0.0010	0.00019	0.00025	0.0015	0.000064	0.000044
Risk:	2.5E-07	7.4E-07	1.4E-07	2.5E-08	2.5E-07	6.3E-09	4.3E-09
Pennant Hills/Cheltenham							
Total Population (part of suburbs):	15184	15184	15184	15184	15184	15184	15184
% population in assessment age-group:	74%	16%	16%	100%	74%	100%	100%
Population weighted Δx (µg/m^3):	-0.1950	-0.1950	-0.1950	-0.1950	-0.1950	-0.1950	-0.1950
Relative Risk:	0.9988695	0.9998440	0.9999200	0.9998167	0.9974679	0.9998108	0.9996295
Attributable fraction (AF):	-1.1E-03	-1.6E-04	-8.0E-05	-1.8E-04	-2.5E-03	-1.9E-04	-3.7E-04
Increased number of cases in population:	-0.1382	-0.0863	-0.01668	-0.01865	-0.1398	-0.004711	-0.003208
Risk:	-1.2E-05	-3.6E-05	-7.0E-06	-1.2E-06	-1.2E-05	-3.1E-07	-2.1E-07
Wahroonga/Warrawee:							
Total Population (part of suburb):	16284	16284	16284	16284	16284	16284	16284
% population in assessment age-group:	62%	18%	18%	100%	62%	100%	100%
Population weighted Δx (µg/m^3):	-0.0193	-0.0193	-0.0193	-0.0193	-0.0193	-0.0193	-0.0193
Relative Risk:	0.999888	0.999985	0.999992	0.999982	0.999749	0.999981	0.999963
Attributable fraction (AF):	-1.1E-04	-1.5E-05	-7.9E-06	-1.8E-05	-2.5E-04	-1.9E-05	-3.7E-05
Increased number of cases in population:	-0.012	-0.010	-0.0020	-0.0020	-0.012	-0.00050	-0.00034
Risk:	-1.2E-06	-3.6E-06	-7.0E-07	-1.2E-07	-1.2E-06	-3.1E-08	-2.1E-08
Hornsby/Waitara							
Total Population (part of suburbs):	17527	17527	17527	17527	17527	17527	17527
% population in assessment age-group:	62%	12%	12%	100%	62%	100%	100%
Population weighted Δx (µg/m^3):	-0.0116	-0.0116	-0.0116	-0.0116	-0.0116	-0.0116	-0.0116
Relative Risk:	0.999933	0.999991	0.999995	0.999989	0.999849	0.999989	0.999978
Attributable fraction (AF):	-6.7E-05	-9.3E-06	-4.8E-06	-1.1E-05	-1.5E-04	-1.1E-05	-2.2E-05
Increased number of cases in population:	-0.0080	-0.0044	-0.00085	-0.0013	-0.0080	-0.00032	-0.00022
Risk:	-7.3E-07	-2.2E-06	-4.2E-07	-7.3E-08	-7.4E-07	-1.8E-08	-1.3E-08
Normanhurst/Thornleigh/Westleigh							
Total Population (part of suburbs):	11181	11181	11181	11181	11181	11181	11181
% population in assessment age-group:	61%	19%	19%	100%	61%	100%	100%
Population weighted Δx (µg/m^3):	-0.2228	-0.2228	-0.2228	-0.2228	-0.2228	-0.2228	-0.2228
Relative Risk:	0.998709	0.999822	0.999909	0.999791	0.997108	0.999784	0.999577
Attributable fraction (AF):	-1.3E-03	-1.8E-04	-9.1E-05	-2.1E-04	-2.9E-03	-2.2E-04	-4.2E-04
Increased number of cases in population:	-0.0959	-0.0861	-0.01664	-0.01569	-0.0969	-0.00396	-0.002698
Risk:	-1.4E-05	-4.2E-05	-8.0E-06	-1.4E-06	-1.4E-05	-3.5E-07	-2.4E-07
Change in population risk for all suburbs	**-3.0E-05**	**-8.9E-05**	**-1.7E-05**	**-3.0E-06**	**-3.0E-05**	**-7.5E-07**	**-5.1E-07**
Change in incidence for all suburbs	**-0.265**	**-0.193**	**-0.037**	**-0.039**	**-0.268**	**-0.010**	**-0.007**

(blank page)

Appendix E Calculations for design analysis A

E1 General

This appendix presents calculations relevant top predicted health impacts associated with design analysis A, the theoretical maximum peak hour traffic flow.

