11 Human health risk

This chapter outlines the potential human health impacts and quantifies the risks to human health associated with the M4-M5 Link project (the project), including:

- An outline of the methodology used to undertake the human health risk assessment
- A summary of the existing environment relevant to human health
- A description of the potential impacts of the project on human health during construction and operation
- Environmental management measures to be implemented to minimise any potential impacts of the project on human health.

A detailed human health risk assessment has been prepared and is included in **Appendix K** (Technical working paper: Human health risk assessment).

The Secretary of the NSW Department of Planning and Environment (DP&E) has issued environmental assessment requirements for the project. These are referred to as Secretary's Environmental Assessment Requirements (SEARs). **Table 11-1** sets outs these requirements and the associated desired performance outcomes that relate to human health, and identifies where they have been addressed in this environmental impact statement (EIS).

Table 11-1 SEARs – human health

Desired Performance Outcome	SEARs	Where addressed in the EIS
3. Health and Safety The project avoids or minimises any adverse health impacts arising from the project. The project avoids, to the greatest extent possible, risk to public safety.	1. The Proponent must assess the potential health impacts of the project, in accordance with the current guidelines.	Potential health impacts during construction and operation are discussed in **section 11.4**, **section 11.5, section 11.6** and **11.9**.
	2. The assessment must: (a) describe how the design of the proposal minimises adverse health impacts;	**Section 11.2** describes the key design aspects of the project that minimise adverse health impacts.
	(b) assess human health impacts from the operation and use of the tunnel under a range of conditions, including worst case operating conditions and the full length of all tunnels in the WestConnex scheme;	Human health impacts from the operation and use of the tunnel are discussed in **section 11.5**.
	(c) human health risks and costs associated with the proposal, including those associated with air quality, noise and vibration, and social impacts on the adjacent and surrounding areas during the construction and operation of the proposal;	Human health risks and costs associated with the proposal are described in **sections 11.4.1** (air quality) **11.4.2** (noise and vibration and **11.6** (social and economic impacts).
	(d) include both incremental changes in exposure from existing background pollutant levels and the cumulative impacts of project specific and existing pollutant levels at the location of the receivers (including public open space areas);	Incremental changes in exposure from existing background pollutant levels and the cumulative impacts of the project are discussed in **section 11.5** and **section 11.6**.

Desired Performance Outcome	SEARs		Where addressed in the EIS
	(e)	assess the likely risks of the project to public safety, paying particular attention to pedestrian safety, subsidence risks, bushfire risks and the handling and use of dangerous goods;	The likely risks of the project to public safety are discussed in **section 11.5.3**. Assessment of subsidence risks is provided in **Chapter 19** (Groundwater).
	(f)	include a cumulative human health impact assessment inclusive of in-tunnel, local and regional impacts due to the operation of and potential continuous travel through the M4 East and New M5 Motorways and surface roads.	Cumulative operational human health impacts are discussed in **section 11.5.1** and in **Chapter 26** (Cumulative impacts).

11.1 Assessment methodology

The methodology for the human health risk assessment is based on defining, quantifying where feasible, and assessing the potential risks to human health from the construction and operation of the project. The assessment focussed on the key impacts on local and regional air quality, in-tunnel air quality for tunnel users, noise and vibration and social changes.

11.1.1 Overview

The methodology adopted for the human health risk assessment is in accordance with national and international guidance that is endorsed or accepted by Australian health and environmental authorities, and includes, but is not limited to:

- Air Quality in and Around Traffic Tunnels (National Health and Medical Research Council (NHMRC) 2008)
- *Environmental Health Risk Assessment: Guidelines for Assessing Human Health Risks from Environmental Hazards: 2012* (enHealth 2012b)
- *Health Impact Assessment Guidelines* (enHealth 2001)
- *Health Impact Assessment: A Practical Guide* (NSW Health 2007)
- *Australian Exposure Factors Guide* (enHealth 2012a)
- *Schedule B8 Guideline on Community Engagement and Risk Communication* (National Environment Protection Council Schedule (NEPC) 1999 amended 2013a)
- National Environmental Protection (Air Toxics) Measure, Impact Statement for the National Environment Protection (Air Toxics) Measure (NEPC 2003)
- *Risk Assessment Guidance for Superfund: Volume I Human Health Evaluation Manual (Part F, Supplemental Guidance for Inhalation Risk Assessment)* (United States Environmental Protection Agency (USEPA) 2009b)
- State Environmental Planning Policy (SEPP) No. 33 – Hazardous and Offensive Development (NSW).

More specifically, in relation to the assessment of health impacts associated with exposure to nitrogen dioxide and particulate matter, guidelines available from the NEPC (Burgers & Walsh 2002; NEPC 1998, 2002, 2003, 2009, 2010), World Health Organization (WHO) (Ostro 2004; WHO 2003, 2006b, 2006a, 2013b) and the USEPA (USEPA 2005b, 2009b) have been used as required. In addition, the following has been considered:

- Building NSW Better Health, Health considerations for urban development and renewal in the Sydney Local Health District (NSW Health 2016)

- *Healthy Urban Development Checklist, A guide for health services when commenting on development policies, plans and proposals* (NSW Health 2009)
- Methodology for Valuing the Health Impacts of Changes in Particle Emissions (NSW Environment Protection Authority (NSW EPA) 2013).

This chapter considers the following issues in relation to the assessment of human health impacts:

- Existing conditions (in relation to air quality and noise)
- How the design of the project minimises adverse health impacts
- Human health risks and costs associated with the project, including those associated with air quality, noise and vibration, and social impacts, during the construction and operation of the proposal and estimation of short-term (acute) and long-term (chronic) impacts during construction and operation of the project
- Human health impacts on users of the tunnels and external receivers of air and noise emissions from the operation of the tunnels under a range of conditions, including a worst case operating condition
- Consideration of cumulative impacts includes the project, the other approved stages of WestConnex, and other related projects comprising the proposed future Sydney Gateway Western Harbour Tunnel and Beaches Link and F6 Extension projects.

The detailed principles, methodology and limitations of the toxicity and risk assessment are provided in section 3 of **Appendix K** (Technical working paper: Human health risk assessment).

11.1.2 Study area

The study area for the human health risk assessment overlaps with study areas considered in the M4 East and New M5 projects and is consistent with the area over which impacts on air quality have been considered, referred to as the GRAL domain. The domain extends well beyond the project footprint to allow for the traffic interactions between the project, other WestConnex projects (in particular the M4 East and New M5) and other future projects (Sydney Gateway, Western Harbour Tunnel and Beaches Link and F6 Extension). The study area is the area shown within the black line in **Figure 11-1**. A smaller study area closer to the project footprint has been considered for the assessment of soil and noise and vibration impacts.

The population considered in this assessment include those who live or work within the vicinity of the project footprint as well as the broader population associated with the overall WestConnex program of works. The study area covers a large number of individual suburbs that sit within the following local government areas (LGAs):

- Canada Bay
- Strathfield
- Burwood
- Inner West (amalgamation of former Ashfield, Leichhardt and Marrickville LGAs)
- City of Sydney
- Botany Bay
- Rockdale
- Canterbury
- Georges River (amalgamation of former Hurstville and Kogarah LGAs).

The above LGAs reflect those defined in 2016 following amalgamations and are consistent with the LGAs for which NSW Health provide some data. Some health data relates to the former LGAs.

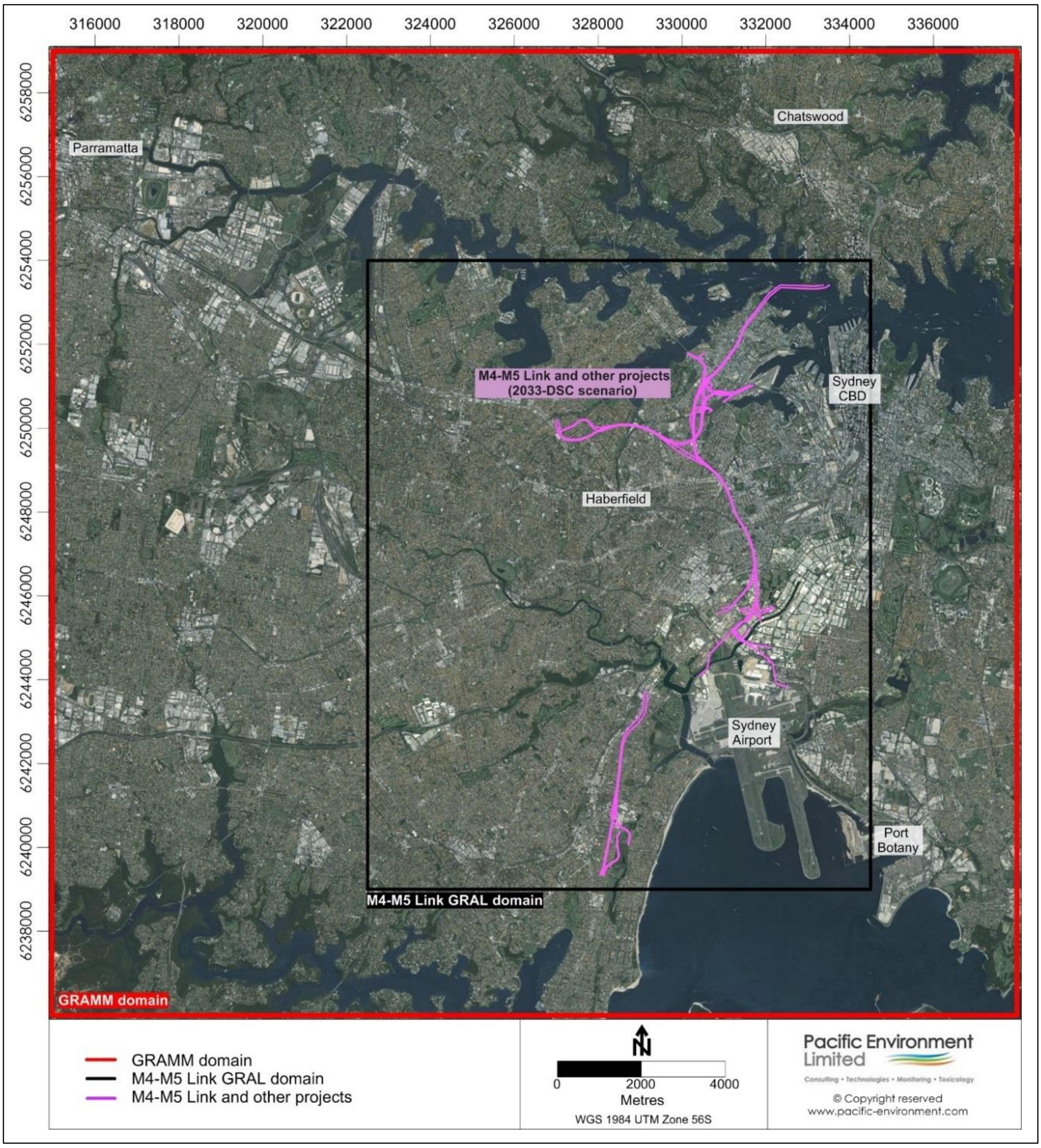

Figure 11-1 Human health risk assessment study area

11.1.3 Sensitive receivers

The assessment of potential impacts on the surrounding community, particularly in relation to air quality, has considered the location where maximum impacts from the project may occur. In addition, impacts on the wider community have also been considered. Within the wider community, a number of additional locations, referred to as 'community receivers', have been identified in the suburbs close to the project.

Community receptors are locations in the local community where more sensitive members of the population, such as infants and young children, the elderly or those with existing health conditions or illnesses, may spend a significant period of time. These locations may comprise hospitals, child care facilities, schools and aged care homes/facilities. **Table 11-2** presents a list of the community receptors included in this assessment. This is representative only and is not intended to comprise an exhaustive list of community receptors in the study area. The location of the sensitive or community receptors is presented in **Figure 11-2**.

Table 11-2 Community receptors included in human health risk assessment

	Receptor name	Type of receptor	Suburb
CR01	The Jimmy Little Community Centre	Community	Lilyfield
CR02	Balmain Cove Early Learning Centre	Child care	Rozelle
CR03	Rosebud Cottage Child Care Centre	Child care	Rozelle
CR04	Sydney Community College	Higher education	Rozelle
CR05	Rozelle Total Health	Health	Rozelle
CR06	Laurel Tree House Child Care Centre	Child care	Glebe
CR07	Bridge Road School	School - Primary	Camperdown
CR08	NHMRC Clinical Trials Centre	Health	Camperdown
CR09	Annandale Public School	School - Primary	Annandale
CR10	The University of Notre Dame Australia	Higher education	Chippendale
CR11	Laverty Pathology	Health	Annandale
CR12	Little VIP's Childcare Centre	Child care	Haberfield
CR13	Dobroyd Point Public School	School - Primary	Haberfield
CR14	Peek A Boo Early Learning Centre	Child care	Haberfield
CR15	Rozelle Child Care Centre	Child care	Lilyfield
CR16	Sydney Secondary College Leichhardt Campus	School - Secondary	Leichhardt
CR17	Rose Cottage Child Care Centre	Child care	Leichhardt
CR18	Inner Sydney Montessori	School - Primary	Lilyfield
CR19	Leichhardt Little Stars Nursery & Early Learning Centre	Child care	Leichhardt
CR20	Leichhardt Montessori Academy	Child-care	Leichhardt
CR21	St Basil's Sister Dorothea Village	Aged care	Annandale
CR22	St Thomas Child Care Centre	Child care	Rozelle
CR23	Billy Kids Lilyfield Early Learning Centre	Child care	Lilyfield
CR24	Little Learning School	Child care	Alexandria
CR25	Newtown Public School Combined Out of School Hours Care	School - Primary	Newtown
CR26	The Athena School	School – K to year 10	Newtown
CR27	Camdenville Public School	School - Primary	Newtown
CR28	St Joan of Arc Home for the Aged	Aged care	Haberfield
CR29	Inner West Education Centre	Education – K to year 8	Haberfield
CR30	St Peters Community Pre-school	Pre-school	St Peters
CR31	Rozelle Public School	School - Primary	Rozelle
CR32	Lilyfield Early Learning Centre	Child-care	Lilyfield
CR33	Sydney Secondary College Blackwattle Bay	School – Years 11 and 12	Glebe
CR34	Erskineville Public School	School - Primary	Erskineville
CR35	Haberfield Public School	School - Primary	Haberfield
CR36	The Infants Home	Early childhood including children with special needs	Ashfield
CR37	St Peters Public School	School - Primary	St Peters
CR38	Active Kids	Child-care	Mascot
CR39	Alexandria Early Learning Centre	Child-care	Alexandria
CR40	Sydney Park Childcare Centre	Child-care	Alexandria

In addition to these community receptors, about 86,375 individual receptors have been modelled in the streets/suburbs located in the study area. These individual receptors represent a range of uses including residential, workplaces or recreational (open space) areas in the surrounding community, as detailed in **Table 11-3**.

Table 11-3 Summary of RWR receptor types

Receptor type	Number	% of total
Aged care	20	0.02%
Child care/pre-school	129	0.15%
Commercial	2,766	3.20%
Community	1,941	2.25%
Further education	18	0.02%
Hospital	4	0.00%
Hotel	30	0.03%
Industrial	2,093	2.42%
Medical practice	125	0.14%
Mixed use	514	0.60%
Park/sport/recreation	1,018	1.18%
Place of worship	106	0.12%
Residential	75,157	87.01%
School	206	0.24%
Other[1]	2,248	2.60%
Total	**86,375**	**100.00%[2]**

Note:

1 'Other' includes car parks, garages, veterinary practices, construction sites, certain zoning categories (DM – Deferred Matter; G – Special Purposes Zone – Infrastructure; SP1 – Special Activities; SP2 – Infrastructure) and any other unidentified types

2 Total of receptor types does not add up to exactly 100 per cent due to rounding

These receptors are referred to as residential, workplace and recreational (RWR) receivers. The RWR includes all other community receivers located in the study area, not specifically included in **Table 11-2**. The maximum impacts from all the RWR receivers have also been evaluated so that all exposures that may occur within the community are addressed.

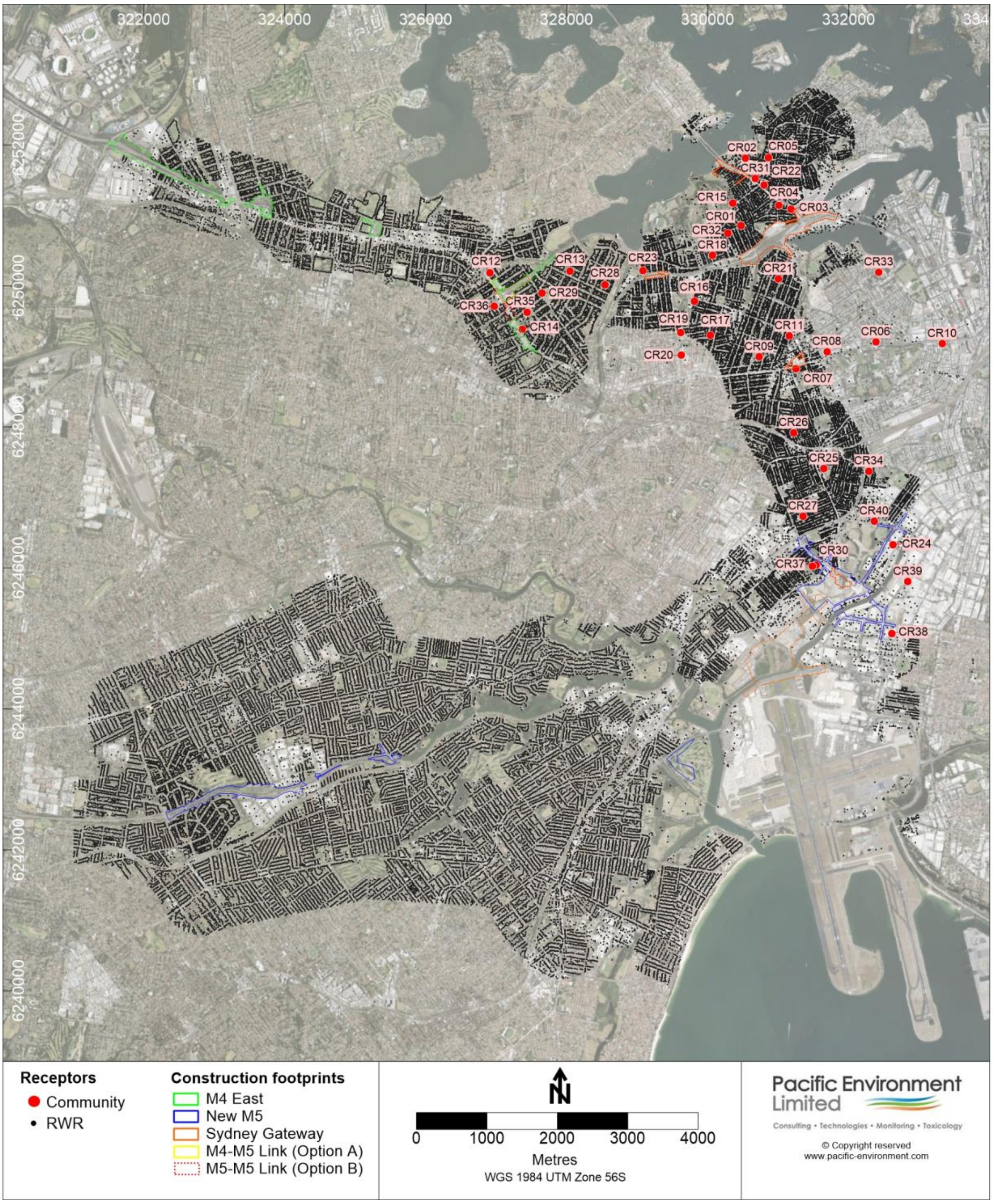

Figure 11-2 Community receptors evaluated in the human health risk assessment

11.2 Project design to minimise health impacts

The majority of the project footprint is underground. This includes the mainline tunnels as well as the Rozelle interchange and the Iron Cove Link. This means that road traffic noise is avoided during operation of the project except where entry and exit ramps come to the surface. It also means that emissions from vehicles are removed from surface roads and dispersed from elevated ventilation outlets with minimal impact on local air quality (see **section 11.5.1** and refer to **Chapter 9** (Air quality)).

