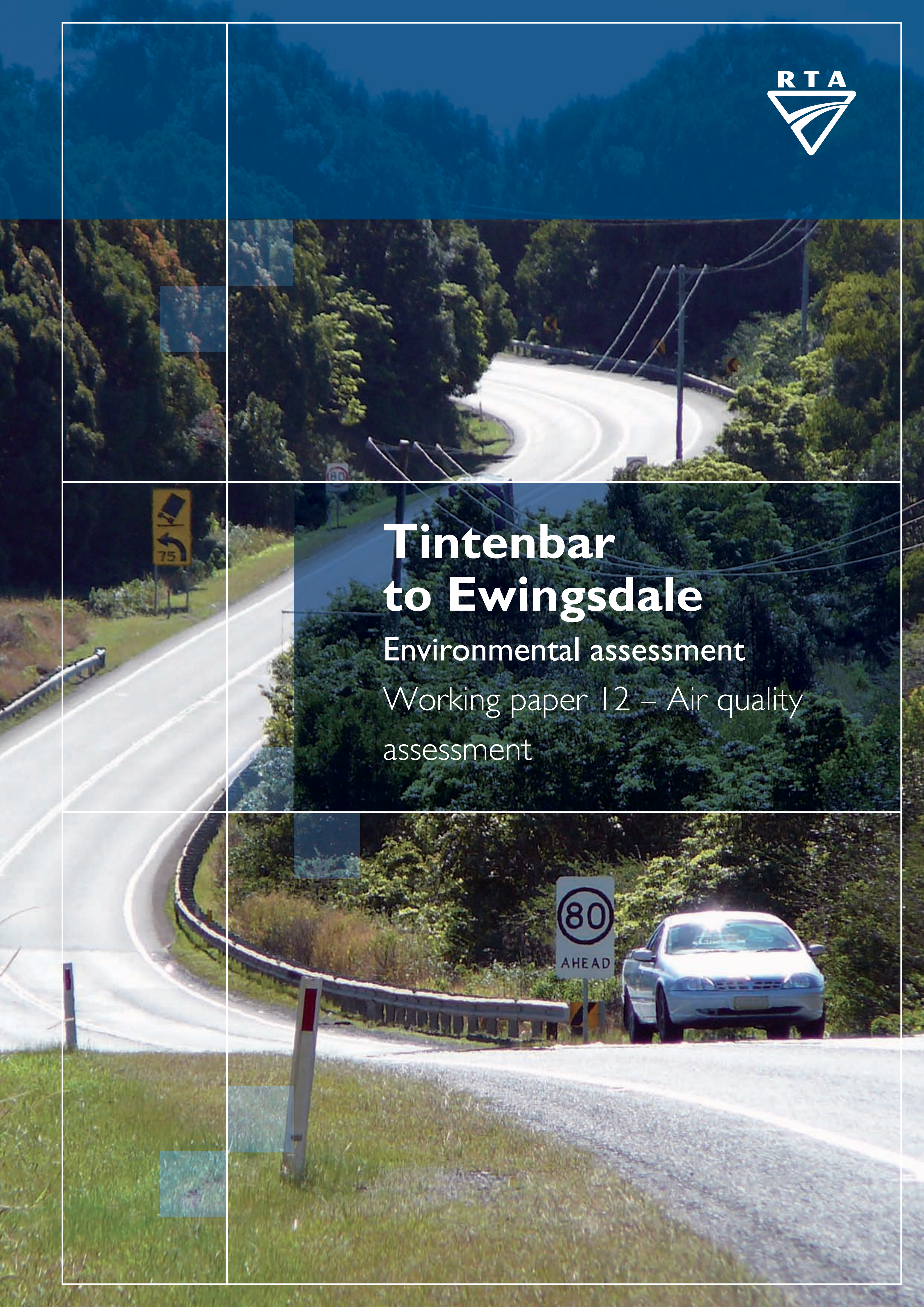

Tintenbar to Ewingsdale

Environmental assessment

Working paper 12 – Air quality assessment

AIR QUALITY ASSESSMENT:
UPGRADE OF THE PACIFIC HIGHWAY FROM TINTENBAR TO EWINGSDALE

June 2008

Prepared for
Arup

by
Holmes Air Sciences

Suite 2B, 14 Glen St
Eastwood NSW 2122
Phone : (02) 9874 8644
Fax : (02) 9874 8904
Email : has@holmair.com.au

EXECUTIVE SUMMARY

The following report presents an analysis of the air quality impacts of the proposed upgrade of the Pacific Highway from Tintenbar to Ewingsdale (the "Project"). The Project involves the construction and operation of approximately 17 kilometres (km) of dual carriageway, commencing from the northern section of the Ballina Bypass, through to Ewingsdale Road on the New South Wales (NSW) north coast. The Project also includes a 340 m long tunnel. This study focuses on air quality impacts arising from the Project.

Computer-based dispersion modelling has been used to quantify air quality impacts. The modelling provided information to assess the likely effect of the Project on local air quality. From the assessments that have been undertaken the following conclusions were drawn:

- Predicted pollutant concentrations (carbon monoxide, nitrogen dioxide and particulate matter) were below the relevant air quality criteria at all sensitive receptor locations for both the base and proposed upgrade cases.
- The proposed upgrade would provide the benefit of splitting the traffic and therefore providing some additional dispersion of the emissions.
- Predicted concentrations in the vicinity of the tunnel portals are all well within air quality criteria, taking account of conservative estimates of background concentrations.
- The proposed upgrade would approach to within 30 m of the Newrybar school playing fields where the predicted worst-case concentrations of pollutants would not cause significant deterioration of the air quality.

It was therefore concluded that there would be no adverse air quality impacts as a direct result of the Project.

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1. INTRODUCTION

This report has been prepared by Holmes Air Sciences for Arup, who are in turn acting for the NSW Roads and Traffic Authority (RTA). The RTA has proposed to upgrade the Pacific Highway between Tintenbar and Ewingsdale, on the north coast of New South Wales (NSW) (the "Project"). The purpose of this report is to quantitatively assess air quality impacts associated with the Project.

The Project involves the construction and operation of approximately 17 km of dual carriageway, commencing from the northern section of the Ballina Bypass approximately 100 m north of Ross Lane, through to Ewingsdale Road in the north.

The air quality assessment is based on the use of a computer-based dispersion model to predict air pollutant concentrations near selected sections of the road. The assessment considers the major air pollutants arising from motor vehicles and assesses the effect that the roadway could have on existing air quality. The dispersion model predictions have been compared to relevant regulatory air quality criteria.

In summary, the report provides information on the following:

- Proposed upgrade alignment and road design.
- Air quality criteria relevant for this project.
- Climatic and meteorological conditions in the area.
- Existing air quality in the area.
- Methods used for determining pollutant emissions and impacts.
- Model results and interpretation of predicted air quality impacts.

2. PREFERRED PROJECT

This section provides a description of the proposed upgrade.

The length of the proposed upgrade would be approximately 17 km starting at Ross Lane in Tintenbar and extending to the north to the existing Ewingsdale interchange, near the settlement of Ewingsdale. At Ross Lane, the proposed upgrade would connect to the north end of the Ballina bypass. The route is shown in **Figure 1**. Generally the proposed upgrade would be in close proximity to existing highway corridor from Ross Lane to the Bangalow bypass. The existing highway would be maintained for local and regional traffic.

From Bangalow, the proposed upgrade would diverge away from the Bangalow bypass to the northeast through Tinderbox valley. From there, the proposed upgrade would avoid the steep grades of St Helena Hill by way of a tunnel approximately 340 m long and 45 m below the ridge line. **Figure 2** shows the proposed location of the tunnel section.

North of the tunnel, the proposed upgrade alignment is located immediately to the east of the existing highway before tying into the Ewingsdale interchange.

The general features of the proposed upgrade would be:

- Four-lane divided carriageways (two lanes in each direction), with a wide median allowing for the future addition of a third lane in each direction.
- Class M standard over the full length of the proposed upgrade. In accordance with the RTA's Pacific Highway Design Guidelines, 'Class M' projects are designed to 110 km/h freeway standard. This means a controlled access road with divided carriageways, no access for traffic between interchanges, grade separation at all intersections and alternative routes available for local traffic through the provision of service roads or local arterial road networks.
- Conversion of the Ross Lane interchange into a full interchange by construction of north-facing ramps providing access between the local road network and the proposed upgraded highway to the north. A partial interchange at Ross Lane will be constructed as part of the Ballina bypass project.
- Modifications to the existing Ewingsdale interchange to provide full access between the modified local and regional road network and the highway.
- A half interchange at Ivy Lane. North-facing ramps would provide access between the local road network and the proposed upgraded highway to the north.
- A half interchange at Bangalow. South-facing ramps would provide access between the local road network, including to Bangalow and Lismore, and the proposed upgrade to the south. This arrangement would replicate the arrangement with the existing Bangalow bypass which also has south-facing ramps only.
- Six twin bridges and four underpasses allowing roads and creeks to pass underneath the proposed upgrade. These would include twin bridges above Byron Creek and the existing Casino-Murwillumbah railway on the north side of Byron Creek.
- Two bridges carrying local roads over the proposed upgrade, one for Broken Head Road and one about 500 m north of Lawlers Lane providing access to several

properties east of the upgrade. Protection screens would be provided on both bridges.

- Emergency u-turn and median crossovers at about 2.5 km intervals. These facilities incorporate lay-bys where vehicles could safely pull off the upgraded highway.
- Sedimentation basins to intercept run-off for treatment before discharging into the natural watercourses.
- Medians and outer verges, including safety barriers where required.
- Signage providing clear directions for traffic at the Ross Lane, Ivy Lane, Bangalow and Ewingsdale interchanges.
- Relatively flat gradients compared to the existing highway, with the maximum grade just south of Bangalow being approximately 5.4% over 1300 metres. There would also be a 4.4% grade over almost 2 km on the north side of the tunnel. An additional southbound climbing lane would be provided in both sections so that slow moving trucks would not be a significant safety hazard to other vehicles.
- The existing highway would be retained as a continuous road for local and regional traffic. It is further anticipated that between Ross Lane and Bangalow the existing highway would be handed over to the councils. Between Bangalow and Ewingsdale the existing highway would continue to function as a regional link between Lismore/Bangalow and the north and would be retained by RTA.
- Two significant diversions of the existing highway are proposed to retain it as a continuous local road. The first is just north of Emigrant Creek where the existing highway would be diverted underneath the bridge taking the proposed upgrade over Emigrant Creek. The other diversion is where the existing highway south of the Ewingsdale interchange is being diverted to a roundabout on the western side of the interchange.
- Additional local roads and property access would be provided including:
    - safe access to all properties affected by the proposed upgrade, either directly to the existing highway or indirectly via a new local access road.
    - new local roads as required to link the proposed interchanges with the existing highway and other local access roads.
- The proposed upgrade would incorporate twin parallel tunnels under St Helena ridge. The tunnels would each be about 340 m long and about 45 m below St Helena Road. One tunnel would be provided for each carriageway, separated by a rock pillar. The northbound tunnel would be 11.5 m wide between barriers, providing sufficient width for linemarking as 3 lanes in each direction if required in the future. The southbound tunnel would be 12.5 m wide to incorporate the southbound climbing lane while still allowing 1 m wide shoulders on each side. In view of the additional southbound lane proposed initially, there is no provision for adding an additional lane to the southbound carriageway through the tunnel. The precise dimensions of the tunnel may be modified slightly during detailed design.
- Intersections and interchanges designed to achieve at least a level of service C, 20 years after opening for the 100th highest hourly volume.

Land use in the project area is a mix of rural and rural residential with the main townships being Bangalow, Newrybar and Ewingsdale. The dominant land use is agriculture, including sugar cane and beef cattle grazing. There are rural residential clusters across the area as well as individual rural residential allotments located among larger rural land holdings. There are a number of community buildings within the area such as schools, religious buildings, local halls, and a cemetery.

3. AIR QUALITY CRITERIA

When assessing any project where pollutant emissions are involved, it is necessary to compare the impacts with relevant air quality criteria. Air quality criteria are used to assess the potential for ambient air quality to give rise to adverse health or nuisance effects.

The most significant emissions produced from motor vehicles are CO, NO_x and PM_{10}. **Table 1** summarises the current air quality assessment criteria noted by the Department of Environment and Climate Change (DECC). Generally, the air quality criteria relate to the total burden of pollutants in the air and not just the pollutants from the sources being modelled. In other words, some consideration of background levels needs to be made when using these criteria to assess impacts. The estimation of appropriate background levels will be discussed further in **Section 4.3**.

The primary air quality objective for most projects is to ensure that the air quality criteria listed in **Table 1** are not exceeded at any location where there is a possibility of human exposure for the time period relevant to the criterion. However, it is good environmental practice to pursue any opportunities that may exist to minimise exposure to these pollutants. The criteria are set to protect to the health of all sensitive receptor types.

Table 1 : Air quality criteria relevant to this project

Pollutant	Criterion	Averaging period	Agency
Carbon monoxide (CO)	**25 ppm or 30 mg/m^3** 9 ppm or 10 mg/m^3	**1-hour maximum** 8-hour maximum	DECC DECC
Nitrogen dioxide (NO_2)	**0.12 ppm or 246 µg/m^3** 0.03 ppm or 62 µg/m^3	**1-hour maximum** Annual mean	DECC DECC
Particulate matter less than 10 µm (PM_{10})	**50 µg/m^3** 30 µg/m^3	**24-hour maximum** Annual mean	DECC DECC
Particulate matter less than 2.5 µm ($PM_{2.5}$)	25 µg/m^3 8 µg/m^3	24-hour maximum Annual average	NEPM NEPM
Air Toxics (investigation levels only and not project-specific goals)			
Benzene	0.003 ppm	Annual average	NEPM (Air Toxics)
Benzo(a)pyrene	0.3 ng/m^3	Annual average	NEPM (Air Toxics)
Formaldehyde	0.04 ppm	24-hour maximum	NEPM (Air Toxics)
Toluene	2 ppm or 8 mg/m^3 1 ppm 0.1 ppm	24-hour maximum 24-hour maximum Annual average	EPA NEPM (Air Toxics) NEPM (Air Toxics)
Xylene	0.25 ppm 0.2 ppm	24-hour maximum Annual average	NEPM (Air Toxics) NEPM (Air Toxics)

In addition, the National Environment Protection Council of Australia (NEPC) has determined a set of air quality criteria for adoption at a national level, which are part of the National Environment Protection Measures (NEPM). Included in **Table 1** are the NEPM standards for $PM_{2.5}$ which are termed "investigation levels" rather than criteria that are applied on a project basis. There are currently no air quality assessment criteria for $PM_{2.5}$ in NSW. Also included in this table are air quality goals for air toxics developed by NEPC as part of their National Environment Protection (Air Toxics) Measure (**NEPC, 2004**). At this stage values for air toxics are termed "investigation levels" rather than goals which are applied on a project basis.

It is important to note that the standards established as part of the NEPM are designed to be measured to give an 'average' representation of general air quality. That is, the NEPM monitoring protocol was not designed to apply to monitoring peak concentrations from major emission sources (**NEPC, 1998**).

The basis of these air quality criteria and, where relevant, the safety margins that they provide are discussed in detail in **Appendix A**. Also included in **Appendix A** is a discussion of the health effect of diesel emissions. In 2001 the NEPC created a NEPM for diesel vehicle emissions (**NEPC, 2001**).

The Diesel NEPM provides four broad approaches to manage emissions from diesel vehicles:

1. Specify emissions standards for new vehicles and have manufacturers meet them.
2. Provide appropriate clean fuels.
3. Specify emissions standards for in-service vehicles and improve the emissions performance of these vehicles to bring them into compliance with these standards.
4. Reduce vehicle use and encourage efficient driving behaviour.

Under the Diesel NEPM, emissions from in-service diesel vehicles need to be managed as a strategic option for:

- Reducing the exposure of the community to criteria pollutants, smoke and any other negative impacts associated with emissions from diesel road vehicles.
- Achieving the goal of the Air NEPM.

The Diesel NEPM provides the following guidelines to reduce emissions from the in-service diesel fleet:, including:

- Guideline on smoky vehicle programs.
- Guideline on vehicle emission testing and repair programs.
- Guideline on audited maintenance programs for diesel vehicles.
- Guideline on diesel retrofit programs.
- Guideline on diesel engine rebuild programs.

