Chapter

11

Chapter 11

Operational noise and vibration

January 2020

11 Operational noise and vibration

This chapter considers the potential noise and vibration impacts associated with the operation of the project. Potential noise and vibration impacts associated with the construction of the project are included in Chapter 10 (Construction noise and vibration).

A detailed noise and vibration assessment has been carried out for the project and is included in Appendix G (Technical working paper: Noise and vibration).

Common acoustic terms used throughout this chapter are explained in Chapter 10 (Construction noise and vibration).

The Secretary's environmental assessment requirements as they relate to operational noise and vibration and where in the environmental impact statement these have been addressed, are detailed in Table 11-1.

The proposed environmental management measures relevant to operational noise and vibration are included in Section 11.7.

Table 11-1 Secretary's environmental assessment requirements – operational noise and vibration

Secretary's requirement	Where addressed in EIS
Noise and Vibration - Amenity	
1. The Proponent must assess construction and operational noise and vibration impacts in accordance with relevant NSW noise and vibration guidelines. The assessment must take into consideration and address the redistribution of traffic (including on local feeder roads) and operational plant and equipment, and must include consideration of impacts to sensitive receivers and include consideration of sleep disturbance and, as relevant, the characteristics of noise and vibration (for example, low frequency noise).	**Section 11.5** documents the impacts from the redistribution of traffic (including on local feeder roads) and operational plant and equipment. **Chapter 10** (Construction noise and vibration) outlines the relevant NSW noise and vibration guidelines informing the construction noise and vibration assessment.
Noise and Vibration - Structural	
1. The Proponent must assess construction and operation noise and vibration impacts in accordance with relevant NSW noise and vibration guidelines. The assessment must include consideration of impacts to the structural integrity and heritage significance of items (including Aboriginal places and items of environmental heritage).	**Section 11.2, Section 11.6** and **Appendix G** (Technical Working Paper: Noise and Vibration) presents details on the assessment of operation noise and vibration impacts in respect to relevant NSW noise and vibration guidelines as well as the consideration of impacts on the structural integrity of buildings and heritage significance items. **Chapter 10** (Construction noise and vibration) details similar information in respect to construction impacts.

11.1 Legislative and policy framework

Operational road traffic noise relating to State significant infrastructure projects is primarily regulated by the Department of Planning, Industry and Environment through project approval requirements under the *Environmental Planning and Assessment Act 1979*.

In addition, the *Protection of the Environment Operations (Noise Control) Regulation 2017* includes controls on noise from motor vehicles, while the *Heavy Vehicle (Vehicle Standards) National Regulation (NSW)* includes controls on noise from heavy vehicles.

The *Road Noise Policy* (DECCW, 2011) is the NSW Environment Protection Authority guideline which defines criteria to be used in assessing the impact of road traffic noise and to protect amenity and wellbeing. The policy is intended for use during the environmental assessment of road proposals to develop feasible and reasonable noise mitigation measures.

The *Road Noise Policy* (DECCW, 2011) is supported by the *Noise Criteria Guideline* (Roads and Maritime, 2015a) and the *Noise Mitigation Guideline* (Roads and Maritime, 2015b), which present a practical approach in applying the Road Noise Policy and address specific situations relevant to Transport for NSW road projects.

The *Noise Policy for Industry* (NSW EPA 2017a) provides intrusiveness and amenity criteria for fixed facilities that operate continuously and is relevant to the assessment of project components including substations, wastewater treatment plants and ventilation facilities.

11.2 Assessment methodology

The operational noise assessment for the project considered the potential impacts associated with changes in traffic noise and noise from the operation of fixed facilities. The assessment included the following key steps:

- Identification of potentially affected noise catchment areas (NCAs) and noise sensitive receivers, development of a study area for the assessment, and background noise monitoring to determine existing noise levels. These are documented in Chapter 10 (Construction noise and vibration)
- Confirmation of noise and vibration objectives with reference to the Road Noise Policy (DECCW, 2011) and the *Noise Criteria Guideline* (Roads and Maritime, 2015a)
- Selection and definition of the road traffic noise scenarios to be modelled and compared. Operational road traffic noise scenarios are presented in Table 11-2
- Calculation of road traffic noise changes for each scenario and for both the year of opening of the project and ten years after opening
- Prediction of operational noise from fixed facilities using the sound power levels expected from typical plant and equipment, for comparison against Noise Policy for Industry (NSW EPA, 2017a) intrusiveness and amenity criteria
- Identification of environmental management measures to avoid, minimise and mitigate noise and vibration impacts during operation.

Operational road traffic noise scenarios have been modelled at the anticipated year of opening of the project (2027) and ten years later (2037) (Table 11-2). These scenarios have been informed by road traffic volumes from the Sydney Motorway Planning Model (refer to Chapter 9 (Operational Traffic and Transport)).

Table 11-2 Operational road traffic noise modelling scenarios for year of opening of the project (2027) and ten years later (2037)

Scenario	Included projects				
	Western Harbour Tunnel and Warringah Freeway Upgrade	Beaches Link and Gore Hill Freeway Connection	WestConnex program of works	Sydney Gateway	F6 extension[1]
'Do nothing'[2]	×	×	×	×	×
'Do minimum'	×	×	✓	×	×
'Do something'	✓	×	✓	×	×
'Do something cumulative'	✓	✓	✓	✓	✓

Note 1: For assessment at the year of opening Stage 1 of the F6 extension was included in the 'Do something cumulative' scenario. For 2037, the full F6 extension was included.

Note 2: The 'Do nothing' scenario was developed to investigate the project traffic noise impacts on receivers surrounding the surface connection to City West Link at Rozelle without the approved M4-M5, to address the issue of separate projects introducing or redistributing traffic across the road network in the area surrounding the Rozelle Interchange.

11.3 Assessment objectives and criteria

The operational noise and vibration assessment objectives and criteria applied to the project are summarised in the following sections and consider recommendations provided in the guidelines, policies and standards discussed in Section 11.1.

11.3.1 Road traffic noise

Residential receivers

Road traffic noise impacts on residential receivers are assessed using assessment criteria which are based on the type of road a residence is affected by the project. In some instances, residences may be exposed to noise from new and redeveloped roads or different functional classes of roads.

In addition to road traffic noise which exceeds the assessment criteria, large increases in the level of noise can change in the acoustic environment of a location, particularly for quieter areas. To address large increases in noise levels, relative increase criteria are used.

Where criteria for a particular road category or relative increase criteria are exceeded due to the project, reasonable and feasible mitigation is required.

A summary of the applicable road traffic noise criteria for residential receivers in accordance with the *Noise Criteria Guideline* (Roads and Maritime, 2015a) is presented in Table 11-3.

Table 11-3 Road traffic noise criteria for residential receivers (external)

Road category	Type of project/land use	Assessment criteria dB(A)[1]	
		Daytime (7am – 10pm)	**Night–time (10pm – 7am)**
Freeway/ arterial/ sub-arterial roads	Existing residences affected by noise from new freeway/arterial/sub-arterial road corridors.	55 $L_{Aeq(15hour)}$[2]	50 $L_{Aeq(9hour)}$
	Existing residences affected by noise from redevelopment of existing freeway/arterial/sub-arterial roads. Existing residences affected by additional traffic on existing freeways/arterial/sub-arterial roads generated by land use developments.	60 $L_{Aeq(15hour)}$	55 $L_{Aeq(9hour)}$
	Existing residences affected by both new roads and the redevelopment of existing freeway/arterial/sub-arterial roads in a transition zone[3].	55–60 $L_{Aeq(15hour)}$	50–55 $L_{Aeq(9hour)}$
	Existing residences affected by increases in traffic noise of 12dB(A) or more from new freeway/arterial/sub-arterial roads.	42–55 $L_{Aeq(15hour)}$	42–50 $L_{Aeq(9hour)}$
	Existing residences affected by increases in traffic noise of 12dB(A) or more from redevelopment of existing freeway/arterial/sub-arterial roads.	42–60 $L_{Aeq(15hour)}$	42–55 $L_{Aeq(9hour)}$
Local roads	Existing residences affected by noise from new local road corridors.	55 $L_{Aeq(1hour)}$	50 $L_{Aeq(1hour)}$
	Existing residences affected by noise from redevelopment of existing local roads.		
	Existing residences affected by additional traffic on existing local roads generated by land use developments.		

Note 1: dB(A) stands for A-weighted decibel, a unit used to measure noise. Refer to Chapter 10 (Construction noise and vibration) for a comparison of dB(A) for various activities.

Note 2: $L_{Aeq(period)}$ is the A-weighted equivalent noise level. It is the summation of noise events and integrated over a period of time.

Note 3: The applicable noise criteria for a particular receiver would be dependent on its location relative to where the new road joins the redeveloped road (transition zone). See Section 7.1 and Table 1 of the *Noise Criteria Guideline* (Roads and Maritime, 2015a) for further information.

Non-residential receivers

The *Noise Criteria Guideline* (Roads and Maritime, 2015a) also sets criteria for the assessment of road traffic noise on the internal and external areas of non-residential land uses, such as schools, hospitals, places of worship and recreation areas. For sensitive land uses such as schools, hospitals, places of worship and childcare centres, the criteria has been applied to internal areas to provide a conservative assessment of impacts. It is generally accepted that most buildings provide a noise reduction of at least 10dB(A) when windows are left 20 per cent open, without providing additional treatment. Therefore, where the noise goals are internal, a 10dB(A) reduction from external noise levels to internal noise levels has been adopted to allow an external assessment. The applicable criteria are shown in Table 11-4.

Table 11-4 Criteria for non-residential sensitive land uses

Existing sensitive land use	Assessment criteria dB(A)[1]	
	Day (7am – 10pm)	**Night (10pm – 7am)**
School classrooms	40 $L_{Aeq,1hour}$[2] (internal)	–
Hospital wards	35 $L_{Aeq,1hour}$ (internal)	35 $L_{Aeq,1\ hour}$ (internal)
Places of worship	40 $L_{Aeq,1hour}$ (internal)	40 $L_{Aeq,1\ hour}$ (internal)
Open space (active use)	60 $L_{Aeq,15hour}$ (external) when in use	–
Open space (passive use)	55 $L_{Aeq,15hour}$ (external) when in use	–
Childcare facilities	Sleeping rooms 35 $L_{Aeq,1hour}$ (internal) Indoor play areas 40 $L_{Aeq,1hour}$ (internal) Outdoor play areas 55 $L_{Aeq,1hour}$ (external)	–
Aged care facilities	Residential land use noise assessment criteria apply	Residential land use noise assessment criteria apply

Note 1: dB(A) stands for A-weighted decibel, a unit used to measure noise. Refer to Chapter 10 (Construction noise and vibration) for a comparison of dB(A) for various activities.

Note 2: $L_{Aeq(period)}$ is the A-weighted equivalent noise level. It is the summation of noise events and integrated over a period of time.

Road traffic noise impacts from existing roads

The *Noise Criteria Guideline* (Roads and Maritime, 2015a) provides guidance for assessing traffic noise from existing roads not subject to any redevelopment. This is where there is a predicted increase in traffic noise levels by more than 2 dB(A) on other roads due to changes in traffic volumes associated with the project. The criteria are provided in Table 11-5.

Table 11-5 Criteria for existing roads not subject to redevelopment

Existing road category	Target noise level dB(A)[1]	
	Day (7 am – 10 pm)	**Night (10 pm – 7 am)**
Freeway/ arterial/ sub-arterial road	$L_{Aeq(15hour)}$[2] 60 (external)	$L_{Aeq(9hour)}$ 55 (external)
Local road	$L_{Aeq(1hour)}$ 55 (external)	$L_{Aeq(1hour)}$ 50 (external)

Note 1: dB(A) stands for A-weighted decibel, a unit used to measure noise. Refer to Chapter 10 (Construction noise and vibration) for a comparison of dB(A) for various activities.

Note 2: $L_{Aeq(period)}$ is the A-weighted equivalent noise level. It is the summation of noise events and integrated over a period of time.

Maximum road traffic noise levels

Maximum noise levels are generally due to heavy vehicles passing by. The measured maximum noise level and the number of maximum noise level events are used as an indicator of the potential for sleep disturbance.

11.3.2 Sleep disturbance

Guidance for considering sleep disturbance due to maximum noise levels is provided in Practice Note iii of the *Environmental Noise Management Manual* (RTA 2001). The relevant considerations are:

- Calculation of maximum noise levels
- The extent to which the maximum noise levels for individual vehicle pass bys exceed the L_{Aeq} noise level for each hour of the night
- The number of maximum noise events.

At locations where road traffic is continuous rather than intermittent, the $L_{Aeq(9hour)}$ criteria for operational noise assessment accounts for sleep disturbance impacts. However, where the emergence of L_{Amax} over the ambient L_{Aeq} is equal to or greater than 15 dB(A), the $L_{Aeq(9hour)}$ criteria may not sufficiently account for sleep disturbance impacts.

The sleep disturbance assessment does not influence the degree of mitigation required but is used to rank and prioritise design options and noise mitigation strategies.

11.3.3 Operational road traffic mitigation

The ‘Do minimum’ (without the project but with the WestConnex program of works) and the ‘Do something cumulative’ (with the project and other projects) operational road traffic noise model scenarios were used to identify receivers impacted by the project.

The following *Noise Mitigation Guideline* (Roads and Maritime, 2015b) triggers were applied where a sensitive receiver may qualify for consideration of noise mitigation beyond the adoption of road design and traffic management measures:

- The predicted ‘build’ (with the project) noise level exceeds the *Noise Mitigation Guideline* (Roads and Maritime, 2015b) controlling criterion and the noise level increase due to the project (ie the noise predictions for the ‘build’ (with the project) minus the ‘no build’ (without the project)) is greater than 2 dB(A)

- The predicted 'build' (with the project) noise level is 5 dB(A) or more above the criteria (meets or exceeds the cumulative limit) and the receptor is significantly influenced by project road noise, regardless of the incremental impact of the project
- The noise level contribution from the project is acute then it qualifies for consideration of noise mitigation even if noise levels are dominated by another road. Acute noise level for day time (7am to 10pm) $L_{Aeq(15hour)}$ is 65 dB(A) or higher, and for night time (10pm to 7am) $L_{Aeq(9hour)}$ is 60 dB(A) or higher.

A noise barrier analysis was also completed to identify reasonable and feasible locations where barriers would be provided. The analysis follows the *Noise Mitigation Guideline* (Roads and Maritime, 2015b) and *Noise Wall Design Guideline* (Roads and Maritime, 2016b).

11.3.4 Operational noise from fixed facilities

Noise impacts from fixed facilities were assessed against the *Noise Policy for Industry* (NSW EPA, 2017a) which includes both intrusiveness and amenity criteria. The intrusiveness criterion aims to minimise noise increases from a single new development by applying a criterion of 5 dB(A) above background levels, while the amenity criteria aims to limit continuing increases in ambient noise by applying recommended levels for certain receiver types. The more stringent of the two applies.

11.4 Existing noise environment

The existing noise environment, including ambient noise levels, is described in Chapter 10 (Construction noise and vibration). This environment status would also be applicable to the operation stage of the project.

11.5 Assessment of potential impacts – noise

11.5.1 Overview

This section provides an assessment of operational road traffic noise impacts for surface roads associated with the project as well impacts from project operational facilities. This assessment is for environmental impact assessment and planning approval purposes and will be reviewed and adjusted if required during the detailed design phase.

11.5.2 Operational tunnel traffic noise

Noise from traffic travelling through the tunnels would be contained within the tunnels and would not impact noise sensitive receivers or heritage structures. Refer to Section 11.6 for a discussion on ground-borne noise and vibration impacts from traffic travelling through tunnels and portals.

11.5.3 Operational road surface traffic noise before mitigation

The operational road traffic noise model scenarios listed in Table 11-2 were first considered before the inclusion of additional or augmented noise barriers, but do consider the following:

- Existing noise barriers

- Quieter pavement for some surface roads providing up to 2 dB(A) noise reduction benefits (compared to dense graded asphalt).

This analysis is presented below.

'Do something' scenario

Table 11-6 shows predicted changes in noise levels for receivers under a 'Do minimum' (without the project but with the WestConnex program of works) and 'Do something' (with the project and the WestConnex program of works) noise model scenarios for sensitive receiver buildings surrounding the surface connection to City West Link at Rozelle and the Warringah Freeway.

Table 11-6 Predicted changes in noise levels before mitigation (2037 'Do minimum' scenario compared to 'Do something' scenario)[1]

Location	Number of receiver buildings experiencing changes in noise levels from operational traffic					
	Noise level reduction		0 dB(A)[2] – 2 dB(A)		> 2 dB(A)	
	Day	Night	Day	Night	Day	Night
Surface connection to City West Link at Rozelle	590	442	2498	2647	7	6
Warringah Freeway	4652	5487	2058	1223	54	54

Note 1: The 'Do something' scenario includes the Western Harbour Tunnel and Warringah Freeway Upgrade project and WestConnex program of works.

Note 2: dB(A) stands for A-weighted decibel, a unit used to measure noise. Refer to Chapter 10 (Construction noise and vibration) for a comparison of dB(A) for various activities.

Overall:

- The project is predicted to reduce traffic noise for about 57 per cent of receiver buildings within noise catchment areas surrounding the project surface road works
- Forty-two per cent of receiver buildings are predicted to experience traffic noise level increases of less than 2 dB(A) which represents a minor impact that is likely to be barely perceptible
- One per cent of receiver buildings are predicted to experience increases greater than 2 dB(A) due to the project.

The project is predicted to decrease the number of receiver buildings exceeding the relevant noise criteria when compared to the 'Do Minimum' scenario during the day and night periods at noise catchment areas surrounding the Warringah Freeway Upgrade and the Gore Hill Freeway Connection. This is due to traffic being moved from the existing surface roads into the proposed tunnels.

The project is also predicted to increase the number of receiver buildings exceeding the relevant noise criteria when compared to the 'Do minimum' scenario during the day and night periods at noise catchment areas surrounding the surface connection to City West Link at Rozelle. This is due to an anticipated increase in traffic volumes on some surface roads in the area leading to and from the tunnels as motorists travel to and from surrounding areas to utilise the tunnels.

'Do something cumulative' scenario

Table 11-7 shows predicted changes in noise levels for receivers under a 'Do minimum' (without the project but with the WestConnex program of works) and 'Do something cumulative' (with the project and other projects) noise model scenarios for sensitive receiver buildings surrounding the surface connection to City West Link at Rozelle and Warringah Freeway Upgrade

Table 11-7 Predicted changes in noise levels before mitigation (2037 'Do Minimum' scenario compared with 'Do something cumulative' scenario)[1]

Location	Number of receiver buildings experiencing changes in noise levels from operational traffic					
	Noise level reduction		0 dB(A)[2] – 2 dB(A)		> 2 dB(A)	
	Day	Night	Day	Night	Day	Night
Surface connection to City West Link at Rozelle	509	319	2505	2724	81	52
Warringah Freeway Upgrade	5140	5923	1588	808	36	33

Note 1: 'Do something cumulative' scenario includes the following projects: Western Harbour Tunnel and Warringah Freeway Upgrade, Beaches Link and Gore Hill Freeway Connection, WestConnex program of works, Sydney Gateway, and the F6 extension.

Note 2: dB(A) stands for A-weighted decibel, a unit used to measure noise. Refer to Chapter 10 (Construction noise and vibration) for a comparison of dB(A) for various activities.

Refer to Appendix P of Appendix G (Technical working paper: Noise and vibration) for the location of receiver buildings identified in Table 11-7.

Overall:

- The project in combination with other projects is predicted to reduce traffic noise for about 60 per cent of receiver buildings within noise catchment areas surrounding the project surface road works
- Thirty-nine per cent of receiver buildings are predicted to experience traffic noise level increases of less than 2 dB(A), which represents a minor impact that is likely to be barely perceptible
- One per cent of receiver buildings are predicted to experience increases greater than 2 dB(A).

The cumulative traffic from the project and other major road projects is predicted to reduce the number of receiver buildings exceeding the relevant noise criteria when compared to the 'Do minimum' scenario during the day and night periods at noise catchment areas surrounding the Warringah Freeway. This is due to traffic being moved from the existing surface roads into the proposed tunnels.

The cumulative traffic from the project and other major road projects is predicted to increase the number of receiver buildings exceeding the relevant noise criteria when compared to the 'Do minimum' scenario during the day and night periods at noise catchment areas surrounding the surface connection to City West Link at Rozelle. This is due to an anticipated increase in traffic volumes on some surface roads in the area leading to and from the tunnels as motorists travel to and from surrounding areas to utilise the tunnels.

11.5.4 Operational surface road traffic noise after mitigation

Noise barriers

Noise barriers are considered reasonable and feasible where four or more receivers trigger consideration of noise mitigation and are closely grouped (ie facades are separated by less than 20 metres), where the barriers do not make access to properties difficult, and where they are visually acceptable. A maximum allowable height has been adopted for each new and adjusted noise barrier, considering the following factors:

- Noise abatement
- Urban design, overshadowing and visual impacts
- Impacts to private land (including future land uses and development potential)
- Constructability and engineering constraints.

Noise barriers would be provided or extended as part of the project where reasonable and feasible to reduce road traffic noise to acceptable levels for sensitive receivers. Refer to Chapter 5 (Project description) for noise barrier proposed locations.

The project does not propose to remove existing noise barriers.

Receiver buildings potentially eligible for consideration of additional noise mitigation

Further assessment has been conducted to compare the 'Do minimum' and the 'Do something cumulative' scenarios, including proposed low noise pavement and proposed new and existing extended noise barriers.

Table 11-8 identifies the number of receivers to be considered for at-property treatment after low noise pavement and new and existing extended noise barriers have been included. At-property treatments may include but are not limited to ventilation, glazing, window and door seals, sealing of vents and underfloor areas.

Noise mitigation options (quieter pavement, noise barriers, at-property treatment or a combination) will be reviewed and confirmed as part of the further design development taking into consideration community preferences.

Receivers identified for at-property treatment within noise catchment areas surrounding the surface connection to City West Link at Rozelle will be mitigated either:

- Under the M4-M5 Link project Minister's Conditions of Approval (Condition E87), or
- When predicted operational road traffic noise increases greater than 2 dB(A) due to multiple projects.

Therefore, Table 11-8 does not present a summary of at-property treatment for receivers within noise catchment areas surrounding the surface connection to City West Link at Rozelle. At-property treatment requirements will be confirmed during further design development.

Refer to Appendix R of Appendix G (Technical working paper: Noise and vibration) for the location of receiver buildings identified in Table 11-8.

Table 11-8 Receiver buildings potentially eligible for consideration of additional noise mitigation[1]

NCA[2]	Location	Number of receiver floors[3]	Number of receiver buildings
Surface connection to City West Link at Rozelle			
At property treatment to be provided under the M4-M5 Link project Minister's Conditions of Approval (Condition E87) or when predicted operational road traffic noise increases greater than 2 dB(A) due to multiple projects. At-property treatment requirements will be confirmed during further design development.			
Warringah Freeway			
15.4	Lavender Bay	1	1
16.1	Milsons Point	193	17
16.3	North Sydney – south-west	43	5
17.1	Kirribilli	22	12
17.2	Kirribilli	37	10
17.3	North Sydney – east	86	37
17.4	Neutral Bay	67	30
18.1	Kirribilli	2	1
19.1	North Sydney – north-west	55	16
20.1	North Sydney – north-west	37	10
21.1	North Sydney	26	11
21.2	North Sydney	49	13
22.1	North Sydney	41	23
22.3	Crows Nest	14	5
23.1	Neutral Bay	64	43
23.2	North Sydney	48	16
24.1	Crows Nest	13	5
25.1	Cammeray	43	27
28.1	Cremorne	2	1

NCA[2]	Location	Number of receiver floors[3]	Number of receiver buildings
29.1	Cremorne	33	20
30.1	Crows Nest	35	24
30.2	Naremburn	12	11
30.3	Cammeray	11	11
31.2	Cammeray	3	2
31.3	Naremburn	21	18
Total Warringah Freeway		**958**	**369**

Note 1: Number of receivers considered for at-property treatment would be subject to consideration of community preferences and to further design development

Note 2: Noise catchment area is an area where noise and vibration sensitive receivers have similar acoustic environment. Refer to Figure 10-1 in Chapter 10 (Construction noise and vibration) for location of noise catchment areas.

Note 3: Receiver floors represent the individual receiver floor levels of a multi-level building. For example, a 10-storey residential apartment block would have ten receiver floors and one receiver building.

11.5.5 Maximum road traffic noise level

Where road traffic noise dominates the noise environment, maximum noise levels (mainly generated by heavy vehicles) have the potential to cause disturbance to sleep.

Changes in the maximum noise levels and the number of events generating these levels would depend on changes in traffic volumes and changes on road alignment or width.

The project is predicted to increase maximum noise levels events at sensitive receivers within NCA 23.1 where sensitive receivers to the east of the Warringah Freeway are predicted to experience an increase in maximum noise levels and the number of events compared to the existing situation. This is due to the widening of the Warringah Freeway resulting in the southbound carriageway moving closer to the receivers in these NCAs.

Maximum noise levels are not expected to significantly change as a result of the project within other noise catchment areas where no major road realignments or widening would be carried out.

Changes in maximum noise levels are a consideration when prioritising and ranking mitigation strategies and will be considered during further design development. Mitigation measures to be considered are described in Section 11.5.4.

11.5.6 Operational facilities

Table 11-9 compares predicted fixed facility noise levels with *Noise Policy for Industry* (NSW EPA 2017a) intrusiveness and amenity criteria. No criteria exceedances are predicted with the exception of a 3 dB(A) exceedance for the nearest receiver building within NCA 4.2 due to the operation of the Rozelle wastewater treatment plant. Noise predictions and assessment of operational fixed facilities will be updated, when actual types, makes and models of the plant and equipment are confirmed.

Table 11-9 Predicted noise levels ($L_{Aeq,15min}$)[1] from fixed facilities, dB(A)

Location	NCA[2]	Project noise criteria[3]		Predicted noise level
		Intrusiveness	Amenity	
Rozelle	NCA 3.2	49	**43**	35
	NCA 3.3	49	**43**	37
	NCA 4.2	**42**	43	**45**
Cammeray	NCA 26.2	**42**	43	40
	NCA 26.1	46	**43**	38
	NCA 23.1	49	**43**	39
	NCA 23.2	**42**	43	39
	NCA 24.1	**42**	43	37
	NCA 25.1	48	**43**	36
	NCA 29.1	52	**43**	35

Note 1: $L_{Aeq(15min)}$ is the A-weighted equivalent noise level. It is the summation of noise events and integrated over a period of 15 minutes.