Improved active transport links and new open space would be provided on completion of the project (see **sections 11.6.1** and **11.6.3**).

11.3 Existing environment

11.3.1 Population profile

The population within the study area comprise residents and workers as well as those attending schools, day care, hospitals and recreational areas. The composition of the populations located within the study area is expected to be generally consistent with population statistics for the larger individual suburbs that are wholly or partially included in the study area.

Population statistics for the LGAs (based on statistical areas SA3, which differ from the 2016 LGAs) are available from the Australian Bureau of Statistics (ABS) for the Census year 2011 and are summarised in **Table 11-4.** For the purpose of comparison, the population statistics presented also include the statistics for larger statistical population groups in the area (defined by the ABS SA4) and the larger statistical areas of Greater Sydney and the rest of the NSW (excluding Greater Sydney) (as defined by the ABS).

Table 11-4 Summary of population statistics in the study area

Location	Total population		% Population by key age groups					
	Male	Female	0–4	5–19	20–64	65+*	1–14*	30+*
Local statistical areas (SA3)								
Canada Bay	35,938	38,218	6.9	14.9	64.2	14.0	15.5	63.4
Strathfield – Burwood – Ashfield	67,285	69,922	5.7	15.3	65.9	13.1	14.3	59.8
Leichhardt	24,726	27,471	8.2	11.7	69.9	10.2	14.9	67.2
Sydney Inner City	92,089	82,483	3.7	7.0	81.6	7.8	6.2	59.1
Marrickville, Sydenham and Petersham	25,275	25,338	6.5	12.1	70.4	11.1	13.3	63.8
Canterbury	63,067	62,359	7.8	18.9	60.3	13.0	19.2	58.2
Botany	19,492	19,865	6.7	17.1	61.8	14.4	16.8	61.6
Hurstville	56,553	60,050	6.0	17.8	60.8	15.4	16.4	61.2
Kogarah and Rockdale	60,465	62,035	6.6	16.1	62.5	14.8	16.0	61.7
Larger local statistical areas (SA4 – includes SA3 areas)								
Sydney – Inner West	127,950	135,610	6.5	14.5	66.0	12.9	14.8	62.3
Sydney Inner South West	258,320	265,288	7.1	18.6	60.1	14.2	18.2	59.5
Sydney City and Inner South	136,858	127,686	4.7	9.4	76.5	9.4	9.1	60.4
Statistical areas of Sydney and NSW								
Greater Sydney	2,162,221	2,229,453	6.8	18.7	61.7	12.9	17.9	60.0
Rest of NSW (excluding Greater Sydney)	1,239,007	1,273,942	6.3	19.7	55.9	18	18.2	63.0

Notes:

SA = statistical area

SA3 are larger statistical areas that are aggregates of SA2 areas with populations between 30,000 and 130,000

SA4 are larger statistical areas that are aggregates of SA3 areas with populations in excess of 100,000

* Age groups specifically relevant to the characterisation of risk

Based on general population data, the populations in the study area are generally similar to Greater Sydney with the exception of the following:

- Sydney – Inner City, as well as the larger area of Sydney City and Inner South, have a lower proportion of young children, a higher proportion of working aged individuals and a lower proportion of individuals aged over 65 years
- Areas of Marrickville, Sydenham and Petersham, Strathfield, Burwood and Ashfield, Canada Bay and Leichhardt also have a slightly lower proportion of young children.

The estimated population growth from 2011 to 2036 for these areas is:

- Canada Bay: 53.5 per cent
- Strathfield: 74.2 per cent
- Burwood: 68.3 per cent
- Inner West (Ashfield, Leichhardt and Marrickville): 27.7 per cent
- City of Sydney: 72.0 per cent
- Botany: 75.2 per cent
- Canterbury-Bankstown: 49.7 per cent
- Rockdale: 50.2 per cent
- Georges River (Hurstville and Kogarah): 28.5 per cent.

11.3.2 Health of existing population

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

Information in relation to health related behaviours (that 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) is available for the larger populations within the local area health services in Sydney and NSW. This includes risky alcohol drinking, smoking, inadequate consumption of fruit and vegetables, being overweight or obese, and inadequate physical activity.

The study population is largely located within the Sydney Area Health Service and the South Eastern Sydney Area Health Service. The incidence of these health-related behaviours in this area, compared with other health areas in NSW, and the state of NSW (based on data from 2015 and 2016) is illustrated in Figure 4-3 of **Appendix K** (Technical working paper: Human health risk assessment).

Review of this data generally indicates that the population in the Sydney and South Eastern Sydney Area Health Service areas (that include the study area) have:

- Similar rates of risky alcohol drinking and smoking and similar intakes of recommended consumption of fruit and vegetables compared with NSW
- Higher rates of adequate physical activity and lower rates of being overweight and obese compared with NSW.

A review of the data obtained from Health Statistics NSW generally indicates that for the population in the study area, the health statistics (including mortality rates and hospitalisation rates for most categories) are variable but generally similar to those reported in the larger area health services of Sydney and South Eastern Sydney, the wider Sydney metropolitan area and the whole of NSW.

Section 4.5 of **Appendix K** (Technical working paper: Human health risk assessment) provides further details on health related behaviours and health indicators for the study area.

11.3.3 Existing air quality

The project is situated within an urbanised area of Sydney. In large urban areas there is usually a complex interaction of pollution sources, substantial concentration gradients, variable meteorological conditions and local topography, all affecting the quality of the air.

Air quality in the Sydney region has improved over the last few decades. The improvements have been attributed to initiatives which aim to reduce emissions from industry, motor vehicles, businesses and residences. While levels of nitrogen dioxide (NO_2), sulfur dioxide (SO_2) and carbon monoxide (CO) continue to be below national standards, levels of ozone and particulate matter ($PM_{2.5}$ and PM_{10}) can occasionally exceed the standards.

For these pollutants there are a large number of sources in the study area including combustion sources other than from the project, other local construction/earthworks and personal exposures (such as smoking) and risk-taking behaviours that have the potential to affect the health of any population.

More information about existing air quality within the study area is provided in **Chapter 9** (Air quality).

11.3.4 Existing noise and vibration

The noise levels at unattended monitoring locations showed a typical daily trend with lower noise levels during the night-time compared to the daytime and evening periods. This is characteristic of urban and suburban areas where the ambient noise environment is primarily influenced by road traffic. The data is also consistent with observed traffic flows on the adjacent arterial roads which have a relatively small reduction in traffic volumes during the evening compared to the daytime period, and a more significant reduction in volumes during the night-time.

The measured noise levels have been used with consideration of the existing road traffic flows to calibrate the operational noise model and also to establish construction noise management levels for the project.

Background noise levels during construction have been established for the daytime (7.00 am to 6.00 pm, varying from 45 to 68 decibels (dB(A)), evening (6.00 pm to 10.00 pm, varying from 43 to 67 dB(A) and night-time (10.00 pm to 7.00 am, varying from 32 to 51 dB(A)) periods as rating background level (RBL) values determined on the basis of adopted guidelines.

Background noise levels during operation have been established for the daytime (7.00 am to 10.00 pm varying from 54 to 73 dB(A)) as L_{Aeq}(15 hour) and night-time (10.00 pm to 7.00 am varying from 50 to 70 dB(A)) as $L_{Aeq(9\ hour)}$.

More information about the existing noise environment is provided in **Chapter 10** (Noise and vibration).

11.4 Assessment of potential construction impacts

11.4.1 Air quality

Impacts on air quality that may occur during construction as a result of tunnelling activities and surface works has been considered in **Chapter 9** (Air quality).

The assessment of construction air quality was carried out using a qualitative assessment approach. For almost all construction activities, significant impacts on receivers would be avoided through project design and the implementation of effective, industry standard mitigation and management measures. However, dust management measures may not be effective all of the time. In situations where the construction air quality management measures are not fully effective, impacts on the community would generally be temporary and short-term and are not considered to be significant.

Dust management procedures would be included as part of the Construction Environmental Management Plan (CEMP). Measures to manage dust impacts include site management, preparing and maintaining construction sites, maintenance and controls on vehicles and machinery, and waste management (refer to **Chapter 9** (Air quality) for further details). The effectiveness of dust control measures would be monitored and adjusted as required. Where the dust mitigation measures are effectively implemented, impacts on the health of the community would be minimised.

11.4.2 Noise and vibration

As described in **Chapter 10** (Noise and vibration), a worst case noise and vibration assessment (assuming no additional mitigation measures are implemented) was carried out in accordance with the *Interim Construction Noise Guidelines* (NSW Department of Environment and Climate Change (DECC) 2009). For each area assessed, the noise levels at the most affected receivers have been used to represent the whole area.

Potential noise impacts from movement of construction vehicles

Potential increases in noise for sensitive receivers (as defined in **section 11.1.3**) due to construction traffic has been assessed separately from the assessment of noise from other construction activities. Heavy vehicles involved in construction are expected to travel via existing arterial roads (figures showing spoil haulage routes are provided in **Chapter 6** (Construction work)). In all areas evaluated, there are no noticeable increases in noise from construction traffic on the proposed routes during the daytime or night-time.

Ground-borne construction noise

Ground-borne noise occurs when works are being undertaken underground or in some other fashion that results in the vibrations from noise moving through the ground rather than the air. This project involves tunnelling, so many of the more significant noise activities would take place at depth (with a large proportion of the mainline tunnels at depths between around 30 to 60 metres), where activities are expected to occur 24 hours per day.

The roadheader excavation would typically progress at around 20 to 25 metres per week subject to local geology and confirmation of the tunnel excavation methods. Ground-borne noise from roadheader activity is expected to impact about 494 properties, mostly where the tunnel entry and exit ramps would approach the surface road network around the Wattle Street interchange, the Rozelle interchange, the Iron Cove Link and on the approach to the St Peters interchange. It is likely that the excavation by the roadheaders may be perceptible in the evening and during the night for up to about 20 days at each affected receiver as the roadheader passes them, with exceedances of ground-borne noise goals at affected receivers during these periods. Roadheader advance rates would reduce to two to five metres a day around the portals, which may slightly increase the duration of exposure for receivers in these areas.

The modelling addressed the worst-case situation when the tunnelling is occurring immediately beneath a sensitive receiver. Exceedance of the night-time criteria has been identified for sensitive receptors near key construction areas, specifically the Darley Road civil and tunnel site (C4) (with exceedance up to four dB (A)) and the Pyrmont Bridge Road tunnel site (C9) (with exceedance up to five dBA).

Mitigation and management measures include the validation of predicted impacts from the noise and vibration modelling (which is based on a conservative worst-case assessment) and notifying the community of noise impacts anticipated at specific times. At two residential locations, night-time ground-borne noise is predicted to exceed the criteria by 10 dBA or more. At these receivers, additional mitigation measures have been identified that include providing individual briefings on impacts and mitigation measures, providing respite periods, and alternate accommodation.

Vibration impacts

Some items of equipment to be used during construction have the potential to cause unacceptable levels of vibration. Managing the potential for such vibration to actually cause discomfort or structural damage at sensitive receiver locations is based on ensuring suitable separation distances between the equipment and the receiver locations.

The proposed management of vibration impacts involves monitoring of the predicted impacts, advising the community of impacts and offering respite periods to affected residents where human comfort levels are to be exceeded for an extended period of time during any one day.

Blasting

Blasting would be carried out along the length of the tunnel alignment during excavation and would be carefully planned to ensure blast limits are satisfied. Blasting would be undertaken during reduced standard construction hours (between 9.00 am and 5.00 pm, Monday to Friday and 9.00 am to 1.00 pm on Saturday) and would be subject to the provision of respite periods. A description of how blasting would be carried out is provided in **Chapter 6** (Construction work). Further detailed assessment and a blast trial process would be described in a Blast Management Strategy, which would be prepared during the detailed design of the project. An assessment of the impacts of blasting on receivers is provided in **Chapter 10** (Noise and vibration).

11.4.3 Public safety

A range of possible hazards have been identified that have the potential to affect public safety during construction. These are outlined in **Table 11-5** along with discussion on the risks that may be posed by these hazards. Not all the hazards identified in the hazard and risk assessment have been included in the table, only those where there is the potential for risks to public safety. Further detail on project hazards is provided in **Chapter 25** (Hazard and risk).

Table 11-5 Overview of public safety hazards and risks: Construction

Hazard: Public safety	Risk to public safety	Management measures
Storage and handling of dangerous goods on construction sites that may impact the community in the case of a spill or leak.	**Low** The storage volume of dangerous goods on any one construction site is low. In the event of an incident, there would very low potential for an off-site risk.	All materials would be stored in accordance with the Australian Dangerous Goods Code that includes the use of bunding, ventilation of areas where gases are stored, locating stores of these materials away from sensitive areas, and maintaining a register and inventory.
Incidents related to the transport of dangerous goods and hazardous substances on public roads.	**Low** The quantities and frequency of transport for these chemicals is low. All transport would involve using trucks that are suitable to transport these materials, with procedures in place to manage any leaks or spills during an accident.	All materials would be transported in accordance with the Storage and Handling of Dangerous Goods Code of Practice (WorkCover NSW 2005), *Dangerous Goods (Road and Rail Transport) Act 2008* (NSW), Dangerous Goods (Road and Rail Transport) Regulation 2014 (NSW) and relevant Australian Standards.
Tunnel collapse that may affect areas overlying the tunnel alignment.	**Low**	All tunnelling would be undertaken under a permit to tunnel system that requires detailed consideration of ground support performance as well as geotechnical and groundwater conditions for each tunnel section.
Potential acid sulfate soils may result in acidification and the mobilisation of metals, adversely impacting the water quality of waterways used by the public.	**Low**	Standard construction and mitigation measures would be applied to mitigate the potential risks associated with the disturbance of acid sulfate soils.

Hazard: Public safety	Risk to public safety	Management measures
Contamination, specifically the presence of hazardous materials (such as asbestos) and works in areas where contamination is present in soil, which may result in contaminants migrating off-site onto neighbouring properties or into waterways.	**Low**	Removal of asbestos would be required to be undertaken in accordance with procedures detailed in an Asbestos Management Plan for the project, which meet national legislation and guidance.
Flooding of land downgradient of construction sites due to changes to local landform and/or water diversions.	**Low** Flooding risks to off-site areas evaluated though modelling indicate no significant impacts.	Construction sites and permanent operational infrastructure would be designed to minimise the potential for off-site flooding impacts.
Damage to underground utilities, affecting public roadways and services provided to the community.	**Low**	A Utilities Management Strategy (refer to **Appendix F** (Utilities Management Strategy)) has been prepared for the project that identifies management options, including relocation or adjustment of the utilities. This includes consultation with utilities and service infrastructure providers to mitigate the risk of unplanned or unexpected disturbance of utilities.
Bushfire or fire risks that may spread off-site and affect neighbouring properties.	**Low**	The project is in a highly urbanised area that is not in or near a bushfire prone area. Management of construction facilities and activities involving flammable materials and ignition sources would be undertaken to minimise fire risks. High risk construction activities, such as welding and metal work, would be subject to a risk assessment on total fire ban days, and restricted or ceased as appropriate.
Aviation risks, specifically works that may affect the safety of aircraft using Sydney Airport.	**Low**	Construction activities would be carried out to ensure that equipment such as cranes and materials do not intrude into the obstacle limitation surface (OLS) or procedures for air navigation systems operations (PANS-OPS) for Sydney Airport. Ongoing consultation would be undertaken with Australian Government regulatory agencies and Sydney Airport Corporation Limited to ensure all legal obligations and other requirements would be met.

Hazard: Public safety	Risk to public safety	Management measures
Traffic and trucks on surface roads have the potential to increase the risk to public safety due to road incidents.	**Low** Changes to the surface road network may require temporary traffic detours. Construction road traffic volumes are low compared with existing traffic volumes, which is not expected to significantly impact on road safety.	Heavy vehicle movements would involve the use of major roads including Parramatta Road, City West Link, Victoria Road, Pyrmont Bridge Road and the Princes Highway. All traffic detours would be undertaken in accordance with approvals by Roads and Maritime, local councils and the Transport for NSW Transport Management Centre. Property access would be maintained, or alternative access provided. A Construction Traffic and Access Management Plan (CTAMP) would be prepared as part of the CEMP to manage these impacts.
Changes to local roads and active transport pathways may affect pedestrian and cyclist safety.	**Low** Construction and surface road works may require detours by pedestrians and cyclists but these would be temporary.	Alternative safe pedestrian and cyclist access would be provided where it is practical and safe to do so. This would be addressed in the CTAMP.
Subsidence.	**Low** Tunnel induced ground movement that may result in ground settlement is considered to be low along most of the tunnel alignment. In some areas, where shallow tunnelling or multiple tunnels are proposed close to each other, higher levels of settlement are predicted. In these areas, potential settlement impacts require further assessment and potential management.	Further assessment of potential settlement impacts, including modelling would be required during the detailed design. Where ground movement in excess of settlement criteria are predicted a range of design, construction and ground improvement measures (as outlined in Chapter 12 of the EIS) would be considered to reduce impacts. In addition, a range of management measures would be implemented (as detailed in Chapter 12 of the EIS). This includes the preparation and implementation of a Settlement Monitoring Plan, preparation of building condition surveys, repair of cracking or property damage deemed to have occurred from the construction of the project, and preparation of agreements with utility owners and infrastructure owners identifying acceptable levels of settlement, monitoring requirements and measures to be implemented where levels are exceeded.

On the basis of the above there are not considered to be any issues related to construction that have the potential to result in significant safety risks to the public.

