7.4 Health

A technical working paper: human health risk assessment (refer to **Appendix H**) has been prepared to assess the potential impacts from the project on human health. This section provides a summary of the technical working paper.

Table 7-104 sets out the Director-General's Requirements as they relate to human health, and where in the environmental impact statement these have been addressed.

Table 7-104 Director-General's Requirements – human health

Director-General's Requirement	Where addressed
An assessment of construction and operation activities that have the potential to impact on local and regional air quality. The assessment should provide an assessment of the risk associated with potential discharges of fugitive and point source emissions, and include: *consideration of the requirements of Environmental Health Risk Assessment: Guidelines for assessing human health risks from environmental hazards (enHealth, 2012).*	An assessment of potential human health risks is provided in this chapter. This has been undertaken with consideration of the requirements of Environmental Health Risk Assessment: Guidelines for assessing human health risks from environmental hazards (enHealth, 2012). An assessment of potential air quality impacts is provided in **Section 7.3** (Air quality) and the technical working paper: air quality (**Appendix H**)

7.4.1 Assessment methodology overview

The human health risk assessment has been conducted having regard to the guidance provided in Environmental Health Risk Assessment: Guidelines for assessing human health risks from environmental hazards (enHealth, 2012), with additional input from:

- Health Impact Assessment Guidelines (enHealth, 2001).
- Australian Exposure Factor Guidance: Guidelines for assessing human health risks from environmental hazards (enHealth, 2012).
- National Environment Protection (Assessment of Site Contamination) Measure 1999, Schedule B8: Guideline on Community Engagement and Risk Communication (NEPC, 1999).
- Impact Statement of the National Environment Protection (Air Toxics) Measure (NEPC, 2003).
- Risk Assessment Guidance for Superfund, Volume 1: Human Health Evaluation Manual (Part F – Supplemental Guidance for Inhalation Risk) (United States Environmental Protection Agency, 2009a).

The methodology applied to the assessment of human health risks associated with the project has been presented to and discussed with the Ministry of Health (NSW Health) prior to and during the preparation of the assessment.

The human health risk assessment methodology applied to the project reflects the approach recommended by enHealth (2012), which comprises five key components:

- **Issues identification** – identification of the key issues for the project relevant to the human health risk assessment.
- **Hazard assessment** – identification of potential hazards that may lead to a human health impact, and assessment of dose-response relationships (including whether a dose-response threshold exists).
- **Exposure assessment** – identification of potentially exposed populations (including sensitive receiver groups), potential exposure pathways (if they exist) and quantification of exposure for credible exposure pathways and potentially exposed populations.
- **Risk characterisation** – assessment and evaluation of identified human health risks.
- **Risk management** – identification of risk management measures, where relevant.

Scope of the human health risk assessment

Consistent with the issues identification step of the enHealth risk assessment approach (2012), the project has been reviewed to identify potential issues relevant to the human health risk assessment. Relevant issues identified for this human health risk assessment are:

- Air quality impacts during operation, including:
  - Impacts directly related to emissions from the project's ventilation outlets.
  - Changes in air quality along the Pennant Hills Road corridor as a result of traffic changes brought about by the project.
  - In-tunnel air quality and potential impacts on motorists.
- Noise and vibration impacts during construction and operation.

Impacts associated with emissions from the project's ventilation outlets have also been identified as a key area of concern through consultation with the community and stakeholders prior to and during the preparation of this environmental impact statement (refer to **Chapter 6** Consultation). The potential for human health impacts from this source has therefore been given particular attention as part of the human health risk assessment.

Other issues with potential human health implications that were identified but which have not been included in this human health risk assessment include:

- Air quality impacts associated with emissions from tunnel portals. The project does not currently propose portal emissions from the main alignment tunnels, however this approach may be considered in future and would be subject to appropriate assessment and approval.
- Air quality impacts during construction of the project. Based on construction dust mitigation and management measures, and the duration of construction activities, there would be limited potential for significant human health risks during this phase of the project.

- Health risks for project employees during construction and operation. Occupational health and safety is beyond the scope of the Environmental Planning and Assessment Act 1979 and this environmental impact statement. Occupational health and safety issues are being considered separately to this environmental impact statement, consistent with obligations under the Work Health and Safety Act 2011.
- Water quality impacts during construction and operation. Water generated during construction and operation would be treated prior to discharge. Based on the minimum level of water treatment likely to be required to protect the receiving environment, it is unlikely that treated and discharged water would represent a human health risk.
- Waste generation and management. The project is not expected to generate waste materials considered to be hazardous to human health, based on the nature and quantities of wastes generated, and the manner in which wastes would be handled and disposed.
- Changes to traffic conditions and crash rates. The implications of the project for traffic conditions and crash rates have been assessed separately in Section 7.1 (Traffic and transport).

Inputs into the human health risk assessment

The human health risk assessment has been based on:

- The modelled air quality impacts of the project on external receivers for expected traffic conditions in 2019 and in 2029 (refer to **Section 7.3** Air quality and the technical working paper: air quality in **Appendix G**).
- The calculated in-tunnel concentrations of vehicle emissions (refer to **Section 7.3** Air quality).
- The modelled noise and vibration impacts of the project during construction and operation (refer to **Section 7.2** Noise and vibration and the technical working paper: noise and vibration in **Appendix F**).

Additional published literature relating to human health effects, particularly in relation to exposure to air pollutants, has been drawn on as required and as relevant to the human health risk assessment. A list of literature sources for human health studies relied on as part of the human health risk assessment is provided in the technical working paper: human health risk assessment (refer to **Appendix H**).

Quantitative human health risk assessment

A quantitative human health risk assessment has been conducted based on potential air quality impacts from the project at external receivers. This has included:

- Identification of appropriate primary and secondary health indicators in consultation with NSW Health. The health indicators include specified health outcomes for certain age groups within the community.
- Quantification of the increased annual risk of each health outcome for any one individual.
- Quantification of the increased incidence of each health outcome at a community level.

The quantified human health risk assessment has considered the human health implications of changes in air quality:

- Directly related to the operation of the project's ventilation system and ventilation outlets.
- Cumulatively along the Pennant Hills Road corridor, including improvements in air quality as a result of traffic being diverted in to the project's tunnels from surface roads.

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 outcomes) 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 the exposure-response functions relate changes in health outcomes 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.

Qualitative human health risk assessment

In some cases it is not possible to quantify a particular health effect, or there are no quantified thresholds against which to assess the health impact. These issues are nonetheless important to consider as part of the broader human health risk assessment, and have been assessed qualitatively. Issues that have been assessed qualitatively include:

- The impacts of changes in air quality on children with asthma.
- Exposure of motorists to vehicle emissions as they travel through the project's main alignment tunnels.
- Potential health impacts associated with noise and vibration during construction and operation of the project.

7.4.2 Existing environment

This section provides an overview of the community potentially affected by the project including a summary of the existing health of the population. The air quality impacts around the northern and southern interchanges have been a focus of this assessment as these populations are located closest of the project's ventilation outlets. Populations along the Pennant Hills Road corridor would be indirectly affected through changes in surface traffic volumes leading to reductions in vehicle emissions along that corridor. Populations along the entire project alignment may be directly and indirectly affected by noise and vibration during construction and operation, including changes in the distribution of traffic noise once the project is operational.