Note 2: Noise catchment area is an area where noise and vibration sensitive receivers have similar acoustic environment. Refer to Figure 10-1 in Chapter 10 (Construction noise and vibration) for location of noise catchment areas.

Note 3: Project noise levels based on night time period. Most stringent criteria used for assessment is shown in bold font.

11.6 Assessment of operational impacts – ground-borne noise and vibration

The potential for operational ground-borne noise and tactile vibration impacts on nearby sensitive receivers from traffic on project surface roads and tunnels has been reviewed.

Vibration emissions from traffic travelling on roads typically occur where there are irregularities in the road surface (eg pot holes).

As the new and upgraded roads on the surface and in the tunnels associated with the project would be designed and constructed to avoid road irregularities, operational ground-borne noise and tactile vibration impacts from operation traffic are not expected.

Vibration impacts from traffic travelling on the proposed surface roads, through tunnels and portals are considered negligible and are unlikely to result in ground-borne noise or tactile vibration impacts to sensitive receivers directly adjacent to surface roads, tunnels and portals.

Similarly, vibration from operational fixed facilities is not anticipated to exceed objectives given the distance between these facilities and the nearest sensitive receiver.

11.7 Environmental management measures

Environmental management measures for potential noise and vibration impacts during operation are outlined in Table 11-10. Additional measures to address cumulative impacts are included in Chapter 27 (Cumulative impacts).

Table 11-10 Environmental management measures for operational noise and vibration impacts

Ref	Phase	Impact	Environmental management measure	Location
ONV1	Operation	Operational road traffic noise	The operational noise performance of the project will be reviewed during detailed design and operational noise mitigation (low noise pavement, noise barrier, at-property treatment or a combination of treatments) will be confirmed in accordance with relevant policies and guidelines.	WHT/WFU
ONV2	Operation	Operational road traffic noise	Within 12 months of the commencement of the operation of the project, actual operational noise performance will be compared to predicted operational noise performance (as reviewed during detailed design) to analyse the effectiveness of the operational road traffic noise mitigation measures. Additional reasonable and feasible mitigation will be considered where any additional receivers are identified as qualifying for consideration of noise mitigation under the *Noise Mitigation Guideline* (Roads and Maritime, 2015b).	WHT/WFU
ONV3	Operation	Operational fixed facilities	Operational fixed facilities will be designed to meet project specific noise criteria derived in accordance with the *Noise Policy for Industry (NSW EPA, 2017a)*.	WHT/WFU

Western Harbour Tunnel = WHT, Warringah Freeway Upgrade = WFU.

Chapter

12

Chapter 12

Air quality

January 2020

12 Air quality

This chapter outlines the potential air quality impacts associated with the project. A detailed air quality impact assessment has been carried out for the project and is included in Appendix H (Technical working paper: Air quality).

An assessment of potential human health impacts associated with air quality is provided in Chapter 13 (Human health).

The Secretary's environmental assessment requirements as they relate to air quality, and where in the environmental impact statement these have been addressed, are detailed in Table 12-1.

The proposed environmental management measures relevant to air quality are included in Section 12.7.

Table 12-1 Secretary's environmental assessment requirements – air quality

Secretary's requirements	Where addressed in EIS
Air quality	
1. The Proponent must undertake an air quality impact assessment (AQIA) for construction and operation of the project in accordance with the current guidelines.	**Section 12.5** and **Section 12.6** outlines the air quality impacts of the construction and operation of the project respectively.
2. The Proponent must ensure the AQIA also includes the following:	See below.
a. Demonstrated ability to comply with the relevant regulatory framework, specifically the *Protection of the Environment Operations Act 1997* and the Protection of the Environment Operations (Clean Air) Regulation 2010;	**Section 12.1** outlines information in respect to the *Protection of the Environment Operations Act 1997* and the Protection of the Environment Operations (Clean Air) Regulation 2010.
b. The identification of all potential sources of air pollution including details of the location, configuration and design of all potential emission sources including ventilation systems and tunnel portals;	The identification of all potential sources of air pollution during construction and operation are outlined in **Section 12.2**; the configuration and design of ventilation systems and tunnel portals are shown in **Chapter 5** (Project description).
c. A review of vehicle emission trends and an assessment that uses or sources best available information on vehicle emission factors;	Best available information on vehicle emission trends are presented in **Section 12.4**.
d. An assessment of impacts (including human health impacts) from potential emissions of PM_{10}, $PM_{2.5}$, CO, NO_2, and other nitrogen oxides and volatile organic compounds (eg BTEX) including consideration of short and long term exposure periods;	An assessment of impacts of air pollutants during short and long term exposure periods are outlined in **Section 12.6**. Impacts to human health due to the operation of the project is provided in **Section 13.5** (Human Health).

Secretary's requirements	Where addressed in EIS
e. Consider the impacts from the dispersal of these air pollutants on the ambient air quality along the proposal route, proposed ventilation outlets and portals, surface roads, ramps and interchanges and the alternative surface road network;	An assessment of impacts from the dispersal of air pollutants on ambient air quality along the project alignment is outlined in **Section 12.6**.
f. A qualitative assessment of the redistribution of ambient air quality impacts compared with existing conditions, due to the predicted changes in traffic volumes;	A qualitative assessment of the redistribution of ambient air quality impacts in comparison to existing conditions is presented in **Section 12.6.3**.
g. Assessment of worst case scenarios for in-tunnel and ambient air quality, including a range of potential ventilation scenarios and range of traffic scenarios, including worst case design maximum traffic flow scenarios (variable speed) and the worst case breakdown scenario, and discussion of the likely occurrence of each;	**Section 12.6** outlines the assessment of in-tunnel air quality in addition to the assessment of issues related to ambient air quality.
h. Details of the proposed tunnel design and mitigation measures to address in-tunnel air quality and the air quality in the vicinity of portals and any mechanical ventilation systems (ie ventilation outlets and air inlets) including details of proposed air quality monitoring (including frequency and criteria);	Details of the proposed tunnel design and monitoring are presented in **Chapter 5** (Project description), while mitigation and management measures in relation to in-tunnel air quality and air quality in the vicinity of portals and mechanical ventilation systems are outlined in **Section 12.7**.
i. A demonstration of how the project and ventilation design ensures that concentrations of air emissions meet NSW, national and international best practice for in-tunnel and ambient air quality, and taking into consideration the approved criteria for the M4 East project, New M5 project and the In-Tunnel Air Quality (Nitrogen Dioxide) Policy;	Information relating to the design standard of the proposed ventilation system for the project is provided in **Chapter 5** (Project description). Criteria applied in this assessment are discussed in **Section 12.1** and **Section 12.3**. The project and ventilation system has been designed to meet in-tunnel criteria and ambient air quality goals and criteria as outlined in **Section 12.3**.
j. Details of any emergency ventilation systems, such as air intake/exhaust outlets, including protocols for the operation of these systems in emergency situations, potential emission of air pollutants and their dispersal, and safety procedures;	Details of any emergency ventilation systems, such as air intake/ventilation outlets, including protocols for the operation of these systems in emergency situations, potential emission of air pollutants and their dispersal, and safety procedures are presented in **Chapter 5** (Project description).

Secretary's requirements	Where addressed in EIS
k. Details of in-tunnel air quality control measures considered, including air filtration, and justification of the proposed measures or for the exclusion of other measures;	Details of in-tunnel air quality control measures considered, including air filtration, and justification of the proposed measures or for the exclusion of other measures are outlined in **Section 12.7** and expanded upon in **Chapter 5** (Project description). **Chapter 4** (Project development and alternatives), **Section 4.5** provides the ventilation system design alternatives.
l. A description and assessment of the impacts of potential emission sources relating to construction, including details of the proposed mitigation measures to prevent the generation and emission of dust (particulate matter and TSP) and air pollutants (including odours) during the construction of the proposal, particularly in relation to ancillary facilities (such as concrete batching plants), dredge and tunnel spoil handling and storage at Glebe Island and White Bay, the use of mobile plant, stockpiles and the processing and movement of spoil; and	A description and assessment of impacts relating to potential emission sources relating to construction are outlined in **Section 12.5**, while mitigation measures to prevent the generation and emission of dust and other air pollutants (including odours) are presented in **Section 12.7** of this chapter.
m. A cumulative assessment of the in-tunnel, local and regional air quality impacts from the operation of the project and due to the operation of and potential continuous travel through motorway tunnels and surface roads.	The cumulative assessment of the in-tunnel, local and regional air quality impacts, as well as consideration of continuous travel through motorway tunnels, is outlined in **Section 12.6**.

12.1 Legislative and policy framework

The *Protection of the Environment Operations Act 1997* (NSW) (POEO Act) provides the legislative authority for the NSW Environment Protection Authority (EPA) to regulate air emissions in NSW. The Secretary's environmental assessment requirements for the project refer to the POEO Act and the Protection of the Environment Operations (Clean Air) Regulation 2010 (NSW). Although the Regulation specifies concentration limits for air emissions, these limits are designed primarily for industrial activities and the limit values are much higher than those imposed for road tunnels in Sydney. The monitoring and management of dust emissions during construction and the ventilation outlet emissions during operation would be regulated under an Environment Protection Licence prescribed under the POEO Act.

The Australian states and territories manage emissions and air quality. In NSW the statutory methods used for assessing air pollution from stationary sources are listed in the *Modelling and Assessment of Air Pollutants in NSW* (NSW EPA, 2016) (NSW EPA Approved Methods).

As part of the preparation of the air quality impact assessment for the project, the Technical working paper: Air quality (Appendix H) was issued to the Office of the Chief Scientist and Engineer and The Advisory Committee on Tunnel Air Quality (ACTAQ) to carry out a scientific review of the project's air emissions from ventilation outlets.

In February 2018, the NSW Government announced stronger measures on emissions from motorway tunnels and then established a new process for the assessment, determination, and compliance of significant road tunnels (and associated ventilation systems). The process, which applies to the project, is summarised below:

- Prior to public exhibition of the environmental impact statement:
  - The Office of the Chief Scientist and Engineer (OCSE) provides a scientific review of a project's air emissions from ventilation outlets for the Minister of Planning and Public Spaces' consideration
  - The NSW Chief Health Officer releases a statement on the potential health impacts of emissions from tunnel ventilation outlets informed by the review by the OCSE
- The EPA provides technical advice to the Department of Planning, Industry and Environment on operational air quality impacts during the assessment of the Environmental Impact Statement
- The Department of Planning, Industry and Environment seeks advice from an independent air quality expert during the assessment of the environmental impact statement, if required
- If the project is approved, the Department of Planning, Industry and Environment regulates the construction and operation of the project in accordance with the project approval
- The EPA licences emissions from ventilation outlets under the POEO Act.

For the operating years of the project, nitrogen dioxide (NO_2) would be the pollutant that determines the required airflow and drives the design of the tunnel ventilation system. In February 2016, the ACTAQ issued a policy entitled *In-tunnel air quality (nitrogen dioxide) policy* (ACTAQ, 2016). The policy consolidates the approach taken for similar projects (NorthConnex, M4 East and New M5), and requires tunnels to be 'designed and operated so that the tunnel average NO_2 concentration is less than 0.5 ppm as a rolling 15 minute average'. In 2018, ACTAQ released *Technical Paper TP07: Criteria for In-tunnel and Ambient Air Quality* (ACTAQ, 2018a), which concluded that the NO_2 criterion is the most stringent in Australia and compares favourably to the international in-tunnel NO_2 design guidelines which range from between 0.4 ppm to 1 ppm. The tunnel ventilation system would be designed to achieve this criterion.

With regards to regional air quality, the EPA has developed a *Tiered Procedure for Estimating Ground Level Ozone Impacts from Stationary Sources* (ENVIRON, 2011). This procedure was applied to the air quality impact assessment of the project to give an indication of the likely significance of the project's effect on ozone concentrations in the broader Sydney region.

The in-tunnel and ambient air quality assessment was carried out against criteria, or levels of pollutants, that have been adopted by the NSW Government. Schedule 4 of the Protection of the Environment Operations (Clean Air) Regulation 2010 (NSW) specifies standards of concentrations for general activities and plant. The project was assessed against the air quality criteria listed in the NSW EPA Approved Methods.

Odour emissions have been assessed and managed in accordance with the *Technical framework for the assessment and management of odour from stationary sources in NSW* (DEC, 2006). This framework introduces a system that protects the environment and the community from the impacts of odour emissions, while promoting fair and equitable outcomes for the operators of activities that emit odour.

12.2 Assessment methodology

12.2.1 Overview

The assessment methodology for air quality impacts has included the following key tasks:

- Qualitative assessment of potential dust impacts during construction of the project
- Dispersion modelling to assess the potential odour impacts on sensitive receivers resulting from dredging activities and the transport and treatment of dredge materials at White Bay during construction of the project
- Assessment to ensure the tunnel ventilation system can achieve acceptable in-tunnel air quality outcomes for carbon monoxide (CO), NO_2 and visibility during operation of the project
- Modelling of changes in the concentrations of key pollutants at community, residential, workplace and recreational receiver locations for expected traffic and operation of the project under a number of worst case operational scenarios
- Assessment of regional air quality impacts associated with the operation of the project
- Prediction of changes in the levels of three representative odorous pollutants (toluene, xylenes, and acetaldehyde) at receivers with the operation of the project.

The methodology for the assessment of both construction and operational air quality impacts, as well as the modelling inputs and assumptions used to carry out this assessment is provided in full at Appendix H (Technical working paper: Air quality) of this environmental impact statement.

12.2.2 Construction air quality assessment methodology

Air quality impacts as a result of construction of the project include those associated with exhaust emissions and from the generation of dust and odour.

Exhaust emissions during construction would occur as a result of the use of some plant and equipment. These impacts are considered to be minor and unlikely to have a noticeable impact on the surrounding environment. Any impacts associated with exhaust emissions would be managed through the environmental management measures described in Section 12.7.

Some construction activities could also result in the generation of dust and odours. The assessment methodology for the air quality impacts associated with the generation of dust and odour are described below.

Dust assessment

For the purpose of the construction dust assessment, construction activities have been categorised into four types to reflect their potential impacts:

- Demolition is any activity that involves the removal of existing structures
- Earthworks covers the processes of soil stripping, ground levelling, excavation and landscaping, and primarily involves excavating material, haulage, tipping and stockpiling
- Construction is any activity that involves the provision of new structures, or modification or refurbishment of existing structures, including buildings, ventilation outlets and roads
- Track-out involves the transport of dust and dirt from the construction/demolition site onto the public road network using construction vehicles. These materials may then be deposited and re-suspended by vehicles using the road network.

It is difficult to quantify dust emissions from construction activities since it is not possible to predict the weather conditions that will prevail during specific construction activities. The effects of construction on airborne particulate matter would generally be temporary and of relatively short duration, and mitigation should be straightforward since dust suppression measures are routinely employed as 'good practice' at most construction sites. It is therefore common practice to provide a qualitative assessment of potential construction dust impacts. The qualitative assessment approach carried out for the project follows the UK Institute of Air Quality Management's *Guidance on the assessment of dust from demolition and construction* (IAQM, 2014). The IAQM guidance has been adapted for use in NSW, taking into account factors such as the assessment criteria for ambient PM_{10} concentrations (being particulate matter less than or equal to 10 micrometre diameter). The potential construction air quality impacts were assessed based on the proposed works, plant and equipment, and the potential emission sources and levels. The assessment considered the risk of dust deposition and elevated concentrations of dust (as PM_{10}) in the air from construction activities, and potential impacts on amenity, human health and the environment.

Key steps in the assessment included:

- An initial screening to identify whether there is a risk of construction dust impacts based on the proximity of human and ecological receivers to construction activities
- A risk assessment to determine which construction activities have the potential to generate a dust impact based on the scale and nature of the activities, and the sensitivity of nearby human and ecological receivers
- Identification of appropriate dust mitigation and management measures depending on the assessed risk of impact.

Further details of the construction dust assessment methodology are provided in Appendix H (Technical working paper: Air quality) of this environmental impact statement. The assessment of construction dust using the IAQM procedure is outlined in Figure 12-1. The construction dust assessment carried out for the project is summarised in Section 12.5.1.

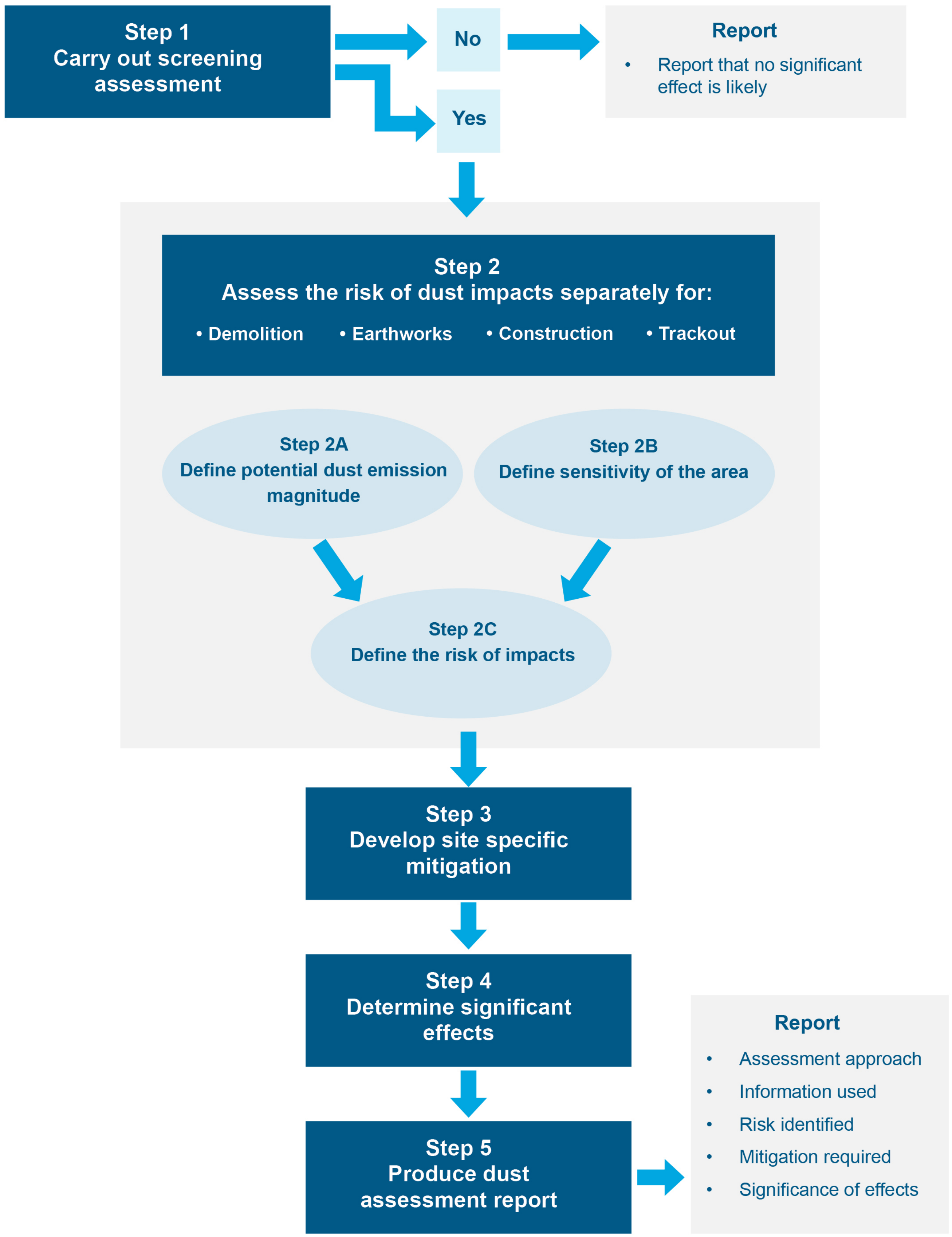

Figure 12-1 Construction dust assessment procedure

Odour assessment

Dispersion modelling has been carried out to assess the potential odour impacts at nearby sensitive receivers during construction of the project, specifically as a result of the dredging activities within Sydney Harbour, and the associated treatment and transport of dredged materials at the White Bay construction support site (WHT3).

Dispersion modelling requires consideration of environmental factors and construction methodologies, including local meteorological conditions and emission rates from potential sources of odour.

Estimates of odour emission rates were taken from measurements made for similar dredging operations. The dispersion model takes a conservative approach and assumes that the total treatment area would be exposed, with odorous material present for every day of the year. In reality, the exposure of odorous material would be much less in terms of both area and duration.

Meteorological data used in the model was obtained from weather stations at Manly, Fort Denison, Randwick and Sydney Airport.

12.2.3 Operational air quality assessment methodology

Air quality impacts from the operation of the project are associated with emissions from vehicles using the project. The impact of vehicle emissions was considered in terms of effects on in-tunnel air quality, local air quality, regional air quality and odour.

In-tunnel air quality

The tunnel ventilation system would be operated to achieve acceptable in-tunnel air quality outcomes for CO, NO_2 and visibility (as a measure of in-tunnel particulate matter concentrations) (refer to Section 12.3.2 for additional information relating to in-tunnel air quality criteria).

In-tunnel air quality modelling was carried out using IDA Tunnel software. The modelling considered traffic volumes, tunnel air flow, vehicle emission levels, and temperature. The modelling incorporated the Western Harbour Tunnel component of the project and all linked motorway tunnel projects (WestConnex and the proposed Beaches Link) and considered the following scenarios:

- Expected traffic – 24-hour operation of the project ventilation system under day-to-day conditions of expected traffic demand in 2027 and 2037
- Worst case traffic – the most onerous traffic conditions for the ventilation system (refer below)
- Travel route scenarios – a worst case trip scenario for in-tunnel exposure to NO_2.

Operational worst case scenarios

Operational worst case scenarios consider emissions from traffic within the tunnels and represent the theoretical maximum pollutant concentrations for all potential traffic operations in the tunnel as well as vehicle breakdown situations. The operational worst case scenarios are very conservative and would result in pollutant emission concentrations that are much higher than those that could occur under any foreseeable operational conditions in the tunnel.

The operational worst case scenarios for the assessment of in-tunnel air quality considered worst case (variable speed) traffic operations and worst case (breakdown or major incident) operations.

The worst case (variable speed) traffic operation scenario represents the upper limit of daily operations on the ventilation system of the mainline tunnels, regardless of the year of operation, and is based on the traffic flow splits of the predicted traffic peak periods with the mainline tunnels reaching a theoretical maximum lane capacity traffic flow rate. This scenario also includes the highest predicted number of buses using the mainline tunnels being introduced into the Beaches Link mainline tunnels, which connect to the Western Harbour Tunnel. The worst case (variable speed) traffic operation scenario was considered under four different average speeds for lane capacity; 20, 40, 60 and 80 kilometres per hour.

The worst case (breakdown or major incident) operation scenario assesses the most onerous traffic case, where congestion that occurs as a result of a breakdown affects the longest length within the mainline tunnel. This worst case operational scenario assumes a breakdown would result in a complete blockage on the specific ramp, causing traffic that would ordinarily use the mainline tunnel to take other routes.

In-tunnel air quality for extended journeys

The assessment for in-tunnel air quality for extended journeys considers the estimated average concentration of NO_2 for the longest potential journey that could be taken by motorists in the connected motorway network. This was identified as a journey that used the project, the proposed Beaches Link tunnel, the WestConnex network and the F6 Extension tunnel network.

Provided that each project satisfies the air quality criteria (which requires NO_2 concentrations to be below an average of 0.5 ppm over the length of each tunnel), the average through the entire network would remain at, or below, 0.5 ppm under all traffic conditions. For this assessment, the estimated journey assessment completed as part of the M4-M5 Link environmental impact statement has been combined with the in-tunnel modelling completed for the 'Do something cumulative 2037' scenario.

Ambient air quality

The potential impacts of the project on ambient air quality during operation were assessed in relation to CO, NO_2, PM_{10} and $PM_{2.5}$ (particulate matter less than or equal to 2.5 micrometre diameter), in accordance with the NSW EPA Approved Methods. The pollutants and criteria considered are outlined in Section 12.3.3.

The following terms have been used to describe the concentration of pollutants at a specific location or receiver:

- Background concentration describes all contributing sources of a pollutant concentration other than road traffic. It includes, contributions from natural sources, industry and domestic activity
- Surface road concentration describes the contribution of pollutants from the surface road network. It includes not only the contribution of the nearest road at the receiver, but also the net contribution of the rest of the modelled road network at the receiver
- Ventilation outlet concentration describes the contribution of pollutants from tunnel ventilation outlets
- Total concentration is the sum of the sources defined above: background, surface road and ventilation outlet concentrations. It may relate to conditions with or without the project under assessment
- The change in concentration due to the project is the difference between the total concentration with the project and the total concentration without the project (increase or decrease), depending on factors such as the redistribution of traffic on the network as a result of the project.

The modelling scenarios, modelling process, receivers considered and approach to the analysis of results are discussed below.

Modelling scenarios

Seven expected traffic scenarios were included in the operational air quality assessment and considered future changes in the composition and performance of the vehicle fleet, as well as predicted traffic speeds, traffic volumes and the distribution of traffic on the road network. The expected traffic scenarios that were modelled are summarised in Table 12-2.

Table 12-2 Operational air quality assessment modelling – expected traffic scenarios

Name	Existing network	Western Harbour Tunnel and Warringah Freeway Upgrade	Beaches Link and Gore Hill Freeway Connection	Full WestConnex	Sydney Gateway	F6 Extension – Stage 1	F6 Extension – Full
Scenario in the base year (2016)							
Base Year (existing conditions)	✓	-	-	-	-	-	-
Scenarios at project opening (2027)							
'Do minimum 2027' (without the project)	✓	-	-	✓	-	-	-
'Do something 2027' (with the project)	✓	✓	-	✓	-	-	-
'Do something cumulative 2027' (with the project and some other projects)	✓	✓	✓	✓	✓	✓	-
Scenarios at 10 years after project opening (2037)							
'Do minimum 2037' (without the project)	✓	-	-	✓	-	-	-
'Do something 2037' (with the project)	✓	✓	-	✓	-	-	-
'Do something cumulative 2037' (with the project and all other projects)	✓	✓	✓	✓	✓		✓

Modelling process

The modelling process involved an emissions model, a meteorological model (Graz Mesoscale Model – GRAMM) and a dispersion model (Graz Lagrangian Model – GRAL). The relationship between these models is illustrated in Figure 12-2.

For each expected traffic scenario, a spatial emissions inventory (emissions model) was developed for road traffic sources within the domain of the dispersion model. The following components were treated separately to take into account potential changes in traffic emissions across the road network:

- Emissions from existing and proposed ventilation outlets for tunnels where portal emissions would, or would not, occur
- Emissions from the portals of a small number of existing tunnels, where these currently occur
- Emissions from the traffic on the surface road network, including any new surface roads associated with the project.