This design analysis has been conducted to ensure that the project's ventilation system is adequately sized to cater for tunnel full of traffic. It assumes that during peak hours, the maximum number of vehicles that can fit into the tunnel (4,000 passenger car units per two lane main alignment tunnel adjusted for speed). This design analysis represents the physical limit of the main alignment tunnels and is based on forecast traffic volumes that are unlikely to eventuate due to a range of factors.

The calculations presented are associated with the assessment of pollutants as presented in the main body of the report.

E2 Assessment of Key Pollutants

On the basis of the guidelines identified and outlined in **Section 4.2** of the main report the following can be noted in relation to potential exposures to nitrogen dioxide and carbon monoxide for design analysis A:

Nitrogen dioxide

- The maximum 1 hour average cumulative (background plus the project) concentration is predicted to be 182 µg/m^3, which is below the acute health based guideline of 246 µg/m^3.
- The maximum annual average cumulative (background plus project) concentration is predicted to be 42.6 µg/m^3, which is below the chronic health based guideline of 62 µg/m^3.

Carbon Monoxide

- The maximum 1 hour average cumulative (background plus the project) concentration is predicted to be 3 804 µg/m^3, which is below the acute health based guideline of 30 000 µg/m^3.
- The maximum 8-hour average cumulative (background plus project) concentration is predicted to be 2 684 µg/m^3, which is below the chronic health based guideline of 10 000 µg/m^3.

All the concentrations of nitrogen dioxide and carbon monoxide are well below the relevant health based guidelines. Hence there are no adverse health effects expected in relation to exposures (acute and chronic) to nitrogen dioxide or carbon monoxide in the local area surrounding the project.

E3 Assessment of Exposure to polycyclic aromatic hydrocarbons and volatile organic compounds

On the basis of the speciation of individual polycyclic aromatic hydrocarbons and volatile organic compounds, and the acute and chronic guidelines identified and outlined in **Section 4.3** of the main report the following has been calculated in relation to potential exposures to these compounds for this scenario:

Table E1 Evaluation of potential acute impacts in local area – design analysis A

Key VOC	Proportion of total VOCs (%)*		Health based acute guideline, and basis (µg/m^3)	Maximum predicted 1-hour average concentration from project** and calculated HI for each interchange			
				Northern interchange		Southern interchange	
	2019	2029		Max Conc. (µg/m^3)	HI	Max Conc. (µg/m^3)	HI
Total VOCs				**7.4**		**9.0**	
Benzene	3.3	3.8	**29[A1] to 170[T1]** (lower value adopted) A1: Acute guideline (1hr to 14 day exposure), based on immunological effects in mice. T1: Acute 1 hour health based guideline, based on depressed peripheral lymphocytes and depressed mitogen-induced blastogenesis (mice study)	0.24	0.0084	0.30	0.010
Toluene	5.6	6.7	**4500[T2]** Acute 1 hour health based guideline, based on eye and nose irritation, increased occurrence of headache and intoxication in human male volunteers	0.42	0.000093	0.51	0.00011
Xylenes	4.6	5.5	**2200[T3]** Acute 1 hour health based guideline, based on mild respiratory effects and subjective symptoms of neurotoxicity in human volunteers	0.34	0.00016	0.42	0.00019
1,3-Butadiene	0.9	1.0	**660[O1]** Acute 1 hour health based guideline, based on developmental effects	0.067	0.000102	0.081	0.00012
Formaldehyde	4.9	3.9	**15[T4]** Acute 1 hour health based guideline, based on eye and nose irritation in human volunteers	0.36	0.024	0.44	0.029
Acetaldehyde	2.1	1.6	**470[O2]** Acute 1 hour health based guideline, based on effects on sensory irritation, bronchoconstriction, eye redness and swelling	0.15	0.00032	0.18	0.00039
			Total HI		0.033		0.040

