TECHNICAL REPORT 7

AIR QUALITY IMPACT ASSESSMENT: BRISBANE NORTHERN LINK PROJECT

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EXECUTIVE SUMMARY

The following report presents an analysis of the air quality impacts of the proposed Brisbane Northern Link Project (the "Project"). The Project involves the construction and operation of an underground toll road (tunnel) between the Western Freeway, in Toowong, and the Inner City Bypass (ICB), at Kelvin Grove. The study focuses on air quality impacts arising from the Project.

The study has attempted to answer the following questions:

- How would air quality change as a result of the Project?
- How do the air quality impacts of the Project compare with the "do nothing" case?
- Would the Project achieve compliance with air quality goals?

Computer-based dispersion modelling has been used as the primary tool to assist with the assessment. Various existing and future scenarios have been simulated and compared in order to gain a greater understanding of the likely impacts that the Project would have on the local air quality. From the assessments that have been undertaken the following conclusions were drawn:

- Pollutant concentrations in the study area in future years (2014+), arising from motor vehicles, would be expected to be similar to existing (2007) concentrations. This is the case both with and without the Project.
- Model results for future years are considered to be conservative since no further improvements to vehicle emissions have been taken into account. Pollutant concentrations in the Greater Brisbane area would be expected to decrease in future years with improvements to motor vehicle emissions.
- Particulate matter concentrations arising from non-motor vehicle sources, such as bushfires, may continue to result in elevated levels on occasions.
- At ground-level the with and without tunnel cases are predicted to be very similar. That is, regional air quality with the Project may be expected to be similar to air quality without the Project.
- At ground-level the highest concentrations due to emissions from ventilation outlets are predicted to be much less than concentrations near busy surface roads.
- Pollutant concentrations at elevated locations due to ventilation outlet emissions would be expected to be below relevant air quality goals.
- The difference in ambient air quality arising from treatment of tunnel emissions by some form of filtration would be difficult to detect. Benefits arising from emissions treatment would most likely be realised in-tunnel and at elevated locations very near the tunnel ventilation outlets.

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

CONTENTS

LIST OF APPENDICES

LIST OF TABLES

LIST OF FIGURES (All figures are at the end of the report)

32. Predicted annual average NO_2 concentrations in 2007 ($\mu g/m^3$)
33. Predicted annual average NO_2 concentrations in 2014 ($\mu g/m^3$)
34. Predicted annual average NO_2 concentrations in 2026 ($\mu g/m^3$)
35. Predicted maximum 24-hour average PM_{10} concentrations in 2007 ($\mu g/m^3$)
36. Predicted maximum 24-hour average PM_{10} concentrations in 2014 ($\mu g/m^3$)
37. Predicted maximum 24-hour average PM_{10} concentrations in 2026 ($\mu g/m^3$)
38. Predicted annual average PM_{10} concentrations in 2007 ($\mu g/m^3$)
39. Predicted annual average PM_{10} concentrations in 2014 ($\mu g/m^3$)
40. Predicted annual average PM_{10} concentrations in 2026 ($\mu g/m^3$)
41. Predicted maximum 24-hour average $PM_{2.5}$ concentrations in 2014 ($\mu g/m^3$)
42. Percentage change from existing (2007) to 2014 for maximum 8-hour average CO
43. Percentage change from existing (2007) to 2014 for maximum 1-hour average NO_2
44. Percentage change from existing (2007) to 2014 for annual average NO_2
45. Percentage change from existing (2007) to 2014 for maximum 24-hour average PM_{10}
46. Percentage change from existing (2007) to 2014 for annual average PM_{10}
47. Predicted maximum 8-hour average CO concentrations above ground-level in 2014 (mg/m^3)
48. Predicted maximum 1-hour average NO_2 concentrations above ground-level in 2014 ($\mu g/m^3$)
49. Predicted annual average NO_2 concentrations above ground-level in 2014 ($\mu g/m^3$)
50. Predicted maximum 24-hour average PM_{10} concentrations above ground-level in 2014 ($\mu g/m^3$)
51. Predicted annual average PM_{10} concentrations above ground-level in 2014 ($\mu g/m^3$)
52. Predicted roadside concentrations near Kelvin Grove Road (north of Herston)
53. Predicted roadside concentrations near Inner City Bypass (west of Kelvin Grove)
54. Predicted roadside concentrations near Hale Street
55. Predicted roadside concentrations near Waterworks Road (north of Ennorgera)
56. Predicted roadside concentrations near Given Terrace
57. Predicted roadside concentrations near Boundary Street (north of Baroona)
58. Predicted roadside concentrations near Milton Road (west of Baroona)
59. Predicted roadside concentrations near Coronation Drive (east of Park)
60. Predicted roadside concentrations near Miskin Road (south of Mt Cootha)
61. Predicted roadside concentrations near Western Freeway (south of Mt Cootha)
62. Comparison of without and with tunnel filtration for maximum 1-hour average NO_2 concentrations in 2014 ($\mu g/m^3$)
63. Comparison of without and with tunnel filtration for annual average NO_2 concentrations in 2014 ($\mu g/m^3$)
64. Comparison of without and with tunnel filtration for maximum 24-hour average PM_{10} concentrations in 2014 ($\mu g/m^3$)
65. Comparison of without and with tunnel filtration for annual average PM_{10} concentrations in 2014 ($\mu g/m^3$)
66. Predicted maximum 24-hour average sub-micrometre particles in 2007 ($particles/cm^3$)
67. Predicted maximum 24-hour average sub-micrometre particles in 2014 ($particles/cm^3$)

GLOSSARY OF TERMS

AADT	Annualised Average Daily Traffic
AL	Airport Link
BCC	Brisbane City Council
CO	Carbon monoxide
DEC	New South Wales Department of Environment and Conservation
DM	"Do Minimal" or "No Tunnel" option
DS	"Do Something" or "With Tunnel" option
DSNB	"Do Something" or "With Tunnel" option with Northern Busway
EPA	Queensland Government Environment Protection Agency
ICB	Inner City Bypass
MAQS	Metropolitan Air Quality Study
NB	Northern Busway
NSBT	North-South Bypass Tunnel
μm	micrometre
$\mu g/m^3$	micrograms per cubic metre
mg/m^3	milligrams per cubic metre
NE	Northeastern Connection
NL	Northern Link
NO_2	Nitrogen dioxide
NO_x	Nitrogen oxides or oxides of nitrogen
NPI	National Pollutant Inventory
NW	Northwestern Connection
O_3	Ozone
PIARC	Permanent International Association of Road Congress
Pb	Lead
$PM_{2.5}$	Particulate matter with equivalent aerodynamic diameter less than 2.5 μm
PM_{10}	Particulate matter with equivalent aerodynamic diameter less than 10 μm
ppm	parts per million
ppb	parts per billion
RAQM	Regional Air Quality Modelling Project
SC	Southern Connection
SO_2	Sulfur dioxide
VKT	Vehicle Kilometres Travelled
VOC	Volatile Organic Compounds
WHO	World Health Organisation

1. INTRODUCTION

This report has been prepared by Holmes Air Sciences for the Sinclair Knight / Connell Wagner Joint Venture (SKM/CW). The purpose of the report is to quantitatively assess air quality impacts associated with the operation of the proposed Northern Link (NL) Tunnel in Brisbane.

The Project involves the construction of a twin road tunnel in central Brisbane between Toowong and Kelvin Grove. **Figure 1** shows the study area and proposed route for the NL.

The air quality assessment is based on the use of computer-based dispersion modelling to predict air pollutant concentrations in the study area. The assessment considers air pollutants arising from motor vehicles using the tunnel and regional surface roads. To assess the effect that the operation of the tunnel 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:

- Description of the Project;
- Air quality standards and goals relevant for the Project;
- Discussion of air quality issues associated with road tunnels;
- Review of climatic and meteorological conditions in the area;
- Review of existing air quality in the area;
- Methods used for determining pollutant emissions and impacts; and
- Interpretation and analysis of predicted air quality impacts.

Cumulative effects of the Project form a significant component of the study while contributions from individual sources are also addressed. The methodology for the study has been formulated to determine how air quality would change as a result of the Project.

2. LOCAL SETTING AND PROJECT DESCRIPTION

Figure 1 shows the extent of area defined for the purposes of this study as the "study area". Landuse within this area includes residential as well as mixed commercial and industrial. High-rise buildings are present, representing the CBD, and Brisbane River meanders through various parts of the study area. **Figure 2** shows the terrain in the study area.

In summary, the Project will include:

- Two separate parallel road tunnels, one for north-bound traffic and one for south-bound traffic;
- A high level ventilation outlet at either end of the tunnels;
- Connections to surface roads at Toowong and Kelvin Grove.

A construction period of approximately three to four years would be required with 2014 being the intended year of opening.

The tunnel will require ventilation in order to maintain in-tunnel pollutant concentrations at acceptable levels. A "longitudinal" ventilation system is proposed whereby air in the tunnel would be drawn into the tunnel from main portals and access ramps. Air flow in the tunnel would be controlled by fans and the "piston" effect of the motor vehicles. Air would be discharged from each tunnel via one of two ventilation outlets. **Figure 3** shows the preferred location for the eastern and western tunnel ventilation outlets. **Figure 4** shows a schematic of air movements in the tunnel and from ventilation outlets.

Traffic information (see **Section 6.2**) suggests that the introduction of the tunnel into the study area would change traffic volumes at various locations. In some areas the traffic volumes are predicted to increase while in other areas traffic volumes would decrease.

The primary effect of the tunnel would be to remove traffic from surface roads that would otherwise be used as the route of the tunnel. From an air quality perspective the consequence of removing traffic from surface roads is a reduction in pollutant concentrations near the surface road. It is important that the air quality impacts of the Project are based on consideration of all changes resulting from the Project. These changes may include:

- Increases and decreases in surface road traffic arising from introducing a tunnel into the road network; and
- Removing emissions from surface roads and venting via tunnel ventilation outlets.

3. AIR QUALITY STANDARDS AND GOALS

In assessing any project with significant air emissions, it is necessary to compare the impacts of the project with relevant air quality goals. Air quality standards or goals are used to assess the potential for ambient air quality to give rise to adverse health or nuisance effects.

The Queensland Government Environment Protection Agency (EPA) have set air quality goals as part of their Environmental Protection (Air) Policy 1997 (**EPA, 1997**). The policy was developed to meet air quality objectives for Queensland's air environment as outlined in the Environmental Protection Act 1994 (**EPA, 1994**).

In addition, the National Environment Protection Council of Australia (NEPC) has determined a set of air quality goals for adoption at a national level, which are part of the National Environment Protection Measures (NEPM). For the purposes of this project the EPA has indicated during discussions that it would be appropriate to adopt the NEPM air quality standards and goals either where there is no set EPA criteria or where the NEPM criteria are more stringent than the set EPA criteria.

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**).

Table 1 lists the air quality goals for criteria pollutants noted by the EPA and NEPM that are relevant for this study. 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. The basis of these air quality goals and, where relevant, the safety margins that they provide are discussed in detail in **Appendix A**.

The primary air quality objective of most projects is to ensure that the air quality goals listed in **Table 1** are not exceeded at any location where there is the possibility of human exposure for the time period relevant to the goal.

Table 1 : Air quality goals relevant to this project

Pollutant	*Goal*	*Averaging Period*	*Agency*
Carbon monoxide (CO)	8 ppm or 10 mg/m^3	8-hour maximum	EPA
	9 ppm or 11 mg/m^3	8-hour maximum	NEPM[1]
Nitrogen dioxide (NO_2)	0.16 or 320 $\mu g/m^3$	1-hour maximum	EPA
	0.12 ppm or 246 $\mu g/m^3$	1-hour maximum[1]	NEPM
	0.03 ppm or 62 $\mu g/m^3$	Annual mean	NEPM
Particulate matter less than 10 μm (PM_{10})	150 $\mu g/m^3$	24-hour maximum	EPA
	50 $\mu g/m^3$	24-hour maximum	NEPM[2]
	50 $\mu g/m^3$	Annual mean	EPA
	(30 $\mu g/m^3$)	(Annual mean)	(NSW DECC)
	(25 $\mu g/m^3$)	(Annual mean)	WHO
Particulate matter less than 2.5 μm ($PM_{2.5}$)	25 $\mu g/m^3$	24-hour maximum	NEPM
	8 $\mu g/m^3$	Annual average	NEPM
Total Suspended Particulate Matter (TSP)	90 $\mu g/m^3$	Annual average	EPA
Sulfur Dioxide (SO_2)	0.25 ppm or 700 $\mu g/m^3$	10-minute maximum	EPA
	0.20 ppm or 570 $\mu g/m^3$	1-hour maximum	NEPM[1], EPA
	0.08 ppm or 225 $\mu g/m^3$	24-hour maximum	NEPM[1]
	0.02 ppm or 60 $\mu g/m^3$	Annual average	NEPM, EPA
Ozone (O_3)	0.10 ppm or 210 $\mu g/m^3$	1-hour maximum	NEPM[1], EPA
	0.08 ppm or 170 $\mu g/m^3$	4-hour maximum	NEPM[1], EPA
Lead (Pb)	1.5 $\mu g/m^3$	90-day average	EPA
	0.5 $\mu g/m^3$	Annual average	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	24-hour maximum	EPA
	1 ppm	24-hour maximum	NEPM (Air Toxics)
	0.1 ppm	Annual average	NEPM (Air Toxics)
Xylene	0.25 ppm	24-hour maximum	NEPM (Air Toxics)
	0.2 ppm	Annual average	NEPM (Air Toxics)

[1] *One day per year maximum allowable exceedances*
[2] *Five days per year maximum allowable exceedances*

Note that Queensland does not have a long-term goal for PM_{10} that is consistent with the 24-hour NEPM goal. The NSW Department of Environment and Climate Change (DECC) and the World Health Organisation (WHO) long-term goals have been included to provide a benchmark for comparison with the 24-hour NEPM goal. The WHO goal of 25 $\mu g/m^3$ is adopted for this Project.

On a local scale, the Brisbane City Council (BCC) developed the Brisbane Air Quality Strategy (BAQS) (**BCC, 2004**) which is intended to provide the framework for air quality management in Brisbane. The BAQS identifies photochemical smog, urban haze and particle pollution and air toxics as high priorities.

Some of key air quality approaches in the BAQS include:

- Reducing emissions from the main source groups;

- Improving the understanding of air pollution processes; and
- Addressing air quality priorities such as local air pollution through better planning.

In addition, the BAQS recognises the ambient air quality guidelines from Commonwealth, State and Local Governments but proposes that an Environmental Policy specific to South East Queensland be developed to place greater priority on local environmental factors.

4. AIR QUALITY ISSUES ASSOCIATED WITH ROADWAY PROJECTS

This section discusses air quality issues relevant to roadway projects such as a tunnel.

4.1 Changes to Air Quality

One objective for roadway projects is to improve air quality or at least to minimise air quality impacts. It is important to review the change in air quality that is likely to occur with the Project. Assessing the change in air quality should take into account any increase or decrease in emissions in the study area due to the Project. Increases or decreases in emissions will arise as a result of a change in the traffic along a particular corridor.

On a regional scale the change in Vehicle Kilometres Travelled (VKT) in the study area will directly influence the change in air quality that would be expected in the study area.

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

- The mode of travel (a measure of the stop/start nature of the traffic flow and the average speed);
- The grade of road; and
- The 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. One benefit of roadway tunnels can be the removal of heavy vehicles from residential surface roads.

4.2 Surface Roads and Tunnels

In terms of emissions from vehicles and resultant pollutant concentrations the difference between surface roads and tunnels lies at the point of emission. Emissions from surface roads are released at ground-level where a greater proportion of the population reside. The surface road relies solely on atmospheric dispersion to reduce the pollutant concentrations between the roadway and the sensitive receptor.

In contrast, tunnel emissions are generally vented via a ventilation outlet(s) assuming that the ventilation system is operated to avoid portal emissions. The point of emission from the tunnel is therefore above ground-level (at the outlet height). This removes the plume from nearby ground-level receptors and, under poor dispersion conditions, there will be minimal impact as the plume does not spread sufficiently to reach the ground. The elevated plume also has a greater volume of atmosphere in which to disperse. An elevated point source is therefore more effective in dispersing pollution than a surface road (line source) with the same emission.

It has been seen from dispersion modelling studies (**Holmes Air Sciences, 2001**) that, provided the tunnel is sufficiently ventilated, significant air quality benefits can be obtained using tunnels. The most significant air quality benefits occur along surface roads which undergo the reduction in traffic as a result of the tunnel.

The ventilation outlets do, however, need to be sited appropriately and where possible not in valleys and not close to high rise buildings.

One of the primary impacts associated with tunnels is a negative perception of ventilation outlets. Outlets are often seen as a new pollution source whereas in most cases the surrounding areas achieve a benefit in local air quality due to the reduction of vehicles on the surface roads. In most cases tunnel ventilation outlets are not a new pollution source, rather, they redistribute existing vehicle emissions that would otherwise be released at ground-level.

4.3 Tunnel Filtration

Filtration is a contentious subject for road tunnels. There are generally two types of tunnel filtration options:

- In-tunnel filtration aimed at reducing pollutant concentrations for motorists using the tunnel; and
- Ventilation outlet filtration aimed at reducing pollutant concentrations emitted to the outside ambient air.

In-tunnel filtration also has the effect of reducing the emission to the outside air.

Dispersion modelling studies (see **Holmes Air Sciences, 2001, 2004, 2006**) have indicated that, even when high levels of filtration efficiency are assumed, the differences to ambient air quality at ground-level would be small and unlikely to be detectable by conventional monitoring instrumentation. Pollutant emissions from surface roads tend to contribute more to ground-level air quality than emissions from the tunnel ventilation outlets. Ultimately, however, the most beneficial option for the treatment of emissions from motor vehicles lies at the point of emission. Controlling emissions from each individual motor vehicle ensures that benefits to air quality would be realised on local and regional scales.

For most of this study the modelling has assumed that there would be no tunnel filtration as part of the Project. The consequence of this assumption, for the purposes of this assessment, is that estimated pollutant emissions from tunnel ventilation outlets would be higher than for a tunnel with filtration equipment fitted. The degree of difference between ventilation outlet emissions for a tunnel with and without filtration will depend on the efficiency of filtration equipment.

In addition, dispersion modelling with tunnel filtration has been conducted to provide some comparisons of the likely effects on air quality.

5. EXISTING ENVIRONMENT

5.1 Preamble

For air quality assessment purposes, the existing environment in the study corridor (refer **Figure 5**) can be characterised by the prevailing meteorology, climate and the existing air quality. This section provides a review of meteorological and ambient air quality monitoring data that have been collected in the study corridor. This information has been used to characterise air quality in typical urban environments, ranging from peak locations near busy roads to background locations such as in parklands. Meteorology will also vary across Brisbane, particularly wind patterns. The meteorology has been incorporated into the study by considering data from several monitoring stations to determine local wind conditions and extrapolating to other areas using a wind-field model.

5.2 Meteorology

Wind patterns are important for the transportation and dispersion of air pollutants. As well as information on prevailing wind patterns, historical data on temperature, humidity and rainfall are presented in this section to give a more complete picture of the local climate.

5.2.1 Dispersion Meteorology

The meteorology in the study corridor would be influenced by several factors including the local terrain and land-use. On a relatively small scale, winds would be largely affected by the local topography. At larger scales, winds are affected by synoptic scale winds, which are modified by sea breezes in the daytime in summer (also to a certain extent in the winter) and also by a complex pattern of regional drainage flows that develop overnight.

Given the relatively diverse terrain and land use in the study corridor, differences in wind patterns at different locations in the study corridor would be expected. These varying wind patterns would arise as a result of the interaction of the air flow with the surrounding topography and the differential heating of the land and water.

In the air quality assessment that has been undertaken for this Project the complex mechanisms that affect air movements in the study corridor are to be assessed to ensure that these patterns are incorporated into the dispersion modelling studies that are done. In the air quality assessment extensive use has been made of the CALPUFF dispersion model which is discussed in more detail **Section 7**. The CALPUFF model, through the use of the CALMET meteorological processor, simulates complex meteorological patterns that exist in a particular region and the effects of local topography and changes in land surface characteristics can be incorporated into the model.

One of the objectives for reviewing local meteorological data is to determine the most suitable sites and years available for the CALPUFF modelling. Typically, one year of hourly records will be sufficient to cover most variations in meteorology that will be experienced at a site, however it is important that the selected year is generally typical of the prevailing meteorology.

Figure 5 shows the location of meteorological monitoring sites which were used to compare localised wind patterns throughout the region. Wind data from four EPA monitoring sites (Brisbane CBD, Rocklea, South Brisbane and Woolloongabba) and two project monitoring sites (Bowen Hills and Kedron) have been reviewed.

The meteorological data collected from all meteorological monitoring sites included hourly records of temperature, wind speed and wind direction. A summary of the data recovery and mean wind speed from each site for 2004, 2005 and 2006 is shown in **Table 2**.

Table 2 : Summary of available wind data from meteorological monitoring sites

Site	2004	2005	2006
Wind speed data recovery percentage (%)			
Brisbane CBD	94	100	100
Rocklea	97	99	99
South Brisbane	97	99	99
Woolloongabba	100	97	100
Bowen Hills (1 Jul 2004 to 1 Dec 2005)	45	82	-
Kedron (10 Jan 2006 to 31 Dec 2006)	-	-	90
Annual average wind speed (m/s)			
Brisbane CBD	0.6	0.7	0.8
Rocklea	2.5	2.4	2.4
South Brisbane	1.6	1.7	1.6
Woolloongabba	2.1	2.1	1.9
Bowen Hills (1 Jul 2004 to 1 Dec 2005)	1.9	1.8	-
Kedron (10 Jan 2006 to 31 Dec 2006)	-	-	1.7

To examine wind patterns from year to year, annual wind roses for each of the EPA monitoring sites for 2004, 2005 and 2006 have been constructed and are shown in **Figure 6**. There are variations in the wind patterns from site to site but it can be seen that wind patterns do not vary substantially from year to year. Therefore, 2005 has been selected for development of the meteorological wind field for the air quality assessment, based on the number of nearby sites available for the modelling and on the completeness of the data records. Also, from comparison of the wind patterns at each monitoring site, 2005 can be considered a representative year.

The following sections describe each of the meteorological data sets in detail, with a focus on the 2005 calendar year.

Brisbane CBD

Figure 7 shows annual and seasonal wind roses for the EPA's Brisbane site for 2005. On an annual basis the winds are predominantly from the north or east-southeast. Very few to no winds are derived from the western sectors and it was noted by EPA that nearby tall buildings shelter the sensors from these winds and also lead to turbulence at this site.

The annual average wind speed at the Brisbane CBD site in 2005 was 0.7 m/s. This site recorded a very high percentage of calms, where winds are less than or equal to 0.5 m/s, at 50% which would be largely due to the sheltering effect of buildings located around the wind sensors.

Rocklea

EPA's Rocklea monitoring station is located in an open area amongst light industrial and residential land use. **Figure 8** shows the annual and seasonal wind roses for this site in 2005. Annually, winds in Rocklea are predominantly from the south to south-west, with some winds also from the north-northeast and east-southeast quadrants. The south-westerly winds tend to be much lighter than the north-easterly winds, which would represent the direction of the sea-breeze. It can be seen from **Figure 8** that the lighter south-westerly winds occur in the cooler months of autumn and winter, while the north-easterly winds occur in warmer months, namely, summer and spring.

Winds in the Rocklea area tend to be stronger than at the other sites examined, as the annual average wind speed for 2005 was 2.4 m/s. This is consistent with the more exposed nature of the site. The percentage of calms in 2005 was 7%.

South Brisbane

The South Brisbane site is located adjacent to the Southeast Freeway and provides information on air quality typically experienced at the boundary of major traffic corridors in southeast Queensland. Meteorological data are also collected at this site and **Figure 9** shows the 2005 annual and seasonal wind roses. Annually, winds at this site are predominantly from the north-east quadrant. This pattern of winds is present in the warmer months of summer and spring. Winds from the south and east-southeast prevail in autumn while in winter, light west-southwest winds dominate. Very few winds from the northwest are measured at this site.

The annual average wind speed from South Brisbane in 2005 was 1.7 m/s and the percentage of calms was 13.4%.

Woolloongabba

As for the South Brisbane site, the EPA's Woolloongabba station is situated close to a busy road (Ipswich Road) which makes it ideal for monitoring air pollution from traffic sources. There are tall buildings nearby which shelter the site from some wind directions.

Figure 10 shows the 2005 annual and seasonal wind roses for Woolloongabba. Winds are variable at this site, but generally comprise light winds from the south-west or stronger winds from the north-east or east-southeast. Very few winds from the north-west are measured at this site.

In 2005, the annual average wind speed at this site was 2.1 m/s and the percentage of calms was 6.9%.

Bowen Hills

Simtars commenced ambient air quality and meteorological monitoring for the North South Bypass Tunnel (NSBT) at Bowen Hills in June 2004. This site is at the north-eastern end of the NL study corridor. Monitoring stopped in December 2005.

Wind data collected in 2005 from this site are shown as wind-roses in **Figure 11**. Like many of the EPA monitoring locations, light winds from the south-west prevail, most commonly in the cooler seasons of the year. The sea-breeze is present as stronger winds from the north-east in the warmer seasons.

This site experienced a relatively high proportion of calm conditions (15.3% or the time) and the annual average wind speed in 2005 was 1.8 m/s.

Kedron

Meteorological and ambient air quality monitoring data from Kedron were collected by Simtars for the Brisbane Airport Link (AL) Project between January 2006 and January 2007.

Figure 12 shows annual and seasonal wind-roses for the Kedron site in 2006. Annually, winds were predominantly from the south-southwest or north-northeast. Summer winds were generally from the north-northeast to east-southeast, representing the direction of the sea-breeze. The winter months generally bring much lighter winds originating from the south-west quadrant. Spring and autumn winds show similarities between both summer and winter.

The annual average wind speed at the Kedron site in 2006 was 1.6 m/s and the percentage of calms was 13.9%. The data from Kedron in 2006 are similar to the data collected at Bowen Hills in 2005.

For the purposes of the air quality assessment, data collected in 2005 from the Rocklea, South Brisbane, Woolloongabba and Bowen Hills meteorological monitoring sites have been considered to be the most suitable datasets for the CALMET meteorological model. The proximity of these sites to the area of interest ensures that they would contain data that are representative of the dispersion conditions in the study corridor. The meteorology at the Brisbane CBD site is affected by the turbulence induced by nearby buildings and the wind data would not be representative of the broader scale wind patterns.

Figure 13 shows the model extents, terrain and landuse information used as input to the CALMET model. **Figure 14** shows a snapshot of winds simulated by the CALMET model for stable night-time conditions. The diagram shows the effect of the terrain on the flow of winds for a particular set of atmospheric conditions. The difference in wind speed and direction at various locations of the study area is evident.

A summary of the data and parameters used as part of the meteorological component of this study are shown in **Table 3**.

Table 3 : Summary of meteorological parameters used for this study

TAPM (v 3.0)	
Number of grids (spacing)	4 (30 km, 10 km, 3 km, 1 km)
Number of grids point	25 x 25 x 25
Year of analysis	Jan 2005 to Dec 2005, with one “spin-up” day
Centre of analysis	Brisbane (27^{o}28’ S, 153^{o}2’ E)
Meteorological data assimilation	Wind velocity data from the Bowen Hills, Rocklea, South Brisbane and Woollongabba sites
CALMET (v 6.212)	
Meteorological grid domain	20 km x 20 km
Meteorological grid resolution	0.5 km
Surface meteorological stations	4 sites: Bowen Hills, Rocklea, South Brisbane and Woollongabba (for temperature, relative humidity and wind velocity). Cloud cover from Brisbane Airport (BoM). Ceiling height and pressure at the four sites by TAPM.
Upper air meteorological station	BoM upper air data records from Brisbane Airport. Missing data were supplemented with predictions by TAPM for Brisbane Airport.
Simulation length	8760 hours (Jan 2005 to Dec 2005)

There were occasional missing soundings in the Bureau of Meteorology (BoM) upper air data for 2004 which were, as noted in **Table 3**, supplemented with upper air predictions from the CSIRO’s prognostic model (The Air Pollution Model, TAPM). TAPM is a prognostic model which has the ability to generate meteorological data for any location in Australia (from 1997 onwards) based on synoptic information determined from the six hourly Limited Area Prediction System (LAPS) (**Puri and others, 1997**). TAPM is further discussed in the user manual (**Hurley, 2002**).

5.2.2 *Atmospheric Stability*

Dispersion models typically require information on atmospheric stability class[1] and mixing height[2]. Plume dispersion models, such as AUSPLUME, usually assume that the atmospheric stability is uniform over the entire study domain and these estimates are commonly calculated from measurements of sigma-theta, cloud cover information or solar radiation and temperature. Hourly estimates of mixing height can be determined by a combination of empirical methods and/or soundings.

The CALPUFF dispersion model, however, obtains estimates of atmospheric stability and mixing height from the CALMET meteorological model. CALMET determines these parameters using the cloud cover data and temperature profiles it is provided in order to run. The output of the CALMET model can subsequently be processed to extract meteorological information for any site of interest in the modelling domain, including atmospheric stability. **Table 4** provides the frequency of occurrence of the six stability classes as determined by CALMET for the four surface meteorological station sites.

Table 4 : Frequency of occurrence of atmospheric stability class

Pasquill-Gifford stability class	Frequency or occurrence for data collected in 2005 (%)			
	Rocklea	South Brisbane	Woolloongabba	Bowen Hills
A	2.6	3.5	3.0	3.6
B	11.2	14.4	13.6	13.8
C	17.2	17.1	17.3	16.7
D	25.4	19.3	20.9	20.5
E	7.5	4.6	5.6	5.9
F	36.0	41.0	39.5	39.6
TOTAL	100	100	100	100

It can be seen from **Table 4** that, at all sites, the most common stability class is determined to be F-class at around 40%. Pollutant dispersion is slow for F-class stabilities since these conditions are generally associated with night-time conditions with light winds and a temperature inversion. Differences in the calculated distribution of stability class is largely due to the different wind speeds at each site, but also from differences in landuse.

Joint wind speed, wind direction and stability class frequency tables generated from the Bowen Hills site (as an example) are presented in **Appendix B**.

5.2.3 *Local Climatic Conditions*

The Bureau of Meteorology collects climatic information from Brisbane Airport, to the east of the study corridor. A range of meteorological data collected from this station are presented in **Table 5** (**Bureau of Meteorology, 2006**). Temperature and humidity data consist of monthly averages of 9 am and 3 pm readings. Also presented are monthly averages of maximum

[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.

and minimum temperatures. Rainfall data consist of mean and median monthly rainfall and the average number of raindays per month.

Table 5 : Climate information relevant to the study corridor

Brisbane Airport	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Mean daily maximum temperature (C)	29.1	28.9	28.1	26.3	23.5	21.2	20.6	21.7	23.8	25.6	27.3	28.6	25.4
Mean daily minimum temperature (C)	20.9	20.9	19.5	16.9	13.8	10.9	9.5	10	12.5	15.6	18	19.8	15.7
Mean 9am air temp (C)	25.7	25.3	24.1	21.5	18	15.1	14.1	15.5	18.9	21.9	23.9	25.3	20.8
Mean 9am wet bulb temp (C)	21.4	21.5	20.5	18.1	15	12.3	11.1	12	14.6	17.1	18.9	20.5	16.9
Mean 9am relative humidity (%)	67	70	71	70	71	70	68	63	60	60	61	63	66
Mean 3pm air temp (C)	27.6	27.5	26.7	25	22.4	20.2	19.6	20.6	22.4	23.9	25.6	26.9	24
Mean 3pm wet bulb temp (C)	22	22.1	21.2	19.2	16.7	14.5	13.6	14.1	15.9	18	19.7	21.3	18.2
Mean 3pm relative humidity (%)	60	61	60	57	55	51	48	45	48	54	57	59	55
Mean monthly rainfall (mm)	157.7	171.7	138.5	90.4	98.8	71.2	62.6	42.7	34.9	94.4	96.5	126.2	1185
Mean no. of raindays	13	14.2	14.1	11	10.5	7.5	7.2	6.6	6.9	10	10	11.5	122.4
Mean daily evaporation (mm)	7.3	6.5	5.8	4.5	3.2	3	3.2	4.1	5.5	6.3	7.2	7.5	5.3
Mean no. of clear days	4.6	4	8.1	9.8	10.8	13	15	16.7	15.6	10.1	8	6.7	122.4
Mean no. of cloudy days	12.4	12.6	11.6	8.6	9.7	7.5	7	5.5	5.1	8.5	9.7	10.5	108.6
Mean daily hours of sunshine	8.5	7.5	7.7	7.4	6.4	7.2	7.4	8.4	8.9	8.5	8.6	8.8	8

Climate averages for Station: 040223 BRISBANE AERO, Commenced: 1929; Last record: 2000; Latitude (deg S): -27.4178; Longitude (deg E): 153.1142; State: QLD. Source: ***Bureau of Meteorology, 2006***

In summer, the average maximum temperature ranges from 28.6°C to 29.1°C and the minimum temperature ranges from 19.8°C to 20.9°C. In winter, the average maximum temperature ranges from 20.6°C to 21.7°C and the minimum temperature ranges from 9.5°C to 10.9°C.

Humidity is generally highest in the morning with the annual average 9 am humidity of 66 percent. By 3 pm the humidity is usually lower with an annual average of 55 percent. The months with the highest humidity on average are March and May with a 9 am averages of 71 percent, and the lowest is August with a 3 pm average of 45 percent.

Rainfall data collected at Brisbane Airport show that the February is usually the wettest month with an average rainfall of 171.7 mm and with an average of 14.2 raindays in the month. The lowest monthly rainfall on average is September, at the end of the winter dry season, with a mean monthly rainfall of 34.9 mm over 6.9 raindays. The average annual rainfall is 1185 mm with an average of 122 raindays each year.

The data from **Table 5** show that the climate in Brisbane is characterised by a wet summer and a dry winter. This is typical of the subtropical climate of South East Queensland.

From November to April the weather in Brisbane is warm, humid and windy with high rainfall and storms. These conditions encourage dispersion of pollutants in the air and the rain absorbs gases and particulate matter, removing them from the air. In the cooler months from May to October, there is less rain and the wind is not as strong, so there will tend to be higher concentrations of primary pollutants such as carbon monoxide.

5.3 Air Quality

5.3.1 Accounting for Background

One of the most difficult aspects in air quality assessments is accounting for the existing levels of pollutants from sources that are not included in the dispersion model. At any location within the airshed the concentration of the pollutant is determined by the contributions from all sources that have at some stage or another been upwind of the location. In the case of PM_{10} for example, the background concentration may contain emissions from the combustion of wood from domestic heating, from bushfires, from industry, other roads, wind blown dust from nearby and remote areas, fragments of pollens, moulds, sea-salts and so on.

In an area such as the Brisbane airshed the background level of pollutants could also include recirculated pollutants which have moved through complicated pathways in sea breeze/land breeze cycles. In general, the further away a particular source is from the area of interest, the smaller will be its contribution to air pollution at the area of interest. However the larger the area considered the greater would be the number of sources contributing to the background.

At any particular location the concentration of a pollutant will vary with time as the dispersion conditions change and as the contributing emission sources change. Including the effects of existing background pollution is difficult in all air quality studies and necessarily involves some approximations. If all emission sources can be included in the modelling study then the problem is very much simplified. When this can be done (that is, all sources are included) the background can be assumed to be zero and the total concentration is accurately represented by the model predictions. In an urban area, with common pollutants such as those from roads it is not possible to include all sources in the model. However, the greater the proportion of relevant emissions that can be included in the model then the smaller is the allowance that needs to be made for background levels and the more accurate the final estimates (predictions plus background) are likely to be.

For the Brisbane NL Project it is necessary to consider emissions from local surface roads, from the tunnel ventilation, from more distant roads and from all other non-transport related emissions of each pollutant. The changes resulting from the Project include emissions from the local surface roads which will experience changed traffic flows as the traffic is redistributed between the tunnel and the local surface roads and as new traffic is brought into the area by the increased capacity of the network provided by the tunnel.

5.3.2 Air Quality Monitoring

This section presents a review of air quality monitoring data that have been collected in and around the study corridor. The data are used as indicators of the existing air quality in various parts of the study area and can be compared with relevant air quality goals.

Data from four EPA air quality monitoring sites (Brisbane CBD, Rocklea, South Brisbane and Woolloongabba) and two road tunnel project monitoring sites (Bowen Hills and Kedron) have been assessed for the purposes of this study. The measurements can be summarised as follows:

- Brisbane CBD included measurements of SO_2, NO_2, PM_{10}, O_3 and CO;
- Rocklea included measurements of O_3, NO_2, PM_{10} and $PM_{2.5}$;
- South Brisbane included measurements of CO, NO_2 and PM_{10};
- Woolloongabba included measurements of CO and PM_{10};
- Bowen Hills, established for the NSBT project, included measurements of CO, NO_2, PM_{10} and $PM_{2.5}$; and
- Kedron, established for the AL project, included measurements of CO, NO_2, PM_{10} and $PM_{2.5}$.

In addition, two monitoring sites have been established for the Project, one at Toowong and another at Kelvin Grove. Monitoring at Toowong commenced in November 2007 and covers the western end of the Project. The Kelvin Grove site covers the eastern end of the Project and was established in July 2008.

Summaries and trends of the criteria pollutants are discussed below.

Carbon Monoxide (CO)
CO has been measured at five locations around the study corridor between 2004 and 2006. **Table 6** summarises the data.

Table 6 : Summary of measured CO concentrations between 2004 and 2006

Site	2004	2005	2006
CO, 8-hour maximum (mg/m^3). Air quality goal = 10 mg/m^3			
Brisbane CBD	4.1	-	-
South Brisbane	5.8	3.8	3.6
Woolloongabba	5.8	5.0	5.1
Bowen Hills	1.9	2.5	-
Kedron	-	-	2.2

None of the five sites have recorded 8-hour average concentrations above the EPA's goal of 10 mg/m^3. The highest measurement has been 5.8 mg/m^3 at the South Brisbane and Woolloongabba sites in 2004. Both of these sites are located near busy roads where high levels from traffic emissions would be expected. At locations further from busy roads, such as Bowen Hills and Kedron, CO concentrations have been lower at between 1.9 and 2.5 mg/m^3 as 8-hour maxima.

Time series of the 8-hour average CO concentrations for each site are presented in **Figure 15**. A seasonal cycle is evident which shows higher CO concentrations in winter and lower concentrations in summer. This reflects the poorer dispersion conditions which prevail in the cooler months.

Nitrogen Dioxide (NO_2)
NO_2 concentrations have been measured at five locations around the study corridor between 2004 and 2006. **Table 7** shows a summary of maximum 1-hour and annual averages, for comparison with the EPA goals.

Table 7 : Summary of measured NO_2 concentrations between 2004 and 2006

Site	2004	2005	2006
NO_2, 1-hour maximum ($\mu g/m^3$). Air quality goal = 246 $\mu g/m^3$			
Brisbane CBD	137.4	-	-
Rocklea	100.5	94.3	94.3
South Brisbane	123.0	104.6	102.5
Bowen Hills	128.8	142.9	-
Kedron	-	-	95.0
NO_2, Annual average ($\mu g/m^3$). Air quality goal = 62 $\mu g/m^3$			
Brisbane CBD	27.6	-	-
Rocklea	19.7	18.5	16.2
South Brisbane	34.2	36.9	34.2
Bowen Hills	45.5	63.4	-
Kedron	-	-	21.9

Maximum 1-hour average NO_2 concentrations have been up to 143 $\mu g/m^3$ at the Bowen Hills site (in 2005). This is below the 246 $\mu g/m^3$ goal.

The hourly NO_2 concentrations are shown graphically in **Figure 16**. As for CO, the NO_2 levels exhibit a seasonal cycle of higher concentrations in the winter and lower concentrations in the summer. Again, this is due to the poorer dispersion conditions which prevail in the cooler months.

Annual average NO_2 concentrations have been below the 62 $\mu g/m^3$ goal at all sites except for Bowen Hills in 2005. The Bowen Hills site was located at the north-eastern end of the study corridor and close to train yards with movements of diesel engines. This source of NO_x was regarded as the most likely explanation for elevated readings at this site.

Annual average NO_2 concentrations near a busy road (the South Brisbane site) have been up to 37 $\mu g/m^3$. In residential locations, Rocklea and Kedron for example, average NO_2 concentrations were lower at between 16 and 22 $\mu g/m^3$.

Some analysis of the percentage of the oxides of nitrogen (NO_X) which has been converted to NO_2 is particularly useful for roadway associated projects as estimates of NO_2 concentrations are commonly derived from NO_x predictions.

Nitrogen oxides are produced in most combustion processes and are formed during the oxidation of nitrogen in the fuel and nitrogen in the air. During high-temperature processes a variety of nitrogen oxides are formed including nitric oxide (NO) and nitrogen dioxide (NO_2). Generally, at the point of emission NO will comprise the greatest proportion of the emission with 95% by volume of the NO_x. The remaining 5% will be mostly NO_2. The effects of NO on human health are such that it is not regarded as an air pollutant at the concentrations at which it is normally found in the environment. NO_x emissions can be of concern in urban environments where the control of photochemical smog is important.

Ultimately, however, all oxides of nitrogen emitted into the atmosphere are oxidised to NO_2 and then further to other higher oxides of nitrogen. The rate at which this oxidisation takes place depends on prevailing atmospheric conditions including temperature, humidity and the presence of other substances in the atmosphere such as ozone. It can vary from a few minutes to many hours. The rate of conversion is quite important because from the point of emission to the point of maximum ground-level concentration there will be an interval of time during which some oxidation will take place. If the dispersion is sufficient to have diluted the plume to the point where the concentration is very low it is unimportant that the oxidation has taken place. However, if the oxidation is rapid and the dispersion slow then high concentrations of NO_2 can occur.

In analysing ratios of the oxides of nitrogen monitoring data, the ratio of NO_2 in the air is inversely proportional to the total NO_x concentration. **Figure 17** shows the relationship for the Rocklea, South Brisbane and Kedron monitoring sites. The ratios of NO_2 to NO_x in the data had average values of 72, 43 and 68% from the Rocklea, South Brisbane and Kedron sites, respectively. These ratios broadly show that the proportion of NO_2 in the NO_x is lower in urban areas (South Brisbane) and higher in residential areas that are further from more sources of NO_x (for example, Rocklea and Kedron).

Also, it should be noted that these ratios do not necessarily reflect the proportion of NO_2 which would be present very close to the emission source. Many studies (see for example **Pacific Power, 1998** and **PPK, 1999**) have reported that when NO_x levels are high, the proportion of NO_2 is low. Monitoring data collected by the RTA in Sydney (**Holmes Air Sciences, 1997**) are also consistent with this trend and indicate that close to roadways (within 60 metres), nitrogen dioxide would make up from 5 to 20% by weight of the total oxides of nitrogen.

Ozone (O_3)

Ozone is a secondary pollutant formed in the atmosphere through a complicated set of reactions involving reactive hydrocarbons, oxides of nitrogen and sunlight. The net result of these reactions is to produce ozone and nitrogen dioxide and other oxidation products, which are collectively referred to as photochemical smog.

Monitoring of ozone has occurred at two locations around the study corridor between 2004 and 2006 and **Table 8** summarises the data.

Table 8 : Summary of measured O_3 concentrations between 2004 and 2006

Site	2004	2005	2006
O_3, 1-hour maximum ($\mu g/m^3$). Air quality goal = 214 $\mu g/m^3$			
Brisbane CBD	134.8	-	-
Rocklea	188.3	173.3	169.1
O_3, 4-hour maximum ($\mu g/m^3$). Air quality goal = 171 $\mu g/m^3$			
Brisbane CBD	115.0	-	-
Rocklea	165.3	143.9	145.0

The EPA has two air quality goals for ozone, a 1-hourly maximum of 214 $\mu g/m^3$ and a 4-hourly maximum of 171 $\mu g/m^3$. These are the same as the NEPM goals. There have been no exceedances of these two goals at either the Brisbane CBD or Rocklea sites. The highest 1-hour average ozone concentration was 188 $\mu g/m^3$ in 2004 at Rocklea. The highest 4-hour average ozone concentration was 165 $\mu g/m^3$, also at Rocklea in 2004.

Figure 18 shows a time series of measured hourly average ozone concentrations. Ozone concentrations exhibit a different seasonal variation from CO and NO_2 with higher concentrations in the warmer months.

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

The presence of particulate matter in the atmosphere can have an adverse effect on health and amenity. Two commonly measured particulate matter classifications are PM_{10} and $PM_{2.5}$ where the subscripts 10 and 2.5 refer to the upper limit of the equivalent aerodynamic diameter (in micrometres [μm]) of the particles in each classification respectively.

There are many sources of particulate matter in an urban environment including motor vehicles, construction activities and sea salt. However, the most common causes of exceedances of PM_{10} and $PM_{2.5}$ air quality goals in Brisbane are widespread events such as dust storms or bushfires.

Table 9 summarises measured PM_{10} concentrations at six monitoring locations between 2004 and 2006.

Table 9 : Summary of measured PM_{10} concentrations between 2004 and 2006

Site	2004	2005	2006
PM_{10}, 24-hour maximum (μg/m³). Air quality goal = 50 μg/m³			
Brisbane CBD	**56.6**	**62.4**	40.1
Rocklea	47.3	**52.6**	39.5
South Brisbane	**88.3**	**69.3**	46.3
Woolloongabba	**65.4**	**66.0**	**51.5**
Bowen Hills	**53.7**	**63.2**	-
Kedron	-	-	33.8
PM_{10}, Annual average (μg/m³). Air quality goal = 50 μg/m³			
Brisbane CBD	17.3	16.4	15.9
Rocklea	19.1	16.7	16.1
South Brisbane	20.8	19.7	19.5
Woolloongabba	22.3	21.7	21.5
Bowen Hills	20.2	16.0	-
Kedron	-	-	13.5

** 24-hour clock average*

All sites, with the exception of Kedron, have recorded at least one 24-hour average concentration above the 50 μg/m³ standard noted by the NEPM. The highest level was 88 μg/m³ at the South Brisbane site in 2004. It should be noted no sites have recorded 24-hour average PM_{10} concentrations above the EPA's goal of 150 μg/m³.

The 24-hour average concentrations can be more closely examined from time series graphs, shown in **Figure 19**. This figure shows that daily PM_{10} concentrations can vary significantly but there are one or two occasions each year when levels exceed the NEPM's 50 μg/m³ standard at each site. For example, one distinct event is observed on 3 February 2005 where all sites monitoring at the time recorded levels above 50 μg/m³. A major dust storm in Brisbane was reported[3] on this day.

Figure 19 highlights a few occasions between 2004 and 2006 where elevated PM_{10} concentrations are observed at all monitoring locations.

Between 2004 and 2006, $PM_{2.5}$ has been measured at Rocklea, Bowen Hills and Kedron. The measurement data are summarised in **Table 10**.

[3] http://www.bom.gov.au/announcements/sevwx/vic/2005feb/index.shtml

Table 10 : Summary of measured $PM_{2.5}$ concentrations between 2004 and 2006

Site	2004	2005	2006
$PM_{2.5}$, 24-hour maximum ($\mu g/m^3$). Air quality goal = 25 $\mu g/m^3$			
Rocklea	**34.9**	18.2	16.6
Bowen Hills	**35.5**	24.1	-
Kedron	-	-	16.2
$PM_{2.5}$, Annual average ($\mu g/m^3$). Air quality goal = 8 $\mu g/m^3$			
Rocklea	**9.1**	6.6	6.2
Bowen Hills	**9.4**	**8.1**	-
Kedron	-	-	6.3

 # The $PM_{2.5}$ goals are referred to as Advisory Reporting Standards and are set for the purpose of gathering data to facilitate a review of these standards as part of the development of the $PM_{2.5}$ NEPM

EPA does not have any $PM_{2.5}$ goals that are to be applied on a project specific basis. The $PM_{2.5}$ goals listed in **Table 10** are referred to under the NEPM as Advisory Reporting Standards which have been set for the purpose of facilitating the collection of data for later development of NEPM standards.

Maximum 24-hour $PM_{2.5}$ goals have exceeded the NEPM standard of 25 $\mu g/m^3$ at both the Rocklea and Bowen Hills sites, suggesting little difference between the suburban (Rocklea) or city (Bowen Hills) environments. Similar to PM_{10}, the highest $PM_{2.5}$ concentrations are most often due to widespread events. From **Table 10**, maximum 24-hour average $PM_{2.5}$ concentrations appear to have decreased slightly from the 2004 levels although this is based on the results from only three monitoring locations.

Annual average $PM_{2.5}$ concentrations above the NEPM's 8 $\mu g/m^3$ standard were recorded at the Rocklea site in 2004 (9.1 $\mu g/m^3$) and at the Bowen Hills site in 2004 (9.4 $\mu g/m^3$) and 2005 (8.1 $\mu g/m^3$).

Figure 20 shows time series graphs of 24-hour average $PM_{2.5}$ concentrations. Unlike the PM_{10} graphs, it is more difficult to identify days when all monitoring sites recorded elevated levels simultaneously, since there have been only two sites measuring $PM_{2.5}$ concentrations at any one time.

The relationship between measured PM_{10} and $PM_{2.5}$ concentrations has been examined for Rocklea, Bowen Hills and Kedron in **Figure 21**. The average ratios of $PM_{2.5}$ to PM_{10} for the monitoring period were calculated to be 46, 50 and 49% for Rocklea, Bowen Hills and Kedron respectively. Typically, the highest $PM_{2.5}$ to PM_{10} ratios are measured in areas where combustion sources (for example, traffic) are dominant.

Sulfur Dioxide (SO_2)

Brisbane CBD is the only relevant EPA monitoring location for the study corridor that has measured SO_2. Measurement data are available for 2004 and are summarised in **Table 11** and **Figure 22** shows the hourly data graphically. Emissions of SO_2 from motor vehicles are minor and this pollutant has not been assessed in this report.

Table 11 : Summary of measured SO_2 concentrations between 2004 and 2006

Site	2004	2005	2006
SO_2, 1-hour maximum (μg/m^3). Air quality goal = 570 μg/m^3			
Brisbane CBD	42.9	-	-
SO_2, 24-hour maximum (μg/m^3). Air quality goal = 225 μg/m^3			
Brisbane CBD	12.6	-	-
SO_2, Annual average (μg/m^3). Air quality goal = 60 μg/m^3			
Brisbane CBD	3.4	-	-

Maximum 1-hour and 24-hour average and annual average SO_2 concentrations have been well below the EPA goals.

Project Monitoring Sites

As mentioned earlier, air quality monitoring has also commenced at Toowong and at Kelvin Grove, specifically for this project. **Table 12** summarises the available data.

Table 12 : Summary of air quality monitoring data from Project sites

Parameter	Toowong (Nov 2007 to Apr 2008)	Kelvin Grove (Jul to Oct 2008)	Relevant air quality goal
CO, 8-hour maximum (mg/m^3)	0.9	-	10
NO_2, 1-hour maximum (μg/m^3)	82.0	-	246
NO_2, Annual average (μg/m^3)	14.6	-	62
PM_{10}, 24-hour* maximum (μg/m^3)	106$^+$	-	50
PM_{10}, Average (μg/m^3)	12	-	25
$PM_{2.5}$, 24-hour* maximum (μg/m^3)	17	-	25$^\#$
$PM_{2.5}$, Average (μg/m^3)	7	-	8$^\#$

** 24-hour clock average*
 # The $PM_{2.5}$ goals are referred to as Advisory Reporting Standards and are set for the purpose of gathering data to facilitate a review of these standards as part of the development of the $PM_{2.5}$ NEPM. The goals are not applied on a project-specific basis.
+ This value was measured on 28th April 2008. The next highest recorded 24-hour average PM_{10} was 32 μg/m^3.

At the time of writing, six months of data were available from the Toowong site. **Table 12** shows that pollutant concentrations at Toowong are similar or slightly lower than concentrations measured at the other monitoring sites. There have been no exceedances of air quality goals, except for 24-hour average PM_{10}, where there has been one day when concentrations exceeded the adopted goal of 50 μg/m^3. The measured value (106 μg/m^3 on 28 April 2008) was lower than the EPA's 150 μg/m^3 goal.

5.4 Summary of Existing Environment

Meteorological and ambient air quality monitoring data from the Brisbane area have been reviewed to characterise the existing environment of the study corridor. The monitoring sites covered a diverse range of settings, including residential areas and parklands to inner-city and high traffic locations. The variety of sites allowed the range of meteorological and air quality conditions to be identified.

Meteorological data collected in the Brisbane area show the following:

- Climate is characterised by a wet summer and a dry winter;

- Light winds from the south-west generally prevail in the cooler months, while a stronger sea-breeze from the north-east is the dominant wind in the warmer months;
- Wind patterns for each monitoring location are similar from year to year; and
- Variations in wind patterns exist from site to site and can be influenced by the land-use of the surrounding environment, such as the presence of buildings;

Ambient air quality data collected in the Brisbane area show the following:

- CO concentrations have been, and are likely to continue to be, below the EPA air quality goal. Compliance with the EPA goal has been exhibited both near busy roads as well as in residential areas and parklands;
- Maximum NO_2 concentrations have been, and are likely to continue to be, below the EPA's short-term air quality goal. One instance where an exceedance of the annual average NO_2 goal has been recorded at a location near a train yard with movements of diesel engines. However, annual average NO_2 concentrations at the remaining monitoring sites, covering busy road as well as residential locations, have been below the EPA's goal;
- Lighter winds and less rain in the cooler months of the year generally lead to higher concentrations of the primary pollutants, CO and NO_2 in particular, at most monitoring locations;
- Ozone and SO_2 concentrations are below the EPA's air quality goals at all monitoring locations;
- Short-term (that is, daily) PM_{10} concentrations have exceeded the NEPM standard at all monitoring locations on at least one occasion in recent years. These events generally coincide with widespread dust storms or bushfires which can influence large areas. Widespread dust storms or bushfires generally trigger elevated levels at all monitoring locations. There have been no exceedances of the EPA goal, which is less stringent than the NEPM standard, however, the EPA has proposed to adopt the NEPM standard as a goal for the current project.
- Annual average PM_{10} concentrations are below the EPA's air quality goals at all monitoring locations;
- Short-term (daily) and annual average $PM_{2.5}$ concentrations have been above the NEPM "Advisory Reporting Standards" on occasions at two of the three monitoring locations. As for PM_{10}, the highest $PM_{2.5}$ concentrations are usually influenced by widespread events.

6. ESTIMATION OF POLLUTANT EMISSIONS FROM ROADS

This section provides information relating to the estimation of pollutant emissions from a road section with known traffic volume. Sources of emission factors are discussed as well as the traffic information used in the study. A summary of the calculated pollutant emissions for the tunnel and various surface roads is provided in this section.

6.1 Emission Data

The most significant emissions produced from motor vehicles are CO, NO_x, hydrocarbons 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 goals.

As discussed in **Section 4**, 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.

Sources of emission factors which have been referenced for the purposes of this project include:

- World Road Association, referred to as PIARC (formerly the Permanent International Association of Road Congress); and
- The South-east Queensland Region Air Emissions Inventory.

6.1.1 PIARC

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**) as the basis of design for longitudinal 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 particularly relevant for emission estimation from road tunnels.

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; and
- 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 C**.

6.1.2 South-east Queensland Region Air Emissions Inventory

A partnership between the Brisbane City Council (BCC) and the EPA produced a local Queensland vehicle emission database as part of the South-east Queensland region Air Emissions Inventory (**EPA & BCC, 2004**). Included in this database are estimates of current vehicle emission rates as well as projections to future years.

It is understood that the development of the vehicle emissions database has taken into consideration future vehicle design rules and likely fuel standards. Emission rates are provided for the south-east Queensland region for 2000 for different vehicle types. In addition, fleet-average exhaust emission factors are provided for 2005 and 2011.

For the purposes of this study the vehicle emission data from the South-east Queensland region Air Emissions Inventory have been used for comparative purposes with the PIARC data. The PIARC information has been the primary emission data source. **Appendix C** provides some comparisons of vehicle emissions generated for the south-east Queensland region using both the PIARC methodology and the Air Emissions Inventory data. The comparison indicated that the two data sources generally resulted in similar emission rates for future years, the PIARC methodology adopted for this study was found to be slightly more conservative.