The GRAMM meteorological model predicted wind fields (three-dimensional spatial pattern of winds). Predicted wind fields then became an input into the dispersion model following alignment with meteorological observations.

The GRAL dispersion model predicted potential ground-level pollutant concentrations by simulating the movement of individual 'particles' of a pollutant emitted from an emission source in a three-dimensional wind field.

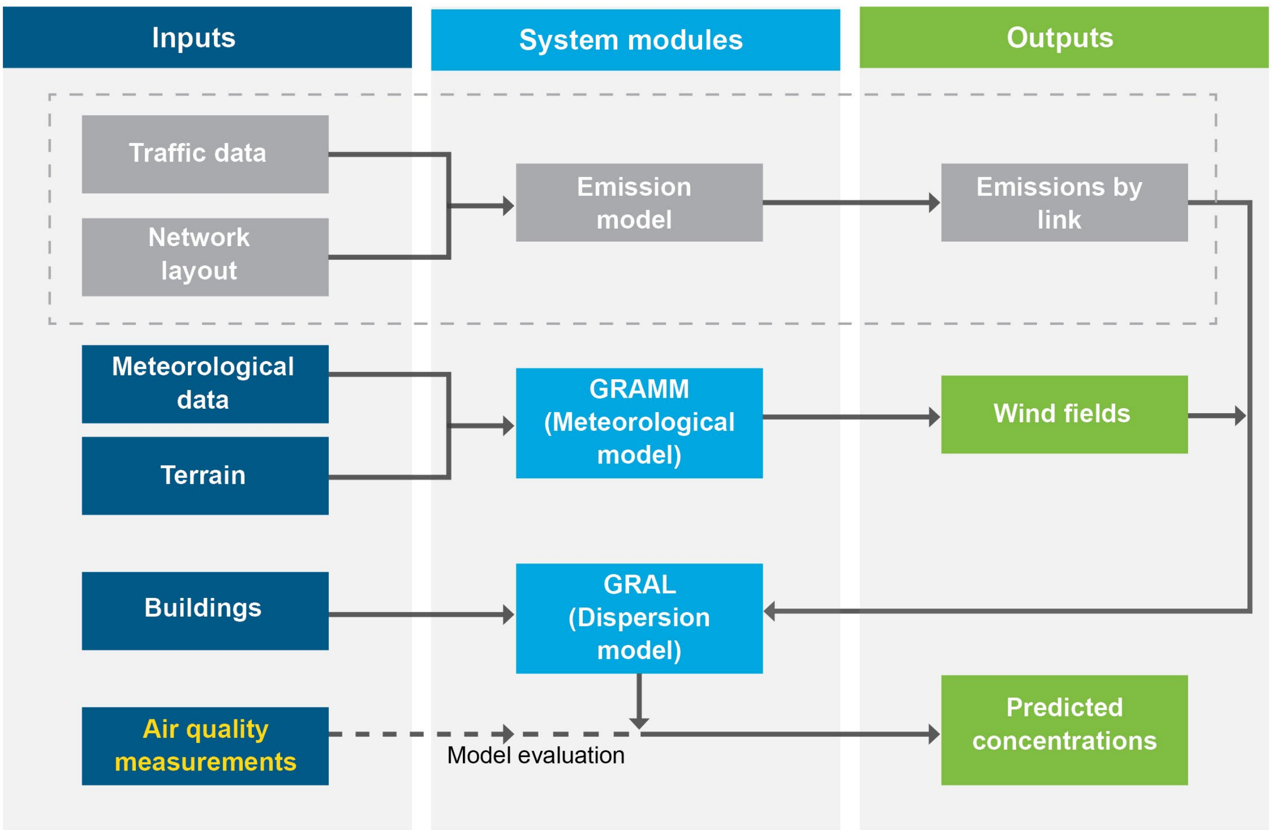

Figure 12-2 Overview of operational air quality modelling process

Receivers

Receivers are defined as anywhere someone works or resides, or may work or reside, including residential areas, hospitals, hotels, shopping centres, playgrounds and recreational centres. Due to its location in a highly built-up area, the dispersion modelling domain for the project contains many receivers.

Two types of receivers were considered in the air quality assessment:

- 'Community receivers'. These were taken to be representative of particularly sensitive locations such as schools, child care centres and hospitals within a zone of about 500 to 600 metres either side of the Western Harbour Tunnel and Beaches Link program of works corridor, and generally near significantly affected roadways. In total, 42 community receivers were included in the assessment (refer to Figure 12-3)
- 'Residential, workplace and recreational receivers'. These were all discrete receiver locations along the Western Harbour Tunnel and Beaches Link program of works corridor, and mainly covered residential and commercial land uses. In total, 35,490 residential, workplace and recreational receiver locations (including the 42 community receivers) were considered in the assessment of project air quality impacts.

The identified community and residential, workplace and recreational receiver locations were representative and not exhaustive. They have been selected using professional judgement to demonstrate potential impacts at a more detailed level.

The main emphasis in the assessment was on ground-level concentrations (as specified in the NSW EPA Approved Methods). However, at several locations there are multi-storey residential and commercial buildings and the potential impacts of the project at these elevated points are likely to be different to the impacts at ground level. Elevated receivers were therefore evaluated separately.

Based on a review of available building height information, four elevated receiver heights were selected to cover both existing buildings and future developments at 10 metres, 20 metres, 30 metres and 45 metres.

The modelling domain extended well beyond the project to allow for the traffic interactions between Beaches Link and Gore Hill Freeway Connection project and the M4-M5 Link project, as well as changes along affected surface roads. A large model domain also increased the number of meteorological and air quality monitoring stations that could be included for model evaluation purposes.

Regional air quality

The potential impacts of the project on air quality more widely across the Sydney region were assessed through consideration of the changes in emissions across the road network. The regional air quality impacts of a project can also be considered in terms of its capacity to influence ozone production. As noted in Section 12.1, the NSW EPA has developed a Tiered Procedure for Estimating Ground Level Ozone Impacts from Stationary Sources (ENVIRON, 2011). Although this procedure does not relate specifically to road projects, it was applied here to give an indication of the likely significance of the project's effect on ozone concentrations in the broader Sydney region.

Odour

The generation of odours from motor vehicle emissions tend to be very localised and short-lived, and there are unlikely to be any significant, predictable or detectable changes in odour due to the project. Odour was assessed based on the maximum change in 1-hour total hydrocarbon concentrations as a result of the project, which was converted into an equivalent change for three of the odorous pollutants identified in the NSW EPA Approved Methods (toluene, xylenes, and acetaldehyde). These pollutants were taken to be representative of other odorous pollutants from motor vehicles.

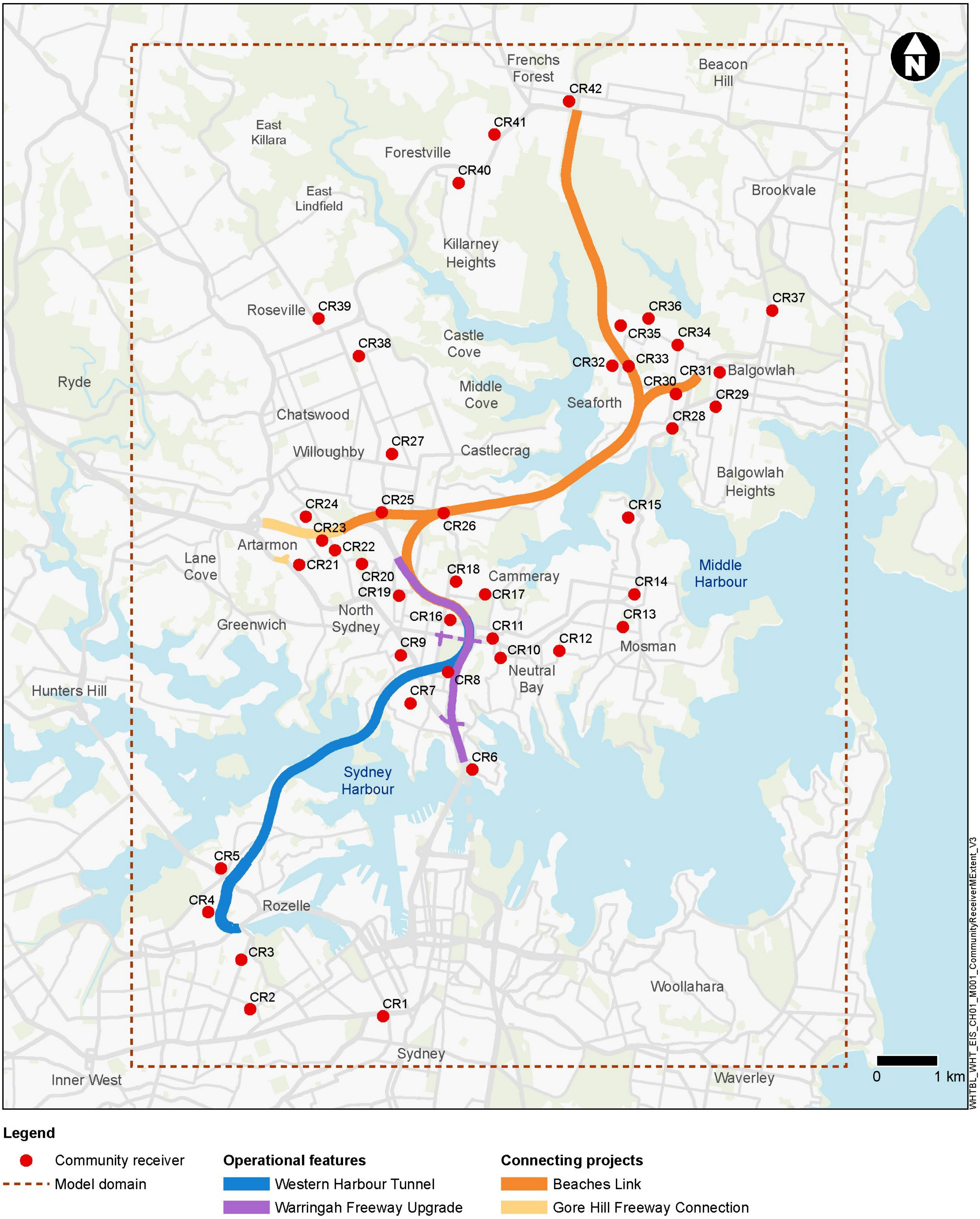

Figure 12-3 Location of community receivers and model domain

12.3 Criteria and standards

12.3.1 Overview

There are two types of criteria and standards that are relevant to the assessment of air quality impacts from construction and operation of the project:

- In-tunnel air quality criteria, which apply to the air quality inside the mainline tunnels
- Ambient air quality criteria and standards, which apply to outdoor air quality.

Air quality criteria and standards applied to the assessment of the project are outlined in the following sections, with further details provided in Appendix H (Technical working paper: Air quality).

12.3.2 In-tunnel air quality criteria

The project has been designed to achieve in-tunnel air quality that is protective of human health and amenity and provides a safe travel environment. Further details of the project's ventilation system design are provided in Chapter 5 (Project description).

The project's ventilation system would be operated to achieve the in-tunnel air quality criteria summarised in Table 12-3. The in-tunnel air quality limits for the project reflect those identified by the ACTAQ (ACTAQ, 2016 and ACTAQ, 2018a) and are consistent with the limits imposed on recent motorway projects in NSW.

Table 12-3 In-tunnel operational limits for CO, NO_2 and visibility

Parameter	Averaging period	Criteria
CO	3-minute (rolling), single point exposure limit	200 ppm
	15-minute (rolling), average along tunnel length	87 ppm
	30-minute (rolling), average along tunnel length	50 ppm
NO_2	15-minute (rolling), average along tunnel length	0.5 ppm
Visibility	15-minute (rolling), at any point in the tunnel	0.005 m^{-1}

12.3.3 Ambient air quality criteria

Air quality criteria and standards applied to the assessment of the project are outlined in the following sections, with further details provided in Appendix H (Technical working paper: Air quality), including Annexure B of that report.

Air pollutant criteria

The ambient air quality criteria applied to the assessment of the project are set in NSW EPA Approved Methods and summarised in Table 12-4. Some of these criteria are among the most stringent worldwide (see Annexure B of Appendix H (Technical working paper: Air quality)). For example, the annual average $PM_{2.5}$ criterion used, and on which the health metrics are based, is the lowest in world, including the World Health Organisation.

Table 12-4 Ambient air quality criteria applied to the assessment of the project

Pollutant	Criteria	Averaging period
CO	30 mg/m^3	1 hour
	10 mg/m^3	8 hours (rolling)
NO_2	246 $\mu g/m^3$	1 hour
	62 $\mu g/m^3$	1 year
PM_{10}	50 $\mu g/m^3$	24 hours
	25 $\mu g/m^3$	1 year
$PM_{2.5}$	25 $\mu g/m^3$	24 hours
	20 $\mu g/m^3$ (goal by 2025)	24 hours
	8 $\mu g/m^3$	1 year
	7 $\mu g/m^3$ (goal by 2025)	1 year
Benzene*	0.029 mg/m^3	1 hour
Polycyclic aromatic hydrocarbons (PAHs) (as benzo(a)pyrene)[1]	0.0004 mg/m^3	1 hour
Formaldehyde[1]	0.02 mg/m^3	1 hour
1,3-butadiene[1]	0.04 mg/m^3	1 hour
Ethylbenzene[1]	8 mg/m^3	1 hour

Note 1: These compounds were taken to be representative of the much wider range of air toxics associated with motor vehicles

Odour criteria

The NSW EPA Approved Methods provides assessment criteria for complex mixtures of odorous compounds, as summarised in Table 12-5. These criteria are 99th percentile values, meaning that they must not be exceeded more than one per cent of the time.

Table 12-5 Assessment criteria for odour

Population of affected community	Criteria for complex mixtures of odour (OU)
≤ ~2	7
~10	6
~30	5
~125	4
~500	3
Urban (>2000) and/or schools and hospitals	2

For the assessment of operational odour impacts, the change in the maximum 1-hour total hydrocarbon concentration as a result of the project was calculated at each of the residential, workplace and recreational receiver locations. The hydrocarbon pollutants were taken to be representative of other odorous pollutants from motor vehicles. The odorous pollutants assessed along with their relevant criteria include:

- Toluene (360 $\mu g/m^3$)
- Xylene (190 $\mu g/m^3$)
- Acetaldehyde (42 $\mu g/m^3$).

12.4 Existing environment

Air quality in a region is influenced by a number of factors including the terrain, meteorology (weather patterns), historical trends in road traffic emissions and the current (ambient) and historical air quality environment.

12.4.1 Meteorology

Analysis of meteorological data found that the Randwick station (operated by the Department of Planning, Industry and Environment (Environment, Energy and Science)) was the most representative of the project corridor. At Randwick, the wind speed and wind direction patterns over the five-year period between 2011 and 2016 were quite consistent. Average wind speeds ranged from 2.4 to 2.6 metres per second.

12.4.2 Vehicle emissions

The most comprehensive source of information on current and future air pollutant emissions in the Sydney area is the emissions inventory compiled periodically by the EPA.

For 2016, the emissions inventory identifies that road transport was the second largest contributor to emissions of CO (34 per cent) and the largest contributor to oxides of nitrogen (NO_X) (47 per cent) in Sydney. The sector was also responsible for substantial proportions of emissions of volatile organic compounds (13 per cent), PM_{10} (nine per cent) and $PM_{2.5}$ (10 per cent). Road transport contributed only two per cent of total sulfur dioxide (SO_2) emissions in Sydney, reflecting the reduced sulfur in road transport fuels in recent years.

Petrol passenger vehicles (mainly cars) accounted for a large proportion of the vehicle kilometres travelled (VKT) in Sydney and exhaust emissions from these vehicles were responsible for 65 per cent of CO from road transport in Sydney in 2016, 37 per cent of NO_X, and 71 per cent of SO_2. They were a minor source of PM_{10} (three per cent) and $PM_{2.5}$ (four per cent). Non-exhaust processes were the largest source of road transport PM_{10} (71 per cent) and $PM_{2.5}$ (57 per cent).

The road transport contribution to CO, volatile organic compounds and NO_X emissions is projected to decrease substantially between 2011 and 2036 due to improvements in emission-control technology. For PM_{10}, $PM_{2.5}$ and SO_2 the road transport contributions are also expected to decrease, but their smaller contributions to these pollutants mean that these decreases would have only a minor impact on total emissions.

12.4.3 Ambient air quality

Air quality in Sydney is monitored across a network of monitoring stations operated by the Department of Planning, Industry and Environment (Environment, Energy and Science), and at project-specific monitoring stations operated by Transport for NSW (formerly Roads and Maritime). A summary of ambient air quality in Sydney is provided in Table 12-6, based on data from these monitoring stations from 2004 to 2018.

Table 12-6 Ambient air quality in Sydney (2004 to 2018)

Air pollutant	Ambient air quality
CO (maximum 1-hour) CO (rolling 8-hour)	All monitoring data shows ambient concentrations well below the air quality criteria of 30 mg/m^3 (1-hour) and 10 mg/m^3 (8-hour). There is a general downward trend in maximum concentrations over time.
NO_2 (maximum 1-hour)	Although variable from year to year, maximum 1-hour NO_2 concentrations are relatively stable in the longer term. Data from all monitoring stations typically range from 80 µg/m^3 to 120 µg/m^3, and continue to be well below the criterion of 246 µg/m^3.
NO_2 (annual mean)	Concentrations at all monitoring stations are well below the air quality criterion of 62 µg/m^3. There is a general downward trend in annual mean concentrations over time.
PM_{10} (maximum 24-hour)	Maximum 24-hour PM_{10} concentrations show a large variation at most stations from year to year. There were multiple exceedances of the 24-hour criterion of 50 µg/m^3, notably 2009, 2016 and 2018 due to events such as dust storms and hazard reduction burns.
PM_{10} (annual mean)	In recent years the annual mean concentration has been between 20 µg/m^3 at most monitoring stations. The monitoring station at Lindfield shows substantially lower concentrations of about 15 µg/m^3 -16 µg/m^3. Monitoring data from stations operated by Transport for NSW (formerly Roads and Maritime) in 2018 increased slightly to around 16 µg/m^3, which is below the air quality criterion of 25 µg/m^3.
$PM_{2.5}$ (annual mean)	$PM_{2.5}$ has only been measured over several years at three of the Department of Planning, Industry and Environment stations reviewed. Concentrations at Chullora and Earlwood showed a similar pattern, with a steady reduction between 2004 and 2012 being followed by a substantial increase in 2013. The main reason for the increase was a change in the measurement method. The increases in measured concentrations meant that background $PM_{2.5}$ concentrations during 2016 to 2018 were already very close to or above the long-term goal of seven µg/m^3.

12.5 Assessment of potential construction impacts

Potential sources of air quality impacts during construction of the project would include:

- Dust generated at construction sites and construction support sites
- Odour generated during handling and management of harbour sediments
- Emissions from plant and equipment used on construction sites and construction support sites
- Blast fumes, if blasting is required during construction of the project.

12.5.1 Dust

Screening assessment

The construction dust assessment considered potential dust impacts across five assessment zones. The construction zones, and their associated construction support sites and surface construction areas are summarised in Table 12-7. Receivers near the construction zones are shown in Figure 12-4.

Table 12-7 Construction assessment zones

Assessment zone	Construction support sites within assessment zone	Surface construction areas within assessment zone, beyond construction support sites
Zone 1	Rozelle Rail Yards (WHT1)	Fitout of operational infrastructure for the Western Harbour Tunnel, including the Rozelle ventilation outlet. Construction works associated with the Rozelle Interchange connection project.
Zone 2	Victoria Road (WHT2)	N/A
Zone 3	White Bay (WHT3)	N/A
Zone 4	Yurulbin Point (WHT4), Sydney Harbour south cofferdam (WHT5), Sydney Harbour north cofferdam (WHT6), Berrys Bay (WHT7)	Construction of the harbour crossing (including dredging and handling of dredged material).
Zone 5	Berry Street north (WHT8), Ridge Street north (WHT9), Cammeray Golf Course (WHT10 and WFU8), Waltham Street (WHT11), Blue Street (WFU1), High Street south (WFU2), High Street north (WFU3), Arthur Street east (WFU4), Berry Street east (WFU5), Ridge Street east (WFU6), Merlin Street (WFU7), Rosalind Street east (WFU9)	Warringah Freeway Upgrade and associated local road upgrade surface works. Construction works associated with Western Harbour Tunnel component. Construction works associated with the Motorway Control Centre.

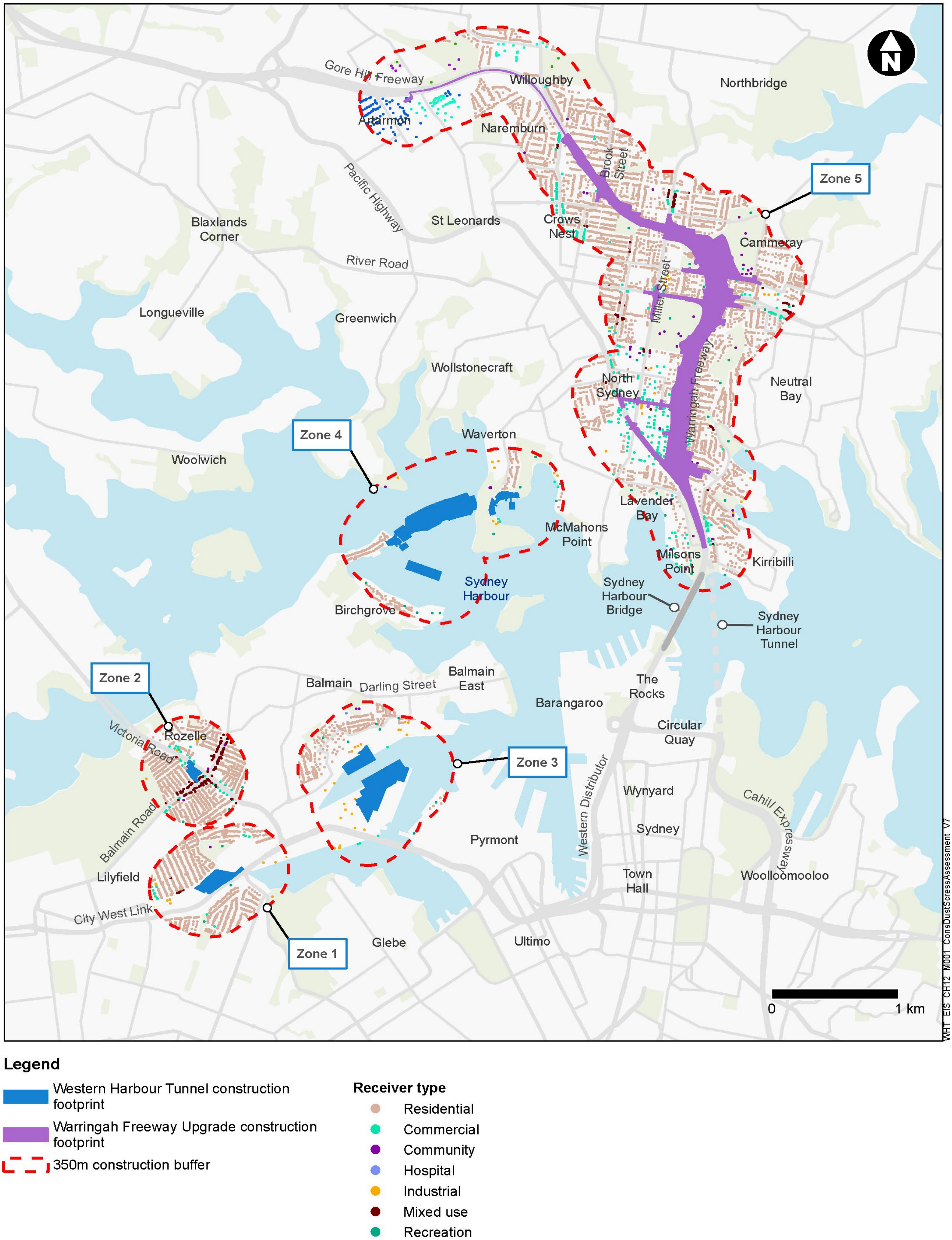

Figure 12-4 Construction dust screening assessment – receivers near the project footprint

Risk assessment

Potential for dust emissions from surface construction works

The potential magnitude of dust emissions from construction activities that would be carried out for demolition, earthworks, construction, and track-out (as defined in Section 12.2.2) is shown in Table 12-8.

Sensitivity of receivers during construction

The sensitivity of receivers to dust settlement effects, human health impacts, and ecological impacts during construction within the five surface construction zones assessed is provided in Table 12-8. The results in Table 12-8 show that:

- For construction dust settlement effects:
  - Zone 1, zone 2, zone 3 and zone 5 were considered to have a high sensitivity to dust settlement effects due to the high number of receivers, located in proximity to surface construction activities
  - Zone 4 was considered to have a medium sensitivity to dust settlement effect. This zone was nominated as having a medium sensitivity as while the receivers would be located near surface construction activities, there are fewer sensitive receivers at this location.
- For human health impacts:
  - The sensitivity of receivers in zone 1, zone 2, zone 3 and zone 5 would be considered high, except for demolition works in zone 1, which would be already complete as part of the WestConnex M4-M5 Link project
  - Zone 4 would have a medium sensitivity to human health risks.
- For ecological impacts, sensitive ecological receivers within zone 4 and zone 5 are located within 20 metres of the construction disturbance footprint. As a result, the sensitivity of these ecological receivers to construction dust would be considered high at these locations.

Risk of dust impacts

The risk of potential dust impacts, without mitigation, is determined by combining the following to provide an overall summary of potential risk:

- The magnitude of potential dust emissions (refer to Table 12-8)
- The sensitivity of the surrounding area to dust settlement effects, human health impacts and ecological impacts (refer to Table 12-8).

The summary of potential risk relating to construction dust is provided in Table 12-8.

Without mitigation, sites and activities that were determined to have a high and medium risk of dust impacts include:

- Rozelle Rail Yards construction support site (WHT1) and surrounds: Medium risk (if unmitigated) of dust settlement from earthworks, construction and track-out, and to human health from earthworks and construction
- Victoria Road construction support site (WHT2): Medium risk (if unmitigated) of dust settlement and to human health from demolition, earthworks and track-out
- White Bay construction support site (WHT3): Medium risk (if unmitigated) of dust settlement and to human health from earthworks and track-out
- Yurulbin Point (WHT4), Sydney Harbour south cofferdam (WHT5), Sydney Harbour north cofferdam (WHT6) and Berrys Bay (WHT7) construction support sites: Medium risk (if unmitigated) of dust settlement and to human health from earthworks. Medium risk to ecological receivers from demolition, earthworks and track-out

- Berry Street north (WHT8), Ridge Street north (WHT9), Cammeray Golf Course (WHT10), Waltham Street (WHT11) and all Warringah Freeway Upgrade component (WFU1-9) construction support sites (including surrounding surface works): High risk (if unmitigated) of dust settlement, to human health and ecological receivers from demolition, earthworks, construction and track-out.

