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Coffs Harbour Bypass

Environmental Impact Statement

September 2019

VOLUME 10

Air quality and human health assessments

Appendix P – Air quality assessment

Appendix Q – Human health risk assessment

RMS.19.1325
ISBN: 978-1-925891-71-3

APPENDIX

P

Appendix P

Air quality assessment

Coffs Harbour Bypass

ARUP

Air Quality Assessment

12 July 2019

Project No.: 0499760

The business of sustainability

Document details	The details entered below are automatically shown on the cover and the main page footer. PLEASE NOTE: This table must NOT be removed from this document.
Document title	Coffs Harbour Bypass
Document subtitle	Air Quality Assessment
Project No.	0499760
Date	12 July 2019
Author	Russ Francis, Jane Barnett
Client Name	Arup

12 July 2019

Coffs Harbour Bypass

Air Quality Assessment

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Acronyms and Abbreviations

Name	Description
AWS	Automatic Weather Station
BoM	Bureau of Meteorology
CO	Carbon monoxide
CSSI	Critical State Significant Infrastructure
EIS	Environmental Impact Statement
EPA	Environment Protection Authority
GRAL	Graz Lagrangian Model
GRAMM	Graz Mesoscale Model
LGA	Local Government Area
NO_x	Oxides of nitrogen
NO_2	Nitrogen dioxide
NSW	New South Wales
$PM_{2.5}$	Airborne particles with a diameter of less than 2.5 µm
PM_{10}	Airborne particles with a diameter of less than 10 µm
UTM	Universal Transverse Mercator
WHO	World Health Organization

1. INTRODUCTION

1.1 Background

Roads and Maritime is seeking approval for the Coffs Harbour Bypass (the project) located to the west of Coffs Harbour urban area in northern New South Wales (NSW). The project is located in the Coffs Harbour local government area (LGA). The approval is being sought under Division 5.2 of the *NSW Environmental Planning and Assessment Act 1979* (EP&A Act) as Critical State Significant Infrastructure (CSSI).

ERM have been engaged by Arup on behalf of Roads and Maritime to carry out an air quality impact assessment that will support the Environmental Impact Statement (EIS) for the project.

The project complements the Pacific Highway upgrade program which, when complete, will provide free flowing dual carriageway conditions for the Pacific Highway between Hexham and the Queensland border. The benefits of the project include:

- Improve road safety by removing through traffic (light and heavy vehicles) and some local traffic from the existing road network will reduce conflicts and improve safety for all road users;
- Improve travel time for through and local traffic, reducing through traffic travel times;
- Improve transport efficiency of the existing Pacific Highway through Coffs Harbour, relieving congestion on the wider Coffs Harbour road network and providing an alternative route for some local trips. This improved transport efficiency and the resulting improvements to accessibility and amenity to the Coffs Harbour CBD would likely result in wider economic benefits for the Coffs Harbour region;
- Improving freight efficiency for heavy vehicles by providing a high standard dual carriageway road to complement the National Land Transport Network, Future Transport Strategy 2056 and the recently upgraded Pacific Highway.

The Pacific Highway upgrade program also seeks to create public value and ensure safety of its workers and travelling public.

A concept design has been developed for the project, which forms the basis of this assessment. This assessment supports the environmental impact statement (EIS) prepared for the project.

This air quality impact assessment comprises of the following components:

- A project description (Section 2)
- Contextual background information on road traffic and air pollution, and a summary of the air quality assessment criteria that are applicable to the Project (Section 3)
- A description of the existing environment, including background air quality (Section 4)
- The methodology for both the operational and construction impacts of the project (Section 5)
- The results for both the operational and construction impacts of the project (Section 6)
- The conclusions and recommendations from the assessment (Section 7).

1.2 Secretary's Environmental Assessment Requirements

The environmental impact assessment for the project will be subject to the Secretary's Environmental Assessment Requirements (SEARs) SSI-7666 issued by the Department of Planning and Environment (DPE). The requirements for air quality are given in Table 1-1.

Table 1-1: Secretary's Environmental Assessment Requirements

Key issue and desired performance outcome	Requirements	Report Section	Current guidelines
The project is designed, constructed and operated in a manner that minimises air quality impacts (including nuisance dust and odour) to minimise risks to human health and the environment to the greatest extent practicable.	1. The Proponent must undertake an air quality impact assessment (AQIA) for construction and operation of the project in accordance with the current guidelines.	All	Approved Methods for the Modelling and Assessment of Air Pollutants in New South Wales (DEC, 2017)
	2. The Proponent must ensure the AQIA also includes the following:		Approved Methods for the Sampling and Analysis of Air Pollutants in NSW (DEC, 2005)
	(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 3 and 5	Technical Framework - Assessment and Management of Odour from Stationary Sources in NSW (DEC, 2006)
	(b) An assessment of the impacts of the construction and operation of the project on sensitive receivers and the local community, including risks to human health.	Section 6	Protection of the Environment Operations Act 1997 and the Protection of the Environment Operations (Clean Air) Regulation (2010).
	(c) Details of the proposed mitigation measures to minimise the generation and emission of dust (particulate matter and TSP) and air pollutants (including odours) during the construction of the project, particularly in relation to the operation of ancillary facilities (such as concrete and asphalt batching), the use of mobile plant and machinery, stockpiles and the processing and movement of spoil, and construction vehicle movement along the alignment.	Section 5.1.3 and 6.1.1	
	(d) A cumulative local and regional air quality impact assessment.	Section 6.2 and 6.3	

2. PROJECT DESCRIPTION

2.1 Project location

The location and regional context of the project is shown in Figure 2-1. The project is located within the Coffs Harbour City Council LGA within the mid north coast region of NSW. The project will begin south of the Englands Road roundabout and will finish at the dual carriageway highway at Sapphire. The project traverses through a variety of developed environments including low density suburbia and rural area settled outside of Coffs Harbour city centre.

Figure 2-1: Project location

2.2 Project elements

Roads and Maritime Services (Roads and Maritime) is seeking approval for the Coffs Harbour Bypass (the project). The approval is being sought under Division 5.2 of the NSW Environmental Planning and Assessment Act 1979 (EP&A Act) as Critical State Significant Infrastructure (CSSI).

The project includes a 12 km bypass of Coffs Harbour from south of Englands Road to Korora Hill in the north and a 2 km upgrade of the existing highway between Korora Hill and Sapphire. The project would provide a four-lane divided highway that bypasses Coffs Harbour, passing through the North Boambee Valley, Roberts Hill and then traversing the foothills of the Coffs Harbour basin to the west and north to Korora Hill.

The key features of the project include:

- Four-lane divided highway from south of Englands Road roundabout to the dual carriageway highway at Sapphire
- Bypass of the Coffs Harbour urban area from south of Englands Road intersection to Korora Hill
- Upgrade of the existing Pacific Highway between Korora Hill and the dual carriageway highway at Sapphire
- Grade-separated interchanges at Englands Road, Coramba Road and Korora Hill
- A one-way local access road along the western side of the project between the southern tie-in and Englands Road, connecting properties to the road network via Englands Road
- A new service road, located east of the project, connecting Solitary Islands Way with James Small Drive and the existing Pacific Highway near Bruxner Park Road
- Three tunnels through ridges at Roberts Hill (around 190 m long), Shephards Lane (around 360 m long), and Gatelys Road (around 450 m long)
- Structures to pass over local roads and creeks as well as a bridge over the North Coast Railway
- A series of cuttings and embankments along the alignment
- Tie-ins and modifications to the local road network to enable local road connections across and around the alignment
- Pedestrian and cycling facilities, including a shared path along the service road tying into the existing shared path on Solitary Islands Way, and a new pedestrian bridge to replace the existing Luke Bowen footbridge with the name being retained
- Relocation of the Kororo Public School bus interchange
- Noise attenuation, including low noise pavement, noise barriers and at-property treatments as required
- Fauna crossing structures including glider poles, underpasses and fencing
- Ancillary work to facilitate construction and operation of the project, including:
    - Adjustment, relocation and/or protection of utilities and services
    - New or adjusted property accesses as required
    - Operational water quality measures and retention basins
    - Temporary construction facilities and work including compound and stockpile sites, concrete/asphalt batching plant, sedimentation basins and access roads (if required).

3. ROAD TRAFFIC POLLUTANTS AND AIR QUALITY CRITERIA

3.1 Road traffic and air pollution

Road traffic is the dominant source of several important air pollutants in Australian cities. The pollutants released from motor vehicles are implicated in a variety of detrimental effects on amenity, health, ecosystems and cultural heritage. The main focus in both research and project assessment is currently on the short-term and long-term effects of road transport pollution on human health. Repeated exposure to vehicle exhaust gases and particles is linked to, amongst other things, aggravated respiratory and cardiovascular disease, changes to lung tissue, changes in the function of the nervous system, and cancer (IARC, 2012; WHO Regional Office for Europe, 2013). Such effects are likely to be exacerbated by the proximity of the population to road traffic[1] and may increase in prevalence as the volume of traffic increases and congestion becomes more frequent. Moreover, health effects account for the majority of the external costs associated with air pollution. The health costs of air pollution in Australia are estimated to be in the order of \$11.1 billion to \$24.3 billion annually, solely as a result of mortality (Begg et al., 2007; Access Economics, 2008). Road transport is an important contributor; the health costs of emissions from road transport in Australia have been estimated to be \$2.7 billion per year (BTRE, 2005).

Many different air pollutants are emitted directly from road vehicles. These are termed ‘primary’ pollutants. In terms of local air quality and health, as well as the quantity emitted, the main primary pollutants from road vehicles are:

- Carbon monoxide (CO)
- Hydrocarbons (HC). In this context the term ‘hydrocarbons’ covers a wide range of compounds which contain carbon and hydrogen
- Oxides of nitrogen (NO_X). By convention, NO_X is the sum of nitric oxide (NO) and nitrogen dioxide (NO_2), and is stated as NO_2-equivalents
- Particulate matter (PM). PM is emitted from vehicle exhaust and as a result of non-exhaust processes such as tyre wear, brake wear and the resuspension of dust on the road surface. The two metrics that are most commonly used are PM_{10} and $PM_{2.5}$, which are particles with an aerodynamic diameter of less than or equal to 10 µm and 2.5 µm respectively.

For many years the emissions of primary pollutants have been regulated through vehicle emission standards. Other pollutants – notably ozone (O_3) and important components of airborne particulate matter – are formed through chemical reactions in the atmosphere. These are termed ‘secondary’ pollutants. Most of the NO_2 in the atmosphere is also secondary in nature.

For this assessment, detailed modelling has been undertaken for CO, NOx and PM (both PM_{10} and $PM_{2.5}$). The assessment criteria for these are discussed in Section 3.2.

[1] The ubiquity of motor vehicles in urban areas, and the discharge of pollution at ground level and near to the population, mean that they tend to be a more important source of human exposure than other sources such as industry **(DSEWPaC, 2011)**.

3.2 Air quality criteria

Regulated air pollutants are often divided into 'criteria' pollutants and 'air toxics'. Criteria pollutants tend to be ubiquitous and emitted in relatively large quantities, and their health effects have been studied in some detail. Air toxics are gaseous or particulate organic pollutants that are present in the air in low concentrations with characteristics such as toxicity or persistence so as to be a hazard to humans, plants or animal life. Some of the health issues associated with vehicle pollutants are discussed in Appendix A.

In NSW the statutory methods that are used to assess the air pollution impacts of projects are detailed in the document *Approved Methods for the Modelling and Assessment of Air Pollutants in NSW* (NSW EPA, 2017). Air quality must be assessed in relation to standards[2] and averaging periods for specific pollutants. However, the Approved Methods do not contain specific information on the assessment of transport projects.

The pollutants, metrics and standards set out for criteria pollutants in the Approved Methods are listed in Table 3-1 for the pollutants assessed. These are drawn from a number of sources, including the National Environment Protection (Ambient Air Quality) Measure for Ambient Air Quality (AAQ NEPM) and the World Health Organization (WHO).

Table 3-1: Air quality standards for assessed pollutants in NSW Approved Methods (NSW EPA, 2017)

Pollutant	Concentration	Averaging period
Nitrogen dioxide (NO_2)	246 µg/m^3	1 hour
	62 µg/m^3	1 year
PM_{10}	50 µg/m^3	24 hours
	25 µg/m^3	1 year
$PM_{2.5}$	25 µg/m^3	24 hours
	8 µg/m^3	1 year
CO	30 mg/m^3	1 hour
	10 mg/m^3	8 hours (rolling mean)

Notes: µg/m^3 – micrograms per cubic metre, mg/m^3 – milligrams per cubic metre.

2 In this report we use the term 'standard' to refer to the numerical value of the concentration for a given pollutant in legislation. The NSW *Approved Methods* refer to 'impact assessment criteria', but for simplicity we have also referred to these as standards in this Report.

4. EXISTING ENVIRONMENT

Dispersion models require information about the meteorology (dispersion characteristics) of the study area, shown in Figure 2-1. In particular, data are required on wind speed, wind direction, temperature, atmospheric stability class and mixing height[3].

The closest available meteorological station was the Bureau of Meteorology (BoM) Automatic Weather Station (AWS) at Coffs Harbour Airport, which is located approximately 6 kilometres (km) from Englands Road interchange and 17 km from the northern end of the project. This weather station was commissioned in 2014 with data becoming available in 2015. The measurements of wind speed and direction from this station were used to compile wind roses for the three years of available data (2015, 2016 and 2017), and these are shown in Figure 4-1, Figure 4-2 and Figure 4-3 respectively.

On an annual basis, the most common winds are from the south-west and northern quadrants, with smaller varying degrees of winds from the eastern to southern quadrants. North-easterlies are most common in spring and summer, while south-westerlies and north-westerlies are most common in autumn and winter.

The mean wind speeds from 2011 to 2017 are consistent over the years, varying between 4.1 metres per second (m/s) and 4.4 m/s. The annual mean percentage of calms (wind speeds of less than 0.5 m/s) were also very consistent varying between 1.2 and 1.8 per cent. Analysis of these six years of data show that 2017 is a representative year and it has been used for this assessment.

Long-term wind data from Coffs Harbour are also available from when records began in 1943. However, these values were only recorded for specific times during the day, not on an hourly basis as with more recent data. The wind rose for 9am covering the period from 1943 – 2015 shows that the dominant wind direction is from the southwest, similar to the annual pattern for the last 7 years discussed above.

[3] The term mixing height refers to the height of the turbulent layer of air near the earth's surface into which ground-level emissions will be rapidly mixed. A plume emitted above the mixed-layer will remain isolated from the ground until such time as the mixed-layer reaches the height of the plume. The height of the mixed-layer is controlled mainly by convection (resulting from solar heating of the ground) and by mechanically generated turbulence as the wind blows over the rough ground.

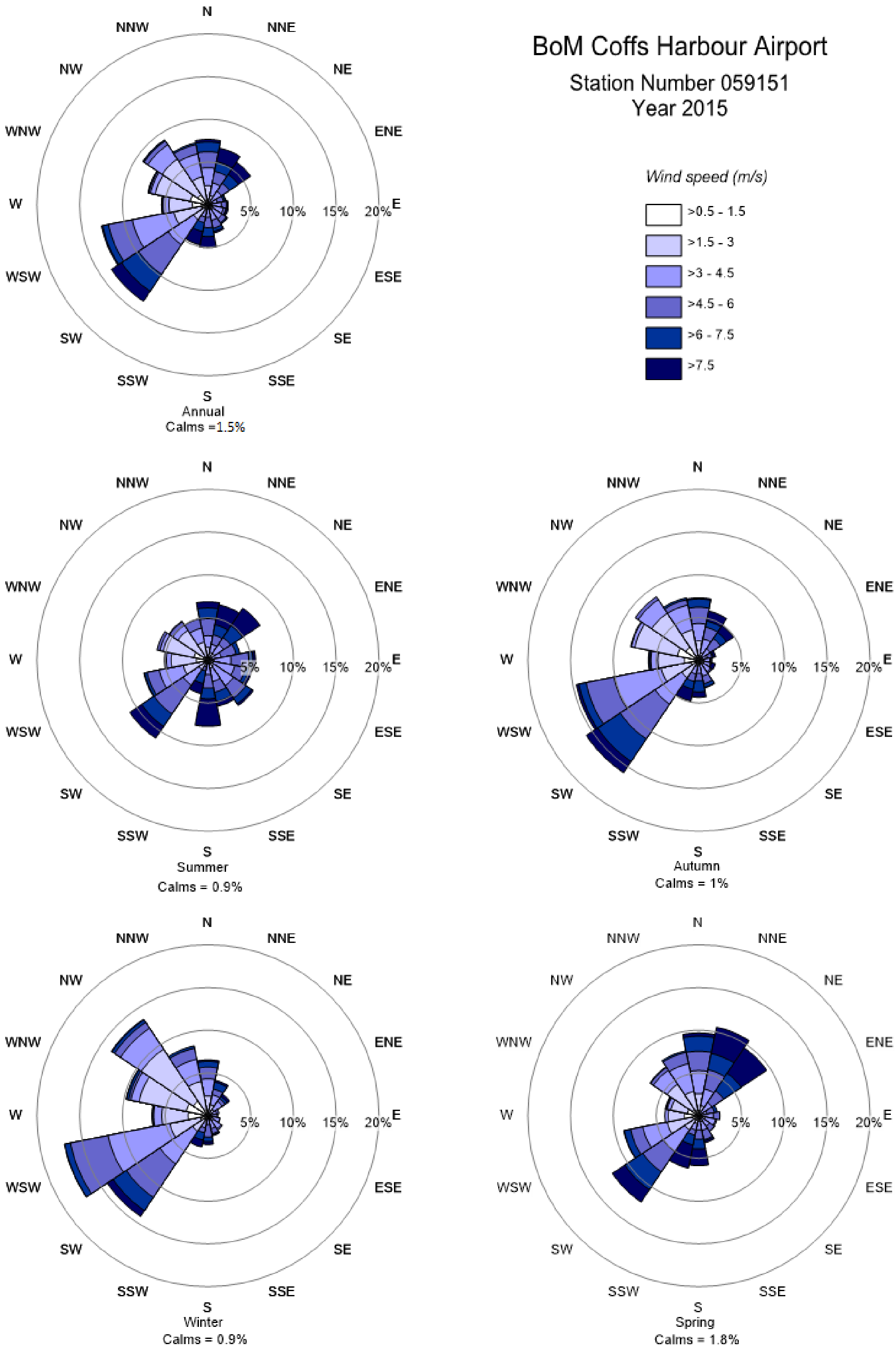


Figure 4-1: Annual and seasonal wind roses for BoM Coffs Harbour AWS for 2015

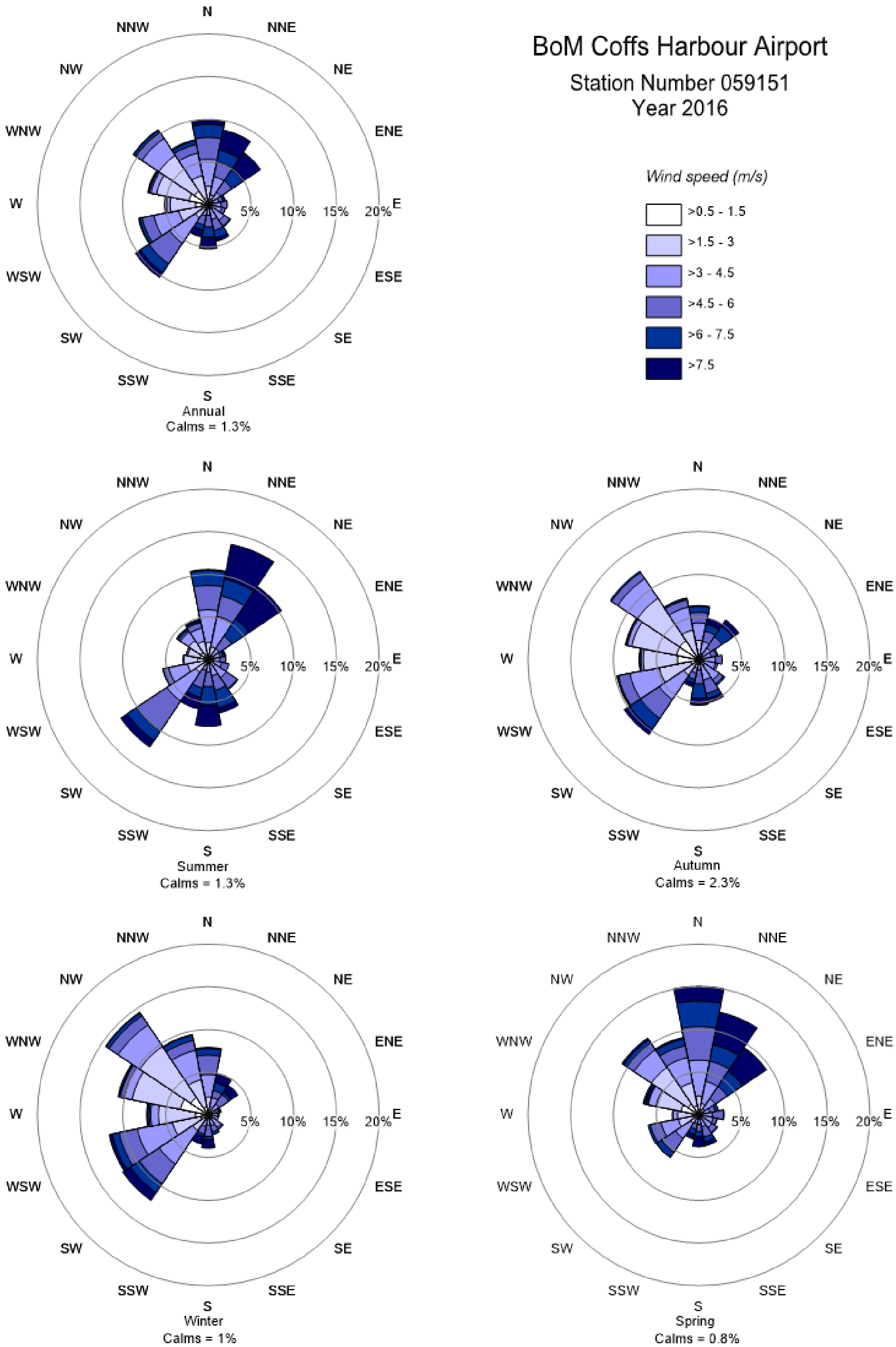


Figure 4-2: Annual and seasonal wind roses for BoM Coffs Harbour AWS for 2016

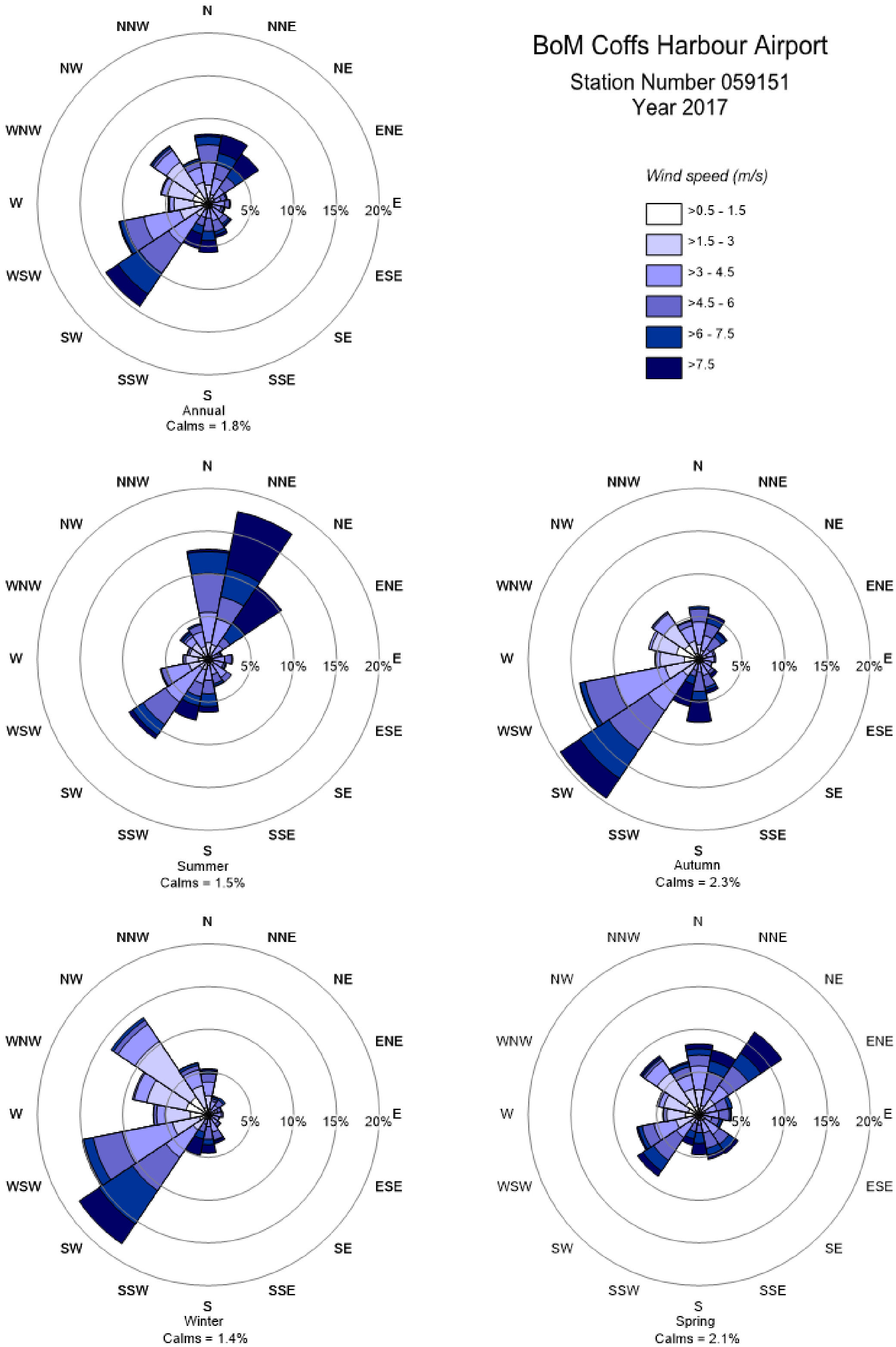


Figure 4-3: Annual and seasonal wind roses for BoM Coffs Harbour AWS for 2017

4.1 Existing air quality and background concentrations

Air quality monitoring has not been undertaken specifically for the project. However, the NSW Office of Environment and Heritage (OEH) monitors air quality at numerous locations around NSW. One of these sites, Albion Park South, is likely to be reasonably representative of the conditions in the area of the Coffs Harbour Bypass as it is coastal and near a built up area which has a major highway running through it. These data were used in the 2015 assessment of the Albion Park Rail Bypass which also ran inland of the existing highway (Pacific Environment, 2015a). The assumptions made concerning background values using the Albion Park South data are described below.

The monitoring location at Albion Park South does not measure CO and so background concentrations of CO for this assessment have been gathered from the OEH Newcastle monitor. Neither Newcastle nor Albion Park South is close to Coffs Harbour, but Newcastle is potentially less representative in terms of landuse. However, Newcastle is likely to provide a conservative estimate of background CO concentrations.

Table 4-1 summarises the NO_2, PM_{10} and $PM_{2.5}$ monitoring data from the Albion Park South OEH site and CO monitoring data from Newcastle.

Table 4-1: Summary of OEH monitoring data from Albion Park South and Newcastle

Year	Albion Park South								Newcastle	
	NO_X (µg/m^3)		NO_2 (µg/m^3)		PM_{10} (µg/m^3)		$PM_{2.5}$ (µg/m^3)		CO (mg/m^3)	
	Max 1-hour mean	Annual mean	Max 1-hour mean	Annual mean	Max 24-hour mean	Annual mean	Max 24-hour mean	Annual mean	Max 1-hour mean	Annual mean
Criterion	N/A	N/A	246	62	50	25	25	8	30	N/A
2011	139	10.3	82	4.1	51	13.6	-	-	3.90	0.18
2012	117	10.3	82	4.3	44	13.6	-	-	3.49	0.17
2013	148	10.3	76	7.6	69	14.7	-	-	3.49	0.20
2014	170	8.2	80	8.6	48	16.2	-	-	5.34	0.38
2015	152	6.2	96	6.2	41	14.0	21.1	6.4	3.49	0.80
2016	133	10.3	88	8.2	43	14.9	30.7	7.2	4.31	0.40
2017	133	10.3	78	8.2	45	15.3	19.3	6.6	2.87	0.51
2018	140	7.7	80	8.2	94	17.8	29.4	6.8	2.46	0.55
Period average	**-**	**9.2**	**-**	**6.9**	**-**	**15.0**	**-**	**6.8**	**3.67**	**0.40**
Period maximum	**170**	**10.3**	**96**	**8.6**	**94**	**17.8**	**30.7**	**7.2**	**-**	**-**

The highest annual mean NO_2 concentration was 8.6 µg/m^3 measured in 2013, which is well below the air quality criterion of 62 µg/m^3. The highest one-hour mean NO_2 concentration was 96 µg/m^3, measured in 2015, which again is well below the one-hour mean air quality criterion of 246 µg/m^3. The maximum one-hour mean NOx concentration over the 8 year data period was 170 µg/m³ and the average annual mean NOx value was 9.2 µg/m³. These values were added to model results and used for the NOx to NO_2 conversion.

The highest annual mean PM_{10} concentration was 17.8 µg/m³, well below the annual mean air quality criterion of 25 µg/m³. The average value over the 8 years of data is 15.0 µg/m³, and this was taken to be the background annual mean PM_{10} concentration for the assessment.

The highest annual mean $PM_{2.5}$ concentration was 7.2 µg/m³, just below the annual mean air quality criterion of 8 µg/m³. The average value over the 4 years of data is 6.8 µg/m³, and this was taken to be the background annual mean $PM_{2.5}$ concentration for the assessment.

As shown in Table 4-1 above, the 24-hour mean PM_{10} criterion of 50 µg/m³ was exceeded at the Albion Park South site in 2011, 2013 and 2018. These exceedances were generally due to regional events such as bushfires or dust storms rather than specific local sources. Using the maximum monitored concentrations as background levels to which the contribution from the project can be added is therefore an overly conservative and unrealistic approach, especially in the case of particulate matter.

24-hour average PM_{10} and $PM_{2.5}$ concentrations fluctuate considerably from day to day. To more appropriately assess the cumulative PM_{10} and $PM_{2.5}$ impacts of the project, it was necessary to remove the influence of the short-term spikes or peaks in the monitoring data. For the purposes of this assessment, it is reasonable (and still conservative) to take a background 24-hour mean concentration for PM_{10} and $PM_{2.5}$ as the 99th percentile of the data (i.e. the concentration that would only be exceeded on one per cent of days). This approach removes the influence of extreme values, usually due to regional events such as bushfires, but retains a conservative upper bound to be used as background value on which to base the cumulative assessment. This value was 40.5 µg/m³, for PM_{10} and 16.6 µg/m³ for $PM_{2.5}$.

The highest maximum one-hour CO concentration was 5.34 µg/m³, recorded in 2014, well below the annual mean air quality criterion of 30 µg/m³. The average value over 8 years of data is 3.67 µg/m³, and this was taken to be the background one-hour concentration for the assessment. The rolling 8-hour mean was calculated from the one-hour data. The yearly maximum one-hour mean and 8-hour means were compared for each of the eight years of data and a ratio of 0.803 was calculated. This ratio was applied to the total predicted maximum one-hour concentration for each receptor to generate maximum 8-hour concentrations.

A summary of the background concentrations used in the assessment is provided Table 4-2.

Table 4-2: Summary of background concentrations

Pollutant	Background concentration (µg/m³)		
	Annual mean	24-hour mean	Maximum 1-hour mean
NOx (for NOx to NO_2 conversion)	9.2	N/A	170
PM_{10}	15.0	40.5	N/A
$PM_{2.5}$	6.8	16.6	N/A
CO	N/A	N/A	3.67

Note: N/A = not applicable.

4.2 Sensitive receptors

There are a number of sensitive receptors, namely schools and residences, along the proposed alignment and those within a few hundred metres of the alignment are shown in Figure 4-4.

Figure 4-4: Modelled sensitive receptors near the proposed bypass alignment and existing Pacific Highway

5. METHODOLOGY

5.1 Construction impacts on air quality

5.1.1 Background

This Chapter deals with the potential impacts of the construction phase of the project. The main air pollution and amenity issues at construction sites are:

- Annoyance impacts due to dust deposition (soiling of surfaces) and visible dust plumes (annoyance impacts include such things as dust on surfaces like cars, washing, swimming pools, rainwater tanks etc.)
- Elevated PM_{10} concentrations due to dust-generating activities
- Exhaust emissions from diesel-powered construction equipment.

Exhaust emissions from on-site plant and site traffic are unlikely to have a significant impact on local air quality, and in the majority of cases they will not need to be quantitatively assessed. Other potential impacts need to be considered on a site-by-site basis (IAQM, 2014). The total vehicles per day required for construction comprises only 1% of the total using the current Pacific Highway (2016) and does not therefore warrant a separate quantitative assessment.

A wide range of demolition and construction equipment is likely to be used for the project and the associated infrastructure.

Dust emissions can occur during the preparation of the land (eg demolition and earth moving) and during construction itself, and can vary substantially from day to day depending on the level of activity, the specific operations being undertaken, and the weather conditions. A significant portion of the emissions result from site plant and road vehicles moving over temporary unsealed roads and open ground or disturbed areas. If dirt or mud is tracked onto public roads, dust emissions can occur at some distance from the construction site (IAQM, 2014). Other sources will include land clearing, crushing and screening rock, wind erosion, crushing and screening as well as excavating and loading spoil material. Blasting rock can also be a significant source of dust if unmitigated.

The risk of dust impacts from a demolition/construction site causing loss of amenity and/or health or ecological impacts is related to the following:

- The nature of the activities being undertaken
- The duration of the activities
- The size of the site and area disturbed
- The meteorological conditions (wind speed, direction and rainfall). Adverse impacts are more likely to occur downwind of the site and during drier periods.
- The proximity of receptors to the activities
- The sensitivity of the receptors to dust
- The adequacy of the mitigation measures applied to reduce or eliminate dust.

It is very difficult to quantify dust emissions from construction activities. Dust emissions can vary substantially from day to day depending on the level of activity, the operations being undertaken, and the local weather conditions (which may result in dust generation even when there is no construction activity at the site). It is difficult to predict what the weather conditions would be when specific construction activities are undertaken, and it is therefore very difficult to accurately quantify dust emissions from construction using a model. Any effects of construction on PM concentrations would also tend to be temporary and relatively short-lived. The assessment and control of construction-related air quality therefore focused on identifying and managing risk.

The construction assessment involved the application of a semi-quantitative risk-based approach following the guidance developed by the UK Institute of Air Quality Management (IAQM, 2014), and adapted by ERM to conditions representative of Coffs Harbour. The approach was also tailored according to the nature of the project. The assessment involved the following main steps:

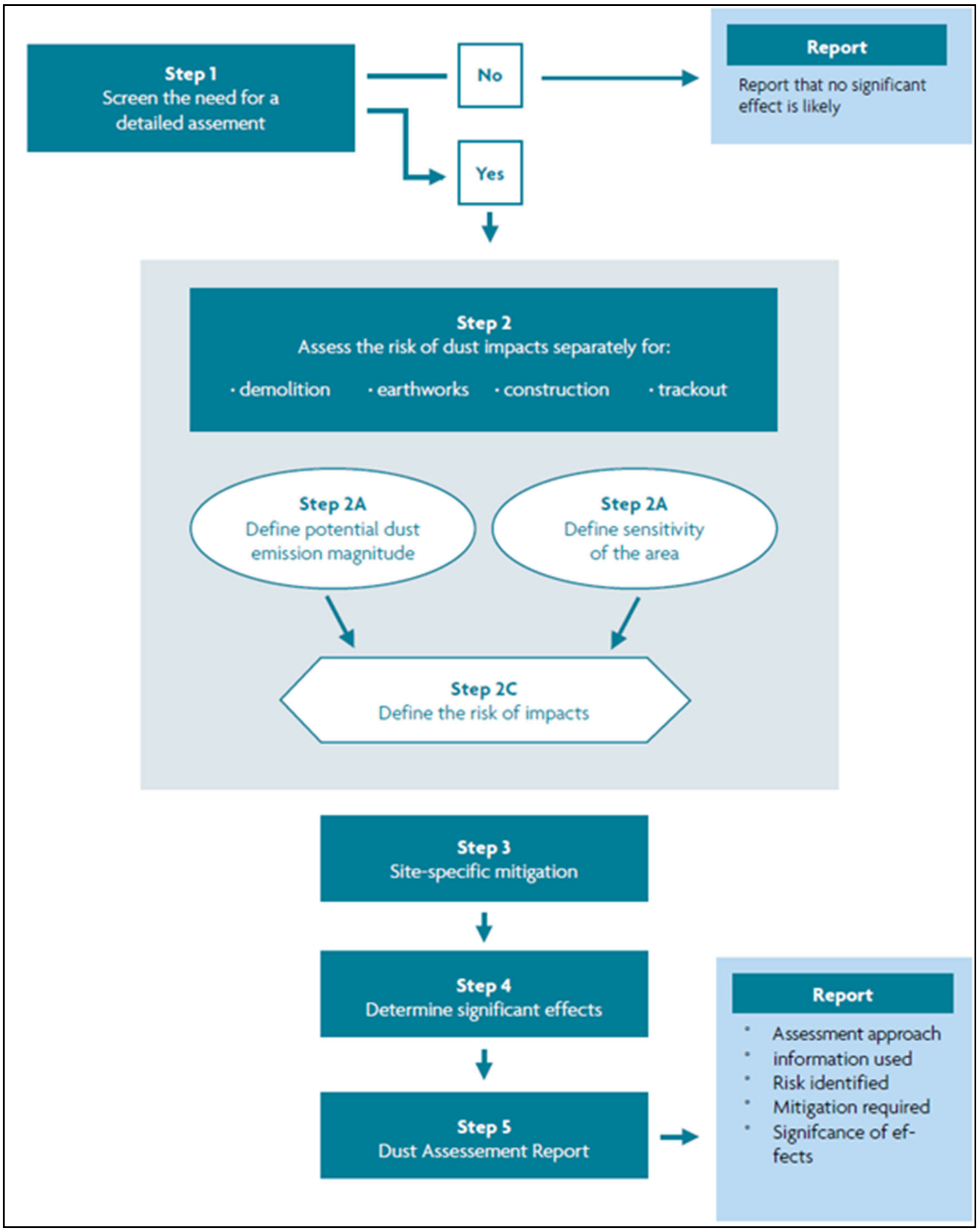
- The identification of the construction activities that would be likely to occur in relation to the project
- The division of activities according to their different potential impacts: demolition, earthworks, construction and vehicle track-out. Risks were assessed in relation to the size of the project, the volume of traffic on unsealed roads, and the locations of sensitive receivers.
- The identification of project-specific management/mitigation measures to minimise the risk of any potential impacts.

5.1.2 Overview of the Method

The IAQM assessment procedure for assessing risk is shown in Figure 5-1. Professional judgement is required in some steps, and where justification cannot be given a precautionary approach should be adopted.

Activities on construction sites can be divided into four types to reflect their different potential impacts, and the potential for dust emissions is assessed for each activity that is likely to take place. These activities are:

- Demolition. Demolition is any activity that involves the removal of existing structures. This may also be referred to as de-construction, specifically when a building is to be removed a small part at a time
- Earthworks. This covers the processes of blasting, crushing and screening, clearing, soil stripping, ground levelling, excavation and landscaping. Earthworks will primarily involve excavating material, haulage, tipping and stockpiling
- Construction. Construction is any activity that involves the provision of new structures, modification or refurbishment. A structure will include a residential dwelling, office building, retail outlet, road, etc
- Track-out. This involves the transport of dust and dirt by Heavy Duty Vehicles (HDVs) from the construction/demolition site onto the public road network, where it may be deposited and then re-suspended by vehicles using the network.



Source: IAQM, 2014

Figure 5-1: Steps in an assessment of construction dust

The assessment methodology considers three separate dust impacts:

- Annoyance impacts due to dust soiling
- The risk of health effects due to an increase in exposure to PM10
- Harm to ecological receptors.

The assessment is used to define appropriate mitigation measures to minimise the risk of any potential impacts. The assessment steps, as they were applied to the project, are described in Appendix B.

5.1.3 Odour

The project SEARs require the consideration of potential odour. There may also be some short term impacts with regard to odour from laying asphalt, bitumen sealing and other earthworks stabilisation activities. This is only likely to be an issue for receptors in very close proximity to these activities and potentially only under certain meteorological conditions and are not likely to be long-term impacts.

5.2 Operational impacts on air quality

5.2.1 Scenarios

The emissions and dispersion models have been run for a number of different operational scenarios to incorporate existing conditions as well as future years with (build) and without (no build) the project in place. The following four scenarios were considered in the assessment:

- Opening year (2024) without the project – No Build
- Opening year (2024) with the project – Build
- Opening year +10 years (2034) without the project – No Build
- Opening year +10 years (2034) with the project – Build

5.2.2 Emission modelling – Surface Roads

5.2.2.1 Model selection

The NSW Environment Protection Authority (EPA) emissions model was used to calculate emissions for surface roads. The main reasons for this choice were as follows:

- The model has been developed to a high standard; it is one of the most sophisticated m[odels that has been developed for calculating emissions from road vehicles in NSW
- Many of the emission factors have been derived using an extensive database of Australian measurements. They allow for the deterioration in emissions performance with mileage, the effects of tampering or failures in emission-control systems, and the use of ethanol in petrol
- The model includes emission factors for specific road types
- Emission projections for several future years are available, taking into account the technological changes in the vehicle fleet
- The model includes cold-start emissions.

5.2.2.2 Traffic volume and composition

Only two roads were included in the dispersion modelling – Pacific Highway and the proposed Coffs Harbour Bypass. The proposed bypass was split into four links and Pacific Highway was split into six links.

The links and the total daily traffic volumes used for each link for each scenario are provided in Table 5-1. The traffic data was provided to ERM by ARUP, using the Coffs Harbour Strategic Transport Model based on a base year of 2016.

Detailed hourly traffic flows were used in the emissions model. The default EPA vehicle types which were used to determine vehicle splits are summarised in Table 5-2.

Table 5-1: Total daily traffic volumes used for each link (vehicles per day)

Section	2024	2024	2034	2034
	Build	No build	Build	No build
Proposed bypass				
South of Englands Road	13,129	-	14,674	-
Englands Road to Coramba Road	21,794	-	24,755	-
Coramba Road to Korora Hill	15,564	-	17,752	-
North of Korora Hill	30,564	-	34,396	-
Pacific Highway				
South of Stadium Drive	40,965	36,795	44,862	40,617
Stadium Drive to Cook Drive	23,234	29,980	25,734	33,923
Cook Drive to Bray Street	19,424	25,372	21,062	27,867
Bray Street to Arthur Street	31,258	41,144	34,294	45,352
Arthur Street to Korora Hill	30,605	43,611	34,610	48,189
North of Korora Hill	5,105	33,949	5,397	37,664

Table 5-2: Vehicle types in the NSW EPA emissions model

Code	Vehicle type	Vehicles included
CP	Petrol car[(a)]	Petrol car, 4WD[(e)], SUV[(f)] and people-mover, LPG[(g)] car/4WD
CD	Diesel car[(a)]	Diesel car, 4WD, SUV and people-mover
LCV-P	Petrol LCV[(b)]	Petrol light commercial vehicle <3.5 tonnes GVM[(h)]
LCV-D	Diesel LCV	Diesel light commercial vehicle <3.5 tonnes GVM
HDV-P	Petrol HDV[(c)]	Petrol heavy commercial vehicle <3.5 tonnes GVM
RT	Diesel rigid HGV[(d)]	Diesel commercial vehicle 3.5 t < GVM <25 t
AT	Diesel articulated HGV	Diesel commercial vehicle >25 tonnes GVM
BusD	Diesel bus	Diesel bus >3.5 tonnes GVM
MC	Motorcycle	Powered two-wheel vehicle

Notes:
(a)Referred to as 'passenger vehicle' in the inventory
(b) LCV = light commercial vehicle
(c) HDV = heavy-duty vehicle
(d) HGV = heavy goods vehicle
(e) 4WD = four-wheel drive
(f) SUV = sports-utility vehicle
(g) LPG = liquefied petroleum gas
(h) GVM = gross vehicle mass

5.2.2.3 Vehicle emission rates

Hourly traffic volumes for each link were split by northbound and southbound and entered into the emissions model along with link length, gradient and speed. Each road link is considered a separate source group for the purposes of modelling. An average mass emission rate (kg/km/h) for each road link/source group for each pollutant is calculated based on the inputs described. For each road link/source group, hourly 'modulation factors' (ratios, relative to the average emission rate for each source group) were calculated for each hour of the day to capture hourly variation. The mass emission rate and modulation factors were entered into GRAL.

5.2.3 Emissions modelling – Tunnel Portals

The Coffs Harbour Bypass has three proposed short tunnels through ridges at Roberts Hill ridge (around 190 m long), Shephards Lane (around 360 m long), and Gatelys Road (around 450 m long). Based on the relatively short length of the tunnels, emissions from portals are permitted. The locations of the tunnels are presented in Figure 2-1.

For the dispersion modelling, there are six portals which are as follows:

- Roberts Hill Northbound exit
- Roberts Hill Southbound exit
- Shephards Lane Northbound exit
- Shephards Lane Southbound exit
- Gatelys Road Northbound exit
- Gatelys Road Southbound exit

Air velocities at each of the six tunnel portals, caused by the piston effect of vehicles, were calculated. Figure 5-2 to Figure 5-7 presents the portal exit velocities for each of the six portals. Full details of air velocity at portals for the six named portals has been prepared by Forschungsgesellscaft für Verbrennungskraftmaschinen und Thermodynamik mbH FVT which is included as Appendix D.

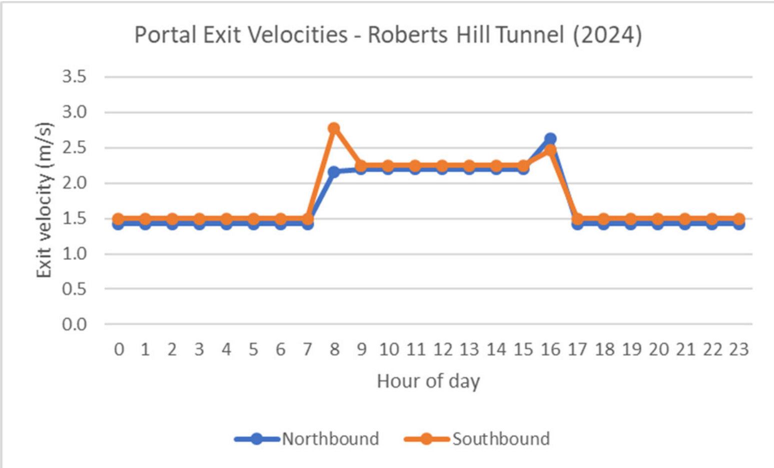


Figure 5-2: Portal exit velocities for Roberts Hill Tunnel 2024

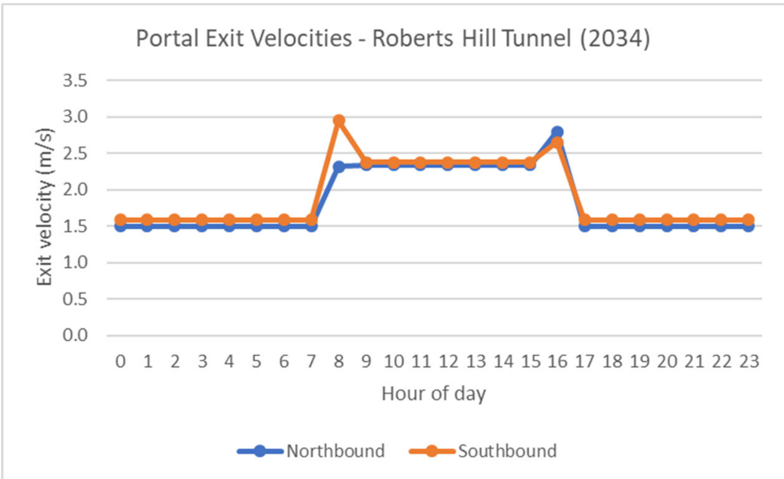


Figure 5-3: Portal exit velocities for Roberts Hill Tunnel 2034

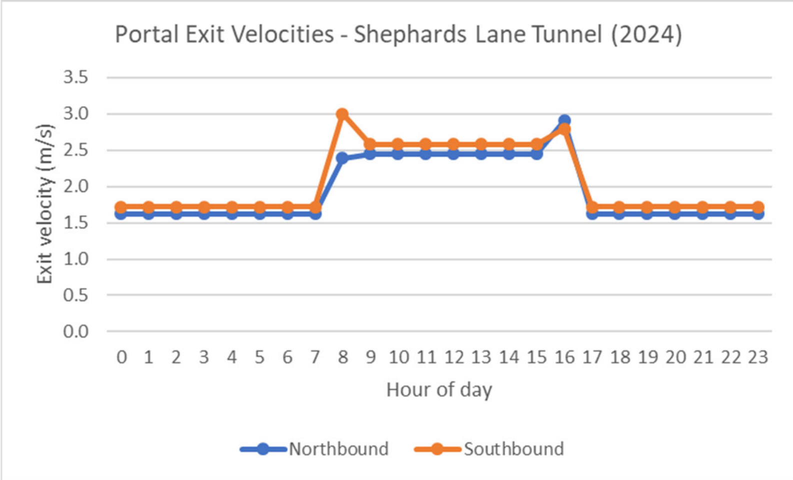


Figure 5-4: Portal exit velocities for Shephards Lane Tunnel 2024

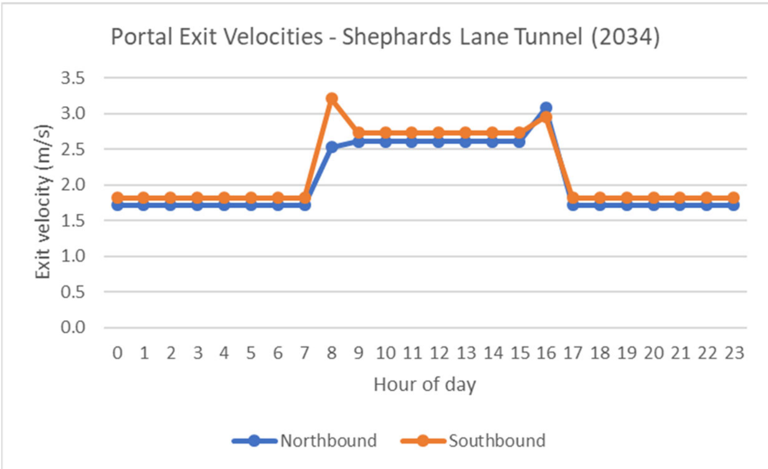


Figure 5-5: Portal exit velocities for Shephards Lane Tunnel 2034

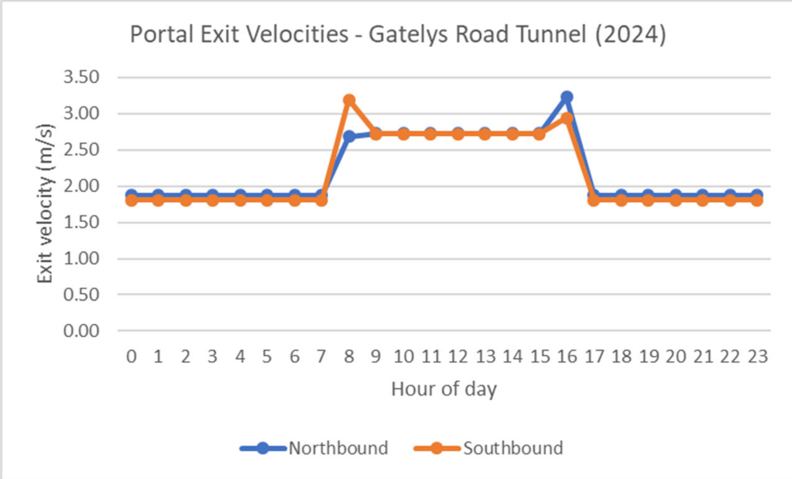


Figure 5-6: Portal exit velocities for Gately Road Tunnel 2024

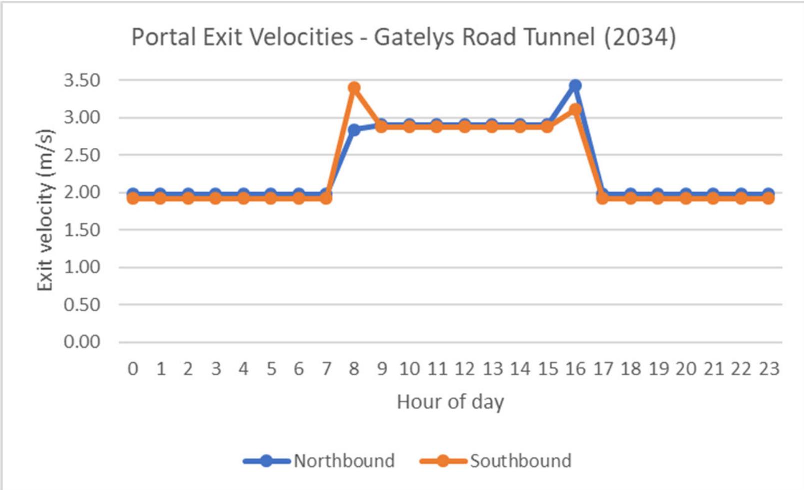


Figure 5-7: Portal exit velocities for Gately Road Tunnel 2034

The calculation of the exit velocities was used to determine the number of source groups for the modelling. The incorporation of the source groups allows hourly variations to be captured in the modelling. For each portal three source groups were created, each source group representing a distinct change in exit velocity. Take, for example, Roberts Hill Northbound portal for 2024 (Figure 5-2). It can be seen that the exit velocity is constant from 00:00 to 07:00, and 17:00 to 23:00, representing one source group. The exit velocity increases at 08:00 but is once again relatively constant from 08:00 to 15:00, representing a second source group. Finally there is a peak at 16:00 which represents the third source group.

An average mass emission rate (kg/h) was estimated for each pollutant for each source group for each portal. The emissions were estimated using the NSW EPA model (which has been evaluated using real-world air pollution measurements) in conjunction with simplified tunnel geometry and traffic data. For each source group, hourly ‘modulation factors’ (ratios, relative to the average emission rate for each source group) were calculated for each hour of the day to capture the hourly variation. No seasonal variation was built into the emission rates. The mass emission rate and modulation factors were entered into GRAL.

5.2.4 Dispersion modelling

5.2.4.1 Model selection

The Graz Lagrangian (GRAL) micro-scale dispersion model has been used for the assessment of all major traffic air quality assessments in NSW for the past four years, including the evaluation of all road tunnel ventilation outlets associated with the WestConnex network. As such, it is considered an appropriate tool for the current application.

The model system consists of two main modules: a prognostic wind field model (Graz Mesoscale Model – GRAMM) and a dispersion model (GRAL itself). An overview of the GRAMM/GRAL modelling system is presented in Figure 5-8. The system has in-built algorithms for calculating emission rates (the grey area of the Figure), but these were replaced by the project-specific emission rates.

GRAMM is the meteorological driver for the GRAL system. Its main features include the use of prognostic wind fields, a terrain-following grid, and the computation of surface energy balance. GRAL is a Lagrangian model, whereby ground-level pollutant concentrations are predicted by simulating the movement of individual 'particles' of a pollutant emitted from an emission source in a three-dimensional wind field. The trajectory of each of the particles is determined by a mean velocity component and a fluctuating (random) velocity component.

GRAL stores concentration fields for user-defined source groups. Up to 99 source groups can be defined (e.g. traffic, domestic heating, industry), and each source group can have specific monthly and hourly emission variations. In this way annual mean, maximum daily mean, or maximum concentrations for other defined periods can be computed. Usually, about 500–600 different meteorological situations are sufficient to characterise the dispersion conditions in an area during all 8,760 hours of the year.

Other general parameters required by the GRAL software include surface roughness length, dispersion time, the number of traced particles (influences the statistical accuracy of results), counting grids (variable in all three directions), as well as the size of the model domain.

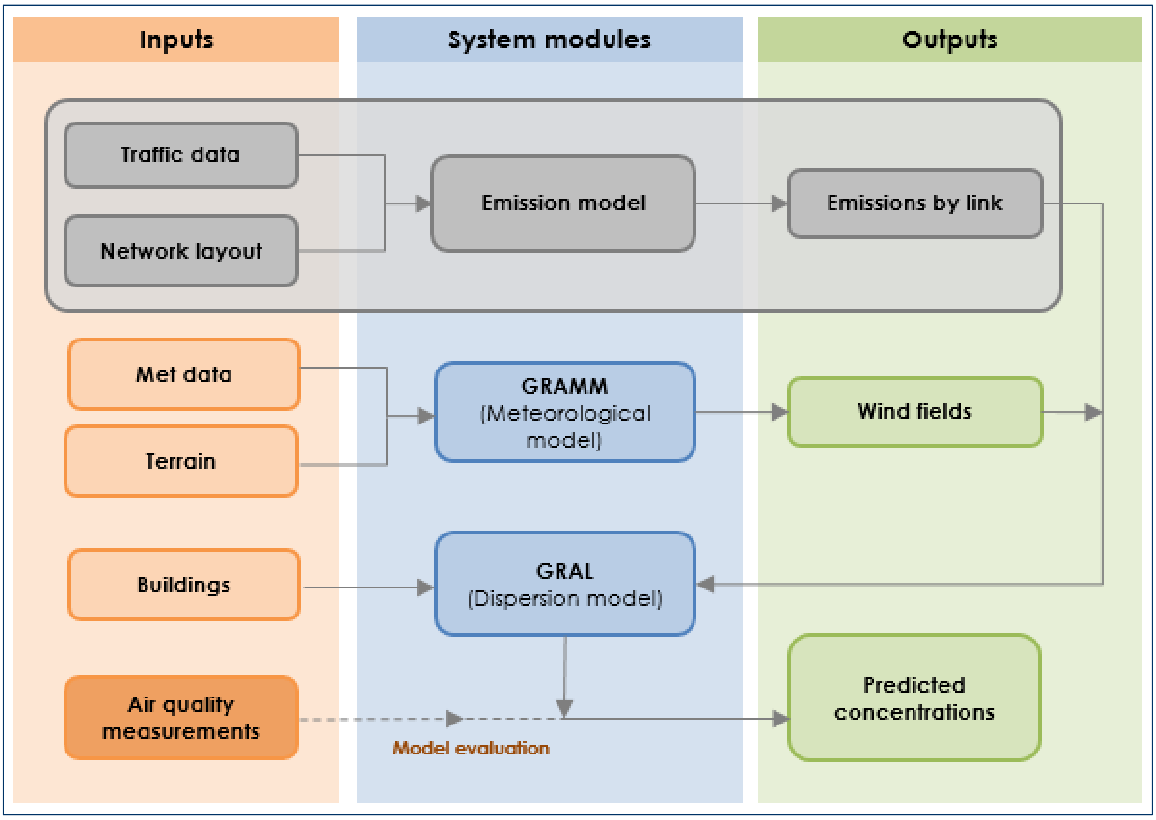


Figure 5-8: Overview of the GRAMM/GRAL modelling system

5.2.4.2 GRAMM domain and set-up

The GRAMM domain was defined so that it covered the entire area encompassing the Coffs Harbour bypass and the Pacific Highway. The domain was 12.8 km along the east-west axis and 16.8 km along the north-south axis.

Table 5-3 presents the meteorological and topographical parameters that were selected in GRAMM.

Table 5-3: GRAMM configuration and set-up parameters

Parameter	Input/value
Meteorology	
Meteorological input data method	Match-to-Observations (MtO)
Meteorological stations used in MtO	BoM Coffs Harbour Airport
Period of meteorology	1 January 2017 – 31 December 2017
Meteorological parameters	Wind speed (m/s), Wind direction (°), stability class (1-7)
Number of wind speed classes	10
Wind speed classes (m/s)	0-0.5, 0.5-1.5, 1.5-2.5, 2.5-3.5, 3.5-4.5, 4.5-5.5, 5.5-6.5, 6.5-7.5, 7.5-9 >9
Number of wind speed sectors	36
Sector size (degrees)	10
Anemometer height above ground (m)	10
Concentration grids and general GRAMM input	
GRAMM domain in UTM (m)	N = 6657800, S = 6641000, E = 517000, W = 504200
Horizontal grid resolution (m)[(a)]	200
Vertical thickness of the first layer (m)[(b)]	10
Number of vertical layers	15
Vertical stretching factor[(c)]	1.3
Relative top level height (m)[(d)]	3874
Maximum time step (s)[(e)]	10
Modelling time (s)	3,600
Relaxation velocity[(f)]	0.1
Relaxation scalars[(f)]	0.1

(a) Defines the horizontal grid size of the flow field.
(b) Defines the cell height of the lowest layer of the flow field. Typical values are 1–2 metres.
(c) Defines how quickly cell heights increase with height above ground. For example, a factor of 1.1 means a cell is 10 per cent higher than the one below it.
(d) Defined as the relative height from the lowest level in the domain.
(e) Defines the amount of time taken to ensure that calculations are done efficiently but stably.
(f) These are chosen to ensure the numerical stability of GRAMM simulations.

Terrain

Terrain data were processed within the GEOM (Geographical/Geometrical grid processor) component of GRAMM. The terrain data for the GRAMM domain were obtained from the Geoscience Australia Elevation Information System (ELVIS) website, and converted into a text file for use in GRAMM. The terrain data used in GRAMM had a resolution of 25 metres. Five metre terrain data from the same source were used to run GRAL.

Although the terrain is not especially complex, a spatially-varying terrain file was used to provide an accurate reflection of the situation.

Land use

A spatially-varying land use file was developed for use in the assessment. Various land use types can be specified in GRAMM, and CORINE (Coordination of Information on the Environment) land cover parameters can be imported. The land use file was based on a visual classification using aerial imagery base maps in ArcGIS. Firstly, a polygon shapefile was digitised using the CORINE land cover classes. Within the GRAMM domain, areas were then classified according to these classes. The resulting file was converted to a 50 metre resolution ASCII raster for use within GRAMM.

5.2.4.3 GRAL domain and set-up

GRAL was configured to provide predictions for a Cartesian grid of points with an equal spacing of 10 metres in both the x and y directions. Typically, GRAMM simulations are performed with a coarse resolution relative to that of the GRAL resolution (in this case a GRAMM resolution of 200 metres) compared with the GRAL resolution of 10 metres) to capture meteorological conditions over a larger study area.

Table 5-4 presents the main parameters selected in GRAL for the model runs.

Table 5-4. GRAL configuration for domain

Parameter	Input/value
General	
GRAL domain in UTM (m)	N = 6655000, S = 6643000, E = 516000, W = 506000
Dispersion time	3600
Number of particles per second(a)	400
Surface roughness(b)	0.5
Latitude(˚)(c)	-30
Buildings	None
Concentration grid	
Vertical thickness of concentration layers (m)	1
Horizontal grid resolution (m)	5
Number of horizontal slices	1
Height above ground level (m)	3 (effectively ground level)

(a) Defines the total number of particles released in each dispersion situation.
(b) Defines the roughness length in the whole model domain. The roughness length alters the shape of the velocity profile near the surface.
(c) Average latitude of the model domain.
(d) Due to the computational intensity of the GRAL model, a limited number of vertical receptor grids were selected.

Figure 5-9 presents the GRAMM and GRAL domain study area.

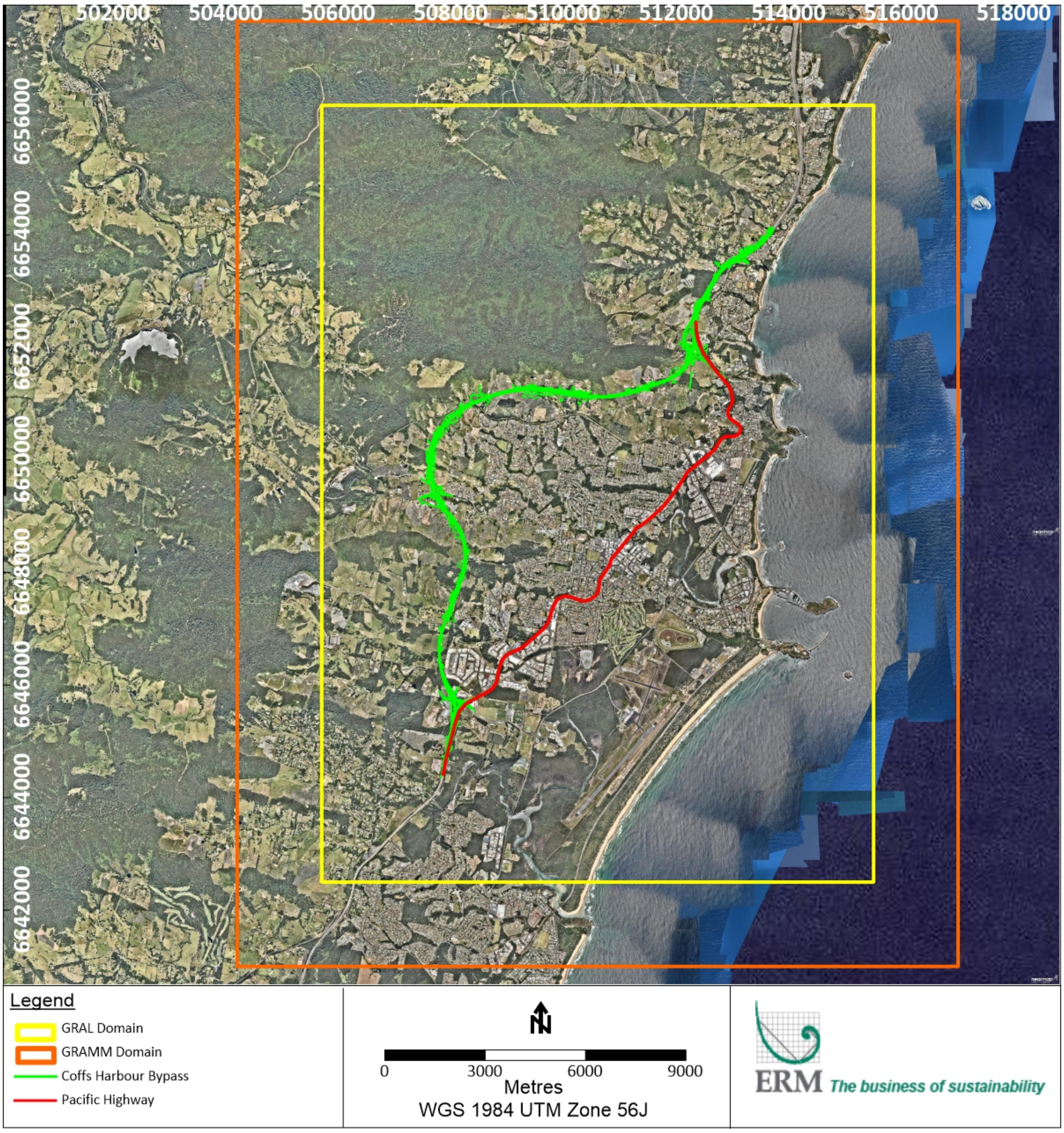


Figure 5-9: Domain study area

5.2.4.4 Receptor locations

Predictions of pollutant concentrations were made for receptors within the GRAL domain at 10 m resolution, surrounding both the existing and proposed road alignments.

5.2.5 NO_x to NO_2 conversion

The GRAL model was used to predict concentrations of NO_X. To determine the NO_2 concentrations at receptors an empirical conversion method has been applied. This approach was taken and accepted in a number of recently approved road infrastructure projects in NSW.