11.5 Assessment of potential operational impacts

11.5.1 Air quality

The assessment of impacts on air quality associated with the operation of the project has considered a range of scenarios that include the existing situation and operation for the future years 2023 and 2033; both with and without the project. The operational air quality assessment has focused on the following key pollutants associated with vehicle emissions:

- Volatile organic compounds (VOCs)

- Polycyclic aromatic hydrocarbons (PAH)
- CO
- NO_2
- Particulate matter ($PM_{2.5}$ and PM_{10}).

Assessment of emissions to air from the project has involved the calculation of emissions from vehicles using the tunnel, and other approved WestConnex project tunnels, under expected traffic conditions (ie operating normally with traffic volumes fluctuating over the day with peak and out of peak traffic loads). In addition, a regulatory worst case scenario has been evaluated. The regulatory worst case assumes that the tunnel(s) is full of vehicles, such that the emissions from the ventilation outlets are at the maximum level, at all hours of the day. This is not a realistic scenario however it is used to demonstrate compliance with regulatory assessment requirements. Additional details on the assessment scenarios and the emission sources considered are provided in **Appendix K** (Technical working paper: Human health risk assessment). Assessment of project related air emissions included a calculation of the changes in emissions to air due to the traffic changes across the network resulting from operation of the project (refer to **Chapter 9** (Air quality)).

There are in-tunnel air quality limits and ventilation outlet emission limits that are required to be met under all operational circumstances (except emergencies such as fire). The tunnel ventilation system and tunnel operational parameters are designed to ensure that the in-tunnel concentration limits are not exceeded and to control the concentration of pollutants discharged to the external environment. Additional details on the operational air quality assessment scenarios, locations of air quality monitoring stations and the emission sources and limits considered are provided in **Chapter 9** (Air quality).

Vehicle emissions

Emissions from vehicles using the project tunnels have been estimated based on an emissions inventory model developed by the NSW EPA (as described in **Appendix I** (Technical working paper: Air quality)) which includes projected emissions improvements up to 2033.

Volatile organic compounds and polycyclic aromatic hydrocarbons

VOCs and PAHs are associated with emissions from vehicles using the mainline tunnels and the local surface road network, with levels dependent on the mix of vehicles. Most of the VOC emissions comprise a range of hydrocarbons. From a toxicity perspective, the key VOCs that have been considered for the vehicle emissions are benzene, toluene, ethylbenzene, and xylenes (BTEX), 1,3-butadiene, acetaldehyde and formaldehyde (consistent with those identified and targeted in studies conducted in Australia on vehicle emissions (Australian Government Department of the Environment 2003 and NSW EPA 2012)).

The maximum increase in total VOCs and PAHs in the community is equal to or lower where the project is operating compared with the situation of no project (ie the project results in no change or a lower total impact of VOCs and PAHs in the community).

The change in VOC and PAH concentrations associated with the project is a decrease for most receptors, however in some areas there is an increase in concentrations associated with the redistribution of emissions from vehicles (primarily associated with surface roads). The following evaluation has been undertaken to assess the potential health impacts associated with the maximum increases predicted.

The assessment of potential health impacts associated with exposure to changes in VOCs and PAHs concentrations in air within the community has been assessed on the basis of the following:

- For VOCs and PAHs that are considered to be genotoxic carcinogens (consistent with guidance provided by enHealth (enHealth 2012b)) an incremental lifetime carcinogenic risk has been calculated. For the VOCs and PAHs evaluated in this assessment a carcinogenic risk calculation has been adopted for the assessment of maximum potential (incremental) increase in benzene, 1,3-butadiene and carcinogenic PAHs (as a benzo(a)pyrene toxicity equivalent (TEQ)). The assessment undertaken has adopted the calculation methodology outlined in Annexure B of **Appendix K** (Technical working paper: Human health risk assessment)

- For other VOCs and PAHs, where the health effects are associated with a threshold (ie a level below which there are no effects), the maximum predicted concentration from all sources (ie background plus the project) of individual VOCs and PAHs associated with the project have been compared against published peer-reviewed health based guidelines that are relevant to acute and chronic exposures (where relevant). The health based guidelines adopted (identified on the basis of guidance from enHealth 2012) are relevant to exposures that may occur to all members of the general public (including sensitive individuals) with no adverse health effects. The guidelines available relate to the duration of exposure and the nature of the health effects considered where:
  - Acute guidelines are based on exposures that may occur for a short period of time (typically between one hour, or up to 14 days). These guidelines are available to assess peak exposures (based on the modelled one-hour average concentration) that may be associated with VOCs in the air
  - Chronic guidelines are based on exposures that may occur all day, every day for a lifetime. These guidelines are available to assess long-term exposures (based on the modelled annual average concentration) that may be associated with VOCs and PAHs in the air.

Table 6-4 and Table 6-5 in **Appendix K** (Technical working paper: Human health risk assessment) provide the adopted acute and chronic health based inhalation guideline criteria for the compounds used as part of the assessment.

Table 11-6 to **Table 11-11** present a summary of the maximum predicted one-hour or annual average concentrations of VOCs and PAHs assessed on the basis of a threshold with comparison against acute and chronic health based guidelines. The table also presents a Hazard Index (HI) which is the ratio of the maximum predicted concentration to the guideline.

Each individual HI is added up to obtain a total HI for all the threshold VOCs and PAHs considered. The total HI is a sum of the potential hazards associated with all the threshold VOCs and PAHs together assuming the health effects are additive, and is evaluated as follows:

- A total HI 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 HI greater than one means that the predicted concentrations (for at least one individual compound) are above the health based guidelines, or that there are at least a few individual VOCs or PAHs where the maximum predicted concentrations are close to the health based guidelines such that there is the potential for the presence of all these together (as a sum) to result in adverse health effects.

The assessment of acute exposures, presented in **Table 11-6** and **Table 11-7**, has compared the maximum predicted total (background plus existing roads and the project) one-hour average concentration against the relevant acute guidelines. This is the maximum one-hour average concentration reported anywhere in the study area, regardless of land use.

The assessment of chronic exposures, presented in **Table 11-8** and **Table 11-9**, has compared the maximum predicted total annual average concentration relevant to residential land use against the relevant chronic guidelines. For exposures in other areas, **Table 11-8** and **Table 11-9** also presents the maximum calculated HI relevant to exposures in commercial/industrial areas, where the maximum change in VOC concentrations is predicted. The calculated HI takes into account that these exposures occur for eight hours per day over 240 days per year.

Table 11-10 and **Table 11-11** presents a summary of the calculated incremental lifetime carcinogenic risk associated with exposure to the maximum predicted change in concentrations of benzene, 1,3-butadiene and carcinogenic PAHs (as benzo(a)pyrene TEQ) in residential areas. The calculation presented assumes residents are exposed to these pollutants all day, every day for a lifetime. The calculated carcinogenic risk for these compounds has been summed, in accordance with enHealth guidance.

The tables also present the calculated total carcinogenic risk relevant to exposures in commercial/industrial areas, where the maximum change in VOCs and PAHs is predicted to occur. This calculation assumes workers are exposed eight hours per day, 240 days per year for 30 years. The calculated risks are considered in conjunction with what are considered negligible, tolerable/acceptable and unacceptable risks. Refer to Annexure C of **Appendix K** (Technical working paper: Human health risk assessment) for further information on what constitutes a negligible, tolerable/acceptable or unacceptable risk.

The values presented in the tables have been rounded to two significant figures for individual calculations and one significant figure for the total HI and total carcinogenic risk, reflecting the level of uncertainty in the calculations presented.

Table 11-6 Assessment of acute exposures to VOCs – maximum impacts in community associated with project: 2023

Key VOC	Maximum predicted 1-hour average concentration associated with project (background plus project) and calculated HI					
	2023: Without project		2023: With project		2023: Cumulative	
	Maximum concentration (µg/m³)	HI	Maximum concentration (µg/m³)	HI	Maximum concentration (µg/m³)	HI
Benzene	17.3	0.030	21.3	0.037	16.5	0.028
Toluene	31.8	0.0021	39.3	0.0026	30	0.0020
Xylenes	26.2	0.0035	32.4	0.0044	25	0.034
1,3-Butadiene	4.6	0.0070	5.7	0.0086	4.4	0.0067
Formaldehyde	12.1	0.24	15.0	0.30	11.6	0.23
Acetaldehyde	7.8	0.017	9.6	0.020	7.0	0.015
Total HI		**0.3**		**0.4**		**0.3**

Table 11-7 Assessment of acute exposures to VOCs – maximum impacts in community associated with project: 2033

Key VOC	Maximum predicted 1-hour average concentration associated with project (background plus project) and calculated HI					
	2033: Without project		2033: With project		2033: Cumulative	
	Maximum concentration (µg/m³)	HI	Maximum concentration (µg/m³)	HI	Maximum concentration (µg/m³)	HI
Benzene	9.7	0.017	9.4	0.016	8.3	0.014
Toluene	17.2	0.0011	16.7	0.0011	14.7	0.0010
Xylenes	14.2	0.0019	13.7	0.0019	12.1	0.0016
1,3-Butadiene	2.6	0.0039	2.6	0.0039	2.3	0.0035
Formaldehyde	11.4	0.23	11.0	0.22	9.7	0.19
Acetaldehyde	5.1	0.011	4.9	0.010	4.1	0.0087
Total HI		**0.3**		**0.3**		**0.2**

Table 11-8 Assessment of chronic exposures to VOCs and PAHs – maximum impacts in community associated with project: 2023

Key VOCs and PAHs	Maximum predicted annual average concentration associated with project (background plus project) and calculated HI – Residential Exposures					
	2023: Without project		2023: With project		2023: Cumulative	
	Max concentration (µg/m³)	HI	Max concentration (µg/m³)	HI	Max concentration (µg/m³)	HI
Benzene	2.2	0.075	2.1	0.071	2.2	0.073
Toluene	9.3	0.0019	9.0	0.0018	9.1	0.0018
Xylenes	6.25	0.028	6.0	0.027	6.1	0.028
Formaldehyde	0.53	0.16	0.43	0.13	0.47	0.14
Acetaldehyde	0.238	0.0264	0.28	0.031	0.29	0.032
Naphthalene	0.085	0.028	0.069	0.023	0.076	0.025
Acenaphthylene	0.0059	3.0×10^{-5}	0.0048	2.4×10^{-5}	0.0053	2.7×10^{-5}
Acenaphthene	0.0024	1.2×10^{-5}	0.002	9.9×10^{-6}	0.0022	1.1×10^{-5}
Fluorene	0.0060	4.3×10^{-5}	0.0049	3.5×10^{-5}	0.0054	3.9×10^{-5}

Key VOCs and PAHs	Maximum predicted annual average concentration associated with project (background plus project) and calculated HI – Residential Exposures					
	2023: Without project		2023: With project		2023: Cumulative	
	Max concentration (µg/m^3)	HI	Max concentration (µg/m^3)	HI	Max concentration (µg/m^3)	HI
Phenanthrene	0.0041	2.9 x10^{-5}	0.0034	2.4 x10^{-5}	0.0037	2.6 x10^{-5}
Anthracene	0.00059	5.9 x10^{-7}	0.00048	4.8 x10^{-7}	0.00053	5.3 x10^{-7}
Fluoranthene	0.00054	3.9 x10^{-6}	0.00045	3.2 x10^{-6}	0.00049	3.5 x10^{-6}
Pyrene	0.00086	8.6 x10^{-6}	0.00070	7.0 x10^{-6}	0.00077	7.7 x10^{-6}
Total HI – Residential		**0.2**		**0.2**		**0.2**
Max HI – Commercial/Industrial		**0.06**		**0.06**		**0.06**

Table 11-9 Assessment of chronic exposures to VOCs and PAHs – maximum impacts in community associated with project: 2033

Key VOCs and PAHs	Maximum predicted annual average concentration associated with project (background plus project) and calculated HI – Residential Exposures					
	2033: Without project		2033: With project		2033: Cumulative	
	Max concentration (µg/m^3)	HI	Max concentration (µg/m^3)	HI	Max concentration (µg/^{m3})	HI
Benzene	1.9	0.063	1.85	0.062	1.8	0.061
Toluene	8.6	0.0017	8.52	0.0017	8.5	0.0017
Xylenes	5.67	0.026	5.61	0.026	5.6	0.025
Formaldehyde	0.46	0.14	0.41	0.12	0.41	0.12
Acetaldehyde	0.14	0.016	0.19	0.021	0.17	0.019
Naphthalene	0.085	0.028	0.069	0.023	0.076	0.025
Acenaphthylene	0.0059	3.0 x10^{-5}	0.0048	2.4 x10^{-5}	0.0053	2.7 x10^{-5}
Acenaphthene	0.0024	1.2 x10^{-5}	0.002	9.9 x10^{-6}	0.0022	1.1 x10^{-5}
Fluorene	0.0060	4.3 x10^{-5}	0.0049	3.5 x10^{-5}	0.0054	3.9 x10^{-5}
Phenanthrene	0.0041	2.9 x10^{-5}	0.0034	2.4 x10^{-5}	0.0037	2.6 x10^{-5}
Anthracene	0.00059	5.9 x10^{-7}	0.00048	4.8 x10^{-7}	0.00053	5.3 x10^{-7}
Fluoranthene	0.00054	3.9 x10^{-6}	0.00045	3.2 x10^{-6}	0.00049	3.5 x10^{-6}
Pyrene	0.00086	8.6 x10^{-6}	0.00070	7.0 x10^{-6}	0.00077	7.7 x10^{-6}
Total HI – Residential		**0.2**		**0.2**		**0.2**
Max HI – Commercial/Industrial		**0.05**		**0.05**		**0.05**

Table 11-10 Assessment of incremental lifetime carcinogenic risk – maximum impacts in community associated with project: 2023

Key VOC	Maximum predicted change in annual average concentration associated with project and cancer risk - Residential			
	2023: With project		2023: Cumulative	
	Maximum concentration (µg/m^3)	ILCR	Maximum concentration (µg/m^3)	ILCR
Benzene	0.061	2 x 10^{-7}	0.095	2 x 10^{-7}
1,3-Butadiene	0.016	3 x 10^{-9}	0.025	5 x 10^{-9}
Benzo(a)pyrene TEQ	0.00045	2 x 10^{-5}	0.00070	2 x 10^{-5}
Total carcinogenic risk - residential		**2 x 10^{-5}**		**2 x 10^{-5}**
Maximum carcinogenic risk – commercial/industrial		**6 x 10^{-6}**		**2 x 10^{-5}**

Note:

ILCR = incremental lifetime carcinogenic risk (refer to Annexure B of **Appendix K** (Technical working paper: Human health risk assessment) for calculation methodology and Table 6-5 of **Appendix K** (Technical working paper: Human health risk assessment) for inhalation unit risk values)

Table 11-11 Assessment of incremental lifetime carcinogenic risk – maximum impacts in community associated with project: 2033

Key VOC	Maximum predicted change in annual average concentration associated with project and cancer risk – Residential			
	2023: With project		2023: Cumulative	
	Maximum concentration (μg/m^3)	ILCR	Maximum concentration (μg/m^3)	ILCR
Benzene	0.04	1×10^{-7}	0.054	1×10^{-7}
1,3-Butadiene	0.011	2×10^{-9}	0.014	3×10^{-9}
Benzo(a)pyrene TEQ	0.00034	1×10^{-5}	0.00046	2×10^{-5}
Total carcinogenic risk – residential		**1×10^{-5}**		**2×10^{-5}**
Maximum carcinogenic risk – commercial/industrial		**5×10^{-6}**		**1×10^{-5}**

Note:

ILCR = incremental lifetime carcinogenic risk (refer to Annexure B of **Appendix K** (Technical working paper: Human health risk assessment) for calculation methodology and Table 6-5 of **Appendix K** (Technical working paper: Human health risk assessment) for inhalation unit risk values)

For the assessment of acute exposures to VOCs (**Table 11-6** and **Table 11-7**), the calculated HI associated with exposure to the maximum concentrations predicted is less than one for 2023, 2033 and the cumulative scenario. On this basis, there are no acute risk issues in the local community associated with the project.

For the assessment of chronic exposures to VOCs and PAHs (**Table 11-8** to **Table 11-11**), the calculated HI associated with exposure to the maximum concentrations predicted is less than or equal to one for 2023, 2033 and the cumulative scenario.

The calculated lifetime cancer risks associated with the maximum change in benzene, 1,3-butadiene and carcinogenic PAHs (as benzo(a)pyrene TEQ) are less than or equal to 2×10^{-5} and are considered to be tolerable. The calculations undertaken for PAHs is based on a conservative estimate of the fraction of emissions from vehicles that comprises PAHs (as a percentage of total VOCs). The approach adopted is therefore expected to overestimate concentrations of PAHs in air. Hence, the calculations presented are considered to be a conservative upper limit estimate.

On this basis, there are not considered to be any chronic health risk issues in the local community associated with the operation of project.

Carbon monoxide

Motor vehicles are the dominant source of CO in air (NSW Department of Environment, Climate Change and Water (DECCW) 2009). Adverse health effects of exposure to carbon monoxide are linked with carboxyhaemoglobin (COHb) in blood. In addition, association between exposure to CO and cardiovascular hospital admissions and mortality, especially in the elderly for cardiac failure, myocardial infarction and ischemic heart disease; and some birth outcomes (such as low birth weights), have been identified (NEPC 2010).

Guidelines are available in Australia from NEPC (2003) and NSW EPA that are based on the protection of adverse health effects associated with CO. Review of these guidelines by NEPC (2010) identified additional supporting studies for the evaluation of potential adverse health effects and indicated that these should be considered in the current review of the National Ambient Air Quality NEPM (no interim or finalisation date available). The air guidelines currently available from NEPC are consistent with health based guidelines currently available from the WHO (2005) and the USEPA (2011), specifically listed to be protective of exposures by sensitive populations including asthmatics, children and the elderly). On this basis, the current NEPC guidelines are considered appropriate for the assessment of potential health impacts associated with the project.

The NEPC ambient air quality guideline for the assessment of exposures to carbon monoxide has considered lowest observed adverse effect level (LOAEL) and no observed adverse effect level (NOAEL) associated with a range of health effects in healthy adults, people with ischemic heart disease and foetal effects. In relation to these data, a guideline level of CO of nine parts per million (ppm) by volume (or 10 milligrams per cubic metre (mg/m^3) or 10,000 micrograms per cubic metre (µg/m^3)) over an eight-hour period was considered to provide protection (for both acute and chronic health effects) for most members of the population. An additional 1.5-fold uncertainty factor to protect more susceptible groups in the population was included. On this basis, the NEPC (and the NSW EPA) guideline is protective of adverse health effects in all individuals, including sensitive individuals.

The NSW EPA has also established a guideline for 15 minute average (100 mg/m^3) and one hour average (30 mg/m^3) concentrations of CO in ambient air. These guidelines are based on criteria established by the WHO (WHO 2000a) using the same data used by the NEPC to establish the guideline (above) with extrapolation to different periods of exposure on the basis of known physiological variables that affect CO uptake.