Notes:

* Percentage of each individual volatile organic compound is based on a weighted average of emissions from the range of vehicle types proposed to be used on the project in 2019 and 2029 (refer to discussion above table)

** Concentrations presented for the 1 hour average are the predicted incremental 99.9th percentile concentrations (as provided from the AQIA)

A1: Acute inhalation guideline (for exposures from 1 hour to 14 days) from review by ATSDR 2008 for benzene

T1: TCEQ 2007, Benzene, Development Support Document. Texas Commission of Environmental Quality, 1 hour average guideline value (include additional 3.3 fold safety factor). This acute guideline is lower than that derived by the OEHHA (based on older studies)

T2: TCEQ 2008, Toluene, Development Support Document. Texas Commission of Environmental Quality, 1 hour average guideline value (include additional 3.3 fold safety factor)

T3: TCEQ 2009, Xylenes, Development Support Document. Texas Commission of Environmental Quality, 1 hour average guideline value (include additional 3.3 fold safety factor)

T4: TCEQ 2008, Formaldehyde, Development Support Document. Texas Commission of Environmental Quality, 1 hour average guideline value (include additional 3.3 fold safety factor). This guideline is noted to be lower than the acute guideline available from the WHO (2000a, 2010) of 100 µg/m^3 for formaldehyde

O1: OEHHA 2013, Acute (1 hour average) guideline derived by the California Office of Environmental Health Hazard Assessment. The guideline developed is lower than developed by TCEQ (2008) based on the same critical study

O2: OEHHA 2008, Acute (1 hour average) guideline derived by the California Office of Environmental Health Hazard Assessment

Table E2 Evaluation of potential chronic impacts in local area – design analysis A

Key VOC	Proportion of total VOCs* (%)		Health based chronic guideline and basis (µg/m^3)	Maximum predicted annual average concentration from project** and calculated HI for each interchange			
				Northern interchange		Southern interchange	
				Max Conc. (µg/m^3)	HI	Max Conc. (µg/m^3)	HI
	2019	2029	**Total VOCs**	**0.20**		**0.21**	
Benzene	3.3	3.8	**1.7**[W1] Benzene is classified as a known human carcinogen by IARC. Chronic guideline based on excess risk of leukaemia	0.0066	0.0039	0.0070	0.0041
Toluene	5.6	6.7	**5000**[U1] Chronic guideline based on neurological effects in an occupational study (converted to public health value using safety factors)	0.0113	2.3X10^{-6}	0.0120	2.4X10^{-6}
Xylenes	4.6	5.5	**220**[A1] Chronic guideline based on mild subjective respiratory and neurological symptoms in an occupational study (converted to public health value using safety factors)	0.0093	0.000042	0.0099	0.000045
1,3-Butadiene	0.9	1.0	**0.3**[U2] 1,3-Butadiene is classified by IARC as a probable human carcinogen. Chronic air guideline based on an excess risk of leukaemia	0.0018	0.0061	0.0019	0.0064
Formaldehyde	4.9	3.9	**3.3**[T1] Formaldehyde is classified by IARC as carcinogenic to humans. The guideline developed is based on the protection of all adverse effects including cancer and non-cancer (including short term effects)	0.0098	0.0030	0.010	0.0031
Acetaldehyde	2.1	1.6	**9**[U3] Chronic guideline based on nasal effects (in a rat study) (converted to a public health value using safety factors)	0.0041	0.00046	0.0044	0.00048
	B		**Total PAHs**	**3.8X10^{-5}**		**5.0X10^{-5}**	
Naphthalene	70		**3**[U4] Chronic guideline based on nasal effects (in a mouse study) (converted to a public health value using safety factors)	2.7X10^{-5}	8.9X10^{-6}	3.5X10^{-5}	1.2X10^{-5}
Acenaphthylene	4.9		200[U5S] Refer to notes for ref U5	1.9X10^{-6}	9.4X10^{-9}	2.5X10^{-6}	1.2X10^{-8}
Acenaphthene	2.0		200[U5]	7.7X10^{-7}	3.8X10^{-9}	1.0X10^{-6}	5.0X10^{-9}
Fluorene	5.0		140[U5]	1.9X10^{-6}	1.4X10^{-8}	2.5X10^{-6}	1.8X10^{-8}
Phenanthrene	3.4		140[U5S]	1.3X10^{-6}	9.3X10^{-9}	1.7X10^{-6}	1.2X10^{-8}
Anthracene	0.49		100[U5]	1.9X10^{-7}	1.9X10^{-9}	2.5X10^{-7}	2.5X10^{-9}
Fluoranthene	0.45		140[U5]	1.7X10^{-7}	1.2X10^{-9}	2.3X10^{-7}	1.6X10^{-9}
Pyrene	0.71		100[U5]	2.7X10^{-7}	2.7X10^{-9}	3.6X10^{-7}	3.6X10^{-9}

