Transport for NSW

Beaches Link and Gore Hill Freeway Connection

Chapter 13

Human health

transport.nsw.gov.au

DECEMBER 2020

13 Human health

This chapter outlines the potential human health impacts associated with the project and identifies measures to address these impacts. A human health impact assessment has been carried out for the project and is included in Appendix I (Technical working paper: Health impact assessment).

The Secretary's environmental assessment requirements as they relate to human health impacts, and where in the environmental impact statement these have been addressed, are detailed in Table 13-1 (Secretary's environmental assessment requirements checklist).

Avoiding or minimising impacts has been a key consideration throughout the design and development process for the Beaches Link and Gore Hill Freeway Connection project. A conservative approach has generally been used in the assessments, with potential impacts presented before implementation of environmental management measures. The proposed environmental management measures relevant to human health impacts are discussed in Section 13.6.

Table 13-1 Secretary's environmental assessment requirements – human health

Secretary's requirement	Where addressed in EIS
Health and Safety	
1. The Proponent must assess the potential health risks from the construction and operation of the project.	**Section 13.4** and **Section 13.5** describe the potential human health risks from the construction and operation of the project.
2. The assessment must: a. describe the current known health status of the potentially affected population;	**Section 13.3** describes the potentially affected community and their current health status.
b. describe how the design of the proposal minimises adverse health impacts and maximises health benefits;	**Section 2.3** of **Appendix I** (Technical working paper: Health impact assessment) outlines how health issues have been considered and benefits maximised in project design. Adverse and beneficial impacts associated with the project are discussed in **Section 13.4** and **Section 13.5**.
c. assess human health risks from the operation and use of the tunnel under a range of conditions, including worst case operating conditions and the potential length of motorway tunnels in Sydney;	**Section 13.5** assesses the human health risks associated with the operation and use of the project.
d. human health risks and costs associated with the construction and operation of the proposal, including those associated with air quality, odours, noise and vibration (including residual noise following application of mitigation measures), construction fatigue, and social impacts (including from acquisitions) on the adjacent and surrounding areas as well as opportunity costs (such as those from	**Section 13.4** and **Section 13.5** outline the construction and operational impacts including those related to air quality, noise and vibration, construction fatigue, social impacts and cumulative impacts associated with the project. **Appendix I** (Technical working paper: Health impact assessment) includes consideration of opportunity costs for particulates, noting there are no methods to quantify health costs other than particulates.

Secretary's requirement	Where addressed in EIS
social infrastructure and active transport impacts) during the construction and operation of the proposal;	
e. 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 most exposed receivers and other sensitive receptors (including public open space areas child care centres, schools, hospitals and aged care facilities);	Health related air quality impacts during operation, including cumulative impacts, are discussed in **Section 13.5**.
f. 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;	**Section 13.4** and **Section 13.5** considers pedestrian/public safety during construction and operation. Subsidence is considered in **Chapter 16** (Geology, soils and groundwater). **Chapter 23** (Hazards and risks) includes an assessment of bushfire risks and the handling and use of dangerous goods.
g. assess the opportunities for health improvement;	Beneficial impacts associated with the project are discussed in **Section 13.4** and **Section 13.5**.
h. assess the distribution of the health risks and benefits; and	The distribution of the health related risks and benefits are presented in **Section 13.4** and **Section 13.5**. Consideration of the distribution of noise and air quality impacts are presented in **Chapter 10** (Construction noise and vibration), **Chapter 11** (Operational noise and vibration) and **Chapter 12** (Air quality).
i. include a cumulative human health risk assessment inclusive of in-tunnel, local and regional impacts due to the operation of and potential continuous travel through motorway tunnels and surface roads.	Health related air quality impacts are discussed in **Section 13.5.1** and **Section 13.5.2**.
Air Quality	
2. The Proponent must ensure the AQIA also includes the following: d. an assessment of impacts (including human health impacts) from potential emissions of PM_{10}, $PM_{2.5}$, CO, NO_2 and other nitrogen oxides and volatile organic compounds (eg BTEX) including consideration of short and long term exposure periods;	Health related air quality impacts are discussed in **Section 13.5.1** and **Section 13.5.2**.

Secretary's requirement	Where addressed in EIS
Water – Quality	
1. The Proponent must: c. identify and estimate the quality and quantity of all pollutants that may be introduced into the water cycle by source and discharge point and describe the nature and degree of impact that any discharge(s) may have on the receiving environment, including consideration of all pollutants that pose a risk of non-trivial harm to human health and the environment;	Potential pollutants of concern are identified in **Chapter 17** (Hydrodynamics and water quality) and **Appendix O** (Technical working paper: Surface water quality and hydrology). An assessment of the potential for construction to introduce pollutants into receiving waterways and discharge quantities and locations are provided in **Chapter 17** (Hydrodynamics and water quality). Practical management measures to be adopted for the project are provided in **Chapter 17** (Hydrodynamics and water quality). Management measures to ensure the protection of human health are outlined in **Section 13.6.**
h. demonstrate that all practical measures to avoid or minimise water pollution and protect human health and the environment from harm are investigated and implemented;	Potential pollutants of concern are identified in **Chapter 17** (Hydrodynamics and water quality) and **Appendix O** (Technical working paper: Surface water quality and hydrology). An assessment of the potential for construction to introduce pollutants into receiving waterways and discharge quantities and locations are provided in **Chapter 17** (Hydrodynamics and water quality). Practical management measures to be adopted for the project are provided in **Chapter 17** (Hydrodynamics and water quality). Management measures to ensure the protection of human health are outlined in **Section 13.6.**
Soils	
3. The Proponent must assess whether the land and harbour sediment is likely to be contaminated and identify if remediation is required, having regard to the ecological and human health risks posed by the contamination in the context of past, existing and future land uses.	**Section 13.4** discusses human health risks and impacts due to potential contaminated soil/groundwater exposure. Further details are presented in **Appendix I** (Technical working paper: Health impact assessment). **Section 16.4**, **Chapter 16** (Geology, soils and groundwater) considers areas of potential and known land and harbour sediment contamination, having regard to risks to human and environmental receivers. Further details are presented in **Appendix M** (Technical working paper: Contamination).

13.1 Legislative and policy framework

The human health impact assessment was carried out in accordance with national and international guidance that is endorsed or accepted by Australian health and environmental authorities and is described below.

13.1.1 Principal guidance

Principle guidance used for the assessment of human health impacts included the following:

- *Health Impact Assessment: A Practical Guide* (Harris et al., 2007)
- *Health Impact Assessment Guidelines*, Environmental Health Committee (enHealth, 2001)
- *Environmental Health Risk Assessment: Guidelines for assessing human health risks from environmental hazards: 2012* (enHealth, 2012)
- *Schedule B8 Guideline on Community Engagement and Risk Communication, National Environment Protection (Assessment of Site Contamination Contamination) Measure* (National Environment Protection Council (NEPC), 2013).

13.1.2 Supporting guidance

Supporting guidance for the health implications of air quality impacts included the following:

- *National Environmental Protection (Air Toxics) Measure, Impact Statement for the National Environment Protection (Air Toxics) Measure,* National Environment Protection Council (NEPC), 2003a
- *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), 2009
- *Building 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 (EPA), 2013a
- *Air Quality in and Around Traffic Tunnels*, National Health and Medical Research Council (NHMRC, 2008a)
- State Environmental Planning Policy No. 33 – Hazardous and Offensive Development
- Assessing the environmental burden of disease at national and local levels, Ostro, 2004 (World Health Organisation).

13.2 Assessment methodology

The methodology for the human health impact assessment is aimed at assessing impacts and risks to human health from the construction and operation of the project. The human health assessment has focused on health related impacts associated with key air quality, noise and vibration and social aspects.

13.2.1 Air quality

The assessment methodology for health impacts related to air quality involved:

- Review of Appendix F (Technical working paper: Traffic and transport) and Appendix H (Technical working paper: Air quality (including the in-tunnel ventilation report which is Annexure K to Appendix H)
- Identification of sensitive receivers within potentially impacted communities surrounding the project, and assessment of the current health metrics for those communities
- Assessment of potential human health impacts from key pollutants during construction and operation of the project.