The effects of airborne dust during construction would be temporary and of relatively short duration. As such, mitigation is considered straightforward because dust suppression measures are routinely employed as 'good practice' at most construction sites and areas of surface disturbance. The proposed environmental management measures are outlined in Section 12.7.

However, even with rigorous air quality management in place, it is not possible to guarantee that the mitigation measures implemented to manage any potential dust impacts during construction would be wholly effective all the time. There is still the residual risk that nearby residences, commercial buildings, hotel, cafés and schools in the vicinity of construction works might experience occasional dust impacts. This does not imply that impacts are likely, or that if they did occur, that they would be frequent or persistent. Overall, construction dust is unlikely to represent a serious ongoing problem. Any effects would be temporary and relatively short-lived, and would likely only arise during dry weather with the wind blowing towards a receiver at a time when dust is being generated and mitigation measures are not fully effective.

Table 12-8 Summary of construction dust risk assessment

Zone	Activity	Step 2A: Potential for dust emissions	Step 2B: Sensitivity of area - Dust settlement	Step 2B: Sensitivity of area - Human health	Step 2B: Sensitivity of area - Ecological	Step 2C: Risk of dust impacts - Dust settlement	Step 2C: Risk of dust impacts - Human health	Step 2C: Risk of dust impacts - Ecological
Zone 1 (WHT1)	Demolition	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Earthworks	Medium	High	Medium	N/A	Medium	Medium	N/A
	Construction	Medium	High	Medium	N/A	Medium	Medium	N/A
	Track-out	Medium	High	Medium	N/A	Medium	Low	N/A
Zone 2 (WHT2)	Demolition	Medium	High	High	N/A	Medium	Medium	N/A
	Earthworks	Medium	High	High	N/A	Medium	Medium	N/A
	Construction	Small	High	High	N/A	Low	Low	N/A
	Track-out	Medium	High	High	N/A	Medium	Medium	N/A
Zone 3 (WHT3)	Demolition	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Earthworks	Medium	High	High	N/A	Medium	Medium	N/A
	Construction	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Track-out	Medium	High	High	N/A	Medium	Medium	N/A

Zone	Activity	Step 2A: Potential for dust emissions	Step 2B: Sensitivity of area - Dust settlement	Step 2B: Sensitivity of area - Human health	Step 2B: Sensitivity of area - Ecological	Step 2C: Risk of dust impacts - Dust settlement	Step 2C: Risk of dust impacts - Human health	Step 2C: Risk of dust impacts - Ecological
Zone 4 (WHT4,5,6,7)	Demolition	Small	Medium	Medium	High	Low	Low	Medium
	Earthworks	Medium	Medium	Medium	High	Medium	Medium	Medium
	Construction	Small	Medium	Medium	High	Low	Low	Low
	Track-out	Medium	Medium	Medium	High	Low	Low	Medium
Zone 5 (WHT8-11 WFU1-9)	Demolition	Large	High	High	High	High	High	High
	Earthworks	Large	High	High	High	High	High	High
	Construction	Large	High	High	High	High	High	High
	Track-out	Large	High	High	High	High	High	High

Dust emissions containing contaminants

There is the potential for dust emissions to contain contaminants mobilised through the disturbance of contaminated soils, and other hazardous materials (such as asbestos fibres or organic matter) during demolition of buildings and other structures. These issues would be considered on a site-by-site basis, and would be adequately managed through standard air quality mitigation and management measures.

Areas identified as containing contaminated soils and other hazardous substances, which may be disturbed during construction include:

- Rozelle Rail Yards, Rozelle
- Birchgrove peninsula, Birchgrove
- Balls Head peninsula
- Warringah Freeway, North Sydney to Cammeray
- Waltham Street, Artarmon.

These areas are described in more detail in Chapter 16 (Geology, soils and groundwater).

12.5.2 Emissions from plant and equipment

The use of on-site diesel-powered vehicles, generators and construction equipment, and the handling and/or on-site storage of fuel and other chemicals, would result in localised increased concentrations of airborne particle matter, CO, NO_x, sulfur dioxide and volatile organic compounds. Minor emissions from these sources would be localised and would be adequately managed with standard environmental management measures.

12.5.3 Emissions during blasting

If blasting for the project is required, it would be carried out underground and there would be no direct emissions from blasting to the external air. Further analysis and assessment of potential blast impacts would be carried out during further design development, including the preparation of a Blast Management Plan. Emissions to ambient air from blasting would be managed to ensure safe working conditions for workers underground.

12.5.4 Odour

Odour assessment has been carried out for dredging activities, stockpiling and treatment works at White Bay.

As part of the harbour construction activities for the project, a large amount of material would be dredged from the harbour bed, bringing potentially odorous material to the surface. Dredged material on the barges would be wet, which would reduce any odour emissions. Any odour impacts from the dredged material would be low, given it would remain wet and located at some distance from any sensitive receiver.

At the White Bay construction support site (WHT3), an area covering about 1000 square metres would be used to stockpile and treat dredged material that is unsuitable for offshore disposal. Following treatment, material would be transferred to sealed trucks for delivery to landfill. Treatment would involve the addition of lime or a polymer to the material to make it spadable.

The results of odour modelling (refer to Figure 12-5) show that the predicted 99^{th} percentile odour concentrations at all of the nearest receivers are below one OU, the theoretical level of detection. The highest concentration across the domain is 0.1 OU, which is well below the theoretical level of detection. Odour impacts would therefore be undetectable for all sensitive receivers near the site.

Legend

- Odour Contour
- Spoil treatment area
- Construction footprint
- Construction support site

Figure 12-5 Predicted 99th percentile odour concentration due to treatment of dredging material (OU)

12.6 Assessment of potential operational impacts

Key areas of consideration with regards to air quality impacts during operation of the project would include:

- In-tunnel air quality, including protection of motorist health and amenity when using the project tunnels and during longer trips through other parts of the motorway network
- Ambient air quality for receivers at ground level, as a result of changes in the distribution of surface traffic and operation of the project's ventilation outlets
- Ambient air quality for elevated receivers in existing and potential future high rise buildings, as a result of operation of the project's ventilation outlets
- Odour caused by odorous compounds in vehicle emissions.

12.6.1 In-tunnel air quality

The project's ventilation system has been designed to achieve the in-tunnel air quality criteria summarised in Section 12.3.2 under all traffic conditions, and to effectively manage smoke in the event of a fire in the project tunnels. The tunnel ventilation system would include:

- Jet fans installed in the ceiling of the project tunnels
- Ventilation tunnels and radial fans to extract air from the project tunnels and to transfer it to motorway facilities
- Ventilation tunnels and radial fans to push fresh air into the project tunnels
- Ventilation fans and other infrastructure within the motorway facilities to manage fresh and tunnel air and ventilation outlets to effectively disperse tunnel air into the atmosphere. Motorway facilities and ventilation outlets for the project are located at the Rozelle Interchange, Rozelle and the Warringah Freeway, Cammeray.

The design and operation of the tunnel ventilation system is shown in Figure 5-1 and described in Section 5.2.7 of Chapter 5 (Project description) and Appendix H (Technical working paper: Air quality).

Simulations have been carried out to demonstrate that in-tunnel air quality criteria would not be exceeded. The simulations consider in-tunnel air quality based on:

- Expected traffic volumes using the project tunnels
- Theoretical maximum traffic volumes using the project tunnels, based on the design capacity of the tunnels at different average traffic speeds
- A breakdown or incident in the project tunnels.

In-tunnel air quality under expected traffic volumes

The change in the peak in-tunnel NO_2 (rolling 15-minute average) emissions throughout the project tunnel and the adjoining tunnels confirm that the tunnel ventilation system would maintain in-tunnel air quality well within operational limits. The predicted in-tunnel NO_2 levels modelled for all 'Do something' and 'Do something cumulative' scenarios in 2027 and 2037 are provided in Section 7 of Annexure K of Appendix H (Technical working paper: Air quality). The in-tunnel operational air quality limits for CO and visibility would also be achieved under all expected traffic scenarios.

In-tunnel air quality under maximum traffic volumes

In-tunnel air quality was assessed with the mainline operating at theoretical maximum lane capacity over the full length of the tunnels (which is not expected to actually occur). Four variable speed scenarios were assessed along all northbound and southbound routes – 20 kilometres per hour, 40 kilometres per hour, 60 kilometres per hour and 80 kilometres per hour. Vehicles travelling at 20 kilometres per hour would result in the highest pollutant levels in the tunnel, due to less air moving through the tunnel, and is considered the worst case variable speed operation scenario.

The predicted in-tunnel NO_2 (rolling 15-minute average) emissions for the worst case northbound route through the tunnel confirms that the tunnel ventilation system would achieve the NO_2 emissions criteria during all variable speed operation scenarios. The in-tunnel operational air quality limits for CO and visibility would also be achieved during all variable speed operation scenarios (refer to Annexure K of Appendix H (Technical working paper: Air quality)).

In-tunnel air quality under worst case breakdown or major incident

The tunnel ventilation system would be designed to cater for various traffic scenarios, including a case where there is a breakdown or major incident at a point along the tunnel. The worst case traffic scenario would be where the resulting congestion due to a breakdown affects the longest length within the tunnel operating at capacity. The worst case scenario was determined to be where a breakdown occurs along the route for traffic travelling north from the M4-M5 Link and to the Warringah Freeway exit ramp (prior to the Beaches Link Tunnel connection).

The predicted in-tunnel NO_2 (rolling 15-minute average) emissions for the worst case vehicle breakdown or major incident in the tunnel confirms that the tunnel ventilation system would achieve the NO_2 emissions criteria during all breakdown scenarios. The highest NO_2 concentration of 0.49 ppm would occur during a breakdown or major incident along the tunnel route between the M4-M5 Link and the Warringah Freeway. The in-tunnel operational air quality limits for NO_2, CO and visibility would also be achieved during all breakdown or major incident scenarios (refer to Annexure K of Appendix H (Technical working paper: Air quality)).

In-tunnel air quality for extended journeys

The extended journey assessment, which considers a journey through the project, the proposed Beaches Link tunnel, WestConnex and the F6 Extension in 2037, has identified that the in-tunnel average NO_2 levels would be below 0.5 ppm. Further detail can found in Section 5.2.7 of the Annexure K of Appendix H (Technical working paper: Air quality).

12.6.2 Ambient air quality (receivers at ground level)

The predicted ambient air quality for the expected traffic scenarios are presented, by pollutant in this section. All results, including tabulated concentrations and contour plots are provided in Appendix H (Technical working paper: Air quality).

For the pollutants assessed, the following has been determined for the 35,490 residential, workplace and recreational receiver locations and 42 community receivers:

- The total ground-level concentration for comparison against the NSW impact assessment criteria and international air quality standards
- The change in the total ground-level concentration. This was calculated as the difference in concentration between the ‘Do something’ and ‘Do minimum’ scenarios, ie the difference in ground-level concentrations as a result of the project
- The contributions of the background, surface road and ventilation outlet sources to the total ground-level concentration.

Due to the number of residential, workplace and recreational receiver locations, ranked plots for pollutant concentrations at each receiver location have been included. In each figure the background concentration, maximum contributions from each source (ventilation outlets and surface roads) and the maximum total concentration have been included for all of the 'Do something' and 'Do something cumulative' scenarios.

For community receivers, a figure showing the pollutant concentrations (background plus the project scenario contribution) at each receiver relative to the air quality criterion has been provided. A second figure showing the change in pollutant concentration as a result of the different project scenario contributions at each receiver has also been provided.

Nitrogen dioxide (NO_2) (maximum 1-hour mean)

Residential, workplace and recreational receiver locations

There are some predicted exceedances of the NSW 1-hour NO_2 criterion (246 µg/m^3), both with and without the project at residential, workplace and recreational receiver locations. In the 'Do minimum 2027' scenario (ie without the project), the maximum concentration of NO_2 exceeds the NSW criterion at 201 receivers (0.6 per cent of all receivers). With the introduction of the project in the 'Do something 2027' scenario, the number of receivers experiencing exceedances of the maximum concentration of NO_2 decreases to 183 receivers (0.5 per cent of all receivers). In the 'Do something cumulative 2027' scenario, the number of receivers experiencing exceedances of the maximum concentration of NO_2 further decreases to 88 receivers (0.2 per cent of all receivers).

In the 'Do minimum 2037' scenario (ie without the project), there are predicted to be exceedances at 234 receivers (0.7 per cent of all receivers), decreasing to 170 receivers (0.5 per cent of all receivers) in the 'Do something 2037' scenario. In the 'Do something cumulative 2037' scenario, the number further decreases to 86 receivers (0.2 per cent of all receivers).

Figure 12-6 shows the predicted contributions of the with-project and cumulative scenarios to the maximum 1-hour mean NO_2 concentration at all of the residential, workplace and recreational receiver locations.

The contribution from ventilation outlets to the maximum 1-hour mean NO_2 concentration at residential, workplace and recreational receiver locations cannot be calculated directly (refer to Section 8.4.11 of Appendix H (Technical working paper: Air quality)). However, given the maximum NO_X contribution by tunnel ventilation outlets at any receiver in any scenario was 60 µg/m^3 and that this did not coincide with maximum contributions from surface roads, the contribution from ventilation outlets would not lead to an exceedance of the 1-hour NO_2 criterion.

Community receivers

Figure 12-7 shows the maximum 1-hour NO_2 concentrations at community receivers in the with-project and cumulative scenarios. At all of these receiver locations in all scenarios assessed, the maximum concentration is predicted to be below the impact assessment criterion of 246 µg/m^3.

Figure 12-8 shows the predicted change in maximum 1-hour mean NO_2 concentration as a result of the project and cumulatively with other projects (the difference between the 'Do something' scenarios and the 'Do minimum' scenarios) in 2027 and 2037. There was a mixture of small (relative to the NSW criterion) increases and decreases across the scenarios assessed and some notable increases in the maximum concentration at a small number of receivers under a number of scenarios assessed, but as noted above, these did not result in any exceedances of the criterion.

In the hour in which the maximum 1-hour NO_2 concentration occurred, the background concentration was the most important source of NO_2, with generally a small contribution from surface roads but with some exceptions where surface roads contributions were greater (up to 50 per cent in some scenarios at a receiver in Seaforth (CR28)). The tunnel ventilation outlet contribution to the maximum NO_2 concentration was either zero or negligible.

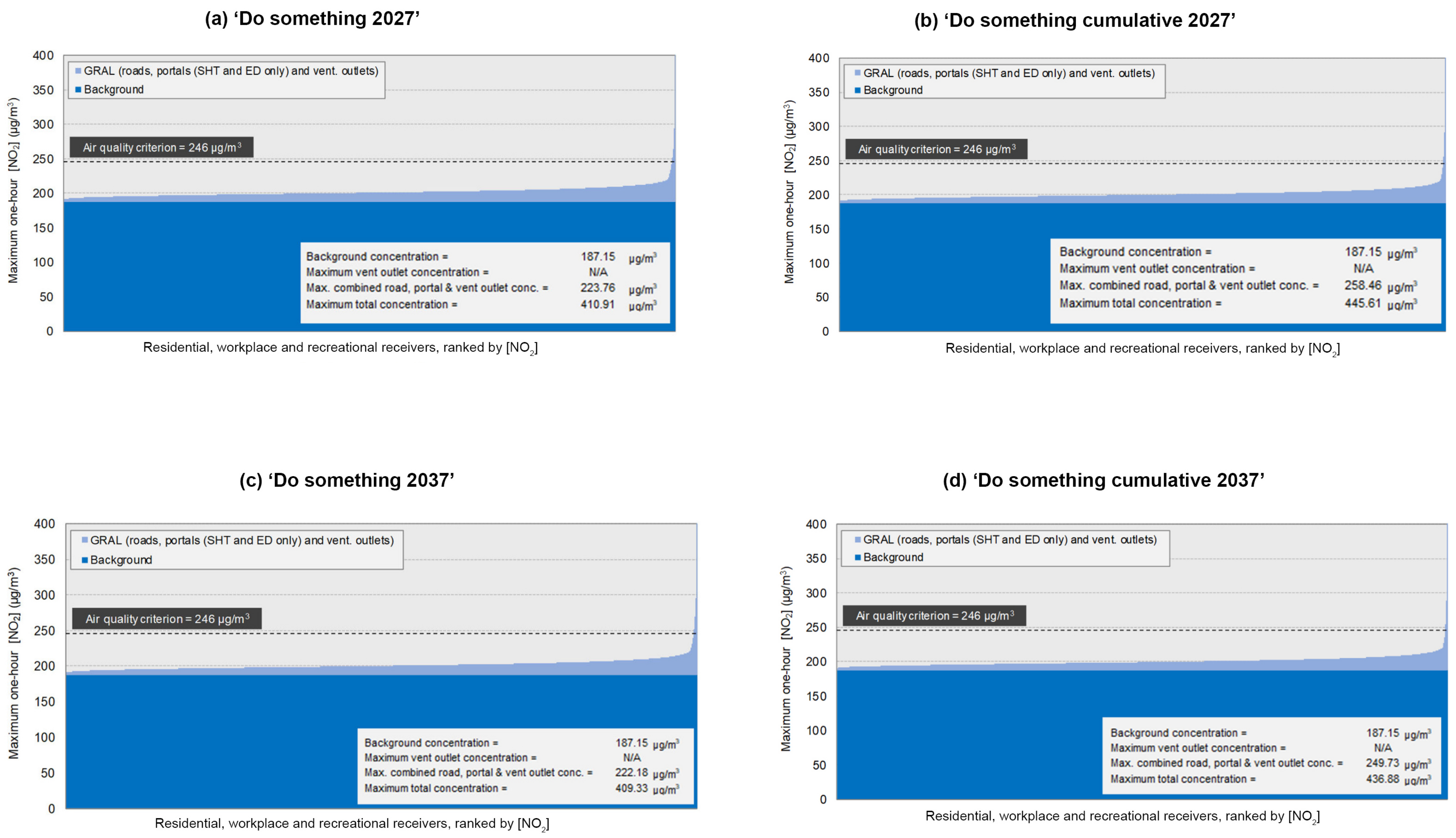

Figure 12-6 Contributions to maximum 1-hour mean NO_2 concentration at residential, workplace and recreational receiver locations

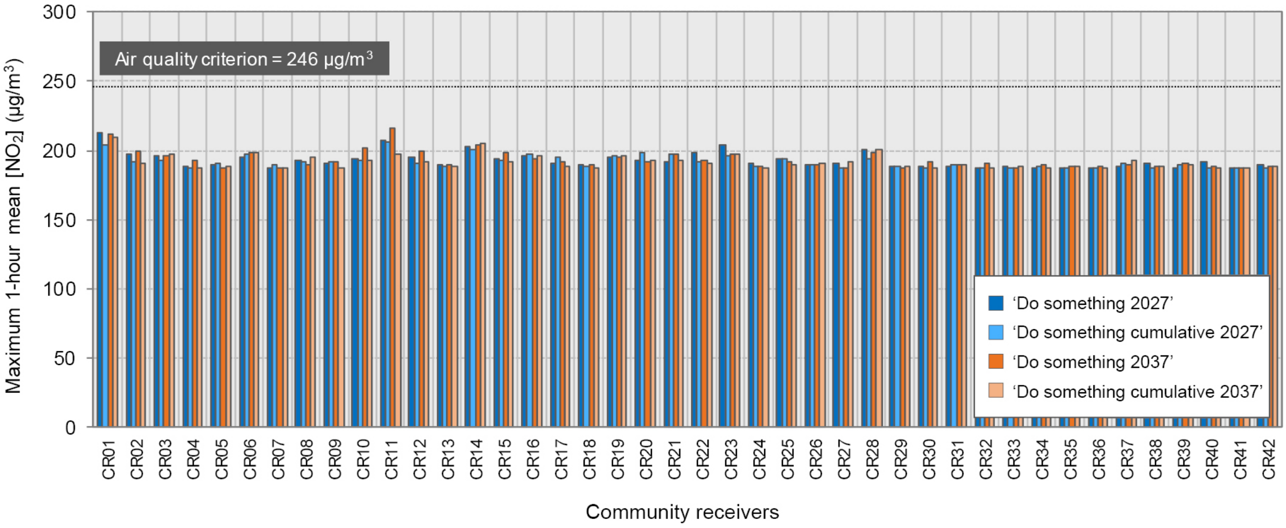

Figure 12-7 Maximum 1-hour mean NO_2 concentration at community receivers

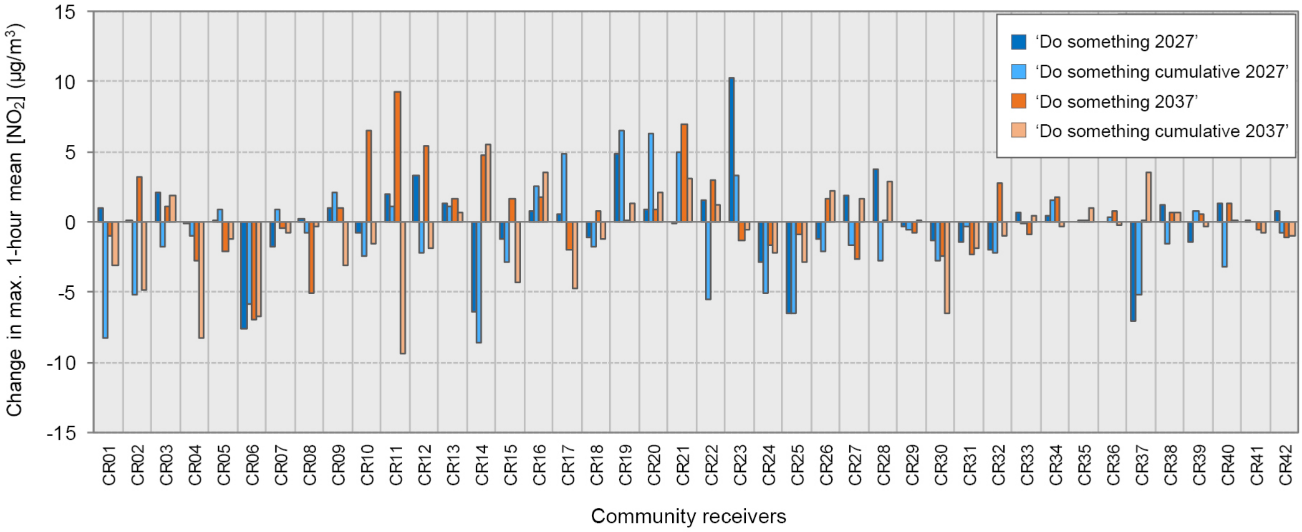

Figure 12-8 Change in maximum 1-hour mean NO_2 concentration at community receivers

Nitrogen dioxide (annual mean)

Residential, workplace and recreational receiver locations

Figure 12-9 shows the predicted contribution of the with-project and cumulative scenarios to annual mean NO_2 concentration at residential, workplace and recreational receiver locations. The predicted annual mean NO_2 concentrations at most (more than 97 per cent) of the receiver locations are between about 13 μg/m^3 and 25 μg/m^3. The annual mean NO_2 criterion of 62 μg/m^3 would not be exceeded at any receiver locations under all scenarios assessed.

The maximum predicted NO_2 contribution from the ventilation outlets would be 0.6 μg/m^3, and the maximum predicted surface road contribution would be 22 μg/m^3. Given that annual mean NO_2 concentrations at most receiver locations would be well below the criterion, the contribution of the ventilation outlets is small.

Community receivers

Figure 12-10 shows the predicted annual mean NO_2 concentrations for the project and cumulative scenarios at community receivers. At all of these locations, except one, the concentration is predicted to be below 30 μg/m^3, and well below the criterion of 62 μg/m^3 for all scenarios assessed.

The single exception is a receiver at Seaforth (CR28) which is located close to the heavily trafficked Manly Road (65,000 vehicles per day), and would have a high NO_2 concentration in the 'Do minimum' scenarios (32.3 μg/m^3 in 2027 and 33.1 μg/m^3 in 2037). The concentration at this receiver would remain above 30 μg/m^3 in the 'Do something' scenarios for 2027 and 2037, as well as in the 'Do something cumulative' scenario for 2037.

Figure 12-11 shows the predicted change in annual mean NO_2 concentration at community receivers as a result of the project and cumulatively with other projects (the difference between the 'Do something' scenarios and the 'Do minimum' scenarios) in 2027 and 2037. The largest predicted increase as a result of the project under the scenarios assessed would be about 2.5 μg/m^3 in the 'Do something 2027 scenario, and four per cent of the criterion. There would also be some notable decreases in concentration in the 'Do something' and 'Do something cumulative' scenarios at some receivers in 2027 and 2037.

For the scenarios assessed, the background component at the community receivers is likely to be responsible for, on average, about 80 to 90 per cent of the predicted total annual mean NO_2, with most of the remainder being due to surface roads. At most community receivers, surface roads would contribute between 10 per cent and 30 per cent of the total annual mean NO_2, but at some receivers close to busy roads there is a more substantial surface road contribution. The contributions of the project's ventilation outlets to the annual mean NO_2 concentrations would be less than three per cent in all scenarios.