Key VOC	Proportion of total VOCs* (%)	Health based chronic guideline and basis (µg/m^3)	Maximum predicted annual average concentration from project** and calculated HI for each interchange			
			Northern interchange		Southern interchange	
			Max Conc. (µg/m^3)	HI	Max Conc. (µg/m^3)	HI
Benzo(a)pyrene TEQ	4.6	**0.00012**[W2] BaP is classified by IARC as a known human carcinogen, which relates to BaP as well as all the other carcinogenic PAHs assessed as a BaP toxicity equivalent value. The chronic guideline is based on protection from lung cancer for an occupational study	$1.8X10^{-6}$	0.015	$2.3X10^{-6}$	0.019
		Total HI (VOCs + PAHs)		**0.028**		**0.033**

Notes:

* Percentage of each individual volatile organic compounds and polycyclic aromatic hydrocarbons is based on a weighted average of emissions from the range of vehicle types proposed to be used on the project in 2019 and 2029, and for normal traffic flow or congested traffic flow (refer to discussion above table)

** Concentrations presented for the annual average are as provided from the AQIA

B Polycyclic aromatic hydrocarbon speciation data for congested traffic flow – utilised in the assessment of the worst-case emissions

W1: WHO 2000 Air Quality Guidelines, value for benzene is based on non-threshold carcinogenic effects (excess lifetime risk of leukaemia). Guideline value based on incremental cancer risk of $1x10^{-5}$, consistent with guidance provided by NEPM (1999 amended 2013) and enHealth (2012)

W2: WHO 2010 Guidelines for Indoor Air Quality, value for BaP is based on non-threshold carcinogenic effects from occupational study of coke workers (lung cancer is critical effect). Guideline value based on incremental cancer risk of $1x10^{-5}$, consistent with guidance provided by NEPM (1999 amended 2013) and enHealth (2012)

T1: TCEQ 2008, Formaldehyde, Development Support Document. Texas Commission of Environmental Quality. The air guideline is derived on the basis of irritation of the eyes and airway discomfort in humans, with review of carcinogenic and other non-carcinogenic effects found to be adequately protected by this guideline. The guideline is more conservative than derived by the WHO (2010)

A1: ATSDR 2007, Toxicological Profile for Xylene, chronic inhalation guideline derived is the most current robust evaluation

U1: USEPA evaluation for toluene (most recently reviewed in 2005). This is the most current evaluation of effects associated with chronic inhalation exposure to toluene and is consistent with the value used to derive the NEPM (1999 amended 2013) health based guidelines

U2: USEPA evaluation of 1,3-butadiene (most recently updated in 2002) with the chronic guideline adopted as the lower from the evaluation of non-threshold carcinogenic effects and non-cancer effects. This is the most conservative evaluation of this compound. A more recent review by TCEQ (2013) on the basis of the same critical studies as well as more current studies resulted in a higher chronic air guideline value.

U3: USEPA evaluation of acetaldehyde (most recently updated in 1991). The guideline established is lower than more recent reviews undertaken by the WHO (2000) and the Californian OEHHA where less conservative evaluations are presented.