When evaluating human health risks with respect to air quality, the quantification of risk involves the calculation of an increased probability of some adverse health effect, disease or mortality occurring, over and above the baseline incidence of that health effect, disease or mortality in the community. A one in a million chance of developing a certain health effect due to exposure to a substance is considered negligible. The risk scale used for the assessment of incremental air quality exposure is as follows:

- Negligible health related risks – less than one chance in a million
- Tolerable or acceptable health related risks – between one chance in a million and one chance in ten thousand
- Unacceptable health related risks – more than one chance in ten thousand.

Further details of the assessment guidelines adopted is provided in the relevant sections below.

13.2.2 Noise and vibration

The assessment methodology for health impacts related to noise and vibration involved:

- Review of technical assessments including Appendix F (Technical working paper: Traffic and transport) and Appendix G (Technical working paper: Noise and vibration)
- Identification of sensitive receivers within potentially impacted communities surrounding the project, and assessment of the current health metrics for those communities
- Assessment of potential human health impacts associated with the generation of noise during construction and operation of the project.

For the following noise guidelines, the noise assessment criteria adopted relate to levels of noise that can be tolerated or permitted above background before some adverse effect (annoyance, discomfort, sleep disturbance or complaints) occurs:

- *Interim Construction Noise Guideline* (Department of Environment and Climate Change (DECC), 2009a),
- *NSW Road Noise Policy* (Department of Environment, Climate Change and Water (DECCW), 2011)
- *NSW Noise Policy for Industry* (NSW Environment Protection Agency (EPA), 2017a)
- *Construction Noise and Vibration Guideline* (Roads and Maritime Services, 2016a)
- *Noise Criteria Guideline* (Roads and Maritime Services, 2015f).

As annoyance would usually occur before physiological and other health-based impacts, annoyance-based criteria are considered to be conservative from a human health impact perspective. Some of the other criteria are based on specific health impacts such as sleep disturbance for the assessment of night-time noise.

13.2.3 Social

The assessment methodology for health impacts related to social aspects involved:

- Review of all available information relevant to the assessment including:
  - Appendix U (Technical working paper: Socio-economic assessment)
  - Data from the Australian Bureau of Statistics
  - Information relevant to local government areas and health districts (in particular Sydney Local Health District and Northern Sydney Local Health District)
- Identification of sensitive receivers within potentially impacted communities surrounding the project, and assessment of the current health metrics for those communities
- Assessment of potential human health impacts associated with public safety, traffic changes, property acquisitions, impacts on open space, changes in community access and connectivity, visual amenity, construction fatigue, economic access and stress and anxiety issues during construction and operation of the project, including short-term and long-term impacts.

13.3 Existing environment

This section outlines the existing environment as it relates to human health including:

- Potentially impacted receivers within the communities surrounding the project
- The current health status of these communities.

The existing environment for air quality, noise and vibration and social aspects are detailed in the following chapters:

- Chapter 12 (Air quality)
- Chapter 10 (Construction noise and vibration)
- Chapter 11 (Operational noise and vibration)
- Chapter 21 (Socio-economics).

13.3.1 Health status of the community

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 excessive alcohol consumption, smoking, inadequate consumption of fruit and vegetables, being overweight or obese, and inadequate physical activity.

The study population is largely located within the Northern Sydney, Sydney and South Eastern Sydney Area Health Services. Review of this data generally indicates that, when compared to NSW as a whole, the population in the Northern, Sydney and South Eastern Sydney Area Health Service areas (that include the study area) have the following characteristics:

- Lower rates of physical inactivity and of being overweight and obese
- Lower rates of smoking (Northern Sydney Local Health District)
- Lower rates of mortality, except for lung cancer, which was lower in the Northern Sydney Health District only

- Lower rates of hospitalisations, except for cardiovascular disease hospitalisations in the South Eastern Sydney District, which are similar to the rates for NSW
- High or very high rates of psychological distress reported in 2015 in the Sydney Local Health District (13.9 per cent) where rates are slightly higher than the state average. In Northern Sydney (10 per cent) and South Eastern Sydney local health districts (9.3 per cent) rates are slightly lower than the state average (11.8 per cent), however none were substantially different
- High or very high rates of psychological distress in Northern Sydney Local Health District has varied between eight and 15 per cent while in the Sydney Local Health District it has varied between 10 and 15 per cent between 2003 and 2015. In the South Eastern Sydney Local Health District, the rate has declined from around 14 per cent in 2003 to less than 10 per cent in 2015.

Section 3.5 of Appendix I (Technical working paper: Health impact assessment) provides further detail on health related behaviours and health indicators for the study area.

13.3.2 Potentially impacted communities

The potentially impacted communities considered in the assessment include those who live or work within the vicinity of the proposed temporary construction support sites, surface connections (ie where the tunnels would interface with the surface road network), motorway facilities, ventilation facilities and the road network associated with the combined Western Harbour Tunnel and Beaches Link program of works as well the adjoining WestConnex M4-M5 Link. The human health impact assessment study area is an amalgamation of the air quality, noise and vibration, and social and economic study areas.

The human health impact assessment considers community receivers identified in the suburbs close to the project. Community receivers 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. Community receiver locations include hospitals, child care facilities, schools and aged care homes/facilities. Details of the sensitive or community receivers included in the assessment are provided in Chapter 12 (Air quality) and Appendix H (Technical working paper: Air quality).

13.4 Assessment of potential construction impacts

Potential impacts on human health during construction have been assessed below in relation to:

- Air quality
- Noise and vibration
- Social impacts.

The following sections provide a high-level overview of the key considerations in these areas, with further detail provided in referenced environmental impact assessment chapters and appendices.

13.4.1 Health related air quality impacts during construction

Air quality impacts and details of the distribution of impacts in the construction period are presented in Chapter 12 (Air quality).

The assessment of construction air quality was carried out using a qualitative assessment approach for dust, emissions and odour impacts.

The construction air quality assessment found that for almost all construction activities, substantial 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 fully effective all 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.

Measures to manage dust impacts include site management, preparing and maintaining temporary construction support sites and disturbance areas, use of water carts, maintenance and controls on vehicles and machinery, waste management and modifying of site activities during atmospheric conditions conducive to dust generation and emission. The effectiveness of dust control measures would be monitored and adjusted as required to ensure impacts on the health of the community are minimised.

Air quality impacts during construction also include exhaust emissions from the use of plant and equipment. These impacts would be minor and unlikely to have a noticeable impact on the surrounding environment and would be managed through standard management measures.

As part of the marine construction activities for the project, a large amount of material would be dredged from the harbour bed, bringing potentially odorous material to the surface, which has the potential to generate odour once exposed to air. However, odours from dredged material from Middle Harbour are unlikely to be detectable at any sensitive receptor.

For tunnelling works proposed at Flat Rock Reserve, there is a risk of encountering odorous waste material and landfill gases from historical waste landfilling activities in the locality. Detailed investigations have not been carried out to confirm the presence and extent of potentially odorous materials and landfill gases within the project site at this location. The investigation that was carried out, however, did not identify putrescible waste and landfill gases in the vicinity of the locations that would be excavated as part the project. This indicates that the risk of encountering odorous materials and landfill gases is low. Further investigations are proposed prior to commencement of excavations to confirm the potential for odour issues based on the detailed construction methodology and identify appropriate mitigation and management measures (if required) to reduce the potential for odour impacts at sensitive receivers in the vicinity. Further landfill gas investigations should be carried out within these areas to assess the potential presence or absence of gas which could potentially impact upon construction and/or operation of the project if not managed appropriately.

Overall, potential air quality impacts during construction are unlikely to result in any health related impacts.

13.4.2 Health related noise and vibration impacts during construction

Potential noise and vibration impacts during construction are presented in Chapter 10 (Construction noise and vibration). Noise impacts in relation to human health have been considered in relation to sleep disturbance, annoyance, hearing impairment, interference with speech and other daily activities, children’s cognitive function, and cardiovascular health.

Noise that may be generated during construction has been modelled based on the type of equipment to be used, the proximity of community receivers, the hours of work, the duration of the activities carried out and the local terrain. Worst case predicted construction noise levels would occur at any one receiver only infrequently, if at all. Typical construction noise levels would be significantly lower than worst case predictions.

This assessment has considered ground-borne noise from tunnelling and rock-hammering, construction vibration generated from tunnelling, surface works, piling and heavy equipment, and underwater noise impacts associated with the construction of the tunnel in Middle Harbour.

This modelling has identified areas where, if unmitigated, potential noise levels may exceed:

- Day, evening or night noise management levels
- Sleep disturbance criteria, including the criteria for awakening.