4. EXISTING ENVIRONMENT

This section describes the dispersion meteorology, general climate and existing air quality of the region. As well as information on prevailing wind patterns, historical data on temperature, humidity and rainfall are presented to give a more complete picture of the local climate.

4.1 Dispersion Meteorology

Dispersion models typically require information on temperature, wind speed, wind direction, atmospheric stability class[1] and mixing height[2]. These factors are important for determining the direction and rate at which pollutants will disperse.

There are no known weather stations near the proposed upgrade which can be used to characterise the local wind patterns. The nearest automatic weather station with wind data that could be used for air dispersion modelling is at Ballina Airport, approximately 10 km to the south of the Project area. This station is operated by the Bureau of Meteorology.

Meteorological conditions in the hills above the escarpment are likely to differ from those experienced at Ballina due to differences in exposure and drainage patterns. Some parts of the proposed upgrade are located to the west of the escarpment amongst steep hilly terrain, whereas Ballina Airport is located on the floodplain to the east of the escarpment. Nevertherless, the Ballina data could contain some broader scale wind patterns of north coast NSW that are common to both areas. The wind data collected from Ballina Airport have been examined for this study.

To aid in the assessment of projects where site-specific meteorological data are not available, the Commonwealth Scientific and Industrial Research Organisation (CSIRO) has developed a prognostic model – The Air Pollution Model (TAPM) – which predicts flows important to local scale meteorology, such as sea breezes and terrain induced flows. It uses data from the Bureau of Meteorology Global AnalysiS and Prediction (GASP). This feeds into the Limited Area Prediction System (LAPS) (**Puri *et al.,* 1997**) which is used to provide meteorological predictions. TAPM uses information such as terrain and sea breezes to fine tune these data to provide meteorological data on a smaller scale, in conjunction with larger scale synoptic scale meteorological fields. The model is discussed further in the user manual (**Hurley, 2002**).

In the absence of suitable site-specific or site representative meteorological data, the DECC have allowed the use of prognostic meteorological models such as TAPM (**DEC, 2005**). A synthetic, site-specific meteorological data set for the study area was created using TAPM Version 2.0 and the resultant wind data have been examined and described below. Tinderbox Valley was the area selected for the TAPM meteorological simulation and it should be noted that TAPM would produce similar output for most regions of the project area.

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[1] In dispersion modelling stability class is used to categorise the rate at which a plume will disperse. In the Pasquill-Gifford-Turner stability class assignment scheme there are six stability classes A through to F. Class A relates to unstable conditions such as might be found on a sunny day with light winds. In such conditions plumes will spread rapidly. Class F relates to stable conditions, such as occur when the sky is clear, the winds are light and an inversion is present. Plume spreading is slow in these circumstances. The intermediate classes B, C, D and E relate to intermediate dispersion conditions.

[2] The term mixed-layer height refers 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 3 shows the annual and seasonal windroses compiled from hourly wind speed and wind direction data collected at Ballina Airport. Annually, the predominant winds are from the north although winds from the west-southwest are also common. The northerly winds are observed in the summer months, while winds from the west-southwest are in winter. Autumn and spring show a combination of the summer and winter patterns.

Calm conditions (winds less than or equal to 0.5 m/s) occur for 12.5% of the time at the Ballina site and the annual average wind speed is 3.9 m/s.

Annual and seasonal windroses created from the TAPM generated wind data are shown in **Figure 4**. The TAPM generated data show some similarities in wind directions to the Ballina Airport data although the wind speeds are higher. The annual average wind speed from the TAPM data was 4.9 m/s (compared with the average for Ballina at 3.9 m/s, discussed above). Also, the TAPM data show a much lower frequency of calm conditions at 0.5%.

In summary, while the Ballina Airport and TAPM derived meteorological data may contain some conditions that are representative of the conditions along the proposed route, it is likely that these data will not contain all the finer scale meteorology along the proposed road reserve. To overcome this limitation, the approach to the assessment has been to use a dispersion model that simulates worst-case meteorology. In this regard, "worst-case" meteorology represents stable atmospheric conditions ("F" class), light winds (1 m/s) and wind directions that produce the maximum concentrations near roadside. The approach to the modelling is further discussed in **Section 6**.

4.2 Local Climatic Conditions

The Bureau of Meteorology collects climatic information from Byron Bay, to the northeast of the proposed upgrade. A range of meteorological data collected from this station are presented in **Table 2** (**Bureau of Meteorology, 2007**).

Temperature and humidity data consist of monthly averages of 9 am and 3 pm readings. Also presented are monthly averages of maximum and minimum temperatures. Rainfall data consist of mean monthly rainfall and the average number of rain days per month.

Table 2 : Climate information for the study area

Byron Bay	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Mean daily maximum temperature (°C)	27.5	27.6	26.5	24.5	22	19.8	19.4	20.3	22.2	23.3	24.7	26.4	23.7
Mean daily minimum temperature (°C)	20.8	20.6	19.5	17.2	15	12.5	11.7	12.5	14.4	16.1	17.8	19.5	16.5
Mean 9 am air temp (°C)	23.8	23.5	22.8	20.7	17.7	15.4	14.5	15.6	18.1	20.1	21.4	22.9	19.7
Mean 9 am wet bulb temp (°C)	21.4	21.4	20.6	18.3	15.1	12.9	11.8	12.6	15	17.2	18.7	20.3	17.1
Mean 9 am relative humidity (%)	81	82	81	79	75	74	71	70	71	74	77	79	76
Mean 3 pm air temp (°C)	25.7	25.7	24.8	22.8	20.2	18.2	17.6	18.5	20	21.4	23.1	24.6	21.9
Mean 3 pm wet bulb temp (°C)	22.4	22.5	21.6	19.6	16.8	14.8	14	14.5	16.3	18	19.6	21.3	18.4
Mean 3 pm relative humidity (%)	74	75	75	73	71	68	66	64	67	71	72	75	71
Mean monthly rainfall (mm)	164.1	184.4	208	183.1	179.6	164.4	107.6	92.8	66.5	102.9	120.3	143.1	1721
Mean no. of raindays	11.1	12.1	13.3	12.3	11.6	9.7	8	7	6.6	8.7	9.2	9.7	9.9
Mean no. of clear days	6	5.1	6.4	7.9	7.9	9.5	12.4	13.7	13.5	9.7	7.8	7.7	9
Mean no. of cloudy days	11.8	11.3	11.2	9.9	10.7	9.8	7.8	6.5	5.9	8.7	9.4	10	9.4

Monthly Climate Statistics for 'BYRON BAY (CAPE BYRON LIGHTHOUSE)' [SN 058009], Commenced: 1948, Last Record: 2007, Latitude: 28.64 Degrees South, Longitude: 153.64 Degrees East, Elevation:95 m, State: NSW.

Temperature data show that February is typically the warmest month with a mean daily maximum of 27.6°C. July is the coldest month with a mean daily minimum of 11.7°C.

Rainfall data collected at Byron Bay show that January is the wettest month with a mean rainfall of 208 mm over 13 rain days. Annually the area experiences, on average, 1,721 mm of rain.

4.2.1 Fogs and frosts

Fog is defined as a "suspension of very small water droplets in the air, reducing visibility at ground level to less than a kilometre". If the visibility exceeds 1000 metres then the obscurity is a mist (**Bureau of Meteorology, 2007**). Fogs occur when there is a temperature inversion in the atmosphere, and are an indicator of stable atmospheric conditions.

Alstonville TFRS is the nearest station to the study area where observations of frost and fog have been recorded for the Bureau of Meteorology. Alstonville is located approximately 10 km to the WNW of Ballina and the station is at an elevation of 140 m above sea level. Fog data collected from 1963 to present suggest that fogs are rare in this area, with only 15 fog and 14 frost observations recorded over 40 years. These observations, supplied by the Bureau of Meteorology, are shown in **Table 3**. Fogs have been observed in the months of February, March, April, May, July, November and December, while frosts have been observed from June to September.

Table 3 : Fog and frost observations at Alstonville Tropical Fruit Research Station

Since 1963	
Fogs	**Frosts**
4/02/1968	12/07/1974
4/06/1974	28/07/1974
19/11/1974	6/08/1974
28/02/1975	25/07/1977
18/03/1975	8/07/1978
20/02/1982	12/07/1978
9/03/1986	13/07/1978
23/04/1986	15/09/1978
28/07/1986	11/08/1979
24/05/1993	12/07/1981
15/02/1997	23/06/1985
22/06/1997	24/06/1985
30/12/1999	25/06/1985
14/03/2004	2/07/2002
8/11/2004	

Community observations indicate that fog frequency in the region is higher than indicated by the observations at Alstonville. The Alstonville station is at a slightly higher elevation than the parts of the proposed upgrade that were identified as being prone to fogs, and may therefore experience fewer fogs. However, the higher frequency of fogs reported by the community may also be because there has been no strict distinction made between fogs and mists.

A map of fog prone areas has been compiled from local community observations, and is presented in **Figure 5**. This map shows that areas of land at lower elevations and confined in valleys are prone to fog formation. To the east of the escarpment, fog is likely to occur up to an elevation of 30 m above sea level, while on the plateau to the west of the escarpment, fog is likely to occur adjacent to streams and is confined by valleys.

4.3 Existing Air Quality

Air quality criteria refer to pollutant levels which include the contribution from specific sources as well as existing sources. To fully assess impacts against all the relevant air quality criteria (discussed in the **Section 3**) it is necessary to have information or estimates on existing pollutant levels in the area in which the modelled sources are likely to contribute to these levels.

Air quality monitoring has not been carried out along the proposed upgrade. However, monitoring data have been collected by the RTA at the Pacific Highway near Coffs Harbour. The monitoring site was located at the Pacific Highway between Korora Public School and the Korora Rural Fire Brigade, north of Coffs Harbour. Due to the proximity of the monitoring location to the highway, the concentrations include traffic emissions and are therefore likely to be higher than background levels in the area. The data therefore give a conservative indication of the air quality that would be experienced on the north coast of NSW close to the Pacific Highway. These data have been used in **Section 7.1** to provide an estimate of background levels of pollutants.

Concentrations of CO, NO_x, NO_2, NO, PM_{10} and $PM_{2.5}$ were measured, along with meteorological data, from October 2005 to January 2006. The maximum 1-hour and 8-hour average CO concentrations were 1.2 mg/m^3 and 0.3 mg/m^3, compared with the DECC criteria of 30 mg/m^3 and 10 mg/m^3, respectively. The 1-hour average and 8-hour average CO data are shown in **Figures 6** and **7** respectively. The maximum 1-hour average NO_2 concentration was

73.8 µg/m^3 compared with the DECC goal of 246 µg/m^3, while the maximum 24-hour average PM_{10} concentration was 37.8 µg/m^3 compared with the DECC goal of 50 µg/m^3. The 1-hour average NO_2 and 24-hour average PM_{10} data are shown in **Figures 8** and **9** respectively.

Although there are no project goals for $PM_{2.5}$ in NSW, it is useful to compare the measured levels shown in **Figure 10.** The maximum measured 24-hour concentration of 15.4 µg/m^3 is below the NEPM goal of 25 µg/m^3.

In summary, all measured levels of pollutants were below their respective air quality goals. These measured values would include emissions from the traffic on the Pacific Highway which would be the major contributor to carbon monoxide and nitrogen dioxide. Particulate matter will have contributions from other sources.

5. ESTIMATION OF POLLUTANT EMISSIONS FROM ROADS

This section provides information relating to the estimation of pollutant emissions from a road section with known or projected traffic volumes. The source of emission factors is discussed as well as the traffic information used in the study. A summary of the calculated pollutant emissions for the various sections of existing and proposed highway is provided in this section.

Emissions from vehicles vary depending on a number of factors. The primary factors which influence the vehicle emissions from a roadway include:

- Mode of travel (a measure of the stop/start nature of the traffic flow and the average speed).
- Grade of road.
- Type of vehicles and vehicle ages.

In general, a congested road with numerous intersections will generate higher emissions than a free flowing road with no intersections. Steeper road grades generate higher emissions due to the higher engine loads, and roads with a higher percentage of heavy vehicles typically generate higher emissions.

5.1 Emission Data

The most significant emissions produced from motor vehicles are CO, NO_x and PM_{10}. Estimated emissions of these pollutants are required as input to computer-based dispersion models in order to predict pollutant concentrations in the area of interest and to compare these concentrations with associated air quality criteria.

As discussed above, the primary factors which influence emissions from vehicles include the mode of travel, the grade of the road and the mix or type of vehicles on the road. It is important to estimate pollutant emissions using as much information as is known about these factors.

The general approach to derive total pollutant emissions from a road section is simply to multiply the total number of vehicles on the road section by the pollutant emission per vehicle (the emission factor). Pollutant emission factors are typically provided in units of grams per kilometre or sometimes as grams per hour. There are a number of sources of these emission factors.

The primary source of emission factors, referenced for this study, are from the World Road Association, referred to as PIARC (formerly the Permanent International Association of Road Congress).

PIARC is a European-based organisation focused on road transport related issues. Technical committees coordinated by PIARC regularly circulate documents on many aspects of roads and road transport, including road tunnels.

In 1995, PIARC published a document (**PIARC, 1995**) primarily as the basis of design for tunnel ventilation systems. The document, entitled "Vehicle emissions, air demand, environment, longitudinal ventilation", also provided comprehensive vehicle emissions factors for different road gradients, vehicle speeds and for vehicles conforming to different European emission standards. Given the detailed emission breakdowns, the PIARC data are very useful for sensitivity testing, such as analysing the effect of changes to road grade, and are useful for emission estimation from most roadway applications.

The 1995 PIARC document described the emission situation up to the year 1995. In 2004, PIARC updated the methodology and emissions information (**PIARC, 2004**) based on activities between 2001 and 2003. The design data are subject to ongoing review due to a steady tightening of emission standard for vehicles.

Since the PIARC emissions data are primarily based on European studies, the emission tables have been modified to take account of the age, vehicle mix, vehicle speed, gradient of road and emissions control technology of the Australian vehicle fleet. The modified tables include emissions of CO, NO_x and PM_{10} by age and type of vehicle. The age of vehicles have been categorised into five periods, corresponding to the introduction of emission standards, and three vehicle type categories.

The vehicle types have been defined as follows:

- Passenger cars using petrol.
- Passenger cars using diesel.
- Heavy goods vehicles using diesel.

The general approach for using the PIARC data was to combine total traffic volume with percentages of vehicles in each age bracket and type category. Using these inputs, as well as road grade and speed information, total emissions for selected sections of road have been generated.

Further details on how the PIARC emission data were related to the Australian vehicle fleet are provided in **Appendix B**.

5.2 Traffic Data

Arup supplied traffic information for various sections of the proposed upgrade. The traffic data made available and used for the purposes of the air quality study included the following:

- Traffic data for 2012 and 2022;
- Traffic counts south of Ivy Lane, south of Bangalow and north of Bangalow Road sections;
- Proposed upgrade as well as existing highway;
- Light and heavy vehicle traffic volumes by hour of day; and
- Scenarios with and without the Project.

Information on registered vehicle types and year of the manufacture data for NSW has been obtained from the Australian Bureau of Statistics (**ABS, 2003**), which was used to derive the percentage of vehicles by age category for modelled years. Registered vehicles in future years have been extrapolated.

The forecast traffic data provided by Arup have been reviewed and the peak hour traffic data are summarised in **Table 4**. These data were used to estimate peak hour vehicle emissions, for use in the dispersion model.

Traffic forecasts for 2022 are higher than for 2012. This will generally relate to higher emissions in 2022 however these will be offset by expected improvements to exhaust emissions over time.

Table 4 : Summary of peak hour traffic forecasts

Section	2012		2022	
	Peak hour traffic	% Heavy	Peak hour traffic	% Heavy
With Project				
Upgraded highway				
South of Ivy Lane	1146	11%	1434	11%
South of Bangalow	1193	10%	1497	10%
North of Bangalow	1035	11%	1300	11%
Existing highway				
South of Ivy Lane	159	5%	199	5%
South of Bangalow	106	5%	133	5%
North of Bangalow	806	6%	1012	6%
Without Project				
Existing highway				
South of Bangalow	1189	11%	1493	11%
North of Bangalow	1673	10%	2100	10%

The sign-posted speed limit for the upgraded highway will be 110 km/h.

Pollutant emissions from each of the road sections presented in **Table 4** have been calculated for input to the CALINE4 dispersion model. The estimated pollutant emissions are discussed below.