U4: USEPA evaluation of naphthalene (most recently updated in 1998). The guideline established is and is consistent with the value used to derive the NEPM (1999 amended 2013) health based guidelines

U5: Guideline available from the USEPA. Chronic guidelines for non-carcinogenic polycyclic aromatic hydrocarbons are based on criteria derived from oral studies (for critical effects on the liver, kidney and haematology) which are then converted to an inhalation value (relevant for the protection of public health, including the use of safety factors) for use in this assessment. The value presented in the above table has been converted from an acceptable dose in mg/kg/day to an acceptable air concentration assuming a body weight of 70kg and inhalation of 20 m^3/day (as per (USEPA 2009a))

U5S: No guideline available for individual polycyclic aromatic hydrocarbon, hence a surrogate compound has been used for the purpose of screening. The surrogate compound is a polycyclic aromatic hydrocarbon of similar structure and toxicity. In relation to the surrogates adopted in this evaluation, acenaphthene has been adopted as a surrogate for acenaphthylene, fluoranthene has been adopted as a surrogate for phenanthrene

Review of the acute assessment indicates that during the design analysis A, the maximum short-duration peak (1 hour average) concentrations of volatile organic compounds (assessed as the key individual volatile organic compounds and as a sum of all the individual volatile organic compounds) in air surrounding the northern and southern interchanges are well below the relevant acute health based guidelines. The maximum HI calculated for acute exposure to the volatile organic compounds is 0.040, well below the target HI of 1 (around 25 times lower than the target HI).

Review of the chronic assessment indicates that during the design analysis A, the maximum long-term average (annual average) concentrations of volatile organic compounds and polycyclic aromatic hydrocarbons (assessed as the key individual volatile organic compound and polycyclic aromatic hydrocarbon compounds and as a sum of all the individual volatile organic compounds and polycyclic aromatic hydrocarbons) in air surrounding the northern and southern interchanges are well below the relevant long-term (chronic) health based guidelines. These are guidelines that are based on the protection of public health for inhalation exposures all day (24 hours), every day (365 days per year) for a lifetime (at least 70 years). The maximum HI calculated for exposure to the volatile organic compounds and polycyclic aromatic hydrocarbons is 0.033, well below the target HI of 1 (around 30 times lower than the target HI).

E4 Assessment of cumulative impacts from particulates

On the basis of the guidelines identified and outlined in **Section 4.4** of the main report and the detailed evaluation presented in the AQIA, the operation of the project is not predicted to result in any additional days of exceedance (over and above exceedances of the guidelines that occurs as a result of bushfires etc).

E5 Assessment of incremental impacts from particulates

On the basis of the approach outlined in **Section 5** of the main report the following can be noted in relation to potential incremental exposures to particulate matter (where a maximum annual average incremental increase in $PM_{2.5}$ = 0.16 µg/m^3 and 0.25 µg/m^3 for the northern and southern interchanges respectively) for design analysis A, for the primary health indicators:

- Mortality, all causes (≥30 years): calculated risk = $1x10^{-5}$ for the northern interchange and $1.6x10^{-5}$ for the southern interchanges.
- Cardiovascular hospitalisations (≥65 years): calculated risk = $3x10^{-5}$ for the northern interchange and $5x10^{-5}$ for the southern interchange.
- Respiratory hospitalisations (≥65 years): calculated risk = $6x10^{-6}$ for the northern interchange and $9x10^{-6}$ for the southern interchange.

The predicted increase in risk for these health endpoints remains within the range of tolerable risks identified and outlined in **Section 5.4** of the main report. This scenario is not considered likely to occur and if it were to occur it would not be every day of the year. Hence the calculations undertaken in relation to increased risk from the northern and southern interchanges do not change the assessment presented in the main report.