NO_X and NO_2 have been measured for several years at a range of locations across Sydney, and the data were analysed with a view to developing empirical assessment methods for NO_2 for road projects. One reason for this analysis was to quantify and address the conservatism in some of the other conversion methods in use, whereby exceedances of NO_2 air quality standards can be predicted even though the monitoring data show that this situation is far from reality.

5.2.5.1 Annual mean concentrations

Figure 5-10 shows the relationship between the annual mean concentrations of NO_X and NO_2 at the monitoring stations in Sydney (both roadside and background sites) between 2004 and 2016. While it is noted that Coffs Harbour is some distance from Sydney, there is a significant amount of data available which can be analysed to show the relationship between NOx and NO_2, which would apply to this assessment. Given the location of the monitors, the dominant source of NOx for the Sydney monitoring stations will be the road traffic. As this assessment applies to road traffic emissions, it is appropriate to also use these data here to determine the relationship between NO_X and NO_2.

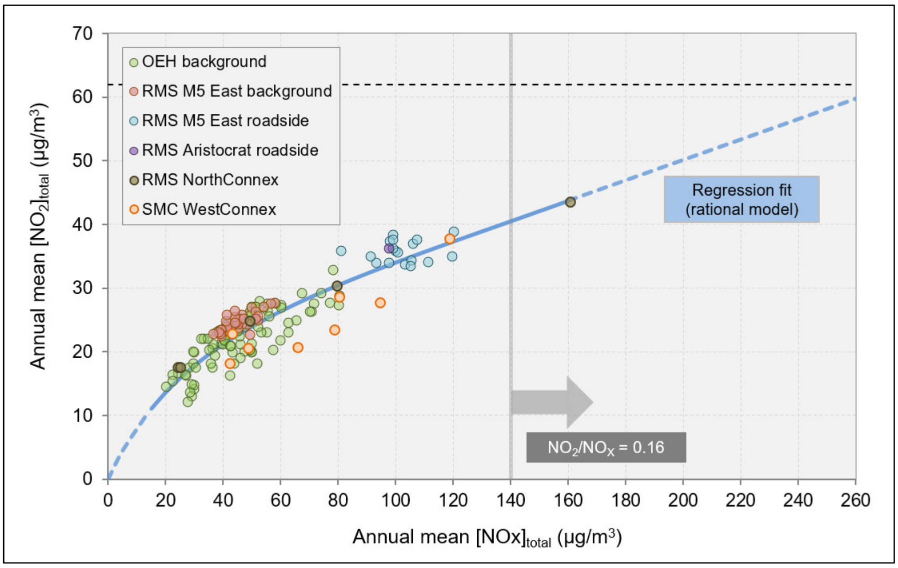


Figure 5-10: Annual mean NOx and NO_2 concentrations at monitoring sites in Sydney

As the values shown are measurements, they equate to $[NOx]_{total}$ and $[NO_2]_{total}$. In the low-NO_X range of the graph there is an excess of ozone and therefore NO_2 formation is limited by the availability of NO. In the high-NO_X range there is an excess of NO, and therefore NO_2 formation is limited by the availability of ozone. The figure also shows that there is not a large amount of scatter in the data, and for this reason a centralestimate approach was considered to be appropriate. This is represented by the solid blue in the figure, which will give the most likely NO_2 concentration for a given NO_X concentration. The dashed lines represent the extrapolation of the function to values below and above the range of measurements.

This function is described by the following equations:

For $[NO_X]_{total}$ values less than or equal to 140 µg/m³:

Equation 1

$$[NO_2]_{total} = \frac{a + b[NOx]_{total}}{1 + c[NOx]_{total} + d([NOx]_{total})^2}$$

Where:

a = -7.6313×10^{-4}

b = 9.9470×10^{-1}

c = 2.3750×10^{-2}

d = -4.5287×10^{-5}

For $\mathbf{[NO_X]_{total}}$ greater than 140 µg/m³ it has been assumed that the available ozone has been consumed and so NO_2 is linearly proportional to NO_X with a NO_2/NO_X ratio of 0.16, representing the current f-NO_2 value for vehicle exhaust quoted by NSW EPA in its response to the EIS for the NorthConnex project (AECOM, 2014):

Equation 2

$$[NO_2]_{total} = 40.513 + (0.16 \times ([NO_X]_{total} - 140))$$

The work presented by Pacific Environment (2015b) suggests that an annual average value for f-NO_2 of 0.16 is an overestimate for the 2016 vehicle fleet, but is likely to be more representative for future years.

The dashed blue line represents the extrapolation of the function to values below and above the range of measurements. Given the absence of high annual mean NO_X concentrations, the extrapolation to concentrations above the measurement range is rather uncertain, but on the basis of the primary NO_2 assumption it is likely to be rather conservative.

Given that the total NO_X concentration was used to determine the total NO_2 concentration, in order to determine the change in NO_2 associated with the project the background NO_2 concentration was subtracted. That is:

Equation 3

$$[NO_2]_{project} = [NO_2]_{total} - [NO_2]_{background}$$

For a given project contribution to NO_X at a receptor, the higher the background NO_X the lower the project NO_2 increment will tend to be, as less ozone will generally be available for converting the NO from the project to NO_2.

The use of the function could theoretically lead to exceedances of the annual mean criterion for NO_2 in NSW of 62 µg/m³. However, a very high annual mean NO_X concentration – more than 260 µg/m³ – would be required. This is much higher than the measurements in NSW have yielded to date.

5.2.5.2 One-hour mean concentrations

One-hour mean NO_X and NO_2 concentrations are much more variable than annual mean concentrations. Patterns in the hourly data can be most easily visualised by plotting the one-hour mean NO_2/NO_X ratio against the one-hour mean NO_X concentration.

The data from all Sydney monitoring sites (background and roadside) between 2004 and 2016 – a total of more than 1.3 million data points – are shown in Figure 5-11.

The solid orange line in Figure 5-11 represents the outer envelope of all data points, and approximates to a conservative upper bound estimate for 2016, or in other words the maximum NO_2/NO_X ratio for a given NOx concentration in 2016. This is described by the following equations:

For $[NOx]_{total}$ values less than or equal to 140 µg/m^3:

Equation 4

$$\frac{[NO_2]_{total}}{[NOx]_{total}} = 1.0$$

For $[NOx]_{total}$ values greater than 130 µg/m^3 and less than or equal to 1,555 µg/m^3:

Equation 5

$$\frac{[NO_2]_{total}}{[NOx]_{total}} = a \times [NOx]_{total}{}^{b}$$

Where:

a = 100
b = -0.94

For $[NOx]_{total}$ values greater than 1,555 µg/m^3 a cut-off for the NO_2/NOx ratio of 0.10 has been assumed. That is:

Equation 6

$$\frac{[NO_2]_{total}}{[NOx]_{total}} = 0.1$$

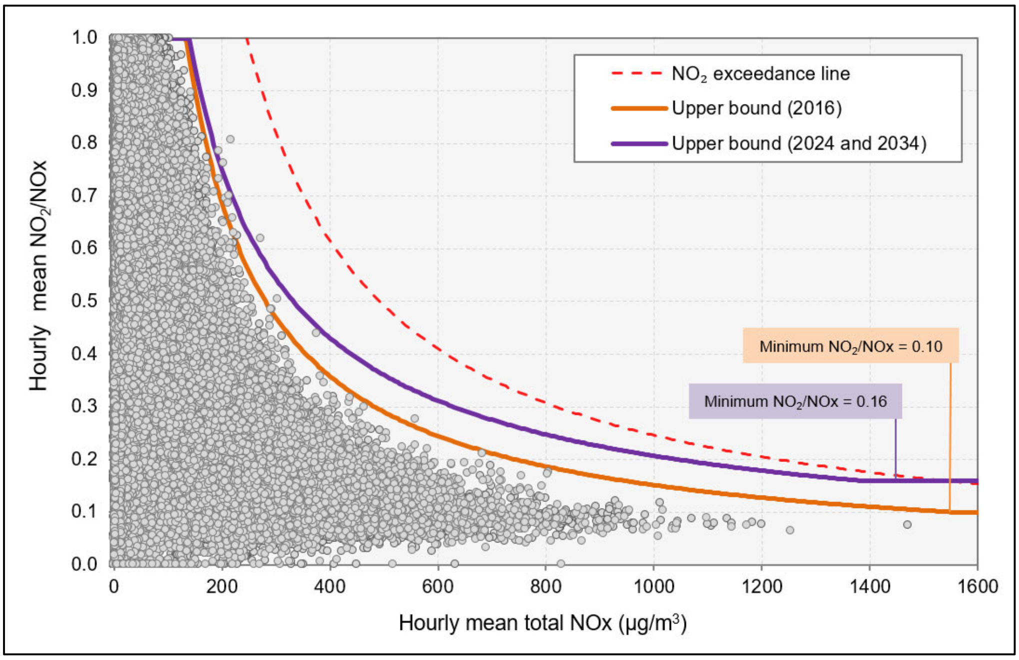


Figure 5-11: Hourly mean NOx and NO_2/NOx ratio for monitoring sites at various locations in Sydney

The dashed red line in Figure 5-11 shows the NO_2/NOx ratio that would be required for an exceedance of the NO_2 criterion of 246 µg/m^3 at each NOx concentration. It is clear from Figure 5-11 that an exceedance of the one-hour criterion for NO_2 cannot be predicted using the upper bound curve for 2016 across a wide range of NOx concentrations.

However, for future years it is possible that the upper bound estimate for 2016 will not be appropriate, given that primary NO_2 emissions could increase. An exploratory analysis by Pacific Environment indicated that, on average for highway traffic in Sydney, f-NO_2 could increase to 0.16 by around 2030 (Pacific Environment (2015b)). Whilst the increase in f-NO_2 would be combined with lower overall NOx emissions, it could be expected that for high ambient NOx concentrations the ambient NO_2/NOx ratio could exceed 0.1. Here, it has been assumed that a minimum value for the NO_2/NOx ratio of 0.16 would be appropriate for the 2024 and 2034 scenarios, and a corresponding conservative upper bound function (the purple line) is shown in Figure 5-11.

This function is described by the following equations:

For $[NOx]_{total}$ values less than or equal to 140 µg/m^3, Equation 4 applies.

For $[NOx]_{total}$ values greater than 140 µg/m^3 and less than or equal to 1,375 µg/m^3, Equation 5 applies with the following coefficients:

a = 52
b = -0.80

For [NOx] total values greater than 1,375 µg/m^3 a cut-off for the NO_2/NOx ratio of 0.16 has been assumed. That is:

Equation 8

$$\frac{[NO_2]_{total}}{[NOx]_{total}} = 0.16$$

Even this assumption would only result in an exceedance of the NO_2 criterion at very high NOx concentrations (above around 1,500 µg/m^3). If a more conservative estimate for the minimum ambient NO_2/NOx ratio of 0.20 were to be assumed, the total NOx concentration required for NO_2 exceedance in Figure 5-11 would be around 1,000 µg/m^3.

5.2.6 Odour

The project SEARs require the consideration of potential odour. Odours associated with motor vehicle emissions tend to be very localised and short-lived, and there are not expected to be any significant, predictable or detectable changes in odour as a result of the project.

6. ASSESSMENT

6.1 Risk of construction impacts on air quality

The results of the risk assessment detailed in Appendix B are summarised in Table 6-1. Taking into account the level of dust generating activity and the proximity and sensitivity of receptor areas, a corresponding level of risk of impact was determined and relevant mitigation measures suggested.

Table 6-1: Summary of risk assessment for the four construction activities

Type of activity	Step 2A: Potential for dust emissions	Step 2B: Sensitivity of area			Step 2C: Risk of dust impacts		
		Dust soiling	Human health	Ecological	Dust soiling	Human health	Ecological
Demolition	Large	High	High	Medium	High Risk	High Risk	High Risk
Earthworks	Large	High	High	Medium	High Risk	High Risk	Medium Risk
Construction	Large	High	High	Medium	High Risk	High Risk	Medium Risk
Track-out	Large	High	High	Medium	High Risk	High Risk	Medium Risk

6.1.1 Mitigation Measures

An Air Quality Management Plan would be produced for the construction of the project. This would contain details of the site-specific mitigation measures to be applied. The main recommended mitigation measures are summarised in Table 6-2. The table is generally consistent with the standard measures used by NSW Roads and Maritime. Additional guidance on the control of dust at construction sites in NSW is provided as part of the NSW EPA Local Government Air Quality Toolkit. Detailed guidance is also available from the UK (GLA, 2006) and the United States (Countess Environmental, 2006).

Table 6-2. Main mitigation measures for construction

Aspect	Measure	Responsibility	Phase
General air quality impacts	An Air Quality Management Plan will be prepared to detail the air quality control measures and procedures to be undertaken during construction, including: Air quality and dust management objectives that are consistent with OEH guidelines. Potential sources and impacts of dust, identifying all dust-sensitive receptors. Mitigation measures to minimise dust impacts on sensitive receptors and the environment. A dust monitoring program to assess compliance with the identified objectives. Contingency plans to be implemented in the event of non-compliances and/or complaints about dust.	Contractor	Pre-construction
Impacts on local air quality during construction	Areas of exposed surface are to be minimised throughout the construction site planning and programming, to reduce the area of potential construction dust emission sources.	Contractor	Construction
	Control measures, such as compaction stabilisation or covering will be implemented in order to minimise dust from stockpile sites.	Contractor	Construction
	Dust suppression measures, such as the use of water carts or soil binders, will be used in any unsealed surfaces and other exposed areas.	Contractor	Construction
	All trucks will be covered when transporting materials to and from the site.	Contractor	Construction
	Construction activities that generate dust will be avoided or modified during high wind periods.	Contractor	Construction
	Work activities will be reviewed if the dust suppression measures are not adequately restricting dust generation.	Contractor	Construction
	Rehabilitation of completed sections will be progressively undertaken.	Contractor	Construction

	Where buildings and structures are required to be demolished, techniques and practices will be developed to minimise dust generation. These would be dependent on the type of materials being demolished, for example, asbestos requires specific measures to be in place.	Contractor	Construction
Exhaust emissions	Construction plant and equipment will be maintained in good working condition to limit impacts on air quality.	Contractor	Construction
	Where practicable, vehicles will be fitted with pollution reduction devices and switched off when not in use.	Contractor	Construction

6.1.2 Significance of Risks

The assessment above has indicated that without mitigation, the risk of dust impacts on the nearest sensitive receptors is high. During construction, the aim should be to prevent significant effects through the use of effective mitigation. Experience shows that this is normally possible. Hence the residual effect will normally be 'not significant' (IAQM, 2014).

However, even with a rigorous Air Quality Management Plan in place, it is not possible to guarantee that the dust mitigation measures will be effective all the time. There is the risk that the closest receptors will experience some dust soiling impacts, potentially effecting such things as tank water, swimming pools and banana and blueberry farms. 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 only arise during dry weather with the wind blowing towards a receptor, at a time when dust is being generated and mitigation measures are not being fully effective. The likely scale of this would not normally be considered sufficient to change the conclusion that with mitigation the effects will be 'not significant'.

Review of the annual and seasonal wind roses (see Figure 4-3) indicates that winds could be capable of transporting emissions towards receptors. In view of the transitional nature of the prevailing winds with respect to the receptors this could occur at any time of year.

Any mobile concrete batching plants that may be required will also need to be managed to ensure the delivery of raw materials and product is done in a way that contains any dust emissions. These operations are generally managed very well and are rarely significant sources of dust.

There are a number of other construction projects and residential developments occurring in the vicinity of this project. Depending on the size and duration of each individual site there may be some potential cumulative impacts. The largest of these projects are the Korora and North Boambee Valley Urban Release Areas (URA) as well as the North Boambee Valley (West) Residential Investigation Area. The Korora URA and the North Boambee Valley (West) Residential Investigation Area are currently not approved.

The Korora URA covers a significant land area at the northern end of the proposed bypass construction footprint, extending from Bruxner Park Road to Sapphire Beach. If approved, construction of individual subdivisions may occur in the same timeframe as the project.

The North Boambee Valley URA is immediately adjacent to the bypass construction footprint between North Boambee Drive and Lakes Drive and is currently under construction. If there is any potential overlap in construction timeframes between this, the North Boambee Valley (West) Residential Investigation Area (directly opposite but as yet not approved) and the project, then there will need to be very careful management of dust emissions to minimise impacts at nearby sensitive receptors.

The Coffs Harbour Hospital Campus Extension and construction of the Elements Estate and Sunset Ridge Stage 2 are also potential construction sites, located towards the southern end of the project. However, these are smaller projects and it is not known whether construction timeframes will overlap.

6.2 Operational impacts on air quality

This section assesses the predicted pollutant concentrations due to emissions from both the existing roads and the project. The predicted concentrations across the modelling domain for 2024 (No Build), 2024 (Build), 2034 (No Build) and 2034 (Build), are provided in Appendix C for PM_{10}, $PM_{2.5}$, NO_2 and CO.

These values include both the background and project contributions, and therefore represent the predicted cumulative impacts of the project. There are no predicted exceedances of the air quality criteria at any sensitive receptors for any of the modelled scenarios. Figure 6-1 to Figure 6-12 show the cumulative predicted concentrations at all the individual receptors described in Section 4.2. For PM_{10} and $PM_{2.5}$, the bar charts show the background concentrations (blue) and the contributions from the surface roads and portals (yellow). The results show no predicted exceedances in any of the assessment criteria. It can also be clearly seen that the contributions from the project are very low in relation to background levels.

For NO_2 predictions, the background levels are incorporated into the conversion calculations from NO_X to NO_2, and so there are no separate background values shown on Figure 6-9 to Figure 6-12.

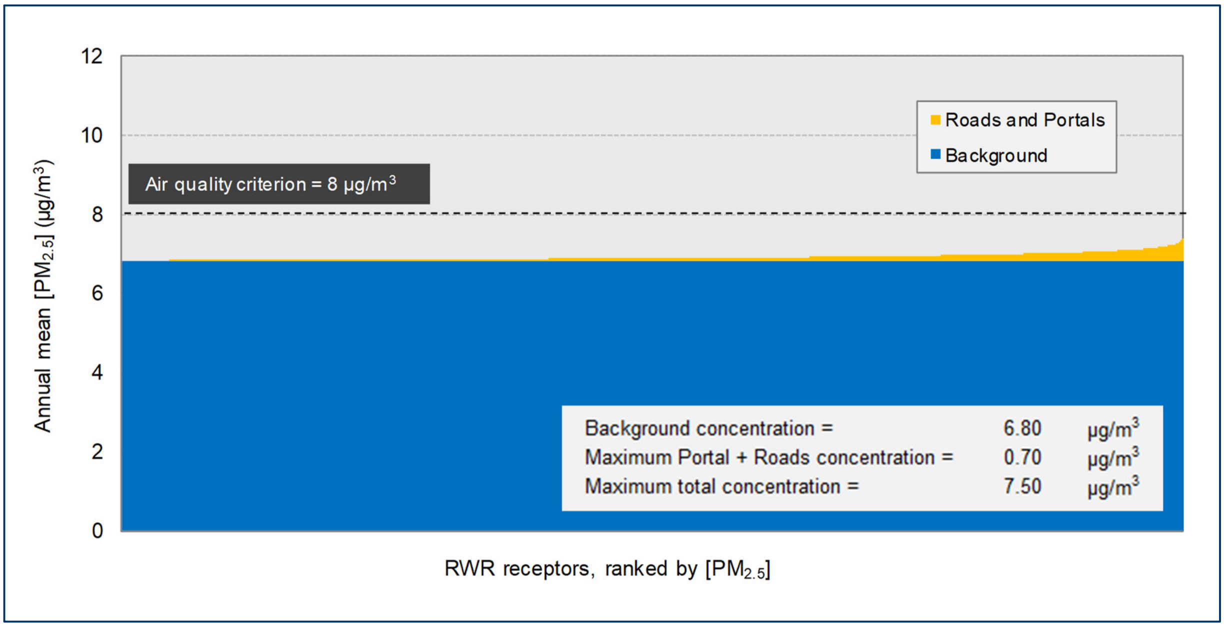


Figure 6-1: Cumulative annual average $PM_{2.5}$ concentrations due to the project for 2024 (µg/m^3)

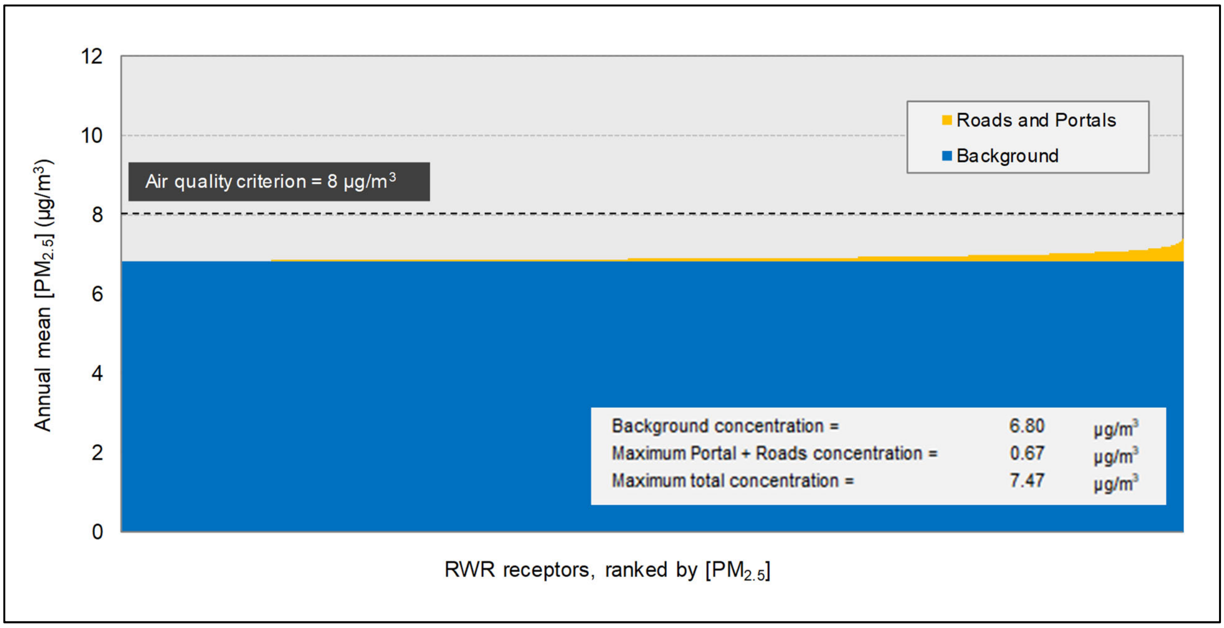


Figure 6-2: Cumulative annual average $PM_{2.5}$ concentrations due to the project for 2034 (µg/m^3)

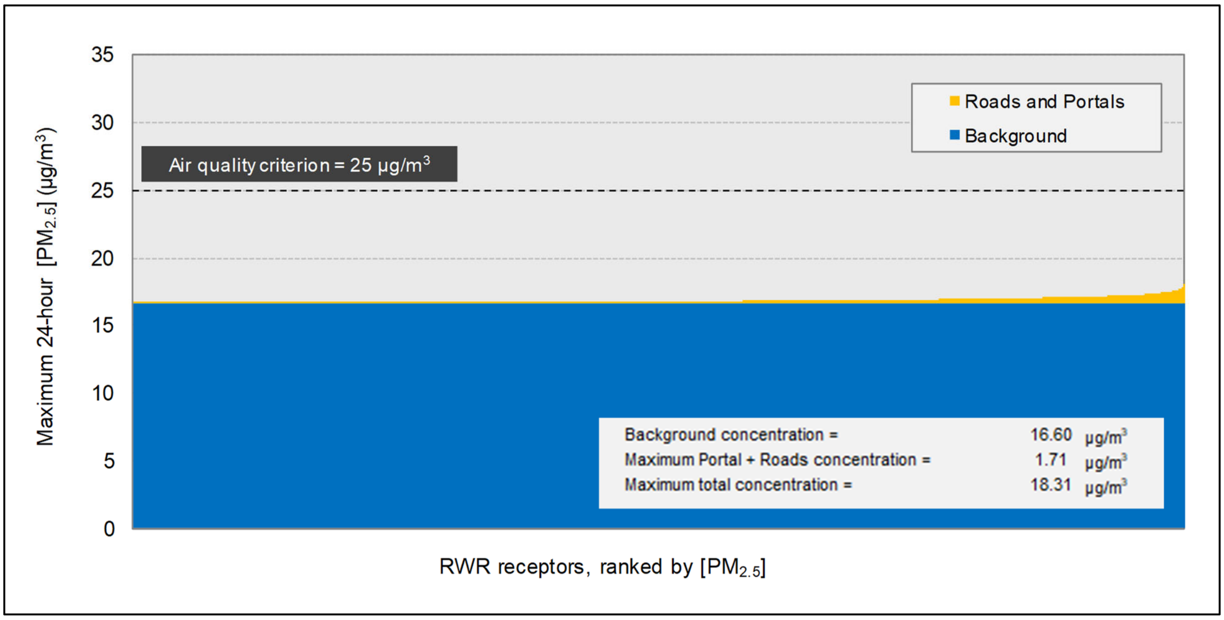


Figure 6-3: Cumulative maximum 24-hour average $PM_{2.5}$ concentrations due to the project for 2024 (µg/m^3)

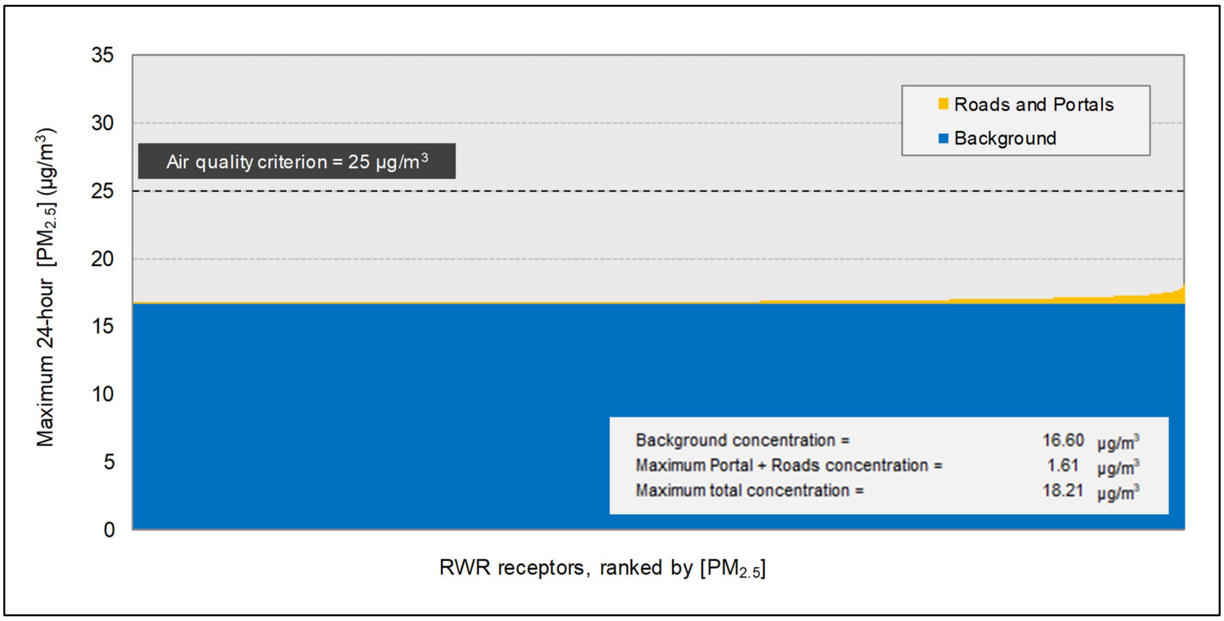


Figure 6-4: Cumulative maximum 24-hour average $PM_{2.5}$ concentrations due to the project for 2034 (µg/m^3)

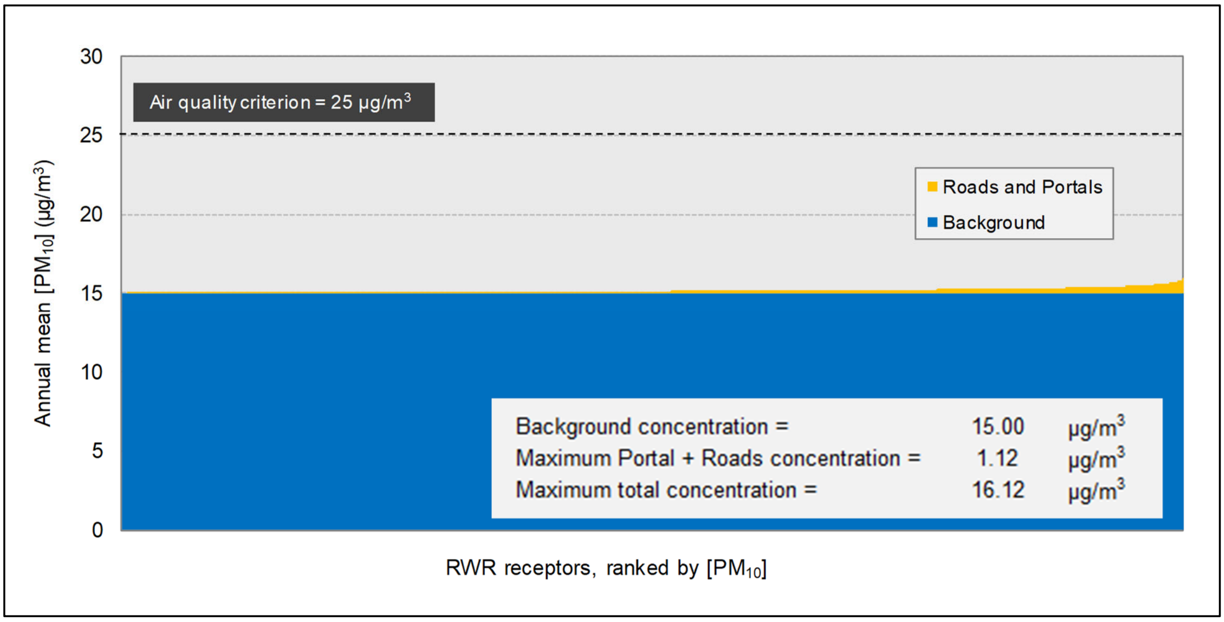


Figure 6-5: Cumulative annual average PM_{10} concentrations due to the project for 2024 (µg/m^3)

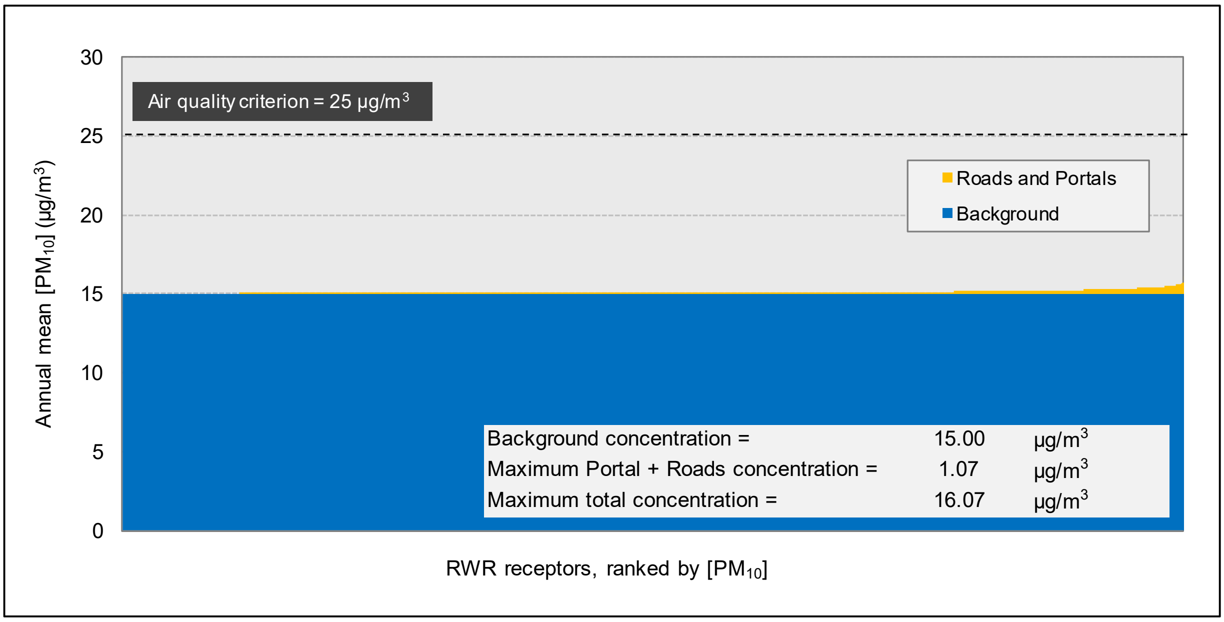


Figure 6-6: Cumulative annual average PM_{10} concentrations due to the project for 2034 (µg/m^3)

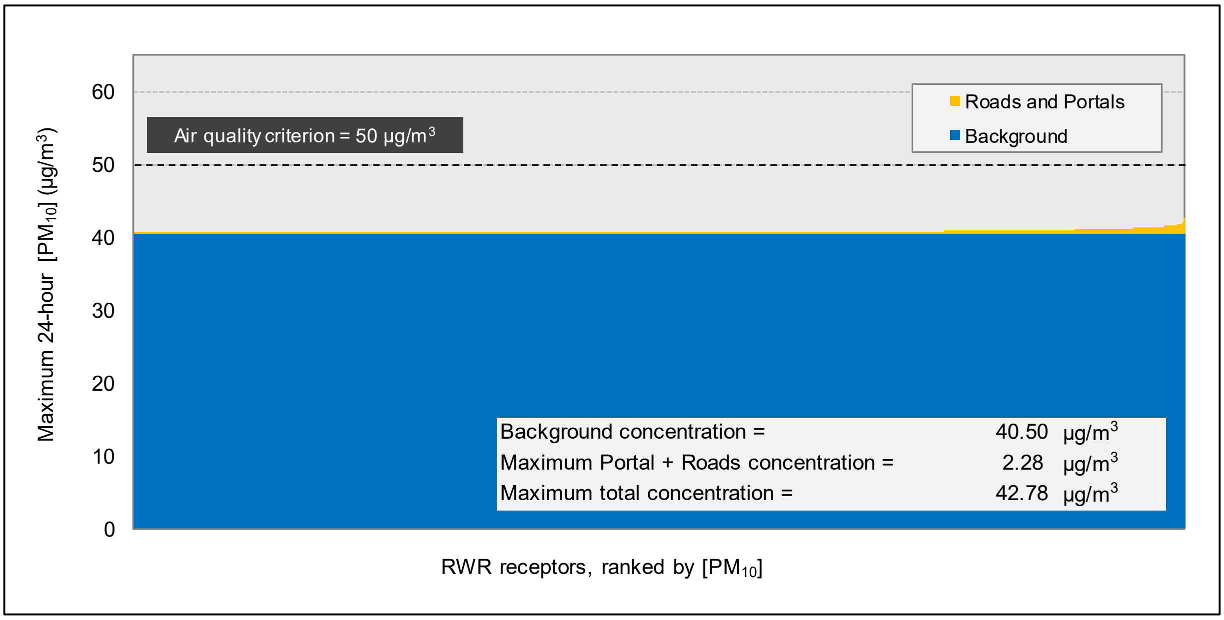


Figure 6-7: Cumulative maximum 24-hour average PM_{10} concentrations due to the project for 2024 (µg/m^3)

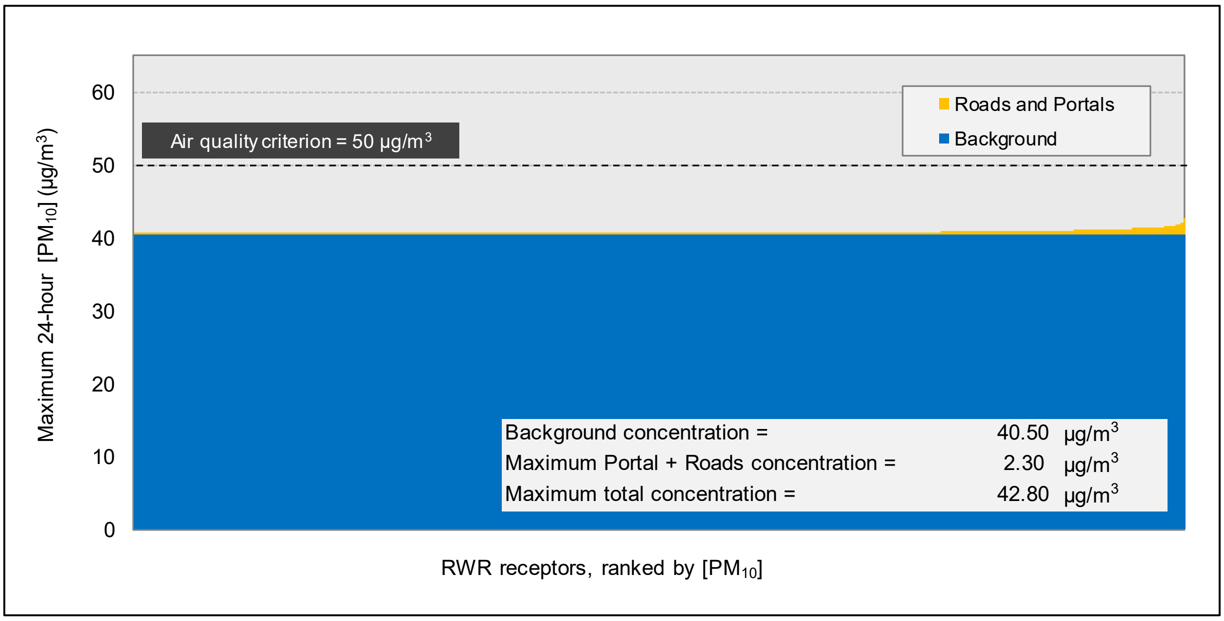


Figure 6-8: Cumulative maximum 24-hour average PM_{10} concentrations due to the project for 2034 (µg/m^3)

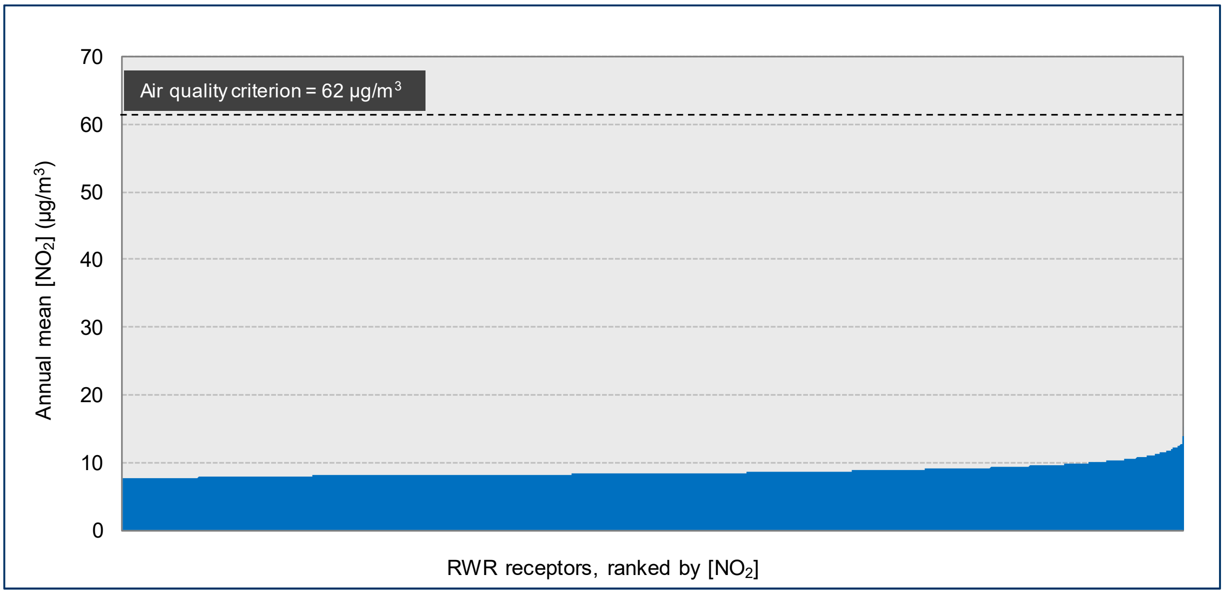


Figure 6-9: Cumulative annual average NO_2 concentrations due to the project for 2024 (µg/m^3)

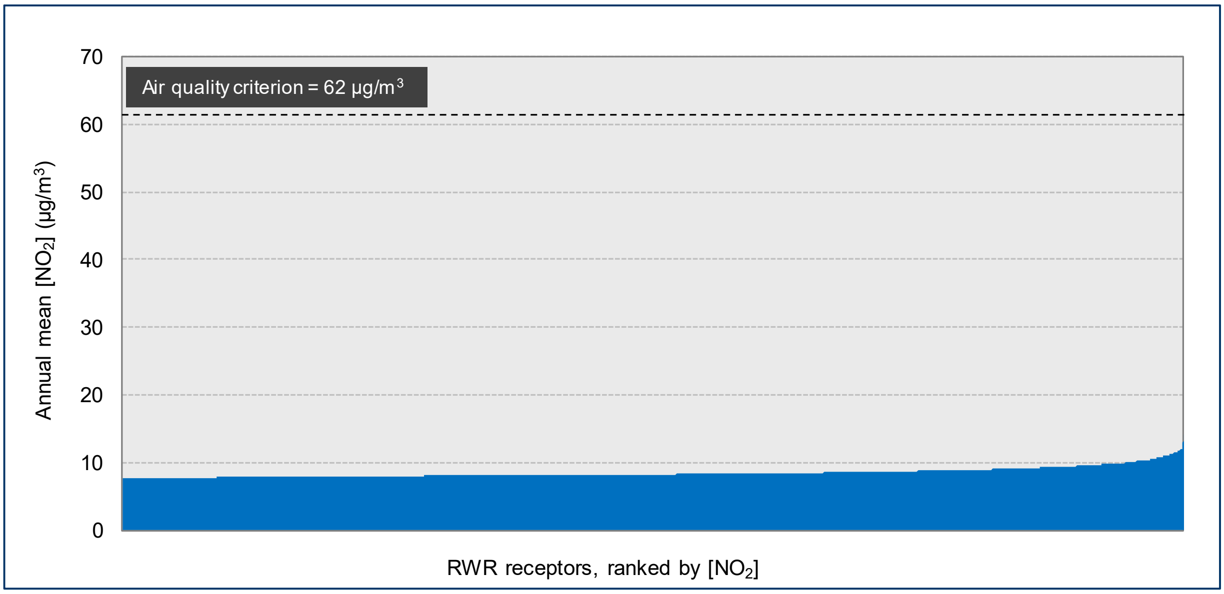


Figure 6-10: Cumulative annual average NO_2 concentrations due to the project for 2034 (µg/m^3)

It is noted again, for NO_2 predictions, the background levels are incorporated into the conversion calculations from NO_X to NO_2, and so there are no separate background values shown on Figure 6-9 to Figure 6-12.

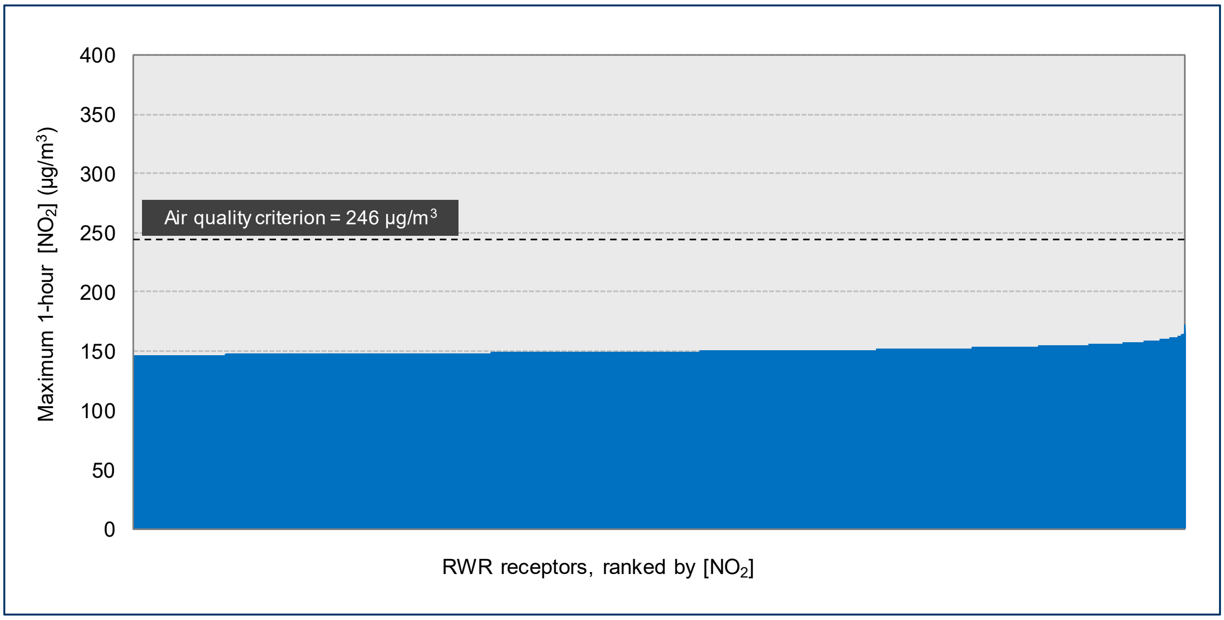


Figure 6-11: Cumulative maximum 1-hour average NO_2 concentrations due to the project for 2024 (µg/m^3)

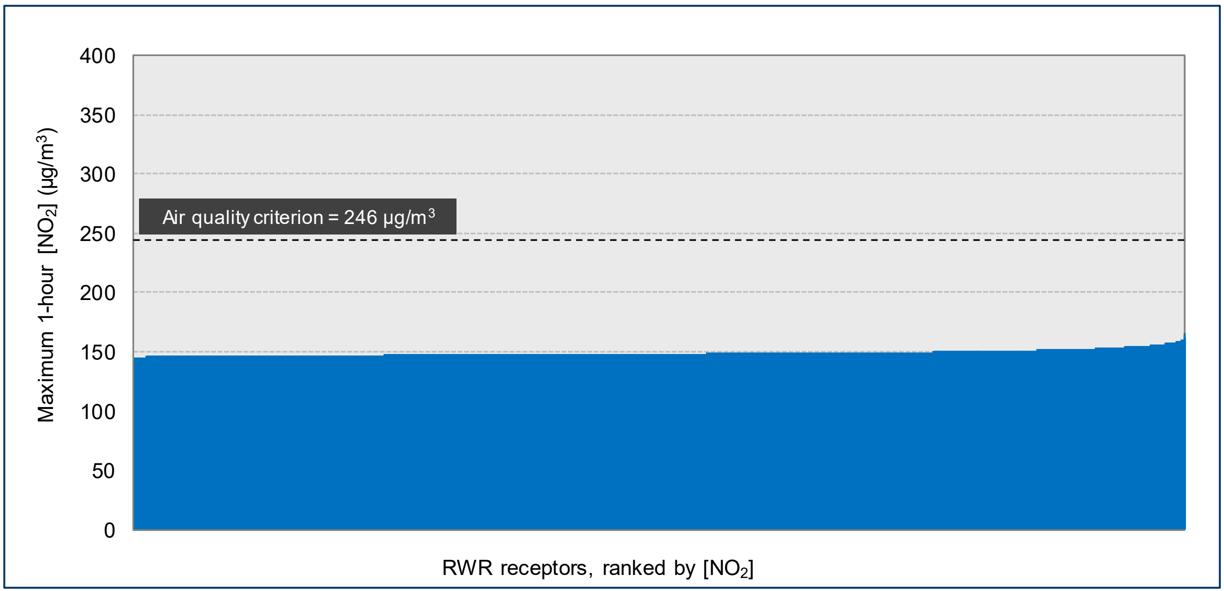


Figure 6-12: Cumulative maximum 1-hour average NO_2 concentrations due to the project for 2034 (µg/m^3)

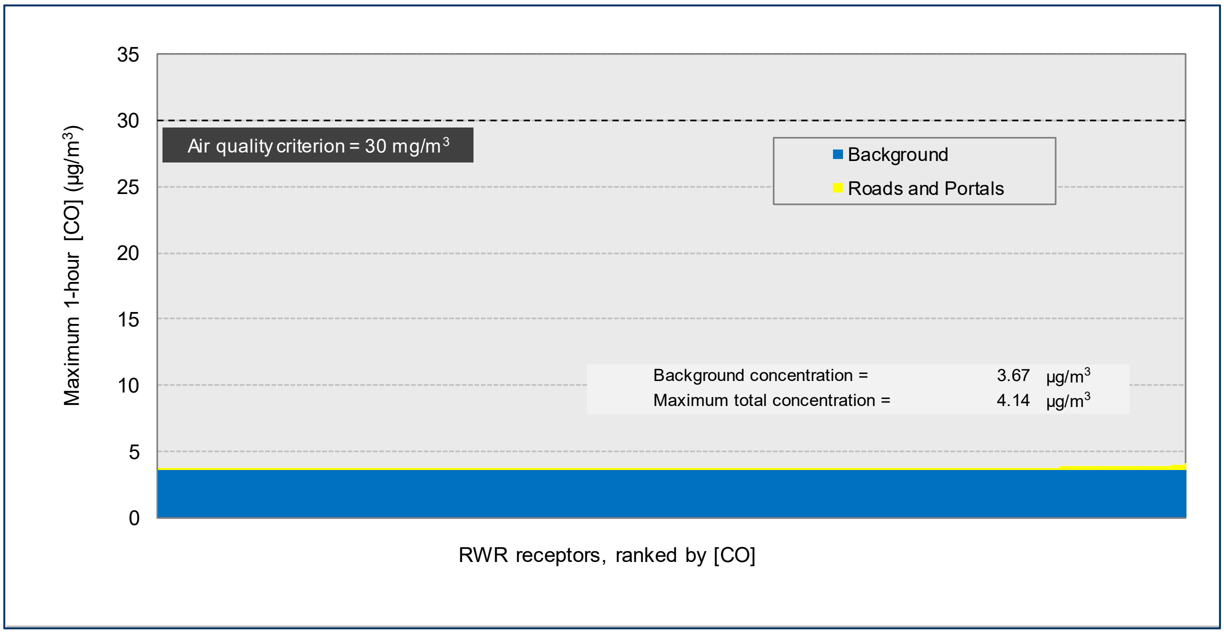


Figure 6-13: Cumulative maximum 1-hour average CO concentrations due to the project for 2024 (µg/m^3)

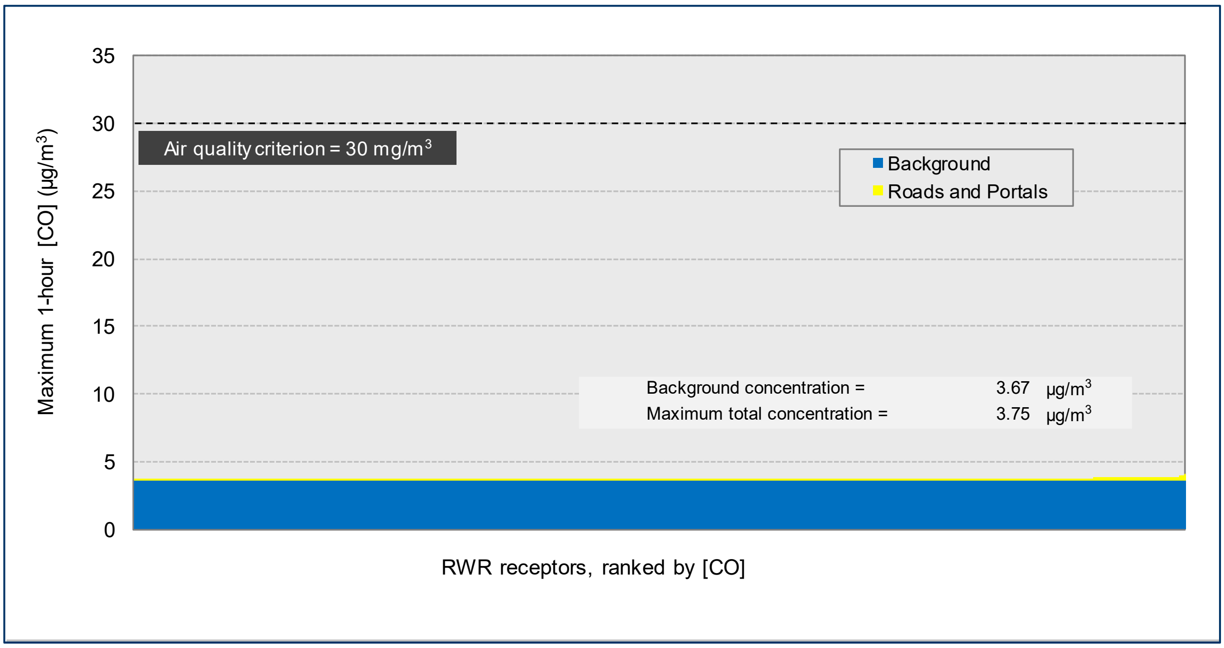


Figure 6-14: Cumulative maximum 1-hour average CO concentrations due to the project for 2034 (µg/m^3)

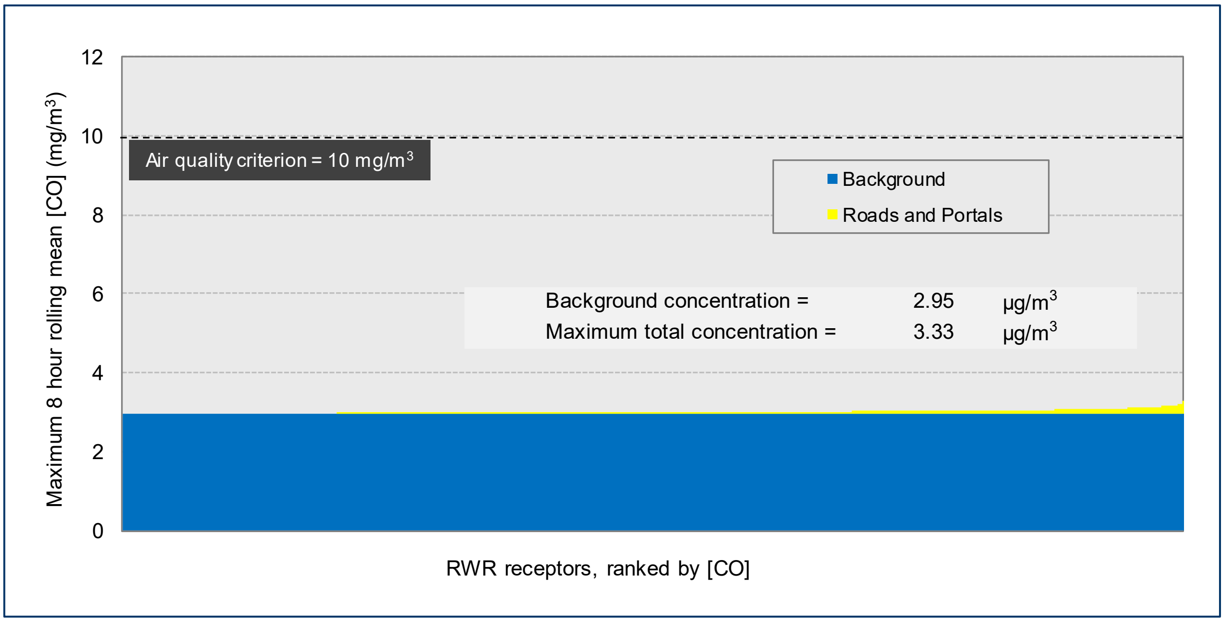


Figure 6-15: Cumulative maximum 8-hour average CO concentrations due to the project for 2024 (µg/m³)

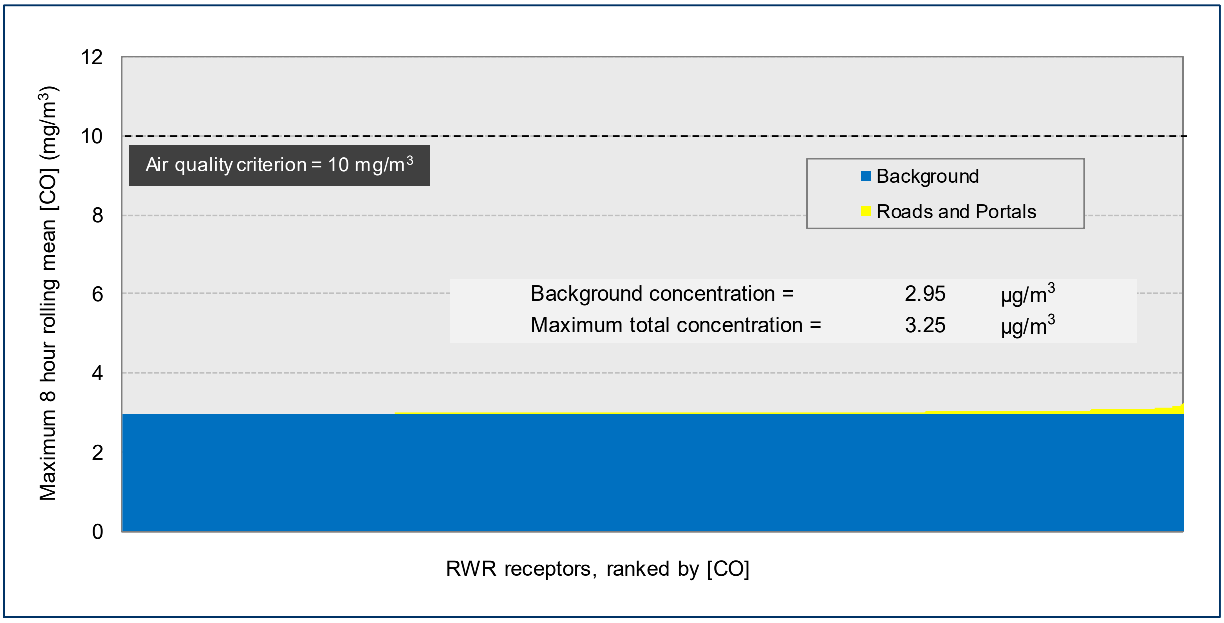


Figure 6-16: Cumulative maximum 8-hour average CO concentrations due to the project for 2034 (µg/m³)

Contributions of vehicle emissions to ambient air quality are historically low, and although these may increase in the immediate vicinity of the bypass, they are predicted to remain well below the relevant air quality criteria. Concentrations are predicted to reduce in 2036 at these locations due to estimated improvements in fuel efficiency. Concentrations will be reduced along the existing Pacific Highway with the project, as through traffic is diverted to the bypass.

Pollutant concentrations are predicted to be lower on the existing Pacific Highway in the 'Build' scenarios, due to reduced traffic volumes using this road as through traffic is redistributed to the project. There will be some localised increase in concentrations along the project, where previously roads did not exist, however, these increases are not predicted to result in any exceedance of the air quality standards.

Figure 6-17 to Figure 6-24 show the relative increases and decreases in NO_2, CO, $PM_{2.5}$ and PM_{10} concentrations for 2024. The same information for 2034 is shown in Figure 6-25 to Figure 6-32. These figures show the Build – No Build scenario, where a negative number (green contours) represents a reduction in predicted concentration (improvement in air quality). Not surprisingly, these are areas around the current Pacific Highway which should see a reduction in traffic volumes. Conversely, purple areas represent a predicted increase in concentrations along the proposed bypass route where there was previously no traffic.

The largest increases are at the portal exits which is expected due to more concentrated emissions as traffic exits each tunnel. These are dispersed relatively quickly with concentrations reduced significantly within a short distance from each portal. There are areas of reduced concentrations (green shading) at the southern and northern of the project, due predominantly to improved traffic flows.

The predicted changes due to the project, shown across the domain in these figures, are also presented for all the individual sensitive receptors in Figure 6-33 to Figure 6-48. Those receptors experiencing an increase in concentration are positive, and those predicted to experience an improvement are negative.

There may be some redistribution of traffic to side roads at new interchanges, such as Coramba Road, but any changes in volumes would be unlikely to result in any measureable change in air quality. Improvements in traffic flow would also help to keep emissions down and reduce impacts.

There is no requirement for management measures for the operation of the project.