5.3 Emission Estimates

Pollutant emissions have been estimated for each tunnel ventilation outlet and for all surface roads discussed in **Section 5.2**. No potential future improvements in vehicle technology or fuel standards have been included in the PIARC emission estimates. This will result in some overestimation of emission rates for future years. Assumed reductions in the proportion of older vehicles in the fleet has, however, simulated some improvement to vehicle emissions in future years.

Traffic speed for all road sections has been set to 100 km/h for all hours of the day since, for heavy vehicles, this is the maximum speed for which PIARC emissions data are available. **Table 5** provides estimated pollutant emissions from the three road sections.

It should be noted that CO emissions (grams per kilometre) generally decrease with increasing speed while NO_x and PM_{10} emissions will generally increase. Since the assumed traffic speed (100 km/h) is near the upper end of the sign-posted speed limit (110 km/h) the calculated NO_x and PM_{10} emissions will tend to be conservative estimates. The calculated CO emissions will be less conservative than those that would be derived by assuming a lower traffic speed however, it will be seen later (**Section 7**) that predicted CO impacts are sufficiently below air quality criteria to allow some variation in the assumed traffic speed and emissions without affecting the conclusions of the assessment.

Table 5 : Estimated emissions from road sections

	South of Ivy Lane (PR)	South of Bangalow (PR)	North of Bangalow (PR)	South of Ivy Lane (EH)	South of Bangalow (EH)	North of Bangalow (EH)
Without Project (2012)						
Peak-hour traffic	0	0	0	1189	1189	1673
CO emissions (g/v-mi)	0	0	0	6.68	6.68	6.69
NO_x emissions (g/v-mi)	0	0	0	2.62	2.62	2.56
PM_{10} emissions (g/v-mi)	0	0	0	0.12	0.12	0.12
With Project (2012)						
Peak-hour traffic	1146	1193	1035	159	106	806
CO emissions (g/v-mi)	6.68	6.69	6.67	6.77	6.77	6.76
NO_x emissions (g/v-mi)	2.62	2.60	2.69	2.08	2.10	2.14
PM_{10} emissions (g/v-mi)	0.12	0.12	0.13	0.08	0.08	0.09
Without Project (2022)						
Peak-hour traffic	0	0	0	1493	1493	2100
CO emissions (g/v-mi)	0	0	0	6.57	6.57	6.58
NO_x emissions (g/v-mi)	0	0	0	2.35	2.35	2.31
PM_{10} emissions (g/v-mi)	0	0	0	0.10	0.10	0.10
With Project (2022)						
Peak-hour traffic	1434	1497	1300	199	133	1012
CO emissions (g/v-mi)	6.57	6.57	6.55	6.71	6.71	6.70
NO_x emissions (g/v-mi)	2.35	2.33	2.41	1.91	1.93	1.96
PM_{10} emissions (g/v-mi)	0.10	0.10	0.10	0.07	0.07	0.07

PR = Proposed route; EH = Existing highway

5.4 Tunnel emissions

In addition to emissions from the selected road sections, modelling has also considered emissions from the portals associated with the 340 m long section of tunnel.

The CALINE4 model which has been used for the assessment and which is discussed in more detail in **Section 6** is not explicitly configured to model emissions from tunnel portals. While this can be undertaken with other dispersion models such as AUSPLUME and CALPUFF, assuming the portal emissions behave as plumes with a limited length, usually 100-300 metres, from experience with roadway tunnel projects where monitoring data have been collected next to portals, these models tend to significantly overestimate impacts around portals.

To overcome this limitation, modelling of portal emissions has been undertaken using CALINE4 using the following approach:

- Emissions within the tunnel have been estimated based on tunnel length and traffic numbers.
- It was assumed that these emissions behaved as plumes and that this added to the existing roadway emissions immediately outside the tunnel portals, to a distance limited by the roadway portal configuration.
- The roadway outside the portal was divided into short links to represent the extent over which the portal emission plume occurred.

- These emissions from the tunnel were converted to equivalent numbers of vehicles and added to the number on the open roadway with the numbers decreasing with distance from the portal.

This approach calculates the mass of emissions in the tunnel and assumes that they are added to the roadway emissions for a short distance from the tunnel portal.

Ginzburg and Schattanek, 1997 developed a methodology to estimate the portal plume length based on the portal configuration, exiting vehicle speed and wind speed based on a series of tests conducted in a wind tunnel. This methodology has been used in numerous roadway projects in the USA, Australia and New Zealand.

Table 6 presents the range of plume lengths that were calculated from the wind tunnel tests.

Table 6: Estimated portal jet lengths under a range of wind speeds and directions

Vehicle speed (km/h)	Portal configuration	Wind Speed		
		1 m/s	3 m/s	6 m/s
		Portal Jet Length[(a)] (m)		
8	With walls	110-120	45-50	40-45
	without walls	90-190	40-45	30-40
24	With walls	250-320	110-250	50-110
	without walls	230-300	130-220	40-110
48	With walls	235-300	150-270	60-125
	without walls	225-260	90-200	60-100

Notes:

(a) Jet length was determined as a distance from the portal where portal concentrations decline by 80%.

Source: Adapted from Ginzberg and Schattanek (1997)

The tunnels in question have no walls between the roadways, and the design speed of the roadway is 110 km/h, however there will be occasions when the vehicle speed will be as low as 20 km/h due to congested flow. As shown in **Table 6**, the maximum speed presented in **Ginzburg and Schattanek, 1997** is 48 km/h, which is considered appropriate for the initial assessment.

The annual average wind speed of the Ballina Airport meteorological data is 3.9 m/s. Therefore a wind speed of 3 m/s as presented in **Ginzburg and Schattanek, 1997** was deemed suitable. A plume length of 200 m was used for the calculations as this provides a reasonable estimate of the likely extent of the plume from the portal exit.

The concentration of pollutants in the portal plume diminishes with distance from the portal. This has been simulated by dividing the plume into a series of links with reducing concentrations from the point of emission.

Table 7 presents a summary of the portal emission rates expressed as g/h. The emission rates were calculated based on the emission rates per vehicle (in g/veh-mi) and the traffic flows north of Bangalow as presented in **Table 5**, and the length of the tunnel assumed to be 340 m.

Table 7: Portal emission rates

Direction	CO (g/h)	NO_x (g/h)	PM_{10} (g/h)
2012			
Southbound	730	294	14
Northbound	730	294	14
2022			
Southbound	900	294	14
Northbound	900	294	14

An example calculation follows:

For NO_x 2012:

Vehicle emission rate = 2.69 g/veh-mi
Vehicle flow one way = 517

Emission rate (g/km/h) = vehicle emission rate [g/veh-mi] x traffic flow [veh/h]/ (km/mi)
= 2.69 [g/veh-mi] x 517 [veh/h] / 1.6093 [km/mi]
= 864 g/km/h

Based on a tunnel length of 0.34 km, the total emission rate in g/h is calculated as follows:
= 864 [g/km/h] x 0.34 [km]
= 294 g/h

Ginzburg and Schattanek, 1997 described the distribution of portal emissions as they exit the tunnel. The plume is split into three sections, with the distribution of emissions decreasing for each section as presented in **Table 8**. For this study, with a plume length of 200 m, the emissions were spread over four 50 metre sections with percentages 42.75, 29.75, 18.5 and 9.

Table 8: Distribution of emissions down length of portal plume

Section	Distribution of emissions (%)
1	57
2	31
3	12

The emission rates for the portal emissions were converted to equivalent numbers of vehicles by using the total g/h from the portal, applying the distribution of emissions for each section, adjusting the emission rate for the length of the plume assumed in this case to be 200 m and adjusting back for the emission rate per vehicle.

For example for NO_x in 2012 for the first section (42.75%) of the plume with a length of 50 m:

Portal emission rate = 294: g/h (see **Table 7**)
Vehicle emissions rate = 2.69 g/veh-mi

Based on a plume length of 200 m, the equivalent numbers of vehicles per hour in the first 50 metres of the plume is calculated as follows:

Equivalent number of vehicles per hour =
(294 [g/h] x 0.4275 [%] x 1.6093 [km/mile]) / (2.69 [g/veh_mi] x 0.050 [km]) = 1504 veh/h

This number of vehicles is added in the model to the number of vehicles on the open section of the roadway for the first 50 metres section of the plume. The equivalent number of vehicles in the next sections of the plume out to a distance of 200 metres are calculated in a similar way with deceasing emissions and therefore decreasing numbers of equivalent vehicles. It is assumed that the plume/jet from the tunnel portal would extend in a straight line in the direction of the roadway.

6. APPROACH TO ASSESSMENT

Emissions from vehicle exhaust have been assessed by using the computer-based model known as CALINE4 to predict pollutant concentrations near selected sections of the existing and proposed roads.

The CALINE series of dispersion models has been widely used in roadway studies throughout Australia to estimate pollutant concentrations close to roadways. The models are steady-state dispersion models which can determine concentrations at receptor locations downwind of "at grade", "fill", "bridges" and "cut section" highways located in relatively uncomplicated terrain. The models are applicable for most wind directions, highway orientations and receptor locations.

CALINE4 requires roadway geometries, receptor locations and vehicular emission rates to predict pollutant concentrations up to a few hundred metres of the roadway. Further details on the CALINE models can be found in the user manuals (US EPA website).

The main purpose of the CALINE4 modelling is to assess air quality impacts very close to selected sections of the existing and proposed highways. Three road sections were subject to CALINE4 modelling.

It was assumed that worst case meteorology prevailed, that is F class stability and 1 m/s wind speed. The model was set to find the worst-case wind angle, that is the wind angle which gave the highest predicted roadside concentration of pollutant.

The approach adopted for the portal emissions has been described in **Section 5.4.**

7. ASSESSMENT OF AIR QUALITY IMPACTS

This section provides an assessment of the air quality impacts associated with the Project. All dispersion model results directly reflect the modelled traffic volumes for the Project.

7.1 Near Surface Roads

This section discusses the predicted roadside concentration of pollutants in the vicinity of the proposed upgrade and the existing highway for selected sections along the route.

Carbon Monoxide

Table 9 presents the predicted maximum 1-hour average carbon monoxide concentrations at selected distances from the roadway for the proposed upgrade and the existing highway, with and without the Project. Predicted concentrations in 2012 and 2022 are provided. The maximum predicted concentrations occur at the kerbside with concentrations declining and the highest levels are predicted to occur at the existing Pacific Highway north of Bangalow in 2012 without the Project. Predictions have been made out to a distance of 100 m from the kerb. The Project has the effect of splitting the traffic between two roadways and results in lower concentrations close to the existing highway with the proposed upgrade in place.

The air quality 1-hour goal for carbon monoxide is 30 mg/m^3 and all predicted concentrations are substantially below this. These predicted concentrations are due to the roadway alone and do not include background concentrations.

The highest predicted level is kerbside on the section north of Bangalow for the existing highway in 2022 where the predicted concentration is 2.6 mg/m^3. Typical background concentrations of carbon monoxide are of the order of 2 mg/m^3 and this is consistent with the measured levels presented in **Section 4.3** which were in fact lower than this. Adding this concentration to the maximum predicted concentration would not result in exceedances of air quality goals (that is, 2 plus 2.6 equals 4.6 mg/m^3 which is less than 30 mg/m^3).

Table 9 : Predicted maximum 1-hour average CO concentrations near roadside

Location	South of Ivy Lane	South of Bangalow	North of Bangalow	South of Ivy Lane	South of Bangalow	North of Bangalow
Air quality goal	1-hour maximum - 30 mg/m^3					
With Project (2012)	**Upgraded highway**			**Existing highway**		
At kerb	1.0	1.1	0.9	0.3	0.2	1.1
10 m from kerb	0.5	0.5	0.5	0.1	0.1	0.4
20 m from kerb	0.4	0.4	0.4	0.1	0.1	0.3
30 m from kerb	0.3	0.3	0.3	0.1	0.0	0.3
50 m from kerb	0.3	0.3	0.2	0.1	0.0	0.2
100 m from kerb	0.2	0.2	0.2	0.0	0.0	0.1
Without Project (2012)	**Upgraded highway**			**Existing highway**		
At kerb	-	-	-	1.6	1.6	2.1
10 m from kerb	-	-	-	0.6	0.6	0.8
20 m from kerb	-	-	-	0.4	0.4	0.6
30 m from kerb	-	-	-	0.3	0.3	0.5
50 m from kerb	-	-	-	0.3	0.3	0.4
100 m from kerb	-	-	-	0.2	0.2	0.2
With Project (2022)	**Upgraded highway**			**Existing highway**		
At kerb	1.2	1.3	1.1	0.3	0.2	1.3
10 m from kerb	0.6	0.6	0.6	0.1	0.1	0.5

Location	South of Ivy Lane	South of Bangalow	North of Bangalow	South of Ivy Lane	South of Bangalow	North of Bangalow
Air quality goal	1-hour maximum - 30 mg/m^3					
20 m from kerb	0.5	0.5	0.4	0.1	0.1	0.4
30 m from kerb	0.4	0.4	0.4	0.1	0.1	0.3
50 m from kerb	0.3	0.3	0.3	0.1	0.0	0.2
100 m from kerb	0.2	0.2	0.2	0.0	0.0	0.2
Without Project (2022)	**Upgraded highway**			**Existing highway**		
At kerb	-	-	-	1.9	1.9	2.6
10 m from kerb	-	-	-	0.7	0.7	1.0
20 m from kerb	-	-	-	0.5	0.5	0.7
30 m from kerb	-	-	-	0.4	0.4	0.5
50 m from kerb	-	-	-	0.3	0.3	0.4
100 m from kerb	-	-	-	0.2	0.2	0.3

Nitrogen Dioxide

Estimating nitrogen dioxide concentrations is more complicated than estimating carbon monoxide concentrations. Nitrogen oxides are initially emitted as a mixture of nitric oxide and other oxides of nitrogen, which are oxidised to nitrogen dioxide. At the point of emission the mixture is generally about 5 percent nitrogen dioxide by mass. However, while the maximum concentrations of total oxides of nitrogen generally occur during peak hour, this is not necessarily the case for nitrogen dioxide. An extensive monitoring program undertaken by the RTA (**RTA, 1997**) indicates that during peak hour the percentage nitrogen dioxide at 10 m from the roadway edge is likely to be about 5 percent. The conversion rate from nitric oxide to nitrogen dioxide at other times of the day may be significantly higher than this although the total oxides of nitrogen levels may be significantly lower than peak hour levels. It is therefore necessary to assume some intermediate value for a worst-case assessment.

Data from the RTA program (**RTA, 1997**) indicates that at 10 m from the roadway a conversion rate of 15 percent by weight is conservative (i.e. an overestimate), but more realistic than the 20 percent assumed in previous EIS studies. At distances of 20 – 60 m from the kerbside the 20 percent conversion rate appears to be appropriate. There are no monitoring data for the kerbside location in the present study, but it is considered that a 15 percent conversion at 10 m is likely to still be conservative. Conversions of 10 percent and 15 percent have been used at 0 m and 10 m respectively, while 20 percent has been assumed for the distances of 20 m, 30 m and 50 m. A conversion of 20 percent has also been assumed for the 100 m predictions.

It can be seen from **Table 10** that the maximum predicted nitrogen dioxide concentration is predicted to occur in a similar circumstance to the maximum carbon monoxide level, that is, for the existing highway north of Bangalow in 2022 without the Project. The predicted kerbside concentration is 89.8 µg/m^3. Even when added to the maximum measured concentration in the Coffs Harbour data, that is 73.8 µg/m^3 this would not result in an exceedance of the air quality goal (that is, 89.8 plus 73.8 equals 163.6 µg/m^3 which is less than 246 µg/m^3).