6.2 Traffic Data

SKM/CW generated traffic information for the Project. The traffic data made available and used for the purposes of the air quality study included the following:

- Annualised Average Daily Traffic (AADT) for years 2007 (existing), 2014, 2016, 2021 and 2026;
- Scenarios “without NL” and “with NL”;
- Modelled 2007 (existing), 2014, 2016, 2021 and 2026 AADT for selected surface roads and in tunnel sections; and
- Indicative flow profiles for light and heavy vehicles by hour of day for each section of tunnel and for surface roads.

Information on registered vehicle types and year of the manufacture data for Queensland has been obtained from the Australian Bureau of Statistics (**ABS, 2003**). **Table 13** presents a summary of these data which have been used to derive the percentage of vehicles by age category for modelled years. Registered vehicles in future years have been extrapolated.

Table 13 : Vehicle mix by year of manufacture

Year of manufacture	Percentage of fleet (Queensland) as at March 2006 (%)
To 1990	22.3
1991-1995	18.2
1996-2000	24.8
2001-2005	33.5
2006(a)	1.0
Not stated	0.2
TOTAL	100.0

Source: ABS, 2006

The modelled AADT data provided by SKM/CW have been reviewed and are summarised in **Table 14**. It should be noted that the traffic data for the tunnel sections and all available surface roads were provided for each direction of travel. Hourly traffic volumes for each of these road sections were determined from the AADT to estimate hourly pollutant emissions.

Table 14 : Summary of AADT on major roads in the study area

Road section name	AADT								
	2007	2014		2016		2021		2026	
	DM	DM	DS	DM	DS	DM	DS	DM	DS
Main Tunnel: Northbound	-	-	28,082	-	29,231	-	33,035	-	36,649
Main Tunnel: Southbound	-	-	25,519	-	28,600	-	30,905	-	34,261
Waterworks Road (W of Payne)	19,104	20,180	19,710	19,950	19,528	19,960	19,500	20,110	19,610
Waterworks Road (W of Coopers)	26,280	26,970	27,260	27,610	27,040	27,630	27,070	27,540	27,030
Waterworks Road (W of Jubilee)	16,340	19,020	16,400	18,180	16,580	18,890	17,040	18,990	17,140
Stuart Road	40,520	53,670	40,160	43,900	40,780	44,640	40,070	46,210	41,470
Ashgrove Ave	9,220	9,680	10,110	9,830	10,060	11,100	11,130	11,630	11,770
Boundary St	9,570	10,930	11,460	10,940	12,290	11,680	12,510	11,960	13,270
Kelvin Grove Road (N of Herston)	60,220	52,750	56,530	53,310	57,190	59,410	65,290	60,000	65,310
New Market Road	20,870	27,420	28,520	27,430	15,150	28,100	17,420	29,430	30,920
Herston Road	16,240	16,060	16,190	16,250	15,500	17,500	17,470	18,170	18,220
Bowen Bridge Road (N of Herston)	58,570	45,890	44,550	46,420	46,000	47,970	46,820	51,710	49,640
ICB (W of Bowen Bridge Road)	52,930	57,140	56,490	56,090	56,720	60,200	59,680	62,510	60,750
Abbortsford Road (N of ICB)	48,550	57,310	56,280	57,510	57,260	61,110	60,510	62,720	61,160
Kingsfordsmith Drive (W of Nugee)	58,130	58,090	58,620	58,820	59,430	62,570	63,180	65,970	59,130
Breakfast Creek Road	35,980	37,710	37,720	38,800	39,400	41,330	41,460	42,940	44,180
Abbortsford Road (S of ICB)	26,240	30,640	30,540	31,940	31,730	33,840	34,350	35,310	35,410
Montpelier Road	17,800	29,720	29,770	30,280	30,810	32,490	33,300	33,660	34,310
Brunswick Street (W of St Pauls Tce)	50,610	27,510	27,140	28,340	27,920	28,400	28,650	28,680	29,510
Water Street	17,350	12,780	11,990	12,680	12,430	15,060	12,450	14,110	59,270
Commercial Road	10,540	13,390	13,460	13,620	13,600	14,160	14,090	14,430	14,340
James Street	12,350	12,760	12,590	12,450	12,320	12,800	12,690	12,930	12,960
Ann Street (near Queen Street)	17,050	18,480	17,990	18,710	18,350	19,510	18,930	19,710	19,240
Ann Street (near George Street)	7,350	8,940	9,130	9,930	9,130	10,250	8,820	10,460	10,020

Road section name	AADT								
	2007	2014		2016		2021		2026	
	DM	DM	DS	DM	DS	DM	DS	DM	DS
ICB (W of Kelvin Grove Road)	74,050	100,890	117,790	103,990	106,000	106,380	111,150	109,210	133,750
Countess Street	43,130	44,940	44,830	47,160	45,750	49,330	45,410	50,320	47,220
Hale Street	86,670	102,370	99,790	104,170	99,740	105,100	105,310	107,910	105,290
Waterworks Road (near Ennorgera)	24,860	26,910	25,810	27,070	26,320	27,280	25,690	28,530	26,730
Given Terrace	12,870	15,710	15,740	13,340	15,910	16,790	15,610	14,030	14,480
Latrobe Terrace	9,560	11,960	11,860	12,420	11,890	13,260	12,500	13,590	12,760
Jubilee Terrace	25,830	27,640	24,230	29,520	24,800	30,540	25,160	30,100	26,030
Simpson Road	8,830	12,460	8,490	13,830	8,820	14,670	8,930	8,830	10,250
Mount Cootha Road	10,640	17,690	10,260	16,370	6,110	17,250	11,660	14,940	14,960
Boundary Street (N of Baroona)	25,220	25,250	25,030	25,050	25,390	25,690	25,410	26,360	24,870
Milton Road (W of Baroona)	50,300	59,890	53,230	58,330	55,100	60,980	57,270	61,120	57,540
Coronation Drive (E of Park)	76,920	72,850	68,430	84,650	58,160	86,680	70,580	88,600	69,950
Miskin Road (S of Mt Cootha)	9,790	9,500	7,810	9,070	8,120	9,850	8,670	10,100	8,550
Western Freeway (S of Mt Cootha)	71,540	84,210	107,040	92,390	118,390	94,340	122,120	98,290	128,830
Western Freeway (S of Moggill)	56,740	65,150	78,790	73,300	88,280	94,440	94,410	81,590	102,330
Moggill Road (E of Marshall lane)	46,200	50,190	50,780	50,550	51,010	50,560	51,190	51,050	51,600
Moggill Road (S of Kenmore)	19,350	23,340	23,480	23,500	23,650	23,580	23,950	23,730	24,090
Walter Taylor Bridge	30,370	31,580	31,570	31,250	31,200	31,810	31,890	31,630	31,720
Moggill Road (near Payne Street)	41,240	46,350	39,140	45,400	39,140	46,710	40,970	47,900	42,000
Swann Road (W of Withmore)	12,160	12,010	11,750	12,390	11,390	12,580	12,220	13,180	12,800
Hawken Drive	4,760	5,370	5,610	5,430	5,400	5,850	5,520	6,260	6,030
Sir Fed Schonnell Drive	15,580	17,320	17,620	17,770	18,190	19,190	17,750	18,770	17,790
Bradfield Highway (Bridge)	91,050	79,830	77,090	79,210	78,570	81,560	81,540	83,260	83,600
Shafston Ave	45,260	51,870	52,770	53,090	53,160	55,670	55,160	56,680	56,870
Wynnum Road	44,090	44,120	44,460	44,510	44,890	44,810	45,240	45,160	45,680
Pacific Mwy (N of Ipswich)	153,300	155,570	154,830	155,660	153,590	157,640	156,560	158,360	157,210
Main St	27,440	26,250	24,900	26,730	24,810	27,980	29,010	29,590	29,710
Logan Road	15,580	15,530	15,470	15,390	14,980	16,260	15,920	16,480	16,040
SE Freeway (N of Okeefe St)	153,480	151,130	149,520	151,020	150,180	153,950	153,750	153,650	155,290
Gladstone Road	14,610	17,250	16,080	17,400	15,910	18,300	17,090	19,200	17,790
Ipswich Road (N of Cornwell)	27,780	46,480	38,500	46,400	37,610	53,400	41,760	58,090	44,100
Fairfiled Road (S of Kadumba)	16,270	22,140	19,730	22,320	19,090	26,460	21,480	30,040	22,680
Annerly Road (near Park Road)	14,970	16,110	15,570	16,400	16,000	17,440	16,580	19,140	17,030
Gladstone Road	14,610	17,250	16,080	17,400	15,910	18,750	17,090	19,680	18,300
Montague Road	10,460	13,530	13,550	13,980	14,090	14,990	14,990	12,170	15,830

DM: "Do Minimal" or no tunnel option
DS: "Do Something" or tunnel option

Pollutant emissions from each of the road sections presented in **Table 14** have been calculated for input to the CALPUFF dispersion model. The estimated pollutant emissions are discussed below.

6.3 Emission Estimates

Pollutant emissions have been estimated for each tunnel ventilation outlet and for all surface roads discussed in **Section 6.2**. 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 and tend to exaggerate the absolute difference between the "without NL" and "with NL" case. Assumed reductions in the proportion of older vehicles in the fleet has, however, simulated some improvement to vehicle emissions in future years.

In order to determine emissions from a ventilation outlet, the source of air which leads into the outlet has been considered (refer to **Figure 4** for a schematic of air movements in the tunnel). The air in the outlet comes from sections of tunnel which have a traffic volume, traffic mix, traffic speed and road grade. These data are included in the process to generate pollutant emissions for each hour of the day for each outlet. Road grade information for each section of tunnel has been provided by SKM/CW.

Traffic speed within the tunnel has been set to 80 km/h outside peak-hour periods. During peak-hour periods a speed of 20 km/h has been used. For this study peak-hour periods in the tunnel have been defined as hours ending 7, 8, 9, 16, 17, 18 and 19 for both directions in the tunnel.

The peak-hour or “congested” periods are consistent with the hours selected for the Cross City Tunnel EIS in Sydney (**RTA, 2000**). A speed of 80 km/h has been assumed for vehicles on the motorways while 50 km/h has been assumed for all other surface roads.

Figure 23 shows the estimated traffic and pollutant emissions (CO, NO_x and PM_{10}) for each hour of the day for the NL in 2014. The profile of emission rates closely follows the traffic profile however the emission rates are also influenced by other factors such as the grade in the tunnel, speed of traffic and the proportion of heavy vehicles in the traffic mix.

Table 15 to **Table 18** provide estimated pollutant emissions from the two ventilation outlets. Similar information is also required by the dispersion model for all the modelled surface roads. Emissions data for all surface roads are not included in the body of this report for ease of reading but the calculations are described in **Appendix C**.

Ventilation flow rates have been provided by the SKM/Connell Wagner Joint Venture. The temperature of the air from the ventilation outlets has been assumed to be at the ambient temperature for the purposes of the assessment. The actual temperature of the air in the outlets is likely to be higher than ambient temperatures because of the heat generated by vehicles in the tunnel. Setting the outlet air temperature to ambient is a conservative approach for assessing impacts at ground level.

Table 15 : Estimated emissions from NL ventilation outlets in 2014

Vent ID	W1				N4			
Location (MGA, m)	497694, 6960574				501840, 6963123			
Base elevation (m)	46.4				42.1			
Height (m)	20				15			
Diameter (m)	6.2				6.2			
Hour	Velocity (m/s)	Emissions (g/s)			Velocity (m/s)	Emissions (g/s)		
		CO	NO_X	PM_{10}		CO	NO_X	PM_{10}
1	6.67	1.04	0.13	0.01	8.33	1.71	0.19	0.01
2	6.67	0.70	0.09	0.00	6.67	0.86	0.12	0.01
3	6.67	0.67	0.09	0.00	6.67	0.86	0.13	0.01
4	6.67	1.05	0.14	0.01	8.33	1.34	0.17	0.01
5	8.33	3.03	0.34	0.02	8.33	3.59	0.41	0.02
6	11.67	9.27	1.00	0.04	13.33	12.29	1.30	0.06
7	15.00	22.21	1.51	0.12	13.33	26.42	2.10	0.16
8	15.00	27.36	3.11	0.26	16.67	32.86	2.98	0.23
9	15.00	27.36	3.11	0.26	16.67	32.86	2.98	0.23
10	15.00	13.35	1.69	0.08	15.00	16.72	1.84	0.08
11	15.00	12.84	1.62	0.08	15.00	15.48	1.75	0.08
12	15.00	12.81	1.64	0.08	15.00	15.08	1.68	0.08
13	15.00	12.70	1.58	0.07	15.00	15.04	1.66	0.07
14	15.00	13.09	1.63	0.08	15.00	15.31	1.67	0.07
15	15.00	15.12	1.82	0.08	15.00	15.38	1.69	0.07
16	15.00	27.96	2.02	0.16	15.00	22.48	1.71	0.13
17	15.00	28.12	2.40	0.20	16.67	35.90	3.08	0.23
18	15.00	28.12	2.40	0.20	16.67	35.90	3.08	0.23
19	15.00	21.15	1.37	0.11	11.67	19.52	1.27	0.09
20	11.67	7.81	0.85	0.04	11.67	9.83	0.93	0.04
21	10.00	5.62	0.63	0.03	8.33	7.05	0.69	0.03
22	10.00	4.85	0.55	0.02	8.33	5.85	0.57	0.02
23	8.33	3.81	0.43	0.02	8.33	4.36	0.44	0.02
24	8.33	2.37	0.29	0.01	8.33	3.30	0.34	0.01
kg/d	-	1089	110	7	-	1260	118	7

Table 16 : Estimated emissions from NL ventilation outlets in 2016

Vent ID	W1				N4			
Location (MGA, m)	497694, 6960574				501840, 6963123			
Base elevation (m)	46.4				42.1			
Height (m)	20				15			
Diameter (m)	6.2				6.2			
Hour	Velocity (m/s)	Emissions (g/s)			Velocity (m/s)	Emissions (g/s)		
		CO	NO_X	PM_{10}		CO	NO_X	PM_{10}
1	6.67	1.07	0.14	0.01	8.33	1.69	0.19	0.01
2	6.67	0.72	0.10	0.00	6.67	0.84	0.12	0.01
3	6.67	0.69	0.10	0.00	6.67	0.85	0.13	0.01
4	6.67	1.08	0.14	0.01	8.33	1.32	0.17	0.01
5	8.33	3.13	0.35	0.02	8.33	3.52	0.41	0.02
6	11.67	9.56	1.03	0.05	13.33	12.06	1.29	0.06
7	15.00	22.72	1.57	0.12	13.33	25.60	2.11	0.15
8	15.00	27.81	3.12	0.25	16.67	34.56	3.15	0.23
9	15.00	27.81	3.12	0.25	16.67	34.56	3.15	0.23
10	15.00	13.78	1.76	0.08	15.00	16.42	1.83	0.08
11	15.00	13.24	1.69	0.08	15.00	15.20	1.74	0.08
12	15.00	13.22	1.71	0.08	15.00	14.82	1.68	0.07
13	15.00	13.10	1.64	0.08	15.00	14.78	1.65	0.07
14	15.00	13.50	1.69	0.08	15.00	15.04	1.66	0.07
15	15.00	15.59	1.89	0.09	15.00	15.10	1.68	0.07
16	15.00	28.61	2.11	0.16	15.00	21.79	1.71	0.12
17	15.00	34.79	2.83	0.22	16.67	33.55	2.89	0.21
18	15.00	34.79	2.83	0.22	16.67	33.55	2.89	0.21
19	15.00	21.64	1.41	0.11	11.67	18.91	1.25	0.09
20	11.67	8.06	0.87	0.04	11.67	9.66	0.91	0.04
21	10.00	5.79	0.64	0.03	8.33	6.92	0.68	0.03
22	10.00	5.00	0.56	0.03	8.33	5.74	0.55	0.02
23	8.33	3.93	0.44	0.02	8.33	4.27	0.43	0.02
24	8.33	2.45	0.30	0.01	8.33	3.24	0.34	0.01
kg/d	-	1159	115	7		1238	117	7

Table 17 : Estimated emissions from NL ventilation outlets in 2021

Vent ID	W1				N4			
Location (MGA, m)	497694, 6960574				501840, 6963123			
Base elevation (m)	46.4				42.1			
Height (m)	20				15			
Diameter (m)	6.2				6.2			
Hour	Velocity (m/s)	Emissions (g/s)			Velocity (m/s)	Emissions (g/s)		
		CO	NO_X	PM_{10}		CO	NO_X	PM_{10}
1	6.67	1.04	0.13	0.01	6.67	1.73	0.18	0.01
2	6.67	0.70	0.09	0.00	6.67	0.87	0.12	0.01
3	6.67	0.67	0.10	0.00	6.67	0.87	0.13	0.01
4	6.67	1.05	0.14	0.01	6.67	1.35	0.17	0.01
5	10.00	3.04	0.33	0.01	8.33	3.61	0.40	0.02
6	13.33	9.30	0.98	0.04	13.33	12.37	1.27	0.05
7	16.67	21.77	1.50	0.11	16.67	25.79	2.06	0.14
8	16.67	26.08	2.90	0.22	18.33	33.66	3.17	0.22
9	16.67	26.08	2.90	0.22	18.33	33.66	3.17	0.22
10	16.67	13.40	1.69	0.08	16.67	16.83	1.81	0.08
11	16.67	12.88	1.62	0.07	15.00	15.59	1.72	0.07
12	16.67	12.86	1.64	0.08	15.00	15.19	1.65	0.07
13	16.67	12.75	1.58	0.07	15.00	15.15	1.63	0.07
14	16.67	13.13	1.62	0.07	15.00	15.42	1.64	0.07
15	16.67	15.17	1.81	0.08	15.00	15.48	1.66	0.07
16	18.33	27.41	2.03	0.15	15.00	21.95	1.67	0.11
17	18.33	30.85	2.52	0.19	18.33	32.70	2.72	0.19
18	18.33	30.85	2.52	0.19	18.33	32.70	2.72	0.19
19	16.67	20.74	1.35	0.10	13.33	19.07	1.22	0.08
20	13.33	7.84	0.83	0.04	11.67	9.90	0.89	0.04
21	11.67	5.64	0.61	0.03	10.00	7.10	0.67	0.03
22	11.67	4.87	0.54	0.02	10.00	5.89	0.55	0.02
23	10.00	3.83	0.42	0.02	8.33	4.39	0.43	0.02
24	10.00	2.39	0.28	0.01	8.33	3.32	0.33	0.01
kg/d	-	1096	108	7		1240	115	6

Table 18 : Estimated emissions from NL ventilation outlets in 2026

Vent ID	W1				N4			
Location (MGA, m)	497694, 6960574				501840, 6963123			
Base elevation (m)	46.4				42.1			
Height (m)	20				15			
Diameter (m)	6.2				6.2			
Hour	Velocity (m/s)	Emissions (g/s)			Velocity (m/s)	Emissions (g/s)		
		CO	NO_X	PM_{10}		CO	NO_X	PM_{10}
1	6.67	1.06	0.14	0.01	6.67	1.75	0.19	0.01
2	6.67	0.71	0.10	0.00	6.67	0.88	0.13	0.01
3	6.67	0.68	0.10	0.00	6.67	0.89	0.14	0.01
4	6.67	1.07	0.14	0.01	6.67	1.37	0.17	0.01
5	10.00	3.09	0.33	0.01	8.33	3.67	0.41	0.02
6	13.33	9.44	0.98	0.04	13.33	12.59	1.29	0.05
7	16.67	21.78	1.54	0.11	16.67	25.85	2.11	0.14
8	16.67	23.12	2.74	0.19	18.33	32.07	2.94	0.19
9	16.67	23.12	2.74	0.19	18.33	32.07	2.94	0.19
10	16.67	13.62	1.76	0.08	16.67	17.13	1.84	0.08
11	16.67	13.09	1.69	0.08	15.00	15.87	1.76	0.07
12	16.67	13.07	1.71	0.08	15.00	15.46	1.69	0.07
13	16.67	12.94	1.64	0.07	15.00	15.42	1.66	0.07
14	16.67	13.34	1.68	0.08	15.00	15.70	1.67	0.07
15	16.67	15.41	1.86	0.08	15.00	15.76	1.69	0.07
16	18.33	27.44	2.10	0.15	15.00	21.99	1.70	0.11
17	18.33	29.89	2.38	0.17	18.33	30.60	2.50	0.16
18	18.33	29.89	2.38	0.17	18.33	30.60	2.50	0.16
19	16.67	20.75	1.37	0.09	13.33	19.09	1.22	0.08
20	13.33	7.95	0.83	0.04	11.67	10.08	0.89	0.04
21	11.67	5.73	0.62	0.03	10.00	7.22	0.67	0.03
22	11.67	4.94	0.54	0.02	10.00	6.00	0.55	0.02
23	10.00	3.89	0.43	0.02	8.33	4.47	0.43	0.02
24	10.00	2.42	0.29	0.01	8.33	3.38	0.34	0.01
kg/d	-	1074	108	6		1224	113	6

Emissions data for selected surface roads in 2014 are provided below in **Table 19**. With the introduction of the NL into the traffic network there would be some re-distribution of emissions. This is evident by the predicted increases and decreases in emissions shown in **Table 19**. Emissions are expressed as kg/km/day.

Table 19 : Estimated emissions from selected surface roads

Road section	Section length (km)	2007 (kg/km/d)			2014 without NL (kg/km/d)			2014 with NL (kg/km/d)		
		CO	NO_x	PM_{10}	CO	NO_x	PM_{10}	CO	NO_x	PM_{10}
Kelvin Grove Road (N of Herston)	2.65	315	48	3.2	222	33	2.0	239	35	2.1
Innercity Bypass (W of Kelvin Grove Road)	1.82	268	100	6.2	294	82	4.4	344	93	5.0
Hale Street	2.36	449	111	8.3	426	84	5.5	416	81	5.4
Waterworks Road (near Ennorgera Tce)	2.93	130	20	1.4	113	17	1.0	109	16	1.0
Given Terrace	1.17	67	11	0.7	66	11	0.7	66	11	0.7
Boundary Street (N of Baroona)	2.50	132	23	1.6	106	17	1.0	105	16	1.0
Milton Road (W of Baroona)	3.30	261	58	4.3	250	46	3.0	223	40	2.6
Coronation Drive (E of Park)	3.40	400	86	6.3	303	61	4.1	286	51	3.3
Miskin Road (S of Mt Cootha)	1.71	51	9	0.6	40	6	0.4	33	6	0.4
Western Freeway (S of Mt Cootha)	3.67	260	68	3.8	247	57	2.9	315	71	3.6

In addition to emissions from the NL tunnel ventilation outlets and major surface roads in the area, the dispersion modelling has also considered emissions from the northern ventilation outlet of the approved NSBT and the southern outlet of the approved AL. The emission characteristics for these outlets have been drawn from the data presented in the AL EIS (**Holmes Air Sciences, 2006**) for inclusion in the current assessment.

7. APPROACH TO ASSESSMENT

Dispersion models have been used as the primary tool to assess air quality impacts arising from this project. This section provides an explanation of the way in which dispersion modelling has been used for air quality assessment purposes.

The approach to the assessment has been to show not only the pollutant concentrations resulting from individual road sections and tunnel ventilation outlets but also the net effect of the Project within the study area. It is an aim of this study to assess any change to air quality that may arise as a result of the Project.

Most of the assessment has made use of the computer-based dispersion model known as CALPUFF. In addition, the dispersion model known as Cal3qhcr has been used. A discussion of some dispersion modelling concepts as well as the application of the CALPUFF and Cal3qhcr models to this project is given below.

7.1 Overview of Dispersion Models

A dispersion model can simply be thought of as a calculation which takes information about a pollutant source and determines a concentration at a specified location. Most dispersion models are now computer-based and may include a user interface.

The primary inputs to a dispersion model include:

- Source information;
- Meteorological information; and
- Receptor information.

Dispersion models require information on the emission sources. There are generally three main source types; point sources, area sources and volume sources. For point sources the dispersion model requires information on the source location, the source height, internal source tip diameter, temperature of emissions, exit velocity of emissions and the mass emission rate of the pollutants to be assessed. Area sources typically describe such things as ponds or exposed surfaces while volume sources can be used to represent emissions discharged from a single point, a building or even located in a series which may be used to represent a roadway. As well as the mass emission rate, area and volume sources require information on the dimensions of the source.

Meteorological data are an important component of dispersion modelling. In order for the model to determine how a pollutant emitted from a source will disperse, it must be given meteorological information relevant to the area in which the pollutant is emitted. Meteorological data will determine such things as the plume path and the ‘spread’ of the plume. Meteorological parameters typically include wind speed, wind direction, temperature, atmospheric stability and mixing height. All of these parameters are provided to the model as a data file which contains hourly records spanning approximately one year. In a non-leap year this would correspond to 8,760 records. The basis for providing the model with a year of data is to ensure that almost all possible meteorological conditions, including seasonal variations, are considered in the simulation. A comprehensive discussion of the meteorology of the study area was provided in **Section 5.2**.

Receptor information is defined by the user and relates to the locations for which predictions of pollutant concentrations are required. Usually the location of receptors are defined at ground-level, where most people reside, however it is also possible to set a receptor at a location above ground. Examples of above-ground or elevated receptors are air intake points on a building.

The calculations within a dispersion model are organised in a series of loops. The first step the model takes is usually to read one hour of meteorological information. Then, in the case of a single source, the model will determine the plume structure and then calculate the resultant pollutant concentration at every receptor specified by the user. Following these calculations the model reads the next hour of meteorological information and the process repeats itself until all hours in the meteorological file have been read. During the simulation the calculations are stored in the computer's memory and once the model run is complete, statistics such as pollutant maxima and averages can be retrieved.

The units of measurement for pollutant mass emission rates are different from the units of measurement for pollutant concentration and may sometimes cause some confusion. Mass emission rate defines the pollutant mass by time (for example, grams per second) while concentration defines the pollutant by volume; grams per cubic metre for example. Air quality goals are generally specified as a concentration.

It should be mentioned that air dispersion models can be classed as being one of two types; a steady-state model or a non steady-state model. A thorough description of the differences between the two model types is not necessary for the purposes of this report, however, it is useful to note that the fundamental difference relates to the simulated plume behaviour.

Steady-state models essentially create a plume which extends to infinity downwind. Once the next hour of meteorological data is read a new plume is created and memory of the plume in the previous hour is lost.

Non steady-state models allow the plume to grow and bend with differences in meteorology over the modelling area. Unlike steady-state models these types of models have a 'memory' of the plume for the previous hours. The concept of non steady-state is a more realistic simulation of plume behaviour than that provided by steady-state models.

7.2 CALMET and CALPUFF

The CALMET/CALPUFF modelling system is considered to be one of the most sophisticated models available. CALPUFF is an advanced computer-based dispersion model that simulates the dispersion of emissions by representing emissions as a series of puffs emitted sequentially. Provided the rate at which the puffs are emitted is sufficiently rapid, the puffs will overlap and the serial release will represent a continuous release.

The advantage of the puff modelling approach over the steady state Gaussian models such as ISCST3 and AUSPLUME, which have also been widely used in source dispersion assessments in the past, is that the progress and dispersion of each individual puff can be treated separately and can be made to account for local wind conditions and the way in which wind conditions at a particular place vary with time.

The CALPUFF model has been chosen as the primary tool for the purposes of this assessment. The main purpose of the CALPUFF modelling is to simulate the air quality impacts of the Project on a regional scale (approximately 20 km by 20 km area) and to show the net effect of introducing the tunnel into the area. The traffic information (see **Section 6.2**) reveals that the introduction of a tunnel into the Brisbane area will change traffic volumes on many of the region's roads. These changes may either be increases or decreases in total traffic volumes. Some roads, such as minor residential roads, are expected to experience relatively little change in traffic volumes. The CALPUFF modelling seeks to simulate these effects.

On the regional scale the pollutant emission sources have been divided into three categories:

1. Ventilation outlets associated with the tunnel
2. Roads generally carrying greater than 20,000 vehicles per day (AADT)
3. Roads generally carrying less than 20,000 vehicles per day (AADT)

Ventilation outlets associated with the tunnel have been represented as point sources in the dispersion model. Source locations, source characteristics and hourly variable pollutant emissions are provided to the model in the form of an external emissions file. Details of emissions from each outlet have been discussed in **Section 6.3**. Existing and, where known, buildings in the vicinity of the ventilation outlets which would influence plume behaviour have been included in the modelling and the PRIME building wake algorithm has been selected.

Roads carrying greater than 20,000 vehicles per day have also been explicitly included as sources in the model. Each road meeting this traffic volume criteria has been represented as a series of volume sources over the length of the road section. Each volume source has a location, elevation, height above ground and two additional parameters relating to the size of the source in the horizontal and vertical planes. Pollutant emissions are modelled to vary by hour of day for every volume source representing part of a road section. **Figure 24** shows the location of all volume sources which have been used to represent roads in the CALPUFF simulations.

It is technically possible to include all other minor roads with known traffic volume in the study area into the model however an alternate approach has been taken in this study to account for these sources. Roads carrying less than 20,000 vehicles per day have been accounted for by adding to the simulation the hourly varying ambient air quality monitoring data. For this approach it was necessary to construct a file for each modelled pollutant which contains hourly records of ambient pollutant concentrations based on the air quality monitoring. The 'background' data files have been constructed from air quality monitoring data, specifically, those collected from the Bowen Hills and Rocklea sites.

In the case of CO and NO_x, emissions contributing to the air quality monitoring data in the Brisbane area would be mainly from motor vehicles. It would therefore be considered appropriate to use an hourly background file to represent the non-modelled roads, that is, roads carrying less than about 20,000 vehicles per day. To create the background files for CO and NO_x, it is also appropriate to use data from a site which may be least influenced by high trafficked roads. Rocklea is considered to be a suitable site for this objective, rather than city-based monitoring sites.

An hourly background NO_2 data file has been created from the Rocklea air quality monitoring data. The background CO data file was created from the Bowen Hills data, in the absence of CO data from non city-based monitoring sites. This is likely to be conservative as there would be some influence from mobile sources at Bowen Hills.

There are many sources of particulate matter in the Brisbane area that would contribute to the measurements reported in the air quality monitoring data. These sources may include bushfires, construction activities and sea salt in addition to motor vehicle emissions. Using a background particulate matter data file to represent emissions from non-modelled roads would therefore not be appropriate in this instance. The approach adopted for particulate matter was to show the predicted contribution of the modelled sources alone and to determine if there would be any additional exceedances of the air quality criteria.

The modelling has been performed using the meteorological information provided by the CALMET model (**Section 5.2**) and the emissions information summarised in **Section 6.3**.

The CALPUFF model simulations include the following scenarios:

- 2007, existing case. Used for model performance analysis and comparison with future scenarios;
- 2014. Intended year for tunnel opening;
- 2016. Two (2) years after intended year for tunnel opening and selected to coincide with NSBT and AL scenarios;
- 2021. Seven (7) years after intended year for tunnel opening; and
- 2026. Twelve (12) years after intended year for tunnel opening.

In addition, “do minimal” (no tunnel) scenarios for 2014, 2016, 2021 and 2026 have been modelled and form a key component of the assessment.

Predictions were made over a large set of ground-level discrete receptors arranged in the study area. Spacing between receptors was set more finely in areas closer to sources and more coarsely in areas further from sources. The receptor spacing and locations have been chosen to provide high resolution model output where needed.

7.3 Cal3qhcr

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.

Cal3qhcr is one of a number of models in the CALINE series and is an enhancement of the Cal3qhc and Caline-3 roadway models to allow real (long-term) meteorological data. Model inputs also include roadway geometries, receptor locations and vehicular emission rates. The model is suitable for predictions within 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 Cal3qhcr modelling is to assess air quality impacts very close to selected roadways resulting from changes to lane configurations and traffic volumes. Although the CALPUFF model can simulate the dispersion of emissions from both line sources and point sources, it was not specifically designed for roadway emissions. In practice CALPUFF does not take account of the dispersion close to the road, where vehicle induced turbulence has significant influence. The CALINE models simulate this turbulence better than CALPUFF.

Ten (10) surface roadways have been selected for analysis using the Cal3qhcr model. These surface roadways are:

- Kelvin Grove Road (north of Herston Road);
- Inner City Bypass (west of Kelvin Grove Road);
- Hale Street;
- Waterworks Road (near Ennorgera Terrace)

- Given Terrace;
- Boundary Street (north of Baroona Road);
- Milton Road (west of Baroona Road);
- Coronation Drive (east of Park Road);
- Miskin Road (south of Mount Cootha Road); and
- Western Freeway (south of Mt Cootha Road).

Figure 25 shows the location of these road sections.

8. ASSESSMENT OF AIR QUALITY IMPACTS

This section provides an assessment of the air quality impacts associated with the Project. Some of the questions which are attempted to be answered in this discussion include:

- How would air quality change from the existing situation as a result of the Project?
- How do the air quality impacts of the Project compare with the "do nothing" case?
- What are the pollutant contributions from ventilation outlets and surface roads?

There are many figures accompanying this report which present the results of the dispersion modelling. The quantity of figures has arisen from the requirement to address many different pollutants, future years and build or no-build cases and to ensure that any possible adverse air quality impacts are not overlooked. It is possible, however, to observe the overall air quality impacts of the Project just by reviewing predictions for one pollutant only as similar trends for different pollutants have been noted. Contour plots showing the dispersion model predictions have been prepared for 2007, 2014 and 2026 only (to reduce the number of figures), while tabulated results are presented for all years.

All dispersion model results directly reflect the modelled traffic volumes for the Project.

8.1 Regional Effects

Figures 26 to **41** have been created from the dispersion modelling results in order to show the effect of the Project (in terms of air quality impacts) at a regional scale. The figures attempt to show the likely pollutant concentrations in the study area arising from sources which include surface roads and tunnel ventilation outlets (in cases where applicable).

The results for regional effects (**Figures 26** to **41**) are grouped by criteria pollutants, averaging time and years. **Table 20** has been created to assist with referencing the figures.

Table 20 : Quick reference to dispersion model results figure number

Pollutant and averaging time case	Simulation		
	2007	2014 (DM and DS)	2026 (DM and DS)
Maximum 8-hour average CO	Figure 26	Figure 27	Figure 28
Maximum 1-hour average NO_2	Figure 29	Figure 30	Figure 31
Annual average NO_2	Figure 32	Figure 33	Figure 34
Maximum 24-hour average PM_{10}	Figure 35	Figure 36	Figure 37
Annual average PM_{10}	Figure 38	Figure 39	Figure 40

It should be noted that predictions for maximum levels (that is, maximum 1-hour, 8-hour and 24-hour averages) do not show the dispersion pattern at any one point in time but show the maximum levels that occurred at each location over the entire meteorological dataset. Annual average prediction plots show the average levels for each location.

In addition to the results presented as absolute pollutant concentrations, **Figures 42** to **46** have been developed to compare the existing situation (2007) with future (2014) with and without tunnel cases. These results are presented as a percentage change in pollutant concentrations.

Comments on the dispersion model results for each of the criteria pollutants are provided below.

Carbon Monoxide
The simulations of CO concentrations in the study area (**Figures 26** to **28**) include surface road sources and tunnel ventilation outlets where appropriate. Background CO concentrations are also included in these predictions.

The first figure in the series of CO plots (**Figure 26**) shows the predictions for 2007. The 2007 simulation can be considered to represent the modelled "existing" situation. Following 2007 are the 2014 and 2026 simulations which include the build and no-build cases. This grouping pattern is maintained for all pollutants.

The following observations were made from the review of the CO model predictions:

- Predictions for the existing case (2007) show that maximum 8-hour average CO concentrations are below the 8-hour maximum air quality goal of 10 mg/m^3. The air quality monitoring data also shows that existing maximum 8-hour average CO concentrations are below 10 mg/m^3.
- CO concentrations in future years (2014+) are predicted to be very similar to existing (2007) concentrations. The likely improvements to vehicle emissions appear to offset projected increases in traffic in the study area. However, the emission estimates have not considered any further tightening of emission standards so the future projections are considered to be conservative.
- As expected, higher CO concentrations are predicted near roads carrying more traffic.
- Predictions for the future (2014+) build and no-build cases are very similar.
- The contribution to ground-level concentrations due to tunnel ventilation outlets (with NL case) appear to be overwhelmed by contributions from the major surface roads.

Nitrogen Dioxide
Predictions of NO_2 concentrations in the study area for existing and future years present a similar story to the CO predictions. These results (**Figures 29** to **34**) also include background NO_2 concentrations.

The following observations were made from the review of the NO_2 model predictions:

- Predictions for the existing case (2007) show that maximum 1-hour average NO_2 concentrations are up to around 160 μg/m^3 near the busy roads in the CBD. These levels are below the 246 μg/m^3 air quality goal. Monitoring data from the sites examined for this study show that existing maximum 1-hour average NO_2 concentrations are below the goal.
- Predictions for the existing case (2007) show that annual average NO_2 concentrations are below the annual air quality goal of 62 μg/m^3. The air quality monitoring data also shows that existing annual average NO_2 concentrations are below 62 μg/m^3.
- NO_2 concentrations in future years (2014+) are predicted to be very similar to existing (2007) concentrations. The likely improvements to vehicle emissions

appear to offset projected increases in traffic in the study area. However, the emission estimates have not considered any further tightening of emission standards so the future projections are considered to be conservative.

- As expected, higher NO_2 concentrations are predicted near roads carrying more traffic.
- Predictions for the future (2014+) build and no-build cases are very similar.
- The contribution to ground-level concentrations due to tunnel ventilation outlets (with NL case) appear to be overwhelmed by contributions from the major surface roads.

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

Figures 35 to **40** present the regional dispersion modelling results for PM_{10}. The most stringent PM_{10} air quality goals from **Table 1** are 50 $\mu g/m^3$ and 25 $\mu g/m^3$ for maximum 24-hour and annual averages respectively. Review of the air quality monitoring data for the study area (**Section 5.3**) showed that existing maximum 24-hour background PM_{10} levels can be above 50 $\mu g/m^3$ (up to 88 $\mu g/m^3$) and the major sources contributing to these levels are most likely bushfires and dust storms. For this reason the concentrations shown in the PM_{10} plots include only the modelled surface roads and ventilation outlet sources.

As for CO and NO_2, there are some common patterns of high and low concentrations predicted in the study area resulting from the modelled sources. The dispersion model predictions for PM_{10} are summarised below:

- Predictions for the existing case (2007) show that PM_{10} concentrations are below the maximum 24-hour and annual average air quality goals (50 and 25 $\mu g/m^3$) however these predictions are due only to the modelled sources and not from any other particulate matter sources.
- PM_{10} concentrations in future years (2014+) are predicted to very similar to existing (2007) concentrations. The likely improvements to vehicle emissions appear to offset projected increases in traffic in the study area. Again, the emission estimates have not considered any further tightening of emission standards so the future projections are considered to be conservative.
- Higher PM_{10} concentrations are predicted near roads carrying more traffic.
- Predictions for the future (2014+) build and no-build cases are very similar.
- The contribution to ground-level concentrations due to tunnel ventilation outlets (with NL case) appear to be overwhelmed by contributions from the major surface roads.

There is a widely held view that the majority of PM_{10} is $PM_{2.5}$ from motor vehicles however some monitoring data for tunnel projects indicate otherwise. For example, monitoring in the tunnel outlet for the M5-East tunnel in Sydney shows that about 35% of the PM_{10} is $PM_{2.5}$, while for the CityLink tunnel in Melbourne, tunnel outlet monitoring shows that about 70% of the PM_{10} is $PM_{2.5}$.

Monitoring data from the Brisbane area (Rocklea, Bowen Hills and Kedron in particular) show that around 50% of the PM_{10} is $PM_{2.5}$ although this fraction relates to ambient particulate matter concentrations. Actual percentages of $PM_{2.5}$ in the PM_{10} from vehicle exhausts and tunnel ventilation outlets will vary, however, for the purposes of this study it has been conservatively assumed that 96% of the PM_{10} is $PM_{2.5}$. This is based on measurements made in diesel exhaust (**Environment Australia, 2003**). Not all PM_{10} emissions from roadways are from diesel exhaust, they also include emissions from tyre and brake wear and emissions from petrol fuelled vehicles. Therefore, in practice the percentage will be less than 96%.

Model predictions for $PM_{2.5}$ are shown in **Figure 41**. As discussed above these predictions take account of modelled surface roads and ventilation outlets where appropriate. No background levels have been included. By assuming that 96% of the PM_{10} is $PM_{2.5}$, the changes in $PM_{2.5}$ with and without the tunnel are relatively minor. As with PM_{10}, the existing background levels already exceed the NEPM goal on occasions.

It is also worth noting that, in terms of total fine particulate loading, very clean environments such as Cape Grim on the north-western coast of Tasmania, which is a global baseline site, recorded average $PM_{2.5}$ levels of 5.8 $\mu g/m^3$ from 2001 to 2003 compared to the NEPM goal of 8 $\mu g/m^3$ for fine particulate matter. This does not leave a large margin for compliance with the NEPM goal in urban areas. While the source of the particulate matter at Cape Grim is predominantly sea salt, the NEPM goal does not distinguish between fine particles of different chemical composition. Future air quality criteria may well incorporate the chemical nature of fine particles and ultrafine particles (particles less than 0.1 μm in diameter) with the view that some particles are more harmful than others.

Table 21 presents the dispersion model results at selected locations in the study area for each of the criteria pollutants. From these results it is possible to assess the performance of the CALPUFF model, that is, by comparing the 2007 predictions with recent air quality monitoring data. Spatial variation (between the different sites) can also be assessed as well as differences between build and no-build cases and existing and future cases.

Table 21 : Predicted criteria pollutant concentrations at selected locations

SITE	2007	2014		2016		2021		2026		Goal
	DM	DM	DS	DM	DS	DM	DS	DM	DS	
Bowen Hills air quality monitoring site										
Maximum 8-hour average CO (mg/m^3)	2.5	2.5	2.5	2.5	2.5	2.5	2.4	2.4	2.4	10
Maximum 1-hour average NO_2 ($\mu g/m^3$)	107.1	103.8	102.9	101.8	101.8	99.9	100.0	98.2	97.9	246
Annual average NO_2 (ug/m^3)	29.5	26.9	26.8	26.2	26.1	25.2	25.1	24.4	24.3	62
Maximum 24-hour average PM_{10} ($\mu g/m^3$)*	3.0	2.1	2.1	1.9	1.8	1.5	1.6	1.3	1.3	50
Annual average PM_{10} ($\mu g/m^3$)*	1.0	0.7	0.7	0.6	0.6	0.5	0.5	0.4	0.4	25
Toowong air quality monitoring site										
Maximum 8-hour average CO (mg/m^3)	2.6	2.6	2.6	2.6	2.5	2.5	2.5	2.5	2.5	10
Maximum 1-hour average NO_2 ($\mu g/m^3$)	121.4	114.0	112.0	112.0	109.9	107.8	106.9	104.7	103.7	246
Annual average NO_2 (ug/m^3)	31.1	28.6	28.3	28.0	27.7	26.8	26.8	25.8	25.7	62
Maximum 24-hour average PM_{10} ($\mu g/m^3$)*	3.7	2.6	2.5	2.4	2.3	2.0	2.0	1.7	1.7	50
Annual average PM_{10} ($\mu g/m^3$)*	1.2	0.8	0.8	0.8	0.7	0.6	0.6	0.5	0.5	25
Brisbane Grammar School										
Maximum 8-hour average CO (mg/m^3)	3.0	2.9	2.9	2.8	2.8	2.8	2.8	2.7	2.7	10
Maximum 1-hour average NO_2 ($\mu g/m^3$)	136.7	122.3	125.0	119.2	119.0	113.7	113.9	110.3	112.6	246
Annual average NO_2 (ug/m^3)	38.8	34.2	34.5	33.3	32.8	31.3	31.4	29.6	30.1	62
Maximum 24-hour average PM_{10} ($\mu g/m^3$)*	5.3	3.7	3.7	3.4	3.3	2.8	2.8	2.4	2.5	50
Annual average PM_{10} ($\mu g/m^3$)*	1.9	1.3	1.3	1.2	1.2	1.0	1.0	0.8	0.9	25

** Predictions due to modelled roads and outlets only.*

For the Bowen Hills and Toowong monitoring sites, the dispersion modelling indicates that pollutant concentrations in future years (2014+) would be very similar to existing (2007) concentrations. This is true for all selected locations in both the with or without tunnel cases. At all selected locations, there are no pollutants where future concentrations are substantially different from existing concentrations.

Spatially, the 2007 model predictions show that CO concentrations at the two monitoring sites are similar. The Toowong and Brisbane Grammar School sites are predicted to experience slightly higher maximum NO_2 concentrations than the Bowen Hills site, most likely because of the closer proximity of these sites to the modelled emission sources such as major roadways. As discussed, the Bowen Hills site appears to have a localised source of NO_2 and this is not fully captured by the model assumptions.

Table 21 also shows that all pollutant concentrations are below air quality goals at each of the monitoring locations for all future year cases.

The predictions for the with tunnel (DS) and without tunnel (DM) cases are very similar and the difference in concentrations between these two cases would be considered difficult to detect by current measurement techniques.

A comparison of the CALPUFF model results with the measured levels is shown by **Table 22**. It can be seen from this table that maximum 8-hour average CO concentrations were generally over-predicted by the modelling at these locations. Predictions of NO_2 concentrations were slightly under-predicted at the Bowen Hills site and over-predicted at the Toowong site. The mismatch between the modelled year (that is, 2007) and the measurement periods is noted as not being ideal for this comparison.

Table 22 : Comparison of modelled and measured concentrations

SITE	Modelled existing (2007)	Measured existing	Goal
Bowen Hills (measurement data available for Jun 2004 to Jun 2005)			
Maximum 8-hour average CO (mg/m^3)	2.5	2.0	10
Maximum 1-hour average NO_2 (ug/m^3)	107	129	246
Annual average NO_2 (ug/m^3)	30	51	62
Toowong (measurement data available for Dec 2007 to Apr 2008)			
Maximum 8-hour average CO (mg/m^3)	2.6	0.9	10
Maximum 1-hour average NO_2 (ug/m^3)	121	82	246
Annual average NO_2 (ug/m^3)	31	15	62

** For the Bowen Hills site, the closest data period to compare with the 2007 model results is between June 2004 and June 2005.*

One of the objectives of using the CALPUFF model was to assess changes to air quality impacts on a regional scale, taking into account changes to traffic volumes. As indicated earlier in this section, the dispersion model results have also been presented to show the difference between existing and future years. These results are shown as a percentage change in pollutant concentrations by **Figures 42** to **46**.

Figure 42 shows the change in maximum 8-hour average CO concentrations from existing (2007) to 2014. Without NL and with NL cases are both shown on this plot. In both the with and without tunnel cases, there are regions of lower and higher concentrations, compared with the existing simulation. The range of percentage change is between about -4% (improvement) to +1% (deterioration). The deterioration occurs near roadways where increases in traffic are forecast, such as the Western Freeway.

When assessing the percentage change at a particular location it is useful to refer to the concentration from which the percentage is derived (2007). In the case of **Figure 42**, the percentages are expressed as a change from the predicted existing concentrations (**Figure 26**). It is possible that large percentage changes could be calculated even though the absolute concentrations are both very small (for example, comparing 0.1 mg/m^3 with 0.2 mg/m^3).

Benefits to CO concentrations are predicted to be observed most notably along sections of the Pacific Motorway. For the no tunnel case, there are few areas where increases to maximum 8-hour average CO concentrations are predicted. For the tunnel case there are some minor increases (of the order of 1%) predicted for CO concentrations near the Western Freeway. The predicted changes to ground-level pollutant concentrations are a result of changes to traffic on surface roads. A “signal” from the tunnel ventilation outlets is not evident in these model results.

Figures 43 and **44** show the change in NO_2 concentrations from existing (2007) to 2014. The maximum 1-hour average NO_2 concentrations are predicted to change between -10% and +2%, depending on the location. Again, it is useful to note that large percentage changes may have been derived from smaller concentrations. The with tunnel and without tunnel cases are very similar – the with tunnel case showing greater improvements around the Milton Road area.

Figures 45 and **46** show the change in PM_{10} concentrations from existing (2007) to 2014. The percentages shown in these plots have been derived by comparing the existing (2007) PM_{10} concentrations plus maximum background concentrations (52 $\mu g/m^3$, measured in 2006 [refer **Table 9**]) with the 2014 PM_{10} concentrations plus maximum background concentrations. Thus, the resultant percentage change is determined to be very small as the maximum background PM_{10} concentrations are high.

8.2 Ventilation Outlets

The purpose of this section is to examine pollutant concentrations due only to emissions from the tunnel ventilation outlets. **Table 23** shows the highest ground-level pollutant concentrations that are predicted in the study area due only to the emissions from the tunnel ventilation outlets. Note that these are the highest concentrations predicted in the study area and that in most areas the concentrations due to ventilation outlets will be much lower than these numbers.

Table 23 : Highest ground-level concentrations due to ventilation outlet emissions

Pollutant and averaging time	Predicted maximum ground-level concentrations due to emissions from each ventilation outlet								Background Concentration	Air quality goal
	2014		2016		2021		2026			
	N4	W1	N4	W1	N4	W1	N4	W1		
Maximum 8-hour average CO (mg/m^3)	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	2.5	10
Maximum 1-hour average NO_2 ($\mu g/m^3$)	3.1	7.0	3.3	8.3	2.7	7.3	2.5	6.8	94.3	246
Annual average NO_2 ($\mu g/m^3$)	0.3	0.9	0.3	0.9	0.3	0.7	0.3	0.7	18.5	62
Maximum 24-hour average PM_{10} ($\mu g/m^3$)	0.3	0.4	0.3	0.4	0.2	0.3	0.2	0.3	52.6	50
Annual average PM_{10} ($\mu g/m^3$)	0.02	0.07	0.02	0.07	0.02	0.05	0.02	0.05	16.7	25

It can be seen from **Table 23** that the highest ground-level concentrations due to all ventilation outlet emissions are well below the associated air quality goals. Of all the pollutants modelled, the maximum 1-hour average NO_2 is predicted to consume the greatest fraction of the air quality goal at less than 3%. These predictions suggest that the ventilation outlets would not be the cause of exceedances of air quality goals. Also included are estimates of background concentrations, based on the monitoring data from Bowen Hills (CO) and Rocklea (NO_2 and PM_{10}) collected in 2005. As discussed in **Section 5.3** this will vary across the modelling domain.

Pollutant concentrations at locations above ground-level have also been assessed as part of this project. **Figures 47** to **51** show predicted pollutant concentrations at 30 and 50 m above ground-level due to emissions from the proposed tunnel ventilation outlets. Results for 2014 are presented.

Figure 47 shows the predicted maximum 8-hour average CO concentrations above ground-level due to emissions from all tunnel ventilation outlets. Maximum levels are predicted to be less than 1 mg/m^3 at all locations both 30 and 50 m above ground-level. This level of impact should demonstrate compliance with the 10 mg/m^3 air quality goal at elevated locations even when considering background levels of up to 5 mg/m^3 (that is, Woolloongabba in 2006, refer Table 6).

Figures 48 and **49** show the predicted maximum 1-hour and annual average NO_2 concentrations at elevated locations due to emissions from tunnel ventilation outlets. Predictions are up to 50 μg/m^3 at 50 m above ground-level and close to vent outlets. This level of impact should demonstrate compliance with the 246 μg/m^3 air quality goal at all elevated locations even when considering recent (2006) background levels of up to 103 μg/m^3. Similarly, for annual average NO_2 concentrations, the highest concentrations are of the order of 5 μg/m^3 – close to the vent outlets and at 50 m above ground-level. Compliance with the 62 μg/m^3 should be comfortably achieved at all elevated locations even when considering annual average NO_2 concentrations (in 2006 the South Brisbane reported an annual average NO_2 concentration of 34 μg/m^3).

Predicted PM_{10} concentrations at elevated locations are provided in **Figures 50** and **51**. Maximum 24-hour average PM_{10} concentrations are predicted to be up to about 5 μg/m^3. Again, this level is predicted at 50 m above ground-level and close to the vent outlets. This is well below the 50 μg/m^3 goal and unlikely to be the cause of exceedances at elevated locations. Annual average PM_{10} concentrations are predicted to be less than 1 μg/m^3 at 30 and 50 m above ground-level at all locations – well below the 25 μg/m^3 goal and compliance at elevated locations would be anticipated.

8.3 Surface Roads

The purpose of this section is to examine pollutant concentrations very close to selected surface roads. Results presented in this section show the effect of emissions from the selected surface road only and do not include contributions from other sources. An objective of this section was to compare existing near roadside pollutant concentrations with future scenarios.

Figures 52 to **61** present the results showing modelled near roadside pollutant concentrations. The predictions have been made using the Cal3qhcr roadway dispersion model. Each figure provides information for a single road section and presents the predictions of CO, NO_2 and PM_{10} concentrations at various distances from the road for existing (2007) and future cases. Predictions have been made at the kerb and 10, 30 and 50 m from the eastern and western kerb of the road section. These predictions are useful for examining the differences between existing and future traffic scenarios.

Model predictions have taken into account a year of meteorological conditions which have been generated by the CALMET model for a location approximately in the centre of the proposed tunnel route.

From examination of the model results the highest pollutant concentrations for 2007 are predicted in the vicinity of Hale Street. This may be expected, given the very high traffic volumes experienced on this road (approximately 87,000 vehicles per day). Predicted pollutant concentrations are highest at the kerb and decrease with distance from the kerb for all road sections. This shows the dispersion effect of distance from the source.

In assessing the magnitude of the predicted pollutant concentrations, an appropriate distance from the kerb should be selected based on the distance to the nearest residences. For example, the separation distance between the kerb and the nearest residences is greater for the Western Freeway than for many of the other selected roads. The most relevant distances from the Western Freeway section would be about 30 m while for most other sections, 10 m from the kerb would be the appropriate distance for the nearest residences.

The following observations were made from the surface road dispersion model predictions:

- Predicted pollutant concentrations are highest at the kerb for each road section.
- Predicted pollutant concentrations for 2007 are highest near Hale Street.
- Road sections where the with tunnel case is predicted to be lower than the without tunnel case include Coronation Drive and Milton Road.
- Road sections where the with tunnel case is predicted to be higher than the without tunnel case include Western Freeway and Inner City Bypass.
- Road sections where the differences between the with tunnel case and without tunnel cases are considered negligible include Hale Street, Waterworks Road, Boundary Street, Given Terrace, Miskin Road and Kelvin Grove Road.
- Improvements in local air quality are observed with reductions in surface traffic that occur as a result of diverting traffic to the tunnel.
- At distances appropriate for the nearest residences, the model predictions for all sections and future years are below the associated air quality goals.

A useful comparison can also be made between predicted maximum pollutant concentrations due only to ventilation outlets (from **Section 8.2**) and maximum pollutant concentrations near surface roads. It is important not to underestimate the pollutant concentrations near surface roads as they are likely to be significantly higher than maximum levels expected as a result of emissions from tunnel ventilation outlets. Also, high pollutant concentrations near surface roads are likely to occur more often than high concentrations due to ventilation outlets.

9. OTHER ISSUES

The foregoing assessment has considered criteria pollutants and the major effects on air quality due to the Project. Other, potentially equally important, issues are discussed in this section.

9.1 Air Toxics

Air toxics are pollutants which are usually present in minor amounts but which have significant long-term health effects and are often carcinogenic. As it is assumed that there is no threshold below which effects are not observed, it is common practice for regulatory authorities not to set ambient goals for these pollutants, but to adopt a risk based approach.

There is limited detailed emissions information available in relation to air toxics from motor vehicles. The approach to assessing these pollutant concentrations has been based on the assumption that there is an association between CO and VOC emissions in the exhaust. Speciation factors for VOCs have then been applied to derive likely emissions of the air toxics considered in this study. Additional air toxics to those which are listed in the NEPM have also been included due to the carcinogenic nature of these substances. Air toxics emission factors have been taken from the National Pollutant Inventory (NPI) database (**NPI, 2000**).

Table 24 provides information required to determine different air toxic emissions from motor vehicles.