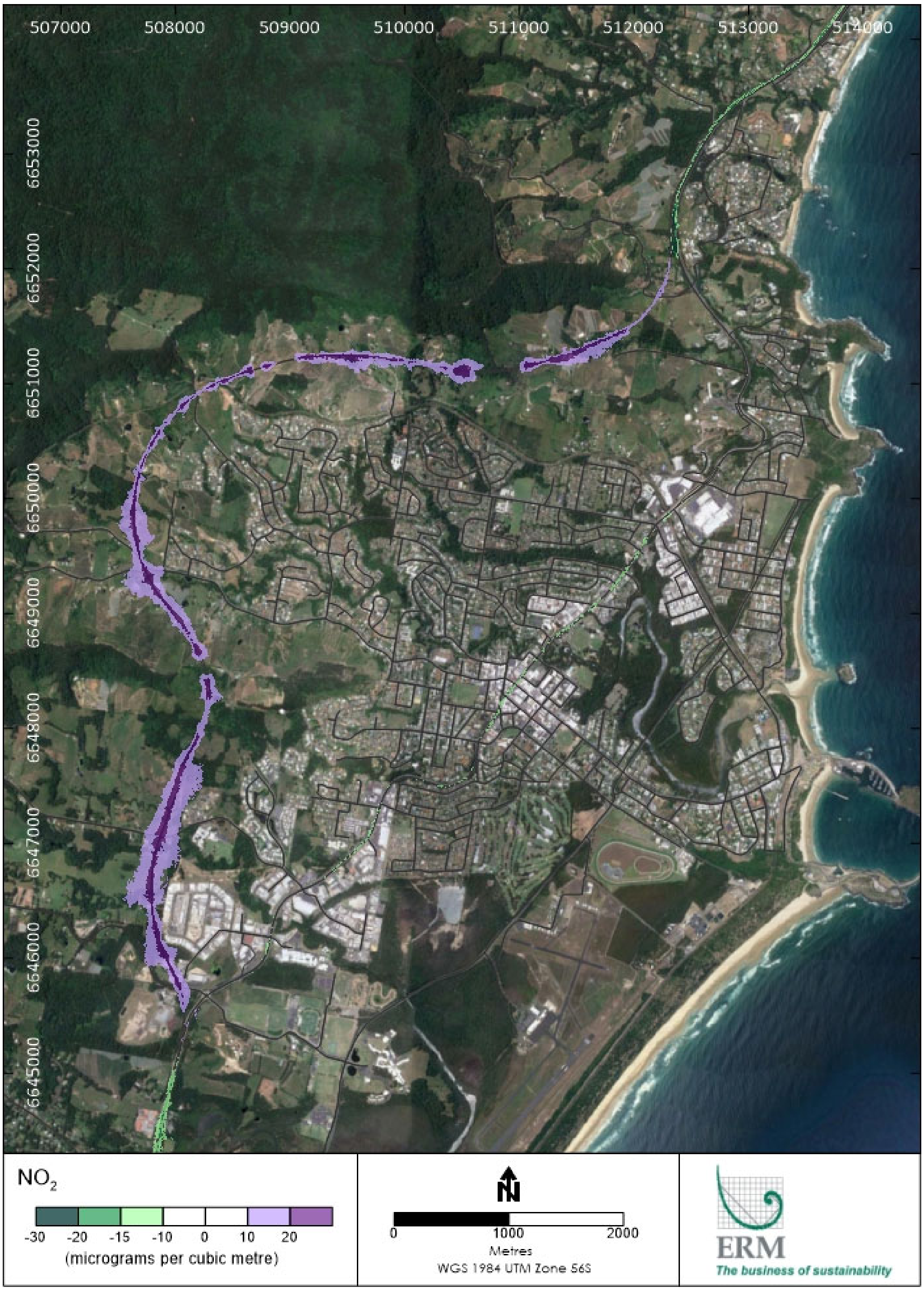


Figure 6-17: Change in predicted maximum 1-hour average NO_2 concentrations due to the project for 2024 ($\mu g/m^3$)

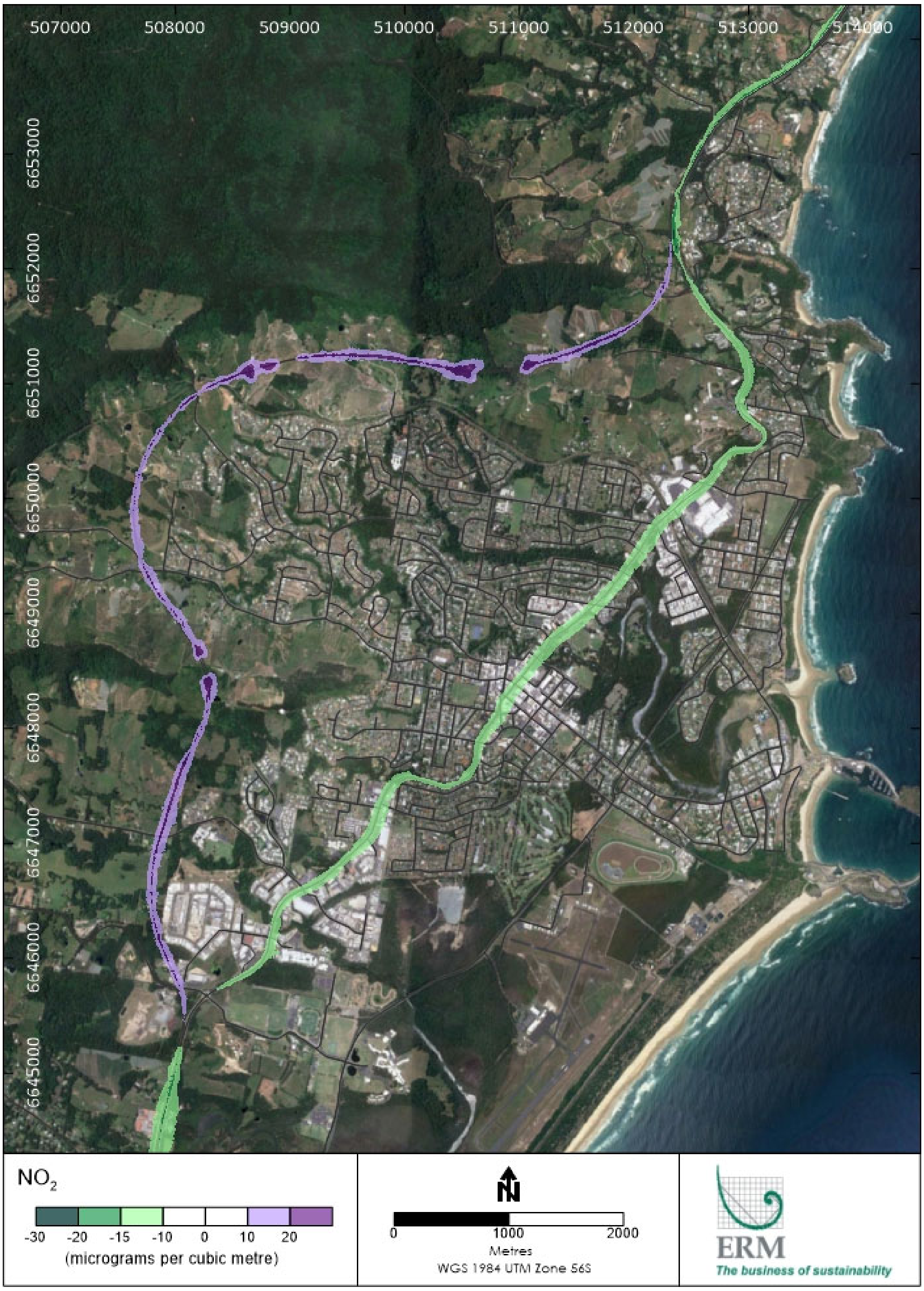


Figure 6-18: Change in predicted annual average NO_2 concentrations due to the project for 2024 (µg/m^3)

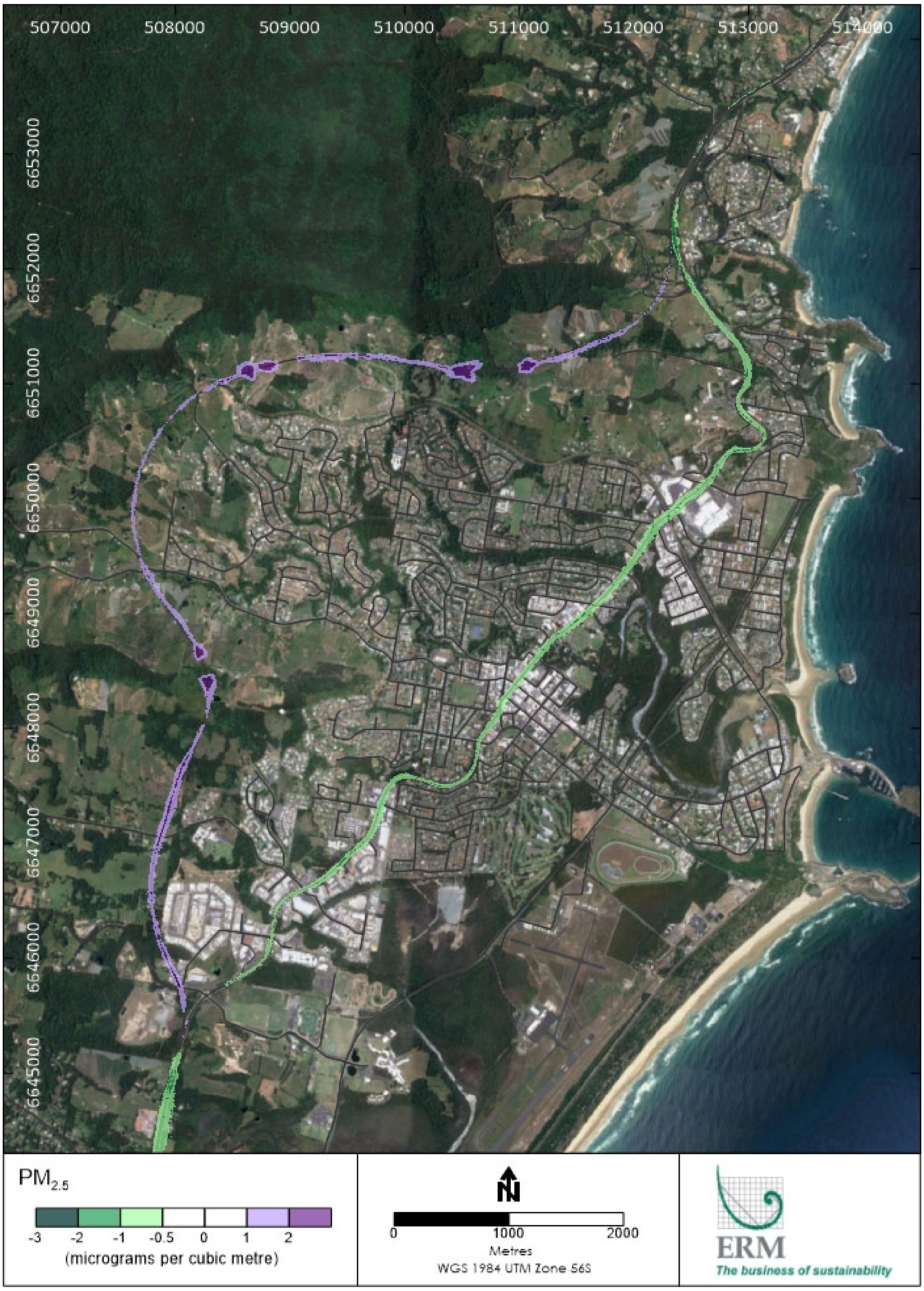


Figure 6-19: Change in predicted maximum 24-hour average $PM_{2.5}$ concentrations due to the project for 2024 (μg/m^3)

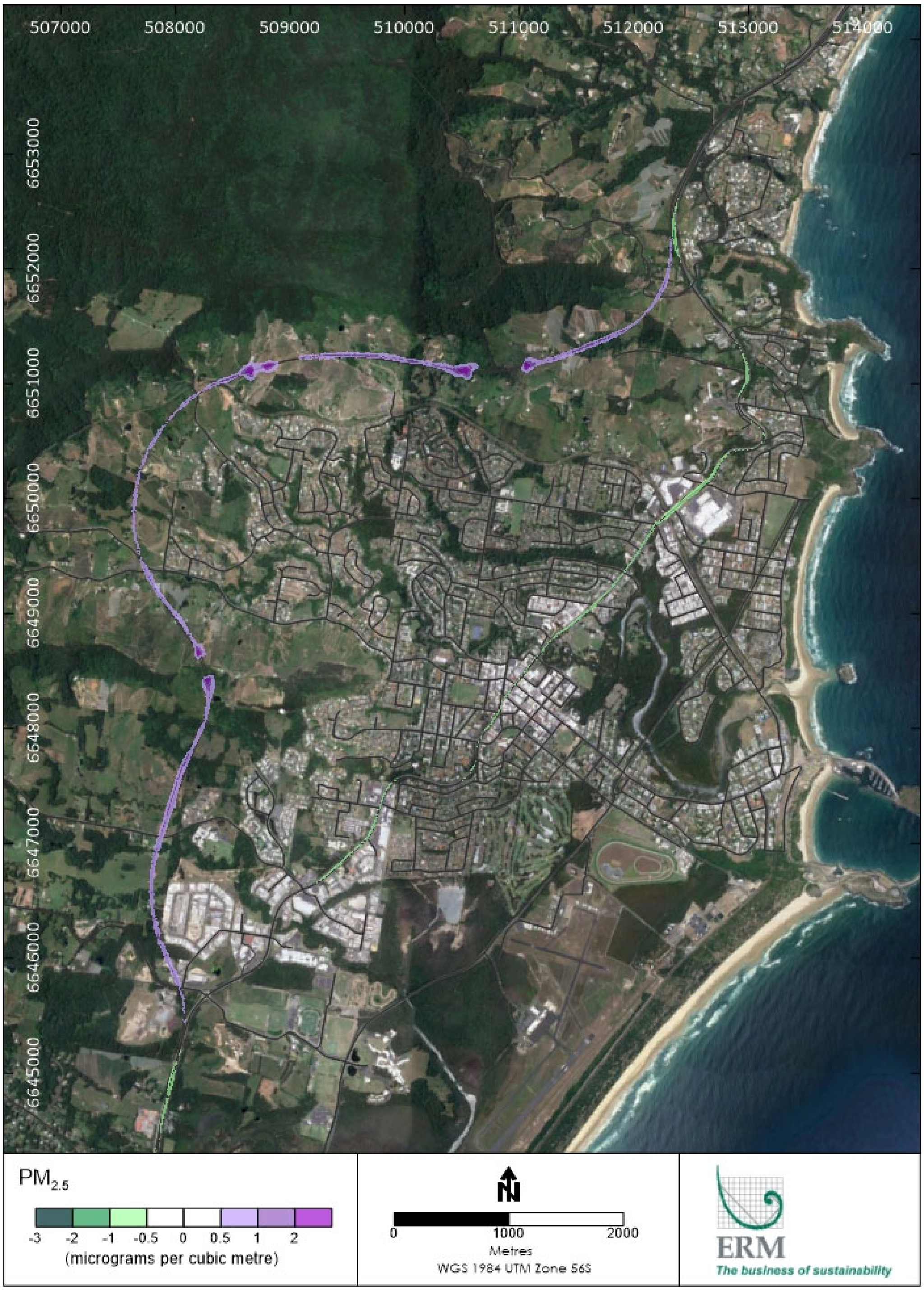


Figure 6-20: Change in predicted annual average $PM_{2.5}$ concentrations due to the project for 2024 (µg/m^3)

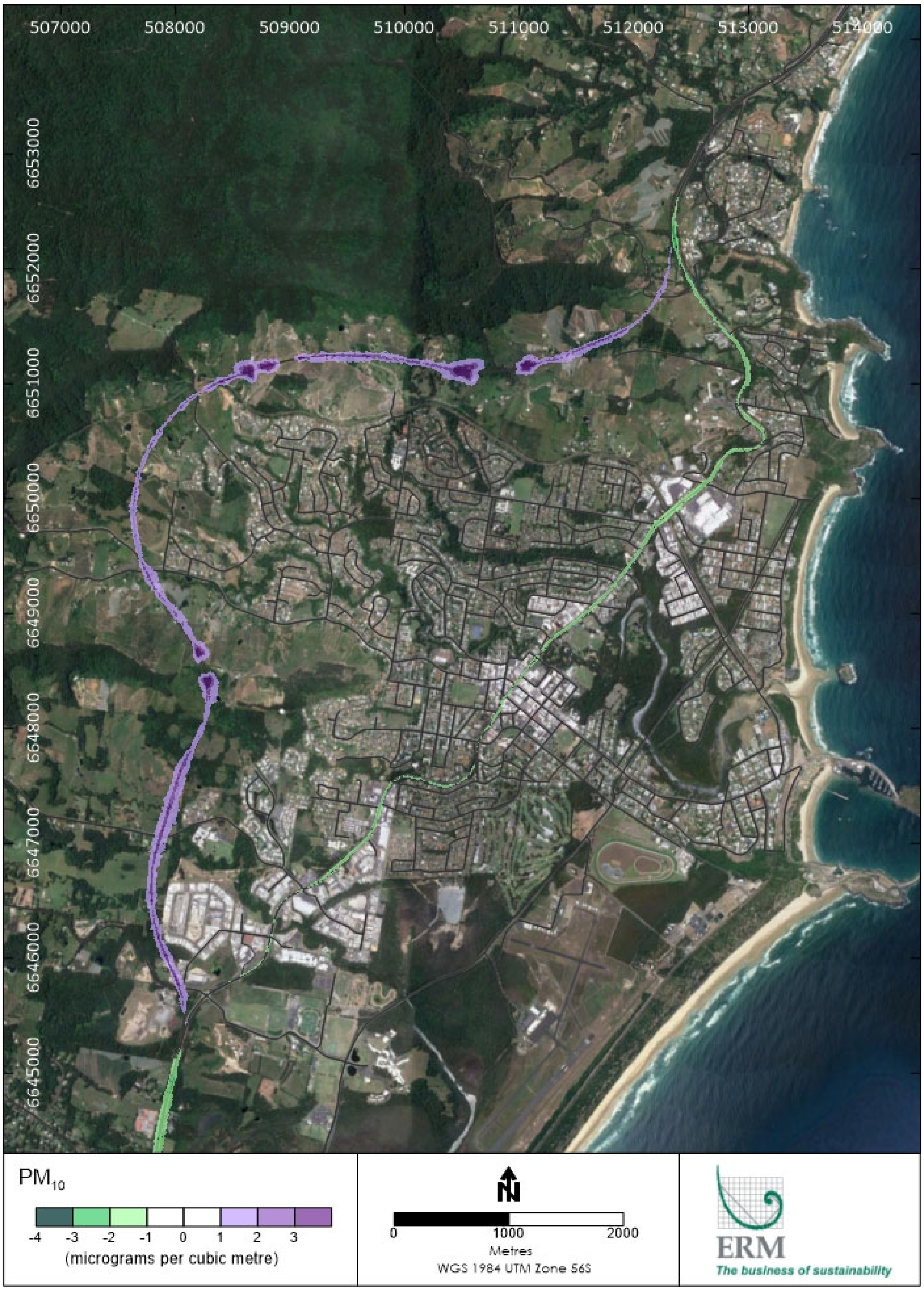


Figure 6-21: Change in predicted maximum 24-hour average PM_{10} concentrations due to the project for 2024 (µg/m³)

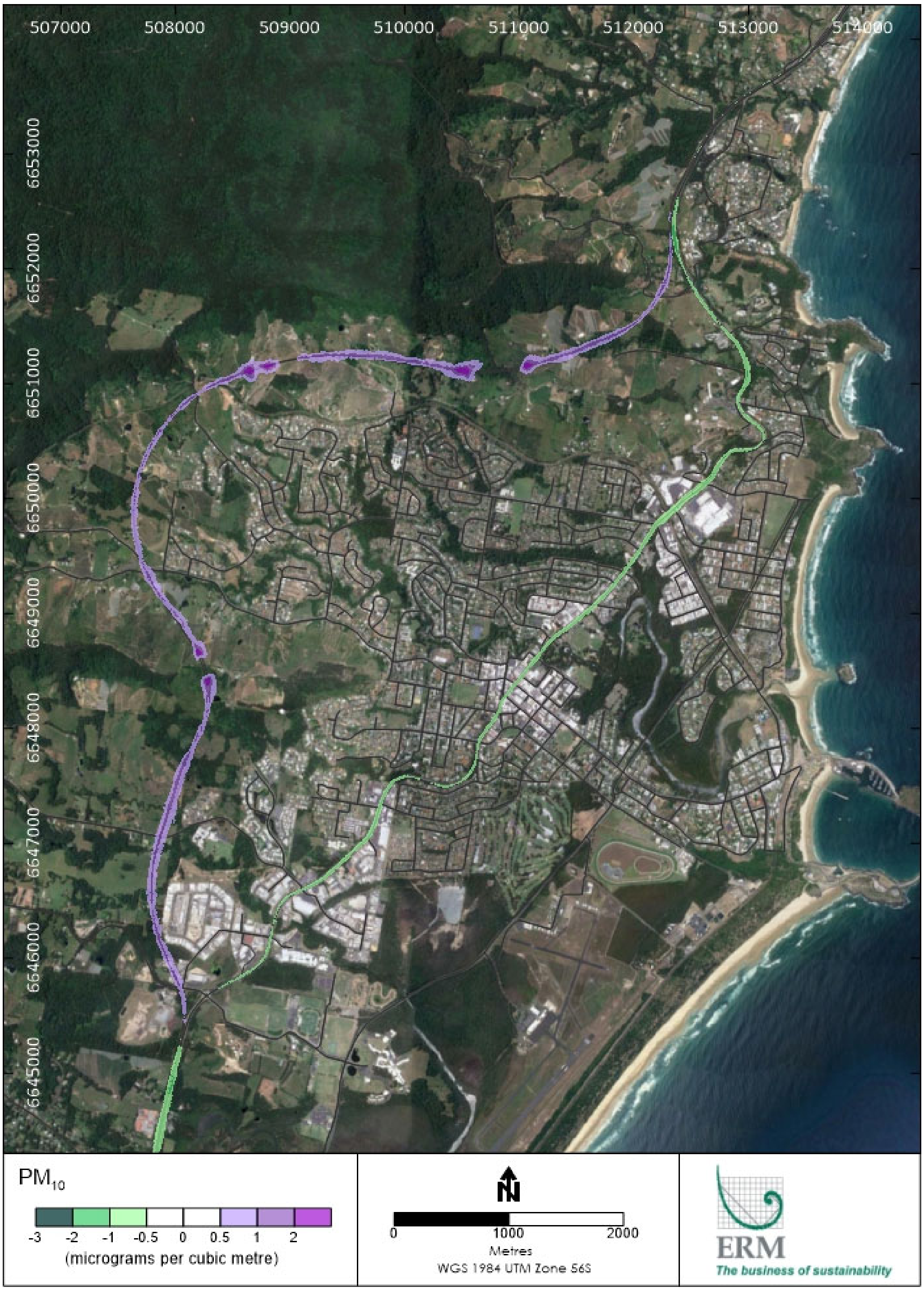


Figure 6-22: Change in predicted maximum annual average PM_{10} concentrations due to the project for 2024 (µg/m^3)

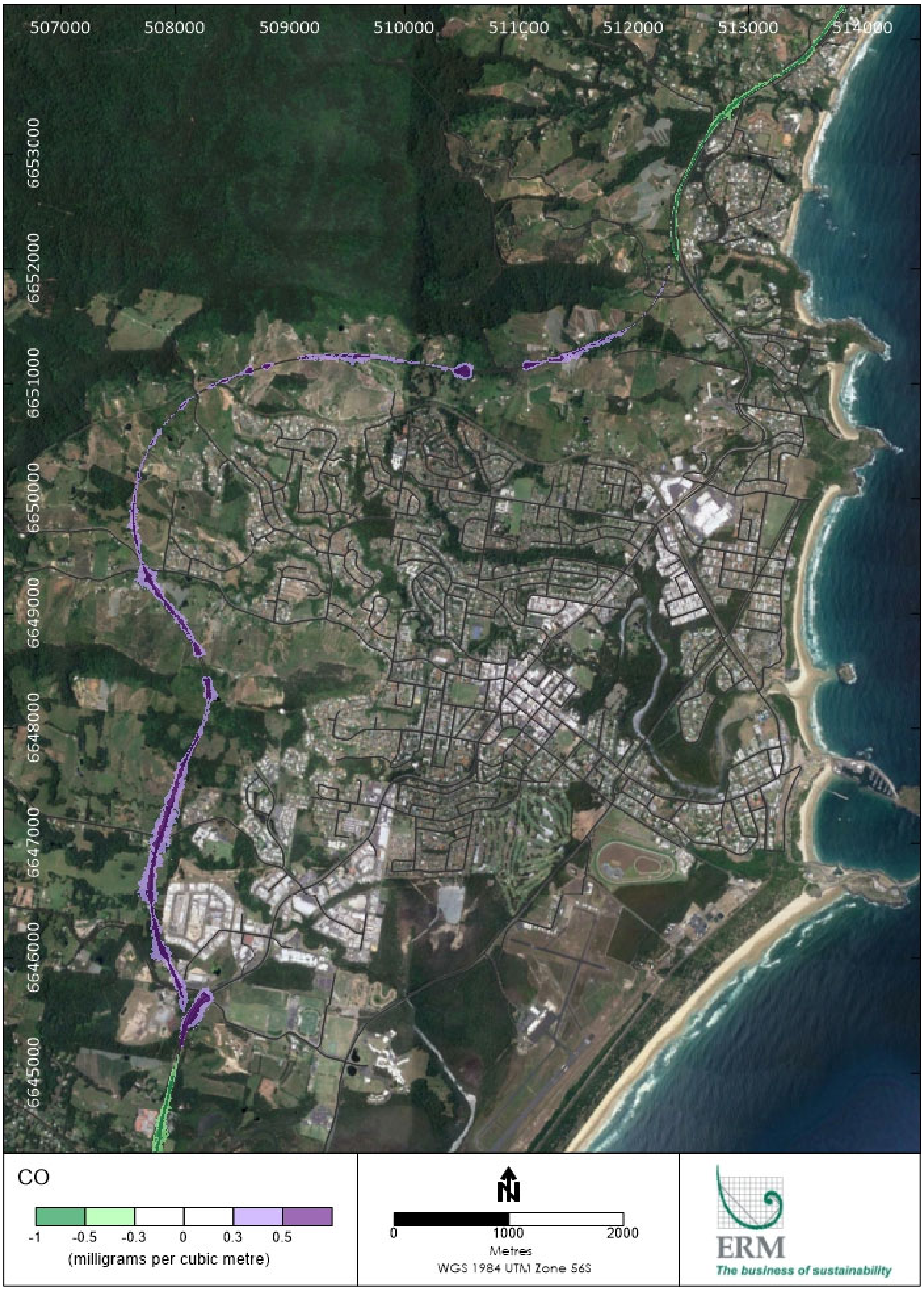


Figure 6-23: Change in predicted maximum 1-hour average CO concentrations due to the project for 2024 (mg/m^3)

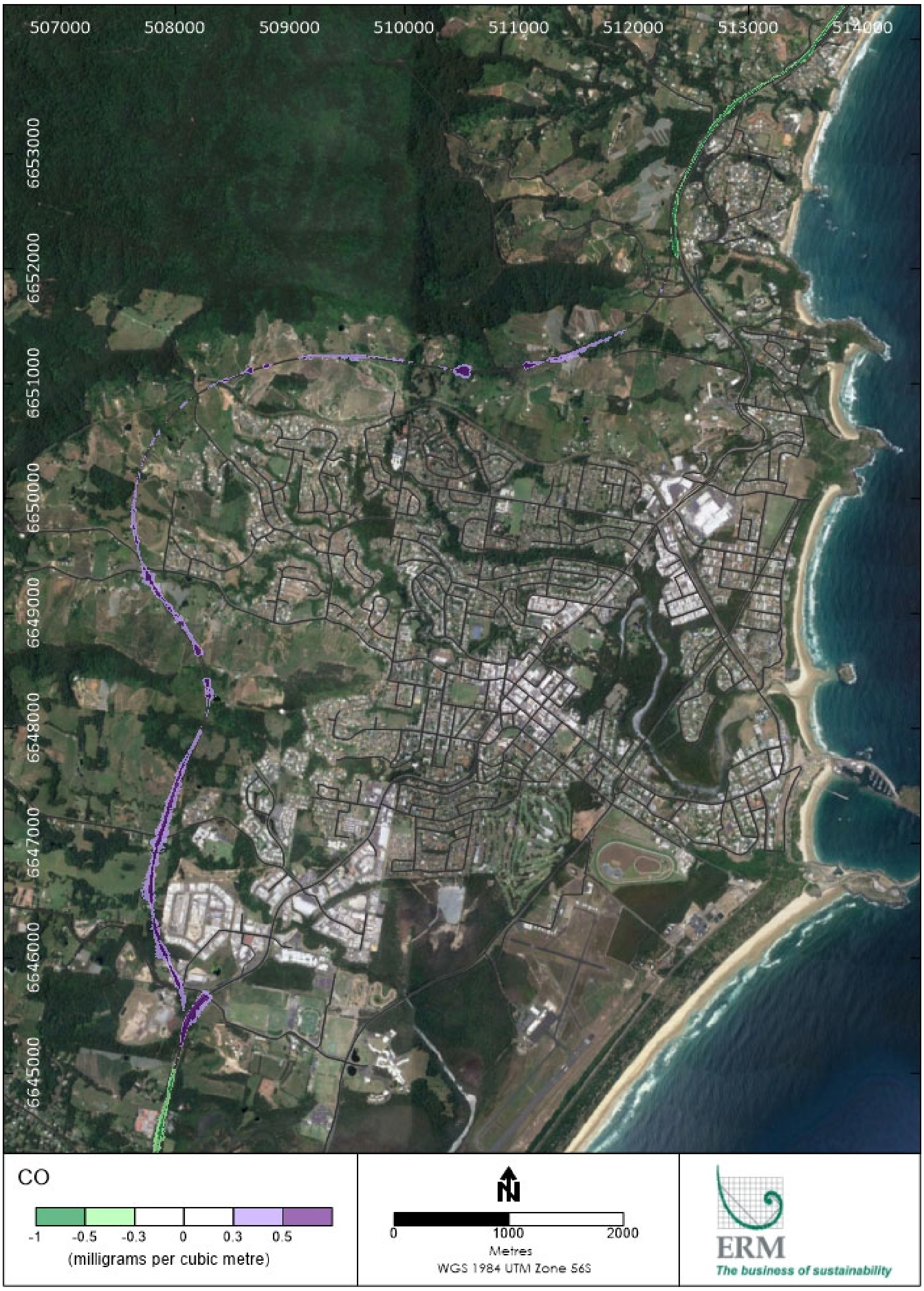


Figure 6-24: Change in predicted maximum 8-hour rolling average CO concentrations due to the project for 2024 (mg/m^3)

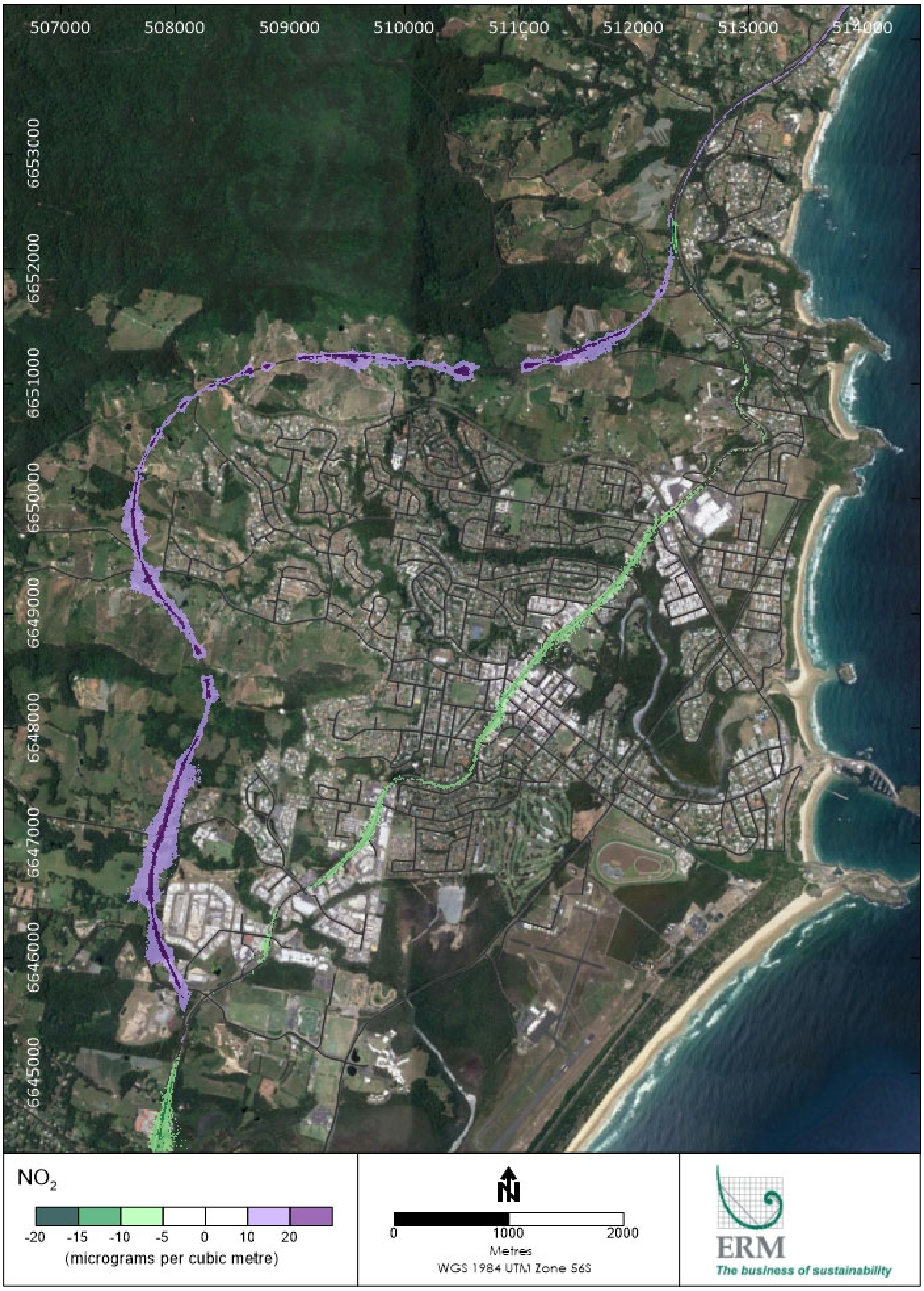


Figure 6-25: Change in predicted maximum 1-hour average NO_2 concentrations due to the project for 2034 (μg/m³)

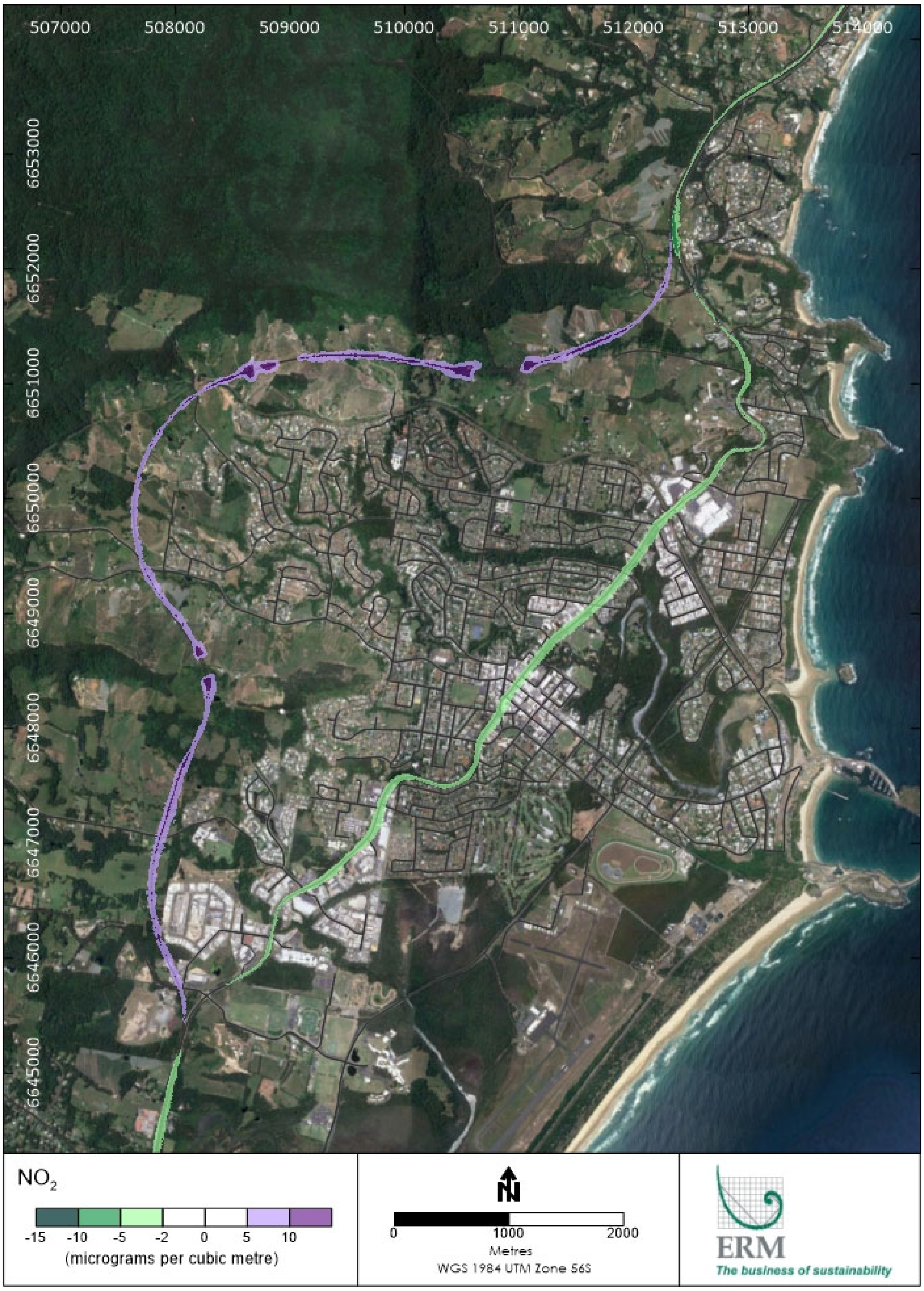


Figure 6-26: Change in predicted annual average NO_2 concentrations due to the project for 2034 (µg/m³)

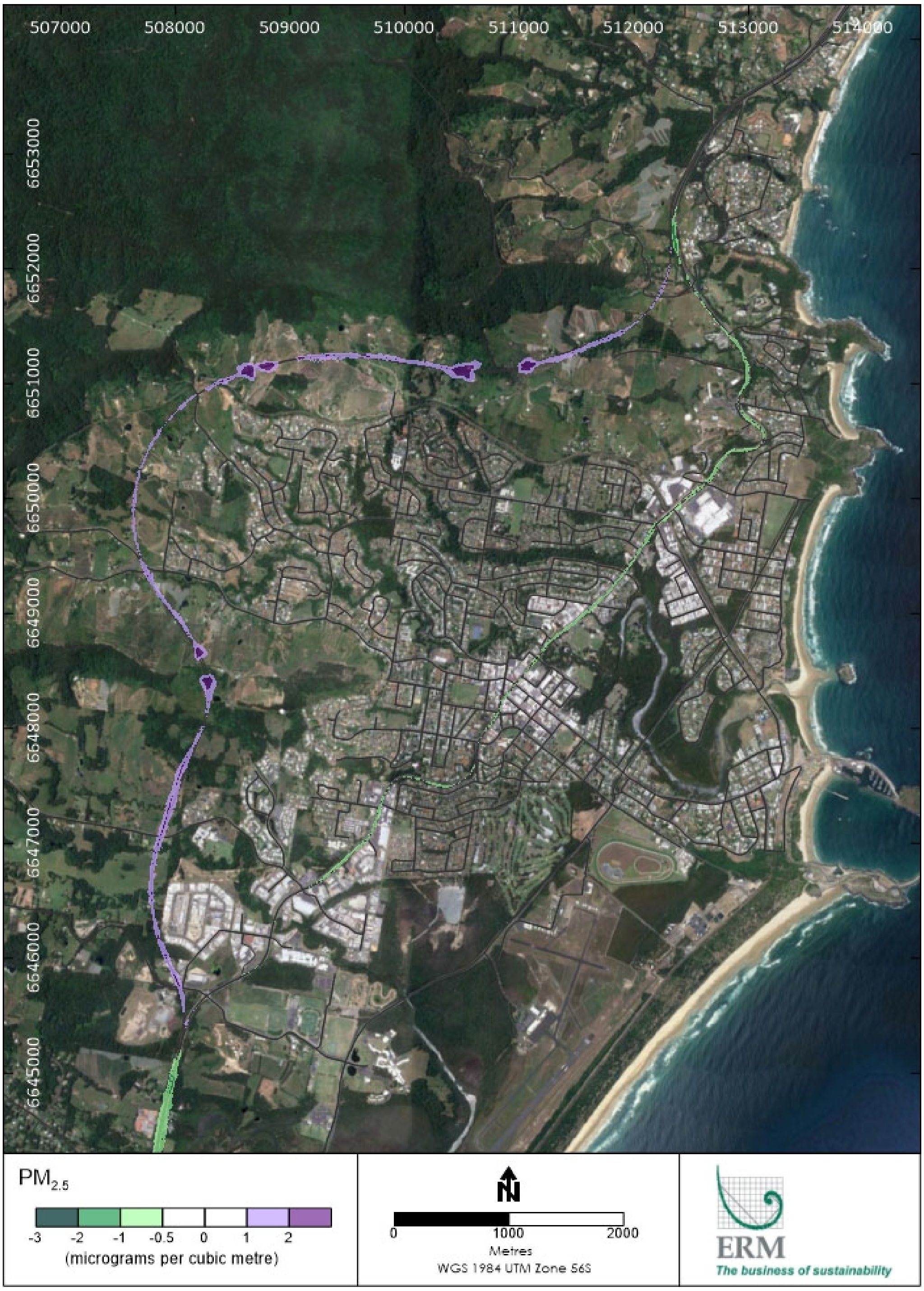


Figure 6-27: Change in predicted maximum 24-hour average $PM_{2.5}$ concentrations due to the project for 2034 (μg/m^3)

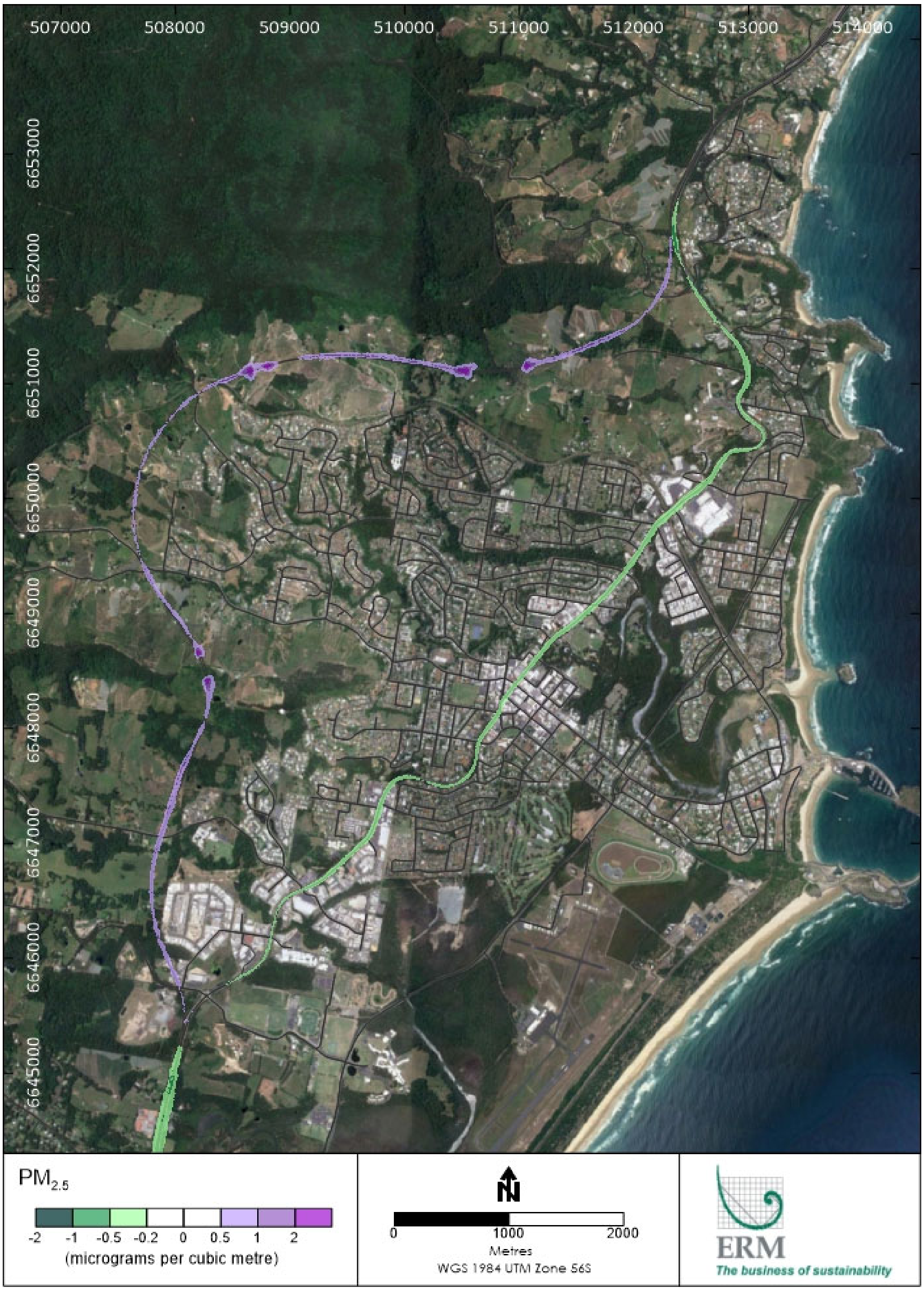


Figure 6-28: Change in predicted annual average $PM_{2.5}$ concentrations due to the project for 2034 (µg/m^3)

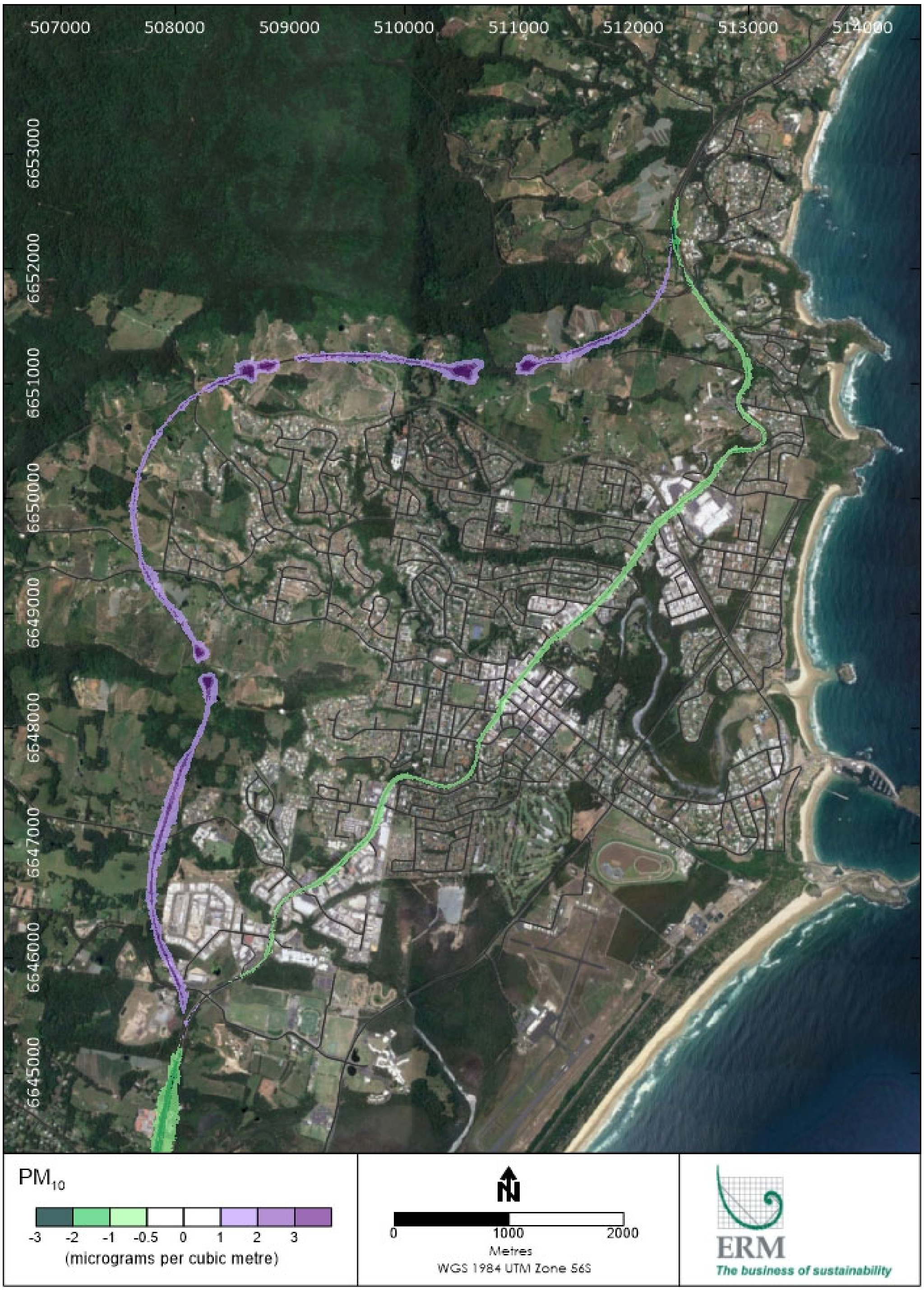


Figure 6-29: Change in predicted maximum 24-hour average PM_{10} concentrations due to the project for 2034 ($\mu g/m^3$)

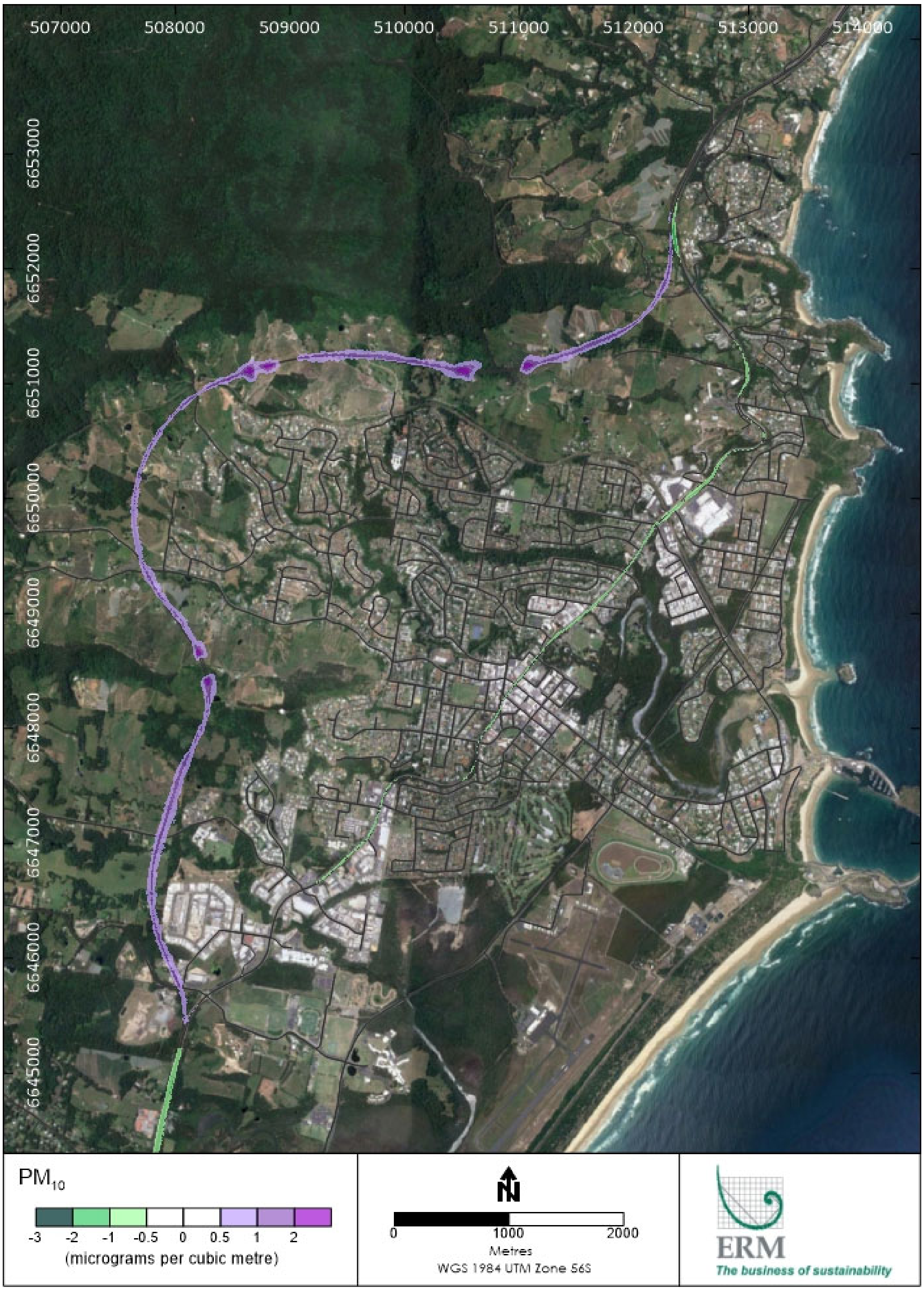


Figure 6-30: Change in predicted maximum annual average PM_{10} concentrations due to the project for 2034 (µg/m^3)

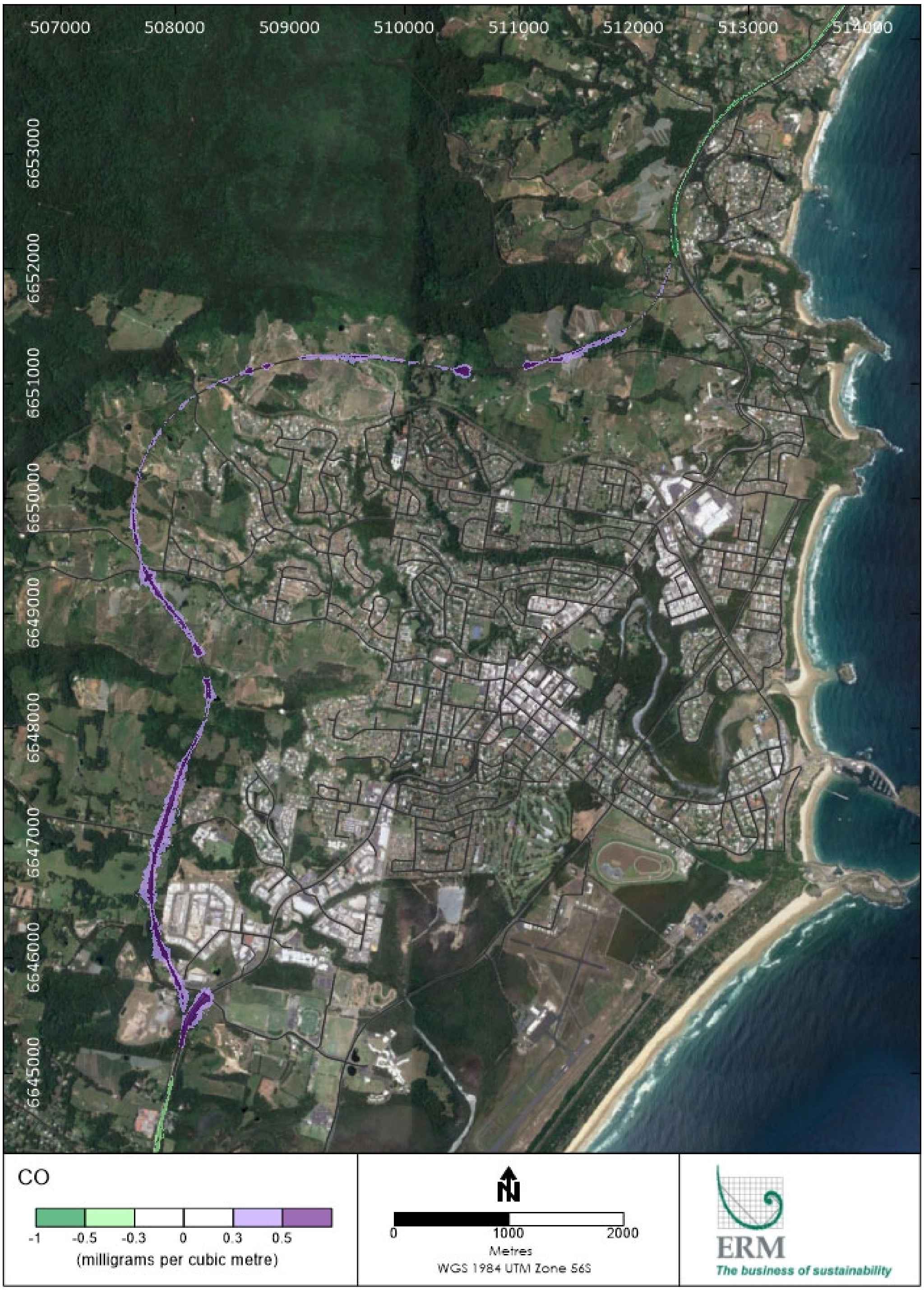


Figure 6-31: Change in predicted maximum 1-hour average CO concentrations due to the project for 2034 (mg/m^3)

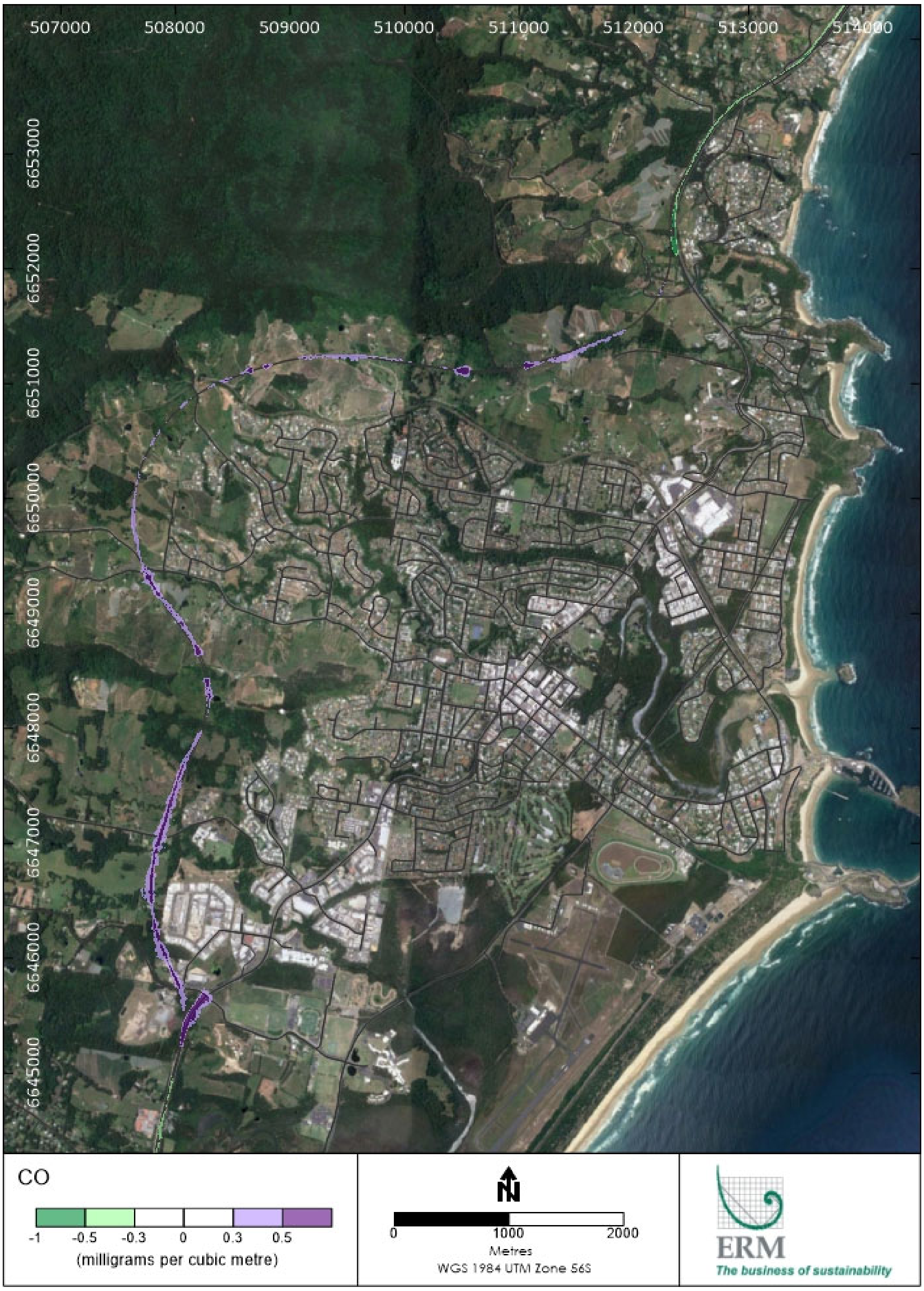


Figure 6-32: Change in predicted maximum 8-hour rolling average CO concentrations due to the project for 2034 (mg/m^3)

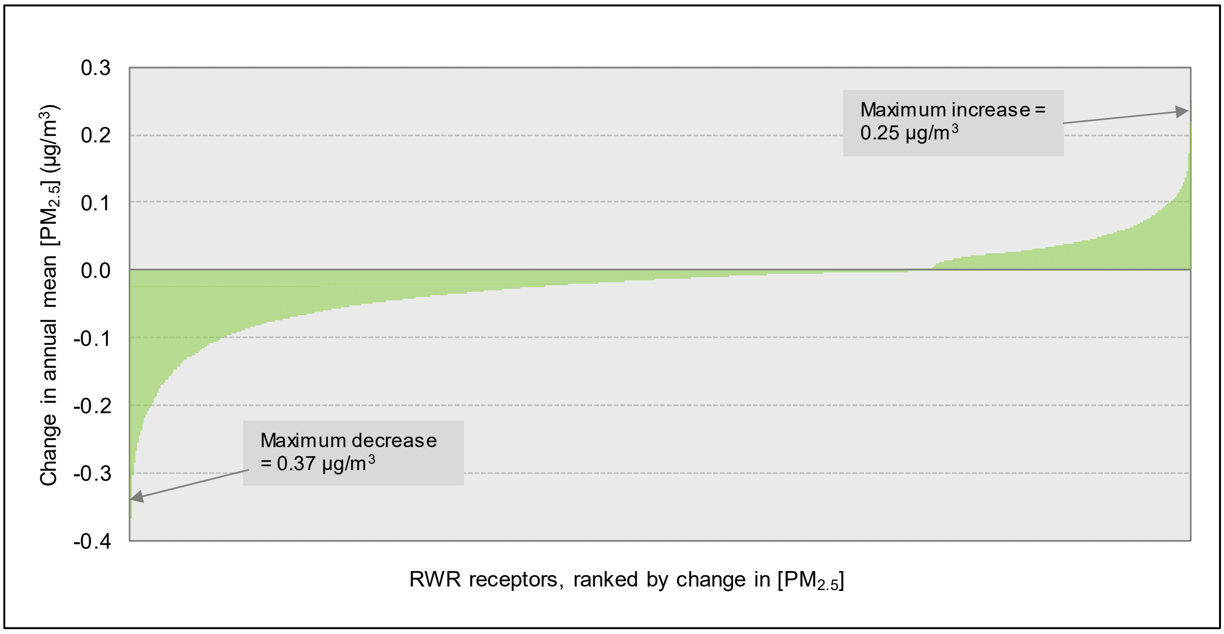


Figure 6-33: Change in predicted annual average $PM_{2.5}$ concentrations at sensitive receptors, due to the project for 2024 ($\mu g/m^3$)

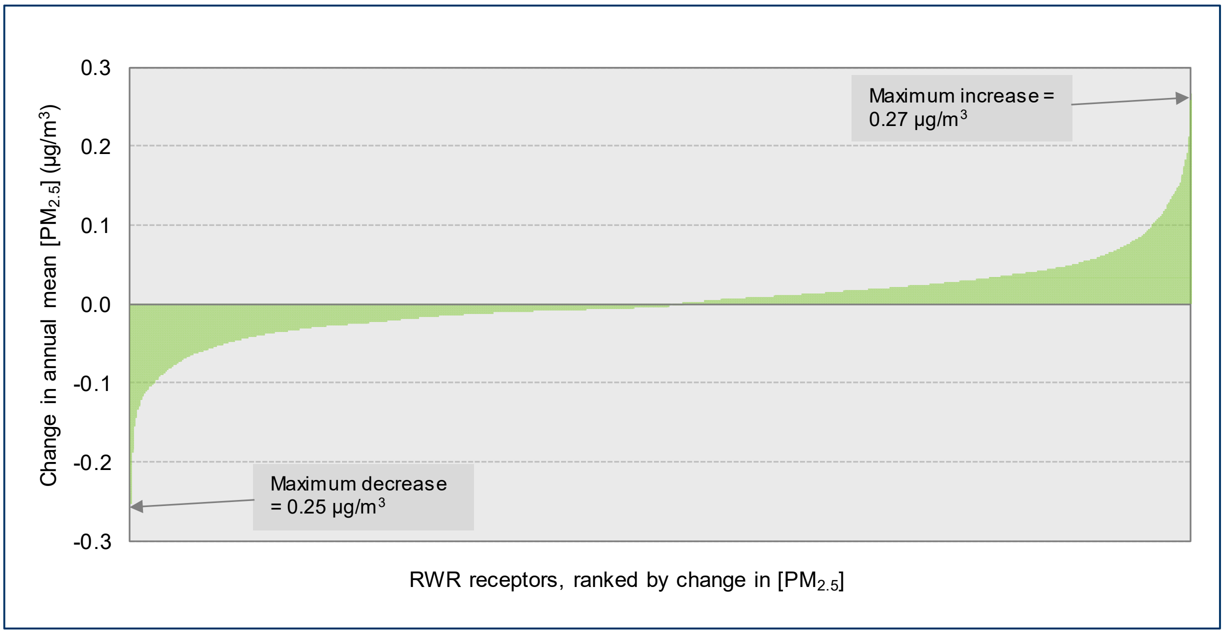


Figure 6-34: Change in predicted annual average $PM_{2.5}$ concentrations at sensitive receptors, due to the project for 2034 ($\mu g/m^3$)

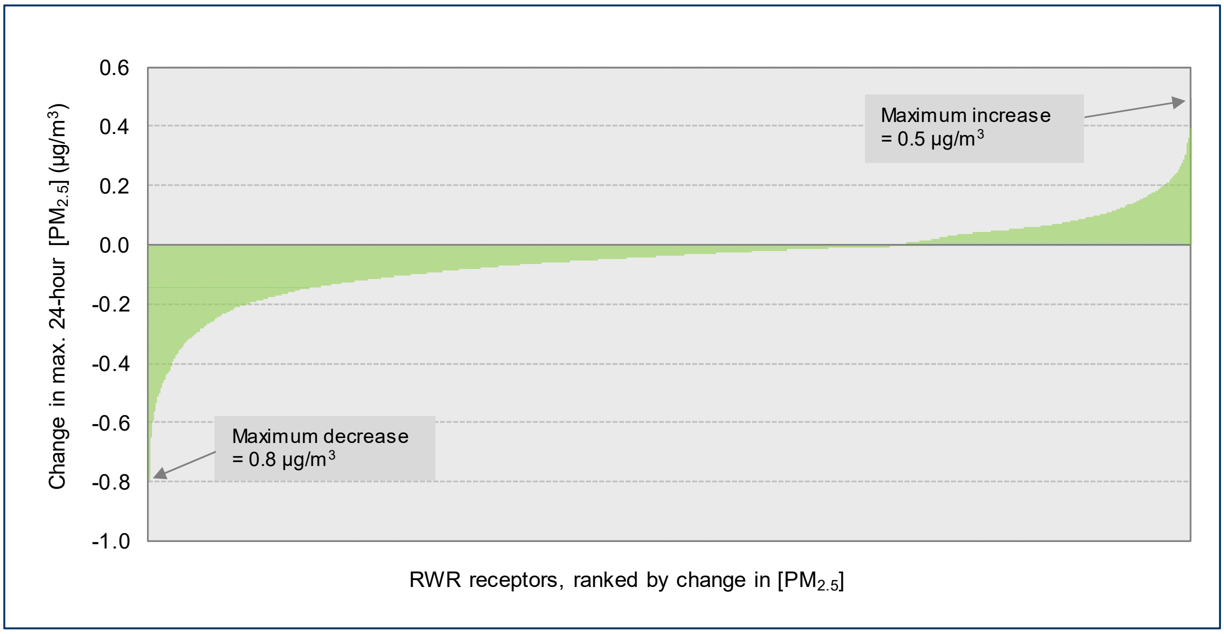


Figure 6-35: Change in predicted maximum 24-hour average $PM_{2.5}$ concentrations at sensitive receptors, due to the project for 2024 (µg/m^3)

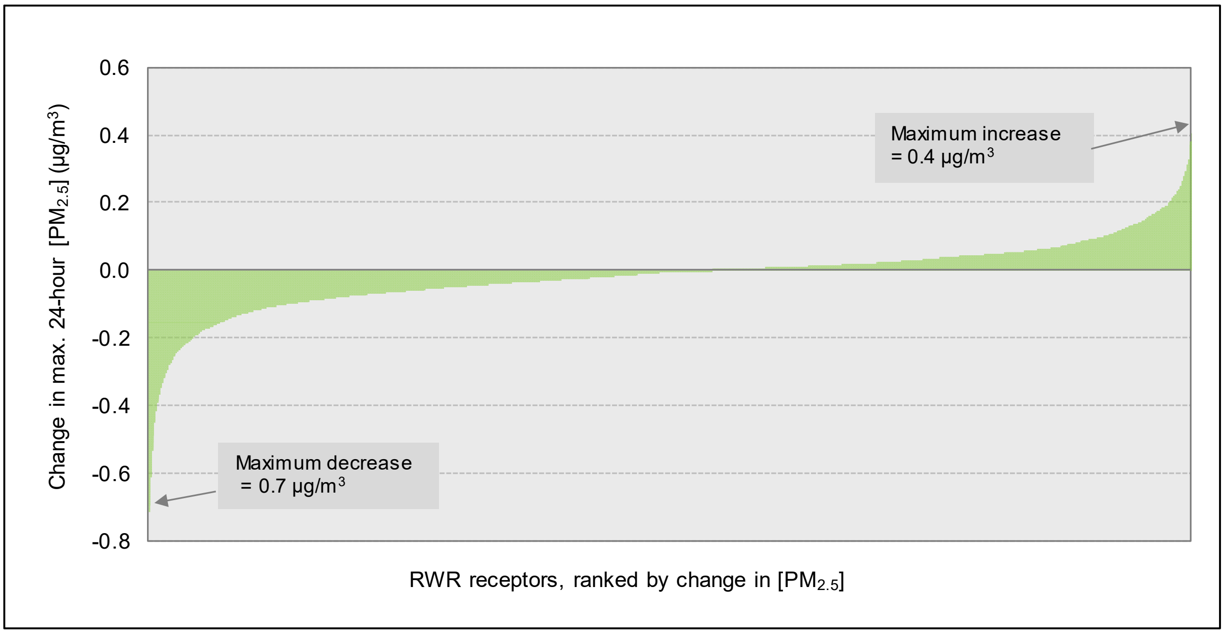


Figure 6-36: Change in predicted maximum 24-hour average $PM_{2.5}$ concentrations at sensitive receptors, due to the project for 2034 (µg/m^3)

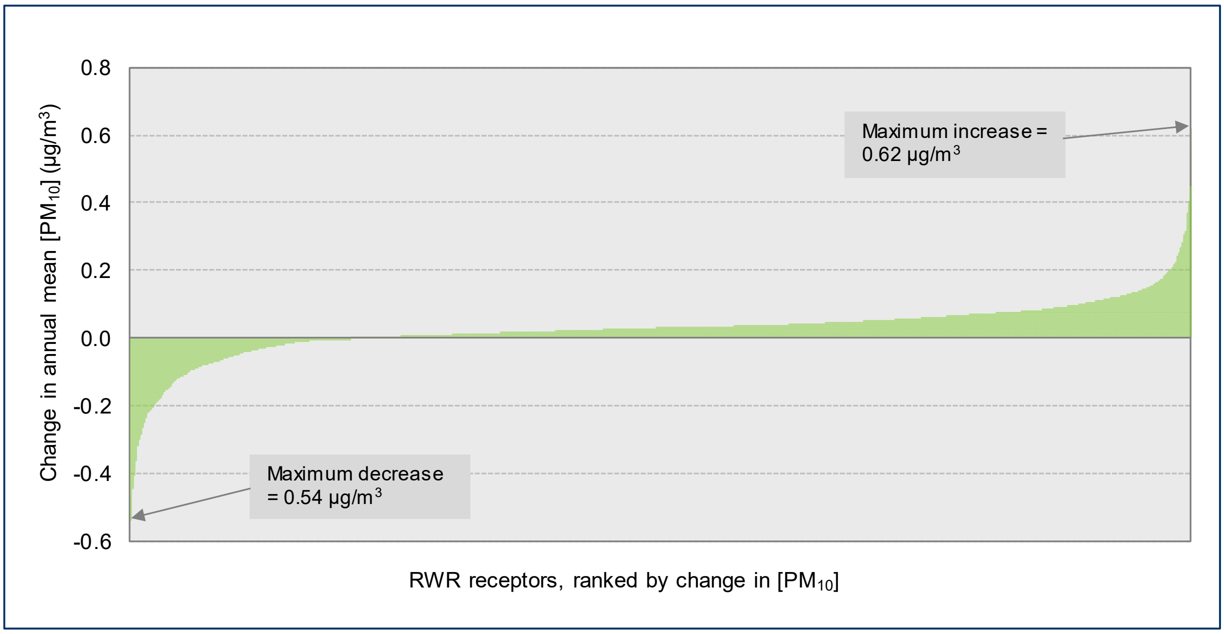


Figure 6-37: Change in predicted annual average PM_{10} concentrations at sensitive receptors, due to the project for 2024 (µg/m^3)