Table 10 : Predicted maximum 1-hour average NO_2 concentrations near roadside

Location	South of Ivy Lane	South of Bangalow	North of Bangalow	South of Ivy Lane	South of Bangalow	North of Bangalow
Air quality goal	1-hour maximum - 246 µg/m^3					
With Project (2012)	**Upgraded highway**			**Existing highway**		
At kerb	40.3	41.3	37.6	8.0	5.6	35.3
10 m from kerb	30.8	31.5	28.9	5.3	3.8	21.0
20 m from kerb	31.3	32.0	29.5	5.0	3.8	19.8

Location	South of Ivy Lane	South of Bangalow	North of Bangalow	South of Ivy Lane	South of Bangalow	North of Bangalow
Air quality goal	1-hour maximum - 246 µg/m^3					
30 m from kerb	26.3	27.0	24.8	4.0	3.0	16.3
50 m from kerb	20.8	21.3	19.5	3.0	2.3	12.3
100 m from kerb	14.5	14.8	13.8	2.0	1.5	8.3
Without Project (2012)	**Upgraded highway**			**Existing highway**		
At kerb	-	-	-	61.1	61.1	81.4
10 m from kerb	-	-	-	35.6	35.6	46.7
20 m from kerb	-	-	-	33.5	33.5	43.8
30 m from kerb	-	-	-	27.3	27.3	35.5
50 m from kerb	-	-	-	20.8	20.8	27.3
100 m from kerb	-	-	-	14.3	14.3	18.5
With Project (2022)	**Upgraded highway**			**Existing highway**		
At kerb	44.0	45.4	41.4	9.0	6.4	39.5
10 m from kerb	33.2	34.1	31.3	5.8	4.1	23.3
20 m from kerb	33.8	34.8	32.0	5.5	4.0	21.8
30 m from kerb	28.5	29.3	27.0	4.5	3.3	17.8
50 m from kerb	22.5	23.3	21.3	3.5	2.5	13.5
100 m from kerb	15.8	16.3	14.8	2.3	1.8	9.3
Without Project (2022)	**Upgraded highway**			**Existing highway**		
At kerb	-	-	-	67.5	67.5	89.8
10 m from kerb	-	-	-	39.0	39.0	50.4
20 m from kerb	-	-	-	36.5	36.5	47.0
30 m from kerb	-	-	-	29.8	29.8	38.3
50 m from kerb	-	-	-	22.8	22.8	29.5
100 m from kerb	-	-	-	15.5	15.5	20.3

Particulate Matter (PM_{10} and $PM_{2.5}$)

The assessment of PM_{10} concentrations has been undertaken using the CALINE4 model. These predicted levels however, are for 1-hour averaging periods while the air quality goal refers to a 24-hour exposure period. Comparing these is therefore a conservative approach (that is an over-prediction) as the maximum predicted 24-hour average will always be lower than the predicted maximum1-hour average, which is based on the peak traffic hour combined with the worst-case meteorology. The relationship between the predicted 1-hour maximum and the 24-hour average will vary with meteorology and daily traffic flow. Work done on the proposed Western Sydney Orbital suggested a time adjustment factor of approximately 0.47 to convert 1-hour predictions to 24-hour averages (**Holmes Air Sciences, 1999**).

In dispersion modelling it is often difficult to account for background concentrations in a rigorous way. Ideally, model predictions made with real meteorological data are added to concurrent background concentrations, but this level of detailed information is rarely available. An alternative approach is to add the maximum predicted level to the maximum background level. This approach is very conservative, but if it results in no exceedances of the air quality goals, no further consideration needs to be given to this issue. Alternatively, an average background can be added to the maximum model predictions. This provides an estimate of how the project will add to existing levels on average but may not account for the worst-case.

It can be seen from **Table 11** that the maximum predicted concentration kerbside is for the existing highway north of Bangalow in 2022. The 1-hour concentration is 37.3 µg/m^3 and adjusting to the 24-hour average, the concentration would be 17.5 µg/m^3. This concentration falls off rapidly from roadside and 10 m from the kerb is likely to be of the order of 7 µg/m^3. When added to the maximum measured concentration for the Coffs Harbour data of 37.8

µg/m^3, this concentration still does not exceed the air quality goal of 50 µg/m^3 (7 plus 37.8 equals 44.8 µg/m^3, which is less than 50 µg/m^3).

Most of the PM_{10} emitted from diesel vehicles will be in the $PM_{2.5}$ fraction. At this stage there are no project-based goals for $PM_{2.5}$ in NSW. However it is useful to compare the predicted concentration with the NEPM goals. If it is assumed conservatively that all the predicted PM_{10} is $PM_{2.5}$, the maximum 24-hour concentration at 10 m from the kerb would be 7 µg/m^3. If this is added to the maximum measured level of 15.4 µg/m^3, this still does not exceed the 24-hour goal of 25 µg/m^3.

Newrybar School is the section south of Bangalow. The proposed upgrade would approach to within 30 metres of the school playing fields where the predicted worst-case 1-hour concentrations of PM_{10} would be approximately 6 µg/m^3 adjusted to 3 µg/m^3 for a 24-hour average in the worst-case. These concentrations would not add substantially to the air quality. Similarly, low concentrations are predicted for the other pollutants at this location.

Table 11 : Predicted maximum 1-hour average PM_{10} concentrations near roadside

Location	South of Ivy Lane	South of Bangalow	North of Bangalow	South of Ivy Lane	South of Bangalow	North of Bangalow
Air quality goal	24-hour maximum -50 µg/m^3					
With Project (2012)	**Upgraded highway**			**Existing highway**		
At kerb	18.6	19.0	17.8	3.1	2.3	14.1
10 m from kerb	9.5	9.6	9.0	1.4	1.0	5.6
20 m from kerb	7.3	7.4	6.9	1.0	0.8	4.0
30 m from kerb	6.1	6.3	5.9	0.8	0.6	3.3
50 m from kerb	4.9	4.9	4.6	0.6	0.5	2.5
100 m from kerb	3.4	3.4	3.3	0.4	0.3	1.6
Without Project (2012)	**Upgraded highway**			**Existing highway**		
At kerb	-	-	-	28.3	28.3	37.1
10 m from kerb	-	-	-	11.0	11.0	14.1
20 m from kerb	-	-	-	7.8	7.8	10.0
30 m from kerb	-	-	-	6.3	6.3	8.1
50 m from kerb	-	-	-	4.9	4.9	6.3
100 m from kerb	-	-	-	3.3	3.3	4.3
With Project (2022)	**Upgraded highway**			**Existing highway**		
At kerb	18.6	19.0	17.8	3.1	2.3	14.3
10 m from kerb	9.4	9.5	9.0	1.4	1.0	5.6
20 m from kerb	7.1	7.3	6.9	1.0	0.8	3.9
30 m from kerb	6.0	6.1	5.8	0.8	0.6	3.3
50 m from kerb	4.8	4.9	4.6	0.6	0.5	2.5
100 m from kerb	3.4	3.4	3.3	0.4	0.3	1.6
Without Project (2022)	**Upgraded highway**			**Existing highway**		
At kerb	-	-	-	28.5	28.5	37.3
10 m from kerb	-	-	-	11.0	11.0	14.0
20 m from kerb	-	-	-	7.8	7.8	9.8
30 m from kerb	-	-	-	6.3	6.3	8.0
50 m from kerb	-	-	-	4.8	4.8	6.1
100 m from kerb	-	-	-	3.3	3.3	4.3

7.2 *Effect of grade*

The above assessment is based on emission rates assuming that the roadway is flat. However there will be some sections of the route with steeper grade.

Table 12 summarises emission rates from traffic travelling 110 km/h for different roadway grades expressed as percentages. Emission rates apply to the 2012 fleet. The predicted roadside concentrations are directly proportional to the emissions rates.

There is a substantial increase of CO emissions with grade, with up to a ten-fold increase from zero to 6% grade. However the predicted concentrations of CO are so far below the goal, that even an increase of this size would not cause any exceedances of air quality goals.

The effect of grade on NO_x and PM_{10} is not as great with two to threefold increase from zero to 6%. Again, the predicted concentrations for these pollutants are low and at 10 metres from the kerb, there would still not be any predicted exceedances of air quality goals.

Table 12 : Change in vehicle emissions with grade

Grade (%)	In 2012 (g/veh-mi)		
	CO	NO_x	PM_{10}
0	6.69	2.56	0.12
2	22.63	3.85	0.17
4	42.30	5.35	0.22
6	67.17	7.35	0.29

7.3 *Tinderbox Valley*

A modelling study of Tinderbox Valley, in the northern section of the proposed upgrade was undertaken for the route selection process (**Holmes Air Sciences 2006).** The predicted roadside levels in the section north of Bangalow in the current study would be representative of this area.

The approach adopted in this current report is more conservative than the previous study and the predicted concentrations of nitrogen dioxide and particulate matter are consequently higher. However the current predictions assume that the maximum emission of these pollutants, which will be predominantly from diesel trucks, occur during the times of poorest dispersion. In practice, the maximum emissions are estimated to occur during the daytime when dispersion is generally more favorable.

Regardless, both modelling studies indicate that the predicted concentrations are well within air quality goals.

7.4 *Near Proposed Tunnel Portals*

Figures 11 to **13** present the predicted concentrations of carbon monoxide, nitrogen dioxide and particulate matter in the vicinity of the tunnel portals. The predictions are for the worst-case hour in terms of traffic combined with the worst-case hour in terms of dispersion.

As was the case with the roadside concentrations, the predicted concentrations are substantially below the relevant goals. For example, the maximum 1-hour concentrations of carbon monoxide in the vicinity of the portals are approximately 0.3 mg/m^3. For nitrogen dioxide the maximum concentrations in the vicinity of the portals are of the order of 25 μg/m^3 and for particulate matter the maximum 1-hour concentrations are of the order of 5 μg/m^3 for both 2012 and 2022. It is not anticipated that there will be any adverse impact on any neighbouring residential areas with this level of pollutant concentration.

Under normal operating conditions the "piston effect" of vehicle induced air flow in each of the unidirectional tunnel bores would provide sufficient natural ventilation to maintain in-tunnel air quality at acceptable levels. With a steady natural air flow through a one way tunnel, in the direction of traffic flow, the in-tunnel pollutant concentrations will increase from the tunnel entrance to maximum levels near the tunnel portal. Therefore, the highest levels in the tunnel will be close to the maximum concentrations predicted and discussed above, which are below ambient air quality criteria.

The risk of fires occurring in the tunnel has identified the need for a number of fire control systems including mechanical ventilation. Longitudinal mechanical ventilation would include jet fans mounted within the tunnel at a limited number of points to create a longitudinal flow of air along the length of the tunnel. The strategy for ventilation within the St Helena tunnel would be to make as much use of natural longitudinal ventilation as possible and supplement this by jet fans for short periods in the event of adverse conditions occurring within the tunnel.

7.5 Potential effects on drinking water

One of the issues which is sometimes raised as a concern near roadways is the potential impacts of airborne pollution on drinking water. While airborne pollutants can enter water systems directly through deposition from the air or through runoff from soil contaminated with fallout, the levels associated with roadways are generally low and localised compared with the type of industrial sources which can contribute to drinking water contamination

Australian Drinking Water Guidelines (ADWG) are published by the National Health and Medical Research Council (NHMRC) / Natural Resource Management Ministerial Council (NRMMC) to provide the water supply industry with guidance on what constitutes good quality drinking water. Water suppliers are guided by these criteria in implementing treatment systems. This would apply to the current situation with the existing Pacific Highway.

Lead deposition in the vicinity of roadways has been a potential issue in the past, however lead is no longer in petrol. PAHs are the other significant motor vehicle emissions (present predominantly in particulate diesel emissions) with the potential to be deposited in the vicinity of roadways. Again any deposition into the waterways is likely to be low and the existing water treatment systems would be designed to comply with relevant guidelines. The proposed upgrade is not predicted to result in any deterioration in air quality and therefore would be very unlikely to result in any deterioration in drinking water quality.

7.6 Particulate matter effects on vegetation

Particulate matter can have a physical and chemical impact on vegetation. The effect of dust deposited on vegetation depends on the characteristics of the dust, plant species and environmental conditions. Factors important to the deposition rate of particulate matter include ambient concentration, atmospheric condition, aerosol properties, surface roughness and vegetation condition. Impacts on vegetation can include physically smothering the leaves, physically blocking the stomata and an increase in leaf temperature. Critical loads vary with plant function and it is not possible to predict the precise nature of one plants response from the known response of another (**Farmer, 1993, Doley, 2006**).

Doley (2006) examined the physical effects of dust on vegetation and suggested that the most sensitive plant functions may be altered with dust loads of about 8 g/m^2 for dust with medium diameters of 50 µm. The DECC air quality criterion for total dust deposition is 4 g/m^2/month which suggests that compliance with this level would provide protection for the most sensitive plant functions. Compliance with the particulate matter concentration criteria for PM_{10} will typically relate to compliance with the dust deposition criteria, so based on the relatively low PM_{10} concentrations predicted, no adverse air quality impacts on vegetation would be expected.

8. CONSTRUCTION IMPACTS

8.1 Dust sources

Dust would be generated from earthworks associated with the proposed upgrade. The total amount of dust would depend on the silt and moisture content in the soil and the types of activities being carried out.

The equipment to be used on-site is likely to include the following:

- Front end loaders
- Excavation plant
- Piling rigs
- Cranes
- Back hoes
- Trenching machines
- Vibrating rollers
- Concrete agitator trucks
- Concrete and asphaltic paving machines
- Concrete pumps
- Water pumps and small equipment
- Water tankers
- Jack hammers
- Bulldozers
- Graders
- Milling machine
- Road sweeper
- Line marking vehicles
- Trucks delivering construction materials
- Low loader transporters
- Light commercial and passenger vehicles

The major sources of dust would be bulldozers, excavators and wind erosion from the exposed surfaces.

8.2 Dust mitigation

The DECC has reviewed the environmental hazards associated with construction/excavation sites and prepared a general document containing safeguards to protect the environment during such activities (**DoH, 2004**). Many of these safeguards relate to controlling water pollution and run off. However, these procedures frequently assist in the control of air pollution. The recommendations of the DECC include the following mitigation measures:

- Watering of haul roads and sealing of roads where possible.
- Wind breaks composed of earth banks and other screens to protect areas by reducing capacity of the wind to raise dust.
- Trucks entering and leaving the site would be well maintained in accordance with the manufacturer's specification to comply with all relevant regulations. Fines may be imposed on vehicles that do not comply with smoke emission standards. Truck movement would be controlled on site and restricted to designated roadways. Truck

wheel washes or other dust removal procedures would be installed to minimise transport of dust offsite.

- If necessary, stop or modify dust-generating activities during periods of high wind.
- Watering/revegetating of stockpiles and exposed areas.

It is recommended that dust monitoring be carried out around the Project area during construction to determine the compliance with dust deposition goals currently noted by the DECC, summarised in **Table 13** below. The interpretation of these goals is that the maximum total dust deposited should be no more than 4 g/m^2/month over a twelve-month period but that there should be not more than an additional 2 g/m^2/month due to project itself.

Table 13 : DECC criteria for dust fallout

Pollutant	Averaging Period	Maximum increase in deposited dust level	Maximum total deposited dust level
Deposited dust	Annual	2 g/m^2/month	4 g/m^2/month

An Air Quality Management Plan (AQMP) for the proposed works is also recommended as part of an overall Construction Environmental Management Plan (CEMP). The general principles of the AQMP are listed below.

- All disturbed areas would be stabilised as soon as practicable to prevent or minimise wind blown dust.
- All unsealed trafficable areas would be kept sufficiently damp during working hours to minimise wind blown or traffic generated dust emissions.
- Water sprays, sprinklers and water carts would be employed if needed to adequately dampen stockpiles, work areas and exposed soils to prevent the emission of dust from the site.
- Stockpiles and handling areas would be maintained in a condition that minimises wind blown or traffic generated dust. Areas that may be inaccessible by water carts would be kept in a condition which minimised wind blown or traffic generated dust using other means.
- All equipment for dust control would be kept in good operating condition. The equipment would be operable at all times with the exception of shutdowns required for maintenance. Construction equipment would be properly maintained to ensure exhaust emissions comply with the *Protection of the Environment Operations (POEO) Act 1997*.
- Silt would be removed from behind filter fences and other erosion control structures on a regular basis, so that collected silt did not become a source of dust; and
- Any dust, soil or mud deposited on public roads by sub contractors, construction activities and vehicle movements would be removed immediately and disposed of appropriately.

No dust sensitive industries have been identified along the route at this stage, however this will be reviewed prior to construction.

9. CONCLUSIONS

This report has assessed the potential air quality impacts of the proposed upgrade to the Pacific Highway from Tintenbar to Ewingsdale. The impacts of the proposed upgrade have been compared with the impacts of the base case where all traffic is assumed to travel on the existing Pacific Highway.

There are no predicted exceedances of air quality goals roadside for carbon monoxide, nitrogen dioxide or particulate matter for either the proposed upgrade or the base case. However the proposed upgrade would provide the benefit of splitting the traffic and therefore providing some additional dispersion of the emissions.