For some aspects, due limited information available on a local scale, population and health statistics have been derived from larger population groups such as the Northern Area Health District and the Greater Sydney Area. Given the similar demographics of the local community to these broader regions, they are representative of the smaller populations around the southern and northern interchanges.

Community profile

The population within the areas surrounding the project comprise residents and workers as well as those attending schools, day-care and recreational areas within the surrounding suburbs. The composition of the local populations around the project is expected to be generally consistent with population statistics for the larger individual suburbs. Population statistics for the suburbs surrounding the project have been sourced from the Australian Bureau of Statistics for the census year 2011 and are summarised in **Table 7-106**. For the purpose of comparison, the population statistics presented also include the statistics for the larger statistical areas of Hornsby South (which includes most of the suburbs of interest for the project), Greater Sydney and the rest of the NSW (excluding greater Sydney).

Table 7-106 Summary of population statistics

Location	Total population		Per cent population by key age groups				
	Male	Female	0-4	5-19	20-64	65+	30+
Around the northern interchange							
Wahroonga	8,001	8,725	5.6%	23%	53.7%	17.7%	62%
North Wahroonga	949	937	4.8%	22.3%	56.6%	16.3%	63%
Warrawee	1,440	1,472	4.6%	23.7%	58.1%	13.6%	58%
Waitara	2,584	2,786	7.8%	14.3%	62.9%	14.9%	64%
Hornsby	9,694	10,169	7.2%	15.7%	65.5%	11.6%	62%
Normanhurst	2,410	2,746	6.6%	22.9%	52%	18.5%	61%
Around the southern interchange							
Carlingford	10,594	10,976	5.2%	20%	58.6%	16.1%	63%
West Pennant Hills	7,813	8,154	5.1%	21.3%	61.2%	12.4%	61%
Beecroft	4,186	4,650	4.7%	21.8%	54.9%	18.5%	63%
North Rocks	3,761	3,864	6.5%	19.9%	57.4%	16.2%	64%
Epping	9,883	10,344	4.8%	18.9%	63%	13.3%	60%
Other suburbs along the Pennant Hills Road corridor							
Thornleigh	3,976	4,139	7.7%	20.6%	58.2%	13.6%	70%
Pennant Hills	3,443	3,588	5.8%	20.0%	58.6%	15.6%	74%
Larger statistical areas							
Hornsby South (Statistical Area)	43,701	46,404	6.2%	19.4%	59.6%	14.7%	62%
Greater Sydney	2,162,221	2,229,453	6.8%	18.7%	61.7%	12.9%	60%
Rest of NSW (excluding greater Sydney)	12,39,007	1,273,942	6.3%	19.7%	55.9%	18%	63%

Source: Australian Bureau of Statistics, Census Data 2011

Based on this general population data, the suburbs surrounding the southern interchange are generally similar to Greater Sydney with the exception of Beecroft where a higher percentage of people aged 65 years and older are present.

The suburbs surrounding the northern interchange are a little more variable with the suburbs of Wahroonga, North Wahroonga and Normanhurst indicating a slightly higher proportion of people aged 5-19 years and 65 years and older (with a corresponding lower proportion of people aged 20-64 years), and the suburbs of Waitara and Hornsby indicating a lower proportion of people aged 5-19 years. The Hornsby South Statistical Area includes most of the suburbs of interest for the project and shows a relatively similar population distribution to that of Greater Sydney.

Existing population health

The health of a local community is influenced by a complex range of interacting factors such as age, socio-economic status, social capital, behaviours, beliefs and lifestyle, life experiences, country of origin, genetic predisposition and access to health and social care.

Health-related behaviours

Health-related behaviours can include both positive and negative behaviours. Negative behaviours may include risky alcohol drinking, smoking, being overweight or obese. Positive behaviours may include sufficient consumption of fruit and vegetables, and adequate physical activity. Negative health-related behaviours are linked to poorer health status and chronic disease including cardiovascular and respiratory diseases, cancer, and other conditions that account for much of the burden of morbidity and mortality in later life.

The study population is grouped in the larger population area of Northern Sydney and Central Coast. The incidence of these health-related behaviours in the Northern Sydney and Central Coast area (representative of the local populations) has been compared with other health areas in NSW, and the state of NSW (based on data from 2009). Review of this data generally indicates that the population in the Northern Sydney and Central Coast area:

- Have similar rates of risky alcohol drinking, being overweight or obese compared with NSW.
- Have similar rates of recommended consumption of vegetables compared with NSW.
- Have higher rates of recommended consumption of fruit compared with NSW.
- Have higher rates of adequate physical activity compared with NSW.

Health indicators

Health indicators include:

- Key mortality indicators: all causes, potentially avoidable, cardiovascular disease, lung cancer and chronic obstructive pulmonary disease (65+ years).
- Hospitalisations: diabetes, cardiovascular disease, asthma (5-34 years) and chronic obstructive pulmonary disease (65+ years).

The incidence of these health indicators reported in the larger Northern Sydney and Central Coast Area Health Service (representative of the local populations) has been compared with other NSW area health services (in urban and regional areas) as well as NSW as a whole. The review of the available data generally indicates that the population in the Northern Sydney area (including the Northern Sydney and Central Coast combined areas where relevant) generally has lower mortality rates, and lower hospitalisation rates for most of categories compared with a number of other health areas and the whole of NSW.

This data indicates that, for the assessment of health impacts from the project, adopting health statistics from the whole of NSW provides a representative summary of the existing health of the population of interest.

Air quality environment

The existing air quality in the study area is described in detail in **Section 7.3** (Air quality) and the technical working paper: air quality (**Appendix G**).

In general, NSW is considered to have good air quality in relation to international standards. Air quality in the Greater Sydney Area is most significantly affected by bushfires (including hazard reduction burns) and dust storms. Transport-related emissions are the largest source of human-related pollution.

In relation to $PM_{2.5}$, review of the sources (emissions) that contribute to the measured $PM_{2.5}$ reported in Sydney indicates that the most significant sources are household activities (including residential wood heaters – with peak emissions in the winter months from wood-smoke). Emissions from road transport in the Sydney area contribute a consistent amount to the total $PM_{2.5}$ emissions throughout the year.

Noise environment

The existing noise environment in the study area is described in detail in **Section 7.2** (Noise and vibration) and the technical working paper: noise and vibration (**Appendix F**).

Existing noise in the study area is dominated by road traffic noise, primarily from the M1 Pacific Motorway, the Pacific Highway, Pennant Hills Road and the Hills M2 Motorway. Noise in the study area is highly dependent on proximity to these existing roads. Typical background noise levels measured throughout the study area are:

- 41 to 59 dB(A) measured as LA_{90}(15-minute) during the day (7 am to 6 pm).
- 42 to 54 dB(A) measured as LA_{90}(15-minute) during the evening (6 pm to 10 pm).
- 30 to 45 dB(A) measured as LA_{90}(15-minute) during the night (10 pm to 7 am).