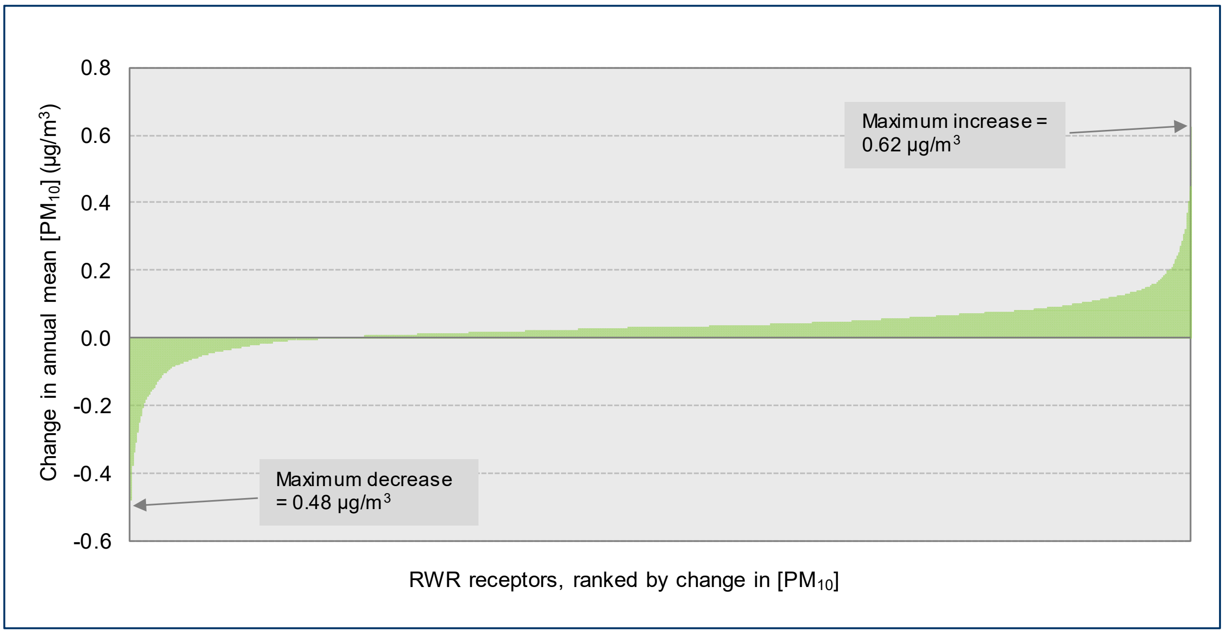


Figure 6-38: Change in predicted annual average PM_{10} concentrations at sensitive receptors, due to the project for 2034 (µg/m^3)

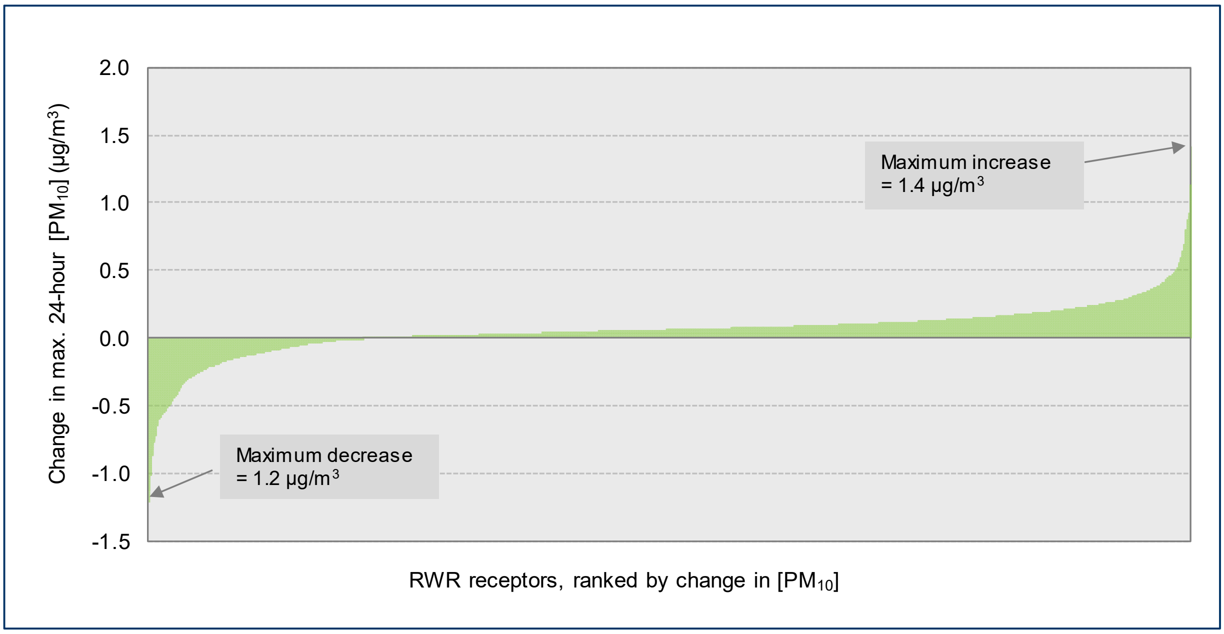


Figure 6-39: Change in predicted maximum 24-hour average PM_{10} concentrations at sensitive receptors, due to the project for 2024 (µg/m^3)

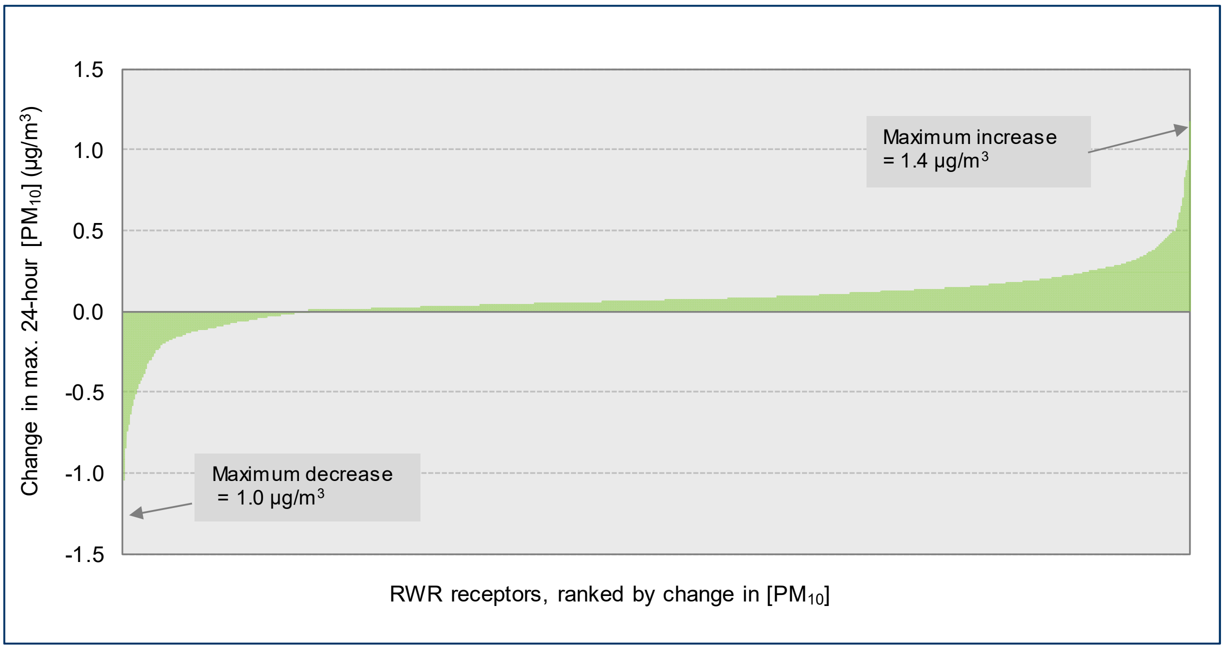


Figure 6-40: Change in predicted maximum 24-hour average PM_{10} concentrations at sensitive receptors, due to the project for 2034 (µg/m^3)

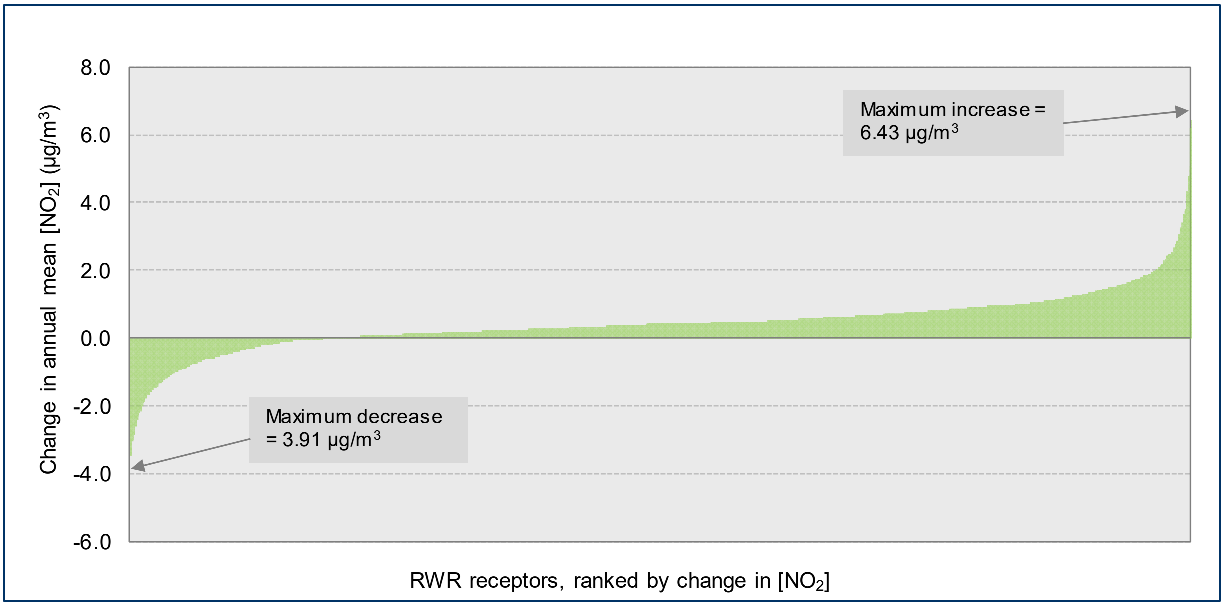


Figure 6-41: Change in predicted annual average NO_2 concentrations at sensitive receptors, due to the project for 2024 (µg/m^3)

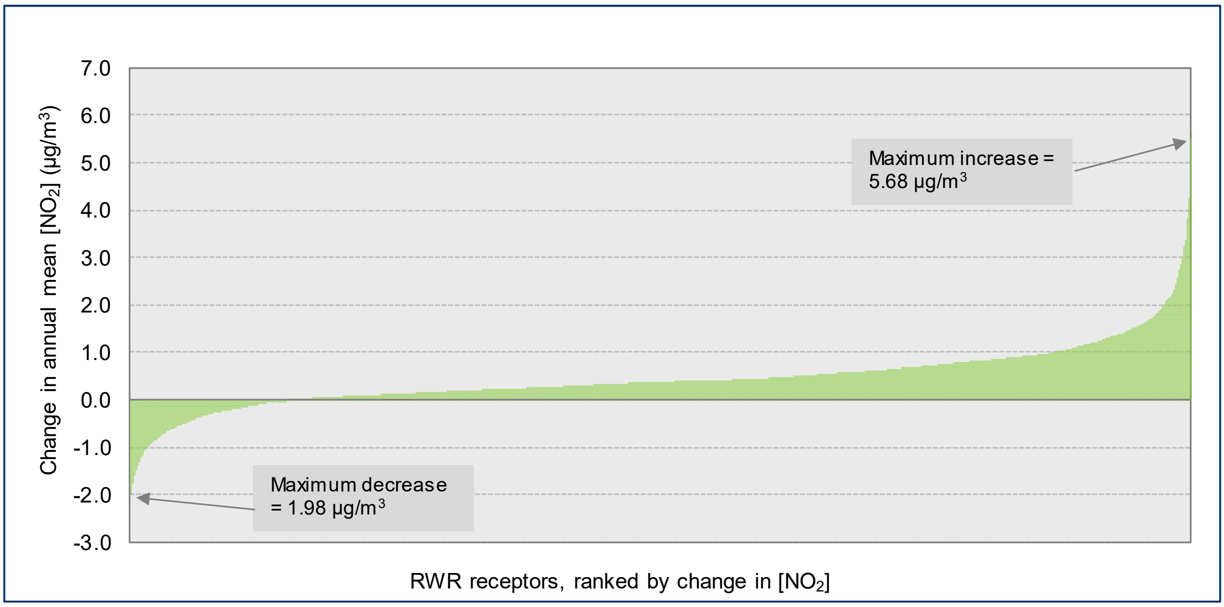


Figure 6-42: Change in predicted annual average NO_2 concentrations at sensitive receptors, due to the project for 2034 (µg/m^3)

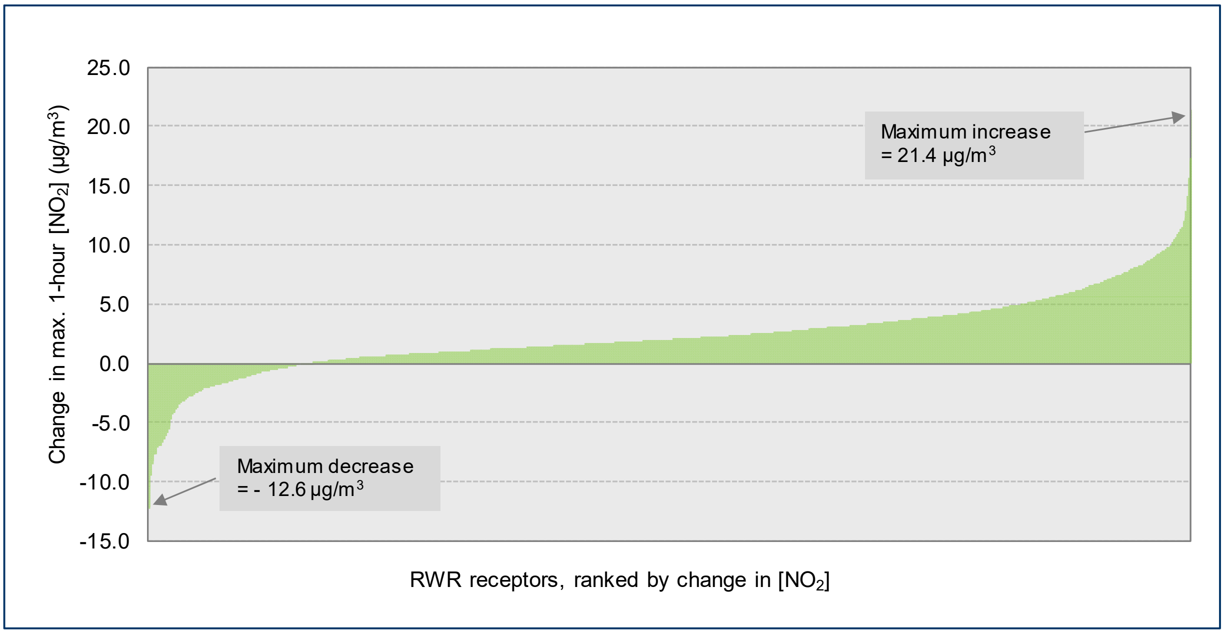


Figure 6-43: Change in predicted maximum 1-hour average NO_2 concentrations at sensitive receptors, due to the project for 2024 (µg/m^3)

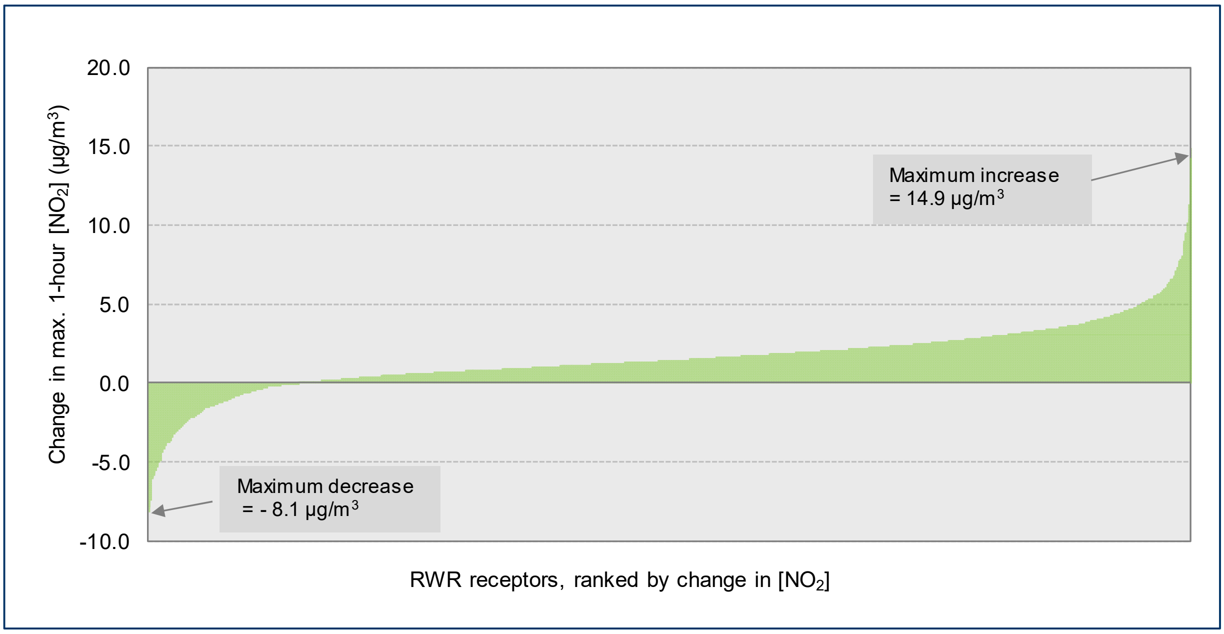


Figure 6-44: Change in predicted maximum 1-hour average NO_2 concentrations at sensitive receptors, due to the project for 2034 (µg/m^3)

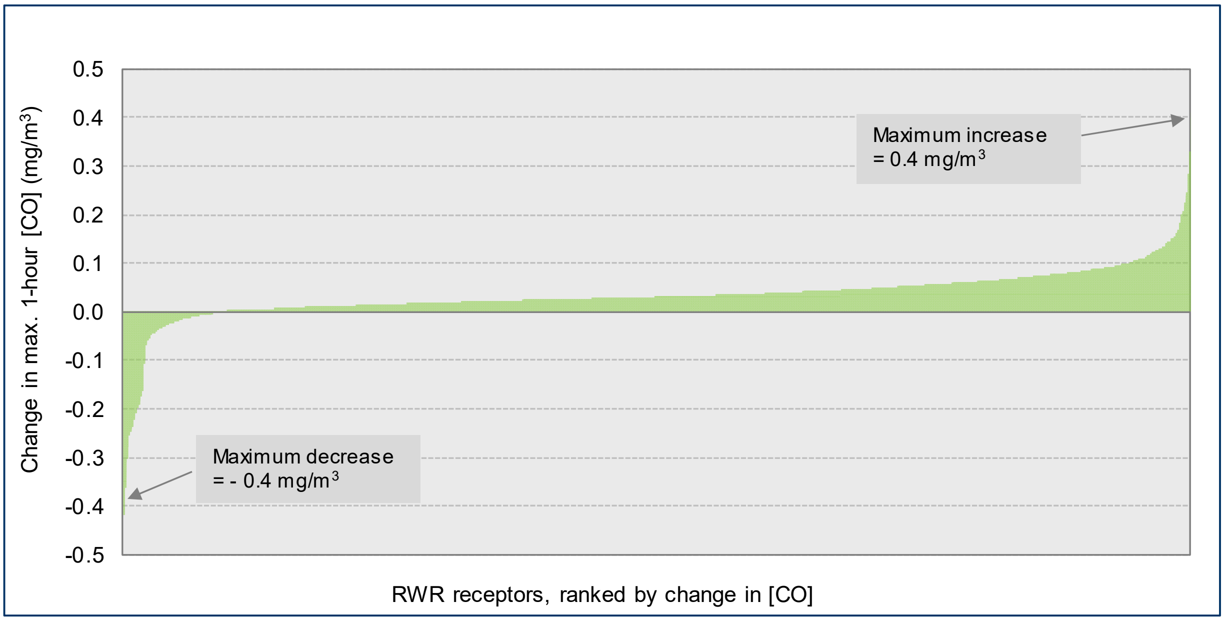


Figure 6-45: Change in predicted maximum 1-hour average CO concentrations at sensitive receptors, due to the project for 2024 (μg/m^3)

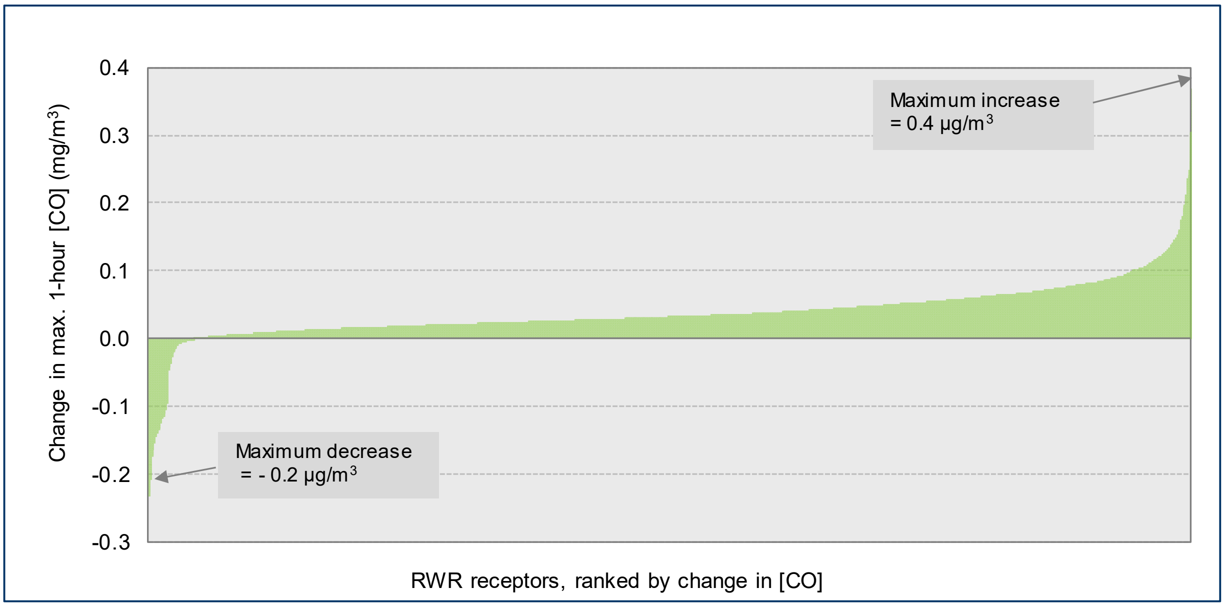


Figure 6-46: Change in predicted maximum 1-hour average CO concentrations at sensitive receptors, due to the project for 2034 (μg/m^3)

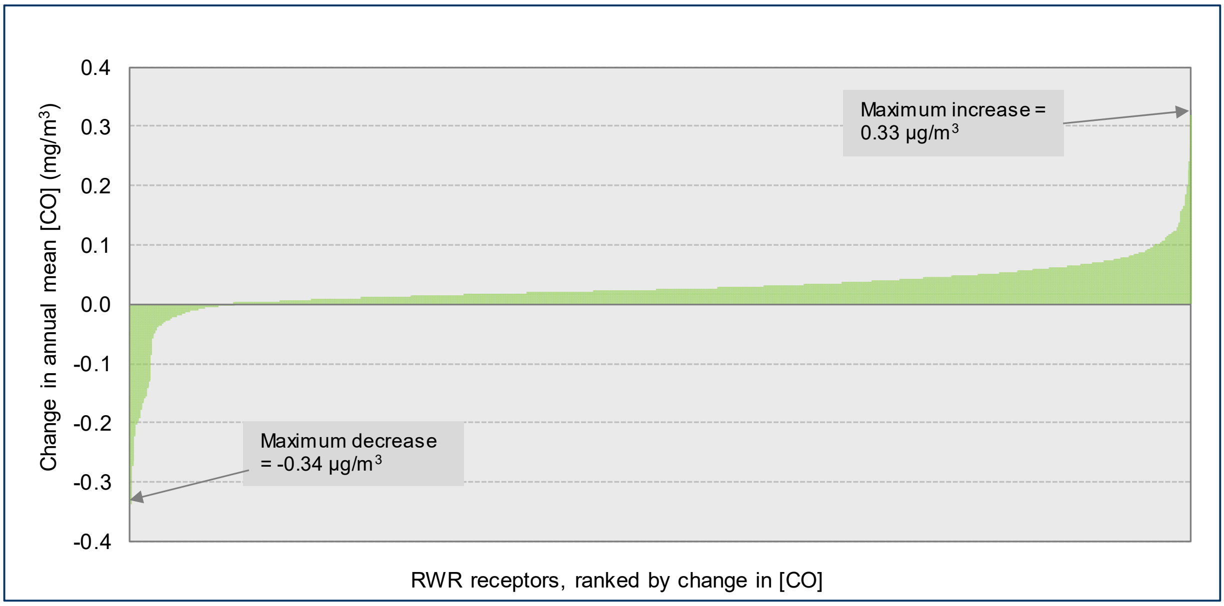


Figure 6-47: Change in predicted maximum 8-hour average CO concentrations at sensitive receptors, due to the project for 2024 (µg/m³)

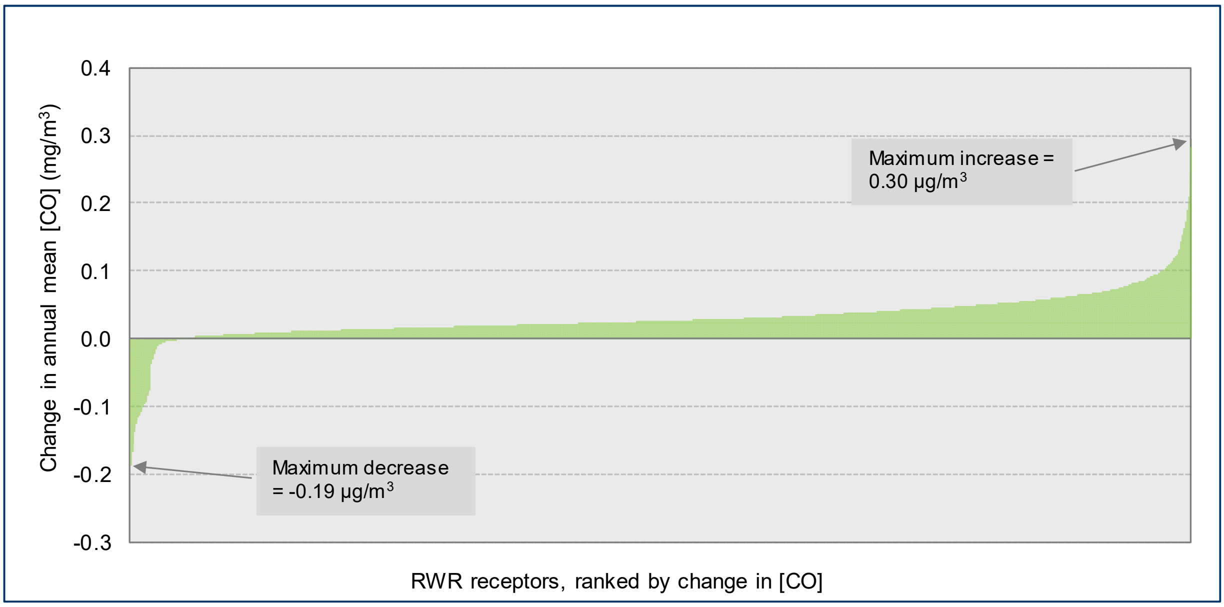


Figure 6-48: Change in predicted maximum 8-hour average CO concentrations at sensitive receptors, due to the project for 2034 (µg/m³)

6.3 Regional operational impacts

There is limited guidance in NSW on the regional air quality impacts of development for primary pollutants. The change in the total emissions resulting from a development can be used as a proxy for such impacts. Regional air quality can also be framed in terms of a change in the capacity for ozone production. NSW EPA has recently developed a Tiered Procedure for Estimating Ground Level Ozone Impacts from Stationary Sources. Whilst this does not relate specifically to road projects, it does given an emission threshold for NOx and VOCs of 90 tonnes/year for new sources for proceeding to a detailed modelling assessment for ozone. The changes in emissions associated with the scheme were well below this threshold. The net change in NOx emissions for the assessed road network in 2024 is estimated to be approximately 34 tonnes per year. The increase is due to the increased travel distance on the bypass as opposed to the current Pacific Highway but still represents a very small proportion of total anthropogenic NOx emissions across NSW. It is therefore concluded that the regional impacts of the project would be negligible, and undetectable in any ambient air quality measurements at urban background locations.

7. CONCLUSIONS

ERM has prepared an air quality assessment for the proposed Coffs Harbour Bypass. In this assessment, the GRAL dispersion model was used to predict the concentrations of NO_2, PM_{10}, $PM_{2.5}$ and CO due to emissions from the proposed bypass and existing Pacific Highway for four dispersion modelling scenarios: ‘No Build’ cases for 2024 and 2034, as well as ‘Build’ cases for 2024 and 2034.

The estimated concentrations of NO_2, PM_{10}, $PM_{2.5}$ and CO were found to be well below the relevant NSW EPA air quality criteria for all modelling scenarios. It was also determined, unsurprisingly, that concentrations were predicted to decrease along the Pacific Highway with the project and increase along the proposed alignment. However, these increases are not likely to result in any exceedances of the air quality assessment criteria at nearby sensitive receptors.

A risk assessment on the construction activities indicated that construction dust is unlikely to represent a serious ongoing problem. Any effects would be temporary and relatively short-lived, and would only arise during dry weather with the wind blowing towards a receptor, at a time when dust is being generated and mitigation measures are not being fully effective. However, it is recommended that an Air Quality Management Plan be produced to cover the construction of the project, and recommendations for elements of this plan have been provided.

8. REFERENCES

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APPENDIX A HEALTH ISSUES ASSOCIATED WITH VEHICLE POLLUTANTS

A1 Health Issues Associated with Vehicle Pollutants

A1.1 Overview

Road vehicles emit a complex mixture of pollutants. These are generated though combustion processes (exhaust emissions of CO, NO_X, PM and many different hydrocarbons), evaporation processes (VOC) and abrasion processes (tyre wear, brake wear, etc). Many of the pollutants emitted from road vehicles have significant effects on health and the environment. They can also react together, and with pollutants from other sources, to form secondary pollutants which can also have adverse effects.

This Appendix provides a brief summary of the impacts of traffic pollutants on health and the environment. Various epidemiological and toxicological studies have linked road traffic emissions to adverse effects on health.

A1.2 Carbon Monoxide

Carbon monoxide (CO) is a colourless, odourless gas. It can be harmful to humans because, when inhaled, it is taken up by haemoglobin in the blood (forming carboxyhaemoglobin) in preference to oxygen, thus reducing the capacity of the blood to transport oxygen. The affinity of CO for haemoglobin is more than 200 times greater than that of oxygen.

At low concentrations the symptoms of CO intoxication in healthy adults include lethargy, and chest pain in people with heart disease. At higher concentrations CO leads to impaired vision and coordination, headaches, dizziness, confusion and nausea. CO is fatal at very high concentrations[4].

Symptoms are not generally reported until the carboxyhaemoglobin level in the blood exceeds 10%. This is approximately the equilibrium value achieved with an ambient atmospheric concentration of 70 mg/m^3 for a person engaged in light activity. There is evidence that there is a risk for individuals with cardiovascular disease at lower carboxyhaemoglobin levels. A carboxyhaemoglobin level in the blood of 40-50% usually leads to death. However, in most Australian towns and cities the levels of CO in ambient air are well below those that are hazardous to human health. Only larger cities do CO levels have the potential to have harmful effects[5].

A1.3 Nitrogen Dioxide

NO_2 is one of the most important pollutants associated with road transport. It is an irritant and oxidant which has been linked to a range of adverse effects, including decrements in lung function, lung function growth, respiratory symptoms, asthma prevalence and incidence, cancer incidence, and birth outcomes (e.g. birth weight). Its most consistent association, however, has been found with respiratory outcomes.

The evidence of associations between ambient NO_2 concentrations and various health effects has strengthened in recent years. In a recent review of health evidence, the WHO Regional Office for Europe (2013) noted that many studies have documented associations between day-to-day variations in NO_2 concentration and variations in mortality, hospital admissions, and respiratory symptoms. There are associations between long-term exposure to NO_2 and mortality and morbidity at concentrations that were at or below the current EU annual mean limit value (40 µg/m^3). Although it is possible that, to some extent, NO_2 acts as a marker of the effects of other traffic pollutants, NO_2 can be regarded as causing some of the health impacts found to be associated with it in epidemiological studies COMEAP (2015).

[4] http://www.epa.gov/iaq/co.html#Health_Effects

[5] http://www.environment.gov.au/protection/publications/factsheet-carbon-monoxide-co

A1.4 Particulate Matter

The biological effects of inhaled particles are determined by their physical and chemical properties, by their sites of deposition, and by their mechanisms of action. The extent to which particles can penetrate the respiratory tract, and their potential for causing health effects, is directly related to their size. With normal nasal breathing, larger particles (those greater than 10 µm) are generally deposited in the extrathoracic part (nose, mouth and throat) of the respiratory tract. They adhere to the mucus in the nose, mouth, pharynx and larger bronchi, and from there are removed by either swallowing or expectorating. Particles between 10 and 2.5 µm can enter bronchial and pulmonary regions of the respiratory tract, with increased deposition during mouth breathing which increases during exercise. However, particles with a diameter of less than 2.5 µm can penetrate deep into the human respiratory system. Fine particles can be deposited in the pulmonary region, and it is these which are of particular concern.

In recent years epidemiological evidence has accumulated indicating that airborne particles have a range of adverse effects on health. These effects – which are diverse in scope, severity and duration - include the following (WHO Regional Office for Europe, 2013; IARC, 2012):

- Premature mortality
- Aggravation of cardiovascular disease such as atherosclerosis
- Aggravation of respiratory disease such as asthma
- Changes to lung tissue, structure and function
- Cancer[6]
- Reproductive and developmental effects
- Changes in the function of the nervous system.

Research shows that particle pollution can exacerbate existing respiratory symptoms, and at high concentrations cause respiratory symptoms. Particles can also adversely impact cardiovascular health. No safe threshold has been identified for the human health effects of particles. The health effects of PM are further complicated by the chemical nature of the particles and by the possibility of synergistic effects with other air pollutants such as sulfur dioxide. Airborne particles also reduce visual amenity and visibility.

Ambient concentrations of PM are most commonly defined in terms of two metrics: PM_{10} and $PM_{2.5}$, the mass concentrations of particles with an aerodynamic diameter of less than 10 µm and 2.5 µm respectively. There are many natural and anthropogenic sources of airborne particles, and as a consequence particulate matter displays a wide range of physical and chemical characteristics. When discussing PM sources and composition it is essential to distinguish between 'primary' and 'secondary' particles. Primary particles are emitted directly into the atmosphere as a result of natural processes (e.g. wind erosion, marine aerosols) and anthropogenic processes involving either combustion (e.g. industrial activity, domestic wood heaters, vehicle exhaust) or abrasion (e.g. road vehicle tyre wear). Secondary particles are not emitted directly, but are formed by reactions involving gas-phase components of the atmosphere. Various studies have shown that secondary particles contribute significantly to PM concentrations, especially $PM_{2.5}$ at background sites, although their characteristics vary significantly with both location and time.

[6] Particles may contain carcinogenic substances such as polycyclic aromatic hydrocarbons (PAHs) or heavy metals.

A1.5 Ozone

Ozone is a strongly oxidising gas, and human exposure to it damages lung tissue and reduces lung function. High concentrations therefore lead to increases in the frequency of respiratory symptoms and in deaths.

Ground-level ozone is not produced directly from emission sources but is created by photochemical reactions involving NO_X and VOCs in the atmosphere.

Ozone is an important component of summer-time smog. It can be transported over long distances, and is therefore regarded as a regional air pollution problem. High concentrations are typically observed downwind of large cities in the summer when photochemical formation is enhanced. Because road transport is a major source of ozone precursors (e.g. NOx and hydrocarbons) it is an important contributor to ground-level concentrations.

APPENDIX B ASSESSMENT OF CONSTRUCTION IMPACTS

B1 Assessment of Construction Impacts

B1.1 Step 1: Screening

Step 1 is a screening assessment. A construction dust assessment will normally be required where:

- There are human receptors within 350 m of the boundary of the site and/or within 50 m of the route(s) used by construction vehicles on the public highway, up to 500 m from the site entrance(s)
- There are ecological receptors within 50 m of the boundary of the site and/or within 50 m of the route(s) used by construction vehicles on the public highway, up to 500 m from the site entrance(s).

In this screening stage the construction area was assumed to be limited to the project construction boundary. It can be seen from Figure B1 that there are sensitive receptors within 350 metres of the boundaries of the project boundary.

B1.2 Step 2: Risk Assessment

In Step 2 the risk of dust arising in sufficient quantities to cause annoyance and/or health effects was determined for each of the four activities (demolition, earthworks, construction, and track-out). Risk categories were assigned to the site based on two factors:

- The scale and nature of the works, which determines the magnitude of potential dust emissions. This is assessed in Step 2A
- The sensitivity of the area. The proximity of sensitive receptors (i.e. the potential for effects). This is assessed in Step 2B.

These factors are combined in Step 2C to give the risk of dust impacts. Risks are described in terms of there being a low, medium or high risk of dust impacts for each of the four separate potential activities. Where there is risk of an impact, then site-specific mitigation will be required in proportion to the level of risk.

Figure B-1: Construction screening assessment

B1.2.1 Step 2A: Potential for Dust Emissions

The criteria for assessing the potential scale of emissions based on the scale and nature of the works are shown in Table B1. Based on these criteria, the appropriate categories for the project are shaded in green.

Table B1: Site categories (scale of works)

Type of activity	Site category		
	Large	Medium	Small
Demolition	Building volume >50,000 m^3, potentially dusty construction material (e.g. concrete), on-site crushing and screening, demolition activities >20 m above ground level.	Building volume 20,000–50,000m^3, potentially dusty construction material, demolition activities 10-20 m above ground level.	Building volume <20,000 m^3, construction material with low potential for dust release (e.g. metal cladding, timber), demolition activities <10 m above ground and during wetter months.
Earthworks	Site area >10,000 m^2, potentially dusty soil type (e.g. clay, which will be prone to suspension when dry due to small particle size), >10 heavy earth-moving vehicles active at any one time, formation of bunds>8 m in height, total material moved >100,000 tonnes.	Site area 2,500-10,000 m^2, moderately dusty soil type (e.g. silt), 5-10 heavy earth moving vehicles active at any one time, formation of bunds 4-8 m in height, total material moved 20,000-100,000 tonnes.	Site area <2,500 m^2, soil type with large grain size (e.g. sand), <5 heavy earth moving vehicles active at any one time, formation of bunds <4 m in height, total material moved <20,000 tonnes, earthworks during wetter months.
Construction	Total building volume >100,000 m^3, piling, on site concrete batching; sandblasting	Building volume 25,000-100,000 m^3, potentially dusty construction material (e.g. concrete), piling, on site concrete batching.	Total building volume <25,000 m^3, construction material with low potential for dust release (e.g. metal cladding or timber).
Track-out	>50 HDV (>3.5t) OUTWARD movements in any one day, potentially dusty surface material (e.g. high clay content), unpaved road length >100 m.	10-50 HDV (>3.5t) OUTWARD movements in any one day, moderately dusty surface material (e.g. high clay content), unpaved road length 50–100 m.	<10 HDV (>3.5t) OUTWARD movements in any one day, surface material with low potential for dust release, unpaved road length <50 m.

Source: IAQM, 2014

B1.2.2 Step 2B: Sensitivity of Area

The sensitivity of the area takes account of the specific sensitivities of local receptors, the proximity and number of the receptors, and the local background PM_{10} concentration. Dust soiling and health impacts are treated separately.

Sensitivity of area to dust soiling effects on people and property

The criteria for determining the sensitivity of an area to dust soiling effects are shown in Table B2. Based on the IAQM guidance[7] the receptor sensitivity was assumed to be 'high'.

Table B2: Criteria for sensitivity of area to dust soiling effects

Receptor sensitivity	Number of receptors	Distance from source (m)			
		<20	<50	<100	<350
High	>100	High	High	Medium	Low
	10-100	High	Medium	Low	Low
	1-10	Medium	Low	Low	Low
Medium	>1	Medium	Low	Low	Low
Low	>1	Low	Low	Low	Low

Source: IAQM, 2014

The number of receptors in each distance band was estimated from an aerial photograph of the site (see Figure B1). The exact counting of the number of 'human receptors' is not required by the IAQM guidance. Instead it is recommended that judgement is used to determine the approximate number of receptors within each distance band. For receptors which are not dwellings, professional judgement should be used to determine the number of human receptors. In the case of this project, the following numbers of receptors per building were assumed:

- Child Care Facility = 30 receptors
- Commercial = 5 receptors
- School = 500 receptors
- Industrial = 10 receptors
- Place of Worship = 20 receptors
- Residential = 5 receptors

The numbers of receptors for each scenario and activity, and the resulting outcomes are shown in Table B3.

7 Professional judgement is used to identify where on the spectrum between high and low sensitivity a receptor lies. High sensitivity receptors can reasonably expect enjoyment of a high level of amenity. The appearance, aesthetics or value of their properties would be diminished by soiling, and the people or properties would reasonably be expected to be present continuously, or at least regularly for extended periods, as part of the normal pattern of use of the land. Indicative examples include dwellings, museums and other culturally important collections, medium and long term car parks and car showrooms.

Table B3: Results - sensitivity to dust soiling effects

Activity	Receptor sensitivity	Number of receptors by distance from source				Sensitivity of area
		<20 m	20-50 m	50-100 m	100-350 m	
Demolition	High	2845	3295	6680	9700	High
Earthworks	High	2845	3295	6680	9700	High
Construction	High	2845	3295	6680	9700	High
Track-out	High	2845	3295	N/A	N/A	High

Sensitivity of area to human health impacts

The criteria for determining the sensitivity of an area to human health impacts caused by construction dust are shown in Table B4. Based on the IAQM guidance[8] the receptor sensitivity was assumed to be 'high'. The numbers of receptors for each scenario and activity, and the resulting outcomes are shown in Table B5.

Table B4: Criteria for sensitivity of area to health impacts

Receptor sensitivity	Annual mean PM_{10} conc. ($\mu g/m^3$)(a)	Number of receptors	Distance from source (m)				
			<20	<50	<100	<200	<350
High	>24	>100	High	High	High	Medium	Low
		10-100	High	High	Medium	Low	Low
		1-10t	High	Medium	Low	Low	Low
	21-24	>100	High	High	Medium	Low	Low
		10-100	High	Medium	Low	Low	Low
		1-10t	High	Medium	Low	Low	Low
	18-21	>100	High	Medium	Low	Low	Low
		10-100	High	Medium	Low	Low	Low
		1-10	Medium	Low	Low	Low	Low
	<18	>100	Medium	Low	Low	Low	Low
		10-100	Low	Low	Low	Low	Low
		1-10	Low	Low	Low	Low	Low
Medium	-	>10	High	Medium	Low	Low	Low
		1-10	Medium	Low	Low	Low	Low
Low	-	>1	Low	Low	Low	Low	Low

Source: IAQM, 2014

[8] The sensitivity of people to the health effects of PM_{10} is based on exposure to elevated concentrations over a 24-hour period. High sensitivity receptors relate to locations where members of the public are exposed over a time period relevant to the air quality objective for PM_{10} (in the case of the 24-hour objectives, a relevant location would be one where individuals may be exposed for eight hours or more in a day). Indicative examples include residential properties. Hospitals, schools and residential care homes should also be considered as having equal sensitivity to residential areas for the purposes of this assessment.

Table B5: Results - sensitivity to health impacts

Activity	Receptor sensitivity	Annual mean PM_{10} conc. (µg/m^3)	Number of receptors by distance from source (m)					Sensitivity of area
			<20	20-50	50-100	100-200	200-350	
Demolition	High	<18	2845	3295	6680	4825	4875	Medium
Earthworks	High	<18	2845	3295	6680	4825	4875	Medium
Construction	High	<18	2845	3295	6680	4825	4875	Medium
Track-out	High	<18	2845	3295	N/A	N/A	N/A	Medium

Sensitivity of ecological impacts

The criteria for determining the sensitivity of an area to ecological impacts from construction dust are provided in Table B6. Based on the IAQM guidance the receptor sensitivity was assumed to be 'medium' for ecologically sensitive areas, which were defined as areas that contained banana and blueberry plantations and the Kororo Nature Reserve within 20 m of the project. The results are shown in Table B7. Receptors within these zones were determined to have a 'medium' sensitivity to ecological impacts, that is, within 20 metres of the construction footprint.

Table B6: Criteria for sensitivity of area to ecological impacts

Receptor sensitivity	Distance from assessment zone boundary (metres)	
	<20	20–50
High	High	Medium
Medium	Medium	Low
Low	Low	Low

Source: IAQM, 2014

Table B7: Results of sensitivity to ecological impacts

Activity	Receptor sensitivity	Distance from zone boundary (metres)	Sensitivity of area
Demolition	Medium	<20	Medium
Earthworks	Medium	<20	Medium
Construction	Medium	<20	Medium
Track-out	Medium	<20	Medium

B1.2.3 Step 2C: Risk of dust impacts

The dust emission potential determined in Step 2A is combined with the sensitivity of the area determined in Step 2B to give the risk of impacts with no mitigation applied. The criteria are shown in Table B6.

The final results for the Step 2 risk assessment are provided in Table B7. The demolition, earthworks, construction and track-out activities were shown to be 'high risk'.

Table B6: Criteria for sensitivity of area to health impacts

Type of activity	Sensitivity of area	Dust emission potential		
		Large	Medium	Small
Demolition	High	High Risk	Medium Risk	Medium Risk
	Medium	High Risk	Medium Risk	Low Risk
	Low	Medium Risk	Low Risk	Negligible
Earthworks	High	High Risk	Medium Risk	Low Risk
	Medium	Medium Risk	Medium Risk	Low Risk
	Low	Low Risk	Low Risk	Negligible
Construction	High	High Risk	Medium Risk	Low Risk
	Medium	Medium Risk	Medium Risk	Low Risk
	Low	Low Risk	Low Risk	Negligible
Track-out	High	High Risk	Medium Risk	Low Risk
	Medium	Medium Risk	Low Risk	Negligible
	Low	Low Risk	Low Risk	Negligible

Source: IAQM, 2014

Table C7: Summary of risk assessment for the four construction activities

Type of activity	Step 2A: Potential for dust emissions	Step 2B: Sensitivity of area			Step 2C: Risk of dust impacts		
		Dust soiling	Human health	Ecological	Dust soiling	Human health	Ecological
Demolition	Large	High	High	High	High	High	High
Earthworks	Large	High	Medium	Medium	High	Medium	Medium
Construction	Large	High	Medium	Medium	High	Medium	Medium
Track-out	Large	High	Medium	Medium	High	Medium	Medium

B1.3 Step 3: Mitigation

Step 3 involved determining mitigation measures for each of the four potential activities in Step 2. This was based on the risk of dust impacts identified in Step 2C. For each activity, the highest risk category was used.

B1.4 Step 4: Significance of Risks

Once the risk of dust impacts has been determined in Step 2C and the appropriate dust mitigation measures identified in Step 3, the final step is to determine whether there are residual significant effects arising from the construction phase of the project.

APPENDIX C PREDICTED CONCENTRATIONS FOR ALL MODELLING SCENARIOS

C1 2024 No Build Scenario

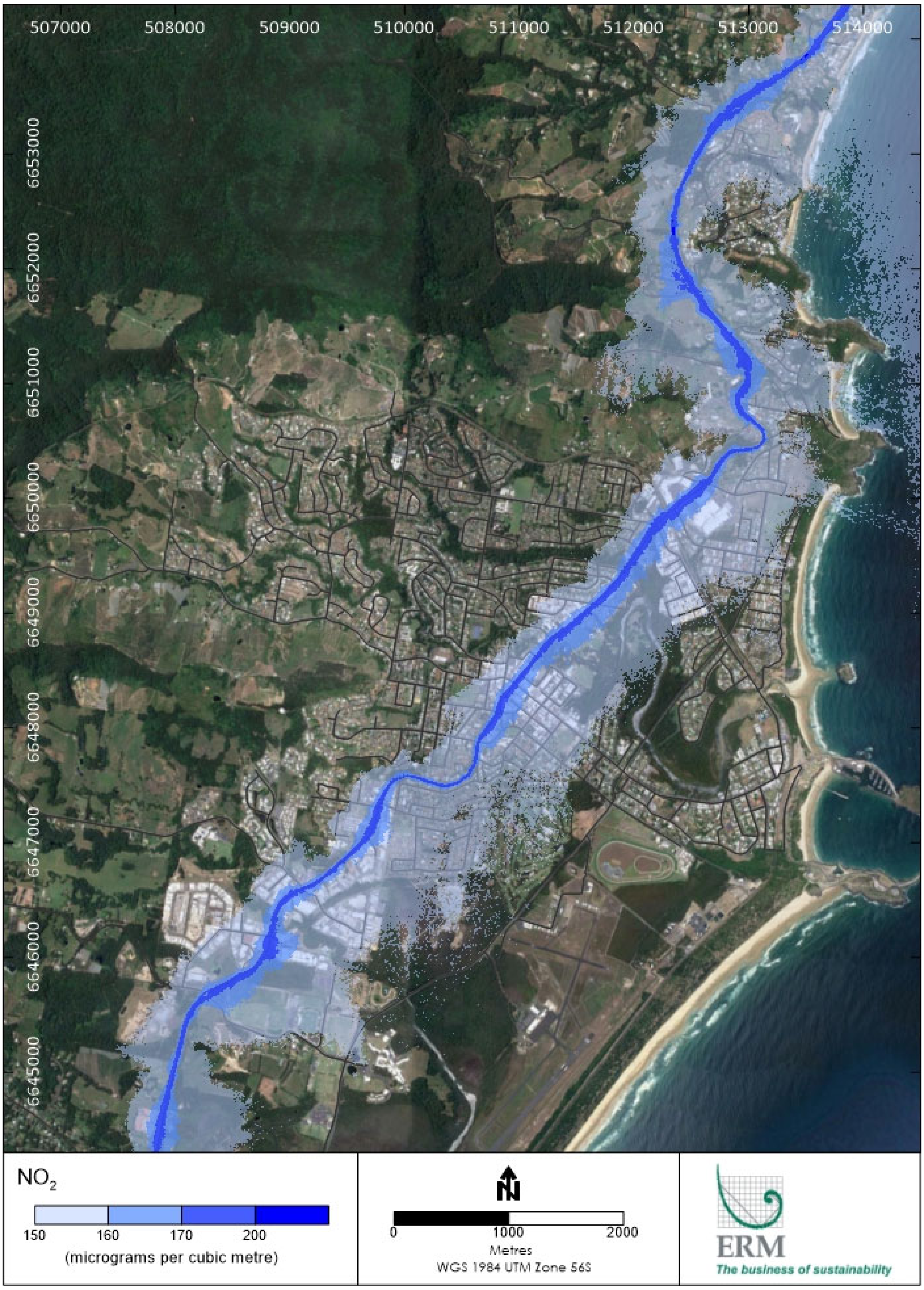

Figure C-1: Predicted maximum 1-hour average cumulative NO_2 concentrations for 2024 – No Build (µg/m^3)

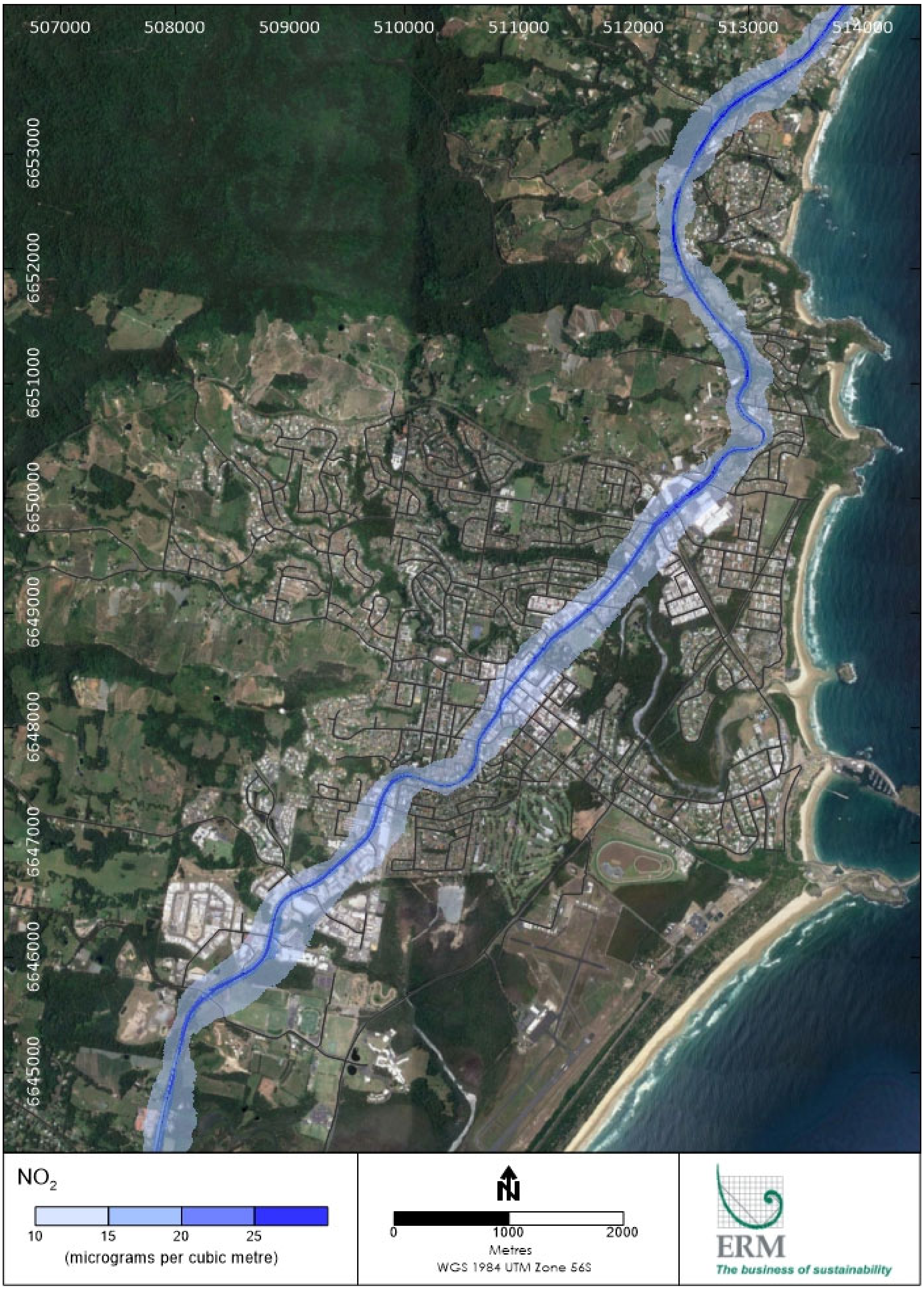

Figure C-2: Predicted annual average cumulative NO_2 concentrations for 2024 – No Build (µg/m^3)

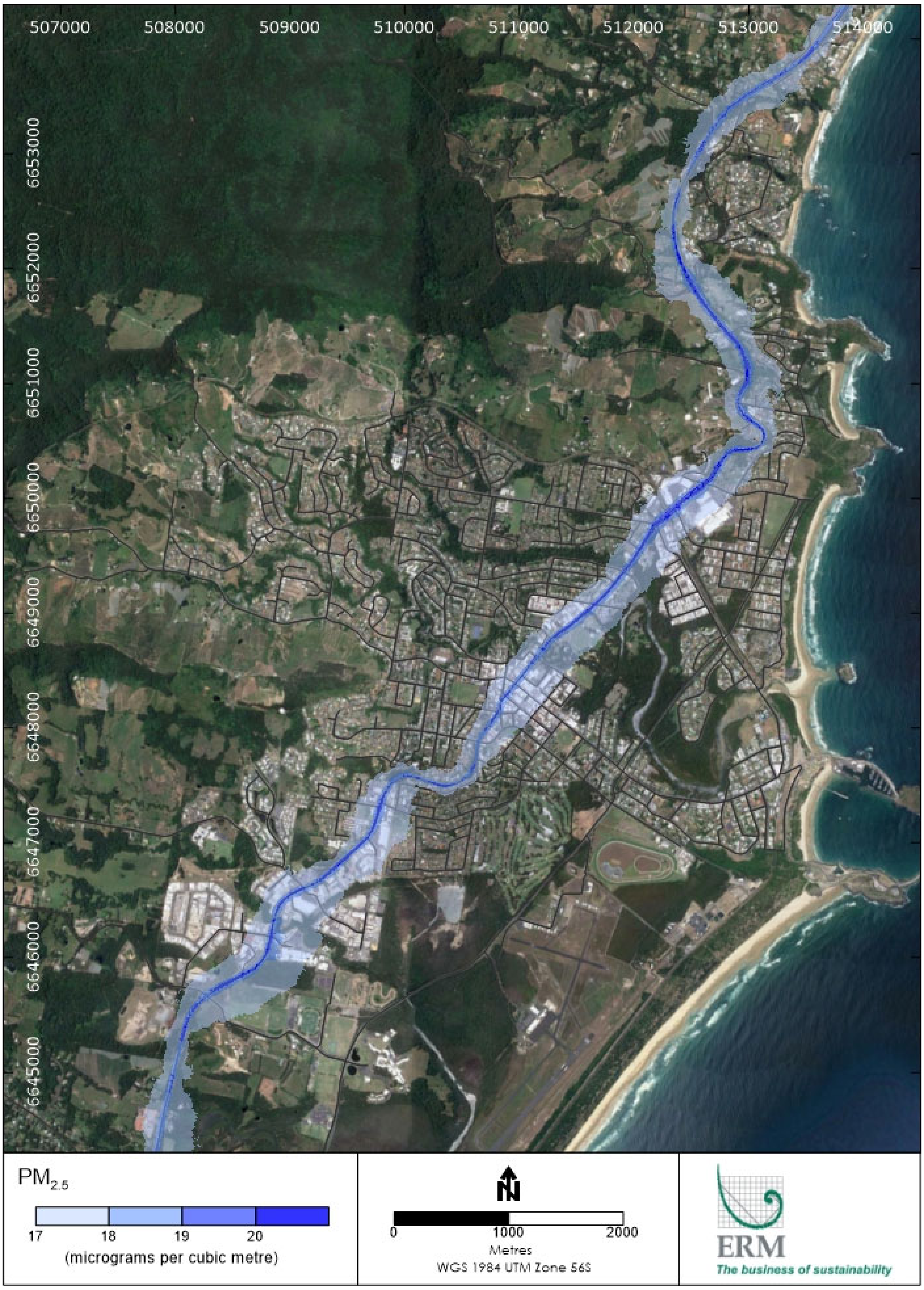

Figure C-3: Predicted maximum 24-hour average cumulative $PM_{2.5}$ concentrations for 2024 – No Build (μg/m^3)

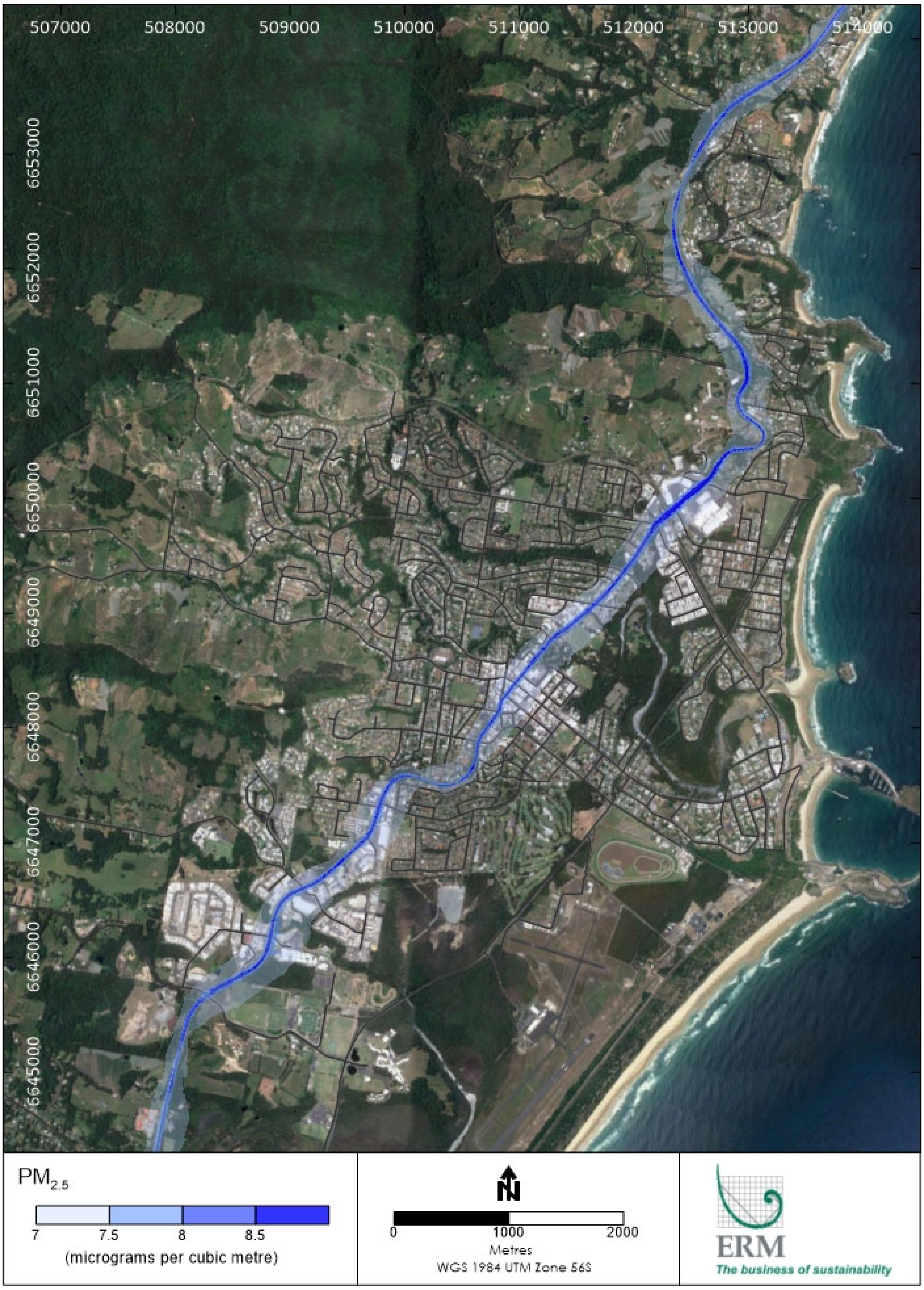

Figure C-4: Predicted annual average cumulative $PM_{2.5}$ concentrations for 2024 – No Build (µg/m^3)

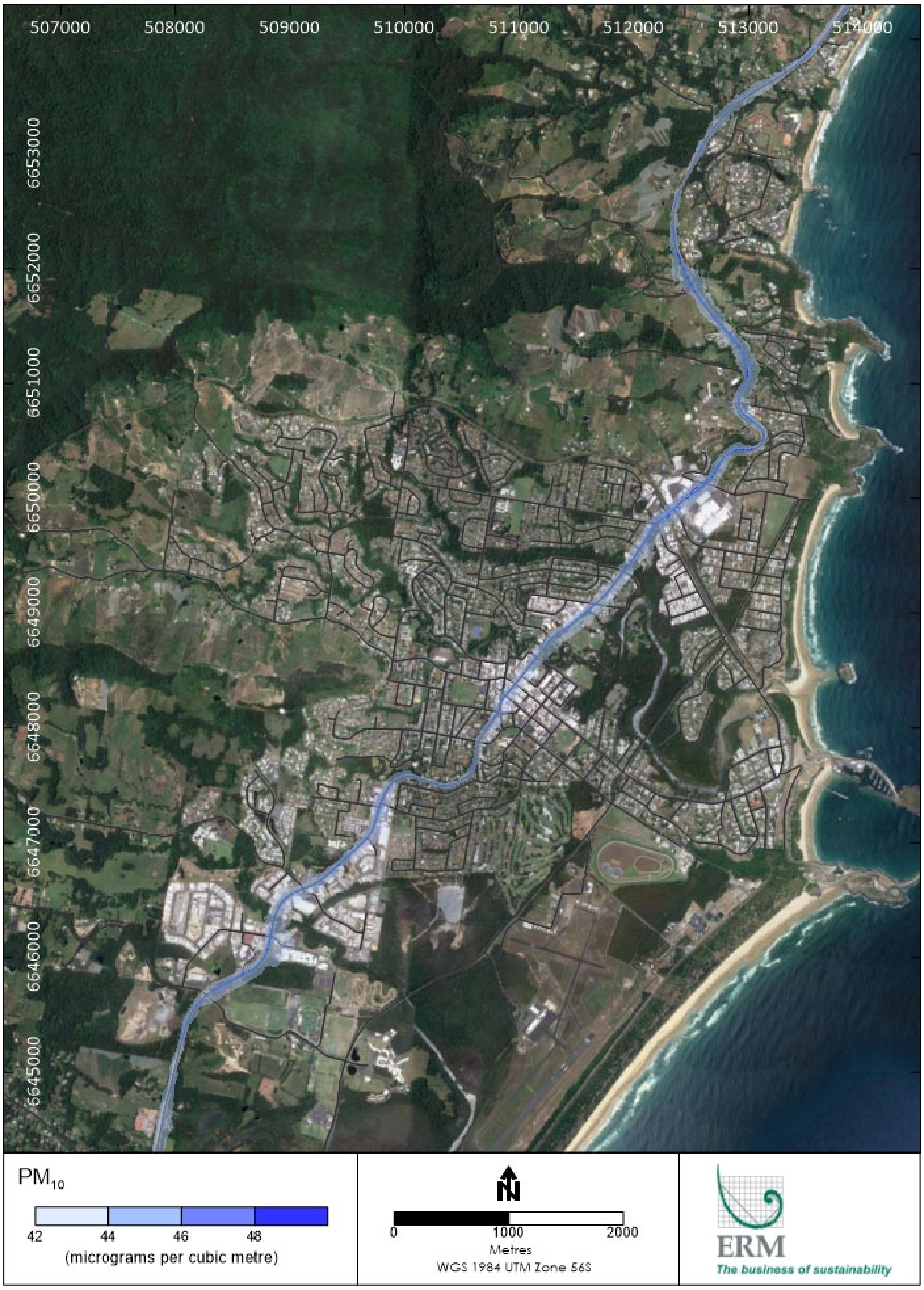

Figure C-5: Predicted maximum 24-hour average cumulative PM_{10} concentrations for 2024 – No Build (μg/m^3)