Results from this modelling, and associated assessments including distribution of potential impacts, are provided in Appendix G (Technical working paper: Noise and vibration) and discussed in Chapter 10 (Construction noise and vibration).

The measures to manage and mitigate potential health impacts associated with noise and vibration during construction include:

- Location and activity specific assessments to confirm ground-borne noise potential impacts
- Proactive engagement with the community including water users for underwater noise
- Noise and vibration monitoring including during piling activities
- Respite periods.

The following sections describe potential impacts related to noise and vibration criteria, possible human health impacts and proposed environmental management measures.

Construction noise impacts from the movement of construction vehicles

Potential increases in noise for sensitive receivers due to construction traffic have been assessed separately from the assessment of noise from other construction activities. Temporary construction support sites have been configured such that heavy vehicles involved in construction are expected to travel via existing major roadways with minimal use of local roads. Use of the temporary construction support sites is unlikely to increase road traffic noise levels by more than 2 dB(A). This change represents a minor impact that is likely to be barely perceptible.

Ground-borne construction noise

Ground-borne noise occurs when vibration is transmitted through the ground and into building structures, where it then produces an audible noise. The project would involve tunnelling using vibration intensive equipment such as roadheaders and rock hammers that have the potential to generate ground-borne noise. Many of the more significant activities with the potential to generate ground-borne noise would take place at depth (with a large proportion of the mainline and ramp tunnels at depths of 10 metres to greater than 50 metres).

Modelling carried out for potential ground-borne noise impacts contemplated the worst case scenario when the tunnelling is occurring immediately beneath a sensitive receiver. The roadheader excavation would typically progress at around 20 to 30 metres per week subject to local geology and confirmation of the tunnel excavation methods. Roadheader advance rates would reduce to two to five metres a day around the tunnel portals, which may slightly increase the duration of exposure for receivers in these areas. Ground-borne noise would typically increase as the roadheader nears a receiver and decrease as the roadheader moves way. It is noted that receivers might also experience ground-borne noise on multiple occasions, associated with excavation of different (adjacent) tunnel tubes and other subsurface elements such as ventilation shafts, cross-passages and niches for motorway operational equipment.

Ground-borne noise from excavation by the roadheaders may be noticeable in some areas during the evening and during the night for one to two weeks at each affected receiver as the roadheader passes below them. Ground-borne noise from roadheader activity is predicted to exceed the night time noise criteria at about 107 residential receiver buildings. Worst case impacts are likely to occur in locations where the tunnel would be relatively shallow, such as in the immediate vicinity of tunnel on ramps and off ramps or tunnel access declines at Cammeray, Northbridge, Balgowlah, Seaforth and Killarney Heights.

Following the excavation by roadheaders, rock hammers would then be required for sub-surface activities that include tunnel floor (bench) excavation, utility and stormwater trench excavation and excavation of niches for tunnel operational equipment. When rock hammers are in use within the tunnel, there is potential for intermittent audible ground-borne noise within buildings at the surface. The potential ground-borne levels would be influenced by the separation distance between the building and work location, the underlying geology and the structure of building. Where rock hammering has the potential to exceed the relevant criteria for ground-borne noise, it would be scheduled during standard construction hours where feasible and reasonable, reducing the potential for associated amenity impacts during the more sensitive evening and night time period. If rock hammering is required outside standard daytime construction hours, ground-borne noise levels could exceed the night time criteria for up to 638 residential receiver buildings and could

exceed the evening criteria for 419 residential receiver buildings, depending on the location of works. It is noted that there are locations in Cammeray, Naremburn, Northbridge Artarmon and Seaforth where it is predicted that rock hammers could be used outside standard construction hours without exceeding the evening and night time ground-borne noise criteria.

Measures to manage and mitigate potential impacts associated with ground-borne noise include location and activity specific assessments to confirm potential impacts, scheduling, and community notification and engagement to confirm that actual ground-borne noise levels and impacts are not worse than predicted.

Airborne construction noise

Chapter 10 (Construction noise and vibration) identifies residential receiver buildings that are predicted to experience noise levels above the noise management levels, in the absence of additional environmental management measures. In some instances, maximum noise levels are also predicted to exceed the sleep disturbance screening level and awakening reaction levels at several receivers.

Where criteria cannot be met there is the potential for annoyance and adverse health effects, such as sleep disturbance, for the receivers in the vicinity of construction sites, particularly where noise increases of greater than 5 dB(A) over extended periods (over a year or more).

Exceedances of the noise management levels and the number of impacted residential receiver buildings would vary over the duration of construction. For example, the predicted worst case airborne noise levels are only likely to occur when works are at the closest point to each receiver building. However, for many work areas, construction activities are mobile and so construction noise levels might routinely be lower than predicted, reducing the potential for annoyance and health impacts. Further, the mitigation and management measures identified in Chapter 10 (Construction noise and vibration) would be implemented to minimise potential health related impacts on the surrounding community. This includes noise management approaches for works that would occur outside of standard construction hours.

Where the recommended noise management levels cannot be achieved, reasonable and feasible mitigation measures would be implemented to reduce potential impacts. Monitoring would also be carried out periodically throughout all stages of construction to ensure that noise and vibration impacts are being appropriately managed, and the effectiveness of implemented mitigation and management measures. Refer to Chapter 10 (Construction noise and vibration) for environmental management measures.

Construction vibration

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 cause discomfort or structural damage at sensitive receiver locations is based on selecting site-specific suitable plant and methods as well as observing suitable separation distances between the equipment and receiver locations for highly vibration-intensive activities.

Vibration monitoring would be carried out to confirm that the adopted controls are effective and respite periods would be offered to affected residents where human comfort levels are to be exceeded for an extended period during any one day.

Underwater noise impacts

Piling and dredging in Middle Harbour would generate underwater noise. Noise can propagate for long distances underwater.

Piling would be required in Middle Harbour to install immersed tube tunnel unit supporting piles and for the construction of cofferdams adjacent to each shore line. Piling would predominately consist of vibratory piling (in harbour sediments), however impact piling would be required to ensure that piles are adequately bedded into the underlying bedrock. Piling has the potential to generate significant underwater noise levels. Impact piling has the potential to generate significantly higher underwater noise levels than vibratory piling and other proposed underwater construction activities.

Dredging also generates underwater noise levels. The potential for dredging to generate significant noise levels is less than for piling.

Underwater sound pressure levels would likely exceed the precautionary guideline of 145 dB re 1µPa in the vicinity of the proposed piling and dredging locations Middle Harbour (Jasco, 2019). The locations in the vicinity of the piling activities that could experience underwater noise levels in excess of this guideline value would vary depending on the type of equipment and operation being carried out and the bathymetry in the vicinity of the activity location. The precautionary guideline value could exceeded at distances of around two kilometres for impact pile driving. The piling program would be refined during detailed construction planning with the consideration of reasonable and feasible alternatives to reduce potential underwater noise levels. It is, however, unlikely there is a feasible alternative construction methodology that does not involve some impact piling.

For divers, a sudden increase in sound pressure levels could startle, or cause discomfort, dizziness and vertigo. Excessive underwater noise can lead to life-threatening situations.

CNV14 (refer to Section 10.7) commits that impact piling in any given week will be carried out over durations of no more than either two hours each work day or six hours on a single work day, to provide respite to noise affected receivers in the vicinity. This would also limit the frequency of potential underwater noise impacts.

The areas affected by elevated underwater noise levels due to project activities would be managed during construction to minimise the risk of potential amenity and health impacts divers and swimmers. This would include monitoring during the early stages of impact piling activities at each location to measure underwater noise levels and compare against acoustic thresholds to confirm the affected areas and appropriate management measures, and a proactive communication strategy to inform water users and other potential stakeholders of the potential impacts and risks. Management measures would be informed by the final construction methodologies and mitigation measures, and management areas. Environmental management measure HH1 would be reviewed and, if required, amended over the course of the piling program to reflect monitoring outcomes.

13.4.3 Health related social impacts during construction

Social impacts in the construction period are presented in Chapter 21 (Socio-economics).

Health related social impacts are discussed below in terms of:

- Changes in traffic, public transport, access and connectivity
- Public safety and contamination
- Property acquisition
- Open space
- Visual amenity
- Construction fatigue
- Economic aspects.