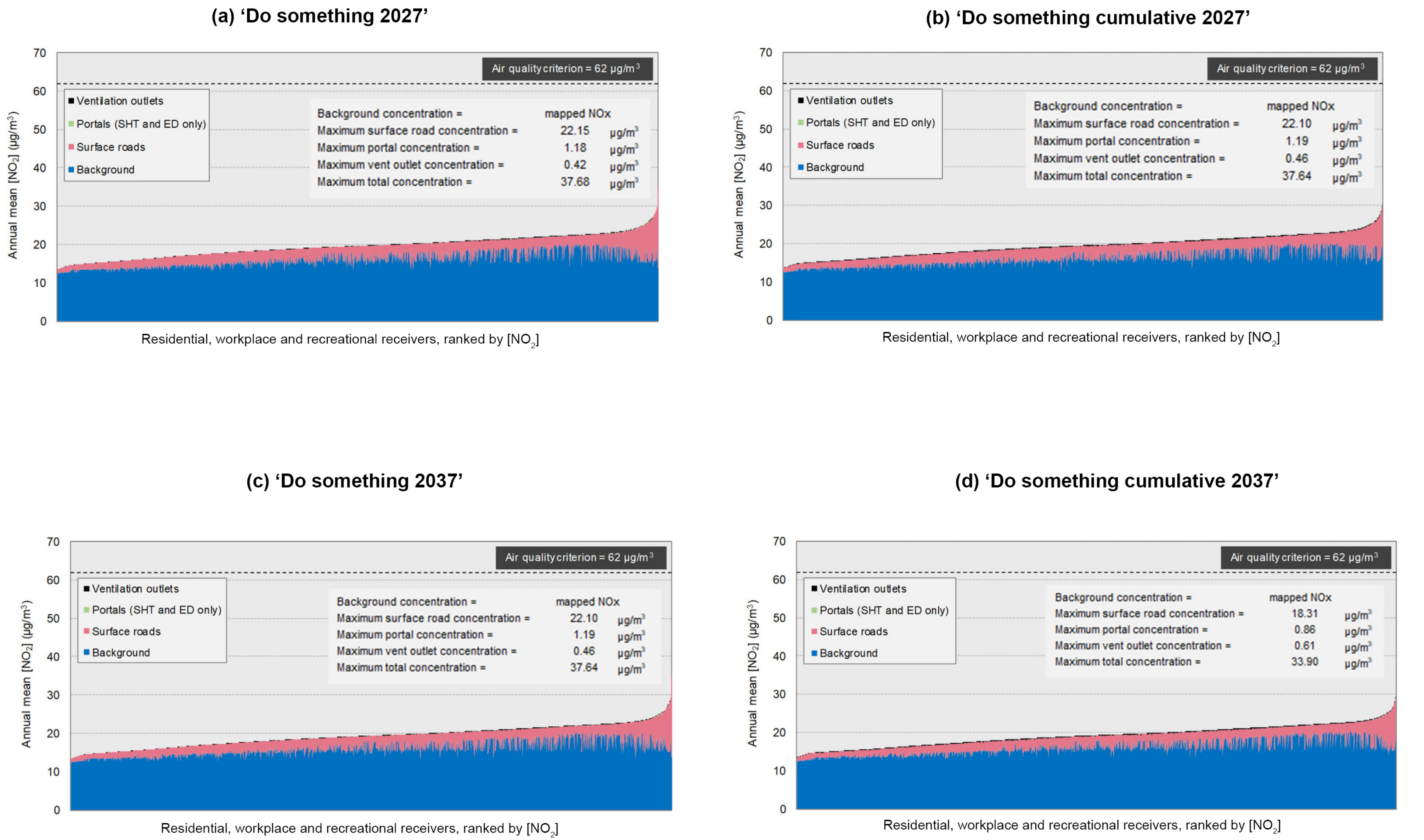

Figure 12-9 Contribution to annual mean NO_2 concentration at residential, workplace and recreational receiver locations

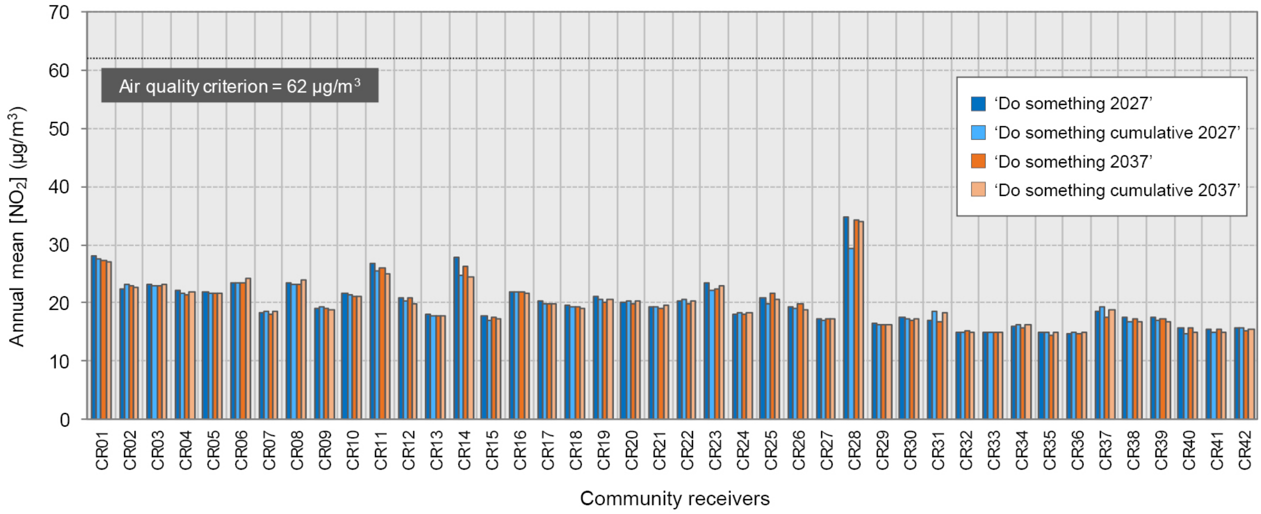

Figure 12-10 Annual mean NO_2 concentration at community receivers

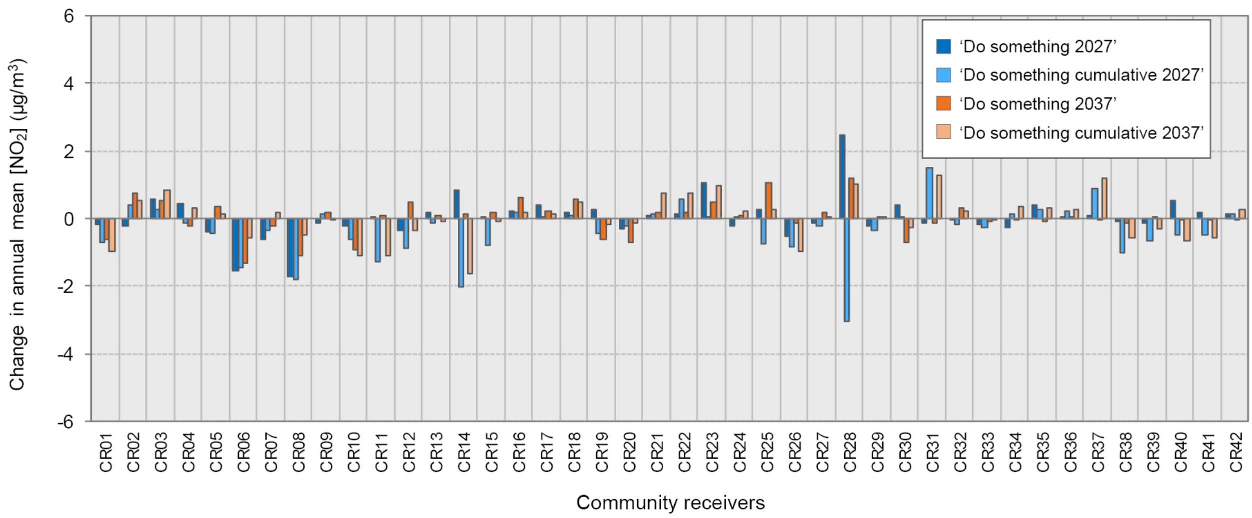

Figure 12-11 Change in annual mean NO_2 concentration at community receivers

PM_{10} (maximum 24-hour mean)

Residential, workplace and recreational receiver locations

Figure 12-12 shows predicted contributions of the with-project and cumulative scenarios to maximum 24-hour mean PM_{10} concentrations at residential, workplace and recreational receiver locations. It demonstrates that (with background concentrations of 48.04 µg/m^3) many of the receivers in the 'Do something' and 'Do something cumulative' scenarios (60 to 67 per cent respectively) would be above the criterion of 50 µg/m^3.

The number of receivers with a concentration above the criterion is predicted to decrease slightly as a result of the project, as follows:

- From 23,065 in the 'Do minimum 2027' scenario to 22,509 in the 'Do something 2027' scenario, decreasing further to 21,239 in the 'Do something cumulative 2027' scenario
- From 24,341 in the 'Do minimum 2037' scenario to 23,841 in the 'Do something 2037' scenario, decreasing further to 22,501 in the 'Do something cumulative 2037' scenario.

For the 'Do something' and 'Do something cumulative' scenarios, the maximum predicted contribution of the project's ventilation outlets at any receiver location would be between 1.3 µg/m^3 and 1.6 µg/m^3.

Community receivers

Figure 12-13 shows the predicted maximum 24-hour mean PM_{10} concentrations at all of the community receivers in the project and cumulative scenarios. The predicted maximum 24-hour mean PM_{10} concentration is predicted to exceed the criterion of 50 µg/m^3 under all modelled scenarios due to elevated background concentrations which occur during extreme events such as dust storms, bushfires and hazard reduction burns.

Figure 12-14 shows the predicted change in maximum 24-hour mean PM_{10} concentration as a result of the project and cumulatively with other projects (the difference between the 'Do something' scenarios and the 'Do minimum' scenarios) in 2027 and 2037. The changes were variable and there were no systematic changes by year or by scenario. At several receivers, there would be a predicted increase in concentration, but this would be less than about one µg/m^3.

The background concentration is the largest contributor to predicted peak 24-hour PM_{10} concentrations under all modelled scenarios. The predicted surface road contribution to the maximum 24-hour PM_{10} concentration at each community receiver is relatively small (generally less than about four µg/m^3).

In the 'Do something' scenarios (ie with the operation of the project), the ventilation outlet contribution at all community receivers is predicted to be negligible, with the largest value being slightly greater than 0.1 µg/m^3. The outlet contributions are predicted to be slightly higher in the cumulative scenarios, although they would still be small, with the maximum outlet contribution of around 1.5 per cent of the air quality criterion is a receiver at Balgowlah (CR31)(0.6 – 0.75 µg/m^3). The maximum outlet contribution at all other community receivers would be less than 0.5 per cent of the air quality criterion (less than 0.2 µg/m^3).

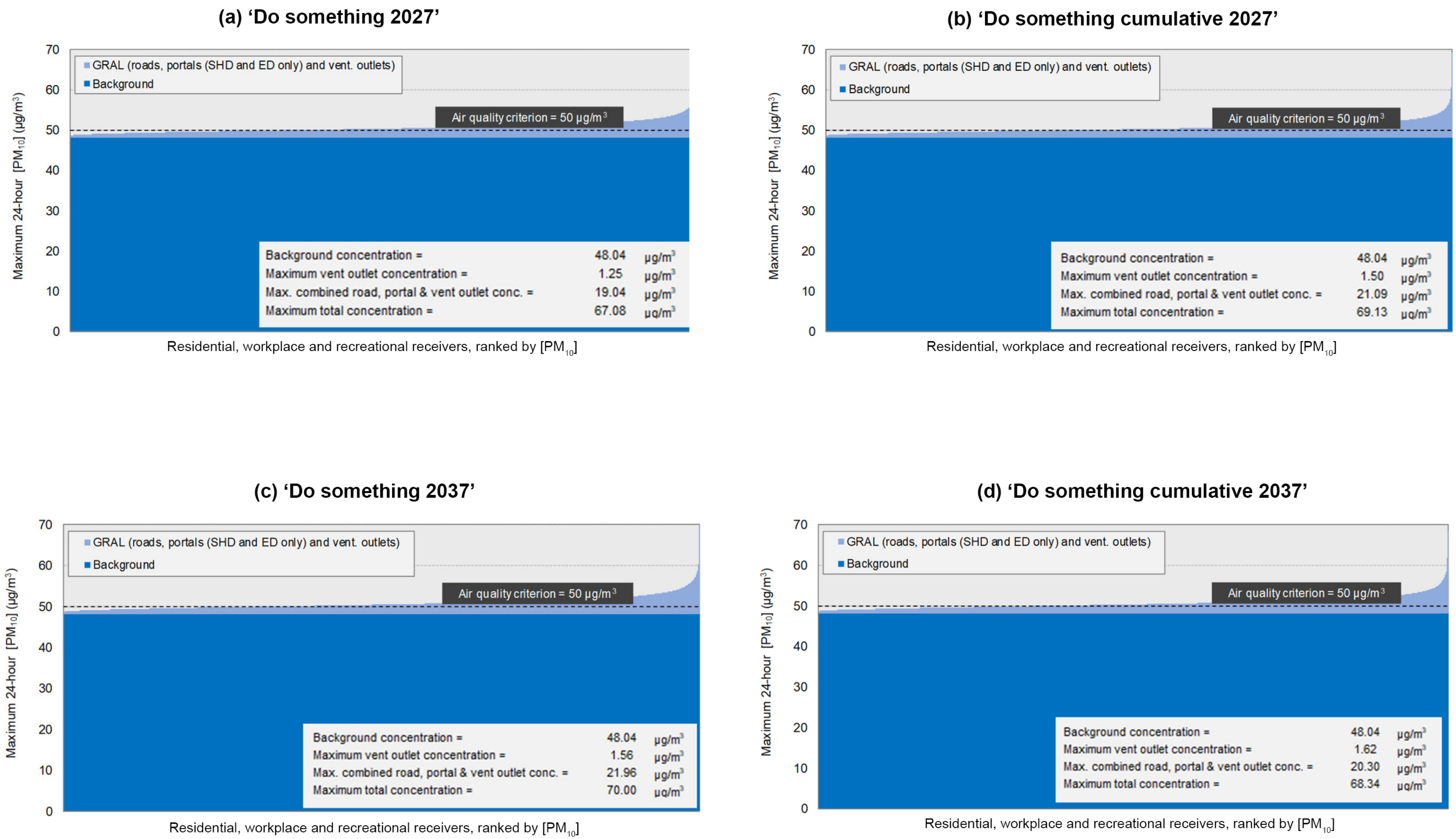

Figure 12-12 Contributions to maximum 24-hour mean PM_{10} concentration at residential, workplace and recreational receiver locations

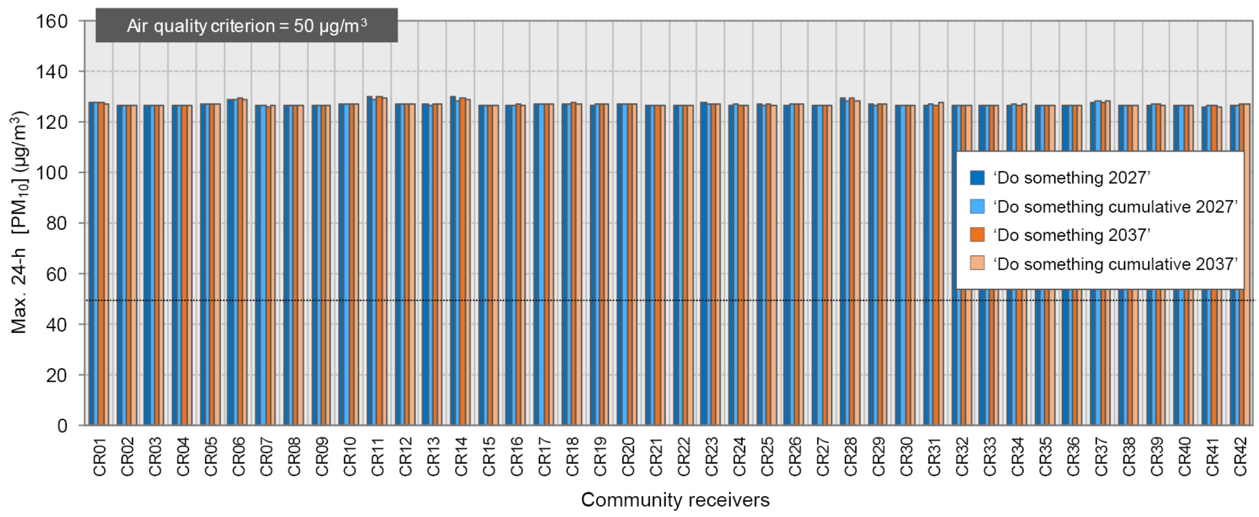

Figure 12-13 Maximum 24-hour mean PM_{10} concentration at community receivers

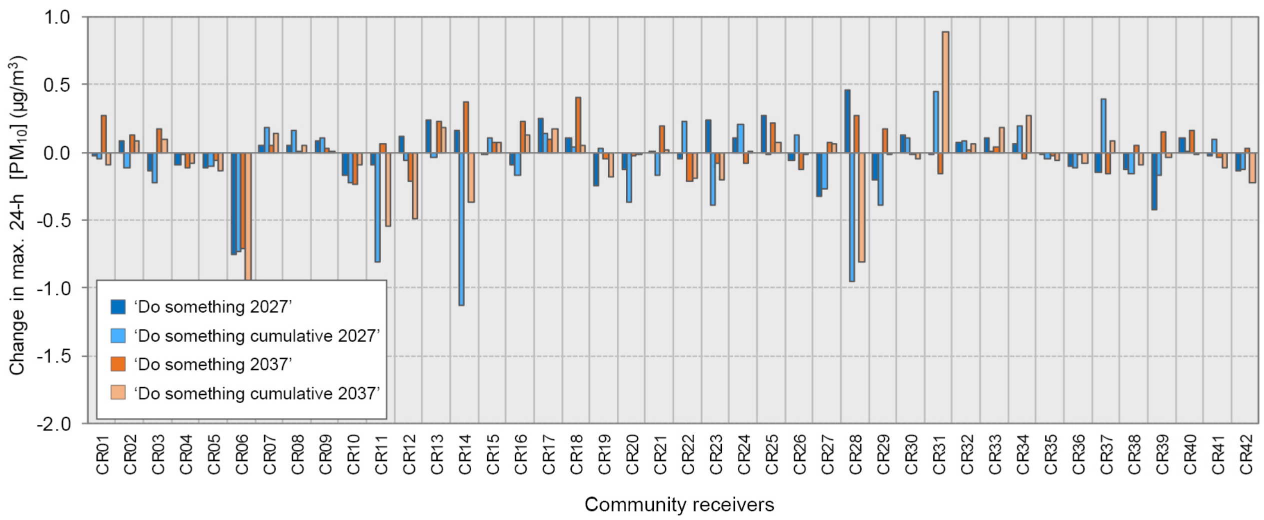

Figure 12-14 Change in maximum 24-hour mean PM_{10} concentration at community receivers

PM_{10} (annual mean)

Residential, workplace and recreational receiver locations

Figure 12-15 shows the with-project and cumulative scenarios predicted contributions to the annual mean PM_{10} concentration at all other residential, workplace and recreational receiver locations. It demonstrates that the concentration at most receivers is predicted to be below 20 µg/m^3, and no receivers are predicted to have a concentration above the criterion of 25 µg/m^3 under all scenarios assessed. The highest predicted concentration at any receiver in a 'Do something' or 'Do something cumulative' scenario for 2027 and 2037 is 23.5 µg/m^3.

The largest predicted surface road contribution would be about 6.6 µg/m^3, with an average of about 0.9 µg/m^3. The largest predicted contribution from the project's ventilation outlets would be 0.3 µg/m^3 in the 'Do something cumulative 2037' scenario.

Community receivers

Figure 12-16 shows the predicted annual mean PM_{10} concentrations at all of the community receivers in the project and cumulative scenarios. PM_{10} concentrations are predicted to be below the criterion of 25 µg/m^3 at all receivers in all scenarios.

Figure 12-17 shows the predicted changes in annual mean PM_{10} concentration as a result of the project and cumulatively with other projects (the difference between the 'Do something' and 'Do something cumulative' scenarios and the 'Do minimum' scenarios) in 2027 and 2037. The largest predicted increase would be about 0.45 µg/m^3 (1.8 per cent of the criterion) at a receiver in Seaforth (CR28) under the 'Do something' scenario, and the largest decrease would be 1.45 µg/m^3, both under the 2037 'Do something cumulative' scenario. Overall, PM_{10} concentrations are predicted to decrease at most of the community receivers under the scenarios assessed.

Annual mean PM_{10} concentrations in the 'Do something' and 'Do something cumulative' scenarios for 2027 and 2037 would be dominated by existing PM_{10} concentrations (background). The predicted contribution from roads at most receivers would be small (up to five µg/m^3) and the contribution from the project's ventilation outlets would be negligible (less than about 0.2 µg/m^3).

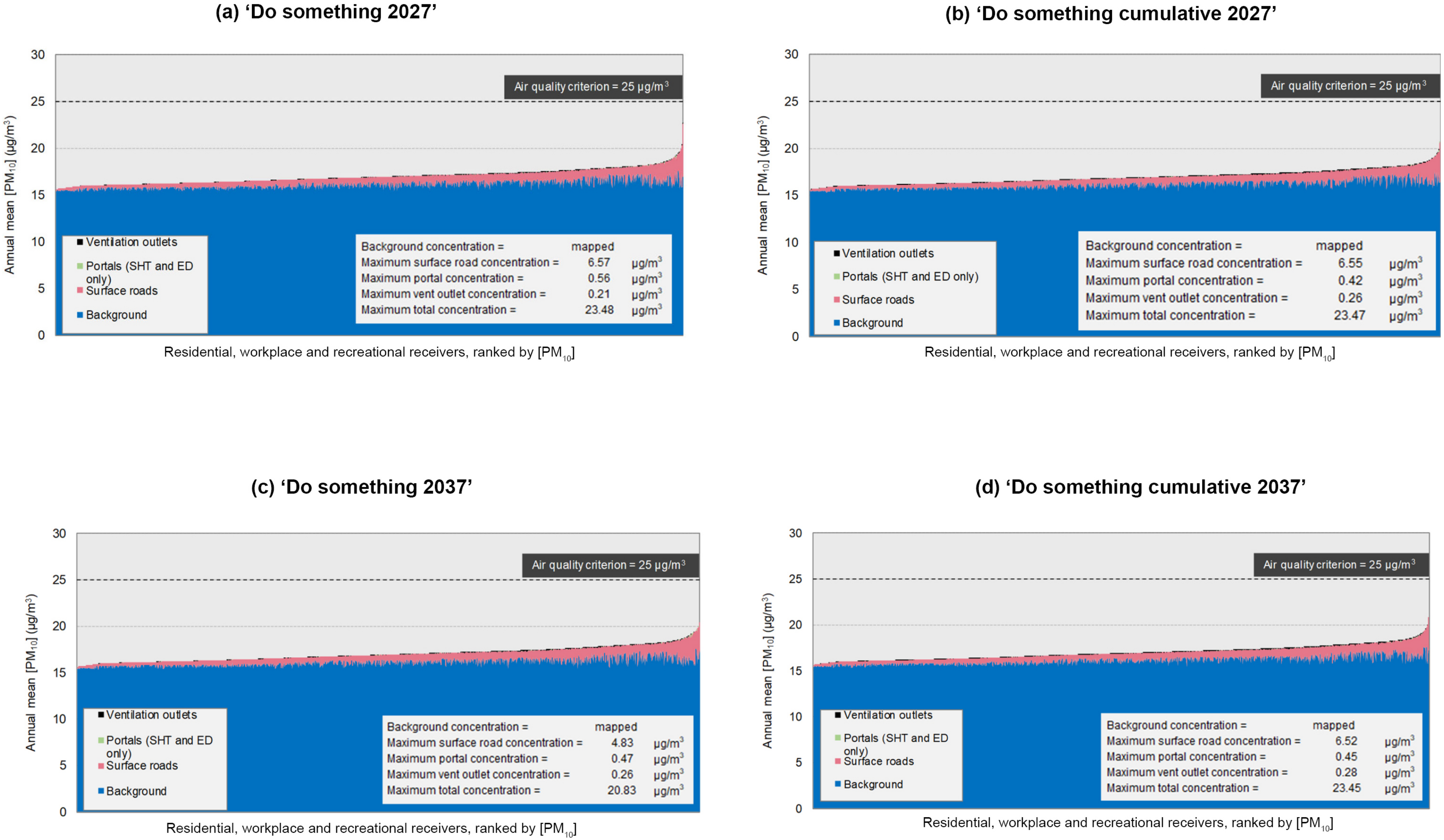

Figure 12-15 Contributions to annual mean PM_{10} concentration at residential, workplace and recreational receiver locations

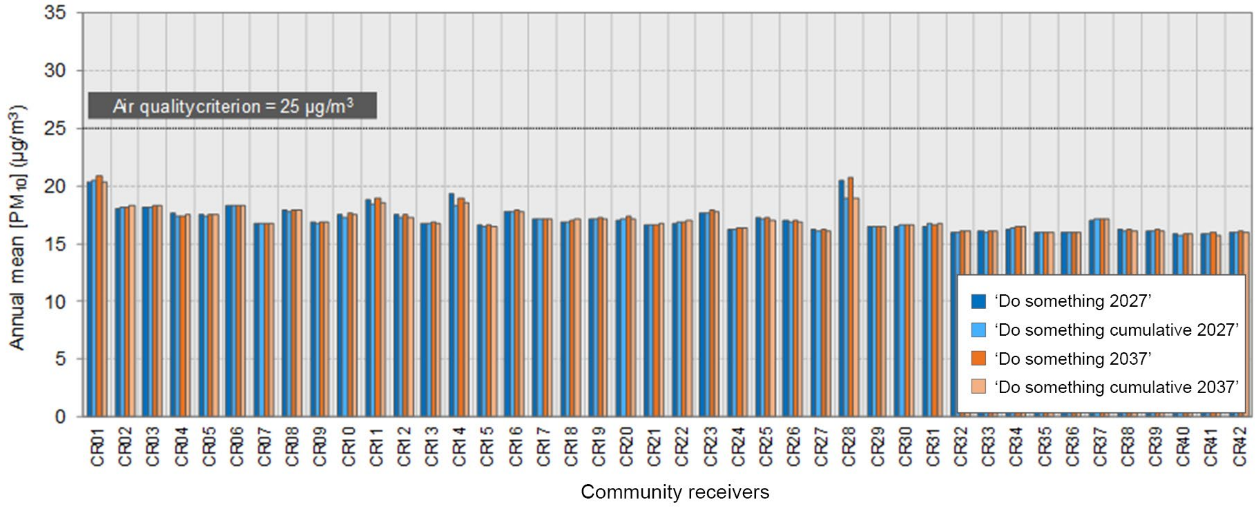

Figure 12-16 Annual mean PM_{10} concentration at community receivers

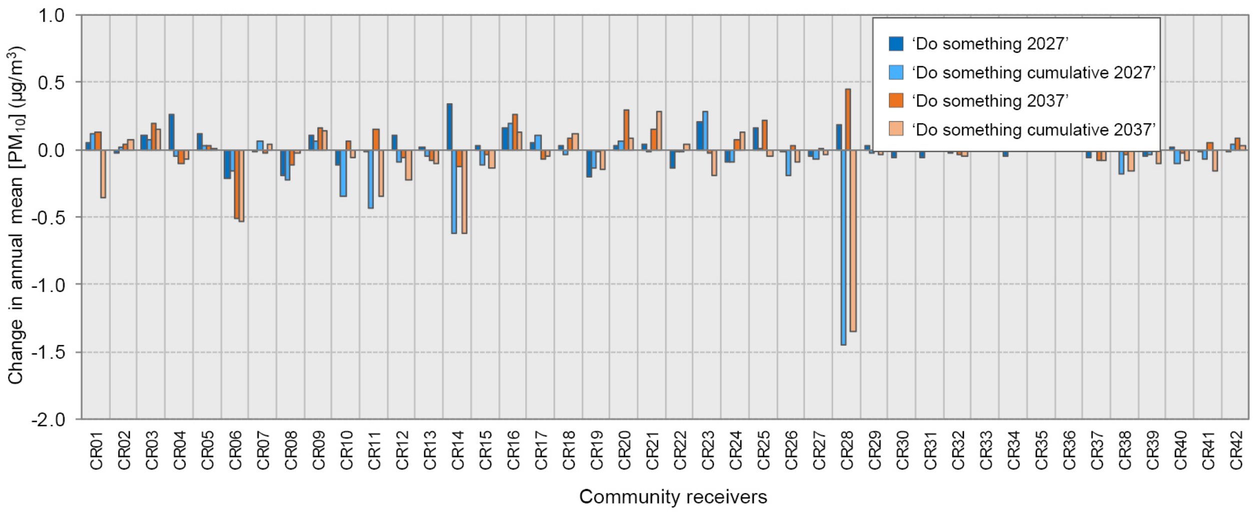

Figure 12-17 Change in annual mean PM_{10} concentration at community receivers

$PM_{2.5}$ (maximum 24-hour mean)

Residential, workplace and recreational receiver locations

Figure 12-18 shows predicted contributions of the project to the maximum 24-hour mean $PM_{2.5}$ concentration at all of the residential, workplace and recreational receiver locations. When considering the relatively high background concentration (22.1 µg/m^3), the concentration at a large proportion of receivers were above the criterion of 25 µg/m^3. The predicted maximum contribution of the project's ventilation outlets would be 1.0 µg/m^3 in the 'Do something cumulative 2037' scenario.