7.4.3 Initial screening assessment (external air quality)

As part of the hazard assessment process recommended by enHealth (2012), an initial screening has been conducted to identify pollutants with the potential to generate a human health effect for external receivers. This initial screening has been conducted to identify pollutants for more detailed assessment, and has consisted of:

- Consideration of modelled pollutant levels against relevant criteria and guidance documents, where these criteria are based on protection levels against adverse health effects. This approach has been undertaken for oxides of nitrogen, carbon monoxide, volatile organic compounds and polycyclic aromatic hydrocarbons.
- Identification of pollutants for which there is no recognised safe level which were automatically carried forward for detailed assessment. This category of pollutants includes particulate matter emissions.

Oxides of nitrogen

Nitrogen oxides refer to a collection of highly reactive gaseous compounds containing nitrogen and oxygen, most of which are colourless and odourless. Nitrogen oxide gases form when fuel is burnt. Motor vehicles, along with industrial, commercial and residential combustion sources, are primary producers of nitrogen oxides.

In terms of health effects, nitrogen dioxide (NO_2) is the primary oxide of nitrogen of interest. Nitrogen dioxide is a colourless and tasteless gas with a sharp odour. The health effects associated with exposure to nitrogen dioxide depend on the duration of exposure as well as the concentration; hence the NSW Environment Protection Authority and the National Environment Protection Council guidelines developed in Australia reflect both acute (short-term) and chronic (long-term) exposures. The current National Environment Protection Council guidelines are consistent with health based guidelines currently available from the World Health Organisation and the United States Environmental Protection Agency, which were specifically develop to be protective of exposures to sensitive populations including asthmatics, children and the elderly. On this basis the current National Environment Protection Council guidelines are appropriate for the assessment of potential health impacts associated with the project.

Table 7-107 provides a summary of the modelled peak cumulative nitrogen dioxide concentrations (project contribution plus background concentration) compared with the relevant National Environment Protection Council guidelines for acute (one hour) and chronic (annual average) exposures.

The modelled peak cumulative concentrations of nitrogen dioxide during operation of the project are well below the acute and chronic National Environment Protection Council guideline values of 246 $\mu g/m^3$ and 62 $\mu g/m^3$ respectively. As a result, no adverse health effects are expected in relation to exposures to nitrogen dioxide in the local area surrounding the project. On this basis, nitrogen dioxide has not been carried forward for more detailed assessment.

Table 7-107 Initial screening of potential hazards – nitrogen dioxide

Location and scenario	Maximum 1-hour average concentration (µg/m³)	Maximum annual average concentration (µg/m³)
NEPC guideline	246	62
Northern interchange		
Forecast traffic flows 2019	150.8	38.7
Forecast traffic flows 2029	159.3	39.9
Southern interchange		
Forecast traffic flows 2019	165.1	42.4
Forecast traffic flows 2029	166.7	42.8

Carbon monoxide

Motor vehicles are the dominant source of carbon monoxide (CO) in the air (DECCW 2009a).

National Environment Protection Council and NSW Environment Protection Authority guidelines available in Australia are based on protection from adverse health effects associated with carbon monoxide. The current National Environment Protection Council guidelines are consistent with health based guidelines currently available from the World Health Organisation and the United States Environmental Protection Agency, which were specifically develop to be protective of exposures to sensitive populations including asthmatics, children and the elderly. On this basis the current National Environment Protection Council guidelines are appropriate for the assessment of potential health impacts associated with the proposed project.

Table 7-108 provides a summary of the modelled peak cumulative carbon monoxide concentrations (project contribution plus background concentration) compared with the relevant National Environment Protection Council guidelines for acute (one hour) and chronic (annual average) exposures.

The modelled peak cumulative concentrations of nitrogen dioxide during operation of the project are well below the acute and chronic National Environment Protection Council guideline values of 30,000 µg/m³ and 10,000 µg/m³ respectively. As a result, no adverse health effects are expected in relation to exposures to carbon monoxide in the local area surrounding the project. On this basis, carbon monoxide has not been carried forward for more detailed assessment.

Table 7-108 Initial screening of potential hazards – carbon monoxide

Location and scenario	Maximum 1-hour average concentration (µg/m^3)	Maximum annual average concentration (µg/m^3)
NEPC guideline	30,000	10,000
Northern interchange		
Forecast traffic flows 2019	3,712	2,634
Forecast traffic flows 2029	3,732	2,656
Southern interchange		
Forecast traffic flows 2019	3,695	2,635
Forecast traffic flows 2029	3,715	2,660

Volatile organic compounds and polycyclic aromatic hydrocarbons

Both volatile organic compounds (VOCs) and polycyclic aromatic hydrocarbons (PAHs) refer to groups of compounds with a mix of different proportions and toxicities. It is the individual compounds within the group that are of importance for evaluating adverse health effects.

The composition of individual compounds in the volatile organic compounds and polycyclic aromatic hydrocarbons vary depending on the source of the emissions. Hence it is important that the key compounds present in emissions calculated for the project are speciated (ie the individual hydrocarbon compounds are identified and quantified as a percentage of the total volatile organic compounds or total polycyclic aromatic hydrocarbons).

The makeup of the volatile organic compound and polycyclic aromatic hydrocarbon emissions depends on the mix of vehicles as these pollutants are emitted in different proportions from motor vehicles and diesel trucks. The age and the fuel used by the vehicle fleet also affect these emissions. The following proportions of passenger cars, light duty vehicles and heavy goods vehicles have been used in the assessment:

- Of the total vehicle fleet using the project tunnels, the proportion that would be heavy goods vehicles has been estimated to be:
  - 2019: 27.8 per cent to 28.6 per cent (the maximum proportion has been used for speciation calculations).
  - 2029: 24.5 per cent to 25.2 per cent (the maximum proportion has been used for speciation calculations).
- The remaining vehicles using the project tunnels would comprise 83.4 per cent passenger vehicles and 16.6 per cent light duty vehicles.
- All of the heavy goods vehicles have been conservatively assumed to be diesel powered.
- Passenger vehicles have been assumed to comprise 92.1 per cent petrol and 7.9 per cent diesel powered vehicles. Conservatively, it has been assumed that no passenger cars are hybrid, electric or LPG fuelled which would have lower emissions than petrol or diesel vehicles.
- Light duty vehicles have been assumed to comprise 50.1 per cent petrol and 49.9 per cent diesel powered vehicles.

The predicted (incremental) concentrations of individual volatile organic compounds and polycyclic aromatic hydrocarbons associated with emissions from the project have been reviewed against published peer-reviewed health based guidelines that are relevant to acute and chronic exposures (where relevant).

The maximum predicted one-hour (acute) and annual average (chronic) concentrations contributed by the project for each individual volatile organic compound and polycyclic aromatic hydrocarbon have been compared to the relevant health based guidelines. A Hazard Index (HI) has been calculated which is the ratio of the maximum predicted concentration of each compound to the guideline value for that compound. The individual Hazard Indexes has then been summed to obtain a total Hazard Index for all the volatile organic compounds and polycyclic aromatic hydrocarbons that have been considered.

The total Hazard Index is the sum of the potential hazards associated with all the volatile organic compounds and polycyclic aromatic hydrocarbons together assuming the health effects are additive, and has been evaluated as follows:

- A total Hazard Index of less than or equal to one means that all the maximum predicted concentrations are below the health based guidelines and there are no additive health impacts of concern.
- A total Hazard Index of greater than one means that there is the potential for adverse health effects, and further more detailed assessment is required.