Measures to manage and mitigate potential health related impacts during construction include:

- Use of communication and traffic control management measures to limit delays and disruptions to road users and for the safety of motorists, cyclists and pedestrians
- Use of silt curtains and a backhoe dredge with a closed bucket attachment to minimise the risk of sediment and contaminants within the sediments being mobilised into the water during dredging
- Management of property acquisition impacts through a property acquisition support service and in accordance with the *Land Acquisition (Just Terms Compensation) Act 1991* (NSW) and the land acquisition reforms announced by the NSW Government in 2016.

- Design of the project to optimise opportunities for the repurposing of remaining project land at Balgowlah to provide new open space and recreation facilities for the community. The residual land would progressively become available through the construction period for use by the community
- Consideration of construction fatigue as when developing the detailed project design and construction methodology to mitigate these impacts where possible.

The following sections describe the potential impacts, possible human health impacts and proposed environmental management measures.

Changes in traffic, public transport, access and connectivity

Changes in traffic, access and connectivity during construction are presented in Chapter 8 (Construction traffic and transport). During construction, potential short-term impacts may include:

- Temporary changes to road conditions, which could include partial and full road closures, diversions and access changes, removal of some on-street parking and reductions in speed limits, changes to property accesses
- Temporary increased construction traffic on roads leading to longer travel times and potentially impacting on community perceptions of safety for motorists, cyclists and pedestrians if not appropriately managed
- Temporary disruptions to public transport services, and changes to road conditions and the temporary relocation of some bus stops near construction works for safety, resulting in possible delays and disruptions for bus users and changes in bus access for some people
- Temporary changes to pedestrian and cycle access near to construction works, resulting in possible disruptions which may result in delays and disruptions to commuters
- Temporary changes to property access near construction works, with suitable access arrangements to be implemented
- Temporary relocation of moorings in the vicinity of works in Middle Harbour, with relocated moorings to be placed as close as possible to their original locations during construction and restored where possible to the original position on completion of construction
- Temporary adjustments to bus priority infrastructure on Burnt Bridge Creek Deviation in Balgowlah would also be required, resulting in a minor increase in bus travel times
- Temporary changes and diversions to pedestrian and cyclist networks have the potential to affect commuter departure times, travel durations, movement patterns and accessibility.

Changes to traffic, access and connectivity during construction have the potential to result in short-term increased levels of stress and anxiety in the local community. Traffic impacts would be managed through standard communication and traffic control management measures, which would limit delays and disruptions to road users as well as ensuring the safety of motorists, cyclists and pedestrians, in consultation with the relevant road authorities.

Public safety and contamination

A range of potential hazards were considered that have the potential to affect public safety during construction of the project. There would be no issues related to construction that have the potential to result in significant safety risks to the community.

Known and potentially contaminated sites, and potential contamination impacts are discussed in Chapter 16 (Geology, Soils and Groundwater). Contamination risk issues to the community would be associated with construction phase of the project, when exposure to contaminated soil, sediment or groundwater would most likely occur during the excavation and construction works. If contamination is identified in construction, measures including the development of appropriate Remediation Action Plans would be put in place so the health of the local community is not impacted.

Sediment sampling was carried out within the proposed locations of Middle Harbour crossing and temporary construction support sites (Douglas Partners and Golder Associates, 2017, Appendix M (Technical working paper: Contamination)). Where sediments require excavation and removal to facilitate construction, the use of silt curtains and a backhoe dredge with a closed bucket attachment would minimise the risk of sediment and contaminants within the sediments being mobilised into the water during dredging. This control in conjunction with the behaviour of sediment bound contaminants means it is unlikely that water quality would be significantly impacted by contaminants mobilised from dredging and marine construction activities (Appendix Q (Technical working paper: Marine water quality).Provided the proposed management measures are adopted, it is expected there would be negligible impacts to human health associated with recreational exposures in areas surrounding the proposed works.

Property acquisition

Property acquisition impacts are presented in Chapter 20 (Land use and property).

The project has been designed to minimise the need for property acquisitions. Wherever possible, temporary construction support sites have been located to minimise the overall property acquisition requirements, as well as impacts on heritage items and ecologically sensitive areas.

The acquisition and relocation of households and businesses due to property acquisition could disrupt social networks and affect health and wellbeing due to raised levels of stress and anxiety. Both a house and a workplace are central to daily routines and the location of these premises influences how a person may travel to/from work or study, the social infrastructure and businesses they visit and the people they interact with.

Impacts associated with property acquisition would be managed through a property acquisition support service and in accordance with the *Land Acquisition (Just Terms Compensation) Act 1991* (NSW) and the land acquisition reforms announced by the NSW Government in 2016.

Loss of open space

Open space (also referred to as 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. Epidemiological studies have been carried out that show a positive relationship between open space and health and wellbeing (de Vries et al. 2003, Health Scotland et al. 2008, Kendal et al. 2016, Maas et al. 2006, Mitchell & Popham 2007). The health benefits of open space in urban areas include the following:

- Protection of people from environmental exposures associated with air pollution and extreme temperature (by regulating microclimates and reducing the urban heat island effect)
- Reduced morbidity
- Improved opportunities for physical activity and exercise
- Improved mental health and feelings of wellbeing, particularly lower stress levels
- Improved opportunities for social interactions.

There are several existing sporting/recreation facilities and parks in the project area that would be impacted by the project including sporting fields, parks and reserves and playgrounds. Impacts on these open spaces include:

- Temporary and permanent loss of a portion of land, including recreation land at Artarmon Park and Cammeray Golf Course, noting that works have been designed to ensure that the golf course can continue to function as a nine hole golf course, subject to some reconfiguration during the construction phase that would temporarily affect golf activities
- Permanently acquiring or temporarily leasing parts of the Balgowlah Golf Course, with construction resulting in the permanent closure of the golf course. However, the project would return an area, equivalent to around 90 per cent of the current open space, to the community as new and improved public open space and recreation facilities

- Temporary use of parks and open space areas for temporary construction support sites (for example parts of Artarmon Park adjacent to Gore Hill Freeway, Flat Rock Reserve and the Spit West Reserve) resulting in the temporary loss of access to and use of land within the construction footprint
- Reduced amenity due to construction activities and temporary construction support sites and changes in noise, dust and visual environment, detracting from the use and enjoyment for users of social infrastructure near the project.

The loss of open space associated with construction of the project would be short term, except for permanent land loss at Balgowlah Golf Course. Other golf courses are accessible in the area and hence, while some additional travel may be required, recreational golf activities are not expected to be substantially affected overall. Alternative open space is located in the area and can be easily accessed by the community, and so the potential effects on community health associated with the temporary use of parks and open space areas during construction would be minimal. The reduced amenity may affect the desirability of active recreational use of some areas. Other recreation areas are available and accessible in the community, hence the potential impact on community health is considered to be minimal. The project has been designed to optimise opportunities for the repurposing of remaining project land at Balgowlah. Residual land, primarily to the east and north of the new access road, would progressively become available through the construction period, which would facilitate re-purposing it to the new and improved open space and recreation facilities. This would allow it to be handed over progressively for use by the community. The new open space and recreation facilities to the west of the proposed access road, between the access road and Burnt Bridge Creek Deviation, would be constructed and handed over to Northern Beaches Council after completion of the project.

Visual amenity

Landscape and visual impacts are presented in Chapter 22 (Urban design and visual amenity).

Visual amenity can be described as the pleasantness of the view or outlook of an identified receiver or group of receivers (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.

During construction, visual amenity throughout the project area has the potential to be affected by factors such as the removal of established vegetation, the installation of construction hoardings and noise barriers and/or the visual appearance of temporary construction support sites. In some areas, the acoustic sheds, hoardings and noise barriers required to manage noise impacts during construction are large and may cause overshadowing. Further factors affecting visual amenity may include the temporary change of view corridors to heritage, open space, water bodies or the city skyline.

For some individuals, changes in visual amenity can increase levels of stress and anxiety. These impacts, however, are typically of short duration as most people adapt to changes in the visual landscape, particularly within an already urbanised area. As a result, most changes in visual impacts are not expected to have a significant impact on the health of the community. Design development has been influenced by urban design principles that have been established for the project, including integrating the project elements and infrastructure into the surrounding environment.

Construction fatigue

Construction fatigue relates to receivers that experience construction impacts from a variety of projects over an extended period 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.