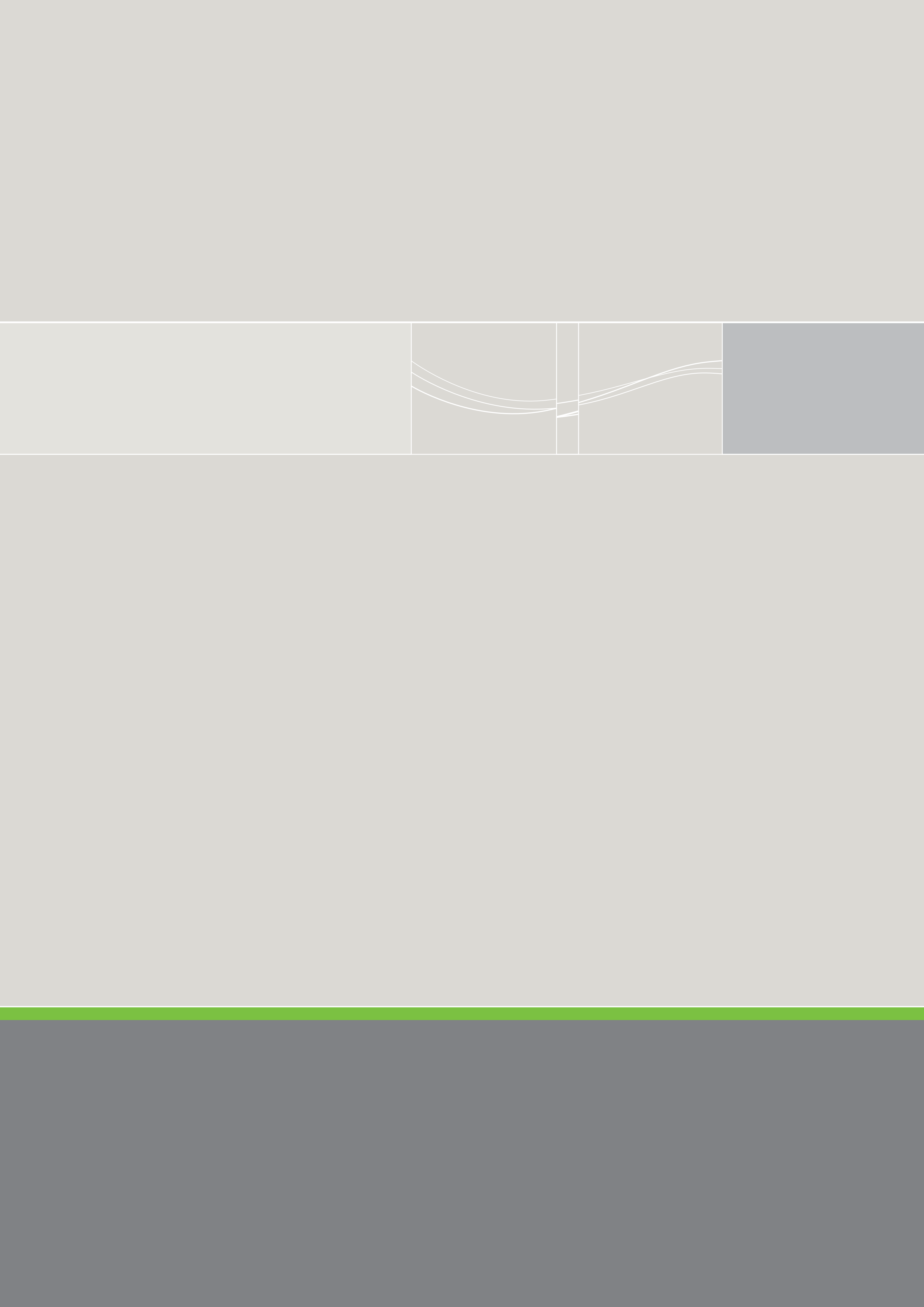
carbon neutral

australian made

recycled

The RMS uses
Greenhouse Friendly™
ENVI Carbon Neutral Paper

ENVI paper is an Australian Government certified Greenhouse Friendly™ Product



carbon neutral

australian made

recycled

The RMS uses
Greenhouse Friendly™
ENVI Carbon Neutral Paper

ENVI paper is an Australian Government certified Greenhouse Friendly™ Product