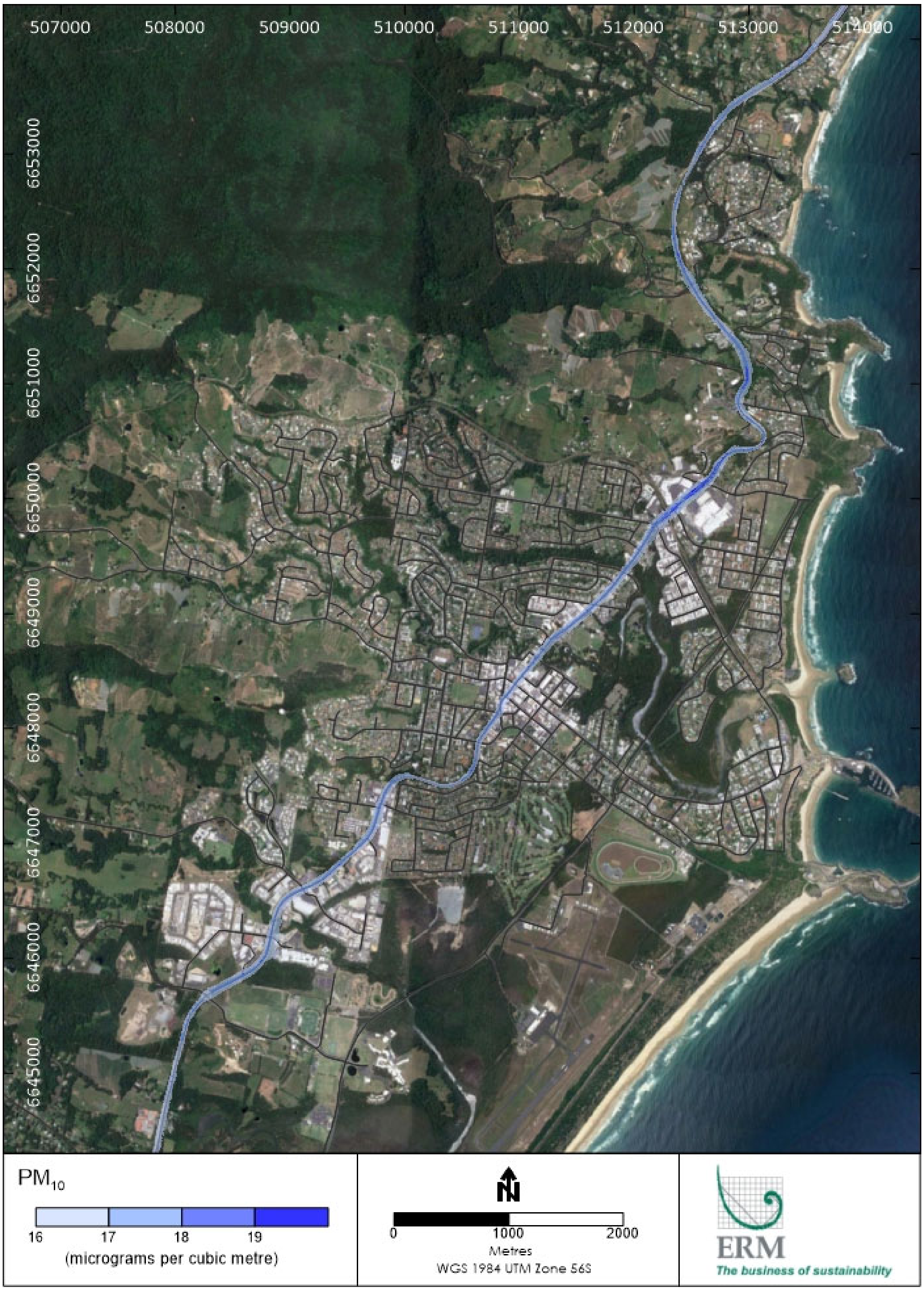

Figure C-6: Predicted annual average cumulative PM_{10} concentrations for 2024 – No Build (µg/m^3)

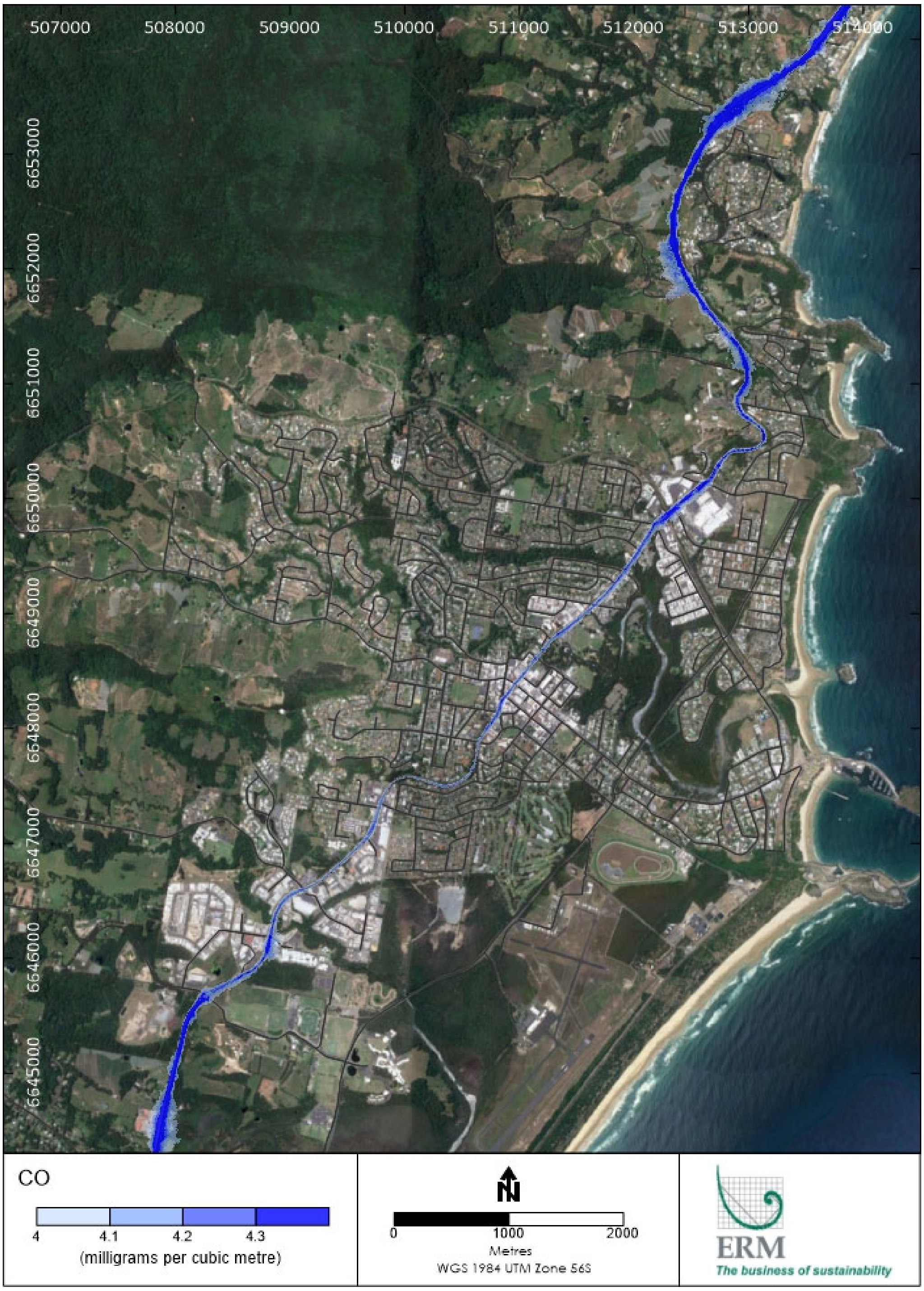

Figure C-7: Predicted maximum 1-hour average cumulative CO concentrations for 2024 – No Build (µg/m^3)

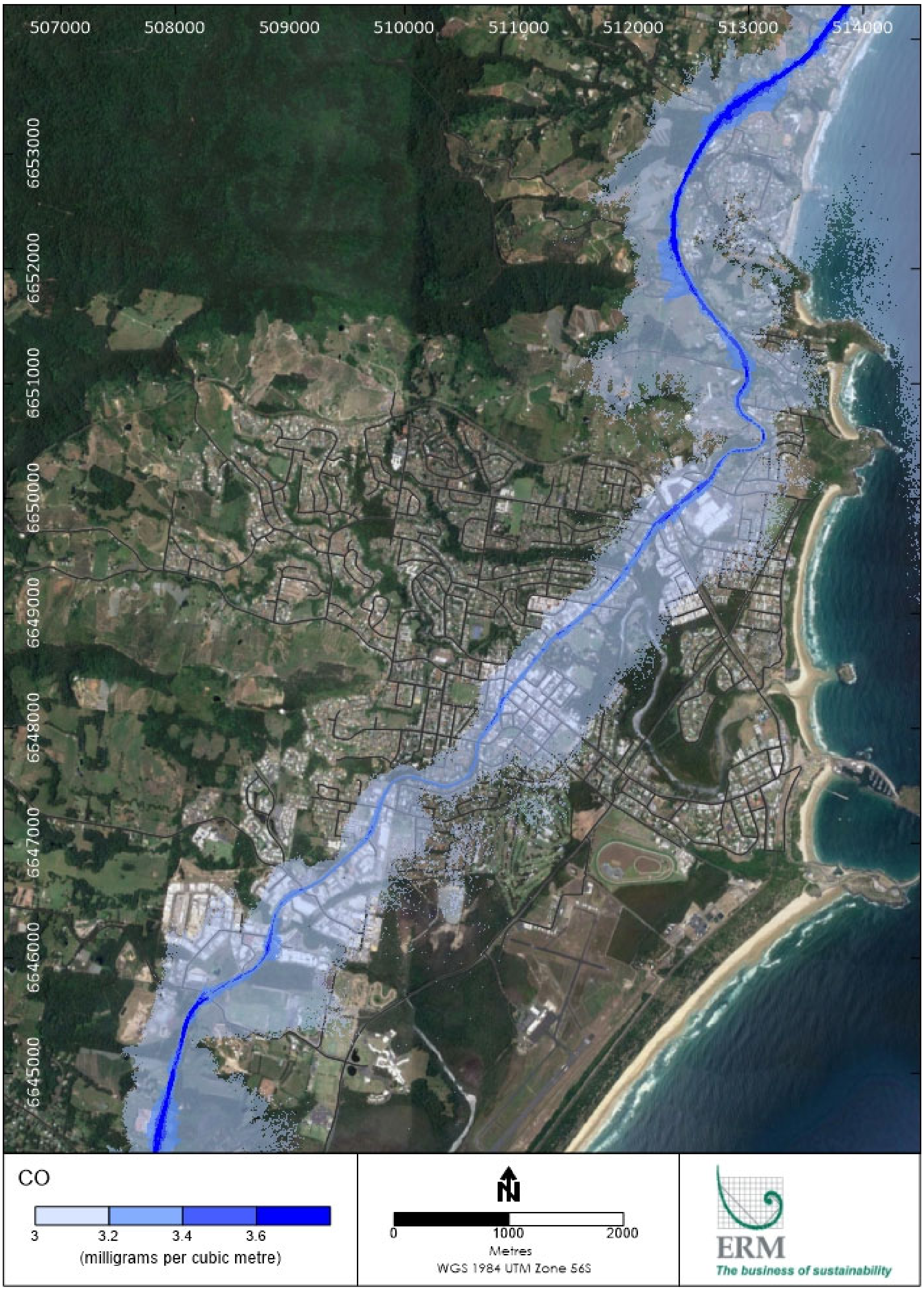

Figure C-8: Predicted maximum 8-hour rolling average cumulative CO concentrations for 2024 – No Build (µg/m^3)

C2 2024 Build Scenario

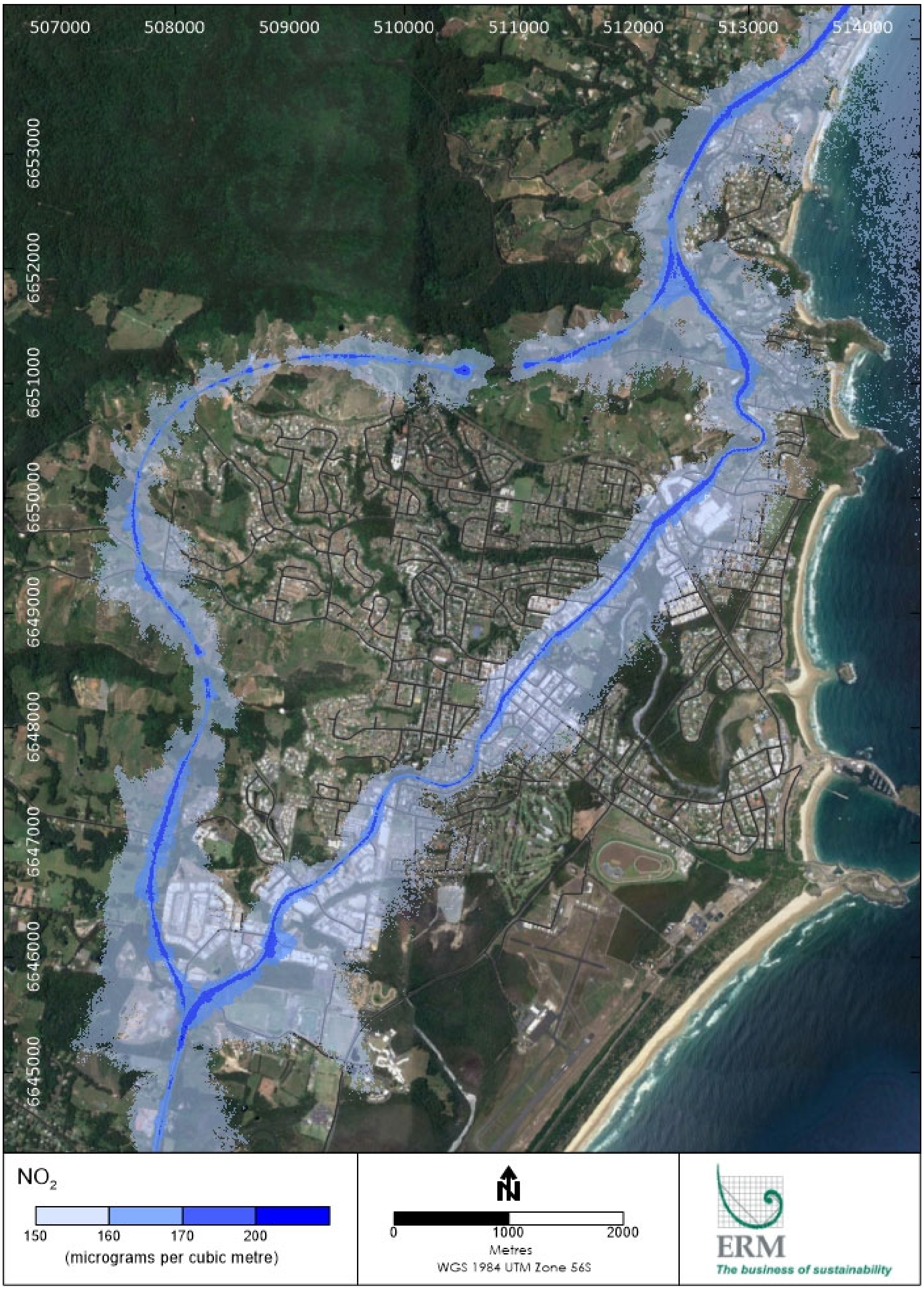

Figure C-9: Predicted maximum 1-hour average cumulative NO_2 concentrations for 2024 – Build ($\mu g/m^3$)

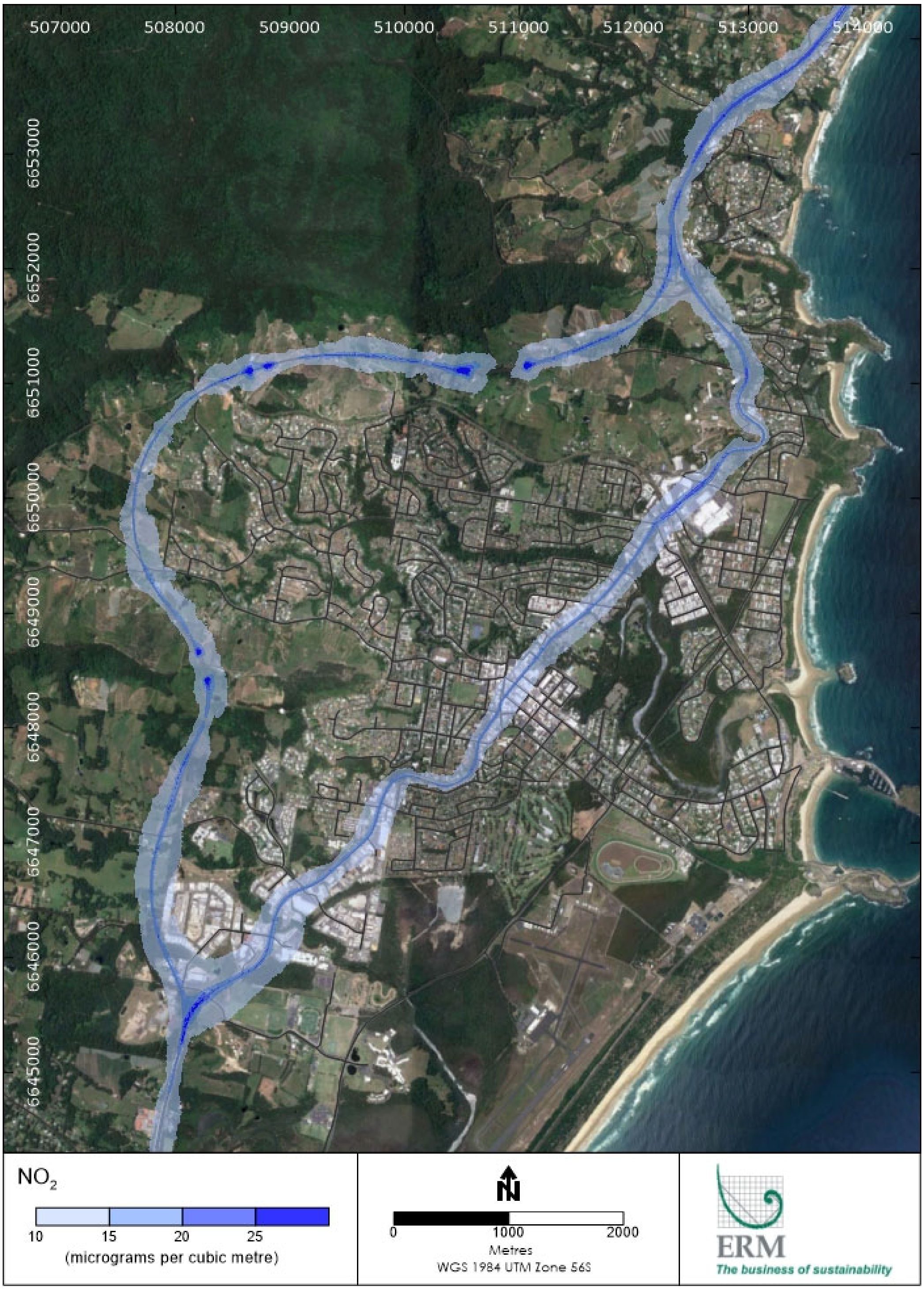

Figure C-10: Predicted annual average cumulative NO_2 concentrations for 2024 – Build (µg/m^3)

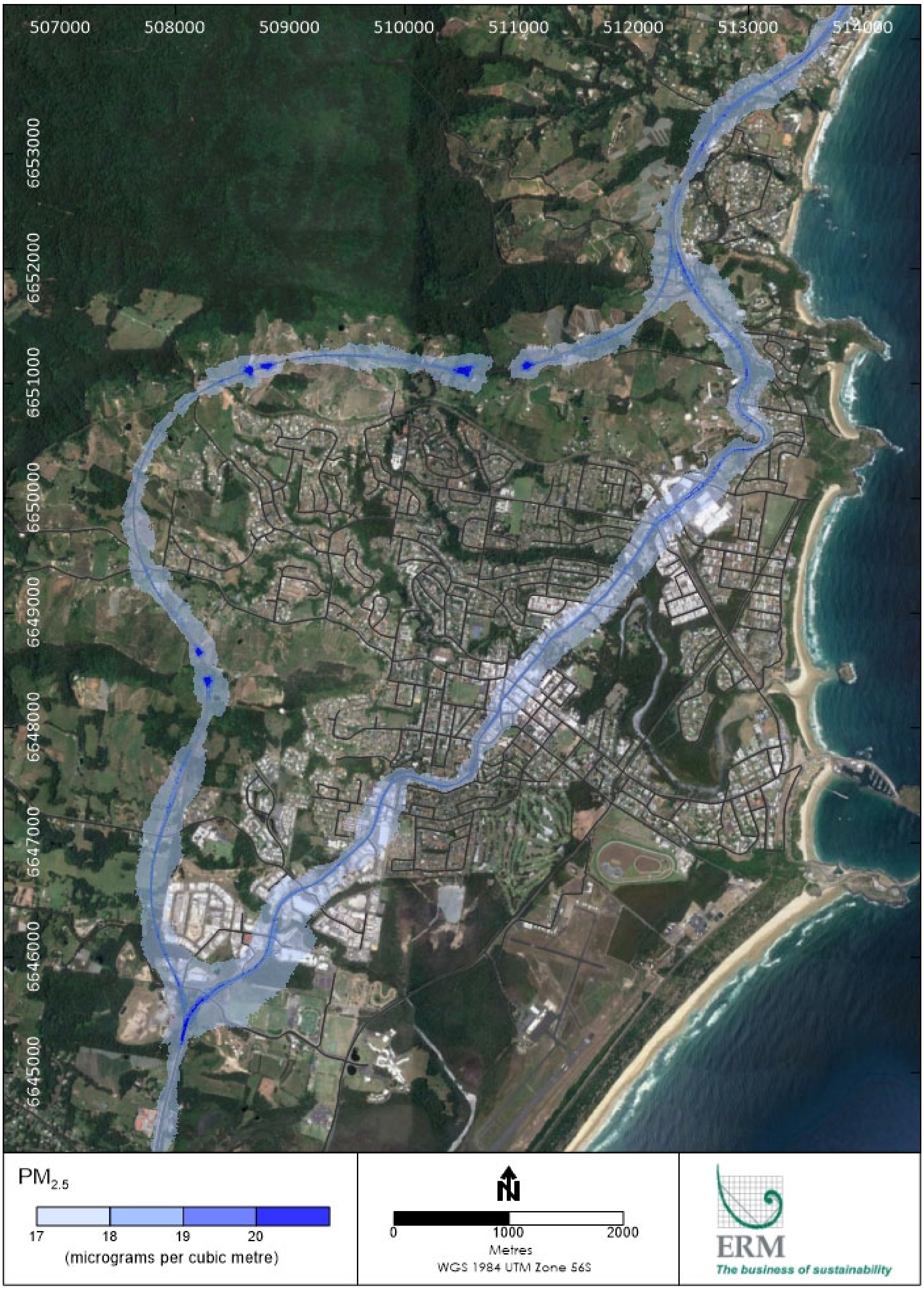

Figure C-11: Predicted maximum 24-hour average cumulative $PM_{2.5}$ concentrations for 2024 – Build (µg/m^3)

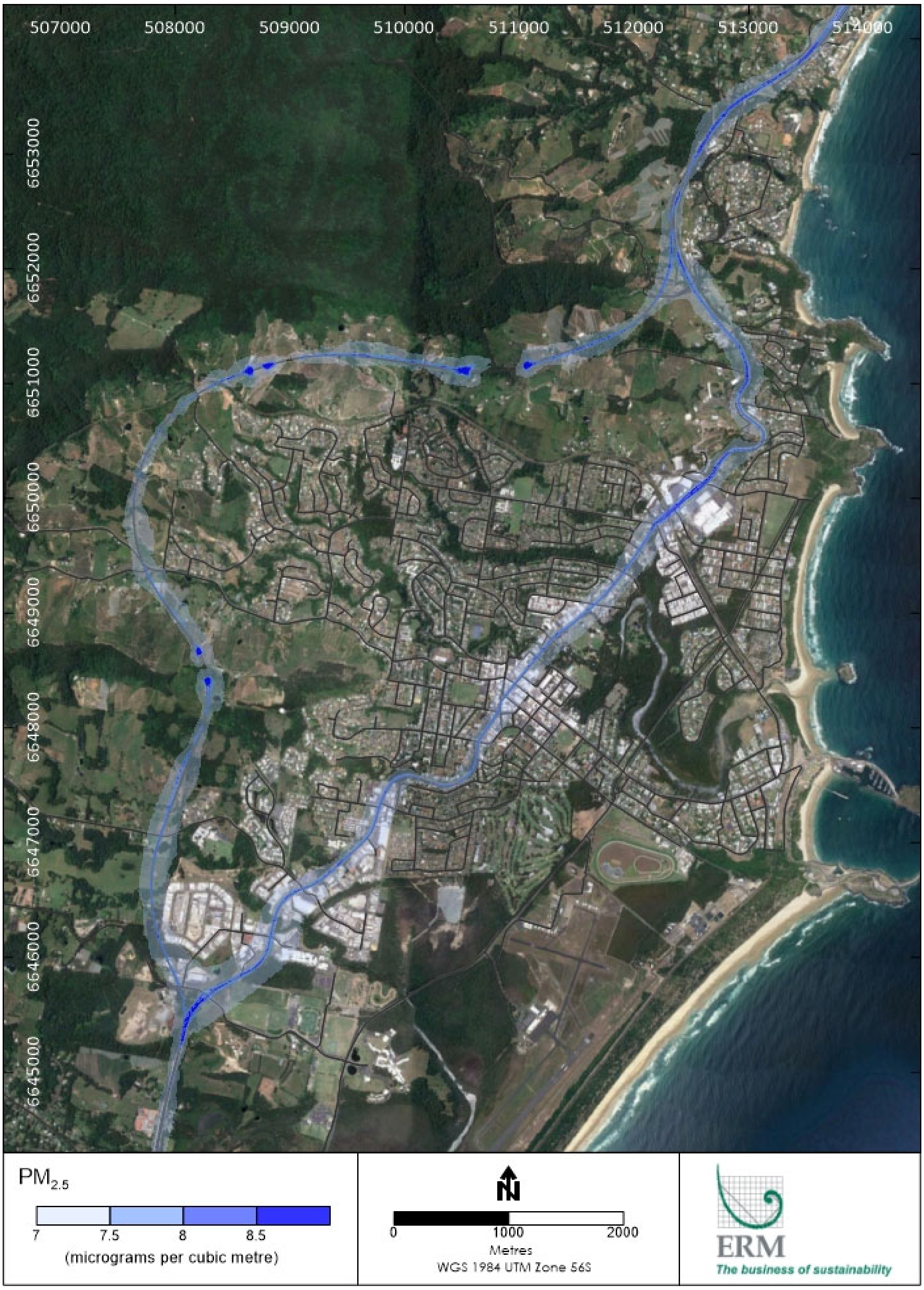

Figure C-12: Predicted annual average cumulative $PM_{2.5}$ concentrations for 2024 – Build (μg/m^3)

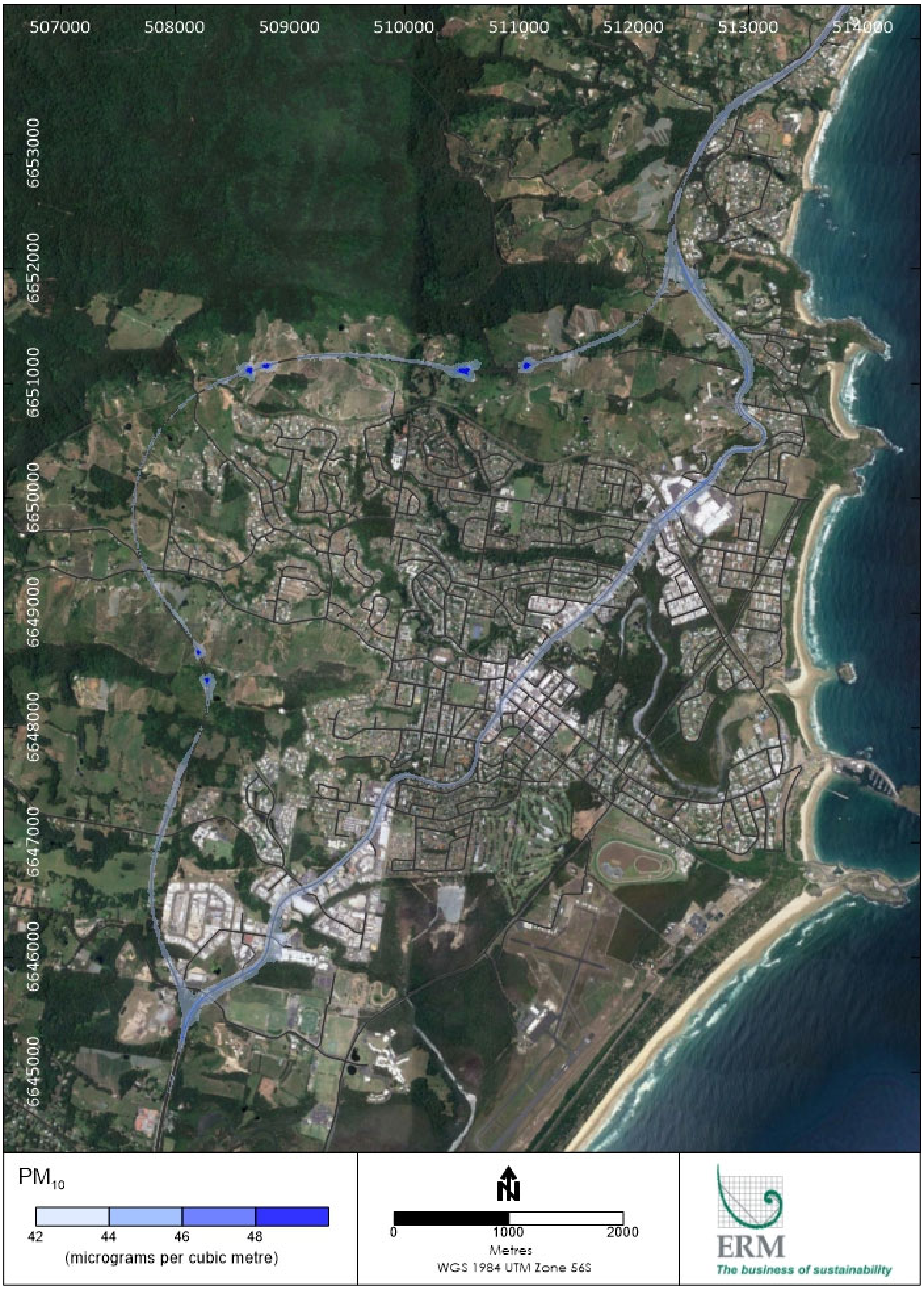

Figure C-13: Predicted maximum 24-hour average cumulative PM_{10} concentrations for 2024 – Build (µg/m^3)

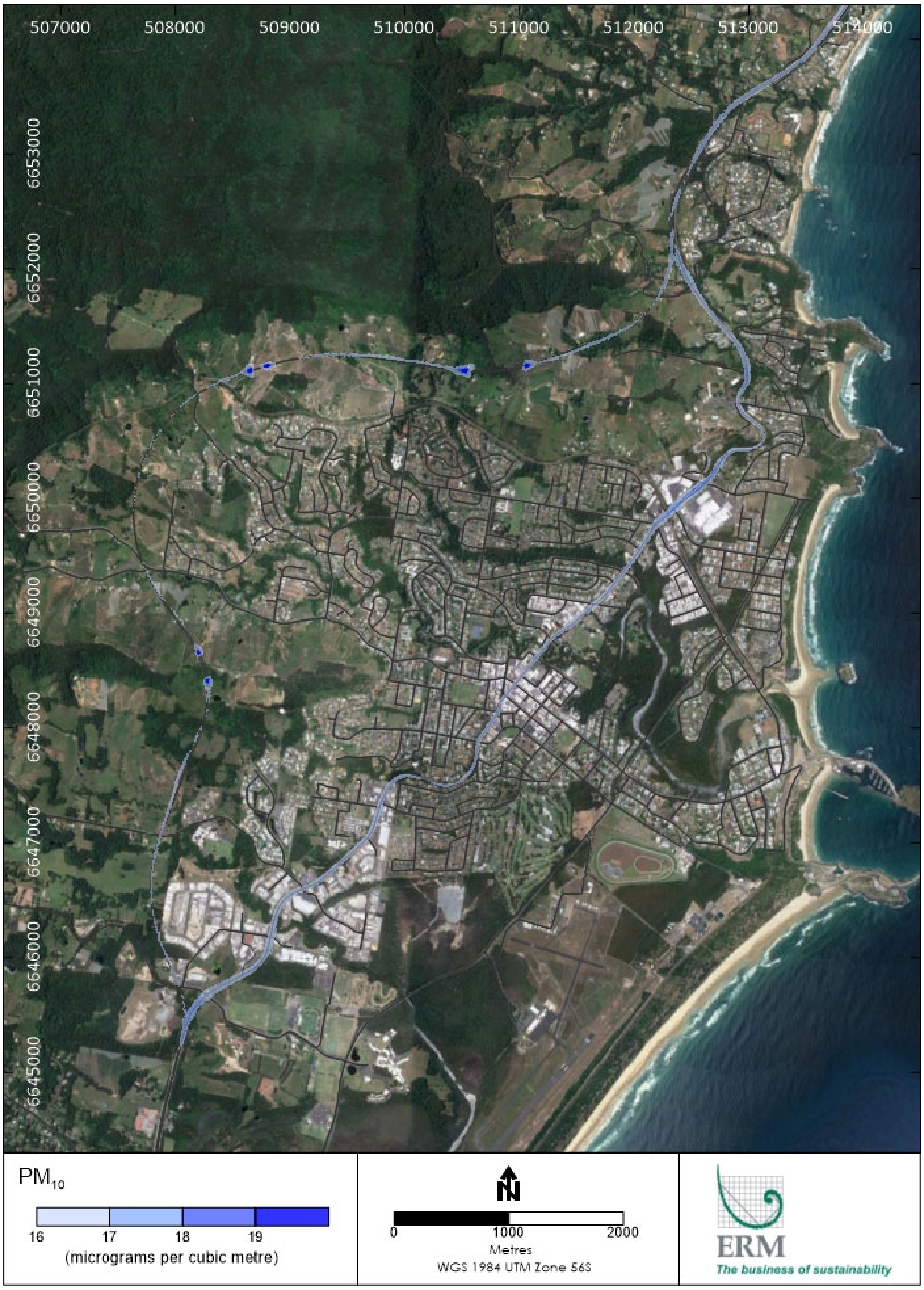

Figure C-14: Predicted annual average cumulative PM_{10} concentrations for 2024 – Build (µg/m^3)

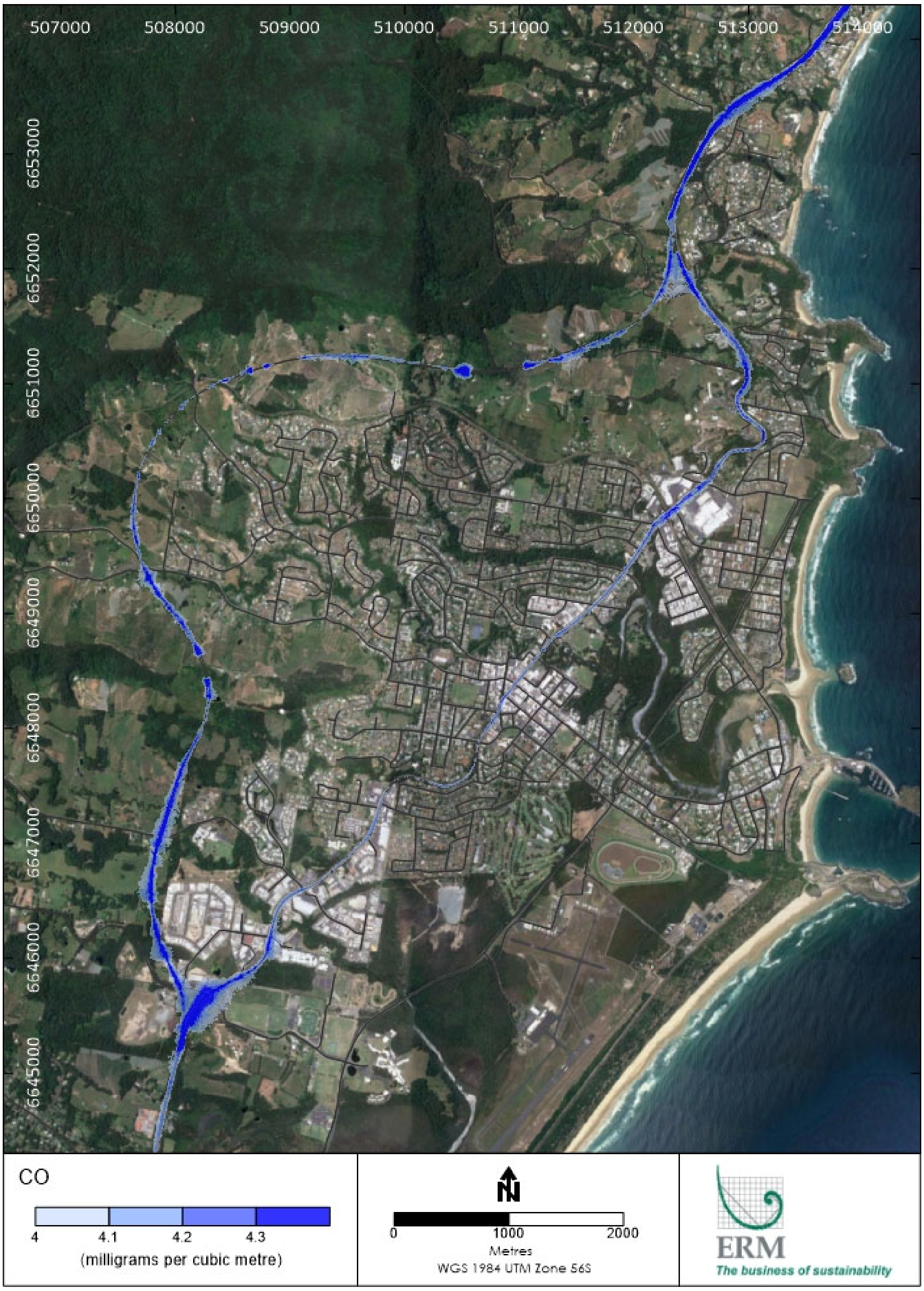

Figure C-15: Predicted maximum 1-hour average cumulative CO concentrations for 2024 – Build (μg/m^3)

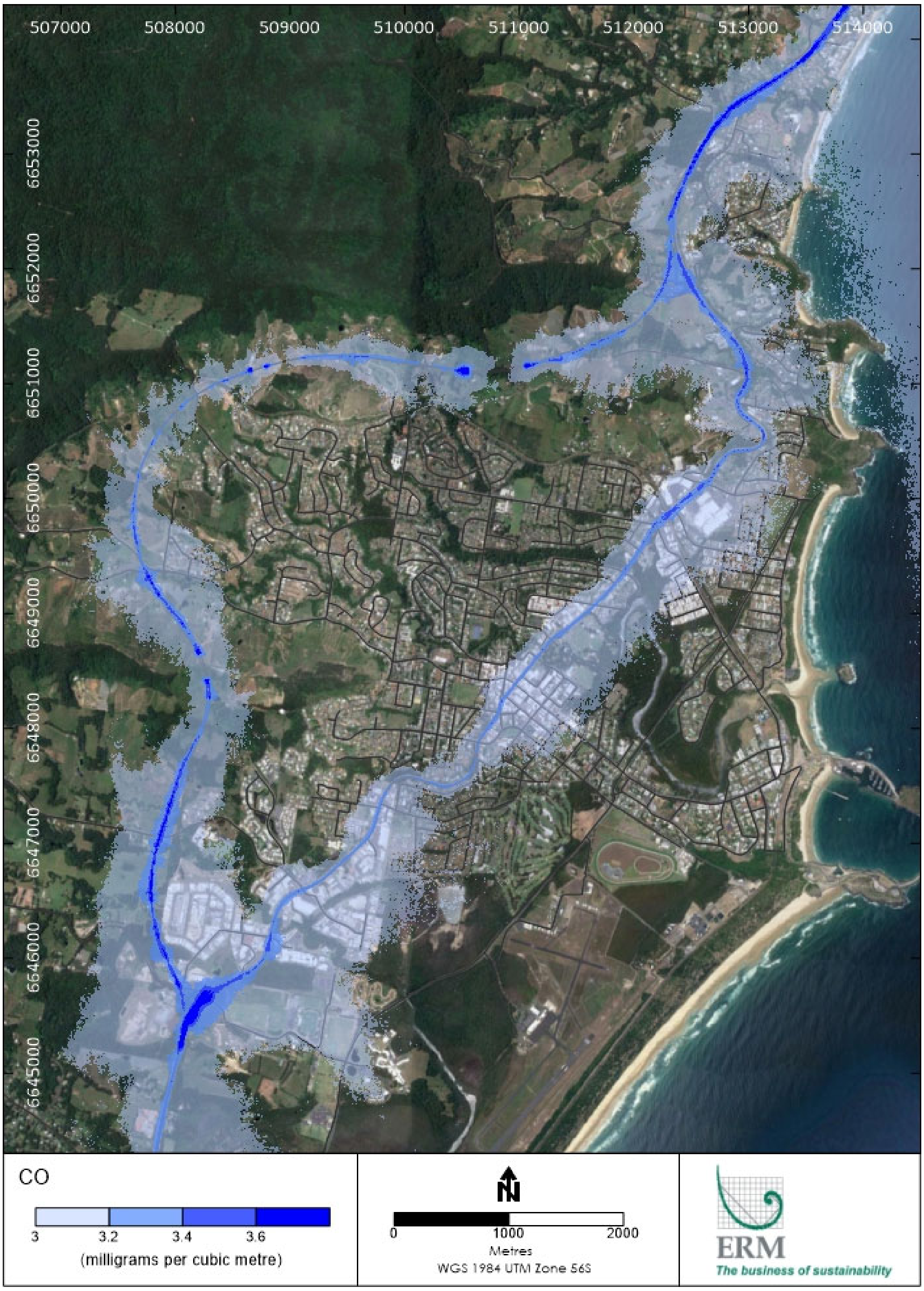

Figure C-16: Predicted maximum 8-hour rolling average cumulative CO concentrations for 2024 – Build (µg/m^3)

C1 2034 No Build Scenario

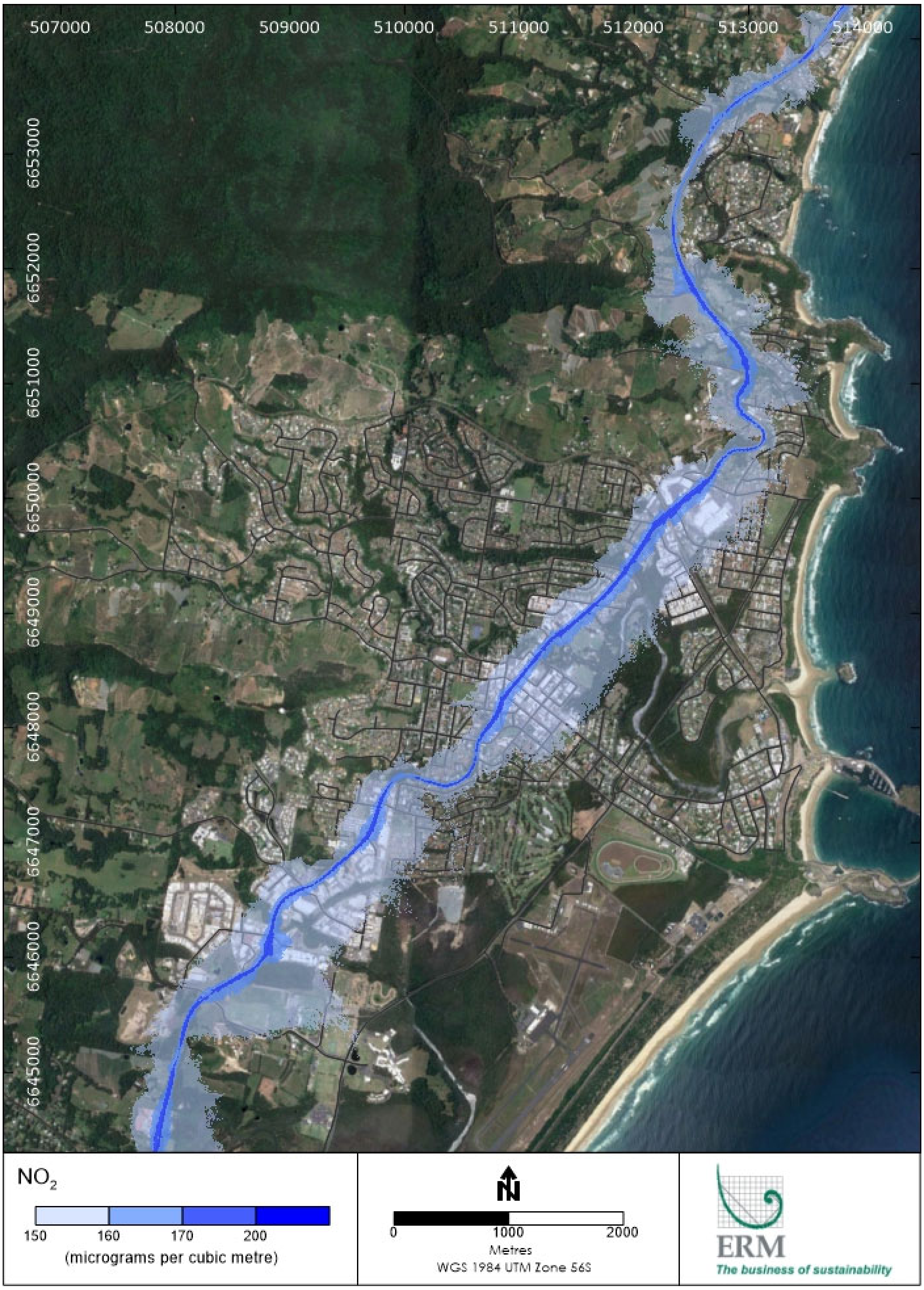

Figure C-17: Predicted maximum 1-hour average cumulative NO_2 concentrations for 2034 – No Build (µg/m^3)

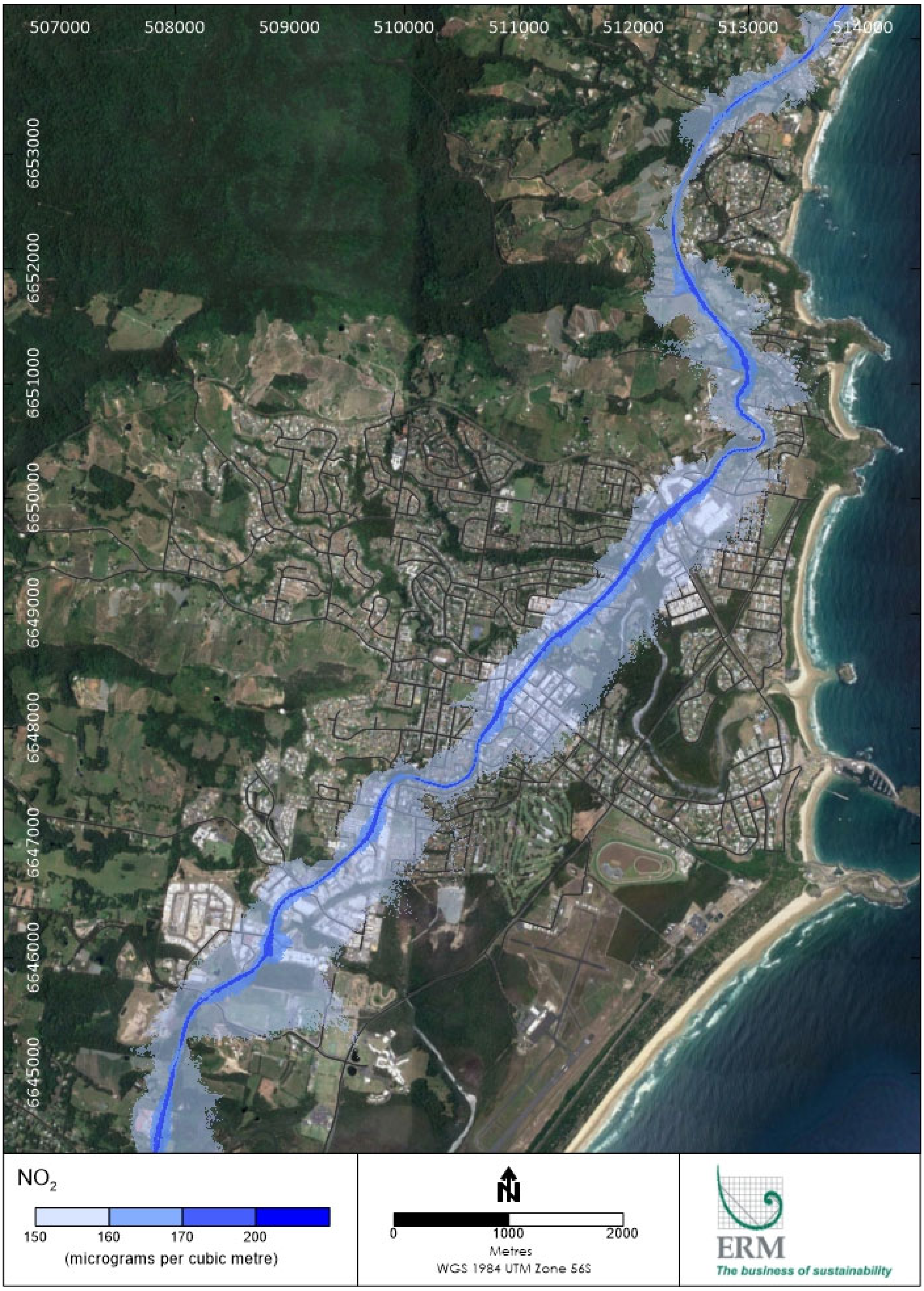

Figure C-18: Predicted annual average cumulative NO_2 concentrations for 2034 – No Build (μg/m^3)

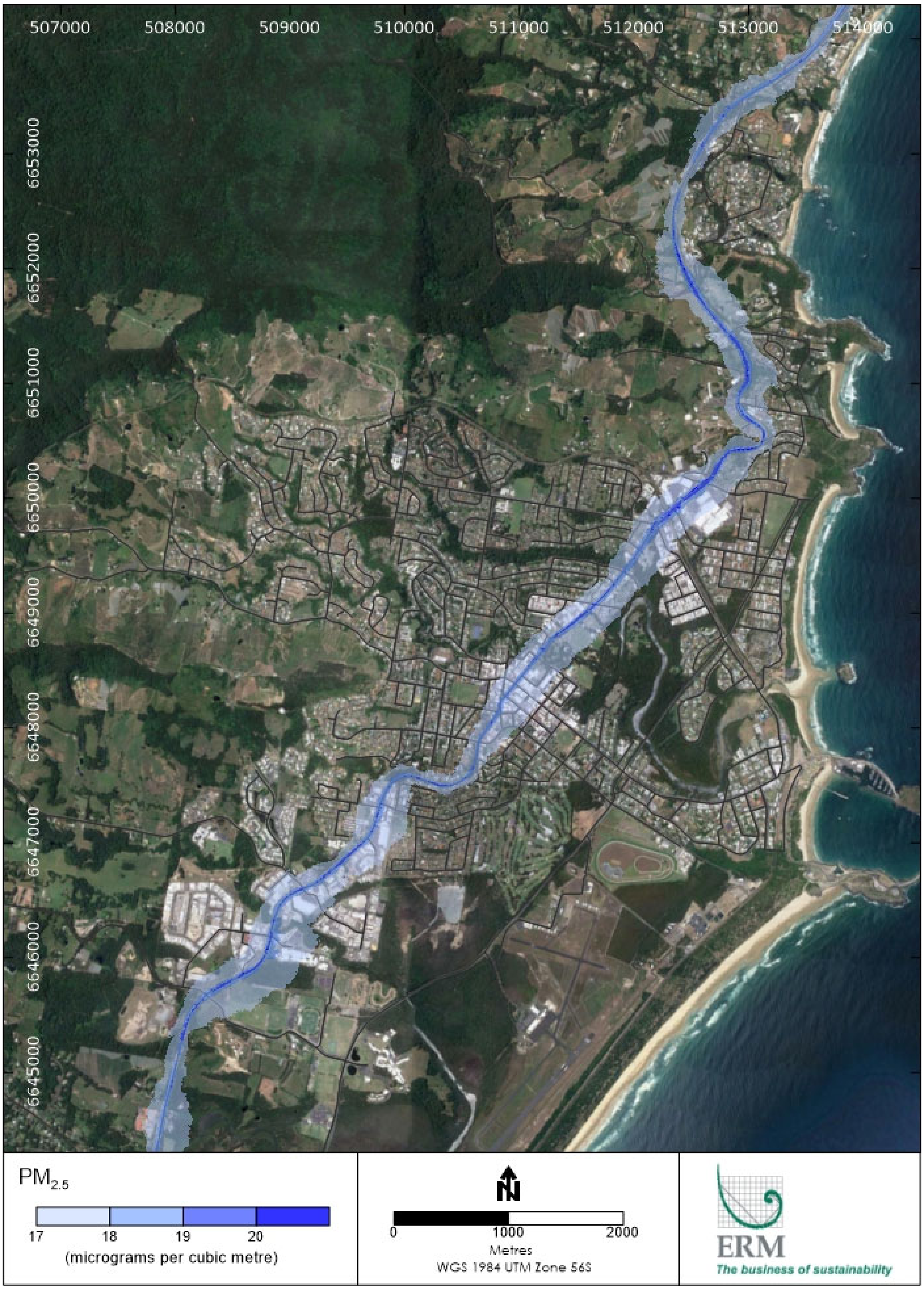

Figure C-19: Predicted maximum 24-hour average cumulative $PM_{2.5}$ concentrations for 2034 – No Build (µg/m^3)

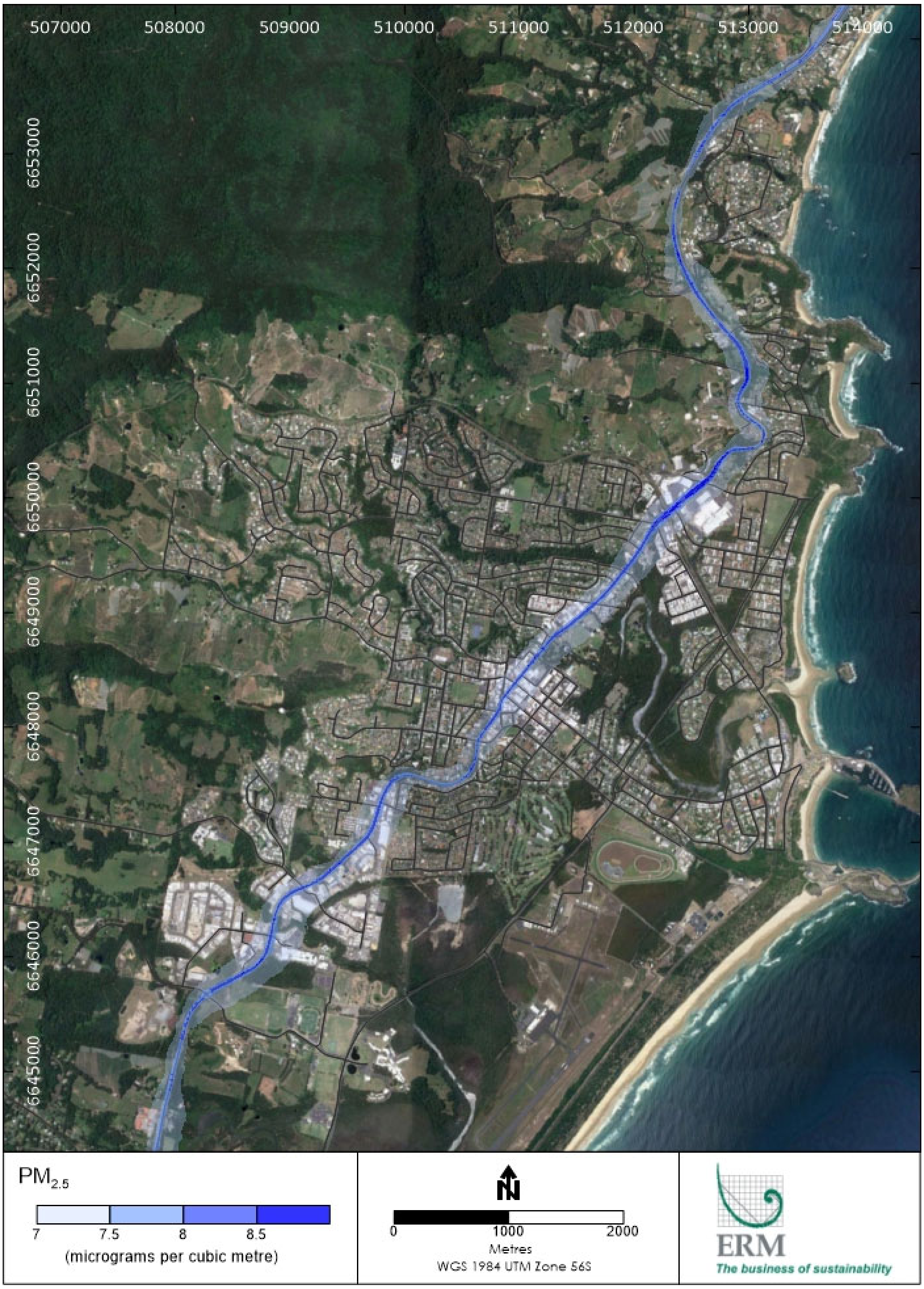

Figure C-20: Predicted annual average cumulative $PM_{2.5}$ concentrations for 2034 – No Build (µg/m^3)

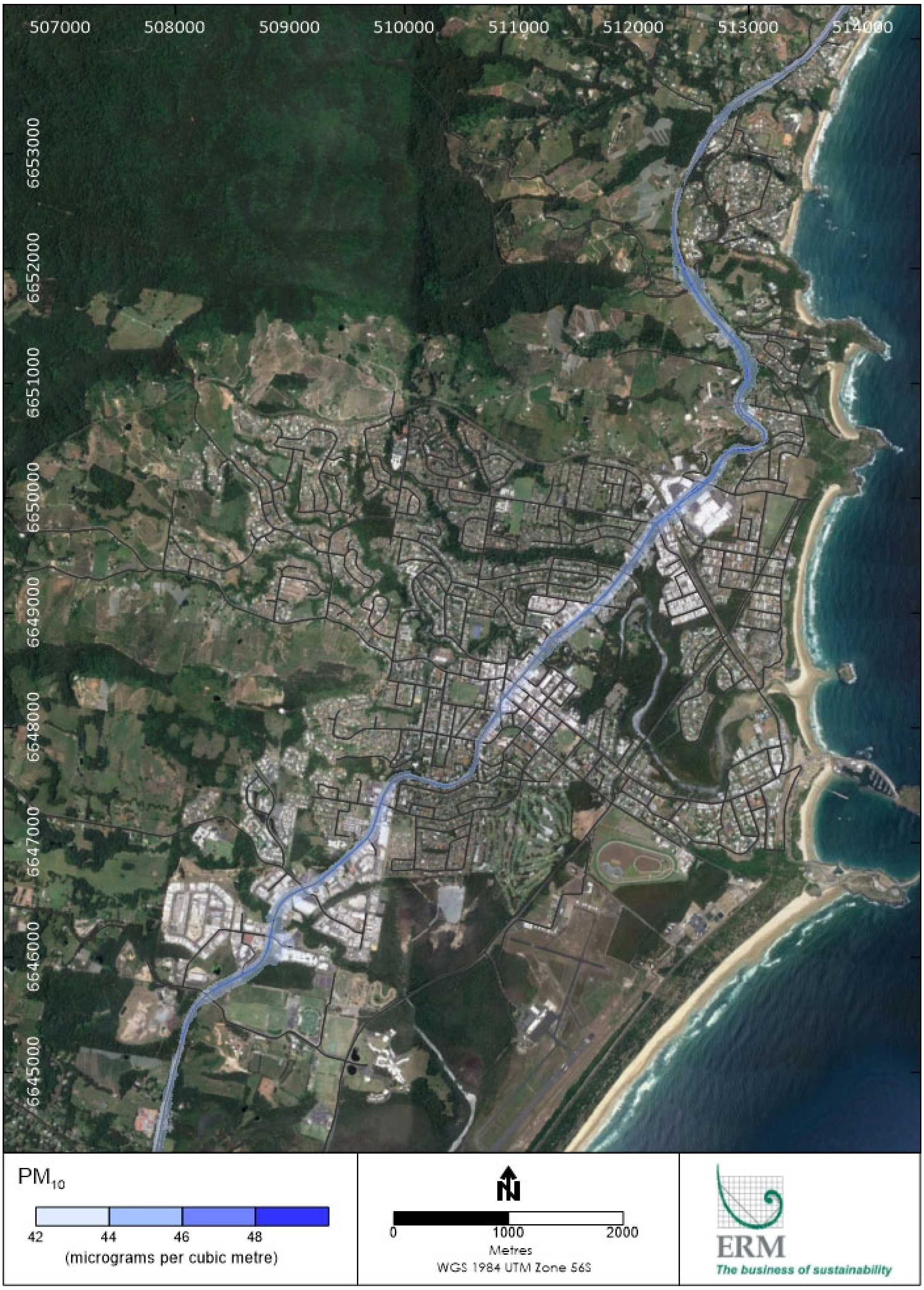

Figure C-21: Predicted maximum 24-hour average cumulative PM_{10} concentrations for 2034 – No Build (µg/m³)

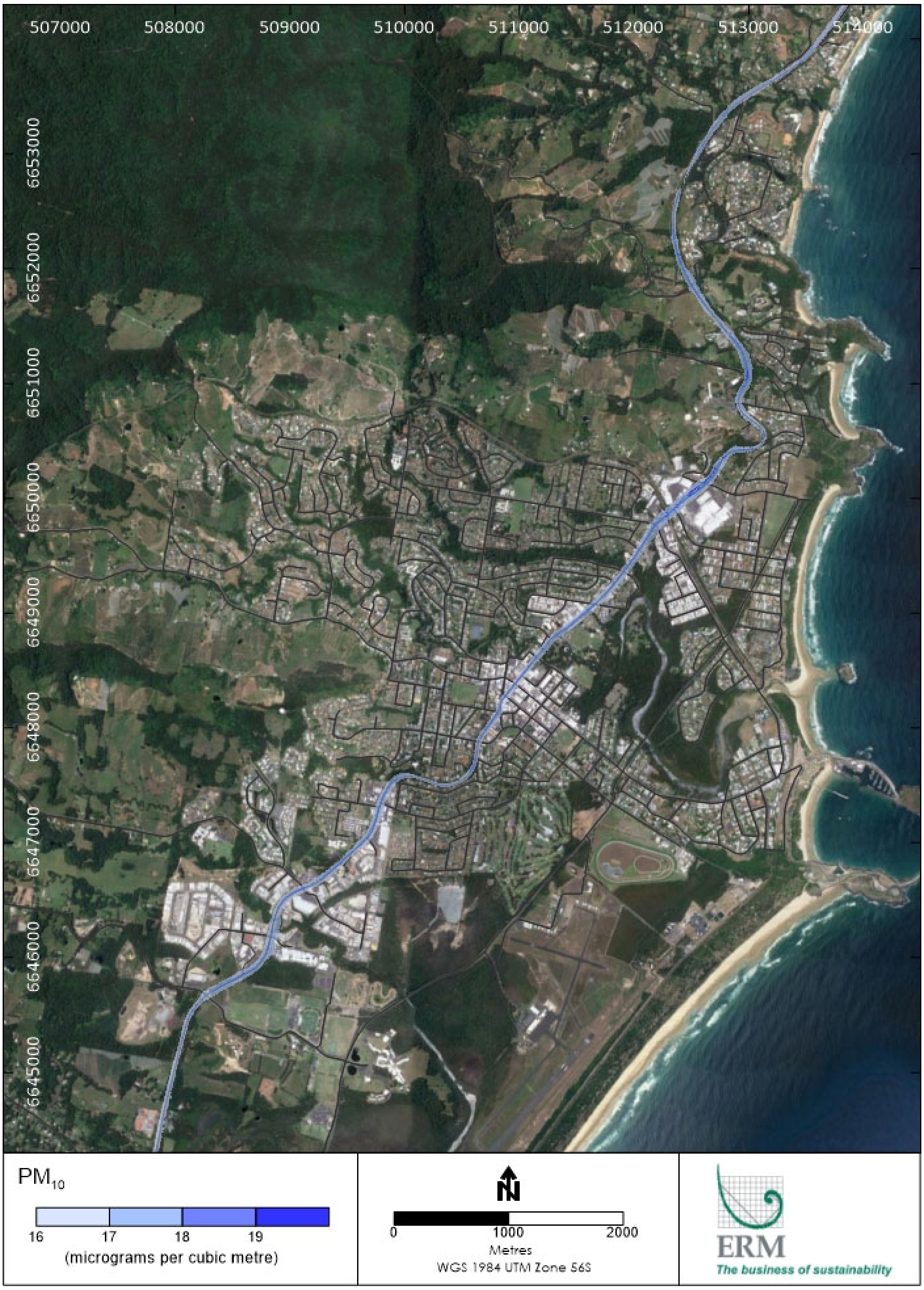

Figure C-22: Predicted annual average cumulative PM_{10} concentrations for 2034 – No Build (µg/m^3)

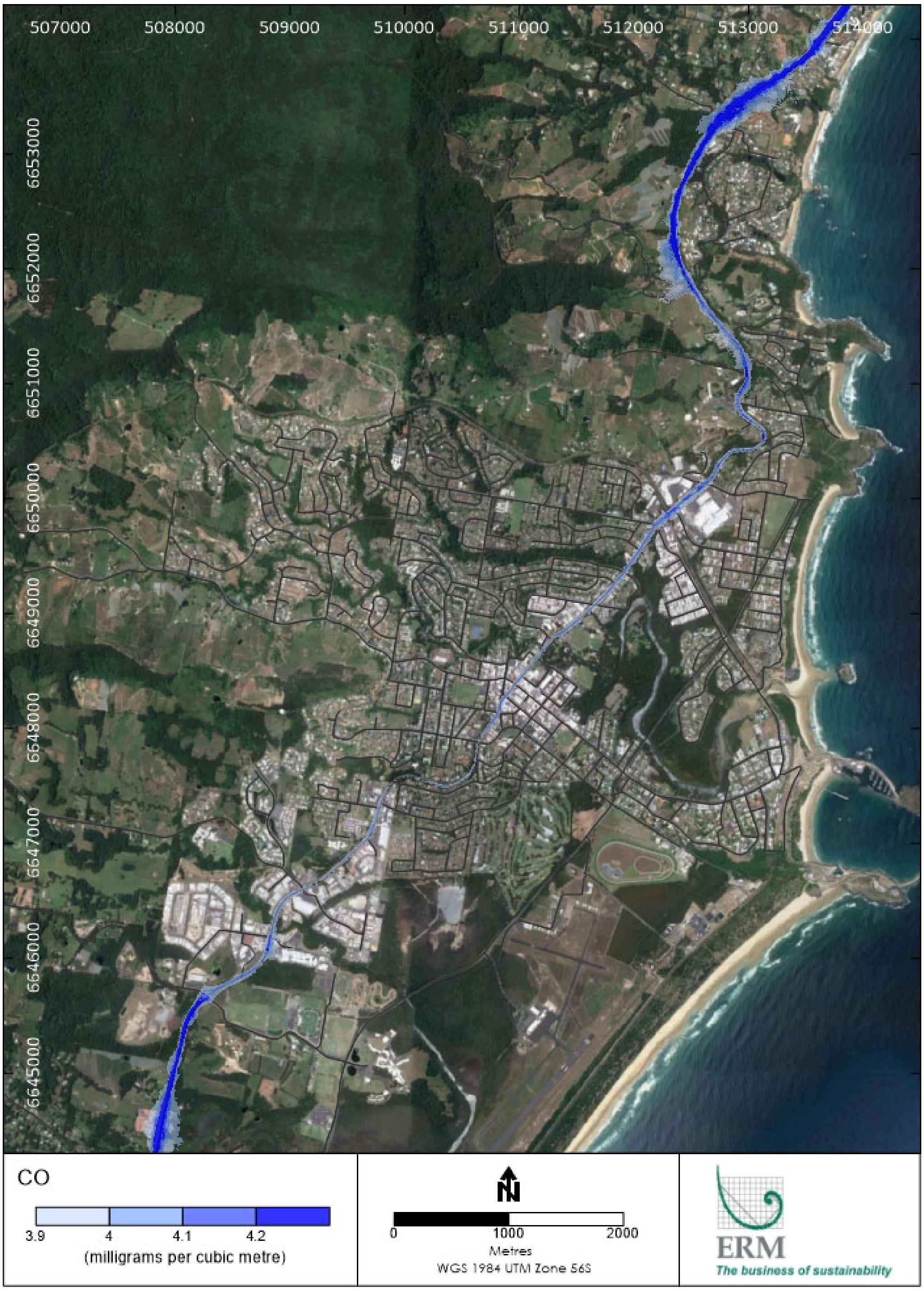

Figure C-23: Predicted maximum 1-hour average cumulative CO concentrations for 2034 – No Build (µg/m^3)