Table 24 : Determination of air toxic emissions from motor vehicles

Emission factors for CO and VOCs (**EPA & BCC, 2004**)			
CO emission factor (g/km)		3.44	
VOC emission factor (g/km)		0.26	
VOC speciation of emissions from motor vehicles (**NPI, 2000**)			
Substance	Weight fraction		Fraction of CO emission
	Petrol exhaust	Diesel exhaust	
1,3 Butadiene	0.00649	0.00115	4.66E-04
Acetaldehyde	0.00437	0.155	1.01E-03
Benzene	0.0658	0.0101	4.72E-03
Benzo(a)pyrene*	3.52×10^{-6}	1.77×10^{-5}	3.30E-07
Formaldehyde	0.0156	0.0826	1.48E-03
Toluene	0.105	0.0147	7.53E-03
Xylene	0.0759	0.0117	5.45E-03

** the Benzo(a)pyrene equivalent in PAHs was taken from **Kahlili et al (1995)***

The fraction of the CO emission calculated to be equivalent to the air toxic emission has been used to determine air toxic concentrations at selected locations. These predictions are presented below in **Table 25**.

At the selected locations, the predicted concentrations for each air toxic are very similar for both the build and no build scenarios. Predicted levels are well below NEPM investigation levels.

Table 25 : Predicted air toxics concentrations at selected locations

SITE	2007 DM	2014 DM	2014 DS	NEPM investigation level
Bowen Hills air quality monitoring site				
Annual average 1,3 Butadiene (mg/m^3)	2.90E-05	2.42E-05	2.40E-05	-
Annual average Acetaldehyde (mg/m^3)	6.29E-05	5.26E-05	5.23E-05	-
Annual average Benzene (mg/m^3)	2.93E-04	2.45E-04	2.43E-04	9.35E-03
Annual average Benzo(a)pyrene (mg/m^3)	2.05E-08	1.71E-08	1.70E-08	3.00E-07
Annual average Formaldehyde (mg/m^3)	9.21E-05	7.69E-05	7.65E-05	-
Annual average Toluene (mg/m^3)	4.67E-04	3.90E-04	3.88E-04	3.84E-01
Annual average Xylene (mg/m^3)	3.38E-04	2.82E-04	2.81E-04	8.44E-01
Maximum 24-hour average Toluene (mg/m^3)	1.48E-03	1.23E-03	1.23E-03	3.84E+00
Maximum 24-hour average Xylene (mg/m^3)	1.07E-03	8.91E-04	8.89E-04	1.06E+00
Toowong air quality monitoring site				
Annual average 1,3 Butadiene (mg/m^3)	4.36E-05	3.85E-05	3.75E-05	-
Annual average Acetaldehyde (mg/m^3)	9.47E-05	8.37E-05	8.14E-05	-
Annual average Benzene (mg/m^3)	4.41E-04	3.90E-04	3.79E-04	9.35E-03
Annual average Benzo(a)pyrene (mg/m^3)	3.09E-08	2.73E-08	2.65E-08	3.00E-07
Annual average Formaldehyde (mg/m^3)	1.39E-04	1.23E-04	1.19E-04	-
Annual average Toluene (mg/m^3)	7.03E-04	6.22E-04	6.05E-04	3.84E-01
Annual average Xylene (mg/m^3)	5.09E-04	4.50E-04	4.38E-04	8.44E-01
Maximum 24-hour average Toluene (mg/m^3)	2.19E-03	1.94E-03	1.87E-03	3.84E+00
Maximum 24-hour average Xylene (mg/m^3)	1.58E-03	1.40E-03	1.35E-03	1.06E+00
Brisbane Grammar School				
Annual average 1,3 Butadiene (mg/m^3)	6.16E-05	5.36E-05	5.44E-05	-
Annual average Acetaldehyde (mg/m^3)	1.34E-04	1.16E-04	1.18E-04	-
Annual average Benzene (mg/m^3)	6.23E-04	5.43E-04	5.51E-04	9.35E-03
Annual average Benzo(a)pyrene (mg/m^3)	4.36E-08	3.80E-08	3.85E-08	3.00E-07
Annual average Formaldehyde (mg/m^3)	1.96E-04	1.70E-04	1.73E-04	-
Annual average Toluene (mg/m^3)	9.94E-04	8.65E-04	8.78E-04	3.84E-01
Annual average Xylene (mg/m^3)	7.19E-04	6.26E-04	6.35E-04	8.44E-01
Maximum 24-hour average Toluene (mg/m^3)	2.82E-03	2.50E-03	2.53E-03	3.84E+00
Maximum 24-hour average Xylene (mg/m^3)	2.04E-03	1.81E-03	1.83E-03	1.06E+00

9.2 Network Analysis

Network traffic statistics for the Greater Brisbane area have been reviewed in order to examine emissions both with and without the NL. The South-east Queensland region Air Emissions Inventory (**EPA & BCC, 2004**) provides estimated fleet-average exhaust emissions factors of regulated pollutants. The emission factors are relevant for the Greater Brisbane area and are given for an average travel speed of 50 km/h.

Network traffic statistics and fleet-average exhaust emission factors have been used to estimate total vehicle emissions for the Greater Brisbane area both with and without the tunnel for 2014. The details of these calculations are provided below in **Table 26**. Emission factors for 2011 have been used for the calculations.

Table 26 : Network traffic and emission statistics

Traffic	2014	
	Without tunnel	With tunnel
Total VKT per AAWT	58,087,900	58,156,000
Total MVKT per year	19,169	19,191
Estimated emissions of criteria pollutants		
VOC (t/y) Emission factor = 0.26 g/km	4984	4990
NO_x (t/y) Emission factor = 0.98 g/km	18786	18808
CO (t/y) Emission factor = 3.44 g/km	65941	66019
PM_{10} (t/y) Emission factor = 0.0405 g/km	776	777

Using a simplified approach of multiplying emission factors by the total vehicle kilometres travelled, the total emissions for the Greater Brisbane area are slightly higher with the tunnel than without the tunnel. The differences are considered to be marginal. The estimate does not take account of the benefit to regional emissions that free-flowing traffic would provide.

9.3 Tunnel Filtration Analysis

An analysis of the effect on local air quality due the NL tunnel fitted with some form of emission treatment has been carried out. **Child** (**2004**) has reviewed various emission treatment technologies and systems for road tunnels and provided information on pollutant removal efficiencies. Typical claimed performance results are as follows:

- 80 to 95% removal efficiency for total suspended particulates; and
- 60% removal efficiency for total oxides of nitrogen.

These performance results were claimed in relation to the CLAIR system and were based on trials conducted in Germany. The quoted figures were among the highest of the total suspended particulates and oxides of nitrogen removal efficiencies presented in the review.

Dispersion modelling has assisted with the analysis of the effects on ambient air quality arising from the NL tunnel both with and without some form of emission treatment. For the analysis it has been assumed that the emission treatment would remove 60% of the NO_x and 90% of the PM_{10} from ventilation outlets emissions.

Figures 62 to **65** show the dispersion modelling results which compare ground-level pollutant concentrations for the NL tunnel without and with emission treatment. Plots for maximum 1-hour and annual average NO_2 and maximum 24-hour and annual average PM_{10} concentration predictions are presented for 2014. These plots show the effect of vehicle emissions from surface roads and from the tunnel's proposed ventilation outlets.

It can be seen from **Figures 62** to **65** that the ground-level pollutant concentrations both without and with tunnel filtration are very similar. Differences to ambient air quality arising solely from emission treatment for the tunnel would be difficult to detect. The model predictions demonstrate that pollutant concentrations in the study area are dominated by emissions from motor vehicles on the surface roads and that emissions treatment for each of the five kilometres (approximately) of tunnels associated with the Project would result in very similar ambient air quality implications to the Project without emissions treatment.

9.4 Ultrafine Particles

Ultrafine particles are defined as those smaller than 0.1 μm in diameter. While ultrafine particles make a small contribution to total particle mass, they make a very large contribution to particle number. Particles in this size range are generally formed from combustion, gas to particle conversion, nucleation and photochemical processes. Some are emitted as primary particles and others are secondary in nature formed from precursor molecules.

While an association between health effects and concentrations of fine particles (those less than 2.5 μm in equivalent aerodynamic diameter) is well established, the role played by the ultrafine particles is less clear. There are plausible mechanisms to suggest that ultrafine particles may indeed be a dominant factor in the health effects of particulate matter, however at this stage the evidence is too limited to develop exposure standards. In addition, methodologies for measuring ultrafine particles are still being developed and there is no widely agreed technique for measuring both ultrafine particle mass and number.

Nevertheless, there is sufficient evidence to warrant further investigation of both the involvement and the mode of action of ultrafine particles in the observed health outcomes associated with exposure to particulate matter. An extensive review of the health effects of ultrafine particles has recently been completed (**Morawska *et al*, 2004**). The review makes recommendations for further work including developing national and local databases for ultrafine particles and standardising measurement technology.

Ultrafine particles cannot be excluded from the environment. They arise from many sources including the combustion of fossil fuels, wood burning as well as natural processes such as nucleation of volatile organic compounds released from vegetation such as eucalypts.

This study has considered the issue of ultrafine particles by modelling the change in particulate numbers resulting from the Project. This assessment needs to be qualified in that there is very limited data available on ultrafine emission rates from vehicles.

Morawska *et al* (**2003**) has derived sub-micrometre particle emission factors for motor vehicles in the Brisbane area. The emission factors provided by Morawska have been used to scale dispersion model predictions of PM_{10} ($\mu g/m^3$) to particle numbers (with units of particles/cm^3). **Table 27** provides details of the calculations.

Table 27 : Particle number emission factors and calculations

Average PM_{10} emission factor from surface roads (by PIARC for 2014)	0.08 g/v-mi (0.05 g/km)
Sub-micrometre particle emission factor (**Morawska *et al*, 2004**)	5.15×10^{13} particles/VKT
Therefore, 1 $\mu g/m^3$ PM_{10} is equivalent to:	1,036 particles/cm^3

Therefore, in terms of emissions factors from the fleet using surface roads, 1 $\mu g/m^3$ of PM_{10} is determined to be equivalent to 1,036 sub-micrometre particles/cm^3. Annual average PM_{10} concentrations, as measured at Woolloongabba in 2006, are of the order of 22 $\mu g/m^3$ which would be equivalent to 22,792 sub-micrometre particles/cm^3, assuming a similar proportion of ultrafine particles. This is of course an oversimplification as the total PM_{10} measured at a particular monitoring site will generally be from a number of sources, not just motor vehicle emissions. Nevertheless, this value is in the range referenced by Morawska *et al* (**2003**) for "Urban concentrations in six Australian cities"; that is, 10,000 to 50,000 particles/cm^3.

Figures 66 and **67** present the predicted maximum 24-hour particle numbers, scaled from PM_{10} predictions. These predictions include emissions from the modelled surface roads as well as ventilation outlets where appropriate. The trends with the particle number predictions (that is, comparisons between scenarios) are the same as those observed for the PM_{10} predictions suggesting very little difference between the build and no build scenarios.

9.5 Cumulative Effects of Ventilation Outlets

Cumulative Impacts at Herston and Bowen Hills

The reference design for Northern Link would place a ventilation outlet in Victoria Park golf course. The northern ventilation outlet for Clem7 will be constructed in Sneyd Street Bowen Hills approximately 1.6kms to the north-east. The southern ventilation outlet for Airport Link will be constructed on land adjacent to Mann Park off Byrne Street Windsor, approximately 2.1kms to the north north-east. The cumulative effects on ground-level concentrations of key pollutants was modelled for this EIS, with the findings summarised in Table 28.

Table 28: Highest ground-level concentrations due to NL (both stacks), AL (southern stack) and NSBT (northern stack) in 2014

Pollutant and averaging time	Concentrations due to NL eastern ventilation outlet	Cumulative concentrations – NSBT, AL & NL ventilation outlets	Background Concentration	Air quality goal
Maximum 8-hour average CO (mg/m^3)	0.1	0.1	2.5	10
Maximum 1-hour average NO_2 ($\mu g/m^3$)	3.1	4.5	94.3	246
Annual average NO_2 ($\mu g/m^3$)	0.3	1.06	18.5	62
Maximum 24-hour average PM_{10} ($\mu g/m^3$)	0.3	0.4	52.6	50
Annual average PM_{10} ($\mu g/m^3$)	0.02	0.05	16.7	25

The cumulative contribution to ground-level concentrations of each of the key pollutants from the ventilation outlets for Northern Link, Clem7 and Airport Link would be well below the goals for ambient air quality, and would not be the cause for any exceedance of the goals. The increase in the predicted maximum 24 hour average PM10 of 0.1μg/m3 is small compared with the goal of 50μg/m3. While the recorded maximum 24 hour average of 52.6μg/m3 for this locality is above the goal, it should be noted that the annual average of 16.7μg/m3 is well below the goal of 25μg/m3, suggesting that the Herston / Bowen Hills / Windsor area is susceptible to the influence of external factors over short periods..

9.6 Portal emissions

The ventilation of the NL tunnel has been configured so that there are minimal portal emissions. However it may be possible under some conditions to allow portal emissions without compromising ambient air quality. The potential benefit would be the reduced fan usage with associated greenhouse gas emission reductions. An option would be to allow portal emissions during off-peak periods and/or times of good atmospheric dispersion. A monitoring network with a feedback to the ventilation system would need to be developed to ensure that there were no exceedances of air quality goals.

10. CONCLUSIONS

This report has assessed the effects on air quality of the proposed Northern Link Tunnel in Brisbane. Dispersion modelling has been used as the primary tool to quantitatively assess pollutant concentrations in the study area.

The conclusions of the study can be summarised as follows:

- Pollutant concentrations in the study area in future years (2014+) arising from motor vehicles would be expected to be similar to existing (2007) concentrations. This is the case both with and without the Project.
- Model results for future years are considered to be conservative since no further improvements to vehicle emissions have been taken into account.
- At ground-level the with and without tunnel cases are predicted to be very similar apart from in the vicinity of roads affected by the Project. Regional air quality with the Project may be expected to be similar to air quality without the Project.
- The most significant changes in air quality are close to surface roadways affected by the Project. The Western freeway and ICB are predicted to experience the most significant increase, however sensitive receptors are generally well removed from these roads (30 m or more). Coronation Drive and Milton Road are predicted to experience the most improvement.
- At ground-level the highest concentrations due to emissions from ventilation outlets are predicted to be much less than concentrations near busy surface roads.
- Pollutant concentrations at elevated locations due to ventilation outlet emissions would be expected to be below relevant air quality goals.
- An analysis of network traffic flow suggests that total emissions in the Greater Brisbane area would be slightly higher with the Project than without. The differences in emissions are considered to be marginal.
- Particulate matter concentrations arising from non-motor vehicle sources, such as bushfires, may continue to result in elevated levels on occasions.
- The difference in ambient air quality arising from treatment of tunnel emissions by some form of filtration would be difficult to detect. Benefits arising from emissions treatment would most likely be realised in-tunnel and at elevated locations very near the tunnel ventilation outlets.

It is concluded from the study that there would be no adverse air quality impacts as a direct result of the Project. The reader should refer to each section of the report for more detailed examination of specific air quality issues associated with the Project.

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APPENDIX A
HEALTH EFFECTS OF POLLUTANTS EMITTED FROM MOTOR VEHICLES

APPENDIX A
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 8-hour goals noted by the EPA and NEPM 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 EPA has not set any air quality goals for nitric oxide, however it has set 1-hour and annual average goals 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 goals 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 Queensland 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 4x10^{-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.

APPENDIX B
JOINT WIND SPEED, WIND DIRECTION AND STABILITY CLASS FREQUENCY TABLES

APPENDIX B
JOINT WIND SPEED, WIND DIRECTION AND STABILITY CLASS FREQUENCY TABLES

This section provides meteorological information including

- A list of missing BoM upper-air data records;
- Joint wind speed, wind direction and stability class frequency tables for Brisbane Airport;

Missing upper-air data records

Upper air data collected by the Bureau of Meteorology at Brisbane Airport in 2005 were not a complete dataset for the purposes of the CALMET modelling. The missing periods are listed below.

```
ORIGINAL CALMET UPn.DAT FILE:
 C:\Jobs\BrisNL\metdata\BoM_Bris_AP\upper_air\up1_2005.dat
TAPM PRODUCED CALMET UPn.DAT FILE:
 C:\Jobs\BrisNL\metdata\tapm\01km_m013016.up
CORRECTED CALMET UPn.DAT FILE:
 C:\Jobs\BrisNL\calmet\up1.dat

Gap between soundings is > 14 hours before: 05020223.  Getting info from TAPM file... Done.
Gap between soundings is > 14 hours before: 05101323.  Getting info from TAPM file... Done.
Gap between soundings is > 14 hours before: 05101811.  Getting info from TAPM file... Done.
Gap between soundings is > 14 hours before: 05102723.  Getting info from TAPM file... Done.
```

The missing soundings were supplemented with output from the TAPM model.

Joint wind speed, wind direction and stability class frequency tables

```
STATISTICS FOR FILE:  C:\Jobs\BrisNL\calmet\ts\Time series data_BH.asc (Bowen Hills by CALMET)
MONTHS: All
HOURS : All
OPTION: Frequency
```

PASQUILL STABILITY CLASS 'A'

Wind Speed Class (m/s)

WIND SECTOR	0.50 TO 1.50	1.50 TO 3.00	3.00 TO 4.50	4.50 TO 6.00	6.00 TO 7.50	7.50 TO 9.00	9.00 TO 10.50	GREATER THAN 10.50	TOTAL
NNE	0.001484	0.003425	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.004910
NE	0.002855	0.004567	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.007422
ENE	0.002284	0.002512	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.004796
E	0.000571	0.000457	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.001028
ESE	0.000343	0.000913	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.001256
SE	0.000228	0.000228	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000457
SSE	0.000228	0.000343	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000571
S	0.000799	0.000343	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.001142
SSW	0.000343	0.000114	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000457
SW	0.000799	0.000343	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.001142
WSW	0.000913	0.000913	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.001827
W	0.001142	0.000685	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.001827
WNW	0.000571	0.000114	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000685
NW	0.000457	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000457
NNW	0.001028	0.000114	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.001142
N	0.001599	0.001256	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.002855
CALM									0.003654
TOTAL	0.015643	0.016328	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.035625

MEAN WIND SPEED (m/s) = 1.46
NUMBER OF OBSERVATIONS = 312

PASQUILL STABILITY CLASS 'B'

Wind Speed Class (m/s)

WIND SECTOR	0.50 TO 1.50	1.50 TO 3.00	3.00 TO 4.50	4.50 TO 6.00	6.00 TO 7.50	7.50 TO 9.00	9.00 TO 10.50	GREATER THAN 10.50	TOTAL
NNE	0.002855	0.003654	0.003083	0.000228	0.000000	0.000000	0.000000	0.000000	0.009820
NE	0.003083	0.006052	0.010391	0.000000	0.000000	0.000000	0.000000	0.000000	0.019525
ENE	0.003425	0.004453	0.007993	0.000000	0.000000	0.000000	0.000000	0.000000	0.015871
E	0.001599	0.002855	0.002284	0.000000	0.000000	0.000000	0.000000	0.000000	0.006737
ESE	0.000913	0.003540	0.003882	0.000343	0.000000	0.000000	0.000000	0.000000	0.008678
SE	0.002284	0.002626	0.003083	0.000457	0.000000	0.000000	0.000000	0.000000	0.008449
SSE	0.002969	0.004225	0.001028	0.000000	0.000000	0.000000	0.000000	0.000000	0.008221
S	0.002055	0.003540	0.000343	0.000000	0.000000	0.000000	0.000000	0.000000	0.005937
SSW	0.003768	0.006052	0.000343	0.000000	0.000000	0.000000	0.000000	0.000000	0.010162
SW	0.006394	0.005024	0.002169	0.000000	0.000000	0.000000	0.000000	0.000000	0.013588
WSW	0.003996	0.002740	0.002169	0.000000	0.000000	0.000000	0.000000	0.000000	0.008906
W	0.001713	0.001827	0.001142	0.000114	0.000000	0.000000	0.000000	0.000000	0.004796
WNW	0.001142	0.000457	0.000114	0.000000	0.000000	0.000000	0.000000	0.000000	0.001713
NW	0.001941	0.000685	0.000228	0.000000	0.000000	0.000000	0.000000	0.000000	0.002855
NNW	0.002284	0.001484	0.000228	0.000000	0.000000	0.000000	0.000000	0.000000	0.003996
N	0.002284	0.002740	0.000457	0.000000	0.000000	0.000000	0.000000	0.000000	0.005481
CALM									0.002969
TOTAL	0.042704	0.051953	0.038936	0.001142	0.000000	0.000000	0.000000	0.000000	0.137703

MEAN WIND SPEED (m/s) = 2.20
NUMBER OF OBSERVATIONS = 1206

PASQUILL STABILITY CLASS 'C'

Wind Speed Class (m/s)

WIND SECTOR	0.50 TO 1.50	1.50 TO 3.00	3.00 TO 4.50	4.50 TO 6.00	6.00 TO 7.50	7.50 TO 9.00	9.00 TO 10.50	GREATER THAN 10.50	TOTAL
NNE	0.002169	0.004681	0.005481	0.002169	0.000000	0.000000	0.000000	0.000000	0.014501
NE	0.002169	0.004453	0.009934	0.000913	0.000000	0.000000	0.000000	0.000000	0.017470
ENE	0.002169	0.005481	0.007193	0.000228	0.000000	0.000000	0.000000	0.000000	0.015072
E	0.002855	0.002169	0.002169	0.000114	0.000000	0.000000	0.000000	0.000000	0.007308
ESE	0.001370	0.003425	0.005481	0.001256	0.000000	0.000000	0.000000	0.000000	0.011532
SE	0.003083	0.002169	0.004339	0.001599	0.000000	0.000000	0.000000	0.000000	0.011190
SSE	0.003540	0.001599	0.000913	0.000228	0.000000	0.000000	0.000000	0.000000	0.006280
S	0.003425	0.003654	0.000343	0.000000	0.000000	0.000000	0.000000	0.000000	0.007422
SSW	0.008449	0.010961	0.001256	0.000000	0.000000	0.000000	0.000000	0.000000	0.020667
SW	0.009477	0.006394	0.001142	0.000114	0.000000	0.000000	0.000000	0.000000	0.017127
WSW	0.003768	0.001827	0.000913	0.000343	0.000000	0.000000	0.000000	0.000000	0.006851
W	0.002855	0.001941	0.002512	0.001827	0.000000	0.000000	0.000000	0.000000	0.009135
WNW	0.002855	0.000685	0.000114	0.000000	0.000000	0.000000	0.000000	0.000000	0.003654
NW	0.001484	0.000913	0.000114	0.000000	0.000000	0.000000	0.000000	0.000000	0.002512
NNW	0.001941	0.000685	0.000343	0.000000	0.000000	0.000000	0.000000	0.000000	0.002969
N	0.002740	0.000913	0.000457	0.000000	0.000000	0.000000	0.000000	0.000000	0.004111
CALM									0.009135
TOTAL	0.054350	0.051953	0.042704	0.008792	0.000000	0.000000	0.000000	0.000000	0.166933

MEAN WIND SPEED (m/s) = 2.23
NUMBER OF OBSERVATIONS = 1462

PASQUILL STABILITY CLASS 'D'

Wind Speed Class (m/s)

WIND SECTOR	0.50 TO 1.50	1.50 TO 3.00	3.00 TO 4.50	4.50 TO 6.00	6.00 TO 7.50	7.50 TO 9.00	9.00 TO 10.50	GREATER THAN 10.50	TOTAL
NNE	0.002398	0.006280	0.011989	0.003311	0.000228	0.000000	0.000000	0.000000	0.024206
NE	0.000571	0.006737	0.009705	0.000114	0.000000	0.000000	0.000000	0.000000	0.017127
ENE	0.001484	0.007879	0.004796	0.000114	0.000000	0.000000	0.000000	0.000000	0.014273
E	0.001256	0.007193	0.003197	0.000000	0.000000	0.000000	0.000000	0.000000	0.011646
ESE	0.001941	0.007993	0.007879	0.000228	0.000000	0.000000	0.000000	0.000000	0.018041
SE	0.002055	0.006508	0.011076	0.000913	0.000000	0.000000	0.000000	0.000000	0.020553
SSE	0.005367	0.007308	0.005595	0.000343	0.000000	0.000000	0.000000	0.000000	0.018612
S	0.002855	0.006508	0.000571	0.000000	0.000000	0.000000	0.000000	0.000000	0.009934
SSW	0.003311	0.015414	0.001599	0.000000	0.000000	0.000000	0.000000	0.000000	0.020324
SW	0.003540	0.007536	0.001256	0.000114	0.000114	0.000000	0.000000	0.000000	0.012560
WSW	0.001142	0.001713	0.000799	0.000799	0.000457	0.000457	0.000000	0.000000	0.005367
W	0.000799	0.001256	0.001827	0.001028	0.001370	0.000228	0.000000	0.000000	0.006508
WNW	0.001370	0.000799	0.000228	0.000000	0.000000	0.000000	0.000000	0.000000	0.002398
NW	0.001028	0.001484	0.000114	0.000000	0.000000	0.000000	0.000000	0.000000	0.002626
NNW	0.002169	0.003425	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.005595
N	0.002512	0.005367	0.001256	0.000343	0.000000	0.000000	0.000000	0.000000	0.009477
CALM									0.005595
TOTAL	0.033798	0.093400	0.061886	0.007308	0.002169	0.000685	0.000000	0.000000	0.204841

MEAN WIND SPEED (m/s) = 2.59
NUMBER OF OBSERVATIONS = 1794

PASQUILL STABILITY CLASS 'E'

Wind Speed Class (m/s)

WIND SECTOR	0.50 TO 1.50	1.50 TO 3.00	3.00 TO 4.50	4.50 TO 6.00	6.00 TO 7.50	7.50 TO 9.00	9.00 TO 10.50	GREATER THAN 10.50	TOTAL
NNE	0.000000	0.004225	0.002740	0.000114	0.000000	0.000000	0.000000	0.000000	0.007079
NE	0.000000	0.003882	0.000913	0.000000	0.000000	0.000000	0.000000	0.000000	0.004796
ENE	0.000000	0.002626	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.002626
E	0.000000	0.001028	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.001028
ESE	0.000000	0.001599	0.000343	0.000000	0.000000	0.000000	0.000000	0.000000	0.001941
SE	0.000000	0.004111	0.001028	0.000000	0.000000	0.000000	0.000000	0.000000	0.005138
SSE	0.000000	0.006394	0.000685	0.000000	0.000000	0.000000	0.000000	0.000000	0.007079
S	0.000000	0.003425	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.003425
SSW	0.000000	0.009705	0.000457	0.000000	0.000000	0.000000	0.000000	0.000000	0.010162
SW	0.000000	0.004339	0.000114	0.000000	0.000000	0.000000	0.000000	0.000000	0.004453
WSW	0.000000	0.001028	0.001599	0.000000	0.000000	0.000000	0.000000	0.000000	0.002626
W	0.000000	0.000913	0.001028	0.000343	0.000000	0.000000	0.000000	0.000000	0.002284
WNW	0.000000	0.000228	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000228
NW	0.000000	0.000114	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000114
NNW	0.000000	0.001028	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.001028
N	0.000000	0.004681	0.000343	0.000228	0.000000	0.000000	0.000000	0.000000	0.005252
CALM									0.000000
TOTAL	0.000000	0.049326	0.009249	0.000685	0.000000	0.000000	0.000000	0.000000	0.059260

MEAN WIND SPEED (m/s) = 2.46
NUMBER OF OBSERVATIONS = 519

PASQUILL STABILITY CLASS 'F'

Wind Speed Class (m/s)

WIND SECTOR	0.50 TO 1.50	1.50 TO 3.00	3.00 TO 4.50	4.50 TO 6.00	6.00 TO 7.50	7.50 TO 9.00	9.00 TO 10.50	GREATER THAN 10.50	TOTAL
NNE	0.012788	0.009934	0.002055	0.000000	0.000000	0.000000	0.000000	0.000000	0.024777
NE	0.011418	0.007993	0.000457	0.000000	0.000000	0.000000	0.000000	0.000000	0.019868
ENE	0.004796	0.003197	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.007993
E	0.007422	0.003540	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.010961
ESE	0.008335	0.004225	0.000114	0.000000	0.000000	0.000000	0.000000	0.000000	0.012674
SE	0.010162	0.006508	0.000457	0.000000	0.000000	0.000000	0.000000	0.000000	0.017127
SSE	0.018269	0.008792	0.000343	0.000000	0.000000	0.000000	0.000000	0.000000	0.027404
S	0.012446	0.004453	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.016899
SSW	0.025120	0.019753	0.000457	0.000000	0.000000	0.000000	0.000000	0.000000	0.045330
SW	0.036195	0.012674	0.000114	0.000000	0.000000	0.000000	0.000000	0.000000	0.048984
WSW	0.014387	0.005823	0.000571	0.000000	0.000000	0.000000	0.000000	0.000000	0.020781
W	0.006851	0.005823	0.000343	0.000000	0.000000	0.000000	0.000000	0.000000	0.013017
WNW	0.012103	0.001827	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.013930
NW	0.019525	0.000457	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.019982
NNW	0.009135	0.001599	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.010733
N	0.015871	0.008221	0.000114	0.000000	0.000000	0.000000	0.000000	0.000000	0.024206
CALM									0.060973
TOTAL	0.224823	0.104818	0.005024	0.000000	0.000000	0.000000	0.000000	0.000000	0.395638

MEAN WIND SPEED (m/s) = 1.16
NUMBER OF OBSERVATIONS = 3465

ALL PASQUILL STABILITY CLASSES

Wind Speed Class (m/s)

WIND SECTOR	0.50 TO 1.50	1.50 TO 3.00	3.00 TO 4.50	4.50 TO 6.00	6.00 TO 7.50	7.50 TO 9.00	9.00 TO 10.50	GREATER THAN 10.50	TOTAL
NNE	0.021694	0.032199	0.025348	0.005823	0.000228	0.000000	0.000000	0.000000	0.085293
NE	0.020096	0.033683	0.031400	0.001028	0.000000	0.000000	0.000000	0.000000	0.086207
ENE	0.014158	0.026148	0.019982	0.000343	0.000000	0.000000	0.000000	0.000000	0.060630
E	0.013702	0.017241	0.007650	0.000114	0.000000	0.000000	0.000000	0.000000	0.038707
ESE	0.012902	0.021694	0.017698	0.001827	0.000000	0.000000	0.000000	0.000000	0.054122
SE	0.017812	0.022151	0.019982	0.002969	0.000000	0.000000	0.000000	0.000000	0.062914
SSE	0.030372	0.028660	0.008564	0.000571	0.000000	0.000000	0.000000	0.000000	0.068166
S	0.021580	0.021923	0.001256	0.000000	0.000000	0.000000	0.000000	0.000000	0.044759
SSW	0.040991	0.062000	0.004111	0.000000	0.000000	0.000000	0.000000	0.000000	0.107102
SW	0.056406	0.036310	0.004796	0.000228	0.000114	0.000000	0.000000	0.000000	0.097853
WSW	0.024206	0.014044	0.006052	0.001142	0.000457	0.000457	0.000000	0.000000	0.046358
W	0.013359	0.012446	0.006851	0.003311	0.001370	0.000228	0.000000	0.000000	0.037566
WNW	0.018041	0.004111	0.000457	0.000000	0.000000	0.000000	0.000000	0.000000	0.022608
NW	0.024435	0.003654	0.000457	0.000000	0.000000	0.000000	0.000000	0.000000	0.028545
NNW	0.016556	0.008335	0.000571	0.000000	0.000000	0.000000	0.000000	0.000000	0.025462
N	0.025006	0.023179	0.002626	0.000571	0.000000	0.000000	0.000000	0.000000	0.051382
CALM									0.082325
TOTAL	0.371318	0.367778	0.157799	0.017926	0.002169	0.000685	0.000000	0.000000	1.000000

MEAN WIND SPEED (m/s) = 1.86
NUMBER OF OBSERVATIONS = 8758

FREQUENCY OF OCCURENCE OF STABILITY CLASSES

- A : 3.6%
- B : 13.8%
- C : 16.7%
- D : 20.5%
- E : 5.9%
- F : 39.6%

STABILITY CLASS BY HOUR OF DAY

Hour	A	B	C	D	E	F
01	0000	0000	0000	0031	0033	0301
02	0000	0000	0000	0036	0025	0304
03	0000	0000	0000	0046	0021	0298
04	0000	0000	0000	0037	0037	0291
05	0000	0000	0000	0031	0027	0307
06	0000	0000	0099	0043	0023	0200
07	0000	0039	0174	0081	0011	0060
08	0000	0093	0189	0083	0000	0000
09	0022	0117	0138	0088	0000	0000
10	0037	0141	0099	0088	0000	0000
11	0086	0147	0066	0066	0000	0000
12	0083	0143	0068	0071	0000	0000
13	0056	0171	0069	0069	0000	0000
14	0026	0168	0094	0077	0000	0000
15	0002	0111	0134	0118	0000	0000
16	0000	0065	0173	0127	0000	0000
17	0000	0011	0129	0225	0000	0000
18	0000	0000	0027	0208	0023	0107
19	0000	0000	0003	0094	0059	0209
20	0000	0000	0000	0039	0070	0256
21	0000	0000	0000	0039	0055	0271
22	0000	0000	0000	0029	0053	0283
23	0000	0000	0000	0034	0046	0284
24	0000	0000	0000	0034	0036	0294

STABILITY CLASS BY MIXING HEIGHT

Mixing height	A	B	C	D	E	F
<=500 m	0001	0082	0467	0613	0427	3455
<=1000 m	0048	0259	0410	0760	0086	0010
<=1500 m	0202	0726	0480	0361	0006	0000
<=2000 m	0060	0130	0101	0050	0000	0000
<=3000 m	0001	0009	0004	0010	0000	0000
>3000 m	0000	0000	0000	0000	0000	0000

MIXING HEIGHT BY HOUR OF DAY

Hour	0000 to 0100	0100 to 0200	0200 to 0400	0400 to 0800	0800 to 1600	1600 to 3200	Greater than 3200
01	0278	0037	0038	0011	0000	0001	0000
02	0286	0037	0031	0009	0001	0001	0000
03	0283	0042	0030	0007	0002	0001	0000
04	0270	0061	0026	0007	0000	0001	0000
05	0295	0038	0023	0007	0001	0001	0000
06	0238	0056	0055	0012	0003	0001	0000
07	0109	0048	0101	0091	0016	0000	0000
08	0000	0038	0091	0152	0083	0001	0000
09	0000	0000	0048	0114	0201	0002	0000
10	0000	0000	0015	0109	0236	0005	0000
11	0000	0000	0005	0071	0277	0012	0000
12	0000	0000	0002	0050	0292	0021	0000
13	0000	0000	0001	0039	0295	0030	0000
14	0000	0000	0001	0030	0292	0042	0000
15	0000	0000	0001	0035	0290	0039	0000
16	0000	0000	0005	0057	0272	0031	0000
17	0011	0011	0028	0102	0199	0014	0000
18	0081	0024	0056	0101	0101	0002	0000
19	0139	0039	0081	0087	0017	0002	0000
20	0176	0047	0078	0055	0008	0001	0000
21	0214	0039	0071	0035	0006	0000	0000
22	0236	0043	0057	0027	0002	0000	0000
23	0247	0050	0047	0018	0002	0000	0000
24	0270	0036	0039	0018	0001	0000	0000

APPENDIX C
VEHICLE EMISSION ESTIMATES

APPENDIX C
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 Queensland 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 Queensland fleet. Queensland vehicles are, on average, 9.8 years old compared with the national average of 10.1 years old (**ABS, 2006**). **Table C1** summarises the Queensland vehicle distribution by age.

Table C1 : Queensland vehicle distribution by age category

Year of manufacture	Total vehicles
To 1990	645,010
1991-1995	528,620
1996-2000	717,507
2001-2005	970,174
2006(a)	29,579
Not stated	6,977
TOTAL	2,897,867

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**).

Table C2 provides a comparison of emissions generated using the adopted PIARC methodology with those generated as part of the South-east Queensland region Air Emissions Inventory. It can be seen that CO emissions are lower than the SEQ Air Emissions Inventory data for current years (say 2000 and 2005) but slightly higher for future (2011) years. Both the NO_x and PM_{10} emission estimates are very close for 2000 and 2005, with the PIARC methodology yielding higher estimates in 2011.

Table C2 : Comparison of SEQ emissions and PIARC

SEQ Emissions Inventory (Box C4) Vehicle running mode at average speed of 50 km/h				Calculated emissions using PIARC (g/v-mi)			
QLD 2000							
Year 2000	CO	NO_x	PM_{10}	Speed	CO	NO_x	PM_{10}
g/mi	16.37	3.01	0.12	50	9.91	2.87	0.16
QLD 2005							
Year 2005	CO	NO_x	PM_{10}	Speed	CO	NO_x	PM_{10}
g/mi	10.27	2.43	0.10	50	9.21	2.64	0.13
QLD 2011							
Year 2011	CO	NO_x	PM_{10}	Speed	CO	NO_x	PM_{10}
g/mi	5.54	1.58	0.07	50	8.66	2.35	0.11

The typical flow profile of traffic is shown by **Table C3** below. These data have been used as the basis for determining a hourly breakdown of petrol cars, diesel cars and heavy diesel vehicles for each road section examined, given the daily total traffic and daily heavy traffic.

Table C3 : Typical flow profile of traffic

Hour of day	Percentage of all vehicles in the day	Percentage of heavy vehicles in the day
1	0.4%	0.4%
2	0.3%	0.4%
3	0.3%	0.4%
4	0.3%	0.5%
5	0.6%	0.9%
6	2.1%	2.8%
7	4.8%	6.7%
8	7.2%	7.6%
9	7.2%	7.6%
10	5.9%	8.1%
11	5.6%	8.0%
12	5.6%	7.7%
13	5.8%	7.6%
14	5.8%	7.5%
15	6.5%	7.8%
16	7.4%	7.5%
17	7.8%	4.1%
18	7.8%	4.1%
19	6.1%	3.4%
20	4.0%	2.1%
21	3.0%	1.7%
22	2.6%	1.4%
23	1.9%	1.1%
24	1.2%	0.8%

Table C4 shows the tunnel grade details that were used for the ventilation outlet emission calculations.

Table C4 : Tunnel grade information used for ventilation outlet emission calculations

NB - Main tunnel (south to north)				NB - Frederick St entry				NB - Kelvin Grove Rd exit			
Start	End	Length (m)	Grade %	Start	End	Length (m)	Grade %	Start	End	Length (m)	Grade %
856	1676	820	-3.6	450	917	467	-3.6	0	128	128	4.7
1676	3241	1565	-1.1	917	1310	393	-6.8	128	800	672	7
3241	4099	858	2.5	1310	1465	155	-1.1	800	900	100	3
4099	4512	413	5								
4512	5141	629	1.7								
5141	5400	259	4.6								
SB - Main tunnel (north to south)				SB - Frederick St exit				NB - Kelvin Grove Rd entry			
Start	End	Length (m)	Grade %	Start	End	Length (m)	Grade %	Start	End	Length (m)	Grade %
5760	5162	598	1.2	0	186	186	1	60	162	102	-2
5162	4522	640	-1.5	186	500	314	7	162	923	761	-7
4522	4100	422	-5	500	890	390	3.8	923	1056	133	-3.5
4100	3243	857	-2.5								
3243	1700	1543	1.1								
1700	858	842	3.5								

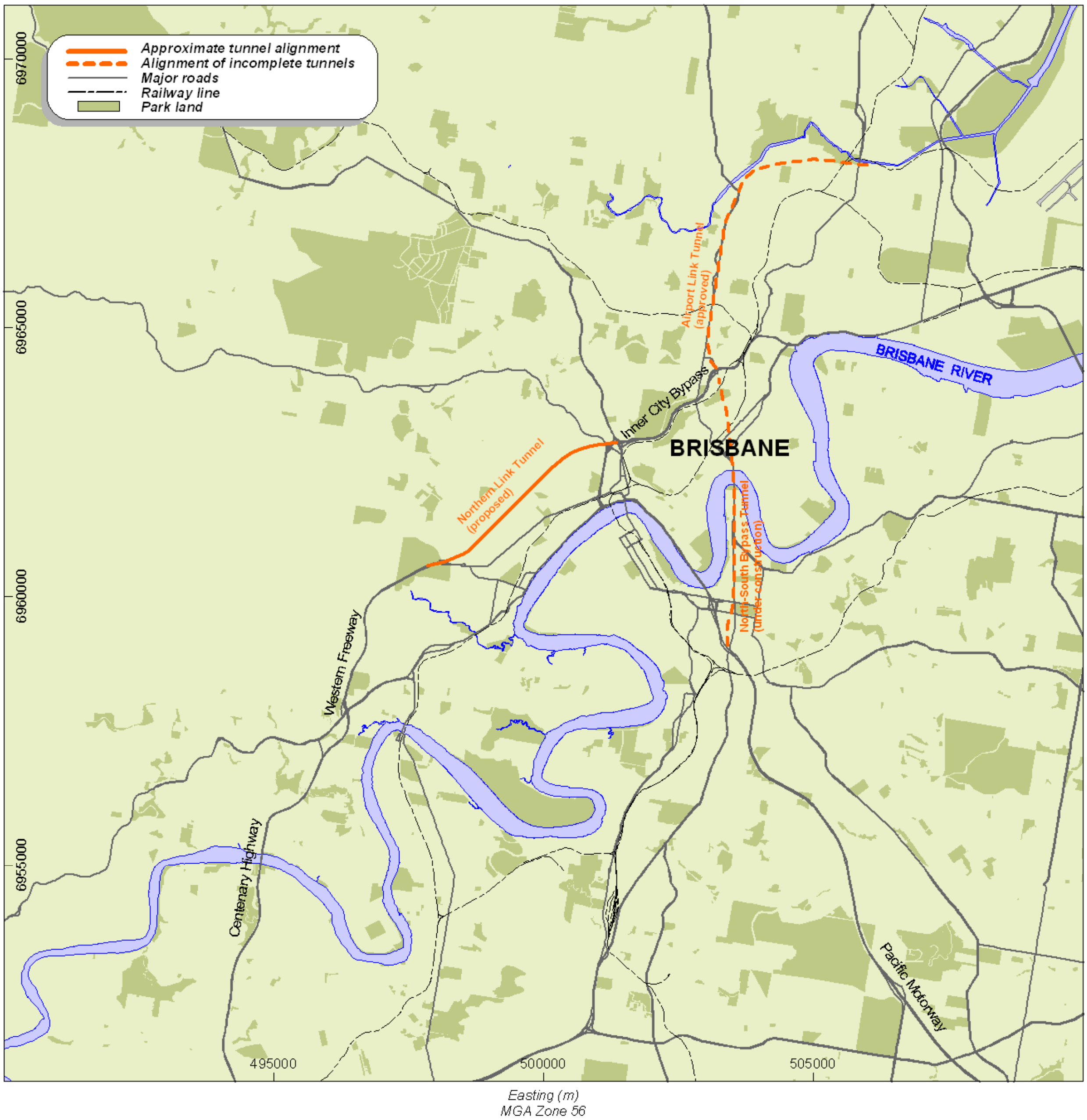
Table C5 shows the sources associated to each road section (also refer to **Figure 24** of main report).

Table C5 : Surface road source allocation for the CALPUFF modelling

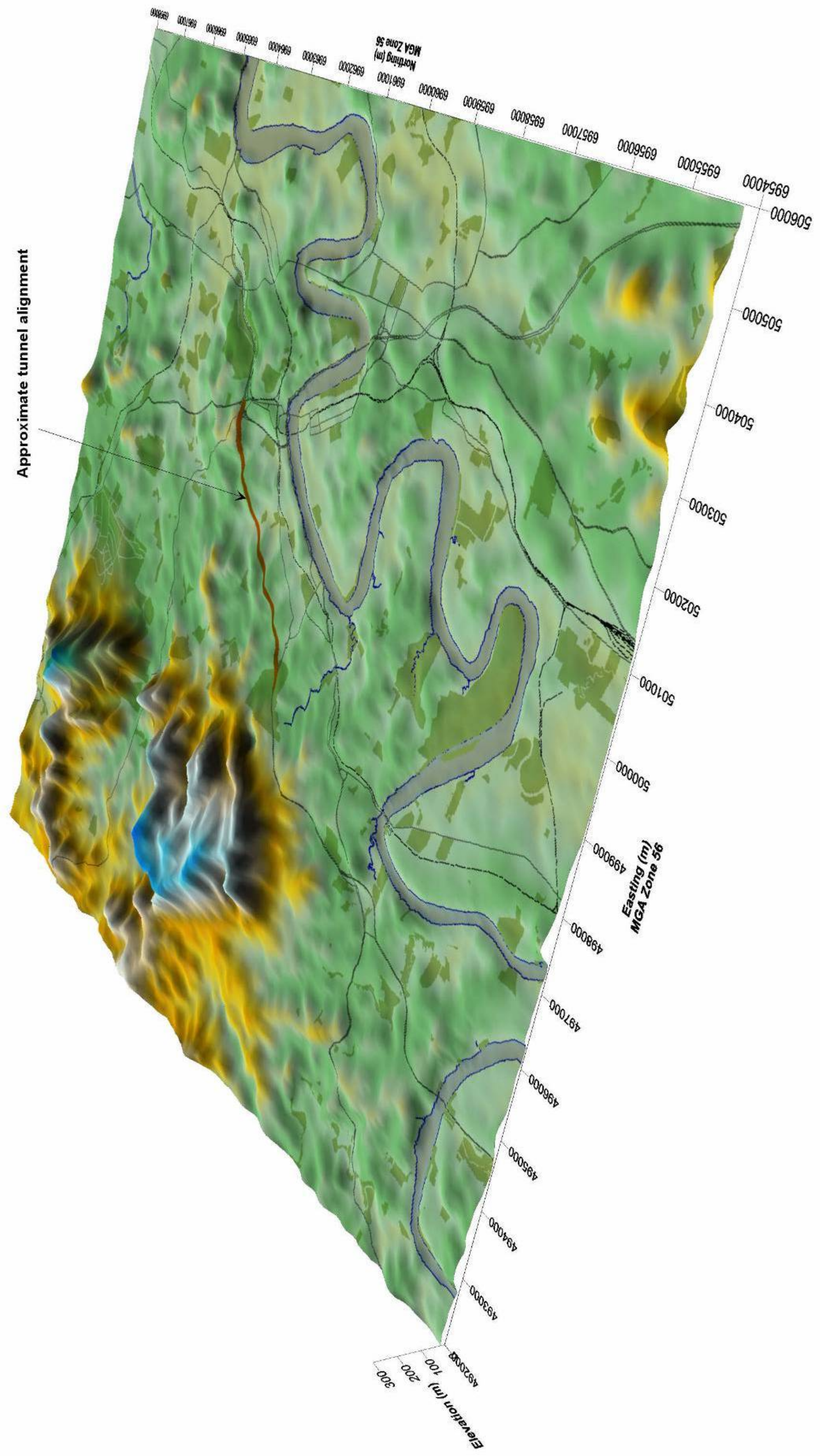
Section Name	Sources associated with this section (refer **Figure 24**)							
Waterworks Road (W of Payne)	257	258	259					
Waterworks Road (W of Coopers)	253	254	255	256				
Waterworks Road (west of Jubilee Street)	236	250	251	252				
Stuart Road	236	237	238	239	260			
Ashgrove Ave	159	245	246	247	248	249		
Boundary St	125	126	127	128	129	132		
Kelvin Grove Road (north of Herston Road)	158	159	160	161	162	163		
New Market Road	143	153	154	155	156	157	158	
Herston Road	147	148	149	150	151	152		
Bowen Bridge Road (north of Herston Road)	142	143	144	145	146			
Innercity Bypass (west of Bowen Bridge Road)	137	138	139	140	141			
Abbortsford Road (north of innercity Bypass)	66	67	68					
Kingsfordsmith Drive (west of Nugee Road)	66	69	70	71	72			
Breakfast Creek Road	73	74	75	76	77	78	79	
Abbortsford Road (south of innercity Bypass)	60	61	62	63	64	65	66	
Montpelier Road	64	76	135					
Brunswick Street (west of St Pauls Terrace)	59	60	136	137				
Water Street	127	133	134	136				
Commercial Road	77	268	269	270				
James Street	79	80	81	82	83			
Ann Street (near Queen Street)	59	124	125					
Ann Street (near George Street)	31	122	123	124				
Innercity Bypass (west of Kelvin Grove Road	137	164	165	166	167	168		
Countess Street	29	130	131	132				
Hale Street	28	29	30	31	168	169	170	
Waterworks Road (near Ennorgera Terrace)	168	236	240	241	242	243	244	245
Given Terrace	171	172	173					

Section Name	Sources associated with this section (refer **Figure 24**)								
Latrobe Terrace	174	175	176						
Jubilee Terrace	232	233	234	235	236				
Simpson Road	226	227	228	229	230	231	232		
Mount Cootha Road	220	221	222	223	224	225			
Boundary Street (north of Baroona Road)	176	183	261	262	263	264			
Milton Road (west of Baroona Road)	177	178	179	180	181	182	183		
Coronation Drive (east of Park Road)	19	20	21	22	23	24	25	26	27	28
Miskin Road (south of Mount Cootha Road)	19	183	265	266	267				
Western Freeway (south of Mt Coo Tha Road)	212	213	214	215	216	217	218	219	220
Western Freeway (S of Moggill)	206	207	208	209	210	211			
Moggill Road (east of Marshall lane)	5	6	7	8	9	10	11		
Moggill Road (S of Kenmore)	1	2	3	4					
Walter Taylor Bridge	198	199	200	201	202	203	204	205	
Moggill Road (near Payne Street)	12	13	14	15	16	17	18	19	
Swann Road (west of Withmore Street)	194	195	196	197					
Hawken Drive	189	190	191	192	193	194			
Sir Fed Schonnell Drive	21	184	185	186	187	188			
Bradfield Highway (Bridge)	55	56	57	58					
Shafston Ave	55	87	88	89					
Wynnum Road	84	85	86						
Pacific Mwy (N of Ipswich)	31	32	33	34	35	36	37	38	39
Main St	39	50	51	52	53	54			
Logan Road	50	90	91	92					
SE Freeway (north of Okeefe St)	39	40	41	42	43	44			
Gladstone Road	105	115	116	117	118	119	120	121	
Ipswich Road (north of Cornwell)	39	45	46	47	48	49			
Fairfiled Road (south of Kadumba Street)	93	94	95	96	97	98			
Annerly Road (near Park Road)	99	100	101	102	103	104			
Gladstone Road	29	104	105	106	107	108			
Montague Road	108	109	110	111	112	113	114		

FIGURES



Location of study area and proposed Northern Link Tunnel



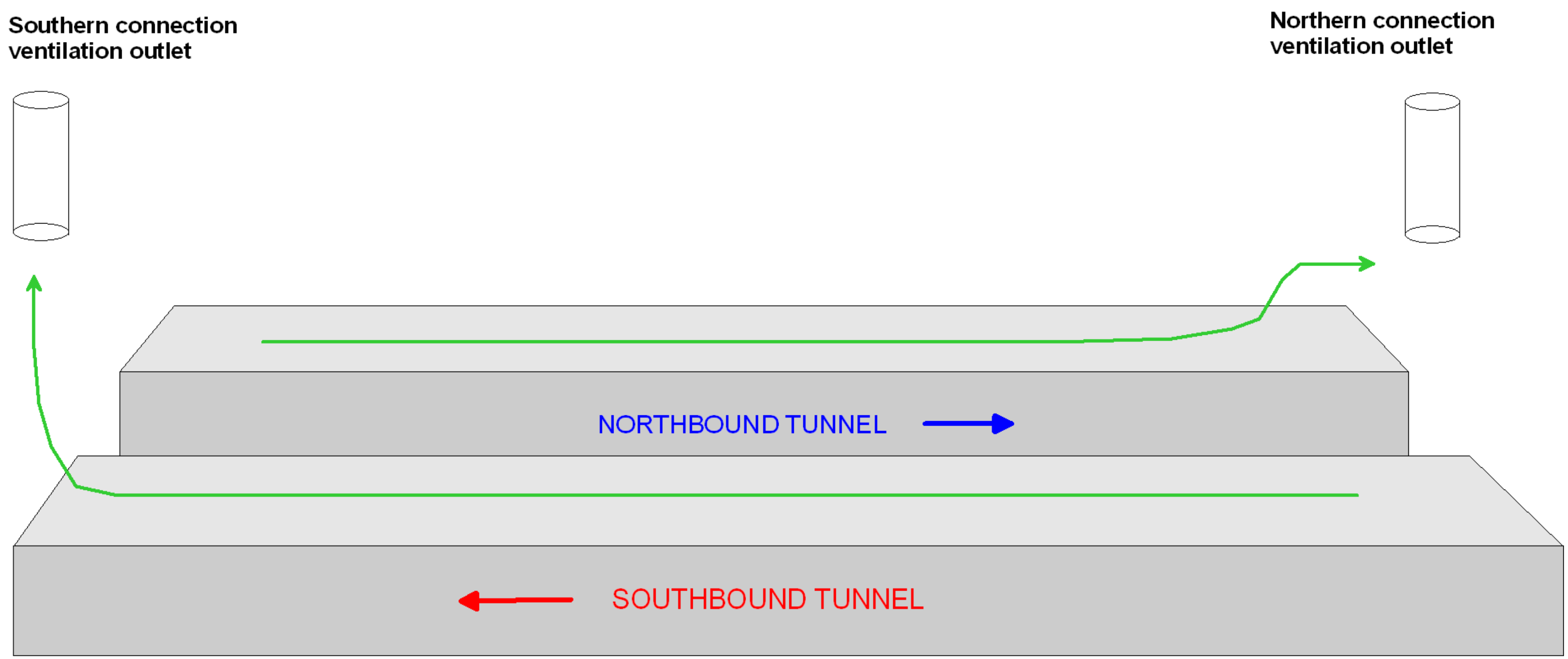
Pseudo three-dimensional representation of the study area