At most receivers, the changes in the maximum 24-hour mean $PM_{2.5}$ concentration would be very small. The largest predicted increase in concentration at any receiver as a result of the project is predicted to be 2.2 µg/m^3, and the largest predicted decrease is 6.3 µg/m^3. Where increases are predicted, they are greater than one µg/m^3 at less than one per cent of receivers.

Community receivers

Figure 12-19 shows the maximum 24-hour mean $PM_{2.5}$ concentrations at all of the community receivers in the project and cumulative scenarios. At all receiver locations, the maximum concentration was above the criterion of 25 µg/m^3, although exceedances would already be predicted without the project.

Figure 12-20 shows the predicted change in maximum 24-hour mean $PM_{2.5}$ with the project and cumulative scenarios at community receivers. Most of the increases in concentration would generally be less than one µg/m^3. The largest increase in maximum 24-hour mean $PM_{2.5}$ concentrations is 2.1 µg/m^3 at a receiver in Seaforth (CR28) in the 'Do something 2037' scenario, which is about eight per cent of the air quality criterion.

In the 'Do something' scenarios (ie with the operation of the project), the ventilation outlet contribution at all community receivers is predicted to be negligible, with the largest value being slightly greater than 0.05 µg/m^3. The outlet contributions are predicted to be slightly higher in the 'Do something cumulative' scenarios, although they would still be small, with the maximum outlet contribution of around 0.4 per cent of the air quality criterion at a receiver in North Sydney (CR09) (0.07 – 0.1 µg/m^3). The maximum outlet contribution at all other community receivers would be less than 0.5 per cent of the air quality criterion (less than 0.1 µg/m^3).

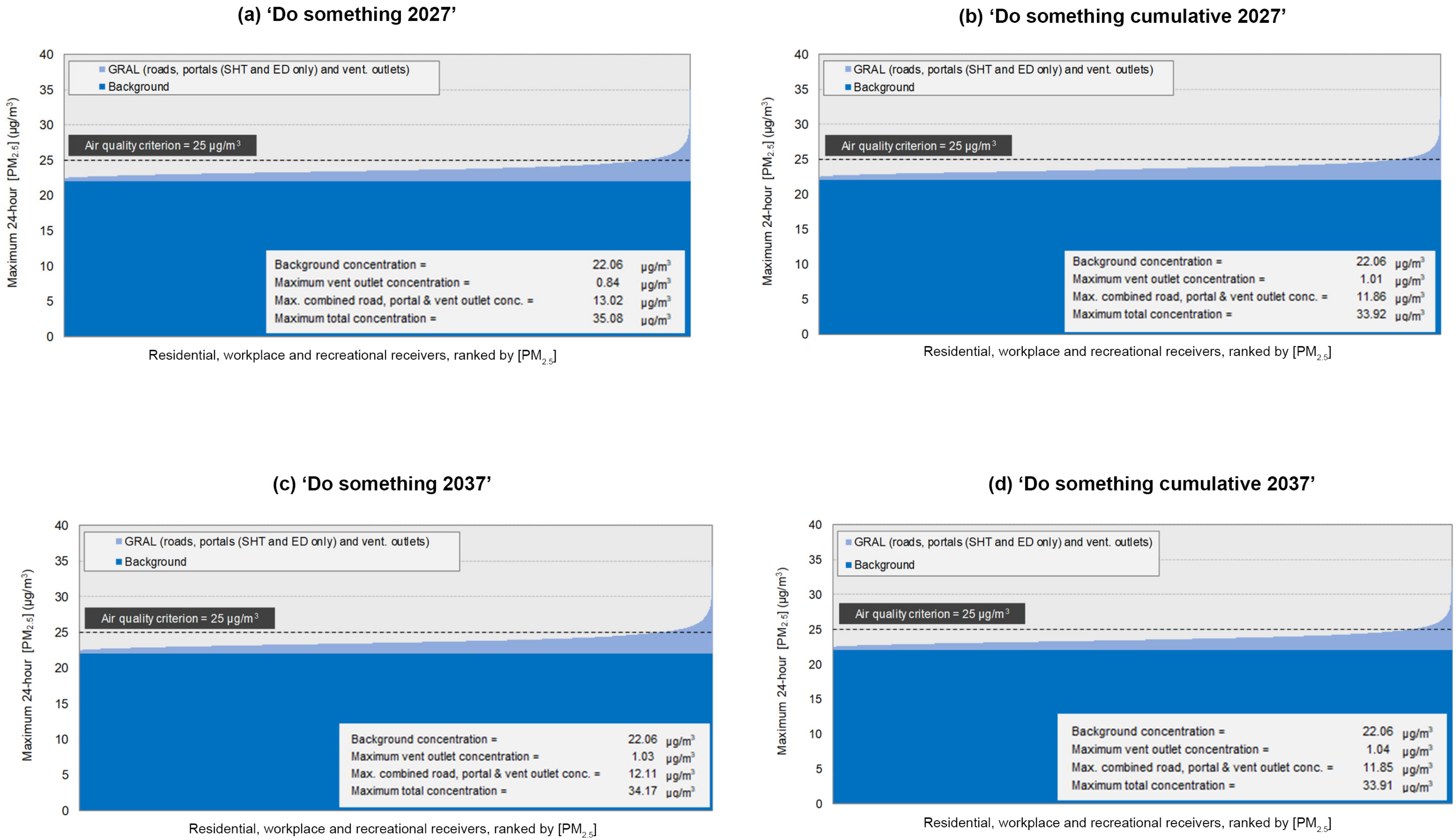

Figure 12-18 Contributions to maximum 24-hour $PM_{2.5}$ mean concentration at residential, workplace and recreational receiver locations

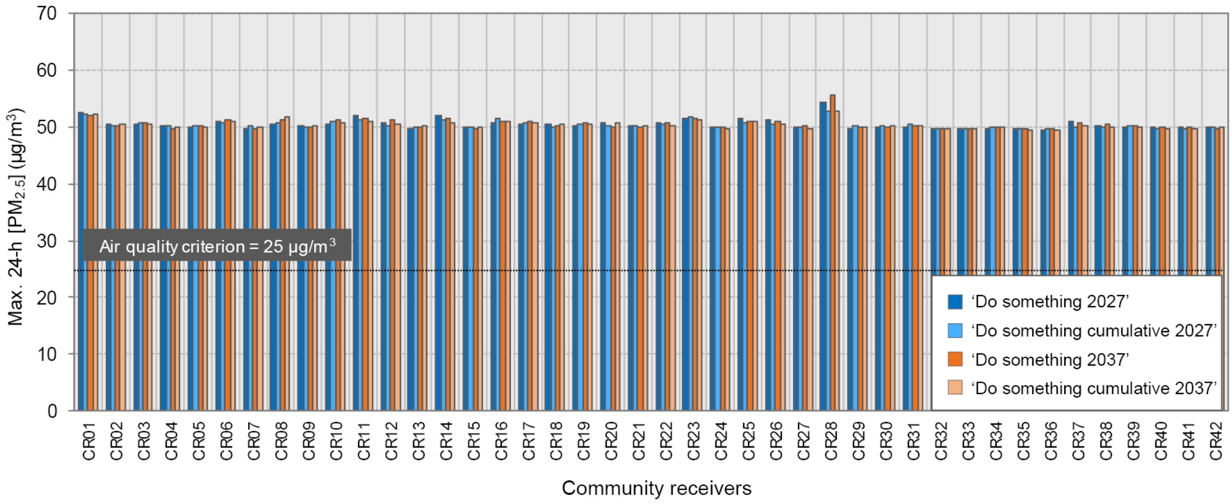

Figure 12-19 Maximum 24-hour $PM_{2.5}$ mean concentration at community receivers

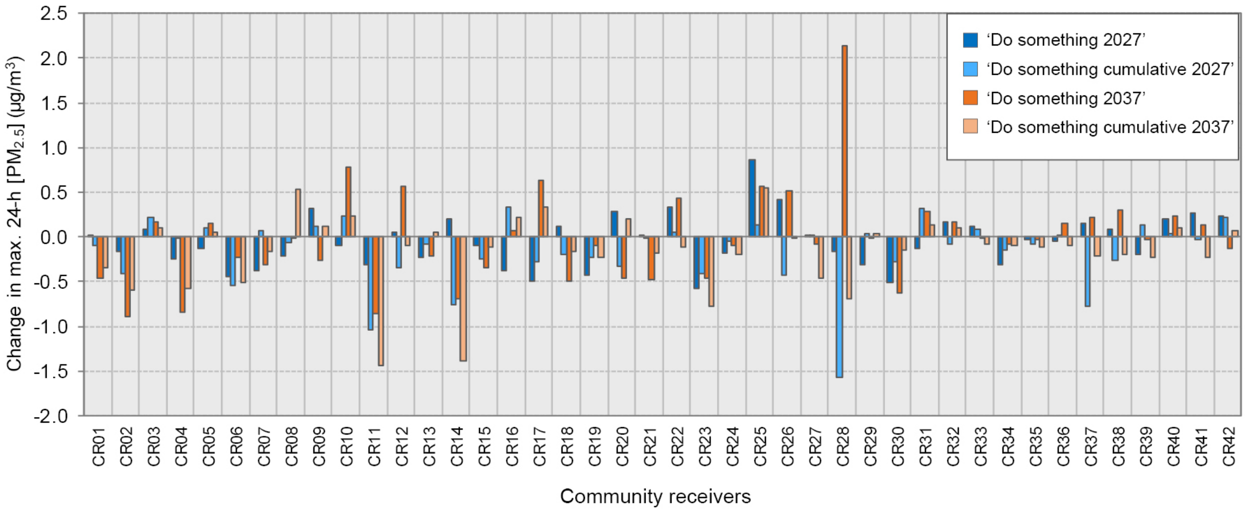

Figure 12-20 Change in maximum 24-hour $PM_{2.5}$ mean concentration at community receivers

$PM_{2.5}$ (annual mean)

Residential, workplace and recreational receiver locations

Figure 12-21 shows predicted contributions of the project to the annual mean $PM_{2.5}$ concentration at all the residential, workplace and recreational receiver locations. It shows that the highest predicted annual mean $PM_{2.5}$ concentration at any receiver location would be 11.9 µg/m^3. In the 'Do something' and 'Do something cumulative' scenarios, the largest surface road contribution at any receiver is predicted to be 4.1 µg/m^3. The largest predicted contribution from the project's ventilation outlets would be 0.18 µg/m^3 in the 'Do something cumulative 2037'.

The largest predicted increase in concentration at any receiver location as a result of the project would be 0.6 µg/m^3, and the largest predicted decrease would be 2.1 µg/m^3.

Community receivers

Figure 12-22 shows the annual mean $PM_{2.5}$ concentrations at all of the community receivers. Given that the mapped background concentration at some community receivers is already very close to the air quality criterion (up to 7.9 µg/m^3), some exceedances of the criterion and the NSW 2025 goal of seven µg/m^3 are predicted as a result of the project. These exceedances also occur in the 'Do minimum' scenarios (ie without the project).

Figure 12-23 shows the predicted change in the annual mean $PM_{2.5}$ as a result of the project and cumulatively with other projects (the difference between the 'Do something' scenarios and the 'Do minimum' scenarios) in 2027 and 2037. Overall, the changes would generally be less than 0.2 µg/m^3. The largest increase in annual mean $PM_{2.5}$ concentration at any community receiver as a result of the project would be 0.19 µg/m^3 in the 'Do something 2037' scenario. This increase is less than 2.5 per cent of the air quality criterion.

The surface road contribution is predicted to be between 0.2 µg/m^3 and 3.2 µg/m^3. The largest predicted contribution from the project's ventilation outlets at any receiver would be 0.1 µg/m^3.

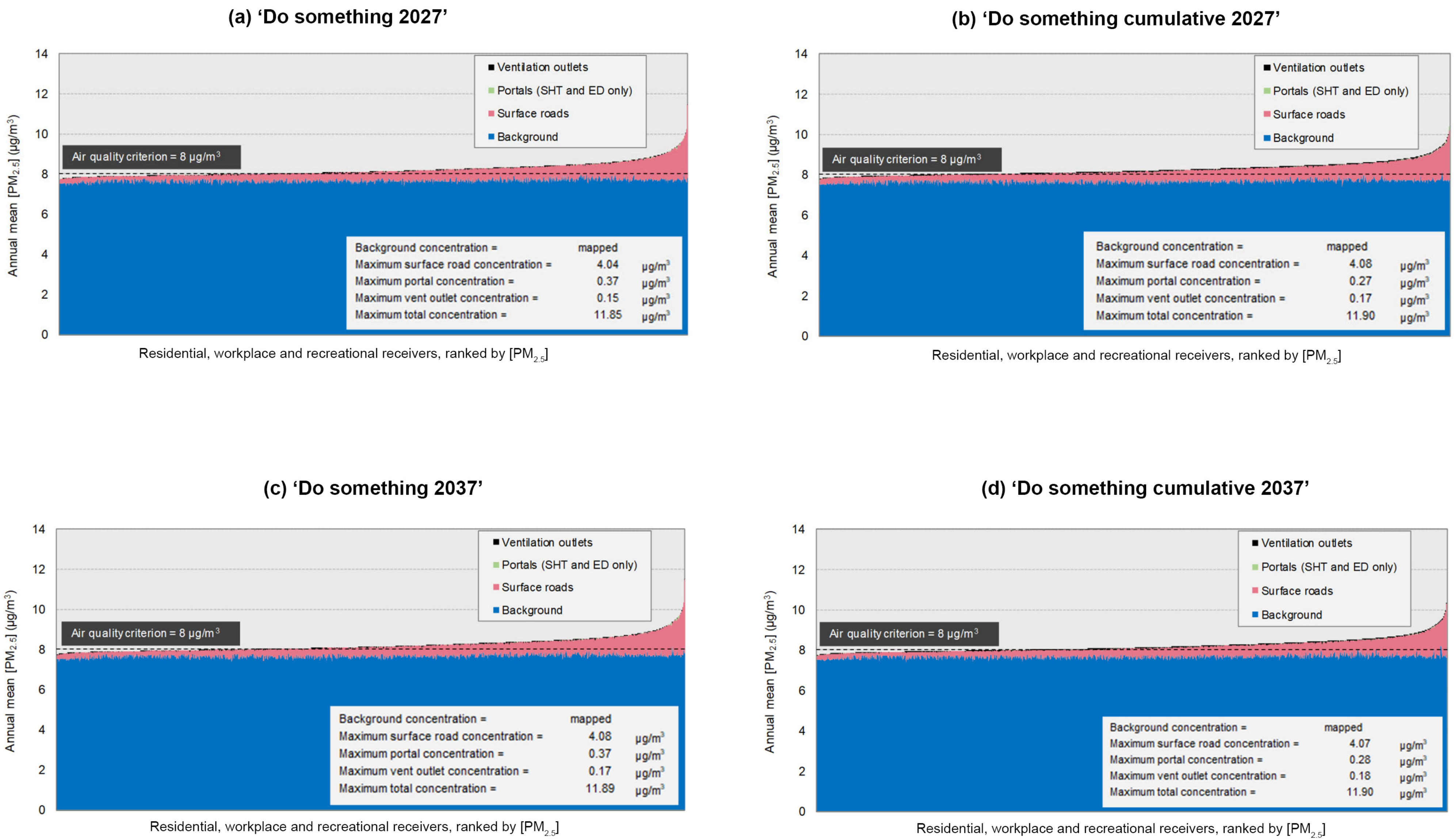

Figure 12-21 Contributions to annual mean $PM_{2.5}$ concentration at residential, workplace and recreational receiver locations

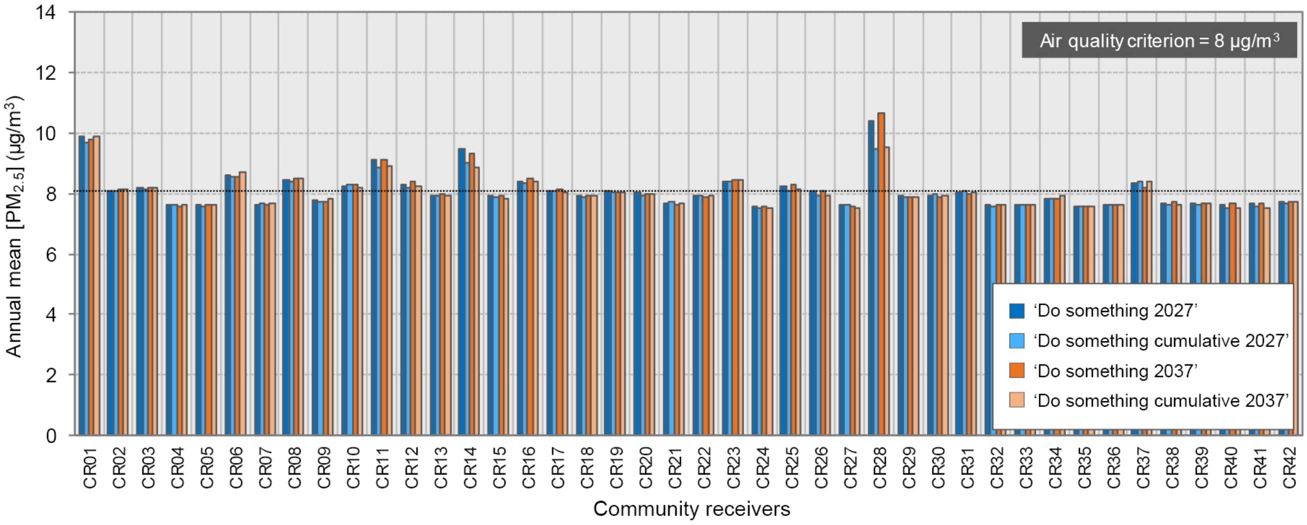

Figure 12-22 Annual mean $PM_{2.5}$ concentration at community receivers

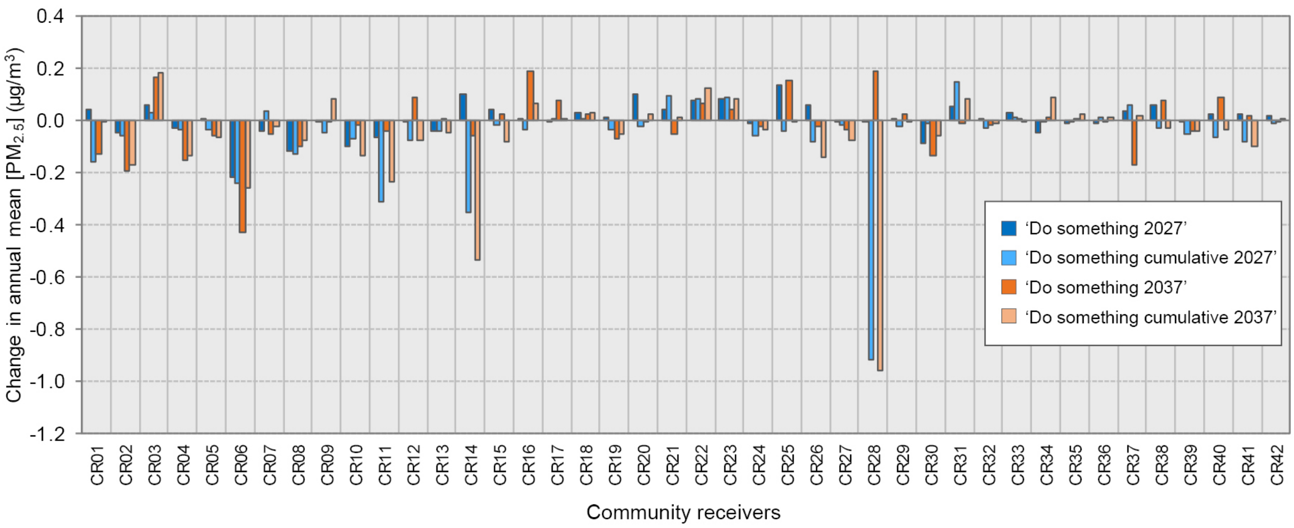

Figure 12-23 Change in annual mean $PM_{2.5}$ concentration at community receivers

Carbon monoxide (CO)

Residential, workplace and recreational receiver locations

The 1-hour and maximum rolling 8-hour mean CO criterion would not be exceeded at any of the receiver locations in any scenario. The highest total 1-hour CO concentrations in any of the 'Do something' or 'Do something cumulative' scenarios is predicted to be 5.5 mg/m^3. The largest predicted contribution from ventilation outlets at any receiver is predicted to be less than 0.1 mg/m^3. Rolling 8-hour mean CO concentrations at all the residential, workplace and recreational receiver locations would be similar to those obtained for maximum 1-hour concentrations.

Community receivers

The CO concentration at all the community receiver locations, is predicted to be well below the impact assessment criterion for both the 1-hour and maximum rolling 8-hour mean CO concentrations.

The largest contribution of surface roads to the maximum total concentration in any of the 'Do something' and 'Do something cumulative' scenarios is predicted to be small for both the 1-hour and maximum rolling 8-hour mean CO concentrations. The contribution of the project's ventilation outlets to the maximum CO concentration is zero or negligible for all receivers.

Polycyclic aromatic hydrocarbons and volatile organic compounds

Five compounds – polycyclic aromatic hydrocarbons, benzene, formaldehyde, 1,3-butadiene and ethylbenzene – were considered in the assessment. These compounds were taken to be representative of the much wider range of air toxics associated with motor vehicles, and have commonly been assessed for road projects.

The predicted changes in the maximum 1-hour concentrations for these compounds showed that there would be minor increases in concentration as a result of the project, however, all concentrations would be well below their respective assessment criterions. The increases (and decreases) for the most affected residential, workplace and recreational receiver locations would be higher for those that are in closer proximity to the surface roads, but in all cases and for all five compounds considered in the assessment, the total predicted concentrations would be well below their respective criteria. For example, the largest change in benzene concentrations at any residential, workplace and recreational receiver location for a 'Do something cumulative' scenario is predicted to be 3.6 µg/m^3 but the total concentration of 8.0 µg/m^3 still remains well below the criterion of 29 µg/m^3 (0.029 mg/m^3).

12.6.3 Redistribution of air quality impacts

Spatial changes in air quality

The spatial changes in pollutant concentrations are assessed with respect to annual mean $PM_{2.5}$ concentration, given its importance in terms of human health risks. However, the spatial changes would be qualitatively similar for all pollutants.

The annual mean $PM_{2.5}$ concentration as a result of the project ('Do something 2027' scenario, relative to 'Do minimum 2027' scenario) is predicted to decrease along the Western Distributor, the Sydney Harbour Bridge and Warringah Freeway due to decreased traffic demand (as more cars would use the Western Harbour Tunnel as an alternative harbour crossing). Decreased traffic demand would result in improved amenity along these built-up road corridors. The human health benefits associated with the decrease in $PM_{2.5}$ concentration as a result of the project is discussed in Chapter 13 (Human health). The changes in $PM_{2.5}$ concentration in the 'Do something 2037' scenario would be broadly similar to the 'Do something 2027' scenario.

For the cumulative scenarios, including the Beaches Link and Gore Hill Freeway Connection project, there would be reductions in $PM_{2.5}$ concentration along Military Road, Spit Road, Manly Road and Warringah Road, due to decreased traffic volumes. Decreased traffic demand on these surface roads (due to more vehicles using the program of works) would result in improved amenity along these roads. There would be an increase in $PM_{2.5}$ concentration along Wakehurst Parkway as a result of the expected increase in traffic demand associated with the Beaches Link and Gore Hill Freeway Connection project. The section of Wakehurst Parkway that would be affected by increased traffic demand, crosses bushland and there are no sensitive receivers close to the road.

Overall, there would be no marked redistribution of air quality impacts, and there would generally be a shift towards lower concentrations. Most notably, there would be no significant increase in concentration at receiver locations which already would have high concentrations in the 'Do minimum' scenarios.

12.6.4 Ambient air quality (elevated receivers)

$PM_{2.5}$ (annual mean)

The changes in annual mean $PM_{2.5}$ concentration in the 'Do something cumulative 2037' scenario was considered for receiver heights of 10 metres, 20 metres, 30 metres and 45 metres above ground level, respectively. Existing buildings at receiver locations are not at all of these heights (eg at a receiver location, an existing building may be up to 10 metres in height, but was assessed at all four selected heights). Statistics relating to the changes in annual mean concentration at all residential, workplace and recreational receiver locations (whether there is an existing building at that location at each height or not) and at receiver locations with an existing building at that height in the model domain are provided in Table 12-9.

