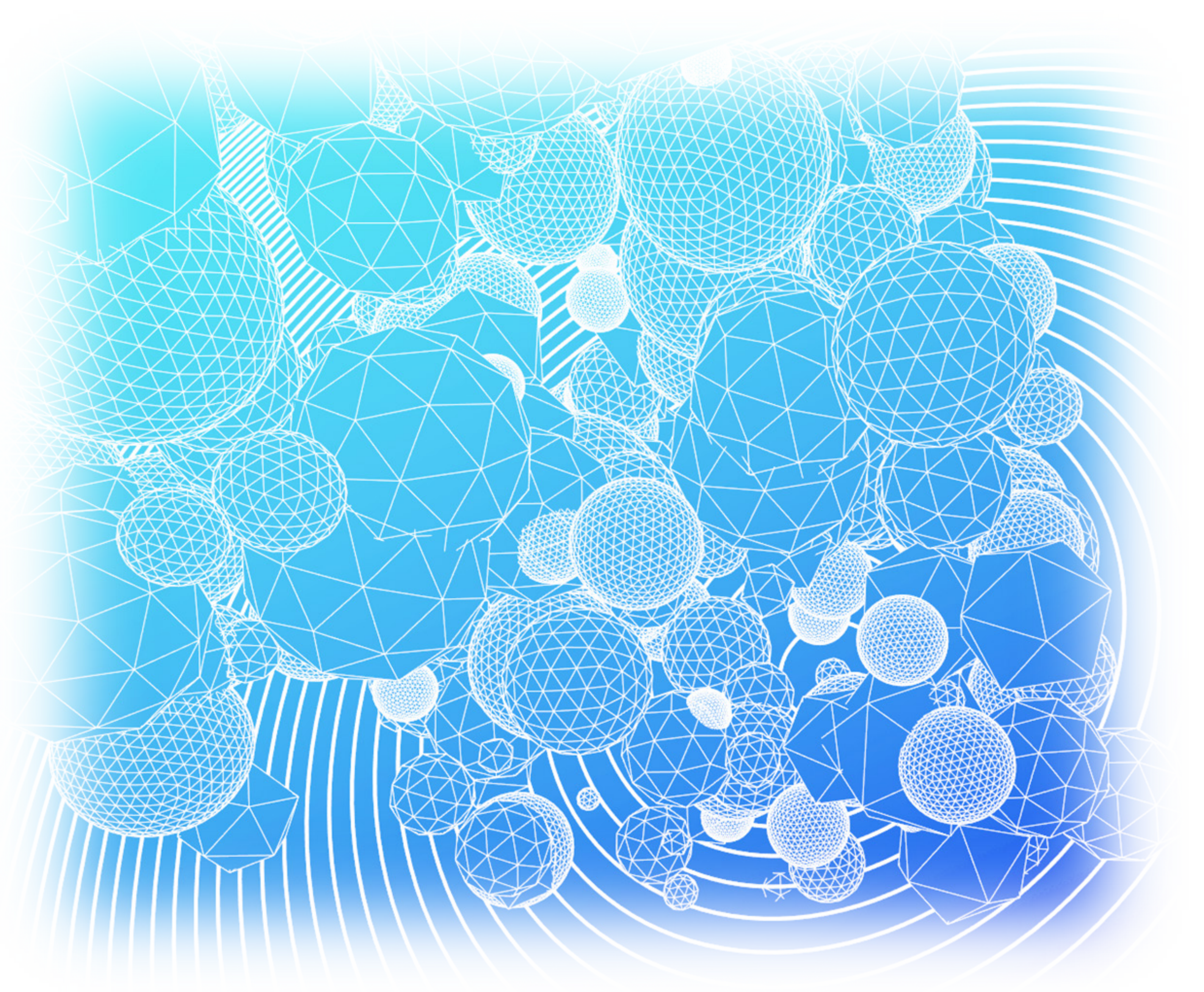
BOTANY RAIL DUPLICATION

TECHNICAL REPORT

Technical Report 13 –
Health Impact Assessment



Botany Rail Duplication Environmental Impact Assessment

Technical Report 13: Health Impact Assessment

22 August 2019

EnRiskS

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Glossary and Abbreviations

ABS	Australian Bureau of Statistics
ARTC	Australian Rail Track Corporation (the proponent)
β coefficient	Beta coefficient
Ballast	Material such as crushed rock or stone used to provide a foundation for a railway track. Ballast usually provides the bed on which railway sleepers are laid, transmits the load from train movements and restrains the track from movement.
Botany Line	A dedicated freight rail line (operated by ARTC) that forms part of the Metropolitan Freight Network. The line extends from near Marrickville Station to Port Botany.
CO	Carbon monoxide
construction ancillary facilities	Temporary facilities during construction that include, but are not limited to, construction work areas, sediment basins, temporary water treatment plants, pre-cast yards and material stockpiles, laydown areas, parking, maintenance workshops and offices, and construction compounds.
construction compound	An area used as the base for construction activities, usually for the storage of plant, equipment and materials, and/or construction site offices and worker facilities.
Council, the	Bayside Council
detailed design	The stage of design where project elements are design in detail, suitable for construction.
DPM	Diesel particulate matter
EIS, the	Botany Rail Duplication environmental impact statement
embankment	A raised area of earth or other materials used to carry a rail line in certain areas.
existing rail corridor	The corridor within which the existing rail infrastructure is located. In the study area, the existing rail corridor is the Botany Line.
formation	The earthworks/material on which the ballast, sleepers and tracks are laid.
heavy vehicles	A heavy vehicle is classified as a Class 3 vehicle (a two-axle truck) or larger, in accordance with the Austroads Vehicle Classification System.
HI	Hazard index
HIA	Health impact assessment
impact	Influence or effect exerted by a project or other activity on the natural, built and community environment.
LGA	local government area
Metropolitan Freight Network	A network of dedicated railway lines for freight in Sydney, linking NSW's rural and interstate rail networks with Port Botany. The Metropolitan Freight Network is managed by ARTC.
NEPC	National Environment Protection Council
NEPM	National Environment Protection Measure
NO_2	Nitrogen dioxide
OLS	Obstacle limitation surface
PM	Particulate matter
$PM_{2.5}$	Particulate matter (airborne dust) with a size of 2.5 micrograms
PM_{10}	Particulate matter (airborne dust) with a size of 10 micrograms

possession	A period of time during which a rail line is closed to train operations to permit work to be carried out on or near the line.
project site, the	The area that would be directly affected by construction (also known as the construction footprint). It includes the location of operational project infrastructure, the area that would be directly disturbed by the movement of construction plant and machinery, and the location of the storage areas/compounds etc, that would be used to construct that infrastructure.
project, the	The construction and operation of the Botany Rail Duplication
Risk	The probability that something would cause injury or harm
Secretary's environmental assessment requirements (SEARs)	Requirements and specifications for an environmental assessment prepared by the Secretary of the Department of Planning and Environment under section 115Y of the *Environmental Planning and Assessment Act 1979* (NSW).
SO_2	Sulfur dioxide
State significant infrastructure	Major transport and services infrastructure considered to have State significance as a result of size, economic value or potential impacts.
study area, the	The study area is defined as the wider area including and surrounding the project site, with the potential to be directly or indirectly affected by the project (e.g. by noise and vibration, visual or traffic impacts). The actual size and extent of the study area varies according to the nature and requirements of each assessment and the relative potential for impacts but which is sufficient to allow for a complete assessment of the proposed project impacts to be undertaken.
$\mu g/m^3$	Microgram per metre cubed
USEPA	United States Environmental Protection Agency
WHO	World Health Organization

Executive summary

Australian Rail Track Corporation (ARTC) proposes to construct and operate a new second track largely within the existing Botany Line rail corridor between Mascot and Botany, in the Bayside local government area (LGA). The Botany Rail Duplication ('the project') would increase freight rail capacity to and from Port Botany.

This health impact assessment (HIA) has been prepared to assess the potential health impacts from the construction and operation of the project.

A HIA is a way of deciding now, what the consequences to health (both positive and negative) of some future action (such as this project) may be. It draws on the available information on the existing health of the community, the available studies in relation to impacts relevant to the project as well as current knowledge in relation to the potential health effects of these impacts.

In this case, this report includes a detailed review of what impacts may occur, who may be exposed to these impacts and whether there is potential for these impacts to result in adverse health effects or positive benefits within the local community. The HIA has been conducted in accordance with national guidance (enHealth 2001, 2012; Harris 2007) and addressed impacts on the community surrounding the project.

Specifically, the assessment has addressed community health impacts from changes in air quality, noise and vibration, public health and contamination and social determinants. No assessment of workers involved in the construction or operation of the project has been undertaken.

Based on the assessment undertaken, where proposed mitigation measures are implemented, no significant impacts on community health have been identified for the project.

More specifically, the following provides an overview of the key outcomes of impacts and benefits identified during the construction and operation of the project:

Health impacts during construction:

- Changes in air quality:
  - Impacts associated with dust generated from construction activities would require management to ensure impacts to community health are minimised.
  - Measures required to be implemented to minimise dust impacts are detailed in *Technical Report 3: Air quality impact assessment*.
- Changes in noise:
  - Where the proposed management measures are implemented (as outlined in *Technical Report 2 - Noise and vibration impact assessment*), the potential for construction noise and vibration to adversely impact community health would be minimised.
  - It should be noted that even where mitigation measures are implemented, some noise impacts may occur where works occur close to sensitive receivers. These impacts are expected to be of short duration, where annoyance and potentially sleep disturbance may occur on occasions.
- Public safety and contamination:
  - Where all proposed management measures are implemented, no community health risk issues of concern were identified in relation to public safety, associated with the project, from issues such as dangerous goods, hazardous incidents or contamination during construction.
- Changes in other social determinants
  - Changes in the urban environment associated with the project have the potential to result in a range of impacts on health and wellbeing of the community. The potential for changes to result in impacts on

health and wellbeing is complex. Changes that may occur have the potential to result in both positive and negative impacts on community health.

  - The construction phase of works has the greatest potential for negative impacts as a result of traffic changes during construction, visual changes and minor changes in access/cohesion of local areas. These may result in increased levels of stress and anxiety within the community. In many cases, the impacts identified are either short-term (associated with construction only) and/or mitigation/management measures have been identified to minimise the impacts on the community.
  - Positive impacts for the project during construction relate to employment, which has the potential to benefit health.

Health impacts during operation:

- Changes in air quality:
  - Impacts within the community: no health impacts have been identified that would be considered to be of significance (ie measurable) within the community
- Changes in noise:
  - Without mitigation, 189 buildings have been identified where rail noise exceeds the health based criteria. While the increases in noise levels associated with the project are unlikely to result in any significant increases in health impacts, the total noise levels and maximum rail noise levels have the potential to be of concern to community health.
  - To ensure health impacts are effectively mitigated, mitigation measures would be required to be designed and implemented as outlined in *Technical Report 2 - Noise and vibration impact assessment.* The mitigation of operational noise impacts should consider treatment at or near the noise sources prior to the implementation of at-property treatments as at-property treatments are less certain (in terms of acceptance and use) and their presence at a property has the potential to also affect the wellbeing of residents.
- Public safety and contamination:
  - No community health risk issues of concern were identified in relation to public safety, associated with the project.
- Changes in other social determinants
  - Operation of the project is associated with positive impacts, which include economic benefits and the potential for reduced freight truck movements in the local area. These impacts have the potential to improve health and wellbeing within the community through the provision of employment, easier access to employment, reduced levels of stress and anxiety.

1. Introduction

1.1 Overview

1.1.1 Background

Australian Rail Track Corporation (ARTC) proposes to construct and operate a new second track largely within the existing Botany Line rail corridor between Mascot and Botany, in the Bayside local government area (LGA). The Botany Rail Duplication ('the project') would increase freight rail capacity to and from Port Botany. The location of the project is shown in Figure 1.1.

The project is State Significant Infrastructure in accordance with Division 5.2 of the NSW *Environmental Planning and Assessment Act 1979* (EP&A Act). As State Significant Infrastructure, the project needs approval from the NSW Minister for Planning and Public Spaces.

This report has been prepared to accompany the environmental impact statement (EIS) to support the application for approval of the project, and address the Secretary of the Department of Planning and Environment's environmental assessment requirements (the SEARs), issued on 21 December 2018.

1.1.2 Overview of the project

The project would involve:

- Track duplication – constructing a new track predominantly within the rail corridor for a distance of about three kilometres.
- Track realignment (slewing) and upgrading – moving some sections of track sideways (slewing) and upgrading some sections of track to improve the alignment of both tracks and minimise impacts to adjoining land uses.
- New crossovers – constructing new rail crossovers to maintain and improve access at two locations (totalling four new crossovers).
- Bridge works – constructing new bridge structures at Mill Stream, Southern Cross Drive, O'Riordan Street and Robey Street (adjacent to the existing bridges), and re-constructing the existing bridge structures at Robey Street and O'Riordan Street.
- Embankment/retaining structures – construction of a new embankment and retaining structures adjacent to Qantas Drive between Robey and O'Riordan streets and a new embankment between the Mill Stream and Botany Road bridges.

Further information on the key elements of the project is provided in the EIS.

Ancillary work would include bi-directional signalling upgrades, drainage work and protecting/relocating utilities.

Subject to approval of the project, construction is planned to start at the end of 2020, and is expected to take about three years for the main construction works to be undertaken. Construction is expected to be completed in late 2023 with commissioning activities undertaken in early 2024.

It is anticipated that some features of the project would be constructed while the existing rail line continues to operate. Other features of the project would need to be constructed during programmed weekend rail possession periods when rail services along the line cease to operate.

The project would operate as part of the existing Botany Line and would continue to be managed by ARTC. ARTC is not responsible for the operation of rolling stock. Train services are currently, and would continue to be, provided by a variety of operators. Following the completion of works, the existing functionality of surrounding infrastructure would be restored.

Key features of the project are shown on Figure 1.2.

Figure 1.1 Botany Rail Duplication location

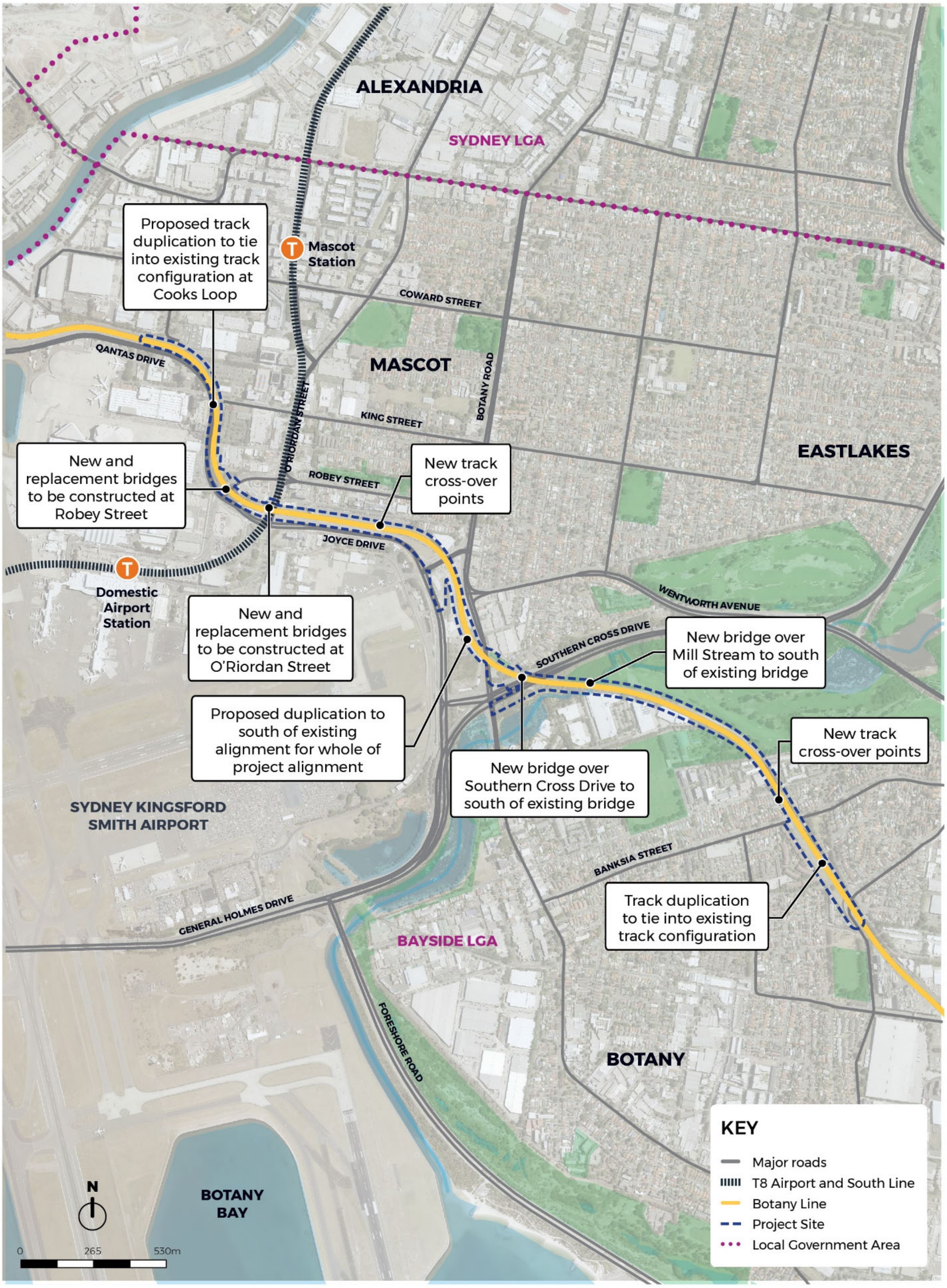

Figure 1.2 Botany Rail Duplication project overview

1.2 Purpose and scope of this report

The purpose of this report is to assess the potential health impacts from the construction and operation of the project. This health impact assessment (HIA) assessment addresses the relevant SEARs for the EIS, as outlined in in Table 2.1.

The report:

- Describes the existing environment, specifically the key characteristics relevant to understanding the existing health of the community surrounding the project.
- Assesses the impacts of constructing and operating the project on the health of the community. In particular the HIA has addressed community health impacts that may be associated with changes in air quality, noise and other impacts that have the potential to affect the health and wellbeing of the community.
- Recommends measures to mitigate the impacts identified.

This report has relied upon the methodology and assessment of the following studies:

- *Botany Rail Duplication EIS, Technical Report 1 – Traffic and transport*
- *Botany Rail Duplication EIS, Technical Report 2 – Noise and vibration impact assessment*
- *Botany Rail Duplication EIS, Technical Report 3 – Air quality impact assessment*
- *Botany Rail Duplication EIS, Technical Report 5 – Contamination*
- *Botany Rail Duplication EIS, Technical Report 12 – Social impact assessment*
- *Botany Rail Duplication EIS. Technical Report 14 - Hazards and risk assessment.*

1.3 Structure of this report

The structure of the report is outlined below.

- Section 1 – provides an introduction to the project and report.
- Section 2 – provides the legislative and policy context for the assessment and the relevant guidance.
- Section 3 – provides the methodology adopted for the assessment.
- Section 4 – describes the existing environment relevant to the assessment of community health impacts.
- Section 5 – outlines the community consultation process and issues identified throughout that process that relate to community health.
- Section 6 – presents the assessment of health impacts related to changes in air quality. The section addresses impacts related to construction and operation.
- Section 7 - presents the assessment of health impacts related to changes in noise. The section addresses impacts related to construction and operation.
- Section 8 – presents the assessment of impacts of the project on public safety. The section addresses impacts related to construction and operation.
- Section 9 – presents the assessment of health impacts related to a range of changes in other social aspects of the project. The section addresses impacts related to construction and operation.
- Section 10 – presents recommended mitigation measures that are identified within the health impact assessment.
- Section 10 – presents a summary of the findings of the health impact assessment, both positive and negative impacts.

- Section 11 – presents any additional management measures identified in the health impact assessment.
- Section 12 – presents the conclusions.
- Section 13 – presents a list of references used within the document.

2. Legislative and policy context

This section summarises the legislation, guidelines and/or policies driving the approach to the assessment.

2.1 Relevant legislation, policies and guidelines

The assessment was undertaken with reference to the following key guidance documents:

2.1.1 EnHealth Health Impact Assessment Guidelines (enHealth 2017)

This guidance aims to promote and enhance the incorporation of health impact assessments into environmental and planning impact assessment generally, thereby improving the consideration of health issues. The document provides an introduction to the health impact assessment process, the different types of assessments that can be undertaken, the principles that may need to be addressed in an assessment, the roles of those involved in an assessment and general information on the preparation of a health impact assessment.

This guidance has informed the content and the methodology selected for this assessment.

2.1.2 EnHealth Environmental Health Risk Assessment: Guidelines for Assessing Human Health Risks from Environmental Hazards (enHealth 2012)

This document provides an outline of the national approach adopted for the assessment of environmental health risks. While risk assessment is part of the health impact assessment process, the conduct of such an assessment typically focuses on key elements within the health impact assessment where a more detailed quantitative assessment of exposure, toxicity and health risk is required, and can be undertaken. The enHealth guidance provides the Australian framework and approach for the conduct of such assessments.

2.1.3 Health Impact Assessment: A Practical Guide (Harris 2007)

This document provides a more practical overview of the health impact assessment process in Australia. The document outlines the key phases and steps involved in conducting a desk based assessment, the key concepts, the different levels of assessment that can be undertaken within a health impact assessment and approaches that can be considered in the conduct of a health impact assessment.

2.1.4 Other guidance

In addition to the above, the following policy and guideline documents have been considered in the preparation of the HIA as background information and to provide context to the assessment process:

- NSW Health, Building Better Health, Health considerations for urban development and renewal in the Sydney Local Health District (NSW Health 2016)
- NSW Health, 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 (EPA 2013)
- NEPC National Environment Protection (Ambient Air Quality) Measure (NEPC 2016)
- NEPC National Environmental Protection (Air Toxics) Measure (NEPC 2004)
- Approved Methods for the Modelling and Assessment of Air Pollutants in New South Wales (NSW EPA 2016)
- State Environmental Planning Policy (SEPP) 33 - Hazardous and Offensive Development.

2.2 Secretary's environmental assessment requirements

The SEARs relevant to health, together with a reference to where they are addressed in this report, are outlined in Table 2.1.

Table 2.1 SEARs relevant to this assessment

Requirements	Where addressed in this report
3. Assessment of Key Issues* (2) For each key issue the Proponent must:	
describe the biophysical and socio-economic environment, as far as it is relevant to that issue;	Section 4
describe the legislative and policy context, as far as it is relevant to the issue;	Section 2
identify, describe and quantify (if possible) the impacts associated with the issue, including the likelihood and consequence (including worst case scenario) of the impact (comprehensive risk assessment), and the cumulative impacts;	Sections 6, 7, 8 and 9
demonstrate how options within the project potentially affect the impacts relevant to the issue;	Sections 6, 7, 8 and 9
demonstrate how potential impacts have been avoided (through design, or construction or operation methodologies);	Sections 6, 7, 8 and 9
detail how likely impacts that have not been avoided through design will be minimised, and the predicted effectiveness of these measures (against performance criteria where relevant); and	Section 3.4
detail how any residual impacts will be managed or offset, and the approach and effectiveness of these measures.	Sections 6, 7, 8 and 9
11. Health and Safety	
The Proponent must assess the potential health impacts of the project, in accordance with the current guidelines.	Guidelines as listed in Section 2
The assessment must:	
describe the current known health status of the affected population	Section 4
assess health risk associated with exposure to environmental hazards	Section 6 – air quality Section 7 – noise Section 8 – safety and contamination
assess the effect of the project on other relevant determinants of health such as the level of physical activity and access to social infrastructure	Section 9
assess opportunities for health improvement;	Sections 6 to 9
assess the distribution of the health risks and benefits; and	Section 8.9
discuss how, in the broader social and economic context of the project, the project will minimise negative health impacts while maximising the health benefits.	Sections 6 to 9
The Proponent must assess the likely risks of the project to public safety, paying particular attention to pedestrian safety, the handling and use of dangerous goods.	Section 8

3. Methodology

This section describes the methodology used to undertake the HIA.

3.1 What is a health risk or impact assessment?

3.1.1 Risk

Risk assessment is used extensively in Australia and overseas to assist in decision making on the acceptability of the risks associated with the presence of contaminants or stressors in the environment and assessment of potential risks to the public. Risk is commonly defined as the chance of injury, damage, or loss. Therefore, to put oneself or the environment ‘at risk’ means to participate, either voluntarily or involuntarily, in an activity or activities that could lead to injury, damage, or loss.

Voluntary risks are those associated with activities that we decide to undertake such as driving a vehicle, riding a motorcycle and smoking cigarettes. Involuntary risks are those associated with activities that may happen to us without our prior consent or forewarning. Acts of nature such as being struck by lightning, fires, floods and tornados, and exposures to environmental contaminants are examples of involuntary risks.

3.1.2 Defining risk and impacts

Risks to the public and the environment are determined by direct observation or by applying mathematical models and a series of assumptions to infer risk. No matter how risks are defined or quantified, they are usually expressed as a probability of adverse effects associated with a particular activity. Risk is typically expressed as a likelihood of occurrence and/or consequence (such as negligible, low or significant) or quantified as a fraction of, or relative to, an acceptable risk number.

Risks or impacts from a range of facilities (eg industrial or infrastructure) are usually assessed through qualitative and/or quantitative risk assessment techniques. In general, risk or impact assessments seek to identify all relevant hazards; assess or quantify their likelihood of occurrence and the consequences associated with these events occurring; and provision of an estimate of the risk levels for people who could be exposed, including those beyond the perimeter boundary of a facility. In this report, quantitative risk is assessed in terms of acceptable, tolerable or unacceptable risk.

Definitions of some of the key terms that are used in the assessment are presented in Appendix A and a more detailed discussion on the determination of acceptable, tolerable or unacceptable risks is presented in Appendix C of this report.

3.2 Approach to the health impact assessment

3.2.1 General

The health impact assessment was undertaken as a desktop assessment, and as such has been conducted using existing information with additional detail obtained via literature review only (as referenced throughout this HIA). The term desk-top assessment is used to describe that the assessment has not involved the collection of any additional data over and above that which would be provided from project-specific EIS technical studies, community consultation and statistics on the existing population.

The impact assessment was undertaken in accordance with the scope as outlined in Section 1.3 and the guidelines outlined in Section 2 and involved both quantitative and qualitative evaluations. Following this approach, the assessment of health impacts relevant to the different areas of evaluation has utilised a range of different methods and approaches, with each specifically relevant to the technical aspect being considered. The following provides an overview of the approach adopted for the assessment of health impacts related to air quality, noise, safety and other social determinants. Specific details related to the assessments undertaken in each of these areas is presented in the relevant chapter (where it specifically relates to the assessment presented).

3.2.2 Study area

As the health impact assessment has relied on the assessments undertaken as part of other technical studies, the study areas evaluated in relation to health impacts are the same as the study areas considered in each of the individual technical studies. These study areas are specific to each technical study and are, therefore, further described in the more detailed assessment of each key area such as air quality (refer to Section 6), noise (refer to Section 7) and social aspects (refer to discussion in Section 9 where relevant). While the extent of the study area does vary between these studies, the study area essentially comprises the community located directly adjacent to and within 1 kilometre of the project. The assessment has also considered the general population within the suburbs presented in Figure 1.2.

3.2.3 Assessment scenarios

The assessment of impacts presented in the technical reports associated with the project has considered a range of scenarios that include the existing situation, construction works and various future operational scenarios both with and without the project (as defined in *Technical Report 3 - Air quality impact assessment* and *Technical Report 2 – Noise and vibration impact assessment*).

The scenarios considered in the HIA are as follows:

- construction
- operation:
    - 2024 at opening, no build
    - 2024 at opening, build (ie with project)
    - 2034, 10 years in the future, no build
    - 2034, 10 years in the future, build (ie with project).

3.2.4 Health impacts from changes in air quality

Section 6 provides a detailed assessment of the potential for changes in air quality due to the project and how these changes might impact health within the community. This assessment has drawn on information provided in the *Technical Report 3 – Air quality impact assessment* and, in some areas, provides a summary of key (and relevant) aspects. Information relevant to the underlying assumptions, methodology and interpretation of impacts relevant to changes in air quality are provided within *Technical Report 3 – Air quality impact assessment*.

The characterisation of health impacts from changes in air quality as a result of the project is complex. Impacts on health have been evaluated for all pollutants evaluated in *Technical Report 3 – Air quality impact assessment* regardless of the outcomes of the air impact assessment.

The assessment undertaken in relation to evaluating health impacts related to changes in air quality involved:

- Presenting a summary of the existing air quality relevant to the study area (*Technical Report 3 – Air quality impact assessment*), presented in Section 6.2.
- Providing a summary of the air quality impact assessment, which provides inputs to the assessment of health impacts (*Technical Report 3 – Air quality impact assessment*) including the study areas considered in the air quality impact assessment for construction and operation, presented in Sections 6.3 and 6.4.

- Assessment of construction impacts on health, presented in Section 6.3. The assessment undertaken for construction impacts is qualitative where potential impacts and the identification of relevant management measures to minimise impacts (including nuisance[1] dust) were evaluated.
- Detailed assessment of the potential health impacts from changes in air quality during operations (exposure and potential impacts), presented in Sections 6.5 to 6.9. Further discussion on the aspects considered in the quantification of operational impacts on health is provided below.
- Outline of the uncertainties within the assessment undertaken in relation to health impacts from air quality (which is key to understanding if the assessment of potential health impacts is conservative, or not) (Section 6.12).

The assessment of health impacts associated with the operation of the project involves the quantification of health risks and impacts. The assessment has utilised outputs from the air quality modelling that are presented within *Technical Report 3 – Air quality impact assessment*. Additional data generated from the air modelling required for the assessment of health impacts, that is relevant to the characterisation of health impacts have also been provided in *Technical Report 3 – Air quality impact assessment*.

The air quality impact assessment modelled incremental changes in the relevant air quality parameters (ie changes in concentrations due to the project alone) and cumulative/total (i.e. background plus project) changes in the study area. Both the incremental and cumulative/total changes, relevant to the operational phase of the project, were used for the health impact assessment to assess potential impacts to health.

The quantification of health impacts from changes in air quality during operations includes:

- **Use of health based air guidelines**: For air pollutants where there is a threshold for acute and chronic effects (ie a level below which there are no health impacts), published health based guidelines have been identified and used in this assessment. The assessment of health impacts has focused on the maximum impacted locations and compared the predicted concentration of these air pollutants (from the project as well as other urban sources) with the air guideline. Where the exposure concentration is less than the air guideline, there is no risk. This approach applies to a number of air toxics (discussed further in **section 6.5**) as well as carbon monoxide (discussed further in **section 6.6**).
- **Calculation of an incremental lifetime cancer risk:** For air pollutants that are considered to be genotoxic carcinogens, there is no threshold. Hence the approach adopted for the assessment of these chemicals is to calculate an incremental lifetime cancer risk, utilising published non-threshold inhalation toxicity reference values (or unit risk values), and an estimation of the maximum increase in air concentration (or exposure) within the community. This results in the calculation of an incremental carcinogenic risk and utilises common risk assessment methods as outlined by enHealth (enHealth 2012). This approach applies to the assessment of some air toxics (discussed further in **section 6.5**) as well as diesel particulate matter (discussed further in **section 6.5**).
- **Calculation of impacts, risks for changes in nitrogen dioxide and particulate matter concentrations:** The data available on health impacts from exposure to nitrogen dioxide and particulate matter, particularly within urban air environments, comes from large population or epidemiological studies (discussed further in **sections 6.7 and 6.8**). These studies enable relationships between exposure and various health effects (specifically mortality [i.e. a shortening of life-span] and morbidity effects). These concentration-response or exposure-response relationships are developed based on large population exposures and are utilised in the assessment of population health, and for establishing ambient (population wide) air guidelines. These relationships are not developed for the assessment of specific sources or localised impacts, as is the case for the assessment of impacts from the project.