FIGURE 2

Northern Connection

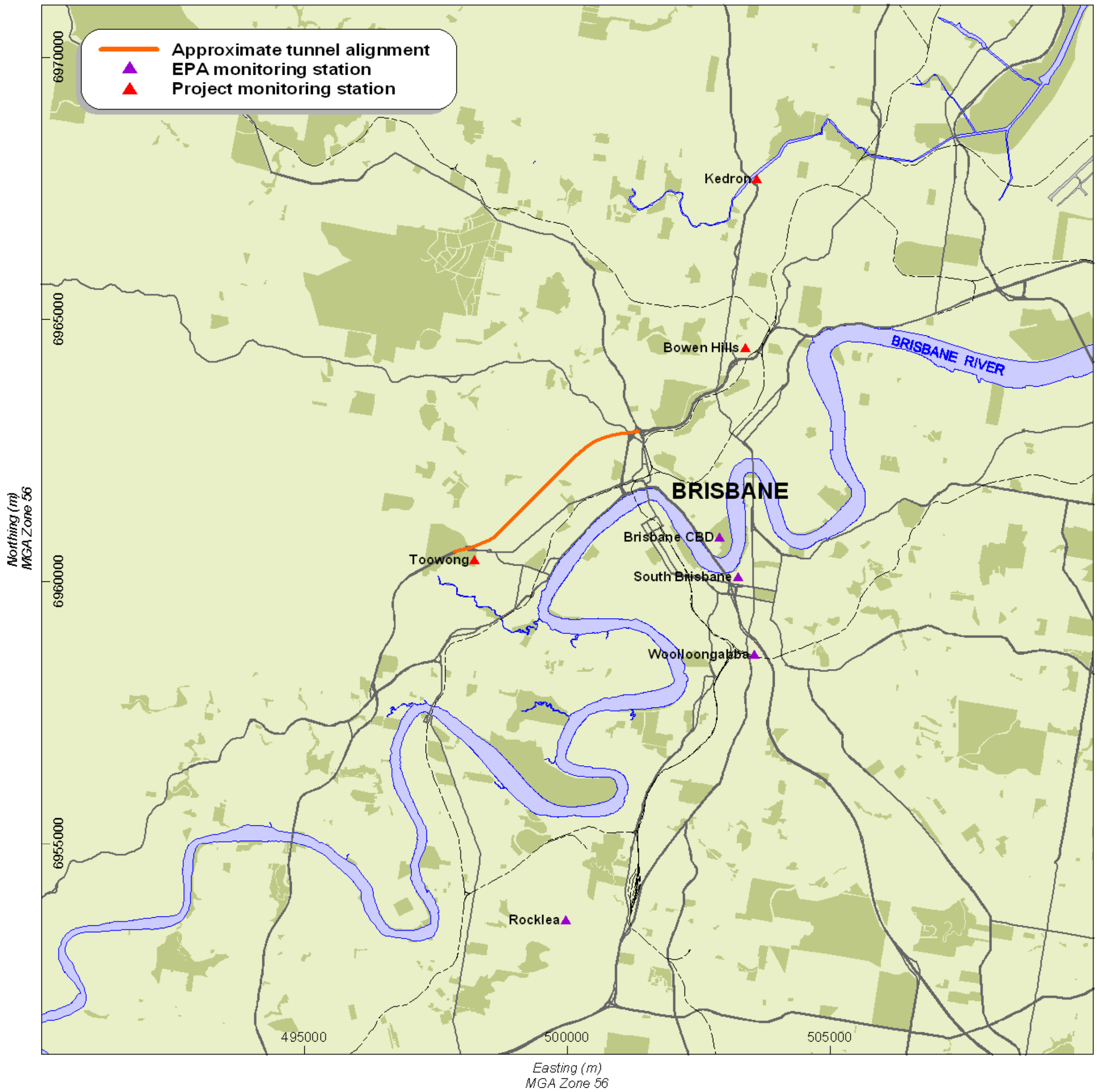
Southern Connection

Location of preferred tunnel ventilation outlets



Schematic of air movements in the tunnel

FIGURE 4



Meteorological and ambient air quality monitoring locations

Annual windroses for EPA monitoring sites between 2004 and 2006

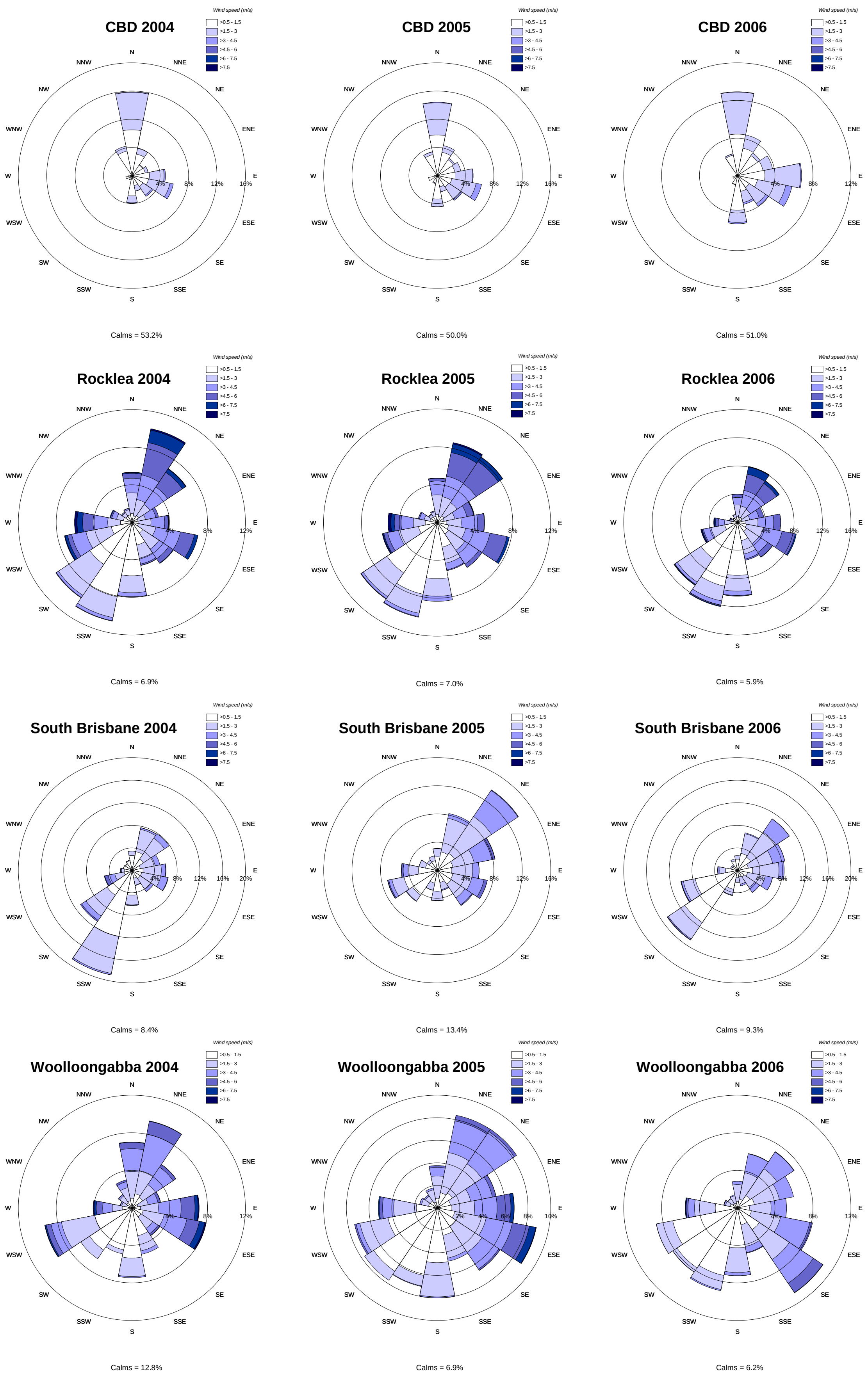
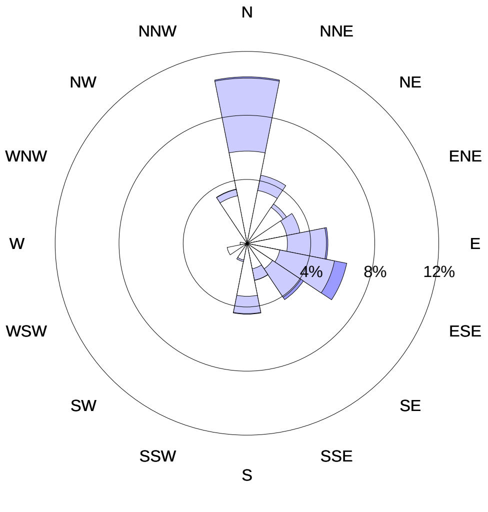
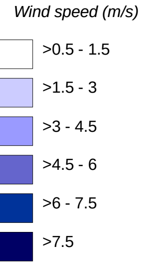


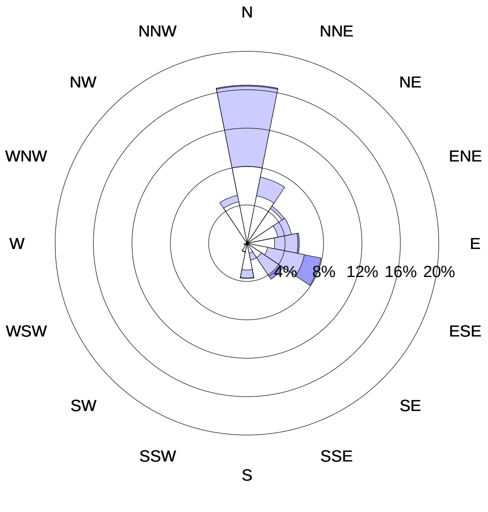
FIGURE 6

Annual and seasonal windroses for Brisbane CBD (2005)

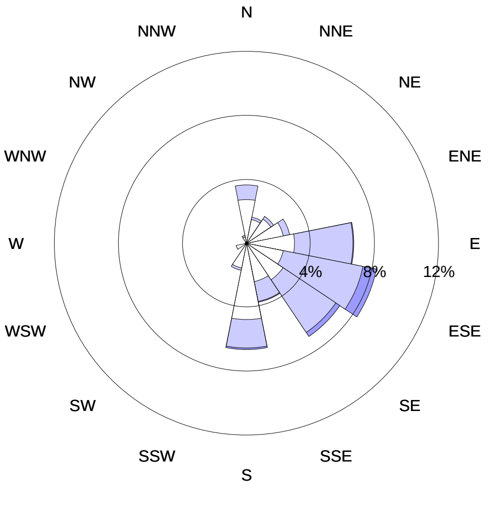


Annual
Calms = 50.0%

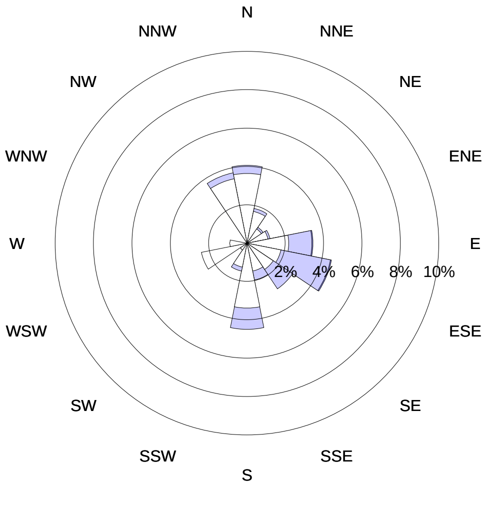




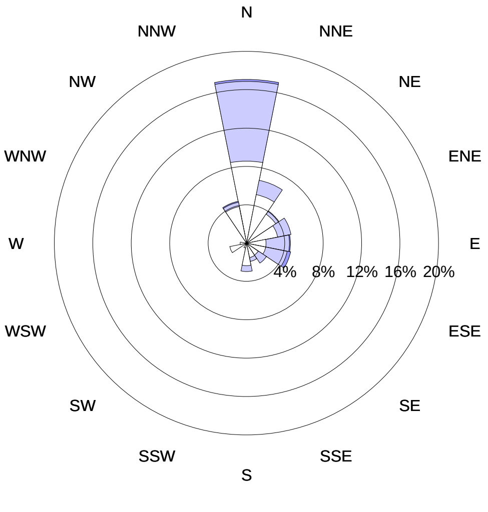
Summer
Calms = 37.5%



Autumn
Calms = 54.4%



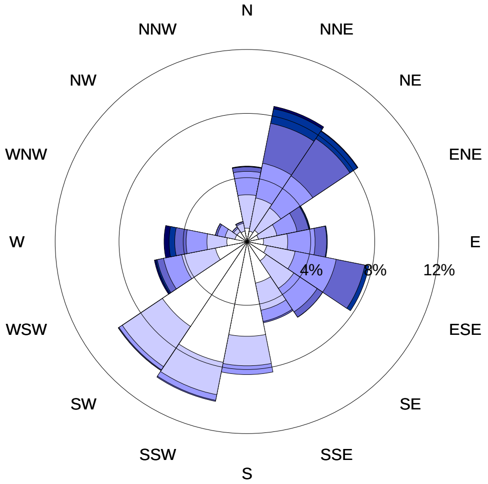
Winter
Calms = 65.7%



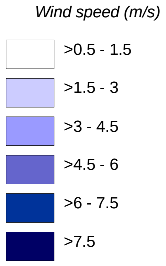
Spring
Calms = 43.2%

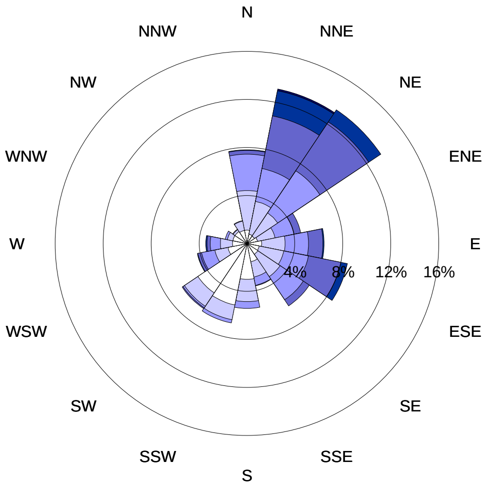
FIGURE 7

Annual and seasonal windroses for Rocklea (2005)

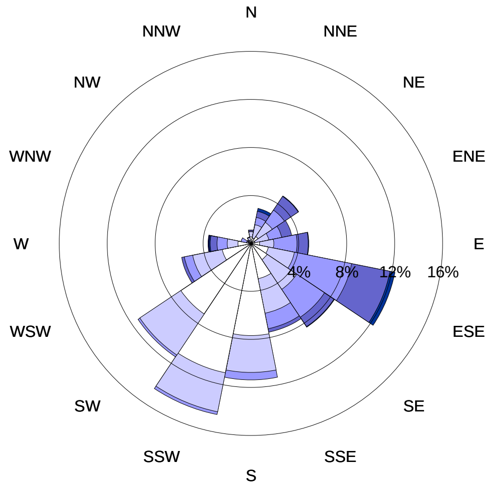


Annual
Calms = 7.0%

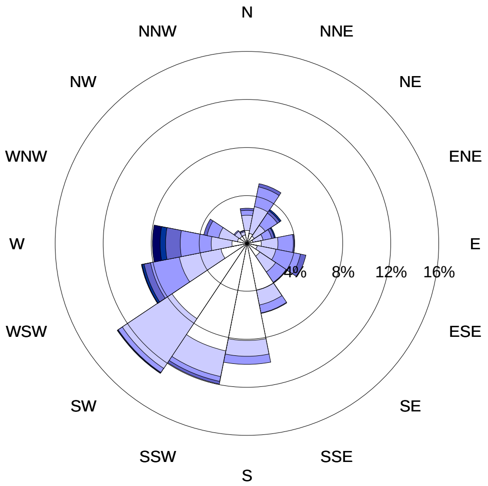




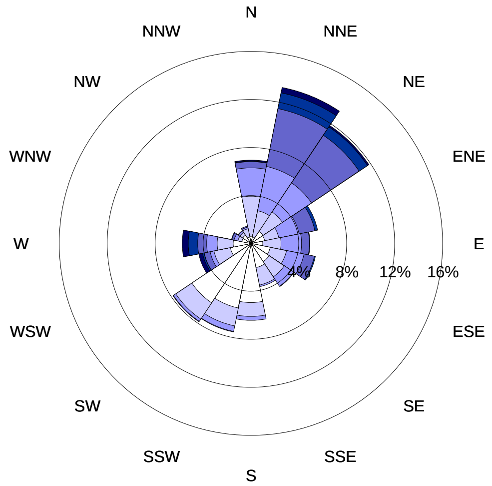
Summer
Calms = 4.8%



Autumn
Calms = 6.2%



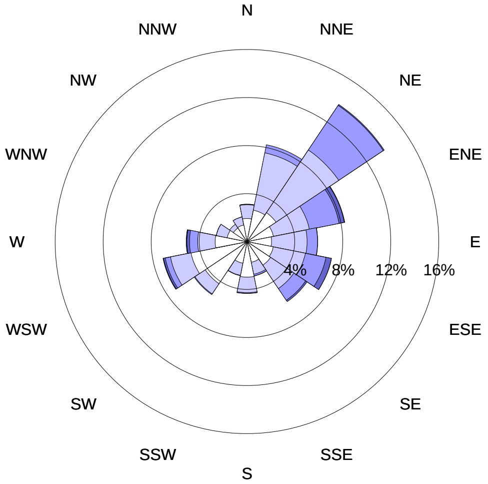
Winter
Calms = 9.4%



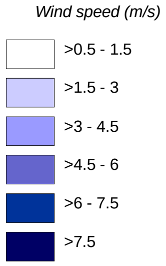
Spring
Calms = 7.6%

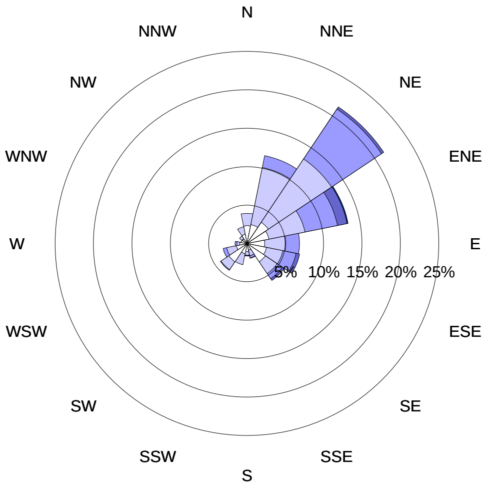
FIGURE 8

Annual and seasonal windroses for South Brisbane (2005)

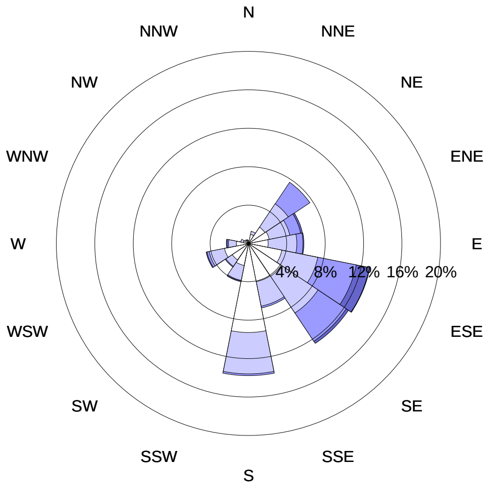


Annual
Calms = 13.4%

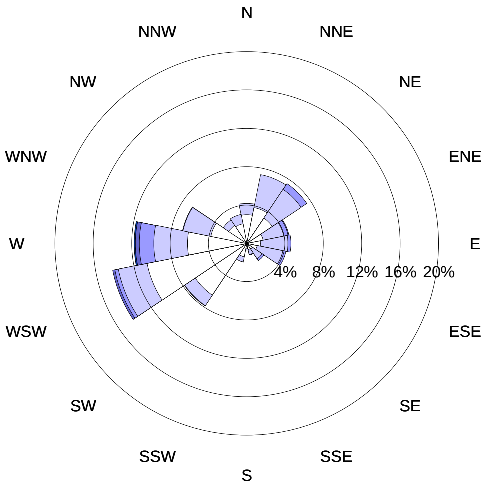




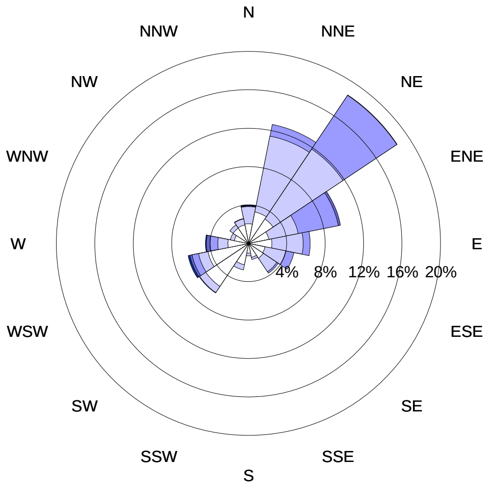
Summer
Calms = 10.5%



Autumn
Calms = 17.8%



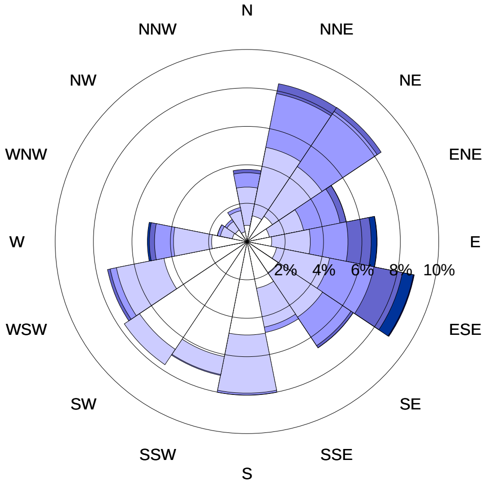
Winter
Calms = 15.1%



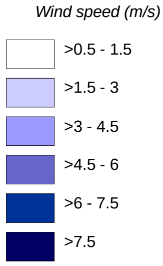
Spring
Calms = 10.3%

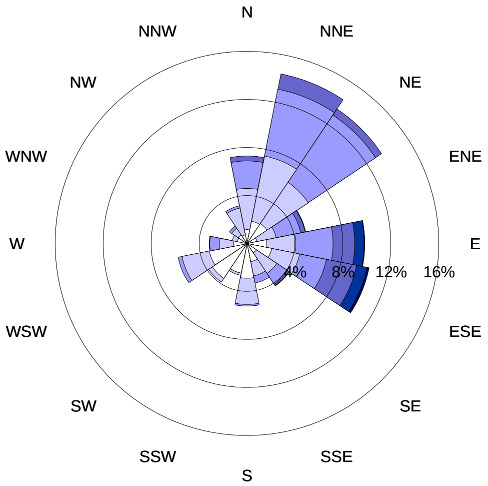
FIGURE 9

Annual and seasonal windroses for Woolloongabba (2005)

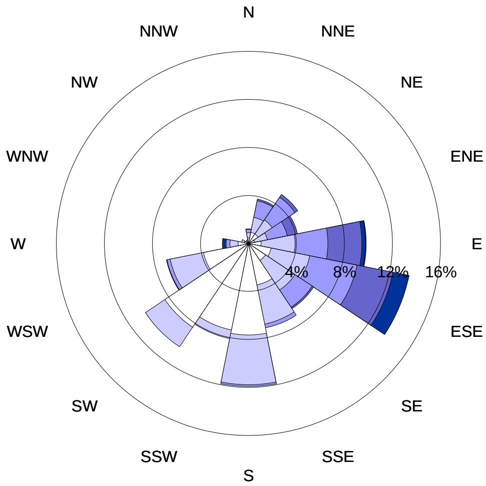


Annual
Calms = 6.9%

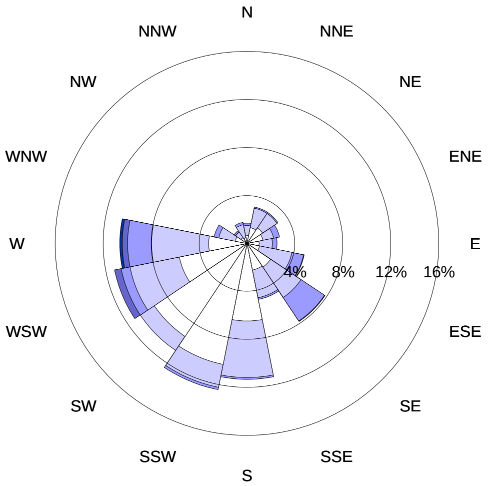




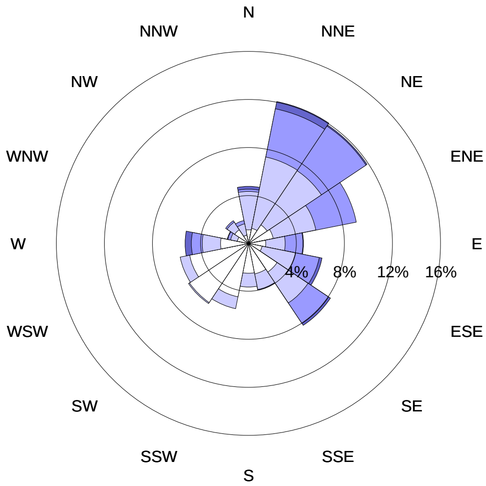
Summer
Calms = 5.1%



Autumn
Calms = 8.2%



Winter
Calms = 7.3%



Spring
Calms = 7.0%

FIGURE 10

Annual and seasonal windroses for Bowen Hills (2005)

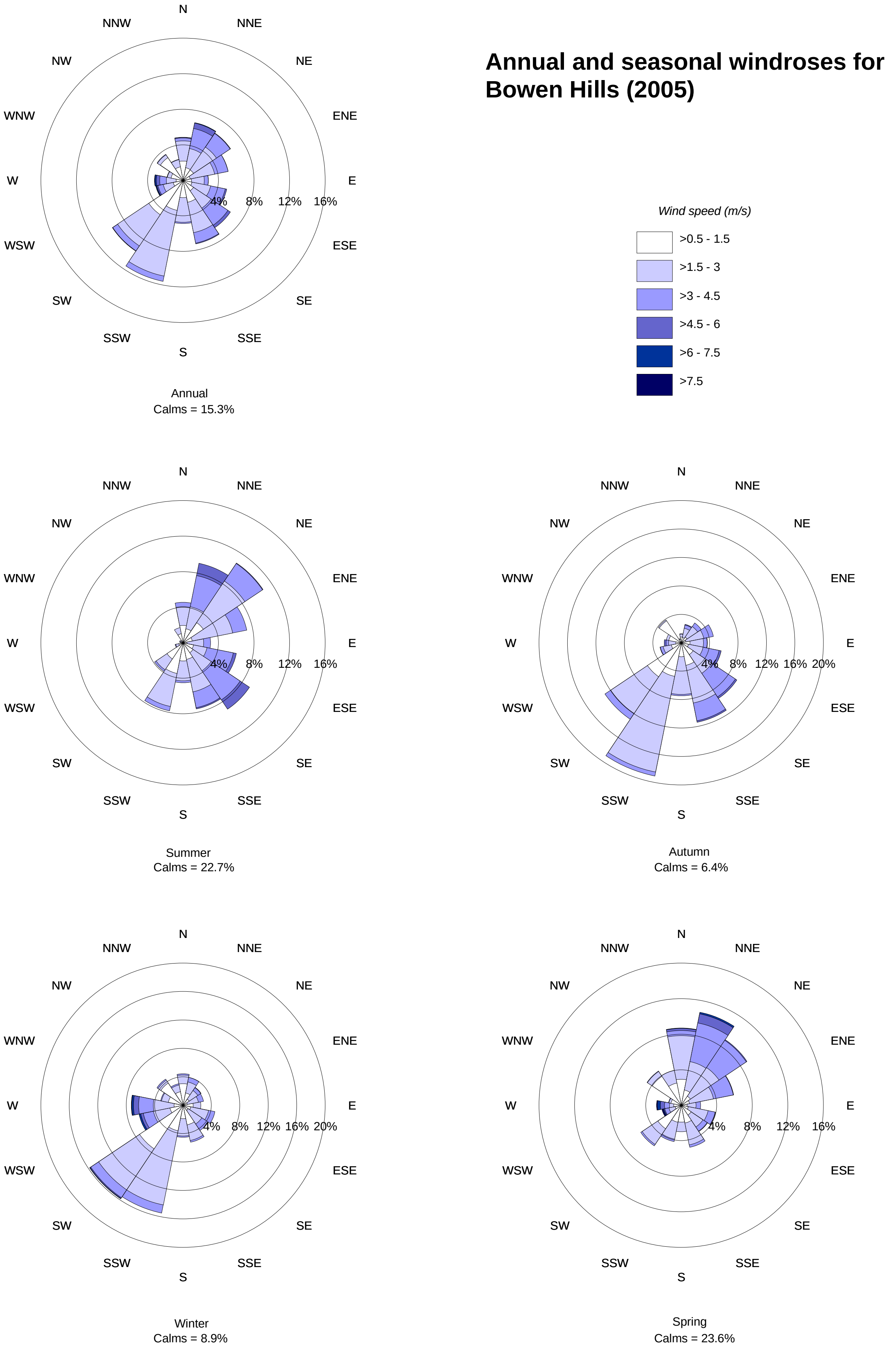
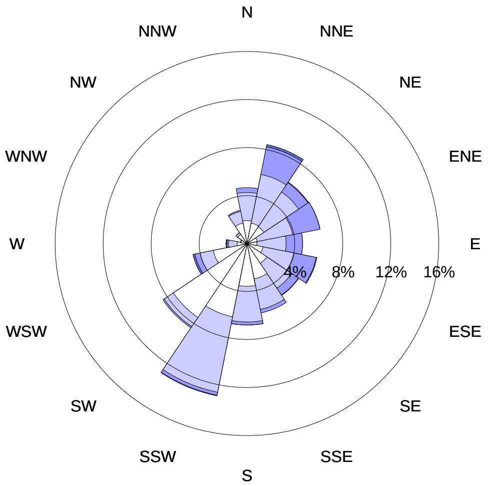
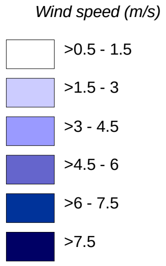


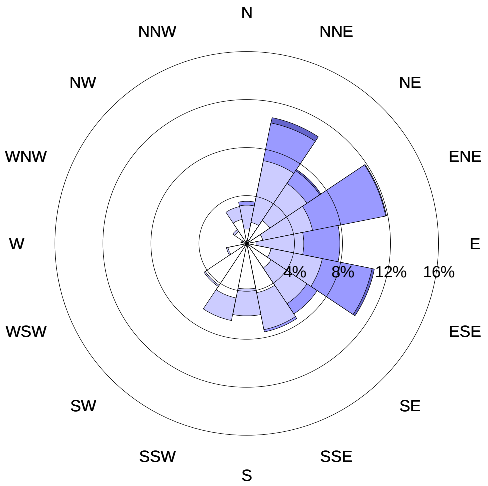
FIGURE 11

Annual and seasonal windroses for Kedron (2006)

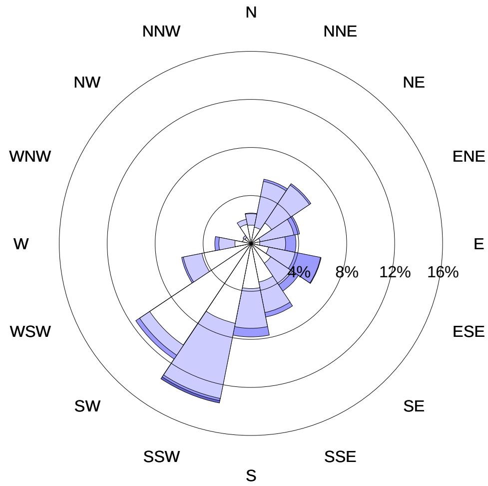


Annual
Calms = 13.9%

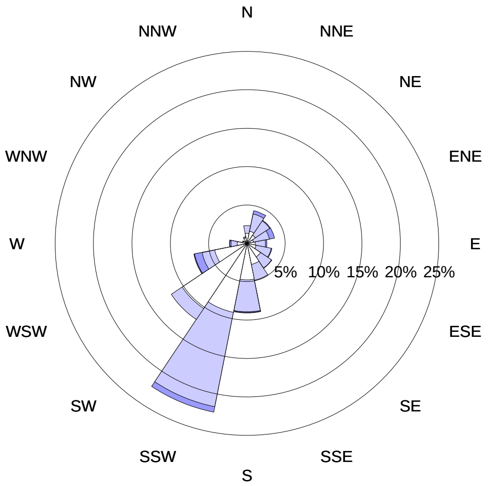




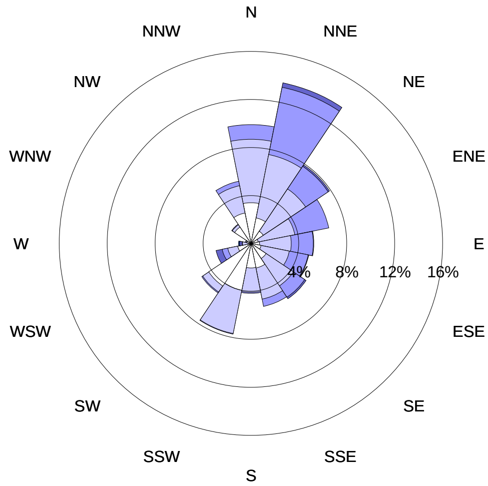
Summer
Calms = 9.4%



Autumn
Calms = 15.8%

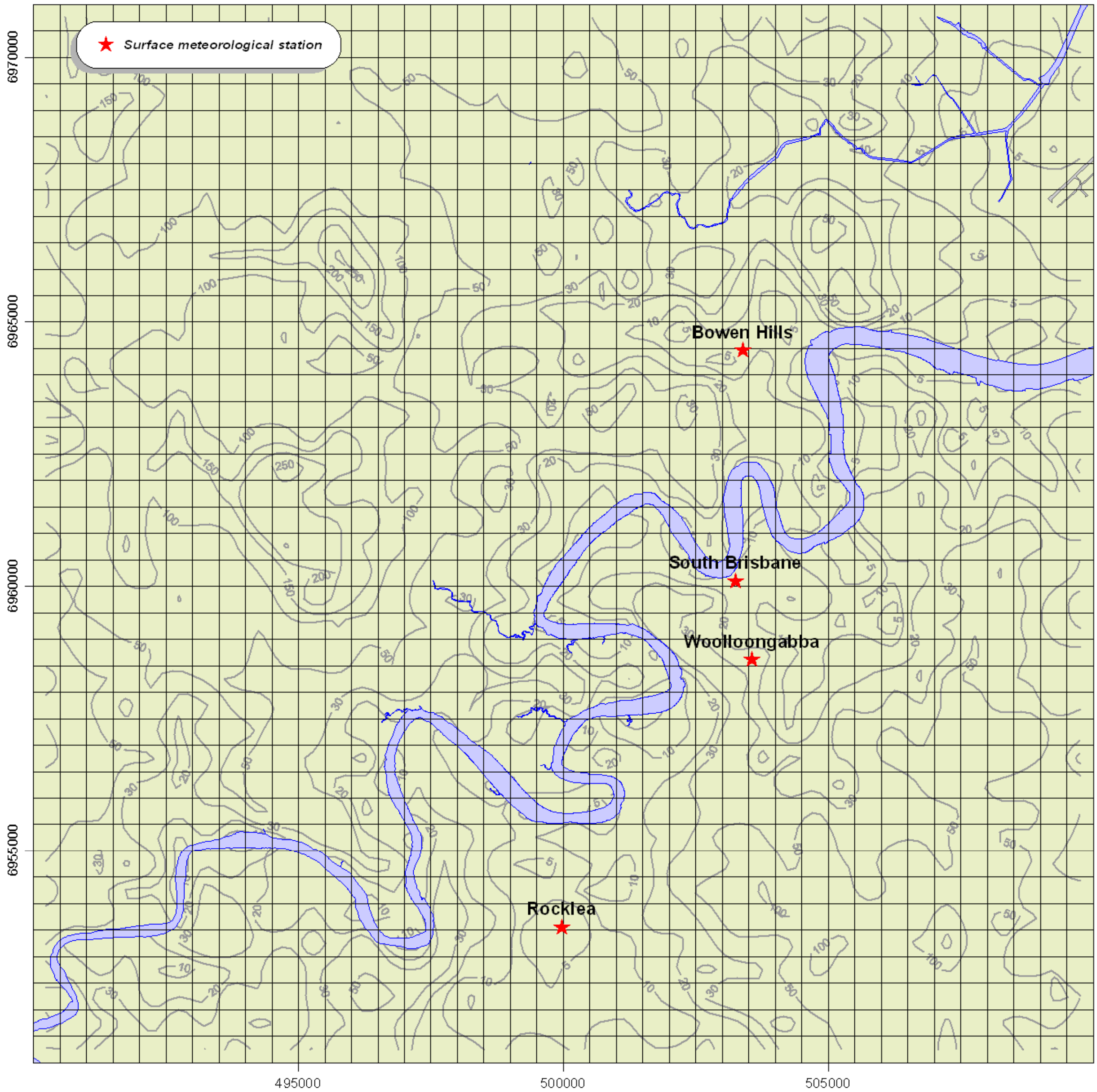


Winter
Calms = 16.9%

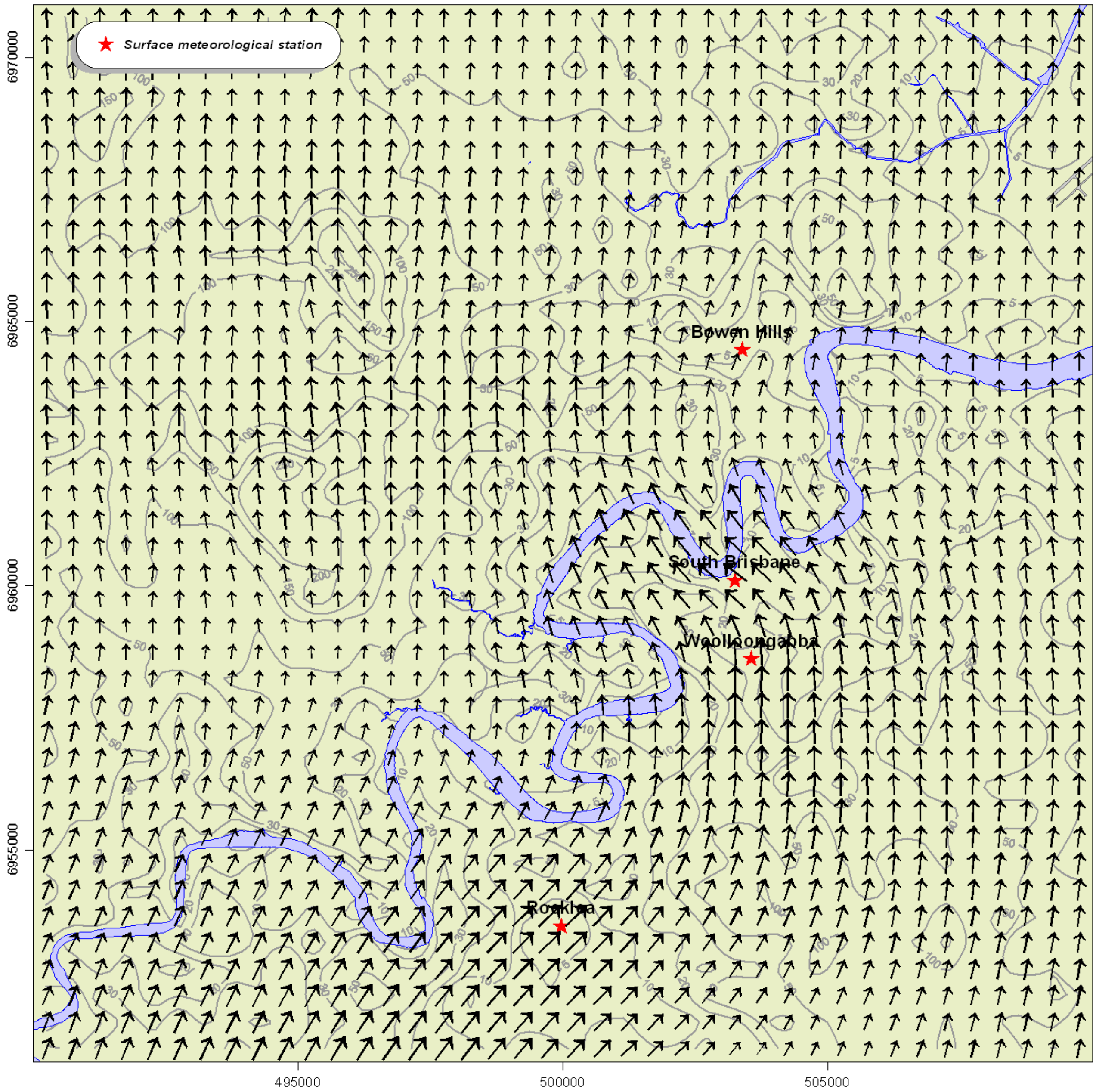


Spring
Calms = 12.5%

FIGURE 12



CALMET model grid, meteorological stations and terrain information



Example of ground-level wind patterns as simulated by CALMET (1 March 2005 hour 1)

Measured CO concentrations in the Brisbane region

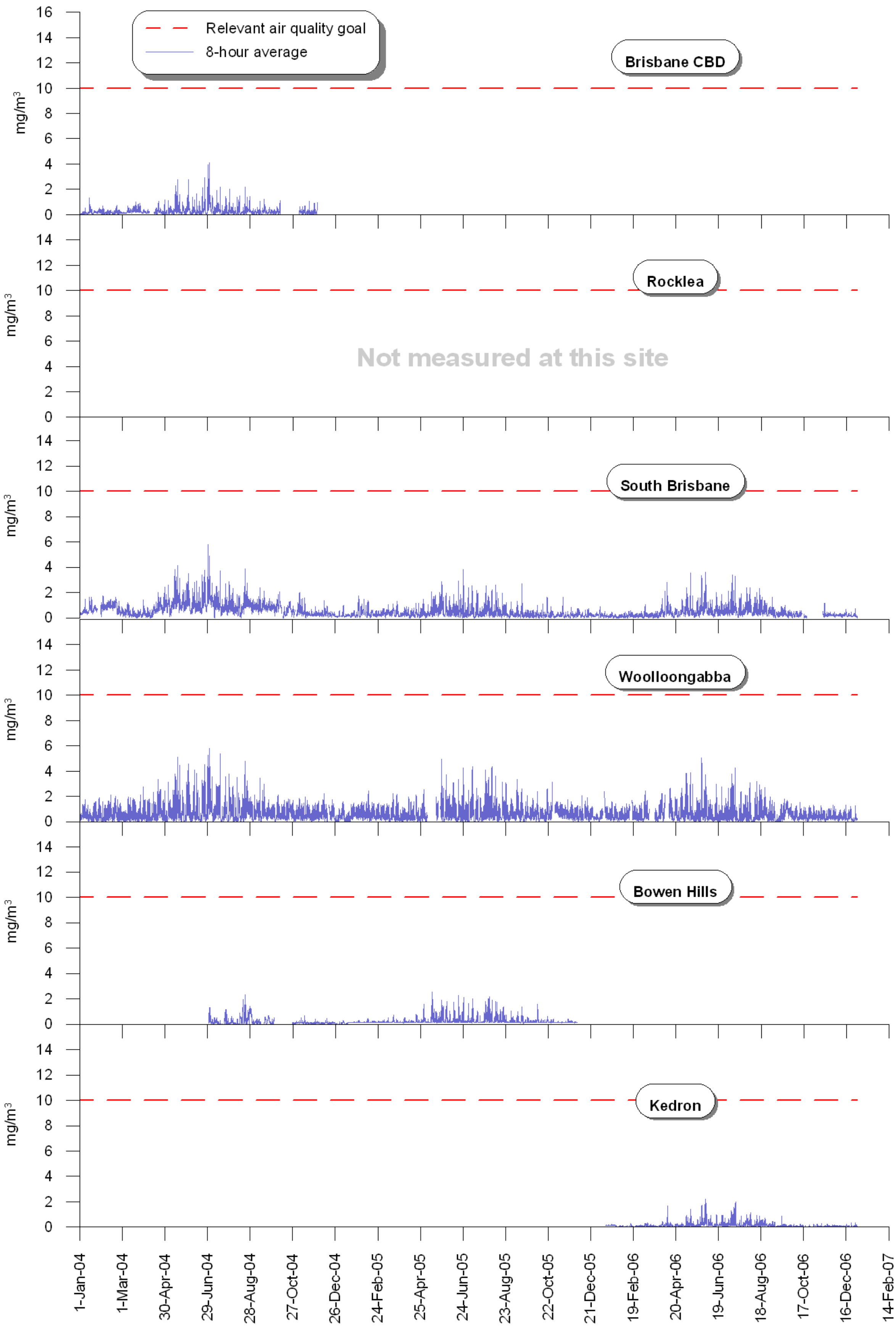


FIGURE 15

Measured NO_2 concentrations in the Brisbane region

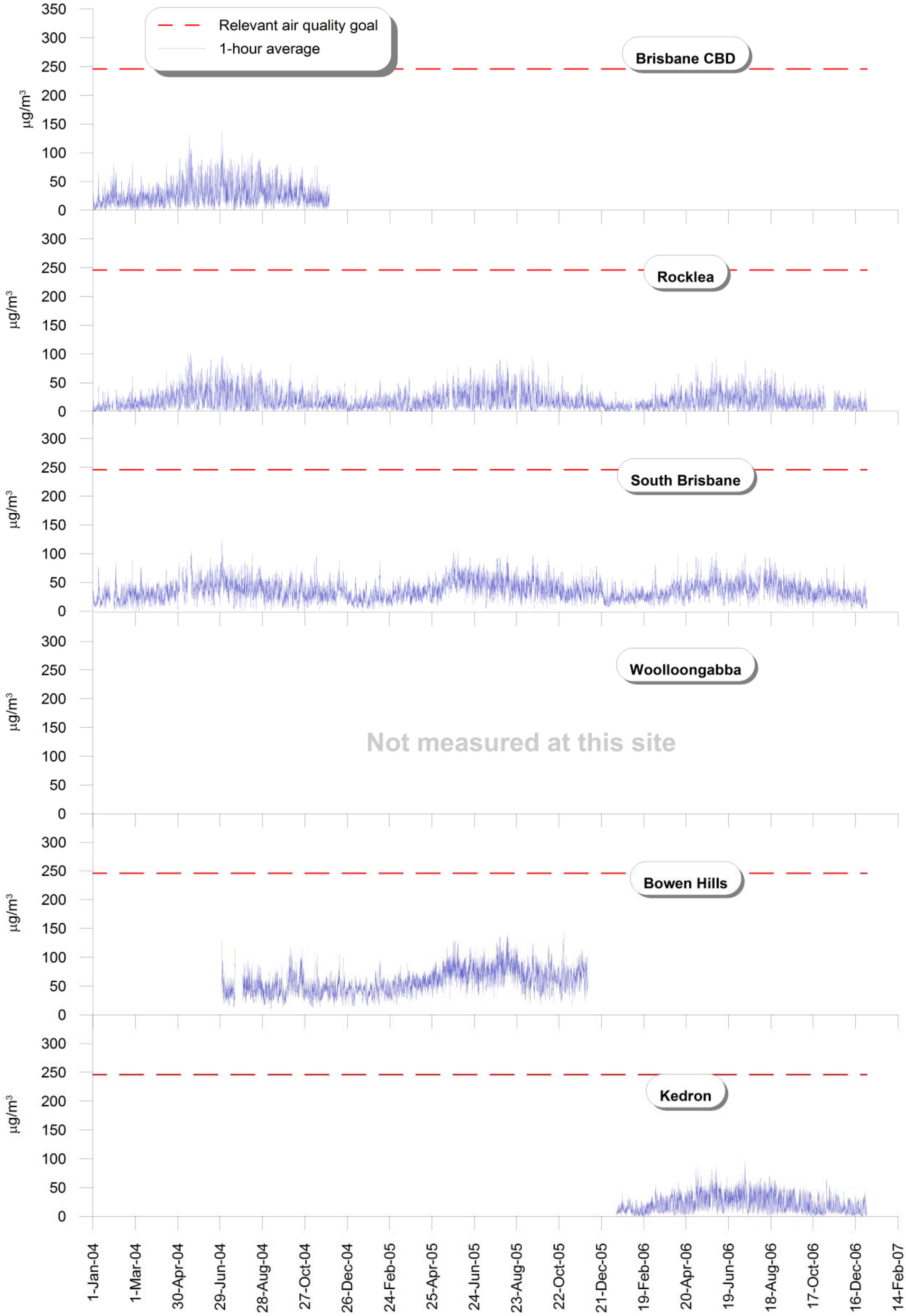
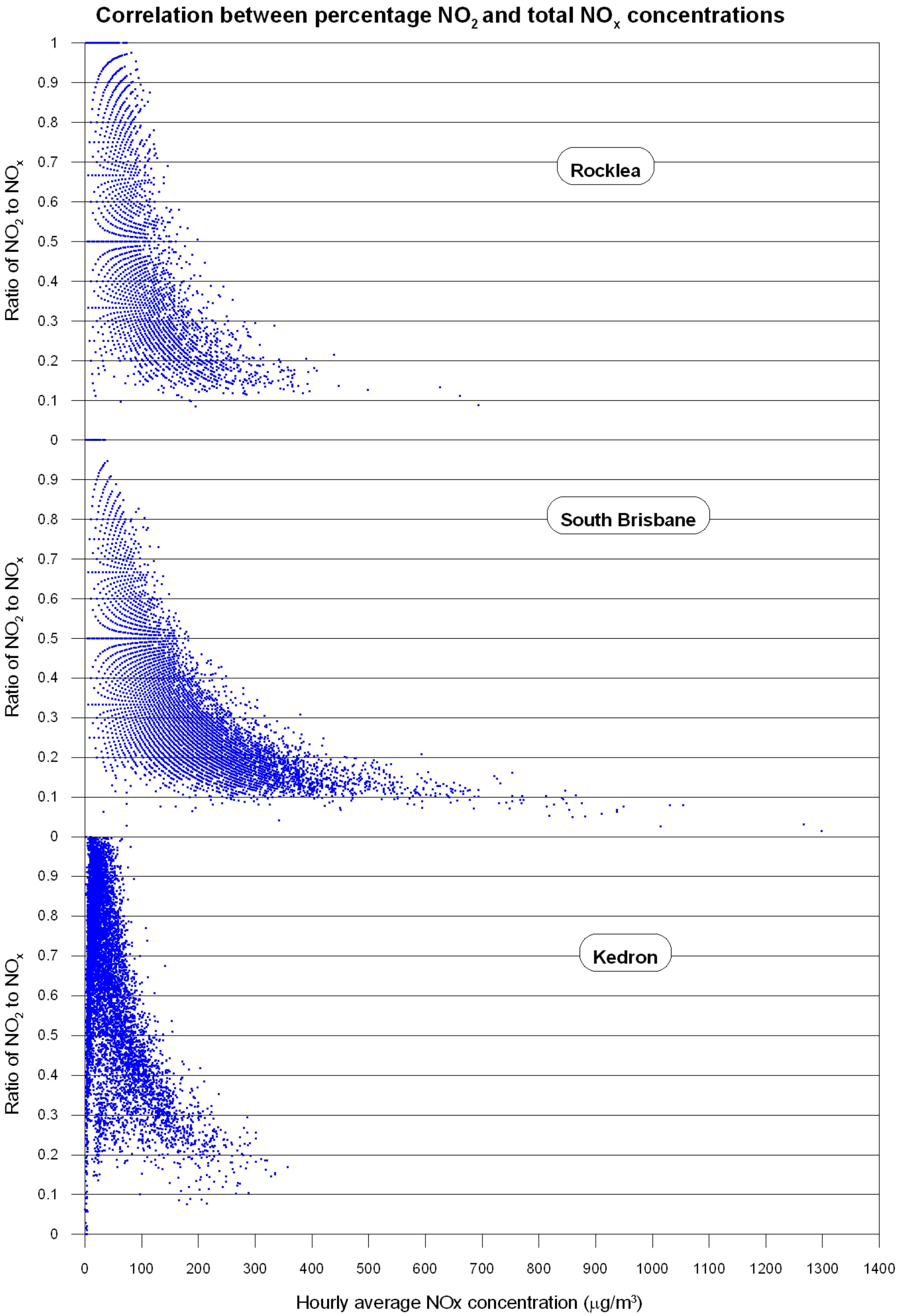


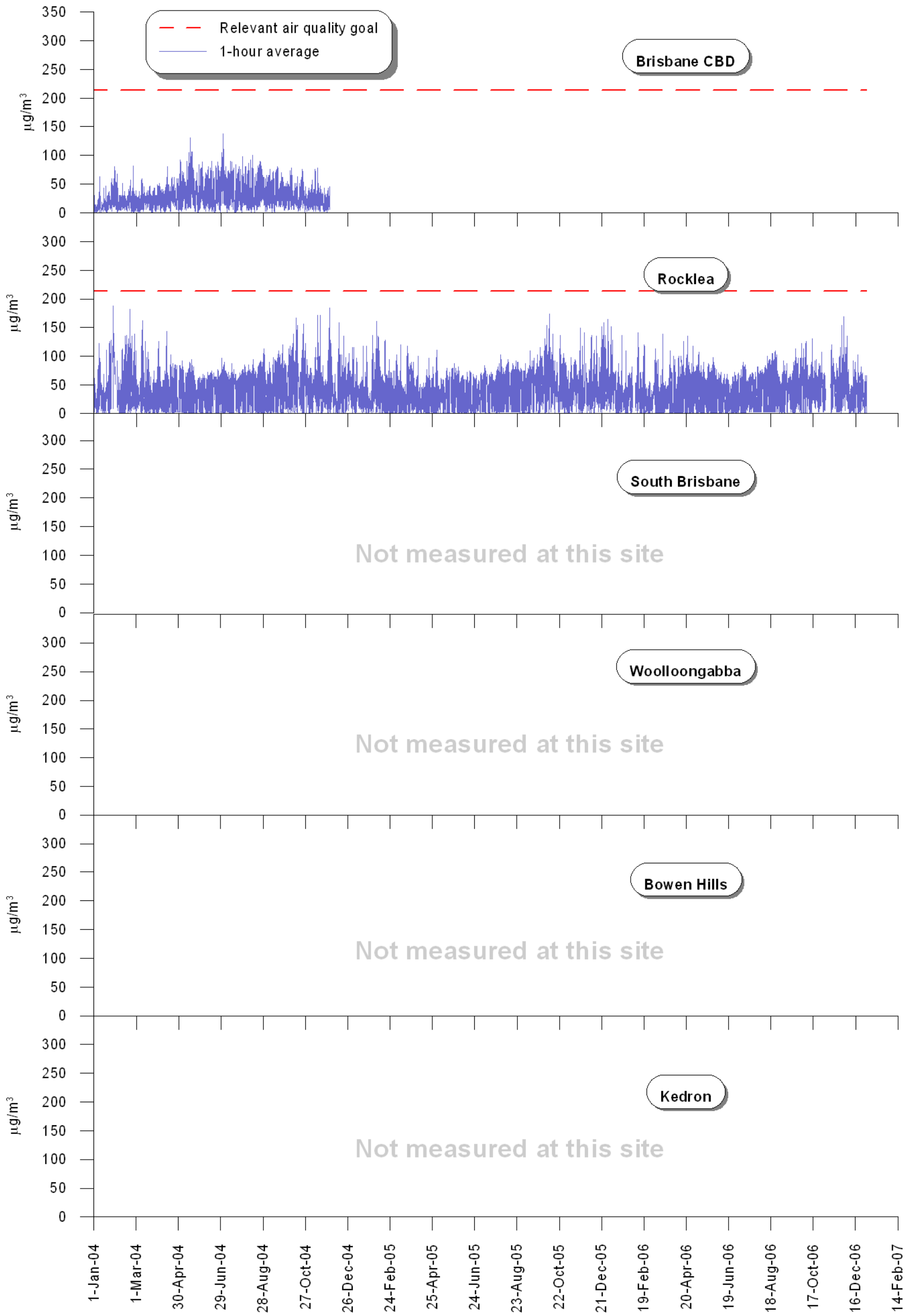
FIGURE 16



Correlation between percentage NO2 and total NOx concentrations
Rocklea
South Brisbane
Kedron
Ratio of NO2 to NOx
Hourly average NOx concentration (µg/m3)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400