Table 7-109 shows the total acute and chronic hazard indexes for the summed volatile organic compound and polycyclic aromatic hydrocarbons for the project. The details of the assessment of each individual concentration against the relevant health guideline and calculation of the hazard indexes are provided in the technical working paper: human health risk assessment (**Appendix H**).

The acute assessment indicates that for the forecast traffic flows using the project in 2019 and in 2029:

- The maximum short-duration peak (one hour average) concentrations of individual volatile organic compounds and polycyclic aromatic hydrocarbons are well below the relevant acute health based guidelines.
- The maximum short-duration peak (one hour average) concentrations of the summed volatile organic compounds and polycyclic aromatic hydrocarbons are well below the relevant short-term (acute) health based guidelines.
- The calculated Hazard Index for all scenarios is well below the target Hazard Index of one. On this basis no further detailed assessment of the peak emissions from the project is warranted.

The chronic assessment indicates that for the forecast traffic flows using the project in 2019 and in 2029:

- The maximum long-term average (annual average) concentrations of individual volatile organic compounds and polycyclic aromatic hydrocarbons are well below the relevant long-term (chronic) health based guidelines.
- The maximum long-term average (annual average) concentrations of the summed volatile organic compounds and polycyclic aromatic hydrocarbons are well below the relevant long-term (chronic) health based guidelines.
- The calculated Hazard Index for all scenarios is well below the target Hazard Index of one. On this basis no further detailed assessment of the long term emissions from the project is warranted.

Table 7-109 Initial screening of potential hazards – volatile organic compounds and polycyclic aromatic hydrocarbons

Location and scenario	Acute (one hour average) calculated total Hazard Index	Chronic (annual average) calculated total Hazard Index
Northern interchange		
Forecast traffic flows 2019	0.018	0.0085
Forecast traffic flows 2029	0.021	0.011
Southern interchange		
Forecast traffic flows 2019	0.017	0.0090
Forecast traffic flows 2029	0.021	0.011

Particulate matter

Particulate matter (PM) is a widespread air pollutant with a mixture of physical and chemical characteristics that vary by location and source. Particulate matter can be derived from natural sources such as crustal dust (soil), pollen and moulds, and other sources that include combustion and industrial processes.

Secondary particulate matter may be formed via atmospheric reactions of primary gaseous emissions. The gases that are the most significant contributors to secondary particulates include nitrogen oxides, ammonia, sulfur oxides, and certain organic gases (derived from vehicle exhaust, combustion sources, agricultural, industrial and biogenic emissions).

The potential for particulate matter to result in adverse health effects is dependent on the size and composition of the particulate matter as it determines how far from an emission source the particulates may be present in air (with larger particulates settling out close to the source and smaller particles remaining airborne for greater distances) and also the potential for adverse effects to occur as a result of exposure.

The common measures of particulate matter that are considered in the assessment of air quality and health risks are:

- **Total suspended particulates -** This refers to all particulate matter with an equivalent particle size below 50 micrometres (µm) in diameter. Total suspended particulates are an indicator of the presence of dust with a wide range of sizes. Larger particles (termed “inspirable”, comprise particles around ten micrometres (µm) and larger) are more of a nuisance as they deposit out of the air (measured as deposited dust) close to the source and, if inhaled, are mostly trapped in the upper respiratory system and do not reach the lungs. Finer particles (smaller than ten micrometres, termed “respirable”) tend to be transported further from the source and are of more concern with respect to human health as these particles can penetrate into the lungs. Hence not all of the dust characterised as total suspended particulates is relevant for the assessment of health risks, and total suspended particulates as a measure of impact has not been further evaluated in this assessment. This assessment has only focused on particulates of a size where significant associations have been identified between exposure and adverse health effects.
- **PM_{10}, $PM_{2.5}$ and PM_1** – These particles are small and have the potential to penetrate beyond the body's natural clearance mechanisms in the nose and upper respiratory system, with smaller particles able to further penetrate into the lower respiratory tract and lungs. It is well accepted nationally and internationally that monitoring for PM_{10} is a good method of determining the community’s exposure to potentially harmful dust (regardless of the source) and is most commonly measured in local and regional air quality monitoring programs. Smaller particles such as $PM_{2.5}$ and PM_1, however, are of most significance with respect to evaluating health effects as a higher proportion of these particles penetrate deep into the lungs. Urban air that has a significant contribution from combustion sources tends to have a significant proportion of $PM_{2.5}$ and PM_1 in ambient air.

As the primary source of both PM_1 and $PM_{2.5}$ in urban air is combustion emissions (including traffic emissions and other domestic and industrial combustion sources), the ratio of PM_1 to $PM_{2.5}$ has been observed to be relatively stable throughout the year within an urban air environment. For the assessment of incremental impacts from the project the ratio of PM_1 to $PM_{2.5}$ is expected to remain stable (as it would be derived from vehicle emissions during the operation of the tunnel).

When assessing health impacts from fine particulates, the robust associations of effects have been determined on the basis of $PM_{2.5}$, as $PM_{2.5}$ is what is commonly measured in urban air. No robust associations (that can be used in a quantitative assessment) are available for PM_1, although the associations developed for $PM_{2.5}$ will include a significant contribution from PM_1. Hence, health effects observed for PM_1 will be captured in the studies that have been conducted on the basis of $PM_{2.5}$.

It is important that the quantitative evaluation of potential health impacts adopts robust health effect associations and utilises particulate matter measures that are collected in the urban air environment. As such, the further assessment of exposure to fine particulate matter has focused on particulates reported / evaluated as $PM_{2.5}$. This evaluation addresses the health effects associated with smaller particles (PM_1) and ultrafine particles, as these particulate fractions form part of the larger $PM_{2.5}$ fraction.

Air quality goals for PM_{10} and $PM_{2.5}$ have been established by the National Environment Protection Council and the NSW Environment Protection Authority that are based on the protection of human health and well-being. The goals apply to average or regional exposures by populations from all sources, not to localised 'hot-spot' areas such as locations near industry, busy roads or mining. They are intended to be compared against ambient air quality monitoring data collected from appropriately sited regional monitoring stations. However, in the absence of alternative measures, these criteria are applied on occasion to assess the potential for impacts to arise at 'hot-spot' locations, particularly for new projects.

Generally, the goals established by the National Environment Protection Council and the NSW Environment Protection Authority are slightly more conservative (health protective) than the those provided by the World Health Organisation, the European Union and the United States Environmental Protection Agency.

Detailed calculations of the 24-hour average concentrations associated with the operation of the project are presented in **Section 7.3** (Air quality) and the technical working paper: air quality (**Appendix G**). These calculations have concluded that emissions from the project would not result in additional exceedences of the relevant criteria. The cumulative annual average concentrations of PM_{10} and $PM_{2.5}$ and calculations show that:

- The maximum background concentration of PM_{10} is 21.22 $\mu g/m^3$ and the maximum predicted cumulative concentration (project plus background) for PM_{10} is 21.35 $\mu g/m^3$. Both these levels are below the annual average guideline of 30 $\mu g/m^3$. The project contribution to the maximum cumulative concentration is very small (0.13 $\mu g/m^3$, or around 0.43 per cent of the guideline).
- The maximum background concentration of $PM_{2.5}$ is 10.16 $\mu g/m^3$ and the maximum predicted cumulative concentration (project plus background) of PM2.5 is 10.29 $\mu g/m^3$. Both these levels are above the annual average advisory reporting standard of 8 $\mu g/m^3$. However, this concentration of $PM_{2.5}$ is dominated by background air quality with only a very small contribution from the project (0.13 $\mu g/m^3$, or 1.63 per cent of the advisory reporting standard).