Table 11-12 presents a summary of the maximum predicted cumulative one-hour average and eight-hour average concentrations of CO for the assessment years 2023 and 2033, without the project, with the project and for the cumulative scenario.

Table 11-12 Review of potential acute and chronic health impacts – carbon monoxide

Scenario	Maximum 1-hour average concentration of carbon monoxide (mg/m^3)			Maximum 8-hour average concentration of carbon monoxide (mg/m^3)		
	Without project	With project	Cumulative	Without project	With project	Cumulative
2023						
Maximum	7.8	7.7	7.4	5.4	5.3	5.2
2033						
Maximum	6.4	6.9	6.0	4.4	4.8	4.2
Relevant health based guideline	**30**			**10**		

All the concentrations of CO presented in the above table are below the relevant health based guidelines. On this basis, it is considered that there would be no adverse health effects in relation to exposures (acute and chronic) to CO in the local area surrounding the project.

Nitrogen dioxide

Motor vehicles, along with industrial, commercial and residential (for example gas heating or cooking) combustion sources, are primary producers of nitrogen oxides, including NO_2. In Sydney, it was estimated that on-road vehicles account for about 62 per cent of emissions of nitrogen oxides, industrial facilities account for 12 per cent, other mobile sources account for about 22 per cent with the remainder from domestic/commercial sources (NSW EPA 2012b).

NO_2 is the only oxide of nitrogen that may be of concern to health (WHO 2000b). NO_2 can cause inflammation of the respiratory system and increase susceptibility to respiratory infection. Exposure to elevated levels of NO_2 has also been associated with increased mortality, particularly related to respiratory disease, and with increased hospital admissions for asthma and heart disease patients (WHO 2013a). Asthmatics, the elderly and people with existing cardiovascular and respiratory disease are particularly susceptible to the effects of NO_2. The health effects associated with exposure to NO_2 depend on the duration of exposure as well as the concentration.

Guidelines are available from the NSW EPA and NEPC (NEPC 2003) which indicate acceptable concentrations of NO_2. These guidelines are based on protection from adverse health effects following both short-term (acute) and longer-term (chronic) exposure for all members of the population including sensitive populations like asthmatics, children and the elderly.

Potential health effects associated with NO_2 consider both comparison with guidelines for cumulative exposure (acute and chronic) and an assessment of incremental impacts on health (associated with changes in air quality from the project).

Assessment of acute exposures

The guideline for the assessment of acute (short-term) exposure is 246 µg/m^3 (or 120 parts per billion by volume (ppbv)) and chronic (long-term or lifetime) exposures of 62 µg/m^3 (or 30 ppbv) is protective of adverse health effects in all individuals, including sensitive individuals.

Table 11-13 presents a summary of the maximum predicted cumulative one-hour average concentration of NO_2 for the modelled scenarios.

Table 11-13 Review of potential acute health impacts – NO_2

Location and scenario	Maximum one hour average concentration of NO_2 (µg/m^3)		
	Without the project	With the project	Cumulative
2023			
Maximum	487	516	435
2033			
Maximum	387	430	415
Acute health based guideline	**246**	**246**	**246**

The maximum cumulative concentrations of NO_2 presented in **Table 11-13** exceed the acute NEPC guideline of 246 µg/m^3 for all the scenarios, with and without the project. The elevated levels listed above are not considered to be representative of exposure concentrations that would occur within the study area. This is due to the combined effect of the approach adopted for converting NOx to NO_2 (that overestimates short-term one-hour average concentrations), and the use of a contemporaneous assessment of background and project impacts. The contemporaneous approach assumes that the highest background concentrations may occur during the same hour as the maximum incremental change from the project. This results in a very high estimate of total NO_2 concentrations that is not likely to occur (refer to **Appendix I** (Technical working paper: Air quality) for more detailed discussion). As a result, the magnitude of the maximum total concentrations reported for NO_2over a one-hour average cannot be used to evaluate the potential for adverse health effects in the community.

As assessment of total concentrations of NO_2 cannot be used to determine the potential for adverse health impacts in the community, and because there is no clear threshold established for community exposures to NO_2, the assessment of incremental exposures is of most relevance. This assessment is discussed later in this section.

Assessment of chronic exposures

The NEPC ambient air quality guideline for the assessment of chronic (long-term) exposures to NO_2 relates to the maximum predicted total (cumulative) annual average concentration in air.

The guideline of 62 µg/m^3 (or 30 ppbv) is based on a LOAEL of the order of 40–80 ppbv (around 75–150 µg/m^3) during early and middle childhood years which can lead to the development of recurrent upper and lower respiratory tract symptoms, such as recurrent 'colds', a productive cough and an increased incidence of respiratory infection with resultant absenteeism from school.

An uncertainty factor of two was applied to the LOAEL to account for susceptible people within the population resulting in a guideline of 20–40 ppbv (38–75 µg/m^3) (NEPC 1998). On this basis, the NEPC (and the NSW Office of Environment and Heritage) chronic guideline is protective of adverse health effects in all individuals, including sensitive individuals.

Table 11-14 presents a summary of the maximum predicted cumulative annual average concentration of NO_2 for the modelled scenarios.

Table 11-14 Review of potential chronic health impacts – NO_2

Location and scenario	Maximum annual average concentration of NO_2 ($\mu g/m^3$)		
2023			
Maximum	44.3	43.7	42.9
2033			
Maximum	40.3	37.3	39.1
Chronic health based guideline	**62**		

All the concentrations of NO_2 presented in **Table 11-14** are below the chronic NEPC guideline of 62 $\mu g/m^3$. Therefore, no adverse health effects are expected in relation to chronic exposures to NO_2 in the local area surrounding the project.

Assessment of incremental exposures

Table 11-15 presents a summary of the health endpoints (or outcomes) considered in this assessment, being the β coefficient, or change in exposure relevant to the calculation of a relative risk. 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 relationships have been identified. Refer to Annexure A of **Appendix K** (Technical working paper: Human health risk assessment) for details on the calculation of a β coefficient from published studies).

The coefficients adopted for the assessment of impacts on mortality and asthma emergency department admissions are derived from the detailed assessment undertaken for the current review of health impacts of air pollution undertaken by NEPC (Golder 2013) and are considered to be robust.

Table 11-15 Adopted exposure-responses relationships for assessment of changes in NO_2 concentrations

Health endpoint	Exposure period	Age group	Adopted β coefficient (also as per cent) for 1 $\mu g/m^3$ increase in NO_2	Reference
Mortality, all causes (non-trauma)	Short-term	30+	0.00188 (0.19%)	Relationship derived from modelling undertaken for five cities in Australia and one day lag (EPHC 2010; Golder 2013)
Mortality, respiratory	Short-term	All ages*	0.00426 (0.43%)	Relationship derived from modelling undertaken for five cities in Australia and one day lag (EPHC 2010; Golder 2013)
Asthma emergency department admissions	Short-term	1–14 years	0.00115 (0.11%)	Relationship established from review conducted on Australian children (Sydney) for the period 1997 to 2001 (Golder 2013; Jalaludin et al. 2008)

Notes:

* Relationships established for all ages, including young children and the elderly.

β = regression/slope coefficient, or the slope of the exposure-response function which can also be expressed as the per cent change in response per one µg/m3 increase in particulate matter exposure.

While the maximum concentrations of NO_2 are lower in the local community with the operation of the project, the concentrations at individual receptors vary. While the concentrations at most receptors decrease with the operation of the project, there are some receptors where there is an increase, associated with the redistribution of emissions from vehicles using surface roads.

Table 11-16 presents the change in individual risk associated with changes in NO_2 at the maximum impacted receptors relevant to the various land uses in the community, as well as the community receptors, for the operational years 2023 and 2033, including the cumulative scenario (refer to **Appendix K** (Technical working paper: Human health risk assessment) for the methodology on the calculation of individual risks). The assessment assumes an individual is exposed at each maximum impacted location over all hours of the day, regardless of the land use. This has been undertaken to address any future changes in land use that may occur during redevelopment. Risks for all other receptors (including other sensitive receivers) are lower than the maximums presented.

All risks are presented to one significant figure, reflecting the level of uncertainty associated with the calculations presented. A summary of the calculated change in individual risk associated with changes in NO_2 concentrations at each community receptor location evaluated is presented in Figure 6-4 of **Appendix K** (Technical working paper: Human health risk assessment).

Table 11-16 Maximum calculated risks associated with short-term exposure to changes in NO_2 concentrations with operation of the project

Scenario and receptor	Maximum change in individual risk from short term exposure to nitrogen dioxide for the following health endpoints		
	Mortality: All causes (ages 30+)	**Mortality: Respiratory (all ages)**	**Asthma ED Admissions (1–14 years)**
2023 – with project			
Maximum residential	5×10^{-5}	6×10^{-6}	4×10^{-5}
Maximum workplace	1×10^{-4}	1×10^{-5}	8×10^{-5}
Maximum childcare and schools	3×10^{-5}	4×10^{-6}	2×10^{-5}
Maximum aged care	4×10^{-6}	5×10^{-7}	3×10^{-6}
Maximum hospitals/medical	3×10^{-5}	3×10^{-6}	2×10^{-5}
Maximum open space	5×10^{-5}	6×10^{-6}	4×10^{-5}
Maximum from sensitive receptors	3×10^{-5}	3×10^{-6}	2×10^{-5}
2023 – cumulative			
Maximum residential	5×10^{-5}	6×10^{-6}	4×10^{-5}
Maximum workplace	2×10^{-4}	2×10^{-5}	1×10^{-4}
Maximum childcare and schools	1×10^{-5}	2×10^{-6}	1×10^{-5}
Maximum aged care	2×10^{-6}	2×10^{-7}	2×10^{-6}
Maximum hospitals/medical	8×10^{-6}	1×10^{-6}	6×10^{-6}
Maximum open space	2×10^{-5}	2×10^{-6}	1×10^{-5}
Maximum from sensitive receptors	1×10^{-5}	1×10^{-6}	9×10^{-6}
2033 – with project			
Maximum residential	6×10^{-5}	7×10^{-6}	5×10^{-5}
Maximum workplace	1×10^{-4}	1×10^{-5}	9×10^{-5}
Maximum childcare and schools	4×10^{-5}	5×10^{-6}	3×10^{-5}
Maximum aged care	7×10^{-6}	8×10^{-7}	5×10^{-6}
Maximum hospitals/medical	4×10^{-5}	4×10^{-6}	3×10^{-5}
Maximum open space	6×10^{-5}	6×10^{-6}	4×10^{-5}
Maximum from sensitive receptors	4×10^{-5}	3×10^{-6}	2×10^{-5}
2033 – cumulative			
Maximum residential	4×10^{-5}	5×10^{-6}	3×10^{-5}
Maximum workplace	2×10^{-4}	2×10^{-5}	1×10^{-4}
Maximum childcare	2×10^{-5}	2×10^{-6}	1×10^{-5}
Maximum aged care	7×10^{-6}	8×10^{-7}	5×10^{-6}
Maximum hospitals/medical	1×10^{-5}	1×10^{-6}	1×10^{-5}
Maximum open space	3×10^{-5}	3×10^{-6}	2×10^{-5}
Maximum from sensitive receptors	7×10^{-6}	8×10^{-7}	5×10^{-6}

Scenario and receptor	Maximum change in individual risk from short term exposure to nitrogen dioxide for the following health endpoints
Negligible risks	**<1 x 10^{-6}**
Tolerable/acceptable risks	**≥1 x 10^{-6} and ≤1 x 10^{-4}**
Unacceptable risks	**>1 x 10^{-4}**

Note:

Shaded cell (purple) exceeds the criteria adopted for acceptable risks, refer to the discussion below

Table 11-17 presents a summary of the calculated change in incidence of the relevant health effects for the population living in the LGAs within the study area, associated with changes in $PM_{2.5}$ concentrations for 2023 and 2033. All calculations relevant to the LGAs, including calculation for each individual suburb considered in the LGAs, are presented in **Appendix K** (Technical working paper: Human health risk assessment).

Table 11-17 Calculated changes in incidence of health effects in population associated with changes in NO_2 concentrations

LGA	Change in population incidence – number of cases					
	2023			2033		
	Mortality – all causes	Mortality – respiratory	Morbidity – asthma ED admissions	Mortality – all causes	Mortality – respiratory	Morbidity – asthma ED admissions
	≥30 years	All ages	1–14 years	≥30 years	All ages	1–14 years
With project						
Canada Bay	-0.024	-0.0044	-0.0045	-0.041	-0.0074	-0.0076
Strathfield*	0.0030	0.00058	0.00055	0.018	0.0034	0.0032
Burwood	-0.016	-0.0031	-0.0029	-0.019	-0.0036	-0.0034
Sydney Inner West	-1.2	-0.20	-0.19	-1.1	-0.19	-0.18
Sydney	-0.35	-0.067	-0.027	-0.15	-0.028	-0.012
Botany	0.15	0.027	0.030	0.21	0.038	0.043
Rockdale	-0.18	-0.034	-0.036	-0.21	-0.039	-0.041
Canterbury-Bankstown	-0.13	-0.026	-0.033	-0.13	-0.025	-0.032
Georges River	-0.098	-0.018	-0.020	-0.12	-0.022	-0.0236
Total for all LGAs	**-2**	**-0.3**	**-0.3**	**-2**	**-0.3**	**-0.3**
Cumulative						
Canada Bay	0.011	0.0020	0.0021	-0.020	-0.0035	-0.0036
Strathfield*	-0.032	-0.0062	-0.0058	-0.019	-0.0037	-0.0035
Burwood	-0.025	-0.0047	-0.0045	-0.023	-0.0045	-0.0042
Sydney Inner West	-1.2	-0.20	-0.20	-1.2	-0.20	-0.19
Sydney	-0.60	-0.12	-0.048	-0.70	-0.14	-0.056
Botany	-0.053	-0.0099	-0.011	-0.022	-0.0041	-0.0046
Rockdale	-0.26	-0.048	-0.051	-0.36	-0.067	-0.071
Canterbury-Bankstown	-0.19	-0.038	-0.048	-0.20	-0.039	-0.050
Georges	-0.14	-0.026	-0.029	-0.15	-0.028	-0.031

LGA	Change in population incidence – number of cases 2023			2033		
	Mortality – all causes	Mortality – respiratory	Morbidity – asthma ED admissions	Mortality – all causes	Mortality – respiratory	Morbidity – asthma ED admissions
	≥30 years	All ages	1–14 years	≥30 years	All ages	1–14 years
River						
Total for all LGAs	**-2**	**-0.5**	**-0.4**	**-3**	**-0.5**	**-0.4**

Notes:

* Includes suburbs in Auburn LGA

ED = emergency department

Negative value indicates that there is a decrease in incidence associated with the project.

Review of the calculated impacts in terms of the change in incidence of the relevant health effects associated with exposure to nitrogen dioxide in the community indicates that the total change in the number of cases relevant to the health effects evaluated, for both 2023 and 2033 is negative, meaning a decrease in incidence as a result of the project. The number of cases is small (a decrease of up to three cases). Therefore the changes are unlikely to be measurable within the community.

Most individual LGAs show a total decrease in health incidence. There are a few LGAs where there is an increase. These increases and decreases are also small, less than two (as a decrease) in individual LGAs for all health effects considered. As a result, these changes are unlikely to be measurable in the community.

The incidence calculations presented in **Table 11-17** are the totals for each LGA. Within these LGAs are a number of smaller suburbs. Review of the incidence calculated for the individual suburbs indicates that these predominantly relate to small decreases in health incidence with some suburbs showing an increase. The largest increase in health incidence for any individual suburb is less than 0.25 cases. Hence there are no individual suburbs within the LGAs where there is a change incidence that is of significance or would be measurable.

Particulate matter

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

Secondary particulate matter is 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).

Particulate matter has been linked to adverse health effects after both short-term exposure (days to weeks) and long-term exposure (months to years). The health effects associated with exposure to particulate matter vary widely (with the respiratory and cardiovascular systems most affected) and include mortality and morbidity effects. The potential for particulate matter to result in adverse health effects is dependent on the size and composition of the particulate matter.

The particle size addressed in the human health risk assessment relate to the particulates most commonly measured in the urban air environment studies, including:

- PM_{10} (particulate matter below 10 micrometres in diameter)
- $PM_{2.5}$ (particulate matter below 2.5 micrometres in diameter).

The current NEPC and NSW EPA air quality goals and criteria for particulate matter are presented in **Table 11-18**.

Table 11-18 Air quality standards for particulate matter

Pollutant	Averaging period	Criteria (µg/m^3)	Reference
PM_{10}	24-hour	50	(NEPC 2016) (NSW EPA 2016)
	Annual	25	(NSW EPA 2016)
$PM_{2.5}$	24-hour	25 with goal of 20 by 2025	(NEPC 2016) (NSW EPA 2016)
	Annual	8 with goal of 7 by 2025	

Table 11-19 and **Table 11-20** present a summary of the maximum total 24-hour average and annual average concentrations of $PM_{2.5}$ and PM_{10} relevant to the assessment of emissions in 2023 and 2033, for the project and for the cumulative case.

Table 11-19 Review of total particulate matter concentrations – 24-hour average

Location and scenario	Maximum 24-hour average $PM_{2.5}$ concentration (µg/m^3)			Maximum 24-hour average PM_{10} concentration (µg/m^3)		
	Without project	With project	Cumulative	Without project	With project	Cumulative
2023						
Maximum	50.2	48.4	47.1	81.0	82.1	80.9
Maximum residential	40.7	40.9	41.7	70.8	70.9	70.7
Maximum commercial	50.2	44.8	46.4	81.0	80.1	80.7
2033						
Maximum	50.7	48.5	48.5	81.3	86.7	81.8
Maximum residential	40.6	39.5	39.3	70.9	70.9	74.4
Maximum commercial	45.9	43.6	48.5	80.1	77.0	81.8
Guideline	**25** **20 by 2025 (goal)**			**50**		

Table 11-20 Review of total particulate matter concentrations – annual average

Location and scenario	Maximum annual average $PM_{2.5}$ concentration (µg/m^3)			Maximum annual average PM_{10} concentration (µg/m^3)		
	Without project	With project	Cumulative	Without project	With project	Cumulative
2023						
Maximum	13.2	14.1	13.6	25.1	26.5	25.9
Maximum residential	11.8	12.3	12.1	22.8	23.7	23.2
Maximum commercial	12.7	12.7	12.6	24.1	23.8	23.7
2033						
Maximum	13.2	14.2	13.5	25.3	26.1	25.8
Maximum residential	11.7	12.3	12	22.6	23.7	23.0
Maximum commercial	12.5	12.1	12.3	23.6	23.4	23.4
Guideline	**8** **7 by 2025 (goal)**			**25**		

The maximum total/cumulative concentrations of $PM_{2.5}$ are above the guidelines for both a 24-hour average and an annual average (including the 2025 goal). This is due to the existing levels of $PM_{2.5}$ in air within the current urban environment. These elevated background levels would be present in the community regardless of the construction and operation of the project. Concentrations of total $PM_{2.5}$, however, are essentially unchanged within the local community with the operation of the project.