FIGURE 17

Measured O_3 concentrations in the Brisbane region



Measured PM_{10} concentrations in the Brisbane region

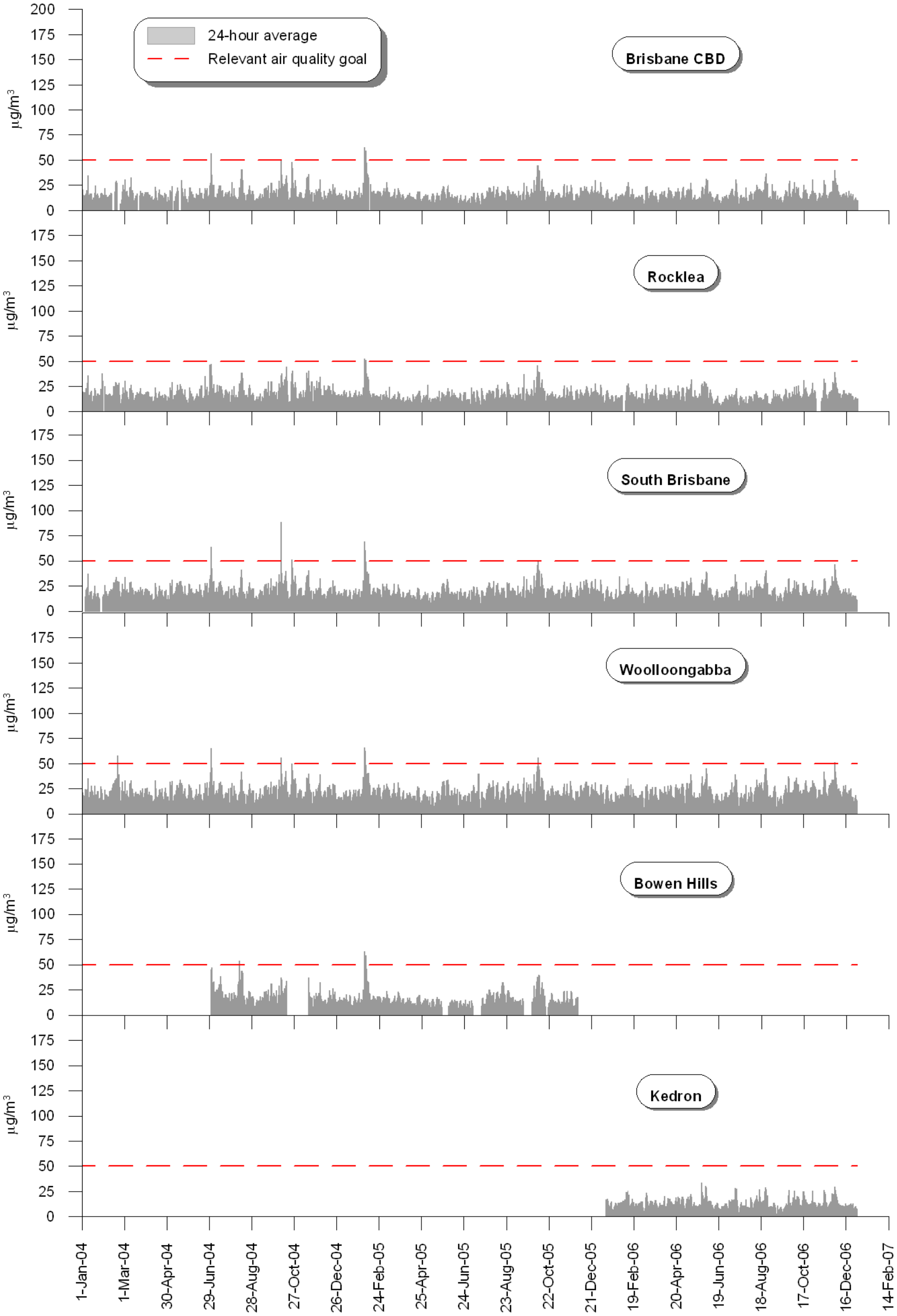


FIGURE 19

Measured $PM_{2.5}$ concentrations in the Brisbane region

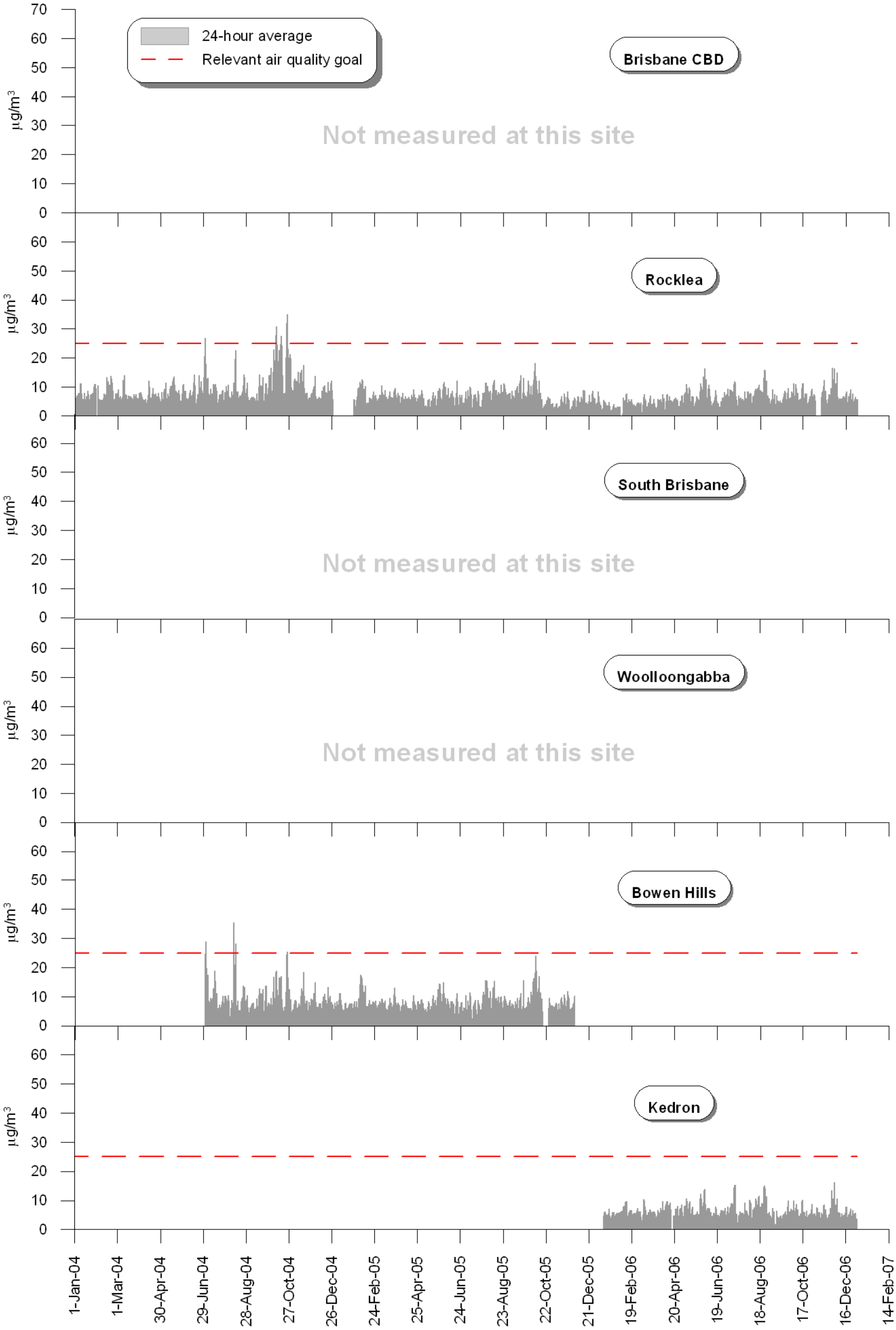


FIGURE 20

Relationship between measured PM_{10} and $PM_{2.5}$ concentrations

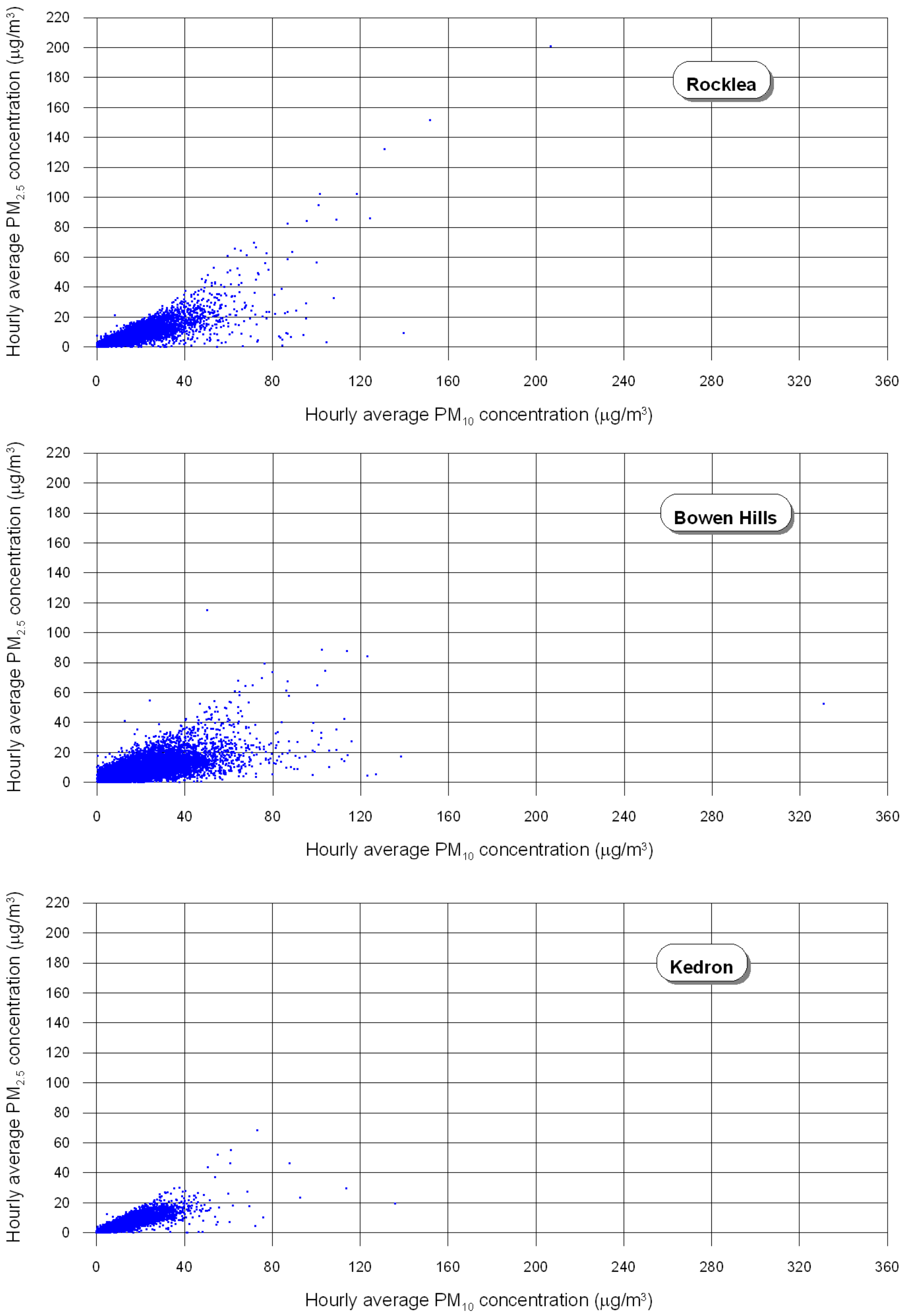
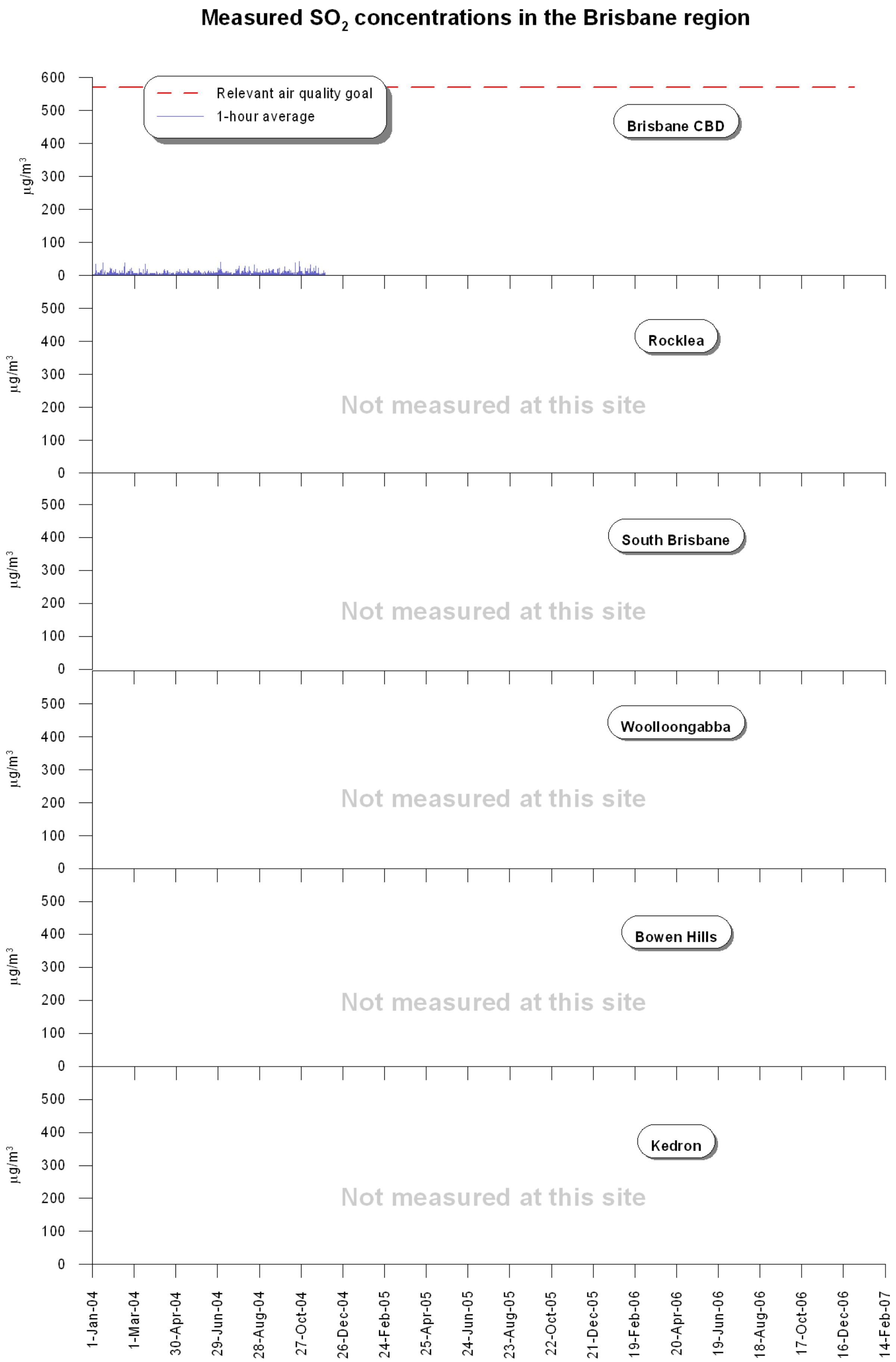


FIGURE 21



Measured SO_2 concentrations in the Brisbane region
Relevant air quality goal
1-hour average
Brisbane CBD
Rocklea
South Brisbane
Woolloongabba
Bowen Hills
Kedron
Not measured at this site
µg/m³
0
100
200
300
400
500
600
1-Jan-04
1-Mar-04
30-Apr-04
29-Jun-04
28-Aug-04
27-Oct-04
26-Dec-04
24-Feb-05
25-Apr-05
24-Jun-05
23-Aug-05
22-Oct-05
21-Dec-05
19-Feb-06
20-Apr-06
19-Jun-06
18-Aug-06
17-Oct-06
16-Dec-06
14-Feb-07

FIGURE 22

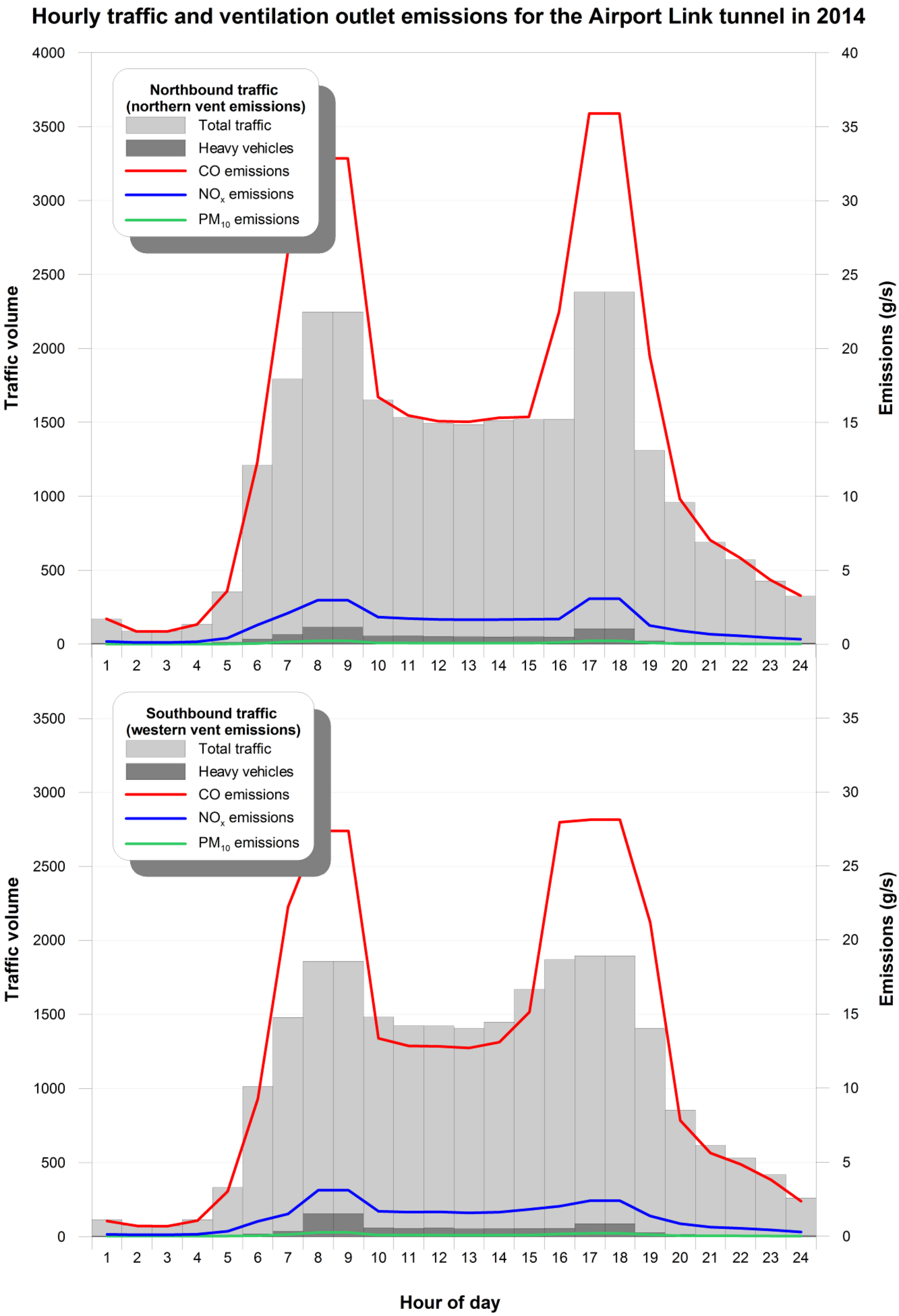
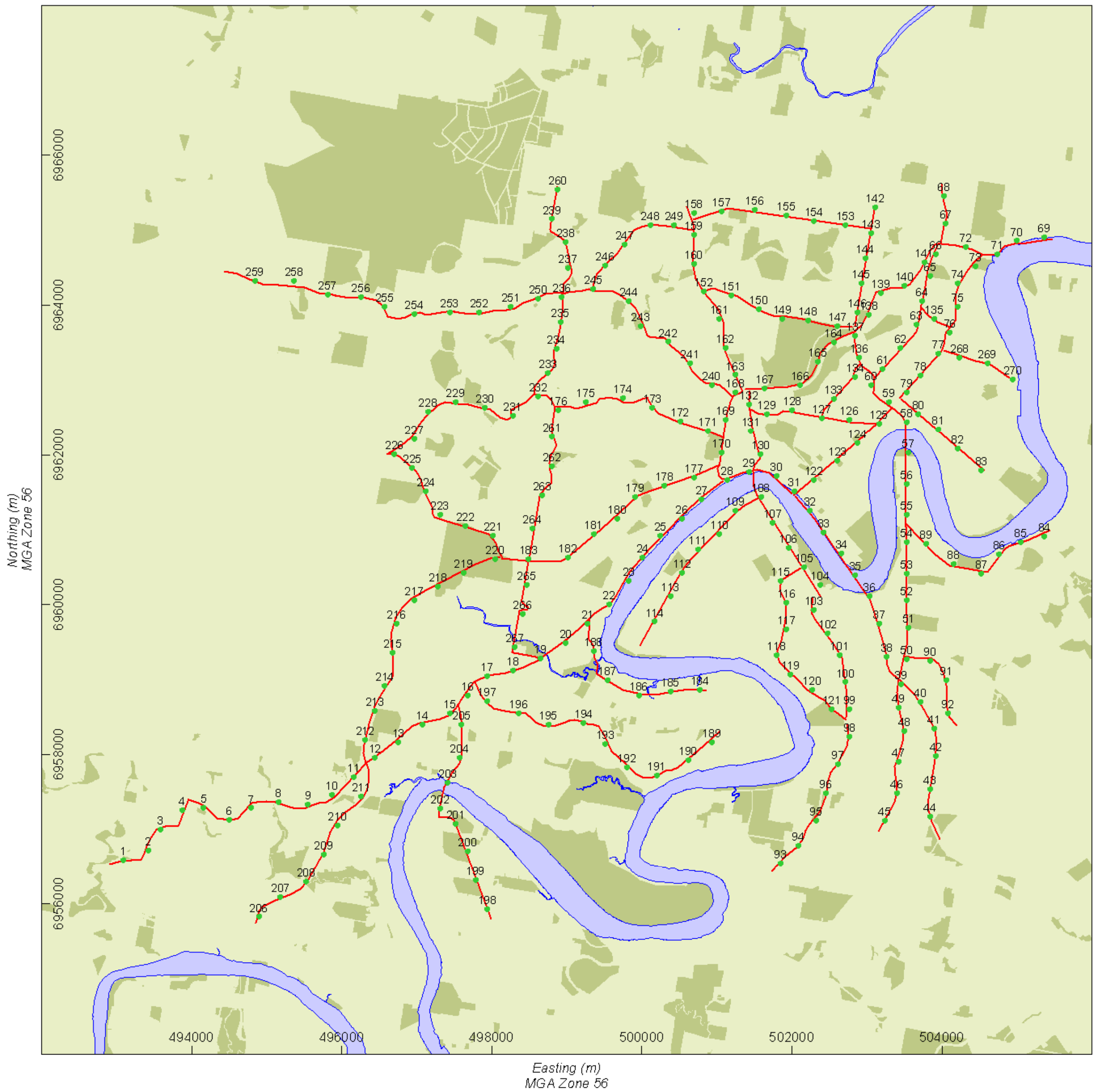
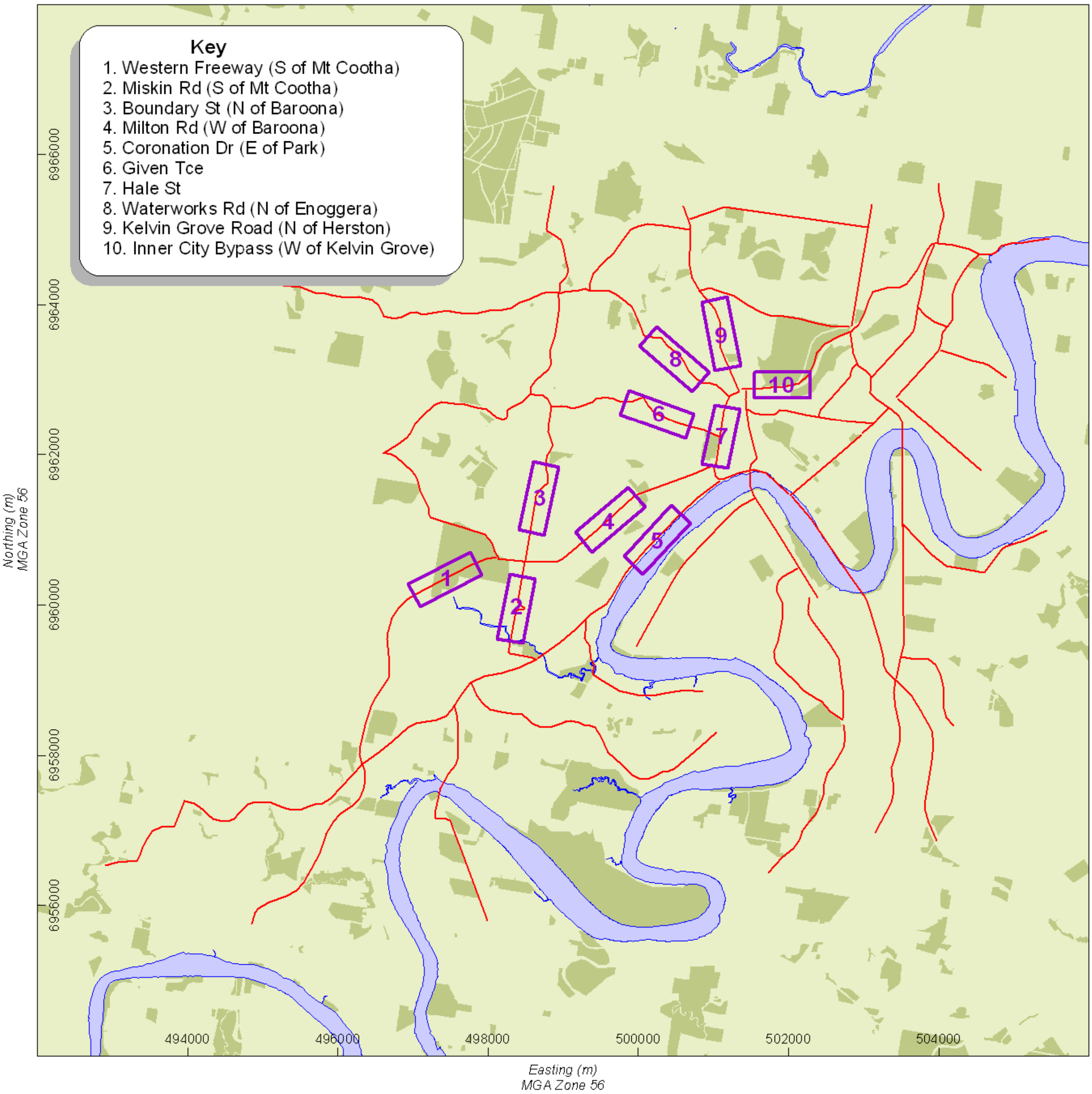

Hourly traffic and ventilation outlet emissions for the Airport Link tunnel in 2014
Northbound traffic
(northern vent emissions)
Total traffic
Heavy vehicles
CO emissions
NOx emissions
PM10 emissions
Southbound traffic
(western vent emissions)
Total traffic
Heavy vehicles
CO emissions
NOx emissions
PM10 emissions
Traffic volume
Emissions (g/s)
Hour of day

FIGURE 23

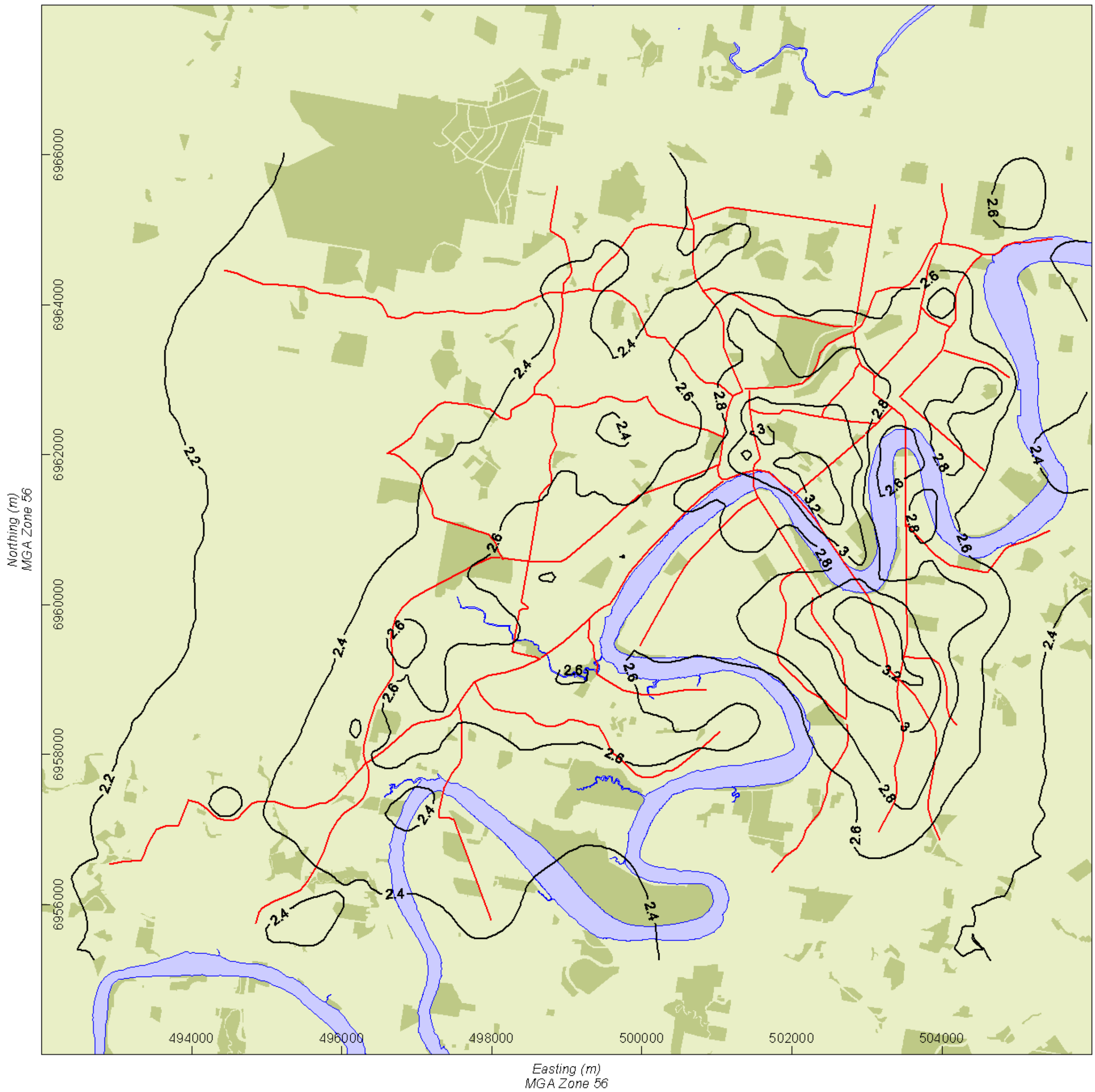


Sources used to represent roadways in the CALPUFF dispersion model



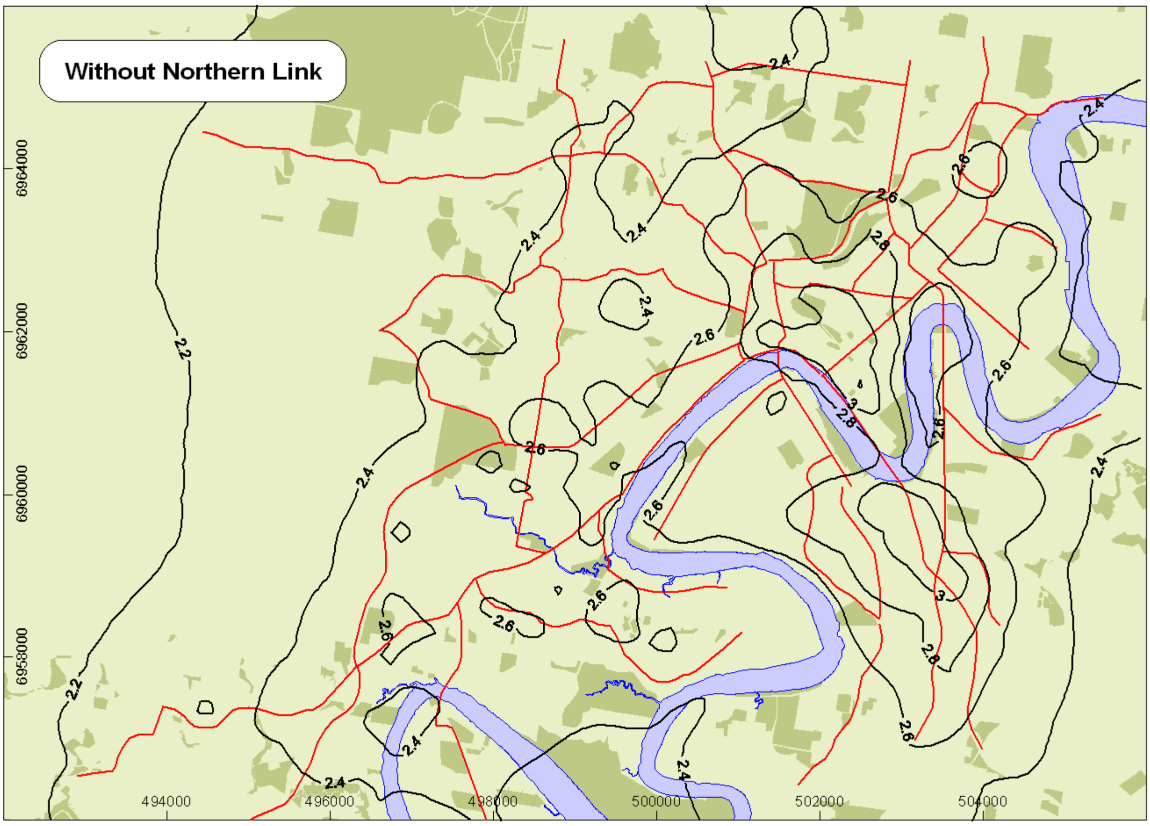
Road sections selected for the CALINE modelling

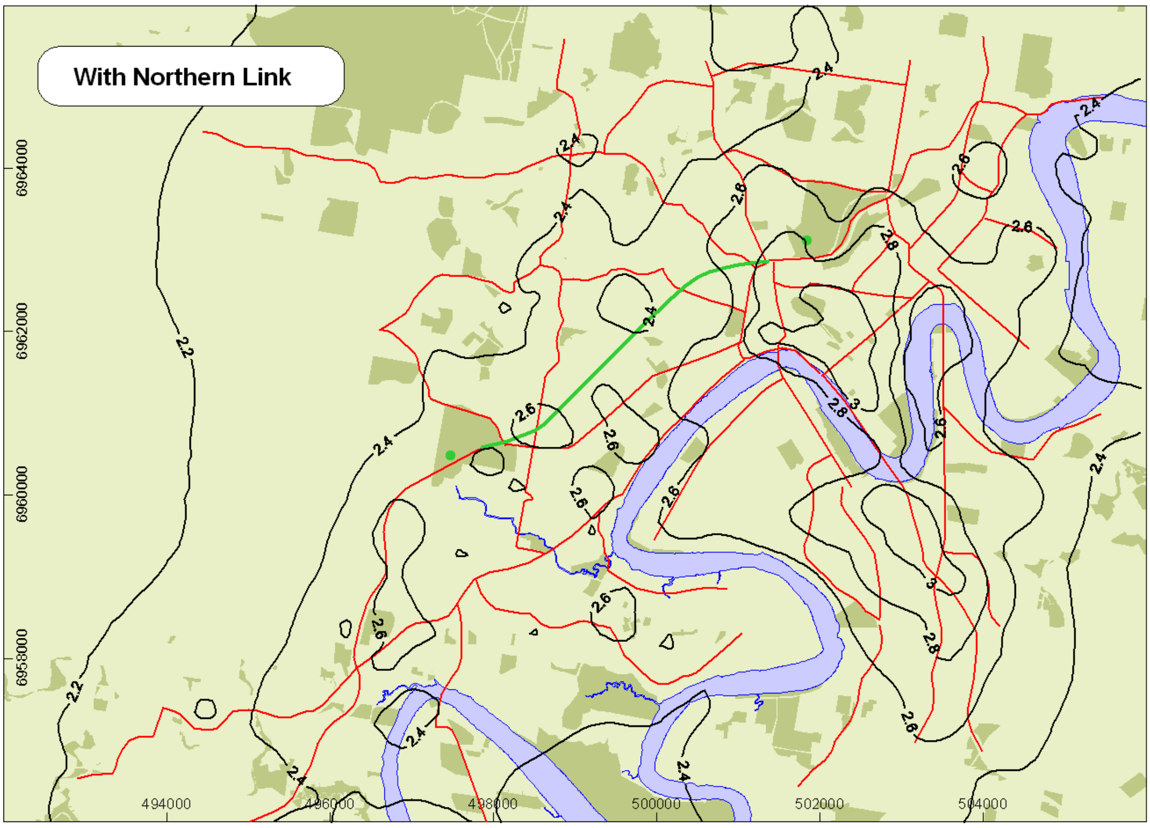
FIGURE 25



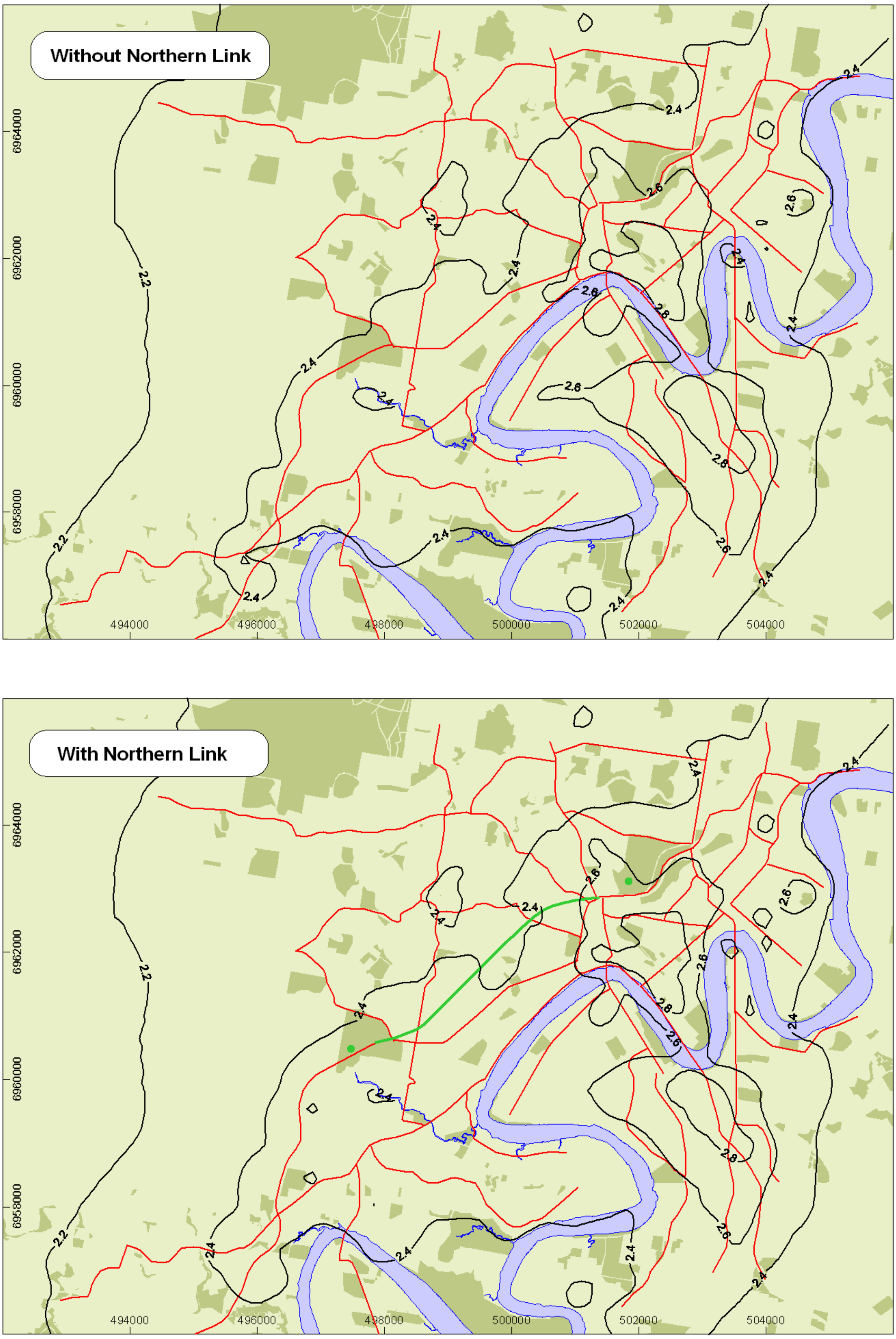
Predicted maximum 8-hour average CO concentrations in 2007 (mg/m³)

FIGURE 26

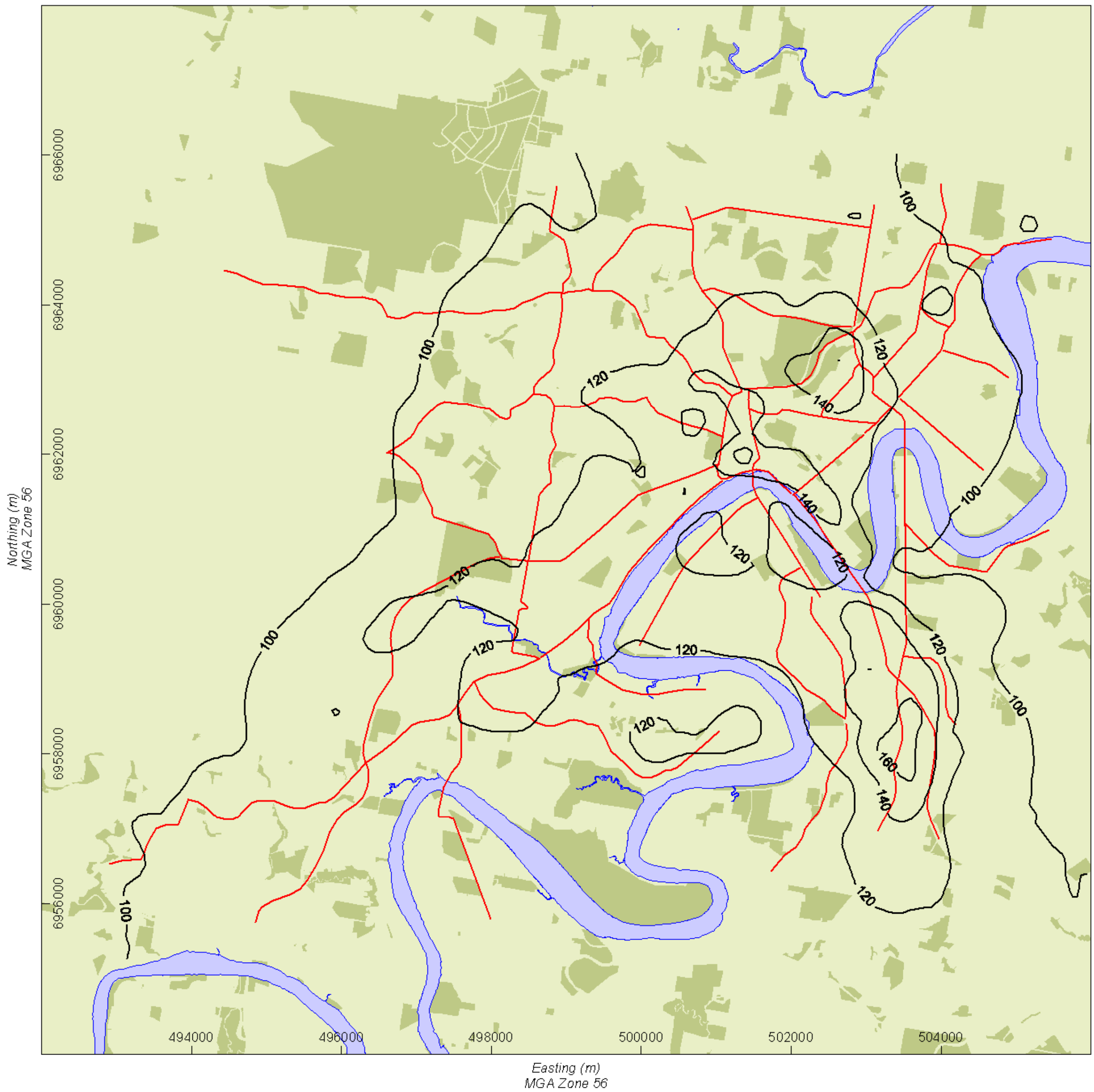




Predicted maximum 8-hour average CO concentrations in 2014 (mg/m^3)

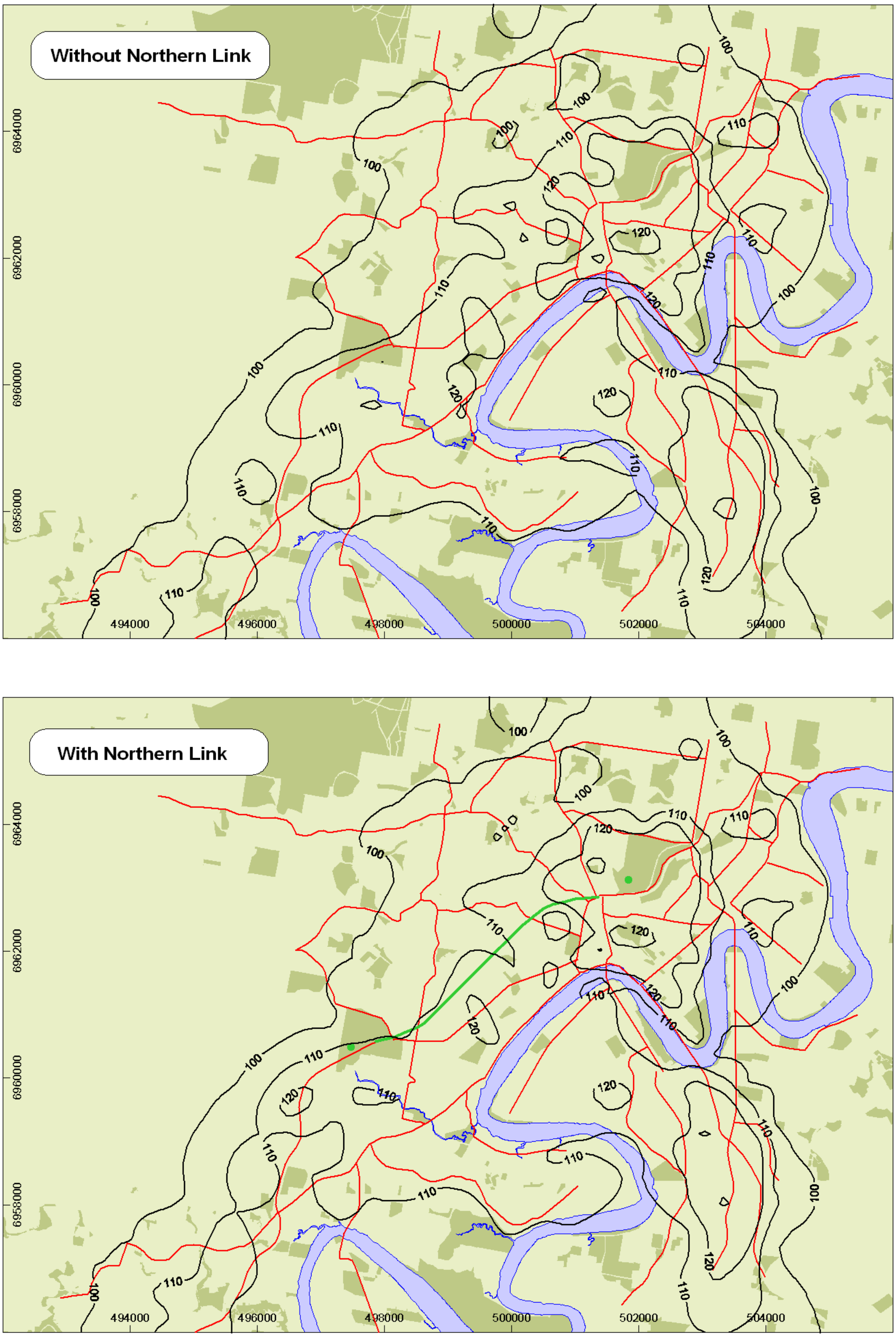


Predicted maximum 8-hour average CO concentrations in 2026 (mg/m^3)

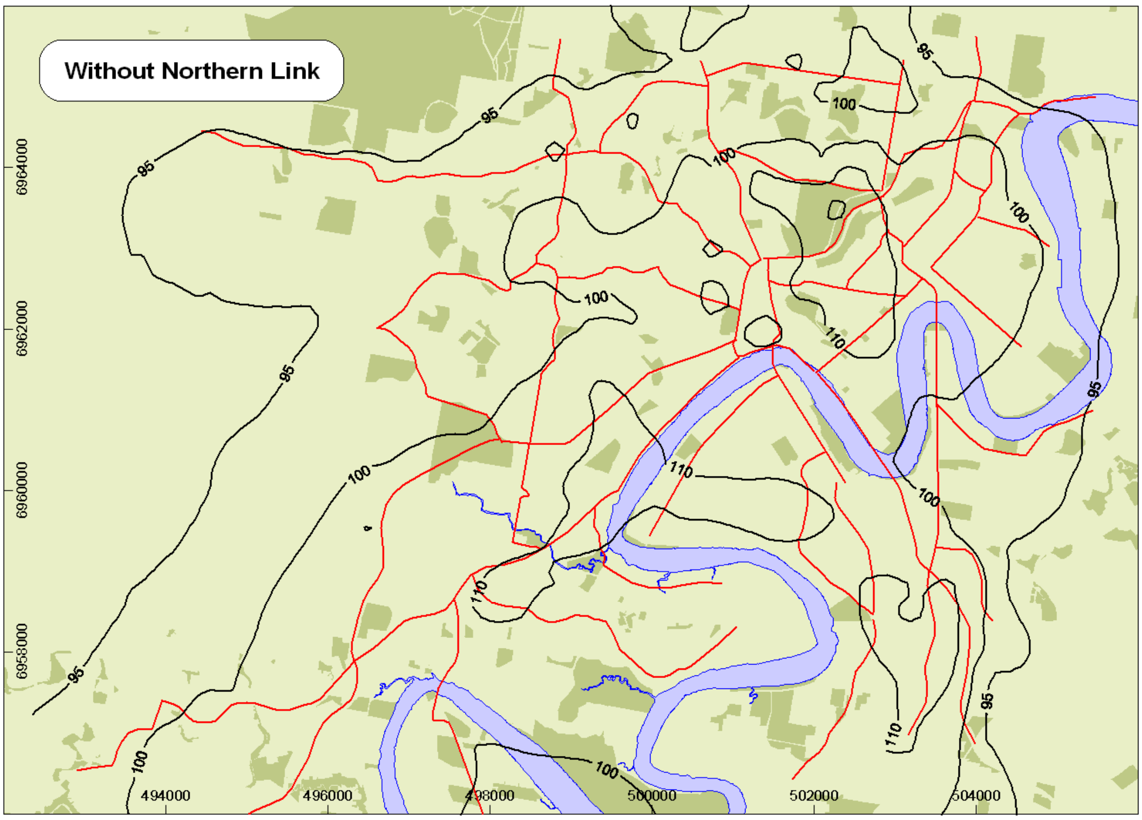


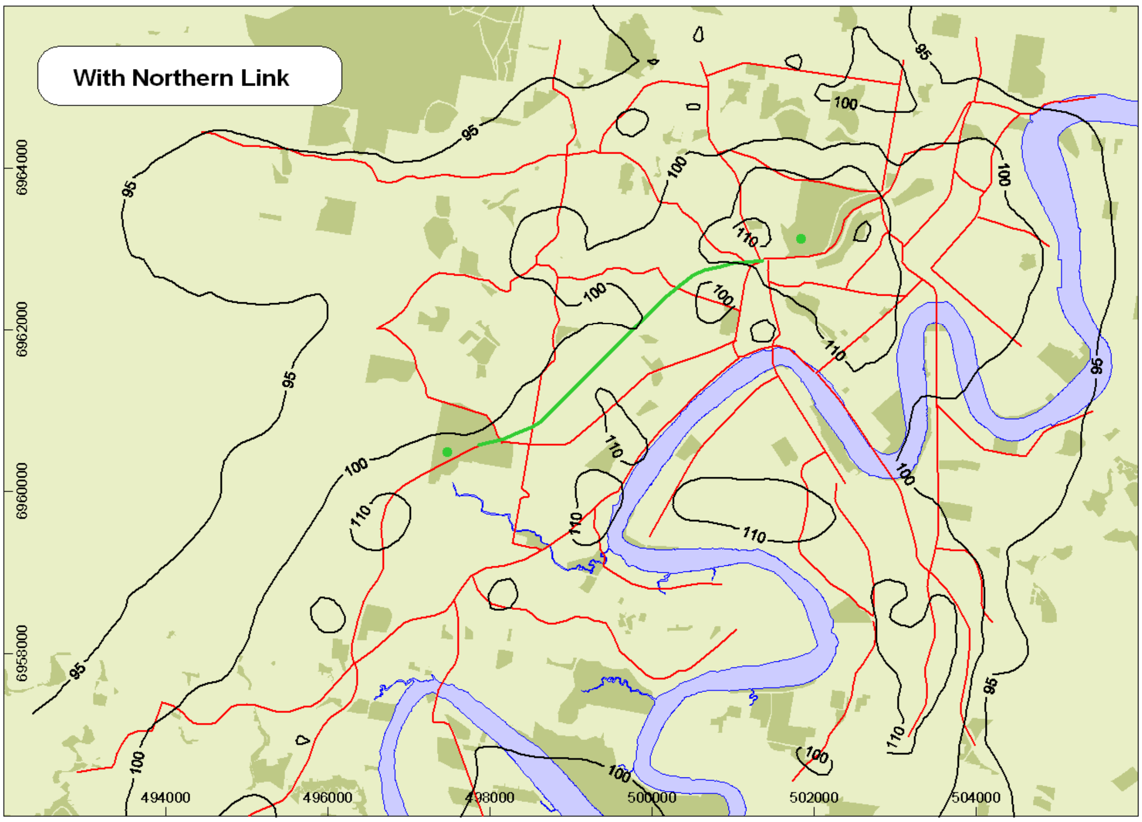
Predicted maximum 1-hour average NO_2 concentrations in 2007 (µg/m^3)

FIGURE 29



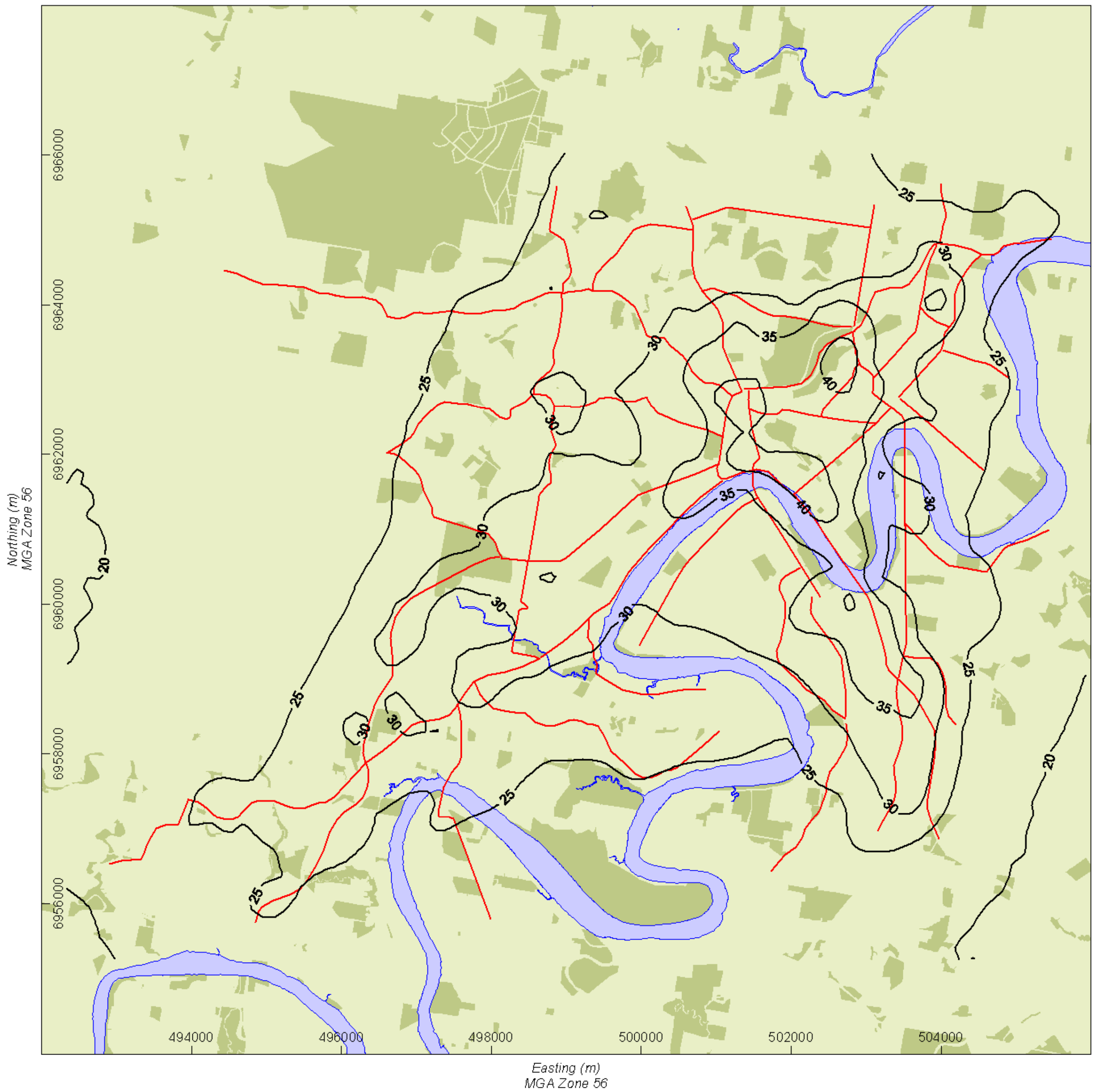
Predicted maximum 1-hour average NO_2 concentrations in 2014 ($\mu g/m^3$)