Table 12-9 Changes in annual mean $PM_{2.5}$ concentration at elevated receiver locations – 'Do something cumulative 2037' compared with 'Do minimum 2037'

Height	Maximum increase in $PM_{2.5}$ concentration at residential, workplace and recreational receiver locations ($\mu g/m^3$) (1)	Number of residential, workplace and recreational receiver locations with an increase of more than 0.1 $\mu g/m^3$ (1)	Maximum increase in $PM_{2.5}$ concentration at residential, workplace and recreational receivers ($\mu g/m^3$) (2)	Number of residential, workplace and recreational receivers with an increase of more than 0.1 $\mu g/m^3$ (2)
Ground level	0.58	1554 (4.4%)	0.58	1554
10 metres	0.37	998 (2.8%)	0.18	25
20 metres	0.24	590 (1.7%)	0.09	0
30 metres	0.48	447 (1.3%)	0.13	2
45 metres	2.06	499 (1.4%)	0.05	0

Note 1: Assumes all residential, workplace and recreational receiver locations exist at all heights irrespective of existing building heights at those locations
Note 2: Only includes existing buildings that exist at each height.

Modelled annual mean $PM_{2.5}$ concentrations resulting from surface roads and portals have a reduced influence at receivers at 10 metres height, compared with those at ground level. However, because the influence of surface roads and portals without the project was also reduced at 10 metres, the spatial distribution of changes in annual mean $PM_{2.5}$ concentration at 10 metres and ground level would be quite similar. The largest changes in concentration at 10 metres would be slightly smaller than those at ground level. The largest increase at the height of 10 metres for the residential, workplace and recreational receiver locations would be 0.37 µg/m^3, which can be compared with the maximum increase for any ground-level receiver in the 'Do something cumulative 2037' scenario of 0.58 µg/m^3.

For receivers at heights of 20 metres, 30 metres and 45 metres, the changes in annual mean $PM_{2.5}$ concentrations associated with surface roads would be negligible at all locations. The largest increases at receivers at 20 metres, 30 metres and 45 metres (assuming that all receivers would exist at all heights) would be 0.24, 0.48 and 2.06 µg/m^3 respectively.

For existing buildings that are at heights of 10 metres, 20 metres, 30 metres and 45 metres, the maximum increase in annual mean $PM_{2.5}$ concentration is 0.18 µg/m^3. No existing buildings at those heights are predicted to exceed 1.7 µg/m^3.

$PM_{2.5}$ (maximum 24-hour mean)

The change in maximum 24-hour mean $PM_{2.5}$ concentration in the 'Do something cumulative 2037' scenario was considered for receiver heights of 10 metres, 20 metres, 30 metres and 45 metres, respectively. As noted previously, existing buildings do not exist at all of these heights at all residential, workplace or recreational receiver locations. Statistics relating to the changes in annual mean concentration at all residential, workplace and recreational receiver locations (whether there is an existing building at that location at those heights or not) and at receiver locations with an existing building at that height in the model domain are provided in Table 12-10.

Table 12-10 Changes in maximum 24-hour $PM_{2.5}$ mean concentration at elevated receivers – 'Do something cumulative 2037' compared with 'Do minimum 2037'

Height	Maximum increase in $PM_{2.5}$ concentration at residential, workplace and recreational receiver locations (µg/m^3) (1)	Number of residential, workplace and recreational receiver locations with an increase of more than 0.5 (µg/m^3) (1)	Maximum increase in $PM_{2.5}$ concentration at residential, workplace and recreational receivers (µg/m^3) (2)	Number of residential, workplace and recreational receivers with an increase of more than 0.5 (µg/m^3) (2)
Ground level	2.20	919 (2.6%)	2.20	919
10 metres	2.07	253 (0.7%)	1.61	43
20 metres	1.46	575 (1.6%)	0.44	0
30 metres	8.67	537 (1.5%)	1.01	2
45 metres	9.02	620 (1.8%)	0.36	0

Note 1: Assumes all residential, workplace and recreational receiver locations exist at all heights
Note 2: Only includes residential, workplace and recreational receiver locations that exist at each height

At modelled receiver heights of 10 metres and 20 metres, the maximum increase in concentration would be slightly lower than at ground level but, as with the annual mean, the spatial distributions of changes would be quite similar. At a height of 30 metres and 45 metres the largest increases in the maximum 24-hour $PM_{2.5}$ concentrations would be near the proposed ventilation outlets, and these large increases would be greater than those at 20 metres, 10 metres and ground level. The largest increase in maximum 24-hour $PM_{2.5}$ concentration at any receiver would be about nine µg/m^3 (18 per cent of the assessment criterion) at a height of 45 metres, while at a height of 30 metres the largest increase was around 8.7 µg/m^3. At heights of both 30 metres and 45 metres, the increase in concentration would be less than 1 µg/m^3 at distances from the outlets of greater than 300 metres (in the worst case).

At a height of 10 metres, there would be only 43 existing receivers at that height with an increase in the maximum 24-hour $PM_{2.5}$ concentration of more than 0.5 µg/m^3. At heights of 20 metres and 45 metres, there would be no existing receivers at those heights with an increase in the maximum 24-hour $PM_{2.5}$ concentration of greater than 0.5 µg/m^3. At a height of 30 metres, there would be two existing receivers with an increase in the maximum 24-hour $PM_{2.5}$ concentration of greater than 0.5 µg/m^3.

Summary of results for elevated receivers

The changes in ambient air quality for elevated receivers can be summarised as follows:

- There are no predicted adverse impacts at any existing buildings at any height
- There are no predicted adverse impacts at any existing or future buildings up to a height of 20 metres
- There are predicted impacts for potential future buildings above 20 metres in height within 300 metres of the ventilation outlets, but this would not necessarily preclude such development. Further consideration at rezoning or development application stage would be required
- There are no restrictions to building heights within 300 metres of the Rozelle Interchange outlet. Within 300 metres of the Warringah Freeway outlet, current planning controls for permissible habitable structures restrict buildings to below 20 metres
- Land use considerations would be required to manage any interaction between the project and future development for buildings with habitable structures above 20 metres and within 300 metres of the ventilation outlet. Further discussion is provided in Chapter 20 (Land use and property).

12.6.5 Regional air quality

The absolute changes in the total emissions resulting from the project can be viewed as a proxy for the project's regional air quality impacts which, based on the results, are likely to be negligible. For example:

- Changes in NO_X emissions for the assessed road network in a given assessment year (2027 and 2037) for the 'Do something' scenario ranged from an increase of one tonne per year to a decrease of around four tonnes per year depending on the scenario. In the 'Do something cumulative' scenarios (2027 and 2037), changes in NO_X emissions ranged from an increase of 28 tonnes per year and an increase of 124 tonnes per year, depending on the scenario. These values equated to small proportions of human activity related NO_X emissions in the Sydney airshed in 2016 (about 53,700 tonnes)
- Any increases in the NO_X emission rate due to the project in a given assessment year (2027 or 2037) would be much smaller than the underlying reduction in the emission rate between 2016 and 2037. This underlying reduction would be about 2000 tonnes per year.

The regional air quality impacts of a project can also relate to capacity to influence ozone production. Project related NO_X emissions are well below the NSW EPA threshold for conducting a further detailed assessment of impacts to ozone.

Overall, the regional impacts of the project would be negligible and undetectable in ambient air quality measurements at background locations.

12.6.6 Odour

For each of the residential, workplace and recreational receivers, the change in the maximum one hour total hydrocarbon concentration as a result of the project was calculated. The largest change in the maximum one hour total hydrocarbon concentration across all receivers was then determined, and this was converted into an equivalent change for three of the odorous pollutants identified in the NSW EPA Approved Methods (toluene, xylenes, and acetaldehyde). Some hydrocarbons emitted from the burning of fuel by motor vehicles create odour. These pollutants were taken to be representative of other odorous pollutants from motor vehicles.

The changes in the levels of three odorous pollutants as a result of the project, and the corresponding odour assessment criteria from the NSW EPA Approved Methods, are shown in Table 12-11. The results show that the predicted change in the maximum 1-hour concentration of each pollutant is well below the corresponding odour assessment criterion in the NSW EPA Approved Methods.

Table 12-11 Odorous pollutant concentrations

Scenario	Maximum predicted increase in total hydrocarbon concentration		
	Toluene ($\mu g/m^3$)	Xylenes ($\mu g/m^3$)	Acetaldehyde ($\mu g/m^3$)
‘Do something 2027’	4.9	4.1	1.1
‘Do something cumulative 2027’	3.6	3.0	0.8
‘Do something 2037’	3.6	3.0	1.2
‘Do something cumulative 2037’	2.5	2.1	0.8
Odour criterion ($\mu g/m^3$)	**360**	**190**	**42**

12.7 Environmental management measures

12.7.1 Management of construction impacts

Environmental management measures relating to air quality impacts during construction are outlined in Table 12-12.

Table 12-12 Environmental management measures for air quality impacts

Ref	Phase	Impact	Environmental management measure	Location
AQ1	Pre-construction	General	Standard construction air quality mitigation and management measures will be detailed in construction management documentation and implemented during construction, such as: a) Reasonable and feasible dust suppression and/or management measures, including the use of water carts, dust sweepers, sprinklers, dust screens, site exit controls (eg wheel washing systems and rumble grids), stabilisation of exposed areas or stockpiles, and surface treatments b) Selection of construction equipment and/or materials handling techniques that minimise the potential for dust generation c) Management measures to minimise dust generation during the transfer, handling and on site storage of spoil and construction materials (such as sand, aggregates or fine materials) (eg the covering of vehicle loads) d) Adjustment or management of dust generating activities during unfavourable weather conditions, where possible e) Minimisation of exposed areas during construction f) Internal project communication protocols to ensure dust-generating activities in the same area are coordinated and mitigated to manage cumulative dust impacts of the project g) Site inspections will be carried out to monitor compliance with implemented measures.	WHT/WFU
AQ2	Construction	General	Dust and air quality complaints will be managed in accordance with the overarching complaints handling process for the project. Appropriate corrective actions; if required, will be taken to reduce emissions in a timely manner.	WHT/WFU

WHT = Western Harbour Tunnel, WFU = Warringah Freeway Upgrade

12.7.2 Management of operational impacts

The Secretary's environmental assessment requirements for the project require details of, and justification for, the air quality management measures that were considered for the project. This section reviews the environmental management measures that are available for improving tunnel-related air quality, and then describes their potential application in the context of the project. The measures are categorised as follows:

- Tunnel design
- Ventilation design and control
- Air treatment systems
- Emission controls and other measures.

Tunnel design

Tunnel infrastructure has been designed so that the generation of pollutant emissions by traffic using the tunnel is minimised. The main considerations are minimising the length of steep gradients and ensuring that lane capacity remains constant or increases from entry to exit point. Traffic management can also be used to improve traffic flows, which results in reduced overall emissions.

Ventilation design and control

There are several reasons why a tunnel needs to be ventilated. The main reasons are:

- Control of the internal environment. It must be safe and comfortable to drive through the tunnel. Vehicle emissions must be sufficiently diluted so as not to be hazardous during normal operation, or when traffic is moving slowly or stationary
- Protection of the external environment. Ventilation, and the dispersion of pollutants, is the most widely used method for minimising the impacts of tunnels on ambient air quality. Collecting emissions and venting them via elevated ventilation outlets is a very efficient way of dispersing pollutants. Studies show that the process of removing surface traffic from heavily trafficked roads and releasing the same amount of pollution from an elevated location results in substantially lower concentrations at sensitive receivers (PIARC 2008a)
- Emergency situations. When a fire occurs in a tunnel, the ventilation system is able to control the heat and smoke in the tunnel so as to permit safe evacuation of occupants, and to provide the emergency services with a safe route to deal with the fire and to rescue any trapped or injured persons
- The ventilation system design options that were considered for the project are discussed in Chapter 4 (Project development and alternatives) and the system adopted for the project is described in Chapter 5 (Project description).

Air treatment systems

There are several air treatment options for mitigating the effects of tunnel operation on both in-tunnel and ambient air quality. Where in-tunnel treatment technologies have been applied to road tunnels, these technologies have focused on the management and treatment of particulates.

In Australia, the issue of air treatment frequently arises during the development of new tunnel projects. All tunnel projects have, however, gravitated towards a decision not to install an air treatment system, and to rely instead on the primary approach of dilution of air pollution (through ventilation systems) (PIARC 2008a; CETU 2016).

An in-tunnel air treatment system – including electrostatic precipitator (ESP) and denitrification technologies – was trialled in the Sydney M5 East tunnel, although measurement campaigns have indicated that emissions from the tunnel ventilation outlet do not have any significant impact on external air quality. The filtration system was installed 500 metres from the western portal in the westbound tunnel. A structure was built to host the ESP and NO_2 treatment systems, fans, offices and ancillary equipment. A 300 metre ventilation duct to connect the plant to the tunnel was also built. The filtered air from the tunnel, rather than being discharged directly outside, is reinjected into the tunnel and then eventually discharged by the existing ventilation outlet. The end-to-end cost of this treatment project was $65 million. The high cost reflects the fact that the tunnel was not originally designed to accommodate such systems (AMOG 2012).

In November 2018, the ACTAQ published a technical paper which reviewed options for treating road tunnel emissions (ACTAQ 2018b). The review concluded that:

- Decisions on how to best manage tunnel air can only be made at the project level. Health-based air quality standards must be a priority; however, engineering and economic factors also need to be taken into account
- Air filtration systems in tunnels are rare around the world. They have high infrastructure, operating and maintenance costs
- Although filtration for particulates or NO_2 is technically feasible, the available technologies will not lower concentrations of other air pollutants
- Alternatives such as portal air extraction (ie no portal emissions) and dispersion via ventilation outlets may achieve the same outcomes as filtration at a lower cost.

The ACTAQ assessment has demonstrated that the appropriate design of ventilation outlets would achieve the same (or better) outcomes as installing air filtration systems – that is, the contribution of tunnel ventilation outlets to pollutant concentrations would be negligible for all receivers.

Emission controls and other measures

Various operational measures are available to manage in-tunnel emissions and ambient air quality. These include the following:

- Traffic management. Traffic management would be employed by tunnel operators to control exposure to vehicle-derived air pollution. Measures can include (PIARC 2008a):
  - Allowing only certain types of vehicle
  - Regulating time of use
  - Tolling (including differential tolling by vehicle type, emission standard, time of day, occupancy)
  - Reducing traffic throughput
  - Lowering the allowed traffic speed
- Incident detection. Early detection of incidents and queues is essential to enable tunnel operators and the highway authority to put effective traffic management in place. Monitoring via CCTV cameras is normally a vital part of the procedure for minimising congestion within tunnels and allowing timely operator response to changes in traffic flow
- Public information and advice. Traffic lights, barriers, variable message signs, radio broadcasts, public address systems (used in emergencies) and other measures can help to provide driver information and hence influence driver behaviour in tunnels
- Cleaning the tunnel regularly assists in reducing concentrations of small particles (PIARC 2008a), as is common practice in existing Sydney tunnels.

Detailed design of the in-tunnel monitoring system would be carried out during future project development phases and would include the following:

- Nitrogen oxide, NO_2, CO and visibility. Monitoring of each pollutant will be carried out throughout the tunnel. The locations of monitoring equipment will generally be at the beginning and end of each ventilation section. This would include, for example, monitors at each entry ramp, exit ramp, merge point and ventilation outlet and supply point. The location of monitors will be governed by the need to meet in-tunnel air quality criteria for all possible journeys through the tunnel system, especially for NO_2. This will require sufficient, appropriately placed monitors to calculate a journey average

- Velocity monitors will be placed in each tunnel ventilation section and at portal entry and exit points. The velocity monitors in combination with the air quality monitors will be used to modulate the ventilation within the tunnel to manage air quality and to ensure net air inflow at all tunnel portals.

Chapter

13

Chapter 13

Human health

January 2020

13 Human health

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

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

The proposed environmental management measures relevant to human health impacts are discussed in Section 13.6.

Table 13-1 Secretary's environmental assessment requirements checklist – Health

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

Secretary's requirement	Where addressed in EIS
e. include both incremental changes in exposure from existing background pollutant levels and the cumulative impacts of project specific and existing pollutant levels at the location of the most exposed receivers and other sensitive receptors (including public open space areas child care centres, schools, hospitals and aged care facilities);	Health related air quality impacts during operation, including cumulative impacts, are discussed in **Section 13.5**.
f. assess the likely risks of the project to public safety, paying particular attention to pedestrian safety, subsidence risks, bushfire risks and the handling and use of dangerous goods;	**Section 13.4** and **Section 13.5** considers pedestrian/public safety during construction and operation. Subsidence is considered in **Chapter 16.4.2** (Geology, soils and groundwater). **Chapter 23** (Hazards and risks) includes an assessment of bushfire risks and the handling and use of dangerous goods.
g. assess the opportunities for health improvement;	Beneficial impacts associated with the project are discussed in **Section 13.4** and **Section 13.5**.
h. assess the distribution of the health risks and benefits; and	The distribution of the health related risks and benefits are presented in **Section 13.4** and **Section 13.5**. Consideration of the distribution of noise and air quality impacts are presented in **Chapter 10** (Construction noise and vibration), **Chapter 11** (Operational noise and vibration) and **Chapter 12** (Air Quality).
i. include a cumulative human health risk assessment inclusive of in-tunnel, local and regional impacts due to the operation of and potential continuous travel through motorway tunnels and surface roads.	Health related air quality impacts are discussed in **Section 13.5.1** and **Section 13.5.2**.
Water – Quality	
1. The Proponent must: h. demonstrate that all practical measures to avoid or minimise water pollution and protect human health and the environment from harm are investigated and implemented;	Practical management measures to be adopted for the project are provided in **Chapter 17** (Hydrodynamics and water quality). Health related risks are considered in **Section 13.4**. Management measures to ensure the protection of human health are outlined in **Section 13.6**.

Secretary's requirement	Where addressed in EIS
Soils	
3. The Proponent must assess whether the land and harbour sediment is likely to be contaminated and identify if remediation is required, having regard to the ecological and human health risks posed by the contamination in the context of past, existing and future land uses. Where assessment and/or remediation is required, the Proponent must document how the assessment and/or remediation would be undertaken in accordance with current guidelines.	**Section 13.4** discusses human health risks and impacts due to potential contaminated soil/groundwater exposure. Further details are presented in **Appendix I** (Technical working paper: Health impact assessment). **Chapter 16.4** (Geology, soils and groundwater) considers areas of potential and known land and harbour sediment contamination, having regard to risks to human and environmental receivers. Further details are presented in **Appendix M** (Technical working paper: Contamination).

13.1 Legislative and policy framework

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

13.1.1 Principal guidance

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

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

13.1.2 Supporting guidance

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

- *National Environmental Protection (Air Toxics) Measure, Impact Statement for the National Environment Protection (Air Toxics) Measure*, National Environment Protection Council (NEPC), 2003a
- *Risk Assessment Guidance for Superfund, Volume I: Human Health Evaluation Manual (Part F, Supplemental Guidance for Inhalation Risk Assessment*), United States Environmental Protection Agency (USEPA), 2009
- *Building Better Health, Health considerations for urban development and renewal in the Sydney Local Health District*, NSW Health 2016
- *Healthy Urban Development Checklist, A guide for health services when commenting on development policies, plans and proposals*, NSW Health, 2009

- *Methodology for Valuing the Health Impacts of Changes in Particle Em*issions, NSW Environment Protection Authority (EPA) 2013
- *Air Quality in and Around Traffic Tunnels*, National Health and Medical Research Council (NHMRC) 2008
- State Environmental Planning Policy No. 33 – Hazardous and Offensive Development
- *Assessing the environmental burden of disease at national and local lev*els, Ostro, 2004.

13.2 Assessment methodology

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

13.2.1 Air quality

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

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

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

- Negligible health related risks – less than one chance in a million ($<1 \times 10^{-6}$)
- Tolerable or acceptable health related risks – between 1×10^{-6} and one chance in ten thousand (1×10^{-4})
- Unacceptable health related risks – more than 1×10^{-4}.

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

13.2.2 Noise and vibration

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

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

For a number of the noise guidelines, the criteria has been established on the basis of noise annoyance, which is considered to be the more sensitive impact and an impact that precedes the physiological impacts. As a result, these guidelines are designed to be protective of all adverse health impacts. Other guidelines are based on specific sensitive health impacts such as sleep disturbance for the assessment of night-time noise.

13.2.3 Social

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

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

13.3 Existing environment

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

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

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

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

13.3.1 Health status of the community

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

Information in relation to health-related behaviours (that are linked to poorer health status and chronic disease including cardiovascular and respiratory diseases, cancer, and other conditions that account for much of the burden of morbidity and mortality in later life) is available for the larger populations within the local area health services in Sydney and NSW. This includes excessive alcohol consumption, smoking, inadequate consumption of fruit and vegetables, being overweight or obese, and inadequate physical activity.

The study population is largely located within the Northern Sydney, Sydney and South Eastern Sydney Area Health Services. Review of this data generally indicates that, when compared to

NSW as a whole, the population in the Northern, Sydney and South Eastern Sydney Area Health Service areas (that include the study area) have:

- Lower rates of physical inactivity and of being overweight and obese
- Lower rates of smoking (Northern Sydney Local Health District)
- Lower rates of mortality, except for lung cancer, which was lower in the Sydney Health District only
- Lower rate of hospitalisations, with the exception of cardiovascular disease hospitalisations in the South Eastern Sydney District, which is similar to the rate for NSW.
- High or very high rates of psychological distress reported in 2015 in the Sydney Local Health District (13.9 per cent) is a little higher than the state average, and in Northern Sydney (10 per cent) and South Eastern Sydney local health districts (9.3 per cent) is a little lower than the state average (11.8 per cent), however none were substantially different
- High or very high rates of psychological distress in Northern Sydney Local Health District has varied between eight and 15 per cent, while in the Sydney Local Health District it has varied between 10 and 15 per cent between 2003 and 2015. In the South Eastern Sydney Local Health District, the rate has declined from around 14 per cent in 2003 to less than 10 per cent in 2015.

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

13.3.2 Potentially impacted communities

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

The human health impact assessment considers community receivers identified in the suburbs close to the project. Community receivers are locations in the local community where more sensitive members of the population, such as infants and young children, the elderly or those with existing health conditions or illnesses, may spend a significant period of time. These locations comprise hospitals, child care facilities, schools and aged care homes/facilities. Details of the sensitive or community receivers included in the assessment are provided in Chapter 12 (Air quality) and Appendix H (Technical working paper: Air quality).

13.4 Assessment of potential construction impacts

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

- Air quality
- Noise and vibration
- Social impacts.

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

13.4.1 Health related air quality impacts during construction

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

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

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

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

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

As part of the marine construction activities for the project, a large amount of material would be dredged from the harbour bed bringing potentially odorous material to the surface, which has the potential to generate odour once exposed to air.

Dredged material on barges would be covered with water which would reduce any odour emissions. Any odour impacts from the dredged material would be low, given it would remain wet and located at some distance from any sensitive receivers during dredging, transportation and treatment. At the White Bay construction support site (WHT3), odour from dredged material would be undetectable for all sensitive receivers near the site.

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

13.4.2 Health related noise and vibration impacts during construction

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

Noise that may be generated during construction has been modelled based on the type of equipment to be used, the proximity of community receivers, the hours of work, the duration of the activities carried out and the local terrain.

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

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

- Day, Evening or Night noise management levels
- Sleep disturbance criteria, including the criteria for awakening.

Results from this modelling, and associated assessments including distribution of potential impacts, are provided in Appendix G (Technical working paper: Noise and vibration) and discussed in Chapter 10 (Construction noise and vibration). The following sections describe potential impacts related to noise and vibration criteria and possible human health impacts.

Construction noise impacts from the movement of construction vehicles

Potential increases in noise for sensitive receptors due to construction traffic has been assessed separately from the assessment of noise from other construction activities. Construction support sites have been configured such that heavy vehicles involved in construction are expected to travel via existing major roadways with minimal use of local roads. Potential exceedances in noise criteria have been identified at Berrys Bay and Cammeray Golf Course.

Ground-borne construction noise

Ground-borne noise occurs when works are being carried out underground or in a way that results in the vibrations from noise moving through the ground rather than the air. The project involves tunnelling, so many of the more significant noise activities would take place at depth (with a large proportion of the mainline tunnels at depths of 10 metres to greater than 50 metres). Ground-borne noise would consist of roadheader and rock hammer tunnelling. Modelling carried out contemplated the worst-case scenario when the tunnelling is occurring immediately beneath a sensitive receiver. The roadheader excavation would typically progress at around 20 to 30 metres per week subject to local geology and confirmation of the tunnel excavation methods. Roadheader advance rates would reduce to two to five metres a day around the tunnel portals, which may slightly increase the duration of exposure for receivers in these areas.

The excavation by the roadheaders may be noticeable in some areas during the evening and during the night for up to about three weeks at each affected receiver as the roadheader passes below them. Ground-borne noise from roadheader activity is expected to exceed the night time noise criteria at about 23 residential properties.

For rock hammering in tunnels, a large number of residential receiver buildings have been identified as exceeding the night time noise management level or evening noise management level (1507 receiver buildings and 731 receiver buildings respectively). Two hundred and seventy one residential receiver buildings have been identified as exceeding the day time noise criteria. Thirty five non-residential receiver buildings may also be affected by ground-borne noise.

Mitigation and management measures include the validation of predicted impacts from the noise and vibration modelling (which is based on a conservative worst-case assessment) and notifying the community of noise impacts anticipated at specific times.

Use of rock hammers during out of hours construction periods would be considered only if verification monitoring during construction determines ground-borne construction noise levels comply with noise management levels.

Airborne construction noise

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

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

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

Following the implementation of all reasonable and feasible mitigation measures, additional measures would be implemented to manage residual noise impacts and to minimise potential health impacts where the recommended noise management levels cannot be achieved. Monitoring would also be carried out periodically throughout all stages of construction to ensure that noise and vibration impacts are being appropriately managed, and the effectiveness of implemented mitigation and management measures.

Construction vibration

Some items of equipment to be used during construction have the potential to cause unacceptable levels of vibration. Managing the potential for such vibration to cause discomfort or structural damage at sensitive receiver locations is based on selecting site-specific suitable plant and methods as well as providing suitable separation distances between the equipment and receiver locations.

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

Underwater noise impacts

Piling in Sydney Harbour would be carried out for the construction of cofferdams at Sydney Harbour south (WHT5) and Sydney Harbour north (WHT6). Piling would predominately consist of vibratory piling (in harbour sediments) and impact piling (through rock). Impact piling would generate higher potential impact compared to vibratory piling.

Sound pressure levels during the installation of piles and dredging would exceed the precautionary guideline of 145 dB re 1μPa (Jasco, 2019). The various headlands and islands that are located near the construction noise source, such as Birchgrove, Ballast Point, Balls Head, Blues Point and Goat Island, are expected to reduce or block acoustic energy that would otherwise propagate through Sydney Harbour (Jasco, 2019). The exceedance of the precautionary guideline would depend on the proximity to construction activities, lessening as distance from construction activities increases. The distances of this exceedance would be better understood in the initial phases of works through monitoring. The piling program would then be refined with the consideration of reasonable and feasible program alternatives and appropriate environmental management measures to minimise underwater noise impacts.