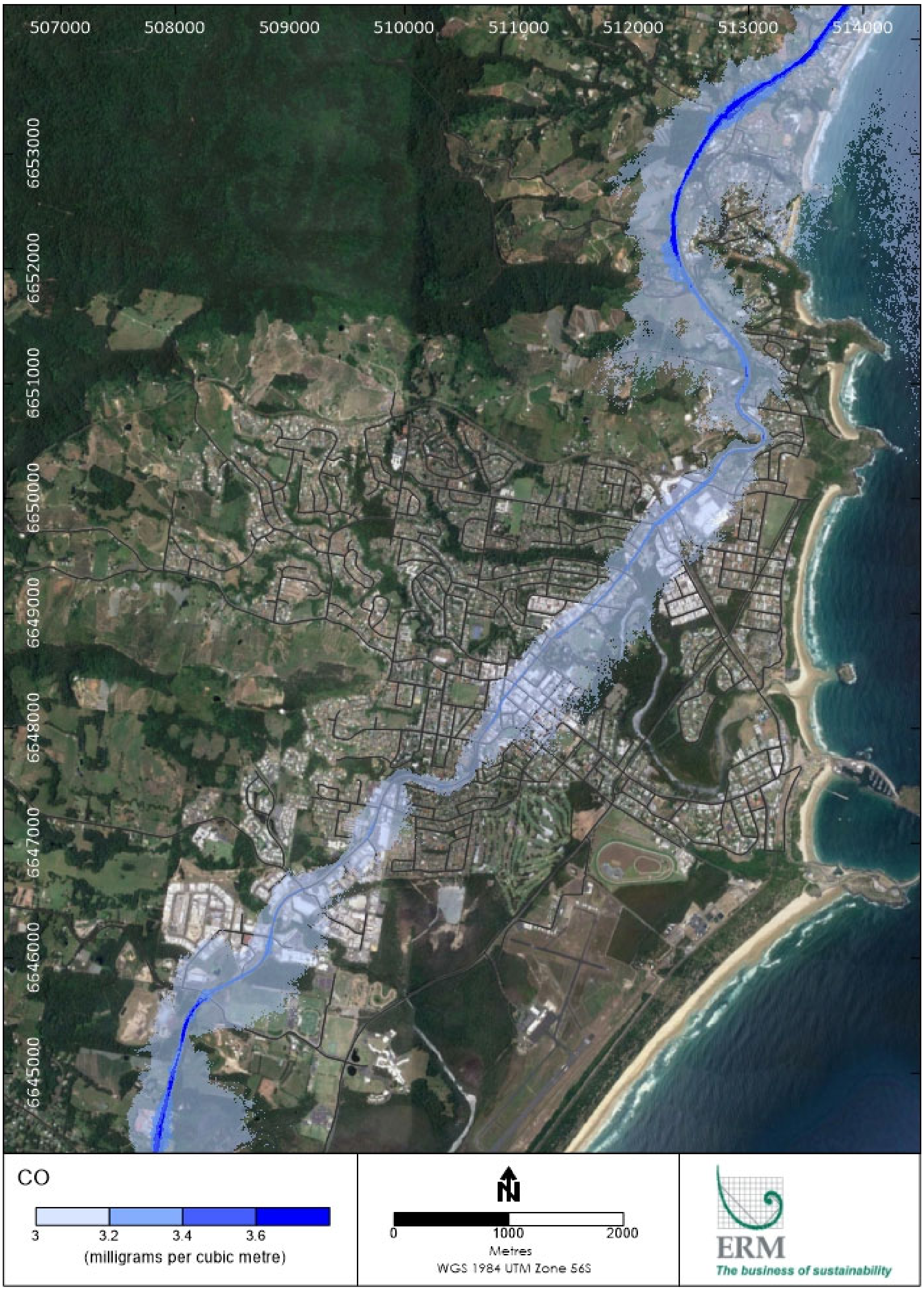

Figure C-24: Predicted maximum 8-hour rolling average cumulative CO concentrations for 2034 – No Build (µg/m^3)

C1 2034 Build Scenario

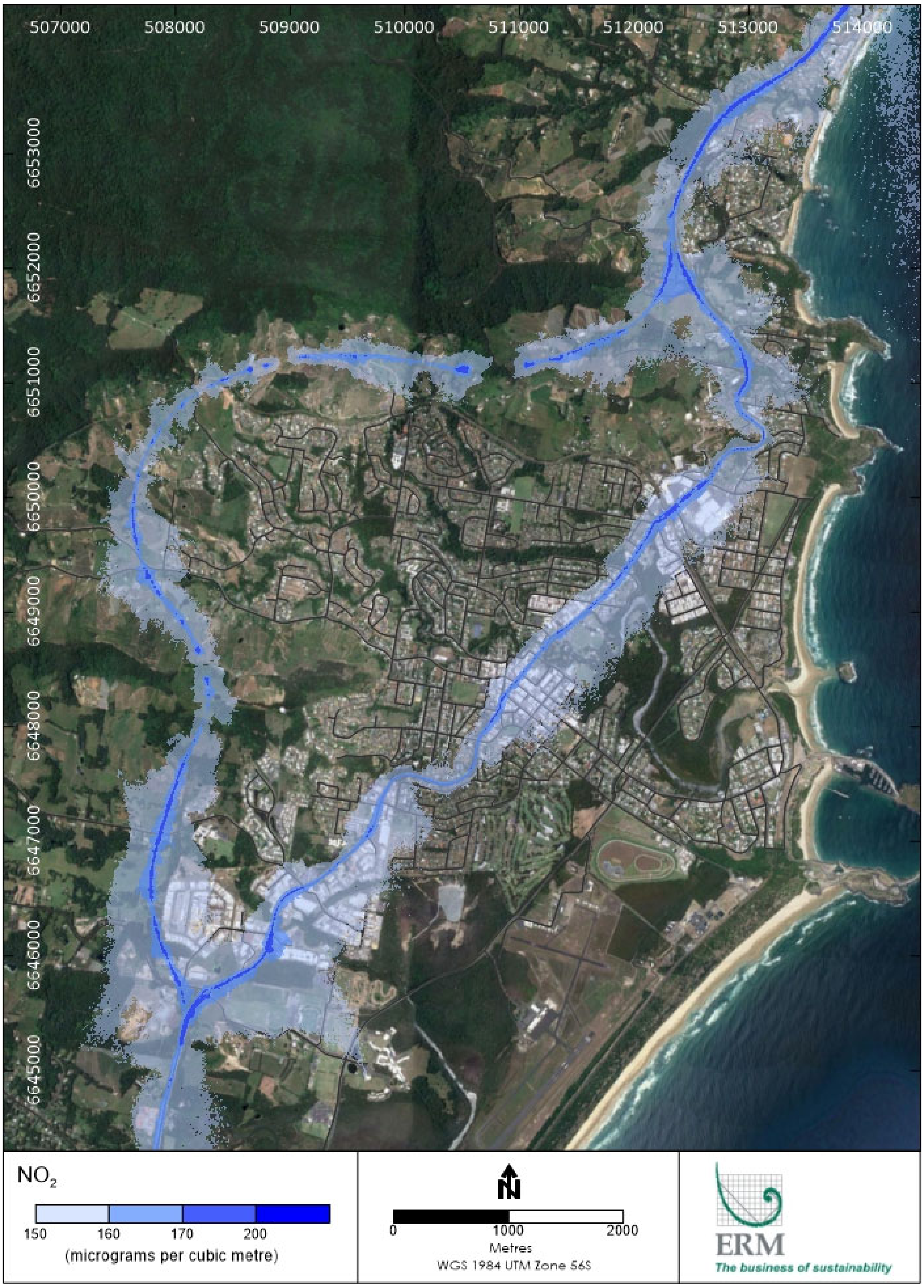

Figure C-25: Predicted maximum 1-hour average cumulative NO_2 concentrations for 2034 – Build ($\mu g/m^3$)

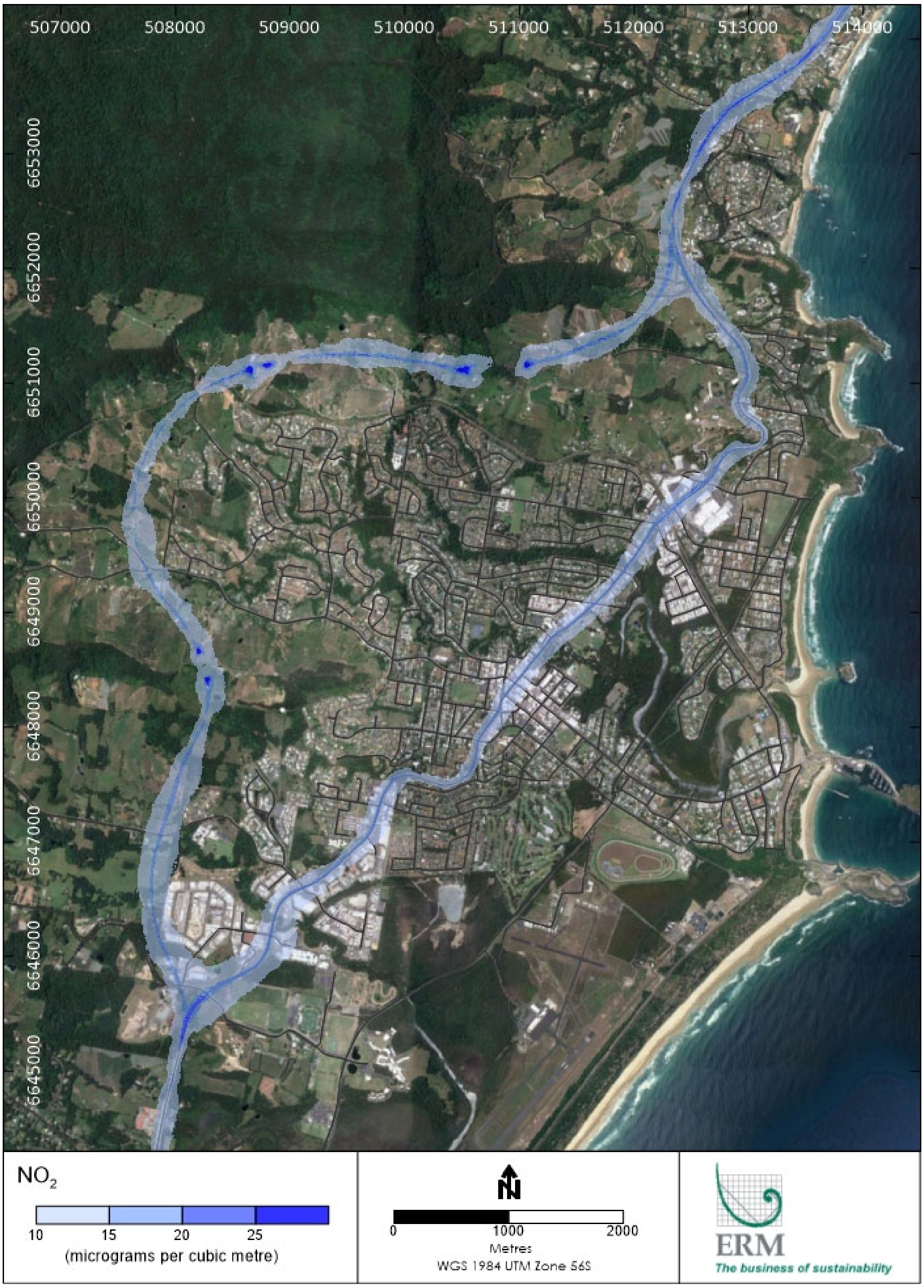

Figure C-26: Predicted annual average cumulative NO_2 concentrations for 2034 – Build (µg/m^3)

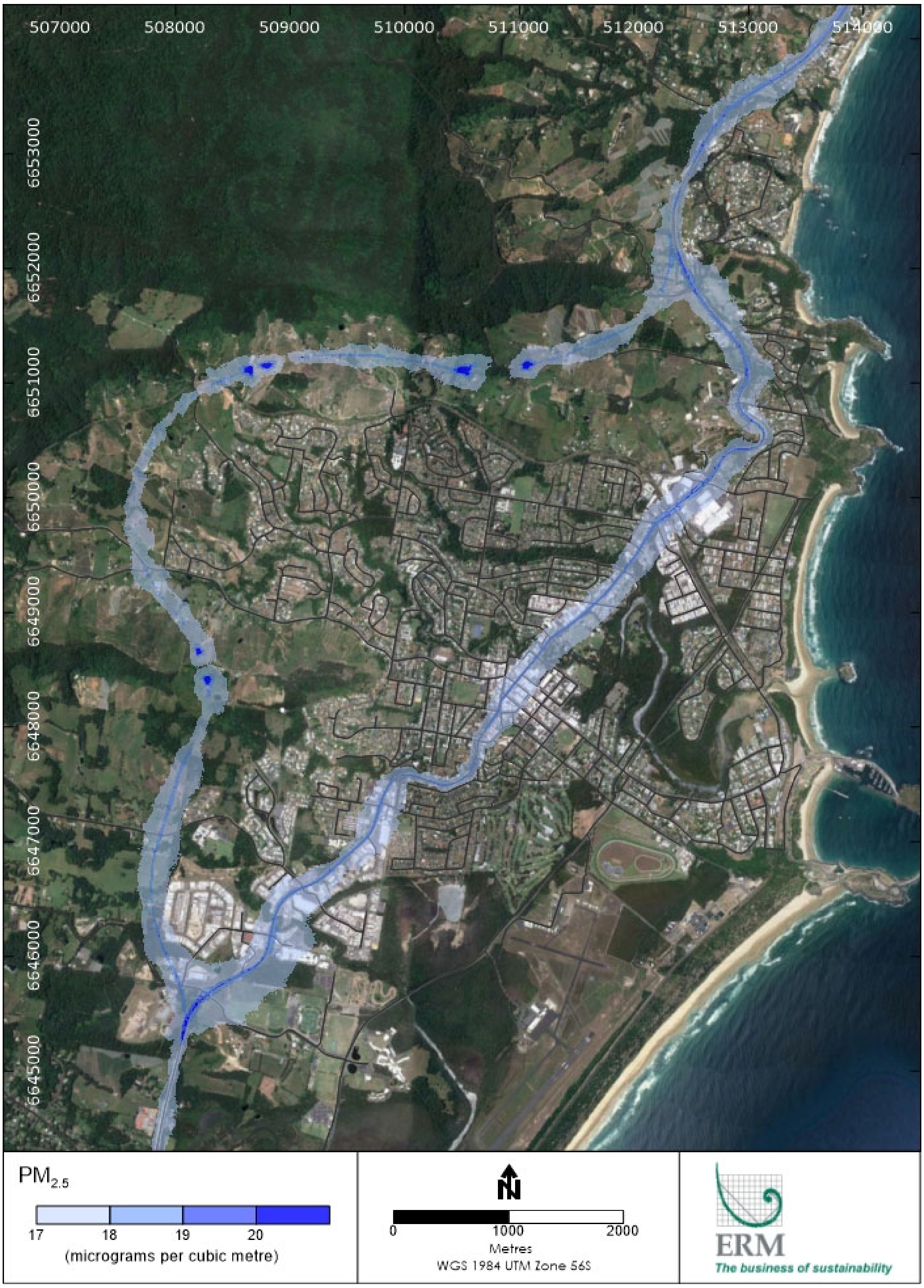

Figure C-27: Predicted maximum 24-hour average cumulative $PM_{2.5}$ concentrations for 2034 – Build (µg/m^3)

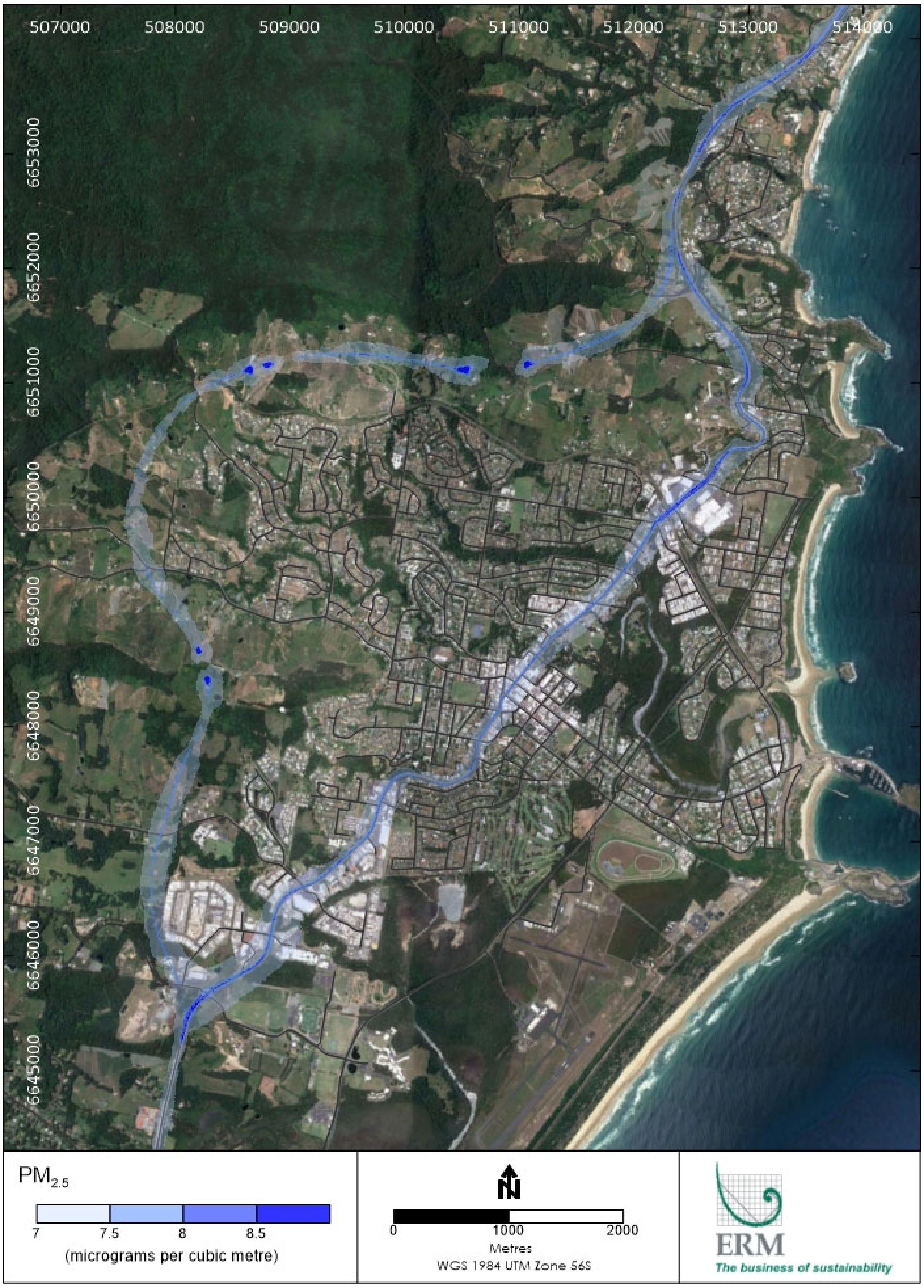

Figure C-28: Predicted annual average cumulative $PM_{2.5}$ concentrations for 2034 – Build (µg/m^3)

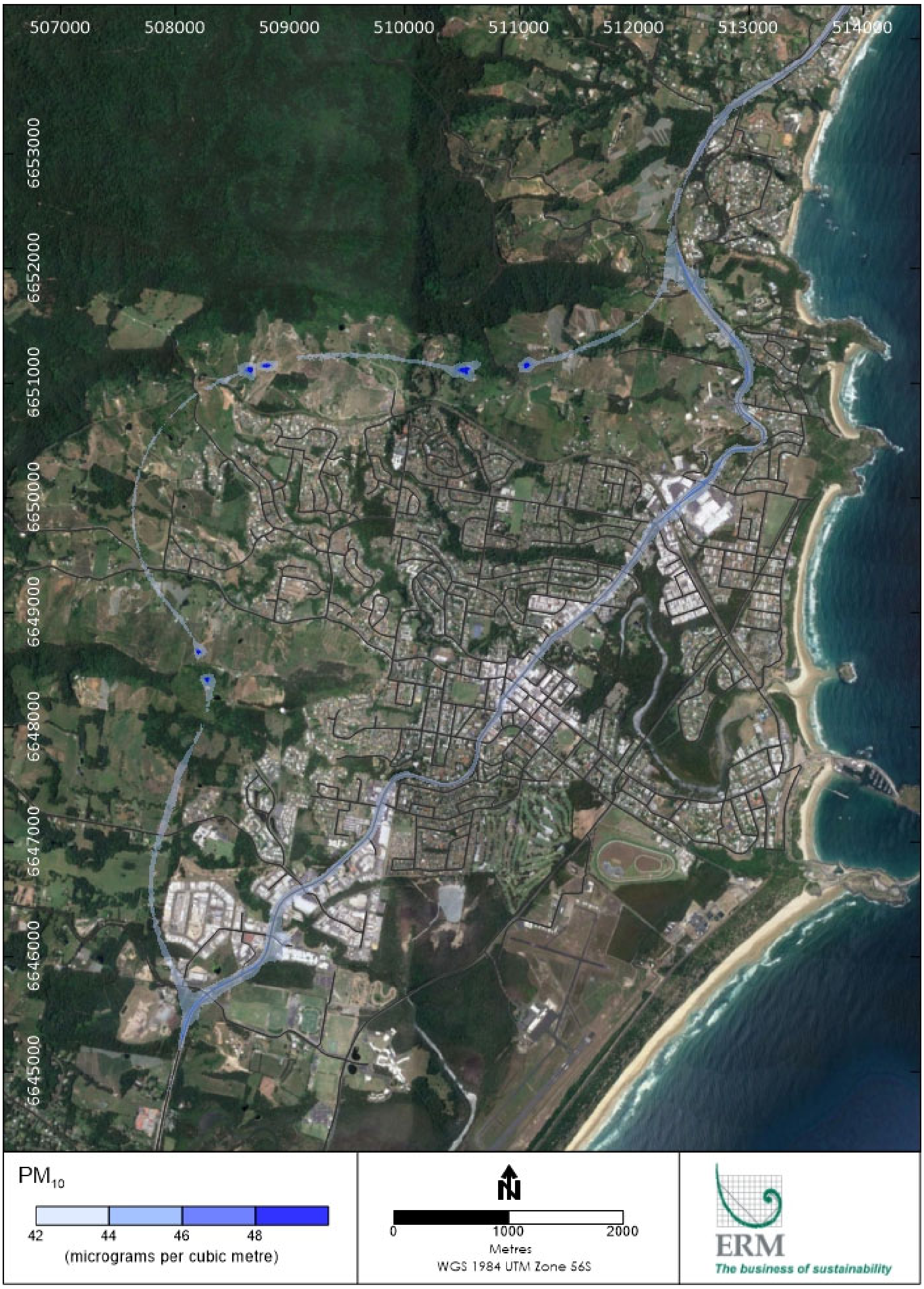

Figure C-29: Predicted maximum 24-hour average cumulative PM_{10} concentrations for 2034 – Build (µg/m^3)

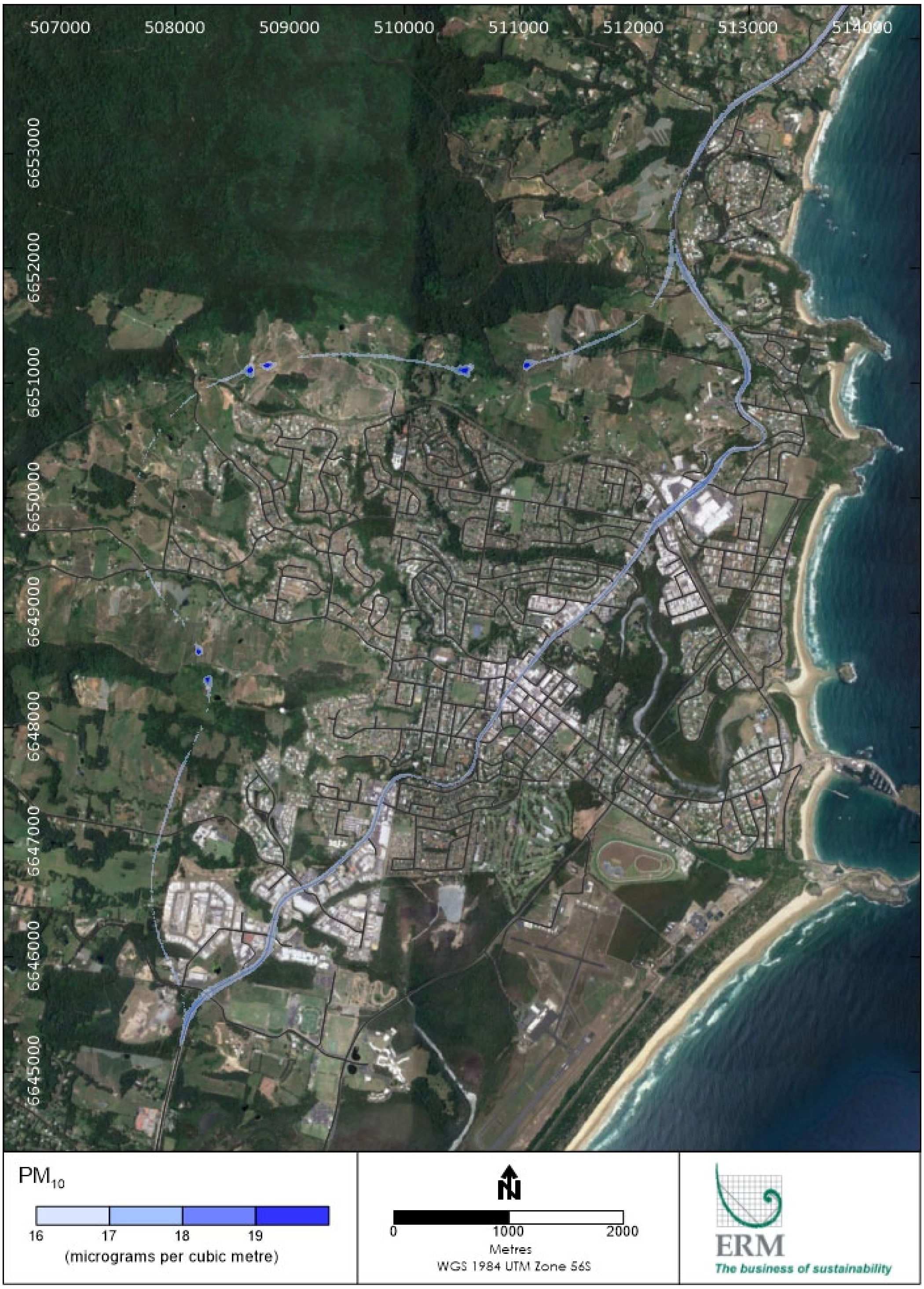

Figure C-30: Predicted annual average cumulative PM_{10} concentrations for 2034 – Build (µg/m^3)

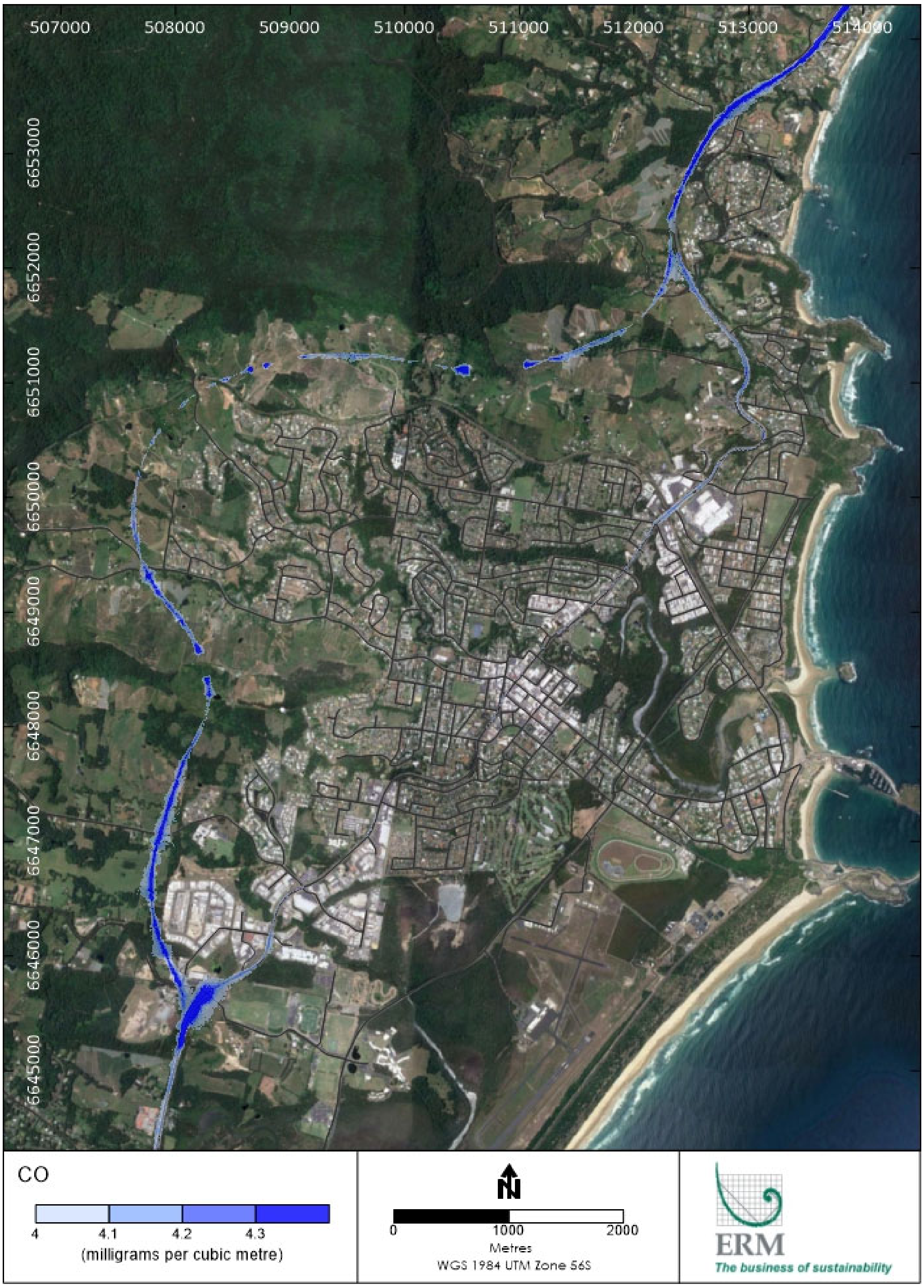

Figure C-31: Predicted maximum 1-hour average cumulative CO concentrations for 2034 – Build (µg/m^3)

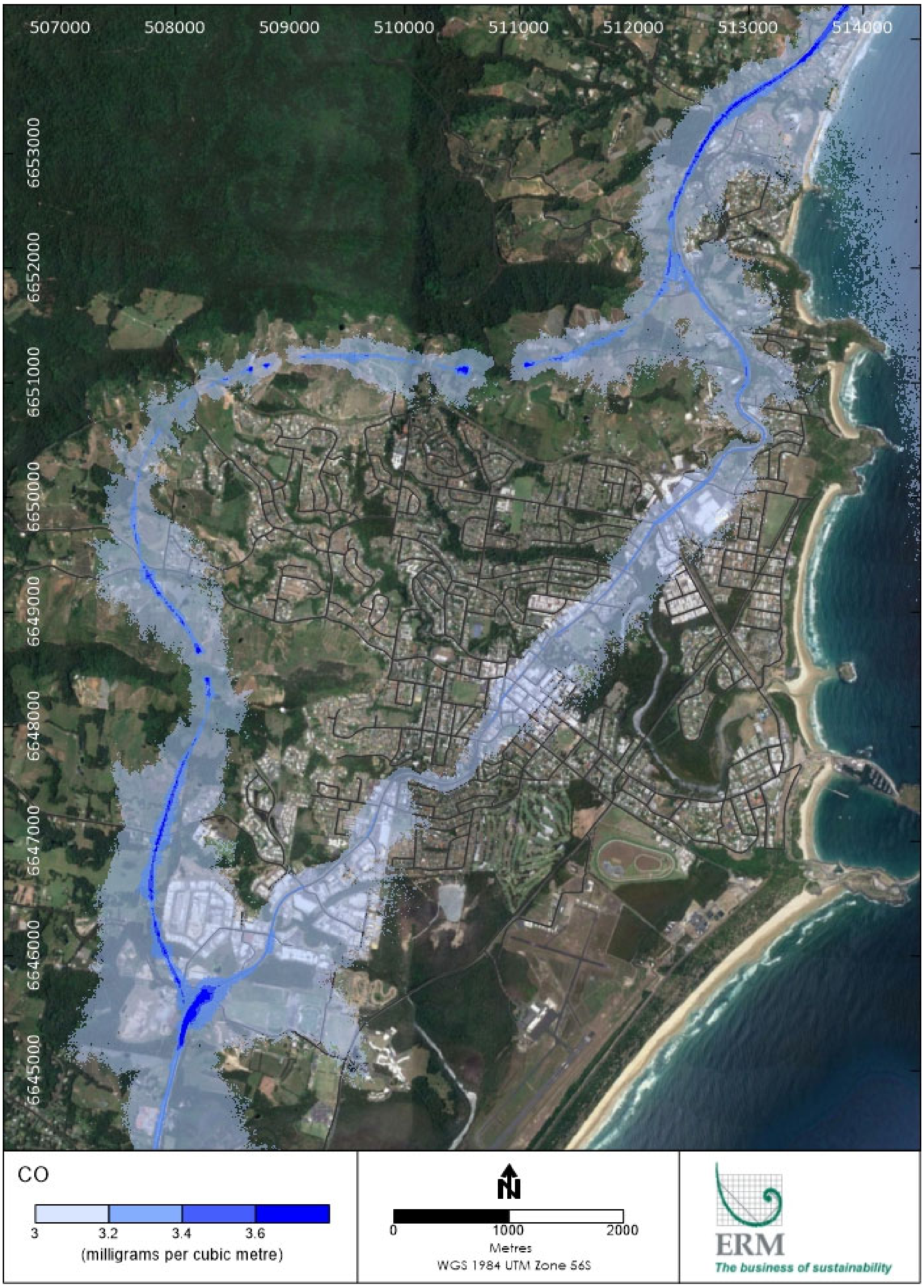

Figure C-32: Predicted maximum 8-hour rolling average cumulative CO concentrations for 2034 – Build (µg/m^3)

APPENDIX D COFFS HARBOUR BYPASS AIR VELOCITY AT PORTALS

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APPENDIX

Q

Appendix P

Appendix Q

Appendix Q

Human health risk assessment

Coffs Harbour Bypass: Human Health Risk Assessment

Prepared for: Roads and Maritime Services

Final Rev: 2
July 2019

Document History and Status

Report Reference	CHB/19/HR001
Revision	Final Rev 2
Date	July 2019
Previous	Draft Rev 1 (June 2019)
Author/Issued by:	Dr Jackie Wright (Fellow ACTRA)

Table of Contents

Appendices

Glossary of Terms and Abbreviations

Term	Meaning
A weighted decibels (dB(A))	The A weighting is a frequency filter applied to measured noise levels to represent how the human ear hears sounds. Adjustments are applied between 10Hz and 20 kHz. When an overall sound level is A-weighted it is expressed in units of dB(A) or dBA.
Acute or short-term exposure	Contact with a substance that occurs only once or for a short period of time, typically an hour or less, but may be up to 14 days.
Absorption	The process of taking in. For a person or an animal, absorption is the process of a substance getting into the body through the eyes, skin, stomach, intestines, or lungs.
Adverse health effect	A change in body function or cell structure that might lead to disease or health problems.
Background level	An average or expected amount of a substance or material in a specific environment, or typical amounts of substances that occur naturally in an environment.
Biodegradation	Decomposition or breakdown of a substance through the action of micro-organisms (such as bacteria or fungi) or other natural physical processes (such as sunlight).
Body burden	The total amount of a substance in the body. Some substances build up in the body because they are stored in fat or bone or because they leave the body very slowly.
Carcinogen	A substance that causes cancer.
Chronic or long-term exposure	Contact with a substance that occurs repeatedly over a long time, with the USEPA indicating defining this as exposures that occur for more than approximately 10% of a lifetime, Exposures that occur for less than 10% of a lifespan are considered sub-chronic.
Co-exposure	Exposure to more than one pollutant or stressor (such as noise) by a population
Combined	In the context of the health impact assessment, combined refers to the sum of exposures from different project impacts: such as impacts on health from emissions to air from the tunnel ventilation facilities plus impacts on health from changes in air impacts from surface roads; or impacts on health from changes in air quality plus impacts on health from changes in noise.
Cumulative	Total exposure, used in the health impact assessment to refer to exposures that include the background plus project, or to multiple different sources from the project
Decibel (dB)	A logarithmic scale is used to describe the level of sound, referenced to a standard level. It is widely accepted that a 3dB change in traffic noise levels (of the same character) is barely, if at all detectable; whereas a change of 5 dB is clearly noticeable. A 10 dB increase is typically considered to sound twice as loud (noting a change of -10 dB would typically sound half as loud).
Detection limit	The lowest concentration of a chemical that can reliably be distinguished from a zero concentration.
Dose	The amount of a substance to which a person is exposed over some time period. Dose is a measurement of exposure. Dose is often expressed as milligrams (amount) per kilogram (a measure of body weight) per day (a measure of time) when people eat or drink contaminated water, food, or soil. In general, the greater the dose, the greater the likelihood of an effect. An ‘exposure dose’ is how much of a substance is encountered in the environment. An ‘absorbed dose’ is the amount of a substance that actually gets into the body through the eyes, skin, stomach, intestines, or lungs.
Exposure	Contact with a substance by swallowing, breathing, or touching the skin or eyes. Exposure may be short-term [acute exposure], of intermediate duration, or long-term [chronic exposure].
Exposure assessment	The process of finding out how people come into contact with a hazardous substance, how often and for how long they are in contact with the substance, and how much of the substance they are in contact with.

Term	Meaning
Exposure pathway	The route a substance takes from its source (where it began) to its end point (where it ends), and how people can come into contact with (or get exposed) to it. An exposure pathway has five parts: a source of contamination (such as chemical leakage into the subsurface); an environmental media and transport mechanism (such as movement through groundwater); a point of exposure (such as a private well); a route of exposure (eating, drinking, breathing, or touching), and a receiver population (people potentially or actually exposed). When all five parts are present, the exposure pathway is termed a completed exposure pathway.
Guideline value	A guideline value is a concentration in soil, sediment, water, biota or air (established by relevant regulatory authorities such as the NSW Department of Environment and Conservation (DEC), or institutions such as the National Health and Medical Research Council (NHMRC) Australia and New Zealand Environment and Conservation Council (ANZECC) and World Health Organisation (WHO)). The guideline value is used to identify conditions below which no adverse effects, nuisance or indirect health effects are expected. The derivation of a guideline value utilises relevant studies on animals or humans and relevant factors to account for inter- and intra-species variations and uncertainty factors. Separate guidelines may be identified for protection of human health, or the environment. Dependent on the source, guidelines have different names, such as investigation level, trigger value, ambient guideline etc.
Inhalation	The act of breathing. A hazardous substance can enter the body this way [see route of exposure].
Intermediate exposure duration	Contact with a substance that occurs for more than 14 days and less than a year [compare with acute exposure and chronic exposure].
L_{10}	The sound pressure level exceeded for 10% of the measurement period. The A-weighted form is denoted 'L_{A10}'.
$L_{A10(18h)}$	The $L_{A10(18\text{-}hour)}$ noise level refers to the noise level exceeded for 10 per cent of the time during an 18-hour period (from 6am to midnight). This noise descriptor is calculated using the arithmetic average of the L_{A10} noise levels for each hour from 6am to midnight.
L_{den}	The average noise level over the day, evening and night (i.e. a 24-hour period).
L_{eq}	Equivalent continuous sound level. The constant sound level which, when occurring over the same period of time, would result in the receptor experiencing the same amount of sound energy. The A-weighted form is denoted 'L_{Aeq}'.
L_{night}	The average noise level over the night-time period, typically between 11pm or midnight and 6am.
LOAEL	Lowest-observed-adverse-effect-level - The lowest tested dose of a substance that has been reported to cause harmful (adverse) health effects in people or animals.
Metabolism	The conversion or breakdown of a substance from one form to another by a living organism.
Morbidity	A diseased condition or state or the incidence or prevalence of disease in a population
Mortality	Death, which may occur as a result of a range of reasons or diseases
NOAEL	No-observed-adverse-effect-level - The highest tested dose of a substance that has been reported to have no harmful (adverse) health effects on people or animals.
Not measurable	The term "no measurable" or "not measurable" is used in this health impact assessment when referring to changes in air quality, noise or health outcomes in a population. For air quality and noise, a change that would be not be measurable is one where the estimated change in the concentration of the pollutant in ambient air, or noise, is so small that it could not be measured - i.e. within the error of the analytical method/measurement equipment. For health outcomes, it refers to exposures that are below a threshold so there are no health effects, or to changes in the number of people that may be affected (i.e. increase or decrease in deaths or hospitalisations) that is within the error/variability of the statistical measures (i.e. is not measurable).
Point of exposure	The place where someone comes into contact with a substance present in the environment [see exposure pathway].
Population	A group or number of people living within a specified area or sharing similar characteristics (such as occupation or age).

Term	Meaning
Receiver population	People who could come into contact with hazardous substances [see exposure pathway].
Risk	The probability that something would cause injury or harm.
Route of exposure	The way people come into contact with a hazardous substance. The three routes of exposure are breathing [inhalation], eating or drinking [ingestion], or contact with the skin [dermal contact]
Toxicity	The degree of danger posed by a substance to human, animal or plant life.
Toxicity data	Characterisation or quantitative value estimated (by recognised authorities) for each individual chemical for relevant exposure pathway (inhalation, oral or dermal), with special emphasis on dose-response characteristics. The data is based on available toxicity studies relevant to humans and/or animals and relevant safety factors.
Toxicological profile	An assessment that examines, summarizes, and interprets information about a hazardous substance to determine harmful levels of exposure and associated health effects. A toxicological profile also identifies significant gaps in knowledge on the substance and describes areas where further research is needed.
Toxicology	The study of the harmful effects of substances on humans or animals.
Uncertainty factor	Mathematical adjustments for reasons of safety when knowledge is incomplete. For example, factors used in the calculation of doses that are not harmful (adverse) to people. These factors are applied to the lowest-observed-adverse-effect-level (LOAEL) or the no-observed-adverse-effect-level (NOAEL) to derive a minimal risk level (MRL). Uncertainty factors are used to account for variations in people's sensitivity, for differences between animals and humans, and for differences between a LOAEL and a NOAEL. Scientists use uncertainty factors when they have some, but not all, the information from animal or human studies to decide whether an exposure would cause harm to people [also sometimes called a safety factor].

Abbreviation	Term
AAQ	Ambient air quality
AQ	Air quality
CEMP	Construction Environment Management Plan
CNVMP	Construction Noise and Vibration Management Plan
CO	Carbon monoxide
COPD	Chronic Obstructive Pulmonary Disease
DECCW	Department of Environment, Climate Change and Water
DPM	Diesel particulate matter
EC	European Commission
HHRA	Human Health Risk Assessment
IARC	International Agency for Research on Cancer
LGA	Local Government Area
LOR	Limit of Reporting
NEPC	National Environment Protection Council
NEPM	National Environment Protection Measure
NHMRC	National Health and Medical Research Council
NO_2	Nitrogen dioxide
PIARC	Permanent International Association of Road Congresses
PM	Particulate matter
$PM_{2.5}$	Particulate matter of aerodynamic diameter 2.5 μm and less
PM_{10}	Particulate matter of aerodynamic diameter 10 μm and less
TSP	Total suspended particulate
USEPA	United States Environmental Protection Agency
WHO	World Health Organization

Section 1. Introduction

1.1 The proposed project

Roads and Maritime Services (Roads and Maritime) is seeking approval for the Coffs Harbour Bypass (the project). The approval is being sought under Division 5.2 of the NSW *Environmental Planning and Assessment Act 1979* (EP&A Act) as Critical State Significant Infrastructure (CSSI).

The project includes a 12 km bypass of Coffs Harbour from south of Englands Road to Korora Hill in the north and a 2 km upgrade of the existing highway between Korora Hill and Sapphire. The project would provide a four-lane divided highway that bypasses Coffs Harbour, passing through the North Boambee Valley, Roberts Hill and then traversing the foothills of the Coffs Harbour basin to the west and north to Korora Hill.

The key features of the project include:

- Four-lane divided highway from south of Englands Road roundabout to the dual carriageway highway at Sapphire
- Bypass of the Coffs Harbour urban area from south of Englands Road intersection to Korora Hill
- Upgrade of the existing Pacific Highway between Korora Hill and the dual carriageway highway at Sapphire
- Grade-separated interchanges at Englands Road, Coramba Road and Korora Hill
- A one-way local access road along the western side of the project between the southern tie-in and Englands Road, connecting properties to the road network via Englands Road
- A new service road, located east of the project, connecting Solitary Islands Way with James Small Drive and the existing Pacific Highway near Bruxner Park Road
- Three tunnels through ridges at Roberts Hill (around 190 m long), Shephards Lane (around 360 m long), and Gatelys Road (around 450 m long)
- Structures to pass over local roads and creeks as well as a bridge over the North Coast Railway
- A series of cuttings and embankments along the alignment
- Tie-ins and modifications to the local road network to enable local road connections across and around the alignment
- Pedestrian and cycling facilities, including a shared path along the service road tying into the existing shared path on Solitary Islands Way, and a new pedestrian bridge to replace the existing Luke Bowen footbridge with the name being retained
- Relocation of the Kororo Public School bus interchange
- Noise attenuation, including low noise pavement, noise barriers and at-property treatments as required
- Fauna crossing structures including glider poles, underpasses and fencing
- Ancillary work to facilitate construction and operation of the project, including:
  - Adjustment, relocation and/or protection of utilities and services
  - New or adjusted property accesses as required
  - Operational water quality measures and retention basins

- Temporary construction facilities and work including compound and stockpile sites, concrete/asphalt batching plant, sedimentation basins and access roads (if required).

Figure 1.1: Project location and key features

1.2 Purpose of this report

The Secretary's Environmental Assessment Requirements (SEARs) for the Coffs Harbour Bypass for the purpose of seeking project approval under Division 5.2 of the *Environmental Planning and Assessment Act 1979* (EP&A Act) does not include the requirement to undertake a detailed health impact assessment. The SEARs do, however, include the following key issues that are relevant to human health:

Table 1: SEARs relevant to human health

Key Issue and Desired Performance Outcome	Requirement	Where addressed in this report
2. Noise and Vibration - Amenity Construction noise and vibration (including airborne noise, ground-borne noise and blasting) are effectively managed to minimise adverse impacts on acoustic amenity. Increases in noise emissions affecting nearby properties and other sensitive receivers during operation of the project are effectively managed to protect the **amenity and wellbeing** of the community.	1. The Proponent must assess construction and operational noise and vibration impacts in accordance with relevant NSW noise and vibration guidelines. The assessment must include consideration of impacts to sensitive receivers, and include consideration of sleep disturbance and, as relevant, the characteristics of noise and vibration.	Section 5
13. Air Quality The project is designed, constructed and operated in a manner that minimises air quality impacts (including nuisance dust and odour) to **minimise risks to human health** and the environment to the greatest extent practicable.	2. The Proponent must ensure the AQIA also includes the following: (b) an assessment of the impacts of the construction and operation of the project on sensitive receivers and the local community, including risks to human health;	Section 4

This report has been prepared to specifically address risks to human health in relation to changes in air quality and noise, relevant to the construction and operational phases of the project. As a result, this report relies on the assessments of impacts related to air quality and noise, as presented in the following reports:

- ERM 2019, Air Quality Assessment, Coffs Harbour Bypass. Report (July 2019).
- Arup 2019, Noise and Vibration Assessment Report, Coffs Harbour Bypass (July 2019).

Section 2. Methodology

2.1 What is a risk assessment?

2.1.1 Risk

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

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

2.1.2 Defining risk and impacts

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

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

A more detailed discussion on the determination of acceptable, tolerable or unacceptable risks is presented in **Appendix C** of this report.

2.2 Guidance

The human health risk assessment presented in this report has been prepared in accordance with Australian guidance, as outlined in the following:

- enHealth Environmental Health Risk Assessment: Guidelines for Assessing Human Health Risks from Environmental Hazards (enHealth 2012b) - This document provides an outline of the national approach adopted for the assessment of environmental health risks. While risk assessment is part of the health impact assessment process, the conduct of such an assessment typically focuses on key elements within the health impact assessment where a more detailed quantitative assessment of exposure, toxicity and health risk is required, and can be undertaken. The enHealth guidance provides the Australian framework and approach for the conduct of such assessments.

- enHealth Health Impact Assessment Guidelines (enHealth 2017)
- NEPC National Environment Protection (Ambient Air Quality) Measure (NEPC 2016)

In addition, the following guidelines have been used, where relevant to address more specific aspects relevant to the assessment of human health risks related to air and noise:

- Approved Methods for the Modelling and Assessment of Air Pollutants in New South Wales (NSW EPA 2016)
- NSW Road Noise Policy (NSW DECCW 2011)
- NSW Noise Policy for Industry (NSW EPA 2017)
- Interim Construction Noise Guideline (NSW DECC 2009).

Where relevant, other international guidance has been adopted and referenced throughout this report.

2.3 Approach to the health risk assessment

2.3.1 General

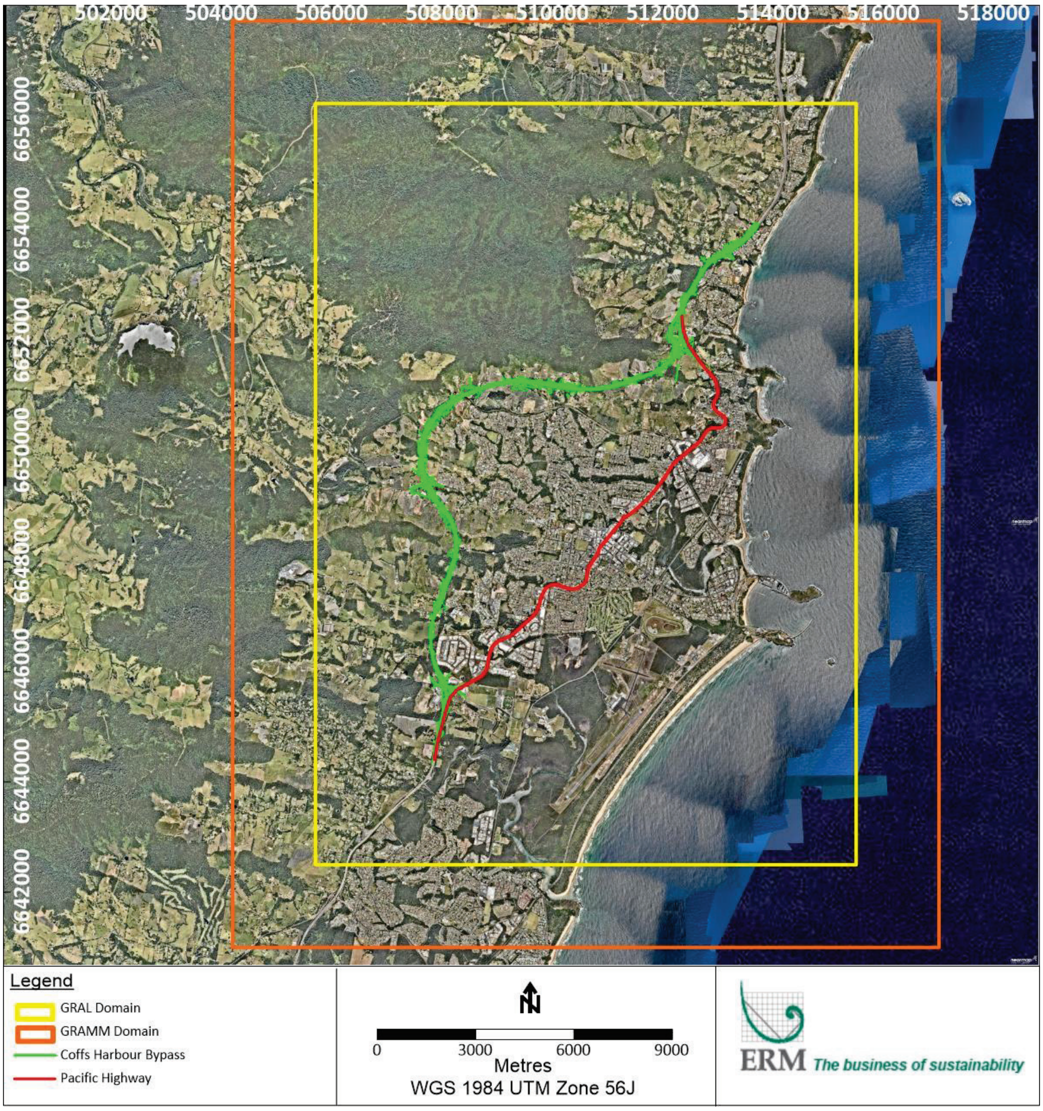
The health risk assessment was undertaken as a desk-top assessment. The term desk-top assessment is used to describe that the assessment has not involved the collection of any additional data over and above that which would be provided from project-specific EIS technical studies, community consultation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

The risk assessment was undertaken in accordance with the scope as outlined in **Section 1.2** and the guidelines outlined in **Section 2.2** and involved both quantitative and qualitative evaluations. Following this approach, the assessment of health impacts relevant to the different areas of evaluation has utilised a range of different methods and approaches, with each specifically relevant to the technical aspect being considered. The following provides an overview of the approach adopted for the assessment of health impacts related to air quality, noise, safety and other social determinants. Specific details related to the assessments undertaken in each of these areas is presented in the relevant chapter (where it specifically relates to the assessment presented).

2.3.2 Study area

The health risk assessment has drawn directly on other specific technical studies undertaken for the EIS such as traffic, air quality and noise. As the health risk assessment has relied on the assessments undertaken in other technical studies, the study areas evaluated in relation to health impacts are the same as the study areas considered in each of the individual technical studies. These study areas are specific to each technical study and are, therefore, further described in the more detailed assessment of each key area such as air quality (refer to **Section 4**) and noise (refer to **Section 5**).

The largest of the study areas evaluated in the technical studies is defined in the Air Quality Assessment (ERM 2019) and illustrated in **Figure 2.1**. This study area is adopted in the health impact assessment as the larger population area to be considered in terms of changes in health.



Note:
GRAMM domain is the larger meteorological domain evaluated in the air quality assessment
GRAL domain is the area in which changes in air quality have been predicted and is the study area adopted for the assessment of health impacts

Figure 2.1: Health study area

2.3.3 Assessment scenarios

The assessment of impacts presented in the technical reports associated with the project has considered a range of scenarios that include the existing situation, construction works and various future operational scenarios both with and without the project.

The operational scenarios have included the following:

- **2024 No build** – Opening year without the project
- **2024 Build** – Opening year with the project
- **2034 No build** – Opening year plus 10 years without the project
- **2034 Build** – Opening year plus 10 years with the project.

2.3.4 Health impacts from changes in air quality

Section 4 provides a detailed assessment of the potential for changes in air quality due to the project and how these changes might impact health within the community. This assessment has drawn on information provided in the Air Quality Assessment (ERM 2019) and, in some areas, provides a summary of key (and relevant) aspects. All details relevant to the underlying assumptions, methodology and interpretation of impacts relevant to changes in air quality are provided within the Air Quality Assessment (ERM 2019).

The HIA has provided an overview of the key aspects of the air quality impact assessment, as it is important to understand how the data used in the health impact assessment has been estimated. Where more detail related to how the air quality assessment was undertaken is required, the reader is directed to the Air Quality Assessment (ERM 2019).

The characterisation of health impacts from changes in air quality as a result of the project is complex. The focus of this assessment relates to changes in carbon monoxide (CO), nitrogen dioxide (NO_2) and particulate matter (PM).

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

- Presenting a summary of the existing air quality relevant to the study area (Air Quality Assessment (ERM 2019)), presented in **Section 4.2**
- Providing a summary of the air quality impact assessment, which provides inputs to the assessment of health impacts (Air Quality Assessment (ERM 2019)) including the study areas considered in the air quality impact assessment for construction and operation, presented in **Sections 4.3 and 4.4**

- Assessment of construction impacts on health, presented in **Section 4.3.** The assessment undertaken for construction impacts is qualitative where potential impacts and the identification of relevant management measures to minimise impacts (including nuisance[1] dust) were evaluated

- Detailed assessment of the potential health impacts from changes in air quality during operations (exposure and potential impacts), presented in **Sections 4.5 to 4.7.** Further discussion on the aspects considered in the quantification of operational impacts on health is provided below

- Outline of the uncertainties within the assessment undertaken in relation to health impacts from air quality (which is key to understanding if the assessment of potential health impacts is conservative, or not) (**Section 4.8** and **Appendix F**).

The assessment of health impacts associated with the operation of the project involves the quantification of health risks and impacts. The assessment has utilised outputs from the air quality modelling that are presented within Air Quality Assessment (ERM 2019). Additional data generated from the air modelling, that is relevant to the characterisation of health risks have also been provided.

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

The quantification of health risks from changes in air quality during operations requires the use of a few different approaches to address the range of air pollutants relevant to this project:

- **Use of health based air guidelines**: For air pollutants where there is a threshold for acute and chronic effects (ie a level below which there are no health impacts), published health based guideline have been identified and used in this assessment. The assessment of health impacts has focused on the maximum impacted locations and compared the predicted concentration of these air pollutants (from the project as well as other sources) with the air guideline. Where the exposure concentration is less than the air guideline, there is no risk. This approach applies to carbon monoxide (discussed further in **Section 4.5**).

- **Calculation of an incremental lifetime cancer risk:** For air pollutants that are considered to be genotoxic carcinogens, there is no threshold. Hence the approach adopted for the assessment of these chemicals is to calculate an incremental lifetime cancer risk, utilising published non-threshold inhalation toxicity reference values (or unit risk values), and an

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

estimation of the maximum increase in air concentration (or exposure) within the community. This results in the calculation of an incremental carcinogenic risk and utilises common risk assessment methods as outlined by enHealth (enHealth 2012b). This approach applies to the assessment diesel particulate matter (discussed further in **Section 4.7**).

- **Calculation of impacts, risks and health burden, for changes in nitrogen dioxide and particulate matter concentrations:** The data available on health impacts from exposure to nitrogen dioxide and particulate matter, particularly within urban air environments, comes from large population or epidemiological studies (discussed further in **Sections 4.6 and 4.7**). These studies enable relationships between exposure and various health effects (specifically mortality [i.e. a shortening of life-span] and morbidity effects). These concentration-response or exposure-response relationships are developed based on large population exposures and are utilised in the assessment of population health, and for establishing ambient (population wide) air guidelines. These relationships are not developed for the assessment of specific sources or localised impacts, as is the case for the assessment of impacts from the project.

  The project involves the construction of new roadway infrastructure that would result in the redistribution of traffic within the community, rather than constructing a new source. As a result, vehicle and truck emissions within the broader community remain much the same which makes the conduct of community or larger population wide assessments of health impacts difficult as the overall health impact is expected to reflect the small change in total vehicle movements. However, as traffic is redistributed at a local level, it is important to also evaluate the potential significance of this redistribution, particularly localised increases in exposure to pollutants with no threshold such as nitrogen dioxide and particulate matter. While this may only affect a small number of households, increases in risk associated with these maximum changes need to be considered.

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

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

  - Calculation of a change in incidence of the health effect occurring within the population or wider community exposed. This calculates the change in the number of cases (mortality or hospitalisations) that may occur for the whole population assumed to be exposed to the changes in nitrogen dioxide or particulate matter concentration estimated.

Acceptable risk levels

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

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

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

The assessment of changes in incidence of particular health indicators in the community results in the calculation of a change in the number of cases (of mortality, hospital or emergency department admissions) within the population evaluated. As discussed in **Appendix C**, where changes in air quality associated with this project are well below 10 cases per year they are considered to be within the normal variability of health statistics, and these changes would not be measurable in any health statistics for the area. For evaluating impacts from this project, a more conservative tenfold margin of safety has been included to determine what changes in incidence may be considered negligible within the study population.

This means that changes in the population incidence of any health effect evaluated that is less than one case per year are considered negligible.

2.3.5 Health impacts from changes in noise

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

Assessment of health impacts from changes in noise associated with the project is presented in **Section 5**. The assessment presented is largely qualitative, with some quantitative assessment included to determine what noise increases are considered to result in unacceptable health impacts.

The approach adopted for the assessment of health impacts from noise and vibration has considered the following (as presented in **Section 5**):

- Understanding of the health impacts related to changes in noise (**Section 5.2**)
- Review of the noise assessment criteria adopted in the Noise and Vibration Assessment (ARUP 2019) to determine if these are protective of health (**Section 5.4**)
- Summary of the noise and vibration impact assessment (presented in the Noise and Vibration Assessment (ARUP 2019)), including the existing noise environment and the study

area considered in the noise and vibration impact assessment (**Section 5.3**), assumptions included in the assessment and outcomes of the assessment (**Section 5.5**)

- What the impacts identified in the noise and vibration impact assessment mean in terms of potential health impacts for construction and operation of the project (**Section 5.5**)
- Outline of the uncertainties within the assessment undertaken in relation to health impacts from noise (which is key to understanding if the assessment of potential health impacts is conservative, or not) (**Section 5.6 and Appendix F**).

2.4 Limitations and considerations

There are certain features of health risk assessment methodology important to acknowledge in the development of any assessment. These relate to the limitations of the methodology and the constraints applied within the health risk assessment to ensure a focus on aspects that can be influenced as part of the project. These are summarised below (also refer to **Appendix F** for discussion of uncertainties):

- A health risk assessment is a systematic tool used to review key aspects of a specific project that may affect the health of the local community. The assessment includes both qualitative and quantitative assessment methods.
- Where quantitative assessment methods are presented, a health risk assessment is typically based on a conservative estimate of impacts in the local community and thus is expected to overestimate the risks for all members of the community.
- A health risk assessment involves a number of aspects where a qualitative assessment is required to be undertaken. Where this is undertaken, it provides a general indication of potential benefits or impacts only.
- The community evaluated in a health risk assessment is limited by the extent of the studies undertaken in informing an EIS. It is not possible to evaluate impacts on the health of the community outside these areas.
- A health risk assessment relies on data provided from other studies prepared for an EIS (as listed in **Section 1.2**). The conclusions of this health impact assessment, therefore, depends on the assumptions and calculations undertaken to generate the data from these other studies utilised in this assessment.
- Conclusions can only be drawn with respect to impacts related to a project as outlined in an EIS. Other health issues, not related to the project, that may be of significance to the local community are not addressed in the health risk assessment.
- The health risk assessment for this project did not address occupational health for construction workers.
- The health risk assessment reflects the current state of knowledge regarding the potential health effects of identified chemicals and pollutants for this project. This knowledge base

may change as more insight into biological processes is gained, further studies are undertaken, and more detailed and critical review of information is conducted.

Section 3. Community profile

3.1 General

This section summarises the demographics and existing health of the community potentially impacted by the project. While the key focus of the assessment was the local community surrounding the project, some aspects of the assessment required consideration of statistics derived from larger populations, such as those within larger Local Government Areas (LGAs), regional NSW and NSW as a whole. Where relevant, information related to both the local community and other larger areas within NSW are presented.

The project would pass through an existing rural and semi-rural landscape in the area located to the west of Coffs Harbour. The project sits to the west of industrial and outer urban areas of Coffs Harbour, as well as the proposed urban growth areas in the local area (as shown on **Figure 3.1**).

The project sits within the LGA of Coffs Harbour (refer to **Figure 3.1**) and also within the northern end of the Mid North Coast Local Health District.

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

- Community groups:
  - Residents
  - Recreational users (such as cyclists and users of recreational open space)
  - Commercial and industrial (e.g. businesses within the project area that may be directly impacted by property acquisitions)
- Sensitive and vulnerable groups within the community groups:
  - Young children (in particular children under the age of 5 years, but also including children up to 14 years)
  - Older populations (>65 years of age)
  - Disabled and those with pre-existing medical conditions
  - Disadvantaged (socio-economically disadvantaged).

These receptors may reside or access any areas within the community. The assessment of air quality impacts has addresses impacts over a large grid, as well as specific receptors within the community. In addition, the noise assessment has considered specific receptors close to the proposed project. These receptors have included sensitive receptors.