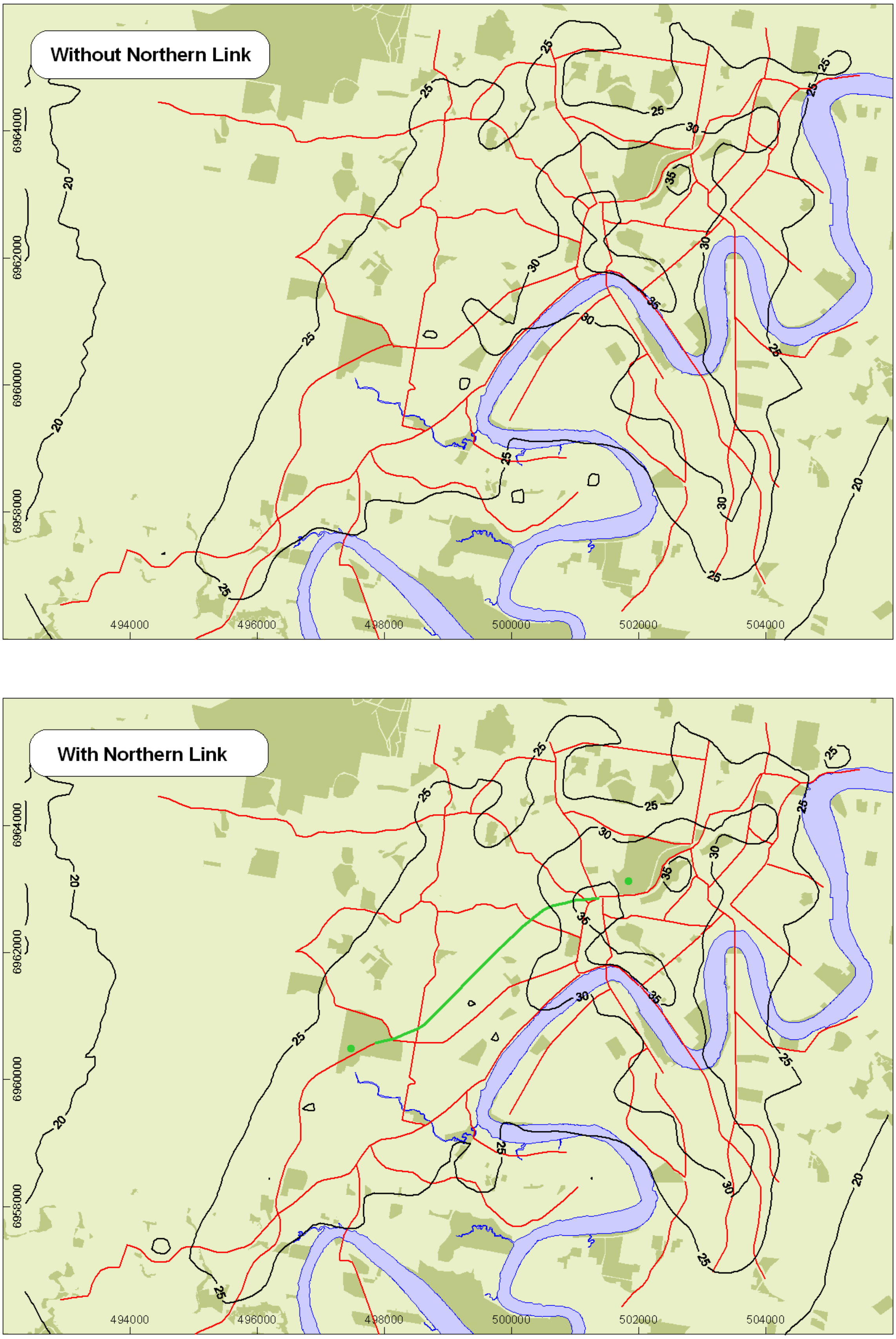


Predicted maximum 1-hour average NO_2 concentrations in 2026 (µg/m^3)

FIGURE 31

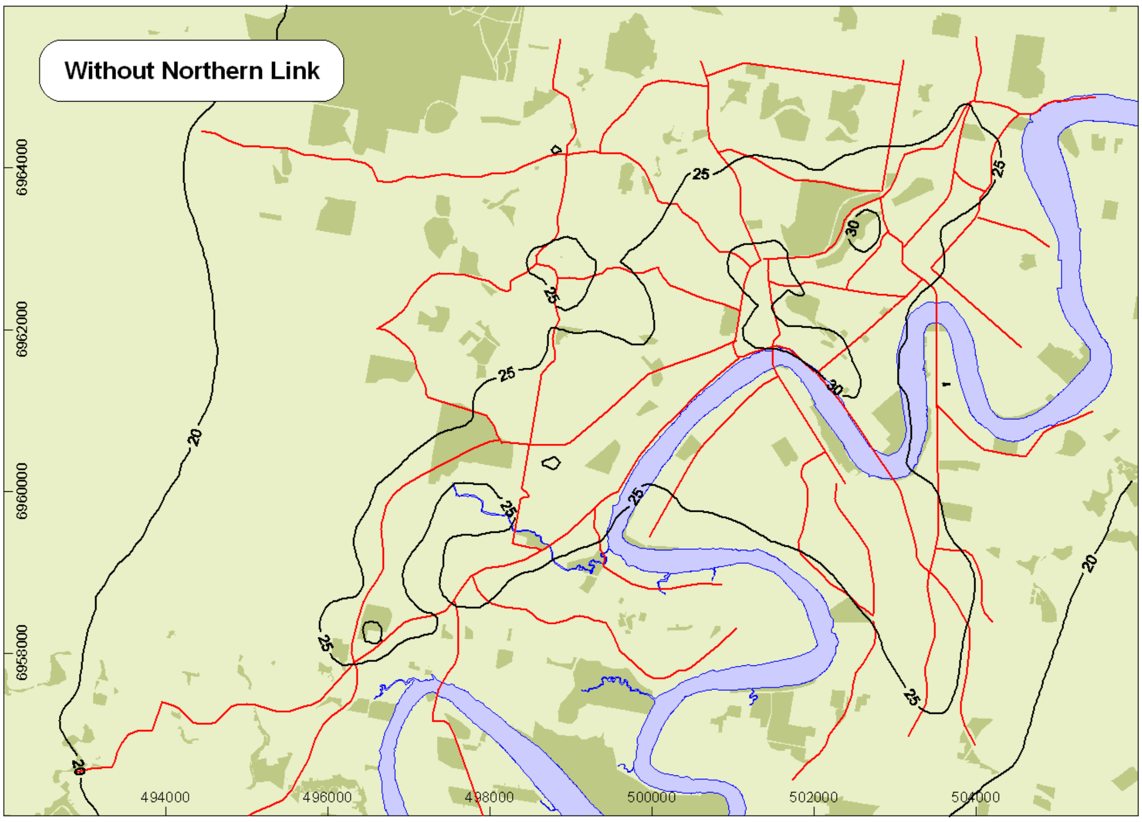


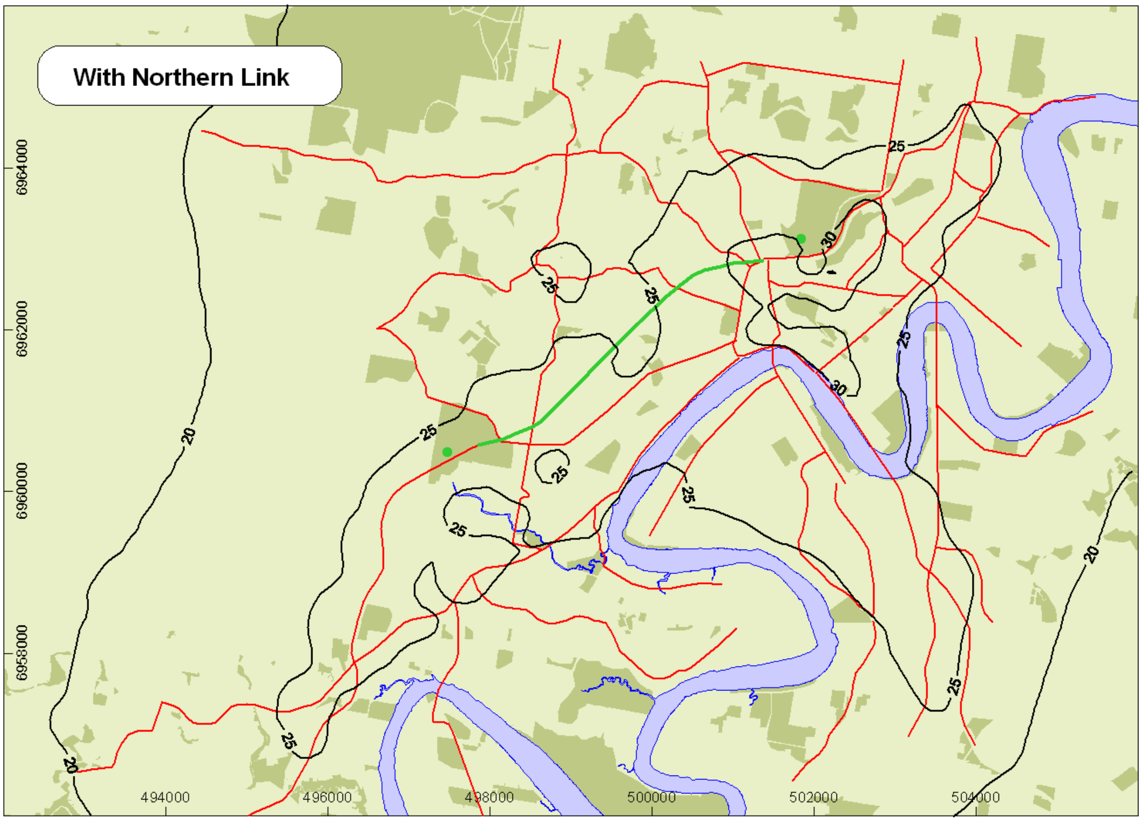
Predicted annual average NO_2 concentrations in 2007 ($\mu g/m^3$)



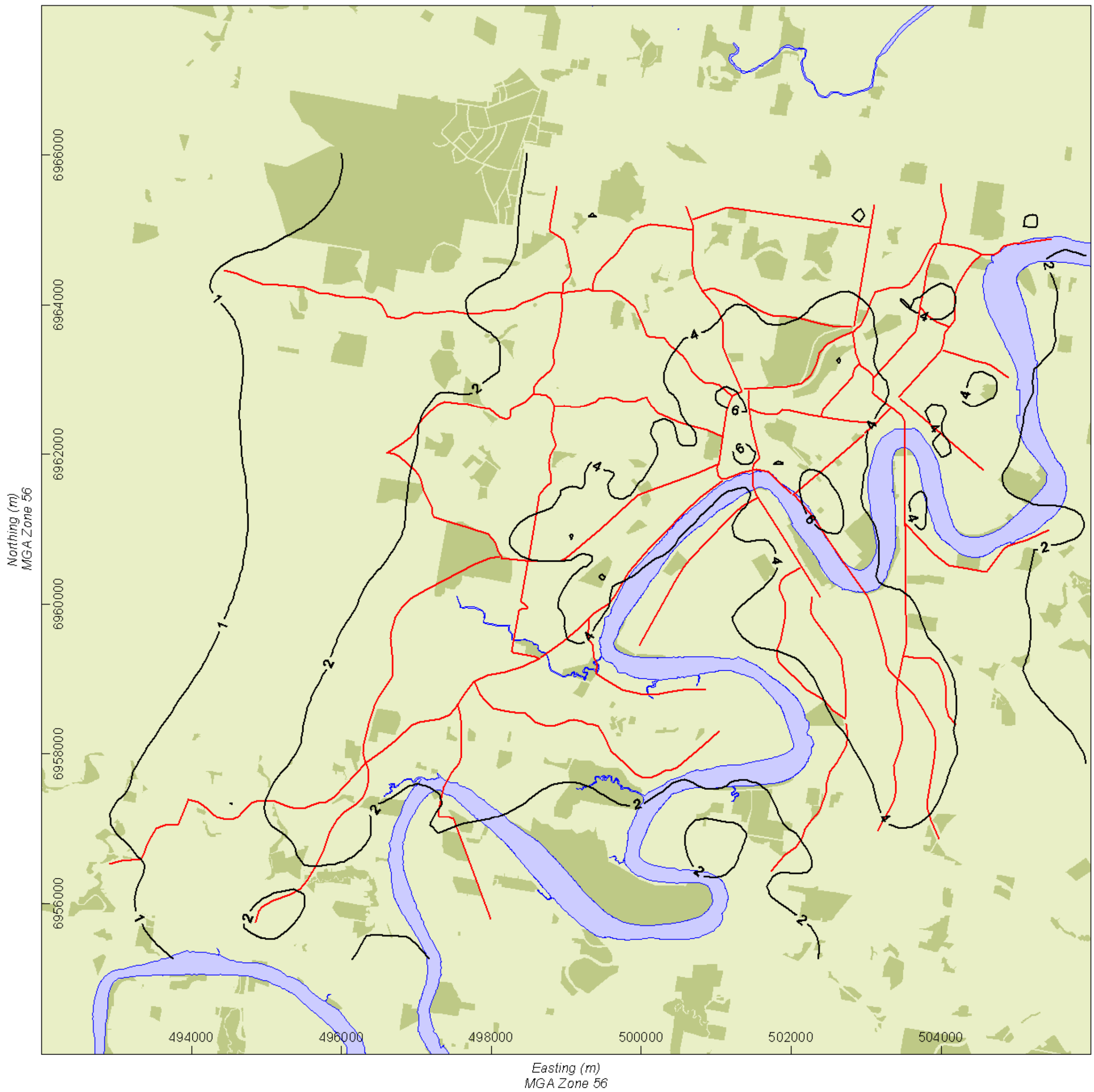
Predicted annual average NO_2 concentrations in 2014 ($\mu g/m^3$)

FIGURE 33



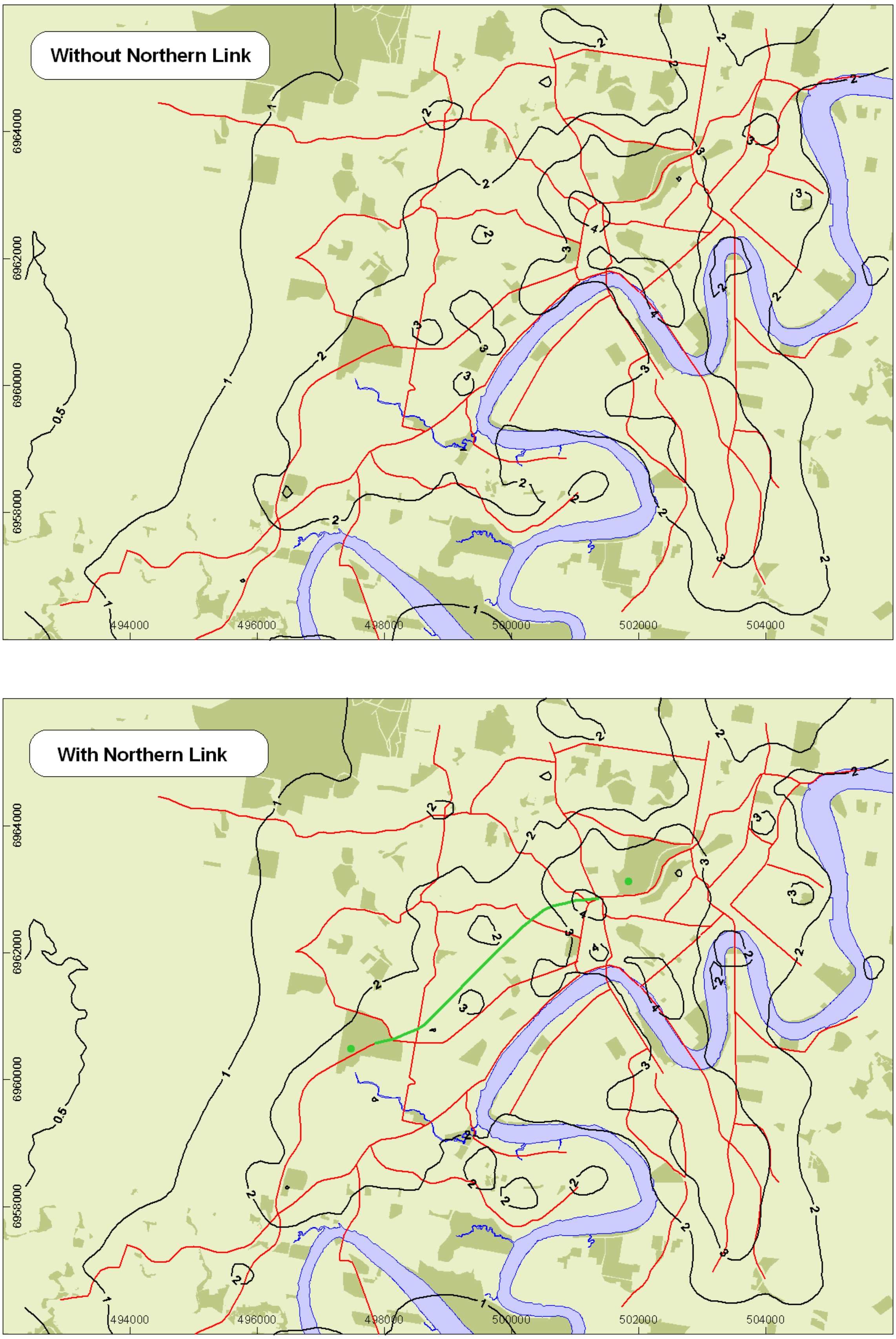


Predicted annual average NO_2 concentrations in 2026 ($\mu g/m^3$)



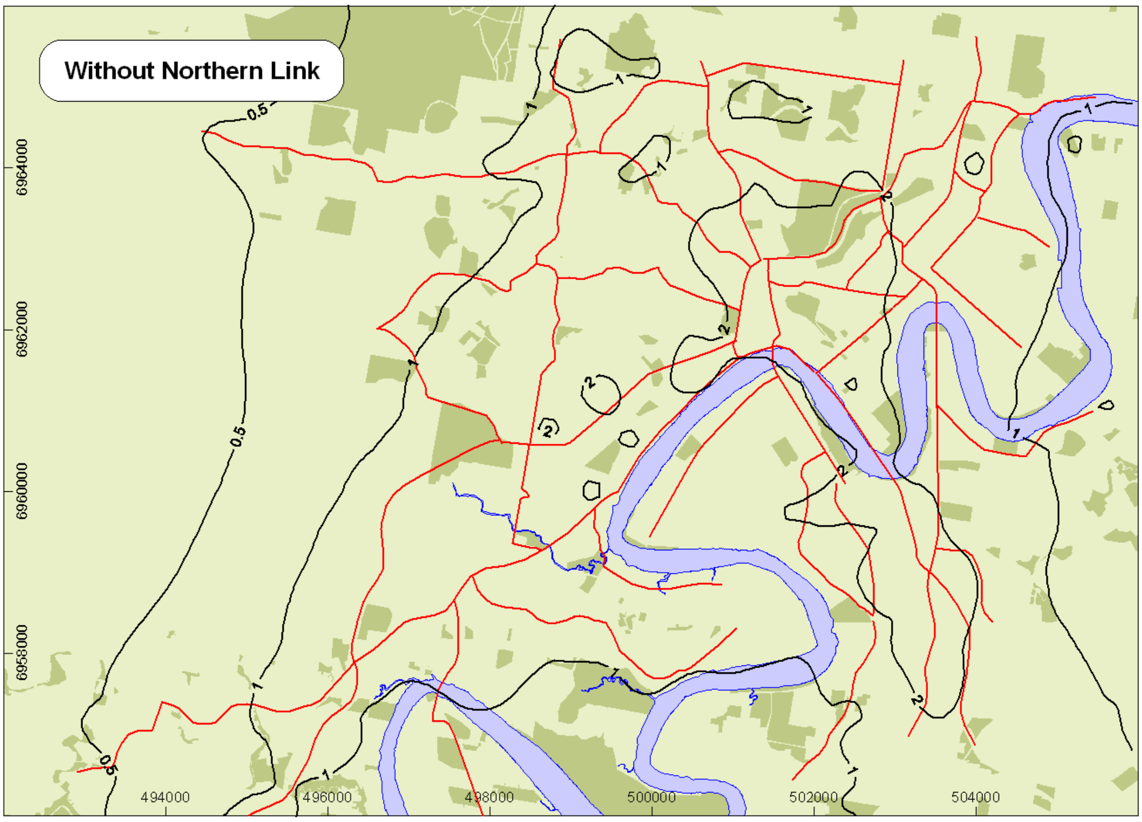
Predicted maximum 24-hour average PM_{10} concentrations in 2007 ($\mu g/m^3$)

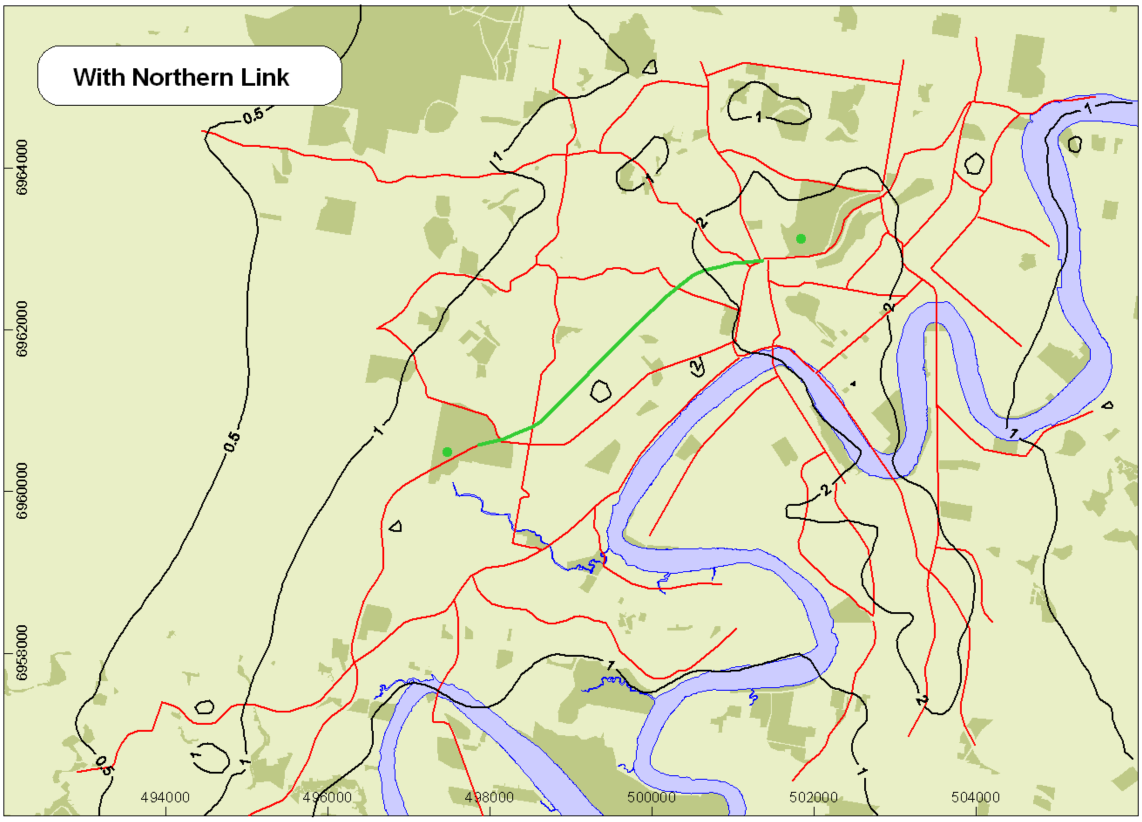
FIGURE 35



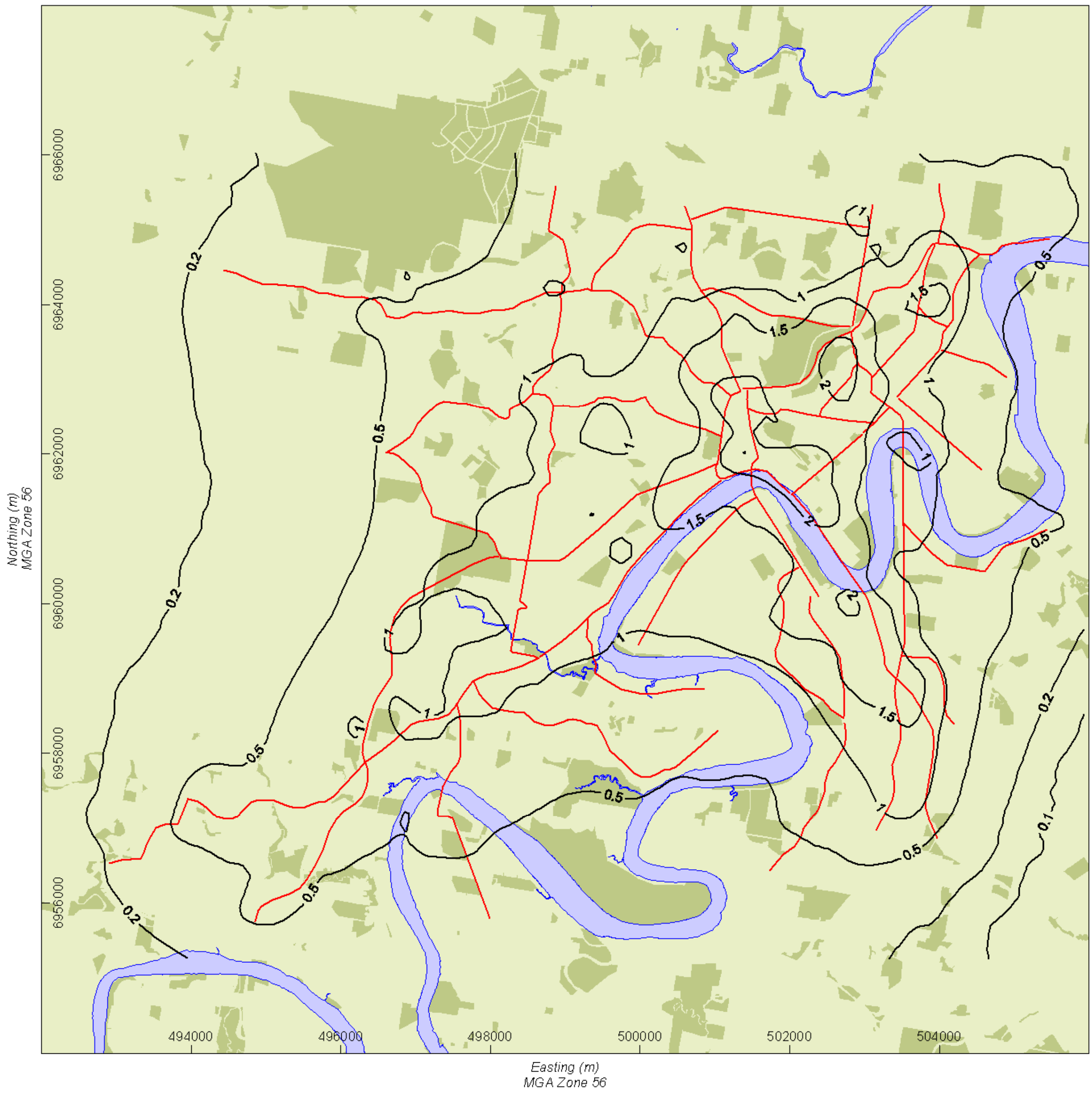
Predicted maximum 24-hour average PM_{10} concentrations in 2014 ($\mu g/m^3$)

FIGURE 36

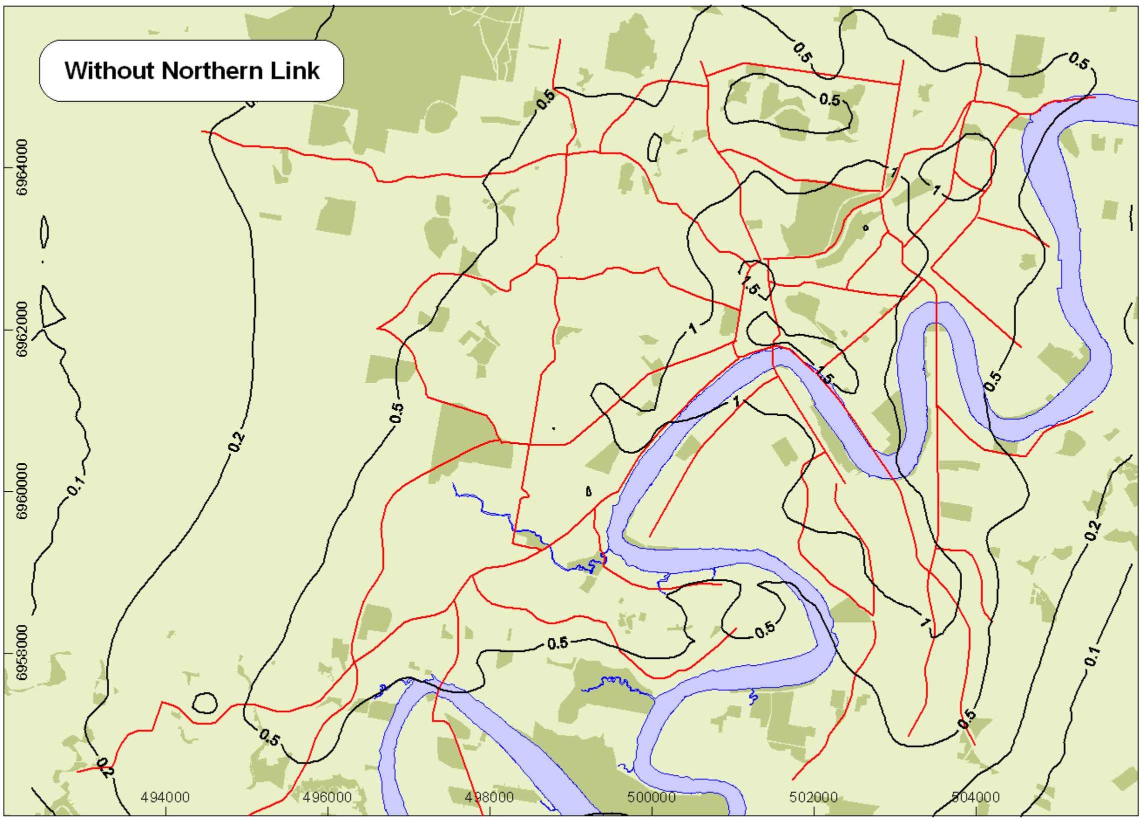


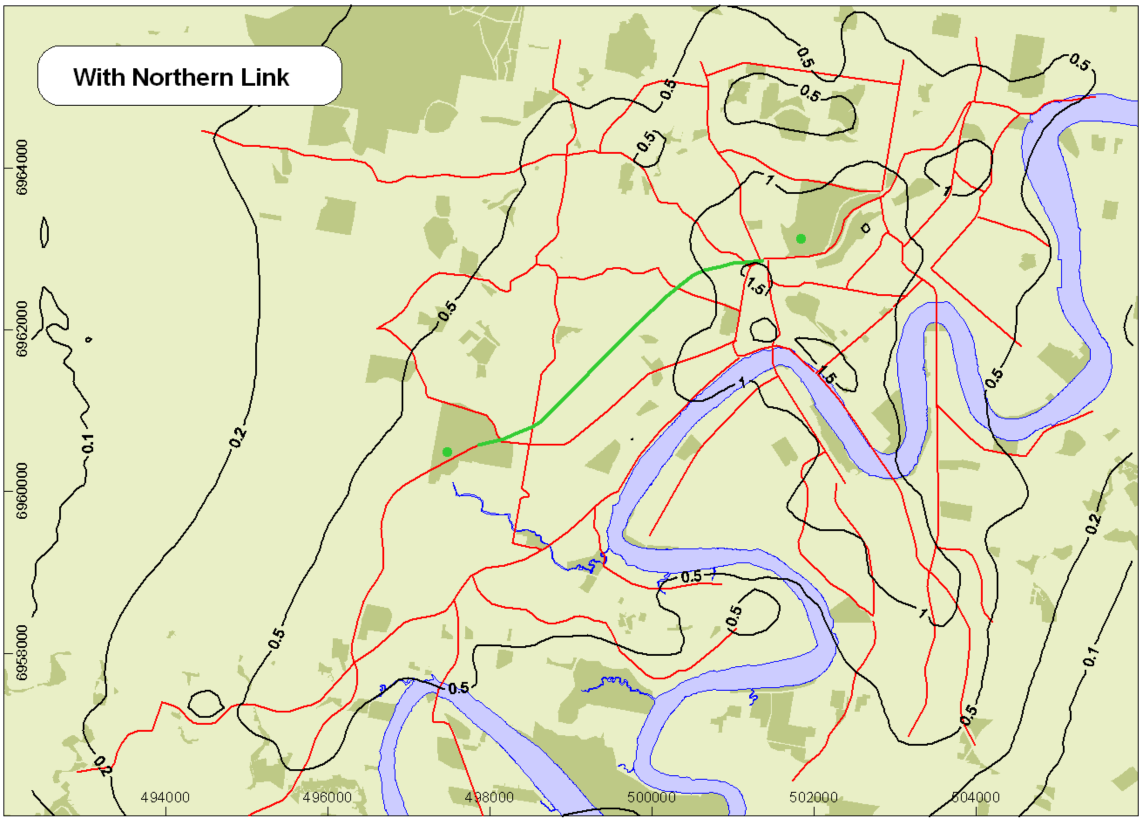


Predicted maximum 24-hour average PM_{10} concentrations in 2026 ($\mu g/m^3$)

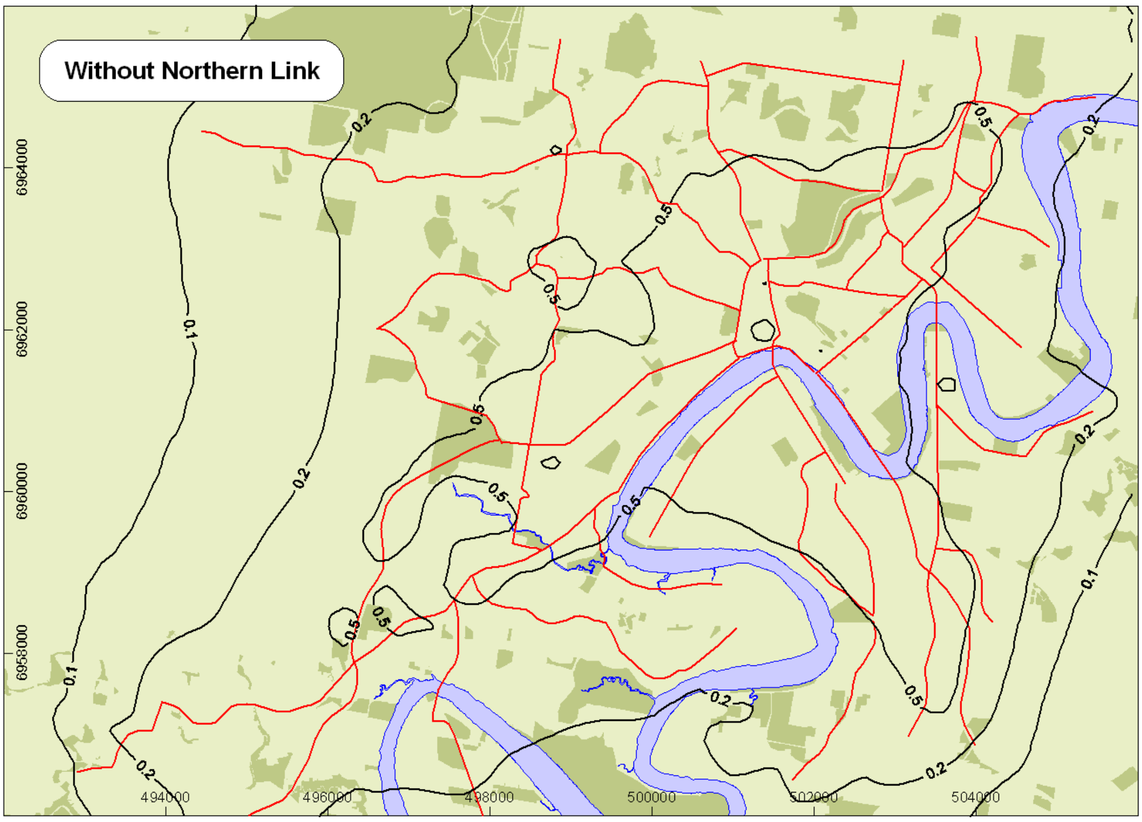


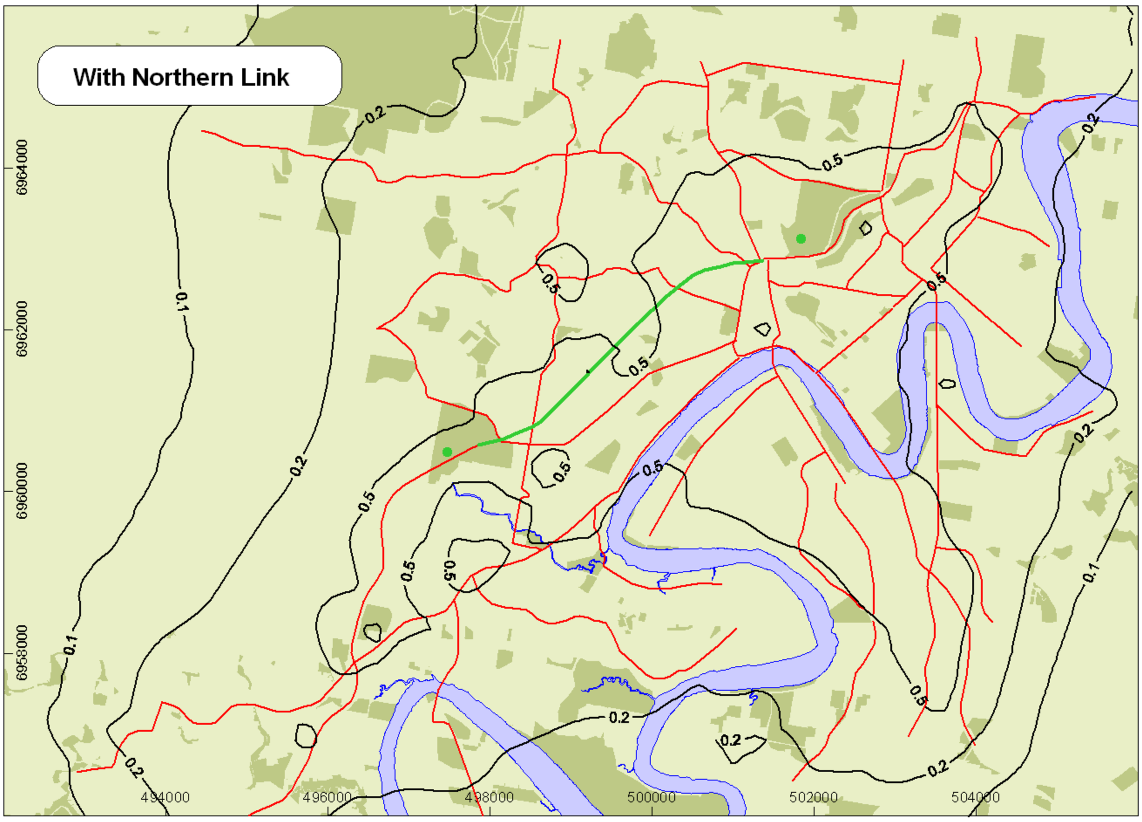
Predicted annual average PM_{10} concentrations in 2007 (µg/m^3)





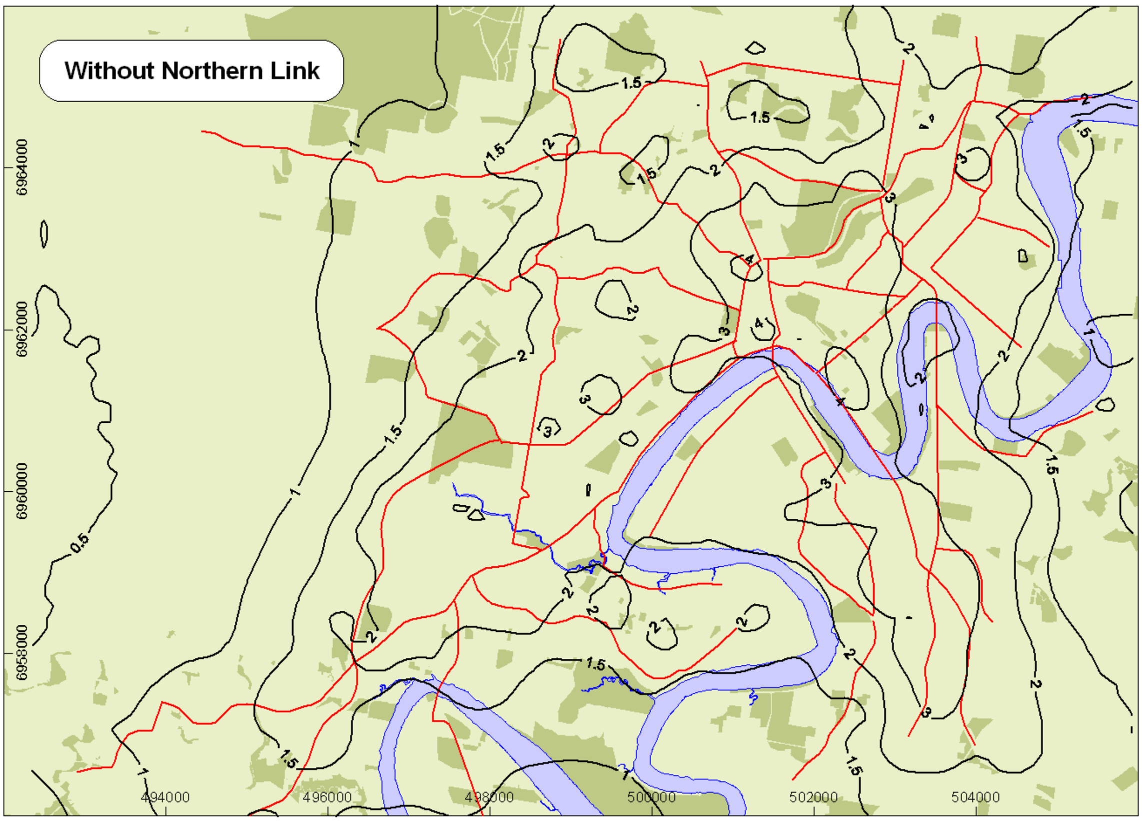
Predicted annual average PM_{10} concentrations in 2014 (µg/m^3)

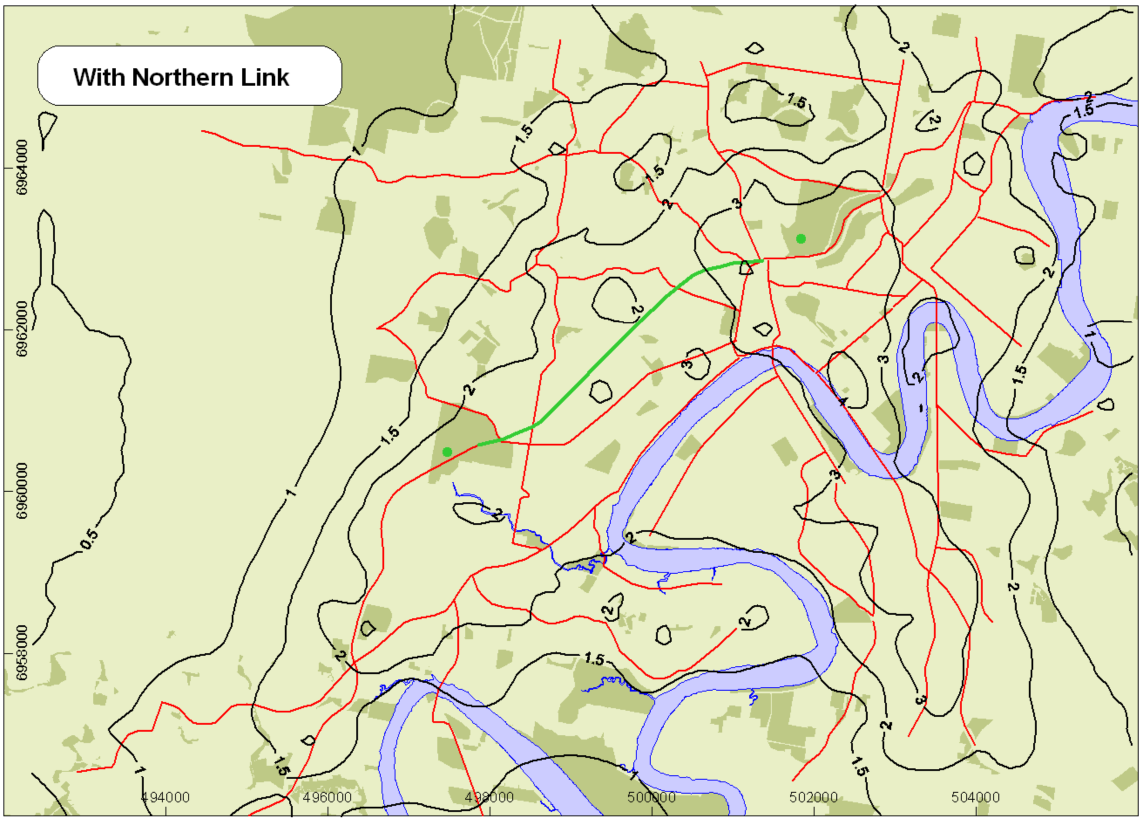




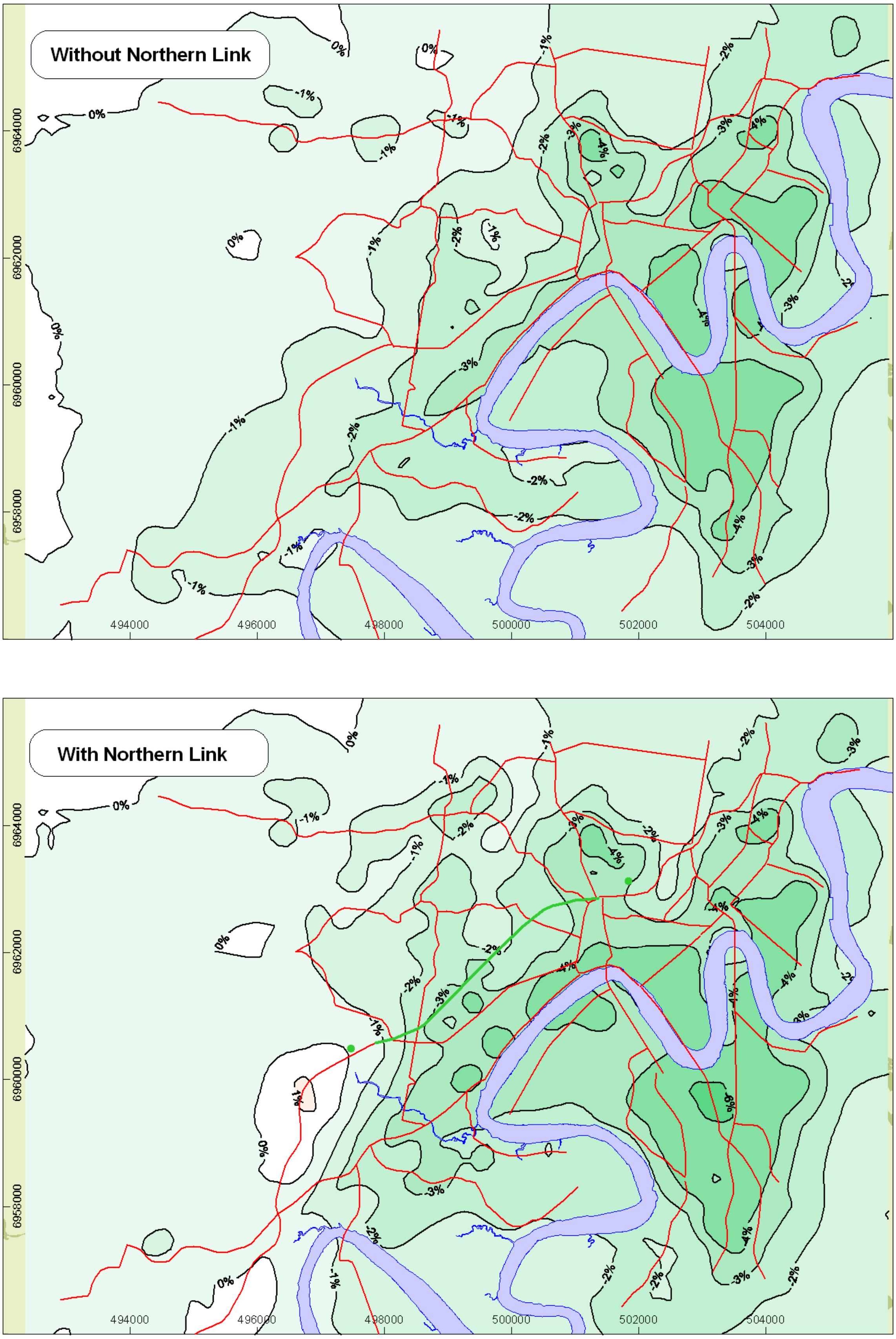
Predicted annual average PM_{10} concentrations in 2026 ($\mu g/m^3$)

FIGURE 40



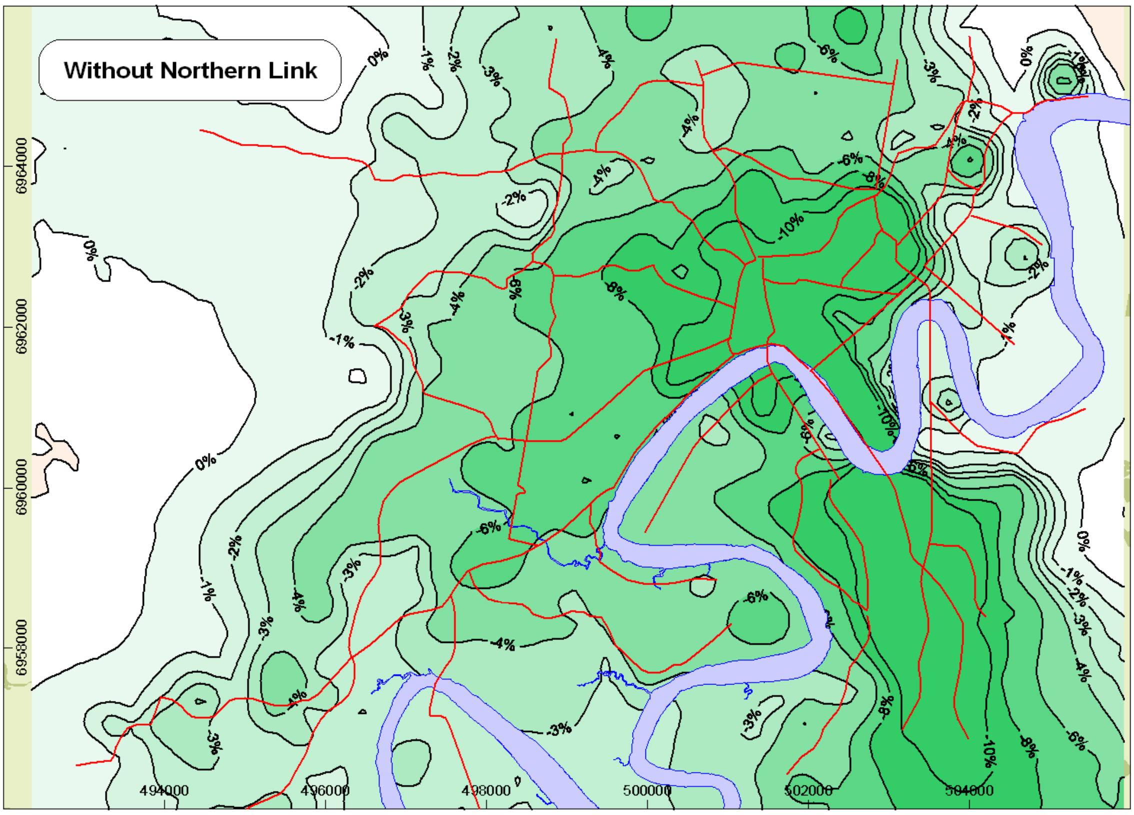


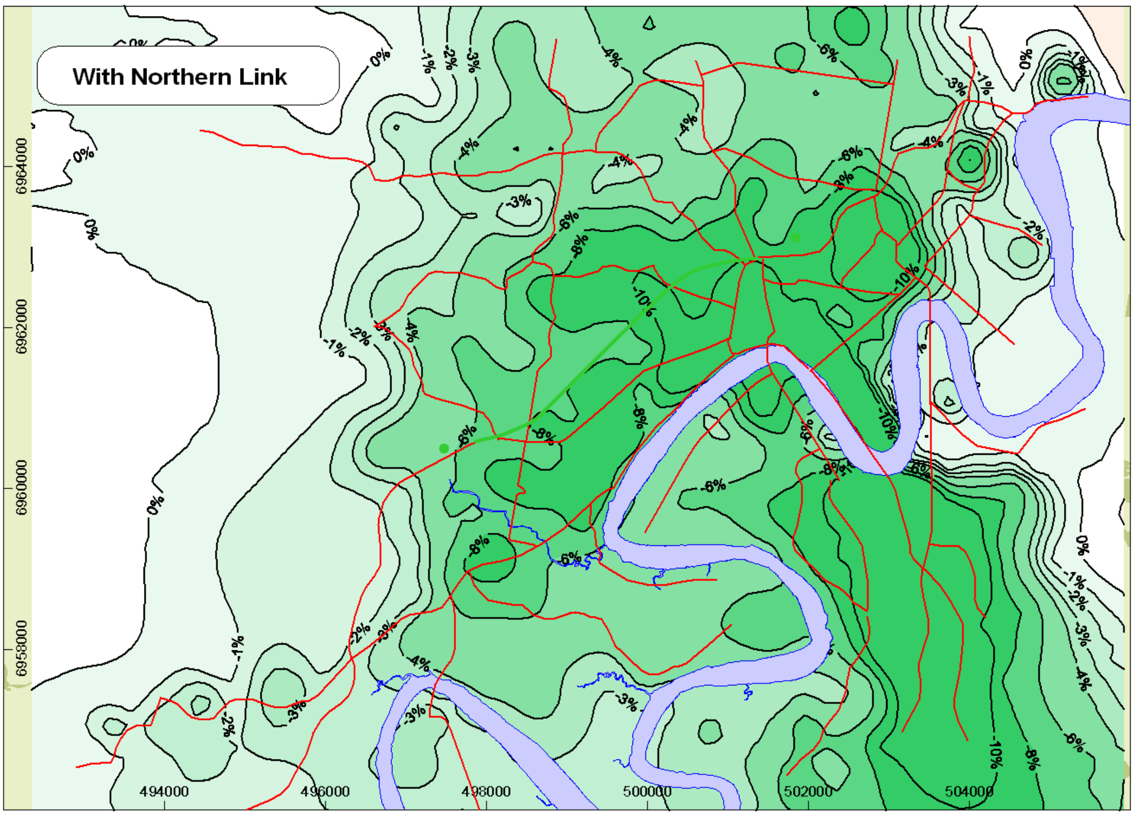
Predicted maximum 24-hour average $PM_{2.5}$ concentrations in 2014 ($\mu g/m^3$)