Based on the methodology outlined above, potential health impacts from changes in nitrogen dioxide and particulate matter associated with the project have been assessed on following basis:

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[1] *Nuisance, as considered in this report relates to: nuisance dust which is dust particles that are too large to penetrate into the lungs (and result in adverse health effects) but will settle out on various surfaces and may create a visible dust layer or require cleaning; nuisance odours which are odours that are noticeable and may be considered offensive. Health effects associated with exposure to chemicals that are the cause of the odours are assessed separately.*

- Calculation of a localised annual risk for each health endpoint. This is the localised change in risk that differs from the baseline risk (or incidence) of the effect occurring for any member of the population, where exposed to the change in nitrogen dioxide or particulate matter concentration estimated. The assessment has considered the maximum localised health risks relevant to the closest community receptors.

Acceptable risk levels

To determine if the calculated incremental carcinogenic risk, localised annual risk or change in incidence within a population from the project may be considered to be acceptable, a number of factors need to be considered. These are discussed further in Appendix C.

Based on the discussion presented in Appendix C, for this assessment localised annual risks have been assessed on the basis of the following:

- Risk < 10^{-6} (or 1 in 1,000,000) is considered to be negligible
- Risk ≥ 10^{-6} and ≤ 10^{-4} is considered to be tolerable (or acceptable)
- Risk > 10^{-4} (or 1 in 10,000) is considered to be unacceptable.

3.2.5 Health impacts from changes in noise and vibration

Review of the current research by enHealth (enHealth 2018) concludes there is sufficient evidence that noise can adversely affect health and assessment of environmental noise should be included in health impact assessments of proposed developments. Hence this assessment has included an assessment of the impact of changes in environmental noise, as a result of the project, on the community.

Assessment of health impacts from changes in noise associated with the project is presented in Section 7. The assessment presented is largely qualitative, with some quantitative assessment included to determine what noise increases are considered to result in unacceptable health impacts, if any.

The approach adopted for the assessment of health impacts from noise and vibration has considered the following (as presented in Section 7):

- Understanding of the health impacts related to changes in noise (**section 7.2**).
- Review of the noise and vibration assessment criteria adopted in *Technical Working Paper 2 – Noise and vibration* to determine if these are protective of health (**section 7.4**).
- Summary of the noise and vibration impact assessment (presented in *Technical Working Paper 2 – Noise and vibration)*, including the existing noise environment and the study area considered in the noise and vibration impact assessment (**section 7.3**), assumptions included in the assessment and outcomes of the assessment (**section 7.5**).
- What the impacts identified in the noise and vibration impact assessment mean in terms of potential health impacts during construction and operation of the project (**section 7.5**).
- Outline of the uncertainties within the assessment undertaken in relation to health impacts from noise (which is key to understanding if the assessment of potential health impacts is conservative, or not) (**section 7.8**).

3.3 Health impacts related to safety and social determinants

Assessment of health impacts relevant to public safety aspects as well as changes in the social and community environment associated with the project is presented in Sections 8 and 9. The evaluation presented relies on information provided in a wide range of other technical studies. The approach adopted in the assessment is as follows:

- Qualitatively assess a range of aspects of the project during construction and operation that may have the potential to affect public safety (**section 8**). This includes consideration of dangerous goods, hazardous materials and contaminated soil/water, acid sulfate soil, flooding, damage to underground utilities, bushfire risks, aviation risks, traffic accidents, pedestrian and cyclist safety.

- Qualitatively assess the social characteristics which have potential to affect the health of the community (both positive and negative impacts). This assessment has considered changes in traffic (including travel times), active transport, changes in recreational uses of the local area, changes in the connectivity (or displacement) of the community and changes in the urban environment (including visual changes). The assessment has also considered construction fatigue and issues related to equity of impacts within the community. The assessment has drawn on published studies relating to health impacts of social changes and the social impact assessment.

The assessment of these issues has addressed both construction and operational phases of the project.

3.4 Incorporation of health issues in the project design

The project has been designed alleviate constraints and increase capacity of Sydney's rail network to improve efficiency and reliability, and to meet existing and future demands. The project design includes new bridges and crossovers to maintain and improve local access to the area, minimising community impacts that may affect overall wellbeing.

The project has been designed to minimise noise and air quality impacts during construction and operation of the rail line, reducing potential impacts on the health of the community.

3.5 Limitations and considerations

There are certain features of health impact assessment methodology that are important to acknowledge particularly in relation to interpreting and understanding the conclusions. These relate to the limitations of the methodology and the constraints applied within the health impact assessment to ensure a focus on aspects that can be influenced as part of the project. These are summarised below:

- A health impact assessment is a systematic tool used to review key aspects of a specific project that may affect the health of the local community. The assessment includes both qualitative and quantitative assessment methods.
- Where quantitative assessment methods are presented, a health impact assessment is typically based on a conservative estimate of impacts in the local community and thus is expected to overestimate the risks for all members of the community.
- A health impact assessment involves a number of aspects where a qualitative assessment is required to be undertaken. Where this is undertaken, it provides a general indication of potential benefits or impacts only.
- The community evaluated in a health impact assessment is limited by the extent of the studies undertaken in informing an EIS. It is not possible to evaluate impacts on the health of the community outside these areas.
- A health impact assessment relies on data provided from other studies prepared for an EIS. The conclusions of this health impact assessment, therefore, depends on the assumptions and calculations undertaken to generate the data from these other studies utilised in this assessment.
- Conclusions can only be drawn with respect to impacts related to a project as outlined in an EIS. Other health issues, not related to the project, that may be of significance to the local community are not addressed in the health impact assessment.
- The health impact assessment for this project did not address occupational health for construction workers.

The health impact assessment reflects the current state of knowledge regarding the potential health effects of identified chemicals and pollutants for this project. This knowledge base may change as more insight into biological processes is gained, further studies are undertaken and more detailed and critical review of information is conducted.

4. Existing environment

4.1 Community profile

This section provides an overview of the communities potentially impacted by the project and presents a summary of the demographics of the population present, information available on key aspects that influence the health of the community and the existing health of the community. The key focus of the assessment presented is the local community within the study area defined in Section 3.2.2.

The population considered in this assessment includes all individuals who live or work (or attend schools and child care facilities) within the study area. The study area covers a large number of individual suburbs that sit within the following LGAs:

- Bayside (amalgamation of former Bayside and Rockdale LGAs)
- Sydney
- Inner West (amalgamation of former Ashfield, Leichhardt and Marrickville LGAs)

The above list reflects the LGAs as defined in 2019 following amalgamations and are consistent with the LGAs for which NSW Health provide some data. It is noted that some data is only available for the former LGAs.

These LGAs are densely populated urban areas.

4.2 Sensitive receptors

The assessment of potential impacts on the surrounding community, has considered maximum impacts from the project. In addition, impacts in the wider community have also been considered. Within the wider community, a number of additional locations, referred to as community receptors, have been identified in the suburbs close to the project.

When considering potential health impacts within any community, health impact assessment considers the whole population as well as specific sensitive or vulnerable groups within the population. These communities and their related sensitive or vulnerable groups are:

- community groups:
  - residents
  - recreational users (such as cyclists and users of recreational open space)
  - commercial and industrial (e.g. businesses within the project area that may be directly impacted by property acquisitions).
- sensitive and vulnerable groups within the community groups:
  - young children (in particular children under the age of 5 years, but also including children up to 14 years)
  - older populations (greater than 65 years of age)
  - disabled and those with pre-existing medical conditions
  - disadvantaged (socio-economically disadvantaged).

These receptors may reside or access any areas within the community.

The air quality impact assessment has considered changes in air quality across a large grid, 22 kilometres by 22 kilometres, with a 200 metre grid resolution. The key impacts evaluated, however relate to the population located close to the proposed project site.

To provide a more specific assessment of potential impacts from the project, 20 representative individual receptors located closest to the project, which includes residential areas have been included in the assessment of air impacts (as shown in Figure 4.1).

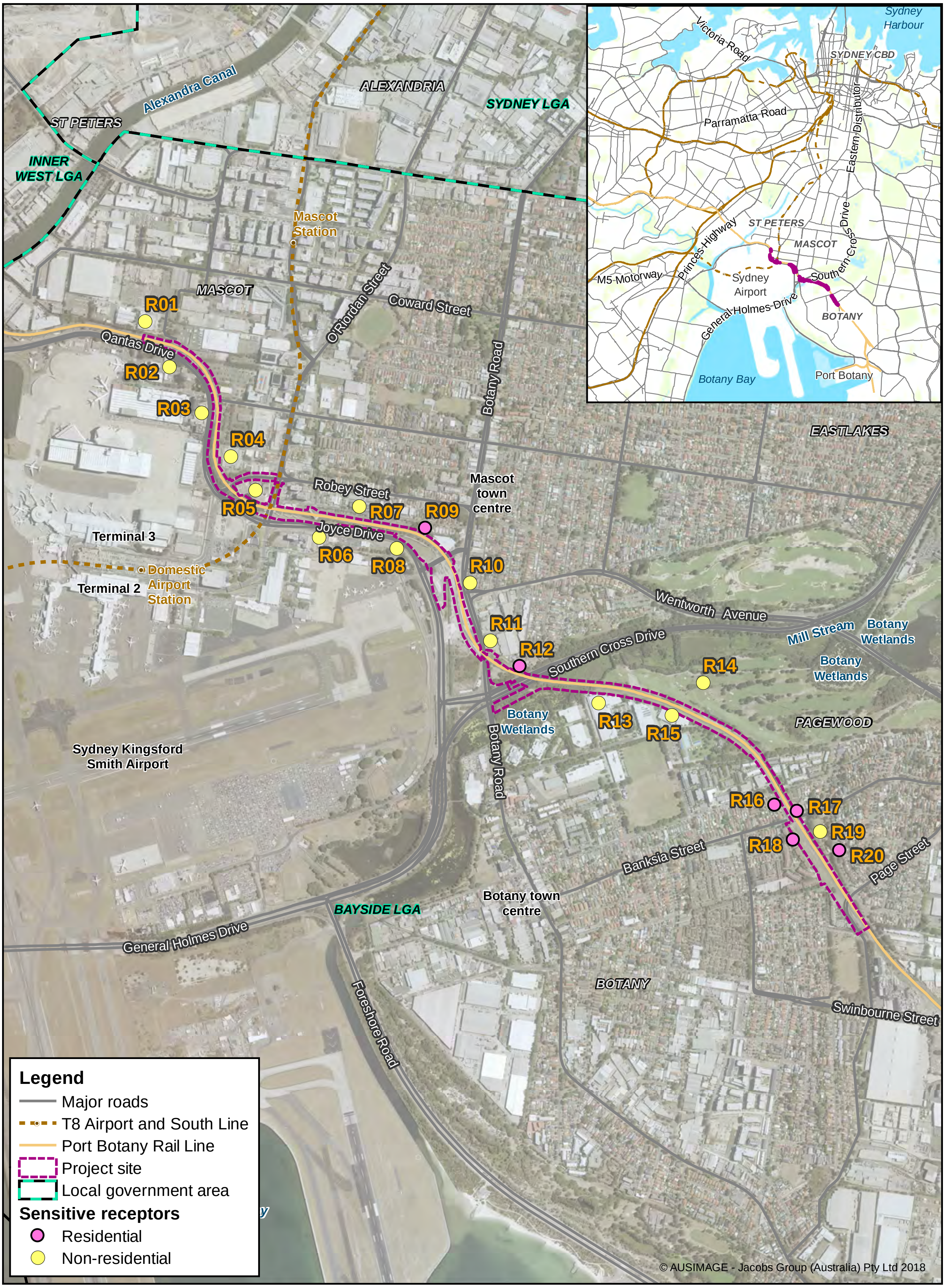


Figure 4-1

Location of community receptors evaluated for changes in air quality

Author: David Naiken
Date: 21/06/2019
Map no: PS113386_GIS_020_A2

4.3 Population profile

The population within the study area consists of residents and workers as well as those attending schools, day care centres, hospitals and recreational areas. The composition of the populations located within the study area is expected to be generally consistent with population statistics for the larger individual suburbs that are wholly or partially included in the study area. Population statistics for the LGAs are available from the ABS for the Census year 2016 and are summarised in Table 4.1. For the purpose of comparison, the population statistics presented also include the statistics for larger statistical population groups in the area (defined by the ABS SA4) and the larger statistical areas of Greater Sydney and the rest of the NSW (excluding Greater Sydney) (as defined by the ABS).

Table 4.2 presents a summary of a selected range of demographic measures relevant to the population of interest with comparison to statistical areas of Greater Sydney and the rest of NSW (excluding Greater Sydney).

Table 4.1: Summary of population statistics in study area

Location	**Total population**		**% Population by key age groups**					
	Male	**Female**	**0–4**	**5–19**	**20–64**	**65+***	**1–14***	**30+***
Local government areas								
Botany #	23,229	23,420	6.2	16.5	64.3	13.0	15.7	59.8
Rockdale #	54,079	55,325	6.1	14.8	63.8	15.3	14.6	61.5
Sydney	107,852	100,530	3.3	7.4	81.0	8.2	5.9	57.6
Inner West	88,736	93,302	5.9	13.2	68.7	12.2	14.1	63.8
Larger local statistical areas (SA4 – includes local government areas)								
Sydney - City and Inner South	161,061	154,483	4.1	9.6	76.9	9.4	8.6	58.9
Sydney – Eastern Suburbs	129,505	137,524	5.5	14.7	65.5	14.3	14.1	61.5
Sydney – Inner South West	282,753	288,670	6.7	18.1	60.7	14.6	17.5	59.6
Statistical areas of Sydney and NSW								
Greater Sydney	2,376,766	2,447,221	6.4	18.2	61.4	13.9	17.4	60.4
Rest of NSW (excluding Greater Sydney)	1,301,717	1,341,813	5.8	18.5	55.1	20.6	17.3	64.6

Ref: Australian Bureau of Statistics, Census Data 2016
SA = statistical area
* Age groups specifically relevant to the characterisation of risk
# (Now amalgamated and known as Bayside Council)

Comparing the populations of the study area to that of Greater Sydney the following is noted:

- Sydney – City and Inner South has a lower proportion of children (0-19 years), a higher proportion of working aged individuals and a lower proportion of individuals aged over 65 years.

- Sydney – Eastern Suburbs has a slightly lower proportion of children and slightly higher proportion of working age individuals.
- At a local government area level:
  - Sydney has a lower proportion of young children (0-4 years).
  - Botany, Rockdale, Sydney and Inner West has a lower proportion, while Canterbury-Bankstown have a higher proportion of children (5-19 years).
  - Botany, Rockdale, Sydney and Inner West, have a higher proportion of working age individuals.
  - Sydney and Inner West has a lower proportion while Rockdale has a higher proportion of individuals aged over 65 years.

The estimated population growth from 2011 to 2036 for these areas are (NSW Planning & Environment 2016):

- Botany: 75.2 per cent growth
- Rockdale: 50.2 per cent growth
- Sydney: 72.0 per cent growth
- Inner West: 28.7 per cent growth

Table 4.2: Selected demographics of population of interest

Location	Median age	Median household income ($/week)	Median mortgage repayment ($/month)	Median rent ($/week)	Average household size (persons)	Unemployment rate (%)
Local government areas						
Botany #	35	1,626	2,400	460	2.7	5.6
Rockdale #	35	1,575	2,167	460	2.7	6.2
Sydney	32	1,926	2,499	565	2.0	6.0
Inner West	36	2,048	2,600	480	2.4	4.8
Larger local statistical areas (SA4 – includes local government areas)						
Sydney - City and Inner South	33	1,894	2,500	550	2.2	5.7
Sydney – Eastern Suburbs	35	2,163	2,900	580	2.4	4.6
Sydney – Inner South West	35	1,431	2,167	415	2.9	7.4
Statistical areas of Sydney and NSW						
Greater Sydney	36	1,750	2,167	440	2.8	6.0
Rest of NSW (excluding Greater Sydney)	43	1,168	1,590	270	2.4	6.6

Source: Australian Bureau of Statistics, Census Data 2016
(Now amalgamated and known as Bayside Council)

The social demographics of an area have some influence on the health of the existing population. As shown in Table 4.2, comparing the populations of the study area to that of Greater Sydney:

- Botany and Rockdale have a lower, while Sydney and Inner West have a higher median income.
- Botany, Sydney and Inner West have higher monthly mortgage repayments.
- Sydney has higher median weekly rental costs.
- Sydney and Inner West have a smaller average household size.
- Inner West have lower unemployment rates.

4.4 Existing health of the population

4.4.1 General

The assessment presented in this report has focused on key pollutants that are associated with construction and combustion sources (from vehicles), including volatile organic compounds, polycyclic aromatic hydrocarbons, carbon monoxide, nitrogen dioxide and particulate matter (namely $PM_{2.5}$ and PM_{10}). For these pollutants, there are a large number of sources in the study area including other combustion sources (wood-fired heating, domestic cooking, industrial emissions), non-combustion sources including other local construction/earthworks. Other aspects that affect the health of an individual include personal exposures (such as smoking) and risk taking behaviours.

When considering the health of a local community there are a large number of factors to consider. 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. Hence, while it is possible to review existing health statistics for the local areas surrounding the project and compare them to the Greater Sydney area and NSW, it is not possible or appropriate to be able to identify a causal source, particularly individual or localised sources.

Information relevant to the health of populations in NSW is available from NSW Health for populations grouped by local health districts (where the project area is located in the South Eastern Sydney Local Health District and Sydney Local Health District). Not all of the health data is available for all of these areas.

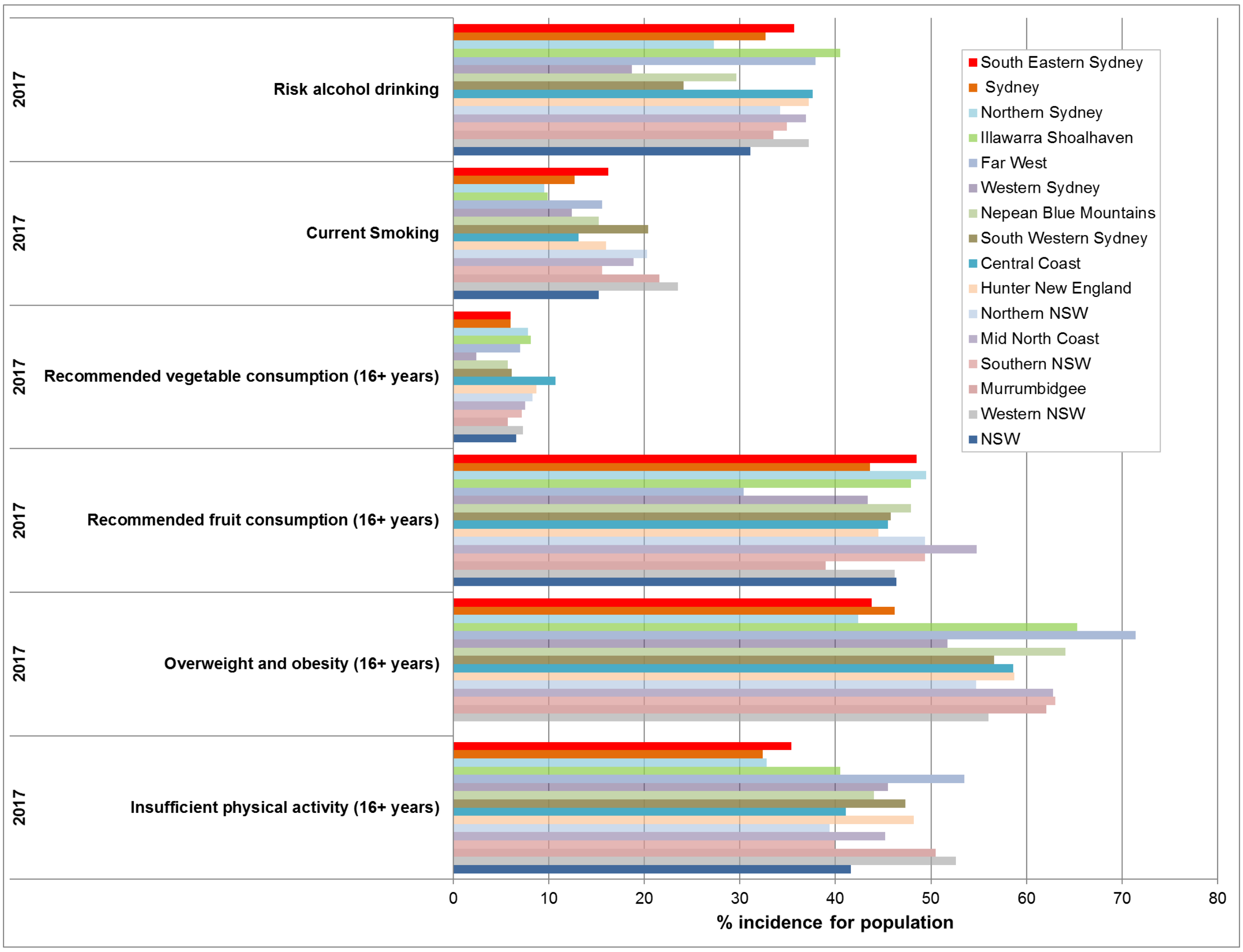
Most of the health indicators presented in this report are not available for each of the smaller suburbs/statistical areas surrounding the site. Health indicators are only available from a mix of larger areas (that incorporate the study area), namely the South Eastern Sydney Local Health District and the Sydney Local Health District. There are few health statistics that are reported for the smaller local government areas relevant to this project. The health statistics for these larger areas (and in some cases data for the Greater Sydney area) are assumed to be representative of the smaller population located within these districts and areas.

4.4.2 Health related behaviours

Health related behaviours that are linked to poorer health status and chronic disease, including cardiovascular and respiratory diseases, cancer, and other conditions, account for much of the burden of morbidity and mortality in later life.

Information in relation to health related behaviours is available for the larger populations within the local health districts in Sydney and NSW. This includes risky alcohol drinking, smoking, consumption of fruit and vegetables, being overweight or obese, and adequate physical activity. The study population is located within the South Eastern Sydney Local Health District and the Sydney Local Health District. The incidence of these health-related behaviours in these districts, compared with other districts in NSW, and the state of NSW (based on NSW Health data from 2017) is illustrated in Figure 4.2.

A review of this data indicates the population in the South Eastern Sydney and Sydney local health districts (that include the study area) have lower rates of physical inactivity and of being overweight and obese compared with NSW. This information is therefore unclear as to whether these health related behaviours and indicators would make the population in the study area more or less vulnerable to other health stressors.



Note: these health related behaviours include those where the behaviour/factor may adversely affect health (eg alcohol drinking, smoking, being overweight/obese and inadequate physical activity) and others where the behaviour/factor may positively affect (enhance) health (eg adequate fruit and vegetable consumption).
Study area is located in the South Eastern Sydney Local Health District (red) and Sydney Local Health District (orange)

Figure 4.2 Summary of incidence of health-related behaviours (Source: HealthStats NSW 2019)

4.4.3 Health indicators

Figure 4.3 presents a comparison of the rates of the key mortality indicators based on data from 2011 to 2016 (depending on the available data) for all causes, potentially avoidable, cardiovascular disease, lung cancer and chronic obstructive pulmonary disease (COPD), reported in the larger South Eastern Sydney and Sydney local health districts, with comparison to other NSW local health districts (in urban and regional areas) as well as NSW as a whole.

Figure 4.4 present a comparison of the rates of the hospitalisations for key health effects based on data from 2015-2016 for diabetes, cardiovascular disease, asthma (5–34 years) and COPD (65+ years) reported in the larger South Eastern Sydney and Sydney local health districts, with comparison to other NSW local health districts (in urban and regional areas) as well as NSW as a whole.

It is noted that the data reported in these figures is based on statistics that are publicly available from NSW Health. Hence some of the statistics for mortality and hospitalisations relate to slightly different health endpoints and/or different age groups. The statistics are included for general comparison and discussion. Actual health statistics considered in the characterisation of risk are presented in Table 4.5.

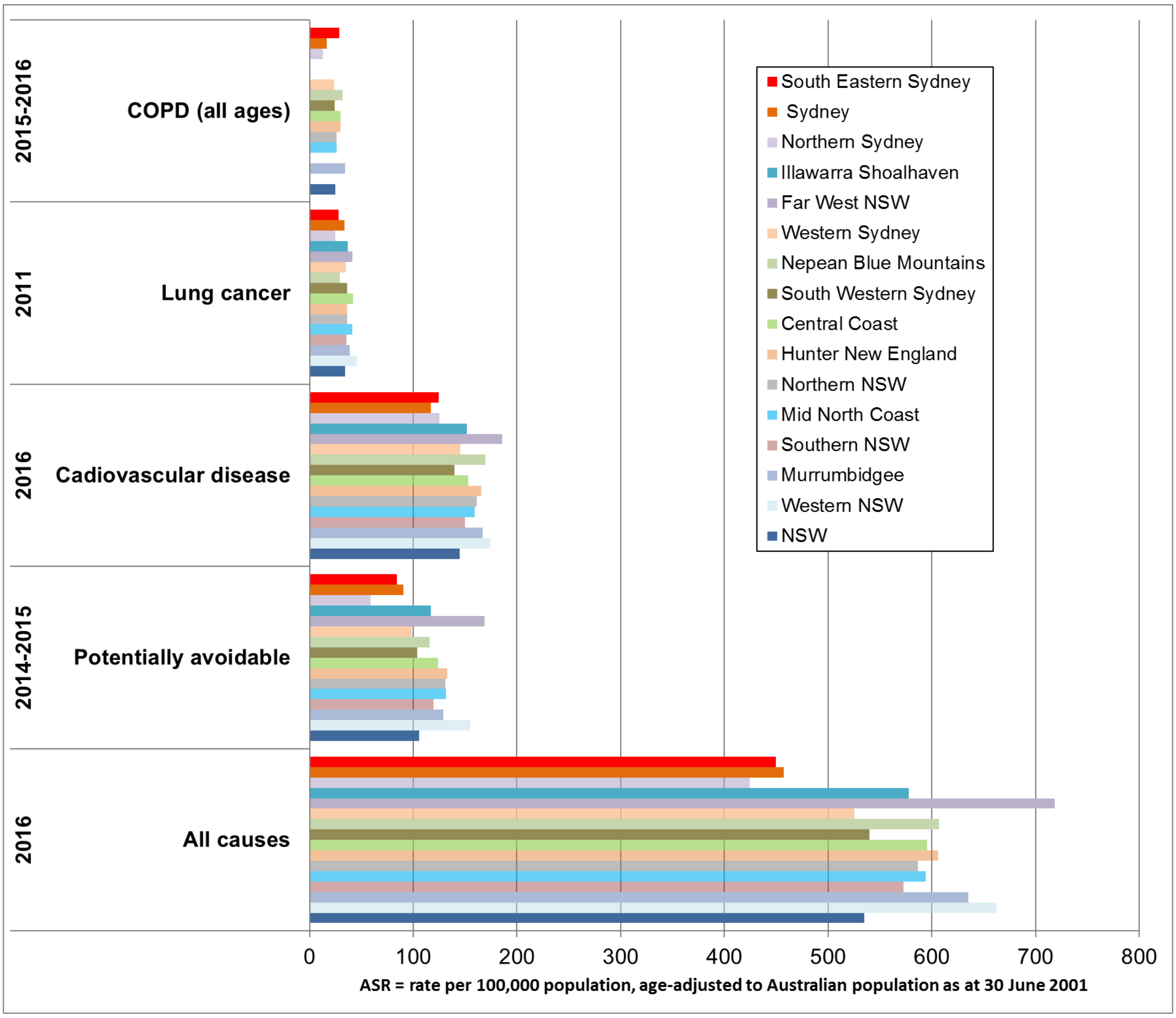


Figure 4.3 Summary of mortality data 2011 - 2016 (Source: HealthStats NSW 2019)

Review of the figure presented above indicates that the rate of mortality for the indicators presented in the South Eastern Sydney and Sydney local health districts are significantly lower than that reported for NSW, except for COPD and lung cancer which was not significant for Sydney Local Health District. This may indicate that the population in the study area is less vulnerable to other health stressors.

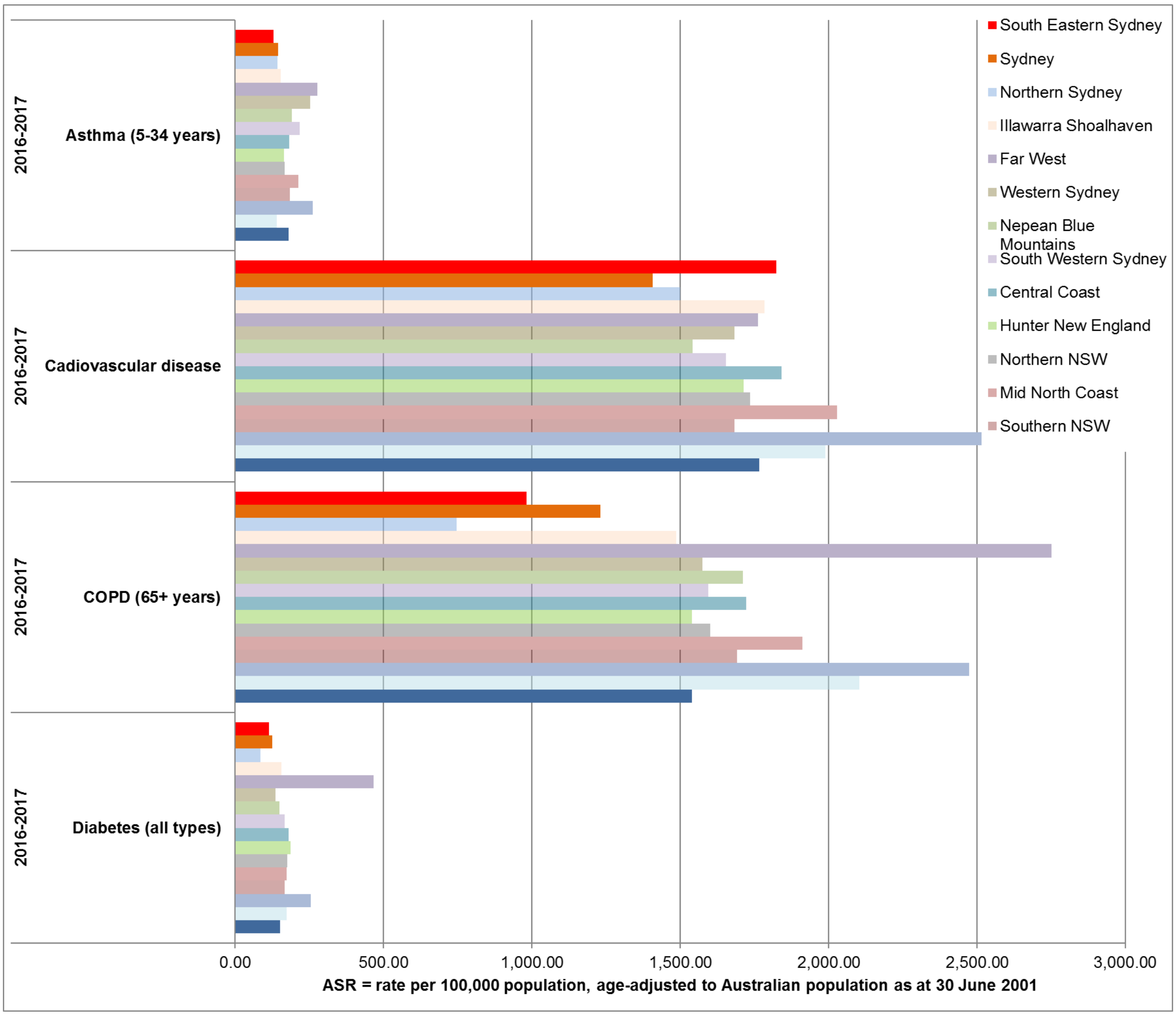


Figure 4.4 Summary of hospitalisation data 2016-2017 (Source: HealthStats NSW 2019)

Review of the figure presented above indicates that the rate of hospitalisations for the indicators presented in the South Eastern Sydney and Sydney local health districts is significantly lower than that reported for NSW, with the exception for cardiovascular disease hospitalisations in South Eastern Sydney, which is similar to the rate for NSW. This may indicate that the population in the study area is less vulnerable to other health stressors.