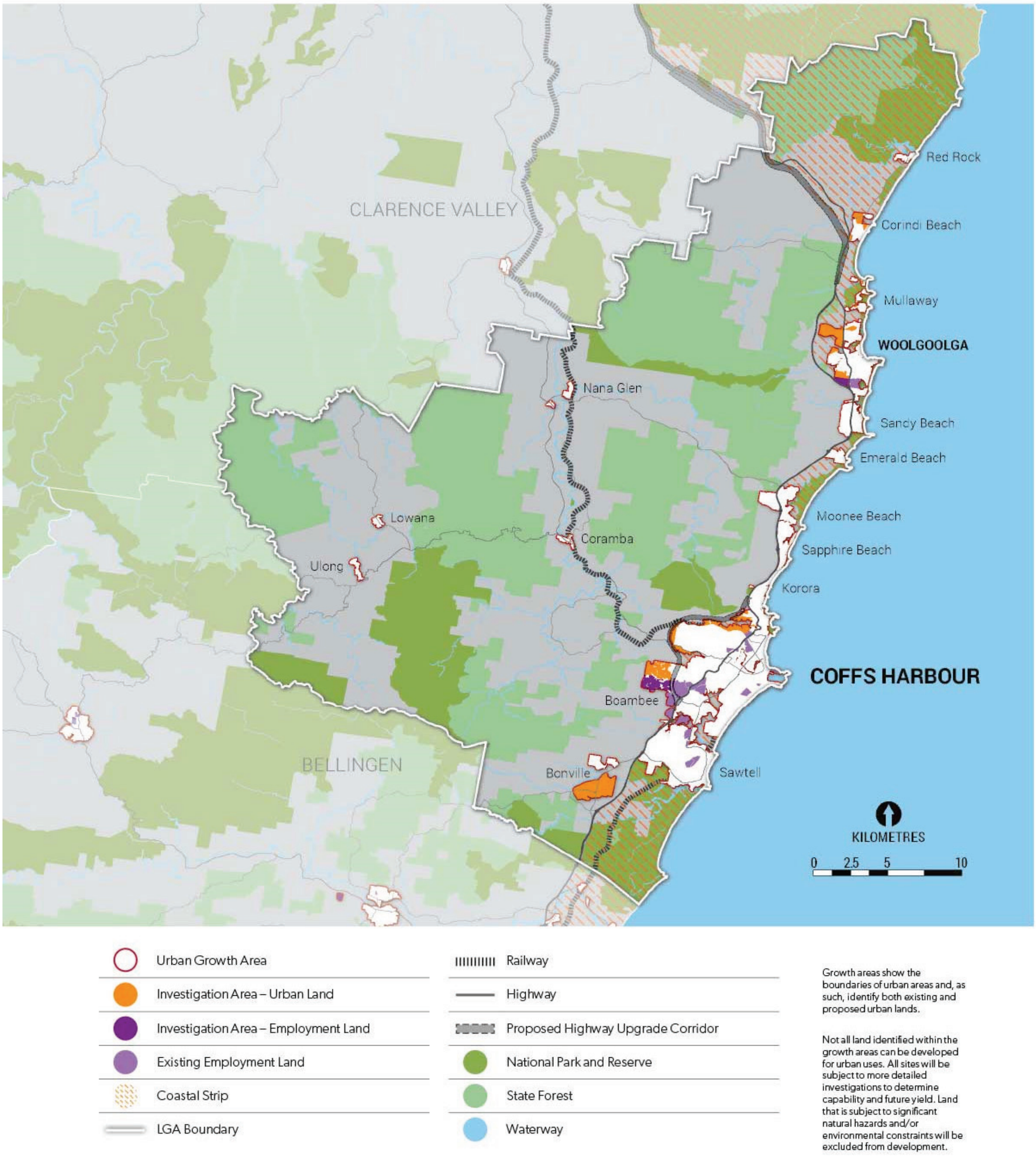


Figure 3.1: Coffs Harbour LGA and urban growth area (from NSW Planning and Environment[2])

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[2] https://www.planning.nsw.gov.au/Plans-for-your-area/Regional-Plans/North-Coast/North-Coast-Regional-Plan/Local-government-narratives-and-urban-growth-area-maps

3.2 Population profile

Population statistics for the suburb/town of Coffs Harbour and local government areas within the study area are available from the Australian Bureau of Statistics for the census year 2016 and are summarised in **Table 3.1**. The composition of the populations located adjacent to the proposed project is expected to be generally consistent with population statistics for the town and LGA of Coffs Harbour. For the purpose of comparison, the population statistics presented also include the larger regional areas of NSW (excluding Sydney Metropolitan areas).

Table 3.1: Population statistics

Location	Population		% Population by key age groups					
	Male	Female	0–4	5–19	20–64	65+*	1–14*	30+*
Suburb/Town								
Coffs Harbour	12,223	13,529	5.5	17.9	54.3	22.3	16.4	64.5
Larger local statistical areas (Local Government Area – includes suburb/town as above)								
Coffs Harbour	35,319	37,629	5.6	18.7	54.7	21.1	17.3	65.5
Statistical areas of NSW								
NSW (excluding Greater Sydney)	1,301,717	1,341,813	5.8	18.5	55.1	20.6	17.3	64.6

Ref: Australian Bureau of Statistics, Census Data 2016

* Age groups specifically relevant to the characterisation of risk in the health impact assessment

Based on this general population data, the population on the area of Coffs Harbour is broadly similar to the LGA and regional NSW. The exception being a slightly lower percentage of children aged 1-14 years and slightly higher percentage of people aged 65 years and older.

In relation to potential future growth of the area, NSW Planning and Environment[3] projects an 18.1 to 26.9 percent increase in population between 2016 and 2036 in the Coffs Harbour LGA

Table 3.2 summarises a selected range of demographic measures relevant to the population of interest with comparison against the larger population areas. This includes the Index of Relative Socio-economic Disadvantage, which is an index that summarises a range of information about the economic and social conditions of people and households in an area. The index uses 5 quintiles (ranging from 1 to 5, with each decile representing 20% of the index range), with a low score or quintile indicating a relatively greater disadvantage (for example, many households with low income, many people with no qualifications) and a high score indicating a general relative lack of disadvantage.

[3] https://www.planning.nsw.gov.au/Research-and-Demography/Demography/Population-projections

Table 3.2: Selected demographics of population of interest

Location	Median age	Median household income ($/week)	Median mortgage repayment ($/month)	Median rent ($/week)	Average household size	Unemployment rate (%)	Index of Relative Socio-economic Disadvantage (quintile)*
State suburbs/Town							
Coffs Harbour	43	1019	1555	295	2.3	7.7	1
Larger local statistical areas (Local Government Areas – includes state suburb/Town as above)							
Coffs Harbour	44	1107	1603	305	2.4	7.3	3
Statistical areas of NSW							
NSW (excluding Greater Sydney)	43	1,168	1,590	270	2.4	6.6	--

Source: Australian Bureau of Statistics, Census Data 2016

* Quintile ranges from 1 which is most disadvantaged to 5 which is the least disadvantaged

Coffs Harbour suburb or town has a low ranking, meaning it is considered most disadvantaged and the population in this area may be more sensitive to health impacts related to the project. When considering the larger LGA, the index suggests a less disadvantaged population, more representative of a state average.

3.3 Existing health of population

3.3.1 General

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

When considering the health of a local community there are a large number of factors to consider. The health of the community is influenced by a complex range of interacting factors including age, socio-economic status, social networks, behaviours, beliefs and lifestyle, life experiences, country of origin, genetic predisposition and access to health and social care. Hence, while it is possible to review existing health statistics for the local areas surrounding the project and compare them to the NSW, it is not possible or appropriate to be able to identify a causal source, particularly individual or localised sources.

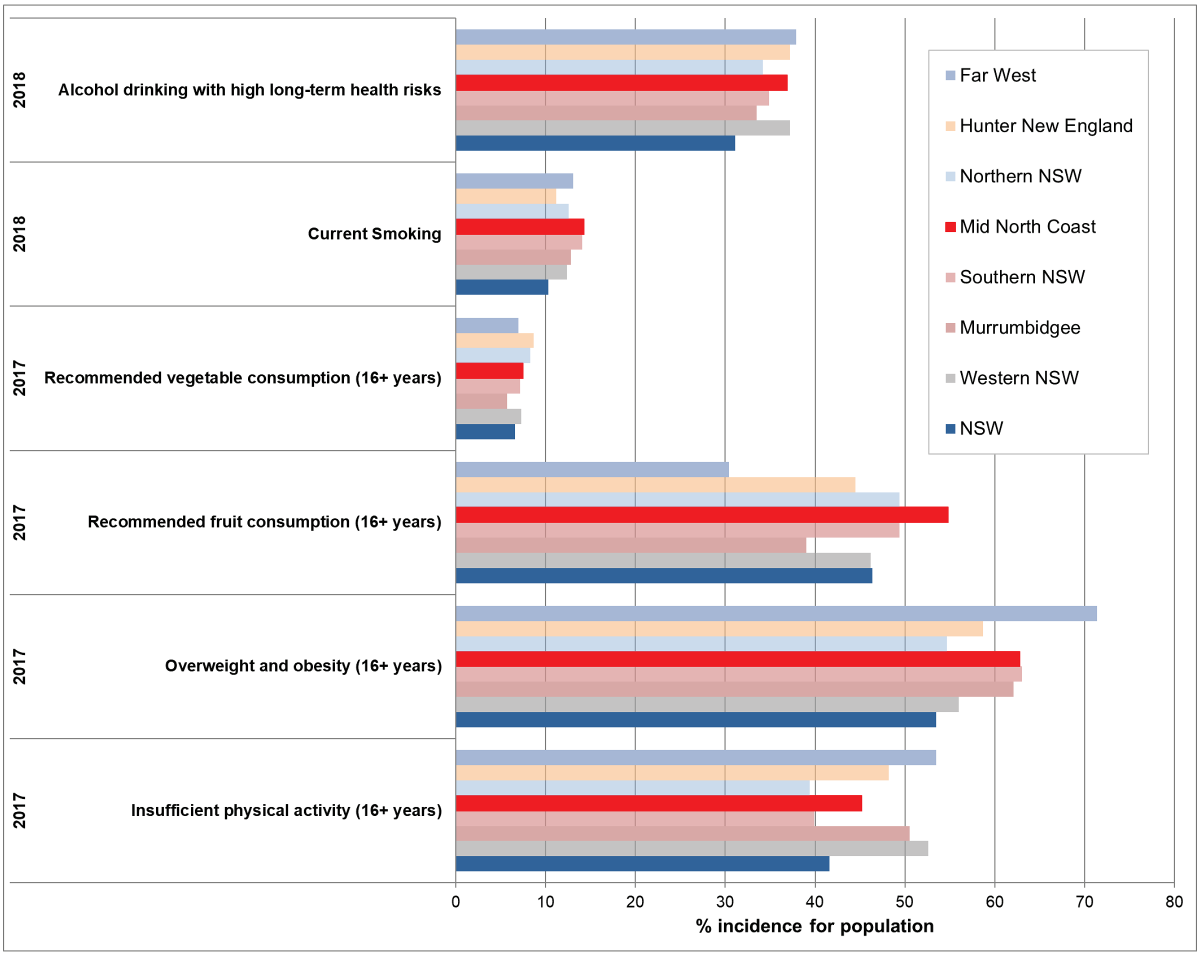
Information relevant to the health of populations in NSW is available from NSW Health for populations grouped by local health districts (where the project area is located in the Mid North Coast Local Health District). Not all of the health data is available for all of these areas.

Most of the health indicators presented in this report are not available for each of the smaller suburbs/statistical areas surrounding the site.

3.3.2 Health-related behaviours

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

Information in relation to health related behaviours is available for the larger populations within the local health districts in Sydney and NSW. This includes risky alcohol drinking, smoking, consumption of fruit and vegetables, being overweight or obese, and adequate physical activity. The study population is located within the Mid North Coast Local Health District. The incidence of these health-related behaviours in the Mid North Coast district, compared with other regional districts in NSW, and all of NSW (based on NSW Health data from 2017 and 2018) is illustrated in **Figure 3.2.**



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

Figure 3.2: Summary of incidence of health-related behaviours (Source: HealthStats NSW 2019)

Review of this data indicates the population in the Mid North Coast Local Health District (that includes the study area) have higher rates of long-term risk alcohol consumption, smoking, insufficient physical exercise, overweight and obesity as well as higher rates of adequate fruit and vegetable intakes compared with NSW.

3.3.3 Health indicators

Figure 3.3 presents a comparison of the rates of the key mortality indicators based on data from 2014-2016 (depending on the available data) for all causes, potentially avoidable, cardiovascular disease, respiratory disease and chronic obstructive pulmonary disease (COPD), reported in the larger Mid North Coast Local Health District, with comparison to other regional NSW local health districts as well as NSW as a whole.

Figure 3.4 present a comparison of the rates of the hospitalisations for key health effects based on data from 2016-2017 for diabetes, cardiovascular disease, asthma (5–34 years) and COPD (65+ years) reported in the larger Mid North Coast Local Health District, with comparison to other regional NSW local health districts as well as NSW as a whole.

It is noted that the data reported in these figures is based on statistics that are publicly available from NSW Health. Hence some of the statistics for mortality and hospitalisations relate to slightly different health endpoints and/or different age groups. The statistics are included for general comparison and discussion. Actual health statistics considered in the characterisation of risk are presented in **Table 3.3**.

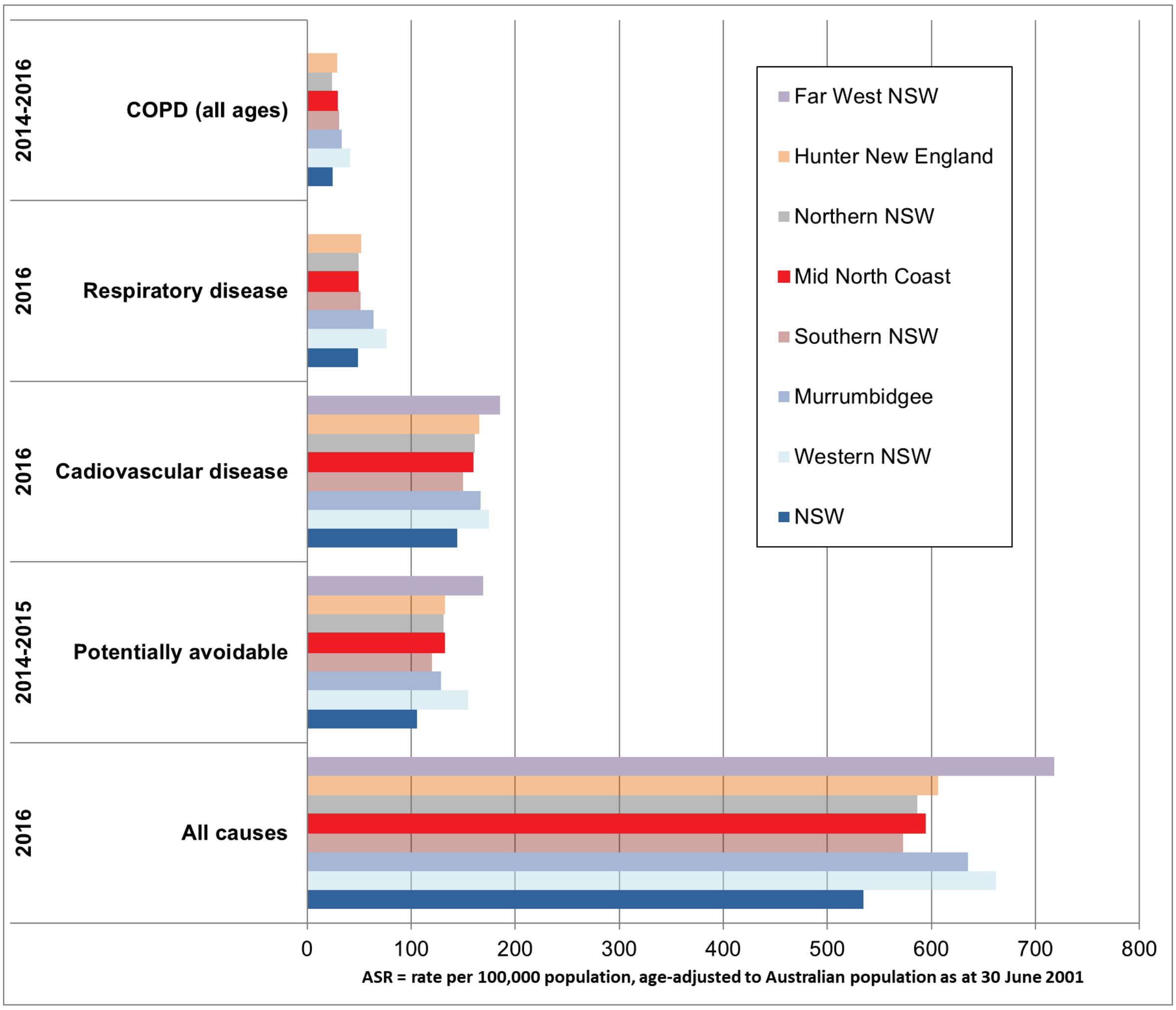


Figure 3.3: Summary of mortality data 2014 - 2016 (Source: HealthStats NSW 2019)

Review of the figure presented above indicate that the rate of mortality for the indicators presented in the Mid North Coast Local Health District are similar to NSW for respiratory disease, including COPD, but higher for cardiovascular disease and all causes.

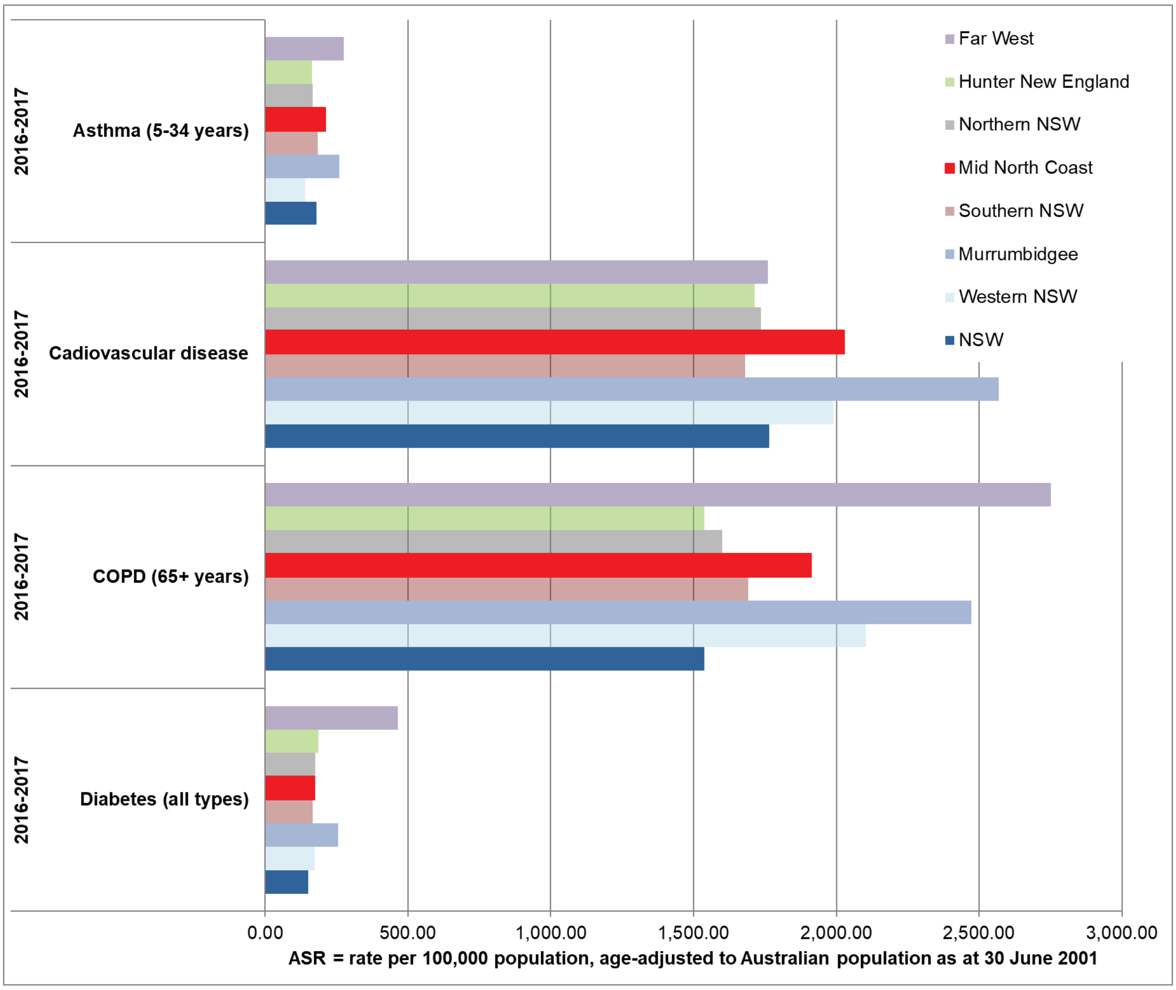


Figure 3.4: Summary of hospitalisation data 2016-2017 (Source: HealthStats NSW 2019)

Review of the figure presented above indicate that the rate of hospitalisations for the indicators presented in the Mid North Coast Local Health District is similar to NSW for diabetes and asthma but higher than NSW for cardiovascular disease and COPD.

Table 3.3: Summary of key health indicators

Health indicator	Data available for population areas (rate per 100,000 population)			
	Coffs Harbour LGA	Mid North Coast LHD	Tamworth (Sydney)*	NSW
Mortality				
All causes – all ages	**555.5** [C]	594.3 [C]	--	537.7 [C]
All causes (non-trauma) ≥30 years	--	--	1322 (976.5)	--
All causes ≥30 years	--	--	**1333 (1026)**	--
Cardiopulmonary ≥30 years	--	--	**368 (412)**	
Cardiovascular – all ages	**154.1** [C]	159.6 [C]	--	144.6 [C]
Respiratory – all ages	--	**48.7**[C]	61 (51.5)	49.1 [C]
Hospitalisations				
Coronary heart disease	505.9 [B]	494.7 [E]	--	495.4 [E]
COPD All ages	322.8 [B]	295.7 [E]	--	236.7 [E]
Cardiovascular disease				
All ages	1927.1 [B]	1840.5 [E]	--	1671.1 [E]
>65 years	--	--	**10512 (9235)**	

Health indicator	Data available for population areas (rate per 100,000 population)			
Respiratory disease				
All ages	--	1684.2 [E]	--	1714.2 [E]
>65 years	--	--	**4180 (3978)**	
Asthma				
Asthma hospitalisations (ages 5–34 years)	--	172.8 [E]	--	138.6 [E]
Asthma emergency department hospitalisations (1–14 years)	--	--	**-- (1209)**	--
Asthma prevalence (current) for children aged 2–15 years	--	12.7% [D]	--	12.9% [D]
Current asthma for ages 16 and over	--	13.3% [D]	--	10.9% [D]

* Data for Tamworth (rural area addressed that is in the northern NSW area) and Sydney Metropolitan area for 2010 based on hospital statistics as reported for 2010 and population data from the ABS for 2011 (relevant to each age group considered) used in review of exposure and risks to inform recommendations for updating the National Environment Protection Measure (NEPM) Ambient Air Quality (AAQ) (Golder 2013)
All other data has been obtained from Health Statistics New South Wales, where: A: 2014–2016 data B: 2016-17 to 2018-18 data C: 2015-2016 or 2016 data D: 2016-2017 or 2017 data E: 2017-2018 data
-- No data available Bold and shaded: Data used in the characterisation

3.4 Overview of existing community and health

Overall, the demography and health of the broader community in the study area is generally somewhat lower (poorer) than NSW in general and Sydney (where compared). It is expected that, at a broad scale, given the general health of this community the population may be more sensitive to changes in air quality and noise that may occur over a period of less than a year to a number of years (such as would occur during construction) as well as operations. However, there may be health benefits from the long-term redistribution of transport, and transport related emissions related to the operation of the project.

Section 4. Assessment of air quality impacts on health

4.1 Introduction

This section assesses the potential for changes in air quality due to the project and how these changes might impact health within the community. This assessment has drawn on information provided in the Air Quality Assessment (ERM 2019) and, in some areas, provides a summary of key (and relevant) aspects. All details relevant to the underlying assumptions, methodology and interpretation of impacts relevant to the data provided in relation to changes in air quality are provided within the Air Quality Assessment (ERM 2019).

The characterisation of health impacts from changes in air quality as a result of the project is complex and has been undertaken in accordance with the methodology outlined in **Section 2.3**.

4.2 Existing air quality

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

The project area is coastal and is expected to be located to the west of an existing built up area (outer suburban and industrial areas of Coffs Harbour), which will include a range of local sources of various pollutants. While local meteorological data is available from Coffs Harbour, existing air quality data is not available for this area. Hence the Air Quality Assessment (ERM 2019) has utilised data from other regional areas such as Albion Park South and Newcastle.

4.3 Overview of air quality assessment: Construction

4.3.1 Air quality impacts

The Air Quality Assessment (ERM 2019) evaluated impacts on air that may occur during construction. The assessment considered impacts that may occur during various surface works and involved a semi quantitative assessment approach, focusing on emissions to air of dust. This approach has been summarised with the outcomes reviewed in terms of potential impacts to human health.

The assessment identified the range of activities during construction (during demolition, earthworks, construction and track-out works), potential emissions from these activities and the location of these activities in relation to sensitive receptors. **Figure 4.1** illustrates the location of the sensitive receptors considered during construction works.

Figure 4.1: Receptors evaluated for construction air quality impacts (ERM 2019)

It is noted that for demolition activities, the *Work Health and Safety Regulation 2011* (NSW) requires that all hazardous materials are properly removed from buildings prior to any demolition works occurring. This is to prevent workers and the public from being exposed these materials and contaminants during the demolition and other construction works. Hence there is no need to further assess the presence of hazardous building materials during construction activities.

This approach then allocated a risk associated with the generation of dust and impacts on human health in the adjacent community. This approach considered the proximity to the source area and the number and type of receptors present. Impacts associated with nuisance dust, health impacts on the community were evaluated. For all demolition, earthworks, construction and track-out activities, where no mitigation measures are implemented, the risk of impacts on human health were evaluated and considered in terms of the location of sensitive receptors.

The sensitivity of human receptors in all areas evaluated, relevant to all activities evaluated, was determined to be "High". In relation to the risk ranking relevant to the impact of dust during construction on human health, this was determined to be "High Risk".

On this basis, appropriate mitigation measures are required to minimise impacts on the local community (including Commonwealth Land) during construction.

4.3.2 Dust mitigation and health impacts

For almost all construction activities, the aim should be to prevent significant impacts on receptors through the use of effective mitigation, to be outlined in an Air Quality Management Plan. Experience from similar construction projects shows that this is normally possible. Hence, where mitigation measures are appropriately implemented, the assessment of construction dust impacts presented in the Air Quality Assessment (ERM 2019) concluded that the residual risk level would normally be "not significant".

However, even with a rigorous Air Quality Management Plan in place, it is not possible to guarantee that the dust mitigation measures would be effective all the time. There is the risk that nearby residences, commercial buildings, hotel, cafés and schools in the immediate vicinity of a construction zone might experience some occasional dust soiling impacts. This does not imply that impacts are likely, or that if they do 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 only arise during dry weather with the wind blowing towards a receptor, at a time when dust is being generated and mitigation measures are not being fully effective. The likely scale of this would not normally be considered sufficient to change the conclusion that with mitigation the effects would be 'not significant'.

The Air Quality Management Plan would be produced and implemented to cover all construction stages of the project. These measures include site management, monitoring, preparing and maintaining the construction sites, maintenance and controls on vehicles and machinery and construction.

Where the above are implemented, the potential for health impacts to occur as a result of dust generated during construction is considered to be low. This assessment outcome does not preclude the deposition of nuisance dust (ie large dust particles) during the works or the presence of short-duration noticeable dust during some works.

4.4 Overview of air quality assessment: Operations

The assessment of changes in air quality associated with the operation of the project has been undertaken on the basis of the road traffic emissions related to the project. Emissions from vehicles travelling on surface roads have been estimated on the basis of an NSW EPA emissions model and predictions on traffic volumes and composition provided by ARUP, based on the Coffs Harbour Strategic Transport Model for the base year 2016.

The project includes a number of short tunnels through ridges at Roberts Hill (around 190 metres long), Shephards Land (around 360 metres long) and Gatelys Road (around 450 metres long). These tunnels are short and designed to have portal emissions. Emissions from these portals, at either end in the direction of travel, are estimated based on traffic volumes and speeds during different hours of the day to provide an exit velocity from each portal.

Emissions from the project were modelled using a Graz Lagrangian (GRAL) dispersion model over a project area as illustrated in **Figure 2.1**, utilising terrain and meteorological data for the larger area (GRAMM area as illustrated on **Figure 2.1**). Air quality impacts were modelled within the GRAL area over a grid with a 10 metre spacing. In addition, a large number of individual receptors were considered within the modelled area, which included schools and residences, as shown in **Figure 4.2**.

Based on the assessment undertaken by ERM (2019) the following was concluded:

- Contributions of vehicle emissions to ambient air quality are historically low, and although these may increase in the immediate vicinity of the bypass, they are predicted to remain well below the relevant air quality criteria.
- Concentrations are predicted to reduce in 2036 due to estimated improvements in fuel efficiency.
- Concentrations will be reduced along the existing Pacific Highway with the project, as through traffic is diverted to the bypass.
- There will be some localised increase in concentrations along the project, where previously roads did not exist, however, these increases are not predicted to result in any exceedance of the air quality standards.
- The largest increases are at the portal exits which is expected due to more concentrated emissions as traffic exits each tunnel. These are dispersed relatively quickly with concentrations reduced significantly within a short distance from each portal.
- There is no requirement for management measures for the operation of the project

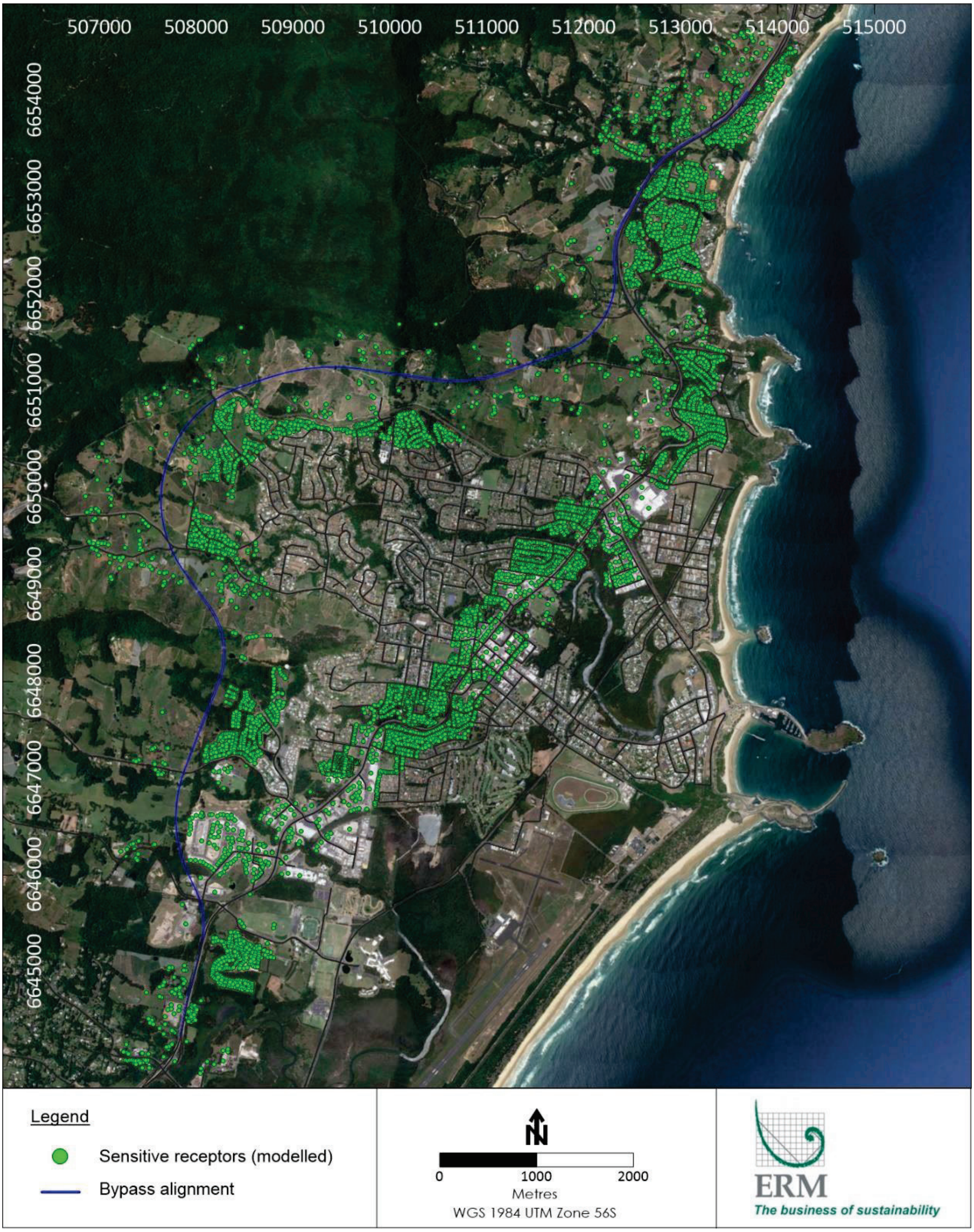


Figure 4.2: Modelled sensitive receptors in Air Quality Assessment (ERM 2019)

4.5 Assessment of health impacts – carbon monoxide

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

Guidelines are available from the NEPC (as standards) (NEPC 2016) that are based on the protection of adverse health effects associated with carbon monoxide. The air standards currently available from NEPC are consistent with health based guidelines currently available from the WHO (WHO 2005, 2010) and the USEPA (2011[4], specifically listed to be protective of exposures by sensitive populations including asthmatics, children and the elderly). On this basis, the current NEPC standards are considered appropriate for the assessment of potential health impacts associated with the project.

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

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

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

Table 4.1 summarises the maximum predicted cumulative (ie project plus background) 1-hour average and 8-hour average concentrations of carbon monoxide for the assessment years 2024 and 2034.

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

Table 4.1: Review of potential acute and chronic health impacts – carbon monoxide (CO)

Scenario	Maximum 1-hour average concentration of CO (mg/m^3)		Maximum 8-hour average concentration of CO (mg/m^3)	
	No project	With project	No project	With project
2024: all receptors	4.3	4.1	3.5	3.3
2034: all receptors	4.5	4.1	3.3	3.3
Relevant health based standard/ guideline	30		10	

All the concentrations of carbon monoxide presented in **Table 4.1** are below the relevant health based standards/guidelines listed at the base of the table. The redistribution of traffic on surface roads results in a reduction in carbon monoxide exposures due to the project compared to the "no build" scenarios.

The project would not change the existing health outcomes in relation to exposures in the community to carbon monoxide, either adversely or beneficially. The changes due to the project are not significant. No adverse health effects are expected in relation to exposures (acute and chronic) to carbon monoxide in the local area surrounding the project.

4.6 Assessment of health impacts – nitrogen dioxide

4.6.1 Approach

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

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

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

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

- Whether the evidence suggests that associations between exposure to nitrogen dioxide concentrations and effects on health are causal. The most current review undertaken by the USEPA (USEPA 2015) specifically evaluated evidence of causation. The review identified that a causal relationship existed for respiratory effects (for short-term exposure with long-term exposures also likely to be causal). All other associations related to exposure to nitrogen dioxide (specifically cardiovascular effects, mortality and cancer) were considered to be suggestive
- Whether the reported associations are distinct from, and additional to, those reported and assessed for exposure to particulate matter. Co-exposures to nitrogen dioxide and particulate matter complicates review and assessment of many of the epidemiology studies as both these air pollutants occur together in urban areas. There is sufficient evidence (epidemiological and mechanistic) to suggest that some of the health effect associations identified relate to exposure to nitrogen dioxide after adjustment/correction for co-exposures with particulate matter (COMEAP 2015)
- Whether the assessment of potential health effects associated with exposure to different levels of nitrogen dioxide can be undertaken on the basis of existing guidelines, or whether specific risk calculations are required to be undertaken. The current guidelines in Australia for the assessment of nitrogen dioxide in air relate to cumulative (total) exposures, and adopt criteria that are considered to be protective of short and long term exposures. It is thus relevant that these guidelines be considered in this assessment
- In addition, the current standards relate to regional air quality, not localised sources and hence use of such standards for the assessment of localised exposures is of limited value.

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

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

4.6.2 Assessment of cumulative exposures

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

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

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

Table 4.2 summarises the maximum predicted cumulative 1-hour average and annual average concentrations of nitrogen dioxide for 2024 and 2034.

Table 4.2: Review of potential acute and chronic health impacts – nitrogen dioxide (NO_2)

Scenario	Maximum total 1-hour average concentration of NO_2 ($\mu g/m^3$)		Maximum total annual average concentration of NO_2 ($\mu g/m^3$)	
Maximum from all receptors	**No project**	**With project**	**No project**	**With project**
2024: all receptors	173	172	17.2	15.3
2034: all receptors	171	166	15.4	14.1
Relevant health based standard	246		62	

All the concentrations of nitrogen dioxide presented in **Table 4.2** are below the relevant health based standards/guidelines listed at the base of the table. For the project scenario, the maximum concentrations of nitrogen dioxide are slightly lower than the no build scenario.

The redistribution of traffic on surface roads results in a number of areas where there will be a reduction in nitrogen dioxide exposures due to the project, and others where there is estimated to be an increase in nitrogen dioxide exposures compared to the "no build" scenarios. To further address potential risks to human health that may be associated with population exposures and localised changes in nitrogen dioxide that relate to the project, incremental risk calculations have been undertaken and are presented in **Section 4.6.3**.

4.6.3 Assessment of incremental exposures

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

Appendices A and D presents the methodology adopted for the calculation of an incremental risk, including the concentration-response functions adopted for the quantification of the key health endpoints evaluated, which include:

- Mortality all causes (all ages);
- Respiratory mortality (all ages); and
- Asthma emergency department admissions (children aged 1-14 years).

Table 4.3 presents the change in localised risk associated with changes in nitrogen dioxide at the maximum impacted receptors relevant to the various land use in the community, for the years 2024 and 2034.

The assessment assumes an individual, at a specific location, is exposed at each maximum impacted location over all hours of the day, regardless of the land use. This has been undertaken to address any future changes in land use that may occur. Risks for all other receptors (including other sensitive receptors) are lower than the maximums presented.

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

Appendix C presents a discussion on levels of the levels of risk that are considered to be negligible, tolerable/acceptable and unacceptable. A summary of these risk levels is included in **Table 4.3**.

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

Table 4.3: Maximum calculated risks associated with exposure to changes in nitrogen dioxide concentrations with operation of the project

Scenario and receptor	Maximum change in localised risk from exposure to nitrogen dioxide for the following health endpoints		
	Mortality: All causes (all ages)	Mortality: Respiratory (all ages)	Asthma ED Admissions (1–14 years)
2024 – with project			
Maximum from all receptors	7E-05	1E-05	9E-05
Maximum residential	6E-05	1E-05	9E-05
Maximum workplace	4E-05	7E-06	5E-05
Maximum childcare and schools	5E-05	1E-05	7E-05
Maximum aged care	2E-05	4E-06	3E-05
Maximum hospitals/medical	5E-07	1E-07	7E-07
Maximum open space	7E-05	1E-05	9E-05
2034 – with project			
Maximum from all receptors	6E-05	1E-05	8E-05
Maximum residential	6E-05	1E-05	8E-05
Maximum workplace	3E-05	7E-06	5E-05
Maximum childcare and schools	4E-05	9E-06	6E-05
Maximum aged care	2E-05	4E-06	3E-05
Maximum hospitals/medical	1E-06	2E-07	2E-06
Maximum open space	6E-05	1E-05	8E-05

Negligible risks	$<1 \times 10^{-6}$
Tolerable/acceptable risks	$\geq 1 \times 10^{-6}$ and $\leq 1 \times 10^{-4}$
Unacceptable risks	$>1 \times 10^{-4}$

The population in the project area is small and hence the calculation of a population incidence (ie change in the number of cases relevant to the health endpoints evaluated) is not vary meaningful. Regardless the potential population risk and incidence has been calculated for the whole population in the study area, where the following was calculated:

- Mortality all causes (all ages):
  - Increased population risk = 5×10^{-6} (2024 and 2034)
  - Increased population incidence (cases per year) = 0.03 (2024 and 2034)
- Respiratory mortality (all ages):
  - Increased population risk = 9×10^{-7} (2024 and 2034)
  - Increased population incidence (cases per year) = 0.005 (2024 and 2034)
- Asthma ED admissions (children aged 1-14 years)
  - Increased population risk = 6×10^{-6} (2024 and 2034)
  - Increased population incidence (cases per year) = 0.006 (2024 and 2034)

Review of **Table 4.3** and the discussion above indicates the following:

- The maximum localised impacts as a result of the redistribution of surface road traffic result in risks that are within the range considered to be acceptable for all land use areas evaluated in the community surrounding the project.

  It is noted that there are some areas where exposures to NO_2 will be lower, particularly adjacent to the existing Pacific Highway as traffic is diverted onto the bypass. Where this occurs there are potential health benefits, with the maximum decrease in risk being 5 x 10^{-5} for 2034 and 3 x 10^{-5} for 2034.

- Where the population is considered more broadly, the population risk is lower than the maximum localised risk, and remains acceptable. The potential population incidence relevant to the health endpoints evaluated is very low and considered to be negligible (ie not measurable in the community).

> Overall, calculated risks (for all health endpoints considered) associated with changes in nitrogen dioxide levels in the community from the project are considered acceptable. The impact of the changes in nitrogen dioxide concentrations on the health of the population (as a population incidence as presented) is very low and would not be measurable within the community.

4.7 Assessment of health impacts – particulates

4.7.1 Particle size

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

Numerous epidemiological studies[5] have reported significant positive associations between particulate air pollution and adverse health outcomes, particularly mortality as well as a range of adverse cardiovascular and respiratory effects.

[5] Epidemiology is the study of diseases in populations. Epidemiological evidence can only show that this risk factor is associated (correlated) with a higher incidence of disease in the population exposed to that risk factor. The higher the

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

- Total suspended particulates (TSP): This refers to all particulates with an equivalent aerodynamic particle[6] size below approximately 50 microns in diameter[7]. It is a fairly gross indicator of the presence of dust with a wide range of sizes. Larger particles (termed 'inspirable', comprise particles around 10 microns and larger) are more of a nuisance as they would deposit out of the air (measured as deposited dust) close to the source and, if inhaled, are mostly trapped in the upper respiratory system[8] and do not reach the lungs. Finer particles (smaller than 10 microns, termed 'respirable') tend to be transported further from the source and are of more concern with respect to human health as these particles can penetrate into the lungs (see following point). Not all of the dust characterised as total suspended particulates is thus relevant for the assessment of health impacts, and total suspended particulates as a measure of impact, has not been further evaluated in this assessment. The assessment has only focused on particulates of a size where significant associations have been identified between exposure and adverse health effects.

- PM_{10} (particulate matter below 10 microns in diameter, µm), $PM_{2.5}$ (particulate matter below 2.5 µm in diameter) and PM_1 (particulate matter below one µm in diameter, often termed very fine particles) and ultrafines (particulate matter below 0.1 µm in diameter), as illustrated in **Figure 4.3.** These particles are small and have the potential to penetrate beyond the body's natural clearance mechanisms of cilia and mucous in the nose and upper respiratory

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correlation the more certain the association. Causation (i.e. that a specific risk factor actually causes a disease) cannot be proven with only epidemiological studies. For causation to be determined a range of other studies need to be considered in conjunction with the epidemiology studies.

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

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

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

system, with smaller particles able to further penetrate into the lower respiratory tract[9] and lungs. Once in the lungs adverse health effects may result (OEHHA 2002).

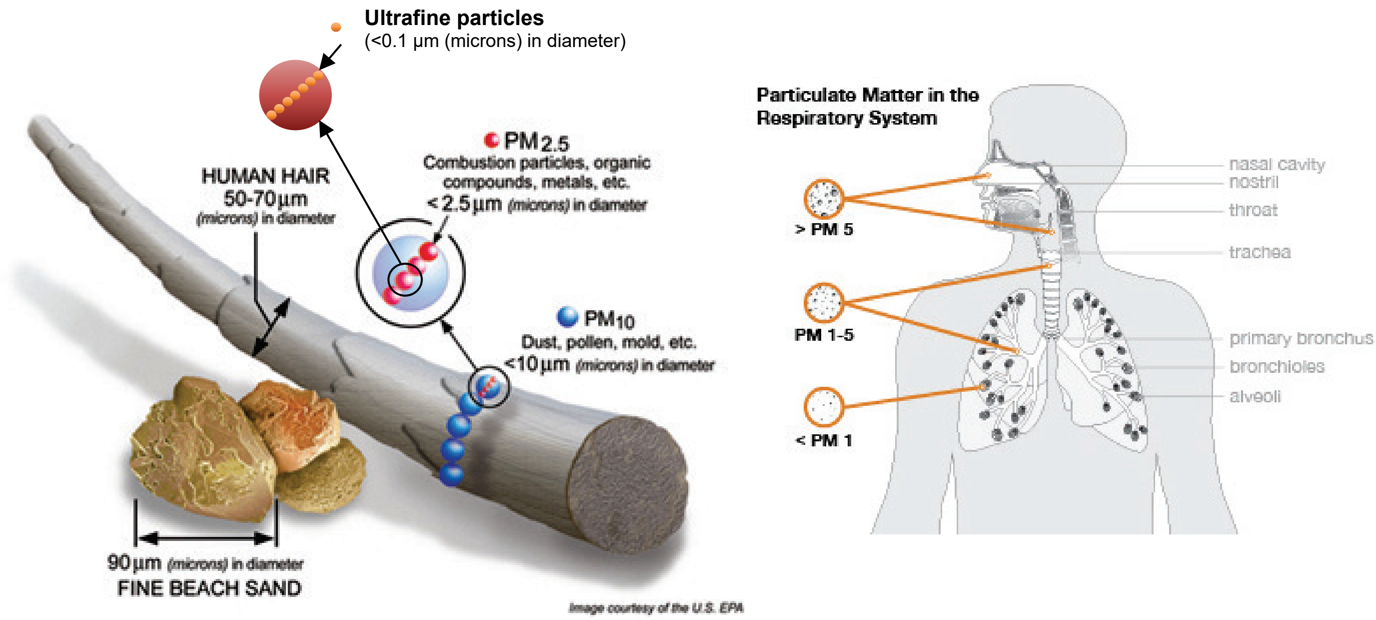

Figure 4.3: Illustrative representation of particle sizes and penetration into the lungs

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

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

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

4.7.2 Health effects

Adverse health effects associated with exposure to particulate matter have been well studied and reviewed by Australian and International agencies. Most of the studies and reviews have focused on population-based epidemiological studies in large urban areas in North America, Europe and Australia, where there have been clear associations determined between health effects and exposure to $PM_{2.5}$ and to a lesser extent, PM_{10}. These studies are complemented by findings from other key investigations conducted in relation to: the characteristics of inhaled particles; deposition and clearance of particles in the respiratory tract; animal and cellular toxicity studies; and studies on inhalation toxicity by human volunteers (NEPC 2010).

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

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

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

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

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

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

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

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

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

4.7.3 Approach to the assessment of particulate exposures

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

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

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

This assessment has therefore been undertaken to consider both cumulative exposure impacts (refer to **Section 4.7.4**) and incremental exposure impacts associated with changes in $PM_{2.5}$ and PM_{10} concentrations that are associated with the project (refer to **Section 4.7.5**). Incremental changes are those due to the project alone while cumulative changes are those where background air quality in addition to those due to the project alone are considered.

4.7.4 Assessment of cumulative exposures

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

The air quality standards and goals for $PM_{2.5}$ and PM_{10} relate to total concentrations in the air (from all sources including the project). The background air quality data used in this project is outlined in the Air Quality Assessment (ERM 2019). The background data includes a contribution of PM that is derived from vehicles that utilise the existing road network, but is not a background for properties adjacent to existing major roadways. Use of this background data would result in some double counting of the contribution of vehicle emissions to air quality in the local area, as the project has assumed emissions from vehicles using the project (or changes in surface road vehicles) are in addition to those currently using roads in the local area. This is a conservative approach.

Table 4.4 summarises the maximum 24-hour average and annual average concentrations of $PM_{2.5}$ and PM_{10} relevant to the assessment of emissions in 2024 and 2034.

Table 4.4: Review of cumulative PM concentrations

Location and scenario	Maximum 24-hour average concentration (µg/m³)				Maximum annual average concentration (µg/m³)			
	$PM_{2.5}$		PM_{10}		$PM_{2.5}$		PM_{10}	
	No project	With Project	No project	With Project	No project	With Project	No project	With Project
2024: All receptors	19.4	18.9	43.3	42.8	8.1	7.8	16.3	16.0
2034: All receptors	19.2	18.9	43.1	42.8	8.1	7.9	16.3	16.1
Standards and goals	**25 (20 as goal for 2025)**		**50**		**8 (7 as goal by 2025)**		**25**	

Review of **Table 4.4** indicates:

- The maximum total/cumulative concentrations of $PM_{2.5}$ from the project are above the relevant standard and goal for an annual average, regardless of the project. This is due to existing levels (i.e. background levels) of $PM_{2.5}$ assumed to be present in the environment.
- The maximum cumulative 24-hour average concentration of $PM_{2.5}$ and PM_{10} and annual average concentrations of PM_{10} from the project are below the relevant standards.
- With the project there is a small decrease in total concentrations of $PM_{2.5}$ and PM_{10} within the local area.

Changes that occur as a result of the redistribution of traffic on surface roads results a number of areas where the project results in a reduction in $PM_{2.5}$ and PM_{10} exposures, and others where there is an increase in $PM_{2.5}$ and PM_{10} exposures.

To further address potential risks to human health that may be associated these localised changes in $PM_{2.5}$ and PM_{10} that relate to the project, incremental risk calculations have been undertaken and are presented in **Section 4.7.5**.

4.7.5 Changes in air quality – incremental exposures

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

Appendices A and E presents the methodology adopted for the calculation of an incremental risk, including the concentration-response functions adopted for the quantification of the key health endpoints evaluated, which include:

- **Primary health endpoints:**
    - Long-term exposure to $PM_{2.5}$ and changes in all-cause mortality (equal or greater than 30 years of age)
    - Short-term exposure and changes to the rate of hospitalisations with cardiovascular and respiratory disease (equal or greater than 65 years of age).

- **Secondary health endpoints (to supplement the primary assessment):**
    - Short-term exposure to PM_{10} and changes in all-cause mortality (all ages)
    - Long-term exposure to $PM_{2.5}$ and changes in cardiopulmonary mortality (equal or greater than 30 years of age)
    - Short-term exposure to $PM_{2.5}$ and changes in cardiovascular and respiratory mortality (all ages)
    - Short-term exposure to $PM_{2.5}$ and changes in emergency department admissions for asthma in children aged 1–14 years.

Table 4.5 presents the change in localised risk associated with changes in $PM_{2.5}$ and PM_{10} at the maximum impacted receptors relevant to the various land use in the community, for the years 2024 and 2034. The calculated risks for the maximum receptor (from all locations and land uses) for both 2024 and 2036 are also illustrated in **Figure 4.4**.

The assessment assumes an individual, at a specific location, is exposed at each maximum impacted location over all hours of the day, regardless of the land use. This has been undertaken to address any future changes in land use that may occur. Risks for all other receptors (including other sensitive receptors) are lower than the maximums presented.

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

Appendix C presents a discussion on levels of the levels of risk that are considered to be negligible, tolerable/acceptable and unacceptable. A summary of these risk levels is included in **Table 4.5**.

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

Table 4.5: Population health risk from changes in $PM_{2.5}$ and PM_{10} concentrations

Maximum for each scenario and land use	Change in population risk from exposure to $PM_{2.5}$ and PM_{10} for the following health endpoints									
	Primary health indicators			Secondary health indicators						
	$PM_{2.5}$: Mortality all causes (ages 30+)	$PM_{2.5}$: Cardiovascular hospitalisations (≥65 years)	$PM_{2.5}$: Respiratory hospitalisations (≥65 years)	PM_{10}: Mortality all causes (all ages)	$PM_{2.5}$: Mortality all causes (all ages)	$PM_{2.5}$: Mortality cardiopulmonary (ages 30+)	$PM_{2.5}$: Mortality cardiovascular (all ages)	$PM_{2.5}$: Mortality respiratory (all ages)	$PM_{2.5}$: Asthma ED admissions (5-14 years)	Diesel particulate matter: lung cancer risk
2024										
All receptors	5E-05	5E-05	1E-05	2E-06	3E-06	3E-05	9E-07	6E-07	1E-05	2E-05
Residential	4E-05	5E-05	1E-05	2E-06	3E-06	3E-05	8E-07	5E-07	1E-05	2E-05
Childcare	5E-06	6E-06	1E-06	2E-07	4E-07	3E-06	1E-07	6E-08	1E-06	2E-06
School	3E-05	4E-05	7E-06	1E-06	2E-06	2E-05	6E-07	4E-07	8E-06	1E-05
Aged Care	4E-06	4E-06	9E-07	2E-07	3E-07	2E-06	7E-08	5E-08	9E-07	2E-06
Hospital and medical	-4E-07	-4E-07	-8E-08	-2E-08	-2E-08	-2E-07	-7E-09	-4E-09	-8E-08	-2E-07
Commercial/industrial	2E-05	3E-05	5E-06	1E-06	2E-06	1E-05	5E-07	3E-07	6E-06	1E-05
Open space	5E-05	5E-05	1E-05	2E-06	3E-06	3E-05	9E-07	6E-07	1E-05	2E-05
2034										
All receptors	5E-05	5E-05	1E-05	2E-06	3E-06	3E-05	9E-07	6E-07	1E-05	2E-05
Residential	4E-05	5E-05	9E-06	2E-06	3E-06	3E-05	8E-07	5E-07	1E-05	2E-05
Childcare	5E-06	6E-06	1E-06	2E-07	4E-07	3E-06	1E-07	6E-08	1E-06	2E-06
School	3E-05	4E-05	7E-06	1E-06	2E-06	2E-05	6E-07	4E-07	8E-06	1E-05
Aged Care	4E-06	4E-06	9E-07	2E-07	3E-07	2E-06	7E-08	5E-08	9E-07	2E-06
Hospital and medical	5E-07	5E-07	1E-07	2E-08	3E-08	3E-07	9E-09	6E-09	1E-07	2E-07
Commercial/industrial	2E-05	3E-05	5E-06	1E-06	2E-06	2E-05	5E-07	3E-07	6E-06	1E-05
Open space	5E-05	5E-05	1E-05	2E-06	3E-06	3E-05	9E-07	6E-07	1E-05	2E-05

Risk criteria	Negligible risk $<1 \times 10^{-6}$
	Tolerable/acceptable risks $\geq 1 \times 10^{-6}$ and $\leq 1 \times 10^{-4}$
	Unacceptable risk > 1 x 10-4

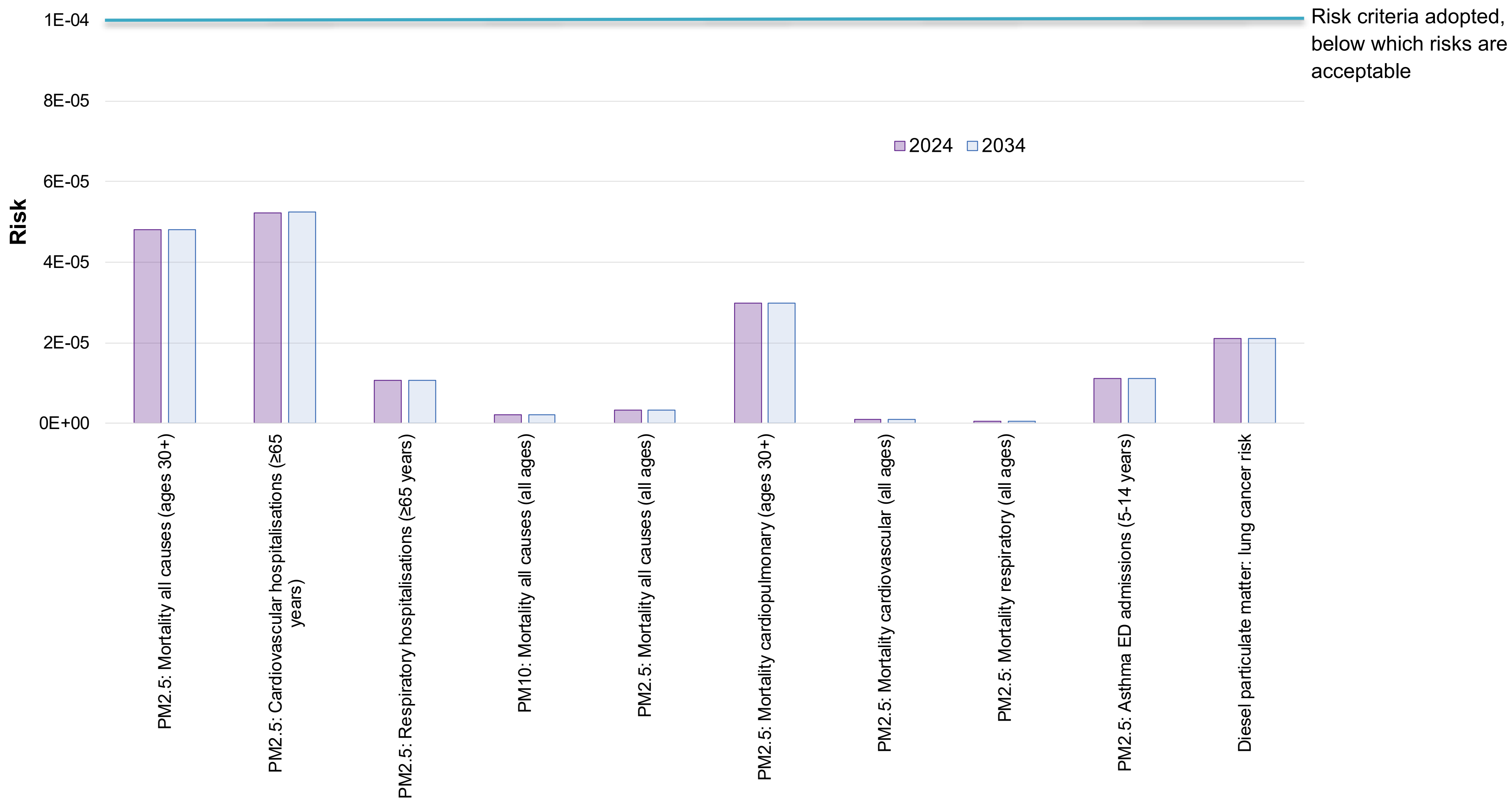

Figure 4.4: Maximum localised health risk (from all receptor locations) from changes in $PM_{2.5}$ and PM_{10}

The population in the project area is small and hence the calculation of a population incidence (ie change in the number of cases relevant to the health endpoints evaluated) is not vary meaningful. Regardless the potential population risk and incidence has been calculated for the whole population in the study area, where the following was calculated for the primary health indicators and asthma:

- Mortality all causes (ages 30 years and older):
  - Increased population risk = 2×10^{-6} (2024) and 3×10^{-6} (2034)
  - Increased population incidence (cases per year) = 0.009 (2024) and 0.01 (2034)
- Cardiovascular hospitalisations (ages 65 years and older):
  - Increased population risk = 3×10^{-6} (2024 and 2034)
  - Increased population incidence (cases per year) = 0.003 (2024) and 0.004 (2034)
- Respiratory hospitalisations (ages 65 years and older)
  - Increased population risk = 5×10^{-7} (2024) and 6×10^{-7} (2034)
  - Increased population incidence (cases per year) = 0.0007 (2024) and 0.0008 (2034)
- Asthma ED admissions (children aged 1-14 years)
  - Increased population risk = 5×10^{-7} (2024) and 6×10^{-7} (2034)
  - Increased population incidence (cases per year) = 0.0005 (2024) and 0.0006 (2034)

Review of **Table 4.5** and the discussion above indicates the following:

- The maximum localised impacts as a result of the redistribution of surface road traffic result in risks that are within the range considered to be acceptable for all land use areas evaluated in the community surrounding the project.

  It is noted that there are some areas where exposures to $PM_{2.5}$ and PM_{10} will be lower, particularly adjacent to the existing Pacific Highway as traffic is diverted onto the bypass. Where this occurs, there are potential health benefits, with the maximum decrease in risk being 5×10^{-5} for 2034 and 4×10^{-5} for 2034.

- Where the population is considered more broadly, the population risk is lower than the maximum localised risk, and remains acceptable. The potential population incidence relevant to the health endpoints evaluated is very low and considered to be negligible (ie not measurable in the community).

Overall, calculated risks (for all health endpoints considered) associated with changes in $PM_{2.5}$ and PM_{10} levels in the community from the project are considered acceptable. The impact of the changes in $PM_{2.5}$ and PM_{10} concentrations on the health of the population (as a population incidence as presented) is very low and would not be measurable within the community.

4.8 Uncertainties

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

Section 5. Assessment of noise impacts on health

5.1 Introduction

This section assesses the potential for changes in noise due to the project and how these changes might impact health within the community. This assessment has drawn on information provided in the Noise and Vibration Assessment Report (ARUP 2019) and, in some areas, provides a summary of key (and relevant) aspects. All details relevant to the underlying assumptions, methodology and interpretation of impacts relevant to the data provided in relation to changes in noise are provided within the Noise and Vibration Assessment Report (ARUP 2019).

The characterisation of health impacts from changes in noise as a result of the project is complex and has been undertaken in accordance with the methodology outlined in **Section 2.3**.

5.2 Health effects associated with environmental noise

5.2.1 General

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

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

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

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

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

Within a community the severity of the health effects of exposure to noise and the number of people who may be affected are schematically illustrated in **Figure 5.1**.

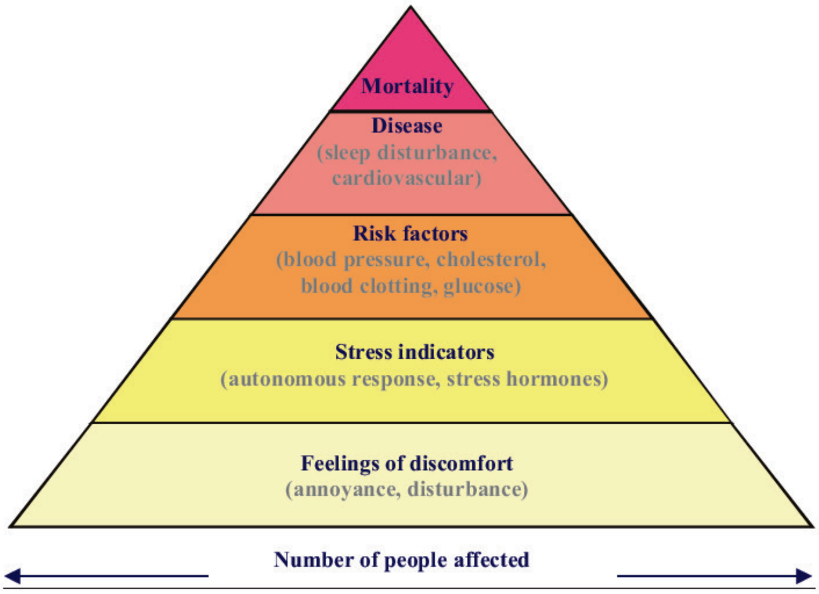

Figure 5.1: Schematic of severity of health effects of exposure to noise and the number of people affected (WHO 2011)

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

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

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

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

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

5.2.2 Health impacts from road traffic noise

Road traffic noise is caused by the combination of rolling noise (noise from tyres on the roadway) and propulsion noise (from engine, exhaust and transmission).

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

Cardiovascular effects

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

High-quality epidemiological evidence on cardiovascular and metabolic effects of environmental noise indicates that exposure to road traffic noise increases the risk of IHD (enHealth 2018; WHO 2018).

A link between noise and hypertension is relatively well established in the relevant literature. Whilst there is not a consensus on the precise causal link between the two, there are a number of credible hypotheses. A leading hypothesis is that exposure to noise could lead to triggering of the nervous system (autonomic) and endocrine system which may lead to increases in blood pressure, changes in heart rate, and the release of stress hormones. Depending on the level of exposure to excess noise, the duration of the exposure and certain attributes of the person exposed, this can cause an imbalance in the person’s normal state (including blood pressure and heart rate), which may make a person hypertensive (consistently increased blood pressure) which can then lead to other cardiovascular diseases (DEFRA 2014). This hypothesis is illustrated in **Figure 5.2**.

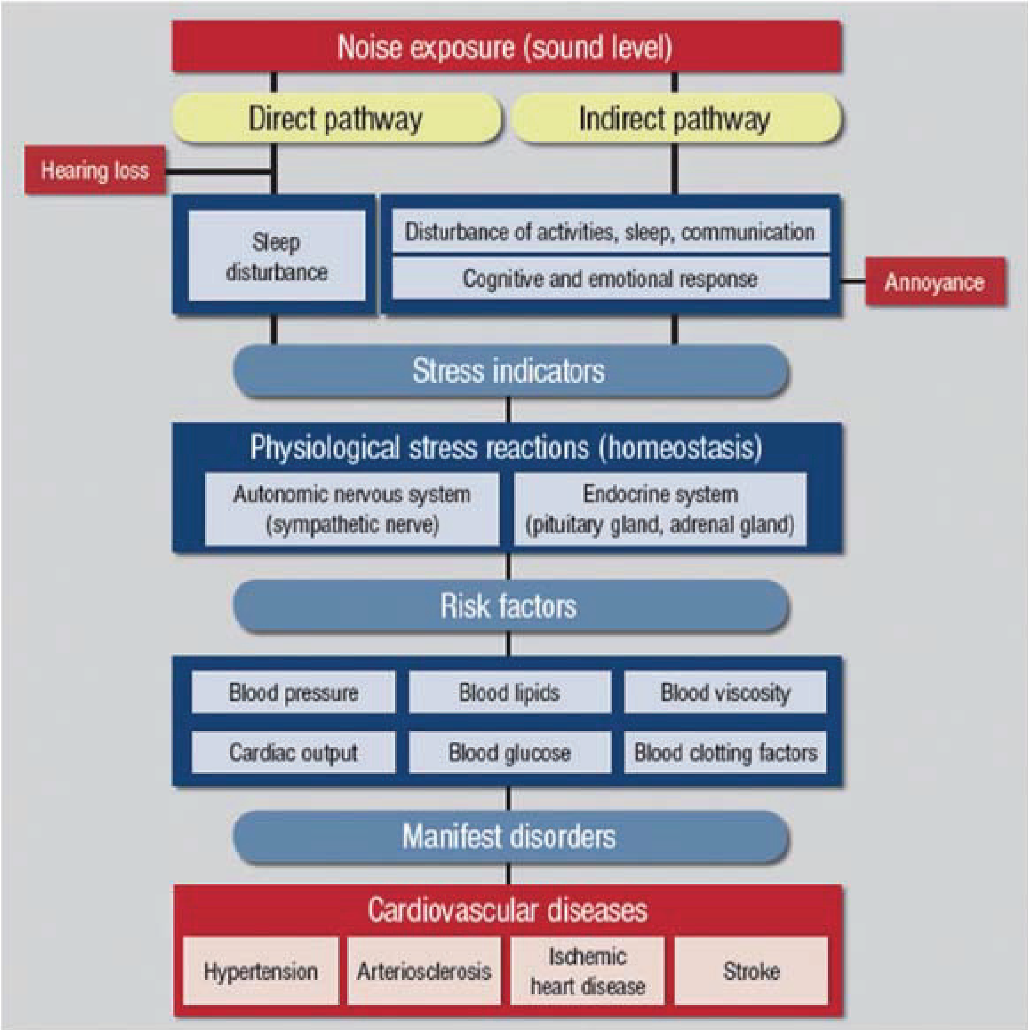

Figure 5.2: Noise reaction model/hypothesis (Babisch 2014)

The available studies regarding road traffic noise and cardiovascular disease risk largely involve meta-analysis (ie statistical analysis that combines the results of multiple scientific studies). A number of studies have been published by Babisch (Babisch 2002, 2006, 2008, 2014; van Kempen & Babisch 2012) and others (WHO 2018) have provided the basis for a number of exposure-response relationships adopted for the assessment of cardiovascular health effects associated with road-traffic noise.

In relation to hypertension the most relevant recent study (van Kempen & Babisch 2012) involved analysis of 27 studies between 1970 and 2010, where a relationship between road traffic noise and hypertension was determined. This relates to the incidence of hypertension in the population and has been adopted by the European Commission for the assessment of health impacts of road noise in Europe (EEA 2014). Review by the WHO (2018) considered that the available studies on the incidence of hypertension and road noise provided evidence that was rated very low quality. The relationship recommended by the WHO relates to a non-statistically significant outcome in relation to hypertension.

For the assessment of IHD, the WHO (WHO 2018) has undertaken a meta-analysis of three cohort studies and four case-control studies that investigated a relationship between road noise and the incidence of IHD. The meta-analysis involved 67 224 participants (from 7033 cases). The relationship established was considered to be based on high quality evidence.