Percentage change from existing (2007) to 2014 for maximum 8-hour average CO

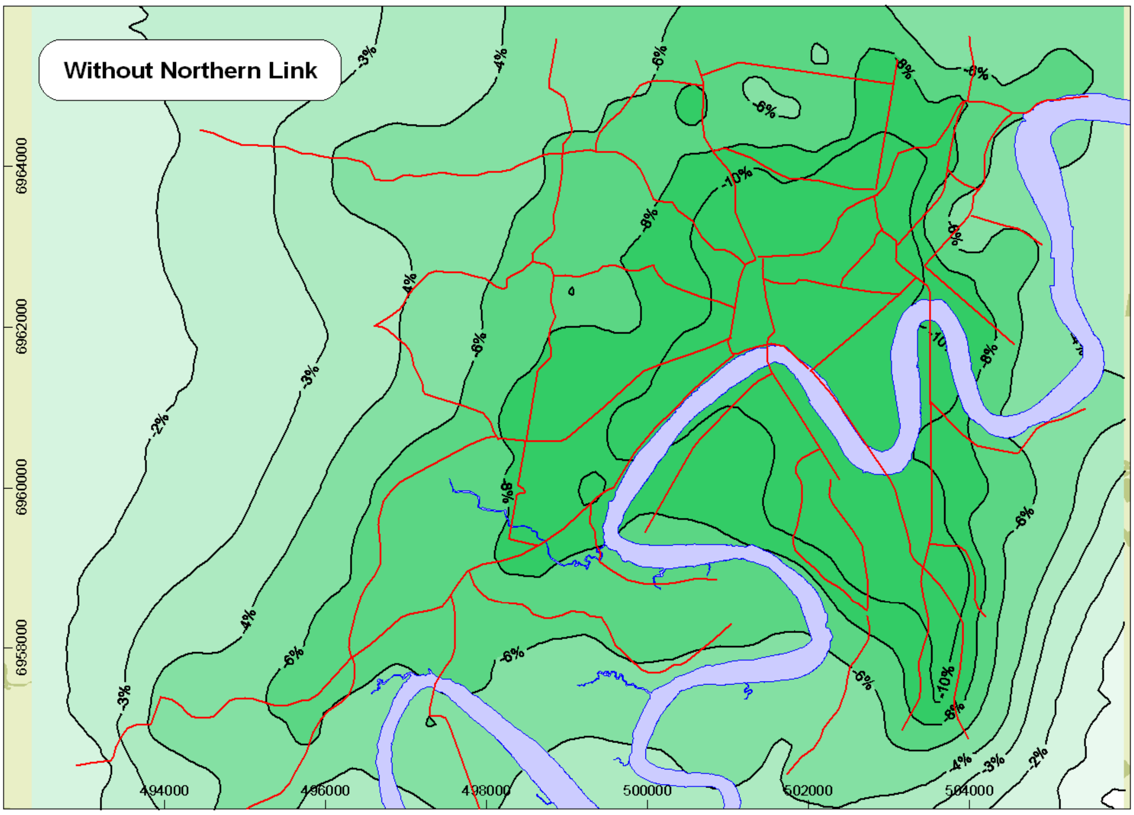
FIGURE 42

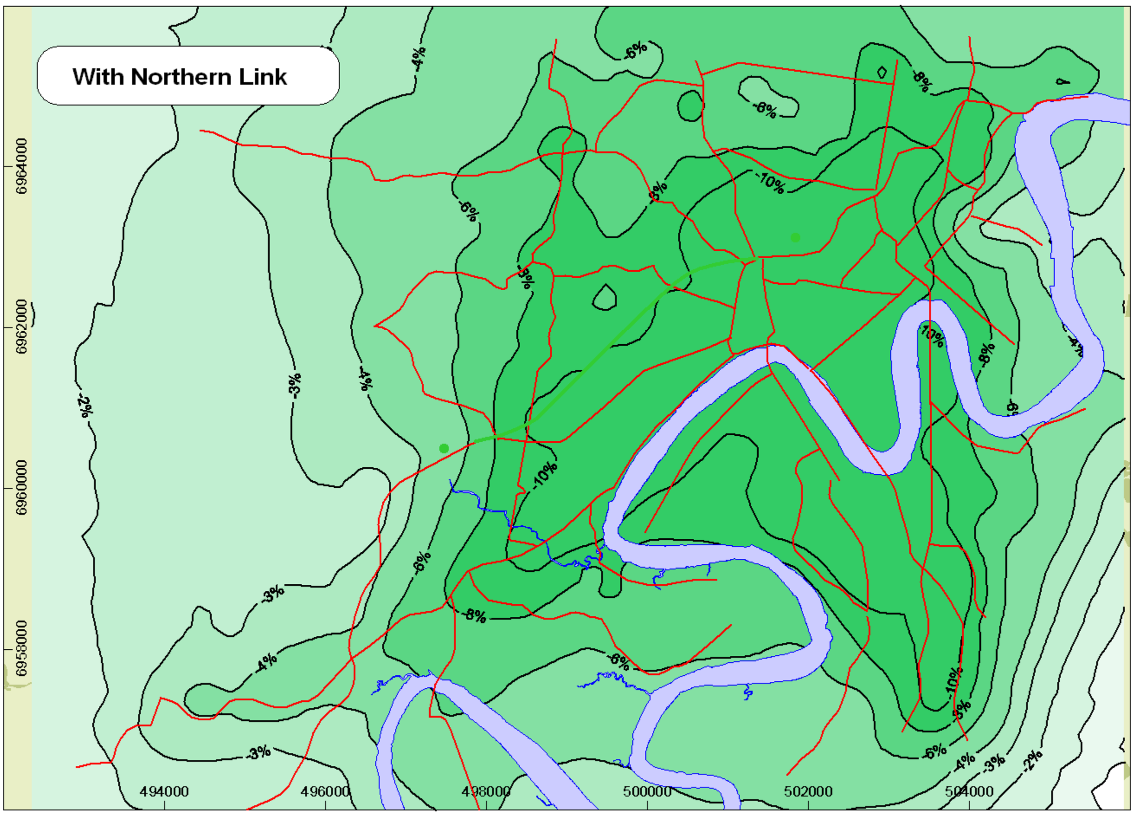




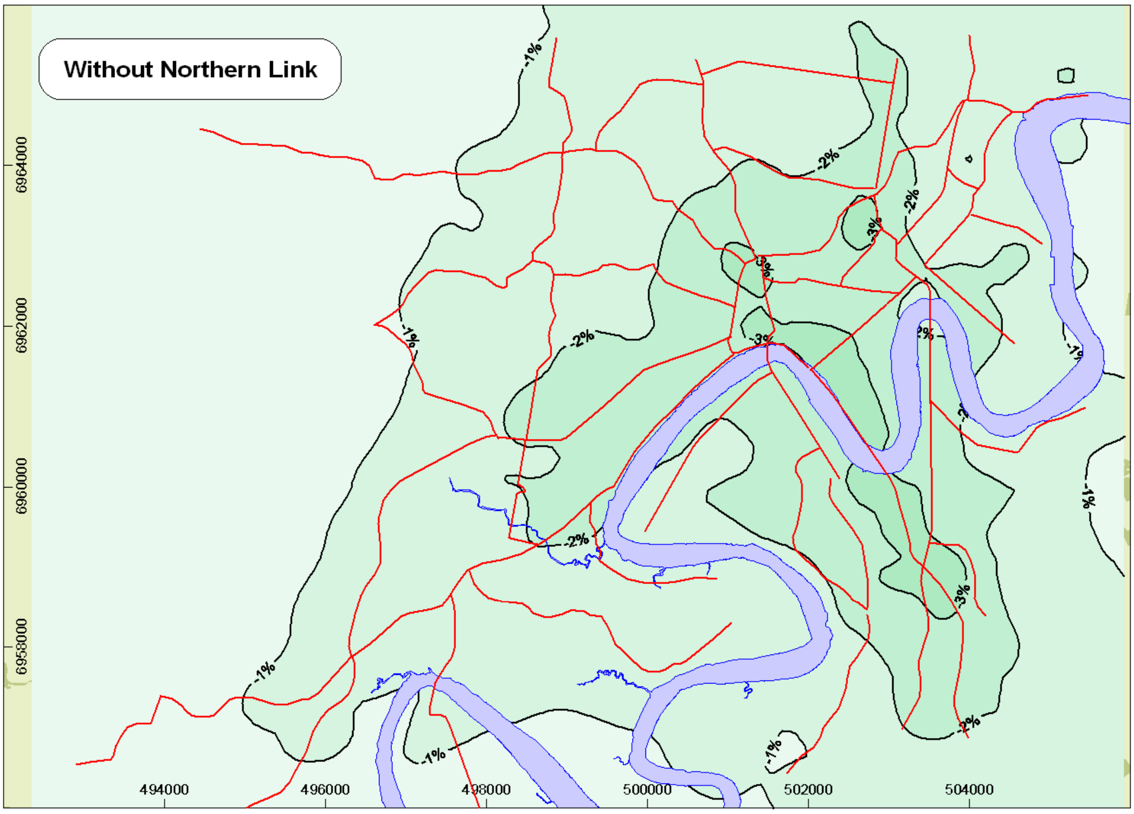
Percentage change from existing (2007) to 2014 for maximum 1-hour average NO_2

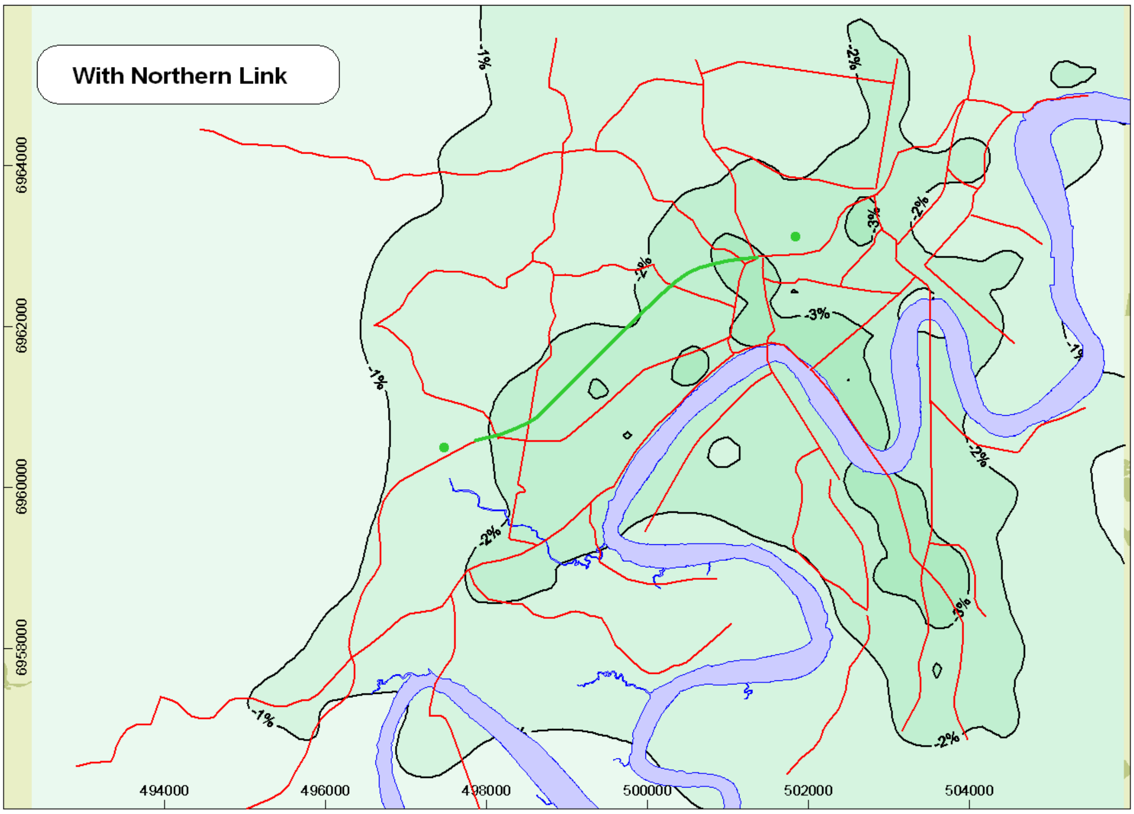
FIGURE 43



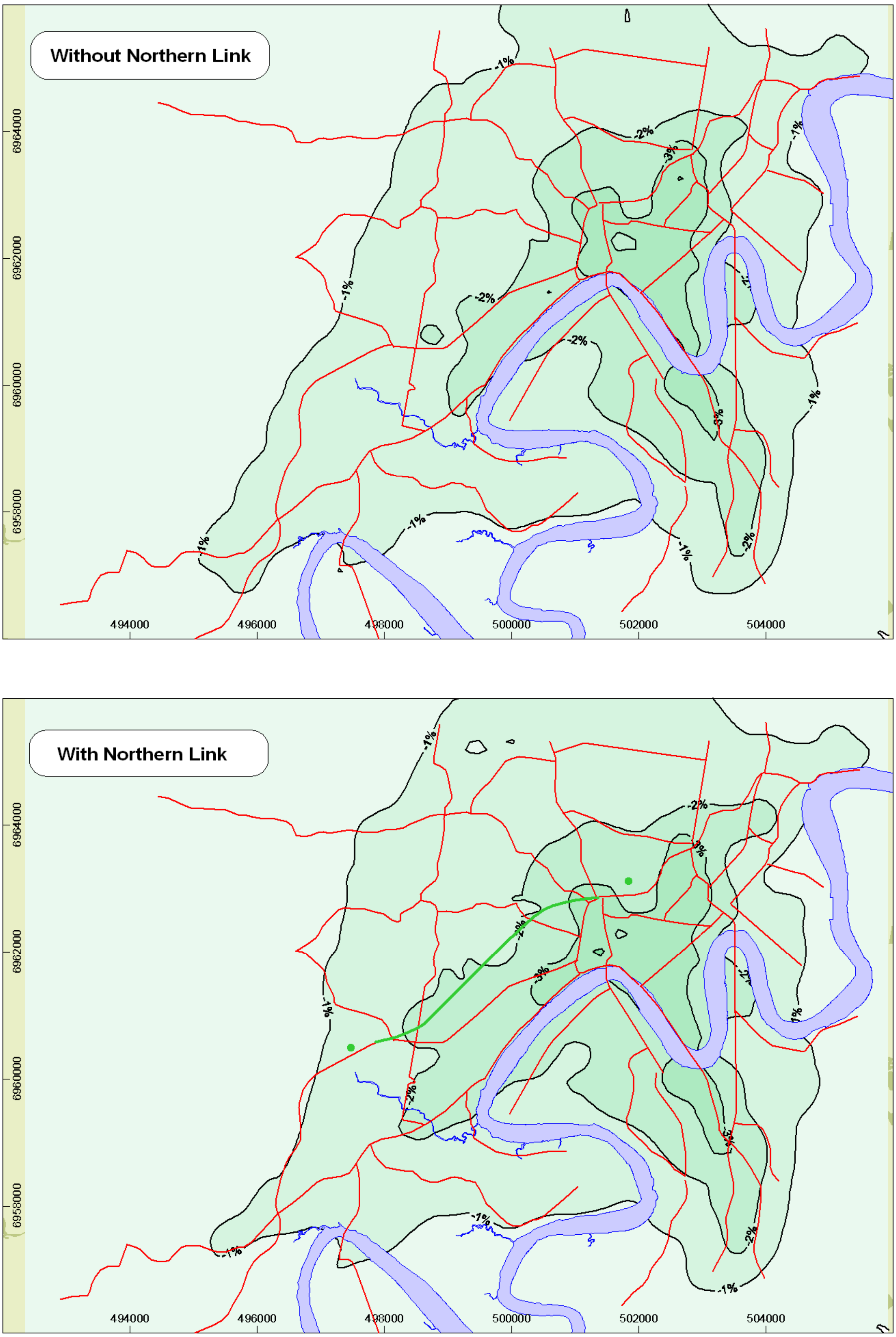


Percentage change from existing (2007) to 2014 for annual average NO_2



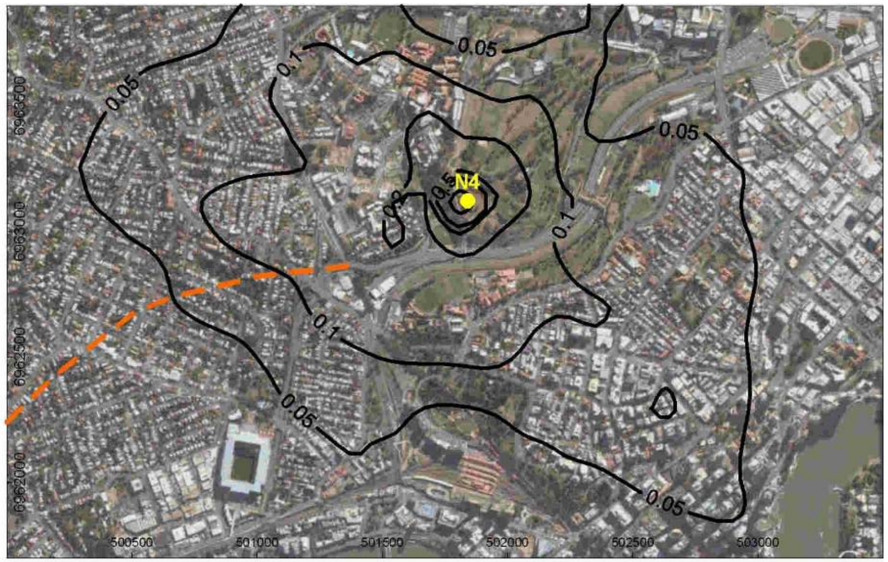


Percentage change from existing (2007) to 2014 for maximum 24-hour average PM_{10}

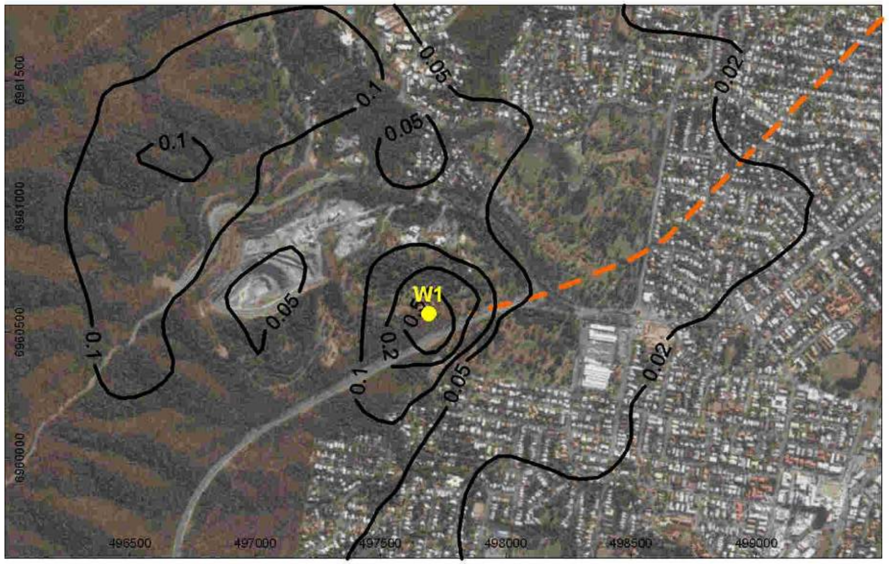


Percentage change from existing (2007) to 2014 for annual average PM_{10}

Southern Connection, 50 m above ground-level



Northern Connection, 50 m above ground-level



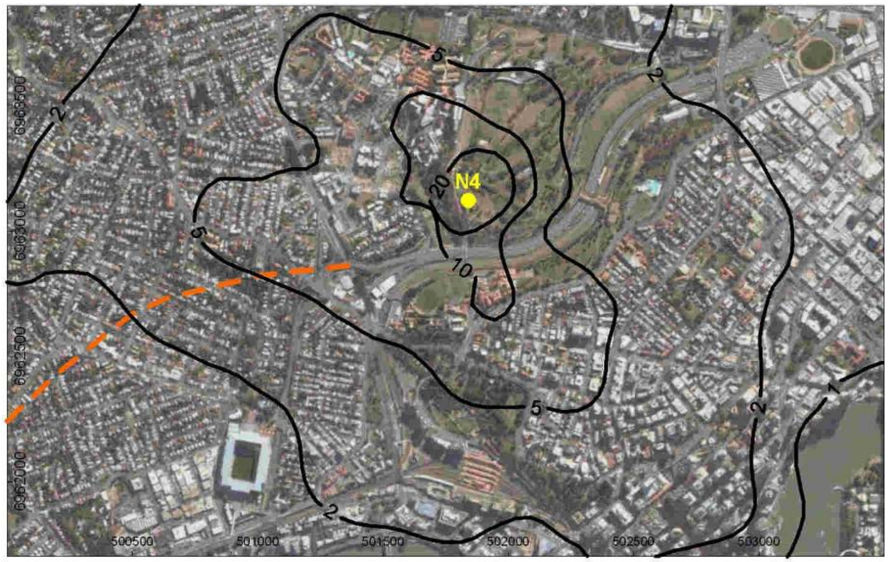
Southern Connection, 30 m above ground-level

Northern Connection, 30 m above ground-level

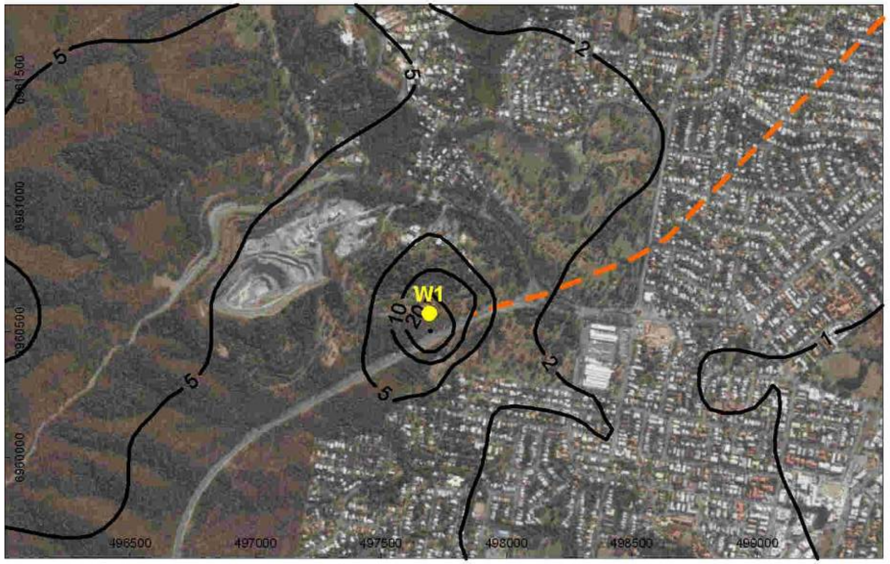
Predicted maximum 8-hour average CO concentrations above ground-level in 2014 (mg/m^3)

FIGURE 47

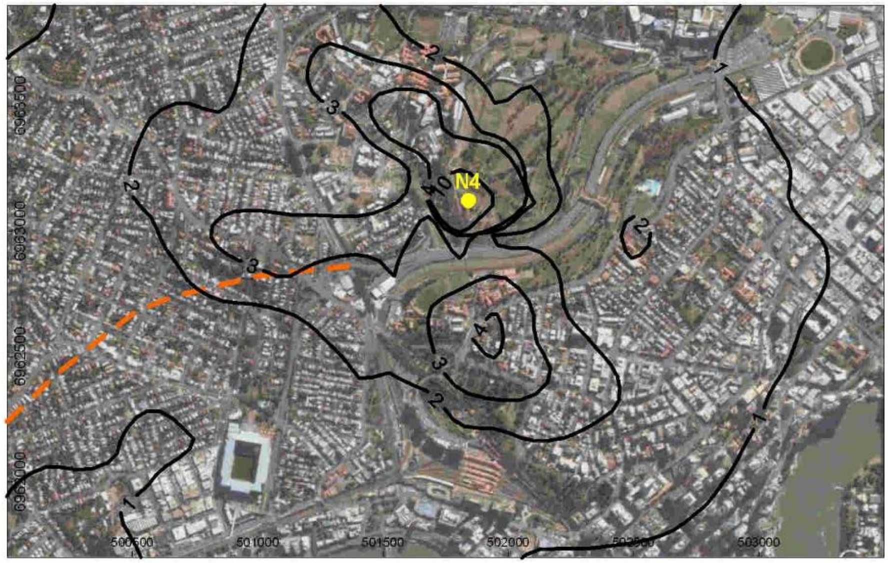
Southern Connection, 50 m above ground-level



Northern Connection, 50 m above ground-level



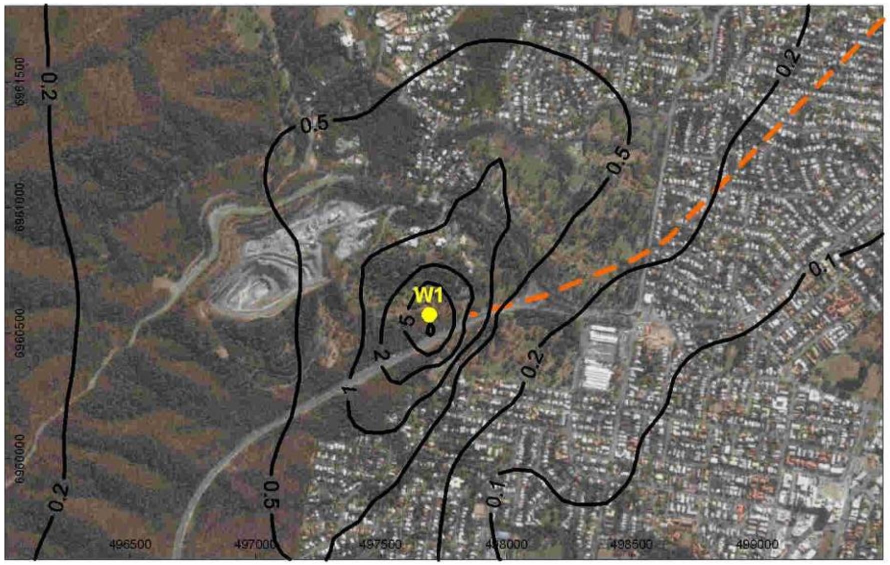
Southern Connection, 30 m above ground-level



Northern Connection, 30 m above ground-level

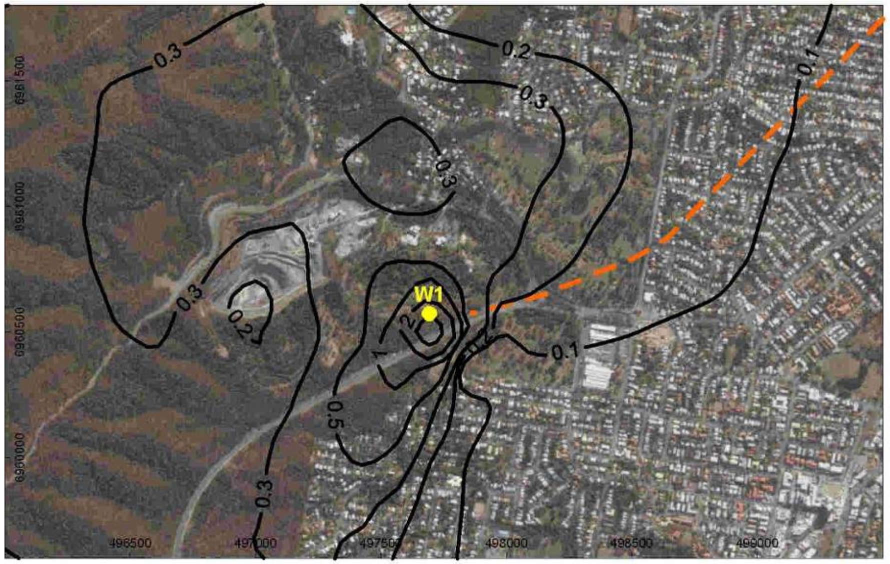
Predicted maximum 1-hour average NO_2 concentrations above ground-level in 2014 (µg/m^3)

FIGURE 48

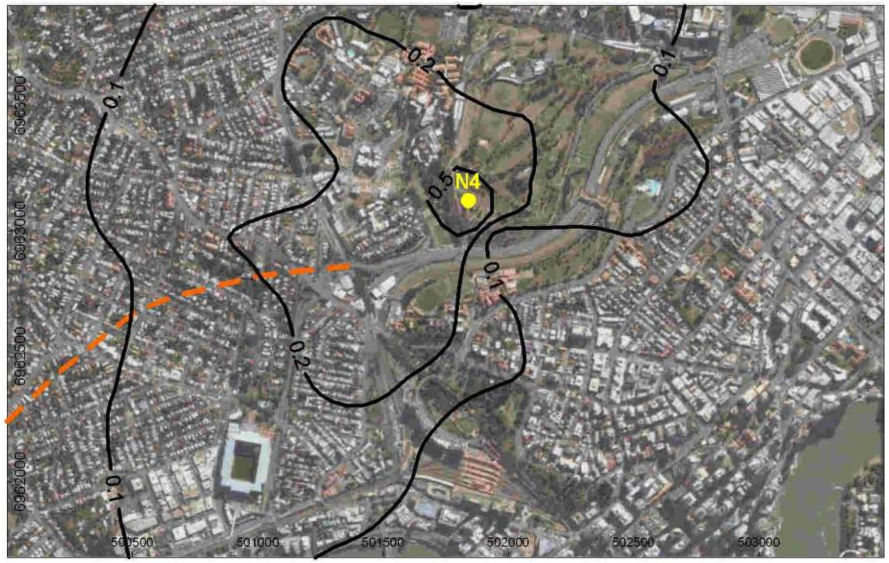


Southern Connection, 50 m above ground-level

Northern Connection, 50 m above ground-level



Southern Connection, 30 m above ground-level



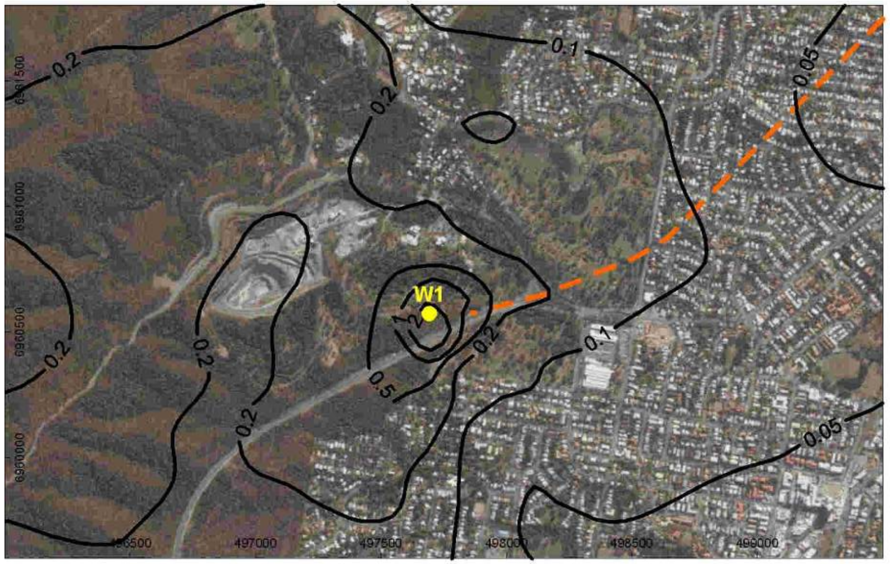
Northern Connection, 30 m above ground-level

Predicted annual average NO_2 concentrations above ground-level in 2014 (µg/m^3)

FIGURE 49

Southern Connection, 50 m above ground-level

Northern Connection, 50 m above ground-level

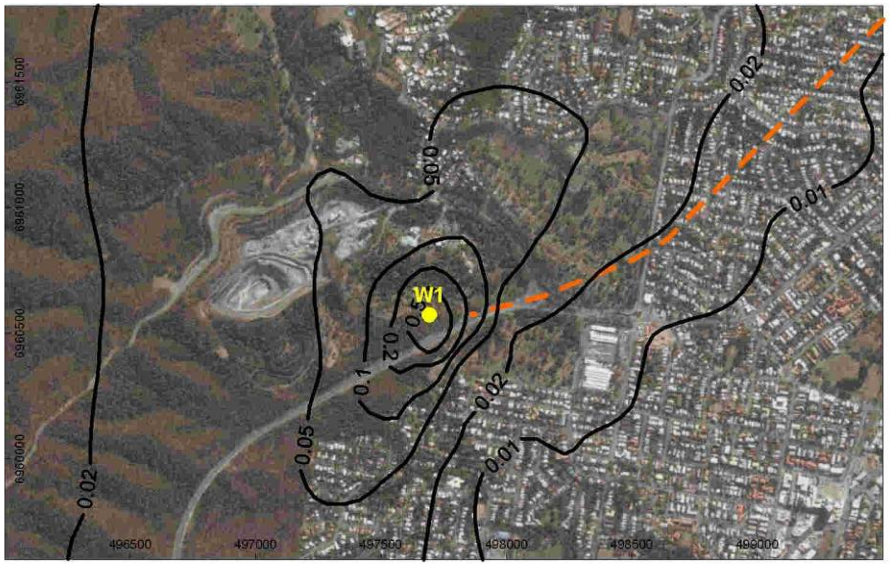


Southern Connection, 30 m above ground-level

Northern Connection, 30 m above ground-level

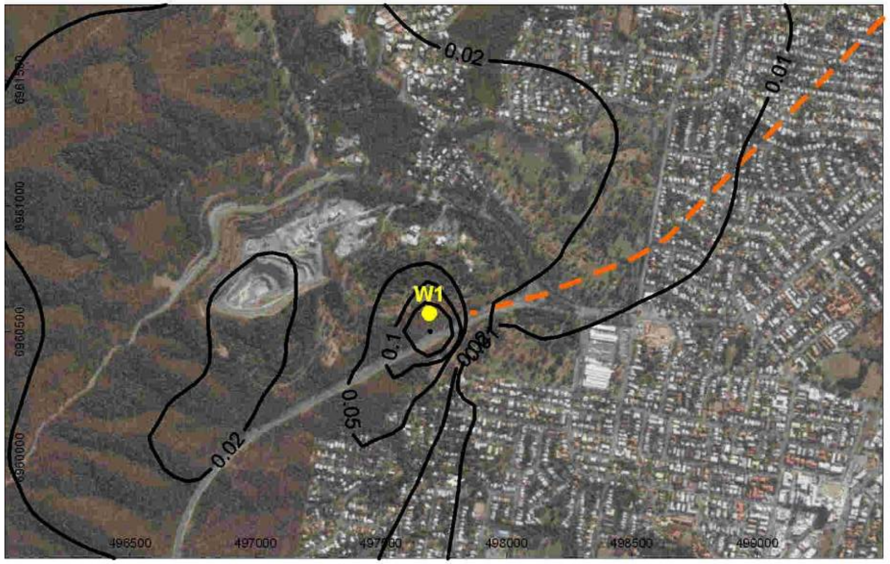
Predicted maximum 24-hour average PM_{10} concentrations above ground-level in 2014 (µg/m^3)

FIGURE 50

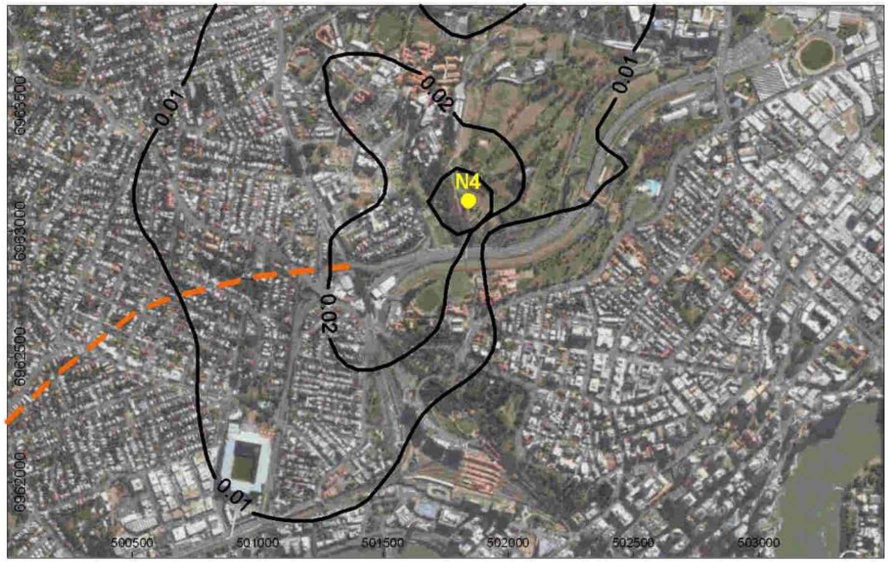


Southern Connection, 50 m above ground-level

Northern Connection, 50 m above ground-level



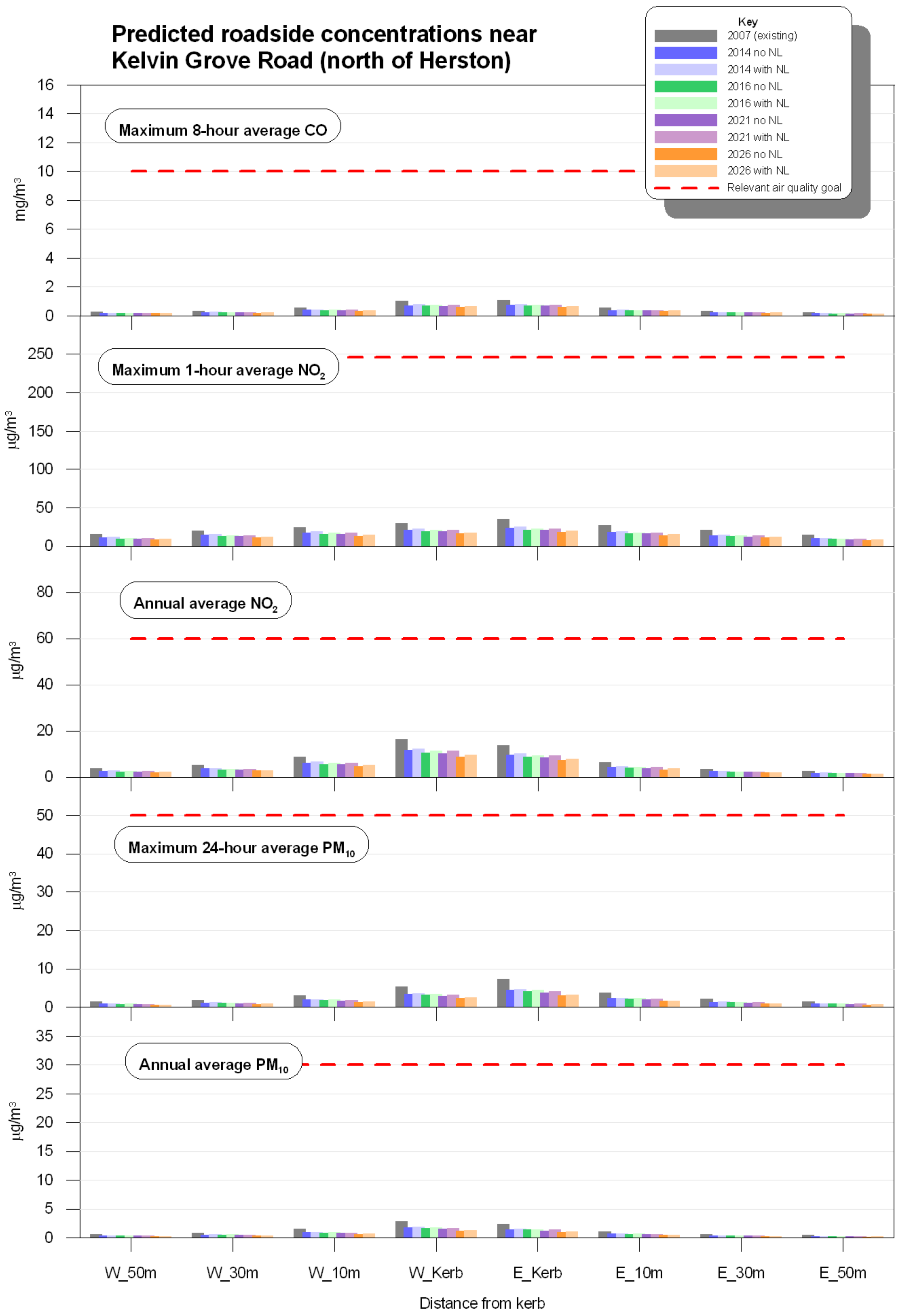
Southern Connection, 30 m above ground-level



Northern Connection, 30 m above ground-level

Predicted annual average PM_{10} concentrations above ground-level in 2014 ($\mu g/m^3$)

FIGURE 51



Predicted roadside concentrations near Kelvin Grove Road (north of Herston)
Key
2007 (existing)
2014 no NL
2014 with NL
2016 no NL
2016 with NL
2021 no NL
2021 with NL
2026 no NL
2026 with NL
Relevant air quality goal
Maximum 8-hour average CO
mg/m3
Maximum 1-hour average NO2
µg/m3
Annual average NO2
µg/m3
Maximum 24-hour average PM10
µg/m3
Annual average PM10
µg/m3
W_50m
W_30m
W_10m
W_Kerb
E_Kerb
E_10m
E_30m
E_50m
Distance from kerb

FIGURE 52

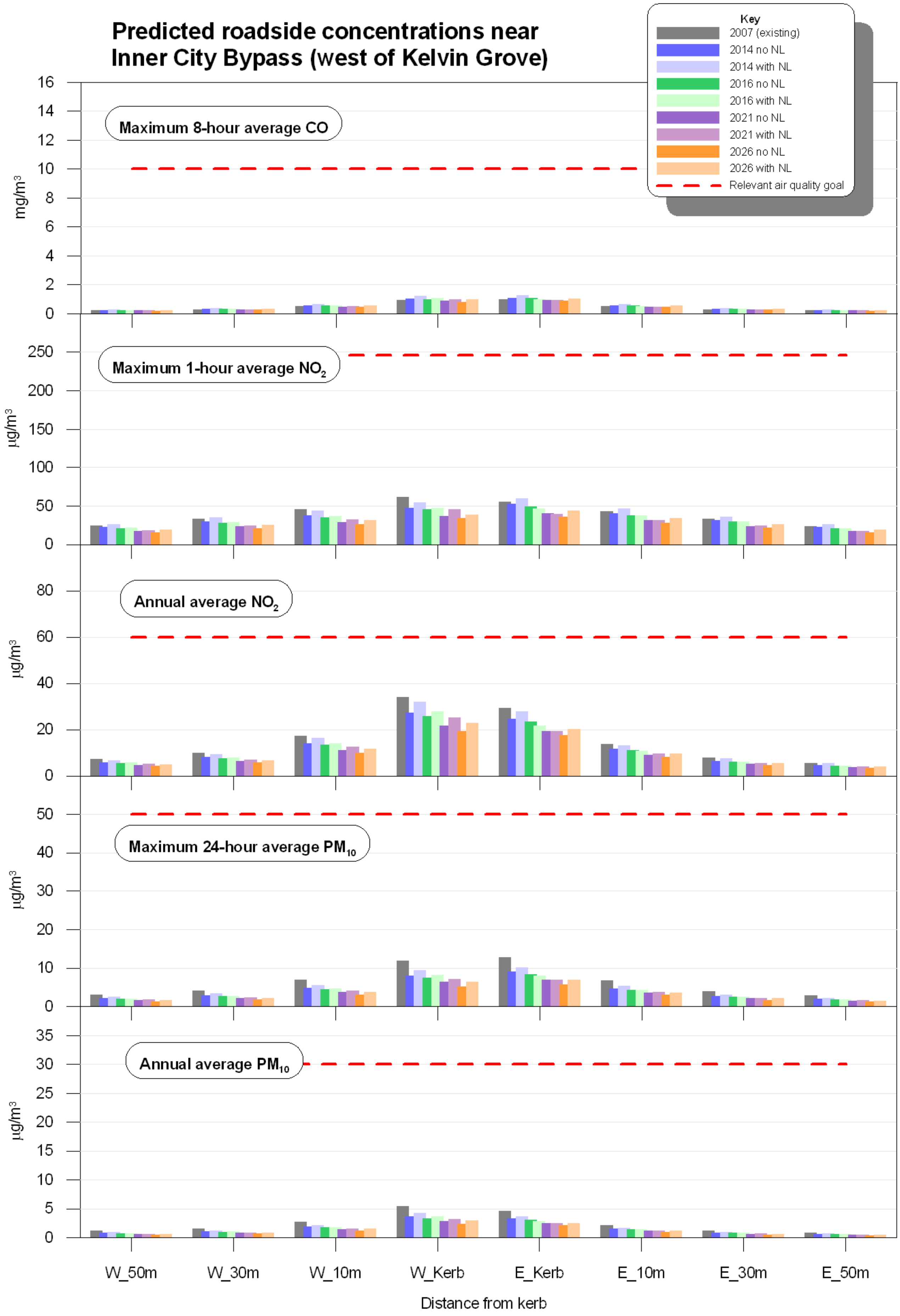

Predicted roadside concentrations near
Inner City Bypass (west of Kelvin Grove)
Key
2007 (existing)
2014 no NL
2014 with NL
2016 no NL
2016 with NL
2021 no NL
2021 with NL
2026 no NL
2026 with NL
Relevant air quality goal
Maximum 8-hour average CO
mg/m3
Maximum 1-hour average NO2
µg/m3
Annual average NO2
µg/m3
Maximum 24-hour average PM10
µg/m3
Annual average PM10
µg/m3
W_50m
W_30m
W_10m
W_Kerb
E_Kerb
E_10m
E_30m
E_50m
Distance from kerb

FIGURE 53

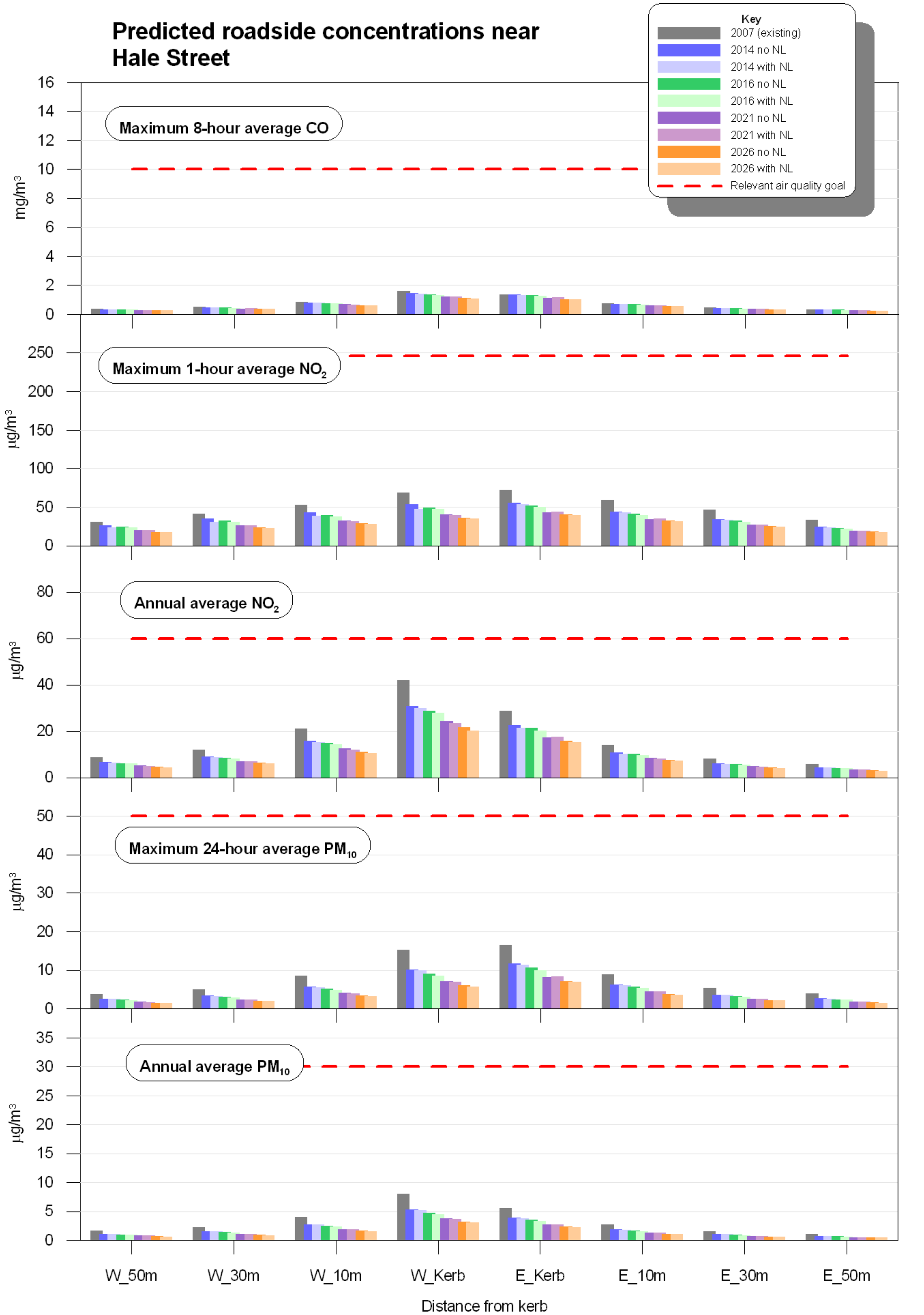

Predicted roadside concentrations near Hale Street
Key
2007 (existing)
2014 no NL
2014 with NL
2016 no NL
2016 with NL
2021 no NL
2021 with NL
2026 no NL
2026 with NL
Relevant air quality goal
Maximum 8-hour average CO
mg/m3
Maximum 1-hour average NO2
µg/m3
Annual average NO2
µg/m3
Maximum 24-hour average PM10
µg/m3
Annual average PM10
µg/m3
W_50m
W_30m
W_10m
W_Kerb
E_Kerb
E_10m
E_30m
E_50m
Distance from kerb

FIGURE 54

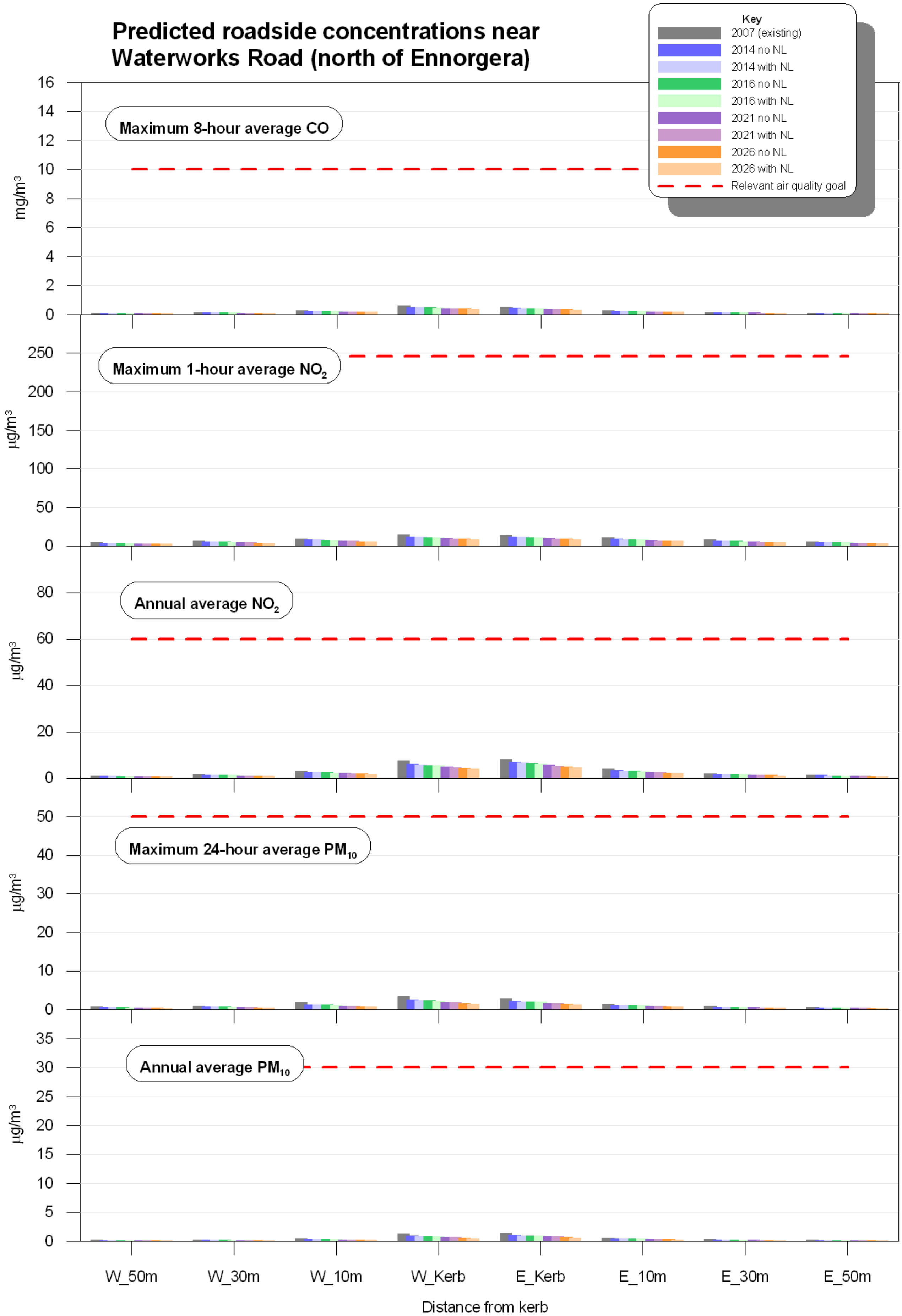

Predicted roadside concentrations near Waterworks Road (north of Ennorgera)
Key
2007 (existing)
2014 no NL
2014 with NL
2016 no NL
2016 with NL
2021 no NL
2021 with NL
2026 no NL
2026 with NL
Relevant air quality goal
Maximum 8-hour average CO
mg/m³
Maximum 1-hour average NO₂
µg/m³
Annual average NO₂
µg/m³
Maximum 24-hour average PM₁₀
µg/m³
Annual average PM₁₀
µg/m³
W_50m
W_30m
W_10m
W_Kerb
E_Kerb
E_10m
E_30m
E_50m
Distance from kerb