In relation to mental health, data from NSW Health indicates the following for adults:

- The rate of high or very high psychological distress reported in 2017 in the South Eastern Sydney local health district (11.2 per cent) is a little lower than the state average (15.1 per cent). The rate for the Sydney local health district (15.3 per cent) is essentially the same as the state average.
- The rate of high or very high psychological distress in Sydney Local Health District has varied between 10.9 and 15.3 per cent between 2003 and 2017. In the South Eastern Sydney Local Health District, the rate has

generally declined from around 14.1 per cent in 2003 to less than 10 per cent in 2015 and 11.2 per cent in 2017.

In relation to some more specific health indicators Table 4.5 presents the available data for the slightly smaller population areas in the LGAs in the study area. These have been compared with available data for the South Eastern Sydney Local Health District, Sydney Local Health District, Sydney and NSW. It is noted that health statistics are not available for the LGAs for all the health endpoints considered in this assessment. Where available, they have been presented for the purpose of comparison with statistics from Sydney and NSW.

The health indicators presented include those that are specifically relevant to the quantification of exposure to nitrogen dioxide and particulate matter presented in Sections 6.7 and 6.8.

Review of the data presented in Table 4.5 generally indicates that for the population in project area, the health statistics (including mortality rates and hospitalisation rates for most of these categories) are variable but generally similar to those reported in the larger local health districts of South Eastern Sydney, Sydney and the wider Sydney metropolitan area and slightly lower than the whole of NSW.

For the assessment of potential health impacts from the project, where specific health statistics for the smaller populations within the project area is not available (and not reliable due to the small size of the population), adopting health statistics from the whole of NSW is considered to provide a representative, if not cautious (eg over estimating existing health issues), summary of the existing health of the population of interest.

The rate of antidepressant medication prescriptions is an indicator that can be used to review changes in stress and anxiety levels within a community, and these are presented in Table 4.4 While these data were not directly used in the HIA, to evaluate specific impacts, the data is relevant to assist in ongoing monitoring of potential indicators of changes that increase or decrease stress and anxiety in the community. In relation to the rate of medication prescriptions for antidepressants it is noted that all local government areas have lower rates of prescription, for all age groups, than the state average. This may indicate that the population in the study area is less vulnerable to other health stressors.

Table 4.3: Summary of key health indicators

Health indicator	**Data available for population areas (rate per 100,000 population)**							
	Botany LGA	**Rockdale LGA**	**Sydney LGA**	**Inner West LGA**	**South Eastern Sydney LHD**	**Sydney LHD**	**Sydney (wider metro area)***	**NSW**
Mortality								
All causes – all ages	**559.7 [C]**	**488.2 [C]**	**453.8 [C]**	**521.8 [C]**	449.4 [C]	**457.0 [C]**	--	537.7 [C]
All causes (non-trauma) ≥30 years	--	--	--	--	--	--	976.5	--
All causes ≥30 years	--	--	--	--	--	--	**1026**	--
Cardiopulmonary ≥30 years	--	--	--	--	--	--	**412**	
Cardiovascular – all ages	**133.8 [C]**	**140.6 [C]**	**113.2 [C]**	**136.7 [C]**	**127.3 [C]**	120.8 [C]	191.8	147.9 [C]
Respiratory – all ages	--	--	--	--	36.7 [A]	**41.3[A]**	51.5	48.2 [A]
Hospitalisations								
Coronary heart disease	840.7 [B]	495.5 [B]	386.2 [B]	262.1 [B]	655.0 [E]	328.3 [E]	--	536.0 [E]
COPD >65 years	--	--	--	--	981.7 [E]	1230.5 [E]	--	1538.9 [E]
COPD All ages	187.6 [B]	170.9 [B]	220.4 [B]	202.9 [B]	145.3 [E]	195.8 [E]	--	253.1 [E]
Cardiovascular disease								
All ages	2026.5 [B]	1583.6 [B]	1418.1 [B]	1314.6 [B]	1407.9 [E]	1512.8 [E]	1976	1787.2 [E]
>65 years	--	--	--	--	--	--	**9235**	
Respiratory disease								
All ages	--	--	--	--	1407.9 [E]	1512.8 [E]	2003	1787.2 [E]
>65 years	--	--	--	--	--	--	**3978**	
Asthma								
Asthma hospitalisations (ages 5–34 years)	--	--	--	--	129.4 [E]	144.2 [E]	--	180.5 [E]
Asthma emergency department hospitalisations (1–14 years)	--	--	--	--	--	--	**1209**	--
Asthma prevalence (current) for children aged 2–15 years	--	--	--	--	9.3% [E]	11.7% [E]	--	12.9% [E]
Current asthma for ages 16 and over	--	--	--	--	8.0% [D]	8.5% [D]	--	10.9% [D]

* Data for Sydney Metropolitan area for 2010 based on hospital statistics as reported for 2010 and population data from the ABS for 2011 (relevant to each age group considered) used in review of exposure and risks to inform recommendations for updating the National Environment Protection Measure (NEPM) Ambient Air Quality (AAQ) (Golder 2013)
All other data has been obtained from Health Statistics New South Wales, where: A: 2014–2016 data B: 2015-16 to 2016-17 data C: 2015-2016 or 2016 data D: 2017 data E: 2016-2017 data
-- No data available **Bold and shaded**: Data used in the characterisation of risk

Table 4.4: **Number of prescriptions for antidepressants per 100,000 people, by LGA in 2014-2015**

Age group	Botany	Sydney Inner City	Marrickville – Sydenham-Petersham	Canterbury	Kogarah - Rockdale	NSW average
17 years and under	4,988	7,284	6,531	3,294	3,502	8,187
18 to 64 years	65,100	76,303	79,279	54,776	58,780	90,959
65 years and over	149,818	159,584	158,224	143,705	152,210	179,771

Data from Australian Atlas of Healthcare Variation, Atlas 2015 (note that the Atlas 2017 did not include mental health data)

4.5 Community concerns

ARTC has undertaken a range of community consultation activities to inform the EIS. These activities have been undertaken between May and June 2019 and included:

- pop-up information booths
- community information sessions
- door knocks
- newsletters.

The key concerns raised during community consultation related to:

- increased noise as a result of construction activities and additional freight trains during operation
- increased vibration, with some residents indicating they currently experience vibration from passing freight trains
- land required to accommodate the project
- access and traffic changes as a result of construction activities.

More specifically, in relation to health, the key community concern related to community health in general as well as the impact of increased levels of noise on health. Some concerns were also raised in relation to pedestrian and cyclist safety and active transport as well as dust impacts particularly during construction.

These community concerns have been addressed in this assessment, with impacts on community health related to changes in air quality (including dust impacts during construction) addressed in Section 5, changes in noise addressed in Section 6 and pedestrian and cyclist safety addressed in Section 7.2.

5. Impacts to human health: Changes in air quality

5.1 Existing air quality

When predicting the impact of any new or modified source of air pollution, it is necessary to take into account the way in which the emissions from the source would interact with existing pollutant levels. Defining these existing levels and the interactions can be challenging, especially in a large urban area such as Sydney where there is a complex mix of sources. It is important to consider both the temporal and spatial variation in pollutant concentrations; these fluctuate a great deal on short time scales, but also show cyclical variations. Moreover, in large urban areas there is usually a complex mix of pollution sources, and substantial concentration gradients. Short-term events such as bushfires, localised meteorological conditions and local topography are also important.

The existing air quality in the study area has been determined in the Air Quality Impact Assessment on the basis of data from Randwick and Earlwood, the closest NSW OEH ambient air monitoring stations.

5.2 Construction impacts

5.2.1 Overview of air quality impact assessment: construction

Technical Report 3 – Air quality impact assessment evaluated impacts on air that may occur during construction. The assessment considered impacts that may occur during various surface works and involved a quantitative assessment approach, focusing on emissions to air of dust. The assessment has also considered and provided comment on other emissions such as combustion emissions from construction vehicles and plant equipment and odours and other volatile emissions during the disturbance of contaminated soil.

The assessment has identified dust emission factors, for coarse dust (total suspended particulates [TSP]) and fine dust as PM_{10} and $PM_{2.5}$ relevant to the various different equipment and activities. Impacts from these activities were then modelled based on average and worst-case conditions (emissions and dispersion conditions), with consideration of dust suppression using watering.

Construction dust impacts were qualified using a dispersion model, AUSPLUME 6.0, in accordance with NSW guidance (NSW EPA 2016). The predicted impacts were compared against short-term, 24-hour average, and long-term, annual average assessment criteria.

Short-term impacts

This approach also considered background, or existing, levels of particulates, which was a significant contributor to the NEPM (NEPC 2016) assessment criteria adopted over a 24-hour period. Based on the assessment undertaken, with consideration of the use of watering to manage dust emissions, no off-site dust impacts were predicted for the average scenario. For the worst-case scenario the PM_{10} criteria was met within 6 metres of the site boundary and there were no off-site impacts for $PM_{2.5}$. In areas where works are closer to residential properties or commercial properties, additional dust mitigation measure have been identified to address worst-case impacts.

Long-term impacts

The assessment of dust impacts during long-term construction works was presented, even though the location of construction works is expected to change throughout the project. By assuming construction activities remain in the same location for a year, the assessment of community impacts is conservative. As with the short-term assessment, existing or background particulate levels of particulates are a significant contributor to the assessment criteria. For the assessment undertaken there are no offsite impacts of TSP or PM_{10}, with the $PM_{2.5}$ criteria met within 7 metres of the site boundary. Given the conservative nature of the assessment long-term $PM_{2.5}$ impacts are not expected during construction. Regardless additional risk management measures have been identified to further minimise the potential for offsite impact.

5.2.2 Dust mitigation and health impacts

For PM_{10} and $PM_{2.5}$ the 24-hour average and annual average criteria that applies is the NEPM ambient air guidelines (NEPC 2016). For the assessment of potential health impacts during construction, use of these guidelines is appropriate and sufficiently protective of health. Where there are impacts predicted during construction that result in exceedance of these guidelines, there is the potential for health impacts. As summarised above, there is the low potential for dust generated during construction to exceed these guidelines within the community, particularly where mitigation measures are implemented. Hence health impacts are considered to be low. The implementation of management measures during construction as outlined in *Technical Report 3: Air quality impact assessment* are appropriate for minimising dust impacts to protect health.

While health impacts are expected to be low with the implementation of proposed mitigation measures there may still be some nuisance dust that is noticeable by the community on occasions. Nuisance dust is dust particles that are too large to penetrate into the lungs (and result in adverse health effects) but will settle out on various surfaces and may create a visible dust layer or require cleaning, and may be considered annoying.

5.3 Overview of air quality impacts during operation

The assessment of changes in air quality associated with the operation of the project has been undertaken on the basis of emissions to air from the operation of the rail line, with particulates (from combustion, wheels and brakes and entrainment of particles in the rail corridor) and combustion emissions from diesel freight and passenger locomotives. These combustion emissions include nitrogen dioxide (NO_2) carbon monoxide (CO), sulfur dioxide (SO_2) and hydrocarbons. Locomotive emissions were determined on the basis of NSW emission factors, the expected locomotive speeds, inclines and declines in the rail line and the number of movements.

Modelling of emissions to air during operation has been undertaken using the dispersion model CALPUFF, an approved model for such uses in NSW (NSW EPA 2016). The modelling considered local meteorological and terrain data, along with details in relation to locomotive emissions. The focus of the air quality impact assessment was on air impacts at the receptor locations closest to the project. These are the 20 receptors outlined in Section 4.2.

Based on the assessment of project operations there were no exceedances of the assessment criteria adopted in *Technical Report 3: Air quality impact assessment*.

The modelling undertaken to assess air quality impacts has been relied on and used in the health impact assessment. The data used to evaluate health impacts relates to key pollutants derived from locomotives, which are sulfur dioxide (refer to Section 6.5), carbon monoxide (evaluated further in Section 6.4), nitrogen dioxide (evaluated further in Section 6.6) and particulates (evaluated further in Section 6.7). For the purpose of the assessment of health impacts, concentrations of these pollutants have been provided for the 20 receptors (for 2024 and 2034), as well as over the whole modelling grid (for 2034).

Other emissions of particulate matter from freight trains are predominantly associated with the following:

- combustion-related particle emissions of diesel locomotives
- wheel and brake actions on rail lines
- entrainment of surface particles in the rail corridor.

However, the particulate matter emissions from wheel and brake actions, as well as entrainment of surface particles emissions are negligible compared with emissions to air from diesel exhaust and hence these sources were not evaluated separately in *Technical Report 3: Air quality impact assessment*.

It is expected that all maintenance works undertaken will involve little or minor dust generating activities, be infrequent and short in duration. Dust generation from maintenance works was considered insignificant and not further assessed in *Technical Report 3: Air quality impact assessment*.

It is noted that the Air Quality Impact Assessment also evaluated total hydrocarbons. The assessment undertaken assumed that 100% of the hydrocarbons released to air from the locomotives was benzene. This is a highly conservative assumption as benzene typically comprise only a very small fraction of hydrocarbons from diesel combustion sources. Benzene (which is a known human carcinogen) is, however, the most toxic hydrocarbon in combustion emissions, so this assumption is conservative.

Even where this conservative assumption was adopted that maximum concentration of hydrocarbons from the project are only 1.6% of the NSW EPA criteria (for benzene). On this basis there are no community health impacts of concern for hydrocarbon emissions and no further, detailed assessment of potential health impacts has been undertaken.

5.4 Assessment of health impacts – carbon monoxide

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

Guidelines are available from the NEPC (as standards) (NEPC 2016) that are based on the protection of adverse health effects associated with carbon monoxide. The air standards currently available from NEPC are consistent with health based guidelines currently available from the WHO (WHO 2005, 2010) and the USEPA (2011[2], specifically listed to be protective of exposures by sensitive populations including asthmatics, children and the elderly). On this basis, the current NEPC standards are considered appropriate for the assessment of potential health impacts associated with the project.

The NEPC ambient air quality standard for the assessment of exposures to carbon monoxide has considered the lowest observed adverse effect level (LOAEL) and the no observed adverse effect level (NOAEL) associated with a range of health effects in healthy adults, with people with ischemic heart disease and with foetal effects.

[2] *Most recent review of the Primary National Ambient Air Quality Standards for Carbon Monoxide published by the USEPA in the Federal Register Volume 76, No. 169, 2011, available from: http://www.gpo.gov/fdsys/pkg/FR-2011-08-31/html/2011-21359.htm*

In relation to these data, a level of carbon monoxide of nine parts per million (ppm) by volume (or 10 milligrams per cubic metre or 10,000 micrograms per cubic metre) over an 8-hour period was considered to provide protection (for both acute and chronic health effects) for most members of the population (NEPC 2016). An additional 1.5-fold uncertainty factor to protect more susceptible groups in the population was included. On this basis, the NEPC standard is protective of adverse health effects in all individuals, including sensitive individuals.

The 1-hour criteria of 30 mg/m^3 (WHO 2000b) is consistent with the more recent update from the WHO (WHO 2010).

Table 6.1 summarises the maximum predicted 1-hour average and 8-hour average concentrations of carbon monoxide for the assessment years 2024 and 2034, in relation to emissions to air from the project. The table presents the maximum from the 20 receptors evaluated as well as the maximum concentrations predicted from the whole modelling grid. No background concentration of CO was identified in the Air Quality Impact Assessment, as no data was available from the closest air monitoring stations.

Table 5.1: Review of potential acute and chronic health impacts – carbon monoxide (CO)

Scenario	Maximum 1-hour average concentration of CO (mg/m3)	Maximum 8-hour average concentration of CO (mg/m3)
20 local receptors		
2024: no project	0.050	0.013
2024: with project	0.057	0.015
2034: no project	0.050	0.013
2034: with project	0.097	0.025
Whole modelling grid		
2034: with project	0.126	0.033
Relevant health based standard/ guideline	**30**	**10**

All the concentrations of carbon monoxide presented in Table 6.1 are well below the relevant health based standards/guidelines listed at the base of the table. The contribution from the project is very small. Hence there are no health impacts of concern in relation to the project.

5.5 Assessment of health impacts – sulfur dioxide

SO_2 is a colourless gas with a pungent odour. It is known to have adverse effects on human health, and is also a major precursor to acid rain, which is associated with the acidification of lakes and streams, accelerated corrosion of buildings and monuments, and reduced visibility. SO_2 contributes to secondary particle formation by reaction with ammonia to form sulfate salts. This can be a significant contributor to $PM_{2.5}$ concentrations in some airsheds (NEPC 2019).

In relation to the available guidelines for the assessment of SO_2, the following can be noted in relation to the protection of human health:

- Both long and short-term health effects were considered in the development of the NEPC guidelines (NEPC 2003, 2016) for SO_2 which has been recently reviewed (NEPC 2019).

- Exposure to SO_2 results in the development of an acute irritant response initially in the upper airways which leads to coughing, wheezing, sputum production, increased incidence of respiratory infections and aggravation of asthma and chronic obstructive airways disease (COPD). The impacts from these effects can be mild, such as an irritant cough through to more serious impacts such as increases in mortality and hospital admissions for respiratory disease and asthma.
- Asthmatics were considered to be particularly susceptible to SO_2 and respond very quickly (10–15 mins) to exposure even at low levels. The severity of the response depends on the concentration of SO_2 and the duration of the exposure (NEPC 2010).
- The current NEPC guidelines (NEPC 2016) were developed to protect against bronchospasm in asthmatics and addressed both acute exposures (based on 1 hour and 24 hour averages) and chronic exposures (based on an annual average). Further review in 2019 determined that the long-term health effects associate with SO_2 are weak (with limited data) and to ongoing use of an annual average guideline may not be suitable.

Further review of health effects associated with exposure to SO_2 by NEPC (NEPC 2010) identified that it was appropriate to establish a guideline based on a threshold (i.e. where exposures below the threshold concentration are not associated with any adverse health effects). Hence it is appropriate that the assessment of potential health effects associated with exposure to SO_2 be undertaken solely on the basis of the NEPC guidelines as these are based on a threshold that is protective of adverse health effects for all individuals. It is noted that the 2019 review (NEPC 2019) identified non-threshold concentration-response functions for consideration of short-term exposures to SO_2. These studies have been used to further review of NEPC ambient air quality guidelines. This assessment is based on the current NEPC guidelines (NEPC 2016).

Table 6.2 summarises the maximum predicted 1-hour average, 24-hour average and annual average concentrations of SO_2 for the assessment years 2024 and 2034 (from *Technical Report 3: Air quality impact assessment)*, in relation to emissions to air from the project. The table presents the maximum from the 20 receptors evaluated as well as the maximum concentrations predicted from the whole modelling grid. Background concentrations have been included in this assessment.

Table 5.2: Review of potential acute and chronic health impacts – sulfur dioxide (SO_2)

Scenario	**Maximum 1-hour average concentration of SO_2 ($\mu g/m^3$)** Including background	**Maximum 24-hour average concentration of SO_2 ($\mu g/m^3$)** Including background	**Maximum annual average concentration of SO_2 ($\mu g/m^3$)** Including background
20 local receptors			
2024: no project	136	15	3.8
2024: with project	119	14	3.5
2034: no project	136	16	4.1
2034: with project	156	15	4.0
Whole modelling grid			
2034: with project	182	NA	7.7
Relevant health based standard/ guideline	**570**	**228**	**60**

All predicted concentrations of SO_2 are well below the adopted health based criteria. Hence there are no health issues of concern in relation to all (acute and chronic) exposures to SO_2 in the local community.

It is noted that the maximum concentrations of SO_2 are also below the proposed reduced criteria of 260 µg/m^3 (1- hour average standard), 196 µg/m^3 (1-hour average goal for 2025) and 52 µg/m^3 (24-hour average standard) (NEPC 2019) should these standards be endorsed post completion of the EIS.

5.6 Assessment of health impacts – nitrogen dioxide

5.6.1 Health effects associated with exposure

Nitrogen oxides (NOx) refer to a collection of highly reactive gases containing nitrogen and oxygen, most of which are colourless and odourless. Nitrogen oxide gases form when fuel is burnt. Diesel engines (including locomotives), petrol engines, and other industrial, commercial and residential (e.g. gas heating or cooking) combustion sources, are primary producers of nitrogen oxides. The main source of nitrogen oxides in urban areas is from on-road vehicles and diesel combustion engines (locomotives).

In terms of health effects, nitrogen dioxide is the only oxide of nitrogen that is of concern (WHO 2000c). Nitrogen dioxide is a colourless and tasteless gas with a sharp odour. Nitrogen dioxide can cause inflammation of the respiratory system and increase susceptibility to respiratory infection. Exposure to elevated levels of nitrogen dioxide has also been associated with increased mortality, particularly related to respiratory disease, and with increased hospital admissions for asthma and heart disease patients (WHO 2013). Asthmatics, the elderly and people with existing cardiovascular and respiratory disease are particularly susceptible to the effects of nitrogen dioxide (Morgan, Broom & Jalaludin 2013; NEPC 2010). The health effects associated with exposure to nitrogen dioxide depend on the duration of exposure as well as the concentration.

Guidelines are available from the NEPC (as standards) (NEPC 2016) which indicate acceptable concentrations of nitrogen dioxide. These guidelines are based on protection from adverse health effects following both short-term (acute) and longer-term (chronic) exposure for all members of the population including sensitive populations like asthmatics, children and the elderly.

When reviewing the available literature on the health effects associated with exposure to nitrogen dioxide it is important to consider the following:

- Whether the evidence suggests that associations between exposure to nitrogen dioxide concentrations and effects on health are causal. The most current review undertaken by the USEPA (USEPA 2015) specifically evaluated evidence of causation. The review identified that a causal relationship existed for respiratory effects (for short-term exposure with long-term exposures also likely to be causal). All other associations related to exposure to nitrogen dioxide (specifically cardiovascular effects, mortality and cancer) were considered to be suggestive.
- Whether the reported associations are distinct from, and additional to, those reported and assessed for exposure to particulate matter. Co-exposures to nitrogen dioxide and particulate matter complicates review and assessment of many of the epidemiology studies as both these air pollutants occur together in urban areas. There is sufficient evidence (epidemiological and mechanistic) to suggest that some of the health effect associations identified relate to exposure to nitrogen dioxide after adjustment/correction for co-exposures with particulate matter (COMEAP 2015).
- Whether the assessment of potential health effects associated with exposure to different levels of nitrogen dioxide can be undertaken on the basis of existing guidelines, or whether specific risk calculations are required to be undertaken. The current guidelines in Australia for the assessment of nitrogen dioxide in air relate to cumulative (total) exposures, and adopt criteria that are considered to be protective of short and long-term exposures. It is thus relevant that these guidelines be considered in this assessment.

- In addition, the current standards relate to regional air quality, not localised sources and hence use of such standards for the assessment of localised exposures is of limited value.

For these situations, it is relevant to also evaluate the impact on community health of the change in nitrogen dioxide concentration in the local community using appropriate risk calculations. For the conduct of risk assessments in relation to exposure to nitrogen dioxide, the WHO (WHO 2013) identified that the strongest evidence of health effects related to respiratory hospitalisations and to a lesser extent mortality (associated with short-term exposures) and recommend that these health endpoints should be considered in any core assessment of health impacts associated with exposure.

On the basis of the above, potential health effects associated with exposure to nitrogen dioxide would be undertaken for the project using both comparison with guidelines (assessing cumulative/total exposures in Section 5.6.2) and an assessment of incremental impacts on health (associated with changes in air quality from the project in Section 5.6.3).

5.6.2 Assessment of cumulative/total exposures

The NEPC ambient air quality guideline for the assessment of acute (short-term) exposures to nitrogen dioxide relates to the maximum predicted total (cumulative) 1-hour average concentration in air. The guideline of 246 micrograms per cubic metre (or 120 parts per billion by volume) is based on a LOAEL of 409–613 micrograms per cubic metre derived from statistical reviews of epidemiological data suggesting an increased incidence of lower respiratory tract symptoms in children and aggravation of asthma. An uncertainty factor of two to protect susceptible people (ie asthmatic children) was applied to the LOAEL (NEPC 1998). On this basis, the NEPC acute guideline is protective of adverse health effects in all individuals, including sensitive individuals.

The NEPC ambient air quality standard for the assessment of chronic (long-term) exposures to nitrogen dioxide relates to the maximum predicted total (cumulative) annual average concentration in air. The standard of 62 micrograms per cubic metre (or 30 parts per billion by volume) is based on a LOAEL of the order of 40–80 parts per billion by volume (around 75–150 micrograms per cubic metre). This relates to the early and middle childhood years when exposure can lead to the development of recurrent upper and lower respiratory tract symptoms, such as recurrent ‘colds’, a productive cough and an increased incidence of respiratory infection with resultant absenteeism from school.

An uncertainty factor of two was applied to the LOAEL to account for susceptible people within the population resulting in a guideline of 20-40 parts per billion by volume (38–75 micrograms per cubic metre) (NEPC 1998). On this basis, the NEPC standard is protective of adverse health effects in all individuals, including sensitive individuals.

Table 6.3 summarises the maximum predicted cumulative/total 1-hour average and annual average concentrations of nitrogen dioxide for the years 2024 and 2034 from the *Technical Report 2: Air quality impact assessment*. The table presents the maximum from the 20 receptors evaluated as well as the maximum concentrations predicted from the whole modelling grid. Background concentrations have been included in this assessment.

The maximum annual average concentration is the annual average concentration at the maximally affected receptor, regardless of land use.

Table 5.3: Review of potential acute and chronic health impacts – nitrogen dioxide (NO_2)

Scenario	Maximum 1-hour average concentration of NO2 (µg/m3) Including background	Maximum annual average concentration of NO2 (µg/m3) Including background
20 local receptors		
2024: no project	138	31
2024: with project	132	28
2034: no project	138	35
2034: with project	166	36
Whole modelling grid		
2034: with project	250	97
Relevant health based standard/ guideline	**570**	**60**

With the exception of the maximum annual average concentration from the whole modelling grid predicted in 2034, all concentrations of nitrogen dioxide presented in the above table, relevant to the assessment of total acute and chronic exposures, are below the NEPC guidelines.

In relation to the maximum modelled concentration across the whole grid, this occurs on the rail line and is not representative of any location where any member of the community would be exposed to at all (as this is not a location that is publicly accessible) for a whole year. As a result, the higher annual average presented for this scenario is not considered to be of concern, as all annual average concentrations predicted at realistic long-term receptor locations adjacent to the rail line are below the NEPC criteria.

It is noted that the NEPC guidelines for nitrogen dioxide are currently under review (NEPC 2019). Current review of the available studies have strengthened the evidence base for independent effects of nitrogen dioxide on health, particularly in terms of long-term effects. It is noted that the maximum concentrations of NO_2 at the 20 closest receptors as identified in Technical Report 3 Air quality impact assessment, are also below the proposed reduced criteria of 170 µg/m^3 (1- hour average standard) and at the same level as the proposed reduced long-term standard of 35 µg/m^3 (annual average standard) (NEPC 2019). The maximum 1-hour average, which may occur in an area where the community may be present for a short period of time, exceeds the proposed standards. This is an area located close to the project but within the off-site community and is considered to be representative of a worst-case exposure relevant to the community.

To further address potential risks to human health that may be associated with population exposures and localised changes in nitrogen dioxide that relate to the project, incremental risk calculations have been undertaken and are presented in Section 5.6.3.

5.6.3 Assessment of incremental exposures

The evidence base supports quantification of effects of short-term (acute) exposure, using the same averaging time as in the relevant studies. The strongest evidence is for respiratory effects, particularly exacerbation of asthma (particularly within children), with some support also for all-cause mortality. These health endpoints have been evaluated in relation to changes in nitrogen dioxide concentrations in air associated with the project, within the local community in 2024 and 2034.

Table 6.4 summarises the health endpoints considered in this assessment of relevant to the calculation of a relative risk (refer to Appendix A for details on the calculation of a β coefficient from published studies). The coefficients adopted for the assessment of impacts on mortality and asthma emergency department admissions are derived from the detailed assessment undertaken for the current review of health impacts of air pollution undertaken by NEPC (Golder 2013) and are considered to be robust.

Table 5.4: Adopted exposure-response relationships for assessment of changes in nitrogen dioxide concentrations

Health endpoint	Exposure period	Age group	Adopted β coefficient (also as %) for 1 µg/m^3 increase in NO_2	Reference
Mortality, all causes (non-trauma)	Short-term	All ages	0.00188 (0.19%)	Relationship derived for from modelling undertaken for 5 cities in Australia and 1 day lag (EPHC 2010; Golder 2013)
Mortality, respiratory	Short-term	All ages*	0.00426 (0.43%)	Relationship derived for from modelling undertaken for 5 cities in Australia and 1 day lag (EPHC 2010; Golder 2013)
Asthma emergency department admissions	Short-term	1–14 years	0.00115 (0.11%)	Relationship established from review conducted on Australian children (Sydney) for the period 1997 to 2001 (Golder 2013; Jalaludin et al. 2008)

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

Table 6.13 presents the change in localised risk associated with changes in nitrogen dioxide at the maximum impacted receptors close to the project, for the operational years 2024 and 2034. The assessment assumes an individual, at a specific location, is exposed at each maximum impacted location over all hours of the day, regardless of the land use. Risks for all other receptors (including other sensitive receptors) are lower than the maximums presented.

All risks calculated are presented to one significant figure, reflecting the level of uncertainty associated with the calculations presented.

Figure 6.1 presents a summary of the calculated change in localised risk associated with changes in nitrogen dioxide concentrations at each community receptor location evaluated.

Appendix C presents a discussion on levels of the levels of risk that are considered to be negligible, tolerable/acceptable and unacceptable. A summary of these risk levels is included in Table 6.5.

Calculations relevant to the characterisation of risks associated with changes in nitrogen dioxide concentrations in the community are presented in Appendix D.