For many of the key health effects associated with exposures to PM_{10} and $PM_{2.5}$ the exposure-response relationship is linear (ie there is no level or threshold below which no adverse effects have been identified). As there is no threshold for potential adverse effects, particulate matter has been carried forward for a more detailed assessment of the incremental increase in exposure as a result of the project.

Exposure to diesel particulate matter

Previous studies indicate that diesel exhaust as measured as diesel particulate matter makes up around six per cent of the total ambient / urban air $PM_{2.5}$ (United States Environmental Protection Agency, 2002). For this project, emissions to air from the operation of the tunnel would include a significant proportion of diesel fuelled trucks. Available evidence indicates that there are human health hazards associated with exposure to diesel particulate matter. The hazards include acute exposure-related symptoms, chronic exposure related non-cancer respiratory effects, and lung cancer.

For the purpose of this assessment it has been assumed that 100 per cent of the incremental $PM_{2.5}$ concentrations (from the project only) are derived from diesel sources. In reality $PM_{2.5}$ would be produced from a variety of fuel sources including diesel and petroleum. As such, this approach provides a conservative assessment of potential particulate matters health risks.

7.4.4 Quantitative human health risk assessment

Based on the initial screening conducted for air emissions from the project (refer to **Section 7.4.3**), particulate matter has been carried forward for further quantified assessment of human health risks. Other pollutants emitted from the project have been identified as below thresholds at which a human health effect would occur.

The potential health impacts associated with particulate matter have been assessed on the basis of two calculations, being:

- **Increased incidence** of each relevant health effect occurring within the exposed population. This calculation identifies the potential increase in the number of cases (mortality or hospitalisations) that may occur for the population assumed to be exposed to the modelled particulate matter concentration.
- **Increased annual risk** for each relevant health effect. 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 modelled particulate matter concentration.

The following sections detail:

- The human health effects considered as part of the quantitative human health risk assessment.
- The acceptable risk levels applied to the quantitative human health risk assessment for calculated increased incidence and increased annual risk of health effects.
- The calculated increased incidence and increased annual risk of health effects when taking into account only the operational air emissions from the project.
- The calculated increased incidence and increased annual risk of health effects when taking into account all changes in air quality along the Pennant Hills Road corridor.

Assessed human health effects

The quantitative assessment of potential health effects associated with exposure to particulate emissions has focused on health outcomes and exposure-response relationships that are robust and relate to $PM_{2.5}$, the more important particulate fraction size relevant for emissions from combustion sources. The health outcomes considered in the quantitative human health risk assessment have been developed in consultation with NSW Health. These are described in **Table 7-110**.

Table 7-110 Health outcomes considered in the quantitative human health risk assessment

Primary health outcomes	Secondary health outcomes
• Long-term exposure to $PM_{2.5}$ on all-cause mortality (≥ 30 years of age). • Short-term exposure on the rate of hospitalisation with cardiovascular disease (≥ 65 years of age). • Short-term exposure on the rate of hospitalisation with respiratory disease (≥ 65 years of age).	• Long-term exposure to $PM_{2.5}$ on cardiopulmonary mortality (≥ 30 years of age). • Short-term exposure to $PM_{2.5}$ on mortality (all causes, cardiovascular and respiratory, all ages). • Short-term exposure to PM_{10} on mortality (all causes and all ages).

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 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 7.4.5**.

Acceptable risk levels

It is not possible to provide a rigid definition of acceptable risk as perception of risk is complex and context-driven. A person's acceptability of risk is dependent of factors such as the potential consequence and the degree of control. It is possible, however, to propose some general guidelines as to what might be an acceptable risk for specific projects and to conduct a human health risk assessment within that context.

Risk is generally considered to be a spectrum of which the two ends are termed 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 the level of risk that may be considered acceptable will lie somewhere between what is negligible and unacceptable.

A risk level of one in a million (1×10^{-6}) has previously been adopted as the negligible end of the spectrum by some regulators, such as the United States Environmental Protection Agency for linear type risks, such as that for health impacts from particulate matter.

While there is no guidance available on what level of risk is considered to be the unacceptable end of the spectrum in the community, a level of one in ten thousand (1×10^{-4} or 100×10^{-6}) 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 and Bartram, 2011)) and in the evaluation of exposures from pollutants in air (DEC, 2005a).

For this assessment, the risk level is also referring an increased risk level of developing a specific adverse health outcome due to exposure to a substance. For example, if the current chance of an individual developing a particular adverse health outcome was 40 per cent, and the increased risk associated with the project was one in one million, an individual's increased risk would be 0.00025 per cent.

Considering the above, the following risk levels have been adopted for this quantitative human health risk assessment in relation to increases in annual risk:

- An increased risk of less than or equal to one in a million (1×10^{-6}) is considered negligible.
- An increased risk of greater than one in ten thousand (100×10^{-6}) is considered unacceptable.
- An increase between these two values is considered acceptable (1×10^{-6} to 100×10^{-6}).

In relation to the calculation of increased incidence of a particular health effect, the calculated increase in cases has been compared to the variability in the number of cases per year of the relevant health effect based on statistics available from NSW Health. Where the calculated increase in the number of cases could not be detected above the normal variability, this increase has been considered to be negligible.

Potential health impacts (operational project air emissions only)

Primary health indicators

A summary of the calculations of increased annual risk and increased incidence for the primary health indicators for the local populations around the southern and northern interchanges is provided in **Table 7-111** and **Table 7-112**. The tables present the results based on the forecast traffic flows for the project in 2019 and in 2029. These tables present the results for the ventilation outlets in isolation. This section should be read in conjunction with **Table 7-114** which presents the project as a whole (that is, the project ventilation outlets and the changed traffic environment of Pennant Hills Road combined). When the project as whole is considered, there would be an overall decrease in the annual incidence for the whole population of the assessed health outcomes.

These results show:

- The increased annual risks for all primary health indicators lie within an acceptable range and are generally closer to being negligible (1×10^{-6}) than unacceptable (100×10^{-6}). These risk levels are conservative and assume continuous exposure to particulate matter concentrations. In practice, these risk levels are likely to be lower based on the mobility of the population, variability in actual particulate levels as a result of the project, and the inherent conservatism in both the air quality and human health risk assessments.
- The increased incidence (number of cases per year) is significantly less than the normal variability in cases per year. This would not be detectable in health statistics and would be negligible in the local community.