The maximum cumulative concentrations of PM_{10} presented in the above tables are above the 24-hour average and annual average guidelines. The maximum concentrations in residential and commercial/industrial (workplace) areas are below the annual average guideline. The elevated levels of total PM_{10} are due to the existing levels of PM_{10} in air within the current urban environment. These elevated background levels would be present in the community regardless of the construction and operation of the project. Concentrations of total PM_{10} are essentially unchanged within the local community with the construction and operation of the project.

The assessment of changes in incidence of particular health indicators in the community results in the calculation of a change in the number of cases (of mortality, hospital or emergency department admissions) within the population evaluated.

Where the number of cases (mortality or hospitalisations) associated with changes in air quality are well below 10 cases per year, they are considered to be within the normal variability of health statistics, and these changes would not be measurable in any health statistics for the area. For evaluating impacts from the project, a more conservative ten-fold margin of safety was included to determine what changes in incidence may be considered negligible within the study population. This means that changes in the population incidence of any evaluated health effect that are less than one case per year are considered negligible.

Table 11-21 and **Table 11-22** present the calculated individual risk associated with changes in $PM_{2.5}$ and PM_{10} concentrations at the maximum impacted residential, child care, schools, aged care, hospital, commercial/industrial and open space areas as well as the minimum impacted community receptor, for the operational years 2023 and 2033. The change in $PM_{2.5}$ and PM_{10} concentration considered in the risk calculations are also included in the tables.

The calculated change in risk at the maximum receptors represents the worst-case impact associated with the project. Risks for all other receptors would be lower than calculated for the maximum receptors. All calculated individual risks are presented in **Appendix K** (Technical working paper: Human health risk assessment).

Table 11-23 and **Table 11-24** present a summary of the calculated change in incidence of the relevant health effects for the population living in the LGAs within the study area, associated with changes in $PM_{2.5}$ concentrations for 2023 and 2033. All calculations relevant to the LGAs, including calculation for each individual suburb considered in the LGAs, are presented in **Appendix K** (Technical working paper: Human health risk assessment).

Table 11-21 Calculated individual risk associated with changes in $PM_{2.5}$ and PM_{10} concentrations – project operations in 2023

Receptor	Change in annual average concentration (µg/m³)		Calculated risks for health endpoints									
			$PM_{2.5}$: Mortality, all causes	$PM_{2.5}$: Cardiovascular hospitalisations	$PM_{2.5}$: Respiratory hospitalisations	PM_{10}: Mortality, all causes	$PM_{2.5}$: Mortality, all causes	$PM_{2.5}$: Mortality, cardiopulmonary	$PM_{2.5}$: Mortality, cardiovascular	$PM_{2.5}$: Mortality, respiratory	$PM_{2.5}$: Asthma emergency department hospitalisations	DPM Lung cancer
	PM_{10}	$PM_{2.5}$	LT	ST	ST	ST	ST	LT	ST	ST	ST	LT
			≥30 yrs	≥65 yrs	≥65 yrs	all	all	≥30 yrs	all	all	1–14 yrs	all
2023 with project												
Maximum residential	0.85	0.51	3×10^{-5}	4×10^{-5}	8×10^{-6}	3×10^{-6}	2×10^{-6}	3×10^{-5}	7×10^{-7}	5×10^{-7}	9×10^{-6}	2×10^{-5}
Maximum childcare	0.33	0.43	3×10^{-5}	3×10^{-5}	7×10^{-6}	1×10^{-6}	2×10^{-6}	2×10^{-5}	6×10^{-7}	4×10^{-7}	8×10^{-6}	1×10^{-5}
Maximum schools	0.29	0.12	7×10^{-6}	9×10^{-6}	2×10^{-6}	9×10^{-7}	6×10^{-7}	6×10^{-6}	2×10^{-7}	1×10^{-7}	2×10^{-6}	4×10^{-6}
Maximum aged care	0.06	0.06	4×10^{-6}	4×10^{-6}	1×10^{-6}	2×10^{-7}	3×10^{-7}	3×10^{-6}	8×10^{-8}	6×10^{-8}	1×10^{-6}	2×10^{-6}
Maximum hospital	0.69	0.20	1×10^{-5}	1×10^{-5}	3×10^{-6}	2×10^{-6}	9×10^{-7}	1×10^{-5}	3×10^{-7}	2×10^{-7}	4×10^{-6}	7×10^{-6}
Maximum commercial/ industrial	1.70	1.16	7×10^{-5}	9×10^{-5}	2×10^{-5}	5×10^{-6}	5×10^{-6}	6×10^{-5}	2×10^{-6}	1×10^{-6}	2×10^{-5}	4×10^{-5}
Maximum open space	1.24	0.78	5×10^{-5}	6×10^{-5}	1×10^{-5}	4×10^{-6}	4×10^{-6}	4×10^{-5}	1×10^{-6}	7×10^{-7}	1×10^{-5}	3×10^{-5}
Maximum community receptors	0.19	0.15	2×10^{-5}	3×10^{-5}	6×10^{-6}	1×10^{-6}	2×10^{-6}	2×10^{-5}	5×10^{-7}	3×10^{-7}	6×10^{-6}	1×10^{-5}
2023 cumulative												
Maximum residential	1.60	0.62	4×10^{-5}	5×10^{-5}	1×10^{-5}	3×10^{-6}	3×10^{-6}	3×10^{-5}	8×10^{-7}	6×10^{-7}	1×10^{-5}	2×10^{-5}
Maximum childcare	0.36	0.26	2×10^{-5}	2×10^{-5}	4×10^{-6}	1×10^{-6}	1×10^{-6}	1×10^{-5}	3×10^{-7}	2×10^{-7}	5×10^{-6}	9×10^{-6}
Maximum schools	0.26	0.15	9×10^{-6}	1×10^{-5}	2×10^{-6}	8×10^{-7}	7×10^{-7}	8×10^{-6}	2×10^{-7}	1×10^{-7}	3×10^{-6}	5×10^{-6}
Maximum aged care	0.10	0.08	5×10^{-6}	6×10^{-6}	1×10^{-6}	3×10^{-7}	4×10^{-7}	4×10^{-6}	1×10^{-7}	8×10^{-8}	1×10^{-6}	3×10^{-6}
Maximum hospital	0.23	0.12	7×10^{-6}	9×10^{-6}	2×10^{-6}	7×10^{-7}	6×10^{-7}	6×10^{-6}	2×10^{-7}	1×10^{-7}	2×10^{-6}	4×10^{-6}
Maximum commercial/ industrial	3.36	2.25	1×10^{-4}	2×10^{-4}	4×10^{-5}	1×10^{-5}	1×10^{-5}	1×10^{-4}	3×10^{-6}	2×10^{-6}	4×10^{-5}	8×10^{-5}
Maximum open space	1.05	0.54	3×10^{-5}	4×10^{-5}	9×10^{-6}	3×10^{-6}	3×10^{-6}	3×10^{-5}	7×10^{-7}	5×10^{-7}	1×10^{-5}	2×10^{-5}
Maximum community receptors	0.14	0.18	1×10^{-5}	1×10^{-5}	3×10^{-6}	7×10^{-7}	9×10^{-7}	1×10^{-5}	3×10^{-7}	2×10^{-7}	3×10^{-6}	7×10^{-6}
Negligible risks			**$<1 \times 10^{-6}$**									
Tolerable/acceptable risks			**$\geq 1 \times 10^{-6}$ and $\leq 1 \times 10^{-4}$**									
Unacceptable risks			**$>1 \times 10^{-4}$**									

Notes: DPM = diesel particulate matter; LT = long term; ST = short term. Shaded cell exceeds the criteria adopted for acceptable risks, refer to the discussion below.

Table 11-22 Calculated individual risk associated with changes in $PM_{2.5}$ and PM_{10} concentrations – project operations in 2033

Receptor	Change in annual average concentration (µg/m³)		Calculated risks for health endpoints									
			$PM_{2.5}$: Mortality, all causes	$PM_{2.5}$: Cardiovascular hospitalisations	$PM_{2.5}$: Respiratory hospitalisations	PM_{10}: Mortality, all causes	$PM_{2.5}$: Mortality, all causes	$PM_{2.5}$: Mortality, cardiopulmonary	$PM_{2.5}$: Mortality, cardiovascular	$PM_{2.5}$: Mortality, respiratory	$PM_{2.5}$: Asthma emergency department hospitalisations	DPM Lung cancer
	PM_{10}	$PM_{2.5}$	LT	ST	ST	ST	ST	LT	ST	ST	ST	LT
			≥30 yrs	≥65 yrs	≥65 yrs	all	all	≥30 yrs	all	all	1–14 yrs	all
2033 with project												
Maximum residential	1.12	0.56	3×10^{-5}	4×10^{-5}	9×10^{-6}	3×10^{-6}	3×10^{-6}	3×10^{-5}	7×10^{-7}	5×10^{-7}	1×10^{-5}	2×10^{-5}
Maximum childcare	0.67	0.39	2×10^{-5}	3×10^{-5}	6×10^{-6}	2×10^{-6}	2×10^{-6}	2×10^{-5}	5×10^{-7}	4×10^{-7}	7×10^{-6}	1×10^{-5}
Maximum schools	0.37	0.15	9×10^{-6}	1×10^{-5}	2×10^{-6}	1×10^{-6}	7×10^{-7}	8×10^{-6}	2×10^{-7}	1×10^{-7}	3×10^{-6}	5×10^{-6}
Maximum aged care	0.11	0.11	7×10^{-6}	8×10^{-6}	2×10^{-6}	3×10^{-7}	5×10^{-7}	6×10^{-6}	1×10^{-7}	1×10^{-7}	2×10^{-6}	4×10^{-6}
Maximum hospital	0.42	0.33	2×10^{-5}	2×10^{-5}	5×10^{-6}	1×10^{-6}	2×10^{-6}	2×10^{-5}	4×10^{-7}	3×10^{-7}	6×10^{-6}	1×10^{-5}
Maximum commercial/ industrial	1.94	1.43	9×10^{-5}	1×10^{-4}	2×10^{-5}	6×10^{-6}	7×10^{-6}	8×10^{-5}	2×10^{-6}	1×10^{-6}	3×10^{-5}	5×10^{-5}
Maximum open space	1.40	0.83	5×10^{-5}	6×10^{-5}	1×10^{-5}	4×10^{-6}	4×10^{-6}	4×10^{-5}	1×10^{-6}	8×10^{-7}	1×10^{-5}	3×10^{-5}
Maximum community receptors	0.23	0.14	3×10^{-5}	4×10^{-5}	9×10^{-6}	2×10^{-6}	3×10^{-6}	3×10^{-5}	7×10^{-7}	5×10^{-7}	1×10^{-5}	1×10^{-5}
2033 cumulative												
Maximum residential	1.26	0.55	3×10^{-5}	4×10^{-5}	9×10^{-6}	3×10^{-6}	3×10^{-6}	3×10^{-5}	7×10^{-7}	5×10^{-7}	1×10^{-5}	2×10^{-5}
Maximum childcare	0.22	0.20	1×10^{-5}	1×10^{-5}	3×10^{-6}	7×10^{-7}	9×10^{-7}	1×10^{-5}	3×10^{-7}	2×10^{-7}	4×10^{-6}	7×10^{-6}
Maximum schools	0.29	0.19	1×10^{-5}	1×10^{-5}	3×10^{-6}	9×10^{-7}	9×10^{-7}	1×10^{-5}	2×10^{-7}	2×10^{-7}	3×10^{-6}	6×10^{-6}
Maximum aged care	0.16	0.06	4×10^{-6}	4×10^{-6}	1×10^{-6}	5×10^{-7}	3×10^{-7}	3×10^{-6}	8×10^{-8}	6×10^{-8}	1×10^{-6}	2×10^{-6}
Maximum hospital	0.52	0.31	2×10^{-5}	2×10^{-5}	5×10^{-6}	2×10^{-6}	1×10^{-6}	2×10^{-5}	4×10^{-7}	3×10^{-7}	6×10^{-6}	1×10^{-5}
Maximum commercial/ industrial	3.74	2.33	1×10^{-4}	2×10^{-4}	4×10^{-5}	1×10^{-5}	1×10^{-5}	1×10^{-4}	3×10^{-6}	2×10^{-6}	4×10^{-5}	8×10^{-5}
Maximum open space	0.92	0.56	3×10^{-5}	4×10^{-5}	9×10^{-6}	3×10^{-6}	3×10^{-6}	3×10^{-5}	7×10^{-7}	5×10^{-7}	1×10^{-5}	2×10^{-5}
Maximum community receptors	0.28	0.15	1×10^{-5}	1×10^{-5}	3×10^{-6}	1×10^{-6}	8×10^{-7}	1×10^{-5}	2×10^{-7}	2×10^{-7}	3×10^{-6}	6×10^{-6}
Negligible risks			**$<1 \times 10^{-6}$**									
Tolerable/acceptable risks			**$\geq 1 \times 10^{-6}$ and $\leq 1 \times 10^{-4}$**									
Unacceptable risks			**$>1 \times 10^{-4}$**									

Notes: DPM = diesel particulate matter; LT = long term; ST = short term. Shaded cell exceeds the criteria adopted for acceptable risks, refer to discussion below.

Table 11-23 Calculated changes in incidence of health effects in population associated with changes in $PM_{2.5}$ concentrations – project in 2023

LGA/ Local statistical areas	Change in population incidence – number of cases							
	Primary indicators			Secondary indicators				
	Mortality – all causes	Hospitalisations – cardiovascular	Hospitalisations – respiratory	Mortality – all causes	Mortality – cardiopulmonary	Mortality – cardiovascular	Mortality – respiratory	Morbidity – asthma ED admissions
	≥30 years	≥65 years	≥65 years	All ages	≥30 years	All ages	All ages	1–14 years
With Project								
Canada Bay	-0.000007	-0.0000020	-0.00000045	-0.00000075	-0.0000067	-0.00000022	-0.00000018	-0.00000055
Strathfield*	-0.0012	-0.00032	-0.000070	-0.00014	-0.0010	-0.000043	-0.000031	-0.000083
Burwood	-0.0018	-0.00048	-0.00011	-0.00026	-0.0016	-0.000066	-0.000046	-0.00013
Sydney Inner West	-0.38	-0.072	-0.016	-0.048	-0.34	-0.014	-0.0090	-0.026
Sydney	-0.0045	-0.00074	-0.00016	-0.00061	-0.0041	-0.00017	-0.00012	-0.00014
Botany	0.072	0.021	0.0046	0.0097	0.065	0.0029	0.0019	0.0059
Rockdale	-0.063	-0.019	-0.0041	-0.0086	-0.057	-0.0025	-0.0016	-0.0049
Canterbury-Bankstown	-0.041	-0.011	-0.0025	-0.0055	-0.037	-0.0016	-0.0011	-0.0041
Georges River	-0.015	-0.0046	-0.0010	-0.0018	-0.013	-0.00051	-0.00038	-0.0012
Total for all LGAs	**-0.4**	**-0.09**	**-0.02**	**-0.06**	**-0.4**	**-0.02**	**-0.01**	**-0.03**
Cumulative								
Canada Bay	0.030	0.0081	0.0018	0.0030	0.027	0.00086	0.00074	0.0022
Strathfield*	-0.0036	-0.0010	-0.00022	-0.00042	-0.0032	-0.00013	-0.00010	-0.00026
Burwood	-0.0013	-0.00036	-0.000079	-0.00019	-0.0012	-0.000050	-0.000035	-0.000095
Sydney Inner West	-0.32	-0.061	-0.013	-0.040	-0.29	-0.011	-0.0075	-0.021
Sydney	-0.044	-0.0073	-0.0016	-0.0060	-0.040	-0.0017	-0.0012	-0.0014
Botany	-0.015	-0.0044	-0.0010	-0.0021	-0.014	-0.00061	-0.00039	-0.0013
Rockdale	-0.071	-0.021	-0.0047	-0.0097	-0.064	-0.0028	-0.0018	-0.0055
Canterbury-Bankstown	-0.054	-0.015	-0.0033	-0.0072	-0.049	-0.0021	-0.0015	-0.0054
Georges River	-0.026	-0.0081	-0.0018	-0.0031	-0.023	-0.00090	-0.00067	-0.0021
Total for all LGAs	**-0.5**	**-0.1**	**-0.02**	**-0.07**	**-0.5**	**-0.02**	**-0.01**	**-0.04**

Notes:

* Includes suburbs in Auburn LGA.

ED = emergency department

Negative value indicates that there is a decrease in incidence associated with the project.

Table 11-24 Calculated changes in incidence of health effects in population associated with changes in $PM_{2.5}$ concentrations– project in 2033

LGA/Local statistical areas	Change in population incidence – number of cases							
	Primary Indicators			Secondary Indicators				
	Mortality – all causes	Hospitalisations – cardiovascular	Hospitalisations – respiratory	Mortality – all causes	Mortality – cardiopulmonary	Mortality – cardiovascular	Mortality – respiratory	Morbidity – asthma ED admissions
	≥30 years	≥65 years	≥65 years	All ages	≥30 years	All ages	All ages	1–14 years
With Project								
Canada Bay	0.0016	0.00043	0.000094	0.00016	0.0014	0.000046	0.000039	0.00011
Strathfield*	-0.0022	-0.00061	-0.00013	-0.00026	-0.0020	-0.000082	-0.000059	-0.00016
Burwood	-0.00094	-0.00026	-0.000056	-0.00014	-0.00085	-0.000035	-0.000025	-0.000068
Sydney Inner West	-0.34	-0.064	-0.014	-0.043	-0.31	-0.012	-0.0080	-0.023
Sydney	0.021	0.0034	0.00075	0.0028	0.019	0.00080	0.00055	0.00066
Botany	0.084	0.024	0.0054	0.011	0.076	0.0033	0.0022	0.0069
Rockdale	-0.070	-0.021	-0.0046	-0.0095	-0.063	-0.0028	-0.0018	-0.0054
Canterbury-Bankstown	-0.033	-0.0092	-0.0020	-0.0044	-0.030	-0.0013	-0.00090	-0.0033
Georges River	-0.023	-0.0073	-0.0016	-0.0028	-0.021	-0.00082	-0.00060	-0.0019
Total for all LGAs	**-0.4**	**-0.07**	**-0.02**	**-0.05**	**-0.3**	**-0.01**	**-0.009**	**-0.03**
Cumulative								
Canada Bay	0.033	0.0090	0.0020	0.0033	0.030	0.0010	0.00082	0.0024
Strathfield*	-0.00063	-0.00017	-0.000038	-0.000073	-0.00056	-0.000023	-0.000017	-0.000045
Burwood	0.0067	0.0018	0.00040	0.0010	0.0060	0.00025	0.00018	0.00048
Sydney Inner West	-0.24	-0.045	-0.0099	-0.030	-0.21	-0.0085	-0.0056	-0.016
Sydney	-0.042	-0.0068	-0.0015	-0.0056	-0.037	-0.0016	-0.0011	-0.0013
Botany	-0.012	-0.0034	-0.00076	-0.0016	-0.011	-0.00047	-0.00030	-0.0010
Rockdale	-0.080	-0.024	-0.0053	-0.011	-0.072	-0.0032	-0.0021	-0.0063
Canterbury-Bankstown	-0.059	-0.016	-0.0036	-0.0078	-0.053	-0.0023	-0.0016	-0.0058
Georges River	-0.014	-0.0045	-0.0010	-0.0017	-0.013	-0.00050	-0.00037	-0.0012
Total for all LGAs	**-0.4**	**-0.09**	**-0.02**	**-0.05**	**-0.4**	**-0.02**	**-0.01**	**-0.03**

Notes:

* Includes suburbs in Auburn LGA.