Table 5.5: Maximum calculated risks associated with exposure to changes in nitrogen dioxide concentrations with operation of the project

Scenario and receptor	**Maximum change in localised risk from exposure to NO_2 for the following health endpoints**		
	Mortality: All causes (all ages)	**Mortality: Respiratory (all ages)**	**Asthma ED Admissions (1–14 years)**
2024 – with project (with project minus no project for 2024)			
Maximum from closest 20 receptors*	-3×10^{-6}	-6×10^{-7}	-4×10^{-6}
Maximum residential*	-4×10^{-6}	-8×10^{-7}	-6×10^{-6}
2034 – with project (with project minus no project for 2024)			
Maximum from closest 20 receptors	1×10^{-5}	3×10^{-6}	2×10^{-5}
Maximum residential	1×10^{-5}	3×10^{-6}	2×10^{-5}
Negligible risks	$<1 \times 10^{-6}$		
Tolerable/acceptable risks	$\geq 1 \times 10^{-6}$ and $\leq 1 \times 10^{-4}$		
Unacceptable risks	$>1 \times 10^{-4}$		

* Negative values mean a decrease in exposure and some health benefit

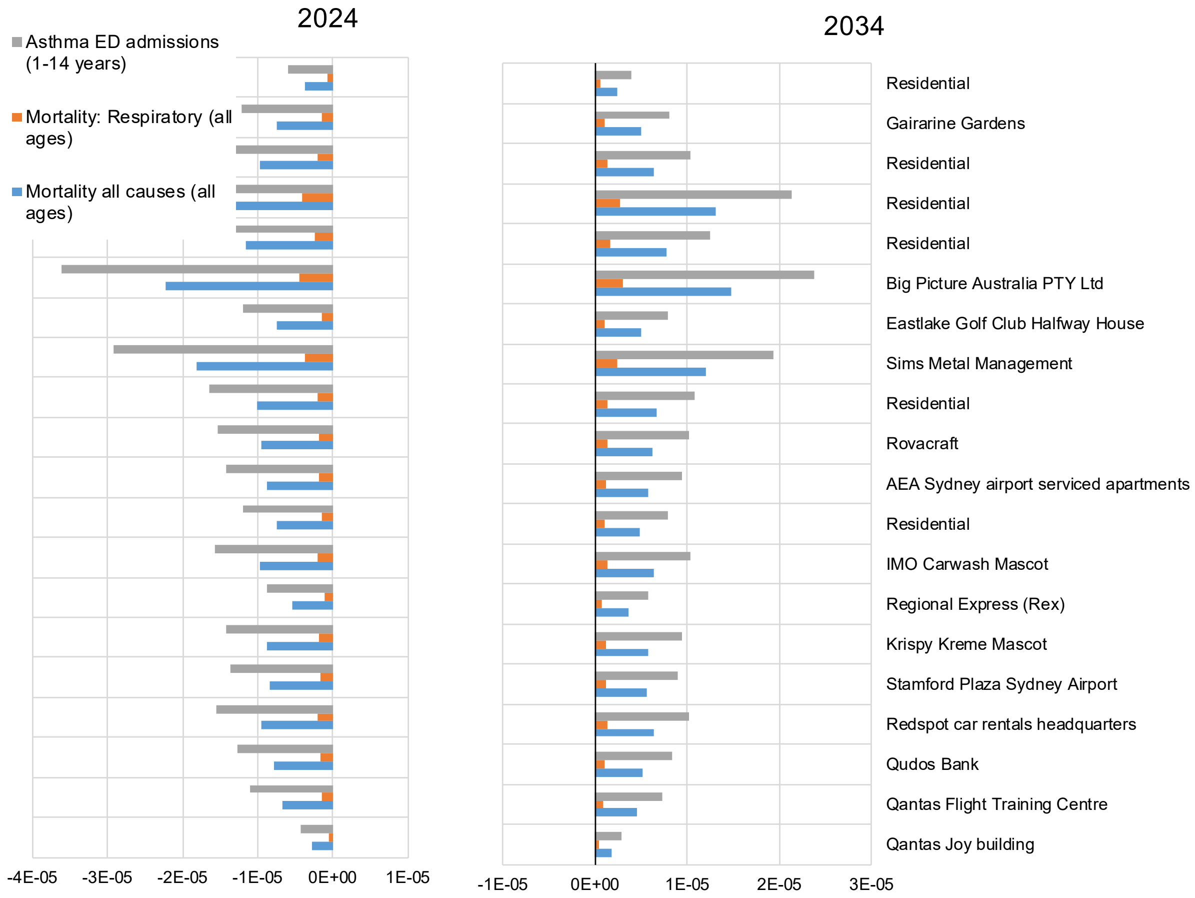


Figure 5.1: Change in calculated risk for key health endpoints associated with total changes in nitrogen dioxide concentrations at community receptors (2024 and 2034) (negative values mean a decrease in exposure and some health benefit)

Review of the calculated risks for community exposures to nitrogen dioxide indicates that all risks are less than 1 x 10^{-4} and are therefore considered to be acceptable. On this basis there are no health risk issues of concern in relation to changes in nitrogen dioxide in the community.

For the assessment of impacts during 2024, the calculated risks indicate a lower level of exposure (compared to 2034) and hence there may be some health benefits. This means that the concentrations of nitrogen dioxide that the community is exposed to is lower in 2024 with the project, than would occur without the project. Where there is a lower level of exposure there is a health benefit (i.e. lower or reduced levels of health risk). It is noted that the risks related to health benefits are small and it would be unlikely that these would be measurable in the community.

5.7 Assessment of health impacts – particulates

5.7.1 Particle size

Particulate matter is a widespread air pollutant with a mixture of physical and chemical characteristics that vary by location (and source). Unlike many other pollutants, particulates comprise a broad class of diverse materials and substances, with varying morphological, chemical, physical and thermodynamic properties, with sizes that vary from less than 0.005 microns to greater than 100 microns. Particulates can be derived from natural sources such as crustal dust (soil), pollen and moulds, and other sources that include combustion and industrial processes. Secondary particulate matter is formed via atmospheric reactions of primary gaseous emissions. The gases that are the most significant contributors to secondary particulates include nitrogen oxides, ammonia, sulfur oxides, and certain organic gases (derived from vehicle exhaust, combustion sources, agricultural, industrial and biogenic emissions).

Numerous epidemiological studies[3] have reported significant positive associations between particulate air pollution and adverse health outcomes, particularly mortality as well as a range of adverse cardiovascular and respiratory effects.

The potential for particulate matter to result in adverse health effects is dependent on the size and composition of the particulate matter. The common measures of particulate matter that are considered in the assessment of air quality and health risks are:

- Total suspended particulates (TSP): This refers to all particulates with an equivalent aerodynamic particle[4] size below about 50 microns in diameter[5]. It is a fairly gross indicator of the presence of dust with a wide range of sizes. Larger particles (termed 'inspirable', comprise particles around 10 microns and larger) are more of a nuisance as they would deposit out of the air (measured as deposited dust) close to the source and, if inhaled, are mostly trapped in the upper respiratory system[6] and do not reach the lungs. Finer particles (smaller than 10 microns, termed 'respirable') tend to be transported further from the source and are of more concern with respect to human health as these particles can penetrate into the lungs (see following point). Not all of the dust characterised as total suspended particulates is thus relevant for the assessment of health impacts, and total suspended particulates as a measure of impact, has not been further evaluated in this assessment. The assessment has only focused on particulates of a size where significant associations have been identified between exposure and adverse health effects.
- PM_{10} (particulate matter below 10 microns in diameter, µm), $PM_{2.5}$ (particulate matter below 2.5 µm in diameter) and PM_1 (particulate matter below one µm in diameter, often termed very fine particles) and ultrafines (particulate matter below 0.1 µm in diameter), as illustrated in Figure 6.2. These particles are small and have the potential to penetrate beyond the body's natural clearance mechanisms of cilia and mucous in the nose and upper respiratory system, with smaller particles able to further penetrate

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3 Epidemiology is the study of diseases in populations. Epidemiological evidence can only show that this risk factor is associated (correlated) with a higher incidence of disease in the population exposed to that risk factor. The higher the correlation the more certain the association. Causation (i.e. that a specific risk factor actually causes a disease) cannot be proven with only epidemiological studies. For causation to be determined a range of other studies need to be considered in conjunction with the epidemiology studies.

4 The term equivalent aerodynamic particle is used to reference the particle to a particle of spherical shape and particle of density one gram per cubic metre.

5 The size, diameter, of dust particles is measured in micrometers (microns).

6 The upper respiratory tract comprises the mouth, nose, throat and trachea. Larger particles are mostly trapped by the cilia and mucosa and swept to the back of the throat and swallowed.

into the lower respiratory tract[7] and lungs. Once in the lungs adverse health effects may result (OEHHA 2002).

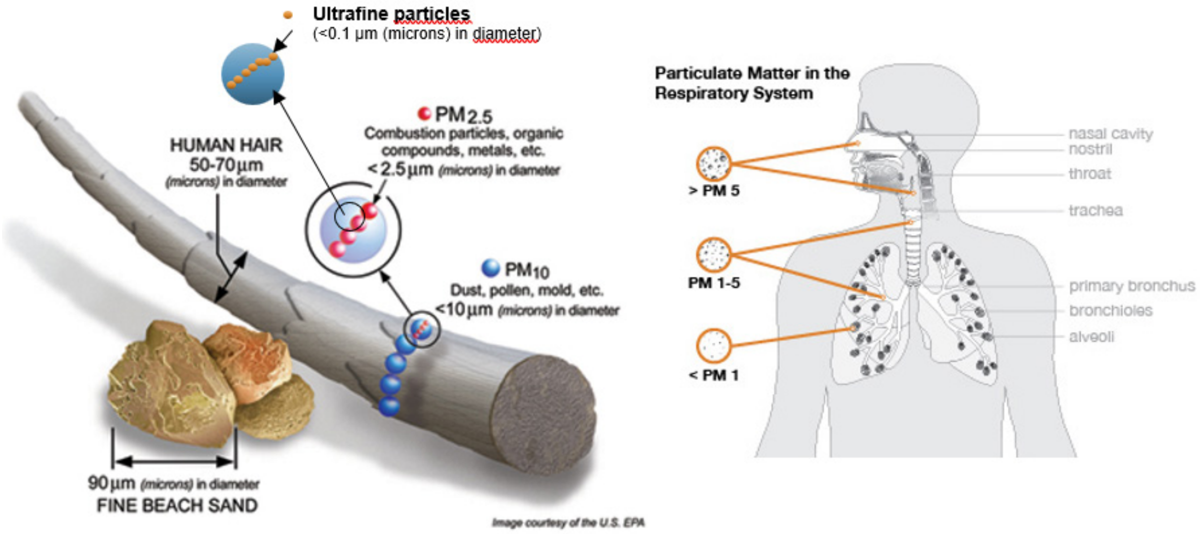

Figure 5.2: Illustrative representation of particle sizes and penetration into the lungs

Evaluation of size alone as a single factor in determining the potential for particulate toxicity is difficult since the potential health effects are not independent of chemical composition. There are certain particulate size fractions that tend to contain certain chemical components. Metals are commonly found attached to fine particulates (less than $PM_{2.5}$) while crustal materials (like soil) are usually larger and are present as PM_{10} or larger. In addition, different sources of particulates have the potential to result in the presence of other pollutants in addition to particulate matter. For example, combustion sources, prevalent in urban areas, result in the emission of particulate matter (more dominated by $PM_{2.5}$) as well as gaseous pollutants (such as nitrogen dioxide and carbon monoxide). This results in what is referred to as co-exposure and is an issue that has to be accounted for when evaluating studies that come from studying health effects in large populations exposed to pollution from many sources (as is the case in urban air).

Where co-exposure is accounted for the available science supports that exposure to fine particulate matter (less than 2.5 µm, $PM_{2.5}$) is associated (and shown to be causal in some cases) with health impacts in the community (USEPA 2012). A more limited body of evidence suggests an association between exposure to larger particles, PM_{10} and adverse health effects (USEPA 2009a, 2018; WHO 2003).

5.7.2 Health effects

Adverse health effects associated with exposure to particulate matter have been well studied and reviewed by Australian and International agencies. Most of the studies and reviews have focused on population-based epidemiological studies in large urban areas in North America, Europe and Australia, where there have been clear associations determined between health effects and exposure to $PM_{2.5}$ and to a lesser extent, PM_{10}. These studies are complemented by findings from other key investigations conducted in relation to: the characteristics of inhaled particles; deposition and clearance of particles in the respiratory

[7] *The lower respiratory tract comprises the smaller bronchioles and alveoli, the area of the lungs where gaseous exchange takes place. The alveoli have a very large surface area and absorption of gases occurs rapidly with subsequent transport to the blood and the rest of the body. Small particles can reach these areas, be dissolved by fluids and absorbed.*

tract; animal and cellular toxicity studies; and studies on inhalation toxicity by human volunteers (NEPC 2010).

Particulate matter has been linked to adverse health effects after both short-term exposure (days to weeks) and long-term exposure (months to years). The health effects associated with exposure to particulate matter vary widely (with the respiratory and cardiovascular systems most affected) and include mortality and morbidity effects.

In relation to mortality, for short-term exposures in a population this relates to the increase in the number of deaths due to existing (underlying) respiratory or cardiovascular disease; for long-term exposures in a population this relates to mortality rates over a lifetime, where long-term exposure is considered to accelerate the progression of disease or even initiate disease.

In relation to morbidity effects, this refers to a wide range of health indicators used to define illness that have been associated with (or caused by) exposure to particulate matter. In relation to exposure to particulate matter, effects are primarily related to the respiratory and cardiovascular system and include (Morawska, Moore & Ristovski 2004; USEPA 2009a, 2018):

- Aggravation of existing respiratory and cardiovascular disease (as indicated by increased hospital admissions and emergency room visits).
- Changes in cardiovascular risk factors such as blood pressure.
- Changes in lung function and increased respiratory symptoms (including asthma).
- Changes to lung tissues and structure.
- Altered respiratory defence mechanisms.

The most recent review of the available studies (USEPA 2018) have also indicated that effects on the nervous system and carcinogenic effects are likely to have a causal relationship with long-term exposures to $PM_{2.5}$. IARC (2013) has classified particulate matter as carcinogenic to humans based on data relevant to lung cancer.

These effects are commonly used as measures of population exposure to particulate matter in community epidemiological studies (from which most of the available data in relation to health effects is derived) and are more often grouped (through the use of hospital codes) into the general categories of cardiovascular morbidity/effects and respiratory morbidity/effects. The available studies provide evidence for increased susceptibility for various populations, particularly older populations, children and those with underlying health conditions (USEPA 2009a).

There is consensus in the available studies and detailed reviews that exposure to fine particulates, $PM_{2.5}$, is associated with (and causal to) cardiovascular and respiratory effects and mortality (all causes) (USEPA 2012). While similar relationships have also been determined for PM_{10}, the supporting studies do not show relationships as clear as shown with $PM_{2.5}$ (USEPA 2012).

There are a number of studies that have been undertaken where other health effects have been evaluated. These studies have a large degree of uncertainty or a limited examination of the relationship and are generally only considered to be suggestive or inadequate (in some cases) of an association with exposure to $PM_{2.5}$ (USEPA 2018). This includes long-term exposures and metabolic effects, male and female reproduction and fertility, pregnancy and birth outcomes; and short-term exposures and nervous system effects (USEPA 2018).

In relation to the key health endpoints relevant to evaluating exposures to $PM_{2.5}$, there are some associated health measures or endpoints where the exposure-response relationships are not as strong or robust as those for the key health endpoints and are considered to be a subset of the key health endpoints. This includes mortality (for different age groups), chronic bronchitis, medication use by adults and children with asthma, respiratory symptoms (including cough), restricted work days, work days lost, school absence and restricted activity days (Anderson et al. 2004; EC 2011b; Ostro 2004; WHO 2006a).

5.7.3 Approach to the assessment of particulate exposures

In relation to the assessment of exposures to particulate matter there is sufficient evidence to demonstrate that there is an association between exposure to $PM_{2.5}$ (and to a lesser extent PM_{10}) and effects on health that are causal.

The available evidence does not suggest a threshold below which health effects do not occur. Accordingly, there are likely to be health effects associated with background levels of $PM_{2.5}$ and PM_{10}, even where the concentrations are below the current guidelines. Standards and goals are currently available for the assessment of $PM_{2.5}$ and PM_{10} in Australia (NEPC 2016). These standards and goals are not based on a defined level of risk that has been determined to be acceptable, rather they are based on balancing the potential risks due to background and urban sources to lower impacts on health in a practical way.

The air quality standards and goals relate to average or regional exposures by populations from all sources, not to localised 'hot-spot' areas such as locations near industry, busy roads or mining. They are intended to be compared against ambient air monitoring data collected from appropriately sited regional monitoring stations. In some cases, there may be local sources (including busy roadways and industry) that result in background levels of PM_{10} and $PM_{2.5}$ that are close to, equal to, or in exceedance of, the air quality standards and goals. Where impacts are being evaluated from a local source it is important to not only consider cumulative/total impacts associated with the project (undertaken using the current air quality goals) but also evaluate the impact of changes in air quality within the local community.

This assessment has therefore been undertaken to consider both cumulative/total exposure impacts (refer to Section 5.7.4) and incremental exposure impacts associated with changes in $PM_{2.5}$ and PM_{10} concentrations that are associated with the project (refer to Section 5.7.5). Incremental changes are those due to the project alone while cumulative/total changes are those where background air quality in addition to those due to the project alone are considered.

5.7.4 Assessment of cumulative/total exposures

The assessment of cumulative/total exposures to $PM_{2.5}$ and PM_{10} is based on a comparison of the cumulative/total concentrations predicted with the current air quality standards and goals presented in the National Environment Protection Council (NEPC) (Ambient Air Quality) Measure (NEPM) (NEPC 2016). These standards and goals are total concentrations in ambient air, within the community, that are based on the most current science in relation to health effects. The most current standards and goals, based on the protection of community health presented by the NEPC, have been further considered in this health impact assessment report.

The air quality standards and goals for $PM_{2.5}$ and PM_{10} relate to total concentrations in the air (from all sources including the project). The background air quality data used in the assessment of this project is outlined in the *Technical Report 3 – Air quality impact assessment*.

Table 5.6 summarises the maximum 24-hour average and annual average concentrations of $PM_{2.5}$ and PM_{10} relevant to the assessment of emissions in 2024 and 2034. The table presents the maximum from the 20 receptors evaluated as well as the maximum concentrations predicted from the whole modelling grid. Background concentrations have been included in this assessment.

Table 5.6: Review of cumulative/total PM concentrations

Location and scenario	Maximum 24-hour average concentration (µg/m^3)		Maximum annual average concentration (µg/m^3)	
	$PM_{2.5}$	PM_{10}	$PM_{2.5}$	PM_{10}
20 local receptors				
2024: No project	23.2	46.7	8.0	18.4
2024: With project	23.2	46.6	8.0	18.4
2034: No project	23.4	46.8	8.0	18.4
2034: With project	23.4	46.8	8.0	18.4
Whole modelling grid				
2034: With project	23.5	46.9	8.1	18.5
Standards and goals	**25 (20 as goal for 2025)**	**50**	**8 (7 as goal by 2025)**	**25**

Review of Table 6.6 indicates:

- The maximum total/cumulative concentrations of $PM_{2.5}$ from the project are equal to or above the relevant standard and goal for the 24-hour (2025 goal) and annual average (standard and 2025 goal), regardless of the project. This is due to existing levels (ie background levels) of $PM_{2.5}$ in the local urban environment and not the contribution from the project.
- The maximum total/cumulative concentrations of PM_{10} from the project are below relevant standard and goal for the 24-hour and annual average.

Concentrations of $PM_{2.5}$ and PM_{10} are essentially unchanged within the local community (outside the rail corridor) with the operation of the project. This means that the project does not change the total level of particulates the community is exposed to.

To further address 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 has been undertaken and are presented in Section 6.7.5.

5.7.5 Assessment of incremental exposures

A detailed assessment of potential health effects associated with exposure to changes in air quality as a result of the project operation has been undertaken. As no threshold has been determined for exposure to $PM_{2.5}$ or PM_{10} the assessment of impacts on health has utilised robust, published, quantitative relationships (exposure-response relationships) that relate a change in $PM_{2.5}$ or PM_{10} concentration with a change in a health indicator. Appendix A presents an overview of the methodology adopted for using exposure-response relationships for the assessment of health impacts in a community.

For the assessment of potential exposures to changes in particulate matter, the assessment focused on health effects and exposure-response relationships that are robust and relate to $PM_{2.5}$, being the more important particulate fraction size relevant for emissions from combustion sources (refer to sections 5.7.1 and 5.7.2). Assessment of health effects from exposure to the larger particles as PM_{10} has also been included.

Table 6.7 summarises the health endpoints considered in this assessment, the relevant health impact functions (from the referenced published studies) and the associated β coefficient relevant to the calculation of a relative risk (refer to Appendix A for details on the calculation of a β coefficient from published studies).

The health impact functions presented in this table are the most current and robust values and are appropriate for the quantification of potential health effects for the health endpoints considered in this assessment.

Table 5.7: Adopted health impact functions and exposure-responses relationships

Health endpoint	Exposure period	Age group	Published relative risk [95 confidence interval] per 10 μg/m³	Adopted β coefficient (as %) for 1 μg/m³ increase in PM	Reference
Primary assessment health endpoints					
$PM_{2.5}$: Mortality, all causes	Long-term	≥30yrs	1.06 [1.04-1.08]	0.0058 (0.58)	Relationship derived for all follow-up time periods to the year 2000 (for approx. 500,000 participants in the US) with adjustment for seven ecologic (neighbourhood level) covariates (Krewski et al. 2009). This study is an extension (additional follow-up and exposure data) of the work undertaken by Pope (2002), is consistent with the findings from California (1999-2002) (Ostro et al. 2006) and is more conservative than the relationships identified in a more recent Australian and New Zealand study (EPHC 2010)
$PM_{2.5}$: Cardiovascular hospital admissions	Short-term	≥65yrs	1.008 [1.0059-1.011]	0.0008 (0.08)	Relationship established for all data and all seasons from US data for 1999 to 2005 for lag 0 (exposure on same-day)(strongest effect identified) (Bell 2012; Bell et al. 2008)
$PM_{2.5}$: Respiratory hospital admissions	Short-term	≥65yrs	1.0041 [1.0009-1.0074]	0.00041 (0.041)	Relationship established for all data and all seasons from US data for 1999 to 2005 for lag 2 (exposure 2 days previous)(strongest effect identified) (Bell 2012; Bell et al. 2008)
Secondary assessment health endpoints					
PM_{10}: Mortality, all causes	Short-term	All ages*	1.006 [1.004-1.008]	0.0006 (0.06)	Based on analysis of data from European studies from 33 cities and includes panel studies of symptomatic children (asthmatics, chronic respiratory conditions) (Anderson et al. 2004)
$PM_{2.5}$: Mortality, all causes	Short-term	All ages*	1.0094 [1.0065-1.0122]	0.00094 (0.094)	Relationship established from study of data from 47 US cities for the years 1999 to 2005 (Zanobetti & Schwartz 2009)

Health endpoint	Exposure period	Age group	Published relative risk [95 confidence interval] per 10 μg/m^3	Adopted β coefficient (as %) for 1 μg/m^3 increase in PM	Reference
$PM_{2.5}$: Cardio-pulmonary mortality	Long-term	≥30yrs	1.14 [1.11-1.17]	0.013 (1.3)	Relationship derived for all follow-up time periods to the year 2000 (for approx. 500,000 participants in the US) with adjustment for seven ecologic (neighbourhood level) covariates (Krewski et al. 2009)
$PM_{2.5}$: Cardiovascular mortality	Short-term	All ages*	1.0097 [1.0051-1.0143]	0.00097 (0.097)	Relationship established from study of data from 47 US cities for the years 1999 to 2005 (Zanobetti & Schwartz 2009)
$PM_{2.5}$: Asthma (emergency department admissions)	Short-term	1-14 years	--	0.00148 (0.148)	Relationship established from review conducted on Australian children (Sydney) for the period 1997 to 2001 (Jalaludin et al. 2008)
$PM_{2.5}$: Respiratory mortality (including lung cancer)	Short-term	All ages*	1.0192 [1.0108-1.0278]	0.0019 (0.19)	Relationship established from study of data from 47 US cities for the years 1999 to 2005 (Zanobetti & Schwartz 2009)

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

Tables 5.8 and 5.9 present the change in localised health risk associated with changes in PM_{10} and $PM_{2.5}$ at the maximum impacted community receptors for the operational years 2024 and 2034 (refer to Appendix A for methodology for the calculation of localised risks). The assessment assumes an individual is exposed at maximum impacted location over all all hours of the day, regardless of the land use. This is the maximum reported within the off-site community. Risks for all other receptors (including other sensitive receptors) are lower than the maximums presented.

All risks are presented to one significant figure, reflecting the level of uncertainty associated with the calculations presented.

Figure 5.3 presents a summary of the calculated change in localised risk associated with changes in PM_{10} and $PM_{2.5}$ concentrations at each community receptor location evaluated.

Appendix C presents a discussion on levels of the levels of risk that are considered to be negligible, tolerable/acceptable and unacceptable. A summary of these risk levels is included in Table 5.8.

Calculations relevant to the characterisation of risks associated with changes in PM_{10} and $PM_{2.5}$ concentrations in the community are presented in Appendix E.

Assessing exposure to diesel particulate matter

In addition to the above exposure-response relationships which represent trends where exposure can lead to some health impacts, potential exposure to diesel particulate matter (DPM) derived from the project has been evaluated.

Diesel exhaust is emitted from diesel engines (locomotives) and can be formed from the gaseous compounds emitted by diesel engines (secondary particulate matter). After emission from the locomotive, diesel exhaust undergoes dilution and chemical and physical transformations in the atmosphere, as well as dispersion and transport in the atmosphere. The atmospheric lifetime for some compounds present in diesel exhaust ranges from hours to days.

Available evidence indicates that there are human health hazards associated with exposure to diesel particulate matter (DPM). The hazards include acute exposure-related symptoms, chronic exposure related non-cancer respiratory effects, and lung cancer. The non-cancer health effects associated with exposure to DPM are adequately addressed on the basis of the current $PM_{2.5}$ and PM_{10} guidelines. However, the potential for exposure to DPM to result in an increased risk of lung cancer in the community requires further consideration. Appendix B presents the methodology adopted for the assessment of lung cancer risks associated with exposure to DPM. In summary, the following has been assumed/undertaken:

- It has been conservatively assumed that 100 per cent of $PM_{2.5}$ predicted in the local community is derived from diesel vehicles and comprises DPM. This is a conservative, yet appropriate assumption given that the source of emissions is from diesel locomotives and no data is available to refine this assumption
- An incremental lifetime risk of lung cancer has been calculated (refer to Appendix B for the details on the methodology used to calculate risk) on the basis of the inhalation toxicity value available from the World Health Organization (WHO 1996).

Table 5-8: Calculated localised risk associated with changes in $PM_{2.5}$ and PM_{10} concentrations – Primary health endpoints

Receptor	**Calculated risks for primary health endpoints**		
	$PM_{2.5}$: Mortality, all causes	**$PM_{2.5}$: CV hosp.**	**$PM_{2.5}$: Resp. hosp.**
	long-term	**short-term**	**short-term**
	≥30 yrs	**≥65 yrs**	**≥65 yrs**
2024 – with project (with project minus no project for 2024)			
Maximum from closest 20 receptors	-1×10^{-7}	-2×10^{-7}	-4×10^{-8}
Maximum residential	-2×10^{-7}	-3×10^{-7}	-6×10^{-8}
2034 – with project (with project minus no project for 2034)			
Maximum from closest 20 receptors	1×10^{-6}	2×10^{-6}	3×10^{-7}
Maximum residential	1×10^{-6}	1×10^{-6}	3×10^{-7}
Negligible risks	**$<1 \times 10^{-6}$**		
Tolerable/acceptable risks	**$\geq 1 \times 10^{-6}$ and $\leq 1 \times 10^{-4}$**		
Unacceptable risks	**$>1 \times 10^{-4}$**		

Negative values mean a decrease in exposure and some health benefit

CV = cardiovascular, CP = cardiopulmonary, Resp = respiratory, hosp. = hospitalisations, DPM = diesel particulate matter

Table 5-9: Calculated localised risk associated with changes in $PM_{2.5}$ and PM_{10} concentrations – Secondary health endpoints

Receptor	Calculated risks for secondary health endpoints						
	PM_{10}: Mortality, all causes	$PM_{2.5}$: Mortality, all causes	$PM_{2.5}$: Mortality, CP	$PM_{2.5}$: Mortality, CV	$PM_{2.5}$: Mortality, Resp.	$PM_{2.5}$: Asthma ED Hosp.	DPM Lung cancer
	short-term	short-term	long-term	short-term	short-term	short-term	long-term
	all	all	≥30 yrs	all	all	1–14 yrs	all
2024 – with project (with project minus no project for 2024)							
Maximum from closest 20 receptors	-7×10^{-9}	-1×10^{-8}	-1×10^{-7}	-3×10^{-9}	-2×10^{-9}	-4×10^{-8}	-8×10^{-8}
Maximum residential	-1×10^{-8}	-1×10^{-8}	-2×10^{-7}	-4×10^{-9}	-3×10^{-9}	-6×10^{-8}	-1×10^{-7}
2034 – with project (with project minus no project for 2034)							
Maximum from closest 20 receptors	7×10^{-8}	9×10^{-8}	1×10^{-6}	3×10^{-8}	2×10^{-8}	4×10^{-7}	7×10^{-7}
Maximum residential	6×10^{-8}	8×10^{-8}	1×10^{-6}	2×10^{-8}	1×10^{-8}	3×10^{-7}	6×10^{-7}
Negligible risks	**$<1 \times 10^{-6}$**						
Tolerable/ acceptable risks	**$\geq 1 \times 10^{-6}$ and $\leq 1 \times 10^{-4}$**						
Unacceptable risks	**$>1 \times 10^{-4}$**						

Negative values mean a decrease in exposure and some health benefit

CV = cardiovascular, CP = cardiopulmonary, Resp = respiratory, hosp. = hospitalisations, DPM = diesel particulate matter

Figure 5.3: Change in calculated risk for primary health endpoints associated with total changes in $PM_{2.5}$ concentrations at community receptors (2024 and 2034) (negative values mean a decrease in exposure and some health benefit)

Review of the calculated risks for community exposures to fine particulate matter as $PM_{2.5}$ and PM_{10} indicates that all risks are significantly less than 1 x 10^{-4} and are therefore considered to be acceptable. On this basis there are no health risk issues of concern in relation to changes in particulate matter in the community.

For the assessment of impacts during 2024, the calculated risks indicate a lower level of exposure (compared to 2034) and hence there may be some health benefits. This means that the concentrations of particulates that the community is exposed to is lower in 2024 with the project, than would occur without the project. Where there is a lower level of exposure there is a health benefit (i.e. lower or reduced levels of health risk). It is noted that the risks related to health benefits are small and it would be unlikely that these would be measurable in the community.

5.8 Cumulative impacts

The modelling of impacts from changes in air quality has included consideration of existing air quality. This then incorporates emissions to air from regional sources, including existing transport infrastructure.

Technical Report 3 - Air quality impact assessment, has identified the following future sources of emissions in the region:

- Sydney Gateway Road project
- WestConnex New M5

- WestConnex M4-M5
- F6 Extension stage 1
- Banksmeadow Waste transfer Terminal
- Airport East and Airport North road projects

No modelling of cumulative impacts on air quality of the Botany Rail Duplication and these projects either during construction or operation has been undertaken so cumulative impacts to community health cannot be evaluated in detail.