Review of the incidence of stroke and road noise by the WHO (2018) determined that the available cohort studies and cross-sectional studies showed mixed outcomes, with the evidence rated very low to moderate quality. In relation to the risk of stroke from exposure to noise, there are limited meta-analysis type studies available and the studies available combine the risks from noise from road and air transport. A more specific study that just investigated the link between road traffic noise and cardiovascular disease/mortality has been undertaken in London (Halonen et al. 2015). This was a large epidemiological study that identified statistically significant associations between road traffic noise (as modelled to residential dwellings) and hospital admissions for stroke and all-cause mortality. The relationships identified related to exposure to day and evening noise as $L_{Aeq,16h}$. The study corrected for confounders such as $PM_{2.5}$ and NO_2 exposures and has been considered suitable for use in an assessment of noise impacts. The relative risk identified for hospital admissions for stroke is equivalent to that identified from a meta-analysis of air and road noise (Houthuijs et al. 2014).

The relationships determined in the above studies relate to noise exposures in excess of a threshold. The threshold for where these effects are of significance are generally equal to or above the noise criteria adopted for the assessment of operational noise impacts. It is noted, however that in areas already affected by noise at levels above these thresholds, the guidelines relate to an increase in noise attributed to the project, with a guideline of 2 dB(A) adopted. An increase in noise by 2 dB would not be associated with unacceptable cardiovascular risks (where the above exposure-response relationships were considered). In areas where noise levels (as L_{den}) are 55 dB(A) and higher, an increase of 5 dB(A) would result in an increase in mortality risks (all causes, all ages) that would be considered unacceptable (ie greater than $1x10^{-4}$).

Annoyance and sleep disturbance

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

<u>Annoyance</u>

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

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

The available noise guidelines have been developed to address noise annoyance within the community. Hence the increase in noise permitted as a result of the project is small. In many cases the change in noise exposure is reduced as a result of the project. However where noise level changes of 2 dB occur, this has the potential to result in an increase in individuals highly annoyed by noise by 2 per cent, which is well below the level of annoyance of 5 per cent considered to be of concern (or likely to be perceived) by residents (Schomer 2005). For noise levels between 45 and 75 dB(A) (as L_{den}), an increase in noise by 4.5 dB(A) results in the increase in individuals that are highly annoyed by noise to exceed the criteria of 5 per cent and may be considered unacceptable.

Sleep disturbance

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

Studies are available that have evaluated awakening by noise, increased mortality (ie increase in body movements during sleep), self-reported chronic sleep disturbances and medication use (EC 2004). The most easily measurable outcome indicator is self-reported sleep disturbance, where there are a number of epidemiological studies available. From these studies the WHO (WHO 2009, 2011, 2018) identified an exposure response relationship that relates to the percentage of persons sleep disturbed (%SD) and highly sleep disturbed (%HSD) to total levels of noise reported as L_{night} (ie average noise levels during night, which is an 8-hour time period, as measured outdoors). The relationship adopted relates to the assessment of road-traffic noise, with other relationships for air and rail traffic noise. These relationships have been adopted by the WHO (2009, 2011), UK and European Environment Agency (DEFRA 2014; EEA 2010, 2014). Review by the WHO (WHO 2018), considered that the key outcome of %HSD was considered most appropriate for determining actions and outcomes in relation to road noise. For night time noise levels between 45 and 65 dB(A), increases in noise levels at night time of 5, 10, 15 and 20 dB(A) may result in an approximate 3, 7, 12 and 18 per cent increase respectively in individuals who are highly sleep disturbed.

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

Cognitive effects

There is evidence for effects of noise on cognitive performance in children such as lower reading performance (WHO 2011). A major study was undertaken in the EU – RANCH – and this study was reviewed in WHO (2011). The study found an exposure response relationship between noise and cognitive performance in children for aircraft noise but the relationship between performance and noise for road traffic was much less clear (Stansfeld et al. 2005a; Stansfeld et al. 2005b; WHO 2011, 2018). WHO (2011) used the aircraft noise relationships to assess the impact of noise on children's cognitive performance. For this project, it was not considered appropriate to use the relationships based on the impacts of aircraft noise. The same study showed that road traffic alone did not show an association between road traffic noise and adverse changes in children's cognitive functions studied (reading comprehension, episodic memory, working memory, prospective memory or sustained attention), nor with sustained attention, self-reported health, or mental health.

Individual road noise events

It is noted that noise impacts can also occur because of individual noise events, such as engine braking or loud exhausts. The noise measures adopted above for the assessment of the health effects of noise relate to an average/equivalent sound level over different time periods, which, when measured, would include individual noise events. This is the preferred approach for evaluating annoyance and other health effects related to noise (NSW DECCW 2011). Individual noise events are of most significance in relation to the assessment of sleep disturbance. The available research indicates that one or two individual noise events per night, with a maximum indoor noise level of 65-70 dB(A) are not likely to affect health and wellbeing (NSW DECCW 2011). Criteria have been adopted to address maximum noise events, however it is noted that it is not possible to model all individual noise events as these relate to individual vehicles or trucks and individual driving behaviour that cannot be predicted.

5.3 Existing noise environment

The existing noise environment in the project area is described in detail in the Noise and Vibration Assessment Report (ARUP 2019).

In summary, the existing noise environment is characteristic of rural areas with the existing Pacific Highway having a significant influence. Depending on proximity to the existing highway, overall daytime ambient noise levels are generally higher than night-time noise levels. This is due to daytime levels being driven up by the volume of light vehicles but significantly reduced during the night-time. The volume of long-haul road freight vehicles becomes proportionally more significant during the night-time period and hence the determinant of road traffic noise disturbance.

With distance from road traffic noise sources, typical rural soundscape elements dominate the soundscape included flora and fauna and the difference between daytime and night-time ambient noise levels is reduced.

To undertake the noise assessment required for the project, the existing background noise quality, as a Rating Background Level (RBL) and LAeq for various time periods, needed to be assessed as the guidelines that relate to noise impacts from a specific project are based on levels allowable above background. Based on background monitoring undertaken the LAeq day levels range from 45 to 75 dBA, and LAeq night levels range from 39 to 71 dBA.

5.4 Noise assessment criteria

5.4.1 General

Noise issues in NSW are managed by the NSW EPA. The NSW EPA has prepared a number of guidance documents with regard to the types of noise that are considered in relation to construction and operation of the project. The *NSW Road Noise Policy* (RNP) (NSW DECCW 2011) and the Noise Criteria Guideline (NCG) ((NSW Roads and Maritime 2015a) are the key guidelines used to assess noise impacts during operation. In addition, other guidance is available in the Noise Mitigation Guideline (NSW Roads and Maritime 2015b) with maximum noise level guidance provided in the Environmental Noise Management Manual (ENMM) (Roads and Traffic Authority 2001).

For the operation of in-tunnel jet fans (for use in the event of a fire) at the Shephards Lane and Gatelys Road tunnels have been assessed against the NSW Noise Policy for Industry (NPI) (NSW EPA 2017).

During construction, guidance provided in the Construction noise and vibration guideline (CNVG) (Roads & Maritime Services 2016) has been adopted. The CNVG are considered in addition to other relevant policies and guidelines, ass outlined in the Interim Construction Noise Guideline (ICNG) (NSW DECC 2009), RNP and NPI.

In all these policies, there is discussion of the need to balance the economic and social benefits of activities that may generate noise with the protection of the community from the adverse effects of noise. The noise assessment criteria adopted relate to levels of noise that can be tolerated or permitted above background before some adverse effect (annoyance, discomfort, sleep disturbance or complaints) occurs.

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

5.4.2 Construction noise criteria

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

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

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

The Noise and Vibration Assessment Report (ARUP 2019) has considered construction noise impacts for the project.

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

Levels of noise allowable outside standard work hours, particularly at night, are lower than those permitted during normal work hours. Where construction works are planned to extend over more than two consecutive nights a sleep disturbance assessment is required to be undertaken.

Noise management levels are also outlined in the CNVG and ICNG for other sensitive land uses.

The noise criteria adopted relate to construction works conducted during standard operation hours (day time only), out of hours operations (day evening and night works) and criteria relevant to the assessment of sleep disturbance. These criteria are based on the RBL plus a noise increment relevant for these time periods.

The assessment has assumed that properties have openable windows, where external noise levels are typically 10 dB higher than internal noise levels (when windows are open).

The assessment of noise impacts has been undertaken within 29 noise catchment areas (assumed to have background noise levels consistent with the background noise monitoring location within each catchment area).

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

5.4.3 Ground-borne noise criteria

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

- Evening 40 dB(A) LAeq (15 minute)
- Night-time 35 dB(A) LAeq (15 minute).

5.4.4 Operational noise criteria

Operational noise impacts have been evaluated on the basis of the Road Noise Policy (RNP), with additional guidance and criteria provided within Roads and Maritime's *Noise Criteria Guideline* (NCG) and *Noise Mitigation Guideline* (NMG) (NSW DECCW 2011; NSW Roads and Maritime 2015a). The principles underlying the guidance documents are:

- Criteria are based on the road development type a residence is affected by due to the road project
- Adjacent and nearby residences should not have significantly different criteria for the same road
- Criteria for the surrounding road network are assessed where a road project generates an increase in traffic noise greater than 2 dB(A) on the surrounding road network
- Existing quiet areas are to be protected from excessive changes in amenity due to traffic noise.

The project consists of multiple alternating new and redeveloped road segments and hence there are a number of criteria that apply to the project.

For residential areas, criteria are established for properties near either freeway/arterial/sub-arterial roads or local roads. These criteria relate to noise levels during the daytime (7.00 am to 10.00 pm) and night-time (10.00 pm to 7.00 am). Night-time noise criteria are aimed at minimising sleep disturbance. Criteria are also available to assessed noise exposures in other types of buildings, including schools, places of worship, open space, childcare, aged care and hospital facilities.

Where noise criteria relate to internal noise levels, the corresponding external noise criteria is taken to be 10 dB higher (relevant where windows may be open). Higher levels of noise reduction are achieved with windows closed (20-25 dB) or the use of double glazed closed windows (35 dB).

Exceedance of the operational noise guidelines is the trigger to consider noise mitigation.

Guidelines are also available to evaluate maximum noise levels from roadways, such as those from individual vehicles or trucks that have the potential to disturb sleep. While no specific criterion is set to address this specific issue, a number of guidance points may be used to qualify if the maximum noise level is likely to be an issue. These include 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, and the number of times the maximum noise levels for individual vehicle pass-bys exceed the L_{Aeq} noise level for each hour of the night.

The assessment of maximum noise levels at night-time, has also considered the following:

- Maximum internal noise levels below 50-55 dB(A) are unlikely to cause awakening reactions
- One or two noise events per night with maximum internal noise levels of 65-70 dB(A) are not likely to significantly affect health and wellbeing.

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

5.5.1 Construction noise

Applicable NSW legislation and guidelines have been used to inform the construction noise modelling and assessment presented in the Noise and Vibration Assessment report (ARUP 2019). Noise mitigation has been recommended in accordance with these guidelines. These guidelines have been developed taking into consideration current international practices, health impacts of noise and to protect vulnerable people.

Noise that may be generated during construction has been modelled for three construction zones, which include a number of construction sites, based on the type of equipment to be used, where the equipment is to be used in relation to the community receptors, the hours of work, the duration of the activities undertaken and the local terrain. The assessment has also considered construction traffic.

The majority of construction is proposed to be undertaken during standard construction hours, however, evening and night-time work would be required due to specific circumstances (such as deliveries of oversize equipment, minimising traffic disruption, safety reasons, emergencies and reduction in the construction timeframe). Works that may occur outside of standard hours have been considered in the noise modelling.

The modelling evaluated representative worst-case activities relevant to the following scenarios:

- bulk earthworks
- bridges and tunnels
- road works
- site compound activities.

The assessment has considered a range of standard noise mitigation measures, ie those that would be a standard requirement for a range of construction activities. Overall, a worst case assessment has been used in accordance with the ICNG, assuming no additional mitigation measures are implemented.

The noise modelling identified a significant number of residential properties and some schools during each of the four scenarios where construction noise criteria are exceeded during the daytime, for standard hours works, and for daytime, evening and night time periods for out of hours works and sleep disturbance criteria. These exceedances have been ranked as highly noise affected (ie

>75 dB(A)), impacts that are clearly audible (<NML + 10 dB), impacts that are moderately intrusive (≤NML + 20 dB) and impacts that are highly intrusive (>NML + 20 dB). These exceedances are largely due to the proximity of residences and schools to the construction activities. The impacts will be greatest where plant and equipment are closer to the receiver, and lower where these equipment are located further away. Durations of exceedances will vary depending on the nature of the works at each location.

Cumulative noise impacts have been assessed where these activities may occur at the same time as other works for urban estates and subdivisions, or building works. The cumulative assessment identified that at times noise impacts may be greater due to construction activities occurring at the same time in the same areas.

Assessment of ground-borne noise identified distances of 41 metres (daytime) to 51 metres (night time) from the source where the criteria are met.

Construction traffic also has the potential for elevated levels of noise and further assessment and management of these impacts would need to be undertaken in the detailed design.

Mitigation

A range of noise and vibration impacts have been identified during construction. These impacts would be managed through the implementation of a Construction Environmental Management Plan (CEMP) for the project. A Construction Noise and Vibration Management Plan (CNVMP) would also be developed to provide the framework and mechanisms for the management ad mitigation of noise impacts including an Out of Hours Work Procedure. The CNVMP would consider a wide range of management measures and mitigating methods to minimise the impact of noise during construction. A range of mitigation measures are outlined in the Noise and Vibration Assessment Report (ARUP 2019).

Health impacts

Where the proposed management measures are implemented, the potential for construction noise and vibration to adversely impact community health is minimised.

It should be noted that even where mitigation measures are implemented, some noise impacts may occur where works occur close to sensitive receivers. These impacts are expected to be of short duration, where annoyance and potentially sleep disturbance may occur on occasions.

5.5.2 Operational impacts

General

Assessment of operational noise impacts presented in the Noise and Vibration Assessment Report (ARUP 2019) has been undertaken by modelling noise associated with the project.

The assessment of operational noise impacts has considered 28 noise catchment areas. The assessment has also considered Development Applications (DAs) for a number of proposed residential estates or subdivisions within these areas. Some of the DA conditions of approval for these estates or subdivisions include noise criteria.

The noise modelling took into consideration both the location of the project (including topography, meteorology and buildings), physical design changes and project related traffic (volume, composition and speeds). The assessment has also considered existing noise barriers. The assessment considered impacts in the years 2024 and 2034 for the no-build and build scenarios and noise levels were predicted for daytime and night-time periods.

The assessment of road traffic noise has been completed in accordance with the relevant guidelines (as discussed in **Section 5.4**). An assessment was undertaken to determine how well the model estimated noise impacts based on a current scenario (2018). The modelled and measured results were found to be within acceptable tolerances, which are +/- 2 dB(A).

Noise impacts

Based on the noise modelling undertaken, and where no additional noise mitigation is implemented, a significant number of residential homes (1569) and non-residential properties (13) where noise levels are predicted to exceed the operational noise criteria. Of the 1569 residential homes, 1316 qualify for consideration of additional noise mitigation.

Proposed noise mitigation measures include:

- low noise pavements, where the number of residential properties that exceed the operational noise criteria reduce to 1009;
- noise barriers such as mounds and noise walls were investigated and a total of nine have been included for the project. Where both low noise pavements and noise barriers are considered the number of residential properties that exceed the operational noise criteria reduce to 468, of which 44 have noise increases of more than 10 dB, 152 have noise increases between 5 and 10 dB and 272 have noise increases less than 5 dB
- at-property treatments – these would be relevant for receptors where exceedance of noise criteria remains following consideration and low noise pavements and noise barriers

In relation to the existing Pacific Highway the project is proposed to reduce traffic volumes, increase safety and reduce existing noise levels along this route. These noise reductions have not been modelled.

Where changes in the local terrain are considered, changes to rail noise from the North Coast Railway have also been addressed. This did not identify any additional noise receivers where noise mitigation needs to be considered.

Health impacts

Without mitigation there are a number of residential, and other, properties where noise levels exceed the adopted operational noise criteria, that are designed to be protective of health. Review of the noise modelling undertaken indicates the following:

- In all areas evaluated the predicted noise levels exceed thresholds where health effects have been identified (daytime and night-time).

- The most significant exceedances of the NCG are in NCA02, NCA06, NCA15, NCA16, NCA18, NCA19, NCA24, NCA27 and NCA28. Predicted noise increases in these areas are at least 5 dB above the criteria and have the potential to result in unacceptable risks to human health in terms of cardiovascular health, noise annoyance and sleep-disturbance. Hence, where noise mitigation is not implemented there is the potential for unacceptable health impacts at some properties in these noise catchment areas.
- Not all noise mitigation measures will adequately address the increased noise levels, hence there will be the need for some at-property treatments. The effectiveness of at-property treatments to reduce noise impacts in this area would need to be evaluated once all mitigation measures have been identified and designed.

It is noted that the use of at property treatments have a number of downsides, and therefore treatment at or near the source should be the preferred option. At property treatment downsides include:

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

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

5.6 Uncertainties

Any assessment of potential human health risks or impacts needs to consider the uncertainties inherent in the information and data relied upon for undertaking such an assessment as well as the methodology and assumptions adopted in the quantification of risk or impact. **Appendix F** presents a detailed review of the uncertainties relevant to the assessment of health impacts from changes in noise. Overall, the approach adopted is expected to overestimate noise impacts, and hence conclusions drawn from the noise impact assessment in relation to community health would also be overestimated.

5.7 Overview of health impacts of noise

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

- Construction
  - Where the proposed management measures are implemented, the potential for construction noise to adversely impact community health would be minimised.
  - It should be noted that even where mitigation measures are implemented, some noise impacts may occur where works occur close to sensitive receivers. These impacts are expected to be of short duration, where annoyance and potentially sleep disturbance may occur on occasions.
- Operations
  - Without mitigation, 1569 residential buildings and 13 non-residential buildings (including schools) have been identified where road noise exceeds the health based criteria. These impacts are of significance in a large number of noise catchment areas. Increases in noise levels at some locations in these areas have the potential to result in unacceptable risks to human health in terms of cardiovascular health, noise annoyance and sleep-disturbance.
  - To ensure health impacts are effectively mitigated, mitigation measures would be required to be designed and implemented as outlined in the Noise and Vibration Assessment Report (ARUP 2019). The mitigation of operational noise impacts should consider treatment at or near the noise sources prior to the implementation of at-property treatments as at-property treatments are less certain (in terms of acceptance and use) and their presence at a property has the potential to also affect the wellbeing of residents.

Section 6. Conclusions

An assessment of health risks associated with changes in air quality and noise associated with the project has been undertaken. The health risk assessment both the construction and operation of the project in the years 2024 and 2034.

Based on the assessment undertaken and presented in this report the following has been concluded:

Health impacts during construction:

- Changes in air quality:
  - Impacts associated with dust generated from construction activities would require management to ensure impacts to community health are minimised.
  - Measures required to be implemented to minimise dust impacts would be detailed in an Air Quality Management Plan (refer to the Air Quality Assessment (ERM 2019) for further detail)).
  - It is noted that even where dust is managed, this does not preclude the deposition of nuisance dust (ie large dust particles) during the works or the presence of short-duration noticeable dust during some works).
- Changes in noise:
  - Without mitigation a number of noise impacts, in excess of construction noise guidelines during the day, evening and nigh time periods has the potential to adversely impact on the health of residents (and others) during construction activities.
  - Where the proposed management measures are implemented, the potential for construction noise to adversely impact community health would be minimised.
  - It should be noted that even where mitigation measures are implemented, some noise impacts may occur where works occur close to sensitive receivers. These impacts are expected to be of short duration, where annoyance and potentially sleep disturbance may occur on occasions.

Health impacts during operation:

- Changes in air quality:
  - The operation of the project has the potential to result in the redistribution of traffic from the existing Pacific Highway to the bypass. The redistribution of traffic would result in localised areas where air quality impacts occur.
  - Potential risks to human health associated with localised air quality impacts are considered to be acceptable, and not measurable within the community.
- Changes in noise:

- Without mitigation, 1569 residential buildings have been identified where road noise exceeds the health based criteria. These impacts are of significance in a large number of noise catchment areas. Increases in noise levels at some locations in these areas have the potential to result in unacceptable risks to human health in terms of cardiovascular health, noise annoyance and sleep-disturbance.

- To ensure health impacts are effectively mitigated, mitigation measures would be required to be designed and implemented as outlined in the Noise and Vibration Assessment Report (ARUP 2019). The mitigation of operational noise impacts should consider treatment at or near the noise sources prior to the implementation of at-property treatments as at-property treatments are less certain (in terms of acceptance and use) and their presence at a property has the potential to also affect the wellbeing of residents.

Section 7. Report limitations

Environmental Risk Sciences has prepared this report for the use of Roads and Maritime Services in accordance with the usual care and thoroughness of the consulting profession. It is based on generally accepted practices and standards at the time it was prepared. No other warranty, expressed or implied, is made as to the professional advice included in this report.

It is prepared in accordance with the scope of work and for the purpose outlined in **Section 1** of this report.

The methodology adopted and sources of information used are outlined in this report. Environmental Risk Sciences has made no independent verification of this information beyond the agreed scope of works and assumes no responsibility for any inaccuracies or omissions. No indications were found that information contained in the reports for use in this assessment was false.

This report was prepared in May/June 2019 and finalised in July 2019 and is based on the information provided and reviewed at that time. Environmental Risk Sciences disclaims responsibility for any changes that may have occurred after this time.

This report should be read in full and no excerpts are to be taken as representative of the findings. No responsibility is accepted for use of any part of this report in any other context or for any other purpose or by third parties. This report does not purport to give legal advice. Legal advice can only be given by qualified legal practitioners.

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Appendix A Approach to risk assessment using exposure-response relationships

A1 Mortality and morbidity health endpoints

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

In relation to the health effects associated with exposure to nitrogen dioxide and particulate matter, no threshold has been identified. For the assessment of noise, exposures above a threshold have been defined on the basis of an exposure-response relationship. Non-threshold exposure-response relationships have been identified for the health endpoints considered in this assessment.

A2 Quantification of impact and risk

The assessment of health impacts for a particular population associated with exposure to particulate matter has been undertaken utilising the methodology presented by the WHO (Ostro 2004)[10] where the exposure-response relationships identified have been directly considered on the basis of the approach outlined below.

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

- Estimates of the changes in particulate matter exposure levels or noise levels (i.e. incremental impacts) due to the project for the relevant modelled scenarios
- Estimates of the number of people exposed to particulate matter or noise at a given location
- Baseline incidence of the key health endpoints that are relevant to the population exposed

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

- Exposure-response relationships expressed as a percentage change in health endpoint per μg/m^3 change in NO_2 or particulate matter exposure or per dB(A) for noise, where a relative risk (RR) is determined.

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

Noise

Noise impacts have been calculated on the basis of the following:

Equation 1 $$AF_{Noise} = \frac{RR_{dB} - 1}{RR_{dB}} \times P \times B$$

Where:
B = baseline incidence of a given health effect (e.g. mortality rate per person per year)
P = relevant exposed population
RR_{dB} = relative risk, which is given per 10 dB increase, which is then scaled to be a change per dB as outlined in Equation 2

Equation 2 $$RR_{dB} = 1 + \left((RR_{10} - 1)x\frac{dB}{10}\right)$$

Where:
dB = is the noise exposure, or change in noise exposure
P = relevant exposed population
RR10 = relative risk per 10 dB increase from publications

Air quality

For the assessment of changes in air pollution, the attributable fraction/portion (AF) of health effects from air pollution, or impact factor, can be calculated from the relative risk as:

Equation 1 $$AF_{air} = \frac{RR-1}{RR}$$

The assessment of potential risks associated with these exposures involves the calculation of a relative risk (RR). For the purpose of this assessment the shape of the exposure response function used to calculate the relative risk is assumed to be linear[11]. The calculation of a relative risk based on the change in relative risk exposure concentration from baseline/existing (i.e. based on

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

incremental impacts from the project) can be calculated on the basis of the following equation (Ostro 2004):

Equation 4 **RR = exp[β(X-X0)]**

Where:
X-X0 = the change in particulate matter concentration to which the population is exposed (µg/m³)
β = regression/slope coefficient, or the slope of the exposure-response function which can also be expressed as the per cent change in response per 1 µg/m³ increase in particulate matter exposure

Based on this equation, where the published studies have derived relative risk values that are associated with a 10 µg/m³ increase in exposure, the β coefficient can be calculated using the following equation:

Equation 5

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

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

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

Equation 6 ***E=AF x B x P***

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

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

The calculation of an increased incidence (i.e. number of cases) of a particular health endpoint is not relevant to a specific individual, rather this is relevant to a statistically relevant population. This calculation has been undertaken for populations within the suburbs surrounding the proposed project.

When considering the potential impact of the project on the population for changes in air quality, the calculation has been undertaken using the following:

- The relative risk has been calculated for a population weighted annual average incremental increase in concentrations. The population weighted average has been calculated on the basis of the smallest statistical division provided by the Australian Bureau of Statistics within a suburb (i.e. mesh blocks – which are small blocks that cover an area of approximately 30 to 60 urban residences). For each mesh block in a suburb the average incremental increase in concentration has been calculated and multiplied by the population living in the mesh block (data available from the ABS for the 2016 census year). The weighted average has been calculated by summing these calculations for each mesh block in a suburb and dividing by the total population in the suburb (i.e. in all the mesh block)

- The attributable fraction has then been calculated
- Equation 6 has been used to calculate the increased number of cases associated with the incremental impact evaluated. The calculation is undertaken utilising the baseline incidence data relevant for the endpoint considered and the population (for the relevant age groups) present the area evaluated.

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

Equation 7 $E=\beta \times B \times \sum_{mesh}(\Delta X_{mesh} \times P_{mesh})$

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

An additional risk is calculated as:

Equation 2 $Risk=\beta \times \Delta X \times B$

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

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

The above calculation of additional risk can also be undertaken for changes in noise levels in the community.

A3 Quantification of short-and long-term effects

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

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

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

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

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

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

For the calculations presented in this technical working paper that relate to the expected use of the project tunnel - for long-term and short-term effects - annual average concentrations of nitrogen dioxide and particulate matter have thus been utilised.

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

Appendix B Approach to the assessment of carcinogenic risks

B1 Overall approach

For the assessment of potential risks associated with exposure to diesel particulate matter, carcinogenic PAHs, 1,3-dioxane and benzene, a non-threshold cancer risk is calculated. Non-threshold carcinogenic risks are estimated as the incremental probability of an individual developing cancer over a lifetime as a result of exposure to a potential non-threshold carcinogen. The numerical estimate of excess lifetime cancer risk is calculated as follows for inhalation exposures (enHealth 2012b; USEPA 2009a):

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

Where the adjustment factor (AF) is equal to 1, the above calculation assumes the receptor is exposed at the same location for 24 hours of the day, every day, for a lifetime (which is assumed to be 70 years). This assumption is overly conservative for residents and workers in the community surrounding the project. Residents do not live in the one home for a lifetime. Guidance from enHealth indicates that an appropriate assumption for the time living in the one home is 35 years (enHealth 2012a). For the calculation of carcinogenic risks for residents at this site, an AF of 0.5 has been adopted. This reflects exposure over 35 years at the one home, as a factor of the 70 years assumed as the lifetime of concern for the assessment of carcinogenic risk (enHealth 2012b).

Assuming that a resident is at home 24 hours per day, every day for a lifetime is considered to be conservative.

B2 Diesel Particulate Matter

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

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

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

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

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

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

WHO has used data from studies in rats to estimate unit risk values for cancer (WHO 1996). Using four different studies where lung cancer was the cancer endpoint, WHO calculated a range of 1.6×10^{-5} to 7.1×10^{-5} per µg/m^3 (mean value of 3.4×10^{-5} per µg/m^3). This would suggest that an increase in lifetime exposure to diesel particulate matter between 0.14 and 0.625 µg/m^3 could result in a one in one hundred thousand excess risk of cancer.

The California Environmental Protection Agency has proposed a unit lifetime cancer risk of 3.0×10^{-4} per µg/m^3 diesel particulate matter (OEHHA 1998). This was derived from data on exposed workers and based on evidence that suggested unit risks between 1.5×10^{-4} and 15×10^{-4} per µg/m^3. This would suggest that an increase in lifetime exposure to diesel particulate matter of 0.033 µg/m^3 could result in a 1 in 100,000 excess risk of cancer. This estimate has been widely criticised as overestimating the risk and so has not been considered in this assessment.

On the basis of the above, the WHO cancer unit risk value (mean value of 3.4×10^{-5} per µg/m^3) has been used to evaluate potential excess lifetime risks associated with incremental impacts from diesel particulate matter exposures. Diesel particulate matter has not been specifically modelled in the AQAR; rather diesel particulate matter is part of the $PM_{2.5}$ assessment. For the purpose of this assessment it has been conservatively assumed that 100 per cent of the incremental $PM_{2.5}$ (from the project only) is derived from diesel sources. This is conservative as not all the vehicles using the tunnel (and emitting $PM_{2.5}$) would be diesel powered (as currently there is a mix of petrol, diesel, LPG and hybrid-electric powered vehicles with the proportion of alternative fuels rising in the future).

The assessment of exposure to diesel particulate matter has utilised an assumption that 100% of $PM_{2.5}$ comprises diesel particulate matter.

Appendix C Acceptable risk levels

C1 General

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

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

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

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

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

- The certainty and severity of the risk
- The reversibility of the health effect

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

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

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

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

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

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

In the context of human health risks, 10^{-6} is a shorthand description for an increased chance of 0.000001 in 1 (one chance in a million) of developing a specific adverse health effect due to exposure (over a lifetime or a shorter duration as relevant for particulate matter) to a substance. The number 10^{-5} represents 1 chance in 100,000, and so on.

Where cancer may be considered, lifetime exposure to a substance associated with a cancer risk of 1×10^{-6} would increase an individual's current chances of developing cancer from all causes (which is

40 per cent, or 0.4 – the background incidence of cancer in a lifetime) from 0.4 to 0.400001, an increase of 0.00025 per cent.

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

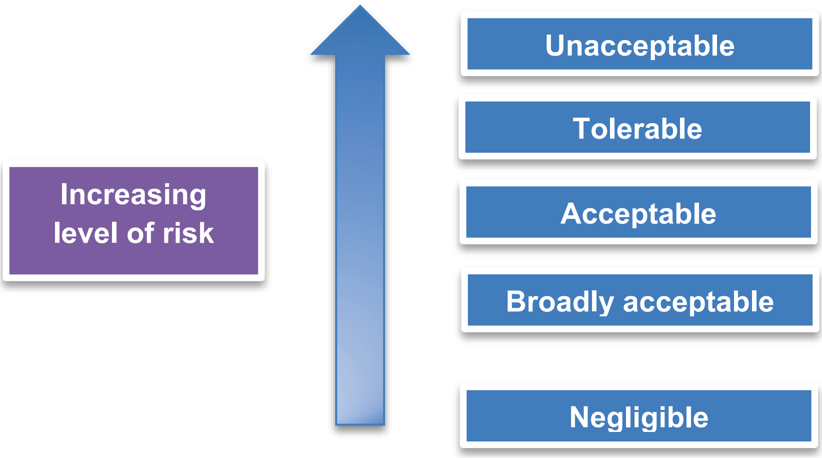
To provide more context in relation to the concept of a one in a million risk, the following presents a range of everyday life occurrences. The activity and the time spent undertaking the activity that is associated with reaching a risk of one in a million for mortality are listed below (Higson 1989;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

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

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

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

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



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

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

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

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

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

- It falls below an arbitrary defined probability
- It falls below some level that is already tolerated
- It falls below an arbitrary defined attributable fraction of total disease burden in the community
- The cost of reducing the risk would exceed the costs saved
- The cost of reducing the risk would exceed the costs saved when the 'costs of suffering' are also factored in
- The opportunity costs would be better spent on other, more pressing, public health problems
- Public health professionals say it is acceptable
- The general public say it is acceptable (or more likely, do not say it is not)
- Politicians say it is acceptable.

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

Further discussion (McClure 2014) on the level of acceptable risk indicates that the actual size of the exposed population needs to be taken into account. Where the exposed population is, say, 100 people exposed over a lifetime, then if each person is subject to a 1 in 10,000 individual risk from the exposure, then the risk to the 100 person population is 0.0001 times 100, which equals 0.01; (i.e., there would not be one person affected by the health outcome evaluated). And this is still conservative because it is unlikely that all 100 persons would be in the one place for their lifetime and the exposure would stay the same for that time. In such a case, it is suggested that using the 1 in 10,000 individual risk threshold (which EPA considers to be at the upper end of the acceptable range) because that is not expected to result in even one person impacted by the health effect evaluated.

There is no rational basis for using 1 in 100,000 criteria, much less 1 in million or 1 in 1 million as an acceptable non-threshold risk criteria for all situations.

This is why it is important to also evaluate the population health incidence for the health endpoints evaluated in the health impact assessment as this part of the assessment does not provide an individual risk, but considers the risk over a larger population to determine the incidence. The health impact assessment has evaluated incidence associated with changes in particulate and nitrogen dioxide exposures and there are no population impacts where there is more than 1 person that may be affected.

C3 Additional context on defining acceptable risks for nitrogen dioxide, particulates and noise

The population is always be exposed to particulates and noise at some level. In addition, it is noted that the calculation of incremental risks associated with changes in particulates and noise have not been commonly undertaken for specific projects in Australia or Internationally. Typically, the exposure-response relationships adopted are used to determine population-wide guidelines based on health benefits/costs. No acceptable risk level is defined by the NEPC or WHO in establishing any of the current air quality or noise guidelines.

When considering risks posed by stressors/pollutants to which a population is constantly exposed, some analogy can be made to radon. Acceptable cancer risk levels adopted in the US for inside homes (where natural radon levels affect populations) range from 3 in 100 for residents who are smokers to 2-7 in 1000.

For particulate exposures, the change in particulate levels evaluated for the project should also be considered in the context of the variability of particulate exposures that occur throughout any one day. Particulates are generated from a wide range of activities, with many of these occurring indoors. This can result in higher levels of particulate exposures occurring indoors from a wide range of indoor sources, well in excess of outdoor air or any change in outdoor air levels. **Figure C1** presents a comparison of the maximum change in $PM_{2.5}$ concentrations predicted for the project with comparison against other changes in $PM_{2.5}$ associated with daily activities. This figure shows that over a day (24 hours) the maximum change in $PM^{2.5}$ from the project is very small when compared with changes from other sources people are exposed to over the course of the day which would result in changes in risk levels (for the health endpoints evaluated in the health impact assessment) in excess of 10^{-4}. Similarly, when considering short duration events the maximum change on $PM_{2.5}$ from the project is similar to the changes that occur during vacuuming and cooking.

To provide further context, particulate risks calculated for other major projects in Australia (completed, approved or being completed) are summarised in **Table C1**. This table shows the levels of risk associated with changes in $PM_{2.5}$ from a range of projects. These risks generally lie in the range 10^{-4} to 10^{-6} with some resulting in risks in excess of 10^{-4}. It could be inferred that these risks have been accepted by the community/regulators, in most cases without having had the actual level of risk calculated (as is presented in this report).

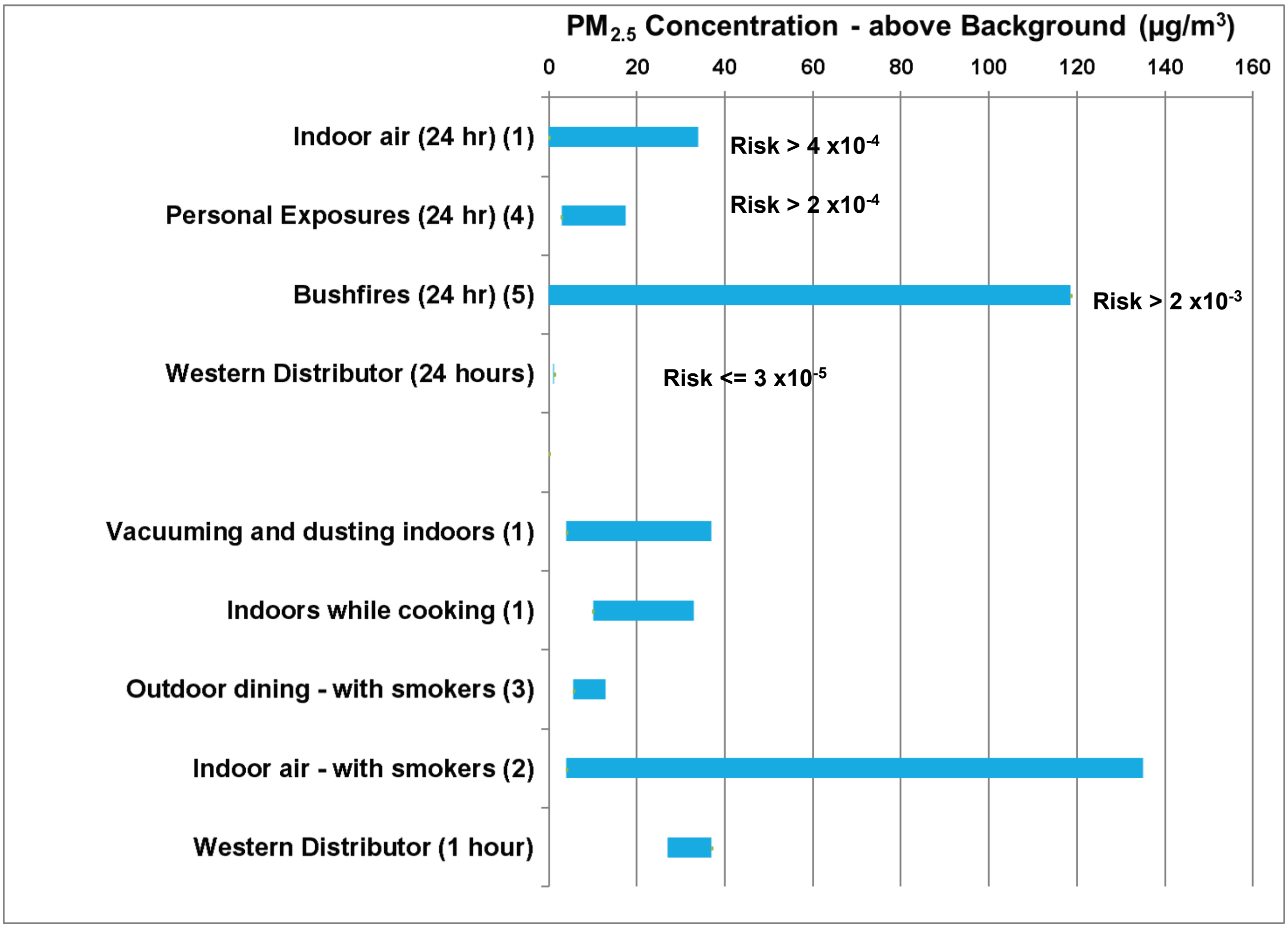


Figure C1: Comparison of incremental (above background) $PM_{2.5}$ concentrations for a range of events and activities

1 – Data for range of indoor activities for homes in Brisbane (Morawska et al. 2004). Range for 24 hour average concentrations is similar to but lower than reported in other studies in Australia (CAWCR 2010). The peak $PM_{2.5}$ concentrations in the kitchen during cooking have been reported to be significantly higher than present in the graph above, with levels up to 745 µg/m^3 (He et al. 2004). The range reported for cooking activities in Australia are similar to the range reported in other countries (Abdullahi et al. 2013).

2 – Data for $PM_{2.5}$ levels in indoor venues in Western Australia (Stafford et al. 2010).

3 – Data for $PM_{2.5}$ in 69 outdoor dining areas in Melbourne (Cameron et al. 2010).

4 – Personal exposures throughout a day that include cooking, cleaning, burning of candles and other activities undertaken throughout the day (increment presented is the 25th to 75th percentile above the median background) (Sorensen et al. 2005).

5 – Data for 24 hour measurements of $PM_{2.5}$ that include bushfire events in Sydney (Burgers & Walsh 2002). Significantly higher peak concentrations of $PM_{2.5}$ (>500 µg/m^3) are often reported when bushfires are present (CSIRO 2008)

Table C1: Summary and comparison of calculated $PM_{2.5}$ risks in off-site community areas for projects completed, approved or under construction in Australia

Max Incremental PM increase from project (µg/m^3, annual average)	Max Incremental Individual Risk
0.1 (NorthConnex and WestConnex)	$2x10^{-5}$, 2 in 100,000
0.07 (M5 stack and Brisbane Northern Link Project)	1 in 100,000
0.1 to 1.3 (major roadway widening/upgrade)	2 in 100,000 to 2 in 10,000
0.2 to 1.4 (thermal desorption remediation projects – Homebush Bay and Villawood)	4 in 100,000 to 3 in 10,000
0.6 to 1.5 (long-term development/construction)	1 to 3 in 10,000
Up to 4 (quarry)	7 in 10,000

C4 Determining project-specific risk criteria

Determining an acceptable risk level for the assessment of incremental risks from exposure to air pollutants and noise is challenging as there is currently no specific guidance available. When determining what may be an acceptable risk level, approaches that are available from other regulatory guidance has been considered. These guidance relate to an incremental lifetime or annual risk level that may be applied at either a community exposure level or an individual level. The calculation of risks associated with nitrogen dioxide, particulate and noise exposures relates to an annual risk and hence reference to other guidance to determine an acceptable risk relates to chronic risks.

Table C2 presents a summary of the available guidance on chronic risk levels available in other guidance, particularly related to the assessment of air pollution.

Table C2: Risk levels in other Australian regulatory guidance

Source	Incremental risk		
	1 in 1,000,000	**1 in 100,000**	**1 in 10,000**
Air pollution based guidance			
NEPC (NEPC 2011) (community/population mortality risks)		As low as possible but this is upper limit	
NSW Health 2017 (community/population mortality from smoke events up to 3 months)	< Negligible ↔ Low	↔ Moderate	≥High
NSW EPA (NSW EPA 2016) for the assessment of localised impacts from specific projects	<Negligible	↔ Requires best practice to minimise emissions	>Unacceptable
Other guidance (not specifically air pollution based)			
NSW Planning (NSW Planning 2011) for annual fatality risks from hazardous industry	↔ Acceptable		
NEPC (contaminated land) (NEPC 1999 amended 2013) for the assessment of lifetime exposures to genotoxic carcinogens – localised impacts	<Negligible	≤Acceptable >Unacceptable	
NHMRC (drinking water) (NHMRC 2011 updated 2018) for the assessment of lifetime exposures to genotoxic carcinogens – population impacts	≤Acceptable (basis for drinking water guidelines)		

In addition to the above, a number of recent road tunnel projects (NorthConnex and WestConnex in NSW and West Gate Tunnel in Victoria) have adopted project-specific criteria of <1 in 1,000,000 (10^{-6}) as a negligible risk, > 1 in 10,000 (10^{-4}) as an unacceptable risk and between 1 in 1,000,000 (10^{-6}) and 1 in 10,000 (10^{-4}) as an acceptable or tolerable risk. These projects have been approved.

Based on the discussion presented above it is apparent that providing a clear definition of an acceptable risk is challenging. For this project, however the following has been determined and adopted.

Negligible risk

There is a general consensus that risks below 10^{-6} are considered to be negligible.

Acceptable risk

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

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

The acceptability of risk also depends on the population exposed to the pollutant or stressor, and the type of risk calculation undertaken.

For the assessment of localised impacts relevant to the assessment of nitrogen dioxide and particulate matter, there is limited guidance available. The assessment of community/population risk provides an evaluation of potential health impacts within a larger population based on the average (or population weighted average) change in exposure that occurs within that population or region. For the assessment of nitrogen dioxide and particulate matter such calculations are appropriate as they draw on exposure-response relationships that are derived from population wide epidemiological studies (where regional or average air quality is evaluated against changes in population health).

Within any such region or larger population there will be areas where exposures and risks will be higher, as some individuals are located closer to localised sources, and some areas where exposures and risks will be lower, as some individuals will be well away from localised sources. This will also be the case, but not evaluated, with the populations considered in the underlying epidemiological studies from which the exposure-response relationships are derived. For the assessment of a local source, it is important to provide an upper limit for the localised exposures and risks to minimise health impacts associated with these sources. Such a limit will be higher than that adopted for the assessment of community/population risks as noted above. However, it should not be so large that risks are in the range that is considered to be unacceptable.

A level of 10^{-4} for increased risk (one chance in 10,000) has been generally adopted by health authorities as a point where risk is considered to be unacceptable in the development of drinking water guidelines (that impact on whole populations) (for exposure to carcinogens as well as for annual risks of disease (Fewtrell & Bartram 2001)), from the USEPA and in the evaluation of exposures from air pollutants from specific sources (NSW DEC 2005). Hence it is relevant to consider an upper limit for a localised risk that is no greater than 10^{-4} (above which risk would be considered unacceptable).

This upper level of risk for the assessment of localised impacts, 10^{-4}, is 10 times higher than the level adopted for the assessment of community or population risks (NEPC 2011). Adopting an upper limit for the assessment of localised impacts that is 10 times higher than that adopted for population exposures is consistent with the difference in acceptable risks adopted for population exposures to carcinogens (10^{-6} as outlined by the NHMRC (NHMRC 2011 updated 2018)) and the assessment of localised carcinogenic risks from contaminated land (10^{-5} as outlined by NEPC (NEPC 1999 amended 2013)).

On the basis of the above an upper limit or management risk level of 10^{-4} has been determined to assist in the interpretation of localised impacts.

C5 Determination of significance of population impacts

The assessment of potential health impacts associated with emissions to air from the project has not only calculated an increased annual risk, relevant to the health endpoints considered, but also a change in the incidence, ie the additional (or saving of) number of cases, of the adverse effects occurring within the population potentially exposed. The calculated change in incidence need to be considered in terms of what may be significant.

In relation to the calculated change in incidence of an adverse health effect occurring in a population, the following is noted for the primary health indicators (based on statistics available from NSW Health):

- In relation to mortality (all causes), the health statistics available show that for the year 2011/2012 the variability in all admissions data reported (based on the 95 per cent confidence interval for data reported in Sydney) is around ± 2.5 per cent. This is the variability in the data reported in one year. Each year the mortality rate also varies with around one per cent variability reported in the mortality rate (number reported for all causes) between 2010/11 and 2011/12. Based on the population considered in this assessment and the baseline incidence, a one per cent variability results in ± 10 cases per year. Changes in mortality within this range would not be detected (above normal variability) in the health statistics

- In relation to cardiovascular disease hospitalisations, the health statistics available show that for the year 2013/2014 the variability in all admissions data reported (based on the 95 percent confidence interval for data reported in Sydney) is around ± two percent. This is the variability in the data reported in one year. Each year the rate of hospitalisations (all ages) also varies with around two to three per cent variability reported in the number of hospitalisations for people aged 65 years and older in each year between 2010/11 and 2013/14. Based on the baseline incidence of cardiovascular hospitalisations considered in this assessment for individuals aged 65 years and the population considered in this assessment a variability of two per cent equates to ± 40 cases per year. Changes in cardiovascular hospitalisations in the population aged 65 years and older within this range would not be detected (above normal variability) in the health statistics

- In relation to respiratory disease hospitalisations, the health statistics available show that for the year 2013/2014 the variability in all admissions data reported (based on the 95 per cent confidence interval for data reported in Sydney) is around ± six per cent. This is the variability in the data reported in one year. Each year the rate of hospitalisations (all ages) also varies with around three to four per cent variability reported in the number of hospitalisations (all ages) in each year between 2011 and 2014. Based on the baseline incidence of respiratory hospitalisations considered in this assessment for individuals aged 65 years and older, and the population evaluated in this assessment, a variability of three per cent equates to ± 25 cases per year. Changes in respiratory hospitalisations in the population aged 65 years and older within this range would not be detected (above normal variability) in the health statistics.

Where changes in air quality associated with this project are well below 10 cases per year they are considered to be within the normal variability of health statistics. For evaluating impacts form this project a 10 fold margin of safety has been included to determine what changes in incidence may be considered negligible within the study population. This means that changes in the population incidence of any health effect evaluated that is less than one case per year are considered negligible.

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Appendix D Health risk calculations: changes in nitrogen dioxide exposures

Health impacts associated with changes in nitrogen dioxide have been calculated on the basis of predicted changes in annual average nitrogen dioxide concentrations for 2024 and 2034.

Risks and population incidence have been calculated for each individual receptor for the health endpoints and exposure-response functions listed in **Table D1**.

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

Table D1: Adopted exposure-response relationships for assessment of changes in nitrogen dioxide concentrations

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

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

The attached spreadsheets present the calculations undertaken for population/community risks and incidence as well as localised changes.

To assist in understanding the calculations presented an example calculation is presented below in relation to mortality (all cause), for the maximum localised change in nitrogen dioxide concentration in 2034. The air quality modelling provided the change in nitrogen dioxide from all individual receptors with the maximum change in annual average for this scenario being 5.68 μg/m^3.

Risk = β x ΔX x B

ΔX = change in annual average concentration of nitrogen dioxide with the project = 5.68 μg/m^3

B = baseline incidence relevant to all cause mortality (all ages), which is 555.5 per 100,000 for Coffs Harbour LGA, or 0.005555 per person (refer to **Table 3.3**)

Risk = 0.00188 x 5.68 x 0.005555 = 5.9 x 10^{-5} = 6 x 10^{-5} rounded to 1 significant figures.

Appendix E Health risk calculations: changes in particulate exposures

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

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

The specific health effects (or endpoints) evaluated in this assessment include:

- Primary health endpoints:
  - Long-term exposure to $PM_{2.5}$ and changes in all-cause mortality (equal or greater than 30 years of age)
  - Short-term exposure and changes to the rate of hospitalisations with cardiovascular and respiratory disease (equal or greater than 65 years of age).
- Secondary health endpoints (to supplement the primary assessment):
  - Short-term exposure to PM_{10} and changes in all-cause mortality (all ages)
  - Long-term exposure to $PM_{2.5}$ and changes in cardiopulmonary mortality (equal or greater than 30 years of age)
  - Short-term exposure to $PM_{2.5}$ and changes in cardiovascular and respiratory mortality (all ages)
  - Short-term exposure to $PM_{2.5}$ and changes in emergency department admissions for asthma in children aged 1–14 years.

Table E1 summarises the health endpoints considered in this assessment, the relevant health impact functions (from the referenced published studies) and the associated β coefficient relevant to the calculation of a relative risk (refer to **Appendix A** for details on the calculation of a β coefficient from published studies).

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

Table E1: Adopted health impact functions and exposure-responses relationships

Health endpoint	Exposure period	Age group	Published relative risk [95 confidence interval] per 10 µg/m^3	Adopted β coefficient (as %) for 1 µg/m^3 increase in PM	Reference
Primary assessment health endpoints					
$PM_{2.5}$: Mortality, all causes	Long-term	≥30yrs	1.06 [1.04-1.08]	0.0058 (0.58)	Relationship derived for all follow-up time periods to the year 2000 (for approx. 500,000 participants in the US) with adjustment for seven ecologic (neighbourhood level) covariates (Krewski et al. 2009). This study is an extension (additional follow-up and exposure data) of the work undertaken by Pope (2002), is consistent with the findings from California (1999-2002) (Ostro et al. 2006) and is more conservative than the relationships identified in a more recent Australian and New Zealand study (EPHC 2010)
$PM_{2.5}$: Cardiovascular hospital admissions	Short-term	≥65yrs	1.008 [1.0059-1.011]	0.0008 (0.08)	Relationship established for all data and all seasons from US data for 1999 to 2005 for lag 0 (exposure on same-day)(strongest effect identified) (Bell 2012; Bell et al. 2008)
$PM_{2.5}$: Respiratory hospital admissions	Short-term	≥65yrs	1.0041 [1.0009-1.0074]	0.00041 (0.041)	Relationship established for all data and all seasons from US data for 1999 to 2005 for lag 2 (exposure 2 days previous)(strongest effect identified) (Bell 2012; Bell et al. 2008)
Secondary assessment health endpoints					
PM_{10}: Mortality, all causes	Short-term	All ages*	1.006 [1.004-1.008]	0.0006 (0.06)	Based on analysis of data from European studies from 33 cities and includes panel studies of symptomatic children (asthmatics, chronic respiratory conditions) (Anderson et al. 2004)
$PM_{2.5}$: Mortality, all causes	Short-term	All ages*	1.0094 [1.0065-1.0122]	0.00094 (0.094)	Relationship established from study of data from 47 US cities for the years 1999 to 2005 (Zanobetti & Schwartz 2009)
$PM_{2.5}$: Cardio-pulmonary mortality	Long-term	≥30yrs	1.14 [1.11-1.17]	0.013 (1.3)	Relationship derived for all follow-up time periods to the year 2000 (for approx. 500,000 participants in the US) with adjustment for seven ecologic (neighbourhood level) covariates (Krewski et al. 2009)
$PM_{2.5}$: Cardiovascular mortality	Short-term	All ages*	1.0097 [1.0051-1.0143]	0.00097 (0.097)	Relationship established from study of data from 47 US cities for the years 1999 to 2005 (Zanobetti & Schwartz 2009)

Health endpoint	Exposure period	Age group	Published relative risk [95 confidence interval] per 10 µg/m³	Adopted β coefficient (as %) for 1 µg/m³ increase in PM	Reference
$PM_{2.5}$: Asthma (emergency department admissions)	Short-term	1-14 years	--	0.00148 (0.148)	Relationship established from review conducted on Australian children (Sydney) for the period 1997 to 2001 (Jalaludin et al. 2008)
$PM_{2.5}$: Respiratory mortality (including lung cancer)	Short-term	All ages*	1.0192 [1.0108-1.0278]	0.0019 (0.19)	Relationship established from study of data from 47 US cities for the years 1999 to 2005 (Zanobetti & Schwartz 2009)

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

The attached spreadsheets present the calculations undertaken.

To assist in understanding the calculations presented an example calculation is presented below in relation to mortality (all cause for ages 30 years and older), for the maximum localised change in $PM_{2.5}$ concentration for the maximum impacted receptor in 2034. The air quality modelling provided the change in $PM_{2.5}$ from all individual receptors, with the maximum change in annual average for this scenario being 0.62 µg/m³.

Risk = β x ΔX x B

ΔX = change in annual average concentration of $PM_{2.5}$ with the project = 0.62 µg/m³

B = baseline incidence relevant to all cause mortality (ages 30 years and older). Where the maximum risks are being calculated, the baseline incidence for Coffs Harbour LGA = 1333 per 100,000 population = 0.01333 per person (refer to **Table 3.3**)

Risk = 0.0058 x 0.62 x 0.01333 = 4.8 x 10^{-5} = 5 x 10^{-5} rounded to 1 significant figure

Appendix F Uncertainties

F1 Overview

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

F2 Exposure concentrations and noise levels

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

Air quality

The air quality impact assessment (refer to the Air Quality Assessment (ERM 2019)) incorporates information on traffic volumes and composition from the traffic model and other information on the design of the project. The air quality assessment was conducted, as far as possible, with the intention of providing 'accurate' or 'realistic' estimates of pollutant emissions and concentrations. The estimation of air concentrations within the community utilises air dispersion models that are approved by the NSW EPA as suitable for providing estimates of air quality from surface road traffic. The modelling incorporates information on the local area such as terrain, meteorology and measured existing air quality. A number of conservative assumptions have been adopted in the modelling which means it is likely to have overestimated potential impacts.

Noise assessment

The noise impact assessment (refer to the Noise and Vibration Assessment report (ARUP 2019)) incorporates information on traffic volumes and composition from the traffic model and other information on the design of the project. The modelling also incorporates measured background noise levels and a range of inputs and assumptions in relation to noise generated from the project.

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

The model used in the assessment was validated based on existing information and traffic information. The accuracy of the model was observed to be acceptable and is noted to be generally consistent with experience on previous projects.

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

F3 Approach to the assessment of risk for particulates

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

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

Exposure-response functions

The choice of exposure-response functions for the quantification of potential health impacts is important. For mortality health endpoints, many of the exposure-mortality functions have been replicated throughout the world. While many of these have shown consistent outcomes, the calculated relative risk estimates for these studies do vary. This is illustrated by **Figures F1 to F3** that show the variability in the relative risk estimates calculated in published studies for the US (and Canadian) population that are relevant to the primary health endpoints considered in this assessment (USEPA 2012). A similar variability is observed where additional studies from Europe, Asia and Australia/New Zealand are considered.

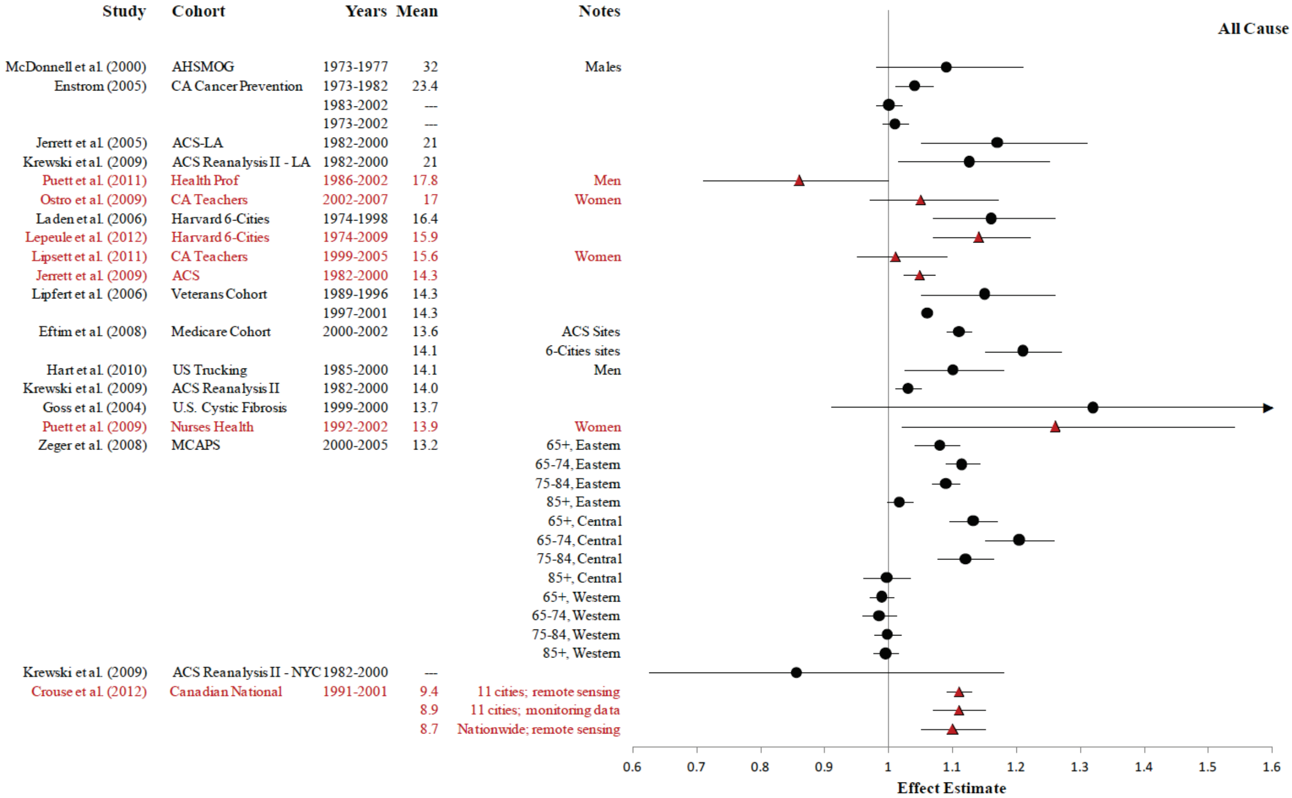

Figure F1: All-cause mortality relative risk estimates for long-term exposure to $PM_{2.5}$ (USEPA 2012, note studies in red are those completed since 2009)

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

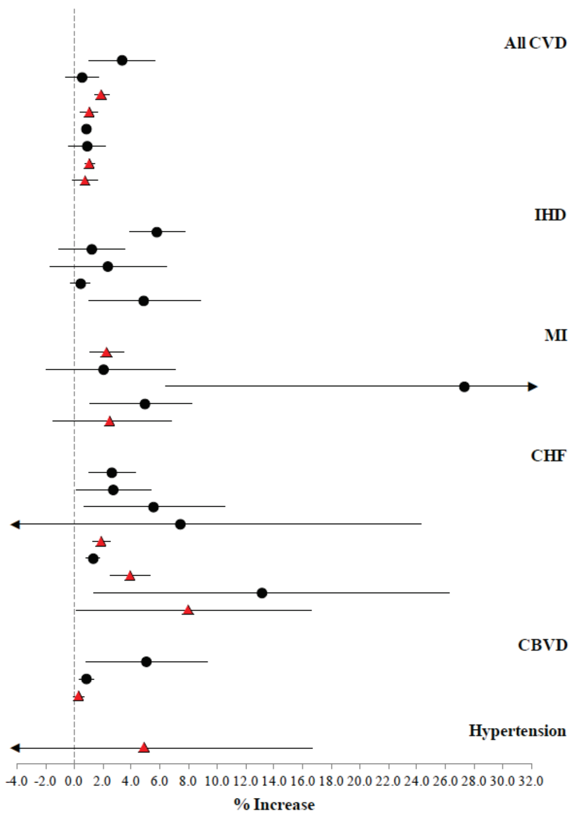

Figure F2: Per cent increase in cardiovascular-related hospital admissions for a 10 microgram per cubic metre increase in short-term (24-hour average) exposure to $PM_{2.5}$ (USEPA 2012, note studies in red are those completed since 2009)

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

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

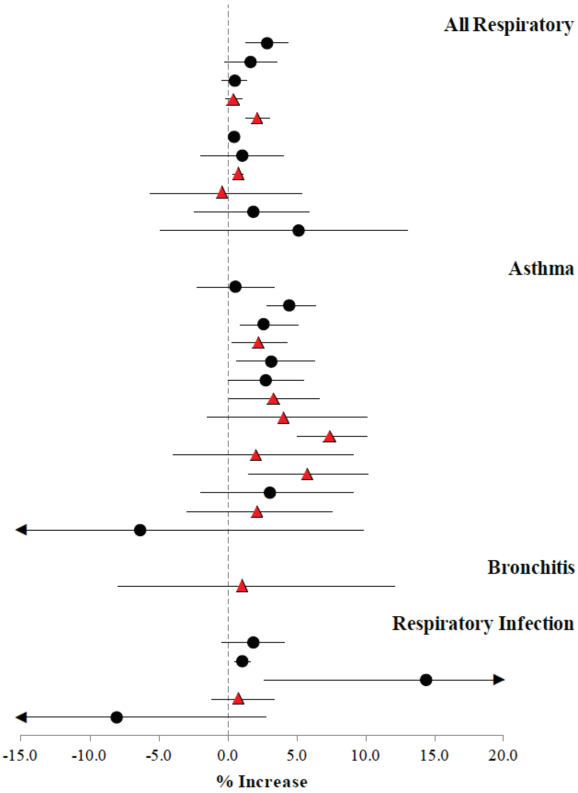

Figure F3: Per cent increase in respiratory-related hospital admissions for a 10 micrograms per cubic metre increase in short-term (24-hour average) exposure to $PM_{2.5}$ (USEPA 2012, note studies in red are those completed since 2009)

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

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

Shape of exposure-response function

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

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

Diesel particulate matter evaluation

The assessment of exposure to diesel particulate matter has assumed that 100 per cent of the $PM_{2.5}$ associated with the project is derived from diesel sources. This is considered to be a conservative assumption.

The health hazard conclusions associated with exposure to diesel particulate matter are based on studies that are dominated by exhaust emissions from diesel engines built prior to the mid-1990s. With current engine use including some new and many older engines (engines typically stay in service for a long time), the health hazard conclusions, in general, are likely to be applicable to engines currently in use.

However as new and cleaner diesel engines, together with different diesel fuels, replace a substantial number of existing engines; the general applicability of the health hazard conclusions may require further evaluation. The NEPC (NEPC 2009) has established a program to reduce diesel emissions from the Australian heavy vehicle fleet. This is expected to lower the potential for all diesel emissions over time.

An increase in the number of vehicle kilometres travelled (more than estimated in the traffic modelling) may limit the benefits of cleaner diesel vehicles.

F4 Approach to the assessment of risk for noise

The association between exposure to noise and adverse health effects is well documented and there are a number of robust studies available to characterise these effects. A number of relationships adopted in this assessment come from research where data from a number of studies have been combined. The available studies that are used to determine these relationships often utilise different measures of noise levels (differing between covering average day and evening or day evening and night) and different methods for measuring the disease end-points. This results in the use of some conservative assumptions when combining these data.

Many of the available studies relate to health effects in males, or include populations that are predominantly male. The reported outcomes of these studies have been assumed to equally apply to females.

F5 Co-pollutants and co-exposures

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

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

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

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

F6 Selected health outcomes

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

F7 Exposure time/duration

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

F8 Changing population size and demographics

The assessment presented has utilised information on the size of the population and distribution of the population in relevant ages from the ABS Census data from 2016. As discussed in the report the population in the study area is projected to increase significantly by 2036. In addition, a number of the LGAs are expecting a significant increase in the proportion of the population aged 65+ years.

The increase in population size and distribution does not affect the calculation of an individual risk. The key aspect that does affect this calculation is the baseline incidence of the health effects within the population. Based on statistics from NSW Health the baseline incidence of most of the health effects evaluated in this assessment have been relatively stable or decreasing over time (with improvements in health care). Changes in the population over time are not expected to result in any increase in the calculated individual risk.

For the calculation of the change in incidence in the community, the size and distribution of the population is important. The incidence numbers calculated for the project are low and unmeasurable, and even if the population were doubled the incidence of the key health effects would remain low and unmeasurable within the community.

F9 Baseline incidence for asthma

Some concern has been raised in the community that the baseline incidence of asthma reported in the statistics for the LGAs may not reflect more localised suburbs, or part suburbs, where the incidence of asthma may be perceived to be higher.

The calculated individual risks relevant to asthma presented in the health impact assessment have been further evaluated assuming that the baseline incidence reported for all the LGAs is double. Where this is assumed the calculated risk increases, but remains well below the unacceptable risk level of 10^{-4}.

This change in baseline incidence for asthma does not change the conclusions presented in this assessment.

F10 Application of exposure-response functions to small populations

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

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

F11 Overall evaluation of uncertainty

Overall the assessment of health impacts presented in this report has incorporated a range of assumptions and models that would have resulted in an overestimation of impacts. The most significant factors that result in the assessment providing conservative outcomes are as follows:

- Modelling of air quality impacts – this has included a range of conservative assumptions about the type of vehicles and the emissions to air that may come from these vehicles over time. The assessment has also utilised a model to predict ground level concentrations (i.e. concentrations in the community) that are expected to be conservative.
- Assessment of noise impacts – this has been undertaken using a largely qualitative approach, however some quantitative estimates of risk and levels of annoyance and sleep disturbance has been included. These estimates are based on modelled predicted changes in noise levels which are expected to be conservative. In addition, the assessment of health

impacts has utilised the maximum daily change in noise in the community, rather than the change in annual average noise levels (which the noise exposure – response (health effects) relationships are based on).

- Community exposures – there are a number of assumptions adopted in the characterisation of exposure that would have overestimated exposure:

  - It is assumed that the maximum changes in localised air quality, regardless of where this may occur (e.g. industrial area, in a roadway, open space area or residential area), affects a resident

  - All exposures to changes in air quality and noise that occur, in all areas, assume that all residents are at home all day, every day for a lifetime, and that changes in outdoor air pollution are mirrored indoors.

  The above is expected to overestimate exposures and risks in the community.

- Exposure-response – the relationships utilised in this assessment are based on the most current, robust studies that are relate to health effects from exposure to changes in nitrogen dioxide, particulates and noise. The relationships adopted come from large epidemiology studies that include a number of co-pollutants (i.e. exposure occurs to a wide range of factors not just the pollutant being evaluated) and confounding factors that can result in more conservative relationships being developed. In addition, it is assumed the relationships adopted are linear and apply to small changes in air quality or noise, at levels that would not be measurable with air monitoring or noise monitoring equipment.

F12 References

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