The assessment of construction fatigue in this report includes the following projects that may immediately precede or overlap with the construction phase of the project:

- Western Harbour Tunnel and Warringah Freeway Upgrade (North Sydney, Cammeray and Artarmon)
- Sydney Metro City & Southwest (Chatswood to Sydenham).

As outlined in Chapter 27 (Cumulative impacts), the potential cumulative impacts during construction of the project based on likely interactions with other projects may occur around North Sydney and Cammeray, Artarmon, and Naremburn and Willoughby. Cumulative impacts could be generated by interactions between the project and the Western Harbour Tunnel and Warringah Freeway Upgrade at North Sydney, Cammeray and Artarmon and the Sydney Metro City & Southwest (Chatswood to Sydenham) at Artarmon. Potential impacts considered most likely to result in construction fatigue include construction traffic and parking, construction noise and vibration, visual and amenity impacts, and impacts to community perceptions of public health and safety. There is also potential for residential receivers around Naremburn and Willoughby to experience construction fatigue as a result of the project and its proximity to Western Harbour Tunnel and Warringah Freeway Upgrade construction sites. Construction fatigue at this location is likely to be limited to temporary increases in construction noise and are expected to be minor.

The project design and construction methodology has been developed with consideration of these impacts and attempts to mitigate many of these where possible. The community consultation framework presented in Chapter 7 (Stakeholder and community engagement) and Appendix E (Community consultation framework) has also been developed with consideration of complaint fatigue and includes procedures to proactively manage this issue where feasible and reasonable. Potential cumulative construction impacts would be managed in accordance with the measures outlined in Chapter 27 (Cumulative impacts).

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. 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.

It is noted that both positive and negative effects may occur for some businesses during construction activities. While construction activities may bring greater demand from construction workers, lack of access to businesses through reduced parking and physical barriers could impact on local economies. Specific consultation would be carried out with businesses potentially impacted during construction. Consultation would aim to identify specific potential construction impacts for individual businesses. Based on consultation with businesses potentially impacted, feasible and reasonable measures would be identified and implemented to minimise business impacts.

13.5 Assessment of potential operational impacts

Impacts on human health during operation have been assessed below in relation to:

- Air quality impacts outside the tunnels
- Air quality impacts inside the tunnels
- Noise and vibration impacts
- Social impacts.

Some of the key findings of the assessments, as discussed below, indicate:

- There would be no significant changes in the incidence of health impacts associated with exposure to NO_2 in the community as a result of the project

- Concentrations of total particulate matter ($PM_{2.5}$ and PM_{10}) within the local community would essentially remain unchanged in most cases with the operation of the project. The potential incident of health impacts associated with exposure to particulate matter is anticipated to remain unchanged as a result of the project
- No health impacts due to exposures to CO are anticipated in the local area surrounding the project as a result of the project
- No significant health impacts are anticipated within the tunnel due to exposures to vehicle emissions under any plausible traffic and tunnel operational scenarios
- For most receivers assessed, the project would result in either reduced or relatively minor changes in traffic noise levels. In areas where there is a reduction in traffic noise there would be associated health benefits in these communities
- Where traffic noise levels are predicted to increase, additional mitigation measures would be implemented to reduce potential amenity and associated health impacts
- Public safety is anticipated to improve as a result of improvements to road safety with reduced traffic volumes along key road transport corridors
- New or upgraded pedestrian and cyclist infrastructure is anticipated to encourage increased active transport, with associated improvements in community health and wellbeing
- Most changes in visual impacts are not expected to have a significant impact on the health of the community.

13.5.1 Health related ambient air quality impacts during operation

Air quality impacts and details of the distribution of impacts outside of the tunnel during operation, are presented in Chapter 12 (Air quality). The tunnel ventilation system and tunnel operational parameters for the project have been designed to ensure the in-tunnel air quality concentration limits are not exceeded under any plausible tunnel operation scenarios, including major breakdowns, and to control the concentration of pollutants discharged to the external environment.

The assessment of impacts on air quality associated with the operation of the project considered a range of expected traffic scenarios that includes the operation of the project in 2027 and 2037 ('Do something'), both with and without the project and including other projects ('Do something cumulative'). For further details of the scenarios considered, refer to Chapter 12 (Air quality).

This assessment included a calculation of the emissions from vehicles using the tunnel and surface roads in the vicinity under expected traffic conditions (ie operating normally with traffic volumes fluctuating over the day to reflect peak and out of peak periods).

In addition, a regulatory worst case scenario has been evaluated. The regulatory worst case assumes the emissions from the ventilation outlets are at the maximum levels permitted by regulatory criteria at all hours of the day. While not a realistic scenario, it is used to demonstrate that contributions from the ventilation outlets to air quality at ground level under even the most extreme of conditions would still be negligible. Further detail is available in Section 5.10 of Appendix I (Technical working paper: Health impact assessment).

Health related air quality impacts outside of the tunnel have been assessed for nitrogen dioxide, particulate matter, carbon monoxide and air toxics. Health related air quality impacts associated with particulate matter on elevated receivers have also been assessed.

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 nitrogen dioxide (NO_2). In Sydney, it was estimated that on-road vehicles account for about 55 per cent of emissions of nitrogen oxides, industrial facilities account for 13 per cent, other mobile sources account for about 27 per cent with the remainder from domestic/commercial sources (NSW EPA, 2019).

NO_2 is the only oxide of nitrogen that may be of concern to health (World Health Organisation (WHO), 2000). NO_2 can cause inflammation of the respiratory system and increase susceptibility to respiratory infection. 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 Environment Protection Authority and National Environment Protection Council (NEPC) (NEPC, 2003b) that indicate acceptable concentrations of NO_2. The assessment of acute exposures relates to the maximum predicted total one-hour average concentration in air and considers the 'Do minimum', 'Do something' and 'Do something cumulative' scenarios. An acute exposure guideline of 246 micrograms per cubic metre of NO_2 in air over a one-hour average period has been adopted for the project. The assessment of chronic exposures relates to the maximum predicted annual average concentration in air, and considers the 'Do minimum', 'Do something' and 'Do something cumulative' scenarios. A chronic exposure guideline of 62 micrograms per cubic metre of NO_2 in air, averaged over a year, has been adopted for the project. An uncertainty factor of two was applied to both the acute and chronic exposure guidelines to account for susceptible people (ie asthmatic children). On this basis, the acute and chronic exposure guidelines are protective of adverse health effects in all individuals, including sensitive individuals 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

As there is no clear community threshold established for acute exposures to NO_2, the assessment of incremental exposures is of most relevance to potential human health impacts and is discussed further below.

Assessment of chronic exposures

The National Environment Protection Council 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 (NEPC, 2003b).

The assessment completed for the project indicates that all concentrations of NO_2 would be below the chronic guideline by more than 15 micrograms per cubic metre for all scenarios. Therefore, no adverse health impacts would be expected as a result of chronic exposures to NO_2 from the project.

Assessment of incremental exposures

The assessment indicates that the individual risks (ie of mortality (respiratory and all causes) and asthma admissions) calculated for changes in NO_2 levels associated with the project would be less than one in ten thousand for residential areas, commercial/industrial areas, childcare centres, schools, aged care homes and open space areas and all community receivers and would therefore be considered tolerable and acceptable.

Review of the calculated impacts in terms of the change in incidence of the relevant health impacts associated with exposure to NO_2 in the whole community, associated with the 'Do something' and 'Do something cumulative' scenarios, indicates the following:

- The total change in the number of cases relevant to the health impacts evaluated, for both 2027 and 2037 ('Do something' and 'Do something cumulative') is negative, meaning a decrease in incidence as a result of the project (due to the redistribution of traffic on surface roads). The change, however, is small, with a decrease of approximately one case, this change would not be measurable within the community
- 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. Overall, there are no individual suburbs within the Local Government Areas (LGAs) where there is a change in incidence that is of significance or would be measurable.

Overall, there would be no significant changes in the incidence of health impacts associated with exposure to NO_2 in the community as a result of the project.

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.

Particulate matter has been linked to adverse health effects after both short-term and long-term exposure. 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 sizes 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 National Environment Protection Council and NSW Environment Protection Authority air quality goals and guidelines/standards for particulate matter are presented in Chapter 12 (Air quality).

The assessment of potential health impacts associated with particulate matter generated by vehicles using the tunnel considered both total exposure impacts and incremental exposure impacts associated with changes in $PM_{2.5}$ and PM_{10} concentrations as a result of the project.