Table 7-111 Maximum increased annual risk – primary health indicators (project only)

Primary health indicator	Maximum increased annual risk 2019	2029
Northern interchange		
Mortality from all causes (≥ 30 years of age)	Five in one million (5×10^{-6})	Seven in one million (7×10^{-6})
Rate of hospitalisation with cardiovascular disease (≥ 65 years of age)	Twenty in one million (20×10^{-6})	Twenty in one million (20×10^{-6})
Rate of hospitalisation with respiratory disease (≥ 65 years of age)	Three in one million (3×10^{-6})	Four in one million (4×10^{-6})
Southern interchange		
Mortality from all causes (≥ 30 years of age)	Seven in one million (7×10^{-6})	Eight in one million (8×10^{-6})
Rate of hospitalisation with cardiovascular disease (≥ 65 years of age)	Twenty in one million (20×10^{-6})	Twenty in one million (20×10^{-6})
Rate of hospitalisation with respiratory disease (≥ 65 years of age)	Four in one million (4×10^{-6})	Five in one million (5×10^{-6})

Table 7-112 Increased incidence – primary health indicators (project only)

Primary health indicator	Baseline incidence per year (per 100,000)	Normal incidence variability (cases per year)	Increased incidence (cases per year) 2019	2029
Northern interchange				
Mortality from all causes (≥ 30 years of age)	1,087	1	0.03	0.04
Rate of hospitalisation with cardiovascular disease (≥ 65 years of age)	23,352	40	0.02	0.03
Rate of hospitalisation with respiratory disease (≥ 65 years of age)	8,807	17	0.005	0.005
Southern interchange				
Mortality from all causes (≥ 30 years of age)	1,087	1	0.03	0.03
Rate of hospitalisation with cardiovascular disease (≥ 65 years of age)	23,352	40	0.02	0.02
Rate of hospitalisation with respiratory disease (≥ 65 years of age)	8,807	17	0.004	0.004

An increased annual incidence of 0.001 in a suburb (eg, North Wahroonga or North Rocks) means that the entire population of that suburb would need to live in the same homes in this suburb for 1000 years for one extra case (of the health outcome assessed) to occur in the population.

Secondary health indicators

A summary of the calculations of increased annual risk for the secondary health indicators for the local populations around the southern and northern interchanges is provided in **Table 7-113**. The tables present the results based on the forecast traffic flows for the project in 2019 and in 2029.

These results show that the increases annual risks are calculated to be between 0.09 in one million (0.09×10^{-6}) and eight in one million (8×10^{-6}). This is generally within the lower range of acceptable (ie closer to being negligible), with some indicators considered to be in the negligible range ($<1 \times 10^{-6}$).

Table 7-113 Maximum increased annual risk – secondary health indicators (project only)

Primary health indicator	Maximum increased annual risk 2019	2029
Northern interchange		
Mortality from all causes (PM_{10}, short-term, all ages)	0.3 in one million (0.3×10^{-6})	0.4 in one million (0.4×10^{-6})
Mortality from all causes ($PM_{2.5}$, short-term, all ages)	0.5 in one million (0.5×10^{-6})	0.7 in one million (0.7×10^{-6})
Mortality – cardiopulmonary ($PM_{2.5}$, long-term, ≥ 30 years of age)	Five in one million (5×10^{-6})	Seven in one million (7×10^{-6})
Mortality – cardiovascular ($PM_{2.5}$, short-term, all ages)	0.1 in one million (0.1×10^{-6})	0.2 in one million (0.2×10^{-6})
Mortality – respiratory ($PM_{2.5}$, short-term, all ages)	0.09 in one million (0.09×10^{-6})	0.1 in one million (0.1×10^{-6})
Southern interchange		
Mortality from all causes (PM_{10}, short-term, all ages)	0.5 in one million (0.5×10^{-6})	0.5 in one million (0.5×10^{-6})
Mortality from all causes ($PM_{2.5}$, short-term, all ages)	0.7 in one million (0.7×10^{-6})	0.8 in one million (0.8×10^{-6})
Mortality – cardiopulmonary ($PM_{2.5}$, long-term, ≥ 30 years of age)	Seven in one million (7×10^{-6})	Eight in one million (8×10^{-6})
Mortality – cardiovascular ($PM_{2.5}$, short-term, all ages)	0.2 in one million (0.2×10^{-6})	0.2 in one million (0.2×10^{-6})
Mortality – respiratory ($PM_{2.5}$, short-term, all ages)	0.1 in one million (0.1×10^{-6})	0.1 in one million (0.1×10^{-6})

Diesel particulate matter

The incremental lifetime risk of cancer associated with potential exposure to diesel particulate matter has been calculated based on the most affected receiver location (highest modelled air quality impacts) and assuming that all particulate matter is generated from the combustion of diesel fuel. This calculation therefore conservatively overestimates the likely incremental lifetime risk of cancer.

At the maximum impacted location, the incremental lifetime risk of cancer from exposure to diesel particulate matter has been calculated to be:

- Five in one million (5×10^{-6}) for the 2019 forecast traffic flows at the southern interchange.
- Three in one million (3×10^{-6}) for the 2029 forecast traffic flows at the southern interchange.
- Four in one million (4×10^{-6}) for the 2019 forecast traffic flows at the northern interchange.
- Four in one million (4×10^{-6}) for the 2029 forecast traffic flows at the northern interchange

The levels of risk are marginally different between the southern and northern interchanges due to the differences in forecast traffic flows though each main alignment tunnel and the dispersion of the plume due to localised meteorological conditions.

The increased annual risk and increased lifetime risk for exposure to diesel particulate matter remains within and towards the lower end of the range of acceptable risks.

Potential health impacts (Pennant Hills Road corridor)

As detailed in **Section 7.3** (Air quality), the project would have a net positive effect on air quality when considered in the context of air quality improvements along the Pennant Hills Road corridor. This would be because low level decreases in air quality around the northern and southern interchanges would be offset by significant improvements in air quality along Pennant Hills Road.

The human health implications of this net improvement in air quality have been calculated and assessed for primary health indicators. Changes in annual risk for primary health indicators (both positive and negative changes) are presented in the technical working paper: human health risk assessment (refer to **Appendix H**) on a suburb by suburb basis. These calculations show that the positive changes in annual risk for primary health indicators are both wider spread and greater in magnitude than the limited adverse changes in annual risk for the same primary indicators. The net change in annual risk for each primary health indicator is positive when taking into account changes in air quality along the Pennant Hills Road corridor as a result of the project.

Table 7-114 summarises the net changes in the incidence of primary health outcomes along the Pennant Hills corridor during operation of the project in 2019 and in 2029. The negative values in the table indicate a decrease in the incidence of each primary health outcome – that is, an improvement in human health outcomes when considering net changes along the corridor. Comparison of these values to the values for the same health outcomes presented in **Table 7-107** (project only) illustrates that the net human health benefit of the project is significantly higher than the minor increase in the incidence of primary health outcomes for adversely affected populations.

Table 7-114 Changes in incidence – primary health indicators (Pennant Hills Road corridor)

Primary health indicator	Baseline incidence per year (per 100,000)	Normal incidence variability (cases per year)	Change in incidence (cases per year) 2019	2029
Pennant Hills Road corridor				
Mortality from all causes (≥ 30 years of age)	1,087	1	-0.2	-0.3
Rate of hospitalisation with cardiovascular disease (≥ 65 years of age)	23,352	40	-0.2	-0.2
Rate of hospitalisation with respiratory disease (≥ 65 years of age)	8,807	17	-0.03	-0.04

7.4.5 Qualitative human health risk assessments

The following sections provide qualitative human health risk assessments relating to:

- The impacts of changes in air quality on children with asthma.
- Exposure of motorists to vehicle emissions as they travel through the project's main alignment tunnels.
- Potential health impacts associated with noise and vibration during construction and operation of the project.