ED = emergency department

Negative value indicates that there is a decrease in incidence associated with the project.

Review of the calculated changes in risk indicates the following in relation to impacts associated with the expected operation of the project in 2023 and 2033:

- A number of the calculated individual risks for the community receptors are negative, meaning that the operation of the project would result in lower levels of risk, when compared with the situation where the project is not operating
- The maximum risks calculated for exposures in residential areas are less than $1x10^{-4}$ and considered to be tolerable/acceptable
- The maximum risks calculated for exposures in commercial/industrial areas are between $8x10^{-7}$ and $2x10^{-4}$. The maximum risk level of $2x10^{-4}$ exceeds the adopted criteria for determining unacceptable risks. Impacts that result in exceedance of the adopted risk criteria occur only in the existing industrial location north and northwest of Sydney Airport, between Airport Drive, Alexandria Canal and the Princes Highway. The calculation presented relates to exposures that occur at this location for all hours of the day, all of the time. As this area is a workplace, not somewhere people live, the calculated risk is expected to overestimate risks by a factor of about 4.5, hence actual risks in theses industrial areas are expected to be lower and tolerable. Given the proximity of these areas to Sydney Airport (runways and flight paths) it is considered unlikely that they would be rezoned for residential use, hence it is not relevant to evaluate future residential exposures at this location. In addition, the calculated risks relate to predicted increases in $PM_{2.5}$, principally related to the Sydney Gateway project. Surface road emissions related to the Sydney Gateway project have been estimated on the basis of provisional information in relation to roadway layout only. The maximum impacts predicted are on roadways/locations that may be within the future roadway alignments. The Sydney Gateway project would be subject to separate environmental assessment and approval, at which time a more detailed assessment of impacts in this area would be undertaken
- The worst case scenario for potential exposure is where a resident works at the maximum impacted workplace and lives at the maximum impacted residential location. Where this may occur, the maximum risk is just less than $1x10^{-4}$, which is considered tolerable/acceptable
- All maximum risks calculated for continuous exposures in child care centres, schools, aged care homes and open space areas are below $1x10^{-4}$ and considered to be tolerable/acceptable
- In relation to impacts on the health of the population in the local community, the calculated change in incidence of the health indicators evaluated shows that the increased incidence of the evaluated health effects occurring in the population in the study area ranges from 0.007 to 0.2 cases per year, which would not be measurable and is considered to be negligible.

Review of the calculated impacts in terms of the change in incidence of the relevant health effects for $PM_{2.5}$ in the community, indicates the following:

- The total change in the number of cases relevant to the health effects evaluated, for both 2023 and 2033 is negative, meaning a decrease in incidence as a result of the project. However, the number of cases is very small, being less than one for all health effects considered. As a result, these changes would not be measurable within the community
- Most individual LGAs show a total decrease in health incidence. There are a few LGAs where there is an increase. These increases and decreases are also very small, less than one for all health effects considered. As a result, these changes would not be measurable in the community
- The incidence calculations presented in **Table 11-23** and **Table 11-24** are the totals for each LGA. Within these LGAs are a number of suburbs. The calculated change in incidence relevant to each of these suburbs has also been evaluated. Review of the incidence calculated for the individual suburbs indicates that these predominantly relate to small decreases in health incidence with some suburbs showing an increase. The largest increase in health incidence for any individual suburb is less than 0.1 cases. Hence there are no individual suburbs within the LGAs where there is a change incidence that is of significance or would be measurable.

Elevated receivers

Further assessment of elevated receivers was undertaken in relation to potential health impacts at both 10 metres and 30 metres above ground level, representative of potential exposures that may occur in multi-storey buildings.

Impacts that are derived from changes in emissions from surface roads are expected to decrease with height above the roadway. However, in areas closest to the ventilation outlets there is the potential for increased impacts with height.

The assessment of potential impacts at 10 and 30 metres above ground level has focused on the worst case scenario, being the 2033 cumulative case, associated with impacts from all components of the WestConnex program of works plus other road related infrastructure projects. The maximum change in $PM_{2.5}$ relevant to this scenario was evaluated, which does not relate to any existing multi-storey building, rather the maximum value change anywhere in the study area. As the approach adopted in **Appendix I** (Technical working paper: Air quality) is a screening level assessment, no other pollutants have been evaluated. The results would be relevant to the construction of future multi-storey buildings in the study area.

Table 11-25 presents the calculated risks associated with the maximum predicted change in $PM_{2.5}$ concentrations at a height of 10 and 30 metres above ground level, throughout the study area. Impacts at existing multi-storey buildings are significantly lower than presented in this table, with changes in $PM_{2.5}$ annual average concentrations predicted to be <0.05 µg/m^3.

Table 11-25 Calculated individual risk associated with changes in $PM_{2.5}$ concentrations – cumulative scenario in 2033 for elevated receptors

Health Endpoint	Maximum calculated 10 m height	Maximum calculated 30 m height
Change in annual average concentration		
$PM_{2.5}$ (µg/m^3)	0.79	5.6
Primary health indicators: $PM_{2.5}$		
Mortality all causes (long-term effects, ages 30+)	5×10^{-5}	3×10^{-4}
Cardiovascular hospitalisations (short-term effects, ages 65+)	6×10^{-5}	4×10^{-4}
Respiratory hospitalisations (short-term effects, ages 65+)	1×10^{-5}	9×10^{-5}
Secondary health indicators: $PM_{2.5}$		
Mortality all causes (short-term effects, all ages)	4×10^{-6}	3×10^{-5}
Mortality, cardiopulmonary (long-term effects, ages 30+)	4×10^{-5}	3×10^{-4}
Mortality, cardiovascular (short-term effects, all ages)	1×10^{-6}	7×10^{-6}
Mortality, respiratory (short-term effects, all ages)	7×10^{-7}	5×10^{-6}
Asthma emergency department hospitalisations (1–14 years)	1×10^{-5}	1×10^{-4}
Negligible risks	**$<1 \times 10^{-6}$**	
Tolerable/acceptable risks	**$\geq 1 \times 10^{-6}$ and $\leq 1 \times 10^{-4}$**	
Unacceptable risks	**$>1 \times 10^{-4}$**	

Note:

Shaded cells indicate calculated risks that are considered unacceptable.

The calculations presented in **Table 11-25** indicate the following:

- At a height of 10 metres above ground level within the study area, the maximum change in $PM_{2.5}$ is lower than at ground level (refer to **Table 11-21** and **Table 11-22**) and results in risks that are considered to range from negligible to tolerable/acceptable
- At a height of 30 metres above ground level within the study area, the maximum change in $PM_{2.5}$ is significantly greater than at ground level and at 10 metres above ground level and results in risks that are considered to be unacceptable. Further review of the impacts predicted at 30 metres above ground level height indicates the following:
  - The impacts identified at 30 metres above ground level are localised and close to the ventilation outlets, with the maximum increases more specifically located adjacent to the Campbell Road ventilation facility at the St Peters interchange
  - The maximum increase in $PM_{2.5}$ at existing industrial premises was 1.8 µg/m^3, and the maximum increase at the closest residential area is 1.44 µg/m^3 which are associated with small changes in risk that are considered to be tolerable/acceptable
  - There are currently no buildings above 8.3 metres in height close to the St Peters interchange, hence the maximum risks calculated are hypothetical at this stage.

To address the potential health impacts identified, planning controls should be developed in the vicinity of the Campbell Road ventilation facility at St Peters interchange to ensure future developments at heights above 10 metres are not adversely impacted by the ventilation outlets. Development of planning controls would be supported by detailed modelling addressing all relevant pollutants and averaging periods.

Assessment of in-tunnel air quality impacts

In February 2016, the NSW Government Advisory Committee on Tunnel Air Quality (ACTAQ) issued a document entitled 'In-tunnel air quality (nitrogen dioxide) policy' (ACTAQ 2016). That document further consolidated the approach taken earlier for the NorthConnex, M4 East and New M5 projects. The policy wording requires tunnels to be *'designed and operated so that the tunnel average nitrogen dioxide (NO_2) concentration is less than 0.5 ppm as a rolling 15 minute average'*.

For the project and associated integrated analysis for the WestConnex program of works, the 'tunnel average' has been interpreted as a 'route average', being the 'length-weighted average pollutant concentration over a portal-to-portal route through the system'. Tunnel average NO_2 has been assessed for every possible route through the system under all circumstances with this assessment considering the highest average NO_2 concentration is reported.

The tunnel ventilation system would be designed and operated so that the in-tunnel air quality limits, consistent with those in the conditions of approval for NorthConnex and the approved WestConnex projects, are not exceeded. Further detail on the method for calculation of the length-weighted average for NO_2 is provided in Annexure L of **Appendix I** (Technical working paper: Air quality).

Concentrations in the tunnel are expected to vary depending on:

- Time of day: pollutant concentrations within the tunnels have been estimated to vary by a factor of up to 10 times (depending on the particular pollutant and location within the mainline tunnels) from periods of low traffic to peak traffic
- Location within the mainline tunnels and ventilation facilities: concentrations of pollutants would gradually increase from the tunnel entrance to the next offtake to a ventilation outlet. The average exposure for a motorist would be around half of the maximum concentration within the 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:

- M4-M5 Link mainline tunnels:
  - The time spent within the mainline tunnels would be limited, taking around five to six minutes to travel the full distance of the tunnel (when travelling at 80 kilometres per hour). During peak times the duration of travel may be slightly longer depending on the speed of traffic flow in the tunnel. As the pollutant concentrations are not the same in all parts of the tunnel, with concentrations increasing with distance from the entry portal, the amount of time exposed to the maximum concentration would be much lower (around one minute). The average exposure through the whole tunnel would be lower than about half the maximum (at the end of the tunnel)
  - The concentration of pollutants within the vehicle itself would be lower, 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 about 70–75 per cent for carbon monoxide and NO_2, 80 per cent for fine particulates and 50 per cent for VOCs
- Assessment of cumulative exposures in tunnels:
  - It is expected that users of the project may also use part of other connecting tunnels for their trip. This may include the M4 East or the New M5 tunnels, both of which directly connect into the M4-M5 Link mainline tunnels. There are other projects proposed that would also connect with the M4-M5 Link. This means motorists may be travelling inside a tunnel for a longer distance and duration. Given that the M4 East and New M5 both run east-west it is unlikely

anyone would utilise the full length of the tunnels, from the start of the M4 East to the end of the New M5 (or the other direction), during any one trip. It is more likely that trips may utilise either the M4 East or New M5 and part of, or all of, the M4-M5 Link

  - There may be individuals who utilise the network of tunnels in the Sydney area on a frequent basis, throughout the day. This includes taxi drivers, courier drivers and some truck drivers. More frequent exposures in these tunnels have been considered below.

The following sections provide further discussion on the range of concentrations predicted within the mainline tunnels.

Carbon monoxide

The 2033 maximum one-hour concentration of CO predicted in the M4 East, M4-M5 Link and New M5 tunnels, including the proposed future F6 Extension (travelling in both directions), follow the same pattern and are similar in magnitude, with the exception that the M4-M5 Link maximum concentrations are slightly lower in 2033.

Detailed discussion of in-tunnel CO concentrations is provided in **Appendix K** (Technical working paper: Human health risk assessment). A summary is provided below:

- The maximum one-hour average concentration of CO in the tunnels is predicted to be less than 10 ppm in all scenarios. These concentrations are lower than the health based guideline of 25 ppm (one-hour average) established by the WHO (WHO 2010) and 34 ppm established by the USEPA (NHMRC 2008). The concentrations are lower than the Permanent International Association of Road Congress (PIARC) in-tunnel limits (Longley 2014)
- The tunnels are designed to meet in-tunnel limits for CO. While actual concentrations in the tunnels are expected to be lower than these limits, where the limits are met the following can be said:
  - The in-tunnel limit for CO of 87 ppm as a 15-minute average is equivalent to the health based guideline of 90 ppm (15-minute average) established by the WHO (WHO 2010)
  - The in-tunnel limit for CO of 50 ppm as a 30-minute average is the same as the health based guideline of 50 ppm (30-minute average) established by the WHO (WHO 2000c).

There are no health issues of concern in relation to in-tunnel exposures to CO, either in the M4-M5 Link mainline tunnels or during longer journeys that may include the M4 East, New M5 or other projects where exposures inside the tunnels may be potentially closer to 30 minutes.

Nitrogen dioxide

The 2033 maximum one-hour concentration of NO_2 predicted in the M4 East, M4-M5 Link and New M5 tunnels including the proposed future F6 Extension (travelling in both directions), follow the same pattern and are similar in magnitude, with the exception that the M4-M5 Link maximum concentrations are slightly lower in 2033.

Detailed discussion of in-tunnel NO_2 concentrations is provided in **Appendix K** (Technical working paper: Human health risk assessment).

The following summarises the NO_2 concentrations predicted within the combined project tunnels:

- The maximum concentrations in any of the tunnels varies depending on the direction and time of travel and location within the tunnels. Where there are major interchanges, air from the tunnels is exhausted to ambient air via the ventilation facilities and fresh air enters the tunnel. This results in a reduction in concentrations at these locations. The concentrations then increase again with further travel through subsequent tunnels. The maximum concentration that may be present inside any of the tunnels is estimated to be around 0.8 ppm in the M4 East tunnel, prior to exiting the tunnel at the Wattle Street interchange
- The average concentration that may be within each tunnel segment, or over a trip that involves travel through connecting tunnels, would be lower than the maximum concentrations noted above. The average concentration of NO2 would vary depending on the time of day and tunnels used. The time spent inside tunnels during these trips would also vary. As noted previously it is unlikely that anyone would travel the full length of the WestConnex tunnels (around 21.5 kilometres) in

any one trip. If the full length of the tunnels was used, travelling at 80 kilometres per hour, the time spent in the tunnels would be about 30 minutes. It is more likely that travel within the WestConnex tunnels would cover about half this distance, which may result in travel times inside the tunnels ranging from about 15 minutes at 80 kilometres per hour to 30 minutes when the traffic is slower at 40 kilometres per hour.

The concentrations discussed above relate to NO_2 levels inside the tunnels, not inside the vehicles. A study of NO_2 concentrations inside vehicles travelling in Sydney and using existing road tunnels was commissioned by Roads and Maritime in 2016 (Pacific Environment Limited 2016) to better understand the relationship between NO_2 outside the vehicle and inside the vehicle. The study involved a range of vehicles considered representative of the existing vehicle fleet, travelling through existing tunnels in Sydney and simulating travel times between 45 minutes and 60 minutes over a distance of 30 kilometres.

The concentration of NO_2 that entered a vehicle depended on the concentration outside the vehicle as well as the air exchange rate relevant to the individual vehicle. The air exchange rate depends on the ventilation, ie whether on recirculation or not, and a range of factors relevant to the vehicle air tightness.

The study found that the using the vehicle ventilation in recirculation mode can significantly reduce concentrations of NO_2 inside vehicles. The ratio of indoor to outdoor concentrations ranged from 0.06 to 0.32. This is consistent with the findings from a NSW Health study on vehicles using the M5 East tunnel, where an indoor to outdoor ratio of 0.25 to 0.3 was determined for NO_2 where ventilation is set to recirculation. When ventilation was not set to recirculation the concentration of NO_2 was higher inside the vehicles, and in some cases accumulated inside the vehicle after travelling through short tunnels.

Concentrations of NO_2 inside vehicle that may use different routes for travel under the expected traffic conditions, including the longest length of combined tunnels connecting the M4 to the M5 motorways, are generally well below the 15-minute average and one-hour average guidelines. There are two short travel segments where the average concentration of NO_2 exceeds the one-hour average concentration, however the time spent in these segments would be very short and hence it is not applicable to compare the average concentrations against a one-hour average. The concentrations of NO_2 in these segments is well below the 15-minute average guideline.

Under an extreme congestion scenario, where vehicles are travelling at 20 kilometres per hour, in-tunnel and potential in-vehicle NO_2 levels are higher. In addition, it is likely that the amount of time spent in the tunnel would be longer, with the longest travel segments potentially taking an hour to cover. The average concentrations of NO_2 in-vehicle range from 0.09 to 0.14 ppm. These averages are around the one-hour average guideline of 0.12 ppm, with some minor exceedance. It is highly unlikely that the extreme congestion conditions would occur, and that if it does occur, that it would persist for long journey of up to 21.7 kilometres inside the tunnels. Hence the assessment presented is expected to be conservative. On this basis, it is not considered likely that significant adverse health effects would occur as a result of travel that may occur during congested conditions.

In relation to travel by motorcycles, or passengers in vehicles where advice to keep windows up and ventilation on recirculation is not adopted, potential exposures within the tunnels during expected traffic conditions, over the various travel segments, varies between 0.009 to 0.47 ppm, with most of the concentrations in the range 0.1 to 0.3 ppm. The concentrations are below the 15-minute average guideline, which would be relevant for travel by motorcycle through most of the travel segments. Travel through longer segments (around 20 kilometres) may take longer, around 20 minutes (or slightly longer). The available health data does not suggest that exposures for a period of 20–30 minutes would be of greater concern than for 15-minutes. As such no significant health effects are expected to occur.

Particulate matter

There are no health based guidelines available for the assessment of short-duration exposures to particulate matter within a tunnel. In-tunnel criteria relate to visibility (and safety in using the tunnel). It is expected that the concentration of particulate matter within the tunnel would be higher than ambient air concentrations, and the concentration of particulate matter would increase with increasing distance travelled through the tunnel.

Potential concentrations of particulate matter inside the tunnel are derived from exhaust as well as non-exhaust sources. Non-exhaust sources include tyre and brake wear and dust from surface road wear and the resuspension of road dust. The modelling of particulate matter and visibility issues within the tunnel has considered both sources. **Table 11-26** presents a summary of the peak concentrations of particulate matter estimated inside the tunnels in 2023, for the expected traffic conditions.