The predicted concentrations in the vicinity of the tunnel portals are all well within air quality goals, taking account of conservative estimates of background concentrations. The proposed upgrade would approach to within 30 metres of the Newrybar school playing fields where the predicted worst-case concentrations of pollutants would not cause significant deterioration of the air quality.

It is concluded that based on predicted traffic numbers, there will be no adverse impacts on air quality as a result of the project.

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APPENDIX A
HEALTH EFFECTS OF POLLUTANTS EMITTED FROM MOTOR VEHICLES

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HEALTH EFFECTS OF POLLUTANTS EMITTED FROM MOTOR VEHICLES

The following sections discuss the health effects of the various pollutants and compounds referred to in the report.

Carbon monoxide

Carbon monoxide can be harmful to humans because its affinity for haemoglobin is more than 200 times greater than that of oxygen. When it is inhaled it is taken up by the blood and therefore reduces the capacity of the blood to transport oxygen. This process is reversible and reducing the exposure will lead to the establishment of a new equilibrium with a period of three hours being the approximate time required to reach 50% of the equilibrium value.

Symptoms of carbon monoxide intoxication are lassitude and headaches; however these are generally not reported until the concentrations of carboxyhaemoglobin in the blood are in excess of 10% of saturation. This is approximately the equilibrium value achieved with an ambient atmospheric concentration of 70 mg/m^3 for a person engaged in light activity. However, there is evidence that there is a risk for individuals with cardiovascular disease when the carboxyhaemoglobin concentration reaches 4% and the WHO recommends that ambient concentrations be kept to values which would protect individuals from exceeding the 4% level.

The criteria noted by the DECC provide a significant margin for safety, however this is appropriate for this type of guideline, which is designed to protect a wide range of people in the community including the very young and elderly.

Oxides of nitrogen

Nitrogen oxides (NO_x) emitted from combustion sources are comprised mainly of nitric oxide (NO, approximately 95% at the point of emission) and nitrogen dioxide (NO_2, approximately 5% at the point of emission). Nitric oxide is much less harmful to humans than nitrogen dioxide and is not generally considered a pollutant with health impacts at the concentrations normally found in urban environments. Concern with nitric oxide relates to its transformation to nitrogen dioxide and its role in the formation of photochemical smog. Nitrogen dioxide has been reported to have an effect on respiratory and lung function.

The DECC has not set any air quality criteria for nitric oxide, however it has set 1-hour and annual average criteria for nitrogen dioxide.

Particulate matter

The presence of particulate matter in the atmosphere can have an adverse effect on health and amenity. The health effects of particles are largely related to the extent to which they can penetrate the respiratory tract. Larger particles, that is those greater than 10 µm, generally adhere to the mucous in the nose, mouth, pharynx and larger bronchi and from there are removed by either swallowing or expectorating. Finer particles can enter bronchial and pulmonary regions of the respiratory tract, with increased deposition during mouth breathing which increases during exercise. The very fine particles can be deposited in the pulmonary region and it is these which are of particular concern.

The health effects of particulate matter 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.

Much of the recent concern over the health effects of fine particulate matter is based on investigations carried out in the US, with the view to quantifying the health risks associated with both long-term and short-term exposure to airborne particulate matter. The study is colloquially referred to as "The Six Cities Study" from the original work by **Dockery et al. (1993)**, which determined a relationship between fine particulate matter (defined as particles smaller than 2.5 µm in diameter) in the air and mortality in six US cities.

The basic findings of the Six Cities Study is that there is an increase in mortality with increasing concentrations of fine particulate matter. The conclusions appear to be robust and have been supported by subsequent studies and as far as can be determined are not confounded by other known variables. It is important to note that the observed association between fine particles and mortality is statistical. The particles are not the primary cause of death, but are one of many environmental and other risk factors. More recently the statistical associations have been revised downwards based on a review of the statistical methods used, but the association remains (**HEI, 2003**). However the current Australian air quality criteria for particulate matter are still based on the more conservative associations.

Hydrocarbons

Hydrocarbons alone do not generally pose a problem at the concentrations commonly experienced. However, some hydrocarbons such as benzene are known to have an adverse effect on human health (see later), but the effects are thought to occur at concentrations higher than the levels of exposure found at roadsides from traffic emissions. Hydrocarbons do play a significant role in photochemical smog formation and until recently the air quality standards adopted by the US EPA for non-methane hydrocarbons have been applied in NSW. However it has been recognised that this goal does not distinguish the reactive species which are involved in smog formation from the total hydrocarbon concentration and this air quality goal has been abandoned by the US EPA.

There is growing concern about the amount of benzene released in motor vehicle emissions, especially in Europe where fuel has a higher benzene and aromatic content than in Australia. At present NSW has no ambient air quality goals for benzene. The Victorian EPA currently has a limit of 0.10 mg/m^3 (0.033 ppm) (3-minute average). Many in the scientific community hold the view that there is no safe limit for benzene. The WHO specifies a risk factor for developing leukaemia of 4×10^{-6} for a lifetime exposure to 1 µg/m^3. The United Kingdom has an annual average ambient benzene goal of 5 parts per billion (ppb) or 16 µg/m^3 to be achieved by 2005. The 5 ppb goal is based on the "No Observable Adverse Effect Level" from the findings of the UK Expert Panel on Air Quality Standards that the risk of leukaemia in workers would not be detectable when the average working lifetime exposure to benzene was less than 500 ppb. Two safety factors of 10 were then applied to derive the goal of 5 ppb. The NEPM (Air Toxics) air quality goal for benzene is 3 ppb.

Effects of particle pollution

The human respiratory system has in-built defensive systems that prevent particles larger than approximately 10 µm from reaching the more sensitive parts of the respiratory system. Respirable particles (PM_{10}) are a health concern because they are easily inhaled and retained in the lung. The epidemiological evidence for the health impacts of particles is based on the mass of particles in the atmosphere with the fine fraction of PM_{10} ($PM_{2.5}$) showing a stronger correlation with health impacts than the total mass of PM_{10}. It is likely that it may be the even finer particles (ultrafine, less than 0.1 microns) which are the main contributor to health impacts and it is also possible that it is the number of particles rather than the mass which is important. At this stage however, the total mass of PM_{10} and $PM_{2.5}$ provides a reasonable surrogate for measuring the "healthiness" or otherwise of the ambient air in urban environments.

Furthermore there are no agreed methods for the routine measurement of ultrafine particles or particle numbers and no ambient goals for these measures of particle pollution.

It is important to note that the observed association between fine particles and mortality is statistical. The particles are not the primary cause of death, but are one of many environmental and other risk factors. More recently the statistical associations have been revised downwards based on a review of the statistical methods used, but the association remains (**HEI, 2003**). However the current Australian air quality goals for particulate matter are still based on the more conservative associations.

The air quality goals for particulate matter do not reflect their chemical composition, however it is recognised that not all particles are the same in terms of health impacts. As noted above, emissions from diesel vehicles are a major contributor to particle pollution in urban environments and, in addition, the particles are associated with carcinogenic material, including polycyclic aromatic hydrocarbons.

Effects of diesel emissions

In 1999 **Cohen and Nikula (1999)** published a substantial review of the health effects of diesel exhaust and in 2002 the US EPA completed a major review of the effects of diesel engine exhaust (**US EPA 2002**). Based on a review of these two publications it can be concluded that the chemical composition of diesel exhaust is reasonably well known and that diesel exhaust contains substances that are known to be harmful to health, both because of the form in which they occur (fine particles as well as gases) and their composition.

From a health perspective diesel exhaust (DE) is a complex mixture of gases and particulate matter. Almost all (~92%) of the particles in diesel exhaust are less than 1 µm in diameter and absorb unburnt hydrocarbons and other potentially carcinogenic organic compounds such as polycyclic aromatic hydrocarbons (**CARB, 1998**). These small particles are capable of reaching the deepest parts of the respiratory system.

Harmful effects are believed to include an increase in the incidence of cancer and other effects such as the exacerbation of asthma symptoms and irritation and inflammation symptoms. Actual human exposures are difficult to determine accurately and dose response relationships are less well known.

The US EPA has used animal studies to estimate that a lifetime exposure to 1 $\mu g/m^3$ would produce 1 excess cancer per 100,000 people. The most recent US EPA review (**US EPA, 2002 Page 6-32)** concludes that exposure to "5 $\mu g/m^3$ of diesel PM is a chronic exposure level likely to be without an appreciable risk of adverse human health effects". They consider that this is consistent with their annual average standard of 15 $\mu g/m^3$ for $PM_{2.5}$, which of course includes all sources of fine particles, not just particles associated with diesel exhaust.

This level therefore provides some benchmark for assessing the impacts of diesel emission from roadways.

Exposure to diesel emissions from roadways

This section discusses some specific studies which have been undertaken in Australia, targeted on measuring particulate pollution in the vicinity of roadways. These studies are in addition to the ongoing monitoring which regulators in most jurisdictions already undertake to assist them in managing local airsheds.

While ambient measurements cannot readily distinguish between specific sources of particulate pollution contributing to the total load, it is nevertheless possible to infer from these studies that traffic emissions are contributing significantly to the measured levels.

Monitoring undertaken by the Victorian EPA in Francis Street Yarraville (**EPA, Victoria, 2001**) and near a major road in Brisbane (**Hitchins et al., 2000**) indicate that the ambient air in the vicinity of roadways, particularly those carrying a high proportion of diesel traffic, carries a significant pollutant loading from roadway emissions. At Yarraville, the monitored levels of particulate pollution, both PM_{10} and $PM_{2.5}$ were higher than those measured at other EPA sites, including a major arterial site, while other pollutants were within acceptable levels. In Brisbane, a decrease in fine and ultra fine particle numbers as distance from the road increased indicated that these particles were related to vehicle exhaust emissions.

In terms of reducing exposure to roadway emissions in the community, in the short term, it may be possible to influence local levels of pollutants on a given street by traffic management, but in the longer term, the best solution is to reduce tailpipe vehicle emissions.

APPENDIX B
VEHICLE EMISSION ESTIMATES

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VEHICLE EMISSION ESTIMATES

PIARC (**PIARC, 2004**) provides CO, NO_x and particulate emission tables for vehicles under different European emission standards which are both speed and road gradient dependent. The emission tables provided by PIARC have been modified to take account of the age, vehicle mix, vehicle speed, gradient of road and emissions control technology of the Australian vehicle fleet. The long term policy of the Australian Design Rules is to fully harmonize Australian regulations with Euro standards.

The modified PIARC tables include emissions of CO, NO_x and PM_{10} by age and type of vehicle. The ages of vehicle have been categorised into five periods, corresponding to the introduction of Australian emission standards, and three vehicle type categories.

The vehicle types have been defined as follows:

- Passenger cars using petrol;
- Passenger cars using diesel; and
- Heavy goods vehicles using diesel.

The percentages of vehicles in NSW falling within each age category have been sourced from the Australian Bureau of Statistics (**ABS, 2003**) in order to relate the PIARC emissions to the NSW fleet. **Table B1** summarises the NSW vehicle distribution by age.

Table B1 : NSW vehicle distribution by age category

Year of manufacture	Total vehicles
To 1985	555,632
1986-1990	632,412
1991-1995	891,069
1996-2000	1,285,016
2001-2003	575,863
Not stated	4,858
TOTAL	3,944,850

Ageing factors for vehicles with catalytic converters have been included in the calculations. Also, the assumed weight of heavy vehicles has been taken to be 20 t which is used for adjustment of heavy vehicle emission factors.

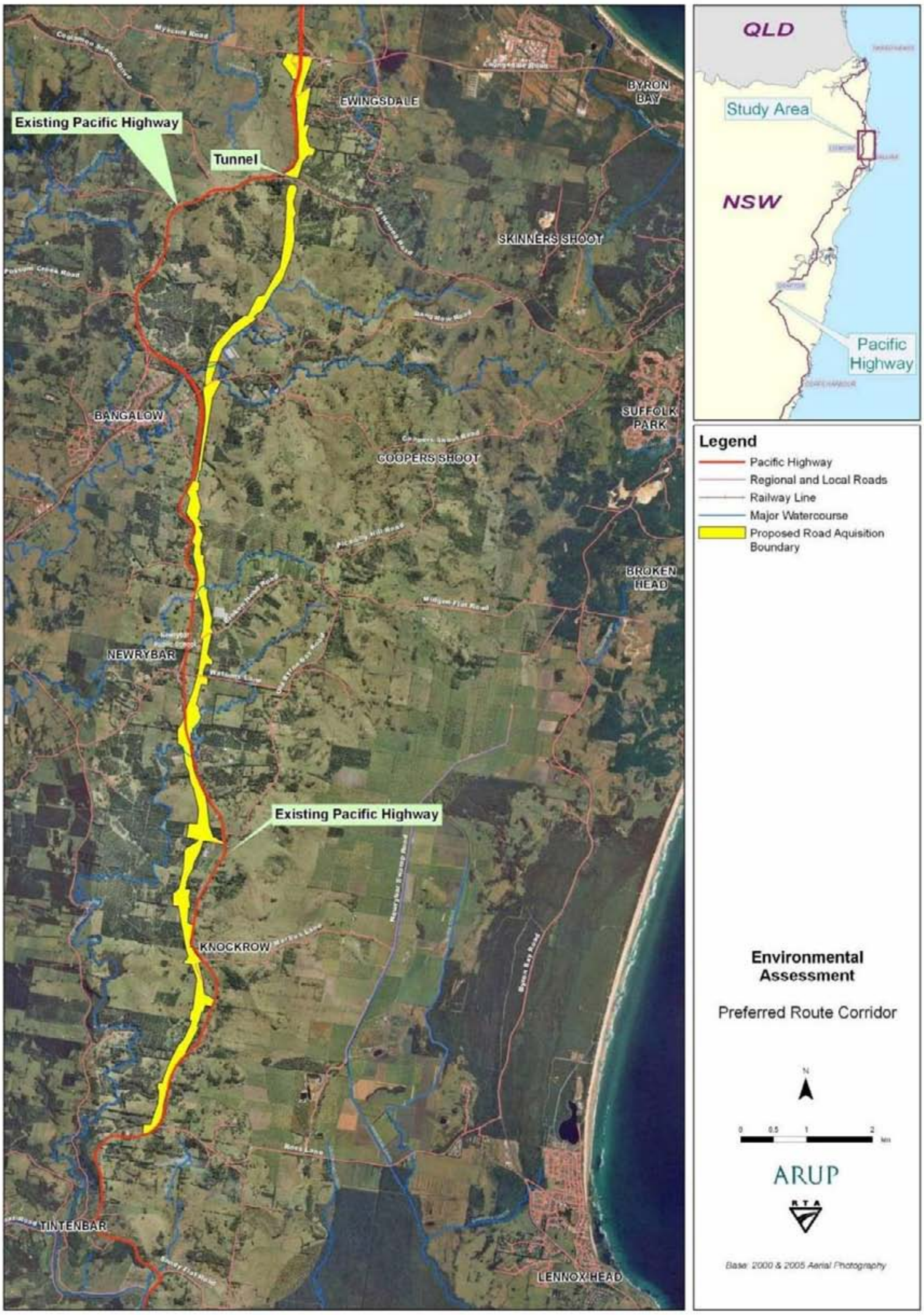
PM_{10} from brake and tyre wear has been taken to be 0.0089 g/km (**Carnovale and Tilly, 1995**).

The fraction of heavy vehicles by hour of day is shown by **Table B2** below. These data were used to determine hourly vehicles emissions and, in turn, to isolate the hour with the highest emissions.