It is acknowledged in *Technical Report 3 - Air quality impact assessment*, that the operation of the above mentioned projects have the potential to increase air quality pollutant emissions. It deemed unlikely that future cumulative air quality criteria exceedances would occur due to the project due to the following reasons:

- Incremental impacts due to the operation of the project account for a relatively small portion of the assessment criteria and localised around the location of the rail duplication.
- Air quality assessments would be completed for the above mentioned projects that supply mitigation measures to reduce the likelihood of any future air quality criteria exceedances.

In relation to construction works, all such projects would require the implementation of appropriate management plans to minimise the generation of dust, and impacts on community health. Where all these projects implement such plans appropriately cumulative impacts during construction should be minimised. In relation to operational impacts, potential health impacts related to emissions to air from the Botany Rail Duplication are localised and very low and it is unlikely that these would make a significant contribution to any cumulative impacts to community health.

5.9 Uncertainties

Any assessment of potential human health risks or impacts needs to consider the uncertainties inherent in the information and data relied upon for undertaking such an assessment as well as the methodology and assumptions adopted in the quantification of risk or impact. Appendix F presents a detailed review of the uncertainties relevant to the assessment of health impacts from changes in air quality. Overall, the approach adopted is expected to overestimate exposures and risks (ie health impacts) within the community.

5.10 Summary of key findings

This section provided an assessment of health impacts within the community in relation to changes in air quality, where impacts from construction and operation are considered. The assessment of health impacts has determined the following:

- Construction
  - The focus of the assessment of construction impacts relates to the generation of dust. Provided the proposed dust mitigation measures are implemented, the potential for dust from the project to be of concern to the health of the community is low.
  - While health impacts are expected to be low with the implementation of proposed mitigation measures there may still be some nuisance dust (too large to result in health effects) that is noticeable by the community on occasions.
- Operations

- Where there were increases in pollutant concentrations (relevant to emissions from diesel locomotives which include benzene, CO, SO_2, NO_2, $PM_{2.5}$ and diesel particulate matter), these were low and were not considered to be of significance or of concern in relation to community health.

6. Impacts to human health: Changes in noise and vibration

6.1 Health effects associated with environmental noise

6.1.1 General

Environmental noise has been identified (enHealth 2018; I-INCE 2011; WHO 2011, 2018) as a growing concern in urban areas because it has negative effects on quality of life and wellbeing and has the potential for causing harmful physiological health effects. With increasingly urbanised societies, impacts of noise on communities have the potential to increase over time.

Sound is a natural phenomenon that only becomes noise when it has some undesirable effect on people or animals. Unlike chemical pollution, noise energy does not accumulate either in the body or in the environment, but it can have both short-term and long-term adverse effects on people. These health effects include (WHO 1999, 2011, 2018):

- sleep disturbance (sleep fragmentation that can affect psychomotor performance, memory consolidation, creativity, risk-taking behaviour and risk of accidents)
- cardiovascular health
- annoyance
- hearing impairment and tinnitus
- cognitive impairment (effects on reading and oral comprehension, short and long-term memory deficits, attention deficit).

Other effects for which evidence of health impacts exists, and are considered to be important, but for which the evidence is weaker, include:

- Effects on quality of life, wellbeing and mental health (usually in the form of exacerbation of existing issues for vulnerable populations rather than direct effects).
- Adverse birth outcomes (pre-term delivery, low birth weight and congenital abnormalities).
- Metabolic outcomes (type 2 diabetes and obesity).

Within a community the severity of the health effects of exposure to noise and the number of people who may be affected are schematically illustrated in **Figure 6.1**.

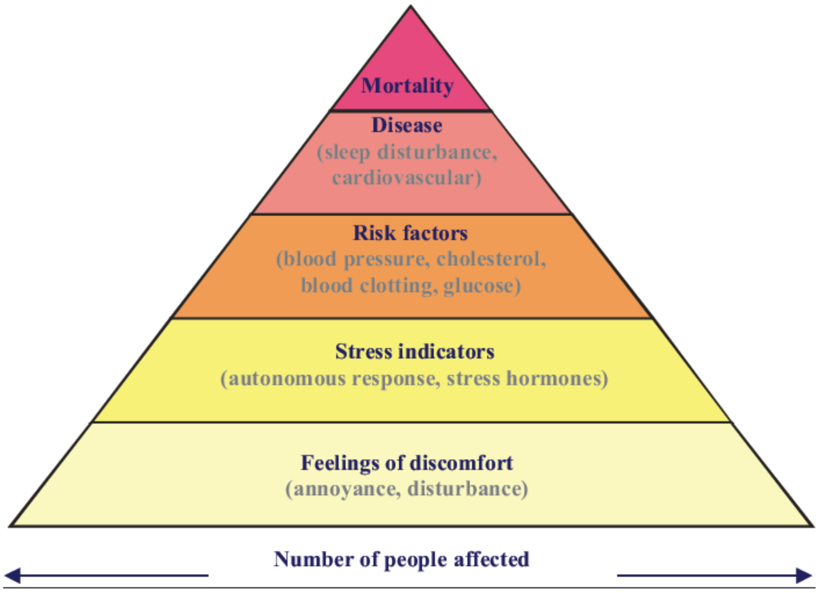

Figure 6.1: Schematic of severity of health effects of exposure to noise and the number of people affected (WHO 2011)

Often, annoyance is a major consideration because it reflects the community's dislike of noise and their concerns about the full range of potential negative effects, and it affects the greatest number of people in the population (I-INCE 2011; WHO 2011, 2018).

There are many possible reasons for noise annoyance in different situations. Noise can interfere with speech communication or other desired activities. Noise can contribute to sleep disturbance which has the potential to lead to other long-term health effects. Sometimes noise is just perceived as being inappropriate in a particular setting without there being any objectively measurable effect at all. In this respect, the context in which sound becomes noise can be more important than the sound level itself (I-INCE 2011; WHO 2011, 2018).

Different individuals have different sensitivities to types of noise and this reflects differences in expectations and attitudes more than it reflects any differences in underlying auditory physiology. A noise level that is perceived as reasonable by one person in one context (e.g. in their kitchen when preparing a meal) may be considered completely unacceptable by that same person in another context (e.g. in their bedroom when they are trying to sleep). In this case the annoyance relates, in part, to the intrusion from the noise. Similarly, a noise level considered to be completely unacceptable by one person, may be of little consequence to another even if they are in the same room. In this case, the annoyance depends almost entirely on the personal preferences, lifestyles and attitudes of the listeners concerned (I-INCE 2011; WHO 2011, 2018).

Perceptible vibration (e.g. from construction activities) also has the potential to cause annoyance or sleep disturbance and so adverse health outcomes in the same way as airborne noise. However, the health evidence available relates to occupational exposures or the use of vibration in medical treatments. No data is available to evaluate health effects associated with community exposures to perceptible vibrations (I-INCE 2011; WHO 2011, 2018).

It is against this background that an assessment of potential noise impacts of the project on health was undertaken.

6.1.2 Health impacts from rail noise

Rail noise is caused by the combination of rolling noise (noise from wheels on the rails, including squealing of wheels) and idling/propulsion noise (from locomotives).

A number of large international studies are available that have specifically evaluated health impacts associated with exposure to noise, with some specifically addressing rail noise. Where exposure to rail noise is associated with, or can be shown to be causal, adverse health effects an exposure-response relationship is often established. The main health effects that have been studied in these types of investigations in relation to rail noise are annoyance, sleep disturbance, cardiovascular disease, stroke and memory/concentration (cognitive) effects. The most recent review of noise and impacts on health, presented by the WHO (WHO 2018) included a detailed review of the available literature, including impacts specifically related to rail noise.

Cardiovascular effects

Cardiovascular diseases are the class of diseases that involve the heart or blood vessels, both arteries and veins. These diseases can be separated by end target organ and health outcomes. Strokes reflecting cerebrovascular events and ischaemic heart disease (IHD) or Coronary Heart disease (CHD) are the most common representation of cardiovascular disease.

High-quality epidemiological evidence on cardiovascular and metabolic effects of environmental noise indicates that exposure to environmental noise increases the risk of IHD (enHealth 2018; WHO 2018). However, in relation to rail noise the limited studies available did not find a statistically significant relationship with IHD.

A link between environmental noise and hypertension is relatively well established in the relevant literature. Whilst there is not a consensus on the precise causal link between the two, there are a number of credible hypotheses. A leading hypothesis is that exposure to noise could lead to triggering of the nervous system (autonomic) and endocrine system which may lead to increases in blood pressure, changes in heart rate, and the release of stress hormones. Depending on the level of exposure to excess noise, the duration of the exposure and certain attributes of the person exposed, this can cause an imbalance in the person’s normal state (including blood pressure and heart rate), which may make a person hypertensive (consistently increased blood pressure) which can then lead to other cardiovascular diseases (DEFRA 2014). This hypothesis is illustrated in **Figure 6.2**.

The available studies regarding rail noise and hypertension are limited, with only one study, of low quality, identifying a relationship.

Review of the incidence of stroke and rail noise by the WHO (2018) determined that the available studies did not show any statistically significant relationship with stroke.

It is noted that many of the studies relating to the assessment of rail noise are small in size and hence being able to determine significant health outcomes in these studies is difficult.

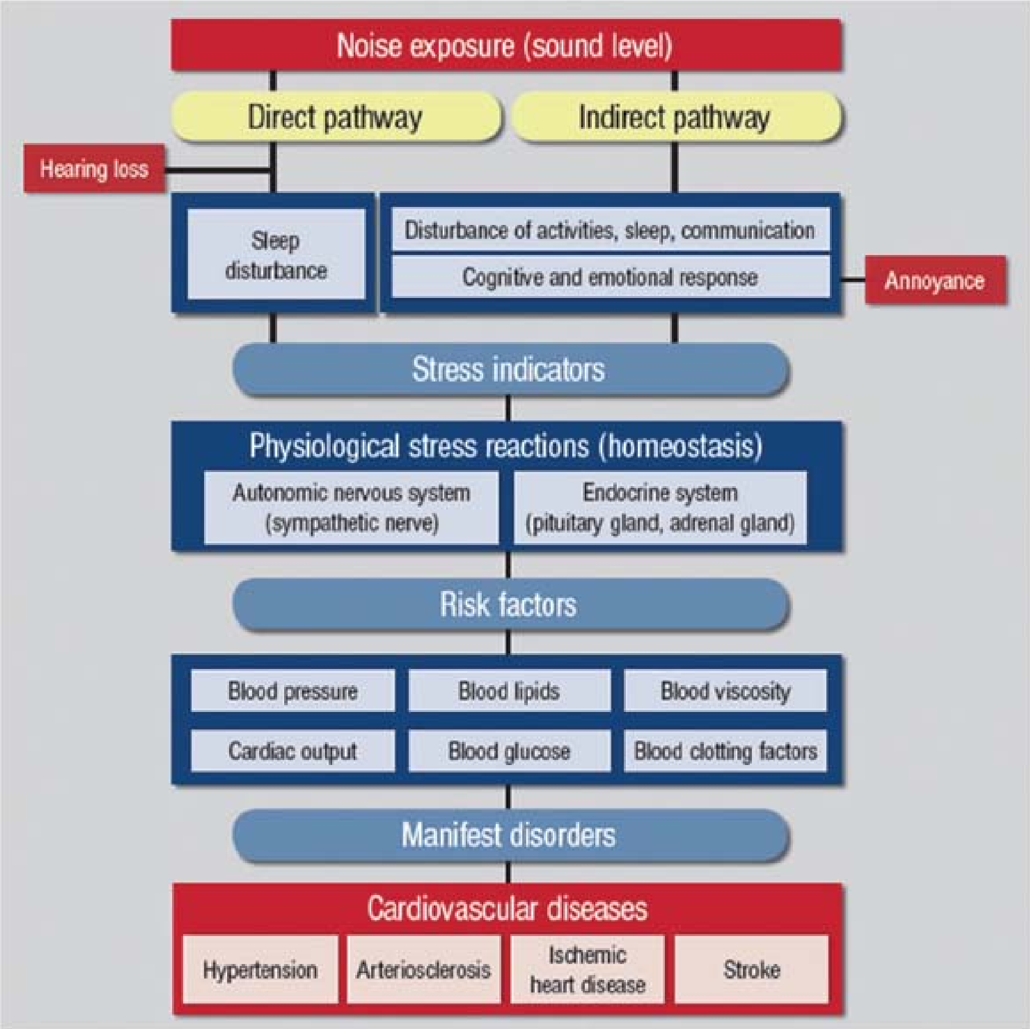

Figure 6.2: Noise reaction model/hypothesis (Babisch 2014)

Annoyance and sleep disturbance

Changes in annoyance and sleep disturbance associated with noise are considered to be pathways for the key health indicators listed above. However, these issues are of importance to the local community and so it is relevant to evaluate the changes in levels of annoyance and sleep disturbance as a result of noise from the operation of the project within the community.

Annoyance

Annoyance is a feeling of displeasure associated with any agent or condition known or believed by an individual or group to adversely affect them. Annoyance following exposure to prolonged high levels of environmental noise may also result in a variety of other negative emotions, for example feelings of anger, depression, helplessness, anxiety and exhaustion (EEA 2014).

Annoyance levels can be reliably measured by means of an ISO Standard, ISO 15666 (ISO 2003) defined questionnaire, which has enabled the identification of relationships between annoyance and noise sources. The European Commission (EC 2002) conducted a review of the available data and provided recommendations on relationships that define the percentage of persons annoyed (%A) and the percentage of persons highly annoyed (%HA) to total levels of noise reported as L_{DEN} (ie average noise levels during the day, evening and night). These relationships were established for exposure to aircraft noise, road traffic noise and rail traffic noise, and have been adopted by the UK and European Environment Agency (DEFRA 2014; EEA 2010, 2014). These relationships have also been reviewed by the WHO (WHO 2018), where the key outcome of %HA relevant to rail noise (Guski, Schreckenberg & Schuemer 2017) was considered most appropriate for determining actions and outcomes. It is noted that rail noise causes less annoyance than road traffic and aircraft noise (Gidlöf-Gunnarsson et al. 2012)

The available noise guidelines have been developed to address noise annoyance within the community (refer to Section 6.3). Where noise level changes of 2 dB occur, based on the relationships between noise and %HA noted above, this has the potential to result in an increase in individuals highly annoyed by noise by 0.7 per cent, which is well below the level of annoyance of 5 per cent considered to be of concern (or likely to be perceived) by residents (Schomer 2005). For individuals highly annoyed by noise to exceed the criteria of 5 per cent (which may be considered unacceptable) noise levels would need to increase by 14 dB.

Sleep disturbance

It is relatively well-established that night time noise exposure can have an impact on sleep (enHealth 2018; WHO 2009, 2011, 2018). Noise can cause difficulty in falling asleep, awakening and alterations to the depth of sleep, especially a reduction in the proportion of healthy rapid eye movement sleep. Other primary physiological effects induced by noise during sleep can include increased blood pressure, increased heart rate, vasoconstriction, changes in respiration and increased body movements (WHO 2011). Exposure to night-time noise also may induce secondary effects, or so-called after-effects. These are effects that can be measured the day following exposure, while the individual is awake, and include increased fatigue, depression and reduced performance.

Studies are available that have evaluated awakening by noise, increased mortality (ie increase in body movements during sleep), self-reported chronic sleep disturbances and medication use (EC 2004). The most easily measurable outcome indicator is self-reported sleep disturbance, where there are a number of epidemiological studies available. From these studies the WHO (WHO 2009, 2011, 2018) identified an exposure response relationship that relates to the percentage of persons sleep disturbed (%SD) and highly sleep disturbed (%HSD) to total levels of noise reported as L_{night} (ie average noise levels during night, which is an 8-hour time period, as measured outdoors). Review by the WHO (WHO 2018), considered that the key outcome of %HSD was considered most appropriate for determining actions and outcomes in relation to rail noise. For night time noise, increases in noise levels of 5, 10, 15 and 20 dB(A) may result in an approximate 1.5, 3, 4.5 and 6 per cent increase respectively in individuals who are highly sleep disturbed.

The available noise guidelines include criteria to address sleep disturbance that are based on the above studies and relationships. Hence compliance with these guidelines would address health impacts associated with sleep disturbance in the community.

Cognitive effects

There is evidence for effects of environmental noise on cognitive performance in children such as lower reading performance (WHO 2011). However, there is a lack of studies available that specifically relate to rail noise.

6.2 Existing noise environment

The project is located in the suburbs of Mascot, Botany and Pagewood and is close to a number of major existing road and rail transportation corridors, including Sydney Kingsford Smith Airport which is located to the south west of the project.

Existing noise levels at the project site are generally dominated by transportation noise, with road, rail and aircraft noise affecting most locations during the daytime. During the evening and night-time ambient noise levels typically decrease due to a reduction in road traffic volumes on the surrounding road network. There is also a curfew on flights at Sydney Airport from 11 pm to 6 am.

To undertake the noise assessment required for the project, the existing background noise quality needed to be assessed as the guidelines that relate to noise impacts from a specific project are based on levels allowable above background.

Technical Report 2 - Noise and vibration impact assessment has identified eight noise catchment areas (NCAs) that include a range of land uses in the study area. These are shown on Figure 7.3. The NCAs include residential areas as well as other non-residential sensitive noise receivers such as hotels, recreational areas, educational and childcare and places of worship.

To determine existing or background noise levels in the project area, ambient noise surveys (including attended noise measurements) were conducted in June, September and October 2018. Monitoring was undertaken by a noise logger. A noise logger measures the noise level over the sample period and then determines L_{A1}, L_{A10}, L_{A90}, L_{Amax} and L_{Aeq} levels of the noise environment. The A-weighting is a frequency filter applied to represent how the human ear hears sound. The L_{A1}, L_{A10} and L_{A90} levels are the levels exceeded for 1 per cent, 10 per cent and 90 per cent of the sample period respectively. The L_{Amax} level is the maximum noise levels due to individual noise events. The L_{A90} level is taken as the background noise level also known as the rated background level (RBL). The L_{Aeq} level is the energy averaged noise level over a defined period and is known as Average Noise Level. These noise measures are typically used to define noise during a day, evening or night-time period.

Rated background levels in the project area ranged from 39 to 60 dBA during the day (7.00 am to 6.00 pm), 41 to 58 dBA during the evening (6.00 pm to 10.00 pm) and 37 to 53 dBA during the night (10.00 pm to 7.00 am).

Noise levels measured between 7 metres and 19 metres of the track during train passbys were in the range of 91 to 115 dBA as LAmax.

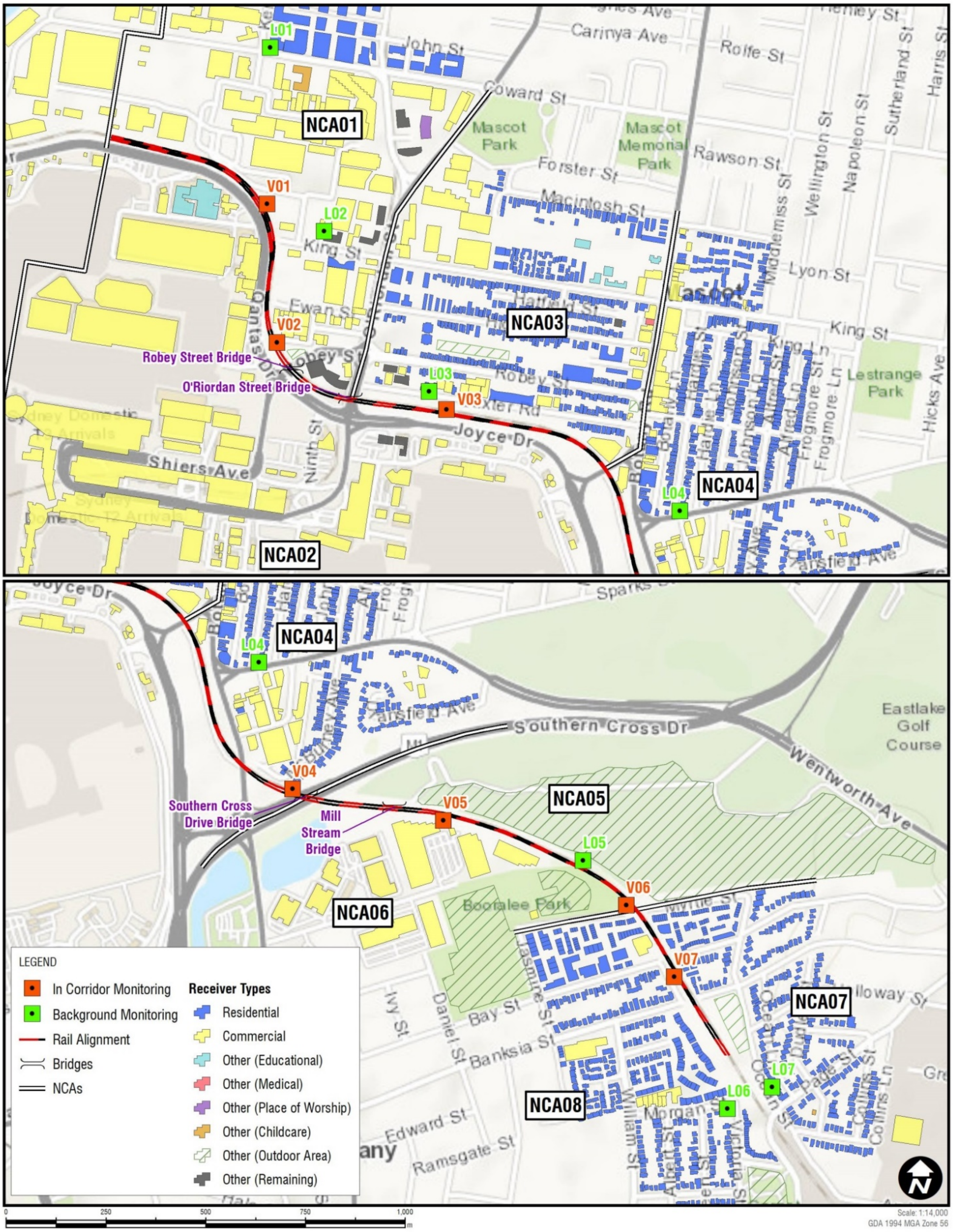

Figure 6.3 Noise catchment areas

6.3 Noise and vibration assessment criteria

6.3.1 General

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

- Construction – including ground-borne noise and vibration.
- Operations – relevant to rail noise.

The following sections provide an overview of the guidelines adopted for each of these aspects. In particular, the basis for the guidelines and relevance to the protection of health and wellbeing is noted.

6.3.2 Construction noise criteria

People are usually more tolerant to noise and vibration during the construction phase of projects than during normal operation. This response results from recognition that the construction emissions are of a temporary nature – especially if the most noise-intensive construction impacts occur during the less sensitive daytime period. For these reasons, acceptable noise and vibration levels are normally higher during construction than during operations.

Construction often requires the use of heavy machinery which can generate high noise and vibration levels at nearby buildings and receptors. For some equipment, there is limited opportunity to mitigate the noise and vibration levels in a cost-effective manner and hence the potential impacts should be minimised by using feasible and reasonable management techniques.

At any particular location, the potential impacts can vary greatly depending on factors such as the relative proximity of sensitive receptors, the overall duration of the construction works, the intensity of the noise and vibration levels, the time at which the construction works are undertaken, and the character of the noise or vibration emissions.

Technical Report 2 - Noise and vibration impact assessment has considered construction noise impacts associated with construction activities for the project.

The NSW Interim Construction Noise Guideline (ICNG) (NSW DECC 2009) has been adopted for the assessment of noise during construction works. These guidelines require that noise impacts from the project be predicted at sensitive receptors. These noise levels are then compared with the project specific criteria, referred to as noise management levels (NMLs), which are based on an increase above background levels. Where an exceedance occurs, the guidelines require that the proponent must apply all feasible and reasonable work practices to minimise impacts. The management levels are based on levels of noise above background that may result in reactions (or complaints) by the community. The levels are based on some reaction (noise affected) and a strong reaction (highly noise affected).

Levels of noise allowable outside standard work hours, particularly at night, are lower than the criteria during normal work hours. Where construction works are planned to extend over more than two consecutive nights a sleep disturbance assessment is required to be undertaken. The noise assessment has adopted a guideline of existing background plus 15 dB for night-time works resulting in noise criteria in the range 52 to 65 dBA as $LA_{eq,15\text{-}minute}$. Based on the available information on the levels of noise that result in sleep disturbance the following should be noted:

- A maximum internal noise level below 50–55 dB(A) is considered unlikely to cause awakening.
- External noise levels of 60–65 dB(A) are unlikely to result in awakening reactions, where it is assumed that an open window provides up to 10 dB(A) attenuation of noise from outdoors to indoors.

The night-time noise criteria adopted for this assessment sits in the range noted above.

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

The ICNG does not provide direct reference to an appropriate criterion to assess the noise arising from construction traffic on public roads. However, it does refer to the NSW EPA Road Noise Policy (RNP) (NSW DECCW 2011) which presents a discussion on assessing feasible and reasonable mitigation measures. In assessing feasible and reasonable mitigation measures, an increase of up to 2 dB(A) represents a minor impact that is considered barely perceptible to the average person. Therefore, the noise goal applied to traffic movements on public roads generated during the construction phase of the project is an increase in existing road traffic noise levels of no more than 2 dB(A).

6.3.3 Ground-borne noise criteria

The ICNG provides residential noise management levels for ground-borne noise (ie vibration transmitted through the ground into buildings which results in an audible noise indoors), which are applicable when ground-borne noise levels are higher than the corresponding airborne construction noise levels. The ICNG provides ground-borne noise levels at residences for evening and night-time periods only, as the objectives are to protect the amenity and sleep of people when they are at home. The following ground-borne noise levels are applicable for residences:

- evening 40 dB(A) LAeq (15 minute)
- night-time 35 dB(A) LAeq (15 minute).

6.3.4 Vibration criteria

The effects of vibration on buildings can be divided into three main categories:

- Human comfort: Those in which the occupants or users of the building are inconvenienced or possibly disturbed. These guidelines are of most relevance to the assessment of community health. Intermittent vibration has been evaluated on the basis of the NSW EPA guideline Assessing Vibration: A Technical Guideline (NSW DEC 2006), which is based on vibration dose values. The criteria for vibration dose values are based on the potential for annoyance (based on the level of vibration over the assessment period). Guidelines for continuous and impulsive vibration are dependent on the time of day they occur and the activity taking place that could be affected.
- Building contents: Those where the building contents may be affected. As people perceive floor vibration well before levels are likely to cause damage to building contents and structures, for most areas controlling vibration to manage human comfort would also address damage to building contents. No separate criteria are adopted to evaluate this aspect.
- Structural damage: Those in which the integrity of the building or the structure itself may be prejudiced (structural damage). Most commonly specified ‘safe’ structural vibration limits are designed to minimise the risk of threshold or cosmetic surface cracks, and are set well below the levels that have potential to cause damage to the main structure. The assessment of potential structural damage has been undertaken in accordance with Australian Standard AS2187, British Standard BS 7385 and German Standard DIN 4150:Part 3-1999 (DIN 1999).

Based on the guidance above minimum working distances are available for various vibration intensive equipment, such that there is protection of human comfort and cosmetic damage.

6.3.5 Operational noise criteria

Operational noise impacts have been evaluated on the basis of the Rail Infrastructure Noise Guideline (RING)(NSW EPA 2013). This guidance provides trigger levels for new rail developments as well as redevelopment of existing rail lines (relevant to this project). For residential receivers that are based on an increase in existing noise levels (by 2 dBA for LAeq(period) or 3dBA for LAmax) and the criteria for total rail noise for day and night-time periods. Lower noise criteria are established for the night-time period.

It is noted that an increase of up to 2 dBA for LAeq(period) represents a minor impact that is considered barely perceptible to the average person.

Noise triggers are also available for other non-residential noise sensitive receivers.

Ground-borne noise trigger levels are also provided for day and night-time periods to address perceivable vibration impacts from a low frequency rumble that may occur from passing trains. To further address vibration impacts from operational trains, vibration criteria provided to protect human comfort are utilised. These are guidelines based on a vibration dose, relevant to residential areas and other land uses for day and/or night-time periods.

Where there is an exceedance of the trigger levels in the RING, mitigation measures need to be considered to reduce the predicted noise impacts.

6.4 Overview of noise and vibration assessment and evaluation of health impacts

6.4.1 Construction impacts

Noise

Applicable NSW legislation and guidelines have been used to inform the construction noise modelling and assessment presented in *Technical Report 2 - Noise and vibration impact assessment*. Noise mitigation has been recommended in accordance with these guidelines. These guidelines have been developed taking into consideration current international practices, health impacts of noise and to protect vulnerable people.

Noise that may be generated during construction has been modelled based on the type of equipment to be used, where the equipment is to be used in relation to the community receptors, the hours of work, the duration of the activities undertaken and the local terrain. Modelling was undertaken at a number of construction sites within the project area.

Construction is proposed to be undertaken during standard construction hours where possible, however due to the nature of the existing environment, out of hours work will be required sometimes to minimise impacts on existing road and rail and for safety reasons. A range of activities have been considered for the out of hours works.

The assessment has considered a range of standard noise mitigation measures, ie those that would be a standard requirement for a range of construction activities. In some situations, impacts from construction noise and vibration may be unavoidable, particularly where works are undertaken in close proximity to the community. Where this occurs a range of additional mitigation measures have been identified to manage these impacts.

Overall, a worst case assessment has been used in accordance with the ICNG, assuming no additional mitigation measures are implemented. For each area assessed, the noise levels at the most affected receptor have been used to represent the whole noise catchment area.

For residential receptors in the NCAs, a number of exceedances of construction noise criteria have been identified during the day, evening and night-time periods, for a range of activities. This includes exceedances of the noise criteria by more than 20 dBA. The maximum noise impacts occur in NCA07 and NCA08 where residential receivers are located closest to the proposed works. Noise impacts have also been predicted in NCA03 and NCA04.

The greatest impacts occur during the use of peak noise equipment such as rock-breakers, concrete saws or ballast tampers. A number of high noise impact works have been identified during the construction works that include enabling works, construction compounds, site establishment works, bridge works and track works.

As with residential impacts, a number of exceedances of noise criteria have been identified for the non-residential sensitive noise receivers. The higher impacts occur at hotels during the day and night-time periods.

A number of residential receivers have also been identified as highly noise affected during the various high noise impact works, where noise levels of 75 dBA or greater are predicted.

In relation to night-time works and sleep disturbance the assessment identified that it is likely that the sleep disturbance criteria will be exceeded where works occur near to residential receptors. Hence these impacts require mitigation.

The noise assessment determined that construction traffic is unlikely to result in a noticeable increased in noise levels, where vehicles are using major roads. Where smaller local roads are used, construction traffic noise may be noticeable.

Ground-borne noise

Ground-borne noise occurs when works are being undertaken under the ground surface or in some other fashion that results in the vibrations from noise moving through the ground rather than the air. When vibrations reach a building they enter the foundations, which are subject to a coupling loss and are then transmitted into the walls and ceiling. The excitation of the walls and ceiling results in the generation of low-frequency noise which could be audible if the vibration levels are high enough. The noise is typically considered to be a low ‘rumble’.