Table 11-26 Predicted peak concentrations of particulate matter in-tunnel: 2023

Scenario/Tunnel segment	Peak particulate matter concentration (mg/m^3)			
	Exhaust		Non-exhaust sources	
	With project	Cumulative	With project	Cumulative
M4-M5				
M4 East	0.05	0.07	0.31	0.39
M4-M5 Link	0.07	0.09	0.42	0.52
New M5 including F6 Extension	0.07	0.08	0.56	0.64
M5-M4				
New M5 including F6 Extension	0.03	0.03	0.36	0.2
M4-M5 Link	0.06	0.07	0.35	0.44
M4 East	0.1	0.12	0.6	0.68

The characteristics of particulate matter derived from exhaust and non-exhaust sources would be different. The tunnel design and air quality assessment for the project is based on non-exhaust particulate matter emission factors that relate to PM_{10} and $PM_{2.5}$ from relevant emissions studies. Particulate matter from exhausts is expected to be largely fine particulates (ie PM_{10} and $PM_{2.5}$) that are of importance to health.

Detailed discussion of in-tunnel particulate matter concentrations is provided in **Appendix K** (Technical working paper: Human health risk assessment). A summary is provided below:

- The in-tunnel concentrations for particulate matter are taken to be PM_{10} concentrations where concentrations of $PM_{2.5}$ are likely to comprise a significant portion of the PM_{10} concentration, particularly for exhaust emissions
- PM10 concentrations within the tunnels are dominated by non-exhaust sources
- The maximum concentration of PM_{10} in the tunnels evaluated is up to 0.7 mg/m^3 for the project, and 0.8 mg/m^3 for the cumulative scenario. The average concentration in the tunnels would be lower than the peak concentration predicted, potentially up to 50 per cent of that reported as the peak concentration. When windows are up and vehicle ventilation is in recirculation mode, the average level of PM_{10} inside a vehicle would be lower, potentially up to 0.08 mg/m^3.

Carbon dioxide

To minimise in-vehicle exposure to carbon dioxide (CO_2) and particulate matter, tunnel signage and communications would advise motorists using the tunnels to wind up windows and place ventilation on recirculation. Health issues that may arise from such advice relate to the potential build-up of CO_2 inside the vehicle. An assessment of in-vehicle levels of CO_2 and potential effects on the health and safety of drivers travelling through tunnels over varying distances and durations was completed by Roads and Maritime in 2017. Based on this study for vehicles that may include between one and five occupants, travelling through tunnels for up to an hour, the levels of CO_2 were not expected to adversely affect driver safety.

Assessment of potential exposures that may occur for periods of time up to two hours, where ventilation is left on recirculation, indicates that there may be levels of CO_2 inside a vehicle where there are one or more passengers that may affect an already fatigued driver.

There is a general lack of guidance or regulations in terms of the design or use of vehicle ventilation systems in vehicles in Australia. Hence there is currently no advice to drivers on the suitable use of ventilation in various circumstances, to minimise the potential for effects on already fatigued drivers.

Where Roads and Maritime provides specific advice to drivers entering road tunnels to put ventilation on recirculation, it would also be necessary to provide advice that recirculation should be switched off and not left on for an extended period of time, after exiting the tunnel.

11.5.2 Noise and vibration

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

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:

- Sleep disturbance (sleep fragmentation that can affect psychomotor performance, memory consolidation, creativity, risk-taking behaviour and risk of accidents)
- 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)
- Tinnitis (which manifests as a ringing in the ears when no physical noise is present, can also result in sleep disturbance, anxiety, depression, communication and listening problems, frustration, irritability, inability to work, reduced efficiency and a restricted participation in social life)
- Cognitive impairment in children (including deficits in long term memory and reading comprehension)
- Some evidence of indirect effects such as impacts on the immune system.

Annoyance can be a major consideration because it reflects the community's dislike of noise and their concerns about the full range of potential negative effects from a project. It also affects the greatest number of people in the population.

Potential noise impacts have been assessed against Australian (more specifically NSW) 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* (INP) (NSW EPA 2009), the *NSW Interim Construction Noise Guideline* (DECC 2009), and the *NSW Road Noise Policy* (RNP) (DECCW 2011). All of these policies are based on the annoyance effects of noise, which may result in health impacts (subject to long-term exposure), as outlined in the reviews published by the following organisations:

- World Health Organization – *Guidelines on Community Noise – Health effects of noise* (WHO 1999)
- World Health Organization – *Night Noise Guidelines for Europe* (WHO 2009)
- International Institute of Noise Control Engineering – *Guidelines for Community Noise Impact Assessment and Mitigation* (I-INCE 2011)

- Environmental Health Council of Australia – *The health effects of environmental noise – other than hearing loss* (enHealth 2004).

The assessment of potential health impacts relating to noise has focused on whether the guidelines/criteria that have been established can be met. The NSW noise policies and guidelines against which this project is assessed are designed to protect the most sensitive receivers from annoyance and sleep disturbance. Where the guidelines cannot be met there is the potential to interfere with communication, disturb sleep and cause annoyance. Further, communities subjected to long-term exposure of acute noise levels may experience impairment of cardiovascular health and reduced cognitive performance in children.

The noise modelling for the project has been undertaken to address impacts associated with the operation of the project in 2023 and 2033, including a cumulative scenario. The modelling has evaluated noise impacts at the façade of all buildings, including on all floors of multi-storey buildings. An assessment was undertaken to determine how well the model estimated noise impacts based on a current scenario. The modelled and measured results were found to be within acceptable tolerances, which are ± two dB(A).

The assessment of operational noise impacts and the mitigation measures considered are described in **Chapter 10** (Noise and vibration).

For over 60 per cent of the receptors evaluated, noise levels will be reduced as a consequence of the project, resulting in associated health benefits. However, the worst case assessment also predicts that noise criteria and vibration criteria will be exceeded at a number of properties adjacent to the project during construction and operation without mitigation measures.

The worst-case levels estimated are sufficiently high for some receptors during some works that health impacts are likely to occur. These properties are located south of Victoria Road adjacent to the Iron Cove Link tunnel portals; and to the west of Victoria Road near Lilyfield Road. These are primarily related to the new road alignment being closer to residential homes, and the removal of buildings closest to the road (that previously were a barrier to noise from the roadway). A number of properties have also been identified where cumulative noise impacts exceed the relevant guidelines.

Without mitigation, a significant number of receivers have been identified in most noise catchment areas (NCA) where exceedances of the daytime and night-time noise criteria are predicted during construction. The change in noise levels are predicted up to two dB(A) at most receivers, with more significant increases up to five dB(A) at a smaller number of receivers (with less than one per cent of receivers experiencing noise increases of two to five dB(A)).

The detailed design for the mitigation measures will be outlined in the Construction Noise and Vibration Management Plan (CNVMP) as discussed in **Appendix J** (Technical working paper: Noise and vibration). The aim of the mitigation measures should be to reduce noise and vibration to levels that comply with the management goals established in this assessment. If it is not possible to achieve compliance with these goals, health impacts for the affected community are likely.

While these mitigation measures are required to ensure that the environment where people spend most of the day (ie indoors) is not associated with adverse health impacts from excessive noise, it does assume that residents take up in-property treatment measures and where they do, they keep external windows and doors shut and have minimal use of outdoor areas.

In urban areas particularly where existing levels of noise are 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 improve wellbeing 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 in-property 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 in-property treatment would be required to enable the noise criteria to be met, and minimise the potential for adverse health effects associated with the project. However, such treatments may have other effects (as discussed above) which will also need to be managed/considered.

11.5.3 Public safety

A range of potential hazards have been identified that have the potential to affect public safety during the operation of the project, principally in relation to traffic accidents. These are outlined in **Table 11-27**, along with discussion on the risks that may be posed by these hazards. Not all the hazards identified in the hazard and risk assessment have been included in the table, only those where there is the potential for risks to public safety.

Table 11-27 Overview of public safety hazards and risks: Operation

Hazard: Public safety	Risk to public safety	Management measures
Storage, handling and transport of dangerous goods required for maintenance of the project, that may impact on the off-site community.	**Low** The storage volumes are very minor, with limited and infrequent transport of these materials required.	All materials would be stored and transported in accordance with relevant legislation and Australian Standards.
Transport of dangerous goods and hazardous substances in project tunnels.	**Low** The transport of these materials would be prohibited within the tunnels (as per Regulation Road Rules 2014, Regulation 300-2).	Signage would be provided near tunnel entry portals advising of the restrictions to ensure compliance with Regulation 300-2.
Traffic accidents in the tunnels.	**Low to moderate** All use of public roadways carries an inherent risk of vehicle collision. The project has been designed to minimise these risks for travel within the tunnels. The project also provides fire and life safety requirements.	Mitigation includes use of height detection systems prior to tunnel entry portals, tunnel barrier gates to prevent access if the tunnel is closed, closed-circuit television throughout the tunnel, adjustable speed signs, provision of breakdown bays and emergency phones, provision of pedestrian cross-passages to enable safe evacuation from the tunnel, automated fire detection, longitudinal ventilation to push smoke in the direction of traffic flow away from a fire source towards a ventilation facility or portal, and a water deluge system that can be activated manually or automatically. An Incident Response Plan would be developed and implemented in the event of an accident or incident in the tunnels.
Traffic accidents on surface roads.	**Moderate**, however the risk is considered to be reduced with the project.	While the design of the project has been developed to inherently minimise the likelihood of incidents and crashes, the project does not significantly change the design of existing surface road infrastructure. The project would involve a reduction in traffic on some roadways, which has the potential to reduce crash rates and improve pedestrian and cyclist safety.

Hazard: Public safety	Risk to public safety	Management measures
Electromagnetic fields (EMF) from new substations at motorway operations complexes at Darley Road (MOC1), Rozelle West (MOC2), Rozelle East (MOC3), Iron Cove Link (MOC4) and Campbell Road (MOC5).	**Low**	The detailed design of project substations would ensure that the exposure limits for the general public in the Draft Radiation Standard – Exposure Limits for Magnetic Fields (Australian Radiation Protection and Nuclear Safety Agency, December 2006) would not be exceeded at the boundary of the substation sites.
Bushfire risks.	**Low** The project is in a highly urbanised area that is not in or near a bushfire prone area.	Operational infrastructure is largely invulnerable to bushfires as it is not combustible. Regular maintenance would be undertaken at operational sites to prevent a build-up of natural fuel such as vegetation and debris.
Aviation risks, specifically works that may affect the safety of aircraft using Sydney Airport.	**Low**	The project design has considered airspace protection and associated risk and hazards. This includes the design of lighting and the ventilation facilities to ensure they meet the safety requirements set by the NSW Government and regulatory agencies.
Subsidence.	**Low** Tunnel induced ground movement that may result in ground settlement is considered to be low along most of the tunnel alignment. In some areas, where shallow tunnelling or multiple tunnels are proposed close to each other, higher levels of settlement are predicted. In these areas, potential settlement impacts require further assessment and potential management.	Further assessment of potential settlement impacts, including modelling would be required during the detailed design. Where ground movement in excess of settlement criteria are predicted a range of design, construction and ground improvement measures (as outlined in **Chapter 12** (Land use and property)) would be considered to reduce impacts. In addition, a range of management measures would be implemented (as detailed in **Chapter 12** (Land use and property)). This includes the preparation and implementation of a Settlement Monitoring Plan, preparation of building condition surveys, repair of cracking or property damage deemed to have occurred from the construction of the project, and preparation of agreements with utility owners and infrastructure owners identifying acceptable levels of settlement, monitoring requirements and measures to be implemented where levels are exceeded.

On the basis of the above there are not considered to be any issues related to the operation of the project that have the potential to result in significant safety risks to the community.

11.6 Assessment of potential social impacts on health

The WHO defines health as a dynamic state of complete physical, mental and social wellbeing and not merely the absence of disease or infirmity. Hence the assessment of health should include both the traditional/medical definition that focuses on illness and disease as well as the broader social definition that includes the general health and wellbeing of a population.

There are a range of other impacts associated with the project, other than the direct impacts from changes to air quality and levels of noise and vibrations that can affect the health and wellbeing of the community in a more indirect way. Changes within a community that may be associated with the project may be differentially distributed. Population groups that may be advantaged or disadvantaged based on age, gender, socio-economic status, geographic location, cultural background, aboriginality, current health status and existing disability may be affected in different ways by the project related changes. This aspect relates to the equity of the impacts in the local community (see **section 11.6.6**).

This section specifically evaluates changes that have the potential to indirectly affect the health and wellbeing of the community. In addition, this section provides a review of whether there are any impacts that are likely to be more significant in any section of the community, and if these areas may result in inequitable impacts on the health of the population. Further details can be found in **Chapter 14** (Social and economic).

11.6.1 Changes to traffic and transport

Construction

A number of changes to local roads are proposed during the construction phase of works. While it is expected that access to all properties on the local roads would be maintained during the construction works, some permanent and temporary closures or reduced capacity of some local roads may affect the movement of local traffic through the area. In relation to traffic changes around the project footprint during construction, most of the issues that are relevant to community health relate to public safety, which are addressed in **section 11.4.3** and **section 11.5.3**.

In addition to safety risks to the public, construction works are expected to result in some increases in travel times for motorists, bus travel, pedestrians and cyclists. These changes have the potential to result in increased levels of stress and anxiety in the local community (as discussed in **section 11.9**). These impacts, however, are expected to occur during the period of construction only.

A car parking and access strategy would be prepared as part of the CTAMP for the project, detailing temporary road closures and including traffic control procedures, signage requirements, construction traffic management requirements of the relevant Roads and Maritime manuals and procedures as well as Australian Standards.

Operations

Once the project is complete, it is expected that reductions in vehicle delays in a number of areas would occur. Traffic congestion and long commuting times can contribute to increased levels of stress and fatigue, more aggressive behaviour and increased traffic and accident risks on residential and local roads as drivers try to avoid congested areas (Hansson et al. 2011). Increased travel times reduce the available time to spend on heathy behaviours such as exercise, or engage in social interactions with family and friends. Long commute times are also associated with sleep disturbance, low self-rated health and absence from work (Hansson et al. 2011). Reducing travel times and road congestion is expected to reduce these health impacts.

Public transport

Access to public transport is important, particularly for people who cannot or are unable to drive (such as the elderly and those with disabilities). Lack of good access to public transport for these individuals can result in increased feelings of isolation, helplessness and dependence.

During construction of the project, public transport in and around the project footprint would be affected. The construction of the project would not directly affect heavy rail or light rail services. However, passenger access to stations may be affected by temporary traffic changes and congestion arising from the presence of construction works. Most impacts to public transport as a result of the project relate to bus travel, where construction activities would result in the relocation of some bus stops and bus travel times are forecast to increase along some routes in the peak periods.

Once the project is complete, from a public transport network perspective, the project is expected to generally facilitate faster and more reliable morning and evening outbound bus journeys in 2023 and 2033. However in some areas, some bus journey times are forecast to increase due to traffic congestion, for example along the Western Distributor and Anzac Bridge combined with increased demands to Bathurst Street and the Sydney Harbour Bridge.

Pedestrian and cyclist access

Walking and cycling have many health benefits including maintaining a healthy weight and improved mental status (Hansson et al. 2011; Lindström 2008; Wen & Rissel 2008; WHO 2000b).

There is currently a network of cyclist paths in the study area, comprising a mixture of separated cycleways and on road paths in areas of low to medium traffic. The current cycling network is predominantly oriented to recreational trips rather than commuter trips with dedicated cycleways concentrated within recreational spaces and along the Rozelle Bay/Blackwattle Bay foreshore.

As identified in the Active Transport Strategy in **Appendix N** (Technical working paper: Active transport strategy), significant and highly valued active transport networks include the Bay Run, Glebe foreshore, Anzac Bridge cycleway and the northern part of the Greenway (the active transport connection between Cooks River and Iron Cove). The shared path along Whites Creek to Buruwan Park is also used by cyclists and pedestrians. Shared pedestrian and cyclist paths also run both sides of Victoria Road with important overpasses provided at the city end of Victoria Road and across City West Link to provide connection to the water.

During construction, alterations to pedestrian and cyclist networks have the potential to affect commuter departure times, travel durations, movement patterns and accessibility. Construction and operation of the project would result in changes to pedestrian and cyclist access, including temporary and permanent closures or diversions of some pathways and pedestrian bridges.

Upgraded and additional facilities for pedestrians and cyclists would be provided as part of the project including the delivery of active transport links around permanent operational infrastructure. This would include two new bridges over City West Link connecting the communities of Rozelle, Balmain, Lilyfield, Glebe and Annandale, and an upgraded east-west connection between Lilyfield Road, the Rozelle Rail Yards, The Bays Precinct and Anzac Bridge.

The diversions and detours for active transport are described in **Chapter 8** (Traffic and transport).

Impacts on health and emergency services

The existing arterial roads and the local road network are currently used by emergency services to travel to and from call-outs. Construction of the project may require temporary traffic diversions, road occupation, temporary road closures and alternative property access arrangements.

The CTAMP for the project would be developed in consultation with relevant emergency services, ensuring that procedures are in place to maintain safe, priority access for emergency vehicles through construction zones. Additionally, local emergency services would be periodically updated on the staging and progress of construction works. The project would not impact access to health or emergency services.

11.6.2 Property acquisitions

The design of the project has been developed to minimise the need for surface property acquisition and impacts on other residential and open space areas. There would, however, be a number of property acquisitions as well as other temporary and permanent impacts on land use associated with the project.

The acquisition and relocation of households and businesses due to property acquisition can disrupt social networks and affect health and wellbeing due to raised levels of stress and anxiety. This includes increased levels of stress and anxiety during the process of negotiating reasonable compensation. The purchase of a new home and moving house can be one of the most significant events in a person’s life. Both a house and a workplace are central to daily routine with the location of these premises influencing how a person may travel to/from work or study, the social infrastructure and businesses they visit and the people they interact with.

All acquisition required for the project would be undertaken in accordance with the *Land Acquisition (Just Terms Compensation) Act 1991* (NSW), the *Land Acquisition Information Guide* (NSW Government 2014) and the land acquisition reforms announced by the NSW Government in 2016 (NSW Government, 2016), which can be viewed online.[1] Relocation and some other categories of expenses would be claimable under this Act.

11.6.3 Green space

Green space within urban areas includes green corridors (paths, rivers and canals), grassland, parks and gardens, outdoor sporting facilities, playing fields and children play areas. A review of international epidemiological studies shows a positive relationship between green space and health and wellbeing (de Vries et al. 2003; Health Scotland 2008; Kendal et al. 2016; Maas et al. 2006; Mitchell & Popham 2007). The outcomes of these studies did depend on the quality of the available green space. They showed that green space areas in low socio-economic areas often had poor facilities, higher levels of graffiti, vacant/boarded up buildings and lower levels of safety. These studies showed that such spaces had few health benefits.

The health benefits of green space in urban areas include the following (Health Scotland 2008; Kendal et al. 2016; Lee & Maheswaran 2011):

- Green space areas that include large trees and shrubs can protect people from environmental exposures associated with flooding, air pollution, noise and extreme temperature (by regulating microclimates and reducing the urban heat island effect)
- Reduced morbidity
- Improved opportunities for physical activity and exercise. The benefits depend on a range of factors including the distance, ease of access, size of green space, location in relation to connectivity to residential or workplace areas, attractiveness, available facilities (particularly where used by specific sporting clubs) and multi-use (ie including children play areas, gardens, seating, sporting facilities that can be used by a wide range of the community for different purposes)
- Improved mental health and feelings of wellbeing, particularly lower stress levels
- Improve opportunities for social interactions.