FIGURE 55

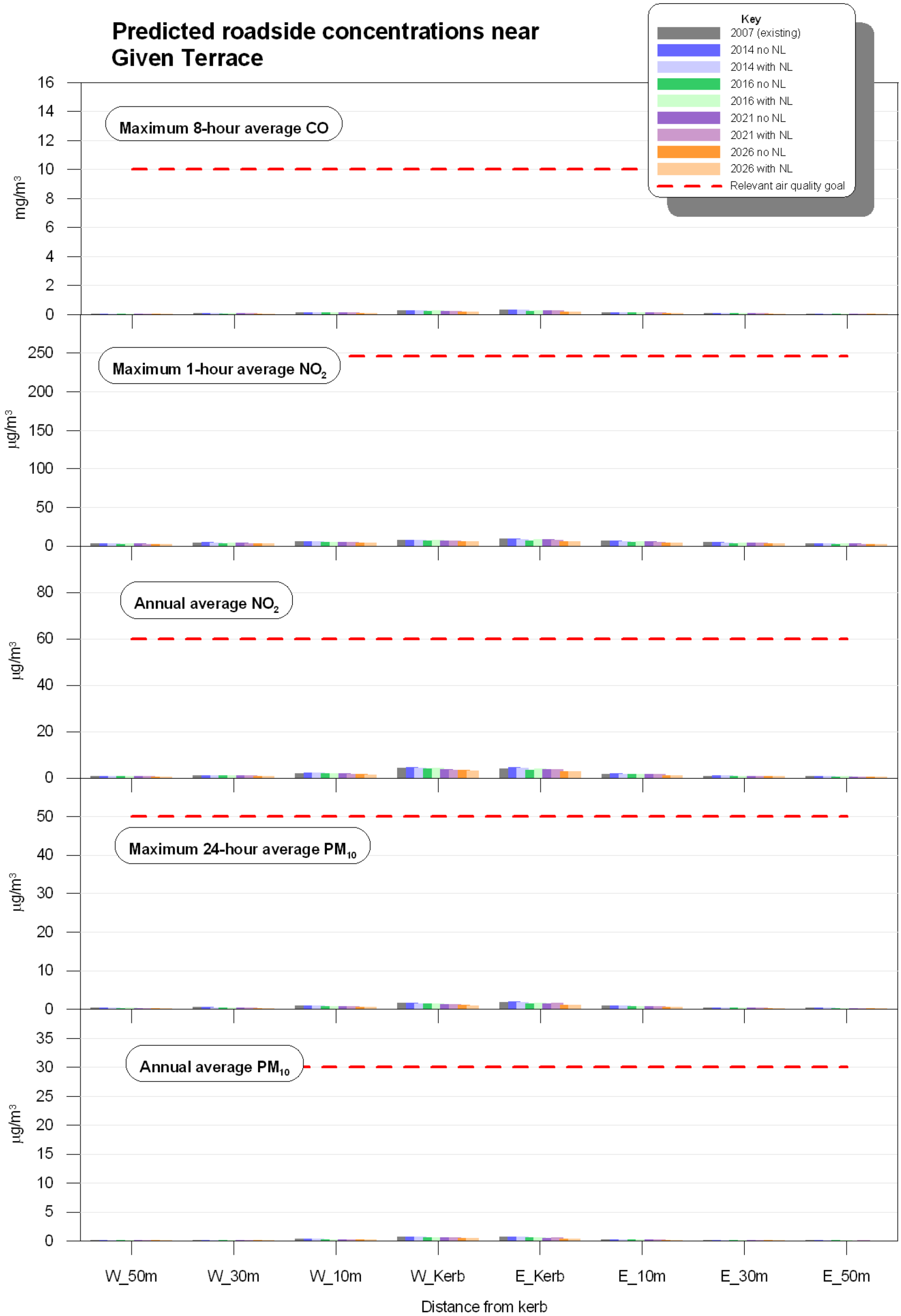
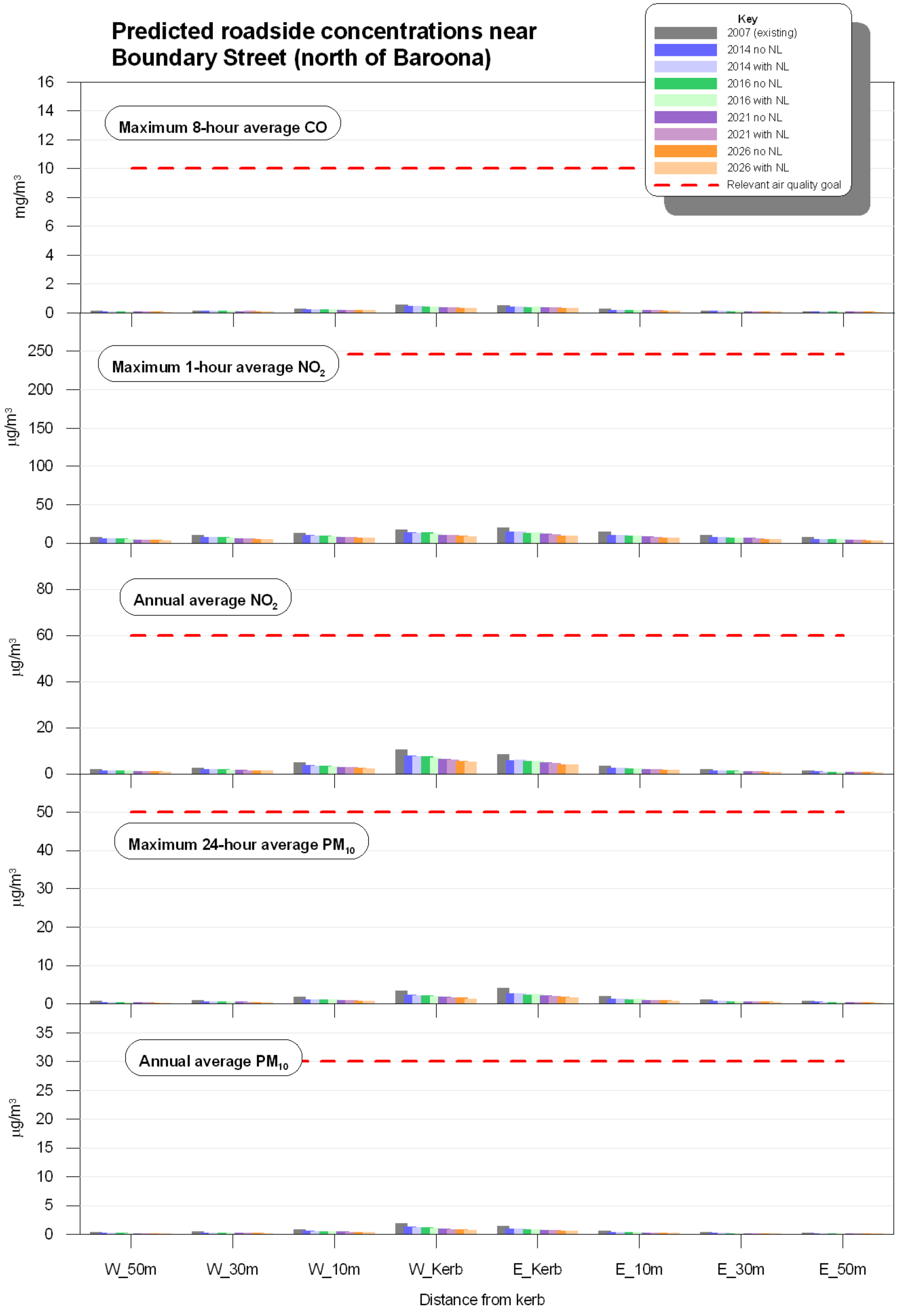
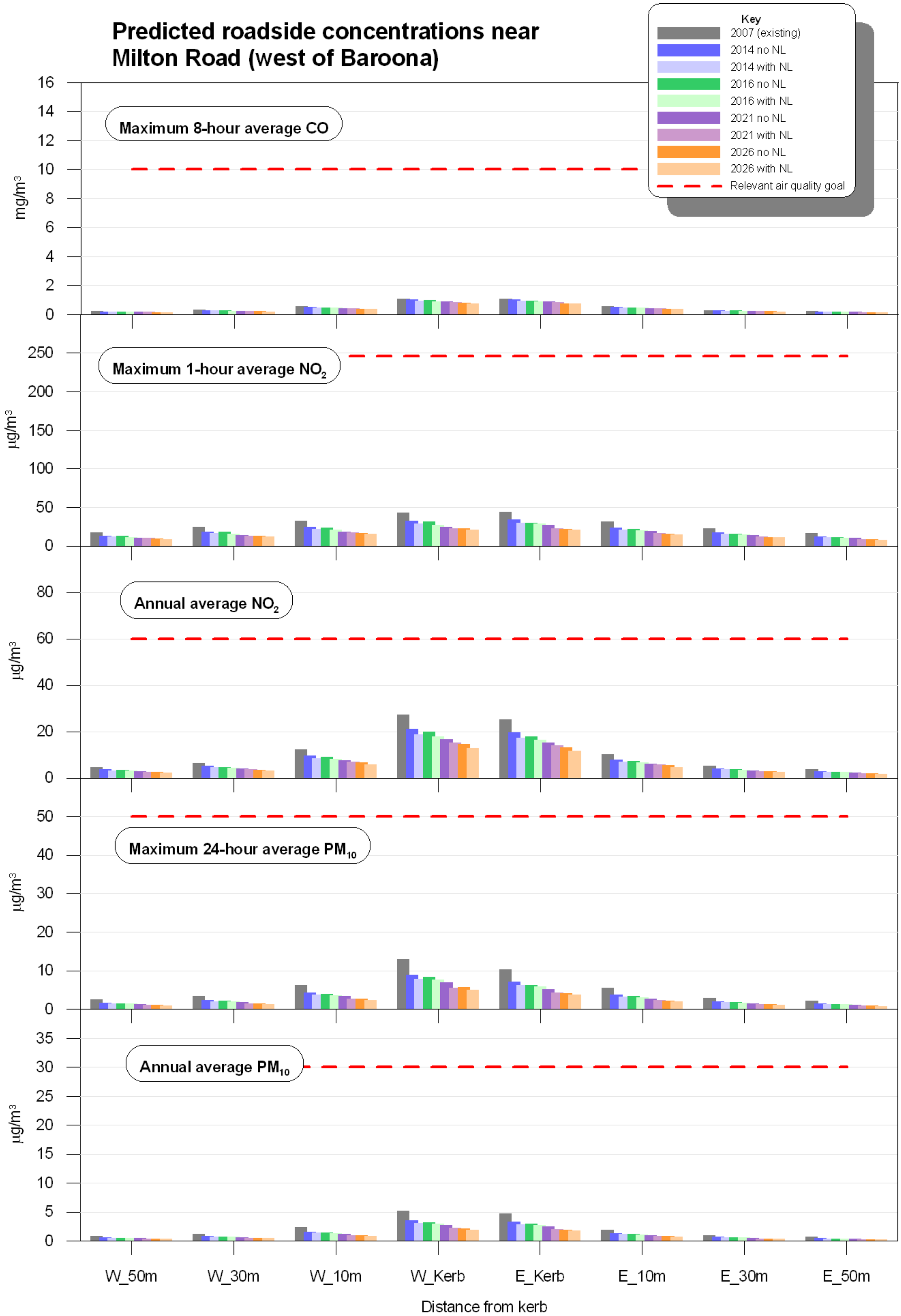

Predicted roadside concentrations near Given Terrace
Key
2007 (existing)
2014 no NL
2014 with NL
2016 no NL
2016 with NL
2021 no NL
2021 with NL
2026 no NL
2026 with NL
Relevant air quality goal
Maximum 8-hour average CO
mg/m3
Maximum 1-hour average NO2
µg/m3
Annual average NO2
µg/m3
Maximum 24-hour average PM10
µg/m3
Annual average PM10
µg/m3
W_50m
W_30m
W_10m
W_Kerb
E_Kerb
E_10m
E_30m
E_50m
Distance from kerb

FIGURE 56



Predicted roadside concentrations near Boundary Street (north of Baroona)
Key
2007 (existing)
2014 no NL
2014 with NL
2016 no NL
2016 with NL
2021 no NL
2021 with NL
2026 no NL
2026 with NL
Relevant air quality goal
Maximum 8-hour average CO
mg/m3
Maximum 1-hour average NO2
µg/m3
Annual average NO2
µg/m3
Maximum 24-hour average PM10
µg/m3
Annual average PM10
µg/m3
W_50m
W_30m
W_10m
W_Kerb
E_Kerb
E_10m
E_30m
E_50m
Distance from kerb

FIGURE 57



Predicted roadside concentrations near Milton Road (west of Baroona)
Key
2007 (existing)
2014 no NL
2014 with NL
2016 no NL
2016 with NL
2021 no NL
2021 with NL
2026 no NL
2026 with NL
Relevant air quality goal
Maximum 8-hour average CO
mg/m3
Maximum 1-hour average NO2
µg/m3
Annual average NO2
µg/m3
Maximum 24-hour average PM10
µg/m3
Annual average PM10
µg/m3
W_50m
W_30m
W_10m
W_Kerb
E_Kerb
E_10m
E_30m
E_50m
Distance from kerb

FIGURE 58

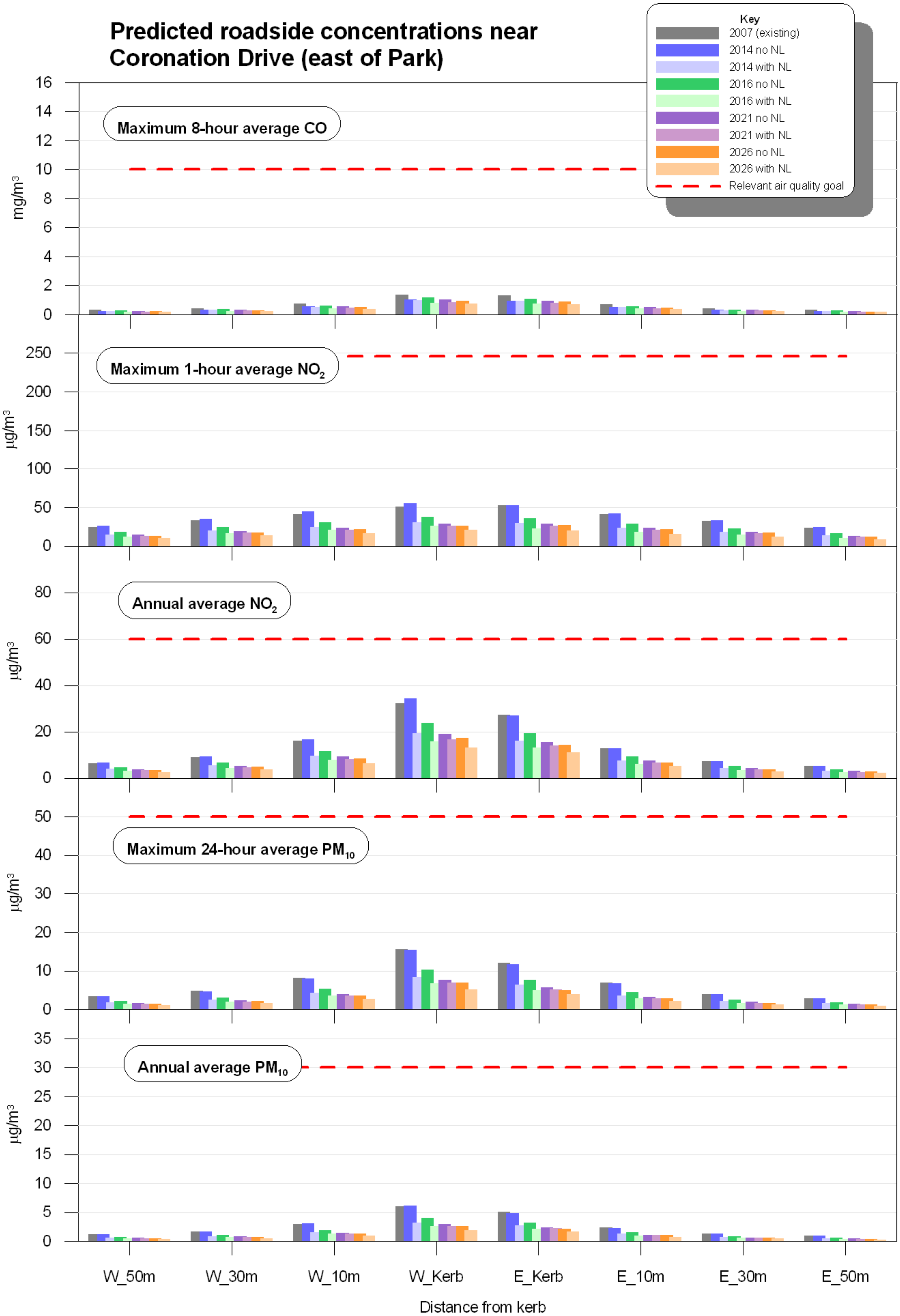

Predicted roadside concentrations near Coronation Drive (east of Park)
Key
2007 (existing)
2014 no NL
2014 with NL
2016 no NL
2016 with NL
2021 no NL
2021 with NL
2026 no NL
2026 with NL
Relevant air quality goal
Maximum 8-hour average CO
mg/m3
Maximum 1-hour average NO2
µg/m3
Annual average NO2
µg/m3
Maximum 24-hour average PM10
µg/m3
Annual average PM10
µg/m3
W_50m
W_30m
W_10m
W_Kerb
E_Kerb
E_10m
E_30m
E_50m
Distance from kerb

FIGURE 59

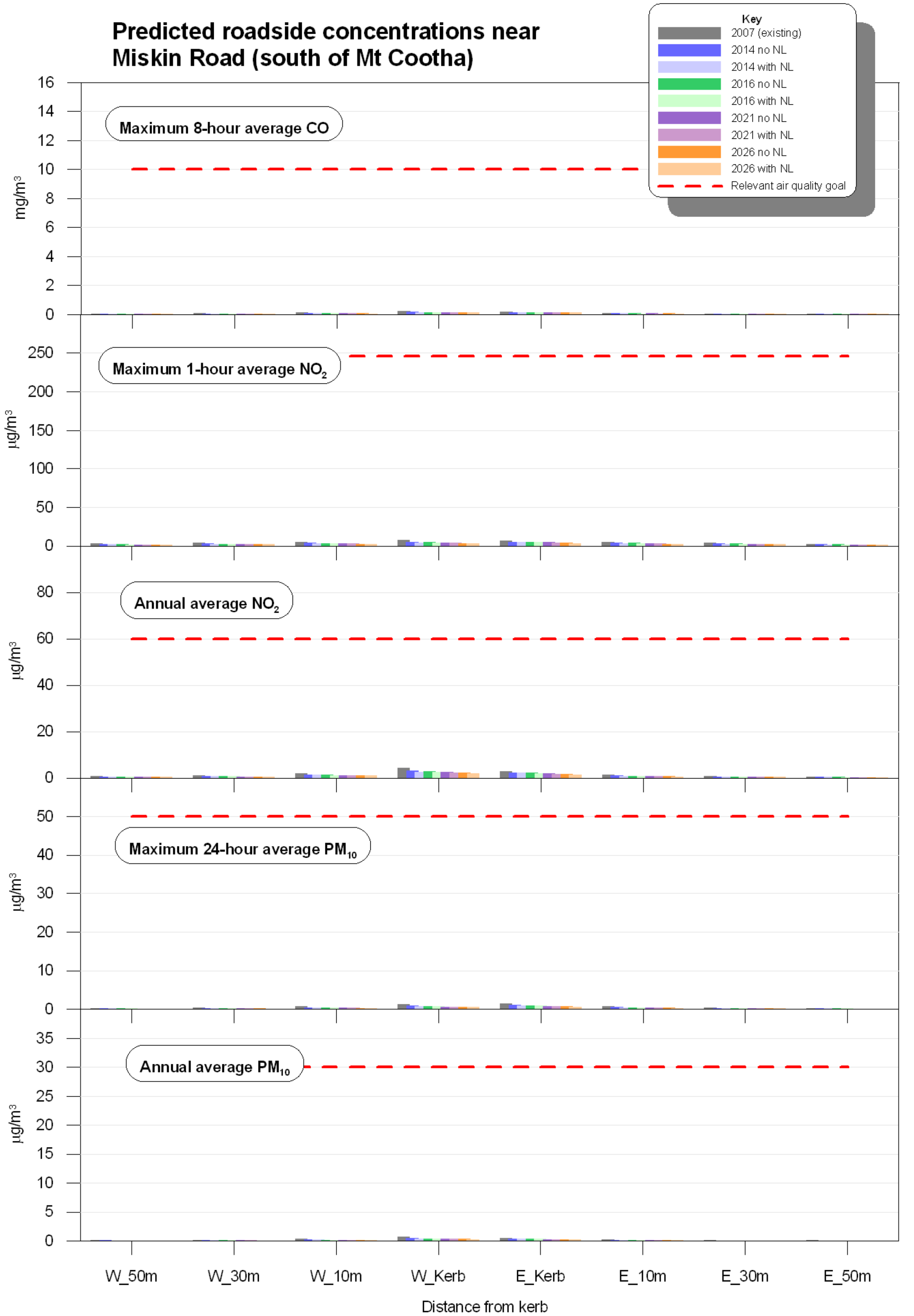
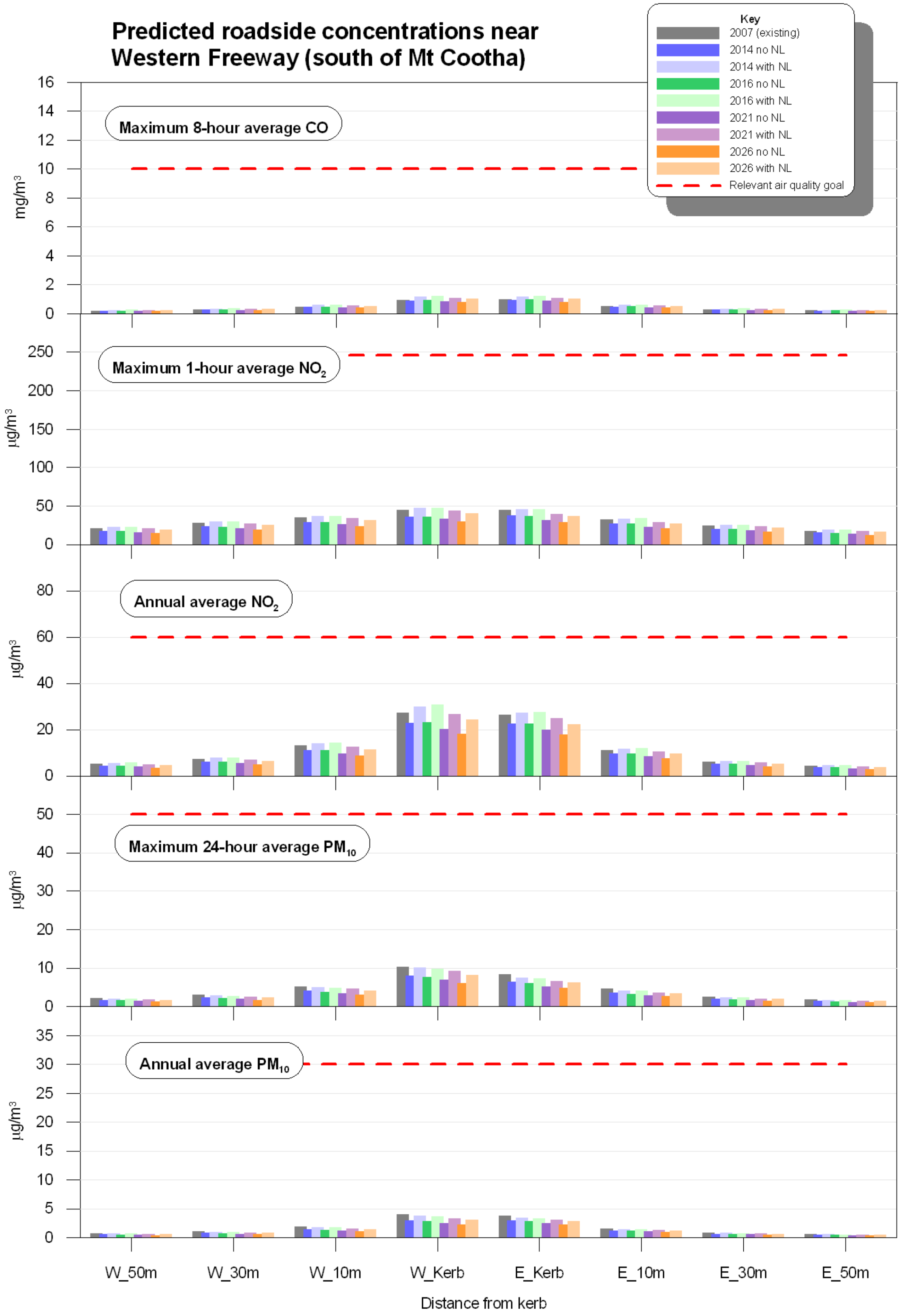
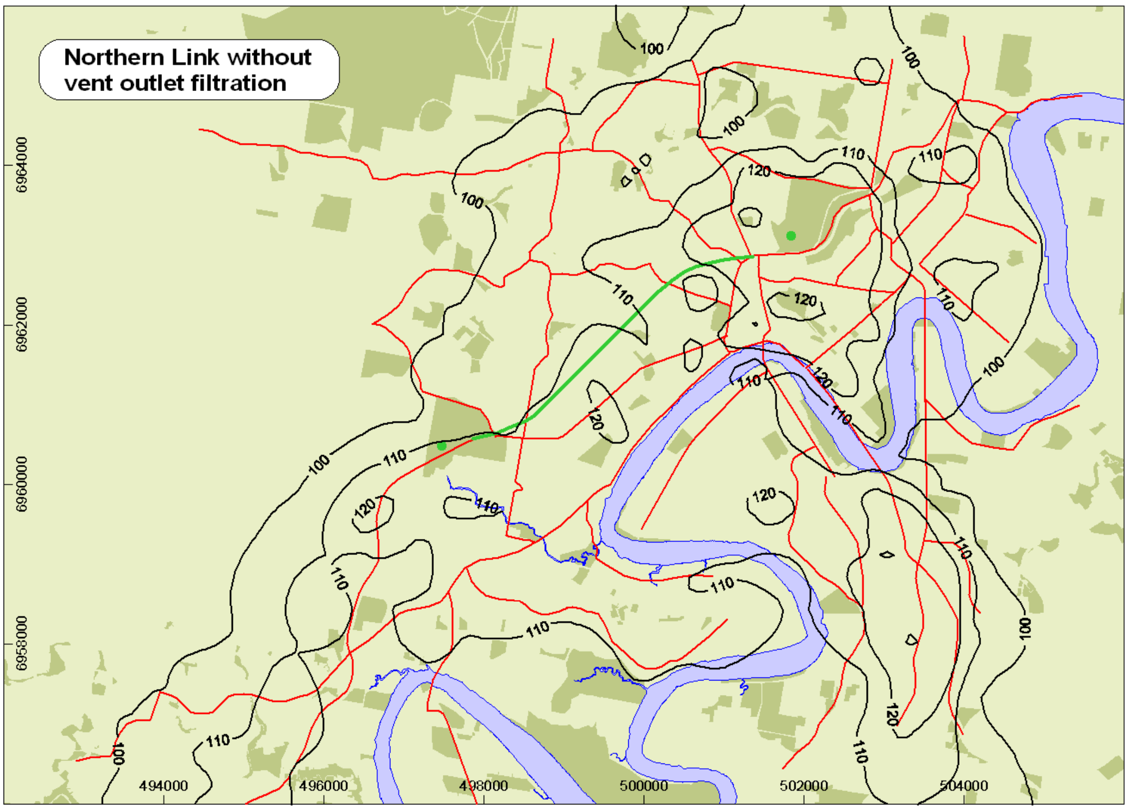

Predicted roadside concentrations near Miskin Road (south of Mt Cootha)
Key
2007 (existing)
2014 no NL
2014 with NL
2016 no NL
2016 with NL
2021 no NL
2021 with NL
2026 no NL
2026 with NL
Relevant air quality goal
Maximum 8-hour average CO
mg/m3
Maximum 1-hour average NO2
µg/m3
Annual average NO2
µg/m3
Maximum 24-hour average PM10
µg/m3
Annual average PM10
µg/m3
W_50m
W_30m
W_10m
W_Kerb
E_Kerb
E_10m
E_30m
E_50m
Distance from kerb

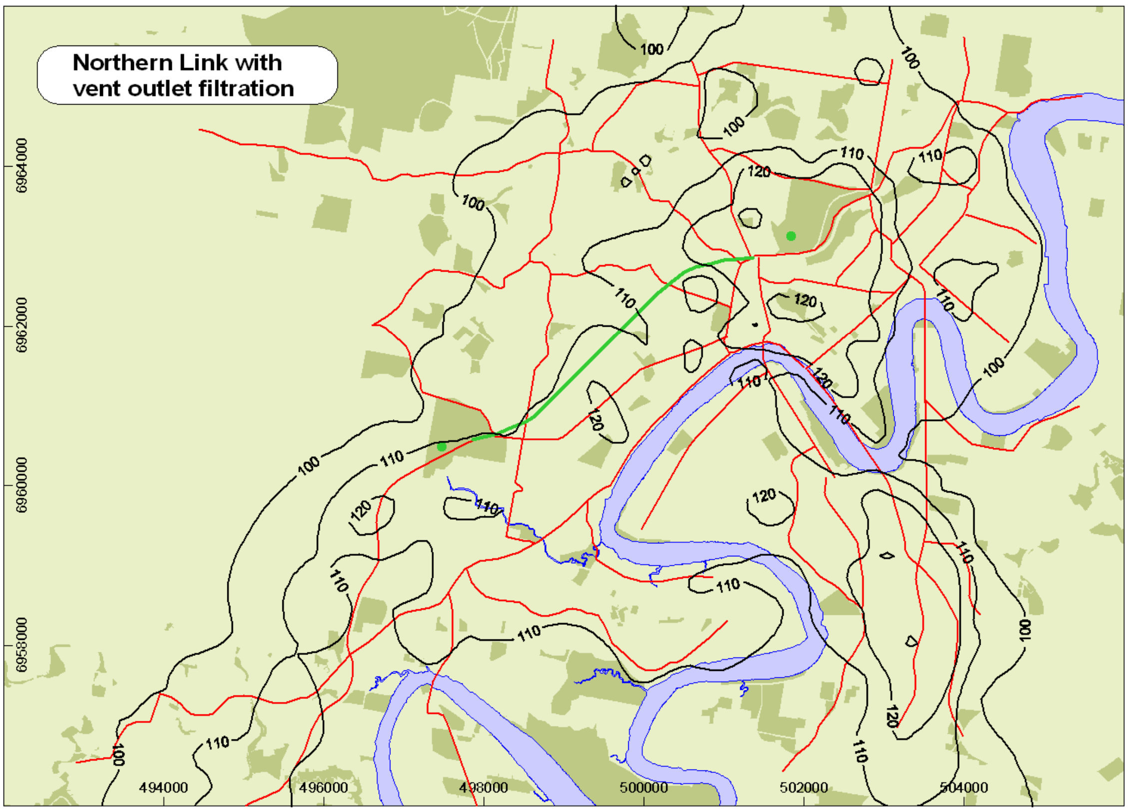
FIGURE 60



Predicted roadside concentrations near Western Freeway (south of Mt Coot-tha)
Key
2007 (existing)
2014 no NL
2014 with NL
2016 no NL
2016 with NL
2021 no NL
2021 with NL
2026 no NL
2026 with NL
Relevant air quality goal
Maximum 8-hour average CO
mg/m3
Maximum 1-hour average NO2
µg/m3
Annual average NO2
µg/m3
Maximum 24-hour average PM10
µg/m3
Annual average PM10
µg/m3
W_50m
W_30m
W_10m
W_Kerb
E_Kerb
E_10m
E_30m
E_50m
Distance from kerb

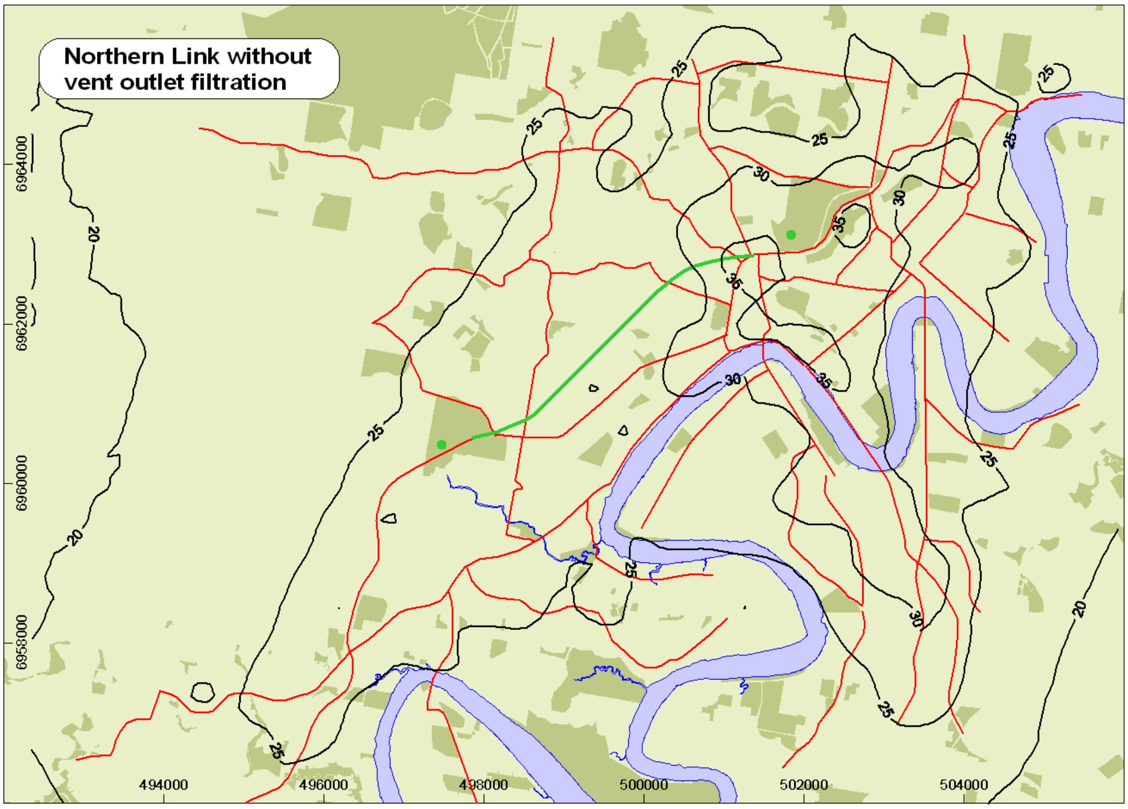
FIGURE 61

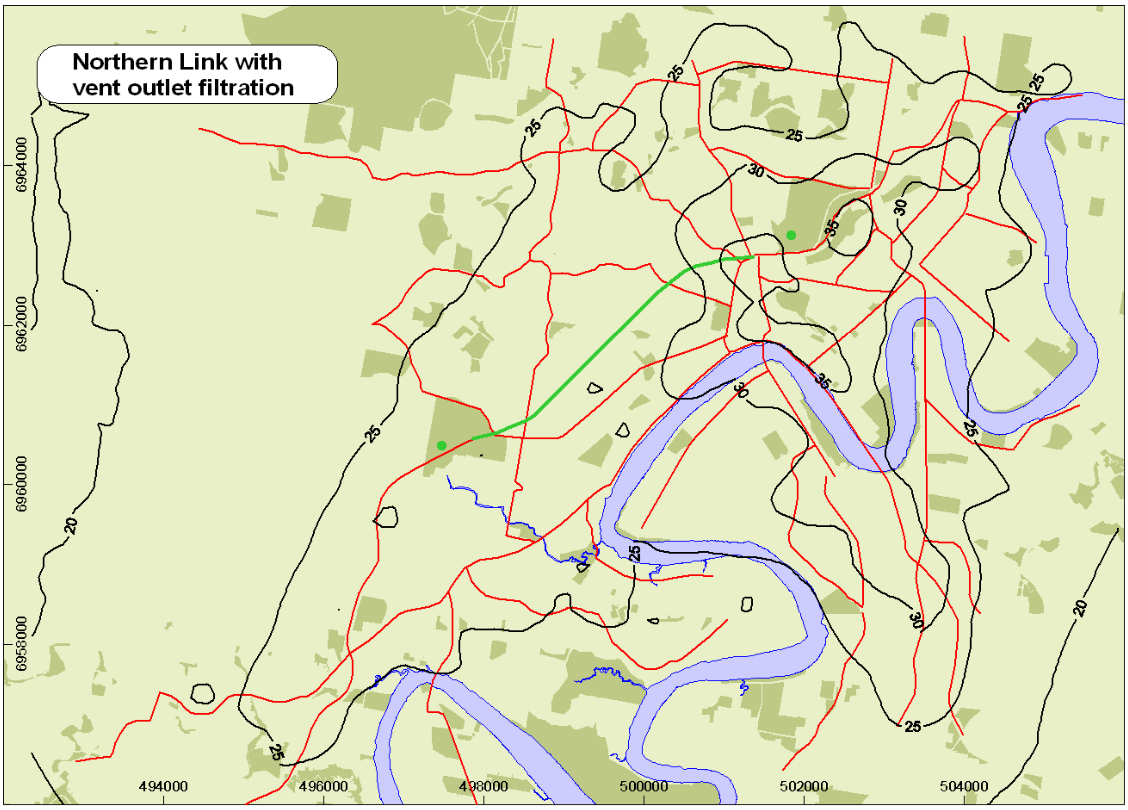




Comparison of without and with tunnel filtration for maximum 1-hour average NO_2 concentrations in 2014 (µg/m^3)

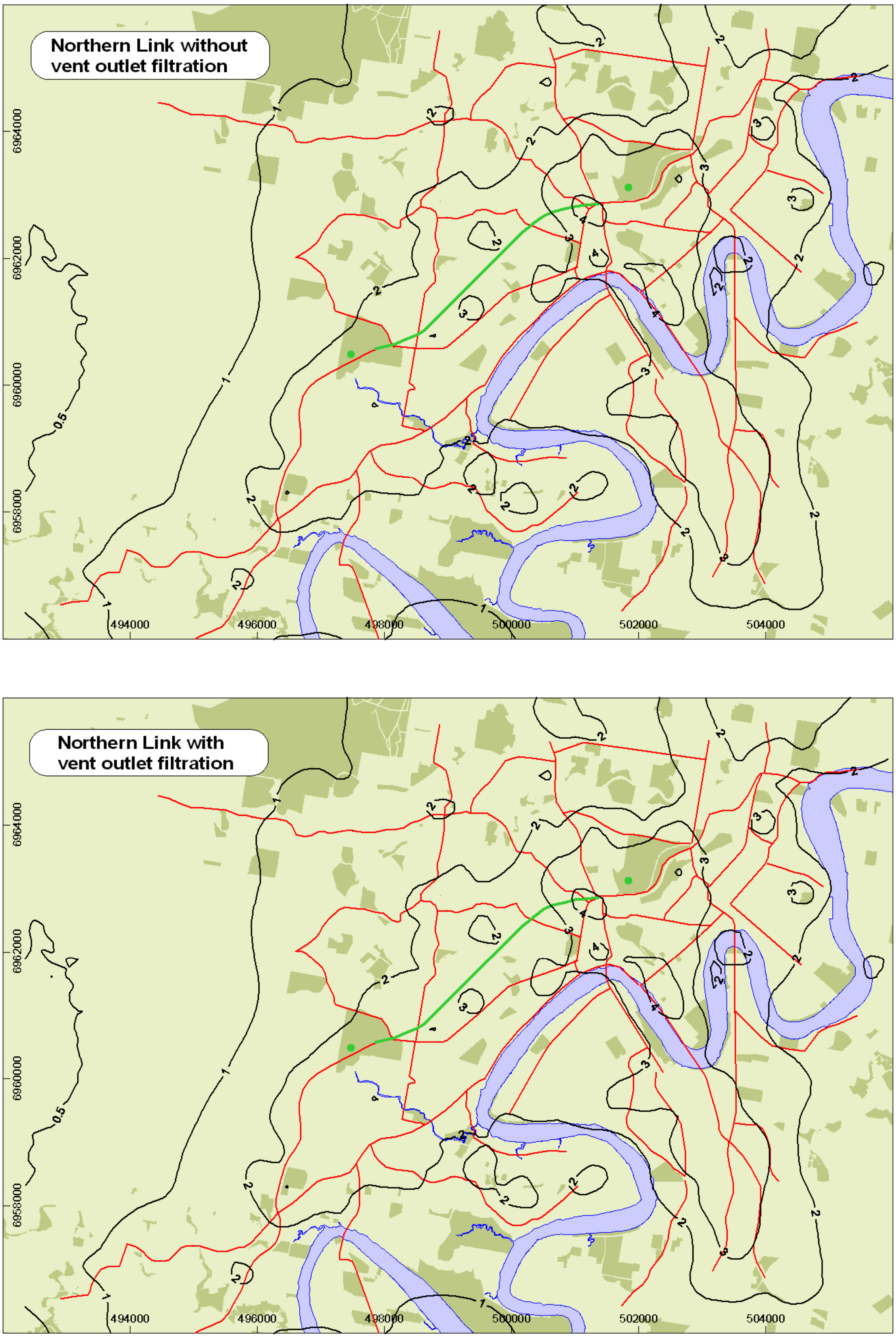
FIGURE 62





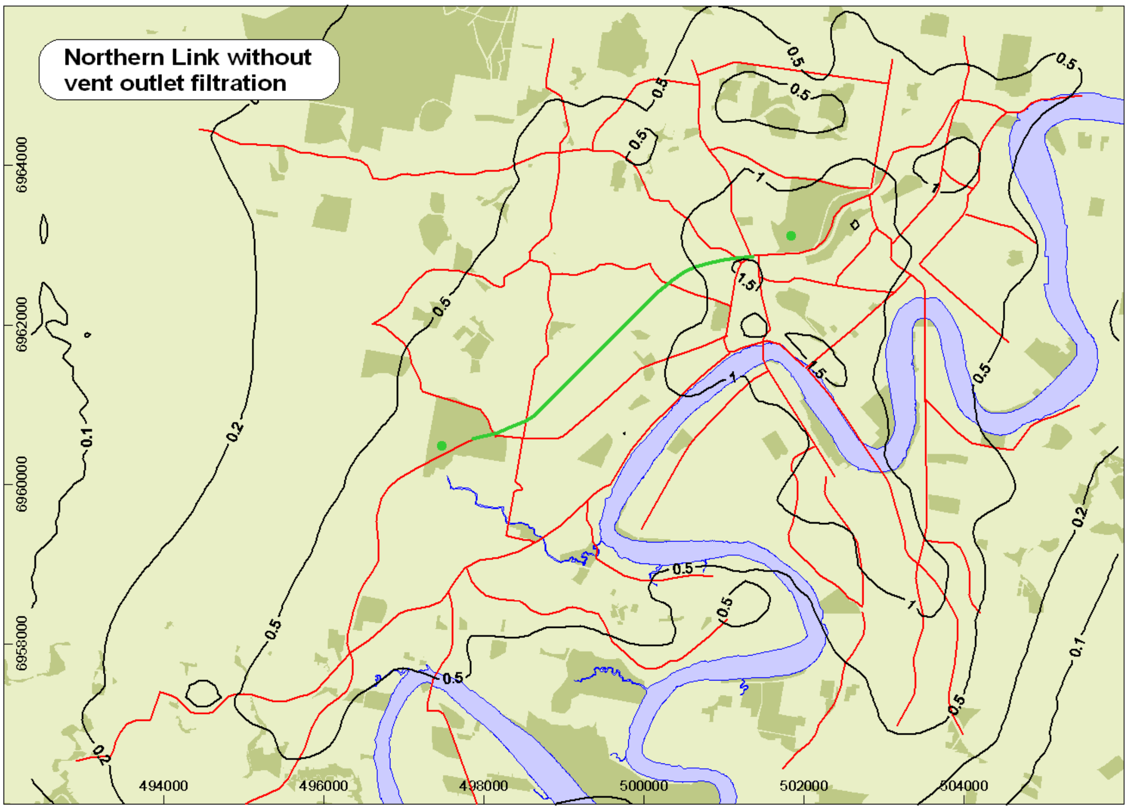
Comparison of without and with tunnel filtration for annual average NO_2 concentrations in 2014 (µg/m^3)

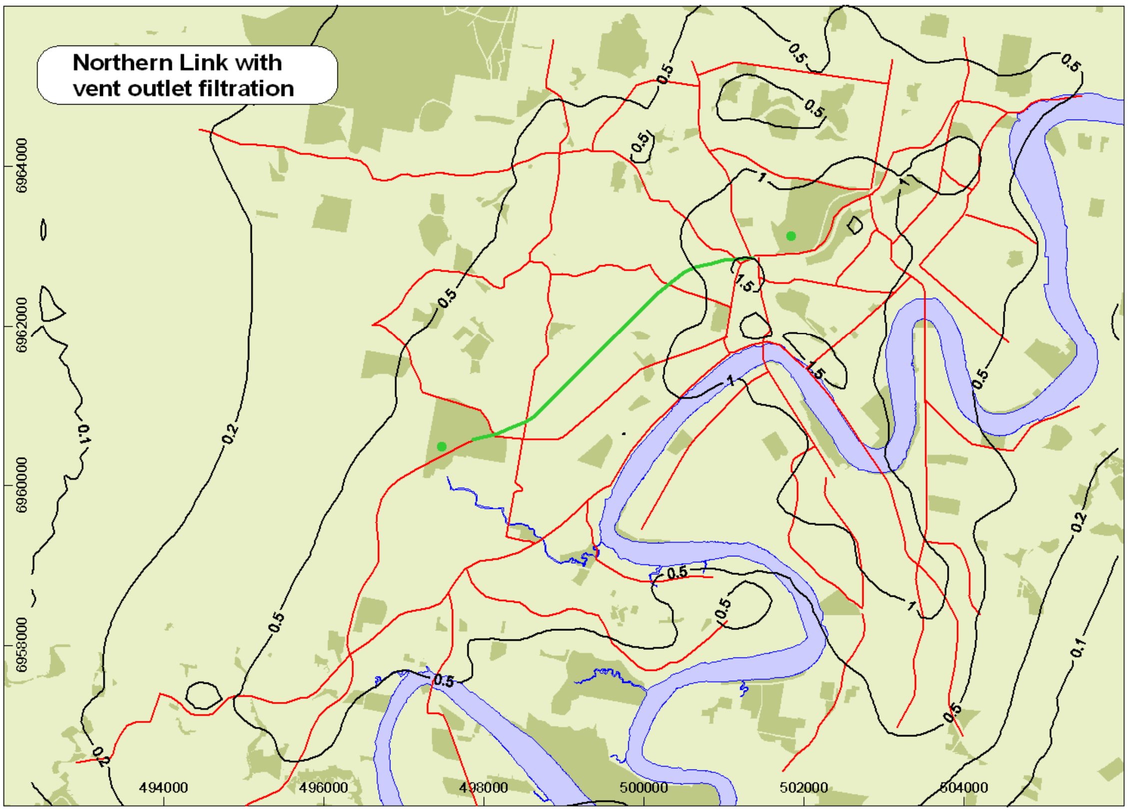
FIGURE 63



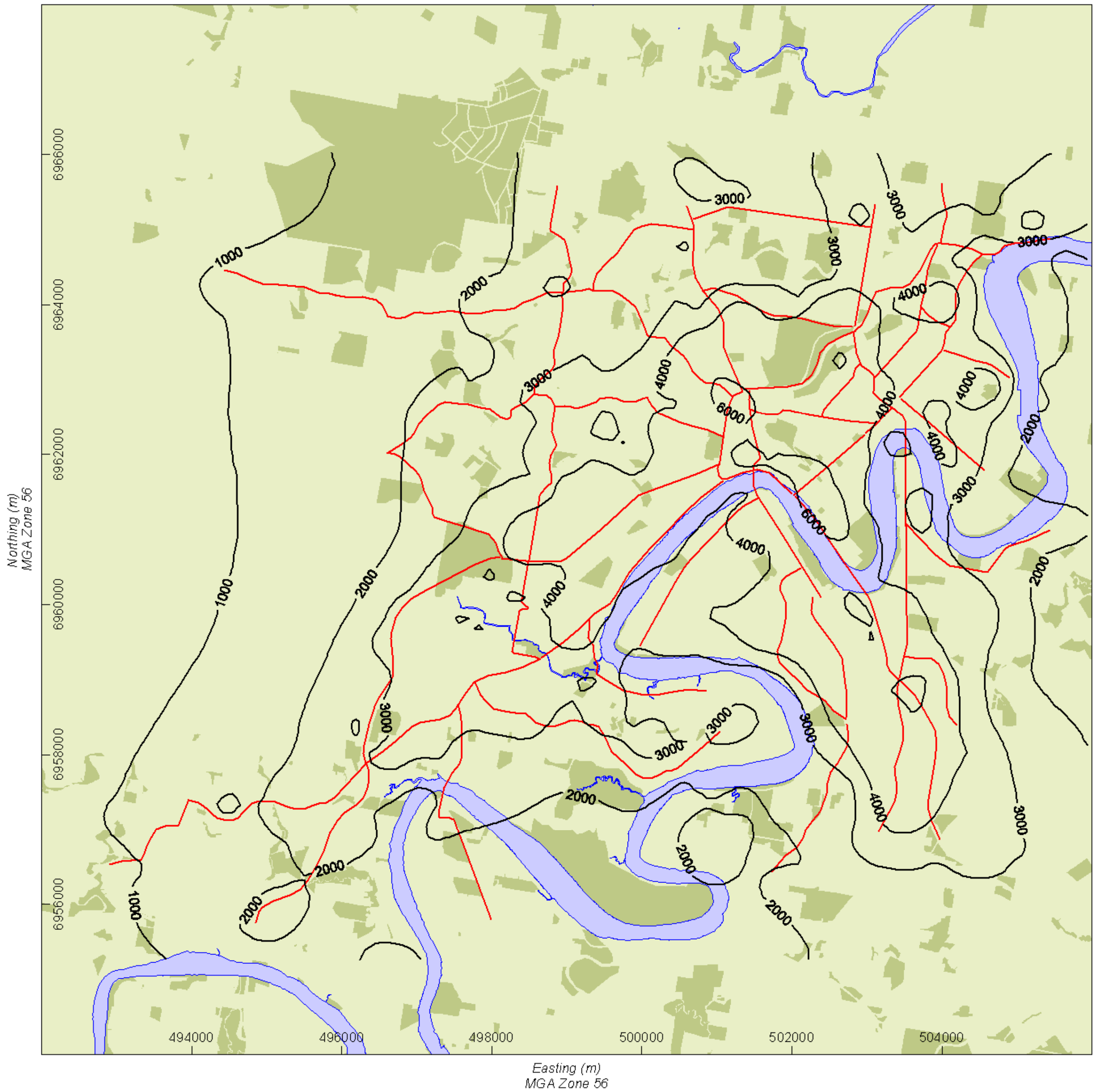
Comparison of without and with tunnel filtration for maximum 24-hour average PM_{10} concentrations in 2014 ($\mu g/m^3$)

FIGURE 64

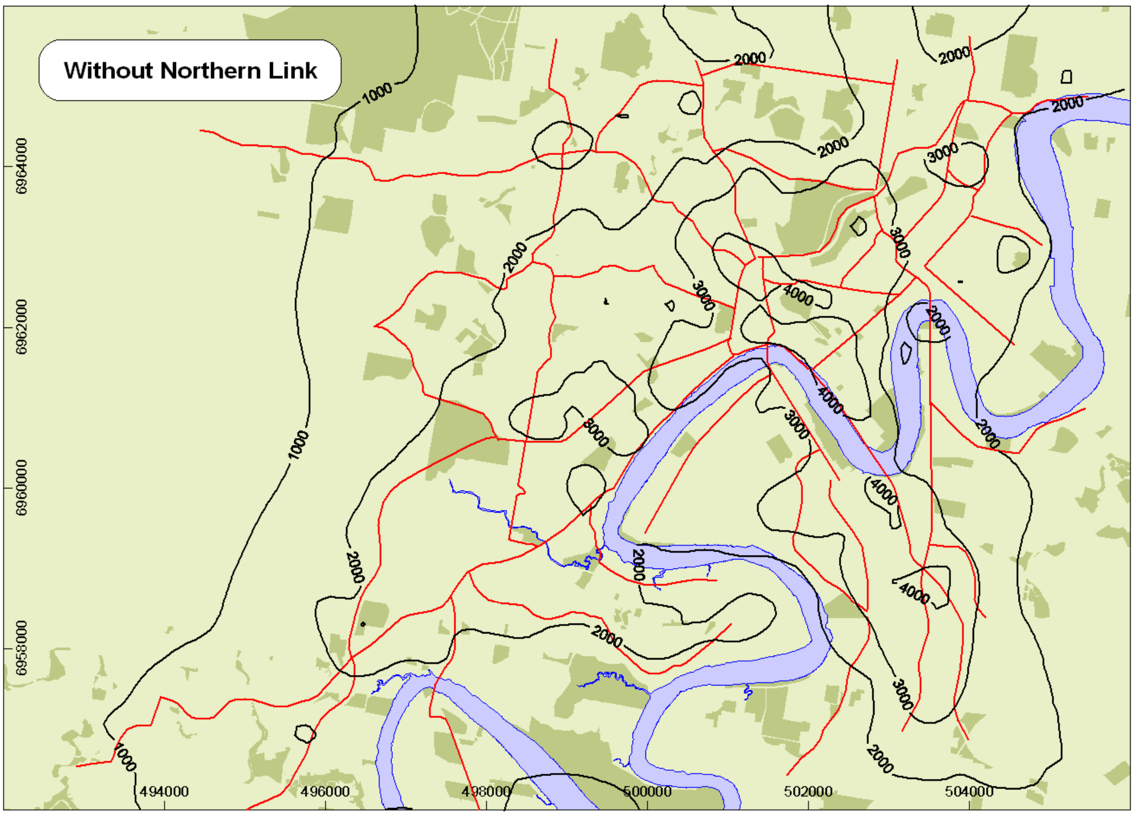


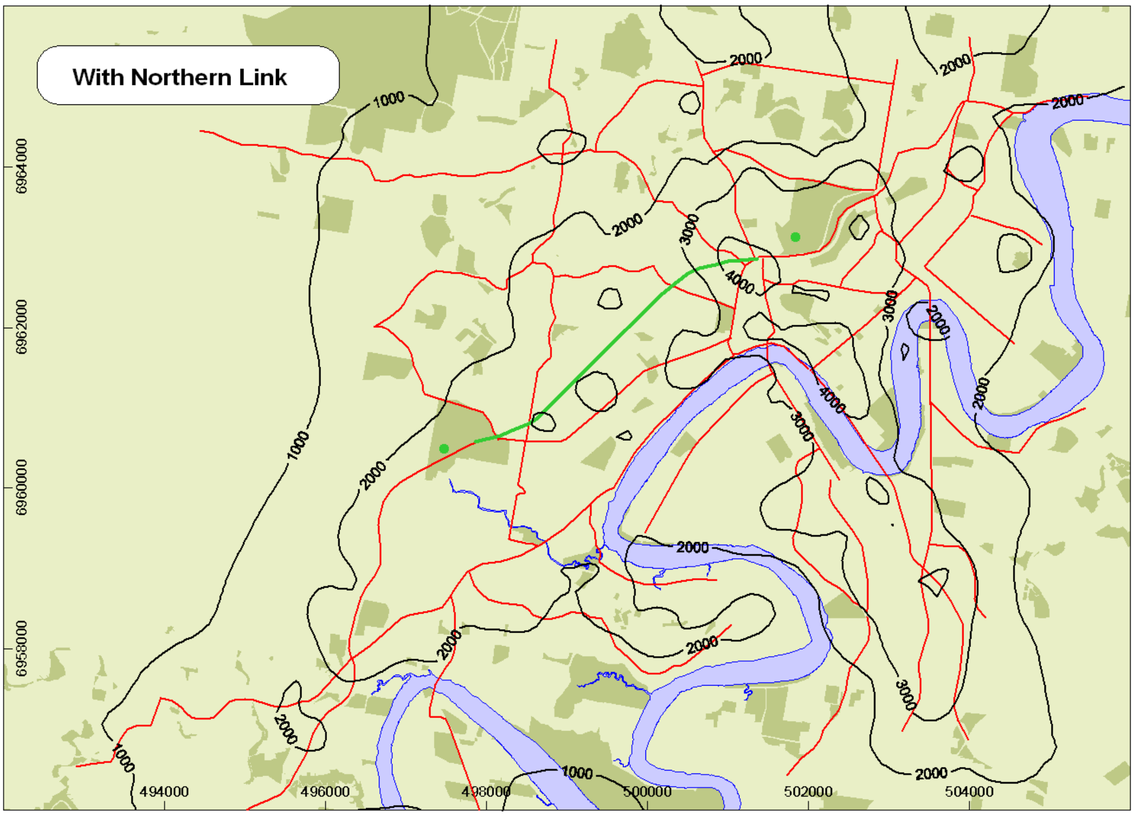


Comparison of without and with tunnel filtration for annual average PM_{10} concentrations in 2014 ($\mu g/m^3$)



Predicted maximum 24-hour average sub-micrometre particles in 2007 (particles/m^3)





Predicted maximum 24-hour average sub-micrometre particles in 2014 (particles/m^3)

FIGURE 67