The potential impacts have been assessed qualitatively because the health effect is either not able to be robustly quantified, and/ or there are no quantified thresholds against which to assess the health impact. These issues are nonetheless important, and have been qualitatively assessed to ensure a comprehensive assessment of relevant human health implications of the project.

Asthma

A common concern in relation to exposure to particulate matter relates to the potential for impacts on children with asthma. One way of measuring aggravation of asthma is through monitoring the use of bronchodilators (also known as asthma relievers or 'inhalers'). This assessment has considered the potential change in annual incidence through a calculation of the changed in use of asthma relievers due to the changes in particulate matter from the project. The assessment has considered the incremental increases in particulate matter from the ventilation outlets as well as overall project change (ie the ventilation outlets and the change in traffic volumes on Pennant Hills Road).

Based on modelled change in PM_{10} concentrations during operation of the project, the change in number of days per year of asthma reliever use has been calculated to be:

- Around the southern interchange (West Pennant Hills):
  - 0.07 days per year for the ventilation outlet only.
  - – 0.1 days per year for the project as a whole (ie a decrease in number of days per year).
- Around the northern interchange (Wahroonga):
  - 0.10 days per year from the ventilation outlet only.
  - – 0.08 days per year for the project as a whole (ie a decrease in number of days per year).

When the project is considered as a whole an overall decrease in the number of days of bronchodilator use by children is predicted. The calculated change in bronchodilator use in children is very low and would not be measurable within the local community.

In-tunnel exposures

Concentrations of vehicle emissions have been calculated along the main alignment tunnels. The outcomes of these calculations are summarised in **Table 7-98** during peak hours (refer to **Section 7.3** Air quality) and shown graphically in the technical working paper: human health risk assessment (refer to **Appendix H**) for each hour the day in 2019 and in 2029.

In-tunnel emissions have been calculated using internationally-recognised vehicle emission factors prepared by the Permanent International Association of Road Congress (2012), which provide Australian-specific emissions based on fleet distribution data and emission standards relevant to Australia. The Permanent International Association of Road Congress emission factors have been 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 has been added to the emission factors within the Permanent International Association of Road Congress (2012). This is expected to result in conservative emissions estimates when used for inventory purposes. As discussed in **Section 7.3**, a peer review by Pacific Environment on the emissions inventory for the project 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 (**Appendix G**).

The actual exposure of a motorist to vehicle emissions within the main alignment tunnels would be affected by:

- **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 periods.
- **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.
- **Journey duration**. Exposure to in-tunnel vehicle emissions would depend on total time within the project tunnels. For example, free flowing traffic traveling at 80 kilometres per hour would spend less than seven minutes within a main alignment tunnel.
- **Type of vehicle**. Closing car windows and recirculating air can significantly reduce exposures to in-tunnel vehicle emissions. Measurements conducted by NSW Health in relation to the M5 East Motorway tunnels (NSW Health, 2003) have identified that closing car windows and the switching the ventilation to recirculation can reduce exposures by around 70 to 75 per cent for carbon monoxide and nitrogen dioxide, by around 80 per cent for particulate matter and by around 50 per cent for volatile organic compounds.

A summary of the qualitative assessment of in-tunnel exposures to vehicle emissions is provided below. Expected in-tunnel concentrations of pollutants have been compared with experience in other road tunnels, and compared with available air quality standards in comparable jurisdictions (where no Australian standard for in-tunnel air quality are in place). The NHMRC (2008) has published measured concentrations of pollutants 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 data collection varies significantly. This makes it difficult to directly compare the range of reported concentrations with the concentrations predicted in this assessment (that is, the comparisons presented are over different averaging / exposure periods).

Carbon monoxide

- The hourly concentrations of carbon monoxide within the main alignment tunnels are expected to range from less than 1 mg/m^3 at the entry portals to around 4 mg/m^3 during peak hours at the ventilation offtake for the southbound main alignment tunnel and around 8 mg/m^3 during peak hours at the ventilation offtake for the northbound main alignment tunnel.
- The concentrations reported in other tunnels (in Sydney and around the world) range from 6 mg/m^3 to 44 mg/m^3 varying over peak and non-peak periods measured for different averaging periods (for example, a transect of five to ten minutes to an average over three hours). (NHMRC, 2008).
- The expected hourly concentration of around 8 mg/m^3, and the average concentration of around 4 mg/m^3 are both lower than the World Health Organization guidelines for 15-minute exposures (100 mg/m^3) and 30-minute exposures (57 mg/m^3).
- Closing car windows and recirculating are can reduce these calculated exposures by around 70 to 75 per cent. Based on a reduction of 70 per cent, this could result in in-vehicle average exposures of around 1.2 mg/m^3.
- Calculated concentrations are also below US Environmental Protection Agency guidelines for in-tunnel exposures, which range from 40 mg/m^3 for 45 to 60 minute exposures, to 138 mg/m^3 for peak period traffic (< 15 minutes) (NHMRC, 2008).

Nitrogen dioxide

- The hourly concentrations of nitrogen dioxide within the main alignment tunnels are expected to range from less than 0.1 mg/m^3 at the entry portals to around 0.4 mg/m^3 during peak hours at the ventilation offtake for the southbound main alignment tunnel and around 0.9 mg/m^3 during peak hours at the ventilation offtake for the northbound main alignment tunnel.
- The average exposure for a motorist using the southbound main alignment tunnel during peak hour would be around 0.2 mg/m^3 and for a motorist using the northbound main alignment tunnel around 0.5 mg/m^3.
- Closing car windows and recirculating are can reduce these calculated exposures by around 70 to 75 per cent. Based on a reduction of 70 per cent, this could result in in-vehicle average exposures during peak hour of around 0.06 mg/m^3 in the southbound main alignment tunnel and around 0.15 mg/m^3 in the northbound main alignment tunnel.

- The average concentrations of nitrogen dioxide reported in other tunnels (in Sydney and around the world) typically range from 0.09 to 0.5 mg/m^3 with levels up to 0.75 mg/m^3 reported during peak periods. However, 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 end of a tunnel (where exposure is very short, ie minutes) levels up to 1.5 mg/m^3 have been reported (NHMRC, 2008).
- The calculated concentrations of nitrogen dioxide are below the in-tunnel pollution limits available from other countries including:
  - Norwegian Public Road Administration (NPRA) guidelines of 1.4 mg/m^3 at the tunnel midpoint, and 2.8 mg/m^3 at the tunnel ends.
  - Belgium guideline of 0.9 mg/m^3 for exposures of less than 20 minutes.
  - French guideline of 0.75 mg/m^3 for a 15-minute average exposure period.