Green space areas in urban areas may also present some hazards, such as attracting anti-social behaviours (particularly in isolated areas), providing areas for drug or sexual activity and unintentional injuries from sports or use of playground equipment. It has also been found that individuals from ethnic or minority groups and those with disabilities are less frequent users of green spaces (Health Scotland 2008; Kendal *et al* 2016; Lee & Maheswaran 2011).

There are a number of sporting/recreational facilities and parks in and around the project footprint that include sporting fields, playgrounds, parks and reserves. The project has been designed to minimise impacts on existing recreational facilities. This is of particular note for the Glebe foreshore, the Bay Run and Easton Park.

Following completion of the construction works it is proposed that the Rozelle Rail Yards would be developed as open space that includes a constructed wetland and additional pedestrian and cyclist infrastructure. This improved open space area would provide the community at Rozelle with increased opportunity for active recreation, potentially improving health. This open space would also connect surrounding communities to Rozelle through the extension of green space between Bicentennial Park and Easton Park. Additional opportunities for open space would be created at Rozelle near the Iron Cove Link portals. The development of these areas of open space would be detailed through an urban design and landscape plan (UDLP).

New open space to be created by the project would be designed with consideration of Crime Prevention Through Environmental Design (CPTED) principles, as outlined in **Appendix L** (Technical

[1] https://www.finance.nsw.gov.au/sites/default/files/NSW_Government_Response.pdf

working paper: Urban design) and **Chapter 13** (Urban design and visual amenity). This includes regard for creating safe, well-lit areas, provision of passive surveillance and other measures.

11.6.4 Changes in community

Roads and motorways can divide residential communities and hinder social contact. The presence of busy roads inhibits residents from socialising and children from playing, or accessing nearby recreational areas. Heavy traffic also affects child development (WHO 2000b). Children learn how to make responsible decisions, how to behave in different situations and develop a relationship with their environment and community through independent mobility. Where children have the opportunity to be able to play in local streets or safely access local parks they have been found to have twice as many social contacts as those where such activities are prevented by heavy traffic.

Social connectedness and relationships are important aspects of feeling safe and secure. Streets with heavy traffic have been associated with fewer neighbourhood social support networks and has been linked to adverse health outcomes (WHO 2000b).

Any temporary and permanent changes to the access to social infrastructure, community resources or to other desirable locations (such as employment, study, friends and family) and safety to movement may affect community networks and in turn trigger community severance.

Community severance effects often occur during major transportation projects due to detours in the local road network, changes to active and public transport routes, and connector roads receiving an increase or decrease in traffic movements. The changes to the road networks particularly along City West Link, Victoria Road, The Crescent, Lilyfield Road and Darley Road may contribute to feelings of community severance and disconnection.

Construction of the project would include the removal of two pedestrian bridges across Victoria Road and City West Link which are popular for both recreational and commuter pedestrian and cyclist traffic. The removal of these bridges, despite the temporary alternatives, may reduce community cohesion and sense of access to place. These connections provide important access to Rozelle Bay and through to the Glebe foreshore walkways. The civil site at The Crescent would also temporarily reduce the connection for pedestrian and cyclists to the Glebe foreshore walkways for residents of both Rozelle and Annandale.

However, once completed, the M4-M5 Link project includes a range of changes to the active transport network as previously noted, this would include two new bridges over City West Link connecting the communities of Rozelle, Balmain, Lilyfield, Glebe and Annandale, and an upgraded east-west connection between Lilyfield Road, the Rozelle Rail Yards, The Bays Precinct and Anzac Bridge.

Further detail is provided in **Appendix H** (Technical working paper: Traffic and transport) and **Chapter 8** (Traffic and transport). Improvements to the active transport network, including improvements to transport connections, would have a positive benefit on community health. Where active transport opportunities are improved and offer safe alternatives to driving and public transport, they can encourage more active recreation and commuting activities.

11.6.5 Visual changes

Visual amenity can be described as the pleasantness of the view or outlook of an identified receptor or group of receptors (eg residences, recreational users). Visual amenity is an important part of an area's identity and offers a wide variety of benefits to the community in terms of quality of life, wellbeing and economic activity. For some individuals, changes in visual amenity can increase levels of stress and anxiety. However, these impacts are typically of short duration as most people adapt to changes in the visual landscape, particularly within an already urbanised area. As a result, changes in visual amenity are not expected to have a significant impact on the health of the community.

During construction, visual amenity in and around the project footprint has the potential to be affected by factors such as the removal of established vegetation, the installation of construction hoardings and/or the visual appearance of construction sites. Further factors may include the alteration of view corridors to heritage, open space, water bodies or the city skyline.

The operational project would include changes to local visual amenity due to the presence of new and amended infrastructure, landscaping (which includes changes to landform and planting of vegetation) and urban design features.

The urban design and landscape works that would be carried out by the project would be documented in a UDLP. A UDLP would be prepared in consultation with stakeholders and the community prior to the commencement of permanent built surface works and/or landscape works and would present an integrated urban design for the project.

A detailed review and finalisation of architectural treatment of the project operational infrastructure, including ventilation facilities, would be undertaken during detailed design. The architectural treatment of these facilities would be guided by ventilation facility performance requirements, the outcomes of community consultation and the urban design principles identified in **Chapter 13** (Urban design and visual assessment).

Landscaping works would be carried out adjacent to disturbed areas, around operational infrastructure (such as ventilation facilities), and in areas of new open space that would be provided at the Rozelle Rail Yards and adjacent to Victoria Road at Rozelle. Areas where permanent operational infrastructure is proposed have been reviewed against the urban design principles developed for the project, which are outlined in **Chapter 13** (Urban design and visual assessment).

11.6.6 Equity

The health effects associated with impacts related to transport projects are not equally distributed across the community. Groups at higher risk, or more sensitive to impacts, include:

- Elderly
- Individuals with pre-existing health problems
- Infants and young children
- Individuals with disabilities
- Individuals who live in areas of higher levels of air or noise pollution.

Often impacts can accumulate in the same areas, which may already have poorer socio-economic and health status, most commonly due to the affordability of housing in areas that are closer to main roads, industry or rail infrastructure. Disadvantaged urban areas are commonly characterised by high traffic volumes, higher levels of air and noise pollution, feelings of insecurity and lower levels of social interactions and physical activity in the community.

To further evaluate potential equity issues associated with the project, the location of impacts identified in relation to air quality, noise and traffic were reviewed individually and in combination, in conjunction with available information on the location of sensitive community groups.

In many urban areas housing prices are lower along main roadways. The median house prices in the study area are variable; however in most areas they are consistent with the Sydney average. Some public housing is located in the study area; however, these properties are mixed in with privately owned property such that there are no specific areas with higher populations of public housing tenants. Hence there are no social equity issues identified in relation to the change in air quality in the local community.

There are no areas identified in the local community where the combined impact from changes in noise and air quality would be different from the conclusions presented for the individual assessment of air quality and noise impacts.

Suburbs in the study area that, based on the 2011 census data, are slightly more disadvantaged (in relation to the Socio-Economic Index for Areas (SEIFA)) include Glebe, Eveleigh and Marrickville, as well as populations in the Canterbury area. There are no project related air quality or noise impacts (including during cumulative scenarios) that are of significance in these areas. Impacts on human health in these areas would be lower than predicted for the maximum impacted individuals.

Residents located adjacent to a number of key surface roads, particularly City West Link, Parramatta Road, Princes Highway, part of Victoria Road at Rozelle, Southern Cross Drive and the M5 Motorway would benefit from reduced traffic volumes, potentially improved traffic and pedestrian safety, and improvements (albeit small and not measurable) in air quality and noise.

11.7 Economic aspects

The construction expenditure of the project would be of significant benefit to the economy. This expenditure would inject economic stimulus benefits into the local, regional and state economies. Ongoing or improved economic vitality is of significant health benefit to the community, as described below.

Employment opportunities would grow in the region through the potential increase in business customers and through the increase in demand for construction workers. The increase in demand for labour may increase wages in the region, particularly for construction workers, who would be in high demand.

The acquisition and relocation of some businesses can result in impacts on local economies. In addition, changes to access during construction may also adversely impact on some local businesses. To minimise these impacts the project would include development of a Business Management Strategy (refer to **Appendix P** (Technical working paper: Social and economic) for a detailed description of what this would entail).

Freight and commercial vehicle movements are an important component of the economy. Numerous industries are dependent upon efficient transport to service operational requirements. Transport for NSW estimated that freight and logistics contributed $58 billion to NSW State Gross Product (GSP) in 2011. This represented 13.8 per cent of NSW GSP at the time.

An objective of the M4-M5 Link project is to encourage heavy and commercial vehicle movements into the tunnel, increasing efficiencies and reducing *'freight costs through increased travel speeds and reliability and reducing the distances travelled by freight vehicles'.*

The transport and traffic modelling conducted for the project highlighted that there could potentially be substantial benefits for freight and commercial vehicle movements during the operation of the M4-M5 Link. The subsequent effects of the operation of the M4-M5 Link on business productivity include:

- Reduced cost of commercial and freight movements
- Increased productivity from reduced congestion and travel times for commercial and freight movements
- Increased economic output as a result of increased efficiency in freight and commercial vehicle movements.

The modelling determined that a significant number of freight vehicles diverted from surface roads into the project tunnels with an expectation of travel time savings. This in turn would improve travel times on existing major arterial surface roads such as Victoria Road, Parramatta Road and the Princes Highway for commuters and light commercial vehicles.

11.7.1 Road tolling

The social and economic impacts associated with a new toll road are diverse and far ranging, with the level of the effect being related to which road users are targeted and the amount charged.

The implementation of road tolls can have direct impacts on travel times, reduced emissions and traffic accidents, as well as other less direct impacts on social inequality, company movements, and effects on the regional/national economy which are more difficult to quantify and are generally documented qualitatively.

A potential impact of tolling is the increase in congestion volumes on surrounding roads as a result of toll avoidance (ie 'rat-running'). The use of a toll road can also increase the cost of living and can exacerbate social inequality. Specifically, the impact of toll roads on households can be assessed as a function of household income, urban spatial structure, and available mobility choices. Depending on the travel routes of individuals, and the individual economic situation, there may be a proportion of the population that would avoid the use of tollways due to affordability.

Funding of WestConnex, as proposed in the *WestConnex Updated Strategic Business Case* (Sydney Motorway Corporation 2015), assumes a distance based toll would be implemented on operation of each component project. Distance based tolling means that motorists would only pay tolls for the sections of the motorway they use. The proceeds of the toll on each component project once operational would be applied to fund the construction of other components of the WestConnex program of works. A maximum toll for the use of the M4-M5 Link would be $6.50 (2017 dollars).Tolls for the entire WestConnex motorway would be capped at a maximum amount of $8.60 (2017 dollars) for cars and light commercial vehicles and a distance of around 40 kilometres. This would provide significant time and cost savings for motorists. Cars and light commercial vehicles would pay one third of the toll for heavy commercial vehicles. Tolls would escalate up to a maximum of four per cent or the consumer price index (CPI) per year (whichever is greater) until 2040. After that, CPI would apply.

The project would enhance the benefits of the WestConnex program of works for travel between western Sydney and the Sydney CBD. For example, a person driving a car in 2017 from Penrith to the Sydney CBD currently has the option of travelling along the M4 Motorway, which ends at Concord, and then would need to travel on the congested surface road network to the Sydney CBD. An alternative route between Penrith and the CBD using the M4 Motorway, WestLink M7, the Hills M2 Motorway, Lane Cove Tunnel and the Sydney Harbour Bridge or the Sydney Harbour Tunnel would cost around $22.00 in tolls ($2017) and is a distance of around 55 kilometres. After opening in 2023, the project would provide a journey using the M4 Motorway straight through to Anzac Bridge, via the M4-M5 Link, for a toll capped at $8.60 (2017 dollars) and a distance of around 40 kilometres. This would provide significant time and cost savings for motorists.

The magnitude of tolls proposed for the project, including consideration of toll avoidance, has been factored into the traffic modelling, and subsequent air quality and noise modelling, and hence impacts on the health of the community have been considered.

11.8 Construction fatigue

Construction fatigue relates to receptors that experience construction impacts from a variety of projects over an extended period of time with few or no breaks between construction periods. Construction fatigue typically relates to traffic and access disruptions, noise and vibration, air quality, visual amenity and social impacts from projects that have overlapping construction phases or are back to back.

For the key areas, where construction fatigue may be of concern, the following was identified:

- Haberfield/Ashfield: construction activities associated with the M4 East project as well as the M4-M5 Link within the construction ancillary facilities in Haberfield would result in surrounding communities being exposed to construction noise, traffic and dust for longer periods of time. Areas potentially affected (depending on which construction ancillary facilities are utilised during the construction of the M4-M5 Link project) are located:
  - Adjacent to the Northcote Street civil site
  - Adjacent to the Wattle Street civil and tunnel site
  - Adjacent to the Haberfield civil and tunnel site/Haberfield civil site
  - Adjacent to the Parramatta Road East civil site and Parramatta Road West civil and tunnel site

  In these areas, additional mitigation measures are identified, specifically an increase in the height of hoarding around the construction sites and at-receptor noise mitigation (where required), to address these longer duration noise impacts
- Rozelle: construction activities associated with the project and other infrastructure projects, namely the CBD and South East Light Rail Rozelle maintenance depot, the proposed future Western Harbour Tunnel and Beaches Link and site management works may result in construction noise for longer periods of time. Areas that may be affected are located:
  - Adjoining Lilyfield Road between Justin Street and Ryan Street
  - Adjoining Brenan Street between Starling Street and White Street

In these areas additional mitigation measures were identified, specifically an increase in the height of hoarding around the construction sites, and upgrading of the acoustic shed performance and at-receptor noise mitigation (where required), to address these longer duration noise impacts. Under this scenario there are a number (345 receptors) that may be impacted by vibration at levels that exceed the human comfort criteria. These impacts will require monitoring and management

- St Peters: construction activities associated with the New M5 and the M4-M5 Link would result in exposure to construction noise for longer periods of time. Areas affected are:
  - Adjacent to Campbell Road.

In these areas, additional mitigation measures are recommended that include optimising the design of acoustic sheds, noise barriers/hoarding and management measures and at-receptor noise mitigation (where required), to address these longer duration noise impacts.

11.9 Stress and anxiety issues

A number of changes within the community have the potential to affect levels of stress and anxiety. Some changes may result in a lowering of feelings of stress and anxiety while there are others that may result in higher levels within the community or individuals, depending on personal circumstances. In addition, construction fatigue from overlapping and consecutive infrastructure projects and ongoing urban developments may result in elevated levels of stress and anxiety for extended periods of time. This is discussed in more detail in **Appendix K** (Technical working paper: Human health risk assessment) and in **Chapter 26** (Cumulative impacts).

Chronic and persistent negative stress, or distress, can lead to many adverse health problems including physical illness and mental, emotional and social problems. Response to stress would vary between individuals with genetic inheritance and personal/environmental experiences of importance (Schneiderman, Ironson & Siegel 2005).

An acute stressful event results in changes to the nervous, cardiovascular, endocrine and immune systems, more commonly known as the 'fight or flight' response (Schneiderman, Ironson & Siegel 2005). Unless there is an accident or other significant event, such acute stress events are not expected to be associated with construction or operation of the project.

For shorter-term events, stress causes the immune system to release hormones that trigger the production of white blood cells that fight infection and other disease-fighting elements. This response is important for fighting injuries and acute illness. However, this activity within the body is not beneficial if it occurs for a long period of time. Hormones released during extended or chronic stress can inhibit the production of cytokines (the messengers that allow cells to talk to each other to fight infection), lowering the body's ability to fight infections. This makes some individuals more susceptible to infections, and they may also experience more severe infections. It can also trigger a flare up of pre-existing autoimmune diseases (which are a range of diseases where the immune system gets confused and starts attacking healthy cells) (Mills, Reiss & Dombeck 2008; Schneiderman, Ironson & Siegel 2005).

Other physiological effects associated with chronic stress include (Brosschot, Gerin & Thayer 2006; McEwen, Bruce S. 2008; McEwen, B. S. & Stellar 1993; Mills, Reiss & Dombeck 2008; Moreno-Villanueva & Bürkle 2015):

- Digestive disorders, with hormones released in response to stress causing a number of people to experience stomach ache or diarrhoea, with appetite also affected in some individuals (resulting in under-eating or over-eating)
- Chronic activation of stress hormones can raise an individual's heart rate, cause chest pain and/or heart palpitations and increase blood pressure and blood lipid (fat) levels. Sustained high levels of cholesterol and other fatty substances can lead to atherosclerosis and other cardiovascular disease and sometimes a heart attack (Pimple et al. 2015; Seldenrijk et al. 2015)
- Cortisol levels, released at higher levels with stress, play a role in the accumulation of abdominal fat, which has been linked to a range of other health conditions

- Stress can cause muscles to contract or tighten, causing tension aches and pains (Ortego et al. 2016).

Some individuals respond to elevated levels of stress by taking up or continuing unhealthy stress coping strategies such as smoking, drinking or overeating, all of which are associated with significant health risks.

Chronic levels of stress have also been found to cause or exacerbate existing mental health issues, including mood disorders such as depression and anxiety, cognitive problems, personality changes and problem behaviours. It can also affect individuals with pre-existing bipolar disorders.

More generally, it must be noted that urbanisation, or increased urbanisation, regardless of specific projects has been found to affect levels of stress and mental health (Srivastava 2009). These impacts are greater where there is urbanisation without improvements in infrastructure to improve equitable access to employment and social areas/communities (Srivastava 2009). The role of either acute or long-term environmental stress on the health of any community, in general and for specific project(s), including the WestConnex projects, cannot be quantified.

There are a wide range of complex factors that influence health and wellbeing, specifically mental health. It is not possible to determine any specific outcomes that may occur as a result of a specific project, or number of projects. However, it is noted that within any urban environment there would be a wide range of stressors present from infrastructure projects as well as other urban developments that may or may not contribute to the health effects outlined above.

The project, along with the other approved WestConnex projects, aims to improve infrastructure and access within the urban environment. Hence on a broader scale these long-term projects, while they require management of construction impacts, may assist in reducing stress and associated physiological and mental health impacts within the urban environment.

11.10 Management of impacts

Management measures to minimise impacts on human health during construction and operation of the project are provided in the following chapters:

- Transport and travel management measures – **Chapter 8** (Traffic and transport)
- Air quality management measures – **Chapter 9** (Air quality)
- Noise and vibration management measures – **Chapter 10** (Noise and vibration)
- Property acquisition and relocation services – **Chapter 12** (Land use and property)
- Social impact management measures – **Chapter 14** (Social and economic).