The majority of receivers are sufficiently distant from the works for ground-borne noise impacts to be minimal. Where residential receivers are located near to construction works, airborne noise levels would typically be dominant over the ground-borne component, however, several hotels are located close to the project and due to their existing high facade and glazing performance, would potentially be affected by ground-borne noise when vibration intensive equipment is in use nearby.

The extent of the impacts would be dependent on the requirement for vibration generating works in areas near to hotels, the location of sensitive uses inside the building relative to the works and the existing facade performance in the potentially affected locations.

Vibration

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

The assessment identified that there are some receivers within the minimum working distance criteria for human comfort. Occupants of these buildings may be able to perceive vibration impacts at times when vibration intensive equipment is in used. These impacts are likely to only occur for relatively short durations.

The assessment identified some buildings within the minimum working distance criteria for cosmetic/structural damage. For these areas further management of these works is required prior to construction works proceeding.

Mitigation

A range of noise and vibration impacts have been identified during construction. These impacts would be managed through the implementation of a site environmental management plan for the enabling works and a Construction Environmental Management Plan (CEMP) for the main construction works of the project. Site specific Construction Noise and Vibration Management Plans (CNVMP) and Construction Noise and Vibration Impact Statements (CNVIS) would also be developed before any main construction works begin. These plans provide a detailed assessment of the potential impacts from the work and define the site specific mitigation and management measures to be used to control the impacts, particularly where evening or night-time works are required.

These management plans would consider a wide range of management measures and mitigating methods to minimise the impact of noise during construction (refer to *Technical Report 2 - Noise and vibration impact assessment*). This include noise monitoring to confirm the effectiveness of noise mitigation measures.

Health impacts

Without the proposed management measures there is the potential for construction noise to result in health impacts within the community such as noise annoyance and sleep disturbance.

Where the proposed management measures are implemented, the potential for construction noise and vibration to adversely impact community health is minimised. It should be noted that even where mitigation measures are implemented, some noise impacts may occur where works occur close to sensitive receivers. These impacts are expected to be of short duration, where annoyance and potentially sleep disturbance may occur on occasions.

6.4.2 Operational impacts

General

Assessment of operational noise impacts presented in *Technical Report 2 - Noise and vibration impact assessment* has been undertaken by modelling noise associated with the project.

The noise modelling took into consideration both the location of the project (including topography, meteorology and buildings), physical design of the rail line (including tail line curves, gradient and bridges), train speeds and volumes. The assessment considered the scenarios, without project and with project in the years 2024 and 2034.

The assessment of rail noise has been completed in accordance with the relevant guidelines (as discussed in Section 7.4). An assessment was undertaken to determine how well the model estimated noise impacts based on a current scenario (2018). The modelled and measured results were found to be within acceptable tolerances, which are +/- 2 dB(A), with the exception of one location where the model underestimated noise by 4.1 dB (where the model was not predicting wheel squeal from a small number of train wagons, nor representative of the broader fleet).

Noise

The area evaluated is subject to existing high levels of operational rail noise, with noise levels in many areas already exceeding the RING trigger levels.

The project, however would introduce additional rail noise, with exceedances of the noise trigger levels identified at residential receivers in NCA01, NCA03, NCA04, NCA07 and NCA08, during the day and night-time periods and for the maximum noise levels.

For the operational year 2034, the following should be noted for residential receivers in the impacted NCAs:

- Daytime noise levels (as $LA_{eq,day}$) are predicted to increase by 2 to 3.4 dBA
- Night-time noise levels (as $LA_{eq,night}$) are predicted to increase by 2.4 to 3.4 dBA
- Maximum noise levels (as LA_{max}) are predicted to increase by 6.1 to 7.9 dBA

The locations of the exceedances of the noise triggers in the NCAs are shown in Figure 7.4. A total of 182 residential and 7 non-residential buildings have been identified where the noise triggers are exceeded.

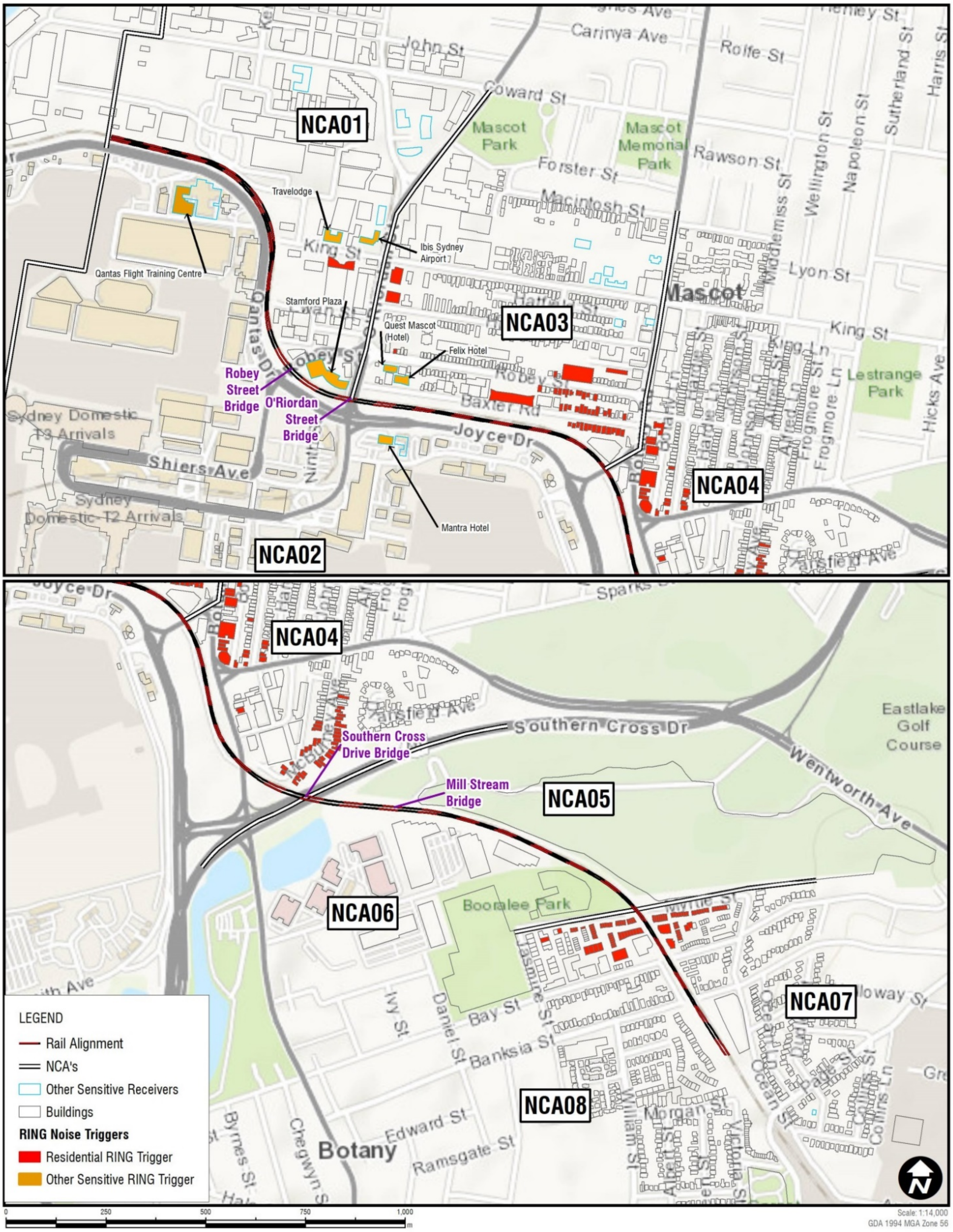

Figure 6.4 Location of operational noise trigger exceedances

Ground-borne noise

Increases in ground-borne noise that results in exceedance of the trigger levels has been identified at 45 residential receivers during the night-time period. These are locations in close proximity to the rail track. These impacts are in NCA03, NCA04, NCA07 and NCA08. These are areas, however where airborne noise would be expected to dominate internal noise levels.

Vibration

The project complies with operational vibration criteria.

Mitigation

Operational noise impacts can be managed in a variety of ways. A range of potential mitigation measures that include source control, controls along the rail line (such as noise barriers) and at-property treatments have been presented in *Technical Report 2 - Noise and vibration impact assessment*. Specific recommendations to minimise operational noise impacts have been provided and further assessed:

- Track lubrication systems, which reduce noise impacts associated with curves. This mitigation system can reduce the number of impacted receivers from 189 to 36.
- Noise barriers – the installation of noise barriers has been considered in the assessment at the specific locations with barriers in NCA03 (Baxter Road) and NCA08 (Myrtle Street) identified as potentially feasible.
- At property treatment – this is a final measure, where the mitigation measures outlined above are not sufficient or not feasible. This includes architectural treatments such as thicker glazing and doors and upgraded façade constructions to achieve appropriate internal noise levels.

The final operational noise mitigation strategy would be determined as the project progresses and would likely use a combination of the approaches outlined above.

Health impacts

Without mitigation there are a number of residential, and other, properties where noise levels exceed the adopted operational noise criteria, that are designed to be protective of health. A review of the noise modelling undertaken indicates the following (also refer to the discussion in Section 7.2):

- Predicted noise levels exceed thresholds where health effects have been identified (daytime and night-time) at a number of locations:
  - around King Street (NCA01)
  - near Baxter Road (NCA03)
  - near Botany Road and McBurney Avenue (NCA04)
  - along Myrtle Street (NCA07 and NCA08).
- The predicted increases in noise levels during the day and night-time periods are below a level where health impacts from rail noise on annoyance and sleep disturbance are considered to be unacceptable (refer to discussion in Section 6.1.2). Hence noise increases predicted in these areas are unlikely to be associated with unacceptable increases in health impacts.
- The total noise levels in these areas, including the maximum noise levels, however exceed thresholds for adverse health effects related to environmental noise, and thresholds for minimising rail noise impacts suggested by the WHO (2018). Hence minimising noise impacts from rail noise will minimise health impacts within the community. This remains relevant even in areas where there is existing elevated levels of noise from various sources as any reduction in noise exposure in the community will be of some benefit (albeit small).

It is noted that the use of at property treatments, which are suggested as a final mitigation measure have a number of issues, and therefore treatment at or near the source should be the preferred option. Negative impacts which may arise from at property treatment include:

- Potential reduction in the use of outdoor areas. In urban areas particularly where existing levels of noise are dominated by road traffic noise, access to outdoor green space areas that are not (perceived to be) impacted by noise (eg where there is a quiet side of a specific property or there is access to a quiet green space areas close to the residential home) have been found to significantly improve wellbeing and lower levels of stress (Gidlöf-Gunnarsson & Öhrström 2007). Impacts on the use and enjoyment of outdoor areas due to increased noise may result in increased levels of stress at individual properties.
- The requirement that residents take up at-property treatment measures and where they do, they keep external windows and doors shut (to make the noise treatments effective). Where specific residents/properties do not take up recommended at-property treatments to mitigate noise indoors there is the potential for noise levels at these properties to exceed the relevant guidelines/criteria. In these situations, there is the potential for adverse health effects, particularly annoyance and sleep disturbance, to occur.

Community consultation would be an important part of the process in addressing noise impacts for the project as there are a number of individual homes where at-property treatment would be required to enable the noise criteria to be met and minimise the potential for adverse health effects associated with the project. However, such treatments may have other effects (as discussed above) which would also need to be managed/considered.

6.5 Cumulative impacts

6.5.1 Construction

Technical Report 2 - Noise and vibration impact assessment has included an assessment of noise impacts that may occur where there are construction activities from the project as well as other construction projects, such as Sydney Gateway road, WestConnex New M5, WestConnex M4-M5 and the relocation of the Qantas Flight Training Centre.

The cumulative assessment considered the potential for these works to occur concurrently or consecutively (one after another) and result in exposure to construction noise impacts for a longer period of time.

Cumulative impacts are most likely to occur as a result of the Sydney Gateway road project and Botany Rail Duplication, as these works are expected to include some overlap in areas (particularly the western section of the Botany Rail Duplication study area). Where Sydney Gateway road project works are operating concurrently with Botany Rail Duplication works near to receivers, the increase could be the same as described above for cumulative Botany Rail Duplication works, ie a theoretical increase of around 3 dB for most locations. Additional management and mitigation measures designed to address these cumulative impacts would be developed in consultation with the affected community to minimise the impacts.

Construction of the new Qantas Flight Training Centre may result in these works occurring at the same time as the Botany Rail Duplication. The receptors likely to be impacted are predominantly commercial (with the Travelodge hotel and King Apartments also nearby) and noise from the Qantas construction works are expected to dominate.

Consecutive impacts may occur where the various projects overlap and there may be a combined effect from the increased duration of impacts from construction. This effect is also termed ‘construction fatigue’, with several hotels in NCA01 and NCA02 near the Joyce Drive and O-Riordan Street intersection being potentially affected, together with areas of residential receivers on Baxter Road in NCA03 and on Botany Road and McBurney Avenue in NCA04.

The potential consecutive impacts from the project and other major projects should be considered further in detailed design when detailed construction planning is developed. Specific management and mitigation measures to address potential consecutive impacts should be investigated and developed to minimise the impacts in consultation with the affected community.

6.5.2 Operation

Where the operation of the Botany Rail Duplication and the Sydney Gateway road project are considered together, potential cumulative noise impacts have not been quantified in *Technical Report 2 - Noise and vibration impact assessment* due to the different noise characteristics of road and rail noise. The location where cumulative noise impacts may be relevant is at the Joyce Drive and O'Riordan Street intersection, however, health impacts related to cumulative noise impacts cannot be evaluated as these works were not assessed in the noise impact assessment. Noise management measures identified in both the Botany Rail Duplication and Sydney Gateway road projects may have some overlap for a number of properties, which may of benefit to the health of residents in these areas. Where this occurs the mitigation measures should be coordinated to minimise disruption and conflicting/confusing information being provided to residents.

6.6 Summary of key findings

The assessment of health impacts associated with changes in noise as a result of the project has been undertaken on the basis of a qualitative assessment, where the following has been determined:

- Construction:
  - Where the proposed management measures are implemented, the potential for construction noise and vibration to adversely impact community health would be minimised.
  - It should be noted that even where mitigation measures are implemented, some noise impacts may occur where works occur close to sensitive receivers. These impacts are expected to be of short duration, where annoyance and potentially sleep disturbance may occur on occasions.
- Operations
  - Without mitigation, 189 buildings have been identified where rail noise exceeds the health based criteria. These impacts are of significance in NCA01, NCA03, NCA04, NCA07 and NCA08. While the increases in noise levels associated with the project are unlikely to result in any significant increases in health impacts, the total noise levels and maximum rail noise levels have the potential to be of concern to community health.
  - To ensure health impacts are effectively mitigated, mitigation measures would be required to be designed and implemented as outlined in *Technical Report 2 - Noise and vibration impact assessment.* The mitigation of operational noise impacts would consider treatment at or near the noise sources (through the use of track lubrication and noise barriers, where feasible and appropriate) prior to the implementation of at-property treatments as at-property treatments are less certain (in terms of acceptance and use) and their presence at a property has the potential to also affect the wellbeing of residents.

7. Public safety and contamination

7.1 Introduction

This section provides a review of the potential risks posed to public safety, associated with the project. This section also presents a review of health impacts associated with the presence and management of contamination (in soil or water) relevant to the project.

This section only addresses risks to the community, ie risks that only have the potential to adversely affect the community. Issues relevant to workplace health and safety during construction (including contamination remediation) and operation have not been further discussed or addressed.

Evaluation of public safety has considered information presented in *Technical Report 14 - Hazards and risk assessment*. This assessment was undertaken in accordance with the *State Environmental Planning Policy No. 33 Hazardous and Offensive Developments* (SEPP 33), that identified and addresses risks during construction and operation. Pedestrian safety aspects are addressed in detail in *Technical Report 1 - Traffic and transport*. Issues from these assessments specifically relevant to public health and safety have been further detailed in this section.

Health impacts associated with contamination have been assessed on the basis of *Technical Report 5 - Contamination report*.

7.2 Public safety

A range of potential hazards have been identified that have the potential to affect public safety during construction and operation. These are outlined in Table 7.1, along with discussion on risks that may be posed by these hazards. Not all the hazards identified in the Hazard and Risk assessment have been included in the table, only those where there is the potential for risks to community/public safety.

Table 7.1: Overview of public safety hazards and risks

Hazard: Public safety	Risk to public safety		Management measures
	Construction	**Operation**	
Storage and handling of dangerous goods on construction sites that may impact on the off-site community	Medium The storage would comply with screening thresholds prescribed under SEPP 33.	NA	Only low quantities to be stored. All materials would be stored in accordance with appropriate Acts, Standards and Codes.
Transport of dangerous goods and hazardous substances on public roads within the community	Low The transportation would be in quantities less than with screening thresholds prescribed under SEPP 33.	Low The rail line will be used to transport a range of goods that would include dangerous goods which would be required to be packaged and transported in accordance with all relevant regulations and codes	All materials would be transported in accordance with the *Storage and Handling of Dangerous Goods Code of Practice* (WorkCover NSW 2005), *Dangerous Goods (Road and Rail Transport) Act 2008* (NSW), *Dangerous Goods (Road and Rail Transport) Regulation 2014* (NSW) and relevant Australian Standards. During operation, management of the rolling stock and goods transported would continue to be managed by the rail operators, as is currently done.
Damage to underground utilities, affecting roadways and services provided to the community	Low to medium Medium risks identified for gas and fuel pipelines should these be damaged (and there is ignition), or power lines	NA	A preliminary assessment of utilities in the area has been undertaken as well as consultation with utilities and service infrastructure providers to mitigate the risk of unplanned or unexpected disturbance of utilities. Independently facilitated AS 2885.6 SMS workshops will be completed with each high pressure pipeline owner and construction contractor. The SMS workshops will be conducted once design has reached a level that enables completion of a compliant AS 2885.6 process. This level is considered to be design for construction.
Pedestrian and cyclist safety	Low to moderate Increase in construction traffic may result in intermittent disruptions to pedestrians and cyclists at existing footpaths and crossings as well as construction compound gates. Where Robey Road or O'Riordan Street is	No impacts During operation there are no changes to the existing road network, pedestrian footpaths or bus networks.	A site environmental management plan for enabling works and a Construction Transport, Traffic and Access Management Plan (CTTAMP), as part of the Construction Environmental Management Plan for the main construction works would consider safe routes for pedestrians and cyclists during construction

Hazard: Public safety	Risk to public safety		Management measures
	Construction	Operation	
	closed pedestrians and cyclists would be diverted onto adjacent roads.		

On the basis of the above, there are no issues related to construction and operation (that are not expected to be managed) that have the potential to result in significant public safety risks to the community.

7.3 Contamination

7.3.1 General

Contamination risk issues to the community are more relevant to the construction phase of the project because exposure to contaminated soil or groundwater would most likely occur during the excavation and construction phase, if not appropriately managed. The interaction with contamination and the community during the operations phase is primarily related to spills and accidents associated with the completed project. *Technical Report 5 - Contamination report* has considered the location of the construction activities in relation to known areas of contamination in soil and groundwater, as well as issues associated with the impact of construction on the environment, where the community may be exposed.

The assessment of contamination identified a number of project areas where contamination issues require further assessment, in relation to the project:

- Area 1 – Eastern Area: where asbestos has been identified in several locations and perfluorooctane sulfonate (PFOS) was reported above investigation levels in Mill Pond.
- Area 2 – Western Area: where some Asbestos containing material (ACM) fragments have been observed in some locations.

7.3.2 Construction

Construction works proposed to be undertaken for the project have been considered in each of the Project areas. The assessment of potential impacts related to the presence of contamination has considered the known nature and extent of contamination as well as the location and nature of construction works.

The risk of acid sulfate soil (ASS) needs to be managed in some areas with the implementation of an ASS Management Plan (ASSMP).

In Area 1, the key risks identified relate to the presence of uncontrolled fill containing asbestos, and the potential for asbestos fibres to be released to air, where they may blow offsite, during construction works. Asbestos impacts in this area have been identified for remediation prior to construction works.

In Area 2 the potential presence of ACM may also give risk to the release of asbestos fibres, should this material be damaged or disturbed during construction. Hence the management of asbestos in soil during construction is required.

Construction excavation activities may intersect groundwater at isolated locations during wet weather, but it is unlikely intersection will occur during dry conditions. Construction techniques that do not require dewatering will be adopted, hence there is no need to manage groundwater during these works. Any contact with groundwater during piling may require the management of PFAS contaminated water.

A range of risk management measures are outlined in *Technical Report 5 - Contamination report* to minimise the potential for contamination to pose a risk to human health or the environment. Where these are implemented, there are no risk issues of concern in relation to community health.

7.3.3 Operation

The primary operational impact or impact from maintenance activities related to the project is the potential contamination of soil, surface water and groundwater arising from intermittent vehicle accidents, leaks and spills on the rail track. However, as the project is located within an existing operational rail corridor, this would not introduce new sources of contamination to the surrounding environment. The increase in frequency of vehicle accidents, leaks and spills is expected to be negligible. Where remediation occurred during construction, impacts would be managed and there may be some ongoing monitoring or management required in accordance with ARTC's existing environmental management system.

Where the above is considered there are no risk issues of concern in relation to community health.

8. Impacts of other project changes on community health

8.1 Introduction

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

The assessment of changes in air quality and noise on the health of the local community (presented in Sections 6 and 7) addressed key aspects that have the potential to directly affect health.

This section has more specifically evaluated changes in the community that have the potential to indirectly affect the health and wellbeing of the community. This section also provides a review of whether there are any impacts that are likely to be more significant in any section of the community, and if these areas may result in inequitable impacts on the health of the population. This may affect population groups that may be advantaged or disadvantaged based on age, gender, socioeconomic status, geographic location, cultural background, aboriginality, current health status or existing disability. The evaluation presented in this section provides a qualitative evaluation of potential health impacts on the community.

Within an urban environment there are a wide range of complex factors (acting and interacting at different scales) that can affect health and wellbeing. This is conceptualised in Section 10, and specifically Figure 10.1, which also presents a summary of the outcomes of this assessment. The broad range of factors identified may result in either positive or negative impacts on health and wellbeing. It is noted that no single element or determinant acts in isolation. Health and wellbeing in the urban environment depends on the sum of the total interactions between many factors. It is within this complex model that changes associated with the project have been evaluated in relation to impacts on health and wellbeing.

Technical Report 12 - Social impact assessment provides details in relation to many of the social impacts associated with the project. Aspects that are specifically relevant to potential impacts on the health and wellbeing of the community, either positive or negative, have been further highlighted in this section.

Many of the project impacts have the potential to change levels of stress and anxiety within the community. These changes may be negative or positive, both of which can affect the health and wellbeing of the community. Heath implications of changes in stress and anxiety are further discussed in Section 8.8.

8.2 Transport

8.2.1 Construction

A number of key constriction activities were identified in *Technical Report 1 - Traffic and transport*, that have the potential to impact on the local transport network. This includes the temporary closure of major roads (Robey Street and O'Riordan Street) or the closure of lanes on roads (including Southern Cross Drive) to facilitate construction works. These activities would result in delays in the local road network. Increased levels of congestion and longer travel times have the potential to increase levels of stress and anxiety in local commuters as well as those that commute to the area for work or travel. A CTTAMP, as part of the Construction Environmental Management Plan would be developed to manage most of the impacts and minimise delays. While it is unlikely that there would be no delays to traffic in the local area, where the impacts are managed and mitigated as proposed, the potential impacts on community health are expected to be minimal.

8.2.2 Operations

The project would have no impact on the road network upon completion. Hence there would be no health impacts.

The project would improve the efficiency of the rail network and may have a secondary impact on the reduction of trucks travelling to and from Port Botany. The reduction in trucks travelling on local roads has the potential to improve public access and safety in the area, as well as reduce levels of stress and anxiety (where these are present as a result of the presence of trucks on local roads). Where this occurs, there are potential health benefits for the local community.

8.2.3 Public transport

The project construction would have no impact on the operation of passenger trains and no bus stops would be impacted. There may be some delays to bus travel during construction, however these impacts would be minimised through the implementation of the CTTAMP.

The project would have no impact on the existing public transport network upon completion. Hence there would be no health impacts.

8.2.4 Pedestrian and cycle safety

The potential increase in construction traffic on the nominated construction vehicle routes and in particular at the access gates to the rail corridor, may lead to intermittent disruptions to pedestrian and cyclist movements along the existing adjacent footpaths and intersection crossing points. The impact on pedestrian and cyclist safety will also be at its greatest in vicinity of the gates due to the increased vehicle activity. Where Robey Street or O'Riordan Street is closed pedestrians and cyclists would be diverted onto adjacent roads. These impacts would be mitigated through the implementation of the CTTAMP which would include the provision of safe routes for pedestrians and cyclists during construction.

Following completion of construction, no changes to the pedestrian or cycle access and safety is proposed. The potential reduction in trucks on local roads may improve perceptions of road safety and enable more people to use active transport within the local area.

Active transport within proximity to the study area has been raised as a concern by Bayside Councillors in relation to this project. Given that the project would be within the existing rail corridor, changes to access and connectivity are not expected. Changes to the road network and on-road cycle routes that occur during construction would be restored to their condition upon completion of the construction of the project. There would be no permanent impact to existing active transport routes, or community health, and the project would not preclude future links within the study area.

8.3 Green space

Green space within urban areas includes green corridors (paths, rivers and canals), grassland, parks and gardens, outdoor sporting facilities, playing fields and children play areas. At a fundamental level there are links between human health/wellbeing and nature/biodiversity including within the urban setting (Brown & Grant 2005; EC 2011a; WHO 2015).

Epidemiological studies have been undertaken that show a positive relationship between green space and health and wellbeing (de Vries et al. 2003; Health Scotland 2008; Kendal et al. 2016; Maas et al. 2006; Mitchell & Popham 2007). The outcomes of these international studies depend on the quality of the available green space. They showed that green space areas in low socioeconomic areas often had poor facilities, higher levels of graffiti, vacant/boarded up buildings and lower levels of safety. These studies showed that such spaces had few health benefits.

The health benefits of green space in urban areas include the following (Health Scotland 2008; Kendal et al. 2016; Lee & Maheswaran 2011; Rozek et al. 2018):

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

Green space areas in urban areas may also present some hazards, such as attracting anti-social behaviours (particularly in isolated areas), providing areas for drug or sexual activity and unintentional injuries from sports or use of playground equipment. It has also been found that individuals from ethnic or minority groups and those with disabilities are less frequent users of green spaces areas (Friedrich, Hillier & Chiaradia 2009; Lee & Maheswaran 2011). It is noted that the detailed review of health benefits of urban green space areas undertaken by Lee (Lee & Maheswaran 2011) determined that there is only weak evidence for links between physical, mental health and wellbeing and urban green space. However, many of the studies are limited and confounded by other factors which affects the ability to be able to draw conclusions. More recent reviews (that include a number of Australian studies) (Dickinson 2018; Rozek et al. 2018) conclude that access to high-quality public open space encourages people to be physically active and supports good mental and physical health. This is particularly evident where there is good access (ie walking distance and even up to 5 kilometres) to green public space particularly where the open space are large and had desired amenities, safe or perceived safe walking neighbourhoods with good access and connections to green space, the green space area was considered safe, aesthetically pleasing, included desired amenities (such as playgrounds, picnic tables, skate parks barbeques and toilets) and well maintained. The specific design and existing quality of green space that may be available in the local area has not been assessed in this report, only the changes that may occur as a result of the project have been assessed in *Technical Report - 12 Social impact assessment*.

The project is not expected to have any significant changes to community access to and use of green space. *Technical Report - 12 Social impact assessment*, notes that green space close to the project site areas may be affected by increased noise or and changes to the visual aspects during construction and may be less desirable for access and use by the community, however these impacts are expected to be minor and temporary. In addition McBurney Avenue Reserve is being considered as a material storage area during construction, which would affect community access, with access being restricted to the existing walking paths only. This is a small passive open space area used as a through link to other areas hence impacts to this area are considered low.

On the basis of the above there are no positive or negative impacts expected on community health in relation to project impacts to green space.

8.4 Community access and connectivity

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

Social connectedness and relationships are important aspects of feeling safe and secure. Streets with heavy traffic have been associated with fewer neighbourhood social support networks and has been linked to adverse health outcomes (WHO 2000a). Any temporary and permanent changes to the access to social infrastructure, community resources or to other desirable locations (such as employment, study, friends and family) and safety to movement may affect community networks and in turn trigger community severance.

Community severance effects often occur during major transportation projects (during construction and operation) due to detours in the local road network, changes to active and public transport routes, and connector roads receiving an increase or decrease in traffic movements. The changes to the road networks may contribute to feelings of community severance and disconnection.

Construction of the project would involve the temporary disruption of pedestrian and cycleway routes and increased travel times (for road users and bus passengers) is likely to occur.

Once operational the project would not affect community access or cohesion in the local area as the project is in the same corridor as the existing rail line.

It is noted that the project would reduce the number of containers moved via truck, diverting these to rail. Hence the potential for reduced truck movements in the local area may reduce congestion, improve travel times and community safety.

8.5 Visual changes

Visual amenity can be described as the pleasantness of the view or outlook of an identified receptor or group of receptors (eg residences, recreational users). Visual amenity is an important part of an area’s identity and offers a wide variety of benefits to the community in terms of quality of life, wellbeing and economic activity. For some individuals, changes in visual amenity can increase levels of stress and anxiety. 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.

Construction of the project will result in some visual changes, with some vegetation being removed and some areas having views of construction compounds and activities.

The operation of the project will result in some visual changes in the community. This includes a second rail line and increased rail movements. Once construction is complete the project would reinstate vegetation, where feasible, to provide visual screening. This may result in some visual changes in some areas. These visual changes are not significant and would not be expected to significantly impact on community wellbeing.

8.6 Economic aspects

The economic aspects of the project are where there is the potential to benefit community health. This is of particular relevance in relation to improved freight transport efficiencies, reduced road congestion (where increased capacity is diverted to rail) and travel times, and increased employment in the local areas. During construction the peak employment workforce is estimated to be about 270 to 405 people, with indirect benefits on local businesses also identified.

These economic benefits are a factor influencing community health with lowered levels of stress and anxiety related to congestion (potential for improved access to travel and transport) and employment opportunities during construction.

The health of the local community could be further enhanced should the project encourage local employment. There are a range of health benefits associated with employment, including providing financial means to obtain better living standards as well as benefits to mental health.

8.7 Cumulative impacts and construction fatigue

Cumulative impacts may occur as a result of the construction and operation of the project occurring at the same time, or immediately before or after other major developments in the area. This is specifically relevant to the construction impacts associated with the Botany Rail Duplication, Sydney Gateway road project, works at the St Peters Interchange (WestConnex New M5), Sydney Airport T2/T3 Ground Access Solutions and ongoing urban development (including the construction of a new Hotel).

Construction fatigue relates to receptors that experience construction impacts from a variety of projects over an extended period of time with few or no breaks between construction periods. Construction fatigue typically relates to traffic and access disruptions, noise and vibration, air quality, visual amenity and social impacts from projects that have overlapping construction phases or are back to back. Construction impacts on that occur in this manner are no longer considered to be transient and/or short-term.

Where combined impacts are considered, there are enhanced benefits, including health benefits, in terms of employment (with a greater demand for workers across all the major projects) and increased use of local businesses. In relation to local access issues, the conduct of a number of projects at the same time could more significantly impact on travel times and safe access to local areas as pedestrians and cyclists.

Impacts that are of particular importance when considering construction fatigue include dust generation, noise and vibration, traffic and transport (including congestion, pedestrian access and cycle access) and visual amenity.