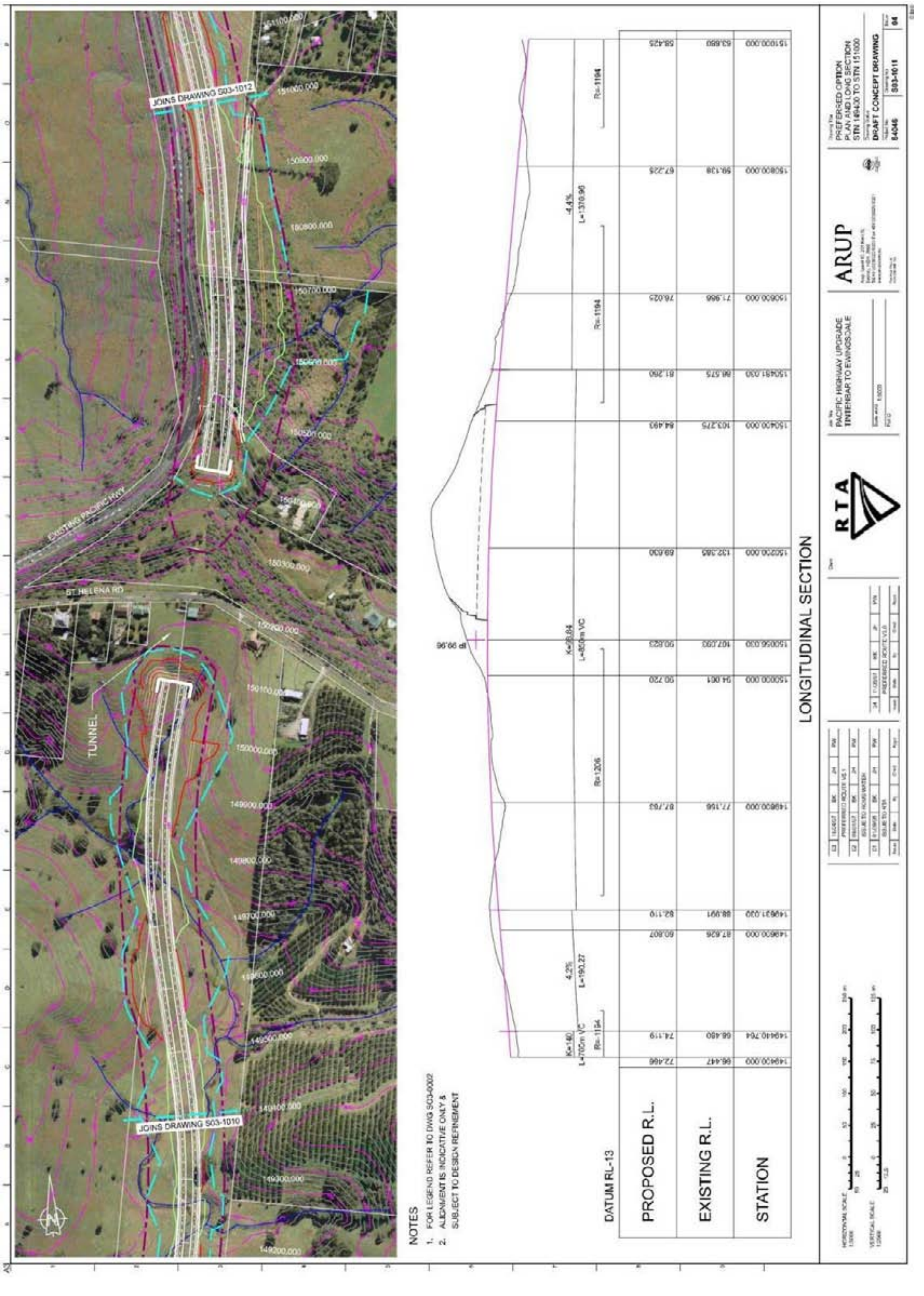
Table B2 : Fraction of heavy vehicles by hour of day

Hour	With project						Without project		
	PR - South of Ivy Lane	PR - South of Bangalow	PR - North of Bangalow	EH - South of Ivy Lane	EH - South of Bangalow	EH - North of Bangalow	EH - South of Ivy Lane	EH - South of Bangalow	EH - North of Bangalow
1	0.50	0.49	0.53	0.20	0.21	0.22	0.50	0.50	0.46
2	0.60	0.59	0.64	0.21	0.22	0.24	0.60	0.60	0.49
3	0.60	0.59	0.64	0.41	0.42	0.46	0.60	0.60	0.54
4	0.65	0.63	0.69	0.31	0.32	0.35	0.64	0.64	0.50
5	0.54	0.52	0.57	0.35	0.36	0.39	0.53	0.53	0.38
6	0.40	0.39	0.42	0.24	0.25	0.27	0.40	0.40	0.28
7	0.24	0.24	0.26	0.13	0.13	0.14	0.24	0.24	0.19
8	0.15	0.15	0.16	0.07	0.07	0.08	0.15	0.15	0.13
9	0.12	0.12	0.13	0.06	0.06	0.07	0.12	0.12	0.10
10	0.11	0.11	0.12	0.06	0.06	0.07	0.11	0.11	0.10
11	0.10	0.10	0.11	0.07	0.07	0.08	0.10	0.10	0.10
12	0.11	0.10	0.11	0.08	0.08	0.09	0.11	0.11	0.10
13	0.11	0.11	0.12	0.08	0.08	0.08	0.11	0.11	0.10
14	0.11	0.11	0.11	0.07	0.07	0.08	0.11	0.11	0.10
15	0.12	0.12	0.13	0.06	0.07	0.07	0.12	0.12	0.10
16	0.11	0.10	0.11	0.06	0.06	0.07	0.11	0.11	0.10
17	0.11	0.10	0.11	0.05	0.05	0.06	0.11	0.11	0.10
18	0.11	0.10	0.11	0.04	0.05	0.05	0.11	0.11	0.09
19	0.15	0.15	0.16	0.03	0.04	0.04	0.15	0.15	0.14
20	0.20	0.19	0.21	0.05	0.05	0.06	0.20	0.20	0.19
21	0.28	0.27	0.29	0.10	0.11	0.11	0.28	0.28	0.24
22	0.37	0.36	0.39	0.06	0.07	0.07	0.36	0.36	0.32
23	0.41	0.40	0.43	0.08	0.08	0.08	0.40	0.40	0.34
24	0.48	0.47	0.51	0.09	0.09	0.10	0.48	0.48	0.40

FIGURES



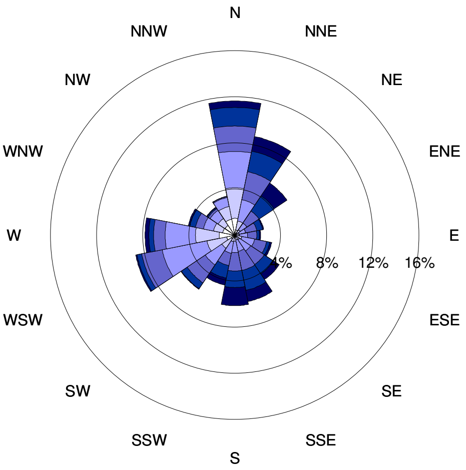
Project area



Proposed tunnel section of the route

FIGURE 2

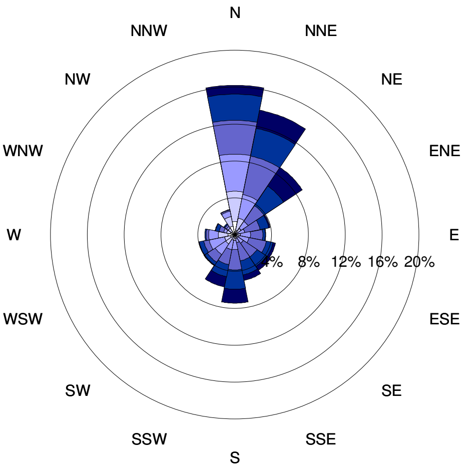
Annual and seasonal windroses for Ballina Airport (BoM data, Dec 2003 to Nov 2004)



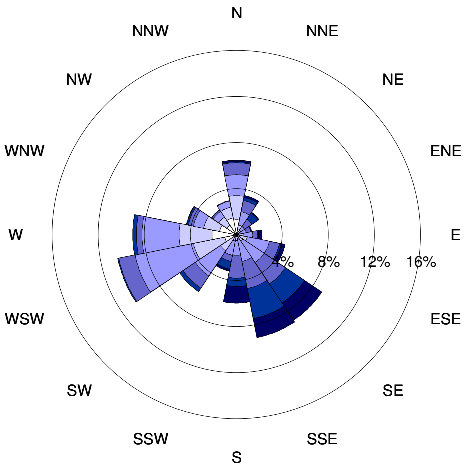
Annual
Calms = 12.5%

Wind speed (m/s)

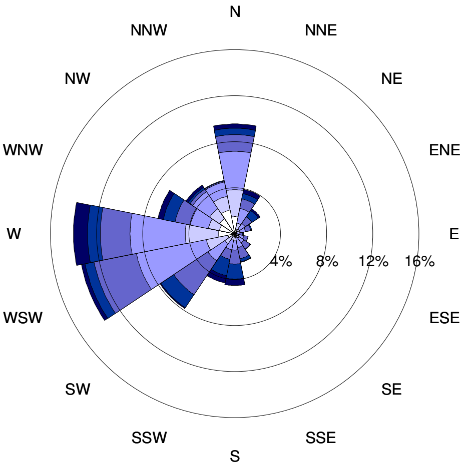
□ >0.5 - 1.5
▨ >1.5 - 3
▨ >3 - 4.5
▨ >4.5 - 6
■ >6 - 7.5
■ >7.5



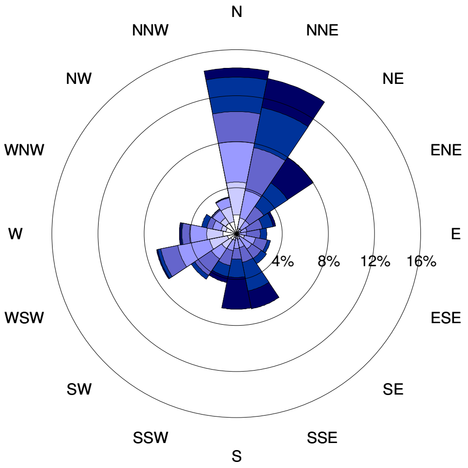
Summer
Calms = 8.9%



Autumn
Calms = 17.1%



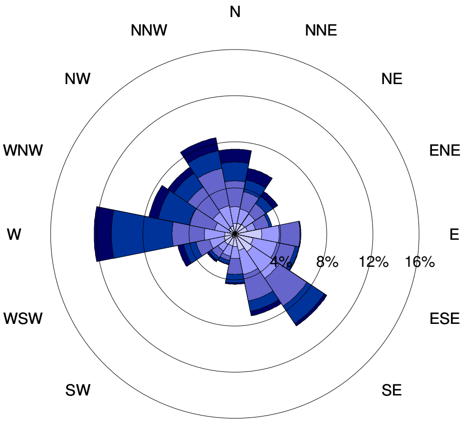
Winter
Calms = 15.4%



Spring
Calms = 8.3%

FIGURE 3

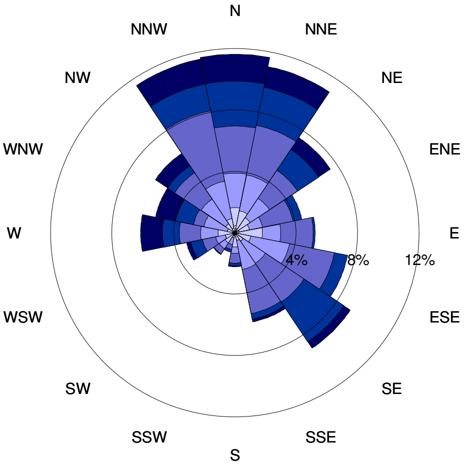
Annual and seasonal windroses for Tinderbox Valley (2004 by TAPM)



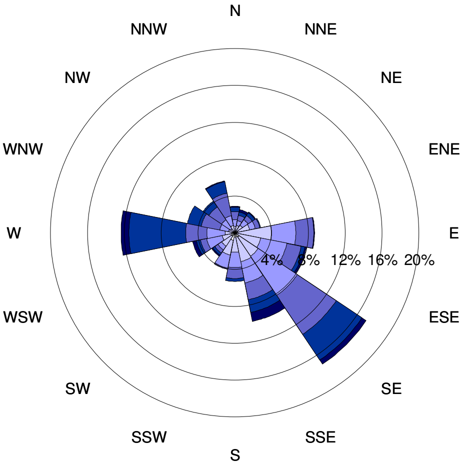
Annual
Calms = 0.5%

Wind speed (m/s)

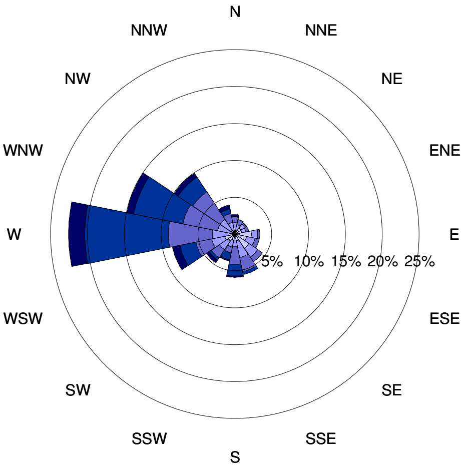
☐ >0.5 - 1.5
■ >1.5 - 3
■ >3 - 4.5
■ >4.5 - 6
■ >6 - 7.5
■ >7.5