The assessment of total exposures involves the assessment of total concentrations of particulate matter in the air from all sources including the project and considers background air quality data for the project.

To assess potential risks to human health that may be associated with localised changes (or redistribution) in exposures to $PM_{2.5}$ and PM_{10} that relate to the project, an assessment of incremental impacts was carried out.

Consideration of opportunity costs associated with particulate matter impacts is provided in Section 5.12 of Appendix I (Health Impact Assessment).

Assessment of total exposures

Due in large part to the existing levels of $PM_{2.5}$ in the air within the urban environment, the maximum total concentrations of $PM_{2.5}$ are above the guidelines for both the 24-hour average and the annual average (including the 2025 goal set by NEPC (2016) with or without the operation of the project. 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, would be essentially unchanged or slightly lower in most cases within the study area with the operation of the project only ('Do something') and in conjunction with other road tunnel projects by 2037 ('Do something cumulative').

Similarly, the maximum total concentrations of PM_{10} would exceed the 24-hour average guidelines. The maximum total concentrations of PM_{10} would also exceed the annual average guideline in most cases with or without the operation of the project but would be below the guideline in the cumulative scenario ('Do something cumulative'). The elevated levels of total PM_{10} is due to the existing levels of PM_{10} in the air within the existing urban environment. These elevated background levels would be present in the community regardless of the operation of the project. Concentrations of total PM_{10}, however, are essentially unchanged in most cases within the local community with the operation of the project in 2027 and 2037.

Assessment of incremental exposures

The calculated changes in risk (associated with individual mortality, cardiovascular illness, respiratory or asthma hospitalisations, and lung cancer) associated with the expected operation of the project in 2027 and 2037 ('Do something'), including the cumulative scenarios ('Do something cumulative') indicates the maximum risks associated with the changes to $PM_{2.5}$ and PM_{10} concentrations would be less than or equal to one in ten thousand, for exposures in residential, commercial and industrial areas, childcare centres, schools, aged care homes and open space areas. This is considered to be tolerable or acceptable.

A review of the calculated impacts in terms of the change in incidence of the relevant health impacts for $PM_{2.5}$ in the community (being the change in the number of cases per year of mortality, hospital or emergency department admissions), indicates the following:

- The total change in the number of cases (totals for each local government area considered) relevant to the health impacts evaluated for the project in 2027 ('Do something') are mostly negative, meaning an overall decrease in incidence as a result of the project. The number of cases, however is small, with a decrease of approximately one case. This change would not be measurable within the community
- Within these local government areas there are several smaller suburbs. 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 would be less than one case per year. Therefore, there would be no individual suburbs within the LGAs assessed for which the increased health incidence would be of significance or measurable.

Assessment of elevated receivers

The air quality impact assessment (Appendix H (Technical working paper: Air quality)) carried out a screening assessment of potential issues related to exposures that may occur at elevated receivers to model concentrations of $PM_{2.5}$ at 10 metres, 20 metres, 30 metres and 45 metres above ground level in the 'Do something cumulative 2037' scenario. These heights were chosen as a representative of potential exposures that may occur in multi-storey buildings. The assessment has evaluated the impacts at these heights across the study area, regardless of whether a multi-storey building is present or not, as well as receivers that do currently exist at these heights. For existing receivers, more than 90 per cent of the receiver buildings assessed have a height of less than 10 metres, with less than 0.5 per cent having a height of 40 metres or more.

The calculated health risks associated with changes in annual $PM_{2.5}$ concentrations for elevated receivers at 10, 20 and 30 metre heights would range from negligible to acceptable and are not in areas where elevated receptors are currently present.

Further assessment (see Annexure H of Appendix I (Technical working paper: Health impact assessment)) was carried out relating to exposure to NO_2 and volatile organic compounds within in 300 metres of the ventilation outlets for the project, at the Warringah Freeway, the Gore Hill Freeway, the Burnt Bridge Creek Deviation and Wakehurst Parkway. Based on the assessment carried out, the following was identified:

- The assessment of potential health risks for elevated receptors is dominated by the assessment of individual risks relevant to changes in NO_2 and $PM_{2.5}$
- No unacceptable risks have been identified considering existing and expected traffic emissions
- For the regulatory worst case emissions, unacceptable risks have been identified for elevated receptors in the 300 metres adjacent to ventilation outlets at the Warringah Freeway, the Gore Hill Freeway and the Wakehurst Parkway for elevated receptors that may be present at 45 metres height.

The implications of this assessment on surrounding land use is discussed in considered in Chapter 20 (Land use and property). Land use considerations would be required to manage any

interaction between the project and future development for buildings with habitable structures above 20 metres within 300 metres of the ventilation outlet.

Carbon monoxide

Motor vehicles are the dominant source of carbon monoxide (CO) in the air (NSW Department of Environment, Climate Change and Water (DECCW, 2010a)). Adverse health effects of exposure to CO 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).

The assessment completed for this project indicates that all concentrations would be below the relevant health-based guidelines presented in the *National Environment Protection (Ambient Air Quality) Measure* (NEPC, 2003b), which is consistent with international guidelines currently prescribed by the WHO (2005) and USEPA (2011). Therefore, no acute or chronic health impacts are expected as a result of the project for all scenarios in relation to exposures to CO in the local area surrounding the project.

Volatile organic compounds and polycyclic aromatic hydrocarbons

Air toxics assessed for the project include volatile organic compounds (VOCs) and polycyclic aromatic hydrocarbons (PAHs) and are associated with emissions from vehicles using the mainline tunnels and adjacent surface road network. From a toxicity perspective, the key VOCs from vehicle emissions that have been considered 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 (NSW EPA, 2019).

The assessment of acute and chronic exposures of air toxics involves calculating a hazard index for each pollutant, which is the ratio of the maximum predicted concentration of the pollutant to their respective guidelines. Each individual hazard index is added up to obtain a total hazard index for all the air toxics considered. The total hazard index is a sum of the potential hazards associated with all the air toxics together assuming the health effects are additive, and is evaluated as follows (enHealth, 2012):

- A total Hazard Index less than or equal to one means all the maximum predicted concentrations are below the health based guidelines and there are no additive health impacts of concern
- A total Hazard Index greater than one means the predicted concentrations (for at least one individual compound) are above the health based guidelines, or there are at least a few individual air toxics 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.

Assessment of acute exposure

The assessment indicates the total Hazard Index predicted for acute exposures to VOCs would be less than one for the ‘Do something’ and ‘Do something cumulative’ scenarios for 2027 and 2037. Based on this, there would be no acute risk issues predicted in the local community as a result of the project.

Assessment of chronic exposure and incremental lifetime carcinogenic risk

For the assessment of chronic exposures to VOCs and PAHs, the total Hazard Index associated with exposure to the predicted maximum concentrations would be less than one for the ‘Do something’ and ‘Do something cumulative’ scenarios for 2027 and 2037. 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 four in one hundred thousand and are considered to be tolerable. The approach adopted is expected to overestimate concentrations of PAHs in air. Hence the calculations presented are a conservative upper limit estimate. Based on

this, there would be no chronic health risk issues predicted in the local community as a result of the project.

13.5.2 Health related in-tunnel air quality impacts during operation

Air quality in-tunnel impacts in the operational period are presented in Chapter 12 (Air Quality). The tunnel ventilation system would be designed and operated so that the operational in-tunnel air quality limits would not be exceeded. The ventilation report is provided as Annexure K to Appendix H (Technical working paper: Air quality).

Health related in-tunnel air quality impacts in operation have been assessed for nitrogen dioxide, particulate matter, carbon monoxide and carbon dioxide. This includes cumulative exposures for users of the project and connected tunnel network, or frequent users of the tunnel network.

Nitrogen dioxide

A study of nitrogen dioxide (NO_2) concentrations inside vehicles travelling in Sydney and using existing road tunnels was commissioned by Roads and Maritime Services (now Transport for NSW) in 2016 (Pacific Environment Limited (PEL), 2016) to better understand the relationship between NO_2 outside the vehicle, and inside the vehicle. Within existing tunnels investigated in the study, trip average concentrations of NO_2 were generally less than 0.15 parts per million (ppm) (PEL, 2016). During periods of high traffic volumes and a high proportion of heavy vehicles, the trip average concentrations inside the M5 East tunnels have been recorded in excess of the 0.5 ppm criterion, with levels up to 0.7 ppm. The average concentrations inside the vehicles when ventilation was on recirculation, however, were less than 0.2 ppm. The most recent tunnels in Sydney are designed to ensure that trip average concentrations of NO_2 do not exceed the 0.5 ppm criterion.