Piling would occur during standard construction hours with respite periods required for impact piling (Appendix G (Technical working paper: Noise and Vibration)). A marine exclusion area would also be provided in the immediate vicinity of construction activities to manage navigation conflicts.

For divers, a sudden increase in sound pressure levels could potentially startle, or cause discomfort, dizziness and vertigo. Some startled divers subjected to excessive sound pressure level can potentially place themselves in a life-threatening situation.

A hierarchy of risk management measures would be implemented for divers and recreational swimmers within the area where exceedances of the precautionary guideline of 145 dB re 1μPa are predicted to potentially occur. This would be supported by a proactive communication strategy. Management measures would be informed by the final construction methodologies and mitigation measures, and an initial trial of piling to validate thresholds and management areas.

Management measures for underwater noise impacts would be implemented according to the type of works occurring and the extent to which exceedances of the precautionary guideline are predicted (the management zone). Management measures would be reviewed and, if required, amended over the piling program to reflect monitoring outcomes.

13.4.3 Health related social impacts during construction

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

Health related social impacts are discussed below in terms of:

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

Changes in traffic, public transport, access and connectivity

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

- Temporary changes to road conditions, which could include partial and full road closures, diversions and access changes, shared user path closures, removal of on-street parking and reductions in speed limits, changes to property accesses
- Increased construction traffic on roads leading to longer travel times and potentially impacting on community perceptions of safety for motorists, cyclists and pedestrians if not appropriately managed
- Potential disruptions to public transport services including from the temporary closure of Birchgrove Wharf, and changes to road conditions and the temporary relocation of some bus stops near to construction works for safety, resulting in possible delays and disruptions for bus users and changes in bus access for some people
- Changes to pedestrian and cycle access near to construction works, resulting in possible disruptions which may result in delays and disruptions to commuters
- Temporary changes to property access near construction works, with suitable access arrangements to be implemented
- Relocation of swing moorings in the vicinity of Berrys Bay construction support site (WHT7), with relocated moorings to be placed as close as possible to the original location during construction and restored where possible to the original position on completion of construction.

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

Public safety and contamination

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

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

Sediment sampling was carried out within the Sydney Harbour crossing and at construction support sites at White Bay and Berrys Bay (Douglas Partners and Golder Associates, 2017; Appendix M (Technical working Paper: Contamination)). Where sediments require excavation and removal to facilitate construction, the use of silt curtains and a backhoe dredge with a closed bucket attachment would minimise the risk of sediment, and contaminants within the sediments, being mobilised into the water during dredging. This control in conjunction with the behaviour of sediment bound contaminants means it is unlikely that water quality would be significantly impacted by contaminants mobilised from dredging and marine construction activities (Appendix Q (Technical working paper: Marine water quality)).

Provided the proposed management measures are adopted, it is expected that there would be negligible impacts to human health in the event that recreational exposures occur in areas surrounding the proposed works.

Property acquisitions

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

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

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

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

Loss of 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’s play areas. Epidemiological studies have been carried out 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 health benefits of green space in urban areas include the following:

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

There are a number of existing sporting/recreational facilities and parks in the project area, that include sporting fields, parks and reserves and playgrounds. Impacts on these green spaces include:

- Temporary and permanent loss of a portion of land, including recreation land at Cammeray Golf Course – noting that Western Harbour Tunnel and Beaches Link program of works has been designed to enable Cammeray Golf Course to remain operational during construction and operation
- Temporary use of public open space areas for construction sites (for example, Yurulbin Park and St Leonards Park), resulting in the temporary loss of access to and use of land within the construction footprint
- Reduced amenity due to construction activities and construction support sites and changes in noise, dust and visual environment, detracting from the use and enjoyment for users of social infrastructure near the project.

The reduced amenity may affect the desirability of active recreational use of some areas. Alternate green spaces are available in the project area and are accessible by the community, and so the potential effects on community health associated from the temporary use of parks and open space areas during construction is considered to be minimal.

Visual amenity

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

Visual amenity can be described as the pleasantness of the view or outlook of an identified receiver or a group of receivers (eg residences, recreational users). Visual amenity is an important part of an area's identity and offers a wide variety of benefits to the community in terms of quality of life, wellbeing and economic activity.

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

For some individuals, changes in visual amenity can increase levels of stress and anxiety. These impacts, however, are typically of short duration as most people adapt to changes in the visual landscape, particularly within an already urbanised area. As a result, most changes in visual impacts are not expected to have a significant impact on the health of the community.

Construction fatigue

Construction fatigue relates to receivers 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.

The assessment of construction fatigue includes the following projects that may overlap with the construction phase of the project:

- M4-M5 Link
- White Bay and Glebe Island projects

- Sydney Metro City & Southwest (Chatswood to Sydenham), including the White Bay truck marshalling yard
- The New Sydney Fish Markets
- Sydney Metro West
- Projects within North Sydney (eg commercial developments)
- Beaches Link and Gore Hill Freeway Connection.

As outlined in Chapter 27 (Cumulative impacts), the areas of greatest potential for cumulative impacts are in Rozelle and White Bay in the south, and in North Sydney and Cammeray in the north. These impacts are most likely to be generated by interactions between the project, the M4-M5 Link, projects in White Bay and Glebe Island, Beaches Link and Gore Hill Freeway Connection, Sydney Metro City & Southwest (Chatswood to Sydenham) and Sydney Metro West.

Based on the environmental impact assessment for the project and for the projects listed above, potential impacts considered most likely to result in construction fatigue include construction traffic and parking, construction noise and vibration, visual and amenity impacts, and impacts to community perceptions of public health and safety.

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

Economic aspects

The construction expenditure of the project would be of significant benefit to the economy. This expenditure would inject economic stimulus benefits into the local, regional and state economies. Ongoing or improved economic vitality is of significant health benefit to the community. Employment opportunities would grow in the construction period through the potential increase in business customers and through the increase in demand for construction workers.

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

13.5 Assessment of potential operational impacts

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

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

13.5.1 Health related ambient air quality impacts during operation

Air quality impacts and details of the distribution of impacts outside of the tunnel during operation are presented in Chapter 12 (Air Quality).

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

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

In addition, a regulatory worst-case scenario has been evaluated. The regulatory worst case assumes that the tunnel is full of vehicles, such that the emissions from the ventilation outlets are at the maximum level, at all hours of the day. This is not a realistic scenario however it is used to demonstrate compliance with regulatory assessment requirements. Further detail is available in Section 5.10 of Appendix I (Technical working paper: Health impact assessment).

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

The tunnel ventilation system and tunnel operational parameters for the project have been designed so that the in-tunnel air quality concentration limits are not exceeded, and to control the concentration of pollutants discharged to the external environment. The predicted ambient air quality for the expected traffic scenarios are presented, by pollutant, in Chapter 12 (Air quality).

Nitrogen dioxide

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

NO_2 is the only oxide of nitrogen that may be of concern to health (World Health Organisation (WHO), 2000). NO_2 can cause inflammation of the respiratory system and increase susceptibility to respiratory infection. The health effects associated with exposure to NO_2 depend on the duration of exposure as well as the concentration.

Guidelines are available from the NSW EPA and NEPC (NEPC, 2003b) which indicate acceptable concentrations of NO_2. The assessment of acute exposures relates to the maximum predicted total one-hour average concentration in air and considers the 'Do minimum', 'Do something' and 'Do something cumulative' scenarios. An acute exposure guideline of 246 micrograms per cubic metre of NO_2 in air over a one-hour average period has been adopted for the project. The assessment of chronic exposures relates to the maximum predicted annual average concentration in air, and considers the 'Do minimum', 'Do something' and 'Do something cumulative' scenarios. A chronic exposure guideline of 62 micrograms per cubic metre of nitrogen dioxide in air over a one-hour average period has been adopted for the project. An uncertainty factor of two was applied to both the acute and chronic exposure guidelines to account for susceptible people (ie asthmatic children). On this basis, the acute and chronic exposure guidelines are protective of adverse health effects in all individuals, including sensitive individuals like asthmatics, children and the elderly.

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

Assessment of acute exposures

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

Assessment of chronic exposures

The NEPC ambient air quality guideline for the assessment of chronic (long-term) exposures to NO_2 relates to the maximum predicted total (cumulative) annual average concentration in air (NEPC, 2003b).

The assessment completed for the project indicates that all concentrations of NO_2 would be below the chronic guideline by more than 15 µg/m^3 for all scenarios. Therefore, no adverse health impacts would be expected as a result of chronic exposures to NO_2 from the project.

The operation of the project would provide some human health benefit by lowering the concentrations of NO_2 in the local community because of the removal of traffic demand from some surface roads.

Assessment of incremental exposures

The assessment indicates that the individual risks (ie of mortality (respiratory and all causes) and asthma admissions) calculated for changes in NO_2 levels associated with the project would be less than $1x10^{-4}$ (1 in 10,000) for residential areas, commercial/industrial areas, childcare centres, schools, aged care homes and open space areas and all community receivers and would therefore be considered tolerable and acceptable.

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

- The total change in the number of cases relevant to the health impacts evaluated, for both 2027 and 2037 ('Do something' and 'Do something cumulative') is negative, meaning a decrease in incidence as a result of the project (due to the redistribution of traffic on surface roads). The change however is small, with a decrease of around one case
- Review of the incidence calculated for the individual suburbs indicates that these predominantly relate to small decreases in health incidence with some suburbs showing an increase. The largest increase in health incidence for any individual suburb is less than one case/person.

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

Particulate matter

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

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

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

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

The current NEPC and NSW Environment Protection Authority (EPA) air quality goals and guidelines/standards for particulate matter are presented in Chapter 12 (Air quality).

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

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

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

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

Assessment of total exposures

Due in large part to the existing levels of $PM_{2.5}$ in air within the existing urban environment, the maximum total concentrations of $PM_{2.5}$ are above the guidelines for both a 24-hour average and the annual average (including the 2025 goal by NEPC (2016)) with or without the operation of the project. These elevated background levels would be present in the community regardless of the construction and operation of the project. Concentrations of total $PM_{2.5}$, however, are essentially unchanged to slightly lower in most cases within the local community with the operation of the project only (‘Do something’) and in conjunction with other road tunnel projects by 2037 (‘Do something cumulative’).

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

Assessment of incremental exposures

The calculated changes in risk (associated with individual mortality; cardiovascular illness, respiratory or asthma hospitalisations; and lung cancer) associated with the expected operation of the project in 2027 and 2037 (‘Do something’), including the cumulative scenarios (‘Do something cumulative’) indicates the maximum risks associated with the changes to $PM_{2.5}$ and PM_{10} concentrations would be below $1x10^{-4}$ (1 in 10,000) for exposures in residential, commercial and industrial areas, childcare centres, schools, aged care homes and open space areas. This is considered to be tolerable or acceptable.

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

- The total change in the number of cases (totals for each local government area (LGA) considered) relevant to the health effects evaluated for the project in 2027 (‘Do something’) are mostly negative, meaning an overall decrease in incidence as a result of the project
- The total change in the number of cases (totals for each Local Government Area (LGA) considered) relevant to some of the health impacts evaluated for the ‘Do something cumulative 2027’ scenarios is positive, indicating an increase. These increases are small (less than one case per year for all health impacts considered). There are also small negative changes associated with some health impacts considered. These changes (positive and negative) would not be measurable within the community and the impacts are considered to be negligible

- The total change in the number of cases (totals for each Local Government Area (LGA) considered) relevant to all the health impacts evaluated for the 'Do something 2037' and 'Do something cumulative 2037' scenarios are negative, meaning a decrease in incidence as a result of the project (due to the redistribution of traffic demand on surface roads)
- Many of the individual LGAs show a total decrease in health incidence. There are a few LGAs where there is an increase. These increases and decreases are also very small, less than one case per year for all health impacts considered. As a result, these changes would not be measurable in the community and the impacts are considered to be negligible
- Within these LGAs there are a number of smaller suburbs. The incidence calculated for the individual suburbs indicates that these predominantly relate to small decreases in health incidence with some suburbs showing an increase. The largest increase in health incidence for any individual suburb would be less than one case per year. Therefore, there would be no individual suburbs within the LGAs assessed for which the increased health incidence would be of significance or measurable.

Assessment of elevated receivers

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

The calculated health risks associated with changes in annual $PM_{2.5}$ concentrations for elevated receivers at 10, 20 and 30 metre heights would range from negligible to acceptable and are not expected to result in any measurable health-related impacts.

For elevated receptors at 45 metres height, the maximum increase in $PM_{2.5}$ and individual risks are higher, with the maximum individual risk exceeding 1×10^{-4}, which is considered unacceptable. However, the maximum increases in $PM_{2.5}$ and individual risks are at locations close to the ventilation outlets, where there are no buildings of that height present. The maximum predicted increase in $PM_{2.5}$ at an existing building that is about 45 metres in height is 0.05 $\mu g/m^3$, where the maximum individual risk is 4×10^{-6}, which is considered tolerable/acceptable.

The implications of this assessment on surrounding land use is discussed in considered in Chapter 20 (Land use and property). Land use considerations would be required to manage any interaction between the project and future development for buildings with habitable structures above 20 metres and within 300 metres of the ventilation outlet.

Carbon monoxide

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

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

Volatile organic compounds and polycyclic aromatic hydrocarbons

Air toxics assessed for the project include volatile organic compounds (VOCs) and polycyclic aromatic hydrocarbons (PAHs) and are associated with emissions from vehicles using the mainline tunnels and adjacent surface road network. From a toxicity perspective, the key VOCs from vehicle emissions that have been considered are benzene, toluene, ethylbenzene, and xylenes (BTEX), 1,3-butadiene, acetaldehyde and formaldehyde (consistent with those identified and targeted in studies conducted in Australia on vehicle emissions (NSW EPA, 2012a).

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

- A total Hazard Index less than or equal to one means that all the maximum predicted concentrations are below the health based guidelines and there are no additive health impacts of concern
- A total Hazard Index greater than one means that the predicted concentrations (for at least one individual compound) are above the health based guidelines, or that there are at least a few individual air toxics where the maximum predicted concentrations are close to the health based guidelines such that there is the potential for the presence of all these together (as a sum) to result in adverse health effects.

Assessment of acute exposure

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

Assessment of chronic exposure and incremental lifetime carcinogenic risk

For the assessment of chronic exposures to VOCs and PAHs, the total Hazard Index associated with exposure to the predicted maximum concentrations would be less than one for the Do something' and 'Do something cumulative' scenarios for 2027 and 2037. The calculated lifetime cancer risks associated with the maximum change in benzene, 1,3-butadiene and carcinogenic PAHs (as benzo(a)pyrene TEQ) are less than or equal to 2×10^{-5} and are considered to be tolerable. The approach adopted is expected to overestimate concentrations of PAHs in air. Hence the calculations presented are considered to be a conservative upper limit estimate.

13.5.2 Health related air quality (in-tunnel) impacts during operation

Air quality in-tunnel impacts in the operational period are presented in Chapter 12 (Air Quality).

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

The tunnel ventilation system would be designed and operated so that the operational in-tunnel air quality limits would not be exceeded. The ventilation report is provided as an annexure to Appendix H (Technical working paper: Air quality).

Nitrogen dioxide

A study of NO_2 concentrations inside vehicles travelling in Sydney and using existing road tunnels was commissioned by Roads and Maritime (now Transport for NSW) in 2016 (PEL, 2016) to better understand the relationship between NO_2 outside the vehicle, and inside the vehicle. Within existing tunnels investigated in the study, concentrations of NO_2 were generally less than 0.15 ppm, however during periods of high traffic volumes and a high proportion of heavy vehicles, the concentrations inside existing tunnels exceeded 0.5 ppm, with levels up to 0.7 ppm. Inside these tunnels with high external concentrations of NO_2 dioxide, the average concentrations inside the vehicles, when ventilation was on recirculation was less than 0.2 ppm.

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

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

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

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

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

Particulate matter

Potential concentrations of particulate matter inside the tunnel are derived from exhaust as well as non-exhaust sources. Non-exhaust sources include tyre and brake wear and dust from surface road wear and the resuspension of road dust. The modelling of particulate matter and visibility issues within the tunnel has considered both sources.

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

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

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

Carbon monoxide

The operational in-tunnel limits for carbon monoxide have been adopted based on the conditions of approval for other Sydney road projects. The assessment indicates that there would be no health issues of concern related to in-tunnel exposures to carbon monoxide for motorists using the project, or for motorists with longer journeys that include the project. Furthermore, closing car windows and switching the ventilation to recirculation can reduce exposures by about 70–75 per cent for carbon monoxide.

Carbon dioxide

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

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

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

13.5.3 Health related noise and vibration impacts during operation

Noise and vibration impacts in the operational period are presented in Chapter 11 (Operational noise and vibration). Sound is a natural phenomenon that only becomes noise when it has some undesirable effect on people or animals. Noise and vibration can potentially have both short-term and long-term adverse effects on people. These health effects can include:

- Sleep disturbance (sleep fragmentation that can affect psychomotor performance, memory consolidation, creativity, risk-taking behaviour and risk of accidents)
- Annoyance
- Hearing impairment
- Interference with speech and other daily activities
- Children’s school performance (through effects on memory and concentration)
- Cardiovascular health.

Other potential effects which may occur, but for which the evidence is weaker, include:

- Effects on mental health (usually in the form of exacerbation of existing issues for vulnerable populations rather than direct effects)
- Tinnitus (which manifests as a ringing in the ears when no physical noise is present, can also result in sleep disturbance, anxiety, depression, communication and listening problems, frustration, irritability, inability to work, reduced efficiency and a restricted participation in social life)
- Cognitive impairment in children (including deficits in long term memory and reading comprehension)
- Some evidence of indirect effects such as impacts on the immune system.

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

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

The noise modelling for the project has been carried out to address impacts associated with the operation of the project in 2027 and 2037 ('Do something'), including a cumulative scenario ('Do something cumulative'). The modelling has evaluated noise impacts at the façade of all buildings, including on all floors of multi-storey buildings. An assessment was carried out to determine how well the model estimated noise impacts based on a current scenario. The modelled and measured results were found to be within acceptable tolerances, which are ±2 dB(A).

For the majority of receivers assessed, the project would result in either reduced or relatively minor changes in traffic noise levels. This includes a reduction in traffic noise at a significant number of receiver buildings at Warringah Freeway due to the project (around 75 per cent) as a result of the redistribution of traffic. In areas where there is a reduction in traffic noise, there would be associated health benefits in these communities. However, the assessment also predicts that without mitigation, around one percent of receiver buildings adjacent to the project would experience incremental noise increases greater than 2 dB(A), which may result in health impacts if not appropriately mitigated. Additionally, a number of properties have also been identified where additional mitigation is required due to existing high road traffic noise levels in exceedance of the cumulative noise limit criterion or because traffic noise levels are acute (refer to Chapter 11 (Operational noise and vibration). These elevated noise levels would be present without the project and the implementation of additional noise mitigation would result in lower levels of noise experienced at these receiver buildings.

Mitigation measures considered during operation would principally involve the use of low noise pavement and noise barriers. However, a number of receiver buildings have been identified for being eligible for at-property treatment surrounding the Rozelle Interchange and to the Warringah Freeway Upgrade (refer to Chapter 11 (Operational noise and vibration)) under the 'Do something cumulative' scenario. Where noise mitigation measures are proposed, no significant health impacts are expected. For most properties the implementation of mitigation measures (including at-property treatment) would reduce overall noise impacts from existing noise which triggered the need for mitigation, as well as project related noise. The outcome is expected to be an overall improvement in noise levels within the community (compared with the existing situation) and some potential for improvements in community health.

13.5.4 Health related social impacts during operation

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

Health related social impacts are discussed below in terms of:

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

Changes in traffic, public transport, access and connectivity

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

The project would improve regional access and connectivity for road based public transport, freight and servicing, private vehicles and other road users by providing an alternate crossing of Sydney Harbour. The project would improve travel times on key corridors (such as the Western Distributor, Sydney Harbour Bridge, Sydney Harbour Tunnel and the Victoria Road corridor), improving traffic flow and journey times for buses, freight and other vehicles accessing key commercial and employment centres including the Sydney CBD and North Sydney.

Localised traffic and transport impacts, including localised delays and increased traffic demands on some roads and intersections, may result from the operation of the project at either end of the project where it would integrate with the existing transport network (refer to Chapter 9, Section 9.4 (Operational traffic and transport)). These localised delays would generally be offset by large travel time benefits provided by the project at the broader network level (for example, the project would improve travel times by up to 75 per cent for travel between North Sydney and Rozelle). The impacts of increased traffic demand and delays in the North Sydney area would be further minimised through the North Sydney Integrated Transport Program, which is being developed by Transport for NSW.

Traffic congestion and long commuting times can contribute to increased levels of stress and fatigue, more aggressive behaviour and increased traffic and accident risks on residential and local roads as drivers try to avoid congested areas (Hansson et al. 2011). Increased travel times reduce the available time to spend on healthy behaviours such as exercise or engage in social interactions with family and friends. Long commute times are also associated with sleep disturbance, low self-rated health and absence from work (Hansson et al. 2011). Reducing travel times and road congestion is expected to reduce these health impacts. From a public transport network perspective, the project, once complete, is expected to improve access to public transport and improve journey times for buses for local and regional communities.

Public safety

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

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

Green space

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

Yurulbin Park

After construction, the project is not expected to impact on the ongoing use or functioning of the park and facilities within the park.

Cammeray Golf Course

The project would occupy parts of the golf course as required as part of the Warringah Freeway Upgrade and to accommodate the motorway facilities (including an access road). This would require the reconfiguration of the golf course to allow its ongoing use.

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

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

St Leonards Park

Should the project require the permanent strip acquisition of a small area of St Leonards Park to accommodate upgrades to the Falcon Street/Miller Street intersection as part of the Warringah Freeway Upgrade, the ongoing use or functioning of the park and facilities within the park is not expected to be impacted. Further review of the impacts in this area is currently being carried out and permanent impacts to St Leonards Park would be minimised or, where possible eliminated.

ANZAC Avenue Reserve

The project would require the permanent strip acquisition of a small area of ANZAC Avenue Reserve to accommodate the widening of the Warringah Freeway. This is not expected to impact on the ongoing use or functioning of the park and facilities within the park.

ANZAC Park

After construction, the project is not expected to impact on the ongoing use or functioning of the park and facilities within the park.

Merlin Street Reserve

The project would require the permanent strip acquisition of a small area of Merlin Street Reserve to accommodate the widening of the Warringah Freeway. This is not expected to impact on the ongoing use or functioning of the park and facilities within the park.

Rose Avenue Reserve

The project would permanently affect a strip of Rose Avenue Reserve to accommodate the widening of the Warringah Freeway. This is not expected to impact on the ongoing use of the reserve.

Jeaffreson Jackson Reserve

After construction, the project is not expected to impact on the ongoing use or functioning of the park.

Visual amenity

The operational project would include changes to local visual amenity due to the presence of new and modified/upgraded infrastructure (including motorway facilities, ventilation outlets, wastewater treatment plants, substations, bridges and drainage channels), landscaping and urban design features.

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

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

Economic aspects

Economic impacts are presented in Chapter 21 (Socio-economics). The operational impacts on business are predicted to be positive with improved connectivity and accessibility to business centres. Some localised impacts to access may be experienced due to alternative route arrangements, potentially resulting in delays or inefficiencies. However, these effects are considered minor in comparison to the broader benefits across the region.

Freight and commercial vehicle movements are an important component of the economy. Numerous industries are dependent upon efficient transport to service operational requirements. Transport for NSW estimated that freight and logistics contributed $66 billion to NSW Gross State Product (GSP) (Transport for NSW, 2018a).

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

The transport modelling carried out for the project highlighted that the project would result in substantial travel time savings for freight vehicles, improving their productivity and increasing the efficiency of the freight network particularly for trips that currently use Sydney Harbour Bridge. Improvements in the efficiency and reliability of these transport networks would likely result in increased productivity, reduced costs and broader economic benefits for these workforces.

Road tolling

While no decision on tolls has yet been made, works for Western Harbour Tunnel and Warringah Freeway Upgrade includes provision for tolling gantries for northbound traffic should the government elect to introduce a northbound toll. The implementation of road tolls can have direct impacts on the management of congestion, which has an impact on economic productivity, and social elements such as stress, time with family and friends, cost and environmental amenity such as reduced traffic emissions.

One impact is the potential to increase congestion volumes on surrounding roads as a result of toll avoidance. The use of a toll road can also increase the cost of living and can exacerbate social inequality. Specifically, the impact of roads tolls on households can be assessed as a function of household income, urban spatial structure, and available mobility choices. Depending on the travel routes of individuals, and the individual economic situation, there would be a proportion of the population that avoid the use of tollways due to affordability. In July 2019, the NSW Government implemented a toll relief initiative to ease the cost of living for frequent NSW toll road users through the provision of half-priced or free vehicle registration.

13.6 Environmental management measures

Key environmental management measures relating to human health impacts are mentioned in other chapters within this environmental impact statement, particularly

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

Additional environmental management measures specific to human health impacts are provided in Table 13-2.

Table 13-2 Environmental management measures for human health impacts

Ref	Phase	Impact	Environmental management measure	Location
HH1	Construction	Underwater noise impacts	Monitoring during piling activities will be carried out to validate the predicted underwater acoustic thresholds and management areas, and to further adapt management measures (as required). This will include a monitoring program with an initial trial of piling with corresponding communication measures to validate the predicted underwater acoustic thresholds and management areas. The monitoring results and management areas will be peer-reviewed prior to implementation to ensure they are appropriately protective of health.	WHT (Sydney Harbour)
HH2	Construction	Underwater noise impacts	Communication and management measures will be implemented during construction to manage potential underwater noise impacts to water-based recreational users during dredging and piling activities in Sydney Harbour. The communication tools and management measures that would be contemplated within the management zone include: a) Coordination of piling programs to minimise interaction with significant planned events on the harbour, where feasible and reasonable b) Communication of the piling program and management area so that recreational users know when the piling, dredging and other noise generating activities will be taking place, what they can expect, and the zones to minimise the possibility of being startled from a sudden increase in sound pressure underwater c) Direct communication with key local recreational stakeholders during the piling and dredging program to provide up-to-date scheduling d) Use of advertisements, signage, letter box drops and project updates to communicate the implementation of a management area during the works. This could include floating markers or signage on approach to the construction work	(WHT) Sydney Harbour

Ref	Phase	Impact	Environmental management measure	Location
			e) Surveillance within the areas in which the precautionary guideline level is exceeded to proactively monitor users prior to and during relevant activities that could pose a risk to recreational users.	

Note: WHT = Western Harbour Tunnel

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