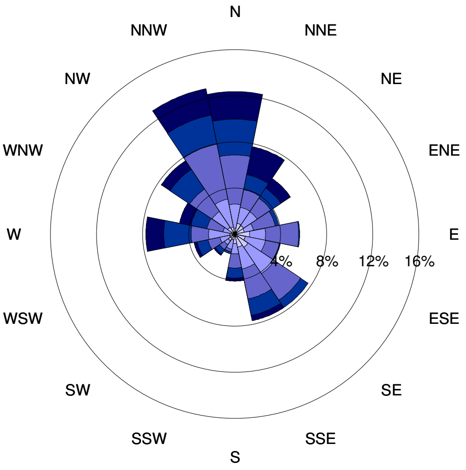
Summer
Calms = 0.3%



Autumn
Calms = 1.0%

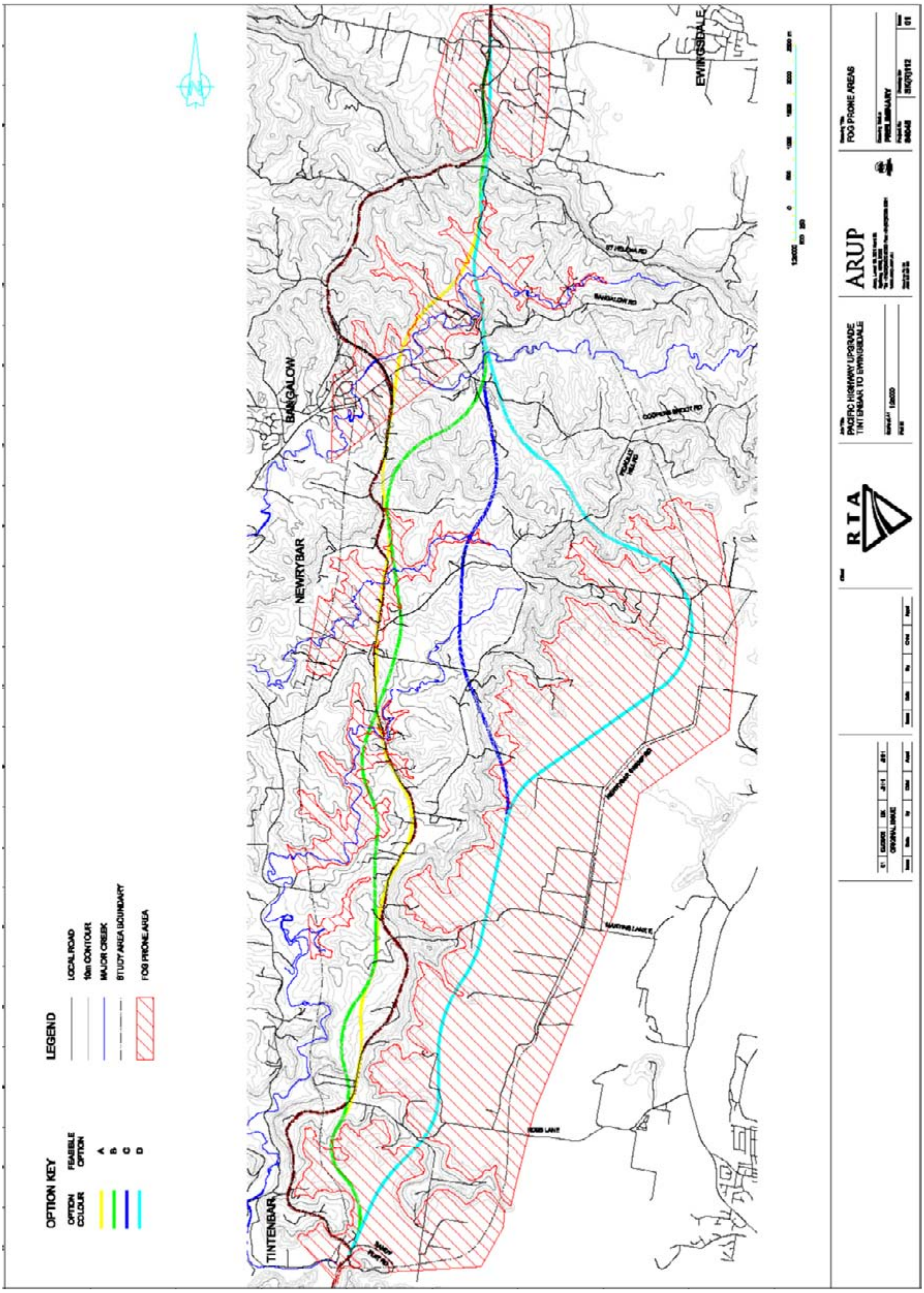


Winter
Calms = 0.4%



Spring
Calms = 0.4%

FIGURE 4



Fog map compiled from local observations

FIGURE 5

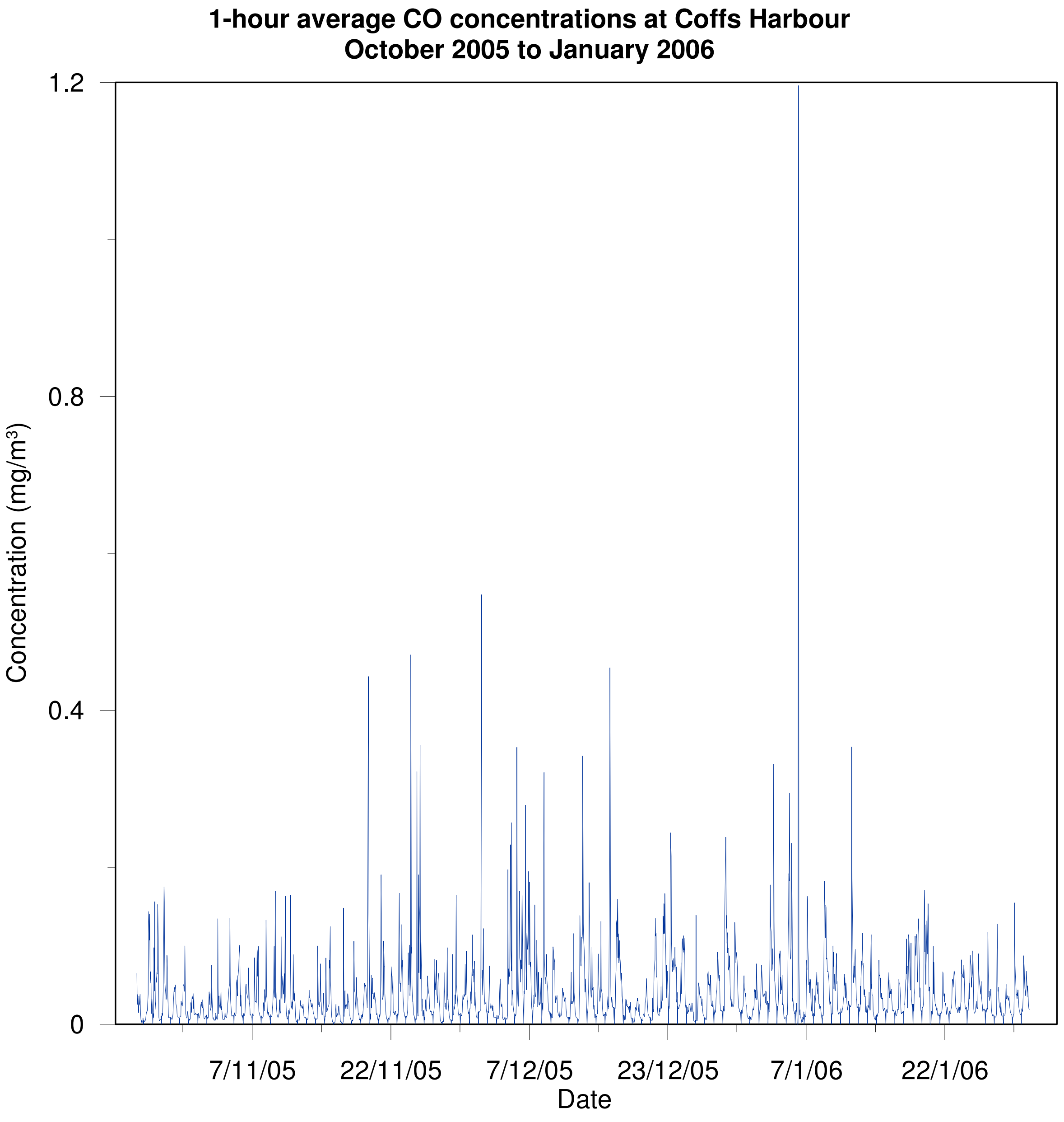

1-hour average CO concentrations at Coffs Harbour
October 2005 to January 2006
1.2
0.8
0.4
0
Concentration (mg/m³)
7/11/05
22/11/05
7/12/05
23/12/05
7/1/06
22/1/06
Date

FIGURE 6

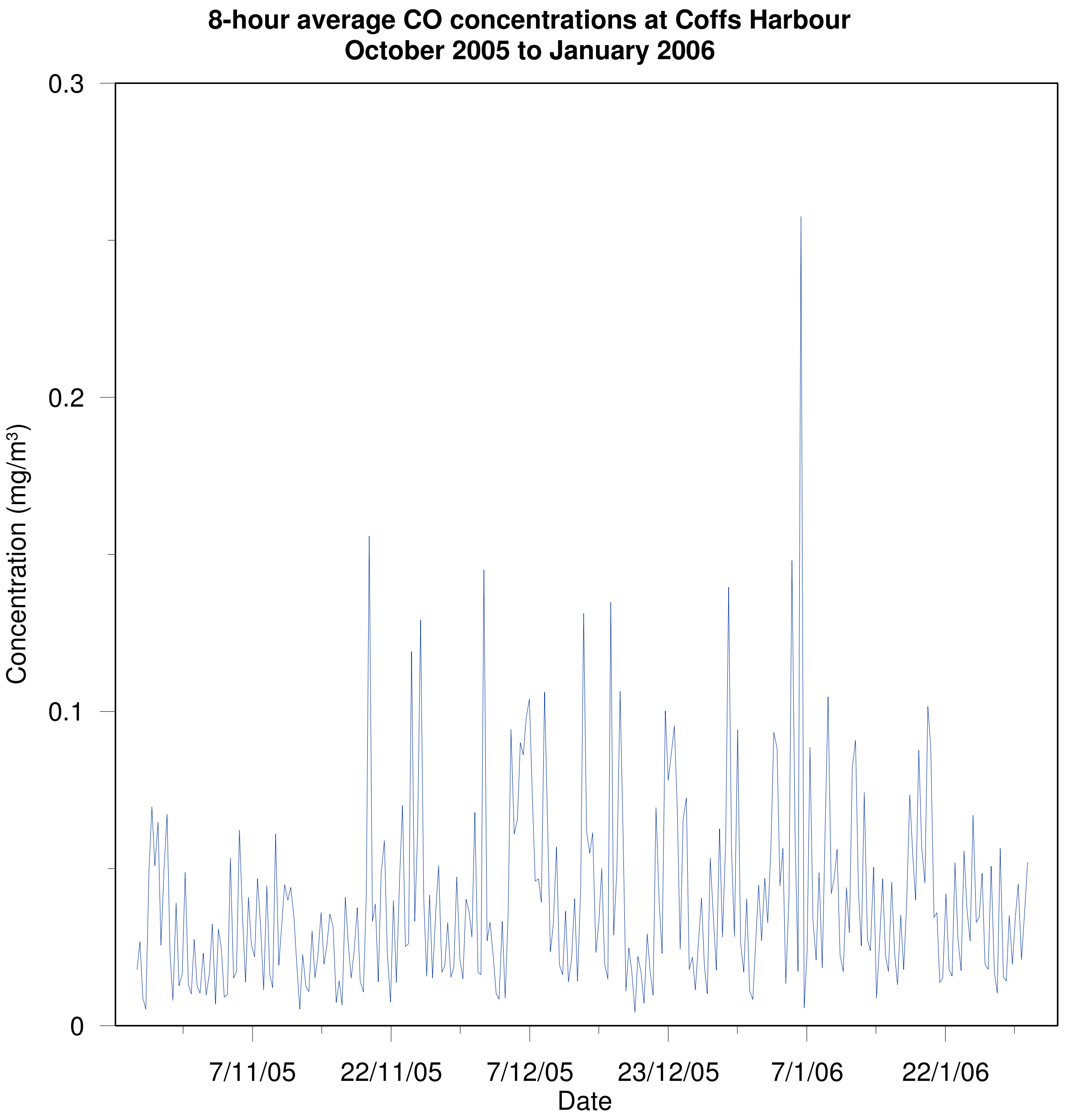

8-hour average CO concentrations at Coffs Harbour
October 2005 to January 2006
0.3
0.2
0.1
0
Concentration (mg/m³)
7/11/05
22/11/05
7/12/05
23/12/05
7/1/06
22/1/06
Date

FIGURE 7

FIGURE 8

1-hour average concentrations of NO_2 at Coffs Harbour
October 2005 to January 2006

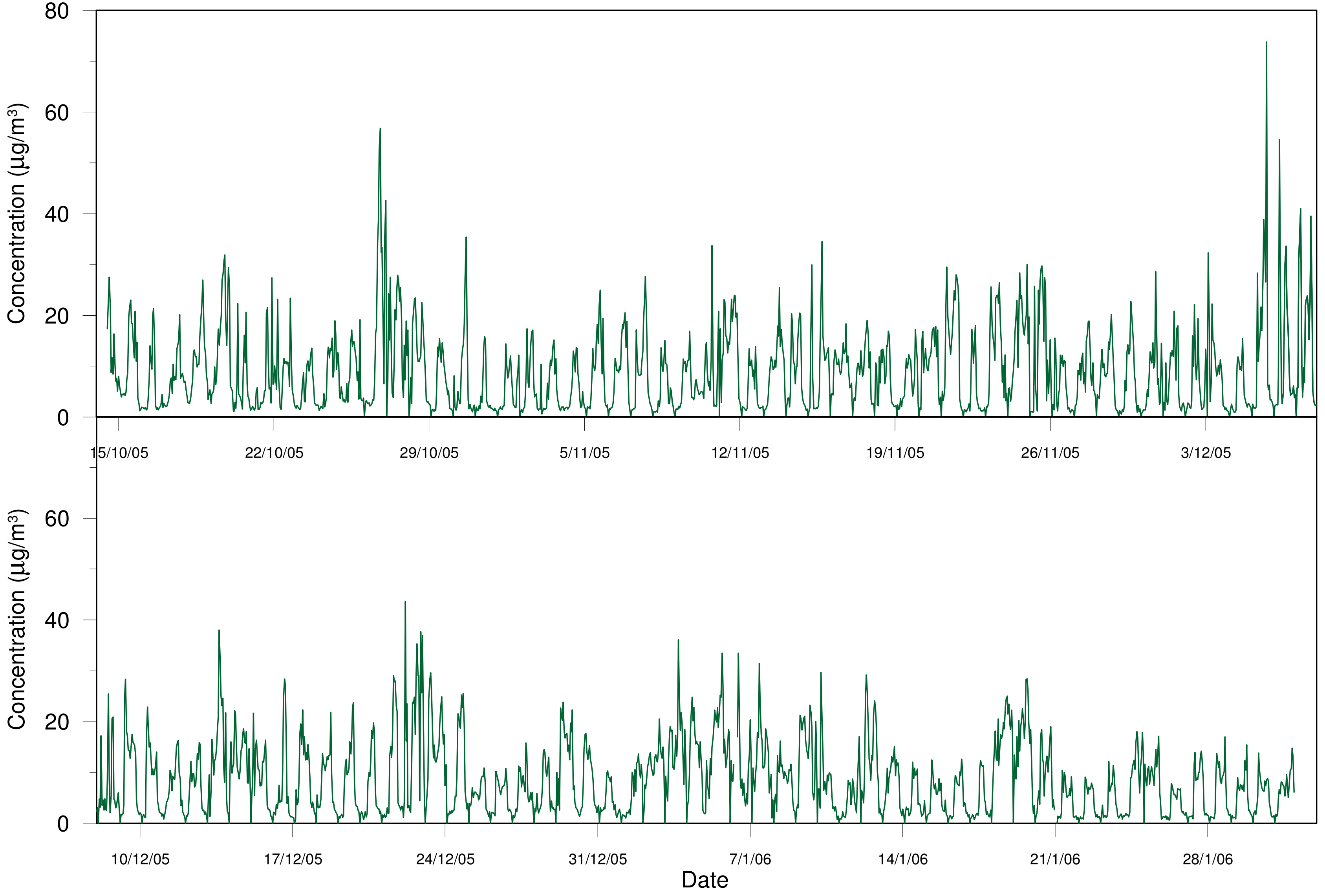
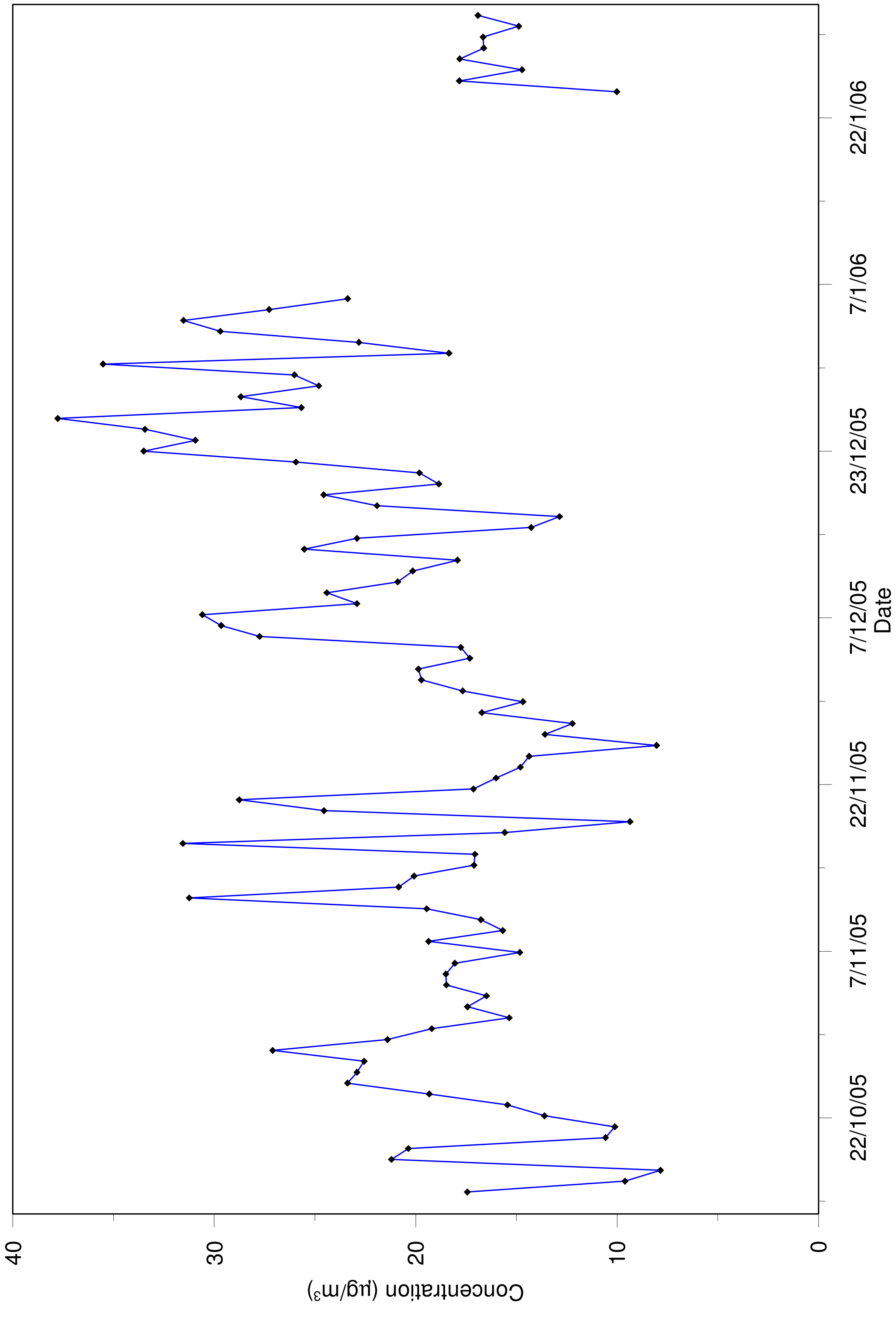
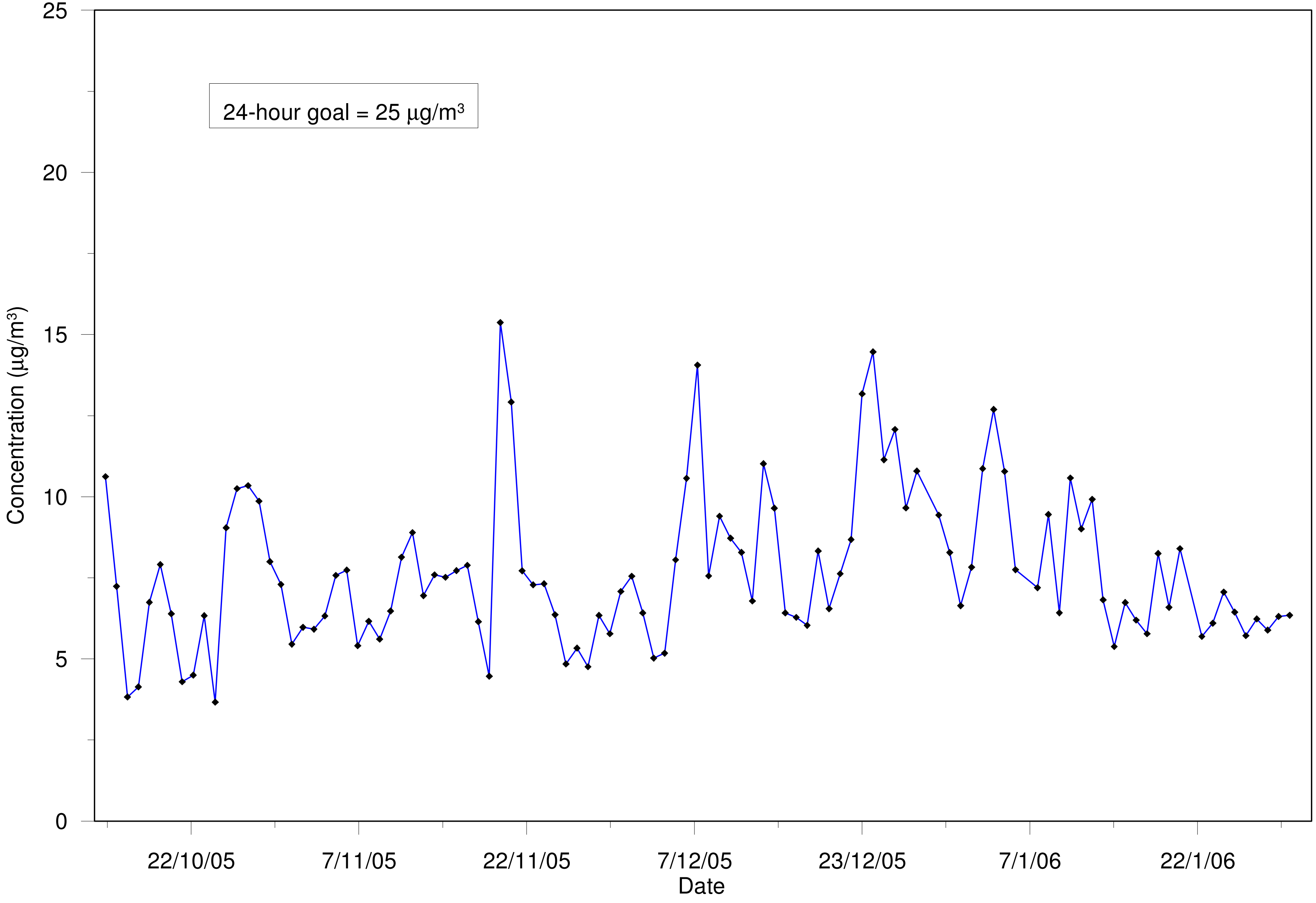