The project's ventilation systems have been designed to achieve the in-tunnel air quality criteria for NO_2 of 0.5 ppm (tunnel average as a rolling 15-minute average) for all traffic scenarios, including the worst case variable speed and breakdown scenarios. Recent reviews of health effects of exposure to NO_2 supports the NO_2 criteria for up to 60 minutes of exposure (NSW Health, 2018).

The average concentration in the tunnels considered in the 'Do something cumulative' scenario in 2037 would vary throughout the day, with the average concentration through the entire tunnel (trip average) would be expected to be (at most) around 0.25 ppm, which is less than the in-tunnel limit of 0.5 ppm. Lower average concentrations may occur within vehicles with windows up and ventilation on recirculation. A summary of the health effects of short-term exposures to NO_2 is provided in Section 6.3 of Appendix I (Technical working paper: Health impact assessment). As discussed in Appendix I, no significant health impacts are expected as a result of the project from exposures to NO_2 within vehicles using the tunnels, as the trip average concentrations would be below 0.5 ppm.

Individuals using motorbikes would not have the opportunity to reduce exposure inside the tunnel through the use of vehicle ventilation controls. However, the time spent inside tunnels under congested conditions would be less than other users given their ability to lane filter during heavy traffic.

The in-tunnel NO_2 criterion may not be protective of all health effects for all individuals. For severe asthmatic individuals travelling by motorcycle or within vehicles where advice to keep windows up and ventilation on recirculation is not adopted, there is the potential for these individuals to experience some minor change in respiratory response after using the tunnels following prolonged exposure (refer to Section 6.3 of the Appendix I (Health impact assessment)).

For individuals involved in occupations that may require more regular use of the road network, such as point to point transport and courier drivers, there is the potential for these individuals to make more frequent and varied trips over different travel segments in any one day. For these drivers, it is important that they keep their windows up and vehicle ventilation on recirculation to minimise exposures throughout the day.

Particulate matter

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.

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 tunnels). It is expected the concentration of particulate matter within the tunnels would be higher than ambient air concentrations, and the concentration of particulate matter would increase with increasing distance travelled through the tunnels.

Exposures that may occur within the tunnels would be consistent with expected variability of exposure to particulate matter throughout any day where a range of activities are carried out in an urban setting. Keeping windows closed and switching ventilation to recirculation has been shown to reduce exposures inside the vehicle by up to 80 per cent (NSW Health, 2003). While noting no guidelines are available for very short duration exposures, this would further reduce exposure to motorists.

In congested conditions inside the tunnels, it is not considered likely that significant adverse health impacts would occur.

Carbon monoxide

The operational in-tunnel limits for CO have been adopted based on the conditions of approval for other Sydney road projects. The assessment indicates there would be no health issues of concern related to in-tunnel exposures to CO. Furthermore, closing vehicle windows and switching the ventilation to recirculation can reduce exposures by about 70 to 75 per cent for CO.

Carbon dioxide

A study was carried out on behalf of Transport for NSW (enRiskS, 2017) to determine carbon dioxide (CO_2) levels for passengers in vehicles travelling through tunnels (ie to represent the likely conditions for the project). This study found that for passengers in vehicles travelling through tunnels for a period of up to an hour, levels of CO_2 would not be expected to adversely affect driver safety. However, for periods of exposure up to two hours where ventilation is left on recirculation, levels of CO_2 inside a vehicle where there are one or more passengers may affect an already fatigued driver.

The assessment indicates that where Transport for NSW provides specific advice to drivers entering road tunnels to put vehicle ventilation on recirculation, further advice may need to be provided that recirculation should be switched off at some point after using the tunnel network and not left on for an extended period of time. However, this situation would be considered rare as travel time in the tunnels is unlikely to be for such extended periods.

Overall, no significant health impacts related to exposure to CO_2 would be expected in the operation of the project.

13.5.3 Health related noise and vibration impacts during operation

Noise and vibration impacts in the operational period are presented in Chapter 11 (Operational noise and vibration). Sound is a natural phenomenon that only becomes noise when it has some undesirable effect on people or animals. Noise and vibration can potentially 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 potential effects which may occur, 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)
- Tinnitus (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.

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 carried out to address impacts associated with the operation of the project in 2027 and 2037 ('Do something'), including a cumulative scenario ('Do something cumulative'). The modelling has evaluated noise impacts at the façade of all buildings, including on all floors of multi-storey buildings. An assessment was carried out 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 ± 2 dB(A).

For most receivers assessed, the project would result in either reduced or relatively minor changes in traffic noise levels. In areas where there is a reduction in traffic noise, as a result of the project due to a decrease in traffic volumes on parts of the surface road network, there would be associated health benefits in these communities. However, the assessment also predicts that without mitigation, incremental noise increases greater than 2 dB(A) would be experienced at several properties adjacent to the project during operation, which may result in health impacts if not appropriately mitigated. Additionally, many properties have been identified where cumulative noise levels exceed the relevant guidelines, with and without the project.

Mitigation measures considered to address potential road traffic noise levels during operation would principally involve the use of quieter pavements, noise barriers and at-property treatments. The use of the use of quieter pavements and noise barriers are favoured, as they provide a benefit to external and internal spaces. Even with appropriate mitigation measures in place, however, 616 buildings under the 'Do something cumulative' scenario are still predicted to be eligible for consideration for at-property treatment. It is noted, however, that most receivers predicted to experience exceedances of the operational road traffic noise criteria already experience exceedances (ie the reason for additional mitigation is existing noise levels, rather than predicted increases due to the project). In this regard, installation of at-property treatments would also be addressing existing road traffic noise and amenity issues and the project would have a positive impact on community amenity and health. Further details are presented in Chapter 11 (Operational noise and vibration).

Where there are predicted increases in road traffic noise and the specific individuals impacted do not take up the recommended at-property treatments, there is the potential for adverse health effects including increased levels of noise annoyance and sleep disturbance. While of at-property treatments can reduce impacts within a dwelling, they do not generally reduce noise levels in external areas. The number of properties subject to increases in noise levels which may be of concern to health as a result of the project, however, is very small. If at-property treatments area appropriate and are installed at the properties, the impact on road traffic noise levels within dwelling will be adequately reduced and no significant health impacts are expected.

13.5.4 Health related social impacts during operation

Social impacts in the operation period are presented in Chapter 21 (Socio-economics).

Health related social impacts are discussed below in terms of:

- Changes in traffic, public transport, access and connectivity
- Public safety
- Open space
- Visual amenity
- Economic aspects and
- Road tolling.

Changes in traffic, public transport, access and connectivity

Changes in traffic, access and connectivity during operation are presented in Chapter 9 (Operational traffic and transport).

The project would improve regional access and connectivity for road based public transport, freight and servicing, private vehicles and other road users by providing an alternate crossing of Middle Harbour. The project would improve travel times on the Military Road/Spit Road corridor, Warringah Road and Eastern Valley Way. It would enable better access to jobs and businesses, with direct access to the new Northern Beaches Hospital at Frenchs Forest, and better access to businesses on the Northern Beaches from Greater Sydney. The project would also enhance the resilience of the road network due to reduced demand on other surface roads, including Frenchs Forest Road and the Ourimbah Road, and would enable a major reduction of heavy vehicle traffic on the Warringah Road, Spit Road and Military Road corridor. The substantial additional travel that would be facilitated by the project would also increase localised traffic demands at either ends of the project where it would be integrated with the existing transportation network. At some locations there would be some residual delay at these interface precincts. This includes some increases in localised delays for traffic through French Forest, particularly on Warringah Road and Wakehurst Parkway as a result of changes to traffic patterns caused by the project. In such cases localised delays at these precincts would be offset by the strategic travel time benefits provided by the project at the broader network level.

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. From a public transport network perspective, the project, once complete, is expected to improve access to public transport and improve journey times for buses for local and regional communities.

Public safety

A range of potential hazards were considered that have the potential to affect public safety during the operation of the project, principally in relation to traffic accidents. It was identified there are no issues related to operation that have the potential to result in significant safety risks to the community.