Where these impacts occur for extended periods of time, there is the potential that increased levels of stress and anxiety may also continue for extended periods of time. Health effects associated with stress and anxiety are further discussed in Section 9.8.

Where possible, these impacts may be minimised through the better coordination (planning and scheduling) and communication of construction activities for the various projects. This would minimise health impacts associated with construction fatigue, however it is noted that implementing such a process would be difficult given the scale or each of the projects being undertaken in this area.

8.8 Stress and anxiety issues

A number of changes within the community (discussed in Sections 8.3 to 8.6) have the potential to affect levels of stress and anxiety. Some changes may result in a lowering of feelings of stress and anxiety, and there are others that may result in higher levels of stress or anxiety within the community. In addition, construction fatigue (as discussed in Section 8.7) from the combined road projects, other infrastructure projects and ongoing urban developments associated with urban growth, may result in elevated levels of stress and anxiety for extended periods of time.

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

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

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

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

- Digestive disorders, with hormones released in response to stress causing a number of people to experience stomach ache or diarrhoea, with appetite also affected in some individuals (resulting in under-eating or over-eating).
- Chronic activation of stress hormones can raise an individual's heart rate, cause chest pain and/or heart palpitations and increase blood pressure and blood lipid (fat) levels. Sustained high levels of cholesterol and other fatty substances can lead to atherosclerosis and other cardiovascular disease and sometimes a heart attack (Pimple et al. 2015; Seldenrijk et al. 2015).
- Cortisol levels, release at higher levels with stress, play a role in the accumulation of abdominal fat, which has been linked to a range of other health conditions.
- Stress can cause muscles to contract or tighten, cause tension aches and pains (Ortego et al. 2016).

Some individuals respond to elevated levels of stress by taking up or continuing unhealthy stress coping strategies such as smoking, drinking or overeating, all of which are associated with significant health risks. Chronic levels of stress have also been found to cause or exacerbate existing mental health issues, including mood disorders such as depression and anxiety, cognitive problems, personality changes and problem behaviours. It can also affect individuals with pre-existing bipolar disorders.

By-products of stress hormones can act as sedatives (chemical substances which cause us to become calm or fatigued). When such hormone by-products occur in large amounts (which would happen under conditions of chronic stress), they may contribute to a sustained feeling of low energy or depression. Habitual patterns of thought which influence appraisal and increase the likelihood that a person would experience stress as negative (such as low self-efficacy, or a conviction that you are incapable of managing stress) can also increase the likelihood that a person would become depressed. It is normal to experience a range of moods, both high and low, in everyday life. While some "down in the dumps" feelings are a part of life, sometimes, people fall into depressing feelings that persist and start interfering with their ability to complete daily activities, hold a job, and enjoy successful interpersonal relationships (Mills, Reiss & Dombeck 2008; Schneiderman, Ironson & Siegel 2005).

Some people who are stressed may show relatively mild outward signs of anxiety, such as fidgeting, biting their fingernails, tapping their feet, etc. In other people, chronic activation of stress hormones can contribute to severe feelings of anxiety (eg racing heartbeat, nausea, sweaty palms, etc.), feelings of helplessness and a sense of impending doom. Thought patterns that lead to stress (and depression, as described above) can also leave people vulnerable to intense anxiety feelings (Mills, Reiss & Dombeck 2008).

Anxiety or dread feelings that persist for an extended period of time; which cause people to worry excessively about upcoming situations (or potential situations); which lead to avoidance; and cause people to have difficulty coping with everyday situations may be symptoms of one or more anxiety disorders (Mills, Reiss & Dombeck 2008).

More generally, it must be noted that urbanisation, or increased urbanisation, regardless of specific projects has been found to affect levels of stress and mental health (Srivastava 2009). These impacts are greater where there is urbanisation without improvements in infrastructure to improve equitable access to employment and social areas/communities (Srivastava 2009).

The role of either acute or long-term environmental stress on the health of any community, in general and for specific project(s), including the Sydney Gateway project, cannot be quantified. There are a wide range of complex factors that influence health and wellbeing, specifically mental health. It is not possible to determine any specific outcomes that may occur as a result of a specific project, or number of projects. However, it is noted that within any urban environment there will be a wide range of stressors present from infrastructure projects as well as other urban developments that may or may not contribute to the health effects outlined above.

It is noted other approved infrastructure projects in the local area are aimed at improving infrastructure, connections and access within the urban environment. Hence on a broader scale, Botany Rail Duplication and the other longer-term projects, while requiring long-term management to minimise construction impacts, may assist in reducing stress and associated physiological and mental health impacts within the urban environment.

8.9 Equity

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

- elderly
- individuals with pre-existing health problems
- infants and young children
- individuals with disabilities
- individuals who live in areas of higher levels of air or noise pollution.

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

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

It is noted that in many urban areas, housing prices are lower adjacent to major transport infrastructure such as main roads and rail lines. The median house prices in the study area are variable, however in most areas they are consistent with the Sydney average. Some public housing is located in the study area; however, these properties are mixed in with privately owned property such that there are no specific areas with higher populations of public housing tenants.

Review of the predicted increases in key air pollutants (in particular nitrogen dioxide and $PM_{2.5}$) and noise has identified that these occur in areas close to the project as the key source of these issues is the operation of the locomotives on the rail line. The assessment presented has addressed the maximum impacted locations adjacent to the project. There may be some areas where maximum increases in both air pollutants and noise may occur. Health impacts from these issues are not necessarily additive with many of the studies relied on for the characterisation of health impacts are from urban environments where both air and noise impacts affect health. While operational noise requires mitigation, where this mitigation is implemented and is effective, and impacts from air pollutant are considered, the impacts would be no different to those evaluated separately for changes in air quality and noise.

8.10 Summary of key findings

Changes in the urban environment associated with the project have the potential to result in a range of impacts on health and wellbeing of the community. The potential for changes to result in impacts on health and wellbeing is complex. Changes that may occur have the potential to result in both positive and negative impacts on community health.

The duplication of the Botany Line would unlock additional rail network capacity (with improved travel times through the Botany Line), resulting in a potential increase in the number of freight rail services supporting the movement of goods. The increased rail capacity has the potential to reduce the number of number of trucks in the region. The reduction of heavy vehicle traffic on the road network would not only free up capacity for general traffic, it also has the potential to provide road safety advantages (refer to *Technical Report 1 - Traffic and transport*). These impacts have the potential to improve health and wellbeing within the community through the provision of employment, easier access to employment, reduced levels of stress and anxiety.

Negative impacts may occur as a result of traffic changes during construction, visual changes, air and noise impacts (refer to Sections 6 and 7). These may result in increased levels of stress and anxiety. Most impacts identified are either short-term (associated with construction only) and/or mitigation/management measures have been identified to minimise the impacts on the community.

9. Summary of health impacts

Within an urban environment there are a wide range of complex factors (acting and interacting at different scales) that can affect health and wellbeing. This is conceptualised in Figure 10.1 which is based on the diagram presented by the International Council for Science and similar to that defined by the WHO (ICSU 2011). The factors identified may result in either positive or negative impacts on health and wellbeing during both construction and operation. It is noted that no single element or determinant acts in isolation. Health and wellbeing in the urban environment depends on the sum of the total interactions between many factors.

Potential impacts related to this project are summarised on the figure, showing both positive and negative impacts. The figure illustrates the complexity of making definitive conclusions in relation to health impacts in the community. However, it is noted that where negative impacts have been identified, impacts to the community would be minimised through the implementation of appropriate mitigation or management measures.

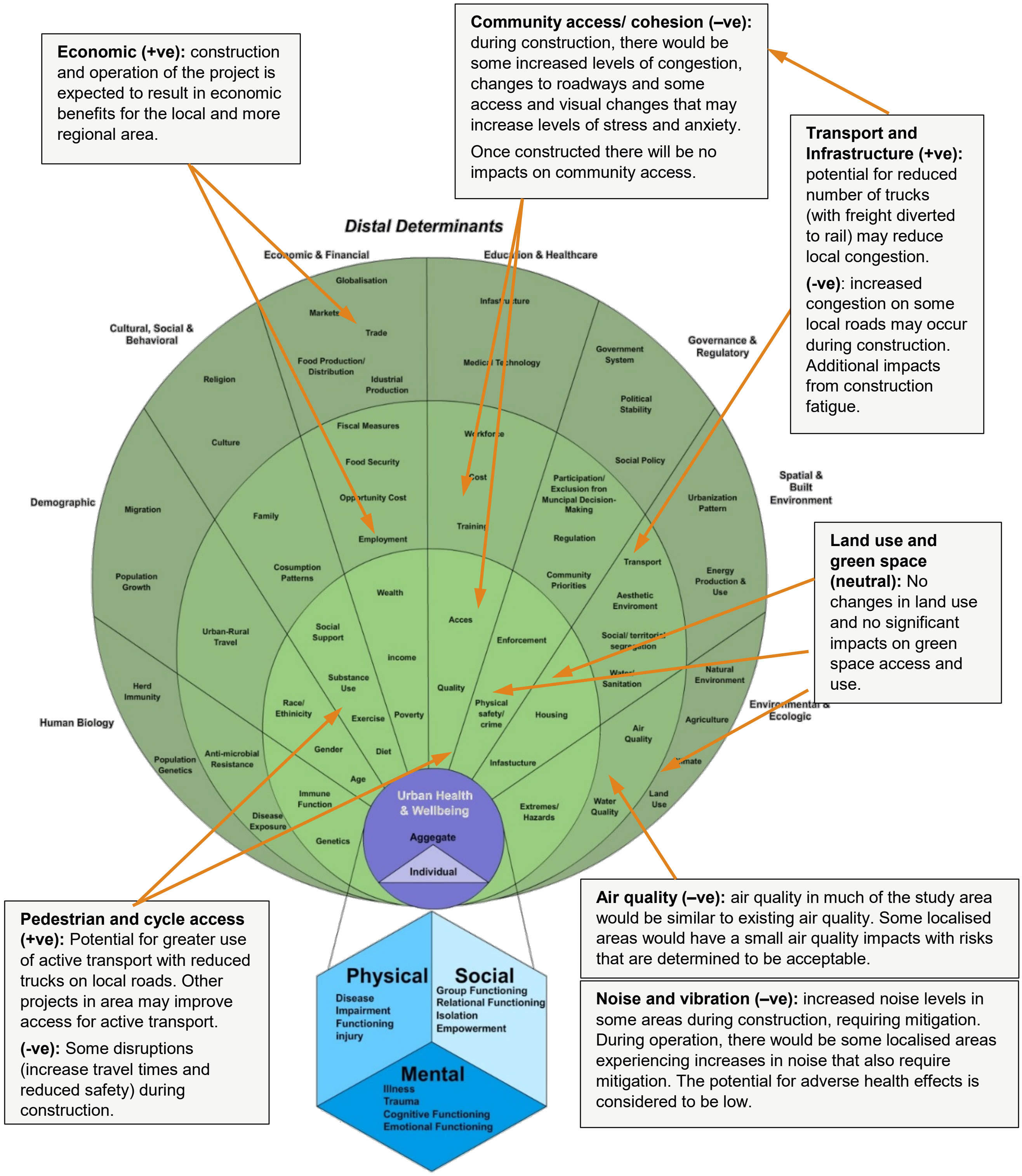

Figure 9.1: Conceptual framework for determinants of health and wellbeing in the urban environment and potential impacts from project (ICSU 2011)

10. Management of impacts

10.1 Approach

As described in the EIS Chapter 6 (Project features and operation) and Chapter 7 (Construction), design development and construction planning has focused on avoiding and/or minimising the potential for environmental impacts during all key phases of the process.

Even with the approach to avoid and minimise impacts, there is still the potential for residual impacts to occur from the project.

Mitigation measures would be managed through the following:

- ARTC's Site environmental management plans (EMP(s) for enabling works.
- Project specific CEMP for main construction works.
- Community and stakeholder engagement plan.
- ARTC's environmental management system for operation of the project.

10.2 List of mitigation measures

Mitigation measures relevant to this health impact assessment have been identified in the following technical reports:

- *Botany Rail Duplication EIS, Technical Report 1 - Traffic and transport*
- *Botany Rail Duplication EIS, Technical Report 2 - Noise and vibration impact assessment*
- *Botany Rail Duplication EIS, Technical Report 3 - Air quality impact assessment*
- *Botany Rail Duplication EIS, Technical Report 5 - Contamination report*
- *Botany Rail Duplication EIS, Technical Report 12 - Social impact assessment.*

There are no additional management measures identified in the HIA.

11. Conclusion

The assessment of potential health impacts associated with the project involved evaluation of a wide range of impacts that have the potential to affect the health and wellbeing of the community. The assessment has utilised a range of methods to evaluate potential health impacts within the project area.

Based on the assessment undertaken, where proposed mitigation measures are implemented, no significant impacts on community health have been identified.

More specifically, the following provides an overview of the key outcomes of impacts and benefits identified during the construction and operation of the project:

Health impacts during construction:

- Changes in air quality:
  - Impacts associated with dust generated from construction activities would require management to ensure impacts to community health are minimised.
  - Measures required to be implemented to minimise dust impacts are detailed in the *Technical Report 3 - Air quality impact assessment*.
- Changes in noise:
  - Where the proposed management measures are implemented (as outlined in *Technical Report 2 - Noise and vibration impact assessment*), the potential for construction noise and vibration to adversely impact community health would be minimised.
  - It should be noted that even where mitigation measures are implemented, some noise impacts may occur where works occur close to sensitive receivers. These impacts are expected to be of short duration, where annoyance and potentially sleep disturbance may occur on occasions.
- Public safety and contamination:
  - Where all proposed management measures are implemented, no community health risk issues of concern were identified in relation to public safety, associated with the project, from issues such as dangerous goods, hazardous incidents or contamination during construction.
- Changes in other social determinants
  - Changes in the urban environment associated with the project have the potential to result in a range of impacts on health and wellbeing of the community. The potential for changes to result in impacts on health and wellbeing is complex. Changes that may occur have the potential to result in both positive and negative impacts on community health.
  - The construction phase of works has the greatest potential for negative impacts as a result of traffic changes during construction, visual changes and minor changes in access/cohesion of local areas. These may result in increased levels of stress and anxiety within the community. In many cases, the impacts identified are either short-term (associated with construction only) and/or mitigation/management measures have been identified to minimise the impacts on the community.
  - Positive impacts for the project during construction relate to employment, which has the potential to benefit health.

Health impacts during operation:

- Changes in air quality:
  - Impacts within the community: no health impacts have been identified that would be considered to be of significance (ie measurable) within the community
- Changes in noise:

  - Without mitigation, 189 buildings have been identified where rail noise exceeds the health based criteria. These impacts are of significance in NCA01, NCA03, NCA04, NCA07 and NCA08. While the increases in noise levels associated with the project are unlikely to result in any significant increases in health impacts, the total noise levels and maximum rail noise levels have the potential to be of concern to community health.
  - To ensure health impacts are effectively mitigated, mitigation measures would be required to be designed and implemented as outlined in *Technical Report 2 - Noise and vibration impact assessment.* The mitigation of operational noise impacts should consider treatment at or near the noise sources prior to the implementation of at-property treatments as at-property treatments are less certain (in terms of acceptance and use) and their presence at a property has the potential to also affect the wellbeing of residents.
- Public safety and contamination:
  - No community health risk issues of concern were identified in relation to public safety, associated with the project.
- Changes in other social determinants
  - Operation of the project is associated with positive impacts, which include economic benefits and the potential for reduced freight truck movements in the local area. These impacts have the potential to improve health and wellbeing within the community through the provision of employment, easier access to employment, reduced levels of stress and anxiety.

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Appendix A
Approach to risk assessment using exposure-response relationships

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A1. Overview

This Appendix summarises the approach adopted for the assessment of risk on the basis of exposure-response relationships.

A2. Mortality and morbidity health endpoints

A quantitative assessment of risk for these endpoints uses a mathematical relationship between an exposure concentration (ie concentration in air) and a response (namely a health effect). This relationship is termed an exposure-response relationship and is relevant to the range of health effects (or endpoints) identified as relevant (to the nature of the emissions assessed) and robust (as identified in the main document). An exposure-response relationship can have a threshold, where there is a safe level of exposure, below which there are no adverse effects; or the relationship can have no threshold (and is regarded as linear) where there is some potential for adverse effects at any level of exposure.

In relation to the health effects associated with exposure to nitrogen dioxide and particulate matter, no threshold has been identified. Non-threshold exposure-response relationships have been identified for the health endpoints considered in this assessment.

The assessment of potential risks associated with exposure to particulate matter involves the calculation of a relative risk (RR). For the purpose of this assessment the shape of the exposure-response function used to calculate the relative risk is assumed to be linear[8]. The calculation of a relative risk based on the change in relative risk exposure concentration from baseline/existing (ie based on incremental impacts from the project) can be calculated on the basis of the following equation (Ostro 2004):

Equation 1 $$RR = \exp[\beta(X-X0)]$$

Where:
X-X0 = the change in particulate matter concentration to which the population is exposed (μg/m^3)
β = regression/slope coefficient, or the slope of the exposure-response function which can also be expressed as the per cent change in response per 1 μg/m^3 increase in particulate matter exposure.

Based on this equation, where the published studies have derived relative risk values that are associated with a 10 micrograms per cubic metre increase in exposure, the β coefficient can be calculated using the following equation:

8 Some reviews have identified that a log-linear exposure-response function may be more relevant for some of the health endpoints considered in this assessment. Review of outcomes where a log-linear exposure-response function has been adopted (Ostro 2004) for $PM_{2.5}$ identified that the log-linear relationship calculated slightly higher relative risks compared with the linear relationship within the range 10–30 micrograms per cubic metre,(relevant for evaluating potential impacts associated with air quality goals or guidelines) but lower relative risks below and above this range. For this assessment (where impacts from a particular project are being evaluated) the impacts assessed relate to concentrations of $PM_{2.5}$ that are well below 10 micrograms per cubic metre and hence use of the linear relationship is expected to provide a more conservative estimate of relative risk.

Equation 2 $$\beta = \frac{\ln(RR)}{10}$$

Where:
RR = relative risk for the relevant health endpoint as published (µg/m³)
10 = increase in particulate matter concentration associated with the RR (where the RR is associated with a 10 µg/m³ increase in concentration).

A3. Quantification of impact and risk

The assessment of health impacts for a particular population associated with exposure to particulate matter has been undertaken utilising the methodology presented by the WHO (Ostro 2004)[9] where the exposure-response relationships identified have been directly considered on the basis of the approach outlined below.

The calculation of changes in health endpoints associated with exposure to nitrogen dioxide and particulate matter as outlined by the WHO (Ostro 2004) has considered the following four elements:

- Estimates of the changes in particulate matter exposure levels (ie incremental impacts) due to the project for the relevant modelled scenarios
- Estimates of the number of people exposed to particulate matter at a given location
- Baseline incidence of the key health endpoints that are relevant to the population exposed
- Exposure-response relationships expressed as a percentage change in health endpoint per microgram per cubic metre change in NO_2 or particulate matter exposure, where a relative risk (RR) is determined (refer to Equation 1).

From the above, the increased incidence of a health endpoint corresponding to a particular change in particulate matter concentrations can be calculated using the following approach:

The attributable fraction/portion (AF) of health effects from air pollution, or impact factor, can be calculated from the relative risk (calculated for the incremental change in concentration considered as per Equation 1) as:

Equation 3 $$AF=\frac{RR-1}{RR}$$

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

Equation 4 $$E=AF \times B \times P$$

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

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9 For regional guidance, such as that provided for Europe by the WHO WHO 2006a, Health risks or particulate matter from long-range transboundary air pollution regional background incidence data for relevant health endpoints are combined with exposure-response functions to present an impact function, which is expressed as the number/change in incidence/new cases per 100,000 population exposed per microgram per cubic metre change in particulate matter exposure. These impact functions are simpler to use than the approach adopted in this assessment, however in utilising this approach it is assumed that the baseline incidence of the health effects is consistent throughout the whole population (as used in the studies) and is specifically applicable to the sub-population group being evaluated. For the assessment of exposures in the areas evaluated surrounding the project it is more relevant to utilise local data in relation to baseline incidence rather than assume that the population is similar to that in Europe (where these relationships are derived).

The above approach (while presented slightly differently) is consistent with that presented in Australia (Burgers & Walsh 2002), US (OEHHA 2002; USEPA 2005, 2010) and Europe (Martuzzi et al. 2002; Sjoberg et al. 2009).

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

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

The above approach can be simplified (mathematically, where the incremental change in particulate concentration is low, less than one microgram per cubic metre) as follows:

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

Where:
β = slope coefficient relevant to the per cent change in response to a 1 μg/m³ change in exposure concentration
B = baseline incidence of a given health effect per person (eg annual mortality rate)
ΔXmesh = change (increment) in exposure concentration in μg/m³ as an average within a small area defined as a mesh block (from the ABS – where many mesh blocks make up a suburb)
Pmesh = population (residential – based on data from the ABS) within each small mesh block

An additional risk can then be calculated as:

Equation 6 $$Risk = \beta \times \Delta X \times B$$

Where:
β = slope coefficient relevant to the per cent change in response to a 1 μg/m³ change in exposure
ΔX = change (increment) in exposure concentration in μg/m³ relevant to the project at the point of exposure
B = baseline incidence of a given health effect per person (eg annual mortality rate)

This calculation provides an annual risk for individuals exposed to changes in air quality from the project at specific locations (such as the maximum, or at specific sensitive receptor locations). The calculated risk does not take into account the duration of exposure at any one location and hence is considered to be representative of a population risk.

A4. Quantification of short and long term effects

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

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

Short term effects are also assessed on the basis of an exposure-response function that is expressed as a percentage change in endpoint per microgram per cubic metre change in concentration. For short term effects, the calculations relate to daily changes in nitrogen dioxide and particulate matter exposures to calculate changes in daily effects endpoints. While it may be possible to measure daily incidence of the evaluated health endpoints in a large population study specifically designed to include such data, it is not common to collect such data in hospitals nor are effects measurable in smaller communities. Instead these calculations relate to a parameter that is measurable, such as annual incidence of hospitalisations, mortality or lung cancer risks. The calculation of an annual incidence or additional risk can be undertaken using two approaches (Ostro 2004; USEPA 2010):

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

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

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

Hence for the calculations presented in this technical report that relate to the expected use of the project tunnel, for both long term and short term effects, annual average concentrations of nitrogen dioxide and particulate matter have been utilised.

Where short term worst case exposures are assessed (such as those related to a breakdown in the tunnel) short term, daily, calculations have been undertaken to assessed short term health endpoints. This has been undertaken as the exposure being assessed relates to an infrequent short duration event. It would not occur each day of the year and hence it is not appropriate to assess on the basis of an annual average.

Appendix B
Approach to the assessment of cancer risks

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B1. Overview

This Appendix summarises the approach adopted for the assessment of carcinogenic risks. This relates to the assessment of diesel particulate matter. Toxicity reference values relevant to these chemicals, with the exception of diesel particulate matter are presented in Section 6 of the main report.

B2. Diesel particulate matter

Diesel exhaust (DE) is emitted from diesel engines (vehicle engines) and can be formed from the gaseous compounds emitted by diesel engines (secondary particulate matter). After emission from the exhaust pipe, diesel exhaust undergoes dilution and chemical and physical transformations in the atmosphere, as well as dispersion and transport in the atmosphere. The atmospheric lifetime for some compounds present in diesel exhaust ranges from hours to days.

Data from the USEPA (USEPA 2002) indicates that diesel exhaust as measured as diesel particulate matter made up about six per cent of the total ambient/urban air $PM_{2.5}$. In this project, emissions to air from the operation of the tunnel include a significant proportion of diesel powered vehicles. Available evidence indicates that there are human health hazards associated with exposure to diesel particulate matter. The hazards include acute exposure-related symptoms, chronic exposure related non-cancer respiratory effects, and lung cancer.

In relation to non-carcinogenic effects, acute or short term (eg episodic) exposure to diesel particulate matter can cause acute irritation (eg eye, throat, bronchial), neurophysiological symptoms (eg light-headedness, nausea), and respiratory symptoms (cough, phlegm). There also is evidence for an immunologic effect-exacerbation of allergenic responses to known allergens and asthma-like symptoms. Chronic effects include respiratory effects. The review of these effects (USEPA 2002) identified a threshold concentration for the assessment of chronic non-carcinogenic effects. The review conducted by the USEPA also concluded that exposures to diesel particulate matter also consider $PM_{2.5}$ goals (as these also address the presence of diesel particulate matter in urban air environments). The review found that the diesel particulate matter chronic guideline would also be met if the $PM_{2.5}$ guideline was met.

Review of exposures to diesel particulate matter (USEPA 2002) identified that such exposures are 'likely to be carcinogenic to humans by inhalation'. A more recent review by IARC (Attfield et al. 2012; IARC 2012; Silverman et al. 2012) classified diesel engine exhaust as carcinogenic to humans (Group 1) based on sufficient evidence that exposure is associated with an increased risk for lung cancer. In addition, outdoor air pollution and particulate matter (that includes diesel particulate matter) have been classified by IARC as carcinogenic to humans based on sufficient evidence of lung cancer.

Many of the organic compounds present in diesel exhaust are known to have mutagenic and carcinogenic properties and hence it is appropriate that a non-threshold approach is considered for the quantification of lung-cancer endpoints.

In relation to quantifying carcinogenic risks associated with exposure to diesel exhaust, the USEPA (USEPA 2002) has not established a non-threshold value (due to uncertainties identified in the available data).

WHO has used data from studies in rats to estimate unit risk values for cancer (WHO 1996). Using four different studies where lung cancer was the cancer endpoint, WHO calculated a range of 1.6×10^{-5} to 7.1×10^{-5} per microgram per cubic metres (mean value of 3.4×10^{-5} per microgram per cubic metres). This would suggest that an increase in lifetime exposure to diesel particulate matter between 0.14 and 0.625 microgram per cubic metres could result in a one in one hundred thousand excess risk of cancer.

The California Environmental Protection Agency has proposed a unit lifetime cancer risk of 3.0×10^{-4} per microgram per cubic metres diesel particulate matter (OEHHA 1998). This was derived from data on exposed workers and based on evidence that suggested unit risks between 1.5×10^{-4} and 15×10^{-4} per microgram per cubic metres. This would suggest that an increase in lifetime exposure to diesel particulate matter of 0.033 microgram per cubic metres could result in a one in one hundred thousand excess risk of cancer. This estimate has been widely criticised as overestimating the risk and hence has not been considered in this assessment.

On the basis of the above, the WHO cancer unit risk value (mean value of 3.4 x 10^{-5} per microgram per cubic metres) has been used to evaluate potential excess lifetime risks associated with incremental impacts from diesel particulate matter exposures.

Diesel particulate matter has not been specifically modelled in *Technical Report 3 - Air quality impact assessment*; rather diesel particulate matter is part of the $PM_{2.5}$ assessment. For the purpose of this assessment it has been conservatively assumed that 100 per cent of the incremental $PM_{2.5}$ (from the project only) is derived from diesel sources.

B3. Calculation of carcinogenic risk

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

Equation B1 Carcinogenic Risk (inhalation) = Concentration in Air x Inhalation Unit Risk

Appendix C
Acceptable risk levels

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C1. General

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

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

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

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

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

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

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

C2. 10^{-6} as an 'acceptable' risk level?

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

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

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

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

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

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

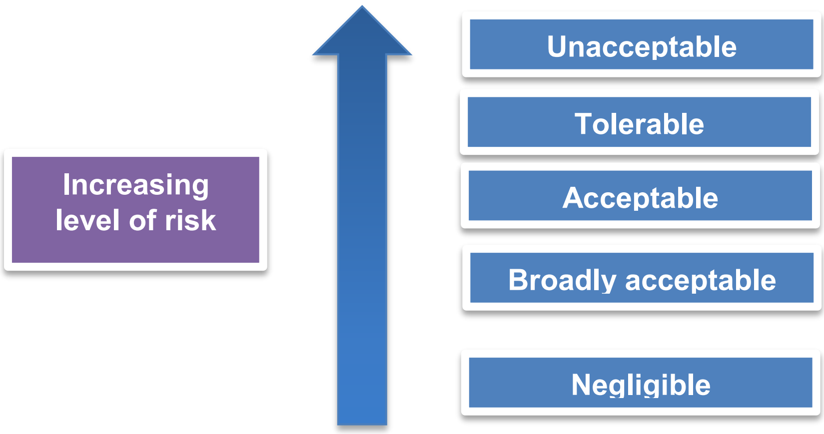
To provide more context in relation to the concept of a one in a million risk, the following presents a range of everyday life occurrences. The activity and the time spent undertaking the activity that is associated with reaching a risk of one in a million for mortality are listed below (Higson 1989;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

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

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

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

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



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

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

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

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

The following is a list of standpoints that could be used as a basis for determining when a risk is acceptable or, perhaps, tolerable. The WHO (Fewtrell & Bartram 2001) address standards related to water quality. They offer the following guidelines for determining acceptable risk. A risk is acceptable when:

- It falls below an arbitrary defined probability
- It falls below some level that is already tolerated
- It falls below an arbitrary defined attributable fraction of total disease burden in the community

- The cost of reducing the risk would exceed the costs saved
- The cost of reducing the risk would exceed the costs saved when the ‘costs of suffering’ are also factored in
- The opportunity costs would be better spent on other, more pressing, public health problems
- Public health professionals say it is acceptable
- The general public say it is acceptable (or more likely, do not say it is not)
- Politicians say it is acceptable.

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

C3. Overall

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

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

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

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

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

When considering the impacts associated with this project, it is important to note that there are a range of benefits associated with the project and the design of the project has incorporated measures to minimise exposures to traffic-related emissions in the local areas. Hence for this project the calculated risks have been considered to be tolerable when in the range of 10^{-6} and 10^{-4} of increased risk and where the increased incidence of the health impacts are considered to be insignificant.