FIGURE 9

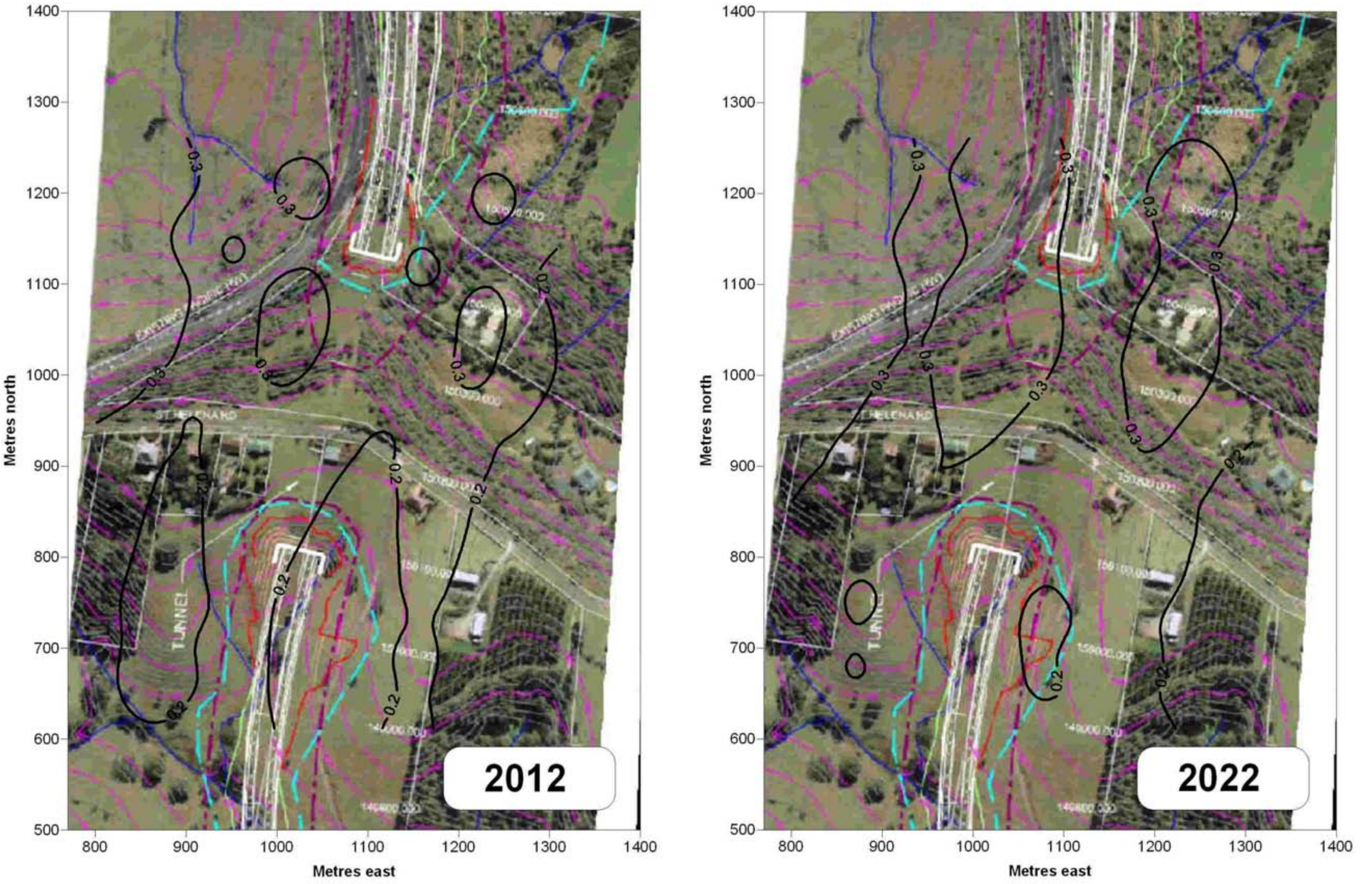


24-hour average concentrations of PM_{10} at Coffs Harbour
October 2005 to January 2006

FIGURE 10

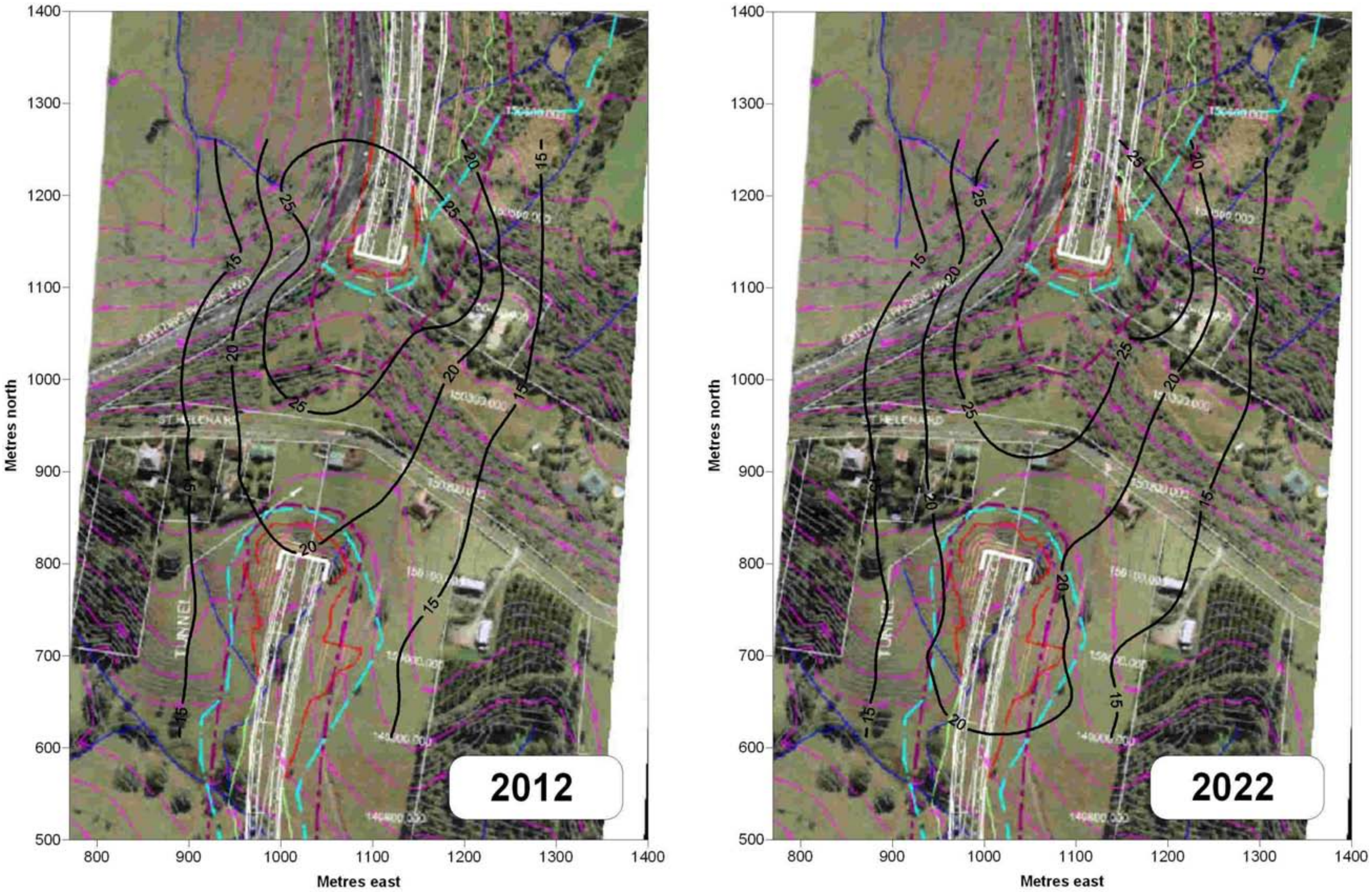


24-hour average concentrations of $PM_{2.5}$ at Coffs Harbour
October 2005 to January 2006



Predicted maximum 1-hour average CO concentrations near tunnel portals (mg/m3)

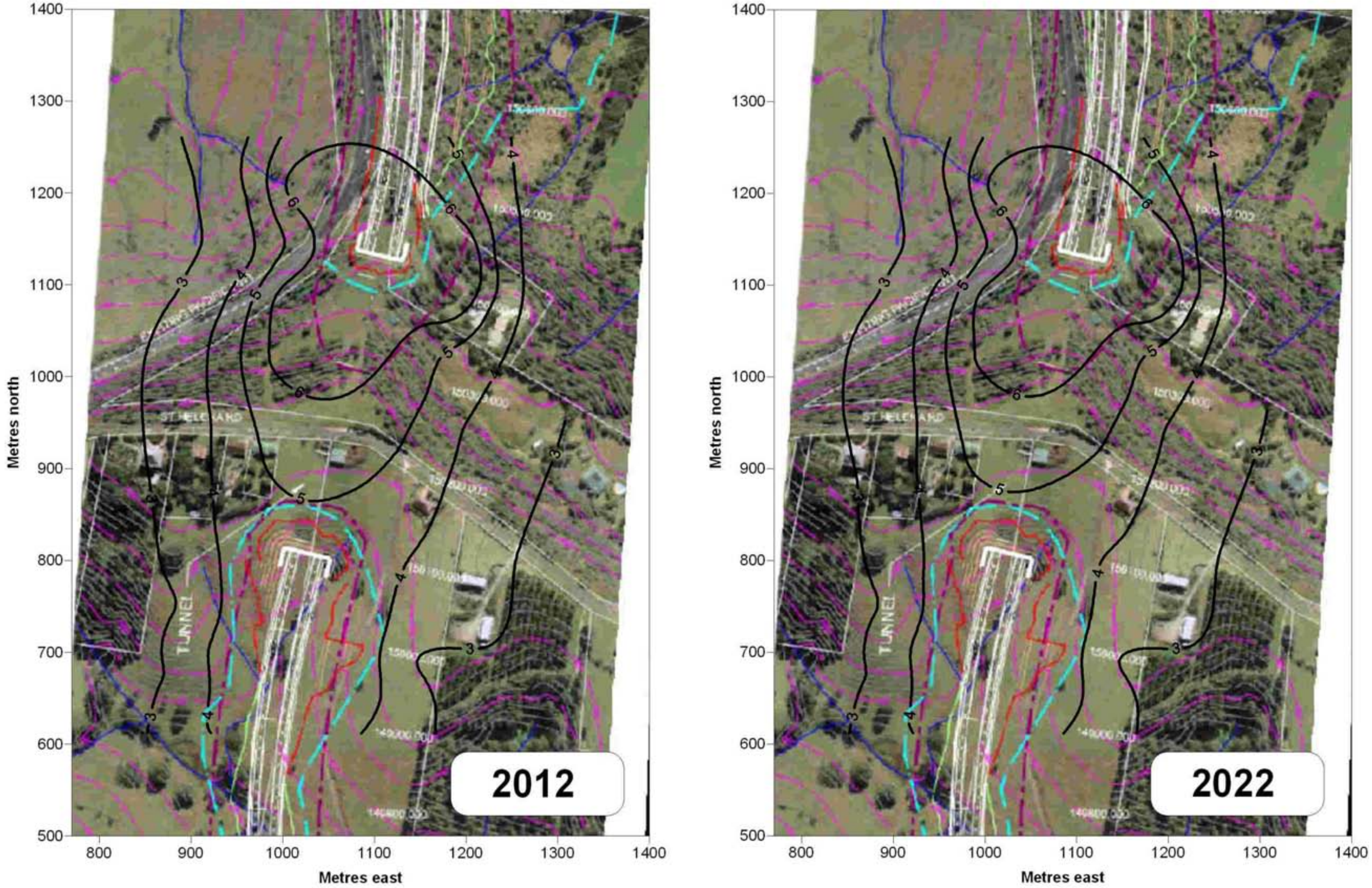
FIGURE 11



Predicted maximum 1-hour average NO2 concentrations
near tunnel portals (ug/m3)

FIGURE 12

FIGURE 13



Predicted maximum 1-hour average PM10 concentrations
near tunnel portals (ug/m3)