Improvements to road safety with reduced traffic volumes along key road transport corridors, and new or upgraded pedestrian and cyclist infrastructure would improve pedestrian and cyclist safety. Therefore, there would be a beneficial health impact in terms of public safety.

Open space

The health benefits of greenspace are described in Section 13.4.3. Impacts on greenspace during operation are summarised below.

Cammeray Golf Course

The project would occupy parts of the golf course acquired as part of the Western Harbour Tunnel and Warringah Freeway Upgrade project to accommodate a temporary construction support site and Beaches Link motorway facilities (including an access road) (see Section 13.4.3). This would require the reconfiguration of the golf course to allow its ongoing use, noting that golf activities would likely be temporarily affected during the reconfiguration. The site would initially be established as a temporary construction support site for the Western Harbour Tunnel and Warringah Freeway Upgrade project. Potential impacts to the golf course were assessed as part of the environmental impact statement for Western Harbour Tunnel and Warringah Freeway Upgrade (Transport for NSW, 2020b).

The establishment of the operational facilities would change the visual setting of this location, when viewed from within the golf course and adjoining sporting facilities, and surrounding locations, including the Warringah Freeway and Ernest Street.

Landscaping and other architectural treatments would be provided to reduce the visual impacts of these facilities when viewed from some locations.

Artarmon Park

The project would require the permanent acquisition of a portion of land at Artarmon Park to accommodate road infrastructure associated with the Gore Hill Freeway Connection. This is not expected to impact on the ongoing use or functioning of the park and facilities within the park.

Balgowlah Golf Course

Acquisition and temporary leasing of Balgowlah Golf Course during construction (see Section 13.4.3) would result in the permanent closure of the golf course (and club). This would require members and visitors to access golf courses elsewhere, impacting on social networks associated with the club. It is likely some members would use the closure of the club as a reason to stop playing golf. This is most likely to be long-term members or older golfers, potentially impacting individuals' general levels of physical activity, and overall wellbeing associated with the possible loss of social networks and personal relationships.

However, engagement with Northern Beaches Council has identified potential for the residual land to be returned as new and improved open space and recreation facilities. Use of the residual land for such facilities would align with the Northern Beaches Sportsground Strategy (Northern Beaches Council, 2017a) and address the current under supply of sporting grounds available for public use in the local area.

A dedicated consultation process jointly led by Transport for NSW and Northern Beaches Council would take place to give the community an opportunity to provide input on the final layout of the new and improved open space and recreation facilities at Balgowlah. This consultation would be separate to the consultation for the environmental impact statement. This process would start after the environmental impact statement public exhibition period and well in advance of construction starting. As part of this consultation process, a community reference group would be established,

with representative stakeholder groups and the community, to support Transport for NSW and Northern Beaches Council with the development of this important public space. The project would return an area, equivalent to around 90 per cent of the current open space, to the community as new and improved public open space and recreation facilities.

Spit West Reserve

Land within Spit West Reserve affected by the project during construction would be rehabilitated and reinstated and no operational impacts would be expected.

Flat Rock Reserve

Land affected by the project at Flat Rock Reserve during construction would be rehabilitated and reinstated. The final land use of the temporary construction support site after project completion would be subject to further consultation with Willoughby City Council and the community. No operational impacts would be expected.

Visual amenity

The operational project would include changes to local visual amenity due to the presence of new and amended infrastructure (including motorway facilities, ventilation outlets, water treatment plants, substations, bridges, retaining walls, flood walls, noise walls and drainage channels), landscaping and urban design features.

Changes in visual amenity have the potential to increase levels of stress and anxiety, however, most people adapt to changes in the visual landscape, particularly within an already urbanised area. Where long term visual impacts would be negative, mitigation measures including landscape screening would be utilised where feasible to reduce these impacts. Design development has been influenced by urban design principles that have been established for the project including integrating the project elements and infrastructure into the surrounding environment. A detailed review and finalisation of architectural treatment of the project operational infrastructure would be carried out during further design development.

As a result, most changes in visual impacts are not expected to have a significant impact on the health of the community.

Economic aspects

Economic impacts are presented in Chapter 21 (Socio-economics). The operational impacts on business would be beneficial for employee and customer access, servicing and delivery and demand for services across most business centres. Some business centres would also benefit from improvements in passing trade, character and amenity and business visibility. However, any impact is considered to be moderate to low, given the sensitivity of the centre and the magnitude of change by the project. Further changes are also expected in this area as associated with the development of the Northern Beaches Hospital Precinct Structure Plan.

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 $66 billion to NSW State Gross Product (GSP) in 2011, this represented 13.8 per cent of NSW GSP at the time.

The project would encourage heavy and commercial vehicle movements into the tunnel, due to increased efficiencies and reducing freight costs through increased travel speeds and reliability and reduced travel distances.

The transport modelling carried out for the project highlighted that the project would result in substantial potential benefits for freight and commercial vehicle movements. Improvements in the efficiency and reliability of these transport networks would likely result in increased productivity, reduced costs and broader economic benefits for these workforces. Ongoing or improved economic vitality is of significant health benefit to the community. Employment opportunities would grow in the region through the potential increase in business customers and improved regional connectivity as a result of the project.

Road tolling

The implementation of road tolls can have direct impacts on the management of congestion, which has an impact on economic productivity, and social elements such as stress, time with family and friends, cost and environmental amenity such as reduced traffic emissions.

One impact is the potential to increase congestion volumes on surrounding roads as a result of toll avoidance. The use of a toll road can also increase the cost of living and can exacerbate social inequality. Specifically, the impact of roads tolls 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 would be a proportion of the population that avoid the use of tollways due to affordability. In July 2018, the NSW Government implemented a toll relief initiative to ease the cost of living for frequent NSW toll road users through the provision of free vehicle registration. This was expanded in July 2019 to also provide half-priced vehicle registration for eligible road users.

13.6 Environmental management measures

Key environmental management measures specific to human health impacts are provided in Table 13-2. In addition, environmental management measures relating to human health impacts are also provided in other chapters within this environmental impact statement, particularly:

- Transport and travel management measures – Chapter 8 (Construction traffic and transport and Chapter 9 (Operational traffic and transport)
- Air quality management measures – Chapter 12 (Air quality)
- Noise and vibration management measures – Chapter 10 (Construction noise and vibration) and Chapter 11 (Operational noise and vibration)
- Contamination management measures – Chapter 16 (Geology, soils and groundwater)
- Property acquisition and relocation services – Chapter 20 (Land use and property)
- Social impact management measures – Chapter 21 (Socio-economics)
- Visual amenity measures – Chapter 22 (Urban design and visual amenity)
- Cumulative impact measures – Chapter 27 (Cumulative impacts).

Table 13-2 Environmental management measures – human health

Ref	Phase	Impact	Environmental management measure	Location
HH1	Construction	Underwater noise impacts	Monitoring during the early stages of impact piling activities at each location will be carried out to measure underwater noise levels and compare against acoustic thresholds to confirm the extent of areas that need to be managed with respect to underwater noise, and to confirm appropriate management measures (as required). Appropriate management measures will be implemented during impact piling. The monitoring results, management areas and proposed management measures will be peer-reviewed to ensure they adequately address potential health impacts. Monitoring will be carried out following implementation of management measures (as required) to confirm they are appropriate and to	BL (Middle Harbour)

Ref	Phase	Impact	Environmental management measure	Location
			identify any additional management measures required.	
HH2	Construction	Underwater noise impacts	Communication and management measures will be implemented during construction to manage potential underwater noise impacts to water-based recreational users during dredging and piling activities in Middle Harbour. The communication tools and management measures that would be contemplated within the management zone include: a) Coordination of piling programs with the planned activities of key recreational stakeholders to minimise interaction with planned or peak activity periods of these stakeholders, where feasible and reasonable b) Communication of the piling program and management area so recreational users know when the piling, dredging and other noise generating activities will be taking place, what they can expect, and the zones to minimise the possibility of being startled from a sudden increase in sound pressure underwater c) Direct communication with key local recreational stakeholders during the piling and dredging program to provide up-to-date scheduling d) Use of advertisements, signage, letter box drops and project updates to communicate the implementation of a management area during the works. This could include floating markers or signage on approach to the construction work e) Surveillance within the areas in which precautionary guideline level is exceeded to proactively monitor users in the prior to and during relevant activities that could pose a risk to recreational users.	BL (Middle Harbour)

Note: BL = Beaches Link