Particulate matter ($PM_{2.5}$)

- The hourly concentrations of $PM_{2.5}$ within the main alignment tunnels are expected to range from less than 0.1 mg/m^3 at the entry portals to around 0.35 mg/m^3 during peak hours at the ventilation offtake for the southbound main alignment tunnel and around 0.55 mg/m^3 during peak hours at the ventilation offtake for the northbound main alignment tunnel. As discussed in **Section 7.3**, these concentrations are determined using emission factors from PIARC, and are conservative when compared to those published by the NSW Environment Protection Authority, particularly in relation to $PM_{2.5}$.
- The average exposure for a motorist using the southbound main alignment tunnel during peak hour would be around 0.2mg/m^3 and for a motorist using the northbound main alignment tunnel around 0.3mg/m^3.
- Closing car windows and recirculating are can reduce these calculated exposures by around 80 per cent. This could result in in-vehicle average exposures during peak hour of around 0.04mg/m^3 in the southbound main alignment tunnel and around 0.06mg/m^3 in the northbound main alignment tunnel.
- The average concentrations of $PM_{2.5}$ reported in other tunnels (in Sydney and around the world) typically range from around 0.03 to 0.343 mg/m^3 varying over peak and non-peak periods and with averaging times (ranging from a 1 hour averages, peak hour average, daytime average, and 24 hour averages) (NHMRC 2008 and AMOG 2012).
- Exposure-response relationships for health effects associated with exposure to particulate matter have been developed based on 24-hour average concentrations of $PM_{2.5}$ in urban air. These relationships do not provide applicable and reliable guidance of potential health effects for much shorter exposure periods, as would be the case for motorists passing through the main alignment tunnels in a matter of minutes
- A recent review of available studies in relation to short-duration exposures to particulate matter conducted by the World Health Organization (WHO, 2013) has identified the following:
  - Epidemiological and clinical studies have demonstrated that short duration (less than daily) exposure to particulate matter can lead to adverse changes in the respiratory and cardiovascular systems, particularly exacerbation of existing disease. This is generally consistent with the outcomes of studies reviewed by the US Environmental Protection Agency (USEPA, 2009b).

- Available studies do not cover a range of exposure concentrations, nor do they address other variables such as co-pollutants (gases) or repeated short duration exposures.
- The studies have not determined whether a one-hour exposure would lead to the same health outcomes as a similar dose spread over a longer period (24 hours), or if an exposure-response relationship could be determined for short duration exposures.
- Exposures that may occur during the use of various transportation methods (such as traveling within cars or buses) have been found to contribute to and affect 24-hour personal exposures.

- Exposures to particulate matter for people traveling within vehicles in Europe vary from 0.022 mg/m^3 to 0.085 mg/m^3 for passenger cars and 0.026 to 0.13 mg/m^3 for bus travel (ETC, 2013).
- Concentrations of $PM_{2.5}$ have been measured within cars in Sydney (where tunnel travel was not part of the journey) ranging from 0.009 to 0.045 mg/m^3 (NSW Health, 2004).

Polycyclic aromatic hydrocarbons

- The hourly concentrations of polycyclic aromatic hydrocarbons within the main alignment tunnels are expected to range from less than 0.00001 mg/m^3 at the entry portals to around 0.00007 mg/m^3 during peak hours at the ventilation offtake for the southbound main alignment tunnel and around 0.0001 mg/m^3 during peak hours at the ventilation offtake for the northbound main alignment tunnel.
- The maximum predicted concentration of carcinogenic polycyclic aromatic hydrocarbons within the main alignment tunnels has been estimated at 0.000000009 mg/m^3 (as benzo[a]pyrene toxicity equivalent).
- The concentrations of carcinogenic polycyclic aromatic hydrocarbons reported in other tunnels (in Sydney and around the world) range from 0.000000009 mg/m^3 to 0.000000118 mg/m^3 at differing averaging periods (ranging from hours to 24 hour) (NHMRC 2008).
- There are no guidelines for short term peak exposures to polycyclic aromatic hydrocarbons that would be relevant to assessment of exposures within the main alignment tunnels. However, the calculated incremental carcinogenic risks for very short duration exposures (in the order of minutes) to carcinogenic polycyclic aromatic hydrocarbons at the concentration mentioned above would be less than one in one million ($< 1 \times 10^{-6}$). This level of risk is considered to be negligible.

Volatile organic compounds

- The hourly concentrations of volatile organic compounds within the main alignment tunnels are expected to range from less than 0.1 mg/m^3 at the entry portals to around 0.4 mg/m^3 during peak hours at the ventilation offtake for the southbound main alignment tunnel and around 0.7 mg/m^3 during peak hours at the ventilation offtake for the northbound main alignment tunnel.
- The average exposure for a motorist using the southbound main alignment tunnel during peak hour would be around 0.2 mg/m^3 and for a motorist using the northbound main alignment tunnel around 0.4 mg/m^3.
- Closing car windows and recirculating are can reduce these calculated exposures by around 50 per cent. This could result in in-vehicle average exposures during peak hour of around 0.1 mg/m^3 in the southbound main alignment tunnel and around 0.2 mg/m^3 in the northbound main alignment tunnel.

- Based on speciation of individual volatile organic compounds, the maximum in-tunnel concentration of benzene is expected to be around 0.02 mg/m^3, for toluene around 0.04 mg/m^3 and formaldehyde around 0.04 mg/m^3. The concentrations are comparable to monitored concentrations in road tunnels in Sydney and around the world (NHMRC, 2008).
- These concentrations are also consistent, but slightly lower than concentrations measured in cars in Sydney (where tunnel travel was not part of the journey) (NSW Health, 2008) which have been recorded ranging from 0.04 to 0.07 mg/m^3 for benzene, and from 0.1 to 0.2 mg/m^3 for toluene.
- Based on speciation of individual volatile organic compounds, all concentrations of individual compounds (and all components together) are below acute guidelines. Hence no adverse health effects are expected on the basis of exposures to volatile organic compounds within the main alignment tunnels.

Health impacts of noise and vibration

The results of the assessment for construction and operational noise and vibration are provided in **Section 7.2** (Noise and vibration) and the technical working paper: noise and vibration (**Appendix F**).

The potential health outcomes from exposure to noise for which there is strong evidence include:

- Sleep disturbance.
- Annoyance.
- Hearing impairment.
- Children’s school performance through effects on memory and concentration.
- Cardiovascular disease.

Other health outcomes, where there is not strong evidence linking noise to the effect, may include increasing difficulty in understanding what others are saying and effects on mental health (usually in the form of exacerbation of issues for vulnerable populations rather than direct effects).

The construction noise guidelines and the operational road noise guidelines applicable to the project have considered the health effects of noise and the relevant guidance from the World Health Organisation and the Environmental Health Council of Australia in determining appropriate noise criteria.

Noise levels that do not comply with the criteria set out in these policies would have the potential to have negative health outcomes for the community. The worst case assessment predicts that noise criteria would be exceeded at a number of properties in the absence of additional noise mitigation measures. These additional mitigation measures are identified in **Section 7.2** (Noise and vibration) and would be further developed prior to construction as part of the Construction Noise and Vibration Management Plan.

In relation to operational noise impacts, **Section 7.2** (Noise and vibration) and the technical working paper: noise and vibration (**Appendix F**) identify locations where noise barriers and at-property acoustic treatments would be required based on the current project design.

These measures would be reviewed based on the detailed design for the project. Community consultation would be undertaken during this process in order to address the potential operational noise impacts of the project.

7.4.6 Environmental management measures

The potential human health risks from the project are associated with air quality and noise and vibration impacts. As such the mitigation measures relevant to human health include:

- Operational air quality mitigation and monitoring identified in **Section 7.3** (Air quality).
- Construction and operational noise and vibration mitigation measures identified in **Section 7.2** (Noise and vibration).

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