Appendix D
Risk calculations: Nitrogen dioxide

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Quantification of Effects - NO_2
Botany Rail Duplication

	2024			2034		
Air quality indicator:	NO2	NO2	NO2	NO2	NO2	NO2
Endpoint:	Mortality - All Causes	Mortality - Respiratory	Asthma - ED Hospital admissions	Mortality - All Causes	Mortality - Respiratory	Asthma - ED Hospital admissions
Effect Exposure Duration:	Short-term	Short-term	Short-term	Short-term	Short-term	Short-term
Age Group:	All ages	All ages	1-14 years	All ages	All ages	1-14 years
β (change in effect per 1 µg/m³ NO2) (as per Table 6.4)	0.00188	0.00426	0.00115	0.00188	0.00426	0.00115
Annual Baseline Incidence (as per Table 4.3)						
Annual baseline incidence (per 100,000)	457	41.3	1209	457	41.3	1209
Baseline Incidence (per person per year)	0.00457	0.000413	0.01209	0.00457	0.000413	0.01209

Sensitive Receptors	Change in Annual Average NO2 Concentration (µg/m³)	Risk	Risk	Risk	Change in Annual Average NO2 Concentration (µg/m³)	Risk	Risk	Risk
Community Receptors								
Qantas Joy building	-0.314	-3E-06	-6E-07	-4E-06	0.207	2E-06	4E-07	3E-06
Qantas Flight Training Centre	-0.788	-7E-06	-1E-06	-1E-05	0.521	4E-06	9E-07	7E-06
Qudos Bank	-0.909	-8E-06	-2E-06	-1E-05	0.600	5E-06	1E-06	8E-06
Redspot car rentals headquarters	-1.111	-1E-05	-2E-06	-2E-05	0.733	6E-06	1E-06	1E-05
Stamford Plaza Sydney Airport	-0.981	-8E-06	-2E-06	-1E-05	0.648	6E-06	1E-06	9E-06
Krispy Kreme Mascot	-1.022	-9E-06	-2E-06	-1E-05	0.675	6E-06	1E-06	9E-06
Regional Express (Rex)	-0.630	-5E-06	-1E-06	-9E-06	0.416	4E-06	7E-07	6E-06
IMO Carwash Mascot	-1.128	-1E-05	-2E-06	-2E-05	0.745	6E-06	1E-06	1E-05
Residential	-0.862	-7E-06	-2E-06	-1E-05	0.569	5E-06	1E-06	8E-06
AEA Sydney airport serviced apartments	-1.021	-9E-06	-2E-06	-1E-05	0.674	6E-06	1E-06	9E-06
Rovacraft	-1.105	-9E-06	-2E-06	-2E-05	0.730	6E-06	1E-06	1E-05
Residential	-1.179	-1E-05	-2E-06	-2E-05	0.778	7E-06	1E-06	1E-05
Sims Metal Management	-2.102	-2E-05	-4E-06	-3E-05	1.389	1E-05	2E-06	2E-05
Eastlake Golf Club Halfway House	-0.866	-7E-06	-2E-06	-1E-05	0.572	5E-06	1E-06	8E-06
Big Picture Australia PTY Ltd	-2.593	-2E-05	-5E-06	-4E-05	1.712	1E-05	3E-06	2E-05
Residential	-1.350	-1E-05	-2E-06	-2E-05	0.892	8E-06	2E-06	1E-05
Residential	-2.315	-2E-05	-4E-06	-3E-05	1.529	1E-05	3E-06	2E-05
Residential	-1.128	-1E-05	-2E-06	-2E-05	0.745	6E-06	1E-06	1E-05
Gairarine Gardens	-0.868	-7E-06	-2E-06	-1E-05	0.573	5E-06	1E-06	8E-06
Residential	-0.432	-4E-06	-8E-07	-6E-06	0.285	2E-06	5E-07	4E-06

Appendix E
Risk calculations: Particulates

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Quantification of Effects - $PM_{2.5}$ and PM_{10}
Botany Rail Duplication 2024

Air quality indicator:	**$PM_{2.5}$**	**$PM_{2.5}$**	**$PM_{2.5}$**	**PM_{10}**	**$PM_{2.5}$**	**$PM_{2.5}$**	**$PM_{2.5}$**	**$PM_{2.5}$**	**$PM_{2.5}$**	**DPM**
Endpoint:	**Mortality - All Causes**	**Hospitalisations - Cardiovascular**	**Hospitalisations - Respiratory**	**Mortality - All Causes**	**Mortality - All Causes**	**Mortality - Cardiopulmonary**	**Mortality - Cardiovascular**	**Mortality - Respiratory**	**Morbidity - Asthma ED Admissions**	**Increased risk - lung cancer**
Effect Exposure Duration:	Long-term	Short-term	Short-term	Short-Term	Short-Term	Long-term	Short-Term	Short-Term	Short-Term	Based on WHO
Age Group:	≥ 30 years	≥ 65 years	≥ 65 years	All ages	All ages	≥ 30 years	All ages	All ages	1-14 years	inhalation unit risk
β (change in effect per 1 μg/m³) (as per Table 6.7)	0.0058	0.0008	0.00041	0.0006	0.00094	0.013	0.00097	0.0019	0.00148	3.40E-05
Annual Baseline Incidence (as per Table 4.3)										(ug/m3)-1
Annual baseline incidence (per 100,000)	1026	9235	3978	457	457	412	127.3	41.3	1209	
Baseline Incidence (per person per year)	0.01026	0.09235	0.03978	0.00457	0.00457	0.00412	0.001273	0.000413	0.01209	

Sensitive Receptors	**Change in Annual Average PM10 Concentration (μg/m³)**	**Change in Annual Average PM2.5 Concentration (μg/m³)**	**Risk**	**Risk**	**Risk**	**Risk**	**Risk**	**Risk**	**Risk**	**Risk**	**Risk**	**Risk**
Qantas Joy building	-0.0026	-0.0025	-1E-07	-2E-07	-4E-08	-7E-09	-1E-08	-1E-07	-3E-09	-2E-09	-4E-08	**-8E-08**
Qantas Flight Training Centre	-0.0065	-0.0062	-4E-07	-5E-07	-1E-07	-2E-08	-3E-08	-3E-07	-8E-09	-5E-09	-1E-07	**-2E-07**
Qudos Bank	-0.0075	-0.0071	-4E-07	-5E-07	-1E-07	-2E-08	-3E-08	-4E-07	-9E-09	-6E-09	-1E-07	**-2E-07**
Redspot car rentals headquarters	-0.0092	-0.0087	-5E-07	-6E-07	-1E-07	-3E-08	-4E-08	-5E-07	-1E-08	-7E-09	-2E-07	**-3E-07**
Stamford Plaza Sydney Airport	-0.0081	-0.0077	-5E-07	-6E-07	-1E-07	-2E-08	-3E-08	-4E-07	-1E-08	-6E-09	-1E-07	**-3E-07**
Krispy Kreme Mascot	-0.0085	-0.0080	-5E-07	-6E-07	-1E-07	-2E-08	-3E-08	-4E-07	-1E-08	-6E-09	-1E-07	**-3E-07**
Regional Express (Rex)	-0.0052	-0.0049	-3E-07	-4E-07	-8E-08	-1E-08	-2E-08	-3E-07	-6E-09	-4E-09	-9E-08	**-2E-07**
IMO Carwash Mascot	-0.0094	-0.0089	-5E-07	-7E-07	-1E-07	-3E-08	-4E-08	-5E-07	-1E-08	-7E-09	-2E-07	**-3E-07**
Residential	-0.0071	-0.0068	-4E-07	-5E-07	-1E-07	-2E-08	-3E-08	-4E-07	-8E-09	-5E-09	-1E-07	**-2E-07**
AEA Sydney airport serviced apartments	-0.0085	-0.0080	-5E-07	-6E-07	-1E-07	-2E-08	-3E-08	-4E-07	-1E-08	-6E-09	-1E-07	**-3E-07**
Rovacraft	-0.0092	-0.0087	-5E-07	-6E-07	-1E-07	-3E-08	-4E-08	-5E-07	-1E-08	-7E-09	-2E-07	**-3E-07**
Residential	-0.0098	-0.0093	-6E-07	-7E-07	-2E-07	-3E-08	-4E-08	-5E-07	-1E-08	-7E-09	-2E-07	**-3E-07**
Sims Metal Management	-0.0174	-0.0165	-1E-06	-1E-06	-3E-07	-5E-08	-7E-08	-9E-07	-2E-08	-1E-08	-3E-07	**-6E-07**
Eastlake Golf Club Halfway House	-0.0072	-0.0068	-4E-07	-5E-07	-1E-07	-2E-08	-3E-08	-4E-07	-8E-09	-5E-09	-1E-07	**-2E-07**
Big Picture Australia PTY Ltd	-0.0215	-0.0204	-1E-06	-2E-06	-3E-07	-6E-08	-9E-08	-1E-06	-3E-08	-2E-08	-4E-07	**-7E-07**
Residential	-0.0112	-0.0106	-6E-07	-8E-07	-2E-07	-3E-08	-5E-08	-6E-07	-1E-08	-8E-09	-2E-07	**-4E-07**
Residential	-0.0192	-0.0182	-1E-06	-1E-06	-3E-07	-5E-08	-8E-08	-1E-06	-2E-08	-1E-08	-3E-07	**-6E-07**
Residential	-0.0094	-0.0089	-5E-07	-7E-07	-1E-07	-3E-08	-4E-08	-5E-07	-1E-08	-7E-09	-2E-07	**-3E-07**
Gairarine Gardens	-0.0072	-0.0068	-4E-07	-5E-07	-1E-07	-2E-08	-3E-08	-4E-07	-8E-09	-5E-09	-1E-07	**-2E-07**
Residential	-0.0036	-0.0034	-2E-07	-3E-07	-6E-08	-1E-08	-1E-08	-2E-07	-4E-09	-3E-09	-6E-08	**-1E-07**

Quantification of Effects - $PM_{2.5}$ and PM_{10}
Botany Rail Duplication 2034

Air quality indicator:	$PM_{2.5}$	$PM_{2.5}$	$PM_{2.5}$	PM_{10}	$PM_{2.5}$	$PM_{2.5}$	$PM_{2.5}$	$PM_{2.5}$	$PM_{2.5}$	DPM
Endpoint:	**Mortality - All Causes**	**Hospitalisations - Cardiovascular**	**Hospitalisations - Respiratory**	**Mortality - All Causes**	**Mortality - All Causes**	**Mortality - Cardiopulmonary**	**Mortality - Cardiovascular**	**Mortality - Respiratory**	**Morbidity - Asthma ED Admissions**	**Increased risk - lung cancer**
Effect Exposure Duration:	Long-term	Short-term	Short-term	Short-Term	Short-Term	Long-term	Short-Term	Short-Term	Short-Term	Based on WHO
Age Group:	≥ 30 years	≥ 65 years	≥ 65 years	All ages	All ages	≥ 30 years	All ages	All ages	1-14 years	inhalation unit risk
β (change in effect per 1 µg/m³) (as per Table 6.7)	0.0058	0.0008	0.00041	0.0006	0.00094	0.013	0.00097	0.0019	0.00148	3.40E-05
Annual Baseline Incidence (as per Table 4.3)										(ug/m3)-1
Annual baseline incidence (per 100,000)	1026	9235	3978	457	457	412	127.3	41.3	1209	
Baseline Incidence (per person per year)	0.01026	0.09235	0.03978	0.00457	0.00457	0.00412	0.001273	0.000413	0.01209	

Sensitive Receptors	Change in Annual Average PM10 Concentration (µg/m³)	Change in Annual Average PM2.5 Concentration (µg/m³)	Risk	Risk	Risk	Risk	Risk	Risk	Risk	Risk	Risk	Risk
Qantas Joy building	0.0029	0.0026	2E-07	2E-07	4E-08	8E-09	1E-08	1E-07	3E-09	2E-09	5E-08	**9E-08**
Qantas Flight Training Centre	0.0072	0.0065	4E-07	5E-07	1E-07	2E-08	3E-08	3E-07	8E-09	5E-09	1E-07	**2E-07**
Qudos Bank	0.0083	0.0075	4E-07	6E-07	1E-07	2E-08	3E-08	4E-07	9E-09	6E-09	1E-07	**3E-07**
Redspot car rentals headquarters	0.0102	0.0092	5E-07	7E-07	1E-07	3E-08	4E-08	5E-07	1E-08	7E-09	2E-07	**3E-07**
Stamford Plaza Sydney Airport	0.0090	0.0081	5E-07	6E-07	1E-07	2E-08	3E-08	4E-07	1E-08	6E-09	1E-07	**3E-07**
Krispy Kreme Mascot	0.0094	0.0084	5E-07	6E-07	1E-07	3E-08	4E-08	5E-07	1E-08	7E-09	2E-07	**3E-07**
Regional Express (Rex)	0.0058	0.0052	3E-07	4E-07	8E-08	2E-08	2E-08	3E-07	6E-09	4E-09	9E-08	**2E-07**
IMO Carwash Mascot	0.0103	0.0093	6E-07	7E-07	2E-07	3E-08	4E-08	5E-07	1E-08	7E-09	2E-07	**3E-07**
Residential	0.0079	0.0071	4E-07	5E-07	1E-07	2E-08	3E-08	4E-07	9E-09	6E-09	1E-07	**2E-07**
AEA Sydney airport serviced apartments	0.0093	0.0084	5E-07	6E-07	1E-07	3E-08	4E-08	5E-07	1E-08	7E-09	2E-07	**3E-07**
Rovacraft	0.0101	0.0091	5E-07	7E-07	1E-07	3E-08	4E-08	5E-07	1E-08	7E-09	2E-07	**3E-07**
Residential	0.0108	0.0097	6E-07	7E-07	2E-07	3E-08	4E-08	5E-07	1E-08	8E-09	2E-07	**3E-07**
Sims Metal Management	0.0192	0.0174	1E-06	1E-06	3E-07	5E-08	7E-08	9E-07	2E-08	1E-08	3E-07	**6E-07**
Eastlake Golf Club Halfway House	0.0079	0.0071	4E-07	5E-07	1E-07	2E-08	3E-08	4E-07	9E-09	6E-09	1E-07	**2E-07**
Big Picture Australia PTY Ltd	0.0237	0.0214	1E-06	2E-06	3E-07	7E-08	9E-08	1E-06	3E-08	2E-08	4E-07	**7E-07**
Residential	0.0124	0.0111	7E-07	8E-07	2E-07	3E-08	5E-08	6E-07	1E-08	9E-09	2E-07	**4E-07**
Residential	0.0212	0.0191	1E-06	1E-06	3E-07	6E-08	8E-08	1E-06	2E-08	1E-08	3E-07	**6E-07**
Residential	0.0103	0.0093	6E-07	7E-07	2E-07	3E-08	4E-08	5E-07	1E-08	7E-09	2E-07	**3E-07**
Gairarine Gardens	0.0079	0.0072	4E-07	5E-07	1E-07	2E-08	3E-08	4E-07	9E-09	6E-09	1E-07	**2E-07**
Residential	0.0040	0.0036	2E-07	3E-07	6E-08	1E-08	2E-08	2E-07	4E-09	3E-09	6E-08	**1E-07**

Appendix F
Uncertainties

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F1. Overview

Any assessment of health risk or health impact incorporates data and information that is associated with some level of uncertainty. In most cases, where there is uncertainty in any of the key data or inputs into an assessment of health risk or health impact, a conservative approach is adopted. This approach is adopted to ensure that the assessment presents an overestimation of potential health impacts, rather than an underestimation. It is therefore important to provide some additional information on the key areas of uncertainty for the health impact assessment to support the conclusions presented.

F2. Exposure concentrations and noise levels

The concentration of various pollutants in air (i.e. exposure concentrations) and noise levels relevant to different locations in the community have been calculated on the basis of a range of input assumptions and modelling. Details of these are presented within the relevant technical reports.

Air quality

The air quality impact assessment (refer to *Technical Report 3 - Air quality impact assessment*) incorporates information on locomotive volumes and other information on the design of the project. The air quality assessment was conducted, as far as possible, with the intention of providing 'accurate' or 'realistic' estimates of pollutant emissions and concentrations. The estimation of air concentrations within the community utilises air dispersion models that are approved by the NSW EPA as suitable for providing estimates of air quality in the local community. The modelling incorporates information on the local area such as terrain, meteorology and measured existing air quality.

Noise assessment

The noise impact assessment (refer to *Noise and Vibration Technical Report* incorporates information on the noise sources relevant to the project. The modelling also incorporates measured background noise levels and a range of inputs and assumptions in relation to noise generated from the project.

For the assessment of construction noise, it has been assumed that all plant/equipment for each scenario at all locations is operating continuously at the same time. This is unlikely to occur and would have overestimated construction noise impacts.

The model used in the assessment was validated based on existing information and traffic information for 2018. The modelling undertaken showed that the noise model provides an acceptable level of accuracy.

The characterisation of health effects associated with changes in noise has been undertaken using the maximum changes in noise during any one day. The noise exposure-response relationships adopted in this assessment relate to annual average changes in noise (at any one location). The use of the daily maximum change in noise is expected to overestimate health impacts derived from noise (in particular localised impacts).

F3. Approach to the assessment of risk for particulates

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

Overall, the epidemiological and toxicological data on which the assessment presented in this report are based on current and robust information for the assessment of risks to human health associated with the potential exposure to particulate matter from combustion sources.

Exposure-response functions

The choice of exposure-response functions for the quantification of potential health impacts is important. For mortality health endpoints, many of the exposure-mortality functions have been replicated throughout the world. While many of these have shown consistent outcomes, the calculated relative risk estimates for these studies do vary. This is illustrated by Figures F.1 to F.3 that show the variability in the relative risk estimates calculated in published studies for the US (and Canadian) population that are relevant to the primary health endpoints considered in this assessment (USEPA 2012). A similar variability is observed where additional studies from Europe, Asia and Australia/New Zealand are considered.

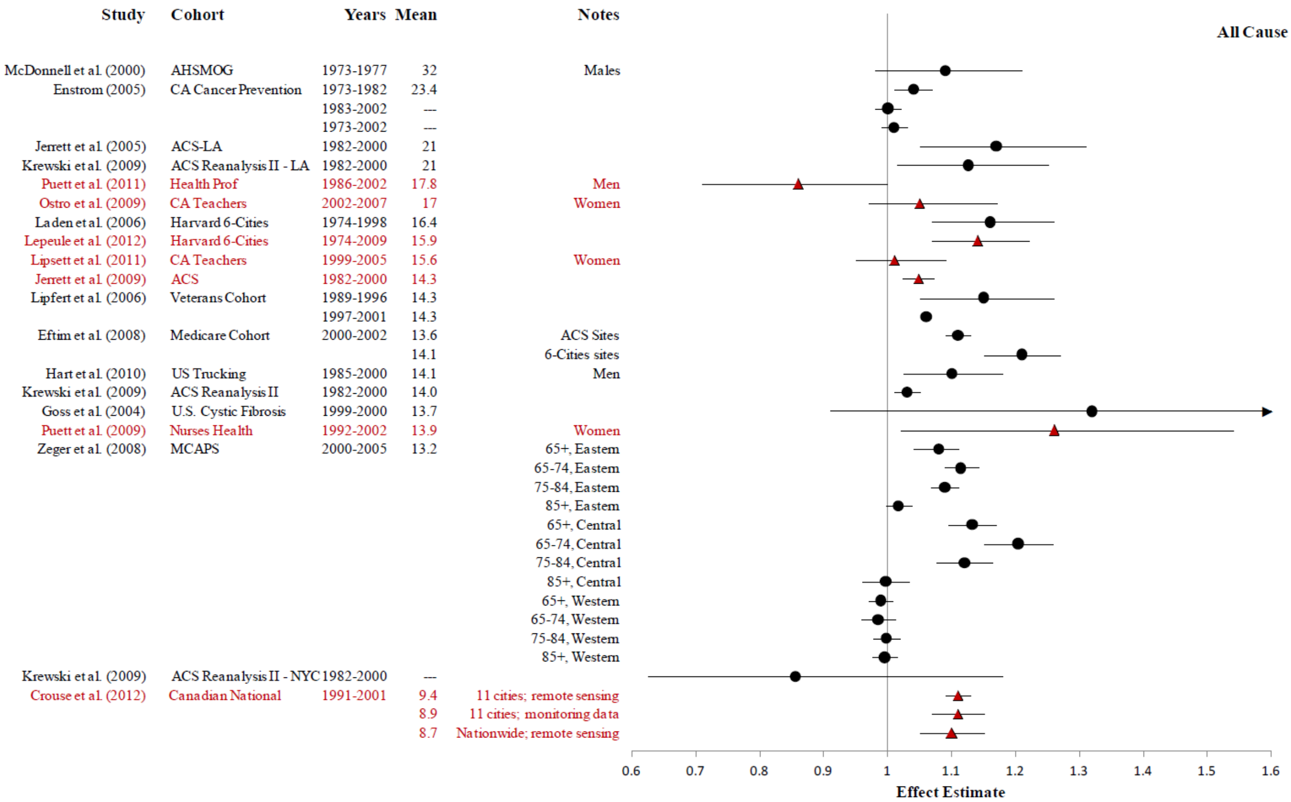

Figure F.1: All-cause mortality relative risk estimates for long-term exposure to $PM_{2.5}$ (USEPA 2012, note studies in red are those completed since 2009)

Study	Location	Age	Lag	Mean	98th
Metzger et al. (2004)	Atlanta, GA	All	0-2	17.8	---
Tolbert et al. (2007)	Atlanta, GA	All	0-2	17.1	---
Zanobetti et al. (2009)*	26 U.S. Communities	65+	0-1	15.3	---
Ito et al. (2011)	New York, NY	40+	0	14.4	---
Bell et al. (2008)	202 U.S. Counties	65+	0	12.9	34.2
Slaughter et al. (2005)	Spokane, WA	All	1	10.8	29.6
Kloog et al. (2012)	New England	65+	0-1	9.6	---
Kim et al. (2012)	Denver, CO	All	0-2 DL	8.0	---
Burnett et al. (1999)	Toronto, CAN	All	0-1	18.0	---
Ito (2003)	Detroit, MI	65+	1	18.0	---
Metzger et al. (2004)	Atlanta, GA	All	0-3	17.8	---
Dominici et al. (2006)	204 U.S. Counties	65+	0-2 DL	13.3	34.8
Pope et al. (2006)	Utah Valley, UT	All	0	10.1-11.3	---
Zanobetti et al. (2009)*	26 U.S. Communities	65+	0-1	15.3	---
Sullivan et al. (2005)	King County, WA	21-98	24 h	12.8	---
Peters et al. (2001)	Boston, MA	61.6a	24 h	12.1	28.2
Zanobetti & Schwartz (2005)	Boston, MA	65+	0	11.1**	---
Stieb et al. (2009)*	7 Canadian cities	All	0	6.7-9.8	---
Burnett et al. (1999)	Toronto, CAN	All	0-2	18.0	---
Ito (2003)	Detroit, MI	65+	1	18.0	---
Metzger et al. (2004)*	Atlanta, GA	All	0-2	17.8	---
Symons et al. (2006)	Baltimore, MD	All	2	16.0	---
Zanobetti et al. (2009)*	26 U.S. Communities	65+	0-1	15.3	---
Dominici et al. (2006)	204 U.S. Counties	65+	0	13.3	34.8
Haley et al. (2009)	New York State	All	0-2	11.1-15.5	---
Pope et al. (2008)	Utah	All	0-13 DL	10.8	44.5
Stieb et al. (2009)*	7 Canadian cities	All	0	6.7-9.8	---
Metzger et al. (2004)*	Atlanta, GA	All	0-2	17.8	---
Dominici et al. (2006)	204 U.S. Counties	65+	0	13.3	34.8
Kloog et al. (2012)	New England	65+	0-1	9.6	---
Szyszkowicz et al. (2012)*	Edmonton, CAN	All	0-3	8.5	---

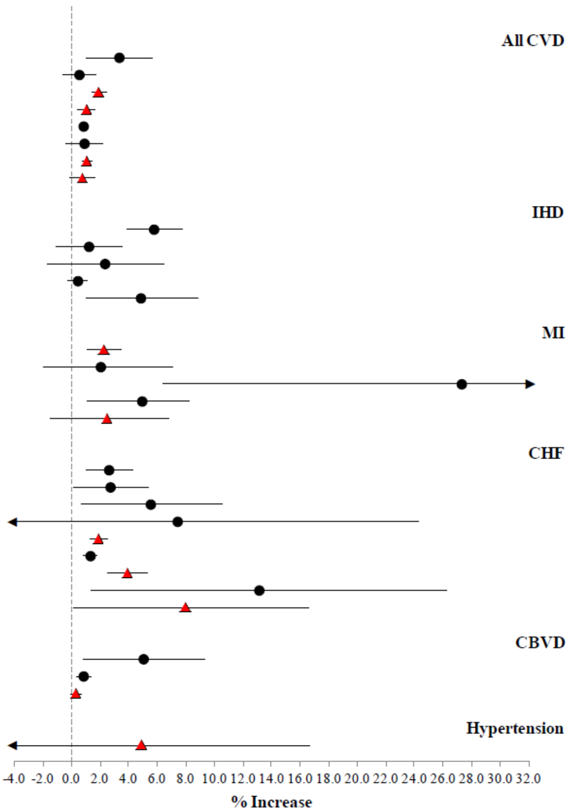

Figure F.2: Per cent increase in cardiovascular-related hospital admissions for a 10 microgram per cubic metre increase in short-term (24-hour average) exposure to $PM_{2.5}$ (USEPA 2012, note studies in red are those completed since 2009)

(note: CVD = cardiovascular disease; IHD = ischemic heart disease; MI = myocardial infarction; CHF = congestive heart failure; CBVD = cerebrovascular disease)

Study	Location	Age	Lag	Mean	98th
Ostro et al. (2009)	6 CA Counties	0-19	3	19.4	---
Peel et al. (2005)	Atlanta, GA	All	0-2	19.2	---
Tolbert et al. (2007)	Atlanta, GA	All	0-2	17.1	---
Darrow et al. (2011)*	Atlanta, GA	All	1	16.0	---
Zanobetti et al. (2009)	26 U.S. communities	65+	0-1	15.3	---
Bell et al. (2008)	202 U.S. counties	65+	2	12.9	34.2
Slaughter et al. (2005)	Spokane	All	1	10.8	29.6
Kloog et al. (2012)	New England	65+	0-1	9.6	---
Kim et al. (2012)	Denver, CO	All	0-14 DL	8.0	---
Fung et al. (2006)	Vancouver	65+	0-2	7.7	---
Chen et al. (2005)	Vancouver	65+	0-2	7.7	---
Peel et al. (2005)*	Atlanta, GA	All	0-2	19.2	---
Ito et al. (2007)*	New York, NY	All	0-1	---	---
Sheppard et al. (2003)	Seattle, WA	All	0	16.7	46.6
Strickland et al. (2010)*	Atlanta, GA	5-17	0-2	16.4	---
NYS DOH (2006)*	Bronx, NY	All	0-4	15.0	---
NYS DOH (2006)*	Manhattan, NY	All	0-4	15.0	---
Li et al. (2011)*	Detroit, MI	2-18	0-4	15.0	---
Glad et al. (2012)*	Pittsburgh, PA	All	0-5	13.3	---
Silverman and Ito (2010)	New York, NY	All	0-1	13.0**	---
Grineski et al. (2011)	El Paso, TX	1+	0-3	12.8	---
Mar et al. (2010)*	Tacoma, WA	All	2	12.3	---
Slaughter et al. (2005)*	Spokane, WA	All	1	10.8	29.6
Stieb et al. (2009)*	7 Canadian cities	All	0	6.7-9.8	---
Chimonas & Gessner (2006)	Anchorage, AK	0-19	0	6.1	---
Grineski et al. (2011)	El Paso, TX	1+	0-3	12.8	---
Peel et al. (2005)*	Atlanta, GA	All	0-3	19.2	---
Dominici et al. (2006)	204 U.S. counties	65+	2	13.3	34.8
Lin et al. (2005)	Ontario, CAN	< 15	0-3	9.6	---
Stieb et al. (2009)*	7 Canadian cities	All	0	6.7-9.8	---
Chimonas & Gessner (2006)	Anchorage, AK	0-19	0	6.1	---

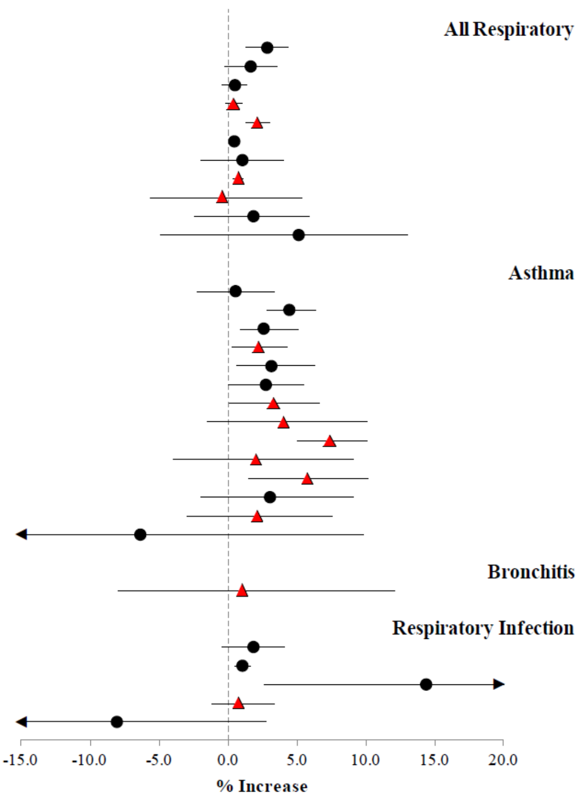

Figure F.3: Per cent increase in respiratory-related hospital admissions for a 10 micrograms per cubic metre increase in short-term (24-hour average) exposure to $PM_{2.5}$ (USEPA 2012, note studies in red are those completed since 2009)

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

Based on the available data, and the detailed reviews undertaken by organisations such as the USEPA (USEPA 2010, 2012) and WHO (WHO 2003, 2006b, 2006a) and NEPC (NEPC 2016), the adopted exposure-response estimates are considered to be current, robust and relevant to the characterisation of impacts from $PM_{2.5}$.

Shape of exposure-response function

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

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

F4. Co-pollutants and co-exposures

For the assessment of nitrogen dioxide, particulates and noise, the exposure-response relationships used in this assessment are based on large epidemiology studies where exposures have occurred in urban areas. These exposures do not relate to only one pollutant or exposures (noise) but a mix of these, and others including occupational and smoking. While many of the studies have endeavoured to correct for exposures to other pollutants and exposures, no study can fully correct for these and there would always be some level of influence from other exposures on the relationships adopted.

In relation to air quality, many of the pollutants evaluated come from a common source (e.g. fuel combustion) so the use of only particulate matter (or nitrogen dioxide) as an index for the mix of pollutants that is in urban air at the time of exposure is reasonable but conservative.

In relation to the assessment of cardiovascular effects from road traffic noise, these effects are also associated with (and occur together with) increased exposures to vehicle emissions, specifically particulate exposures.

For this reason, it is important the health risks and incidence evaluations presented for exposure to nitrogen dioxide, particulates and noise should not be added together as these effects are not necessarily additive, due to the relationships already including co-exposures to all these aspects (and others).

F5. Selected health outcomes

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

F6. Exposure time/duration

The assessment of potential exposure and risk to changes in air quality and noise levels associated with the project has assumed that all areas evaluated are residential and people may be at home for 24 hours of the day for 365 days of the year, for a lifetime. This is a conservative assumption to ensure that all members of the public are adequately addressed in the assessment of health impacts, including the elderly and those with disabilities who may not leave the home very often. As a result, the quantification of risk and health incidence is expected to be an overestimation.

F7. Application of exposure-response functions to small populations

The exposure-response functions have been developed on the basis of epidemiological studies from large urban populations where associations have been determined between health effects (health endpoints) and changes in ambient (regional) pollutant levels (particulates or NO_2). Typically, these exposure response functions are applied to large populations for the purpose of establishing/reviewing air guidelines or reviewing potential impacts of regional air quality issues on large populations.

When applied to small populations (less than larger urban centres such as the whole of Greater Sydney) the uncertainty increases. They do not relate to specific local sources (which occur within a regional airshed), or daily variability in exposure that may occur because of various different activities that may occur in any one day.

F8. Overall evaluation of uncertainty

Overall the assessment of health impacts presented in this report has incorporated a range of assumptions and models that would have resulted in an overestimation of impacts.

End of Document

G2SJV Gateway to Sydney Joint Venture
WSP Australia Pty Limited and GHD Pty Ltd

ABN: 55 836 411 311

Project Office
Level 27 Ernst & Young Centre
680 George Street
Sydney NSW 2000

GPO Box 5394
Sydney NSW 2001

Tel: +61 2 9272 5100
Fax: +61 2 9272 5101